Peace River Hydrobiological Monitoring Program
2016 HBMP Comprehensive Report

Required by

Southwest Florida Water Management District
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Prepared for

Peace River Regional Water Supply Facility

Peace River Manasota Regional
Water Supply Authority

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Acknowledgments

This *Comprehensive Summary Report* includes not only simply updated information and new analyses since the prior summary report, but also provides comprehensive overviews of the Facility's operations, current and projected future water demands, the historical and current HBMP monitoring components, and summaries of the key findings and conclusions presented in both previous HBMP and other documents relative to the Peace River watershed, the lower river and Charlotte Harbor. A corollary goal of this report is to provide an updated single document containing necessary background information for individuals not familiar with the long-term history of the HBMP program and related watershed/estuarine issues.

The long-term historic and current data summarized in this report have been gathered and compiled from a number of sources including EarthBalance, Benchmark Laboratory, VHB, ESA, the U.S Geological Survey, the City of Punta Gorda, and the Peace River Manasota Regional Water Supply Authority. We would also like to acknowledge the efforts of Sam Stone with the Authority for providing information, review and comments. Additionally, a special acknowledgement is extended to Ralph Montgomery who, in his many years of work for the Authority, led the efforts of many in the pursuit of the understanding of the Peace River and its complexities.

The following summarizes the major contributions of the members of the current HBMP project team. Additional detailed information regarding the collected data can be found in the Annual Data Reports submitted to the District.

- **EarthBalance (Florida Environmental)** – currently collects all *in situ* water column physical measurements and the collection of water chemistry samples for both the "fixed" and "moving" station elements of the HBMP.

- **Benchmark Laboratory** – currently conducts all HBMP water chemistry analyses.

- **U.S. Geological Survey (Tampa Office)** – is responsible for all data collected at the three tide gages located in the lower Peace River that continuously collect data at 15 minute intervals. Measurements at each gaging location included measurements of: 1) surface and bottom conductivity; 2) surface and bottom water temperature; 3) and tide stage (water depth).

  Lower Peace River Continuous Recorders

  1. The Harbour Heights gage is designated by USGS as site 02297460, and it is located at the end of a private dock at River Kilometer 15.5.

  2. The second site is designated by USGS as 02297350 and it is located on a dock near Peace River Heights. This upstream monitoring site is located at River Kilometer 26.7.

3. The third site is designated by the USGS as 02297345 and is located at the Facility's intake (RK 29.8). This site is also referred to as Peace River at Platt (Facility).

Gaged Stream Flow

USGS also collects daily stream flow data at a wide number of gaging locations throughout southwest Florida. Flow data from a number of these sites are used by the HBMP program. Data for the period of record were obtained from the USGS web site: (http://waterdata.usgs.gov/fl/nwis/sw/)

1. Peace River at Bartow (02294650)
2. Peace River at Fort Meade (02294898)
3. Peace River at Zolfo Springs (02295637)
4. Peace River at Arcadia (02296750)
5. Joshua Creek at Nocatee (02297100)
6. Horse Creek near Arcadia (02297310)
7. Prairie Creek near Fort Ogden (02298123)
8. Shell Creek near Punta Gorda (02298202)
9. Myakka River near Sarasota (02298830)
10. Big Slough near North Port (02299450)

- **VHB/ESA –** VHB, with assistance from ESA, is currently responsible for all data collected at the Authority HBMP recorders located in the lower Peace River that continuously collect data at 15-minute intervals. Measurements at each of the gaging locations include surface conductivity and water temperature. Previously, Atkins (Tampa office) was responsible for data collection at these locations.

Authority HBMP Lower Peace River Continuous Recorders

1. **RK 9.2 –** Near surface conductivity and temperature are measured at 15-minute intervals from the HBMP continuous recording gage attached to a navigation marker located between the I-75 and U.S.41 Bridges. Data collection began in June 2011 and is continuing.

2. **RK 12.7 (bottom) –** Near bottom (initial depth) conductivity, temperature and dissolved oxygen were recorded at 15-minute intervals from the HBMP continuous recorder attached to a Manatee Speed Zone Sign located on the lower Peace River downstream of Shell Creek (River Kilometer 12.9). Data collection began in May 2008 and continued until June 2011 when the instruments were moved to record near surface measurements.

3. **RK 12.7 (surface) –** Near surface conductivity, temperature and dissolved oxygen are recorded at 15-minute intervals from the HBMP continuous recorder attached to a Manatee Speed Zone Sign located on the lower Peace River downstream of Shell Creek (River Kilometer 12.9). Data collection began in June 2011 and continues.

4. **RK 18.5** – Near surface conductivity and temperature are recorded at 15-minute intervals from the HBMP continuous recorder attached to navigational aid located near the power line crossing. Data collection began in June 2011 and continues.

5. **RK 18.7 (Hunter Creek)** – Near surface conductivity and temperature are recorded at 15-minute intervals from the HBMP continuous recorder attached to Manatee Speed Zone Sign located near the power line crossing near Jim Long Lake. Data collection began in June 2011 and continues.

6. **RK 20.8** – Near surface conductivity and temperature are recorded at 15-minute intervals from the HBMP continuous recorder attached to navigational aid located just downstream on an island. Data collection began in June 2011 and continues.

7. **RK 21.9 –** Near surface conductivity and temperature are measured at 15-minute intervals from the HBMP continuous recording gage attached to the Manatee Speed Zone Sign located on the Peace River near Liverpool side channel (River Kilometer 21.9). Data have been collected at this site since 2006.

8. **RK 23.4** – Near surface conductivity and temperature at 15-minute intervals from the HBMP continuous recording gage attached to the Manatee Speed Zone Sign located on the Peace at River Kilometer 23.4. Data were collected from 2006 until May 2008, after which monitoring at this site was suspended.

9. **RK 24.5** – Near surface conductivity and temperature at 15-minute intervals from the HBMP continuous recording gage attached to the Manatee Speed Zone Sign located on the Peace River just downstream of Navigator Marina (River Kilometer 24.5). Data have been collected at this site since 2006.

10. **RK 30.6** - Near surface conductivity and temperature were measured at 15-minute intervals from the HBMP continuous recording gage attached to the Manatee Speed Zone Sign located on the Peace River just upstream of the Facility (River Kilometer 30.6). Data collection began in May 2008 and was discontinued in June 2011.

11. **RK 31.7** - Near surface conductivity and temperature are measured at 15-minute intervals from the HBMP continuous recording gage attached to the old railroad trestle located on the Peace River upstream of the Facility (River Kilometer 31.7). Data collection began in May 2008 and continues.

- **Peace River/Manasota Regional Water Supply Authority** – provides measurements of daily withdrawals by the facility. Additionally, Sam Stone, with the Authority, provided information, review and comments critical to this report.

- **City of Punta Gorda** – provides measurements of daily withdrawals and data from the Shell Creek HBMP, as well as all historical data collected as part of their HBMP.

2016 HBMP Executive Summary

All of the extensive HBMP analyses completed to date have indicated that neither measured nor modeled changes resulting from Facility withdrawals have been of sufficient magnitude (relative to the far greater natural degree of variation in freshwater inflows) to have affected the long-term physical, chemical or biological characteristics of the lower Peace River/upper Charlotte Harbor estuarine system. Historically, the estimated changes due to Facility withdrawals have been such that they would have been difficult to physically measure given the far greater magnitudes of daily, seasonal and annual naturally occurring variation. The Facility, however, has undergone two major recent expansions (in 2002 and 2009), which substantially increased its ability to withdraw, store, and treat water from the river. In 2010 the District completed a review and adopted a final MFL for the lower Peace River, and the Authority's withdrawal schedule was subsequently modified in 2011. This permit modification seasonally increased the maximum allowed withdrawal percentages, and when combined with the recent expanded Facility has increased the Facility's overall reliability to meet public demand.

The results of statistical models presented in this report estimate increases in salinity changes and the movement of isohaline locations resulting from increased Facility withdrawals. However, these estimated changes due to actual Facility withdrawals continue to remain small in comparison to the relatively far greater magnitude of typical natural daily, seasonal and annual variations. The Facility's modified withdrawal schedule by design directs the largest volumes of diverted river water to occur during the summer wet season, when salinities and isohaline locations are naturally experiencing greater temporal and spatial variation in response to increasing freshwater inflows and when expected impacts to the downstream estuary from greater withdrawals would be less.

The *2016 HBMP Comprehensive Summary Report* follows and extends the summarization and interpretation of long-term HBMP data from previous Summary Reports. The report's primary goals are to provide the District with sufficient analyses to:

- Assess the presence or absence of long-term trends for important HBMP variables;
- Evaluate key relationships between ecological characteristics and freshwater inflows, and determine whether the biological health and productivity of the estuary are showing signs of stress related to natural periods of low freshwater inflow or potential negative influences of Facility withdrawals;
- Assess the presence or absence of adverse ecological impacts and determine the influence Facility withdrawals may have contributed to such impacts;
- Assess the effectiveness of the withdrawal schedule for preventing adverse environmental impacts;
- Provide the District with sufficient analyses of the HBMP data to date to assure that the withdrawal schedule continues to provide adequate resource protection; and

- Evaluate the overall HBMP design and make recommendations regarding implementing modifications.

Chapter 1 - Introduction and HBMP monitoring program overview

This introductory chapter provides an overview for readers unfamiliar with the history of the Peace River Regional Water Supply Facility and the District's associated series of issued Water Use Permits. The introduction reviews the history of the Facility and its permits, as well as the history of the major study elements that have been associated with the forty-one year record of the ongoing HBMP. An extensive HBMP was initially established in 1975, five years prior to completion of construction and actual Peace River Facility withdrawals, to assess the potential for harmful effects of freshwater withdrawals on the estuarine communities of the lower Peace River/upper Charlotte Harbor estuarine system. A number of statistical modeling efforts have been undertaken in conjunction with continuing efforts to refine the HBMP's ability to quantitatively predict the magnitude of potential Facility withdrawal impacts on both the lower river's salinity structure and movement of the freshwater/saltwater interface. The detected and estimated changes in salinity and/or spatial locations of isohalines resulting from Facility freshwater withdrawals have not resulted in pronounced or systematic changes in the salinity structure, water quality, or biological integrity of the estuarine communities of the lower Peace River/upper Charlotte Harbor estuarine system.

The HBMP has incorporated a wide variety of study elements since its initial inception. The HBMP was not conceived to be a rigid monitoring program, but rather a flexible study design that could be periodically restructured based on updated findings and identified research needs. When the first discussion began in 1975 of what might be included within such an effort, very little was known about either salinity/flow relationships, or the spatial/temporal distributions of other physical/chemical water quality parameters in the lower Peace River/upper Charlotte Harbor Estuary. Even less was known about the biological communities that studies in other estuarine systems had indicated could potentially be negatively affected by freshwater diversions. As a result, much of the effort under the initial HBMP study design was directed toward developing sufficient data to statistically describe the spatial distribution and seasonal variability of physical and chemical indicators within this estuarine system, and to determine potential relationships with naturally occurring variation in freshwater inflows. Such HBMP investigations included the collection of monthly *in situ* water column profile characteristics, and surface and near-bottom water chemistry at a wide variety of sites located throughout the estuary.

In addition, initial attempts were begun to determine if key indicator species or biological communities could be identified to assess responses to natural variations in freshwater inflows. Determining the presence of such long-term relationships was thought to be especially important because, with only a small percentage of total flow being diverted, the direct effects of withdrawals were projected to be extremely small in comparison to natural variation. These HBMP elements included: 1) the initial long-term study of the seasonal pattern of juvenile fishes in the upper harbor; 2) studies of benthic indicator species; 3) the investigation of the seasonal distribution of sea stars in the harbor and lower river; and 4) the vegetation study of first and last occurrence of selected plant taxa along the lower Peace River.

In the 1980s, studies of phytoplankton and zooplankton community structure and production were added to the HBMP. These studies were again not intended to directly evaluate the influences of withdrawals, but rather were designed to address issues related to the “health of the estuary” and the influences of naturally occurring extended periods of drought and flood conditions. Two short-term HBMP program elements, the benthic invertebrate study by Mote Marine Laboratory and the fish nursery investigation by USF, were also not designed to directly measure the influences of withdrawals, but rather were designed to investigate the response of biological communities to natural variations in freshwater inflows.

Based on previous Summary HBMP Reports and additional analyses requested by District staff during the permit renewal process, an expanded HBMP was approved by the District in March 1996 as part of the Facility’s 1996 Water Use Permit renewal. Modifications have been made to the HBMP throughout its history, and study elements have been added and deleted in order to enhance the overall knowledge base of the lower Peace River/upper Charlotte Harbor estuarine system. Major monitoring elements, such as water quality, aimed at assessing direct relationships with variations in freshwater inflow have had the longest histories. Other program elements, primarily those focused on assessing indirect biological indicators, have extended over a number of years and then ended once a sufficient baseline level of information had been accumulated. Chapter 1 describes the current and previous HBMP study elements.

Chapter 2.0 - Summaries of recent relevant reports

This chapter provides brief overviews of each of the major studies and reports related to the Peace River watershed, lower Peace River and upper Charlotte Harbor that have been released since those previously summarized in the *2002*, *2006* and *2011 Peace River Comprehensive Summary Reports*. The primary focus of this chapter is to provide concise overviews of the purpose and major conclusions of each of the reviewed studies.

Chapter 3.0 - Status and trends in regional rainfall, flows, and facility withdrawals

The purpose of this chapter is to provide updated graphical and statistical analyses of rainfall and flows over multiple time scales. Recent and historical unusual occurrences (extended droughts and/or unusually wet intervals) are documented and compared to the long-term average statistical characteristics at each of the major tributary gaging locations in the Peace River watershed. When the long-term rainfall data for the Peace River watershed are analyzed as annual totals, the results clearly show both increased variations among the gages and greater indications of both historical wetter and drier intervals. Total annual average Peace River watershed rainfall levels were slightly higher from 1930 to the early 1960s when compared with the period since then.

Annual average wet-season (June-September) rainfall in the Peace River watershed was generally higher during the 1930s through the mid-1960s when compared with the interval from the late 1960s through the early 1990s. Since approximately 1994, there has been a notable increase in wet-season rainfall, contrasted with marked declines in dry-season rainfall throughout the Peace River watershed.

Base flows in the upper portions of the watershed have shown marked declines that can be directly linked to ground water withdrawals and historic reductions in ground water levels and spring flows. Conversely, in a number of the southern Peace River watershed subbasins, base flows in Peace River tributaries have been distinctly augmented by agricultural discharges.

Comparisons indicate that, other than during the warm/dry spring months when the Facility is often not withdrawing water from the Peace River due to the 130 cfs low flow threshold, Facility withdrawals had historically been fairly uniform throughout most of the year, differing primarily between changes in the permits and differences in Facility capacities. Following the 2002 and 2009 major expansions, the annual pattern of withdrawals has begun to more closely follow a seasonal cycle that follows the natural variability in flow. Low river flows have often resulted in extended periods when the Facility is unable to withdraw water from the river. During both the extended droughts of 1999-2001 and 2006-2011 intervals, the Facility did not withdraw water from the lower Peace River for up to 200 days or more, and had to rely solely on stored reserves to meet regional demands. Comparisons of the annual average hydrographs of total gaged flows upstream of the Facility with and without withdrawals indicate very small seasonal differences regardless of the time period tested. The magnitude of these differences is especially small given the fairly large degree of natural variability in flow inherent both among years and over longer decadal periods.

Chapter 4.0 - Salinity in the lower Peace River/upper Charlotte Harbor estuarine system

This chapter provides overview and analyses of the spatial and temporal patterns and trends in salinity in the lower Peace River/upper Charlotte Harbor estuarine system over the 1976-2016 interval of HBMP monitoring. The relationship between freshwater flows and salinity is examined and statistical salinity models are developed for multiple locations along the HBMP monitoring transect. These models are then used to assess the potential influence of withdrawals on the Lower Peace River/Upper Charlotte Harbor estuarine system.

A strong, distinct spatial salinity gradient exists along the lower Peace River monitoring transect with salinity levels much higher in the vicinity of the river mouth and typically near freshwater levels just upstream of the Facility. The greatest inter-annual variability in salinity generally occurs in the surface waters at the most downstream monitoring sites where seasonal differences may reach 35 psu between extended periods of low and high freshwater inflow. However, even bottom salinity levels in the area of the US 41 Bridge (RK 6.6) exhibit similar large inter-annual variation. Statistical trend tests indicated statistically significant progressive increasing upstream movements in the relative spatial distributions of isohaline locations along the HBMP monitoring transect. Periods of extended drought since 1999, affecting rainfalls and river flows throughout southwest Florida, as well as small changes in sea level that have occurred over the monitoring period, may be reflected in these changes.

The relative locations of each of the four HBMP isohalines along the monitoring transect show strong inverse relationships with freshwater inflows. The graphical and statistical analyses indicate that the relative spatial locations of each of the isohalines initially move rapidly downstream with increasing flows. However, over higher ranges of flows the relative slope of change becomes less as do the relationships between flow and isohaline location along the monitoring transect. The observed relationships are confounded due to the importance of both short and long-term preceding conditions, as well as the often increasing physical stratification of the water column under conditions of higher flows.

There is a distinct inverse relationship between measured surface salinities and increases in gaged flow up to 3000 cfs at the most downstream fixed sampling site, located near the river's mouth. However, similar relationships increasingly break down further upstream with increasing flows as surface salinities along the HBMP lower river monitoring transect change from being tidally brackish to always being characteristically freshwater under conditions of increasing freshwater flows. Bottom salinities at the two most downstream monitoring sites show relationships with flows up to about 1000 cfs after which the water column becomes highly stratified and influences of further increases are highly reduced. Moving further upstream both surface and bottom salinities show similar relationships with increasing flows.

A series of site-specific empirical models were developed using average hourly surface conductivity, stage, and gaged freshwater inflow data gathered during the periods-of-record for selected continuous recording locations. Overall, comparative plots of observed salinities with those estimated by the empirical models indicate that the models slightly over-estimate salinities at low observed salinity levels and correspondingly somewhat under-estimate at higher observed salinity levels. However, over the typical range of salinities observed at each of the recorder sites, the models provide a relatively good fit between observed and estimated values. The models provide a fairly simple and straightforward method to analyze and estimate the potential range and magnitude of potential salinity impacts of withdrawals along the lower river downstream of the Facility over the wide range of observed natural temporal and spatial fluctuations due to the combined influences of variations in upstream flows, tides and seasonal wind patterns.

The empirical models developed for surface salinities for the selected recorder locations were used to estimate salinities over the period 1998 through 2016 under two modeling alternatives: "No Withdrawal" Scenario and "Actual Withdrawal" Scenario. Additionally, empirical models were developed to estimate the relative spatial location of each of the four monthly monitored HBMP isohaline locations along the HBMP monitoring transect using methodology similar to that used to estimate salinity at the continuous recorder sites. The results emphasize the very high degrees of long-term, annual, seasonal, and daily salinity variability naturally occurring temporally and spatially along the lower river. These differences are especially notable when comparing wetter intervals with extended periods characterized by lower flows. The modeled results indicate that salinity changes (and movements of the isohalines) due to Facility withdrawals have increased since the most recent expansion and change in the withdrawal schedule. These increases remain relatively small when compared to the range of naturally occurring daily, seasonal and longer term flow/tide related variation along the lower Peace River. The results further indicate that, by design, the largest increases in salinity resulting from the withdrawal schedule are focused into wetter periods, and occur in regions of the lower river that naturally experience relatively large salinity fluctuations. The components of the withdrawal schedule thus effectively reduce the relative potential influences of Facility withdrawals.

Prior reports (PBS&J 2007, Atkins 2013) have identified anthropogenically related trends of increasing specific conductance within a number of the major upstream watershed tributaries to the lower Peace River. The observed changes in the lower portions of the Peace River watershed over recent decades have been primarily associated with increasing land conversions from less to more intense forms of agriculture, which increasingly relies on irrigation using higher conductivity ground water pumped from the upper Floridan aquifer. Additional increases may have occurred as a result of mining activities in the watershed. This chapter presents updates of earlier evaluations of patterns and historical trends in specific conductance and associated water quality characteristics measured at the Peace River at Arcadia gage, both the upstream Joshua and Horse Creek tributaries, and at the fixed HBMP long-term monitoring site located at River Kilometer (RK) 30.7 located immediately upstream of the Peace River Facility's intake. These updated analyses indicate qualitatively that increased specific conductance (and related parameters) are still evident at the sites evaluated upstream of the Facility.

Chapter 5.0 - Patterns and trends of hydrobiological water quality indicators in the lower Peace River/upper Charlotte Harbor estuarine system

This chapter provides overviews and analyses relative to both the patterns and trends of key lower Peace River/upper Charlotte Harbor estuarine system water quality characteristics (other than salinity/specific conductance) over the 1976-2016 interval of HBMP monitoring. Additionally, the chapter evaluates the effects of flow on the identified water quality parameters. It is important to note that concentrations of water quality constituents (such as nutrients) are not affected by freshwater withdrawals. However, the loads of such constituents decrease with increasing freshwater withdrawals. Other factors, such as changes in land use patterns, are also likely to affect changes in water quality. Analyses of period of record HBMP data have illustrated key findings relevant to water quality parameters, other than salinity, in the lower Peace River/upper Charlotte Harbor, and these are summarized below.

Dissolved oxygen levels in the lower Peace River estuarine system show distinct seasonal patterns, with the lowest levels typically occurring during the summer wet-season. Measured levels are generally higher during cooler months, due to lower water temperatures (that increase the ability of the water to hold more dissolved gases) and seasonally increasing wind stress and mixing. Surface dissolved oxygen concentrations along the monitoring transect initially increase slightly under increasing low to moderate levels of flow. However, above some level, further increases in flow tend to progressively depress ambient surface dissolved oxygen levels at each of the fixed locations along the HBMP monitoring transect. The relationship between surface dissolved oxygen concentrations and flow is confounded by the combined influences of seasonal changes in water temperature and salinity. Bottom dissolved oxygen levels at the more downstream sites decline with increasing flow in response to progressive density stratification of the water column. At the more upstream locations, the responses of both surface and bottom dissolved oxygen concentrations are similar to increasing seasonal flows.

Phytoplankton levels (as measured by chlorophyll *a*) in the Peace River and Charlotte Harbor during periods of low to moderate freshwater flow are limited by the availability of inorganic nitrogen. However, as flows increase, water color levels correspondingly increase and phytoplankton production becomes increasingly limited by the ability of light to penetrate the water column. Spatially, the highest chlorophyll *a* levels occur within the two intermediate salinity zones. The statistical trend procedures suggest chlorophyll *a* phytoplankton levels increased within the 20 psu isohaline over the examined time interval. Higher chlorophyll *a* levels are a reflection of the corresponding observed significant higher color levels (that can serve as a proxy for nutrient loadings), and summer wet-season flows that have, on average, characterized portions of proposed warmer AMO phase since 1995.

Ambient inorganic nitrogen concentrations are typically at or near detection limits in the highest salinity reaches of the estuary throughout most of the spring and summer when light levels are high and phytoplankton production is greatest. Concentrations are conversely greater during the fall and winter months. Overall, ambient inorganic nitrogen levels progressively increase moving upstream from high to low salinities. The relationships between dissolved inorganic nitrogen concentration and rates of freshwater inflow are complex. As flows gradually increase following the typical spring dry-season, increasing nitrogen loadings stimulate estuarine phytoplankton production and ambient inorganic nitrogen levels often remain near or at detection limits throughout much of the lower Peace River estuarine system. However, as flows increase further, upstream phytoplankton primary production become color-, rather than nitrogen-, limited and inorganic nitrogen levels rapidly rise with increasing flows. A third condition then occurs at the upstream HBMP sampling locations as both water color and nutrient levels start to decline with further increases in flow. Such changes again reflect seasonal changes in the water quality characteristic of sheet flow to the watershed's major tributaries following longer (and/or higher) amounts of rainfall.

Like inorganic nitrogen, total Kjeldahl nitrogen (TKN) shows distinct seasonal and spatial patterns along the HBMP monitoring transect. Concentrations are typically lower in the more saline waters of the downstream stations, and are also more elevated during the summer wet-season than during the dry-season. The applied statistical trend procedures did not indicate that TKN levels have systematically increased or decreased over the monitoring interval. Large degrees of variation often occur at a given flow depending on the history of flows over both the immediate and longer-term preceding periods. TKN concentrations within the lower Peace River/upper Charlotte Harbor Estuary generally show spatial increases moving upstream, as well as increasing levels under higher freshwater inflows. Several stations exhibited statistically significant, positive correlations of TKN with 7-day average flow.

The lower Peace River/upper Charlotte Harbor estuarine system is naturally high in phosphorus due to the extensive natural phosphate deposits in a number of the major upstream watershed basins. However, a longitudinal gradient, with lower values in more saline waters is observed in the HBMP data. Measured phosphorus levels in the estuary have declined by as much as an order of magnitude since the early 1980s due to changes in upstream mining practices. Phosphorus concentrations generally reflect both the spatial and temporal variation in Peace River freshwater inputs. The highest phosphorus concentrations are typically associated with seasonal lower river flow, when the influences of ground water are more pronounced. Large degrees of variation often occur at a given flow depending on the history of flows over both the immediate and longer-term preceding periods. Concentrations progressively increase upstream towards the freshwater source, and initially rise in response to higher levels of freshwater inflow. However, as freshwater flows increase further and surface water runoff begins to provide an ever greater percentage of total river flow, the actual concentration of ortho-phosphorus (which is usually more than ninety percent total phosphorus) declines.

Silica concentrations exhibit a longitudinal gradient in the lower Peace River, with typically higher levels farther upstream than near the mouth of the river. Seasonally, as freshwater inflows become greater, ambient reactive silica concentrations are shown to both increase and move further downstream into the upper Harbor. Ambient concentrations initially rapidly rise throughout the lower river/upper harbor estuarine system as freshwater inflows increase. Following this marked initial rise however, silica concentrations then remain relatively similar as flows further increase. Silica concentrations have and continue to dramatically increase along the entire length of the lower Peace River monitoring transect. As with the observed increase in phosphorus levels, upstream data collected by the Authority showed very high silica concentrations in discharge waters associated with the Ft. Meade phosphogypsum stack system closure in the Whidden Creek subbasin. However, while phosphorus levels in the lower river/upper harbor appear to have again declined to more normal levels, silica levels continue to remain high.

Water color exhibits a longitudinal gradient in the lower Peace River, with typically higher levels farther upstream than near the mouth of the river. However, very high water levels can extend well into the harbor during extended periods of high flows such as was observed following Hurricane Charlie. Under low Peace River flows, much of the water coming from the watershed originates from sources having low color levels, such as surficial base flows and discharges of deeper aquifer waters associated with agricultural pumping. As flows increase, typical southwest Florida “blackwater” river inflows are a major influence on the lower Peace River/upper Charlotte Harbor estuarine system. Levels of water color at the downstream fixed monitoring sites show steady increases in color levels under ever higher rates of freshwater inflow. Although a number of extensive droughts have characterized much of the more recent historical period, the data also suggest a number of wetter than usual summer wet-seasons have also occurred. The applied statistical trend test procedures indicate that these increases in wet-season flows have resulted in statistically significant increases in average annual ambient water color within estuary.

Chapter 6.0 - Regulatory influences on water withdrawals from the lower Peace River

This chapter provides a summary of the history of the Lower Peace River Minimum Flow and Level (MFL), its relevancy to Authority operations, and its current status. Additionally, the chapter provides a summary of the history of the Facility and the Authority’s water use permit. Finally, the chapter identifies water quality impairments in the Peace River watershed and any associated management responses to such impairments.

The capability of the Peace River Manasota Regional Water Supply Authority to withdraw and utilize water from the Lower Peace River is controlled by many factors. Primarily, the limits of its capabilities are controlled by the water use permit granted by the District to the Authority. However, such limits in the water use permit are made in accordance with Minimum Flows and Levels also established by the District. A revised withdrawal schedule based on the District’s adopted MFL was issued by the District to the Authority on April 26, 2011, and was implemented the following day. While the District's adopted MFL allows seasonal maximum withdrawals of 16%, (Block 1), 29% (Block 2) and 38 % (Block 3), the Authority requested and received maximum withdrawals of 16% (Block 1) and 28% (Blocks 2 and 3) in the permitted diversion schedule. Daily Facility withdrawals had previously been based on the preceding daily average flow measured at only the USGS Arcadia gage. The new District permitted withdrawal schedule instead utilizes the previous day's combined flow based on the readings from three gages upstream of the Facility located on the Peace River at Arcadia (USGS 02297310), Horse Creek (USGS 02297310), and Joshua Creek (USGS 02297100). The low flow cutoff for Facility withdrawals is 130 cfs as measured as the combined flow of the three upstream gages.

April 2011 Revised Authority Lower Peace River Withdrawal Schedule (based on combined USGS gaged flow at three upstream gages)

Block	Allowable Percent Reduction in Flow	
Block 1 (April 20th – June 25th)	16% if flow is above 130 cfs	
Block 2 (October 27th – April 19th)	16% if flow is > 130 cfs	28% if flow > 625 cfs
Block 3 (June 26th – October 26th)	16% if flow is > 130 cfs	28% if flow > 625 cfs

In addition to MFL and water use permit allowance, the ability of the Authority to withdraw and treat water from the Lower Peace River can be affected by the temporary changes in quality of the water in the vicinity of the withdrawal point, availability of off stream storage capacity and routine maintenance.

Chapter 7.0 - Water demand and supply

This chapter provides a synopsis of demand (historical and projected) in the region receiving water from the Peace River, and the related withdrawals from the Peace River. Additionally, this chapter includes a summary of major Facility expansions and capabilities, as well as the Authority's Master Water Supply Plan and identified alternative sources.

In order to meet future projected increases in regional demands, the Peace River Facility has undergone several expansions to enhance its potential ability to meet those projected future needs. These include 6.625 billion gallon off-stream surface reservoirs, as well as a system of 21 aquifer storage/recovery (ASR) wells.

Total supply capacity available from the Authority and its five Customers (Charlotte, DeSoto, Manatee and Sarasota, Counties and the City of North Port) is 102 mgd. This capacity is expected to increase to nearly 107 mgd in 2024 with the development of two wellfields in Manatee County and the City of North Port (Atkins et al 2015). The Authority supplies a significant portion of this capacity. While currently supply exceeds demand, regional water demand is projected to grow resulting in a need for new supply development. The *2015 Regional Water Supply Plan* (Atkins et al 2015) projects that an additional 25 mgd of average annual permitted finished water capacity will need to be developed by the Authority and/or its Customers within the region by 2035. Multiple potential sources of supply were evaluated in the

2015 Regional Water Supply Plan and include brackish wellfields, Peace River Facility surface water system expansion, and Cow Pen Slough surface water facility and expansion.

Chapter 8.0 - Assessing environmental change

This chapter directs the reader to prior *Comprehensive Summary Reports* that have detailed the regulatory basis of review, the rationale for defining significant environmental change, and the hierarchy of management actions proposed under the HBMP to be implemented in response to detected changes that could forewarn of potential future adverse environmental impacts of sufficient magnitude that they would constitute an “adverse change”. Such management actions include data QA/QC audits, comparison of data correlates, redirected sampling efforts, District Governing Board hearings, and remediation. Additionally, the District may, at its discretion, convene a meeting of the HBMP Scientific Review Panel to evaluate detected changes or determine the appropriate regulatory course of action.

Chapter 9.0 - Monitoring program design and modifications to the existing long-term HBMP elements

Based on the overall findings and conclusions presented in this report, the final chapter extends the discussions in previous Summary Reports relative to the potential need for future changes to existing HBMP study elements. The combined elements of the program’s design need to meet the specific expectations and objectives set forth in the permit as well as provide sufficient long-term information on which to base the development of answers to potential future questions that might be expected to arise. In order to effectively meet these goals and objectives, the integrated design of HBMP elements should incorporate the following criteria.

- The program needs to identify appropriate physical and biological indicators, and specific mechanisms of action, potentially subject to significant changes resulting from permitted freshwater withdrawals from the lower Peace River/upper Charlotte Harbor estuarine system.

- The program should determine and predominantly focus its efforts in those geographical regions of the lower river where naturally occurring and Facility induced changes in river flow would be expected to result in the greatest potential for observed changes in identified key estuarine characteristics.

- The design of the HBMP monitoring element should include sufficient spatial and temporal intensity to assure detection of measurable changes in selected physical/chemical/biological parameters resulting from changes in freshwater inflows.

It is important that each HBMP study element, as well as the overall program, have specific clearly stated goals and objectives to effectively meet the design criteria needed to accomplish the monitoring program’s multiple expectations. These goals and objectives need to clearly establish the scientific basis needed to provide sufficient information to meet the District’s criteria for required reasonable assurance, as well as provide meaningful information to both the public and the members of the HBMP Scientific Review Panel. The HBMP design elements further need to be sufficiently flexible to allow incorporation of modifications when and where changes in conditions, or new gathered information, suggest the need for specific monitoring program changes.

The HBMP monitoring design needs to be primarily focused on identifying and incorporating those *critical indicators* known to exhibit marked direct responses to variations in freshwater inflow, since it is these parameter measurements that present the greatest probability of both detecting and assessing the principle underlying causative factor(s) to observed environmental changes.

Since the initiation of HBMP monitoring in 1976, the program has incorporated a number of differing physical, chemical, and biological study elements. Modifications have been made to the elements of the HBMP throughout its history. Historically, those major monitoring elements aimed at assessing direct relationships with variations in freshwater inflow have had the longest histories. Other program elements, primarily those focused on assessing indirect biological indicators, have extended over a number of years and then ended once a sufficient baseline basis of information had been accumulated.

Results from both the “fixed” and “moving” HBMP study elements have indicated the presence of a distinct, seasonally-variable chlorophyll *a* maxima along the lower Peace River/upper Charlotte Harbor monitoring transect. Inclusion of a new HBMP study element employing *in situ* fluorometric methodology to measure chlorophyll *a* was expected to provide the fine-grained spatial information needed to accurately define on a monthly basis both the magnitude and spatial extent of variations in chlorophyll *a* patterns within the lower Peace River/upper Charlotte Harbor Estuary. Accurate spatial determinations of the relative intensity and location of monthly chlorophyll *a* maxima patterns would provide additional information regarding the known seasonal interactions between changes in freshwater flow (relative to additions of both nutrients and color) and the seasonal movement of important estuarine zones of primary (and secondary) production. Based on previous discussions and Scientific Review Panel recommendations, such a monitoring element was added to the HBMP during 2013. Now that several years of data have been collected, it is recommended that an analysis of the utility of this HBMP study element, and recommendations for its future continuance, be made. Should the assessment indicate this HBMP element be continued, then continued assessment and reporting should be done at specific intervals as part of future major summary monitoring program reports.

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Executive Summary

1.0 Introduction

The primary objective of this introductory chapter is to provide a historic overview of the Peace River Facility's history, Southwest Florida Water Management District (District) permitted withdrawal schedules and past and present (ongoing) Hydrobiological Monitoring Program (HBMP) study elements. These monitoring elements have been associated and specified within the "specific conditions" sections of each of the Facility's ongoing series of issued District Water Use Permits. This introduction further summarizes and provides an overview of the *2016 HBMP Comprehensive Summary Report's* general organization and overall primary objectives.

1.1 Overview of the Peace River Facility's History and Permits

In the early 1970s, General Development Utilities (GDU) actively began searching for a major regional water supply that would support the projected population growth for a number of large communities in southwest Florida under construction or planned by its parent company, General Development Corporation (GDC). Projected population estimates at the time suggested that the number of new residents in these planned communities might well exceed a quarter of a million by the year 2020. The primary goal of GDU was to establish a reliable and expandable source of potable water to supply this projected future population growth. After reviewing a number of potential alternative sources, it was determined that the site of the current Peace River Facility in DeSoto County along the predominantly freshwater reach of the tidal lower Peace River provided the greatest opportunity for a sustainable, reliable water supply for the planned future population growth within the three (Charlotte, Sarasota, and DeSoto) county areas within which GDC communities were being constructed or planned for development.

General Development Corporation determined that an assessment study was needed to evaluate the feasibility of locating a regional water supply system on the Peace River in Desoto County near State Road No. 761. Staff from the Rosenstiel School of Marine and Atmospheric Science at University of Miami were contracted to assess the potential environmental impacts to the lower Peace River and upper Charlotte Harbor of projected future freshwater withdrawals.

The information on biological communities and salinity/flow relationships developed during these initial field investigations by University of Miami staff were based on data collected between 1973 and 1974 (Michel *et al.* 1975). During this period, Peace River flows (measured at the Arcadia gage) ranged from a low of 62 cubic feet per second (cfs) to more than 10,000 cfs. Fortuitously, the relationships between salinity and flow developed during this relatively short period of study, and subsequently used in calibrating the initial numerical models during this work, were characteristic of much of the normal range of variation in flows that have subsequently occurred during both extended wet and dry periods.

A series of numerical models were developed to predict changes in salinity at sites extending from near the mouth of the river upstream to the planned future location of the Peace River Facility. Changes in salinities were modeled under worst-case conditions assuming freshwater withdrawals during naturally occurring periods of low river flow. The report (Michel *et al.* 1975) concluded that "under these conditions of flow and withdrawal, biological data indicated that such slight salinity increases, above the naturally occurring values of low flow periods, should add little additional stress on the plants and animals of the study area." This conclusion was based on what was found to be the highly dynamic natural seasonal changes in salinity within portions of the lower Peace River due to difference in flows during wet and dry periods. The final report also strongly recommended that an extensive monitoring program be implemented to assess the validity of the predicted results.

On December 10, 1975, the Consumptive Use Permit #7500016 for the Peace River Regional Water Supply Facility was signed between General Development Utilities, Inc. and the Southwest Florida Water Management District. Specific conditions of the District's initial and subsequent Consumptive Use Permits for the Peace River Facility have set forth requirements for the implementation of a comprehensive HBMP. The District's continuing expressed purpose in mandating this requirement has been to ensure the continuing development of sufficient long-term data needed to establish and assess the responses of various physical, chemical and biological characteristics of the Charlotte Harbor Estuary to seasonal, long-term, and withdrawal related changes in Peace River flow. The long-term HBMP study elements have specifically been designed to evaluate the consequences and significance of natural changes in salinity, water quality and biological characteristics inherently associated with seasonal variations in freshwater input. In particular, a number of monitoring program elements have sought to establish the effects of natural long-term variations in river flow on the overall health of aquatic fauna and flora communities in the lower Peace River and upper Charlotte Harbor. Once having established the influences of natural variations, a corollary goal of the long-term monitoring program has been to determine if freshwater withdrawals by the Peace River Facility can be shown to have measurable impacts or result in quantifiable alterations of the biological communities of the lower Peace River/upper Charlotte Harbor Estuary. A history of the HBMP and descriptions of its major historic study elements are described below.

Construction of the Peace River Facility was completed and withdrawals began in the spring of 1980. As part of the initial construction, a relatively small off-stream surface water reservoir was constructed, and soon thereafter construction began on a series of underground Aquifer Storage Recovery (ASR) wells. Adequate storage was identified early in the initial evaluation and planning for the Peace River Facility as an important component in assuring a reliable source of water given the degree of natural variability in river flows. Unlike many other water treatment facilities that utilize surface water, there is no in-stream barrier in the Peace River to impound water during the typically dry winter and spring months. The District mandated as an initial permit condition that no withdrawals could be made below certain river flow levels. As a result the Peace River Facility has always relied on off-stream storage to maintain water supplies during the dry season and/or drought conditions.

The first permit renewal occurred in 1982. At that time, actual Facility withdrawals had only begun in early 1980, and therefore only a limited number of minor changes were made to the initial HBMP monitoring design. By the second permit renewal in 1988, over a decade of data had been collected as part of the ongoing HBMP studies, and the findings from these data were assessed to make significant modifications to both the monitoring efforts and withdrawal schedule (a summary of the history of the Facility's District Water Use permits is presented in Table 1.1 below).

Prior to 1988, the regulatory limit for maximum daily withdrawals from the Peace River was 22 mgd (34.0 cfs), which could be withdrawn as long as the measured stream flow at the Arcadia gage was above the regulatory minimum flows that had been established for each month of the year. These calculated individual minimum monthly flows were initially based on a general formula that had been established under the District’s first “Water Use Rules” adopted in 1975. This formula used records of the previous twenty years of stream flow to establish a separate minimum flow for each calendar month. The monthly minimum flows for the Peace River used to establish the freshwater withdrawal schedule prior to 1988 ranged from 100 cfs in April and May, up to 664 cfs in September during the summer wet season. As a result, during low flow periods in the spring, maximum daily withdrawals of 34 cfs could reduce flows (as measured at the USGS Peace River at Arcadia gage) by as much as 25 percent on some days. Conversely, during September, no water could be taken from the river until flows exceeded 664 cfs.

When the permit was renewed in 1988, General Development Utility’s consulting scientists and the District agreed that the existing withdrawal schedule caused the Peace River Facility to rely too heavily on periods of low to moderate flows. It was agreed that site-specific information should be used to establish regulatory minimum flows and daily withdrawal limits from the Peace River. Using the long-term data collected under the HBMP, statistical models were developed to analyze the location of the freshwater/saltwater boundary as a function of flow, and predicted salinity changes that might result from permitted withdrawals.

Based on these analyses, the District and GDU agreed that the withdrawal schedule should be modified. A minimum criterion was established with no withdrawals when flows at Arcadia were below 100 cfs during the three typically dry spring months (March through May) and 130 cfs during the remainder of the year. Beyond that, withdrawals could equal up to 10 percent of the daily measured gaged flow at Arcadia, up to a maximum not to exceed 22.0 mgd (34 cfs) as long as daily withdrawals did not reduce river flows below the minimum flow cut off. This schedule allowed withdrawals to more closely follow the natural variability of rainfall and flow.

In 1990 General Develop Utilities parent company GDC filed for bankruptcy protection. Charlotte County took control of GDU facilities within Charlotte County, and ownership of the Peace River Regional Water Supply Facility was transferred to the newly formed Peace River Manasota Regional Water Supply Authority in mid-1991. The Authority was formed and functions through inter-local agreements made among Charlotte, Desoto, Manatee, and Sarasota counties in 1984. As owners of the Peace River Facility, the Authority soon began making plans for expansion of the treatment facilities to both increase reliability and provide additional water to the region beyond that originally envisioned by GDU. A further goal of the Authority has been to develop a series of interconnections among the member county’s water supplies to reduce potential effects of natural disasters and other interruptions in supply and allow improved regional management of water sources. In 2002, the Authority completed a major expansion of the Peace River Facility and its interconnection with the Carlton Water Treatment Facility in Sarasota County as the first step toward this long-term goal.

A twenty-year renewal of the Facility’s Water Use Permit (No. 20010420.0004) was issued by the District to the Authority in March 1996 (Table 1.1). The permit contained specific conditions for the continuation and enhancement of specific study elements for the ongoing lower Peace

River/upper Charlotte Harbor Estuary HBMP and established a series of maximum withdrawal quantities. This permit increased the minimum flows measured at the upstream Arcadia gage, under which no withdrawal could occur, to 130 cfs during all months of the year. Beyond that, withdrawals were still not to exceed ten percent of the preceding day average daily Peace River at Arcadia gaged flow. This permit encouraged the Authority to withdraw, treat and store more river water under high flows while limiting withdrawals to ten percent, and not exceeding the daily pumpage of 90 mgd (139 cfs).

Table 1.1
Summary of Previous Facility Permits

Year	December 1975	March 1979	May 1982	October 1988	March 1996
Water Use Permit Number	27500016	27602923	202923	2010420	2010420.02
Average Permitted River Withdrawal (mgd)	5.0	5.0	8.2	10.7	32.7
Maximum Permitted River Withdrawal (mgd)	12 & 18	12 & 18	22	22	90
Diversion Schedule Low Flow Cut off (cfs)	91 – 664 *	91 – 664 *	100 – 664 *	100 & 130 **	130 **
Maximum Percent Withdrawal of River Flow	5	5	n/a	10	10

* Withdrawals based on historic monthly averages

** Withdrawals are based on percent of actual daily flow from the preceding daily flow at the USGS at Arcadia gage

These initial series of District permitted withdrawal schedules for the Peace River Facility were all far more conservative and well below the “safe” levels originally proposed by the University of Miami Study in the late 1970s. The magnitude of the predicted and observed changes in salinity and isohalines due to Facility freshwater withdrawals have indicated (the previous *HBMP Comprehensive Summary Reports* in 2002 and 2006, as well as the *2007 HBMP Low Flow Pump Test*) that the predicted influences of freshwater withdrawals under the Facility’s 1996 withdrawal schedule typically impacts the daily average salinity along the lower river in the range of 0.1-0.3 ppt. These modeling efforts suggested that any Facility salinity impacts probably could not easily be detected, other than by using continuous recorders, given the normal distributions and daily tidal ranges of salinity along the lower Peace River/upper Charlotte Harbor HBMP monitoring transect. Given the far greater natural daily and seasonal ranges of salinity variation in the lower Peace River/upper Charlotte Harbor estuary and the lack of information regarding the potential consequences of such small salinity changes on tidal estuarine processes, the ecological consequences of these small but predictable changes have been exceptionally difficult to evaluate and predict. Thus, while withdrawals have resulted in predictable changes in salinity, the normal daily and seasonal variability in estuarine salinity distributions indicate that the changes due to Facility withdrawals have not appeared to be of a magnitude likely to be easily measured directly. This suggests that evaluating and predicting the effects of withdrawals on the salinity distributions within the lower Peace River/upper Charlotte Harbor estuarine system might ultimately best be accomplished using hydrographic and statistical modeling approaches in assessing, comparing and quantifying the potential for significant adverse harm to the mechanisms by which Facility withdrawals might lead to significant adverse impacts.

Due to extended drought conditions during 2006 and concern about the upcoming 2007 dry season (Figure 1.1), the Authority asked and received permission from the District in December 2006 to reduce the low flow Peace River at Arcadia withdrawal threshold from 130 cfs to 90 cfs until the end of the drought while still using the 1996 permit's 10 percent criteria. However, due to the unexpected historic low Peace River flows during the summer of 2007, the District issued an additional series of Executive Orders that temporarily modified the Authority's Peace River Facility withdrawal schedule (Table 1.2). The series of District Executive Orders issued by the District in response to the severity of the extended drought modified the withdrawal schedule to include withdrawals based on the total gaged flows upstream of the Facility (Peace River at Arcadia, plus Horse Creek near Arcadia and Joshua Creek near Nocatee). These executive orders also modified the low flow threshold, and increased the allowable percent withdrawals all based on the District's initial draft proposed Lower Peace River Minimum Flow and Level (MFL). The relative recent historic contributions of the USGS gaged freshwater sources to the lower Peace River, both upstream of the Facility and at the U.S. 41 Bridge (which further includes flows from Shell Creek) are presented in Table 1.3.

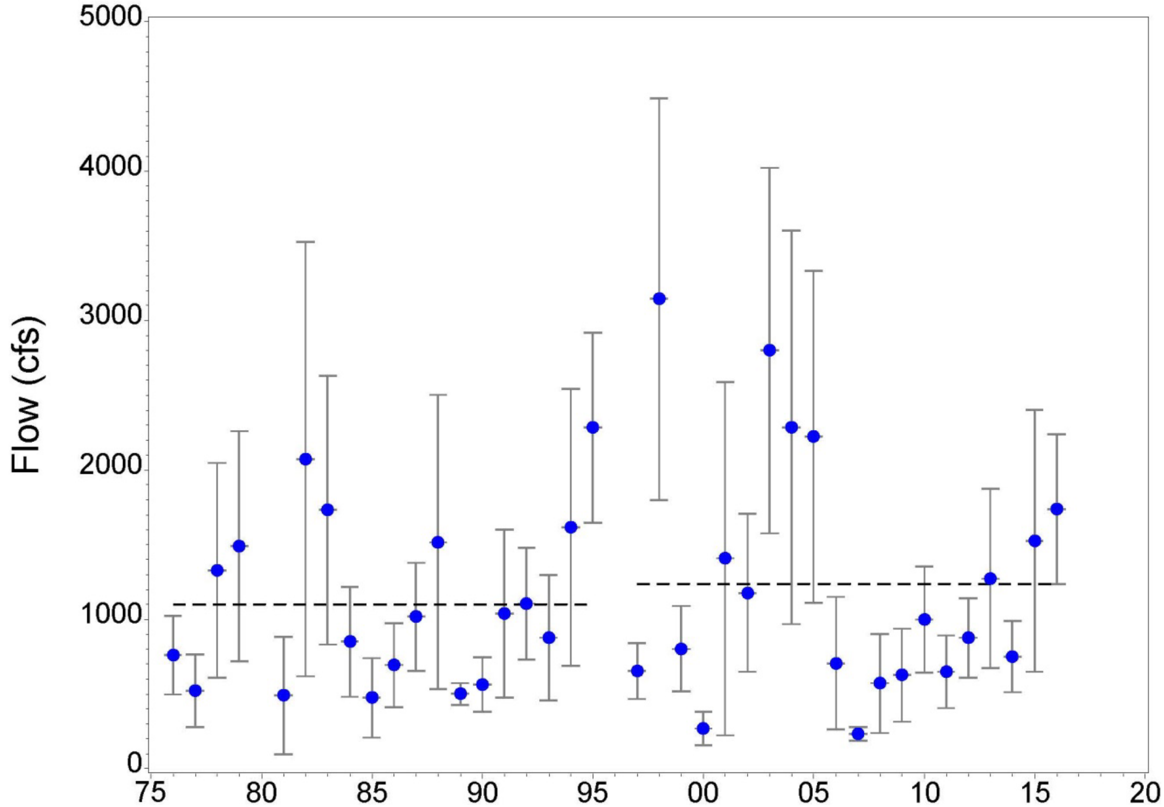

Figure 1.1 Annual monthly mean Peace River at Arcadia, plus Horse and Joshua Creeks gaged flows (with upper and lower 95% confidence intervals) between 1976 and 2016. The figure indicates that while total gaged flows upstream of the Facility since 1994 have been on average slightly higher (133 cfs) than during the previous 18 years of HBMP monitoring, much of the more recent period has been characterized by lower flows over extended periods.

The series of District Executive Orders were initially based on the draft criteria presented in the District's proposed MFL for the lower Peace River (Table 1.4). The District's initial draft MFL for the lower Peace River proposed that during seasonal Block 2 (October 27 to April 19) the maximum permitted Facility withdrawals should be 14 percent of all flows between 90 and 330 cfs based on the combined gaged flows upstream of the Facility. Maximum withdrawals could then increase to 21 percent of the combined gaged flows above the long-term historic median flow of 330 cfs during the Block 2 time interval.

Table 1.2
Modifications to the Normal 1996 Permitted Withdrawal Schedule

Event	Effective Dates	Low Flow Threshold	Gages Used	Percent Withdrawal
Temporary WUP	12/1/06 to 8/12/07	90 cfs	Peace River at Arcadia	10%
Executive Order*	8/13/07 to 8/29/07	130 cfs	Three gages upstream of the Facility	12%
Executive Order*	8/30/07 – 10/31/07	90 cfs	Three gages upstream of the Facility	12%
Executive Order*	11/1/07 – 4/19/08	90 cfs	Three gages upstream of the Facility	14% to 330 cfs 21% above 330 cfs
Executive Order*	4/20/08 – 6/25/08	90 cfs	Three gages upstream of the Facility	10% to 221 cfs 26% above 221 cfs
Executive Order*	6/26/08 – 10/26/08	90 cfs	Three gages upstream of the Facility	12% to 1370 cfs 15% above 1370 cfs
Executive Order*	10/23/08 -7/15/09	90 cfs	Three gages upstream of the Facility	**4/20-6/25** 10% to 221 cfs 26% above 221 cfs **6/26-10/26** 12% to 1370 cfs 15% above1370 cfs **10/27-4/19** 14% to 330 cfs 15% above 330 cfs
Executive Order**	7/16/09 – March 2010	Same as above but increases maximum withdrawal from 90 to 120 mgd		
4/30/10 – Executive Orders ended and withdrawals returned to the original permit conditions				

Table 1.2
Modifications to the Normal 1996 Permitted Withdrawal Schedule

Event	Effective Dates	Low Flow Threshold	Gages Used	Percent Withdrawal
Revised Permit Withdrawal Schedule Based on Adopted MFL	4/27/11 - Present	130 cfs	Three gages upstream of the Facility	**Block I** Apr 20th Jun 25th - 16% **Block II** Oct 27th – Apr 19th 16% if flow < 625 cfs 28% if flow > 625 cfs **Block III** Jun 26th – Oct 26th 16% if flow < 625 cfs 28% if flow > 625 cfs

* Note 1: The temp WUP was extended each month by the governing board until the first Executive Order was approved

** Note 2: Variable percent withdrawal based on District proposed MFL criteria

Table 1.3
Comparisons of Relative Contributions of Gaged Flows Over Recent Historic 1976-2016 Period

Time Period	Percent of Total Gaged Flow at Facility			Percent of Total Gaged Flow at U.S. 41 Bridge			
	Peace at Arcadia	Horse Creek	Joshua Creek	Peace at Arcadia	Horse Creek	Joshua Creek	Shell Creek
1976-2016	75.6	15.1	9.4	57.9	11.5	7.2	23.4

In April 2010 after evaluating comments received on the initial draft report covering both the lower Peace River and Shell Creek MFLs, the District revised its initial draft proposed MFL's by modifying the maximum withdrawals allowable. The District's revised MFL for the lower Peace River eliminated the criteria of adjusting withdrawals based on whether flows were above or below the calculated seasonal mean. The District's revised MFL's instead added a 625 cfs upper threshold prior to changing the allowable percent withdrawal to both Blocks II and III, and delayed determination of a final Shell Creek MFL. In August 2010 the District approved and implemented the final MFL for the lower Peace River (Table 1.5).

Table 1.4
Initial Daft District Proposed Lower Peace River MFL Schedule (based on combined USGS gaged flow at three upstream gages)

Block	Mean Flow	Allowable Percent Reduction if Flow:	
		Below the Median	Above the Median
Block 1 (April 20th – June 25th)	221	10	26
Block 2 (October 27th – April 19th)	330	14	21
Block 3 (June 26th – October 26th)	1370	12	15

Table 1.5
Final Adopted District Lower Peace River MFL Schedule (based on combined USGS gaged flow at three upstream gages)

Block	Allowable Percent Reduction in Flow	
Block 1 (April 20th – June 25th)	16%	
Block 2 (October 27th – April 19th)	16% if flow < 625 cfs	29% if flow > 625 cfs
Block 3 (June 26th – October 26th)	16% if flow < 625 cfs	38% if flow > 625 cfs

The temporary modifications to the Facility's 1996 Water Use Permit presented in Table 1.2 were in direct response to the severity of the 2006/2009 drought. These modifications were not permanent changes to the Authority's 1996 permitted 10 percent withdrawal of river flow based solely on Peace River at Arcadia gaged flows. In 2009, the Authority completed construction of the new 6 billion gallon reservoir, and expansion of maximum pumping capacity of the intake structure on the Peace River. Following the District's 2010 adoption of a final MFL for the lower Peace River, based on the combined flows of the three gaged flows upstream of the Facility (Table 1.5), the Authority requested a revised withdrawal schedule based on the District's adopted MFL. The Authority's goal in making this application was to provide for increased utilization of its recently increased off-stream storage capacity during higher river flows, in order to improve system reliability for the same 32.7 mgd average day delivery of water permitted in the Facilities 1996 District permit conditions.

A revised withdrawal schedule (Table 1.6) based on the District's adopted MFL was issued by the District to the Authority on April 26, 2011, and was implemented the following day. This permit modification maintained the original 32.7 mgd yearly average withdrawal and the maximum monthly allowed withdrawal average of 38.1mgd. The maximum daily diversions from the river were increased from 90 mgd to 120 mgd, in order to allow greater flexibility with the Authority's recent Facility upgrades. While the District's adopted MFL allows seasonal maximum withdrawals of 16%, (Block 1), 29% (Block 2) and 38 % (Block 3), the Authority requested and received maximum withdrawals of 16% (Block 1) and 28 % (Blocks 2 and 3) in the permitted diversion schedule. Daily Facility withdrawals had previously been based on the preceding daily average flow measured at only the USGS Arcadia gage. The new District permitted withdrawal schedule instead utilizes the previous day's combined flow based on the readings from three gages upstream of the Facility located on the Peace River at Arcadia (USGS 02297310), Horse Creek (USGS 02297310), and Joshua Creek (USGS 02297100). The low flow cutoff for Facility withdrawals remained the same as previously permitted at 130 cfs, but was also changed to reflect the combined flow of the three upstream gages.

Table 1.6
April 2011 Revised Authority Lower Peace River Withdrawal Schedule (based on combined USGS gaged flow at three upstream gages)

Block	Allowable Percent Reduction in Flow	
Block 1 (April 20th – June 25th)	16% if flow is above 130 cfs	
Block 2 (October 27th – April 19th)	16% if flow is > 130 cfs	28% if flow > 625 cfs
Block 3 (June 26th – October 26th)	16% if flow is > 130 cfs	28% if flow > 625 cfs

Two additional modifications were made to the Facility's water use permit in 2011. The first occurred in October 2011 and made a small adjustment in the allowable annual average withdrawal increasing it from 32.7 mgd, to 32.855mgd. This permit modification also increased the allowable monthly maximum from 38.1 mgd to 38.3 mgd. The next permit modification occurred in November 2011and didn't change any of the permit conditions other than change the expiration date of the current water use permit from 2016 to 2037, in order to conform to the length of the Facility's existing bonds and to conform to new District rules allowing longer term water use permits.

Even with the District's revision of the withdrawal schedule based on the established MFL for the lower river, there continues to be a large number of days each year when the Peace River Facility does not withdraw water from the river. During 2016, the Facility didn't withdraw water from the river 32 percent (114 days) of the time. Reasons for the Facility not withdrawing water on a given day or time interval can be due to the following:

- The total USGS gaged stream flows upstream of the Facility being below the designated low flow threshold of 130 CFS for freshwater withdrawals
- Poor water quality (conductivity, taste/odor)
- Facility maintenance
- Insufficient storage capacity (full existing storage system) even with the 2009 completion of the new 6 billion gallon reservoir

Extensive analyses of long-term trends and changes in lower Peace River watershed flows and Facility withdrawals are presented and summarized in **Chapter 3**.

1.2 HBMP Study Elements and Studies

In 1976 the initial monitoring elements of the HBMP were designed in coordination with District staff to provide answers to specific questions raised during the original permitting process. These questions raised concerns regarding the potential for negative impacts associated with salinity changes in the lower Peace River/upper Charlotte Harbor estuarine system, resulting from Facility freshwater withdrawals. The HBMP has incorporated a wide variety of study elements since its initial inception, with a number of significant modifications made to the HBMP throughout its history. While the monitoring program's overall level of effort has remained relatively constant, study elements have been added and deleted in order to enhance the overall knowledge base of the lower Peace River/upper Charlotte Harbor estuarine system. Historically, those major monitoring elements aimed at assessing direct relationships with variations in freshwater inflow have had the longest histories of monitoring. While other program elements, such as those primarily focused on assessing indirect biological indicators, have extended over a number of years and then ended once a sufficient baseline level of information had been accumulated. A summary of the time-lines for each of the major historical HBMP components is presented in **Table 1.7**.

Between 1976 and 1996, the staff of the Environmental Quality Laboratory, Inc. (EQL) conducted all elements of the HBMP. Since the expansion of the permit requirements in 1996, individual programs have been divided during different periods among a number of research team members, including:

- U.S. Geological Survey
- ASCI Laboratory (formerly EQL)
- Benchmark Laboratory
- EarthBalance (formerly Florida Environmental)
- Atkins (formerly PBS&J)
- University of South Florida (Dr. Ernst Peebles)
- Mote Marine Laboratory (Dr. Ernie Estevez and Jim Culter)

The HBMP was never conceived to be a rigid monitoring program. Rather it has historically incorporated a flexible study design (adaptive management) that could be periodically restructured based on updated findings and identified research needs. When the first discussion began with District staff in 1975 about what might be included within the initial monitoring effort, very little was known about either salinity/flow relationships, or the spatial/temporal distributions of other physical/chemical water quality parameters in the lower Peace River/upper Charlotte Harbor Estuary. Even less was known about the biological communities that studies in other estuarine systems had indicated could potentially be negatively affected by substantial freshwater diversions. Much of the beginning effort under the initial HBMP study design was therefore directed toward developing sufficient data to statistically describe the spatial distribution and temporal seasonal variability among selected physical and chemical indicators within this estuarine system. The ultimate goal was to identify potential relationships of these selected indicators with natural seasonally occurring variation in freshwater inflows. The initial HBMP investigations included the collection of monthly *in situ* water column profile characteristics, and surface and near-bottom water chemistry at a wide variety of sites located from upstream of the Facility to near Boca Grande Pass.

In addition, initial attempts were begun to determine if key indicator species or biological communities could be identified to further assess responses to natural variations in freshwater inflows. Determining the presence of such long-term relationships was thought to be especially important since, with only a small percentage of total flow being initially diverted, the direct effects of Facility withdrawals were projected to be extremely small in comparison to natural variation. The original HBMP elements included a number of biological studies listed below:

- An initial long-term study of the seasonal pattern of juvenile fishes in the upper harbor;
- Studies of benthic indicator species;
- An investigation of the seasonal distribution of Luidia clathrata (common names include grey, slender or stripped sea star) in upper Charlotte Harbor and up into the lower Peace River (approximately to just downstream of the current I-75 Bridge crossing);
- A long-term vegetation study of first and last occurrence of selected freshwater and saltwater indicator plant taxa along the lower Peace River, and
- Periodic aerial photographic documentation of potential changes in the spatial distribution of major riparian vegetation patterns along the banks of the lower river.

Analysis of data from pre- and post-water treatment plant operation, presented in the August 1982 Summary Report, indicated the need to revise the monitoring program to better evaluate changes in the Charlotte Harbor system due to both natural seasonal and longer-term variations in freshwater inflows, given the relative magnitude and timing of changes due to Facility withdrawals. Further modifications and refinements to the HBMP were further made in 1985 and again in conjunction with the renewal of the Water Use Permit in November 1988.

In the 1980s, studies of zooplankton and phytoplankton community structure and primary production were added to the HBMP. These studies were again not intended to directly evaluate the influences of withdrawals, but rather were designed to address issues related to the “health of the estuary” and the influences of naturally occurring extended periods of drought and flood conditions on key initial components of the estuarine food-chain. The short-term benthic invertebrate study and the fish nursery investigation conducted in the late 1990s were again not designed to measure the influences of withdrawal directly, but rather were intended to investigate the spatial responses of biological communities to natural variations in freshwater inflows.

As a result of findings from these studies, presented in the both the 1993 and 1995 Summary HBMP Reports, as well as additional specific analyses requested by District staff during the permit renewal process, an expanded HBMP was approved by the District in March 1996 as part of the District’s issuance of a 20 year Water Use Permit for the Peace River Facility. An explicit element of the 1996 HBMP modification was the development of standardized station descriptors to be applied across all program elements. As part of a required morphometric study, the "mouth" of the Peace River was defined using U.S. Geological Survey (USGS) standardized protocols as an imaginary line extending from Punta Gorda Point to Hog Island. Since the morphometric study, all new and previous on-going study element monitoring locations have been cross-referenced to this "River Kilometer" identification system. **Figure 1.2** and **Table 1.8** provide a summary of the locations of all of the ongoing long-term fixed study elements and a cross-reference to previous station identifications.

As defined by the District 1996 Water Use Permit conditions, the primary focus and overall objective of the HBMP is to assess the following key issues:

- Monitor river withdrawals from the Peace River by the Facility and evaluate gaged tributary flows from Joshua, Horse and Shell Creeks, as well as the primary Peace River flows measured at Arcadia and direct rainfall to the lower Peace River;

- Evaluate relationships between the ecology of the lower Peace River/upper Charlotte Harbor Estuary and freshwater inflows;

- Monitor selected water quality and biological variables to determine whether the ecological characteristics of the estuary related to freshwater inflows are changing over time;

- Determine the relative degree and magnitude of effects of Peace River withdrawals by the Facility on ecological changes that may be observed in the lower Peace River/upper Charlotte Harbor estuarine system;
- Evaluate whether consumptive freshwater withdrawals significantly contribute to any adverse ecological impacts to the estuary resulting from extended periods of low freshwater inflows; and

- Evaluate whether the withdrawals have had any significant effects on the ecology of the estuary, based on related information such as nutrient loadings, fish abundance, or seagrass distribution data collected by other studies conducted by the District or other parties.

1.2.1 Scientific Review Panel

A Peace River HBMP Scientific Review Panel (Panel) was implemented in conjunction with the 1996 Water Use Permit renewal. The Panel's primary objective was to provide guidance and recommendations to both the District and Authority regarding ongoing monitoring, reports and studies associated with overall lower Peace River/upper Charlotte Harbor Hydrobiological

Monitoring Program. A detailed history of the Panel, as summarized in the *2011 HBMP Comprehensive Summary Report*, can be found in **Appendix A**.

1.2.2 Ongoing Study Elements of the HBMP

The 1996 Water Use Permit renewal specified reporting requirements with respect to data collected and interpreted under the HBMP. In addition to Annual Data Reports, the permit required limited Mid-term Reports and much more extensive Comprehensive Summary Reports be submitted to the District approximately after the third and fifth years of each five-year interval over the duration of the twenty-year permit. Due to increased public concerns regarding long-term hydrologic alterations of freshwater flows in the Peace River watershed and comments received from the Scientific Review Panel, the Authority expanded the level of data analysis in all of the HBMP Reports beyond that originally envisioned by the 1996 permit . The primary focus of these additional increased statistical analyses and evaluations have been specifically directed toward further assessing both the magnitude, temporal and spatial distribution of potential impacts resulting from both current and projected future Facility withdrawals. Due to the increase in analyses included in the Annual Data Reports and Scientific Review Panel comments, the previous 3-year Mid-term Reports have been replaced in favor of appropriate short-term, “special studies” directed toward answering specific questions raised by the Panel and/or District. The following briefly summarizes both the ongoing and some of the major recent changes in the HBMP program elements.

1.2.2.1 Continuous Recorders (USGS and Authority)

During the 1996 permit renewal, the need was identified to begin collecting salinity data at fixed points along the HBMP monitoring longitudinal transect at much greater frequencies than the ongoing monthly monitoring. Such information, combined with corresponding tide/wind influenced gage height, freshwater flows, and withdrawals could then be used to develop detailed spatial and temporal relationships through the development of statistical and/or mechanistic models. These models would allow increased accuracy in assessing the relative magnitudes of short and longer-term salinity changes due to permitted Facility withdrawals (see **Chapter 4.0**). Such salinity changes are expected to result from the interactions and combined influences of seasonally varying withdrawals with natural variations in both flows and tides. A secondary goal of deployment of continuous recorders might be to assess potential long-term changes in river salinity, which might be explained by future predicted long-term progressive increases in sea level.

Following the 1996 renewal of the Facility water use permit, two initial subsurface/near bottom 15-minute recorder locations were established in the lower Peace River by USGS. Responding to comments and recommendations of the HBMP Scientific Review Panel, the Authority itself subsequently deployed three additional continuous subsurface salinity recorders in December of 2005, two additional recorders again in May 2008, and recently three more recorders at the end of June 2011. In December 2009, USGS installed another location, consisting of a pair of near surface and near bottom continuous recorders, immediately adjacent to the Facility’s river intake structure. The three USGS recorder locations provide the Authority the ability to assess river conductance both downstream and at the Facility in real time, in order to prevent the withdrawal of higher conductance water during lower flows above the 130 cfs threshold. The relative locations during 2016 of the recorder array along the lower Peace River HBMP monitoring transect are depicted in **Figure 1.3** and further summarized in **Tables 1.8** and Table 1.9.

Table 1.9

Summary of HBMP 2016 Array of Continuous Recorders on the Peace River

Gage ID, Location and Period of Monitoring	River Kilometer
RK09 (Authority) – Navigation Marker south of I75 Bridge – June 2011 to present	RK 09.2
RK12 (Authority) - Manatee Zone Marker near Shell Creek (near bottom) – May 2008 to Jun 2011	RK 12.7
RK12 (Authority) - Manatee Zone Marker near Shell Creek (surface) – Jun 2011 to present	RK 12.7
HH (USGS - 02297460) – Dock at Harbour Heights - Sep1996 to present	RK 15.5
RK18 (Authority) – Channel Marker in Area of Power Lines – June 2011 to present	RK 18.5
RK18_HC (Authority) - Manatee Zone Marker on Hunter Creek - Jun 2011 to present	RK 18.7
RK20 (Authority) – Channel Marker downstream of Island – June 2011 to present	RK 20.8
RK21 (Authority) - Manatee Zone Marker near Liverpool area - Dec 2005 to present	RK 21.9
RK23 (Authority) - Manatee Zone Marker downstream of Navigator Marina - Dec 2005 to May 2008	RK 23.4
RK24 (Authority) - Manatee Zone Marker gage near Navigator Marina - Dec 2005 to present	RK 24.5
PRH (USGS - 02297350) – Dock at Peace River Heights gage – Nov 1997 to present	RK 26.7
PRP (USGS – 02297345) – Peace River at Platt (Facility) – December 2009 to present	RK 29.8
RK30 (Authority) - Manatee Zone Marker near SR 761 Bridge – May 2008 to June 2011	RK 30.6
RK31 (Authority) - Old Railroad Bridge upstream of Facility – May 2008 to present	RK 31.7

1.2.2.2 Water Chemistry and Water Column Physical Profiles

These HBMP study elements involve the measurement of physical and chemical water quality over time, primarily tracking the overall "health of the estuary." A key goal is to collect sufficient long-term data to be able to statistically describe natural spatial and seasonal variability in the water quality characteristics of the lower Peace River/upper Charlotte Harbor Estuary, and to test for significant changes over time (trends). A second goal is to determine whether significant relationships exist between freshwater inflows and the seasonal/spatial variability of these water quality parameters. If such relationships can be shown, then the ultimate goal is to determine the potential magnitude of change that might result from permitted withdrawals, and compare such predictions with the range of observed natural variability.

Physical and chemical water quality parameters are measured within the lower Peace River/upper Charlotte Harbor Estuary under two different HBMP study elements:

1. During the first part of each month, water quality measurements (physical and chemical) are conducted at four “moving” salinity-based isohaline locations (0, 6, 12 and 20 psu) along a River Kilometer center-line running from the “mouth” of the Peace River upstream to above its junction with Horse Creek, and downstream to Boca Grande Pass. The relative monthly location of each sampling is based on the first occurrence of these specific isohalines (± 0.5 psu), with freshwater being defined as the first occurrence of conductivities less than 500 us/cm (or until reaching the upstream Horse Creek confluence at RK 34.1). The isohaline sampling effort was undertaken in conjunction with the long-term phytoplankton elements of the HBMP. Physical and chemical water quality determinations are also made at RK 30.7 (Station 18) immediately upstream of the Facility’s intake. When station 18 is combined with the results of the “fixed” monthly sampling (described below), this results in approximately bi-weekly information being collected at this spatially important location (RK 30.7).

2. Approximately two weeks after the collection of the “moving” isohalines, water column physical profiles are conducted, near high tide, at sixteen fixed locations along a transect running from just below the river’s mouth upstream to a point just above the Peace River Facility (see **Figure 1.2** and **Table 1.8**). In addition, chemical water quality samples are taken at five of these locations.

Both of these water quality HBMP study elements include physical *in situ* water column profile measurements of characteristic parameters (temperature, dissolved oxygen, pH, conductivity and salinity) at 0.5-meter intervals from the surface to the bottom. In addition both efforts measure the penetration of photosynthetically active radiation (PAR) to determine ambient extinction coefficients at specific sampling locations. Both studies also include the analyses of an extensive list of chemical water quality parameters. The only difference is that at the “fixed” sampling stations both sub-surface and near-bottom samples are collected at each of the five sites, while only sub-surface water chemistry samples are taken as part of “moving” isohaline phytoplankton production study element.

The HBMP Scientific Review Panel agreed during its November 2002 meeting that both the “fixed” and “moving” water quality monitoring programs were important, but that certain water chemistry parameters could be omitted from the sampling regime. The Scientific Review Panel recommended that the District accept the suggested chemical parameter revisions with the caveat that chlorides and silica continue as HBMP parameters. Based on these recommendations, the District agreed to the revised HBMP water chemistry parameter list (**Table 1.10**) starting in January 2003.

1.2.2.3 Phytoplankton Studies

Sub-surface samples are collected in conjunction with the “moving” isohaline sampling of physical and chemical water quality characteristics described above.

Phytoplankton Primary Production – From June 1983 through December 1999, statistically comparable levels of phytoplankton ^{14}C fixation rates were measured monthly at each of the four moving salinity-based isohaline locations. In addition to overall estimates of phytoplankton production, carbon uptake rates were determined for three separate size fractions: 1) greater than 20 microns; 2) 5 to 20 microns; and 3) less than 5 microns. The results of this long-term HBMP study clearly showed the quick response of phytoplankton production to brief pulses of relatively nitrogen rich freshwater into the estuary during the early spring. These results further supported the extreme importance to other components of the estuarine food-web of early spring/summer flows to the estuary during the start of the typical summer wet-season. Based on the extensive nature of the database gathered, *in situ* carbon uptake measurements were omitted from the HBMP in 2000.

Species Composition - A second element of the HBMP phytoplankton study, conducted monthly between 1989 and 2004, sought to quantify the specific responses of major phytoplankton taxonomic groups to variations in the periodicity of freshwater inflow. The developed monthly phytoplankton taxonomic information included: 1) raw counts of the relative taxonomic structure; 2) percent composition of key major taxonomic groups; and 3) summary species diversity and evenness index estimates. This monitoring effort ceased following 2004 based on the recommendations of the Peace River HBMP Scientific Review Panel.

Phytoplankton Biomass Estimates – Although direct *in situ* measurements of carbon uptake rates and enumerations of phytoplankton taxonomic structure are no longer conducted, the HBMP isohaline-based monitoring study element continues to collect monthly information of phytoplankton biomass (chlorophyll *a*), in relation to seasonal and flow-related variations in physical parameters, water column light profiles, and the major chemical constituents associated with phytoplankton growth.

***In Situ* Chlorophyll Transect Monitoring** - Both the “fixed” and “moving” HBMP study elements have previously indicated the existence of seasonally-variable chlorophyll *a* maxima along the lower Peace River/upper Charlotte Harbor monitoring transect. Based on the recommendation of the HBMP Scientific Review Panel, and following consultation with District staff, the Authority volunteered to implement a new HBMP study element beginning in April 2013. This new HBMP study element employs an *in situ* fluorometric chlorophyll *a* methodology to provide the type of enhanced spatial intense information needed to accurately define the monthly magnitude and spatial extent of variations in chlorophyll *a* patterns within the lower Peace River/upper Charlotte Harbor Estuary. Accurate spatial determinations of the relative intensity and location of monthly chlorophyll *a* maxima patterns are expected to provide additional information regarding the known seasonal interactions between changes in freshwater flow (relative to additions of both nutrients and color) in relation to the seasonal movement of important estuarine zones of primary (and secondary) production. An analysis of the utility of this new HBMP study element, and recommendations for its future continuance, are expected to be made following several years of data gathering, and then potentially at specific intervals as part of future major summary monitoring program reports.

1.2.2.4 HBMP Study of Long-Term Changes in Vegetation

At selected intervals between 1976 and 2004, three different HBMP study elements were conducted to assess variations in emergent and riparian vegetation along the lower Peace River. The overall objective of these monitoring programs was to determine the magnitude of annual and longer term changes caused by natural river flow differences between extended wet and dry periods. The objective was to assess the potential magnitude of changes in vegetation patterns along the lower river that could be attributed to current and projected Facility withdrawals.

The vegetative monitoring elements of the HBMP provided information to determine relationships between vegetation patterns and freshwater flows by observing the positions of the freshwater and salt-tolerant plant communities, especially in the salinity transitional zone of the river. A permanent shift of more salt-tolerant plants upriver could be an indication that withdrawals were impacting the river corridor wetlands, as long as natural variability (drought) or other man-made causes could be eliminated.

HBMP studies of long-term changes in vegetation consisted of three elements. Photo-interpretation began in 1976. Initially, aerial infra-red photography of the vegetative communities along the lower Peace River was taken yearly, starting at the US 41 Bridge (River Kilometer 6.6) and extending upstream above the Peace River Facility to near the area where Horse Creek enters the river (River Kilometer 39.5). Under the 1996 HBMP permit modifications, such aerial surveys continued to be conducted at two-year intervals. All post-1996 aerial photography was taken in a corrected, GIS compatible format, thus allowing for accurate quantification of any observed changes. Photo-interpretation of these images, in conjunction with field observations, will periodically be used to develop maps of the river’s vegetation associations. Both qualitative and quantitative data are being used to assess potential changes associated with extended natural periods of both low and high freshwater inflows.

Since 1976, at approximately two-year intervals, the first and last occurrence of a large number of indicator plant species has been recorded along the banks of the Peace River downstream of the Peace River Facility. As part of the vegetation study element of the HBMP, detailed maps using the standardized River Kilometer scale were made, identifying the first and last occurrences of individual and substantial populations of key indicator species. These data were used in conjunction with the aerial photography to assess the influences of long-term natural variations in river flow.

Detailed monitoring of plant communities along the river banks at fixed locations began in 1979 and was expanded under later permits. The vegetative communities at three permanent transect sites were sampled at two-year intervals. At each monitoring location, three transects from the top of the bank to the water edge were surveyed. The vegetation one meter to each side of each transect was identified, and the location and density recorded. The objective of the long-term vegetation data was to be used to further assess the response of the riverine vegetative communities to natural variations in freshwater flows.

Complete and thorough analyses of the long-term results of these vegetation studies were presented in both the *2002 HBMP Comprehensive Summary Report* and the *2004 HBMP Annual Data Report*. These analyses indicated that vegetation patterns along the lower tidal Peace River have remained relatively stable over long periods of time, and show little in the way of consistent responses to natural periods of either high or low freshwater river flow. As a result, based on discussions with both the Scientific Review Panel and District staff, it was determined to suspend the vegetation monitoring elements with the exception of photo-interpretation.

Following 2004 this monitoring element continued at approximately five year intervals with actual photo interpretation or data analysis on an as needed basis.

1.2.2.5 Special Studies Associated with the HBMP

In addition to the monitoring elements of the HBMP summarized above, the revised HBMP program implemented in 1996 also required the Authority to conduct and/or contribute to a number of duration-limited studies designed to answer specific research questions. Comprehensive summaries of these special HBMP studies as well as other recent relevant reports by other research programs in the lower Peace River/upper Charlotte Harbor estuarine system were presented in the *2011 Comprehensive Summary Report* (and are also provided in **Appendix B**). Similar summaries of additional studies of the Peace River and Charlotte Harbor outside of the HBMP completed since that time are summarized in **Chapter 2**.

1.2.2.6 Assessing Significant Environmental Change

Since its inception in 1976, the HBMP has incorporated numerous physical, chemical, and biological study elements directed toward assessing both the overall "health of the estuary" as well as direct and indirect adverse impacts potentially associated with Facility withdrawals. To date none of the extensive HBMP analyses have found or suggested any significant long-term physical, chemical or biological changes in the lower Peace River/upper Charlotte Harbor estuarine system, resulting from either current or historic water withdrawals by the Facility.

The *2002 HBMP Comprehensive Report* proposed an initial approach for determining from the HBMP data whether permitted surface water withdrawals are causing or have caused adverse environmental changes in the lower Peace River estuarine system. In addition, a hierarchy of management actions was proposed to be implemented in response to detected changes that could forewarn potential future changes that would constitute an adverse change.

1.3 Report Organization and Primary Objectives

The following briefly summarizes the organization and primary objectives of each of the following chapters of this *2016 HBMP Comprehensive Summary Report*.

- **Chapter 2.0 - Summarizes the Primary Conclusions and Findings of Recent HBMP and other Reports –** This chapter provides brief overviews of each of the major studies and reports related to the Peace River watershed, lower Peace River and upper Charlotte Harbor that have been released since those previously summarized in the *2011 Peace River Comprehensive Summary Report*. Its primary focus is to provide concise overviews of the purpose and major conclusions of each study. A related appendix is also included that provides similar summaries presented in previous Comprehensive Summary Reports.

- **Chapter 3.0 - Status and Trends in Regional Rainfall, Flows, and Facility Withdrawals –** The purpose of this chapter is to provide updated graphical plots and trend analyses of rainfall and flows in the Peace and Myakka River watersheds over multiple time scales. Recent and historical unusual occurrences (such as extended droughts and unusually wet intervals) are documented and compared to the long-term average statistical characteristics at each of the major tributary gaging locations in the Peace River watershed.

- **Chapter 4.0 – Salinity in the Lower Peace River/Upper Charlotte Harbor Estuarine System –** This chapter examines spatial and temporal trends and patterns in salinity data collected by the HBMP at fixed, moving, and continuous recording stations. Relationships of salinity with flows are also examined. Statistical models relating salinity at both the long-term USGS and Authority continuous recorders to flows, tide stage, and withdrawals are developed or updated (if developed in prior reports). Additionally, the chapter discusses the anthropogenic impacts on salinity including Facility withdrawals, upstream land use changes, and sea level rise.

- **Chapter 5.0 – Water Quality in the Lower Peace River/Upper Charlotte Harbor Estuarine System –** The purpose of this chapter is to provide updated analyses of spatial and temporal patterns and trends for selected HBMP water quality variables, as well as their relationships with flow. Unusual occurrences, such as periods of extended drought, are documented and compared to the long-term statistical water quality characteristics.

- **Chapter 6.0 – Regulatory Impacts on Facility Operations –** The primary objective of this chapter is to describe regulations that impact withdrawals by the Facility. These include a description of the current MFL and the MFL review process, as well as a discussion of water quality impairments in the watershed.

- **Chapter 7.0 – Long-term Water Supply and Demand -** The primary objective of the chapter is to summarize long-term water demand and supply projection, as well as the Authority's Master Water Supply Plan and alternate source studies. This discussion includes a summary of major facility physical expansions and capabilities, regional demand for water, and supply system changes.

- **Chapter 8.0 – Assessing Environmental Change –** This chapter provides reference to prior HBMP Summary Reports that have detailed the regulatory basis of review, the rationale for defining significant environmental change, and the hierarchy of management actions proposed under the HBMP to be implemented in response to detected changes that could forewarn of potential future impacts of sufficient magnitude that they would constitute an "adverse change".

- **Chapter 9.0 - Potential Monitoring Design Modifications to the Existing Long-Term HBMP Elements –** Based on the overall preceding conclusions of the report, this chapter extends the discussions raised in previous Summary Reports, and discusses the potential future need for changes to HBMP study elements.

1.4 Summary

This introduction provides an overview for readers unfamiliar with the history of the Peace River Regional Water Supply Facility and the District's associated series of issued Water Use Permits.

The introduction reviews the history of the major study elements that have been associated with the forty-one year record of the ongoing HBMP.

- The primary goal of the HBMP study elements continues to be to provide the District with sufficient information to determine whether the biological communities of the lower Peace River/upper Charlotte Harbor estuarine system have been, are being, or may be adversely impacted by permitted freshwater withdrawals by the Authority's water treatment facility.
- The continually expanding base of ecological information developed by the HBMP continues to be used to periodically evaluate the effectiveness of the withdrawal schedule with regard to assuring the prevention of significant adverse estuarine impacts.

This *2016 HBMP Comprehensive Summary Report* follows and extends the summarization and interpretation of long-term HBMP data previously submitted in the *2002 HBMP Comprehensive Summary Report*, the *2004 Midterm Interpretive Report*, the *2006 HBMP Comprehensive Summary Report*, and the *2011 HBMP Comprehensive Summary Report*. Its primary goals and objectives are to provide the District with sufficient analyses to:

- Evaluate key relationships between ecological characteristics and freshwater inflows, and determine whether the biological health and productivity of the estuary are showing signs of stress related to natural periods of low freshwater inflow or potential negative influences of Facility withdrawals.
- Assess the presence or absence of long-term trends for important HBMP variables.
- Evaluate the overall HBMP design and make recommendations regarding implementing modifications.
- Assess the presence or absence of adverse ecological impacts and determine the influence Facility withdrawals may have contributed to such impacts.
- Evaluate the potential environmental impacts that may be associated with additional future increased withdrawals from the river and the feasibility of increased water supplies.
- Assess and evaluate the effectiveness of the withdrawal schedule for preventing adverse environmental impacts.

None of the detailed analyses of HBMP data presented in previous HBMP reports have shown that Facility withdrawals have had, or are expected to cause, significant physical or biological adverse impacts within the lower Peace River/upper Charlotte Harbor estuarine system. A key objective of this report is to provide the District with sufficient analyses of the HBMP data to date to assure that the revised withdrawal schedule continues to provide adequate continuing resource protection.

2.0 Summaries of Recent Relevant Reports

Prior *HBMP Comprehensive Summary Reports* (September 2004, April 2008 and December 2013) provided brief overviews of major studies related to the lower Peace River/upper Charlotte Harbor estuary system primarily completed between 1996 and 2011. This chapter continues providing brief overviews of major reports and studies related to the lower Peace River/Charlotte Harbor estuarine system since those previously summarized in the *2011 Comprehensive Summary Report*.

Concise overviews of the purpose and major conclusions of these reports and studies are provided below from oldest to more recent. Similar reviews previously contained within the 2002, 2006, and 2011 *HBMP Comprehensive Summary Reports* are provided in Appendix B.

- *The Charlotte Harbor Seven-County Watershed Report (*CHNEP 2011)
- *Proposed Numeric Nutrient Criteria for the Charlotte Harbor National Estuary Program Estuarine System* (Janicki Environmental 2011)
- *Charlotte Harbor National Estuary Program Oyster Habitat Restoration Plan (*Boswell et al 2012)
- *Status Report for the Southern Water Use Caution Area Specific Conductance Reconnaissance Network (*SWFWMD 2012*)*
- *2012 HBMP Annual Data Report (*Atkins 2013*)*
- *Results of the Florida Department of Environmental Protection, Charlotte Harbor Aquatic Preserves' Seagrass Monitoring Program from 1999-2009* (Brown et al 2013, Florida Scientist)
- *Freshwater Fish Communities and Habitat Use in the Peace River Florida (*Call et al 2013, Florida Scientist)
- *Water Quality Data Analysis Report for the Charlotte Harbor National Estuary Program (*Janicki Environmental 2013*)*
- *Fish Assemblages in the Oligohaline Stretch of a Southwest Florida River during Periods of Extreme Freshwater Inflow Variation (*Stevens et al 2013 Transactions of the American Fisheries Society)
- *The Effects of Environmental Disturbance on the Abundance of Two Recreationally-Important Fishes in a Subtropical Floodplain River (*Blewett and Stevens 2013, Florida Scientist)
- *A Water Clarity Evaluation and Tracking Tool for the Estuarine Waters of Lemon Bay, Charlotte Harbor and Estero Bay, Florida (*Wessel et al 2013, Florida Scientist)
- *Retrospective Analysis and Sea Level Rise Modeling of Coastal Habitat Change in Charlotte Harbor to Identify Restoration and Adaptation Priorities (*Geselbracht et al 2013, Florida Scientist)
- *2013 HBMP Annual Data Report (*Atkins 2014*)*
- *The Optical Model Spectral Validation and Annual Water Clarity Reporting Tool: Final Report (*Dixon and Wessel 2014*)*

- *An Analysis of the Relationships of Freshwater Inflow and Nutrient Loading with Chlorophyll Values and Primary Production Rates in the Lower Peace River (*Atkins 2014*)*
- *Seasonal Differences and Responses to a Tropical Storm Reflected in Diatom Assemblage Changes in a Southwest Florida Watershed (*Nodine and Gaiser 2015 Ecological Indicators)
- *2012 Annual Report Horse Creek Stewardship Program (*Cardno 2015)
- *2015 Regional Water Supply Plan Southern Planning Region (*SWFWMD 2015)
- *City of Punta Gorda Shell Creek HBMP Year Five Comprehensive Summary Report (*Atkins expected 2017)
- *Integrated Regional Water Supply Plan 2015 (*Atkins et al 2015)
- *2014 HBMP Annual Data Report (*Janicki Environmental 2016*)*
- *2015 HBMP Annual Data Report (*Janicki Environmental 2016*)*
- *A spectral optical model and updated water clarity reporting tool for Charlotte Harbor Seagrasses. (*Dixon and Wessel 2016, Florida Scientist*)*
- *Estuary-Specific Numeric Interpretations of the Narrative Nutrient Criterion (62-302.532 FAC)*
- *2016 HBMP Annual Data Report (*Janicki Environmental expected 2017*)*

2.1 The Charlotte Harbor Seven-County Watershed Report (CHNEP, 2011)

This *Watershed Report* reviews the progress achieved in implementing the Comprehensive Conservation and Management Plan (CCMP) that identifies natural resource priorities for the natural environment within the Charlotte Harbor Watershed. Charlotte Harbor National Estuary Program (CHNEP) partners provided the data, analysis and guidance toward development of the report.

The *Watershed Report* addresses questions regarding multiple Charlotte Harbor environmental indicators. The first part of the report addresses several questions related to fish and shellfish. Over a 15-year period of analysis (1996-2010) the report indicates no significant change in fish quantity, however there was a loss of small fish diversity in shallow waters over the last five years of the study. Nonnative fish were reported as rare. Fish and shellfish are noted in the *Watershed Report* to be safely harvested and eaten in Charlotte Harbor's waters. Mercury is documented as a contaminant of concern. The report advised following consumption advisories for fish, not eating large sharks and king mackerels at all, and consuming shellfish only from areas and dates approved for shellfish harvest. In general, shellfish harvest closures were greatest during periods of heavy rainfall when pollutants are washed from the land and into shellfish harvest areas.

The next section of the report focused on fish and wildlife habitat, namely seagrass, mangrove and freshwater wetland habitats. Seagrasses are a vital estuarine habitat, trapping suspended sediments, providing food, and supplying habitat for a variety of sea life. The report states that as of 2008, seagrasses covered more than 95% of their 1950s extent, having expanded 10% since a recorded low in 1999. Boat prop scar damage and water quality degradation are noted as threats to seagrasses. As of 2005, mangroves are reported as covering more than 60,000 acres, providing food and habitat for multiple species, and buffering inland areas from storm surges and wind. The *Watershed Report* states that, since 1990, mangrove area (or extent) has been relatively stable, however more than one third of mangrove shoreline was degraded, primarily as a result of Hurricane Charley. Freshwater wetlands provide many valuable functions including the storage and cleaning of water and the provision of habitat for birds, mammals, reptiles and amphibians. The *Watershed Report* indicates that only 57% of pre-development freshwater wetland areas remained; between 1990 and 2005, another 2.5% of freshwater wetlands were lost. Much of this loss is attributed to agricultural drainage, mining and urban land development. In addition to these three key habitats, the report concludes that more than 18% of natural shoreline has been lost. Of urban mangroves, 52% were trimmed, degrading them. Nonnative plants dominated 3% of the shoreline.

The *Watershed Report* then provides an overview of land management in the watershed. More than 460,000 acres in the watershed at the time of the report were under some form of conservation management; there has been a gain of more than 210,000 acres since 1998. In total, 14% of the watershed land was noted as in conservation. The State of Florida manages the majority of the lands in conservation management, followed by the Water Management Districts, counties with land acquisition programs, and other agencies including the federal government, private land trusts and cities. Almost 49% of the CHNEP's estuarine waters are under state aquatic preserve or federal wildlife refuge management.

In addition to land management, the *Watershed Report* summarizes environmental restoration in the watershed. Between 2000 and 2010, more than 68,000 acres were restored by public and private agencies. All coastal counties and most coastal cities in the watershed had adopted ordinances reducing fertilizer use by 2011, reducing excess nutrients added to the watershed by hundreds of tons every year. Additionally, the District's Facilitation Agricultural Resource Management Systems Program has reduced nutrient pollution and conserved water on more than 115,000 acres of agricultural property within the watershed.

The *Watershed Report* then provides a brief overview of flows in the rivers of the Charlotte Harbor watershed; the Caloosahatchee has the greatest flows, followed by the Peace and Myakka Rivers. River flows are described as a function of rainfall, the size of the watershed feeding the river and the amount of impervious surface. Caloosahatchee flows have been altered by channelization and construction of dams and locks. The District has adopted a minimum mean monthly flow of 300 cfs at Franklin Lock and Dam. The report indicates that the Caloosahatchee River does not receive enough water in the dry season due to demands for irrigation water and receives too much water in the wet season. At the time of the report, the District had set low flow thresholds on the Peace River in Bartow at 17 cfs and in Arcadia at 67 cfs. The report indicates that the alteration of wetlands, streams and lakes, combined with natural periods of drought, has greatly diminished the flow of water in the Peace River and its tributaries and has altered ecosystems, particularly in the northern portions of the watershed. The Myakka River is designated a Wild and Scenic River; significant land acquisition within its watershed renders the Myakka the most natural river in the estuary. The *Watershed Report* states that the Myakka River receives too much flow from dry season irrigation; diversion of Cow Pen Slough flows from the Myakka River basin balances some of this increased flow.

The *Watershed Report* next addresses topics related to water quality and clarity in the watershed. Multiple threats to water quality in the CHNEP are noted, including excessive levels of bacteria, nutrients and turbidity; additional concerns include toxins and harmful algal blooms. The report states that bacteria and nutrient problems are numerous and growing worse. However there are some improving trends in estuaries, likely due to cities replacing septic tanks with central sewer. In 2009, seven of ten Bay Segments did not meet established water clarity targets. Conversely, Pine Island Sound, Tidal Myakka and San Carlos Bay were noted as having excellent water clarity and seagrass extent.

The *Watershed Report* summarizes areas of concern relevant to the health of the estuary. One large concern is water pollution, including excessive nitrogen and phosphorus concentrations and loadings. The biggest per-acre sources of nitrogen pollution are failed septic tanks, feedlots, commercial property and row crops. Commercial property, multifamily residences and mining are the most significant sources of suspended solids. An emerging concern in terms of water pollution is pharmaceuticals and personal care products (PPCPs). Many of these products contain endocrine disrupting ecoestrogens which are capable of altering the normal functions of natural hormones responsible for regulating animal development, reproduction, immune function and other physiological processes.

An additional emerging concern is climate change. Key questions regarding climate change include the degree to which change will continue, how rapidly change will occur and what the long-term human and ecological effects of these changes will be. The Charlotte Harbor region is noted as particularly vulnerable due to the flat topography, naturally poor drainage, and near sea level altitude. The majority of conservation lands and the regional economy have major investments near the coast or lake water bodies and the climate is naturally extreme even in the absence of new changes.

2.2 Proposed Numeric Nutrient Criteria for the Charlotte Harbor National Estuary Program Estuarine System (Janicki Environmental, 2011)

This report details the series of tasks conducted by the Charlotte Harbor National Estuary Program (CHNEP) intended to establish estuarine numeric nutrient criteria (NNC) for the CHNEP segments. The document provides background information on the CHNEP estuarine system and a summary of work completed with respect to estuarine targets. Additionally, the report provides the data and methodology utilized for developing estuarine NNC for the CHNEP estuarine segments, the resulting targets and proposed NNC, and the proposed methodology for implementation and compliance of the CHNEP estuarine NNC. The primary objective of the document is to propose estuarine numeric nutrient criteria specific to the segments of the CHNEP: Dona and Roberts Bay, Upper Lemon Bay, Lower Lemon Bay, Tidal Myakka, Tidal Peace, Charlotte Harbor Proper (composed of East Wall, West Wall, Bokeelia, and Cape Haze), Matlacha Pass, Pine Island Sound, San Carlos Bay, Tidal Caloosahatchee, and Estero Bay. The criteria are expressed as TN concentrations in these segments.

The report describes the use of seagrasses as a living resource basis for developing water quality targets in the CHNEP estuaries. Initial targets were developed in 2005 based on seagrass light requirements at the maximum growth depth and the relationship of water clarity to light attenuators such as color dissolved organic matter, chlorophyll-a and turbidity. In 2009, the CHNEP began to refine the water quality targets based on updated light availability and water quality data based on seagrass acreage and a reference period approach.

Seagrass targets were developed and approved as a CHNEP management tool in 2009 to track changes in an important ecological indicator over time. These targets provide a basis for management decisions regarding issues such as water quality that can influence the distribution and persistence of seagrasses. The targets were defined from analysis of historic and recent aerial surveys of the study area. In addition to targets, the range of acceptable seagrass areas was also defined as the range between the minimum and maximum areas from the recent surveys.

In terms of developing chlorophyll *a* targets, the CHNEP Technical Advisory Committee (TAC) decided to use a similar approach as neighboring estuary programs, but with different thresholds depending on whether or not a segment was classified as “restoration” or “protection”. The “restoration” threshold is more stringent than the “protection” threshold because “restoration” segments have not achieved the desired levels of seagrass coverage. A reference period of 2003-2007 was used to establish the chlorophyll *a* targets which corresponds to the time period used in establishing the water clarity targets for CHNEP. A distinction was made between a target (a desired chlorophyll *a* concentration) and a threshold (a chlorophyll *a* concentration above which undesirable chlorophyll *a* concentrations exist.

The development of NNC for the segments of the CHNEP area followed an evaluation of stressor-response relationships. The approach involved the development of a quantitative relationship between chlorophyll *a* and independent variables such as nutrient loadings, concentrations and estimates of residence time. Following the analyses, NNC in terms of TN concentrations were developed for each segment. The CHNEP Management and Policy committees approved the TAC recommendations for the TN concentration-based numeric criteria (shown below) based on the Reference Period approach, as no appropriate stressor-response relationships were found that could be used to develop defensible numeric nutrient criteria.

Recommended numeric nutrient criteria based on the reference period approach for TN concentration

Segment	Candidate Criterion
Dona and Roberts Bays	0.42 mg/L
Upper Lemon Bay	0.56 mg/L
Lower Lemon Bay	0.62 mg/L
Tidal Myakka	1.02 mg/L
Tidal Peace	1.08 mg/L
Charlotte Harbor Proper	0.67 mg/L
Matlacha Pass	0.58 mg/L
Pine Island Sound	0.57 mg/L
Tidal Caloosahatchee	TBD
San Carlos Bay	0.56 mg/L
Estero Bay	0.63 mg/L

The document proposes a compliance assessment strategy consisting of two steps. The initial step is the comparison of mean annual chlorophyll *a* concentrations in each bay segment to the established thresholds. Compliance is achieved if the threshold is met in that year. Exceedance in more than two years during any five-year period would trigger a second step of an assessment of nitrogen concentrations during that period. Defensible compliance assessment is dependent upon continued monitoring to ensure the annual assessments can be completed for attainment of the proposed chlorophyll *a* thresholds and TN criteria.

Appendices to the document detail (1) the data description and assessment of seagrass, water quality and loadings, (2) criteria expressed as TN and TP concentrations and loads, (3) implementation issues, and (4) maps of the monitoring sites utilized for water quality assessment in each segment.

2.3 Status Report for the Southern Water Use Caution Area Specific Conductance Reconnaissance Network (SWFWMD 2012)

This report summarizes the monitoring results from 2011 Water Quality Monitoring Program (WQMP) of the Southwest Florida Water Management District (District) at 143 surface water stations in the Southern Water Use Caution Area (SWUCA) Specific Conductance Reconnaissance Network (SCRN). The network of streams and canals was established in May 2004 and tracks changes in surface water quality related to elevated levels of specific conductance derived from runoff from agricultural irrigation with mineralized groundwater.

Specific conductance values obtained from the SCRN stations were compared to three target concentrations: (1) 900 uS/cm, (2) 1275 uS/cm, and (3) 775 uS/cm. The 1275 uS/cm represents the FDEP Class I and Class III criteria for specific conductance. To anticipate areas where values may exceed the FDEP criteria, the district has adopted the 900 uS/cm threshold as an indication of groundwater signature characteristics. The reference value of 775 uS/cm is used as a surrogate to assure chloride and TDS are below their respective Class I criteria.

Stations exceeding the 900 uS/cm are referred to the Facilitating Agricultural Resource Management Systems (FARMS) Program for further investigation of potential sources of groundwater runoff in the immediate or surrounding areas. Letters were mailed to landowners requesting permission to sample wells. Sampling of these wells allows FARMS staff to analyze potential FARMS projects that may improve water quality in these areas.

Several key observations are mentioned from the 2011 monitoring:

- 21 percent of the SCRN stations within the SWUCA exceeded the 900 uS/cm threshold for specific conductance during the 2011 dry season sampling events
- Nine percent of the SCRN stations within the SWUCA exceeded the FDEP Class I and Class III surface water quality criteria for specific conductance of 1275 uS/cm during the 2011 dry season sampling events

- The number of exceedances was decreased during the 2011 wet season sampling which is expected given increased wet season precipitation and usually less irrigation with groundwater.
- Eight stations remained above the 900 uS/cm threshold for both dry and wet season sampling indicating these stations are experiencing prolonged influence from groundwater runoff.
- 29 stations were either dry or not flowing during the dry season event; an increase from the 2009 (n=15) and 2010 (n=16) dry season events.

The Peace River Basin exhibited the greatest number of stations exceeding the 900 uS/cm in either the wet or dry season. The report indicates that waters with elevated specific conductance within this area are being addressed through the Shell Creek and Prairie Creek Watersheds Management Plan, and subsequent performance monitoring reports for the Plan.

Two of the stations in the SWUCA SCRN also had Habitat Assessments (HA) and Stream Condition Index (SCI) determinations during the reporting period. Both of the sites exceeded the 900 uS/cm threshold but neither exceeded the 1275 uS/cm Class I and Class III criteria. One site was scored as Category 1 (“exceptional”). The other site was scored as Category 3 (“impaired”) for the overall SCI score.

The report made the following recommendations:

- Continued monitoring of stations showing prolonged influence by highly mineralized waters
- Continued analysis and reporting of network results and the referral of this information to FARMS staff for consideration of potential management actions
- Further follow-up by FARMS staff focus on sub-basins not currently being addressed for highly mineralized water including the Horse Creek sub-basin and the Peace and Myakka Rivers lower sub-basins.
- Enhance monitoring within the SWUCA SCRN by expanding the extent of stations visited, particularly surface water bodies within the Most Impacted Area of the SWUCA in the coastal portions of Manatee, Sarasota and southern Hillsborough County.
- Expansion of HA and SCI testing to additional stations within the SWUCA SCRN, specifically those with exceedances of the 1275 uS/cm threshold.

2.4 Charlotte Harbor National Estuary Program Oyster Habitat Restoration Plan (Boswell et al., 2012)

The purpose of this *Restoration Plan* “is to provide a technically sound, consensus-based approach for identifying oyster habitat restoration goals, methods, and partnerships for the estuaries within the” Charlotte Harbor National Estuary Program (CHNEP). Oyster habitat was defined as substrate upon which a self-sustaining native oyster community develops, providing habitat for commensal flora and fauna.

A Restoration Suitability Model (RSM) was developed to help guide restoration decisions within the CHNEP and progress towards the restoration goal. The model uses GIS data to map locations of suitable restoration areas on a scale of 0-100% suitability. Output from the RSM indicated over 40,000 acres of highly suitable areas for oyster restoration within the study area. The *Restoration Plan* recommends that, prior to any restoration, site-specific field evaluations should be conducted to further evaluate if a site is suitable for oyster restoration, and what type of methods would be most successful.

Limited historical oyster data were available, but estimates show a 90% loss of oyster habitat in the CHNEP study area. Causes of this loss include dredging, oyster mining for road beds, sedimentation and costal development. Commercial harvest may have contributed to a lesser extent. Initial estimates suggest that the CHNEP study area should have 1,000 to 6,000 acres of oyster habitat under ideal conditions. Several short term actions were recommended to achieve this long term goal:

- Map oyster habitats by type within the CHNEP by 2020.
- Design, implement and monitor the success of pilot oyster restoration projects in a variety of habitats in 50% of the CHNEP estuary segments by 2020.
- Increase public awareness of the ecosystem value of native oyster habitats by including community stewardship components in each oyster restoration project.
- Assist partners in seeking funding opportunities to support oyster habitat restoration projects.

The plan provides guidance on permitting, success criteria, monitoring, funding opportunities, and community stewardship. The *Restoration Plan* was intended to be adaptive, incorporating lessons learned into future updates. The next update of the *Restoration Plan* is planned to be completed no later than 2020.

2.5 2012 HBMP Annual Data Report (Atkins, 2013)

This data report represents the 17th *Annual Data Report* submitted under the expanded Hydrobiological Monitoring Program (HBMP) initiated in 1996 in compliance with Water Use Permit 20010420. The report summarizes and compares data collected during 2012 with similar HBMP information previously compiled during various elements of the ongoing long-term monitoring program.

In making comparisons of the 2012 data with averages of similar data collected over the preceding 36-year period (1976-2011), it should be noted that the very wet winter/spring El Niño of 1997/1998 was followed by very dry La Niña conditions that influenced southwest Florida and the entire Peace River watershed between 1999 and early 2002. A weaker El Niño occurred at the end of 2002, and freshwater flows during 2003, 2004 and 2005 were generally above average. Rainfall in the Peace River watershed during the 2006 to 2009 interval, by comparison, was well below average, while seasonal rainfall patterns since then have returned to more normal conditions. However, as has been common in a number of recent years, dry season rainfall during the first part of 2012 was again well below normal.

- **Flows** – Average mean daily Peace River flow of the three combined gages upstream of the Facility during 2012 was 909.8 cfs, which is below the 1146.3 cfs average over the 37 years of HBMP monitoring (1976-2012). In comparison, the average flow during 2012 was well above the annual average flow of 524 cfs over the four-year interval between 2006 and 2009. However, it was also well below the average flow of 2046 cfs over the much wetter five-year interval between 2001 and 2005. Overall, annual mean flow upstream of the Facility during 2012 was just 79.4 percent of the average daily flow over the preceding long-term 1976-2011 period.

- **Withdrawals** – Total Peace River Facility withdrawals during 2012 were approximately 6.7 percent of the total gaged freshwater flow measured at the USGS Arcadia gage, 4.6 percent of the upstream gaged flow at the Facility, and 3.2 percent of the combined average daily inflows upstream of the U.S. 41 Bridge. During the entire period of Peace River Facility withdrawals (1980-2012), total combined withdrawals have been approximately 1.8 percent of the corresponding gaged Peace River at Arcadia flows, 1.3 percent of total gaged flow upstream of the Facility, and only 1.0 percent of the combined daily freshwater flows of the Peace River, and Horse, Joshua, and Shell Creeks.

  There were seven days during 2012 when Peace River Facility withdrawals exceeded the seasonally designated maximum percent allowed by the April 2011 revised permit withdrawal schedule. Such exceedances of the permitted percent withdrawals primarily result from subsequent USGS revisions of the provisional daily flow information available to the Authority at the time of actual withdrawals. During 2012, the facility did not withdraw any water from the river on 175 days or approximately 47 percent of the time.

- **Salinity Spatial Distribution** – While the freshwater inflows to the lower Peace River during 2012 were higher than during the recent severe 2006-2009 drought, through much of the year flows during 2012 were still below their characteristic seasonal flows. The influences of the drier than usual conditions that characterized overall 2012 flows are reflected in the seasonal and average spatial distributions of each of the four sampled moving isohalines along the HBMP monitoring transect. Overall, the relative spatial distributions of each of the isohalines during 2012 reflected slight upstream movements when compared with their previous long-term 1983-2011 averages.

- **Temperature** – Median annual water temperatures during 2012 at each of the four isohalines were, on average, slightly higher than corresponding temperature values measured over the preceding 29-year period (1983-2011). However corresponding mean annual 2012 water temperatures for the year by comparison were generally similar with their long-term averages. Unusually colder than normal seasonal winter water temperatures were observed early in 2010, 2011 as well as 2012. The seasonal annual low water temperatures during these three most recent years were in fact, three of the four coldest observed over the 29-years of monitoring at the four isohaline locations.

- **Water Color –** In comparison to seasonal averages over the preceding long-term historic period (1983-2011), water color levels during 2012 at 0 psu were lower than average, while being higher than the long-term average at the other three more downstream isohalines. During 2012 flows upstream of the Facility were approximately 20 percent below the longer 1976-2012 average, while corresponding Shell Creek flows which enter the lower Peace River further downstream nearer higher salinity harbor waters were more than 12 percent higher than average. These differences in regional rainfall/flows are expressed in the observed spatial differences in seasonal water color among the isohalines.

- **Extinction Coefficient –** The rates of measured light attenuation at each of the four HBMP isohalines reflect the interactions of both ambient color and phytoplankton biomass (chlorophyll *a*). Comparisons of mean extinction values among the four isohalines during 2012 with corresponding long-term averages show much lower levels at the three upstream isohalines (0, 6 and 12 psu), and higher than average at the most downstream, highest area of salinity level (20 psu). This result probably reflects the overall slightly lower than average annual combined flows that seasonally characterized periods of 2012.

- **Nitrite/NitrateNitrogen** - During 2012, the average concentrations of this major inorganic form of nitrogen were generally below the previously observed long-term (1983-2011) historical annual averages. The long-term data clearly indicate that inorganic nitrogen levels were also well below normal in the lower Peace River/upper Charlotte Harbor estuarine system during the recent years of extended drought. Monthly comparisons among the isohalines indicate nitrite/nitrate inorganic nitrogen concentrations in the lower Peace River/upper Charlotte Harbor estuarine system are characterized by a distinct spatial gradient that shows strong responses to seasonal patterns of freshwater inflows. Concentrations typically decrease rapidly with increasing salinity, with inorganic nitrogen levels within the 20 psu isohaline often being near or at method detection limits over much of the year. Normally, estuarine inorganic nitrogen concentrations decline to their lowest levels during the relatively drier spring months as phytoplankton populations respond to increasing water temperatures and light, and increased primary production removes available inorganic nitrogen. As a result, inorganic nitrogen levels in the lower river and upper harbor are typically at their lowest levels in the late spring, just prior to increases in summer wet-season inflows.

- **Ortho-phosphorus** - Estuarine inorganic phosphorus concentrations in the lower Peace River and upper Charlotte Harbor are heavily influenced by the characteristically “very” high natural levels found in the Peace River watershed. As a result, the observed difference in concentrations among the four isohalines primarily reflects conservative dilution by Gulf waters. Unlike inorganic nitrogen, seasonal observed changes in phosphorus concentrations in the estuary are for the most part unaffected by biological uptake. Inorganic phosphorus concentrations entering the estuary system from the Peace

River watershed are typically lower during wetter periods, when a higher proportion of flow results from rainfall runoff/surface flow (rather than coming from groundwater, which is naturally richer in phosphorus). Annual average ortho-phosphorus concentrations at each of the two downstream isohalines (12, 20 psu) were somewhat higher in 2012 than the corresponding long-term averages (1983-2011).

- **Nitrogen to Phosphorus Atomic Ratios** – Calculated atomic inorganic nitrogen to phosphorus ratios for ambient measured concentrations in 2012, as indicated by the long-term averages, show nitrogen to almost always be the limiting macronutrient at each of the four isohalines.

- **Silica** – Seasonally, silica levels in the lower Peace River/upper Charlotte Harbor estuarine system typically peak following periods of high freshwater inflows. Although silica levels also seem to be positively correlated with higher water temperatures (possibly reflecting recycling from riverine/estuarine sediments), historically lower silica concentrations in higher salinity zones of the estuary often occurred during corresponding periods of combined low spring freshwater inflow and spring increases in phytoplankton diatom numbers. Between 1983 and the late 1990s these seasonal patterns of increasing and decreasing reactive silica concentrations remained relatively stable with no indications of any consistent systematic changes over time. However, as discussed in previous HBMP reports, silica levels started showing increasing concentrations during the late 1990s. Then, as flows declined during the extended 1999-2002 drought, silica levels also declined. However, following the return of higher than average flows during 2003-2005 measured silica levels in the estuary again began rapidly increasing. Even though flows over the 2006-2009 interval were below normal, silica levels throughout the lower river/upper harbor estuary continued to reach historically high levels during the summer wet-seasons. However, while peak levels during 2009 and 2010 were somewhat lower than during the immediate preceding years, levels again increased in 2011. Annual average concentrations during 2012 were again well above their long-term averages at each of the four moving isohaline based monitoring locations.

- **Chlorophyll *a*** – The seasonal patterns of freshwater inflows to the estuary during 2012 were characterized by drier than usual conditions during the first five months of the year when compared to the long-term average conditions. Typically, seasonal periods of increased flows produce both higher than average inputs of limiting inorganic nutrients (nitrogen), as well as higher than average levels of water color (resulting in greater light attenuation). Overall, chlorophyll *a* concentrations within the Peace River/upper Charlotte Harbor estuarine salinity zones during 2012 were generally similar to their preceding long-term (1983-2011) corresponding averages. As in previous years, phytoplankton levels within the intermediate (6 and 12 psu) isohalines reflected a balance between stimulation due to increased nitrogen inputs, and light inhibition resulting from higher water color. During previous years, taxonomic counts indicated that such “bloom” events within these intermediate salinity zones were often predominantly characterized by high numbers of dinoflagellates (*Dinophyceae*) or diatoms (*Bacillariophycae*).

The graphical and summary analyses presented in this document do not indicate any substantial changes, or atypical events in either the physical or biological data collected during 2012, other than those previously noted. These include:

- Freshwater inflows during 2012 were influenced by drier than normal conditions during the normal spring dry-season.

- There has been a continuation in the previously noted long-term increase in reactive silica concentrations noted at the lower Peace River/upper Charlotte Harbor monitoring locations.

- There are strong indications that inorganic phosphorus concentrations in the freshwater entering the estuary have increased in recent years, following decades of major declines that began in the late 1970s. However, observations since 2009 have shown that levels have substantially declined again to levels near where they were prior to the observed recent increase.

- The observed recent increases in silica and phosphorus seem to have been linked to the on-going closure of phosphogypsum stack systems in the upper Peace River watershed.

The "limited" analyses presented in the *Annual Data Report* do not suggest that there have been any long-term, systematic changes resulting from either current or historic water withdrawals by the Peace River Regional Water Supply Facility.

2.6 Results of the Florida Department of Environmental Protection, Charlotte Harbor Aquatic Preserves' Seagrass Monitoring Program from 1999-2009 (Brown et al., 2013)

This article appeared in a Charlotte Harbor National Estuary Program (CHNEP) special issue of the journal *Florida Scientist* entitled "The State of Our Watersheds and Estuaries". A description of the annual seagrass monitoring conducted annually by the FDEP throughout the estuaries of Charlotte Harbor is provided. Monitoring has occurred since 1999 at fifty fixed transects throughout the estuarine complex. Water quality and seagrass conditions are monitored to properly manage the aquatic preserves, assess status and trends, and identify areas of concern. Data from the monitoring program have been used by multiple agencies for statewide seagrass reports, establishing water clarity targets, and regulatory review of activities proposed in the preserves. This paper provides a statistical analysis of the program's 2011 report, highlighting significant trends and discussion of the results.

Results from the study indicated that, as a whole, the measured seagrass parameters were stable throughout the region from 1999-2009. Minor declines were noted in 2004 and 2005 due to higher than average rainfall and hurricane events; seagrasses have rebounded since.

The most frequently occurring seagrass species throughout the study area are *Halodule wrightii* (45%, occurring in all estuary regions) and *Thalassia testudinum* (29%, occurring in most regions except the Peace and Myakka Rivers). Total abundance of all seagrass species combined has increased significantly since 2004 (when monitoring of total abundance began), including in the Peace River region. Throughout the study region from 1999-2009 the only species to have a significant increasing trend in abundance was *H. wrightii*. Mean *H. wrightii* density (shoot counts) increased significantly from 2005 to 2009, including in the Peace River region. Across the study area, the maximum depth of seagrass growth increased on average from 1999 to 2009. Additionally, over the study period, epiphyte densities increased significantly over the study area.

The overall trends in abundance and density are influenced by several interacting variables, but the article states the primary driver for the overall trends appears to be related to the amount of freshwater the watershed and estuary received. Seasonal rainfall and anthropogenic flow can cause declines in salinity and water quality and color, chlorophyll and other suspended matter are primary factors causing reduced water clarity and light penetration to the seagrass beds. Species occurrence is heavily influenced by salinity and areas with high variations in salinity due to freshwater inflow, such as the Peace and Myakka Rivers, cannot support stable seagrass populations. This is supported by the data in the report showing the lowest occurrence, abundance and densities of seagrass, as well some of the lowest salinities and water clarity in the estuarine complex.

The article stresses that continuation of the seagrass monitoring program is important in order to properly characterize long term trends. The monitoring data, including annual abundance, densities, species composition, and deep edge of beds, play an integral role in assessing seagrass and estuarine health. The paper concludes that linking additional water quality parameters and future clarity trends to the seagrass monitoring program data will be critical to the management of the Charlotte Harbor estuarine system.

2.7 Freshwater Fish Communities and Habitat Use in the Peace River Florida (Call et al., 2013)

This article appeared in a Charlotte Harbor National Estuary Program (CHNEP) special issue of the journal *Florida Scientist* entitled “The State of Our Watersheds and Estuaries”. The objectives of this study were to:

- Determine fish community metrics in the freshwater portions of the Peace River using stratified-random surveys.
- Identify any differences in fish communities among different sections of the river.
- Evaluate fish species association with quantified habitat.

For this study, sampling was conducted biannually in the fall and spring from 2007 through 2010 to determine if temporal trends in fish community structure correlated with habitat utilization. Fish collection was conducted using electrofishing along discrete transects. Additionally, microhabitat measurements were recorded for each transect, including counts of woody debris, aquatic macrophyte coverage, and substrate type. Water quality parameters were recorded from a multiparameter probe and include temperature, salinity, conductivity, and dissolved oxygen. Additionally, water velocity, turbidity and Secchi depth was measured within each transect.

The results of the study indicated that fish communities differed spatially between sections of the river (Lower, Middle, Upper) but not temporally across seasons or years. In the upper section of the river, macrophyte cover and water velocity best correlated with changes in fish community structure. In the middle section of the river, there were four variables that best correlated with changes in fish community structure. These were Habitat Complexity Index (HCI), woody debris, depth, and water velocity. In the lower section, woody debris was correlated best with changes in fish community structure among sampling events.

2.8 The Effects of Environmental Disturbance on the Abundance of Two Recreationally-Important Fishes in a Subtropical Floodplain River (Blewett and Stevens, 2013)

This article appeared in a Charlotte Harbor National Estuary Program (CHNEP) special issue of the journal *Florida Scientist* entitled “The State of Our Watersheds and Estuaries”. The objective of the study was to describe how disturbance events influence abundance patterns of common snook (*Centropomus undecimalis*) and largemouth bass (*Micropterus salmoides*) in the lower reaches of the Peace River, Florida. These two species are both large fishes but with very different life histories. Common snook are tropical, euryhaline, obligate marine spawners while largemouth bass are a temperate freshwater species.

Seasonal abundances of these species were surveyed in the lower portion of the Peace River from 2004-2010 via electrofishing from a stratified-random sampling design. During and just prior to this period, several environmental disturbances occurred. Hurrian Charley passed directly over the Peace River in August 2004. As the hurricane roughly followed the path of the floodplain, it resulted in extremely high river flows and a large hypoxic event affecting most of the river. This hypoxia was prolonged by the passage of two other hurricanes (Frances and Jeanne) over the watershed. High river flows continued in 2005 with hurricanes Wilma and Arlene over the watershed. During winter 2010, extreme cold temperatures occurred, affecting the flora and fauna of the region.

These disturbance events greatly affected sport fish abundance patterns. After the 2004, hypoxic event, largemouth bass were absent from the mainstem of the lower Peace River and remained so for more than a year. Common snook, however, were up to three times more abundant than during subsequent years (2007-2010). Largemouth bass are an obligate freshwater species, and as such were confined to the river during the hypoxic event, likely experiencing high mortalities as a result. Common snook as a euryhaline species, however, had the ability to leave the areas affected by this event. Additionally, spawning migrations may have already resulted in movement of many of the common snook to the lower portion of the estuary prior to Hurricane Charley. The continued high flows may have provided a substantial habitat base leading to greater use of the river by common snook contributing to the increase in common snook abundance during late 2005.

During sampling events immediately following the passage of cold fronts, a lower abundance of common snook was detected compared with the preceding and following seasons. After the extreme freeze event in 2010, no common snook were collected in the mainstem during regularly schedule winter sampling. Sampling one month later, and particularly by summer and fall, snook abundance returned to levels seen prior to the freeze. During the cold event, common snook likely left the study area to seek deeper water downstream or outside of the mainstem areas sampled. Largemouth bass abundance appeared to be unaffected by the extreme cold event.

The authors conclude that the natural disturbances occurring during the study mark major changes in the abundance patterns of large predators in the Peace River. They state that the findings illustrate the acute effects of environmental events on the abundance of sport fishes and highlight how fishes may respond differently to events in a highly dynamic coastal river system.

2.9 A Water Clarity Evaluation and Tracking Tool for the Estuarine Waters of Lemon Bay, Charlotte Harbor and Estero Bay, Florida (Wessel et al., 2013)

This article appeared in a Charlotte Harbor National Estuary Program (CHNEP) special issue of the journal *Florida Scientist* entitled “The State of Our Watersheds and Estuaries”. The objective of the study was to develop a water clarity evaluation and tracking tool to identify potential deviations from reference period conditions that resulted in stable or increasing seagrass areal extent throughout CHNEP estuarine waters without explicitly identifying the light requirements of seagrass. The tool was developed so that it could be adapted to work with any index of light attenuation and provide a convenient format for reporting on the condition of water clarity in estuarine waters to natural resource decision makers and the general public.

The period 2003-2007 was chosen as the reference period. The 30th and 70th percentile values from the distribution of light attenuation values in this period were selected as benchmarks from which to evaluate light attenuation data on an annual basis. A scoring method was developed to evaluate yearly water quality data for each Charlotte Harbor segment at the benchmark points for each estuarine segment. The scoring system uses a rating scale that varies between -2 and 3. The resulting scores are tabulated and the numerical values reported as color coded grades. The color coded grading system and reporting format was developed to convey the results of annual water quality grades to managers and the public in a convenient format. The generated output can be easily integrated into public media formats including the Water Atlas.

The authors conclude that while the scores and grades used were based on empirical light attenuation data, the tools developed for evaluation and reporting are easily transferable to model based estimates, provided historic water quality data can be used to adequately hindcast model estimates for the reference period. The authors recommend that the monthly sampling be continued at that frequency since the evaluation tool would be sensitive to changes in temporal sampling frequency. As a final recommendation, the authors suggest the evaluation tool be re-evaluated after data are collected through 2012 to assess the sensitivity and concordance of the grades with additional data collected on recent trends in seagrass acreage.

2.10 Retrospective Analysis and Sea Level Rise Modeling of Coastal Habitat Change in Charlotte Harbor to Identify Restoration and Adaptation Priorities (Geselbracht et al., 2013)

This article appeared in a Charlotte Harbor National Estuary Program (CHNEP) special issue of the journal *Florida Scientist* entitled “The State of Our Watersheds and Estuaries”. The purpose of the study was to spatially characterize and quantify both past and future changes in coastal habitats throughout the Charlotte Harbor system to support effective resource management, restoration and climate change adaptation decisions.

The authors conducted a comparative geospatial retrospective analysis of coastal habitat change in the study area over the period 1945 to the most recently available data, which ranged from 1999 to 2007 depending on the location and habitat type. Distributions of saltmarsh, mangrove swamp, tidal flat, seagrass and oyster reef habitat from the period 1945 to 1982 to the most recent distribution information available. Additionally, the authors performed a prospective coastal system analysis by modeling the impacts of sea level rise using the Sea Level Affecting Marshes Model (SLAMM). The modeling was conducted for the years 2000 through 2100 using three different sea level rise scenarios (0.7 m, 1.0 m, and 2.0 m). Four subsites were established to accommodate varying tidal elevations within the Charlotte Harbor system. These included Peace and Myakka River Estuaries, Estero Bay, Caloosahatchee Estuary and Cape Haze. The remainder of the study locations outside of the four subsites was termed the “global site”. Geospatial analysis was then used to compare historic changes in coastal wetland distributions to SLAMM simulated future changes to allow comparisons to an earlier study by Harris et al (1983).

The results of the restrospective analysis indicated that throughout the study area, from 1945 to the most recent available period, saltmarsh and tidal flat habitat increased substantially, while seagrass, mangrove swamp and oyster reef habitat decreased substantially. The authors note, however, that the large increase in tidal flat extent is more likely due to differences in methods and conditions between years than a real gain in tidal flat habitat. Additionally, changes in extent of coastal habitats for sub-area did not always follow the pattern of change observed for the study area as a whole. For the period 1982 to the most recent available period, throughout the study area, seagrass habitat remained relatively stable, saltmarsh increased substantially and mangrove swamp and oyster reef declined.

The results of the prospective SLAMM analyses indicate substantial changes in coastal wetland systems under all three sea level rise scenarios. The modelling results predicted net losses of tidal flat, coastal forest and inland freshwater marsh under all three scenarios. Mangrove swamp and saltmarsh decreased under the fastest rate of sea level rise modeled. The authors note that the prospective analysis did not address seagrass or oyster reef habitat as SLAMM does not address these habitat types. The authors state that seagrass may be able to expand substantially as sea level rises and that oyster reefs may have similar opportunities, but are less likely to expand without human intervention.

The results of these analyses, the authors state, can be used to identify where specific types of coastal wetland restoration are most needed in the Charlotte Harbor study area and support the climate change adaptation planning an implementation underway in the region.

2.11 2013 HBMP Annual Data Report (Atkins, 2014)

This data report represents the 18th *Annual Data Report* submitted under the expanded Hydrobiological Monitoring Program (HBMP) initiated in 1996 in compliance with Water Use Permit 20010420. The report summarizes and compares data collected during 2013 with similar HBMP information previously compiled during various elements of the ongoing long-term monitoring program.

The report notes that, in making comparisons of the 2013 data with similar data collected over the preceding 37 years, it should be considered that rainfall/flow have annually varied considerably during the recent historic period. The very wet winter/spring El Niño of 1997/1998 was followed by very dry La Niña conditions that influenced southwest Florida and the entire Peace River watershed between 1999 and early 2002. A weaker El Niño occurred at the end of 2002, and freshwater flows during 2003, 2004 and 2005 were generally above average. Rainfall in the Peace River watershed during the 2006 to 2009 interval, by comparison, was well below average, while seasonal rainfall patterns since then have returned to more normal conditions. More recent seasonal rainfall patterns during both 2010 and 2013 were near or above normal, while the drier seasons of 2011 and 2012 were well below normal.

Flows – Average mean daily Peace River flow of the three combined gages upstream of the Facility during 2013 was 1339.2 cfs, which was above the 1151.4 cfs average over the 38 years of HBMP monitoring (1976-2013). In comparison, the average flow during 2013 was well above the annual average flow of 524 cfs over the four-year interval between 2006 and 2009. However, it was also well below the average flow of 2046 cfs over the much wetter five-year interval between 2001 and 2005. Overall, annual mean flow upstream of the Facility during 2013 was 116.8 percent of the average daily flow over the preceding long-term 1976-2012 period.

Withdrawals – Total Peace River Facility withdrawals during 2013 were approximately 4.5 percent of the total gaged freshwater flow measured at the USGS Arcadia gage, 3.2 percent of the upstream gaged flow at the Facility, and 2.6 percent of the combined average daily inflows upstream of the U.S. 41 Bridge. During the entire period of Peace River Facility withdrawals (1980-2013), total combined withdrawals have been approximately 1.9 percent of the corresponding gaged Peace River at Arcadia flows, 1.4 percent of total gaged flow upstream of the Facility, and only 1.1 percent of the combined daily freshwater flows of the Peace River, and Horse, Joshua, and Shell Creeks.

There were a number of days during 2013 when Peace River Facility withdrawals exceeded the seasonally designated maximum percent allowed by the April 2011 revised permit withdrawal schedule. Such exceedances of the permitted percent withdrawals primarily result from subsequent USGS revisions of the provisional daily flow information available to the Authority at the time of actual withdrawals. During 2013, the facility did not withdraw any water from the river on 114 days or approximately 31 percent of the time.

Water Temperature –Monthly mean water column temperatures in 2013 followed the strong seasonal pattern typically observed in south Florida. Often, the highest water temperatures in the more upstream, shallower, freshwater reaches of the estuary reach their highest levels in May and then remained similar up until August. By comparison, average water column temperatures in the downstream areas, more influenced by the harbor, often don't reach their highest annual temperature values until July. During 2013, the highest average water column temperatures occurred throughout the lower river/upper harbor estuary during June. The 2013 data clearly shows relatively normal cold conditions during at both the start and end of the year associated with typical winter cold fronts.

Dissolved Oxygen – Previous results have indicated that within the downstream reaches of the river between River Kilometers -2.4 and 10.5, there is typically a wet-season depression of average water column dissolved oxygen levels in response to increased wet-season flows. This seasonal pattern typifies the widely documented hypoxic/anoxic conditions that typically occur in upper Charlotte Harbor as a result of the extreme water column stratification that commonly occurs near the mouth of the river and upper regions of the harbor during the summer. This typical observed seasonal depression of average water column dissolved oxygen concentrations in this reach of the lower river is generally more intense and of greater duration than that observed at the more upstream monitoring sites. During 2013 (as typically observed in previous years) average water column dissolved oxygen levels generally declined as water temperatures increased, reaching their lowest levels during the summer wet-season between June and September throughout both the lower river and upper harbor as both water temperatures and flows increased. The 2013 summer, wet-season column profile data (as has occurred since 2010) indicated the return of normal hypoxic/anoxic dissolved oxygen levels in the upper harbor.

Light Extinction – The 2013 HBMP data indicate that both the timing and magnitude of the ability of light to penetrate into the water column (1 percent depth) exhibits both strong temporal (seasonal) and spatial differences among the "fixed" monitoring sites along the HBMP lower Peace River/upper Charlotte Harbor sampling transect. In many other estuarine systems, the extinction of light is often highly influenced by ambient chlorophyll *a* concentrations (phytoplankton biomass). However, light extinction in the lower Peace River/upper Charlotte Harbor estuarine system is often primarily mediated by water color due to the "black water" characteristics of freshwater inflows from the Peace River watershed. Water clarity during 2013 (as in previous years) was the greatest in the lower river and especially in the upper harbor during both the typical spring dry-season and other periods of lower flows.

Conductivity/Salinity –Seasonally spatial conductivity patterns in the tidal lower Peace River during the very dry first five months of 2013 were similar with previous spring dry-season and late fall conditions over much of the previous decade, when brackish conditions in the lower river extended upstream even beyond the Peace River Facility intake.

Inorganic Nitrite+Nitrate Nitrogen – In the Charlotte Harbor estuarine system inorganic nitrite+nitrate nitrogen concentrations are typically the lowest during the peak of the spring dry-season, when high light and water temperatures result in increased phytoplankton production and freshwater inflows are low. Concentrations rapidly increase in the lower salinity reaches of the estuary with higher flows as nitrogen is carried from the watershed and increasing color reduces light penetration of the water column and limits phytoplankton growth. The data typically indicates a distinct spatial gradient within the lower river/upper harbor estuarine system with higher levels of inorganic nitrogen progressively occurring upstream. During 2013 inorganic nitrogen concentrations were low or at near detection limits during the extended spring/early summer dry-season (April/May). Overall, nitrite+nitrate nitrogen levels in 2013 were similar with the longer-term averages at each of the five fixed stations.

Total Kjeldahl Nitrogen – Typically, total Kjeldahl nitrogen concentrations in the lower Peace River/upper Charlotte Harbor estuarine system are generally the highest during the summer wet-season, reflecting the influences of increased freshwater inflows. Overall, during 2013 the annual average Kjeldahl concentrations at each of the five monitoring locations were very similar to their historic long-term averages.

Ortho-Phosphorus – Inorganic phosphorus concentrations in the Peace River Estuary follow patterns typical of conservative water quality constituents (reflecting dilution rather than biological uptake). Estuarine phosphorus concentrations are primarily influenced by dilution of high ambient levels in Peace River freshwater by saline Gulf water moving up the harbor. Thus the HBMP monitoring data typically indicates distinct spatial patterns in inorganic phosphorus concentrations among the sampling sites, with concentrations being markedly higher upstream than downstream. Following Hurricane Charlie in August 2004 (and the subsequent Hurricanes Frances and Jeanne in September 2004), the data indicated that there were atypical marked increases in inorganic phosphorus levels associated with high levels of hurricane related flows from the Peace River watershed. During the wetter than average conditions in 2005, inorganic phosphorus patterns in the lower river/upper harbor estuarine system returned to more typical seasonal patterns. However, during the dry conditions that characterized the 2006-2008 period, phosphorus concentrations in the lower river/upper harbor estuarine system returned to higher levels not seen in over two decades. Phosphorus concentrations then began to decline during 2009 and have continued to decline to previous observed lower levels. Seasonally, inorganic ortho-phosphorus in 2013 at the five fixed monitoring sites were similar to levels observed prior to the recent observed increase.

Silica – Historically, annual reactive silica concentrations in the Peace River Estuary characteristically have indicated a number of differing temporal and spatial patterns. During the spring dry-season silica levels were normally at their annual lowest concentrations throughout the lower Peace River/upper Charlotte Harbor estuarine system corresponding to depressed flow inputs and periods of increased chlorophyll *a* biomass (potentially reflecting uptake by diatoms in the phytoplankton). Then usually during May and June, as water temperatures increased and the start of the summer wet-season began, concentrations characteristically rapidly increased throughout the estuary. However, reactive silica concentrations during 2013 continued to reflect the recently observed pattern of increased levels noted in previous HBMP reports, with peak silica levels near seasonally historically high levels.

Chlorophyll *a* –Phytoplankton biomass (chlorophyll *a*) patterns in the lower Peace River/upper Charlotte Harbor Estuary are normally characterized by several seasonal peaks throughout the year that differed both seasonally and spatially among the HBMP "fixed" sampling locations. Typically chlorophyll *a* phytoplankton biomass in the lower Peace River/upper Charlotte Harbor

Estuary show distinct increases both during the spring with increasing light and water temperatures and during the late fall after wet-season flows have increased nitrogen levels and associated high color levels begin to decline. Chlorophyll *a* increases (blooms) during 2013 were influenced by both the seasonally low streamflow during the first five months of the year, as well as the high flows during the summer wet-season that resulted in phytoplankton "blooms" stimulated by nitrogen inputs in both the higher and intermediate salinity reaches of the lower river/upper harbor estuary.

The graphical and summary analyses presented in the document do not indicate any substantial changes, or atypical events in either the physical or biological data collected during 2013, other than those previously noted. These include:

- Freshwater inflows during 2013 were influenced by wetter than usual conditions during the typical summer wet-season.

- The previously noted long-term increase in reactive silica concentrations noted at the lower Peace River/upper Charlotte Harbor monitoring locations indicated some decline during 2013.

- Inorganic phosphorus concentrations in the freshwater entering the estuary had increased in recent years, following decades of major declines that began in the late 1970s. However, observations since 2009 have shown that levels have substantially declined again to levels near where they were prior to the observed recent increase.

- The observed recent increases in silica and phosphorus seem to have been linked to the previous closure of phosphogypsum stack systems in the Whidden Creek basin, located in the upper Peace River watershed.

The "limited" analyses presented in the *2013 HBMP Annual Data Report* do not suggest that there have been any long-term, systematic changes resulting from either current or historic water withdrawals by the Peace River Regional Water Supply Facility.

2.12 The Optical Model Spectral Validation and Annual Water Clarity Reporting Tool: Final Report (Dixon and Wessel, 2014)

To further its goals to protect and restore water quality under the Comprehensive Conservation and Management plan (CCMP), the Charlotte Harbor National Estuary Program (CHNEP) is analyzing management tools. The extent of seagrass in the CHNEP study area is a valuable natural resource and a focus of the CHNEP CCMP. The authors state that the continued focus on science-based management tools for seagrass will help to ensure the protection of the vital resource. The purpose of the CHNEP Optical Model Spectral Validation and Annual Water Clarity Reporting Tool Refinement Project was to provide the CHNEP with an empirical optical model in which diffuse attenuation coefficients of photosynthetically activated radiation (PAR, K_{dPAR}) could be reproducibly computed from the water quality monitoring parameters of color or colored dissolved organic matter (CDOM), chlorophyll *a*, and turbidity.

A spectrally explicit optical model was calibrated for each of the 14 seagrass management segments of Charlotte Harbor. Calibration statistics indicated that modeled and observed K_{dPAR} demonstrated good agreement within the range of target depths and water quality conditions relevant to the success of seagrasses in the CHNEP study area. The predicted K_{dPAR} values resulting from the optical model were used to generate annual water clarity scores similar to a previously developed CHNEP Water Clarity Reporting Tool. Comparisons of selected percentiles of individual years to reference period percentiles permitted the assessment of changes in water clarity. Overall scores were computed and categorized based on whether a segment had been designated as a seagrass “Protection” or a “Restoration” target. The authors state that the water clarity estimation tool provides an important and easy to understand method of disseminating complex, non-linear attenuation processes to both public and managers alike. Comparisons of future scores to the reference period are valid as long as the design frequency and spatial density of the monitoring program remain essentially unchanged from the reference period.

2.13 An Analysis of the Relationships of Freshwater Inflow and Nutrient Loading with Chlorophyll Values and Primary Production Rates in the Lower Peace River (Atkins, 2014)

The objective of the project detailed in this report was to statistically analyze long-term data to determine if improved relationships could be developed between chlorophyll *a* (and related primary production estimates) and seasonal variations in freshwater inflow to the lower Peace River and upper Charlotte Harbor estuarine system. Data sources included the long-term Peace River HBMP, daily USGS flow data, District water age data, watershed water quality information from multiple sources (used to estimate nutrient loading rates), and daily solar radiation information from multiple sources. The report was prepared for the District, whose primary interest in the effort centered on expanding and potentially identifying probable sources of temporal/spatial variability in chlorophyll biomass/primary production beyond that previously presented in HBMP reports, and initial effort during the establishment of the existing MFL for the lower Peace River.

The project consisted of six tasks, and this report represents the last of the tasks involving data synthesis and interpretation. The goal of the final task was to summarize the findings of the analyses from the prior five tasks, specifically addressing how phytoplankton chlorophyll *a* biomass and estimated rates of primary production with differing reaches of the study area seasonally vary as a function of natural variability in the rate of freshwater inflow. The report provides a summary of each of the five prior tasks and appendices for each of tasks 1-5 containing technical memos describing the methods and results of each task.

The first task of the project involved obtaining and using available USGS/District/FDEP and HBMP data to update inflows and nutrient concentration information for each of the lower Peace River upstream freshwater tributaries, as well as for the HBMP site at river kilometer (RK) 30.7 (Station 18). The data were utilized to assess relationships between nutrients and flows, as well as compute nutrient loading rates for each of the lower Peace River four primary tributaries. The Task 1 memo (Appendix A of Atkins 2014) presented tabular results and summary graphics. Statistically significant correlations were present at most of the sites for most of the water quality constituents analyzed. Most of the significant correlations were either weak or moderate. Water color was found to have the strongest correlation, and TKN typically exhibited moderate to strong positive responses, with inflow. Various methods for nutrient load estimation were compared, and the monthly average method was selected for use in subsequent analyses.

Task 2 of the project collated solar insolation data from the District, Environmental Quality Lab, UF IFAS, and Mote Marine Lab. The task included the development of statistical relationships among the four datasets to determine the best option(s) to compile the best complete data base for solar insolation for the period 1983 to 2011. Additionally, the task involved preparing an overall summary database of HBMP chlorophyll *a*/primary production, nutrient, physical, and color information. Basic statistical summaries were computed and seasonal variations and univariate relationships with freshwater inflows were assessed. The methods and results were detailed in the technical memos in Appendix B of the report.

Task 3 had the objective of merging water age values generated by the District with chlorophyll *a* and primary production values from project Task 2. Relationships of water age with chlorophyll *a* in various reaches of the Peace River were determined, and analyses were conducted to determine if critical rates of water age might influence chlorophyll *a* concentrations in the lower river. Appendix C of the report provides the full technical memo describing methods and results for this task. Graphical analyses of chlorophyll *a* versus predicted water age did not show consistent strong, distinctive patterns within any of the tested intervals along the lower river transect examined. The authors conclude that the lack of strong patterns in the presented analyses suggest that further improvement may require a multivariate modeling approach (Task 5).

The objective for Task 4 of the project was to develop a statistical based model to predict the location of the chlorophyll maximum as a function of combined gaged freshwater inflow. The Task 4 methods and results are detailed in Appendix D of the report. Lag flow terms for 5, 10, and 15-day average flow were calculated for each sampling date. Linear regressions and power models were evaluated in terms of statistical significance, explanatory power and model fit with the data. The results of the linear regression exhibited poor model fits. The fit and statistical power of the nonlinear equations were stronger; the observed best fit came from using the 5-day lag average flow term.

Task 5 of the project included using graphical and multivariate analytical procedures to assess and determine if specific relationships could be established seasonally between estuarine chlorophyll *a* levels and upstream gaged freshwater inflows (and other measured physical/chemical parameters) in various reaches of the study area. A detailed description of methods and results is contained in Appendix E of the report. The task involved multiple steps including: 1) statistical testing of correlations, 2) simple graphical analyses, 3) 3-D graphical analyses of chlorophyll relative to potential influences using SAS scatter and interpolated surface response approaches, and 4) multivariate statistical analyses including principal components analyses (PCA), and a combined application of the SAS RSREG and STEPWISE analytical procedures. Additionally, factors influencing the high degree of observed variance in phytoplankton population dynamics along the lower Peace River estuary were examined graphically. The graphics indicate that there are general overall temporal/spatial seasonal patterns in annual estuarine chlorophyll levels but there is tremendous interannual variability. The variability is driver primarily by the specific physical/water quality conditions created both by immediate and preceding longer term patterns in freshwater inflows which vary in both timing and magnitude among years. Thus, the authors conclude, the development of accurate and predictable simple statistical models of the relationships between freshwater inflows (and interactions with other physical/chemical parameters) is probably realistically unattainable.

The final chapter of the report provides the data synthesis and integration of the results from the five prior tasks. The chapter assesses the temporal/spatial influences of freshwater inflows, the potential influences of freshwater withdrawals on estuarine phytoplankton levels, and the potential influences on future changes in the timing of withdrawals. Temporal/spatial influences are details, largely revolving around changes in the limiting nutrient in the study area (nitrogen). Seasonal changes in inflow influence the availability of inorganic nitrogen forms, thus affecting primary production. Additionally, seasonal changes in water temperature, water color, and residence time also influence both the availability of nutrients and primary production.

While the various analyses provided insight into the primary factors influencing the seasonal timing and relative locations of seasonal phytoplankton increases in the estuary, applied graphical and statistical multivariate techniques failed to result in applicable predictive models that could then be used to assess potential temporal/spatial changes in chlorophyll levels due to withdrawals from the river. The report thus turned to a conceptual consideration of whether current (or future) withdrawals have the potential to influence the existing variability observed in the spatial/temporal distribution and magnitude of phytoplankton densities in the estuarine system. The report identifies three conceptual major mechanisms by which freshwater withdrawals have the potential to influence chlorophyll levels: 1) decreasing water color, 2) reducing nitrogen loadings, and 3) changing residence times.

Task 5 analyses indicated that peak early summer phytoplankton blooms in the lower river typically coincided with water color levels ranging from 125 to 225 PCU. The upper color level is approximately in the range where the Peace River Facility is physically limited by its pumping capacity to taking 10 percent or less of upstream inflows. Thus, it is unlikely that current Facility withdrawals could reduce color levels enough to result in greater phytoplankton biomass in the lower river.

The report notes that, historically, many estuarine systems worldwide have seen large declines in freshwater inflows due to damming or major diversions and have also experienced substantial changes in economically/recreationally important species often linked to declines in nutrient loadings and phytoplankton production. While Peace River Facility withdrawals have increased over the past decade, as a percentage of upstream flows they still remain a small percent of the levels that have resulted in major changes in other estuarine systems. The authors thus conclude that the current levels of withdrawals are unlikely, when considered on an annual basis, to result in substantial changes in overall estuarine phytoplankton production. However, the authors do note that one season (early summer where initial wet-season flows may only be moderate and intermittent) should be considered separately. Such periods are important times of phytoplankton production in the middle reaches of the lower river and also a period when permitted withdrawals experience a significant jump from 16% to 28% of flows once flows reach

625 cfs. Thus, at least conceptually, withdrawals can take large percentages of relatively moderate flows following the typically driest months of the year when phytoplankton production is responding to the first inflows of limiting nitrogen to the system. There is the potential for withdrawals to briefly reduce phytoplankton production within these areas of the lower river.

With the current schedule of withdrawals, Facility withdrawals have the greatest potential to influence residence times during periods of low (above the minimum cutoff) to intermediate freshwater inflows. Because the spring blooms, occurring under lower flow conditions, occur during a time interval where the Facility is typically not withdrawing, or withdrawing relatively small amounts, it seems unlikely that any changes in residence time due to withdrawals should have much influence on the spring phytoplankton increases since they are typically of short duration and magnitude. Similarly, spring phytoplankton increases in the most upstream reach of the monitoring transect also take place when water ages are relatively long and should be unaffected. Relative to the late spring/early summer increases often seen in the middle reaches of the lower river, it is more likely that the potential negative influences of nutrient withdrawals exceed any enhanced changes due to slightly longer residence times.

The report concludes with a discussion of factors that individually and combined have the potential to shift the timing of Facility withdrawals away from lower flows and more toward periods of higher flows. High conductivity groundwater regionally associated with agricultural discharges to tributary basins upstream of the Facility continue to have the potential to influence both existing and planned future water supplies. There are periods each year when flows exceed the minimum cutoff but conductivity criteria for Authority withdrawals are not met. While the pattern has not limited withdrawals, it is one of the factors that has the potential to move withdrawals towards periods of higher flows when conductivity levels rapidly decline.

The timing of future withdrawals may also be influenced by combined anthropogenic and natural influences on upstream inflows. Long-term declines in the potentiometric surface of the upper Florida aquifer have resulted in historic losses of flows from springs and seeps in geologically karst areas of the upper Peace River watershed, which have been one of the factors seasonally resulting in apparent declines in river base flows. Other hydrologic alterations in some phosphate mined or reclaimed areas in the regional watershed are also noted. Base flows in the watershed have also been affected by changes in discharges and drainage alterations associated with both increasing urbanization and agriculture. The report states that combined natural and anthropogenic influences have affected the annual percent of time when combined gaged flows upstream of the Facility have been less than 200 cfs. Should the pattern of increasing frequency of lower flows continue, it will lead to a higher reliance on intermediate to higher flows.

Finally, the report considers the influence of future sea-level rise on the timing of facility withdrawals. Analyses showed that, given the Facility’s conductivity criteria for withdrawals, the ‘best and median case” projections for 2025/2035 sea level rise would be expected to have comparatively small influence on overall operations. However, the “worst case” estimate for 2035 and the projected “median expected” rise in sea-level rise by 2050 would begin to reduce the Facility’s ability to withdraw water under moderate flow (400-500) cfs conditions. Toward the latter half of the century, increases much above the “best case” scenario could be expected to result in large changes in the ability of the Authority to withdraw water over extended portions of the year.

The report concludes that the combined potential influences can be expected to move withdrawals toward a greater reliance on periods of higher flows. Task 5 analyses indicated that during such periods, estuarine chlorophyll levels are primarily controlled throughout the lower river/upper harbor by the combined influences of low residence times and high water color. Any influences of withdrawals during higher summer flows will be shifted further down into the middle/lower regions of the harbor.

2.14 Seasonal Differences and Responses to a Tropical Storm Reflected in Diatom Assemblage Changes in a Southwest Florida Watershed (Nodine and Gaiser, 2015 Ecological Indicators)

For this study, the authors examined diatom assemblages in the Charlotte Harbor estuary to investigate three main questions: 1) are there differences between diatom assemblages between the wet and dry seasons in a coastal, hydrologically-dynamic watershed; 2) do tropical cyclones alter community composition, and if so, on what time scale?; and 3) what are the key environmental drivers of these changes? Sampling sites extended from Charlotte Harbor upstream through the Caloosahatchee, Myakka and Peace Rivers. Samples were collected during the peak of the dry season and at the end of the wet season in 2012 in order to capture maximal differences in base freshwater flow. In June of that year, Tropical Storm Debby generated approximately 5-10 inches of precipitation over parts of the Charlotte Harbor watershed and cause minor regional flooding. To evaluate changes that occur quickly following a severe rainfall event, samples were also collected within a few days of the storm’s passage as well as approximately two weeks later. Diatom samples included planktonic, tychoplanktonic, and benthic taxa; all taxa were analyzed together as a single assemblage from each site. Water quality data including conductivity, salinity, total phosphorus (TP), total nitrogen (TN), and total organic carbon (TOC) were also analyzed from each site.

Species richness and diversity were found to be not significantly different among sampling times and many of the dominant taxa were prevalent at all sampling times. Nonmetric multi-dimensional scaling (NMDS) ordinations reflected the taxonomic overlap among sampling times and multi-response permutation procedures (MRPP) revealed that diatom assemblages were not significantly different between the wet and dry seasons but were different between storm-effect and no storm-effect periods. Dispersion analysis showed that dissimilarity among diatom assemblages was lower following the storm compared to the seasons with no storm effect, in the whole watershed as well as in each sub-basin. All sub-basins had the highest dispersion index values in the wet and dry seasons, with lower values following the storm; however, Harbor sites had the lowest dispersion immediately after the storm, and dispersion increased two weeks later, while in the Caloosahatchee and Peace Rivers, dispersion decreased immediately after the storm and was further reduced two weeks later. Analysis of similarity (ANSOSIM) indicated the diatom assemblages were significantly different across the watershed between the dry season and the wet season and between the dry season and two weeks following the storm, but not between other sample periods. Indicator species were identified for the wet and dry seasons, as well as for the post-storm sampling events for each sub-basin and in the watershed as a whole.

MRPP of environmental characteristics were significantly different between both wet vs. dry season and between storm-effect and no storm-effect periods. ANOSIM indicated environmental conditions differed between the dry season and all other sample periods, but there were no significant differences among post-storm samples and the wet season. Environmental changes showed different patterns in the sub-basins. Salinity across the watershed decreased from the highest values in the dry season to lower values following the storm that were maintained in the wet season. One site in the mid-Peace River had relatively high concentrations of TN in the dry and wet season and showed a large reduction following the storm that persisted for the two weeks after the storm. Other sites across the watershed had highly variable patterns of TN concentration. Most sites across the watershed had elevated TP concentrations following the storm and maintained comparatively low levels in the dry and wet seasons. The Peace River, which is naturally enriched in TP, had a flashier TP response pattern, with concentrations that increased in the days following the storm but dropped two weeks later and returned to elevated concentrations in the wet season. Most sites across the watershed showed increases in TOC following the storm with relatively low levels in the dry and wet seasons. Salinity and conductivity maintained a relatively high and stable correlation with the diatom assemblage at each sampling time, but relationships with nutrient concentrations changed.

By evaluating the correlation of environmental variables with the diatom assemblages in each sub-basin, the authors conclude that diatom assemblages relate to different variables at different times, and that these controls vary across the watershed. Kendall’s tau correlation coefficients indicate that the strength of the dependence of diatom assemblages on nutrient concentrations varies in relation to season and freshwater flow. TP, for example, has been shown to have a significant relationship with diatom assemblage differences in the watershed, but this study demonstrates that the time and spatial scale of this relationship is important. The authors conclude that changes in dispersion may provide a tool for interpreting changes on longer time scales, through analysis of diatom assemblages in sediment cores. The identification of periods of lower dispersion occurring prior to anthropogenic impacts may enable the identification of times of intense storm activity that pre-date modern records, providing information that can be used to identify long-term patterns and climate cycles that can improve predictions of future changes.

2.15 2012 Annual Report Horse Creek Stewardship Program (Cardno 2015)

This report is the tenth annual report summarizing the status of the Horse Creek Stewardship Program (HCSP). The HCSP is funded and managed by Mosaic and has two purposes. First, it provides a protocol for the collection of information on the physical, chemical and biological characteristics of Horse Creek during Mosaic’s mining activities in the watershed, thus allowing the detection of any adverse conditions that may result from mining. Additionally, it provides mechanisms for corrective action should detrimental changes or trends caused by Mosaic’s activities be found. The overall goals of the program are to ensure that the mining activities do not interfere with Authority withdrawals from the Peace River nor adversely affect Horse Creek, the Peace River, or Charlotte Harbor. Monitoring began in 2003. This report presents the results for 2012 relative to data collected since the program inception and also includes historical data since 1990. Four locations on Horse Creek, two of which are also long-term USGS gaging stations, were monitored for physical, chemical and biological parameters. Additionally, rainfall data were collected daily from three Mosaic gages located in the Horse Creek Basin. Biological sampling is scheduled for three times each year. The report also includes a summary of mining and reclamation activities for 2012.

A total of 76 acres was mined in the Horse Creek Basin at the Mosaic Fort Green Mine in 2012. The report does not cover any mining activities in the Horse Creek Basin that may have been performed by entities other than Mosaic. Three clay settling areas (CSAs) occur at the Fort Green Mine. The settling areas have real-time monitoring of pond level which is relayed to the Authority allowing for an expedited detection and response to any substantial release of wastewater from the settling areas, should such an event occur.

The report provides methods of collection, and results for a variety of components, including various water quantity parameters, ambient water quality, NPDES discharge water quality, benthic macroinvertebrates and fish. Sampling occurred at four Horse Creek locations:

- HCSW-1 - Horse Creek at State Road 64 (USGS Station 02297155)
- HCSW-2 - Horse Creek at County Road 663A (Goose Pond Road)
- HCSW-3 - Horse Creek at State Road 70
- HCSW-4 - Horse Creek at State Road 72 (USGS Station 02297310)

A summary of reported results, compiled from the report’s executive summary, are provided below by category. Water quality and biological results were compared with “trigger values” established for the HCSP. In addition, results were compared with applicable Florida surface water quality standards, which in many cases are the same as the trigger values.

Water Quantity - Although low and median Horse Creek discharge in 2012 was average for the region, rainfall in 2012 was below the long-term average annual rainfall of 52.72 inches (1908-2012). For 2012, temporal patterns of average daily stream flow and stage were similar across all stations, with the majority of high flows and stages occurring during May to August, during the rainy season. In September and October, NPDES contributed up to 75 percent of the streamflow at HCSW-1 compared to rainfall; in late October 2012, NPDES discharge accounted for almost all of the streamflow at HCSW-1. NPDES discharge from August to November was also a lagged response to rain that occurred from late-May to early October 2012; NPDES discharge from the Horse Creek outfalls usually does not occur until sufficient water storage accumulates in the circulation system, resulting in a lag. In general, the lower than average rainfall resulted in lower than average streamflow in Horse Creek, with some lags. There is no evidence that mining and reclamation activities in the basin caused any significant decrease in total streamflow in 2012.

Water Quality – Water quality parameters in 2012 were almost always within the desirable range relative to trigger levels and water quality standards at the station closest to mining (HCSW-1). Trigger levels were exceeded only once at HCSW-1 in 2012 with an alkalinity exceedance in November. At HCSW-2, trigger levels were exceeded for dissolved oxygen during half of the year. The report notes that the reported values for dissolved oxygen at HCSW-2 are the result of natural conditions (proximity to hypoxic segment of stream – Horse Creek

Prairie) and are not related to mining activities. The chlorophyll a trigger level was exceeded during low-flow periods at HCSW-2 in February, April, May, and December, and the pH declined below the acceptable trigger level range in October. HCSW-3 exceeded trigger levels for dissolved oxygen (June-September), calcium (April), sulfate (February-April and June), and TDS (January-April and June). HCSW-4 exceeded trigger levels for specific conductivity (June), dissolved oxygen (July and September), calcium (April-June), iron (July-October), alkalinity (May), sulfate (March-April and June), and TDS (January-June). Dissolved oxygen triggers were exceeded during summer wet months of 2012, when high temperatures reduce the oxygen carrying capacity of the stream. Sulfate, calcium, TDS, and other ions were exceeded in the dry season, when low rainfall and streamflow likely led to increased groundwater inputs from baseflow and agricultural runoff. Dissolved iron concentrations consistently exceeded the trigger value set at HCSW-4, but Mosaic and the Authority agree that the trigger value at that station has been set too low given historical and upstream concentrations of dissolved iron. Based on impact assessments already completed, the report concludes that none of the observed exceedances pose a significant adverse ecological impact to Horse Creek that would be attributable to mining.

Water quality parameters were compared with water quantity variables recorded during the same month: average daily streamflow for the month, average daily NPDES discharge for the month, and total monthly rainfall. In general, pH, dissolved oxygen, and most dissolved ions were higher when the overall quantity of water in the Horse Creek system was low. Specific conductivity, calcium, alkalinity, sulfate, and TDS showed the opposite pattern with NPDES discharge at HCSW-1. Conversely, turbidity, color, iron, and nitrogen were high when the water quantity was also high. When water quantity in Horse Creek is low, the stream may be pooled or slow-moving, leading to algal blooms that may increase pH and chlorophyll *a*. In addition, the majority of water in the stream during low quantity periods may be from groundwater (seepage or agricultural runoff); groundwater has a higher concentration of dissolved ions than surface water. When water quantity is high, an increased amount of sediment and organic debris is washed into the stream, leading to increases in turbidity, color, iron, and nitrogen.

While program triggers were exceeded for several parameters in 2012 and several parameters had statistically significant trends from 2003 to 2012, the exceedances and trends were concluded to be not of immediate concern.

Benthic Macroinvertebrates - Benthic invertebrate habitat assessment scores were “Optimal” to “Sub-optimal” and SCI scores were “Healthy” or “Exceptional” at all stations in 2012; these scores are typical of southwestern Florida streams, including those used to develop the Habitat Assessment and SCI indices. Benthic invertebrate taxa diversity and SCI metrics in Horse Creek exhibit both seasonal and year-to-year variation. Overall, taxa diversity indices and SCI metrics show few monotonic trends over time and are very similar between sampling events and stations. However, HCSW-2 has slightly lower diversity and significantly lower SCI metrics than other stations. Habitat conditions at HCSW-2 are consistently poor, with lower streamflow, dissolved oxygen, and pH than other Horse Creek stations. The source of the poor conditions are related to the lower than average streamflow and rainfall of the previous few years and the presence of Horse Creek Prairie, the large marsh located upstream of the biological sampling station.

Fish - During 2012, 25 species of fish were collected from the four Horse Creek sampling stations. In 2012, one new fish species was collected at HCSW-4, the Orinoco sailfin catfish. Fewer fish species were collected at HCSW-1 during two sampling events in 2012 than the other stations because of the unique characteristics of that sampling location. In addition, water levels and streamflow were fairly high during biological sampling at all stations in October which led to HCSW-2 not being sampled; higher water levels did not allow for some habitats to be reached by our sampling equipment. Abnormally cold winters in 2009 – 2010 and 2010 – 2011 may have led to decreased fish diversity at some stations in 2010 and 2011, with evidence of recovery and recruitment in 2012. Over the period of record, fish richness and diversity was lowest at HCSW-2, with no significant annual trends. Fish communities were similar for all years when stations were combined and for all stations when years were combined. Catch per effort is variable over time and dependent on sampling technique, a station's physical characteristics, water levels, and available recruitment sources. No trends were evident in the abundance of fish from exotic and native fish groups.

2.16 2015 Regional Water Supply Plan Southern Planning Region (SWFWMD 2015)

This volume of the Regional Water Supply Plan (RWSP) for the Southwest Florida Water Management district (District) is an assessment of projected water demands and potential sources of water for the period 2015 to 2035 in the Southern Planning Region, which includes DeSoto, Manatee and Sarasota counties and the portion of Charlotte County within the District. The purpose of the RWSP is to provide the framework for future water management decisions. The RWSP assesses demand and water availability and identifies potential options and associated costs for developing alternate sources as well as fresh groundwater.

Chapter 1 of the RWSP provides an introduction to the Southern Planning RWSP, an overview of the District's accomplishments in implementing the objectives of the prior (2010) RWSP, description of the region including land use, population, hydrology and geology of the area, and a description of the technical investigations that provide the basis for the District's water resource management strategies. The District's accomplishments since completion of the 2010 RWSP are listed for several categories including: 1) alternative water supply, conservation and reuse development, 2) support for water supply planning, 3) minimum flows and levels establishments, 4) quality of water improvement program (QWIP) and well back-plugging, and 5) regulatory and other initiatives. The 2015 RWSP builds on technical investigations undertaken by the District and the United States Geological Survey (USGS) beginning in the 1970s. Investigations conducted in the Southern Planning region and adjacent areas are listed and summarized for multiple categories: 1) water resource investigations, 2) USGS hydrologic investigations, 3) water supply investigations, 4) MFL investigations, and 5) modeling investigations. Collectively, the investigations provide District staff with an understanding of the complex relationships between human activities, climatic cycles, aquifer and surface water interactions, aquifer and surface hydrology, and water quality.

Chapter 2 addresses the resource protection strategies the District has implemented (or is considering implementing) including water use caution areas (WUCAs), minimum flows and levels (MFLs), prevention and recovery strategies, reservations and climate change. Water use caution areas are areas where the District's Governing Board has determine that regional action is necessary to address cumulative water withdrawals that are causing adverse impacts to the water and related natural resources or the public interest. The District established the Southern Water Use Caution Area (SWUCA) in 1992; it encompasses all or portions of eight counties in the southern portion of the District. In 1998, the District initiated an reevaluation of the SWUCA management strategy, and in March 2006, established minimum "low" flows for the upper Peace River, minimum levels for eight lakes along the Lake Wales Ridge in Polk and Highland counties, and a Saltwater Intrusion Minimum Aquifer level (SWIMAL) for the Upper Floridan aquifer (UFA) in the most impacted area (MIA) consisting of the coastal portion of the SWUCA in southern Hillsborough, Manatee and northern Sarasota counties. Since most of these water resources were not meeting their adopted MFLs, the District adopted a recovery strategy for the SWUCA in 2006. In 2013, the District completed the first five-year review of the recovery strategy. MFLs for many of the water bodies were still not being met and the District initiated a series of stakeholder meetings to review results and identify potential recovery options.

Priority water resources with established MFLs in the planning region include the aforementioned MIA of the SWUCA, the Middle Peace River, Upper Braden River, Lower Peace River, Dona Bay/Shakett Creek System, and the Upper and Lower Myakka River. Priority water resources located at least partially in the planning region for which MFLs had not yet been established or are being revaluated at time of the RWSP include: Upper and Lower Little Manatee River, Lower Manatee River, Lower Braden River, lower Peace River reevaluation, Horse Creek, Prairie Creek, and Upper and Lower Shell Creek. A prevention strategy is required to be developed if within 20 years the flow or level in a water body is projected to fall below an applicable MFL. A recovery strategy is required to be developed if the existing flow or level in a water body is below an applicable MFL. The only recovery strategy adopted to date in the planning region is the District's SWUCA recovery strategy. The purpose of the SWUCA recovery strategy is to provide a plan for reducing the rate of saltwater intrusion and restore low flows to the Upper Peace River and lake levels by 2025, while ensuring sufficient water supplies and protecting the investments of existing Water Use Permit (WUP) holders.

The RWSP lists possible effects of climate change on water supply planning efforts which include three primary mechanisms: sea level rise, air temperature rise and changes in precipitation regimes. Sea level rise is projected to be 2.0 to 8.0 inches locally over the 20 year planning period of the report; over a 50 year period, the projected increase is 5.2 to 26 inches. Sea level rise could stress the District's water resources in a number of ways. Inundation or upward migration of coastal wetlands may affect their ability to improve quality of stormwater runoff and provide habitat. Estuarine water encroachment may reduce freshwater withdrawal periods. Saltwater intrusion reduces water quality in aquifers that supply water users and municipal sewer systems may experience infiltration that reduces the quality of reclaimed water. Rising air temperatures would likely increase evaporation resulting in lower surface water levels and increased irrigation demand. Higher air temperatures may also cause declines in water quality raising treatment costs for potable water supply.

Chapter 3 quantifies existing and projected water supply demand through 2035 for various water uses. Demand projections were developed for five sectors; (1) public supply, (2) agriculture, (3) industrial/ commercial, mining/dewatering and power generation, (4) landscape/recreation and

(5) environmental restoration. It is projected that public supply demand will increase by 28.68 MGD for the 5-in-10 (average) condition. For the agriculture sector, trends indicate that activities are expected to increase significantly in the Southern Planning Region during the planning period. For the average 5-in-10 condition, total regional agricultural demand, including non-irrigation demand, is projected to increase by 13.1 percent. Industrial/commercial and mining/dewatering uses within the District include chemical manufacturing, food processing and other miscellaneous uses. Demand is projected to change by -57.3 percent, due primarily to a projected decrease of mining activities in Manatee County. The RWSP projected an increase of 14.3 percent for power generation water demand, occurring solely in Manatee County. The landscape/recreation sector includes the self-supplied water use associated with the irrigation of golf courses, cemeteries, parks, medians, etc. A 43.1 percent increase in demand for landscape/recreation was projected between 2010 and 2035. Environmental restoration comprises quantities of water that need to be developed and/or retired to meet established MFLs. It was estimated that 15 MGD would be needed for recovery of the MOA and was divided equally between the Heartland, Tampa Bay and Southern planning regions. The number will be refined as part of the next five-year assessment of the SWUCA Recovery Strategy. Over all sectors, the projected changes show that 62.97 MGD of additional water supply will need to be acquired from permitted reserves, developed, and/or existing use retired to meet demand in the planning region through 2035.

Chapter 4 evaluates the future water supply potential of traditional and alternative sources. Sources of water that were evaluated include surface water, stormwater, reclaimed water, seawater desalination, brackish groundwater desalination, fresh groundwater and conservation; aquifer storage and recovery (ASR) is also discussed as a storage option with potential to maximize the utilization of surface water and reclaimed water. The amount of water that is potentially available from these sources is compared to the demand projections for the planning region presented in Chapter 3, and a determination is made as to the sufficiency of the sources to meet demand through 2035. The additional quantity of water that will potentially be available from all sources of water in the planning region from 2015 through 2035 could be as high as 303.63 MGD, with the largest quantity occurring in available but unpermitted surface water. Based on a comparison of projected demands (overall additional projected demand = 62.97 MGD) and available supplies (up to 303.63 MGD), it is concluded that sufficient sources of water are available within the planning region to meet projected demands through 2035.

Chapter 5 contains a list of alternative water supply development (WSD) options for local governments, utilities and other water users that includes surface water and stormwater, reclaimed water and water conservation. The development of additional fresh groundwater from the UFA will be limited as a result of environmental impacts from excessive withdrawals and planned reductions in withdrawals that are part of the SWUCA recovery strategy. However, it will be possible to obtain groundwater from the surficial and intermediate aquifers under certain conditions. Options proposing to withdraw brackish groundwater from the UFA may not be permittable in many areas of the planning region due to their potential to exacerbate existing resource problems that have resulted from historical groundwater withdrawals. A wide variety of non-agriculture (residential and industrial/commercial best management practices) and agriculture conservation options are presented. The planning region encompasses a diverse mix of land uses providing opportunities for urban, industrial and agricultural reclaimed water use and opportunities for storage of excess reclaimed water. Capturing and storing water from river/creek systems during times of high flow has the potential to meet the 2035 demand and various options are presented for the Southern Planning Region. Finally, two options for seawater desalination in the planning region (Port Manatee and Venice) were summarized.

Chapter 6 provides an overview of water supply development projects that are currently under development and receiving District funding assistance. In addition to the listed projects under development, the RWSP states that it is probable that additional water supplies are being developed by various entities in the planning region outside of the District's funding programs. Projects are summarized by the following categories: 1) water conservation (non-agriculture and agriculture), 2) reclaimed water, 3) surface water/stormwater, 4) brackish groundwater desalination, and 5) ASR projects.

Chapter 7 inventories the District's ongoing data collection and analysis activities and water resource projects that are classified as water resource development (WRD). The WRD data collection and analysis activities include: 1) hydrologic data collection, 2) MFL program, 3) watershed management planning, 4) quality of water improvement program, and 5) stormwater improvements (implementation of storage and conveyance BMPs). As of FY2015, the District has 14 ongoing projects that meet the definition of water resource development "projects" (regional projects designed to create an identifiable supply of water for existing and/or future reasonable-beneficial uses). The projects include feasibility and research projects for new alternative water supply, FARMS projects to improve agricultural water use efficiency, and environmental restoration projects that assist MFLs recovery.

Finally, Chapter 8 provides an estimate of the capital cost of WSD and WRD projects proposed by the District and its cooperators to meet the water supply demand projected through 2035 and to restore MFLs to impacted natural systems. The chapter includes the following: 1) discussion of the District's statutory responsibilities for funding WSD and WRD projects, 2) identification of utility, water management district, state and federal funding mechanisms, 3) discussion of public-private partnerships and private investment, 4) review of water demands for which water supply and water resource projects should be developed, 5) projection of the amount of funding that is expected to be available from the various funding mechanisms, and 6) comparison of proposed large-scale project costs to the projected funding available. Funding mechanisms include water utilities, the water management district (Cooperative Funding Initiative and district initiatives), state funding (Springs Initiative, Water Protection and Sustainability Program, Florida Forever Program, FARMS Program, West-Central Florida Water Restoration Action Plan), federal funding (USDA Natural Resources Conservation Service programs), and public-private partnerships and private investment. The RWSP states that a minimum of $1.65 billion could potentially be generated or made available to fund the CFI and District Initiative projects necessary to meet the water supply demand through 2035 and to restore MFLs for impacted natural systems. This figure may be conservative, since it is not possible to determine the amount of funding that may be available in the future from the federal government and state legislative appropriations. To develop an estimate of the capital cost of projects necessary to meet demand, the District compiled a list of large-scale WSD projects that have been proposed by the Authority, Tampa Bay Water, Tampa Electric Company and Polk County that will produce up to 49 mgd of water supply within the 2035 planning horizon Districtwide. The RWSP states that the estimate of $1.65 billion in cooperator and District financial resources that will be generated through 2035 for funding is sufficient to meet the projected $1.1 to $1.5 million total cost of the large-scale projects listed.

2.17 Integrated Regional Water Supply Plan 2015 (Atkins et al 2015)

In order to ensure that drinking water needs are met and that supplies are developed in an orderly, cost effective and environmentally sustainable manner, the Authority has instituted a long-term water supply planning process. Critical to this process is the development of an Integrated Regional Water Supply Master Plan (IRWSMP) that is to be updated approximately every five years. This document is the Authority's IRWSMP update for the 2015 through 2035 planning period. It updates and improves upon the 2006 IRWSMP which provided a water supply master plan through 2025. The IRWSMP provides the following:

- Water demand projections for each of the Authority's Customers (Charlotte, DeSoto, Manatee and Sarasota Counties, and the City of North Port) which are then aggregated into regional water demand projections.
- An inventory of existing water supply facilities and capacity for the Authority Customers which are aggregated to determine projected water use deficits that must be addressed through water supply development and demand management strategies.
- A comparison of projected water demands to existing water supply capacity to determine projected surpluses and deficits.
- A summary of each of the Authority's Customer's conservation initiatives and identified opportunities that may further local programs as well as potential opportunities to enhance conservation and demand management.
- Details about potential future water supplies that can be developed to meet the region's water supply needs including ground water, surface water and seawater desalination.
- A discussion of opportunities to further share excess production capacity amongst the Authority's Customers and Partners.
- A description of the existing regional transmission system and regional and local interconnections that enable delivery of supply and sharing of resources.
- Discussion of potable water quality maintenance and identification of measures to ensure that high quality water is delivered throughout the system.
- An evaluation that explores threats to source water from changing conditions such as sea level rise, climatic variations, and land use activities.

Demand Projections – Seven approaches to projecting future water demands were evaluated to identify a range of projected aggregate water demand growth for Authority Customers through 2035, and develop a single recommended most probably annual growth rate. The seven methods yielded aggregate annual water demand growth ranging from a low of 0.34 percent to 1.93 percent. The projected most probably annual growth rate in water demand was estimated to be 1.55 percent. Given an existing Master Water Supply Contract (MWSC) provision that prescribes how the Authority is to develop 20-year water demand projections, and because the projections were similar to those computed in the IRWSMP, the IRWSMP recommends that the Authority use the water use demand projections submitted to the Authority by the Customers in 2014. Thus, water use demand was projected to increase by nearly 47% by 2035. However, it is recommended that the Authority utilized the peak year demand projection methodology in future IRWSMP updates.

Existing Water Supply Capacity – The IRWSMP update includes a description of existing water production facilities owned by the Authority, its Customers and Partners (City of Punta Gorda and the Englewood Water District (EWD)). Facilities that have already received a water use permit (WUP), but are not yet constructed are also discussed, as well as planned treatment capacity improvements at the Peace River Facility scheduled for completion in the spring of 2015. Total average annual and peak month finished water capacities of the Authority's Customers through 2015 are presented in tabular format. The average annual daily finished water capacity available to Authority Customers is over 103 MGD and is projected to increase to nearly 110 MGD; peak month finished water capacity is projected to increase from 128 MGD to nearly 135 MGD.

Water Surpluses and Deficits – The IRWSMP identified deficits by comparing projected water needs to existing finished water capacity on a yearly basis for the duration of the planning period. The projected water "need" is the aggregation of projected water demands (customer use) and a six-percent reserve capacity to be maintained in the system. For future water supply planning, an additional level of safety has been incorporated that establishes that new water supply capacity will be completed and brought on line prior to projected water needs exceeding 90 percent of the average annual finished water supply. The IRWSMP projects that an additional 25 MGD of average annual permitted finished water capacity will need to be developed within the region by 2035.

Conservation – Given the Authority, and its Customers, having a proven track record of water conservation and water use efficiency, both gross and residential per capita water use continues to decline even though they are already well below District per capita water use goals. This is due to many factors including plumbing changes in the Florida Building Code in 1995, the use of EPA's WaterSense certified products and increased efficiency and use of reclaimed water. Other opportunities for water conservation include source management measures aimed at reducing water losses and opportunities to further engage the industrial-commercial-institutional sector on water conservation initiatives. It is estimated that the Authority Customers can achieve another nearly 5 MGD of water conservation savings during the planning period with a cumulative investment of less than $9 million, meeting a significant share of the 25 MGD of new water supply (or water savings) needed by 2035.

Potential Sources of Supply – More than 20 potential supplies were identified and evaluated in the IRWSMP, yielding a dozen potential future water supplies that can collectively supply 124 MGD of new finished water capacity, far greater than the projected need by 2035. These sources include ground water, surface water and sea water supplies. The potential sources are in various stages of development. For example, Punta Gorda is projecting its brackish supply will be online by 2019, while sources such as seawater desalination facilities may not be feasible for decades in this region.

Opportunities to Share Excess Capacity – The ability to share excess water capacity through existing and future expanded regional water transmission main system can greatly facilitate meeting existing and future water demands in a cost effective manner and could potentially delay the need for the next round of capital investment to develop additional supplies. Additionally, excess capacity provides rotational supply in the event of an emergency loss, drought or environmental management needs and provides a supply buffer by allowing adequate time for the development to new water supplies should water demand grow faster than expected. An analysis was conducted to assess the quantities of excess capacity that could potentially be shared. There was projected to be over 30 MGD of excess capacity in 2015. Twelve MGD of this amount is needed for the six percent reserve capacity and ten percent needed in association with the development of new finished water capacity prior to demand exceeding 90 percent of existing finished water capacity. The remaining 18 MGD represents an opportunity for the Authority, Customers and Partners to further expand sharing of excess capacity. Projected excess capacity declines over time as growth leads to additional customer demands.

System Interconnects – The IRWSMP recommends that the Authority should adopt the updated future System Interconnect pipeline projects for the Regional Integrated Loop system as presented in the IRWSMP. Further recommendations include the prioritization of completion of the Phase III (address phased reduction in the Manatee-Sarasota water contract quantities and directly interconnect Manatee County with the regional system) and the Phase I interconnects (provide back-up supply for DeSoto County, aid in addressing Punta Gorda needs, and support future development of new supplies in the Shell/Prairie Creek watershed). Additionally, the IRWSMP recommends the continued development and refinement of the remaining interconnect projects with Customers and Partners to support improved system reliability and efficiently meet the region’s existing and future water supply needs.

Potable and System Water Quality Maintenance - The IRWSMP summarizes water quality characteristics produced at the existing major water treatment plants (WTPs), and within the Authority’s regional transmission and the local distribution systems owned by Authority Customers and Partners. Water quality blending scenarios are also discussed including scenarios related to planned WTPs and regional transmission system enhancements. The IRWSMP concludes that the Authority and Customers do an overall excellent job of maintaining finished water quality throughout the regional and local systems. The IRWSMP makes multiple suggestions for the continuation and/or improvement of water quality maintenance.

Source Water Protection – A number of factors are cited as having the potential to negatively impact future Authority surface water supplies. All of them are of increasing concern primarily under seasonally lower flow conditions. Within the existing and potential surface water supply watersheds there is clear evidence of long-term increasing conductivity levels during lower flows primarily due to agricultural ground water discharges. Additionally, upstream of the Peace River Facility, lower flow water supplies may be further reduced by surface/ground water usage during a proposed expansion of phosphate mining primarily in the Horse Creek basin. In addition to these anthropogenic factors, there are at least two major natural influences with the potential to seasonally influence future Peace River Facility operations. First, there has been a distinct long-term (60 year) increase in the frequency of lower flow conditions. Further, projected future sea-level rise is expected to influence the future availability of lower Peace River water during seasonally lower flow conditions. The IRWSMP states that these factors suggest that two options may need to be considered in the future: 1) increase the ability to withdraw, and 2) build additional off-stream storage to meet projected increases in demand and maintain overall reliability.

2.18 2014 HBMP Annual Data Report (Janicki Environmental 2016)

This document represents the 19th Annual Data Report submitted under the expanded Hydrobiological Monitoring Program (HBMP) initiated in 1996 in compliance with Water Use Permit 20010420. A summary of findings is listed below. It should be noted that rainfall/flow have annually varied considerably during the monitoring period.

Flows – Average mean daily Peace River flow of the three combined gages upstream of the Facility during 2014 was 875.3 cfs, which was below the 1,143.8 cfs average over the 39 years of HBMP monitoring (1976-2014). Overall, annual mean flow upstream of the Facility during 2014 was 76 percent of the average daily flow over the preceding long-term 1976-2013 period.

Withdrawals – Total Peace River Facility withdrawals during 2014 were approximately 6.5 percent of the total gaged freshwater flow measured at the USGS Arcadia gage, 5.4 percent of the upstream gaged flow at the Facility, and 4.6 percent of the combined average daily inflows upstream of the U.S. 41 Bridge. During the entire period of Peace River Facility withdrawals (1980-2014), total combined withdrawals have been approximately 1.98 percent of the corresponding gaged Peace River at Arcadia flows, 1.48 percent of total gaged flow upstream of the Facility, and only 1.1 percent of the combined daily freshwater flows of the Peace River, and Horse, Joshua, and Shell Creeks.

There were a number of days during 2014 when the Facility withdrawals exceeded the seasonally designated maximum percent allowed by the April 2011 revised permit withdrawal schedule. Such exceedances of the permitted percent withdrawals primarily result from subsequent USGS revisions of the provisional daily flow information available to the Authority at the time of actual withdrawals. During 2014, the facility did not withdraw any water from the river on 60 days or approximately 16 percent of the time.

Water Temperature – Monthly mean water column temperatures in 2014 followed the strong seasonal pattern typically observed in south Florida. Often, the highest water temperatures in the more upstream, shallower, freshwater reaches of the estuary reach their highest levels in May and then remain similar up until August. By comparison, average water column temperatures in the downstream areas, more influenced by the harbor, often don’t reach their highest annual temperature values until July. During 2014, the highest average water column temperatures occurred throughout the lower river/upper harbor estuary during June. The 2014 data clearly show relatively normal cold conditions during both the start and end of the year associated with typical winter cold fronts.

Dissolved Oxygen – Previous results have indicated that within the downstream reaches of the river between River Kilometers -2.4 and 10.5, there is typically a wet-season depression of average water column dissolved oxygen (DO) levels in response to increased wet-season flows. This seasonal pattern typifies the widely documented hypoxic/anoxic conditions that typically occur in upper Charlotte Harbor as a result of the extreme water column stratification that commonly occurs near the mouth of the river and upper regions of the harbor during the summer.

This typical observed seasonal depression of average water column DO concentrations in this reach of the lower river is generally more intense and of greater duration than that observed at the more upstream monitoring sites. During 2014 (as typically observed in previous years), average water column DO levels generally declined as water temperatures increased, reaching their lowest levels during the summer wet season between June and September throughout both the lower river and upper harbor as both water temperatures and flows increased. The 2014 summer, wet season column profile data (as has occurred since 2010) indicated the return of normal hypoxic/anoxic dissolved oxygen levels in the upper harbor. This indicated that the flows that occurred during the summer of 2014 were again of sufficient duration and intensity to induce the level of water column stratification necessary to cause the development of extremely low, widespread near-bottom DO levels in upper Charlotte Harbor.

Light Extinction – The 2014 HBMP data indicate that both the timing and magnitude of the ability of light to penetrate into the water column (1 percent depth) exhibits both strong temporal (seasonal) and spatial differences among the “fixed” monitoring sites along the HBMP lower Peace River/upper Charlotte Harbor sampling transect. In many other estuarine systems, the extinction of light is often highly influenced by ambient chlorophyll *a* concentrations (phytoplankton biomass). However, light extinction in the lower Peace River/upper Charlotte Harbor estuarine system is often primarily mediated by water color due to the “black water” characteristics of freshwater inflows from the Peace River watershed. Water clarity during 2014 (as in previous years) was the greatest in the lower river and especially in the upper harbor during both the typical spring dry season and other periods of lower flows.

Conductivity/Salinity – Seasonally spatial conductivity patterns in the tidal lower Peace River during the very dry first five months of 2014 were similar with previous spring dry season and late fall conditions over much of the previous decade, when brackish conditions in the lower river extended upstream even beyond the Peace River Facility intake.

Inorganic Nitrite+Nitrate Nitrogen – In the Charlotte Harbor estuarine system, inorganic nitrite+nitrate nitrogen concentrations are typically the lowest during the peak of the spring dry season, when high light and water temperatures result in increased phytoplankton production and freshwater inflows are low. Concentrations rapidly increase in the lower salinity reaches of the estuary with higher flows as nitrogen is carried from the watershed and increasing color reduces light penetration of the water column and limits phytoplankton growth. The data typically indicate a distinct spatial gradient within the lower river/upper harbor estuarine system with higher levels of inorganic nitrogen progressively occurring upstream. During 2014, inorganic nitrogen concentrations were low or at near-detection limits during the extended spring/early summer dry season (April/May). Overall, nitrite+nitrate nitrogen levels in 2014 were similar with the longer-term averages at each of the five fixed stations.

Total Kjeldahl Nitrogen – Typically, total Kjeldahl nitrogen concentrations in the lower Peace River/upper Charlotte Harbor estuarine system are generally the highest during the summer wet season, reflecting the influences of increased freshwater inflows. Overall, during 2014, the annual average Kjeldahl concentrations at each of the five monitoring locations were very similar to their historic long-term averages.

Ortho-Phosphorus – Inorganic phosphorus concentrations in the Peace River Estuary follow patterns typical of conservative water quality constituents (reflecting dilution rather than biological uptake). Estuarine phosphorus concentrations are primarily influenced by dilution of high ambient levels in Peace River freshwater by saline Gulf water moving up the harbor. Thus the HBMP monitoring data typically indicate distinct spatial patterns in inorganic phosphorus concentrations among the sampling sites, with concentrations being markedly higher upstream than downstream. Following Hurricane Charley in August 2004 (and the subsequent Hurricanes Frances and Jeanne in September 2004), the data indicated that there were atypical marked increases in inorganic phosphorus levels associated with high levels of hurricane-related flows from the Peace River watershed. During the wetter than average conditions in 2005, inorganic phosphorus patterns in the lower river/upper harbor estuarine system returned to more typical seasonal patterns. However, during the dry conditions that characterized the 2006-2008 period, phosphorus concentrations in the lower river/upper harbor estuarine system returned to higher levels not seen in over two decades. Phosphorus concentrations then began to decline during 2009 and have continued to decline to previous observed lower levels. Seasonally, inorganic ortho-phosphorus in 2014 at the five fixed monitoring sites was similar to levels observed prior to the recent observed increase.

Silica – Historically, annual reactive silica concentrations in the Peace River Estuary characteristically have indicated a number of differing temporal and spatial patterns. During the spring dry season, silica levels were normally at their annual lowest concentrations throughout the lower Peace River/upper Charlotte Harbor estuarine system corresponding to depressed flow inputs and periods of increased chlorophyll *a* biomass (potentially reflecting uptake by diatoms in the phytoplankton). Then, usually during May and June, as water temperatures increased and the start of the summer wet season began, concentrations characteristically rapidly increased throughout the estuary. However, reactive silica concentrations during 2014 continued to reflect the recently observed pattern of increased levels noted in previous HBMP reports, with peak silica levels near seasonally historically high levels.

Chlorophyll *a* – Phytoplankton biomass (chlorophyll *a*) patterns in the lower Peace River/upper Charlotte Harbor Estuary are normally characterized by several seasonal peaks throughout the year that differed both seasonally and spatially among the HBMP “fixed” sampling locations. Typically, chlorophyll *a* phytoplankton biomass in the lower Peace River/upper Charlotte Harbor Estuary shows distinct increases both during the spring with increasing light and water temperatures and during the late fall after wet-season flows have increased nitrogen levels and associated high color levels begin to decline. Chlorophyll *a* increases (blooms) during 2014 were influenced by both the seasonally low streamflow during the first five months of the year, as well as the high flows during the summer wet season that resulted in phytoplankton “blooms” stimulated by nitrogen inputs in both the higher and intermediate salinity reaches of the lower river/upper harbor estuary.

The graphical and summary analyses presented in this document do not indicate any substantial changes or atypical events in either the physical or biological data collected during 2014, other than those previously noted. These include:

- Freshwater inflows during 2014 were influenced by relatively average conditions during the typical summer wet season.

- The previously noted long-term increase in reactive silica concentrations noted at the lower Peace River/upper Charlotte Harbor monitoring locations indicated some decline during 2014.

- Inorganic phosphorus concentrations in the freshwater entering the estuary had increased in recent years, following decades of major declines that began in the late 1970s. However, observations since 2009 have shown that levels have substantially declined again to levels near where they were prior to the observed recent increase.

- The observed recent increases in silica and phosphorus seem to have been linked to the previous closure of phosphogypsum stack systems in the Whidden Creek basin, located in the upper Peace River watershed.

The “limited” analyses presented in the *2014 HBMP Annual Data Report* do not suggest that there have been any long-term, systematic changes resulting from either current or historic water withdrawals by the Peace River Regional Water Supply Facility.

2.19 2015 HBMP Annual Data Report (Janicki Environmental 2016)

This document represents the 20th Annual Data Report submitted under the expanded Hydrobiological Monitoring Program (HBMP) initiated in 1996 in compliance with Water Use Permit 20010420. In making comparisons of the 2015 data with similar data collected over the preceding 39-year period (1976-2014), it should be noted that rainfall/flow have annually varied considerably during the recent historic period. Conditions in 2015 were characterized by average to above average flows with higher than normal flows occurring in months from both the typically wet (August-September) and dry (February) seasons.

Flows – Average mean daily Peace River flow of the three combined gages upstream of the Facility during 2015 was 1,584 cfs, which was above the 1,155 cfs average over the 40 years of HBMP monitoring (1976-2015). Overall, annual mean flow upstream of the Facility during 2015 was 133 percent of the average daily flow over the long-term 1976-2015 period.

Withdrawals – Total Peace River Facility withdrawals during 2015 were approximately 3.8 percent of the total gaged freshwater flow measured at the USGS Arcadia gage, 3.0 percent of the upstream gaged flow at the Facility, and 2.4 percent of the combined average daily inflows upstream of the U.S. 41 Bridge. During the entire period of Peace River Facility withdrawals (1980-2015), total combined withdrawals have been approximately 2.1 percent of the corresponding gaged Peace River at Arcadia flows, 1.5 percent of total gaged flow upstream of the Facility, and only 1.2 percent of the combined daily freshwater flows of the Peace River, and Horse, Joshua, and Shell Creeks.

There were a number of days during 2015 when the Facility withdrawals exceeded the seasonally designated maximum percent withdrawals allowed by the April 2011 revised permit withdrawal schedule. Such exceedances of the permitted percent withdrawals primarily result from subsequent USGS revisions of the provisional daily flow information available to the Authority at the time of actual withdrawals. During 2015, the facility did not withdraw any water from the river on 69 days or approximately 19 percent of the time.

Water Temperature – Monthly mean water column temperatures in 2015 followed the strong seasonal pattern typically observed in south Florida. Often, the highest water temperatures in the more upstream, shallower, freshwater reaches of the estuary reach their highest levels in May and then remain similar up until August. By comparison, average water column temperatures in the downstream areas, more influenced by the harbor, often don't reach their highest annual temperature values until July. During 2015, the highest average water column temperatures occurred throughout the lower river/upper harbor estuary during June (more upstream stations) or July (more downstream stations). The 2015 data clearly show relatively normal cold conditions at both the start and end of the year associated with typical winter cold fronts.

Dissolved Oxygen – Previous results have indicated that within the downstream reaches of the river between River Kilometers -2.4 and 10.5, there is typically a wet season depression of average water column dissolved oxygen (DO) levels in response to increased wet season flows. This seasonal pattern typifies the widely documented hypoxic/anoxic conditions that typically occur in upper Charlotte Harbor as a result of the extreme water column stratification that commonly occurs near the mouth of the river and upper regions of the harbor during the summer wet season. This typically observed seasonal depression of average water column DO concentrations in this reach of the lower river is generally more intense and of greater duration than that observed at the more upstream monitoring sites. During 2015 (as typically observed in previous years), average water column DO levels generally declined as water temperatures increased, reaching their lowest levels during the summer wet season between August and September throughout both the lower river and upper harbor as both water temperatures and flows increased. The 2015 summer, wet season column profile data (as has occurred since 2010) indicated the return of normal hypoxic/anoxic dissolved oxygen levels in the upper harbor. This has indicated that the flows occurring during the summer of 2015 were again of sufficient duration and intensity to induce the level of water column stratification necessary to cause the development of extremely low, widespread near-bottom DO levels in upper Charlotte Harbor.

Light Extinction – The 2015 HBMP data indicate that both the timing and magnitude of the ability of light to penetrate into the water column (1 percent depth) exhibits both strong temporal (seasonal) and spatial differences among the "fixed" monitoring sites along the HBMP lower Peace River/upper Charlotte Harbor sampling transect. In many other estuarine systems, the extinction of light is often highly influenced by ambient chlorophyll *a* concentrations (phytoplankton biomass). However, light extinction in the lower Peace River/upper Charlotte Harbor estuarine system is often primarily mediated by water color due to the "black water" characteristics of freshwater inflows from the Peace River watershed. Water clarity during 2015 (as in previous years) was the greatest in the lower river and especially in the upper harbor during both the typical spring dry season and other periods of lower flows.

Conductivity/Salinity – Seasonally spatial conductivity patterns in the tidal lower Peace River were reflective of the normal to above normal flow in 2015. Late fall conditions with low river flow occurred over much of the previous decade, allowing brackish conditions in the lower river to often extended upstream even beyond the Peace River Facility intake.

Inorganic Nitrite+Nitrate Nitrogen – In the Charlotte Harbor estuarine system, inorganic nitrite+nitrate nitrogen concentrations are typically the lowest during the peak of the spring dry season, when freshwater inflows are low and high light and water temperatures result in increased phytoplankton production. Inorganic nitrogen concentrations rapidly increase in the lower salinity reaches of the estuary under higher flow conditions as nitrogen is carried from the watershed and increasing color reduces light penetration of the water column and limits phytoplankton growth. The data typically indicate a distinct spatial gradient within the lower river/upper harbor estuarine system with higher levels of inorganic nitrogen progressively occurring upstream. During 2015, a decrease in inorganic nitrogen was observed during May. At the more upstream stations, a secondary dip in inorganic nitrogen occurred during the above normal flows in August and September. With the exception of RK 15.5 (the middle station), nitrite+nitrate nitrogen levels in 2015 were lower than the longer-term averages at each of the five fixed station locations

Total Kjeldahl Nitrogen – Typically, total Kjeldahl nitrogen (TKN) concentrations in the lower Peace River/upper Charlotte Harbor estuarine system are generally the highest during the summer wet season, reflecting the influences of increased freshwater inflows. In 2015, flows in February were higher than normal levels and TKN levels were also elevated during this month, with the exception of the upper harbor station (RK -2.4). Overall, during 2015, the annual average TKN concentrations were slightly greater than the historic long-term averages

Ortho-Phosphorus – Inorganic phosphorus concentrations in the Peace River Estuary follow patterns typical of conservative water quality constituents (reflecting dilution rather than biological uptake). Estuarine phosphorus concentrations are primarily influenced by dilution of high ambient levels in Peace River freshwater by saline Gulf water moving up the harbor. Thus, the HBMP monitoring data typically indicate distinct spatial patterns in inorganic phosphorus concentrations among the sampling sites, with concentrations being markedly higher upstream than downstream. Following Hurricane Charley in August 2004 (and the subsequent Hurricanes Frances and Jeanne in September 2004), the data indicated that there were atypical marked increases in inorganic phosphorus levels associated with high levels of hurricane-related flows from the Peace River watershed. During the wetter than average conditions in 2005, inorganic phosphorus patterns in the lower river/upper harbor estuarine system returned to more typical seasonal patterns. However, during the dry conditions that characterized the 2006-2008 period, phosphorus concentrations in the lower river/upper harbor estuarine system returned to higher levels not seen in over two decades. Phosphorus concentrations then began to decline during 2009 and have continued to decline to previous observed lower levels. Seasonally, inorganic ortho-phosphorus in 2015 at the five fixed monitoring sites was similar to levels observed prior to the recent observed increase.

Silica – Historically, annual reactive silica concentrations in the Peace River Estuary characteristically have indicated a number of differing temporal and spatial patterns. During the spring dry season, silica levels were normally at their annual lowest concentrations throughout the lower Peace River/upper Charlotte Harbor estuarine system corresponding to depressed flow inputs and periods of increased chlorophyll *a* biomass (potentially reflecting uptake by diatoms in the phytoplankton). Then, usually during May and June, as water temperatures increased and the start of the summer wet season began, concentrations characteristically rapidly increased throughout the estuary. However, reactive silica concentrations during 2015 continued to reflect the recently observed pattern of increased levels noted in previous HBMP reports, with peak silica levels near seasonally historically high levels.

Chlorophyll *a* – Phytoplankton biomass (chlorophyll *a*) patterns in the lower Peace River/upper Charlotte Harbor Estuary are normally characterized by several seasonal peaks throughout the year that differ both seasonally and spatially among the HBMP "fixed" sampling locations. Typically, chlorophyll *a* phytoplankton biomass in the lower Peace River/upper Charlotte Harbor Estuary shows distinct increases both during the spring with increasing light and water temperatures and during the late fall after wet season flows have increased nitrogen levels and associated high color levels begin to decline. Chlorophyll *a* increases (blooms) during 2015 were influenced by the high flows during February and the summer wet-season that resulted in phytoplankton "blooms" stimulated by nitrogen inputs in the higher salinity reaches of the lower river/upper harbor estuary.

The graphical and summary analyses presented in this document do not indicate any substantial changes or atypical events in either the physical or biological data collected during 2015, other than those previously noted. These include:

- Freshwater inflows during 2015 were influenced by higher than average rainfall conditions during the both the typical spring dry and summer wet season.

- The previously noted long-term increase in reactive silica concentrations noted at the lower Peace River/upper Charlotte Harbor monitoring locations continued despite the somewhat lower levels observed during 2014.

- Inorganic phosphorus concentrations in the freshwater entering the estuary had increased in recent years, following decades of major declines that began in the late 1970s. However, observations since 2009 have shown that levels have substantially declined again to levels near where they were prior to the observed recent increase.

- The observed recent increases in silica and phosphorus seem to have been linked to the previous closure of phosphogypsum stack systems in the Whidden Creek basin, located in the upper Peace River watershed.

The "limited" analyses presented in the 2015 HBMP Annual Data Report do not suggest that there have been any long-term, systematic changes resulting from either current or historic water withdrawals by the Peace River Regional Water Supply Facility.

2.20 A spectral optical model and updated water clarity reporting tool for Charlotte Harbor Seagrasses (Dixon and Wessel, 2016)

This article, appearing in *Florida Scientist*, and includes information from the report summarized in section 2.12, describes advances made to quantify how primary light attenuation parameters affect the amount and quality of light reaching seagrass target depths through the development of a spectrally explicit optical model. Water clarity is a limiting factor in determining the depth distribution, and therefore areal extent, of seagrass. Water clarity targets have been established and are based on a reference period (2003-2007), when seagrasses were stable in the estuary, thus eliminating the need to explicitly quantify the light requirements of seagrass or the impacts of other potentially limiting factors such as salinity. The developed optical model is based on partitioned absorption and scattering and is parameterized as a function of color, chlorophyll, and turbidity. The model was developed and validated using empirical data collected throughout Charlotte Harbor National Estuary Program (CHNEP) management areas and produces estimates of attenuation coefficients (K_d) and % Photosynthetically Active Radiation (%PAR) at specified depths. The article describes in detail the data utilized, and the methods used to develop and validate the model. The calibrated model predicts water clarity throughout the estuaries and allows for predictions without reliance on field light estimates which have been shown to include a great deal of uncertainty in the shallow water estuaries.

2.21 Estuary-Specific Numeric Interpretations of the Narrative Nutrient Criterion (62-302.532 FAC)

This document provides a table of estuary-specific numeric interpretations of the narrative nutrient criterion in paragraph 62-305.530(47)(b), FAC. The rule became effective February 17, 2016. The concentration-based estuary interpretations are open water, area-wide averages. Numeric values listed in the table for nutrient and nutrient response values do not apply to wetlands or to tidal tributaries that fluctuate between predominantly marine and predominantly fresh waters during typical climatic and hydrologic conditions unless specifically provided by name in the table. The interpretations expressed as load per million cubic meters of freshwater inflow are the total load of that nutrient to the estuary divided by the total volume of freshwater inflow to that estuary. Criteria specific to Charlotte Harbor/Estero Bay have been extracted from the table within this document and are displayed below. The numeric values in the table will be superseded if a more recent numeric interpretation of the narrative nutrient criterion, such as a Level II Water Quality Based Effluent Limitation (WQBEL), Site Specific Alternative Criterion (SSAC), Total Maximum Daily Load (TMDL), or Reasonable Assurance Demonstration, is established by the FDEP.

For Charlotte Harbor/Estero Bay, the criteria expressed as annual means are arithmetic means and are not to be exceeded more than once in a three year period. For criteria expressed as long-term averages, the long-term average shall be based on data from the most recent seven-year period and shall not be exceeded. Criteria expressed as annual geometric means (AGM) are not to be exceeded more than once in a three year period. For criteria expressed as not to be exceeded in more than 10 percent of the samples, the criteria shall be assessed over the most recent seven year period.

Estuary Specific Numeric Interpretations of the Narrative Nutrient Criterion for Charlotte Harbor/Estero Bay

Estuary	Total Phosphorus	Total Nitrogen	Chlorophyll-a
Dona and Roberts Bay	0.18 mg/L as annual mean	0.42 mg/L as annual mean	4.9 µg/L as annual mean
Upper Lemon Bay	0.26 mg/L as annual mean	0.56 mg/L as annual mean	8.9 µg/L as annual mean
Lower Lemon Bay	0.17 mg/L as annual mean	0.62 mg/L as annual mean	6.1 µg/L as annual mean
Charlotte Harbor Proper	0.19 mg/L as annual mean	0.67 mg/L as annual mean	6.1 µg/L as annual mean
Pine Island Sound	0.06 mg/L as annual mean	0.57 mg/L as annual mean	6.1 µg/L as annual mean
San Carlos Bay	0.045 mg/L as long term average	0.44 mg/L as long term average	3.7 µg/L as long term average
Tidal Myakka River	0.31 mg/L as annual mean	1.02 mg/L as annual mean	11.7 µg/L as annual mean
Tidal Peace River	0.50 mg/L as annual mean	1.08 mg/L as annual mean	12.6 µg/L as annual mean
Matlacha Pass	0.08 mg/L as annual mean	0.58 mg/L as annual mean	6.1 µg/L as annual mean
Estero Bay (including Tidal Imperial River)	0.07 mg/L as annual mean	0.63 mg/L as annual mean	5.9 µg/L as annual mean
Little Hickory Bay	0.070 mg/L as AGM	0.63 mg/L as AGM	5.9 µg/L as AGM
Water Turkey Bay	0.057 mg/L as AGM	0.47 mg/L as AGM	5.8 µg/L as AGM
Moorings Bay	0.040 mg/L, not to be exceeded in more than ten percent of the samples	0.85 mg/L, not to be exceeded in more than ten percent of the samples	8.1 µg/L as AGM
Upper Caloosahatchee River Estuary	0.086 mg/L as long term average	See subsection 62-304.800(2), F.A.C.	4.2 µg/L as long term average
Middle Caloosahatchee River Estuary	0.055 mg/L as long term average	See subsection 62-304.800(2), F.A.C.	6.5 µg/L as long term average
Lower Caloosahatchee River Estuary	0.040 mg/L as long term average	See subsection 62-304.800(2), F.A.C.	5.6 µg/L as long term average

2.22 2016 HBMP Annual Data Report (Janicki Environmental 2017)

This document represents the 21st Annual Data Report submitted under the expanded Hydrobiological Monitoring Program (HBMP) initiated in 1996 in compliance with Water Use Permit 20010420. In making comparisons of the 2016 data with similar data collected over the preceding 40-year period (1976-2015), it should be noted that rainfall/flow have annually varied considerably during the recent historic period.

Flows – Average mean daily Peace River flow of the three combined gages upstream of the Facility during 2016 was 1,690 cfs, which is above the 1,167 cfs average over the 41 years of HBMP monitoring (1976-2016). Overall, annual mean flow upstream of the Facility during 2016 was 144.7 percent of the average daily flow over the long-term 1976-2016 period.

Withdrawals – Total Peace River Facility withdrawals during 2016 were approximately 2.9 percent of the total gaged freshwater flow measured at the USGS Arcadia gage, 2.3 percent of the upstream gaged flow at the Facility, and 1.7 percent of the combined average daily inflows upstream of the U.S. 41 Bridge. During the entire period of Peace River Facility withdrawals (1980-2016), total combined withdrawals have been approximately 2.1 percent of the corresponding gaged Peace River at Arcadia flows, 1.6 percent of total gaged flow upstream of the Facility, and only 1.2 percent of the combined daily freshwater flows of the Peace River, and Horse, Joshua, and Shell Creeks.

There were a number of days during 2016 when Peace River Facility withdrawals exceeded the seasonally designated maximum percent allowed by the April 2011 revised permit withdrawal schedule. Such exceedances of the permitted percent withdrawals primarily result from subsequent USGS revisions of the provisional daily flow information available to the Authority at the time of actual withdrawals. During 2016, the facility did not withdraw any water from the river on 117 days or approximately 32 percent of the time.

Water Temperature – Monthly mean water column temperatures in 2016 followed the strong seasonal pattern typically observed in south Florida. Often, the highest water temperatures in the more upstream, shallower, freshwater reaches of the estuary reach their highest levels in May and then remain similar up until August. By comparison, average water column temperatures in the downstream areas, more influenced by the harbor, often don't reach their highest annual temperature values until July. Dry season temperatures, spanning January-May and October-December, displayed greater variability between months. Historically, the annual peak in water temperatures in the estuary varies between June and August depending on annual variations in cloud cover and differences in seasonal rainfall patterns. Seasonal annual low water temperatures in 2016 were warmer than most annual lows observed in the preceding HBMP period.

Dissolved Oxygen – Previous results have indicated that within the downstream reaches of the river between River Kilometers -2.4 and 10.5, there is typically a wet-season depression of average water column dissolved oxygen (DO) levels in response to increased wet-season flows. This seasonal pattern typifies the widely documented hypoxic/anoxic conditions that typically occur in upper Charlotte Harbor as a result of the extreme water column stratification that commonly occurs near the mouth of the river and upper regions of the harbor during the high summer wet season. This typical observed seasonal depression of average water column dissolved oxygen concentrations in this reach of the lower river is generally more intense and of greater duration than that observed at the more upstream monitoring sites. During 2016, dissolved oxygen levels generally declined as water temperatures increased, resulting in DO levels reaching their lowest levels during summer wet season throughout both the lower river and upper harbor as both water temperatures and flows increased. The 2016 wet season column profile data indicated the return of normal hypoxic/anoxic dissolved oxygen levels in the upper harbor. This indicates that the flows that occurred during the summer of 2016 were again of sufficient duration and intensity to induce the level of water column stratification necessary to cause the development of widespread extremely low near-bottom dissolved oxygen levels in upper Charlotte Harbor.

Light Extinction – The 2016 HBMP data indicate that both the timing and magnitude of the ability of light to penetrate into the water column (1 percent depth) exhibits both strong temporal (seasonal) and spatial differences among the "fixed" monitoring sites along the HBMP lower Peace River/upper Charlotte Harbor sampling transect. Light extinction in the lower Peace River/upper Charlotte Harbor estuarine system is often primarily mediated by existing water color due to the "black water" characteristics of freshwater inflows from the Peace River watershed. Water clarity during 2016 (as in previous years) was the greatest in the lower river and especially in the upper harbor during the typical spring dry season and other periods of lower flows. The influences of the summer wet-season rainfall conditions are clearly evident in comparing the one percent light depths observed between the more downstream lower river/upper harbor monitoring locations with the upstream characteristically freshwater reaches of the lower river.

Conductivity/Salinity – Seasonally spatial conductivity patterns in the tidal lower Peace River were reflective of the normal to above normal flow in 2016.

Inorganic Nitrite+Nitrate Nitrogen – In the Charlotte Harbor estuarine system, inorganic nitrite+nitrate nitrogen concentrations are typically the lowest during the peak of the spring dry season, when high light and water temperatures result in increased phytoplankton production and freshwater inflows are low. Concentrations rapidly increase in the lower salinity reaches of the estuary with higher flows as nitrogen is carried from the watershed and increasing color reduces light penetration of the water column and limits phytoplankton growth. The data typically indicate a distinct spatial gradient within the lower river/upper harbor estuarine system with higher levels of inorganic nitrogen progressively occurring upstream. Nitrite+nitrate nitrogen levels in 2016 were lower than the longer-term averages at each of the five fixed-station locations.

Total Kjeldahl Nitrogen – Typically, total Kjeldahl nitrogen concentrations in the lower Peace River/upper Charlotte Harbor estuarine system are generally the highest during the summer wet season, reflecting the influences of increased freshwater inflows, and this is reflected in 2016 measurements. Overall, during 2016, the annual average Kjeldahl concentrations were slightly greater than the historic long-term averages.

Ortho-Phosphorus – Inorganic phosphorus concentrations in the Peace River Estuary follow patterns typical of conservative water quality constituents (reflecting dilution rather than biological uptake). Estuarine phosphorus concentrations are primarily influenced by dilution of high ambient levels in Peace River freshwater by saline Gulf water moving up the harbor. Thus the HBMP monitoring data typically indicate distinct spatial patterns in inorganic phosphorus concentrations among the sampling sites, with concentrations being markedly higher upstream than downstream. Following Hurricane Charley in August 2004 (and the subsequent Hurricanes Frances and Jeanne storms in September 2004), the data indicated that there were atypical marked increases in inorganic phosphorus levels associated with high levels of hurricane-related flows from the Peace River watershed. During the wetter than average conditions in 2005, inorganic phosphorus patterns in the lower river/upper harbor estuarine system returned to more typical seasonal patterns. However, during the dry conditions that characterized the 2006-2008 period, phosphorus concentrations in the lower river/upper harbor estuarine system returned to higher levels not seen in over two decades. Phosphorus concentrations then began to decline during 2009 and have continued to decline to previous observed lower levels. Inorganic ortho-phosphorus levels in 2016 at the five fixed monitoring sites were lower than the mean long- term values.

Silica – Historically, annual reactive silica concentrations in the Peace River estuary characteristically have indicated a number of differing temporal and spatial patterns. During the spring dry season, silica levels were normally at their annual lowest concentrations throughout the lower Peace River/upper Charlotte Harbor estuarine system corresponding to depressed flow inputs and periods of increased chlorophyll *a* biomass (potentially reflecting uptake by diatoms in the phytoplankton). Then usually during May and June, as water temperatures increased and the start of the summer wet -season began, concentrations characteristically rapidly increased throughout the estuary. Reactive silica concentrations during 2016 continued to reflect the recently observed pattern of increased levels noted in previous HBMP reports, with 2016 average silica levels greater than the long term averages.

Chlorophyll *a* – Phytoplankton biomass (chlorophyll *a*) patterns in the lower Peace River/upper Charlotte Harbor Estuary are normally characterized by several seasonal peaks throughout the year that differ both seasonally and spatially among the HBMP "fixed" sampling locations. Typically, chlorophyll *a* phytoplankton biomass in the lower Peace River/upper Charlotte Harbor Estuary shows distinct increases both during the spring with increasing light and water temperatures and during the late fall after wet season flows have increased nitrogen levels and associated high color levels begin to decline. The common occurrences of such spring and fall phytoplankton increases have often been noted in conjunction with the HBMP isohaline-based monitoring program. Chlorophyll *a* increases (blooms) during 2016 were influenced by the high flows during January/February and the summer wet -season that resulted in phytoplankton "blooms" stimulated by nitrogen inputs in the higher salinity reaches of the lower river/upper harbor estuary. Average 2016 chlorophyll *a* values were slightly lower than the long-term values at all but the most downstream (Harbor) station where 2016 values were more than double the long-term average.

The graphical and summary analyses presented in this document do not indicate any substantial changes or atypical events in either the physical or biological data collected during 2016, other than those previously noted. These include:

- Freshwater inflows during 2016 were influenced by higher than average rainfall conditions during the both the typical spring dry and summer wet season.

- The previously noted long-term increase in reactive silica concentrations noted at the lower Peace River/upper Charlotte Harbor monitoring locations continued despite the somewhat lower levels observed during 2014.

- Inorganic phosphorus concentrations in the freshwater entering the estuary had increased in recent years, following decades of major declines that began in the late 1970s. However, observations since 2009 have shown that levels have substantially declined again to levels near where they were prior to the observed recent increase.

- The observed recent increases in silica and phosphorus seem to have been linked to the previous closure of phosphogypsum stack systems in the Whidden Creek basin, located in the upper Peace River watershed.

The "limited" analyses presented in the *2016 HBMP Annual Data Report* do not suggest that there have been any long-term, systematic changes resulting from either current or historic water withdrawals by the Peace River Regional Water Supply Facility.

3.0 Chapter 3 – Status and Trends in Regional Rainfall, Flows and Facility Withdrawals

The purpose and focus of this chapter are to update similar information presented in the previous *2002*, *2006* and *2011 HBMP Comprehensive Summary Reports*. Provided are analyses of data collected through 2016 relative to both the status and trends of key hydrological elements associated with the Peace River Hydrobiological Monitoring Program (HBMP). Analyses and discussions are presented in relation to the current status and historic trends in the following specific hydrologically related HBMP study elements:

- Status and trends in watershed rainfall patterns;
- Status and trends in gaged watershed freshwater inflows;
- Status and trends in rainfall/flow interactions; and
- History, status and trends in withdrawals.

The primary objective of the presented analyses and summary graphics associated with each of these HBMP elements is to provide an overview of the current hydrological status within the Peace River watershed and lower Peace River/upper Charlotte Harbor estuarine system, and illustrate comparisons with historic longer-term patterns and characteristics. A corollary goal is to describe the important hydrological influences of more infrequent episodic occurrences such as extended periods of extreme drought, the periodic occurrences of unusually wet winter/spring El Niño climatic events, and differences in summer wet-season rainfall/flows due to variations in the frequency of tropical cyclonic patterns.

3.1 Hydrologic Setting

The Peace River watershed (Figure 3.1) covers approximately 1.4 million acres (2,188 square miles) and can be divided into nine major drainage basins within six counties. Most of the watershed is located in Polk, Hardee, DeSoto and northern Charlotte counties, smaller portions extend into Highlands, Manatee and Sarasota counties. The main channel of the Peace River begins northeast of Bartow, in Polk County, at the confluence of Peace Creek Drainage Canal and Saddle Creek, and extends approximately 105 miles south to Charlotte Harbor. Previous studies (PBS&J and W.D. Bender 1999, PBS&J 2007) divided the watershed into eight drainage basins based on the locations of USGS long-term flow gaging stations and included an additional ungaged coastal lower Peace River basin downstream of Arcadia to the tidal river mouth (defined by USGS, McPherson et al. 1997).

These nine basins are listed below.

- Peace River at Bartow
- Peace River at Zolfo Springs
- Payne Creek
- Peace River at Arcadia
- Charlie Creek
- Joshua Creek
- Horse Creek
- Shell Creek (including Prairie Creek)
- Coastal Lower Peace River

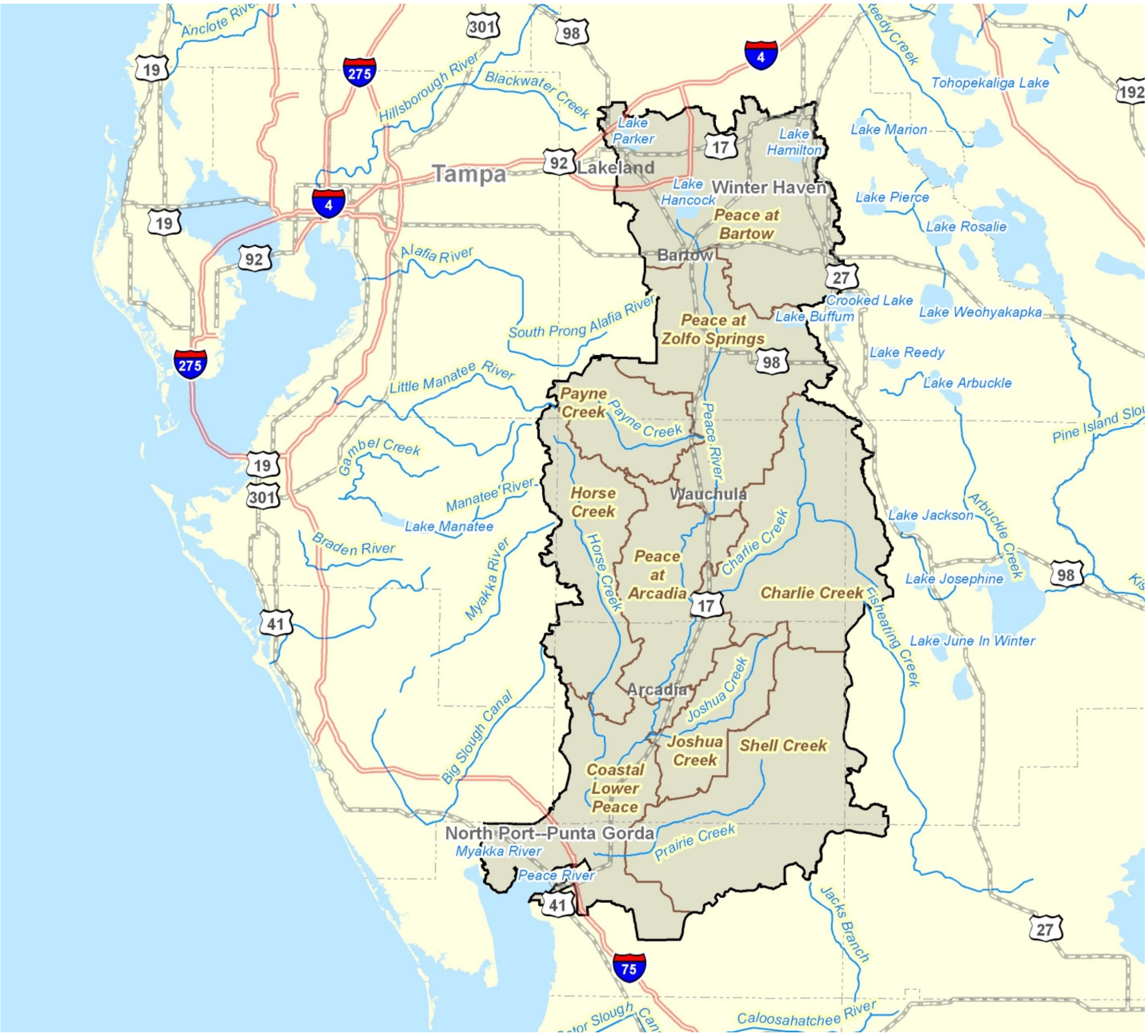

Figure 3.1 Location of the Peace River Watershed in Southwest Florida

The five largest basins in the watershed include the Peace River at Bartow, Peace River at Zolfo Springs, Charlie Creek, Shell Creek, and the Coastal Lower Peace. Each of these basins individually makes up between 12 and 17 percent of the watershed and combined, they comprise roughly 70 percent of the overall watershed area. The remaining four smaller basins (the Peace at Arcadia, Payne Creek, Joshua Creek, and Horse Creek) individually comprise between six and nine percent of the remaining watershed area. Historically, the landscape features and hydrological drainage patterns of these watershed basins have been modified to varying extents by anthropogenic influences, including the expansions of more intense agriculture, urbanization and phosphate mining activities (PBS&J 2007). Hydrologically, such historic and ongoing landform changes have significantly altered both surface water runoff and infiltration rates within broad areas of the Peace River watershed. Such historic and potential future land use changes in the Peace River watershed have the potential to influence both the quantity and quality of available water downstream at the Facility.

3.1.1 Hydrogeology

The Peace River watershed is underlain by three aquifer systems. The uppermost system primarily associated with surface flows is the unconfined surficial aquifer system, which consists of unconsolidated quartz sand, silt, and clayey sand. The depth of the surficial aquifer system varies from only a few feet in some areas to well over a hundred feet in the sand hill ridge areas. Underlying the surficial aquifer system is the confined intermediate aquifer system, consisting of thin, inter-bedded limestones, sands, and phosphatic clays of generally low permeability. The intermediate aquifer system is relatively thin in the upper reaches of the Peace River watershed and thickens to the south. Underlying the intermediate aquifer system, the confined Floridan aquifer system consists of limestone and dolostone formations. The upper Floridan aquifer system is the principal water supply source for most anthropogenic activities accounting for 85 to 90 percent of all anthropogenic ground water use in the Peace River watershed. The depth to the lower Floridan aquifer and its relatively much poorer water quality currently preclude any extensive use of this last aquifer system as a water supply.

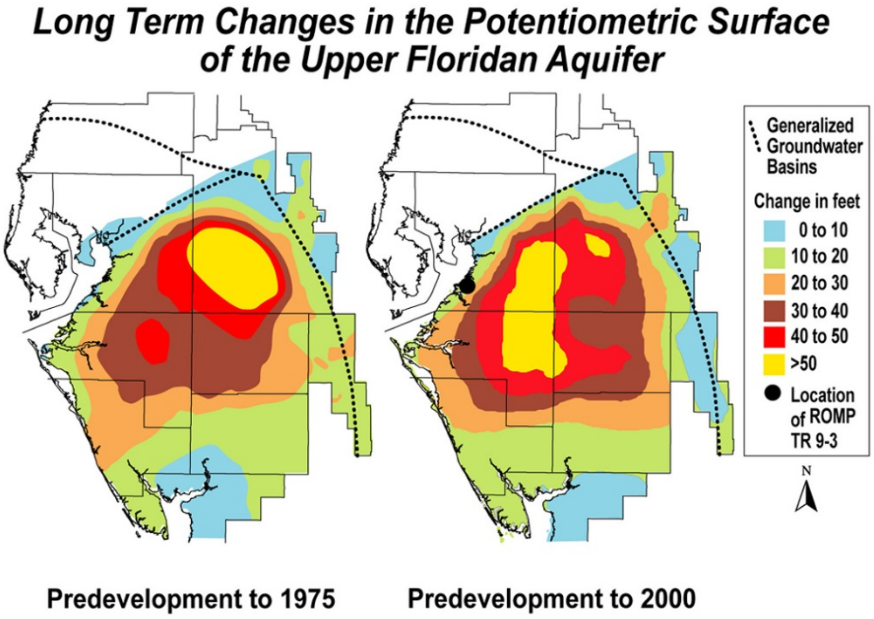

Figure 3.2 Estimated historic changes in the potentiometric surface of the Upper Florida Aquifer (SWFWMD, based on USGS data)

Upstream of Ft. Meade, in the vicinity of the Peace River proper, the terrain and geology are karst in origin, resulting in large sinks and solution features in the river floodplain. Kissengen Spring near Bartow was a significant source of historic base flow to the upper Peace River with average annual estimated flows prior to the mid-1930s of approximately 30 cubic feet per second (cfs). Cessation of flow from the spring circa 1950 has been attributed (Peek 1951, Steward

1966, Hammett 1990, Basso 2003, PBS&J 2007) to the historic decline in the potentiometric surface of the confined aquifers (Intermediate Artesian and Upper Floridan aquifers) caused by the excessive development of the ground water resource, primarily associated with the early expansion of phosphate mining in the upper watershed. The potentiometric surface of the confined aquifers, previously observed above the riverbed, has generally declined tens of feet below the riverbed since the early-1960s (Figure 3.2).

3.1.2 Hydrologic Alterations

This historic loss of flows from springs and seeps has been one of the factors that have affected base flow to the upper portion of the river. However, base flow in the upper Peace River has also been affected by changes in discharges and drainage alterations associated with urbanization, phosphate mining, and agriculture. Phosphate mining and domestic waste discharges to the river have gradually declined since the mid-1980s (SWFWMD 2002). Historically these anthropogenic discharges augmented dry-season base flow and, until recently, obscured much of the historic declines and cessation of spring flows in the upper watershed. As a result, during recent periods portions of low flows in the Peace River between USGS Bartow and Ft. Meade gages actually run from the river into the numerous crevices of the streambed and floodplain resulting in a loss of flows on a significant number of days each year within this upper reach of the river.

Other hydrologic alterations in some mined and reclaimed areas in the upper regions of the watershed have included the change of surface water flows that historically flowed to the river to storage for mining activities and/or seasonal impoundments resulting from disconnected surface depressions. Surface flows in some mined areas may also have been altered subsequent to mining due to increased recharge, as rainwater readily infiltrates the resulting disturbed soil structure, and recharge to the intermediate aquifer increases following loss of the upper confining layers associated with extraction of the phosphate matrix.

The Peace River watershed basins south of phosphate mining influences have also experienced historic increasing ground water demands and extensive hydrologic alterations. These changes are reflected in the cumulative loss of wetland and native upland habitats, and increasing dry-season augmentation of base flow in many tributaries as agriculture in these southern basins has progressively changed from predominantly unimproved pasture to improved pasture and subsequently to increasing areas of more intense farming (citrus and row crops). Agricultural runoff has contributed to increased base flow in the Joshua Creek, Horse Creek and Prairie/Shell Creek basins. In addition, urban land uses in the northern and southern areas of the Peace River watershed have increased impervious surface areas, altered natural hydroperiods, and reduced stream stability, which resulted in the loss of in-stream habitat and degraded water quality, and led to reductions in biological diversity (Arnold and Gibbons 1996, Brant 1999, Shaver and Maxted 1996).

3.1.3 Climate

The climate in the Peace River watershed is subtropical with an annual average temperature of approximately 73 degrees Fahrenheit. The Peace River watershed predominantly lays within the

National Weather Service (NWS) Florida South-Central Region Four, which is characterized by a summer wet-season that accounts for approximately 60 percent of total approximate average annual precipitation for the three long-term gages in the watershed of 52 inches (1915-2016). During this summer wet-season, rainfall patterns are influenced by both frequent localized convective thunderstorm activity and periodic, widespread heavy rains associated with more infrequent tropical cyclonic events. In contrast, the remainder of the year is characterized by rainfall patterns predominantly associated with frontal systems moving down and across the Florida peninsula from the northwest.

The four month wet-season extends from June through September, with June on average having the highest annual average rainfall of 8.3 inches (Figure 3.3). Conversely, November through January typically comprise the three driest months of the year, with rainfall in November only averaging 1.7 inches. October characterizes the transition from the convection based summer wet-season rainfall pattern to the frontal dry-season rainfall pattern.

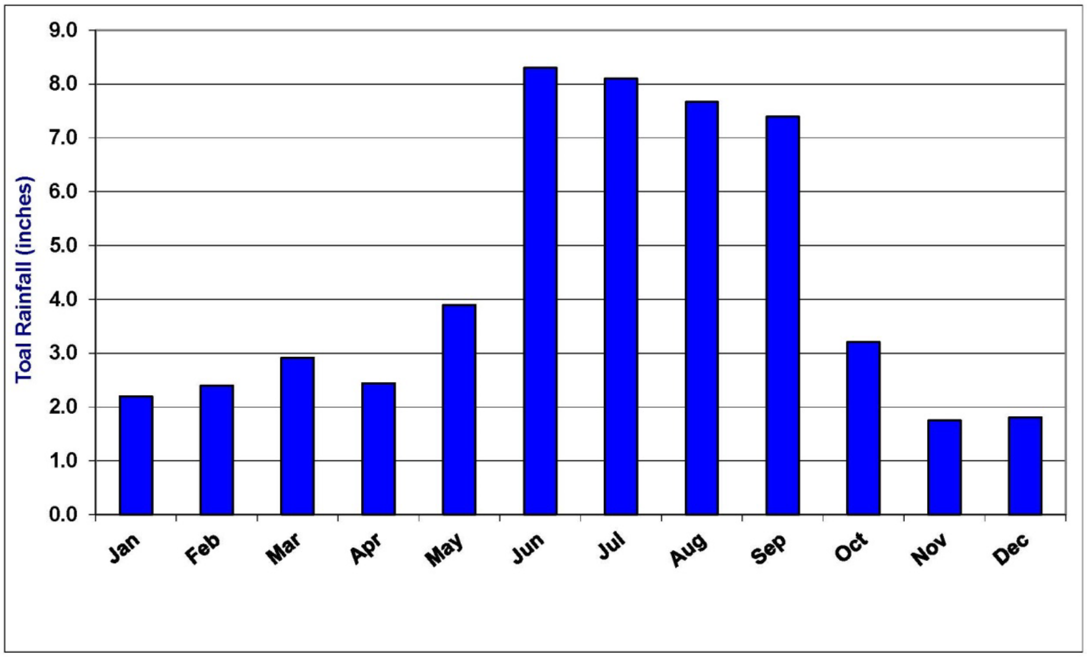

Figure 3.3 Average Monthly Peace River Basin Rainfall (1915-2016)

Low precipitation, combined with higher temperatures and evapotranspiration, characterize the dry spring months and, as a result, streams, wetlands and surficial ground water levels are typically at their lowest during May just prior to the beginning of the four-month summer wet-season (Figure 3.4, note: the annual longer term annual hydrograph of the Arcadia gage is shown due to its much longer historic record. Gaged flows for Horse and Joshua Creeks date only back to the early 1950s). Conversely, during September and October, at the end of the summer wet-season, hydrologic systems and surface flows are usually near or at their annual peaks.

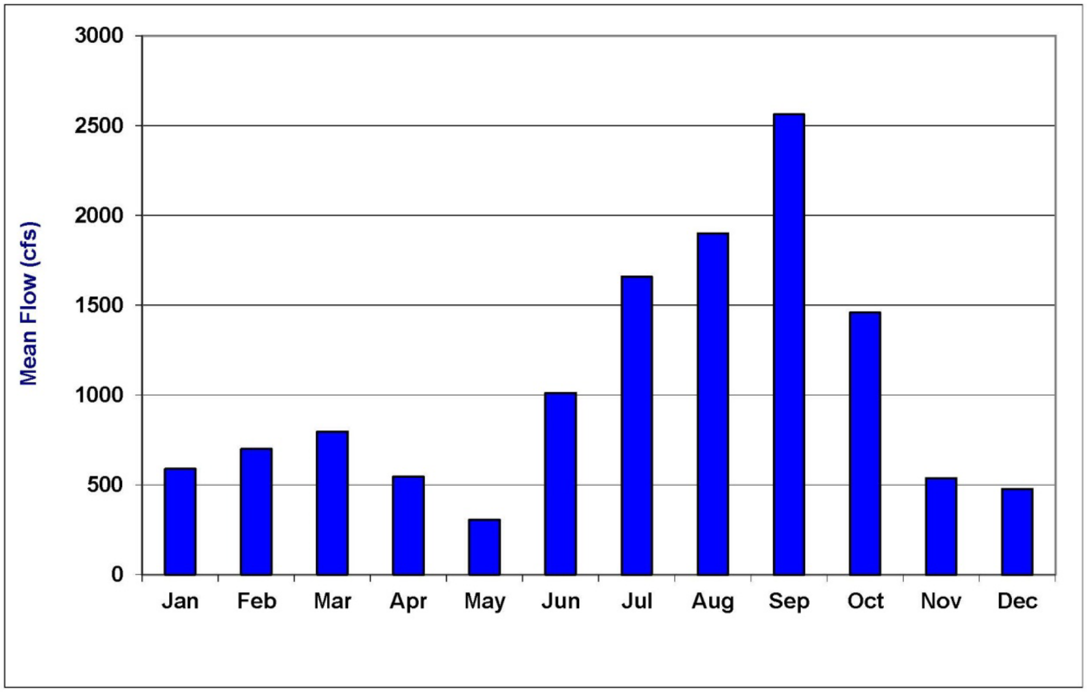

Figure 3.4 Mean monthly flow at the Peace River at Arcadia USGS gage (1932-2016)

Seasonal influences of rainfall on watershed hydrology and surface flows are directly linked to the preceding hydrologic conditions. At the beginning of the summer wet-season, a large proportion of rainfall is incorporated into filling surface and ground water storage (Basso and Schultz 2003.) Conversely, later toward the end of the summer wet-season, soil moisture content is high, ground water levels are near the surface, wetlands and lakes are full, and a large proportion of rainfall contributes directly to runoff (Ross et al. 2001). Under such conditions, relatively small increases in rainfall can result in substantial increases in surface flows (PBS&J 2007).

While the described seasonal patterns in the annual hydrologic conditions are typical, there are wide degrees of both seasonal and annual variability in both rainfall and resulting river flow patterns. Deviations from the normal pattern can span periods of months up to several years. Intense El Niño/Southern Oscillation (ENSO) events, such as occurred in 1982/1983 and 1997/1998, result in atypical extended periods of heavy rainfall during the usually drier winter/spring months and dramatically alter the annual watershed hydroperiod. In both instances,

these unusually wet El Niño periods were subsequently followed by La Niña events and associated periods of extended drought (Coley and Waylen 2006). While short-term extremes of high and low flows influence the water budget in a watershed over periods of years, superimposed over these may be larger cyclic periods that can cover a number of decades (Kelly 2004). An understanding of the underlying causes affecting the duration and magnitude of long-term regional rainfall cycles is therefore important to assessing historic natural and anthropogenic hydrologic changes in both stream flows and ground water levels in the Peace River watershed (Basso and Schultz 2003.)

Climate researchers (Gray et al. 1997 and 2004, Enfield et al. 2001, Knudsen et al. 2011) have suggested that natural climate cycles or phases can persist over multiple decades. One of these cycles, the Atlantic Multidecadal Oscillation (AMO) refers to long-term cool and warm phase differences of only about 1°F (0.6°C) in North Atlantic average sea surface temperatures. An analysis of Atlantic sea surface temperatures suggests that warm AMO phases occurred during 1869-1893, 1926-1969, and from 1995 to date, while cooler phases occurred predominantly during the 1894-1925 and 1970-1994 time periods (Landsea et al. 1999). Climatological data indicate that differences between relatively warm and cool AMO periods affect both air temperature and rainfall patterns over North America and Europe (Gray et al. 1997, Enfield et al. 2001). It has been suggested that slight increases in average sea surface temperature in the Atlantic and Caribbean seas during warmer AMO periods produce more summer rainfall across southern Florida, while cooler AMO phases result in decreased summer rainfall (Enfield et al. 2001, Basso and Schultz 2003, Kelly 2004).

Studies of paleoclimate proxies, including tree rings (Grey et al. 2004) and ice cores, indicate that oscillations similar to those measured from Atlantic sea surface temperatures have commonly occurred over 15-60 year intervals for at least the last thousand years. Analyses of longer cycles suggests that quasi-persistent cycles of approximately 55 to 70 years in the North Atlantic AMO can be linked to internal ocean-atmosphere variability, that has existed over large parts of the Holocene for at least the last 8,000 years (Knudsen et al. 2011). Such cyclical changes predate the modern era of anthropogenic climate influences and indicate that the AMO phases are likely natural climate oscillations. It has further been suggested that during the 20th century, cyclical AMO climate changes have alternately camouflaged or exaggerated the potential effects of global warming making it more difficult to ascertain any confounding influences.

Small increases in average sea surface temperature (see Figure 3.5) in the Atlantic and Caribbean during warmer AMO periods result in increased wet-season rainfall across south Florida, while cooler AMO phases correspond to decreased summer rainfall (Enfield et al. 2001, Basso and Schultz 2003, Kelly 2004). During warm AMO phases, general Atlantic/Caribbean atmospheric circulation patterns predominantly flow from the southeast across the southern Florida peninsula, increasing summer afternoon convective thunderstorm activity and resulting in slightly enhanced wet-season rainfall levels. At the same time, higher North Atlantic sea surface temperatures (Figure 3.5) also result in atmospheric circulation patterns that tend to both increase the frequency and intensity of tropical storms, including those originating in the Sahel region of northwest Africa, while also decreasing high level wind shear in the tropical Atlantic Ocean. During warm AMOs, these factors result in a higher frequency (see Figure 3.6 below) and duration of major tropical cyclones in the Gulf of Mexico, Atlantic and Caribbean Basins (Gray et al. 1997, Landsea et al. 1999). These tropical systems can produce extremely high rainfall events as they move near (or across) Florida and a single storm event can account for as much as a third of the normal total annual wet-season rainfall. Since these storm events are more frequent toward the end of the summer wet-season in August and September, soils in the watershed may be saturated, rivers and lakes are often at high flows and/or levels, and the hurricane associated rainfall events can dramatically influence annual flows and patterns in the watershed.

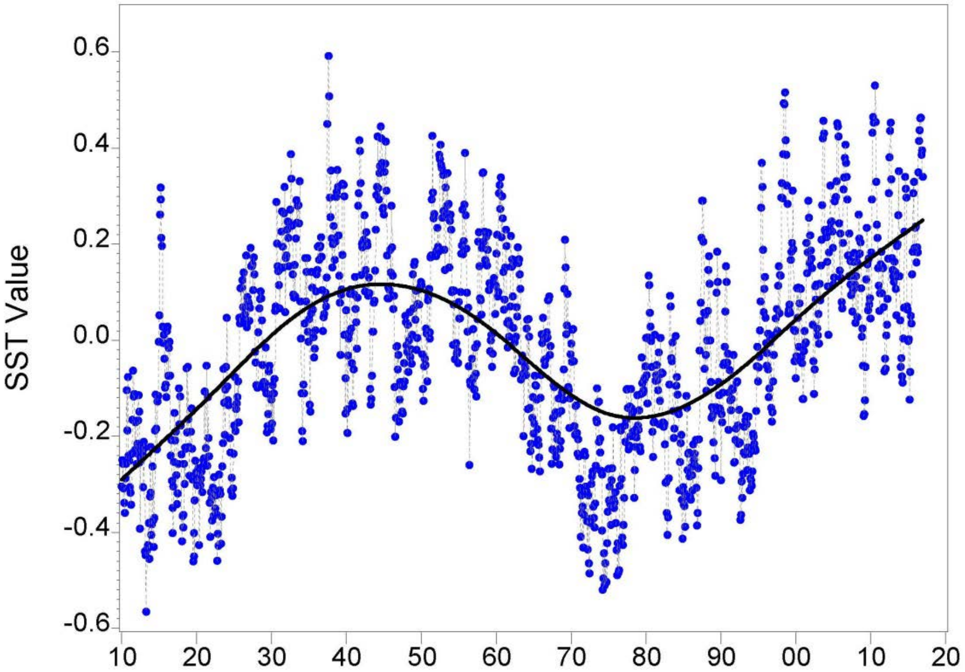

Figure 3.5 Monthly long-term North Atlantic sea surface temperature (SST) values for assessing AMO patterns, 1910-2016.

Several studies (Hickey 1998, Basso and Schultz 2003, Kelly 2004, PBS&J 2007) have expanded upon previous work (Hammett 1990) in which changes in rainfall and/or stream flow patterns and relationships in the Peace River watershed were examined. Hickey (1998) attributed observed declines in rainfall and flows to a reduction in the frequency of tropical storms events prior to and following 1970. Basso and Schultz (2003) found that while annual rainfall has not significantly changed over the last century, partitioning the data into shorter intervals revealed cyclical decadal periods of above or below average rainfall. Using graphical and statistical analytical methods, including 5-year moving averages mean and median statistics, cumulative departure analyses, single mass techniques, and time-series plots, they were able to demonstrate that the decades between the 1930s and 1960s were wetter than recent periods. Mean and median rainfall values at six gaging locations within the Peace River watershed indicated average declines of 4.5 and 5.5 inches/year between the two 30-year periods 1936-1965 and 1966-1995. Changes in wet-season rainfall, primarily linked to the AMO, were found to account for approximately eighty percent of the observed differences between the two periods. An analysis of rainfall changes associated with an observed decline in tropical cyclone activity during 1970-1994 found that approximately one-third of the measured decline in wet-season rainfall was associated with the observed decrease in these storm events. A total of 47 documented tropical cyclones (includes subtropical systems, depressions, tropical storms, and hurricanes) impacted the Peace River watershed during the period 1930-2001. During the warmer AMO phase (1930-1969), 33 tropical storm events affected the basin. In comparison, during the subsequent cooler 1970-1994 AMO period, only 10 tropical systems impacted the watershed. This analysis indicated that the frequency of such intense rainfall storm events influencing the Peace River watershed during the warm AMO phase was approximately double of that which occurred during the cooler period.

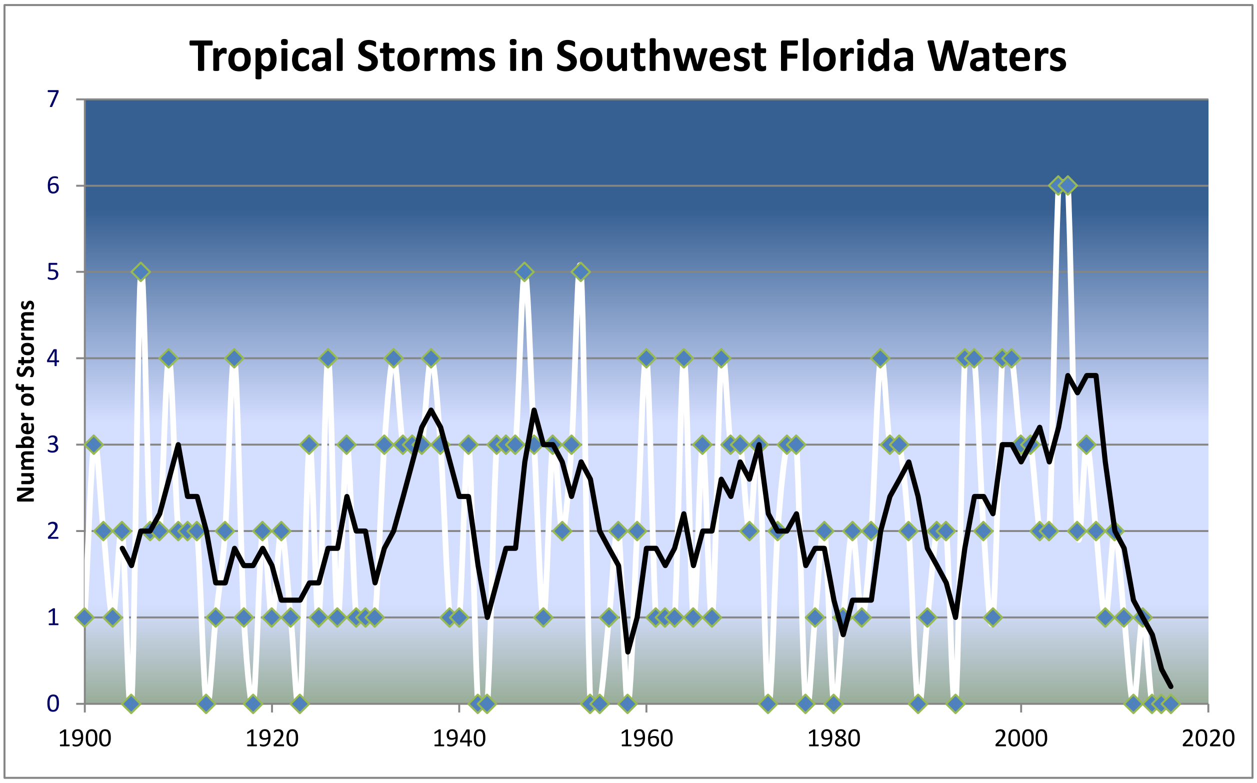

Figure 3.6 Tropical storms (including hurricanes) influencing southwest Florida during the historical period. White line represents the number of storms per year, while black line represents the five year moving average.

During warm AMO phases, the average number of tropical storms that become major hurricanes is significantly greater (at least double) when compared with cooler periods. Since 1995, when the AMO shifted from the preceding approximately 26-year cooler period (1969-1994) to a warmer phase, the frequency of major hurricanes (category 3 or above on the Saffir-Simpson scale) has again increased. Based on the typical duration of alternating AMO phases, the current warm phase may persist from 10-30 more years. To date, models capable of predicting the AMO shifts from one phase to another are unavailable. However, it is possible to determine the probability that a change in the AMO cycle will occur within a given future time frame (Enfield and Cid-Serrano 2005.) Such probability-based projections may be useful with regard to long-term water management planning since the availability of potential surface water supplies can vary considerably between warmer and cooler AMO periods. However, the occurrences of 1999-2001 and recent 2006-2011) dry-season droughts emphasize the point that such warm/wet AMO phases only describe long-term average conditions, and that very dry intervals can (and do) occur during what might be a wetter than average longer time period, and that correspondingly very wet years have occurred during cooler/dry AMO phases.

Figure 3.7 indicates that total seasonally based gaged flows upstream of the Facility since 1994 have been statistically significant slightly higher (133 cfs) on average than during the previous 18 years of HBMP monitoring. However during this "wetter" period, the duration of the lower flows over extended periods (1999-2001 and 2006-2011) has characterized much of the recent period.

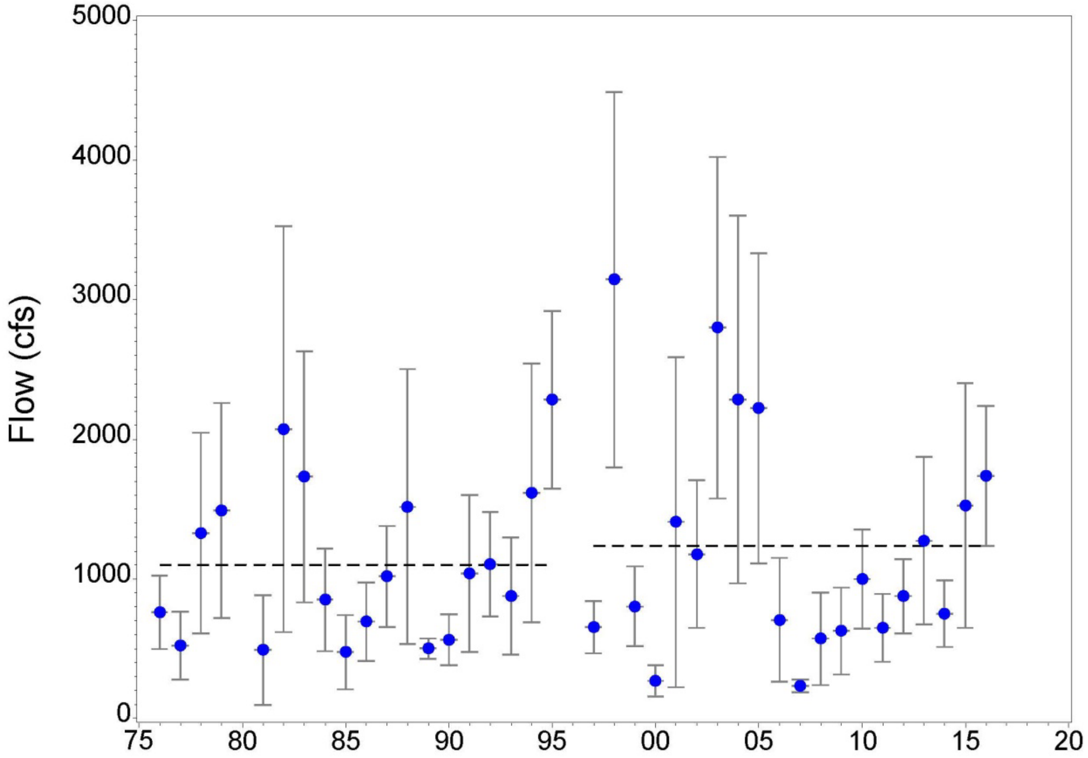

Figure 3.7 Annual monthly mean total USGS gaged flow upstream of the Facility

3.2 Status and Trends in Watershed Rainfall Patterns

Historic period-of-record rainfall data for three representative long-term Peace River watershed basin rainfall gaging stations and a representative gage in the nearby Myakka River watershed were obtained as an initial step in evaluating the status and trends of hydrologic conditions in the Peace River watershed. Table 3.1 provides summary information regarding each of the four selected rainfall gages, including:

- Rainfall gage name,
- Gage SWFWMD (District) identification,
- National Oceanographic and Atmospheric Administration (NOAA) identification,
- Location (latitude & longitude), and
- Historical period-of-record interval of data.

The sites were selected based both on the need to provide a broad spatial range of geographical coverage and the availability of a reliable long-term historical data record.

- **Bartow** – This gage was selected as representative of the northern/upper Peace River watershed, with daily long-term rainfall data having been collected at this site since 1902. The gage is designated ATM0009 in the NOAA rainfall monitoring network, and this same location is designated as 25164 (R142) in the District's web-based data acquisition system.

- **Arcadia** – Historical data from this monitoring site were chosen to characterize rainfall patterns in the central regions of the Peace River watershed. The daily, long-term rainfall record at this location extends back historically to 1908. The Arcadia gage is designated as site ATM0003 in the NOAA monitoring network and as 24570 (R148) by the District.

- **Punta Gorda** – The data from this monitoring gage were used to assess seasonal and long-term rainfall patterns in the lower/coastal region of the lower Peace River watershed, and existing daily records at this gaging site extend back to 1915. This rainfall monitoring gage is designated ATM0117 in the NOAA network and as R255 by the District.

- **Myakka State Park –** This final monitoring gage was selected to provide additional information and assess potential differences in rainfall patterns between the interior Peace River watershed locations and the more coastal Myakka River watershed. The existing daily records at this site only extend back to 1943, and the rainfall gage is designated as ATM0101 in the NOAA network and as R336 by the District.

Table 3.1
Selected Rainfall Gages

Gage Name	SWFWMD Site ID	NOAA Site ID	Latitude	Longitude	Data Record
Peace River Watershed					
Bartow	25164 (R142)	ATM0009	27°53'59.08"	81°50'34.27"	1908-2016
Arcadia	24570 (R148)	ATM0003	27°13'44.17"	81°51'27.28"	1907-2016
Punta Gorda	25105 (R255)	ATM0117	26°55'10.22"	82°00'21.30"	1914-2016
Additional Reference Gage					
Myakka State Park	25793 (R336)	ATM0101	27°14'32.17"	82°10'27.31"	1943-2016

While all the selected gages had relatively complete periods-of-record, in some instance data from a particular site may have been missing for a number of consecutive days for periods of weeks and/or months. In these instances, missing data were substituted using additional available information from the District's rainfall monitoring network using the average values from the two nearest rainfall gages that also had the highest long-term correlations with data from the station with the missing values (PBS&J 2007).

3.2.1 Time-series Plots

Monthly and annual total rainfall values were graphically analyzed for each of the four selected watershed rainfall gages using several alternative methods. Table 3.2 summarizes the various rainfall time-series analyses presented. Summary conclusions based on the results of these alternative graphical analyses of historic rainfall patterns are presented below.

Table 3.2
Time-series Plots of Watershed Rainfall

Long-Term Rainfall Gage	Time Interval	Total Monthly Rainfall	Annual Total Rainfall		
			Overall	Wet-Season	Dry-season
Peace River Watershed					
Bartow	1932-2016	Figure 3.8	Figure 3.13	Figure 3.18	Figure 3.23
Arcadia	1932-2016	Figure 3.9	Figure 3.14	Figure 3.19	Figure 3.24
Punta Gorda	1932-2016	Figure 3.10	Figure 3.15	Figure 3.20	Figure 3.25
Watershed Average	1932-2016	Figure 3.11	Figure 3.16	Figure 3.21	Figure 3.26
Additional Reference Gage					
Myakka State Park	1943-2016	Figure 3.12	Figure 3.17	Figure 3.22	Figure 3.27

Total Monthly Rainfall – Figures 3.8 through 3.12 illustrate time-series plots of total monthly rainfall data from the four selected rainfall gaging locations. Values were plotted for the years 1932-2016 (corresponding to the longest record of gaged flows in the watershed) or the period-of-record for locations with shorter long-term records. These graphics include both monthly total rainfall and a fitted, smoothed line (this line was calculated using the Statistical Analysis Software (SAS) cubic spline method that minimizes the linear combination of the sums of squares of the residuals of the fit as well as the integral of the square of the second derivative). The following summary conclusions are based on these analyses:

- Long-term total monthly rainfall patterns were generally similar among the selected rainfall gages, although more recent rainfall levels (since 2005) at the Bartow site seem to have declined a bit more from the long-term average than at the other gaging sites;

- The natural annual variability in total monthly rainfall totals is sufficient to obscure small changes that may (or may not) have occurred, and there are no indications of any consistent larger changes (or patterns) when the long-term rainfall data are analyzed on a monthly basis; and

- Results of the analyses suggest that total monthly rainfall at the more coastal Punta Gorda and Myakka State Park gages are at times slightly greater than at the two more interior Peace River watershed basin gages.

Total Annual Rainfall – Similar time-series plots of annual (rather than monthly) total rainfalls at the same rainfall monitoring locations were evaluated over the 1932-2016 interval for the three Peace River watershed sites and for the period-of-record (1943-2016) at the Myakka River watershed location. These graphics include a line representing a smoothed five-year moving average, which provides a general indication of long-term patterns after having reduced some of the occurring annual variation.

When the long-term rainfall data for the Peace River watershed locations are viewed as annual totals, the results clearly show both increased variations among the watershed gages and greater indications of both historical wetter and drier intervals. The calculated five-year moving averages, which further reduces short-term background "noise," also indicated relatively longer wetter and dryer intervals over the selected recent historic periods.

Total annual average watershed rainfall levels at the Bartow and Punta Gorda gages, as well as the average of the three Peace River basin gages, indicate slightly higher annual rainfall prior to the 1960s when compared with the period since the late 1960s. Annual rainfall data at the Arcadia gage indicate a similar decline in the late 1960s, however between the mid 1990s and 2016 annual total rainfall levels at the Arcadia NOAA gage have shown an increase.

Total Wet-season and Dry-season Rainfall – To evaluate possible long-term differences in seasonal rainfall patterns, time-series plots similar to those developed for annual total rainfall (above) were also conducted for total annual rainfall for the four month wet-season (June-September) and for the eight drier months (January-May and October-December). Time-series plots of total annual wet-season rainfall data at each of the four selected rainfall monitoring locations are presented in **Figures 3.18** through **3.22**, while corresponding graphics for total annual dry-season rainfall levels are presented in **Figures 3.23** through **3.27**. These graphics also include a statistically smoothed line of the five-year moving average. In evaluating these analyses, it should be noted that the terms wet-season and dry-season are applied relative to the long-term annual average rainfall hydrograph for southwest Florida (**Figure 3.3**).

Annual average wet-season (June-September) rainfall in the Peace River watershed was, in general, slightly higher during the 1930s through the mid-1960s when compared with the interval from the late 1960s through the early 1990s (**Figure 3.21**). Since approximately 1994 there has been a notable increase in wet-season rainfall. (Note: Even though annual wet-season rainfall at the Bartow gage has declined recently.)

All four of the sites show recent marked declines in long-term dry-season (January-May and October-December) rainfall patterns, although periodic high annual totals were observed corresponding to past El Niño events.

3.2.2 Longer Historical Rainfall Patterns in the Peace River Watershed

In order to further evaluate potential longer historic changes in Peace River watershed rainfall patterns, a series of analyses were conducted using the available long-term 1915-2016 data from the Bartow, Arcadia and Punta Gorda rainfall monitoring stations.

The first technique was to plot each annual rainfall value after subtracting it from the basin-specific long-term average for the entire 1915-2016 period. This long-term average was then used as a zero value, against which each annual total was sequentially plotted above or below. A smoothed, five-year moving average was then fitted to the resulting calculated points.

The second method also used the differences between the total annual rainfall and the long-term basin averages. However, in this instance, a year-by-year cumulative sum of the yearly difference was plotted over time. The calculated value for each year therefore represented the running sum of the yearly differences (positive or negative) from the historic 1915-2016 basin average annual rainfall. For example, Figure 3.33 indicates the long-term pattern in annual rainfall relative to the historic average at the NOAA Bartow gage over approximately the last 100 years. This figure shows that there was a period of relatively wetter than average years from roughly 1920 to 1930, and then again during the late 1950s. Since the early 1960s annual rainfall at this site has continued to be below the long-term average with the exception of brief periods during El Niño periods (1982-1983 and 1997-1998) and two recent years (2004-2005) characterized by numerous tropical storms.

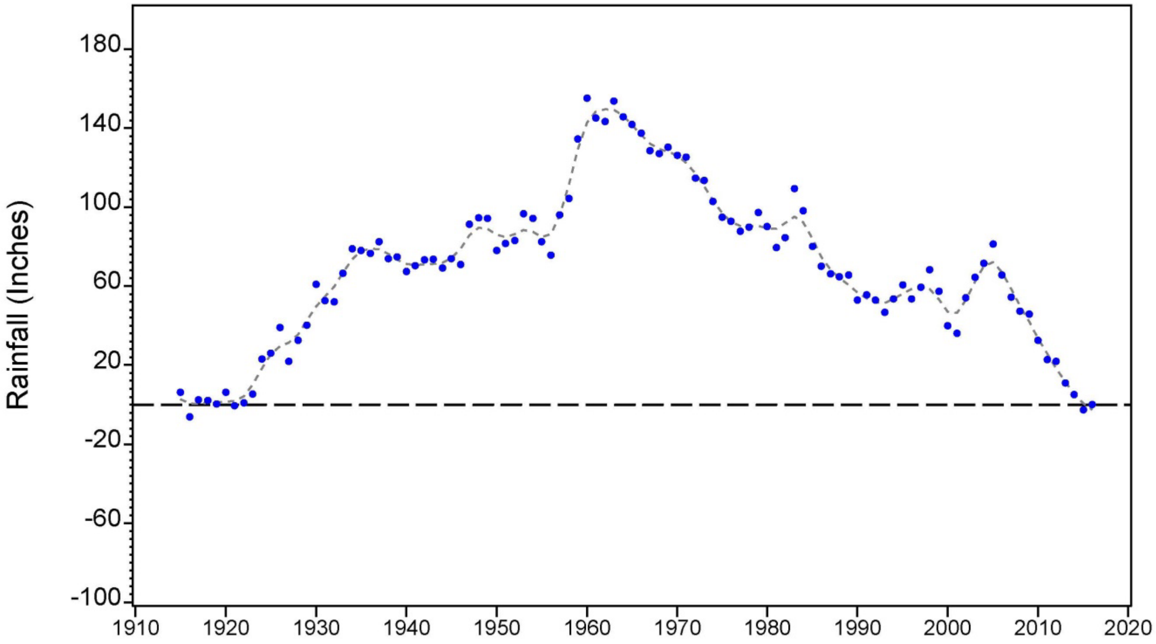

Figure 3.33 Long-term cumulative annual rainfall above 53.3 inches at Bartow NOAA gage (District #25164/R142) 1915-2016

The results of these two differing methods of graphical analyses are presented in Table 3.3 using both total annual rainfalls, as well as separately calculated annual values for just the typical four summer wet-season months (June-September) and the remaining eight drier season months.

Table 3.3
Historic 1915-2016 Long-term Watershed Rainfall Patterns

Rainfall Gage District ID	Overall		Wet-season		Dry-season	
	Annual & 5-Year Moving Average	Cumulative Deviation from Average	Annual & 5-Year Moving Average	Cumulative Deviation from Average	Annual & 5-Year Moving Average	Cumulative Deviation from Average
Peace River Watershed						
Bartow – 25164 (R142)	**Figure 3.28**	**Figure 3.33**	**Figure 3.38**	**Figure 3.43**	**Figure 3.48**	**Figure 3.53**
Arcadia –24570 (R148)	**Figure 3.29**	**Figure 3.34**	**Figure 3.39**	**Figure 3.44**	**Figure 3.49**	**Figure 3.54**
Punta Gorda – 25105 (R255)	**Figure 3.30**	**Figure 3.35**	**Figure 3.40**	**Figure 3.45**	**Figure 3.50**	**Figure 3.55**
Watershed Average	**Figure 3.31**	**Figure 3.36**	**Figure 3.41**	**Figure 3.46**	**Figure 3.51**	**Figure 3.56**
Additional Reference Gage						
Myakka State Park – 25793 (R336)	**Figure 3.32**	**Figure 3.37**	**Figure 3.42**	**Figure 3.47**	**Figure 3.52**	**Figure 3.57**

* Note: Period-of-record for the Myakka rainfall monitoring site extends back to only 1943.

These methods were used to distinguish random variations in average annual rainfall levels from distinct longer-term rainfall patterns in the Peace River watershed. The following conclusions summarize some of the principal findings of these historical rainfall analyses:

- The plots of yearly annual deviations from the historic average annual rainfall for the three gages in the Peace River watershed (**Figure 3.36**) further support the previous conclusions that total annual rainfall in the watershed during the 1940s and 1950s was above the long-term average of 52.1 inches per year, and has often been below that average during much of the time since the early 1960s.

- Analyses of annual deviations conducted after separating yearly rainfall totals into wet-season (June through September) and dry-season (October through December and January through May) indicated slightly higher wet-season rainfall prior to the early 1960s, and increasing again in the early 2000s (particularly during the very wet summers of 2004/2005 due to the unusually high number of tropical storms that influenced summer rainfall totals). In contrast, dry-season rainfall more randomly varied around the long-term average over time, with a notable decline over the past 10-15 years.

- Graphical analyses of cumulative: 1) overall; 2) wet-season; 3) and dry-season rainfall deviations from long-term averages clearly indicate historical differences in watershed rainfall patterns. Although there were differences among the three Peace River watershed rainfall gages, when averaged, total annual rainfall levels were generally average to above average from the early 1920s through approximately the early 1960s and then subsequently decreased until the early 1990s.

- The plots of cumulative wet and dry-season rainfall deviations for the three Peace River watershed gages again demonstrated that annual wet-season rainfall levels from the early 1960s through the first part of the 1990s were lower than the long-term 1915-2016 average. While wet-season rainfall in the Peace River watershed has been somewhat higher than average over the past decade, dry-season rainfall was been decreasing.

3.2.3 Statistical Trend Analyses of Rainfall

The inherent natural variability in southwest Florida rainfall results in high temporal and spatial variability in fixed station rainfall data at both small and larger scales. The objective of the statistical trend analyses (Seasonal Kendall Tau) was to determine if this method of statistical trend analysis could be applied to further describe observed long-term changes in rainfall patterns. The term "trends" is used here to refer to progressive changes over time in a metric (such as the monthly or annual total rainfall), while "seasonal" and shorter-term oscillating patterns are due to repeating natural processes. This method differs from that used by others (Basso and Schultz 2003, Kelly 2004) in which significant differences in rainfall between historic and more recent periods were evaluated by comparing average differences among decadal (or longer) annual total rainfall levels. The Seasonal Kendal Tau statistic differs in that it estimates the slope, or rate, of change over time and determines if the measured rate of change is statistically significant while accounting for serial correlation.

Researchers have proposed a number of parametric and nonparametric (distribution-free) statistical methods for determining the presence or absence of trends, some of which are more robust, than others (see below for definition). The objective of these tests is to separate a pattern (trend) from the “noise” of repeating seasonal and/or random “unexplained noise” in the data. The ability to detect and quantify, or determine the absence of, progressive changes over time is imperative to developing a framework and basis for future management decisions.

- **Parametric versus Nonparametric Methods**. A basic assumption of most parametric statistical tests is that the data distribution is approximately normally distributed (or that it can be transformed to be so). The general overall robustness of parametric tests is dependent on this underlying assumption and provides resistance to the influence of outlier data. However, environmental data in general, and rainfall and flow data in particular, often violate this key underlying assumption of the most commonly applied parametric procedures. Therefore, nonparametric tests are usually considered more robust when analyzing many kinds of environmental data.

- **Robustness, Resistance, and Influence**. “Robustness” refers to the insensitivity to violations of the basic assumptions of a particular statistical procedure. The term “resistance” by comparison is used to refer to the insensitivity to outliers, while the word “influence” is used to describe the effect of extreme observations on summary measures.

Kendall Tau and the Seasonal Kendall Tau tests are nonparametric statistical tests widely used to analyze data for trends where normality cannot be assumed. These methods can be used to determine whether data values are increasing, declining, or remaining relatively level over time. This is accomplished by computing a statistic (Tau) based on the differences among all possible data pairs, thus representing the net direction of movement of the time-series data. The number of positive differences minus the number of negative differences is then determined and this is used to calculate the Mann-Kendall Tau statistic. If the time-series data are systematically increasing (or decreasing) over time, then the Tau statistic will be a relatively large positive (or negative) value. If, however, the change over time is negligible, then the number of positive pairs and the number of negative pairs will be approximately equal, and the Tau statistic will be small. The Tau statistic can thus be viewed as an estimate of the median slope of the set of slopes estimated for the lines connecting all possible pairs of data.

The Seasonal Kendall Tau test incorporates an additional factor to account for seasonal variation. When analyzing monthly data, each month is viewed as a "season" and this method is therefore directly applicable to flow and rainfall data, which are characterized by strong seasonal patterns. As in parametric tests, hypothesis testing for a trend is based on the null hypothesis that “there is no trend.” The null hypothesis can only be rejected if the Tau statistic is sufficiently large at a given level of probability (p-value).

Statistical tests were conducted using either SAS (Statistical Analysis System) programming code developed by the U.S. Environmental Protection Agency (USEPA) for nonparametric analysis of water quality and other environmental data, or DOS (Disk Operating System) code obtained in the early 1980s directly from USGS. The USEPA SAS code is based on (and incorporates) the Seasonal Kendall Tau program code originally developed by USGS to test for trends in flows and water quality data. Both the SAS and DOS codes provide two alternative methods for determining if data exhibit a statistically significant trend at a given level of probability. The first method assumes that the seasonal data are independent, while the second method corrects (or de-trends) for “serial autocorrelations” within the data. Monthly rainfall (and flow) data are often serially correlated (the values in many months are similar to either the preceding or following months). Therefore, statistical Seasonal Kendall Tau probabilities corrected for serial correlations were used for tests of trends in monthly values over selected time intervals. Both Seasonal Kendall Tau programs used also estimate the slope of the calculated trend in units of change per year.

Rainfall data at each of the four long-term gages were tested for statistically significant trends first using monthly totals (**Table 3.4**) and then alternatively based on annual levels (**Table 3.5**). The initial test for trends was conducted over the 1932-2016 time period (corresponding to the longest record of gaged historic flows) for the three Peace River watershed sites, and over the somewhat shorter 1943-2016 period-of-record for the Myakka River watershed gage. These same analyses were then again repeated over the 1976-2016 time period, which corresponds with the interval of HBMP monitoring. The sign and magnitude of the calculated Seasonal Kendall Tau statistic, and the slope indicate direction and degree of change, while the probability values indicate the likelihood that the change is statistically significant. Since monthly rainfall totals are seasonally autocorrelated, the probabilities for these monthly based tests are corrected for serial correlations.

Overall, the results presented in the graphical and statistical analyses of historic rainfall patterns extend and support findings previously described in the *2002*, *2006* and *2011 Peace River HBMP Comprehensive Summary Report* (PBS&J 2004, 2009; Atkins 2013) and the *Peace River Cumulative Impact Study* (PBS&J 2007). The following summarize the key findings regarding the long-term variability of seasonal rainfall patterns in southwest Florida:

- The average annual rainfall pattern for the Peace River watershed (**Figure 3.3**) shows that more than half of the total annual rainfall typically falls within the four-month summer wet-season between June and September.

- However, the results of the time-series plots (see **Table 3.3**) clearly show that over the forty-one year period of HBMP monitoring (1976-2016) there has been considerable unevenness in both seasonally and annually based rainfall levels. The sources of such variability can often be directly linked with influences of major climatic events such as unusually wet winter/spring El Niño periods (1982-1983 and 1997-1998) that were subsequently followed by La Niña influenced extended drought conditions (1985-1990 and 1999-2002), or periodic tropical events such as those that occurred in 2004 when three hurricanes (Charley, Frances, and Jeanne) all directly impacted the Peace River watershed, followed by the high number of tropical lows that influenced summer rainfall during 2005.

- When annual and seasonal rainfall patterns are analyzed over longer historic time intervals, such as 1932-2016 or 1915-2016, more distinctive decadal patterns become apparent.

- Graphical analyses using cumulative differences of historical changes in rainfall patterns indicate that such decadal changes have been small relative to both monthly and annual variations, and that the observed changes in historical rainfall levels have been primarily associated with small changes during the four month summer wet-season.

- The data also suggest that during the historically slightly wetter summer periods from the 1930s to the 1960s rainfall levels in both May and June were somewhat higher than during the drier summers between 1969 and 1994.

- Monthly and annual rainfall levels at the Peace River Bartow gage were statistically significant over the period of record from 1932-2016 (**Tables 3.4** and **3.5**). The other two long-term Peace River locations did not yield statistically significant trends in monthly or annual rainfall for the period 1932-2016.

- Overall, analyses of the rainfall data show apparent differences between the two inland rainfall gages (Bartow and Arcadia), and the more coastal Myakka River recording site. The more coastal rainfall gage has often (especially during drier periods) had slightly higher measured rainfall levels, and the long-term patterns at the more coastal location show neither the distinct wet-season declines following the 1960s nor the recovery following the early 1990s apparent from rainfall measurements at the two inland Peace River watershed gages.

- There were no significant trends in either total monthly or annual rainfall levels over the 1976-2016 HBMP monitoring program period at any of the four tested rainfall locations.

3.3 Status and Trends in Gaged Watershed Freshwater Inflows

A number of studies in recent years have evaluated historic flow trends and patterns in portions of the Peace River watershed and addressed potential causes relative to observed changes in seasonal and longer term flow patterns. The following lists some of these key studies:

- Peek (1951),
- Hammett (1990, 1992, 1998),
- Lewelling and Wylie (1993),
- Coastal Environmental (1996),
- Hickey (1998),
- Lewelling, Tihansky, and Kindinger (1998),
- Flannery and Barcelo (1998),
- Ardaman & Associates (2002),
- Basso and Schultz (2003),
- SDI (2003),
- Basso (2004),
- Kelly (2004),
- Kelly, Munson, and Leeper (2005),
- PBS&J (1999, 2006, 2007, 2009), and
- Janicki Environmental, Inc (2013).

Peek (1951) was one of the first to show a relationship between the loss of flow from Kissengen Spring and the lowering of the potentiometric surface in the Floridan aquifer system. The lowering of the potentionmetric surface occurred due to excessive ground water pumping primarily associated with the expansion of phosphate mining in the upper Peace River watershed. Hammett (1990) subsequently identified statistically significant declines in long-term annual mean discharges at the Peace River at Bartow, Zolfo Springs, and the Arcadia USGS gaging stations over the period between the 1930s and 1984. Hammett also suggested that such observed declines in Peace River flows were probably related to the declines in the water levels in the underlying aquifer systems resulting from increased ground water withdrawals. Her analyses indicated that the largest declines in river flows were in the northern and eastern parts of the watershed where the greatest reductions in the potentiometric ground water surface had occurred.

Lewelling et al. (1998) updated and extended the Hammett (1990) analysis by including the subsequent 10 years of gaged river flows and found the same declining trends when flows were analyzed over the interval from the 1930s to 1994. Other studies (Kelly 2004, Basso 2004 and Kelly et al. 2005) have indicated that there are long-term patterns in the Peace River watershed flows that can be related to the previously discussed cyclical Atlantic Multidecadal Oscillation (AMO) rainfall phases. These studies found decadal differences in mean and median flows that closely match the wet 1932-1969, dry 1969- 1994 and again wet 1994-present AMO phases, and indicated that such changes were primarily associated with decadal differences in summer wet-season flows.

Additional analyses based on USGS flow records through 2004 and 2006 (PBS&J 2007 and 2009) found similar historic flow patterns relative to mean and median monthly flows at long-term USGS gages both within the Peace River and other nearby watersheds. The PBS&J analyses, however, also revealed distinctly different long-term patterns in base flows (lower monthly percentiles) in different regions of the Peace River watershed. Base flows at the USGS gages in those basins found in the upper portions of the watershed show marked declines that can be directly linked to increased ground water withdrawals and historic reductions in ground water levels and spring flows. Historically, loss of the potentiometric surface in the Floridan aquifer system can be traced to the expansion of phosphate mining in the northern watershed. However, over more recent decades, ground water withdrawals associated with mining have declined and been replaced by increases in agricultural demands and potable uses. Agricultural ground water use in the southern Peace River watershed basins have increased to such an extent that base flows in these Peace River tributaries have been distinctly augmented. There are some streams and creeks that were previously seasonally dry that now often have some flow throughout the year due to agricultural discharges.

Janicki Environmental, Inc. (2013) examined trends in streamflow throughout the Charlotte Harbor National Estuary Program study area using Index of Hydrologic Alteration (IHA) metrics computed for USGS flow records through 2010. Results suggested that many alterations to the hydrology have occurred in the Upper Peace River, the Myakka River, the Tidal Caloosahatchee, and tributaries of the Estero Bay watershed. Consistently decreasing trends were observed for many of the flow statistics within the Upper Peace River. Base flows in the Myakka River near Sarasota appeared to be increasing as evidenced by increasing trends in several of the annual minima statistics. Increases in the minima statistics in the Myakka River were noted to have been attributed in other reports as influenced by historical agricultural water use practices and that significant efforts at ameliorating those effects have been made in recent years. Joshua Creek exhibited similar results to the Myakka River with respect to increases in minima statistics over time. However, many of the other gages exhibited no trends indicating stable conditions over the period of record examined.

For this current 2016 *Comprehensive Summary* Report, the gaged flow records for ten long-term USGS stream flow monitoring sites in the Peace River watershed and the Myakka River near Sarasota gage were obtained from the USGS Tampa website. Since USGS flow data are periodically updated from “provisional” data or corrected based on revised information, new period-of-record flow data for each gage were obtained and reviewed from the USGS website rather than simply updating previous HBMP information.

The following summary information for each of the analyzed long-term USGS stream flow gaging locations is presented in **Table 3.6**.

- USGS gage ID number,
- Gage identification name,
- Location (latitude & longitude),

- Elevation of gaging site,
- Basin/watershed area upstream of the gaging location (drainage area), and
- Historical period-of-record interval of data (start through 2016).

Table 3.6
Selected USGS Flow Gages

USGS ID	Gages Within Study Area	Latitude	Longitude	Elevation NGDV29 (meters)	Basin Area (square miles)	Start of Flow Record
Peace River Watershed						
2294650	Peace River at Bartow	27°54'07"	81°49'03"	87.56	390.0	10/01/39
2294898	Peace River at Fort Meade	27°45'04"	81°46'56"	0.00	480.0	06/01/74
2295420	Payne Creek near Bowling Green	27°37'13"	81°49'33"	51.06	121.0	10/01/63
2295637	Peace River at Zolfo Springs	27°30'15"	81°48'04"	30.20	826.0	09/01/33
2296500	Charlie Creek near Gardner	27°22'29"	81°47'48"	21.66	330.0	05/01/50
2296750	Peace River at Arcadia	27°13'19"	81°52'34"	6.00	1367.0	04/01/31
2297100	Joshua Creek at Nocatee	27°09'59"	81°52'47"	3.94	132.0	05/01/50
2297310	Horse Creek near Arcadia	27°11'57"	81°59'19"	10.96	218.0	05/01/50
2298123	Prairie Creek near Fort Ogden	27°03'06"	81°47'05"	25.00	233.0	10/01/63
2298202	Shell Creek near Punta Gorda	26°59'04"	81°56'09"	0.00	373.0	01/01/66
Additional Reference Gage						
2298830	Myakka River near Sarasota	27°14'25"	82°18'50"	7.92	229.0	09/1/36

3.3.1 Time-Series Plots

Time-series plots of monthly flows were plotted for the period-of-record for each of the long-term USGS gaging sites. The organization of these plots within this document is presented in **Table 3.7**. Monthly summary flow statistics were plotted to facilitate evaluation of potential differences among a number of statistics commonly applied to flow metrics.

The graphs include monthly flows as well as a fitted, smoothed line, which was plotted using a SAS cubic spline method that minimizes both the linear combination of the sums of squares of the residuals of the fit as well as the integral of the square of the second derivative. The statistical metrics used included seven monthly flow percentiles, including minimum and maximum values, as well as the monthly mean are as follows:

- P0 Percentile – the minimum or lowest monthly value,
- P10 Percentile – low flow value that was exceeded ninety percent of the time,
- P25 Percentile – low flow value that was exceeded seventy-five percent of the time,
- P50 Percentile – or median value, half of the monthly values were both greater and less,
- P75 Percentile – high flow value that was exceeded only twenty-five percent of the time,

- P90 Percentile – high flow value that was exceeded only ten percent of the time,
- P100 Percentile – the maximum or highest monthly value, and
- Mean- this average monthly value is usually above the median when evaluating flow data.

Among the presented graphics (**Figure 3.58** through **Figure 3.161**), variable scales were selected to provide the context of the full range of data being presented. While the use of such variable scales allows viewing greater detail within individual plots, care needs to be taken when making comparisons among plots. As an example, due to changes in scale, what may appear to be large changes in minimum monthly flows would probably completely disappear when evaluating changes in the maximum monthly values over time.

Similar graphics plotted over the thirty-six year period of HBMP monitoring (1976-2011) were also generated to provide uniform comparisons with other HBMP monitoring elements. The organization of these additional plots is presented in **Table 3.8**.

3.3.2 Statistical Analyses for Trends in Flows, Period-of-Record

River flows can vary both spatially and temporally over both small and large scales due to natural variations in rainfall, as well as anthropogenic influences associated with urbanization, mining, and agricultural practices. The term "trends" is used here to refer to progressive changes over time in a flow metric (such as the monthly mean flow), while "seasonal" and shorter term oscillating patterns are normally due to repeating natural processes. The Seasonal Kendall Tau test incorporates a factor to account for seasonal variation. When analyzing monthly data, each month is viewed as a "season" and this method is therefore directly applicable to southwest Florida's strong seasonal flow patterns (**Figure 3.4**).

Statistical tests were conducted using SAS and DOS programming code developed by the USEPA and USGS for nonparametric analysis of water quality and other environmental data (see previous discussion above in **Section 3.2.3**). **Tables 3.9** through **3.16** provide summary results of Seasonal Kendall Tau tests for trends in flows over the period-of-record for each of the previously discussed time-series plots (**Figure 3.58** through **Figure 3.161**.) In these analyses, trends in flows were tested over the period-of-record for each of the 10 long-term Peace River watershed USGS stream flow gaging sites and the Myakka River near Sarasota gage. Table 3.17 summarizes the tabular organizations of the presented Seasonal Kendall Tau statistical trends of monthly based flow metrics tests analyzed for each of the long-term series at the selected locations.

Table 3.17
Summary of Results of Seasonal Kendall Trend Analyses
(Long-term Period-of-Record)

Flow Metric	Summary Table	Flow Metric	Summary Table
P0 Percentile (Minimum)	**Table 3.9**	P75 Percentile	**Table 3.13**
P10 Percentile	**Table 3.10**	P90 Percentile	**Table 3.14**
P25 Percentile	**Table 3.11**	P100Percentile (Maximum)	**Table 3.15**
P 50 Percentile (Median)	**Table 3.12**	Mean	**Table 3.16**

The specific information presented in these summary tables is as follows:.

- Station identification (USGS ID and gage name);
- Time period designating the first complete year of annual flow data (trends were tested from this period through 2016);
- Number of years over which the trend test was conducted;
- Tau Statistic, for which positive values indicate an increasing trend over time, while negative values indicate a declining trend. The larger the absolute value is, the greater the indicated change over the tested time interval;
- P-values without correction for serial correlations. (These values were not used in these analyses since other analyses have shown that monthly flow values are often highly serially correlated);
- P-values statistically corrected to account for serial correlations (the values used); and
- Slope, which indicates the magnitude of the relative rate of change, with the sign indicating either an increasing or decreasing change over time (trend), the presented value represents the estimated change in units (cfs) per year over the analyzed time interval.

The overall results of Seasonal Kendall Tau trend tests presented in **Tables 3.9** through **3.16** are graphically summarized in **Table 3.18**. Arrows depict significant increasing or decreasing trends for a given flow percentile at each of the USGS gaging sites. Red arrows denote statistically significant trends over the period-of-record at the $P<0.05$ level, while blue arrows indicate significant trends at a lesser $P<0.10$ level. Empty cells indicate no significant trends in flows based on the Seasonal Kendall Tau test results corrected for serial correlations. The following summarizes the observed trends in flows at the USGS gaging sites over the individual periods-of-record, and notes appropriate instances where the present analyses differ notably from those previous reported in the *2011 HBMP Comprehensive Summary Report*:

- The trend analyses indicate that there have been long-term statistically significant declines in flows at the USGS main Peace River stream gages in the upper reaches of the watershed at both Bartow (since 1940) and Zolfo Springs (since 1934).

- Main channel flows in the middle portion of the Peace River watershed, characterized by the Peace River at Arcadia, previously (2011 analyses) indicated statistically significant declines in a number of flow metrics over the period-of-record. Updated 2016 analyses yield highly statistically significant declines over the 85-year period of USGS flow monitoring at Arcadia, for all flow percentiles examined. This is likely due in large part to the persistent drought lasting 2006-2011.

- The southern tributaries of the Peace River watershed have historically exhibited highly augmented base flows linked to dry-season, agricultural irrigation discharges of higher conductivity groundwater (PBS&J 2007, 2009). Previous analyses conducted in the *2006 Comprehensive Summary Report* indicated statistically significant increases in the lower flow percentiles (base flows) at both the Prairie and Shell Creek gages, with all the flow percentiles at the Joshua Creek gage increasing over the long-term period of record. The summary results of *2011 Comprehensive Summary Report* updated trend analyses continued to show significant increases, with the exception of maximum monthly flow, in all the Joshua Creek gage flow metrics. However, the 2011 analyses presented only showed a significant increase in the minimum flow at the Prairie Creek gage and no statistically significant changes in any of the flow percentiles at the USGS Shell Creek gage over the period of record. Updated 2016 analyses (**Table 3.18**) show the continuation of the decreasing trend at Joshua Creek (all metrics), significant increases at Prairie Creek for minimum, P10 and P25 metrics, and no significant changes in any of the flow percentiles at Shell Creek. It is difficult to determine if these observed differences are primarily the result of the recent extended drought from 2006-2011, the District's ongoing efforts to reduce high conductivity agriculture groundwater discharges into the Shell Creek watershed and ultimately into the downstream reservoir that serves as the City of Punta Gorda's primary drinking water supply, or a combination of both.

- The increased flows at the Joshua Creek gaging station are similar to those observed outside the Peace River watershed at the Myakka River near Sarasota gage, which has also historically experienced anthropogenically augmented flows.

- Even with agriculturally augmented dry-season flows in portions of the southern watershed basins, combined total gaged flows upstream of the Facility still show statistically significant declines over the 1951 to 2016 interval for all monthly percentiles. This differs somewhat from the earlier analyses conducted through 2006, where statistically significant declines in total gaged flows upstream of the Facility were apparent in flow percentiles below the median. Again, this difference can be directly attributed to the abnormally low rainfall/flows that characterized much of the 2006-2011 time interval.

The interpretation of such trend comparisons among basins over different time intervals can only be fairly general, since the results of trend analyses can differ appreciably depending on the time intervals tested. An alternative approach, was therefore, applied to identify the time periods over which the trends occurred, and subsequently provide direct comparisons among the various gaging sites in the Peace River watershed basins. A series of Seasonal Kendall Tau trend tests were run for each of the USGS gaging sites using standardized five-year intervals, such that the number of intervals tested for each gage differed depending on the length of the gage's particular period-of-record. The Peace River at Zolfo Springs gage, for example, has a relatively long historic record so trend tests were run in five-year intervals starting in 1935 (1935-2016, 1940-2016, 1945-2016, 1950-2016, etc.). Since it usually requires six to eight years of monthly data to determine statistical significant trends in highly seasonal data, the last interval used for all gages was 2005-2016. In order to facilitate the comparisons among gages, trend tests were conducted for three selected monthly flow metrics as follows:

- Low flow P10 Percentile, which is exceeded ninety percent of the time,
- Median flow P50 Percentile, which is greater and less than half the monthly flows, and
- High flow P90 Percentile, which is exceeded only ten percent of the time.

The results of Seasonal Kendall Tau test for trends among comparable intervals for each of the ten long-term USGS flow gaging stations in the Peace River watershed and the Myakka River near Sarasota gage are summarized graphically in **Table 3.19**. As in **Table 3.18**, the directions of the arrows denote statistically significant increasing or decreasing trends. Red arrows indicate trends between each date and 2016 at the $P<0.05$ level, while blue arrows indicate significant trends at a lower $P<0.10$ level. Empty cells indicate an absence of trends based on the Seasonal Kendall Tau results corrected for serial correlations, while filled boxes indicate that the gaged period of record did not include data for that interval. The following flow trends and generalized patterns are evident in **Table 3.19**. Changes are noted where the current results differ markedly from those in the previous *2006* or *2011 HBMP Comprehensive Summary Report*.

- In general, the high degree of both seasonal and yearly variability in flows requires a lengthy record of monthly flow values to ascertain whether changes over time are statistically significant when correcting for serial correlations.

- Low, median, and higher flows at the three Peace River gages in the main channel (Bartow, Zolfo Springs, and Arcadia) show significant declines over longer time intervals beginning in the 1930s, 1940s, 1950s and 1960s. However, there have not been any statistically significant changes in the tested flow percentiles at any of these three locations since 1975 (42 years).

- Increased flows in Joshua Creek are conspicuous, since the increases occur over most of the gaged period-of-record for low and median flow percentiles when analyzed at flow intervals beginning up to the early 1980s, and for high flow percentiles for flow intervals up to 1970.

- While previous (2006) trend analyses of Prairie Creek flows indicated augmented flows, there was little indication when analyzed through 2016. Again, this gage has a relatively short record making it difficult to determine if this change reflects actions by the District to reduce agricultural groundwater discharges, or simply the severity of the recent period of drought.

- Gaged flows at the Shell Creek dam showed statistically significant declines when analyzed over both the relatively short 1990-2016 and 1995-2016 time intervals. These declines were also detected in 2011 analyses, but not previously (through 2006) suggesting that Shell Creek flows (like those in the main stem of the Peace River) have been highly impacted by the magnitude and duration of the 2006-2011 drought.

- Similarly, previous trend analyses conducted in 2006 indicated significant increases in Horse Creek gaged flows over the 1965-2006, 1970-2006 and 1975-2006 intervals. No such changes were apparent in the current analyses when the data were analyzed through 2016, or in the previous analyses completed through 2011. Again, the recent extended drought is probably the obvious proximate cause of this observed change. However, it should be noted that expanded phosphate mining has been occurring in the upper reaches of the Horse Creek watershed.

- In 2006, the effects of anthropogenic flow augmentations in the Myakka River near Sarasota resulted in substantial statistically significant increases in flows over all periods up to 1975. However, when flows were analyzed through 2011, and again through 2016, the results show increases in flows over the longer time intervals, and statistically significant declines when flows are only analyzed over more recent periods. Again, this dichotomy further reveals the severity of the 2006-2011 drought in watershed flows.

3.3.3 Statistical Analyses for Trends in Flows, 1976-2016

Analogous Seasonal Kendall Tau trend test procedures were next used to analyze monthly flow metrics at each of the previously used USGS gaging sites over the 1976-2016 period, which corresponds with the historic interval of lower Peace River/upper Charlotte HBMP monitoring. The overall results of Seasonal Kendall Tau trends tests presented in **Tables 3.20** through **3.27** are graphically summarized in **Table 3.28**.

Table 3.29 summarizes the organization of the Seasonal Kendall Tau statistical trend test results of monthly based flow metrics from the series of selected locations over the 1976-2016 interval.

Table 3.29
Summary of Results of Seasonal Kendall Trend Analyses
(1976-2011 Period)

Flow Metric	Figure Number	Flow Metric	Figure Number
P0 Percentile (Minimum)	**Table 3.20**	P75 Percentile	**Table 3.24**
P10 Percentile	**Table 3.21**	P90 Percentile	**Table 3.25**
P25 Percentile	**Table 3.22**	P100 Percentile (Maximum)	**Table 3.26**
P50 Percentile (Median)	**Table 3.23**	Mean	**Table 3.27**

The following summarizes the results presented in **Table 3.28** relative to the trend analyses of Peace River watershed flows between 1976 and 2016. Major differences are described between the current results and similar analyses conducted in the *2006* and *2011 HBMP Comprehensive Summary Report*.

- No statistically significant trends in flows at any of the USGS gages along the main stem of the Peace River were previously apparent when flows were previously analyzed over the period between 1976 and 2006. However, when analyzing flows over the period 1976-2011, declines in both the monthly minimum and P10 (Q90) gaged flows at both the Bartow and Zolfo Springs USGS sites were indicated. In the current report, analyes were extended to 2016, and once again, no significant trends in flows along the main stem were apparent (**Table 3.28**).

- Previous trend analyses of flows through 2006, at a number of USGS gaging sites in the southern Peace River watershed basins indicated extensive patterns of increasing flows. Specifically, all flow percentiles at the USGS Joshua Creek at Nocatee gaging location, and flow metrics below the median within Horse and Prairie Creeks all were found to have statistically significantly increased. These basins have experienced extensive expansion and changes from less to more intense agricultural development during the past several decades (PBS&J 2007). Expanded agricultural development has resulted in both increases in surface drainage and ditching, as well as large discharges of ground water to receiving surface waters during seasonally drier periods. These observed increases in high conductivity base flow in the Peace River tributaries upstream of the Facility have resulted in historic water quality changes and potential influences on the downstream Facility during lower spring dry-season flows (PBS&J 2009).

- The current analyses extended through 2016 still show highly augmented flows in the Joshua Creek watershed. However, the only other observed significant increase over the 1976-2016 periods was with regard to minimum monthly flows at the Prairie Creek gage, and a less statistically significant increase in P25 monthly flows at the same location.

- The observed differences in trends may indicate that not only have all three of these southern Peace River watershed basins seen augmented dry-season stream flows due to agricultural ground water pumping, but that the degree of land use and drainage changes that have occurred in the Joshua Creek watershed have also resulted in structural changes that have fundamentally altered hydrologic surface flows in the basin.

3.4 Additional Analyses and Comparisons of USGS Gaged Flows in Peace River Watershed

Several alternative analytical methods were used to further investigate and evaluate historical natural and anthropogenic changes in USGS gaged Peace River basins flows, and provide comparisons with long-term changes in regional rainfall patterns. In many instances, these additional analytical procedures are similar to those applied in previous studies of patterns and changes in Peace River watershed flows and rainfall, listed above in **Section 3.3**.

3.4.1 Comparisons of Flows among Atlantic Multidecadal Oscillation Periods

Graphical and statistical analytical methods were used to evaluate whether the proposed Atlantic Multidecadal Oscillation (AMO) events might account for previously observed patterns of higher flows that occurred during the 1930-1960 time interval, the observed declines in flows during the 1960s and early 1970s, the subsequent signs of increasing flows in the mid 1990s, and the recent historical period that has been characterized by periods of severe drought between 1999-2002 and 2006-2011. The three AMO periods evaluated included the warmer wet phase prior to 1969, the cooler dry interval between 1969 and 1994, and the recent warmer wet period since 1995 (see **Figure 3.5** above). A limitation to these analyses was that the differences in periods of record among the USGS gaging stations made uniform comparisons among the three AMO phases for all of the flow gaging locations impossible.

Comparisons of Average Monthly Flows

This initial method utilized monthly average flows standardized by watershed basin areas and grouped by each of the three AMO periods. Flows were standardized relative to the upstream area (square miles) of each USGS gaging site (see **Table 3.6**) in order to also provide comparable relative estimates of differences among long-term intervals in the contributing flows per unit upstream contributing area among the Peace River watershed basins. The resulting values are shown plotted as average annual hydrographs to evaluate variability and potential differences among the three proposed recent historical AMO phases. Flow statistics using four different flow metrics were calculated for each of the selected Peace River gaging stations and the Myakka River near Sarasota basin to assess potential seasonally based differences relative to possible AMO influences. Annual average hydrographs are presented for each of the flow metrics:

- P10 Percentile – low flow value that was exceeded ninety percent of the time,
- P50 Percentile – or median value, half of the monthly values was both greater and less,
- P90 Percentile – high flow value that was exceeded only ten percent of the time, and
- Mean – the average monthly value (usually above the median for flow data).

Table 3.30 identifies time intervals associated with flow data for each USGS gaging site and indicates the organization of the individual hydrographs presented in **Figures 3.266** through **3.317**. Several distinct differences in the annual average hydrographs among the proposed AMO phases are apparent in the presented figures, as indicated in Figure 3.313 below.

- The historical flow data for several USGS gaging sites (Peace River at Bartow, Peace River at Zolfo Springs and the Peace Rivera at Arcadia; Charlie, Joshua and Horse Creeks ; and the Myakka River near Sarasota) include information from both the proposed warmer “wet” AMO phases prior to 1969 and the more recent period since 1995, as well as what is believed to have been the cooler “dry” phase between 1969-1994. These gaging sites thus provide sufficient long-term records to assess potential historical seasonal differences among the last three apparent AMO periods.

- Comparisons of low (P10) average monthly flows among the three AMO phases clearly indicates higher wet-season (June through September) values for this metric prior to 1969. All of the USGS gaging sites in the mainstem of the Peace River show that the recent interval since 1994 has been characterized by lower P10 flows during the usually drier months of the year, than was characteristic during either of the two preceding AMO intervals. Again, these results reflect the intensities of the recent 1999-2001 and 2006-2011 droughts that have influenced much of southwest Florida.

- No consistent patterns are apparent among the longer term gaging sites in the annual average hydrographs of Median (P50) flows, although within the mainstem of the Peace River median flows were somewhat higher in the wet-season months prior to 1969.

- Wet-season (June-September) summer flows are indicated to have been distinctly higher for both mean and high (P90) flows at the long-term gages (including the combined gaged flow upstream of the Facility) during the two warmer "wet" AMO periods when compared to the cooler "dry" 1969-1994 phase.

- Overall, to date, the recent "wet" AMO interval (since 1994) has been characterized by both generally wetter wet-seasons and drier dry-seasons annually (as expressed by the P10 flows) than the preceding "dry" AMO interval that preceded it (1969-1994). Should this pattern persist, it will put a greater emphasis on the Facility's recent (2009) expanded and enhanced capabilities to withdraw and store water over the relatively shorter intervals of the wet-season, and meet demands from off-stream storage during extended drier periods.

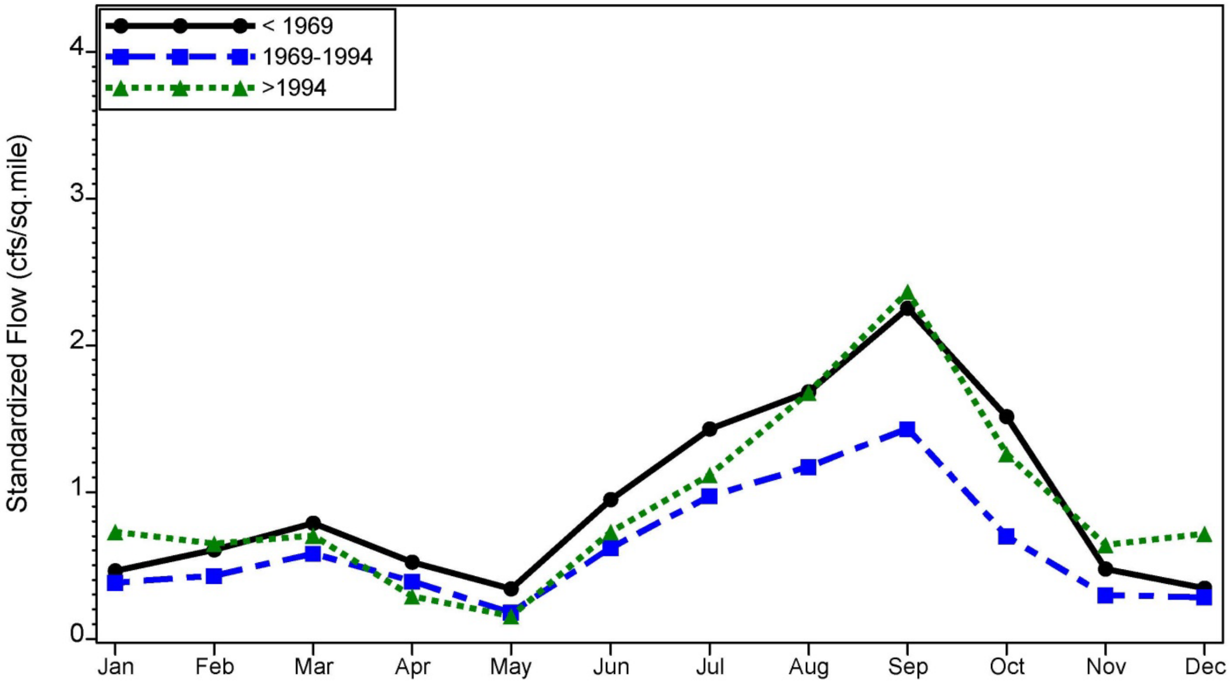

Figure 3.313 Seasonal differences among AMO periods of monthly mean gaged flow upstream of the Facility

Table 3.30

Summary of Seasonal Differences Among Three Historical AMO Periods at Long-term USGS Gages for Differing Flow Metrics

USGS ID	Gage Identification	Time Period of Data	P10 (or Q90)	P50 (or Q50) (Median)	P90 (or Q10)	Mean
Peace River Watershed						
2294650	Peace River At Bartow	1940-2016	Figure 3.266	Figure 3.279	Figure 3.292	Figure 3.305
2294898	Peace River At Fort Meade	1975-2016	Figure 3.267	Figure 3.280	Figure 3.293	Figure 3.306
2295420	Payne Creek Near Bowling Green	1980-2016	Figure 3.268	Figure 3.281	Figure 3.294	Figure 3.307
2295637	Peace River At Zolfo Springs	1934-2016	Figure 3.269	Figure 3.282	Figure 3.295	Figure 3.308
2296500	Charlie Creek Near Gardner	1951-2016	Figure 3.270	Figure 3.283	Figure 3.296	Figure 3.309
2296750	Peace River At Arcadia	1932-2016	Figure 3.271	Figure 3.284	Figure 3.297	Figure 3.310
2297100	Joshua Creek At Nocatee	1951-2016	Figure 3.272	Figure 3.285	Figure 3.298	Figure 3.311
2297310	Horse Creek Near Arcadia	1951-2016	Figure 3.273	Figure 3.286	Figure 3.299	Figure 3.312
	Total Gaged Flow at Facility	1951-2016	Figure 3.274	Figure 3.287	Figure 3.300	Figure 3.313
2298123	Prairie Creek Near Fort Ogden	1978-2016	Figure 3.275	Figure 3.288	Figure 3.301	Figure 3.314
2298202	Shell Creek Near Punta Gorda	1965-2016	Figure 3.276	Figure 3.289	Figure 3.302	Figure 3.315
	Total Gaged Flow to Harbor	1965-2016	Figure 3.277	Figure 3.290	Figure 3.303	Figure 3.316
Reference Basin						
2298830	Myakka River near Sarasota	1937-2016	Figure 3.278	Figure 3.291	Figure 3.304	Figure 3.317

Differences in Cumulative Distributions

Cumulative Distribution Function (CDF) plots were also used to examine potential differences in gaged watershed flows among the three proposed differing AMO intervals. CDF plots are a graphical method often used to evaluate potential differences in frequency distributions among data sets with large numbers of observations. In simple terms, a CDF plot indicates the probability that a measured variable (in this case a basin area standardized daily flow) is less than or equal to x, and can be expressed by the equation that follows.

$$F(x) = \Pr(X < x) = \alpha$$

The expression for variables with continuous distributions can be calculated using the following formula.

$$F(x) = \int_{\infty}^{x} f(u)du$$

Where F(x) is the estimated accumulated probability of the integrated change in the continuous variable (flow).

CDFs were plotted for the three AMO periods: 1) on an overall annual basis; 2) for the four month summer wet-season (June-September) only, and 3) for the remaining eight drier months (October-May). Plots are presented in **Figures 3.318** through **3.356** and summarized in Table 3.31. AMO periods with higher flows have statistical distributions (CDF lines) shifted to the right compared with CDF lines for the drier periods, which are comparatively shifted to the left. The results of the CDF analyses further support the previous conclusions that flows measured at the USGS sites during the 1969-1994 cool "drier" AMO phase were generally lower when compared with flows recorded during the two warmer "wetter" AMO periods (prior to 1969 and following 1994.) The statistical distributions also indicate that differences in the summer wet-season (June-September) flows between the warm and cool AMO periods were generally greater than during the rest of the year (October-May).

Table 3.31
CDF Comparisons Among AMO Periods

USGS ID	Gage Identification	Initial Year of Data	Overall	Wet-season June-October	Dry-season November-May
Peace River Watershed					
2294650	Peace River At Bartow	1940	**Figure 3.318**	**Figure 3.331**	**Figure 3.344**
2294898	Peace River At Fort Meade	1975	**Figure 3.319**	**Figure 3.332**	**Figure 3.345**
2295420	Payne Creek near Bowling Green	1980	**Figure 3.320**	**Figure 3.333**	**Figure 3.346**
2295637	Peace River At Zolfo Springs	1934	**Figure 3.321**	**Figure 3.334**	**Figure 3.347**
2296500	Charlie Creek Near Gardner	1951	**Figure 3.322**	**Figure 3.335**	**Figure 3.348**
2296750	Peace River At Arcadia	1932	**Figure 3.323**	**Figure 3.336**	**Figure 3.349**
2297100	Joshua Creek At Nocatee	1951	**Figure 3.324**	**Figure 3.337**	**Figure 3.350**
2297310	Horse Creek Near Arcadia	1951	**Figure 3.325**	**Figure 3.338**	**Figure 3.351**
	Total Gaged Flow Upstream of the Facility	1951	**Figure 3.326**	**Figure 3.339**	**Figure 3.352**
2298123	Prairie Creek Near Fort Ogden	1978	**Figure 3.327**	**Figure 3.340**	**Figure 3.353**
2298202	Shell Creek Near Punta Gorda	1965	**Figure 3.328**	**Figure 3.341**	**Figure 3.354**

Table 3.31
CDF Comparisons Among AMO Periods

USGS ID	Gage Identification	Initial Year of Data	Overall	Wet-season June-October	Dry-season November-May
	Total Gaged Peace River Flow to Harbor	1965	**Figure 3.329**	**Figure 3.342**	**Figure 3.355**
Other Reference Basins					
2298830	Myakka River near Sarasota	1937	**Figure 3.330**	**Figure 3.343**	**Figure 3.356**

3.4.2 Cumulative Differences in Flows in the Peace River

The preceding analyses (see **Table 3.3** above) of cumulative rainfall differences indicated that during the 1940s and 1950s rainfall was generally above the long-term rainfall average, while during the 1970s and 1980s annual total rainfall was below average. A similar analysis of the cumulative deviation from average of total annual Peace River flow at the Arcadia gage is presented for comparison in **Figure 3.357**. As expected, when plotted as cumulative deviations from the long-term average overall, the observed differences in historic patterns are similar to those previously described for rainfall (**Figure 3.34**). Similar cumulative deviations in flows were also developed for the four month wet-season (**Figure 3.358**) and the eight drier months (**Figure 3.359**). The 85-year plots of both overall and wet-season cumulative Peace River at Arcadia flow deviations exhibit nearly identical patterns. In contrast, the cumulative deviation plot of Peace River at Arcadia dry-season flows indicates periods of declining flows having occurred during both the mid 1930s and 1940s. This same pattern is also apparent in the comparable dry-season cumulative rainfall deviation plots.

Table 3.32
Comparisons of Cumulative Differences in Rainfall and Flow at Arcadia Gages

Rainfall Period	Cumulative Difference in Rainfall*	Cumulative Difference in Flow
Total Annual Rainfall	**Figure 3.34**	**Figure 3.357**
Total Annual Wet-season Rainfall	**Figure 3.44**	**Figure 3.358**
Total Annual Dry-season Rainfall	**Figure 3.54**	**Figure 3.359**

* From previous portion of chapter

Analogous plots of total gaged flows upstream of the Facility are further presented over the 1952-2016 time frame for which there are available data for all three upstream gages (**Figures 3.60**, **3.61** and **3.62**). Again these graphics show the marked declines in both wet and dry-season flows over the period from the late 1960s through the 1990s, with dry-season flows rebounding before those during the normally wetter four summer months. Both wet and dry season flows show marked declines between 2006 and 2011, with wet season flows having increased again in recent years.

3.4.3 Analyses of Cumulative Flow and Rainfall Relationships

A hydrological method that has been used by others (Hammett 1988 and 1990, Hicky 1998, Basso 2002, PBS&J 2007) to evaluate potential historical changes in Peace River watershed flows has been to graph cumulative annual flows over time (sometimes referred to as “single mass plots”). Changes in flow patterns can be evaluated based on changes in the slopes of lines graphically fitted to the cumulative annual flows over time. When “breaks” in the slopes of these fitted lines occur, the corresponding years (along the X-axis) have been interpreted as reflecting periods when natural or anthropogenic influences have changed annual average flows. Similarly, graphical analysis of cumulative annual rainfall totals has been used to detect natural variations in long-term rainfall patterns. An additional application of this method has been to evaluate the relationships between changes in rainfall and flows by graphing cumulative total annual gaged flows against cumulative annual measured basin rainfall (sometimes referred to as “double mass plots”). Breaks in the slopes of fitted lines can be interpreted as indicating changes in the relationships between rainfall and flow during different time intervals. In these plots, the data points represent consecutive years (**Figures 3.365**, **3.368**, **3.371** and **3.374**), which allows specific time periods to be associated with any observed changes in the relationships between rainfall and flow.

Cumulative time-series plots of rainfall and flow (single mass), and flow versus rainfall (double mass) were developed using data from three long-term USGS gages in the Peace River watershed and one outside reference site (Table 3.33). Moving downstream, the three gages along the river’s main stem (Peace River at Bartow, Zolfo Springs and Arcadia) progressively include increasing larger upstream watershed areas. The Myakka River basin was selected for comparison, since it represents a more coastal watershed and the Myakka River also flows into upper Charlotte Harbor. The graphics summarized in Table 3.33 illustrate relationships between flows and rainfall. Annual sums are represented as individual blue dots, the gray solid line is a regression line fitted over the entire period, and the gray dashed lines represent upper and lower ninety-five percent confidence intervals.

Table 3.33
Summary of Plots Comparing Cumulative Plots of Rainfall and Flow Over Historic Periods and Cumulative Mass Plots of Rainfall / Flow Relationships

Rainfall / Flow Gages	First Year of Data Used through 2016	Summary of Total (Mass) Rainfall Over Time	Summary of Total (Mass) Flow Over Time	Double Mass Rainfall / Flow
Peace River Watershed				
Bartow / Peace River at Bartow	1940	Figure 3.363	Figure 3.364	Figure 3.365
Wachula / Peace River at Zolfo Springs	1934	Figure 3.366	Figure 3.367	Figure 3.368
Arcadia / Peace River at Arcadia	1932	Figure 3.369	Figure 3.370	Figure 3.371
Reference Watershed				
Myakka / Myakka at State Park	1943	Figure 3.372	Figure 3.373	Figure 3.374

The following results summarize the observed relative historical changes in patterns of rainfall and flow, and between their relationships:

- Graphics of data from the three main channel USGS gages indicated similar long-term flow patterns;

- The plots of cumulative annual rainfall over time (single mass) indicate only slight variations (oscillation) in rainfall above and below the long-term fitted line, but suggest differences (or breaks) in slopes before the 1960s and again in the early 1990s;

- In comparison, cumulative time-series plots of annual flows indicate distinct long-term patterns when compared to the overall regression line. These plots show marked breaks around 1960 and again in the early1990s;

- Plots of cumulative annual flow versus cumulative annual rainfall (double mass) indicate distinct changes in the relationships between rainfall and flow following two “breaks,” one in the early 1960s and the other in the 1990s;

- These breaks in the relationships between cumulative long-term river flow and rainfall generally coincide with the proposed AMO wet and dry southwest Florida rainfall periods (see previous AMO discussions). Again the influences of both the 1999-2001 and 2006-2011 droughts are evident, although the observed change in slope in the figures since the early 1990s is less than the previous change of slope that occurred in the early 1960s;

- Breaks in cumulative flows and cumulative rainfall relationships are evident in data from all three of the main channel Peace River USGS gaging stations (Peace River at Bartow, Zolfo Springs and Arcadia). However, the differences increase moving upstream. These differences among the gaging locations probably reflect differences in areas of the upstream basins, and the greater influence of anthropogenic ground water impacts on changes in base flow at the more upstream gages; and

- Most of the variation and patterns in annual total flow, rainfall and their relationships in the Peace River watershed coincide with similar long term changes at the referenced Myakka River USGS gaging station (**Figure 3.374**). This suggests that most of the variation in total annual flow at these gages is due to natural long term variations in rainfall in southwest Florida (Kelly 2004). As previously described, the Myakka River watershed is more coastal and has historically had slightly higher and different rainfall patterns than the more interior gaging locations in the Peace River watershed.

3.5 History, Status and Changes in Withdrawals

The primary objective of the following is to provide a brief overview describing historic and recent patterns of consumptive water use in the Peace River watershed, and specifically detail freshwater surface withdrawals from the lower river by the Peace River Facility. The magnitude and seasonal timing of Peace River Facility withdrawals are further compared with the corresponding downstream City of Punta Gorda consumptive use that additionally influences Shell Creek flows to the lower river and upper Charlotte Harbor. A summary and overview of the history of Peace River Facility and estimated regional demands for potable supplies are presented in **Chapter 7**.

3.5.1 Overview of History and Status of Water Use in the Peace River Watershed

Historically, ground water has provided the vast majority of the municipal, industrial, and agricultural consumptive use throughout most of the Peace River watershed. From the 1940s through the 1970s, the dominant ground water use in the upper watershed was associated with phosphate mining. However, in the late 1970s, the phosphate industry implemented a series of practices to reduce ground water consumption, including a greater reliance on capturing and recycling surface waters from mining areas. By the late 1990s, agriculture accounted for approximately 40 percent of the annual ground water use in Polk County, while domestic and industrial uses each accounted for just less than 30 percent of use (SWFWMD 2004). In the southern Peace River watershed basins, the majority of ground water withdrawals has been and remains associated with agricultural uses.

Table 3.34, developed as part of the Peace River Cumulative Impact Study (PBS&J 2007), provides estimates of both historical and recent anthropogenic ground water uses within each of the primary Peace River watershed basins. Agricultural practices throughout the Peace River watershed primarily rely on upper Floridan aquifer ground water, rather than on surface water or the less reliable surficial/intermediate aquifers. Consequently, the conversion of undeveloped and range lands to more intensive forms of agricultural has resulted in increased irrigation and subsequent increases in annual dry-season base flows, especially in the southern watershed tributaries, such as Joshua Creek, Horse Creek and the Prairie/Shell Creek systems (see previous trend results and discussions in **Section 3.3** above).

Table 3.34
Estimated Historic Peace River Watershed Ground Water Use (mgd) by Basin and Selected Reference Periods

Peace River Watershed Basin	1941-1943	1976-1978	1989-1991	1997-1999
Peace River at Bartow	63	176	156	151
Peace River at Zolfo Springs	34	102	100	95
Payne Creek	7	24	24	24
Charlie Creek	11	49	57	62
Peace River at Arcadia	7	30	37	40
Horse Creek	6	27	34	37
Joshua Creek	9	27	33	36
Shell Creek	13	44	54	55
Lower Coastal	5	20	25	26

Figure 3.375 depicts recent available District information on the number, spatial distribution, relative amount, and use of permitted surface and ground water withdrawals throughout the Peace River watershed. This figure clearly shows the relative scale of consumptive uses throughout the watershed and the potential importance of agricultural discharges relative to augmentation of dry-season flows in each of the watershed tributaries.

The two current major withdrawals of surface water for urban uses occur:

- In southern DeSoto County, where the Peace River/Manasota Regional Water Supply Authority (Authority) withdraws water from the Peace River to provide potable supplies for the City of North Port, Charlotte, DeSoto, and Sarasota counties.

- In Charlotte County where the City of Punta Gorda operates a smaller water treatment facility that withdraws surface water from behind the Hendrickson Dam on Shell Creek (**Figure 3.376**).

3.5.2 Peace River Facility Overview

The Authority's Peace River Facility is located on a side-branch adjacent to the main stem of the lower Peace River (Figure 3.377). The Peace River Facility has been operating and withdrawing water from the Peace River since 1980, although the system has only been operated by the Authority since 1991. The Facility presently has the capacity to treat up to 54 million gallons per day (mgd), which is roughly equivalent to withdrawals from the river of 83.6 cubic feet per second (cfs). The existing permitted maximum raw water river diversion capacity of the intake structure is about 120 mgd (185.7 cfs). Raw river water is stored in an off-stream surface reservoir and any excess treated water is stored in the system's twenty-one Aquifer Storage Recovery (ASR) wells. Water can be pumped from the raw water reservoir to the Peace River Facility for treatment, and/or previously treated water can also be recovered from the ASR well system to meet the water supply demands of the Authority's service area. Table 3.35 summarizes the history of major modifications of the Facility's District operating permits (the first of which preceded actual operations).

Figure 3.377 Peace River Facility showing site of withdrawal on a side branch of the river, the expanded treatment facility, and both the original 0.625 and newer 6.0 billion gallon surface reservoirs.

A further permit modification (2010420.08) occurred in November 2011and didn't change any of the permit conditions other than changing the expiration date of the current water use permit from 2016 to 2037, in order to conform to the length of the Facility's existing bonds and to conform to new District rules allowing longer term water use permits.

Table 3.35
Historic Summary of Facility Permits

Permit Conditions	December 1975	March 1979	May 1982	October 1988	March 1996	April & October 2011
Water Use Permit Number	27500016	27602923	202923	2010420	2010420.02	2010420.06 2010420.07
Average Permitted River Withdrawal (mgd)	5.0	5.0	8.2	10.7	32.7	32.7 32.855
Maximum Permitted River Withdrawal (mgd)	monthly Based 12 & 18	monthly Based 12 & 18	22	22	90	120
Diversion Schedule Low Flow Cut off (cfs) at Arcadia Gage	monthly Based 91 – 664	monthly Based 91 – 664	monthly Based 100 – 664	monthly Based 100 & 130	130 year round	130 year round total gaged flow upstream of the Facility
Maximum Percent Withdrawal of River Flow (%)	5	5	n/a	10	10	16% year round 28% when combined flow upstream of the Facility > 625 cfs (except in Block 1, between April 20th and June 25th)

Facility Withdrawal Permit between 1980 and 1988

Prior to 1988, the regulatory limit for maximum daily withdrawals from the Peace River was 22 mgd (34.0 cfs). This permitted quantity could be withdrawn from the lower river as long as the measured stream flow at the Peace River Arcadia gage was above the established minimum regulatory flow for each of the twelve respective months. These monthly minimum flow values were calculated based on a general formula that had been established under the District's first "Water Use Rules" adopted in 1975. The formula applied by the District used the previous twenty years of stream flow records for the USGS Peace River at Arcadia flow gage to establish separate minimum flows for each calendar month. The monthly minimum flows for the Peace River at Arcadia that were used to establish the freshwater withdrawal schedule used between 1980 and 1988 ranged from a low of 100 cfs in April and May, to 664 cfs in September. As a result, during low flow periods in the spring, maximum daily withdrawals of 34 cfs could reduce flows (as measured at Arcadia) by as much as 25 percent on some days. Conversely, the District's water withdrawal schedule during September didn't allow withdrawals from the river until gaged flows at the USGS Peace River at Arcadia gage exceeded 664 cfs.

It should be noted that use of the USGS Peace River at Arcadia gage for establishing minimum flows for Facility withdrawals was originally based on available late 1970s technology needed to easily access the preceding day's provisional estimated flows from the gage via a phone connection. Based on currently available internet based technology the MFL basis for the withdrawal schedule was modified (Table 3.35) to include two additional gaged tributaries upstream of the Facility (Joshua Creek and Horse Creek).

Table 3.36
Percent Flows and Withdrawal at the Facility and to the Upper Harbor (1980-2016)

Total Gaged Flow at:	Relative Percent of USGS Gaged Flows				Long-Term Average Percent Facility Withdrawals*
	Arcadia	Joshua Creek	Horse Creek	Shell Creek	
The Facility	75.1	9.5	15.3	NA	1.57
The US 41 Bridge	57.4	7.3	11.7	23.6	1.20

* As noted below, the relative percentages of flow diversion have substantially increased following both of the recent Facility expansions, and the 2011 modification of the withdrawal schedule under the District's adopted MFL for the lower Peace River.

Facility Withdrawal Permit between 1988 and 1996

When the permit was renewed in 1988, General Development Utilities' consulting scientists and the District agreed that the previous withdrawal schedule caused the Peace River Facility to rely too heavily on periods of low to moderate flows. It was agreed that site-specific information should be used to establish regulatory minimum flows and daily withdrawal limits from the Peace River. Using the long-term data collected under the HBMP, statistical models were developed to analyze the location of the freshwater/saltwater boundary as a function of flow, and predicted salinity changes that might result from permitted withdrawals.

Based on these analyses, District staff and General Development Utilities agreed that the withdrawal schedule should be modified. A minimum criterion was established with no withdrawals when flows at Arcadia were below 100 cfs during the spring months (March April, and May) and 130 cfs during the remainder of the year (Table 3.35). Beyond that, withdrawals could equal up to ten percent of the preceding daily measured Peace River at Arcadia flow, with a daily maximum not to exceed 22.0 mgd (34 cfs). This schedule allowed withdrawals to more closely follow the natural variability of rainfall and flow.

Facility Withdrawal Permit from 1996 to 2011

The District's 1996 twenty-year renewal of the Facility's Water Use Permit (WUP) established a series of maximum withdrawal quantities. This permit renewal increases the minimum flows measured at the upstream Arcadia gage, under which no withdrawal can occur, to 130 cfs during all months of the year. Beyond that, withdrawals were still not to exceed ten percent of the preceding day's average daily Peace River at Arcadia gaged flow, while the upper daily limit was expanded from 22 to 90 mgd. This permit revision allowed the Authority to withdraw, treat and store more water from the river under high flow conditions. In response to the severity of the 2006-2011 drought the District issued a series (summarized in **Chapter 7**) of Executive Orders which provided for temporary modifications of the Facility permitted withdrawal schedule to meet demands.

2011 Facility Withdrawal Permit

In 2009, the Authority completed construction of the new 6 billion gallon reservoir, and expansion of maximum pumping capacity of the intake structure on the Peace River to meet growing demands for water and increase system reliability. Subsequently, in 2010, the District adopted a final MFL for the lower Peace River based on the combined flows of the three gaged flows upstream of the Facility (see **Table 1.5**, in Chapter 1). The Authority therefore requested a revised withdrawal schedule and permit modification based on the District's adopted MFL in order to provide for increased utilization of its increased off-stream storage and improve system reliability for the same 32.7 mgd average day delivery of water permitted in the Facilities existing 1996 District permit.

A revised withdrawal schedule (Table 3.37) based on the District's adopted MFL was issued by the District to the Authority on April 26, 2011. This permit modification maintained both the original 32.7 mgd yearly average and maximum monthly allowed average of 38.1mgd. The maximum daily diversions from the river were increased from 90 mgd to 120 mgd, in order to allow greater flexibility of the Authority's recent Facility upgrades. While daily Facility withdrawals had previously been based on the preceding daily average flow measured at only the USGS Arcadia gage, the new District permitted withdrawal schedule instead utilizes the previous day's combined flow based on the readings from three gages upstream of the Facility located on the Peace River at Arcadia (USGS 02297310), Horse Creek (USGS 02297310), and Joshua Creek (USGS 02297100). The low flow cutoff for Facility withdrawals remained the same as previously permitted at 130 cfs, but was also changed to reflect the combined flow of the three upstream gages.

Table 3.37
April 2011 Revised Authority Lower Peace River Withdrawal Schedule (based on combined USGS gaged flow at three upstream gages)

Block	Allowable Percent Reduction in Flow	
Block 1 (April 20th – June 25th)	16% if flow is above 130 cfs	
Block 2 (October 27th – April 19th)	16% if flow is > 130 cfs	28% if flow > 625 cfs
Block 3 (June 26th – October 26th)	16% if flow is > 130 cfs	28% if flow > 625 cfs

Two additional modifications were made to the Facility's water use permit in 2011. The first occurred in October 2011 and made a small adjustment in the allowable annual average withdrawal increasing it from 32.7 mgd, to 32.855mgd. This permit modification also increased the allowable monthly maximum from 38.1 mgd to 38.3 mgd. The next permit modification occurred in November 2011 and didn't change any of the permit conditions other than change the expiration date of the current water use permit from 2016 to 2037, in order to conform to the length of the Facility's existing bonds and to conform to new District rules allowing longer term water use permits.

Figure 3.378 shows the relative historic relationships between regional demands from the Facility and the amounts of surface water withdrawn from the lower Peace River. The differences between the two primarily reflects the need to replenish accumulated off-stream storage in either the surface reservoirs, or in the series of ASR wells following periods of drought. Some of the differences also reflect the need to replace losses due to evaporation and/or to groundwater. However, such losses are relatively small with an estimated current annual average net loss of about 400 million gallons due to leakage and evaporation. Changes in withdrawals also reflect the major 2001 and 2009 Facility expansions, as well as the droughts in 1999-2001 and more recent 2006-2011 drought. **Table 3.38** provides a complete yearly summary of the history (1980-2016) of the Facility's permitted quantities, capacities, demands and withdrawals.

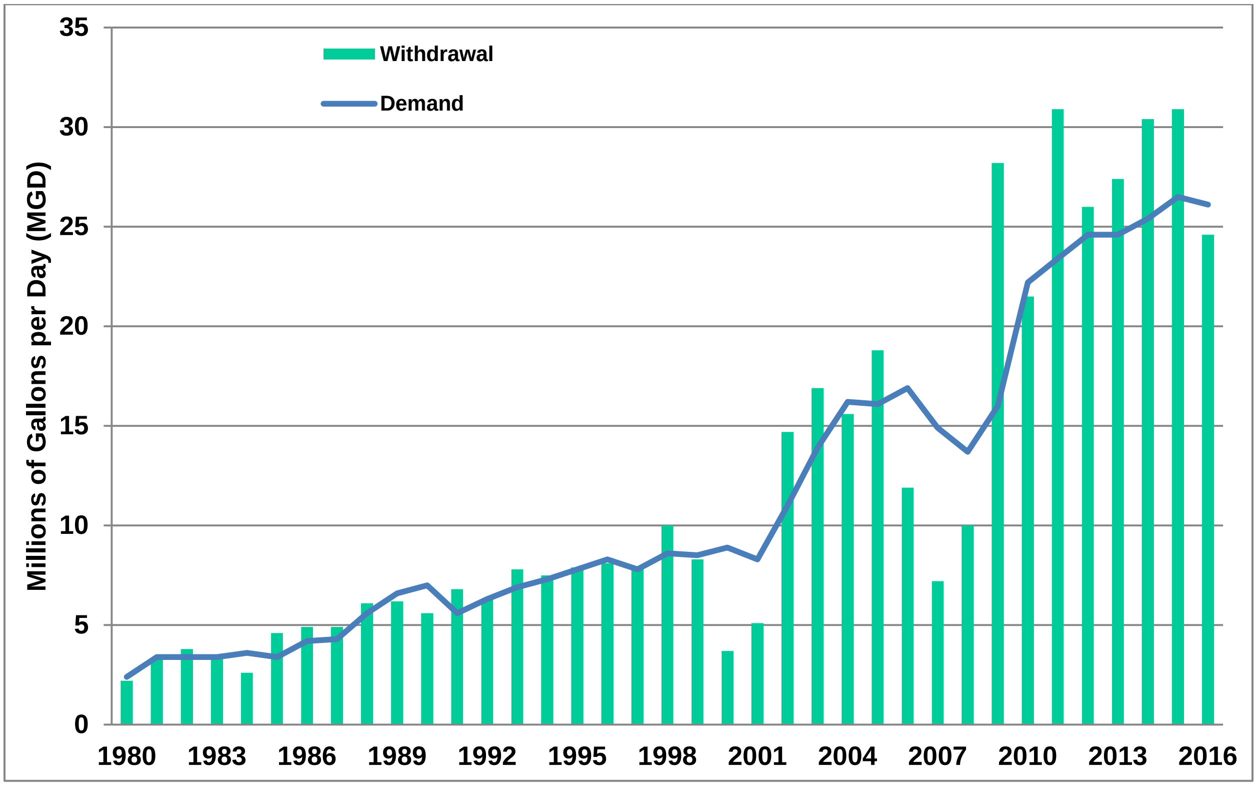

Figure 3.378 Historic annual average Facility demands relative to diversions from the lower Peace River.

Even with the District's revision of the withdrawal schedule based on the established MFL for the lower river, there continues to be a large number of days each year when the Peace River Facility does not withdraw water from the river. During 2016, the Facility did not withdraw water from the river 32 percent (117 days) of the time. Reasons for the Facility not withdrawing water on a given day or time interval can be due to:

- The total USGS gaged stream flows upstream of the Facility being below the designated low flow threshold of 130 CFS for freshwater withdrawals,
- Poor water quality (conductivity, taste/odor) ,

- Facility maintenance, and
- Insufficient immediate storage capacity (full existing storage system) even with the 2009 completion of the new 6 billion gallon reservoir.

3.5.3 Peace River Facility Withdrawals

Since the beginning of Facility withdrawals from the river in March of 1980, average (mean) daily withdrawals have been 18.6 cfs, while median withdrawals have been slightly lower (11.1 cfs). However, as shown above (Figure 3.378) there have been major increases in withdrawals following both the 2001 and 2009 Facility expansions. Mean and median withdrawals since 2001 have been 31.0 and 23.6 cfs respectively. Available permitted quantities are a direct function of flow, and thus when flows are high, available quantities will be relatively high, and vice versa. Actual withdrawals, by comparison, are dependent on a number of factors including pumping capacity, available storage, and demand (**Table 3.38**). Annually, the highest potential availability of water under the permit typically occurs during August and September, while the lowest levels typically occur during May (**Figure 3.4**). The interactions between the availability of flow and the Facility's capacity for withdrawals are indicated by comparisons of withdrawals during the recent droughts, and withdrawals during the characteristically wetter years such as 2003 through 2005. The Facility's ability to quickly refill storage after the normally dry spring season are ultimately limited by upstream flow, as well as the Facility's existing 120 mgd (185.6 cfs) existing pumping capacity and the matching maximum permitted cap on daily withdrawals from the river .

As discussed, beyond the Facility's permitted low flow cutoff of 130 cfs based on the combined flow of the three USGS gages immediately upstream of the Facility, and the 120 mgd maximum daily withdrawal cap, there are a number of additional factors that limit actual daily withdrawals. These include normal Facility maintenance and operations, the Facility's physical capacity to pump water from the river, the capacity of the Facility to store/treat water, and historically variations in seasonal demands. Combined, these have resulted in the Facility at times not withdrawing the full amount of water allotted under the permitted withdrawal schedule. Over time modifications of the District's water use permits (see Table 3.35 above) and increases in Facility capacity have resulted in changes needed to better meet the demands (**Table 3.38**) of the communities serviced by the Facility. The demand for water is generally the highest in the spring dry-season months when flows are characteristically at seasonal low levels, meaning that sufficient water must be withdrawn and stored when it is available, primarily during the summer wet-season months. The recent two Facility expansions in combination with increased storage capacity in the Facility's ASR wells and the second expanded off-stream reservoir allows the Facility greater flexibility to utilize, and store higher flows when they are available. The 1988 philosophical change in the Facility's water use permit to a flow based withdrawal schedule, rather than a fixed predetermined monthly schedule, provided the potential to allow greater withdrawals when sufficient water above the low flow cutoff are available. Through 2016, the facility was able to meet demands operating within the limits set by the water use permit and the Facility's physical capacity. However, during both the recent very dry 1999-2001 La Niña event and the more recent extended drought of 2006-2011, the Facility's stored water reserves were drawn very low prior to completion of the second off-stream reservoir in 2009. Comparisons of potential relative impacts of current and future projected levels of withdrawal relative to Peace River flows vary depending on where flows are being measured. Peace River Facility withdrawals have never exceeded 8.8 percent of the annual gaged flow at Arcadia, 6.6 percent of the total gaged flow upstream of the Facility, or 5.0 percent of the total annual lower Peace River gaged flow to upper Charlotte Harbor (**Table 3.39**). As demand for potable water supplied from the Facility increases in the future, the timing of flows potentially available for withdrawal relative to timing of peak demands may cause some supply issues, especially during extended dry periods unless the Authority continues to expand facilities and storage capacity to meet ever growing public demands for water. During periods when flows are low, but still above the 130 cfs low flow cutoff, the Facility typically withdraws water at, or very near, the daily maximum permitted levels. However, historically, the Facility has withdrawn water well below the daily maximum permitted amount during periods of high flow (**Figure 3.387**). It is expected that as demands from the Facility continue to grow, and possible expanded facilities are added, the difference between plotted lines for permitted and actual withdrawals under higher flows may become more similar (**Figure 3.388)**. Facility expansions have historically occurred incrementally, in response to projected demands balanced against the construction costs of adding both needed and future capacity. Currently, there are only relatively moderate expected demands in supply over the near term, and no major Facility expansions are envisioned . However, over time, additional off-stream storage and pumping capacity from the river may be needed, and actual quantities of water withdrawn from the river may move closer to those quantities theoretically available under the existing permit conditions.

A series of graphical and statistical analyses were conducted in order to provide a comprehensive overview of the current status as well as long-term patterns and trends in freshwater withdrawals by the Facility since it became operational in 1980. An overview of the graphical analyses is presented in Table 3.40.

Table 3.40
Summary Graphics of Facility Freshwater Withdrawals 1980-2016

Figure	Description
Figure 3.379	Daily water treatment facility withdrawals (1980-2016)
Figure 3.380	Monthly mean water treatment facility withdrawals (1980-2016)
Figure 3.381	Total gaged Peace River flows upstream of the Facility vs. withdrawals
Figure 3.382	Total gaged Peace River flows upstream of the Facility vs. withdrawals (for flows 0 to 500 cfs)
Figure 3.383	Total gaged Peace River flows upstream of the Facility vs. % withdrawals
Figure 3.384	Peace River flows at Arcadia vs. % water treatment facility withdrawals
Figure 3.385	Daily Peace River and Shell Creek water treatment facility withdrawals (1980-2016)
Figure 3.386	Average monthly maximum permitted and actual Facility withdrawals (1996-2001)
Figure 3.387	Average monthly maximum permitted and actual Facility withdrawals (2002-2016)

The following observations and conclusions regarding the status and long-term patterns and trends in Facility freshwater withdrawals can be drawn from the presented graphical analyses.

- The time-series plots presented in **Figures 3.379** and **3.380** indicate a number of patterns. The low flow cutoffs based on flows at the USGS Peace River at Arcadia gage have often resulted in periods each year when the Facility does not withdraw water from the river. The effects of the 2000-2001 and extended 2006-2011drought on Facility water withdrawals are clearly evident in both figures. During 2000 the Facility did not withdraw any water from the Peace River 248 days during the year, and relied solely on stored reserves another 219 days during 2001. Again, since 2006 there have been extended periods each year when the Facility has had to rely on its off-stream storage.

- These time-series plots also plainly show the relatively steady increases in the amounts of freshwater withdrawals by the Facility during the past thirty-seven years due to increasing water demands. Also clearly evident is the noticeable increase in maximum Facility withdrawals during the later half of 2002 and 2009 due to the recently completed Facility expansions, which resulted in the Authority's increased ability to both treat and store larger daily amounts of freshwater.

- **Figures 3.381** and **3.382** indicate that once flows exceed the 130 cfs cutoff, withdrawals by the Facility are more dependent on demand and capacity rather than supply, since as indicated, very similar amounts of water have been withdrawn over a wide range of flows. The three time intervals shown reflect the most recent two major Facility expansions.

- **Figures 3.383** and **3.384** indicate withdrawals as percentages over the 1980-2016 time period in relation to finalized "accepted" daily USGS combined gaged flows upstream of the Facility. As indicated, prior to implementation of the ten percent criteria in 1988, the Facility routinely withdrew fairly large percentages of gaged flow during drier periods under the District's original monthly based withdrawal schedule.

- These figures also show that Facility withdrawals at times exceeded the ten percent criterion established in 1988, and have exceeded the sixteen percent threshold under flows below 625 cfs established under the MFL in 2011. The primary reason for these discrepancies stems from the way that stage/flow data are gathered. The Authority uses "provisional" preceding-day flow data from those USGS water level recorders contained in the Facility water use permit to determine the quantity of river water available for diversion on the current day. Currently, these data are taken directly from the USGS Tampa office website. However, after the fact, the USGS checks and evaluates the data from the stage recorder and validates the river cross section a number of times each year. Thus, the daily values used by the Authority are only "provisional" and are occasionally changed by the USGS weeks or months later. It is not uncommon for subsequent determinations of percent withdrawals, based on revised USGS calculations of daily flows, to conclude that daily Facility withdrawals, based on provisional flow information, in fact exceeded the established percent based criterion. Similarly, there are also times when upward revisions would have meant that the Authority could have theoretically withdrawn additional amounts. The Authority and the USGS Tampa office staff have continued to work to reduce such instances to the greatest possible extent. USGS field calibrates the rating curves at each of these gages a number of times annually and any changes are quickly applied to the available real-time web data. (As discussed in **Chapter 7**, between 2006 and late 2010 the District issued a series of executive orders in response to the severity of the extended drought that temporarily altered both the low flow threshold and percentage based withdrawal schedule in the 2006 Water Use Permit).

- **Figure 3.385** compares withdrawals over the 1980-2016 interval between the Peace River Facility and the City of Punta Gorda Shell Creek in-stream reservoir. The City's withdrawals are far smaller and have gradually increased in response to local rather than regional demands. (Note: In 2012, an interconnect was completed between the two facilities that allows up to 6 mgd of treated water to be moved either way, thus enhancing the emergency reliability of both systems).

- **Figures 3.386** indicate that other than during the typically warm/dry spring months when the Peace River Facility often was not withdrawing water from the Peace River due to the 130 cfs cutoff, Facility withdrawals prior to the 2001 expansion were fairly uniform throughout most of the year. Between 2002 and 2006 (following the 2001 Facility expansion and prior to the series of District Executive Orders in response to the extended drought), the annual seasonal pattern in withdrawals saw a marked change (**Figure 3.387**) with a greater emphasis on withdrawing water under higher flows.

An alternative method of evaluating the relative potential magnitude of impacts from Facility withdrawals on the hydrology of the lower Peace River estuarine system is to compare the seasonal structure of the average annual hydrograph with and without withdrawals. Table 3.41 summarizes graphical comparisons of the annual average hydrographs of total upstream gaged flow with and without freshwater withdrawals at two locations along the lower Peace River. The first location is at the Peace River Facility and compares average seasonal gaged flows before and after actual daily withdrawals have been subtracted. The second selected location along the lower river is at the US 41 Bridge and includes Shell Creek flows prior and after including additional surface withdrawals by the City of Punta Gorda.

Graphical comparisons of differences in the annual average hydrographs for three different time intervals are presented. Each of the three selected time periods are characteristic of major differences in the Facility's water use permit criteria and/or Facility capacity (see **Table 3.35** above).

Table 3.41
Differences in Annual Average Hydrographs With and Without Withdrawals

Location	1980-2001	2002-2008	2009-2016
Lower Peace River at Facility	**Figure 3.388**	**Figure 3.390**	**Figure 3.392**
Lower Peace River at US41 Bridge	**Figure 3.389**	**Figure 3.391**	**Figure 3.393**

These analyses show that differences in the annual average hydrograph resulting from actual Facility withdrawals have, to date, been very small regardless of season. This is especially true given the fairly large degree of natural variability inherent both between years and over longer decadal periods (see AMO discussion in **Section 3.4.1**).

3.6 Summary

This chapter updates information presented in previous summary HBMP reports, and provides analyses of data collected through 2016 regarding both the status and trends of key hydrological elements associated with the Peace River Hydrobiological Monitoring Program (HBMP). Analyses and discussions are presented in relation to the current status and historic trends in the following specific hydrologically related HBMP study elements:

- Status and trends in watershed rainfall patterns,
- Status and trends in gaged watershed freshwater inflows,
- Status and trends in rainfall/flow interactions, and
- History, status and trends in withdrawals.

The presented analyses and summary graphics provide overviews of the current hydrological status within the Peace River watershed and lower Peace River/upper Charlotte Harbor estuarine system, and illustrate comparisons with historic longer-term patterns and characteristics. Also described are the important hydrological influences of more infrequent episodic occurrences such as extended periods of extreme drought, the periodic occurrences of unusually wet winter/spring El Niño climatic events, and differences in summer wet-season rainfall/flows due to variations in the frequency of tropical cyclonic patterns.

3.6.1 Hydrologic Setting

The Peace River watershed covers approximately 1.4 million acres (2,188 square miles), and the main channel of the Peace River begins northeast of Bartow, in Polk County, at the confluence of Peace Creek Drainage Canal and Saddle Creek, and extends approximately 105 miles south to Charlotte Harbor. Kissengen Spring near Bartow was a significant source of historic base flow to the upper Peace River with average annual estimated flows prior to the mid-1930s of approximately 30 cubic feet per second (cfs). Cessation of flow from the spring circa 1950 has been attributed to the decline in the hydraulic potential of the confined aquifers caused by the excessive development of the ground water resource, primarily associated with the early expansion of phosphate mining in the upper watershed. The hydraulic potentials of the confined aquifers, previously observed above the riverbed, have generally been tens of feet below the riverbed since the early-1960s. This historic loss of flows from springs and seeps has been one of the factors that have affected base flow to the upper portion of the river. However, base flow in the upper Peace River has also been affected by changes in discharges and drainage alterations associated with urbanization, phosphate mining, and agriculture. Other hydrologic alterations in some mined and reclaimed areas in the upper regions of the watershed have included diversions of surface waters that historically flowed to the river to storage for mining activities and/or seasonal impoundments resulting from disconnected surface depressions. Surface flows in some mined areas may also have been altered subsequent to mining due to increased recharge, as rainwater readily infiltrates the resulting disturbed soil structure, and recharge to the intermediate aquifer increases following loss of the upper confining layers associated with extraction of the phosphate matrix. The Peace River watershed basins south of phosphate mining influences have also experienced historic increasing ground water demands and extensive hydrologic alterations. These changes are reflected in the cumulative loss of wetland and native upland habitats, and increasing dry-season augmentation of base flow in many tributaries as agriculture in these southern basins has progressively changed from predominantly unimproved pasture to improved pasture and subsequently to increasing areas of more intense farming. Agricultural runoff has contributed to increased base flow in the Joshua Creek, Horse Creek and Prairie/Shell Creek basins.

The Peace River watershed predominantly lays within the National Weather Service (NWS) Florida South-Central Region Four, which is characterized by a summer wet-season that accounts for approximately 60 percent of total average annual precipitation of 52 inches (1915-2016). The four month wet-season extends from June through September, with June on average having the highest annual average rainfall of 8.3 inches. Conversely, November through January typically comprise the three driest months of the year, with rainfall in November only averaging 1.7 inches. October characterizes the transition from the convection based summer wet-season rainfall pattern to the frontal dry-season rainfall pattern.

While the described seasonal patterns in the annual hydrologic conditions are typical, there are wide degrees of both seasonal and annual variability in both rainfall and resulting river flow patterns. Deviations from the normal pattern can span periods of months up to several years. Intense El Niño/Southern Oscillation (ENSO) events, such as occurred in 1982/1983 and 1997/1998, result in atypical extended periods of heavy rainfall during the usually drier winter/spring months and dramatically alter the annual watershed hydroperiod. In both instances, these unusually wet El Niño periods were subsequently following by La Niña events and associated periods of extended drought. While short-term extremes of high and low flows influence the water budget in a watershed over periods of years, superimposed over these may be larger cyclic periods that can cover a number of decades.

Climate researchers have suggested that natural climate cycles or phases can persist over multiple decades. One of these cycles, the Atlantic Multidecadal Oscillation (AMO) refers to long-term cool and warm phase differences of only about 1°F (0.6°C) in North Atlantic average sea surface temperatures. An analysis of Atlantic sea surface temperatures suggests that warm AMO phases occurred during 1869-1893, 1926-1969, and from 1995 to date, while cooler phases occurred predominantly during the 1894-1925 and 1970-1994 time periods. It has been suggested that slight increases in average sea surface temperature in the Atlantic and Caribbean seas during warmer AMO periods produce more summer rainfall across southern Florida, while cooler AMO phases result in decreased summer rainfall.

3.6.2 Status and Trends in Watershed Rainfall Patterns

Historic period-of-record rainfall data for three representative long-term Peace River watershed basin rainfall gaging stations and a representative gage in the nearby Myakka River watershed were obtained as an initial step in evaluating the status and trends of hydrologic conditions in the Peace River watershed.

- Long-term total monthly rainfall patterns were similar among the selected rainfall gages.
- The variability in total monthly rainfall is sufficient to obscure changes and patterns when the long-term rainfall data are analyzed on a monthly basis.
- Results of the analyses suggest that total monthly rainfall at the more coastal Punta Gorda and Myakka State Park gages are at times slightly greater than at the two more interior Peace River watershed basin gages.
- When the long-term rainfall data for the Peace River watershed are analyzed as annual totals, the results clearly show both increased variations among the gages and greater indications of both historical wetter and drier intervals (**Figure 3.16**). Total annual average Peace River watershed rainfall levels were slightly higher from 1930 to the early 1960s when compared with the period since then.
- Annual average wet-season (June-September) rainfall in the Peace River watershed was generally higher during the 1930s through the mid-1960s when compared with the interval from the late 1960s through the early 1990s. Since approximately 1994, there has been a notable increase in wet-season rainfall (**Figure 3.21**).
- Dry-season (January-May and October-December) rainfall by comparison, even considering El Niño events, has on average continued to decline since the early 1960s (**Figure 3.26**).
- The plots of yearly annual deviations from the average rainfall further supported the conclusions that total annual rainfall during the 1940s and 1950s was above the long-term average of 52.1 inches per year, and generally below this average during much of the time since the early 1960s (**Figure 3.36**).
- Similar analyses of annual deviations conducted after dividing yearly rainfall totals into wet-season (June through September) and dry-season (October through December and January through May) generally indicate recent higher wet-season rainfall in contrast to declines in dry-season rainfall in the Peace River watershed.

3.6.3 Status and Trends in Gaged Watershed Freshwater Inflows

A number of recent studies have shown long-term patterns in the Peace River watershed flows approximately corresponding with the previously discussed proposed cyclical AMO rainfall phases. Further analyses however have also revealed distinctly different long-term patterns in base flows (lower monthly percentiles) in different regions of the Peace River watershed. Base flows in the upper portions of the watershed have shown marked declines that can be directly linked to ground water withdrawals and historic reductions in ground water levels and spring flows. Conversely, in a number of the southern Peace River watershed subbasins base flows of

Peace River tributaries have been distinctly augmented by agricultural discharges. A number of streams and creeks that were previously seasonally dry have (until the 2006-2011 drought) often had some flow throughout the year due to anthropogenic discharges.

Graphical and statistical analyses were conducted using a wide variety of monthly flow metrics for flows over the available period-of-records for each of the major long-term USGS gages in the Peace River Watershed.

- P0 Percentile – the minimum or lowest monthly value
- P10 Percentile – low flow value that was exceeded ninety percent of the time
- P25 Percentile – low flow value that was exceeded seventy-five percent of the time
- P50 Percentile – or median value, half of the monthly values were both greater and less
- P75 Percentile – high flow value that was exceeded only twenty-five percent of the time
- P90 Percentile – high flow value that was exceeded only ten percent of the time
- P100 Percentile – the maximum or highest monthly value
- Mean- this average monthly value is usually above the median when evaluating flow data

The following summarizes the findings of these analyses.

- The trend analyses indicate that there have been long-term statistically significant declines in all the tested flow metrics (percentiles) over the historic periods of USGS gaging in the upper reaches of the watershed at both Bartow (since 1940) and Zolfo Springs (since 1934).

- Similarly, Peace River at Arcadia flows show statistically significant declines in these same flow metrics over the 80-year period-of-record, as does the combined gaged flow upstream of the Facility (which can be calculated dating back to 1951).

- The observed decline in total gaged flow upstream of the Facility includes flows from Joshua Creek which, due to agricultural augmentation, have statically increased over the same time interval.

- In the *2006 HBMP Comprehensive Summary Report*, gaged flows at a number of the southern Peace River tributaries showed statistically significant increases over their respective periods-of-record (which are of shorter duration than those of the northern gages). Shell Creek flow data indicated increases in the lowest flow percentiles (base flows), while there were increasing trends in Prairie Creek at all percentiles between the monthly minimum and median values. All percentiles of flow at the Joshua Creek gage were found to have increased over time. In the previous analyses conducted through 2011, as well as those extended through 2016, only the minimum flow in Prairie Creek showed an increase over the historic record, and no trends in any of the flow percentiles were found for Shell Creek flows at the Hendrickson Dam. Whether these differences are primarily due to the recent actions by the District to reduce dry-season agricultural discharges of high conductivity groundwater to the Shell Creek Reservoir, or if these differences reflect the severity of the recent 2006-2011 drought isn't clear. However, it should be noted that both Joshua Creek and the upper Myakka River continue to show increased lower flow percentiles due to agricultural discharges over longer time intervals.

- Statistical analyses conducted as part of the *2006 HBMP Comprehensive Summary Report* didn't identify any statistically significant trends in flows at any of the USGS gages along the main stem of the Peace River beginning with the start of HBMP monitoring in 1976. Similar analyses in the *2011 HBMP Comprehensive Summary Report* for data through 2011 found declines (at P=0.10) in both minimum and P10 (Q90) flows at the Bartow and Zolfo USGS gaging sites in the upper watershed. However, current analyses through 2016 did not detect any significant trends in flows along the main stem of the Peace River for the period since 1976.

- Flow metrics (percentiles) at and below the median for the Joshua Creek gaging location over the 1976-2016 time interval show statistically significant increases at the 0.05 level, and at the 0.10 level for P75 and mean percentiles. Minimum flows at Prairie Creek near Fort Ogden were indicated to have significantly increased over the monitoring period, while the vast majority of other flow percentiles showed no significant trend.

- The observed differences in trends may indicate that not only have all three of these southern Peace River watershed basins historically seen augmented dry-season stream flows due to agricultural ground water pumping, but that the degree of land use and drainage changes that have occurred in the Joshua Creek watershed may have also resulted in structural changes that have fundamentally altered hydrologic surface flows in the basin.

3.6.4 Overview of Groundwater and Surface Withdrawals

Historically, ground water has provided the vast majority of the municipal, industrial, and agricultural consumptive use throughout most of the Peace River watershed. From the 1940s through the 1970s, the dominant ground water use in the upper watershed was associated with phosphate mining. However, in the late 1970s, the phosphate industry implemented a series of practices to reduce ground water consumption, including a greater reliance on capturing and recycling rainfall / surface waters from mining areas. By the late 1990s, agriculture accounted for approximately 40 percent of the annual ground water use in Polk County, while domestic and industrial uses each accounted for just less than 30 percent of use. In the southern Peace River watershed basins, the majority of ground water withdrawal has been and continues to remain associated with agricultural uses.

The two current major withdrawals of surface water for urban uses occur in the southern watershed where the Peace River Authority withdraws water from the Peace River in DeSoto County to provide potable supplies for the City of North Port, Charlotte, DeSoto, and Sarasota counties, and the City of Punta Gorda located in Charlotte County operates a smaller water treatment facility that withdraws surface water from behind the Hendrickson Dam on Shell Creek.

Since 2001, a period that includes both the 2001 and 2009 major Peace River Facility expansions, the average daily withdrawals over this eleven-year period have ranged from 0 to 169.8 cfs, with a daily average of 31.0 cfs. Corresponding upstream total gaged flow has ranged from 13.6 to 29,380 cfs, with a mean of 1276.5 and a median of 508.0 cfs. This recent period, contains both periods of unusually high summer flows, as well as extended periods of drought. Under both the 1996 and 2011 withdrawal schedule revisions, available permitted quantities are a direct function of flow, with an included low flow cutoff (130 cfs). Thus when flows are typically high, available quantities are relatively high, and vice versa. Actual annual withdrawals, by comparison (**Table 3.39**), are dependent on a number of factors including the variability in upstream flow, pumping capacity, available storage, and demand. As demand for potable water supplied from the Facility has increased since 1980, the timing of flows potentially available for withdrawal relative to timing of peak demands has historically caused some supply issues during extended dry periods (for example during both 1999-2001 and 2006-2009). Since the late 1990s, when flows are low but still above the 130 cfs low flow cutoff, the Facility typically has often withdrawn water at, or very near, the daily maximum permitted levels. However, until the recent 2009 Facility expansion which dramatically increased river pumping capacity and off-stream storage water, diversion from the river was far below the maximum permitted amount during higher flow periods. The recent major Facility expansion has both increased overall reliability as well as allow water withdrawn from the river to increasingly mimic the natural annual variability relative to the total quantities available under the existing permit conditions.

The following observations and conclusions regarding the status and long-term patterns and trends in Facility freshwater withdrawals can be drawn from the presented graphical analyses.

- Prior to 1988 when flows were not based on a percent of flow, relatively large percentages of low flows were often initially taken under the District's original monthly based withdrawal schedule.

- Time-series plots plainly show the relatively steady increases in the amounts of freshwater withdrawals by the Facility during the past thirty-seven years due to both increasing water demands, as well as off-stream storage capacity. Clearly evident is the noticeable increase in maximum Facility withdrawals following completion of the Facility's 2002 and 2009 expansions, which resulted in the Authority's increased ability to treat and store larger daily amounts of freshwater to be subsequently used during seasonally drier periods.

- Comparisons indicate that other than during the warm/dry spring months when the Facility is often not withdrawing water from the Peace River due to the 130 cfs low flow threshold, Facility withdrawals had historically been fairly uniform throughout most of the year, differing primarily between changes in the permits and differences in Facility capacities. Following the 2002 and 2009 major expansions, the annual pattern of withdrawals has begun to more closely follow a seasonal cycle that follows the natural variability in flow.

- Low river flows have often resulted in extended periods annually when the Facility is unable to withdraw water from the river. During both the extended droughts of 1999-

2001 and 2006-2011 intervals, the Facility did not withdraw water from the lower Peace River for up to 200 days or more, and had to rely solely on stored reserves to meet regional demands.

- Facility withdrawals periodically exceeded the ten percent criteria established in 1988, as well at the sixteen percent criteria in the 2011 withdrawal schedule revision. The primary reason for these discrepancies stems from the way that stage/flow data are gathered. The Authority uses “provisional” preceding day flow data from the water level recorder at the USGS real-time gaging stations to determine the quantity of river water available for diversion in the current day. Currently, these data are taken directly from the USGS website. However, after the fact, the USGS checks and evaluates the data from the stage recorder and validates the river cross section a number of times each year. Thus, the daily values used by the Authority are only “provisional” and are often changed by the USGS weeks or months after the fact. It is not uncommon for subsequent determinations of percent withdrawals, based on revised USGS calculations of daily flows, to conclude that daily Facility withdrawals, based on provisional flow information, in fact exceeded the established percent criteria. Similarly, there are also times when upward revisions would have meant that the Authority could have theoretically withdrawn additional amounts. The Authority and the USGS Tampa office staff have continued to work to reduce such instances to the greatest possible extent.

- Comparisons of the annual average hydrographs of total gaged flows upstream of the Facility with and without withdrawals indicate very small seasonal differences regardless of the time period tested. The magnitude of these differences is especially small given the fairly large degree of natural variability in flow inherent both among years and over longer decadal periods.

4.0 Salinity in the Lower Peace River/Upper Charlotte Harbor Estuarine System

The primary objectives of this section are to provide overviews and analyses of the spatial and temporal patterns and trends in salinity in the lower Peace River/upper Charlotte Harbor estuarine system over the 1976-2016 interval of HBMP monitoring. The relationship between freshwater flows and salinity is examined and statistical salinity models are updated/developed for multiple locations along the HBMP monitoring transect. These models are then used to assess the potential influence of withdrawals on the Lower Peace River/Upper Charlotte Harbor estuarine system.

The following briefly summarizes the different analytical procedures presented in this chapter.

- Graphical and statistical analysis of the patterns and trends in salinity at the four long-term "moving" HBMP isohaline based salinity zones over the period between 1984 and 2016 and at the long-term "fixed" HBMP monitoring stations over the interval from 1976 through 2016.

- The general spatial and temporal variability in observed salinity are summarized, describing differences among the available information from each of the longer term continuous recorder locations. Period-of-record and annual comparison are analyzed to assess the natural expected ranges of salinity variability due to both short-term daily tidal variations as well as much longer seasonal influences under differing flow conditions.

- Updated empirical salinity models are presented using freshwater inflows, stage, and withdrawals data through 2016 from the longer term USGS and HBMP continuous recorder locations, including four stations added since prior models were completed. (Note: tide stage was estimated at the HBMP surface salinity recorders by assessing flow based tidal lags observed among the three USGS recorders, which measure both surface and bottom salinities as well as tide stage).

- Analyses are included summarizing the effectiveness that the Facility's series of water use permits have had in limiting the impacts that freshwater withdrawals have had on the physical/biological resources of the lower Peace River/upper Charlotte Harbor estuarine system.

4.1 HBMP Monitoring Elements for Salinity

Multiple elements of the HBMP provide data on salinity (and/or specific conductivity) along the monitoring transect. These include "moving" isohaline-based monthly water quality monitoring, fixed-station location monthly water quality monitoring, and a series of USGS and Authority owned continuous recorder stations. Each of these monitoring elements is described below.

4.1.1 “Moving” Isohaline-Based Stations

In June 1983, the Environmental Quality Laboratory undertook monthly monitoring of phytoplankton primary productivity and water quality measurements at four salinity-based “moving” isohalines in addition to General Development’s lower Peace River/Charlotte Harbor general background monitoring programs. The selection of the salinity-based sampling zones was originally established on a literature review of known spatial estuarine differences among the major plankton groups.

- Oligohaline Conditions = 0 psu (defined as upstream of 500 us/cm conductivity
- Lower Mesohaline = 5-7 psu
- Upper Mesohaline = 11-13 psu
- Upper Brackish = 20-22 psu

This moving station, salinity-based water quality sampling program element was subsequently added to the HBMP in 1987 in conjunction with other program modifications made during renewal of the water use permit. The monthly moving isohaline based sampling has been included as part of the HBMP since that time. Thus, complete, continuous data are available over the 1983-2016 time interval. The four sampling locations in this study represent non-fixed surface salinity zones, such that the relative monthly spatial location of each isohaline sampling site along the HBMP monitoring transect (Figure 4.1) is largely dependent upon the preceding amounts of Peace River freshwater inflow.

4.1.2 “Fixed” Stations

Historically, between 1976 and 1987, the HBMP water quality monitoring design included the monthly collection of *in situ* physical measurements of water column profile characteristics at a number of fixed station locations along the lower Peace River and in upper Charlotte Harbor. Under the 1996 water use permit’s expansion of the monitoring program, monthly surface and bottom water chemistry data collections were initiated at five of the previous fixed sampling locations along an established transect from near the mouth of the river to upstream of the Facility. In addition to these five water quality monitoring sites, i*n situ* physical water column profile sampling was also resumed at an additional ten fixed sampling locations. These water quality sampling and *in situ* water column profile measurements of the HBMP program elements were undertaken using sampling sites formerly (1976-1990) utilized by General Development’s Environmental Quality Laboratory (EQL) as part of their long-term Peace River/Charlotte Harbor background monitoring program. An additional fixed monthly sampling site was added in 1998 to correspond to the location of the third USGS tide gage that was installed in 1997 at river kilometer (RK) 26.7. The relative locations of these fixed sampling locations are shown in Figure 4.1, and **Table 1.2** provided both the currently used river kilometer centerline designations as well as both the previously used EQL station numbers and USGS sample river mile designations.

Combining the historic EQL background and older HBMP water quality monitoring data with the more recent HBMP monitoring information gathered since 1996 provides both physical *in situ* water column profile information and sub-surface and near-bottom water chemistry data for the complete periods 1976-1989 and 1996-2016 at the five current fixed HBMP water quality sampling locations. These combined data are used in this Chapter to describe the present status as well as test for the presence of long-term changes in salinity/conductivity at these specific selected locations along the lower Peace River HBMP monitoring transect (Figure 4.1). Other water quality parameters are addressed in **Section 5**.

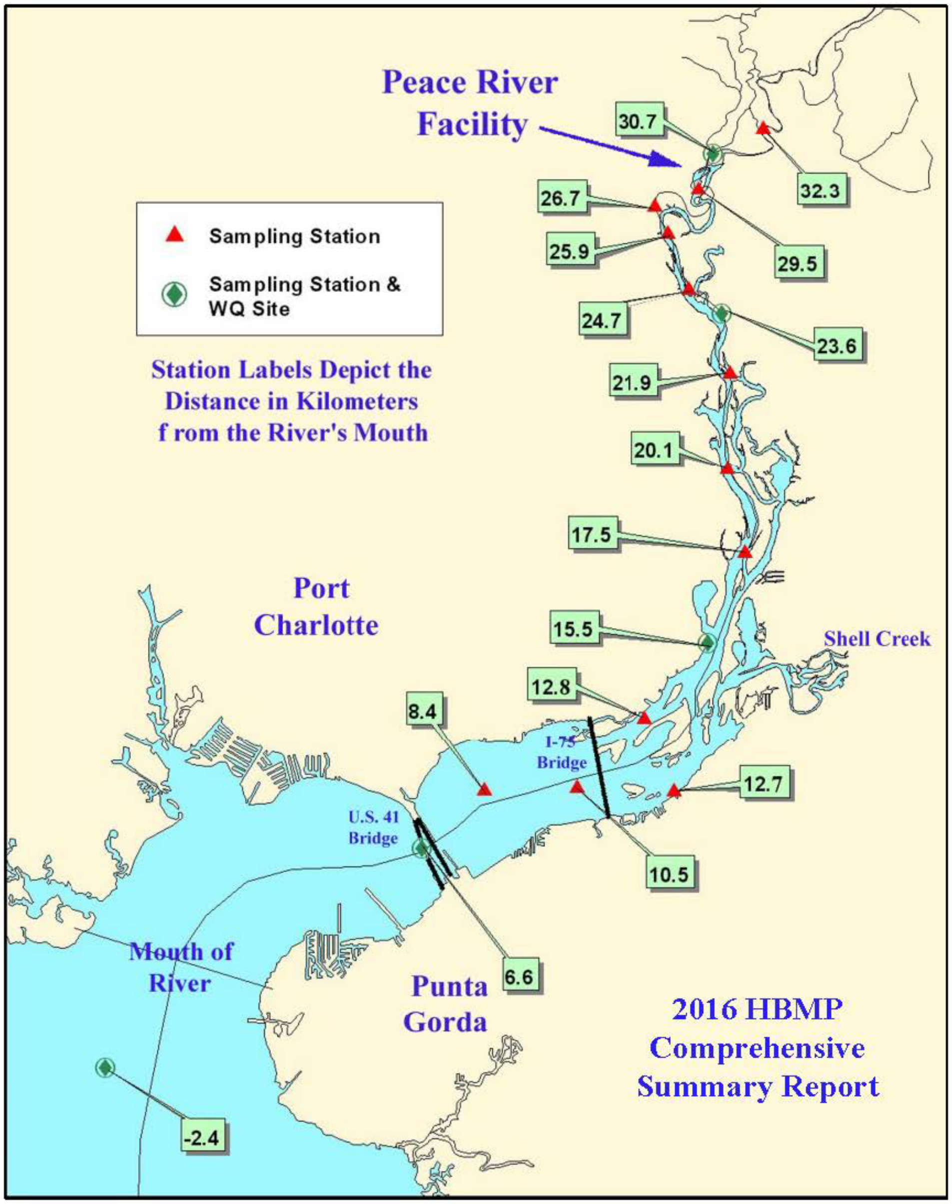

Figure 4.1 HBMP monitoring transect showing fixed-station locations

4.1.3 Continuous Recorder Stations

During the 1996 permit renewal, the need was identified to begin collecting salinity data at fixed points along the HBMP monitoring transect at much greater frequencies than the ongoing monthly monitoring. The availability of such data was expected to provide information for the development of refined statistical and/or new mechanistic models that would allow increased accuracy in assessing the relative magnitudes of short and longer-term salinity changes due to permitted Facility withdrawals. Such changes were expected to result from the interactions and combined influences of natural variations in flows and tides, as well as seasonally varying withdrawals. Two initial recorders were established by USGS to measure both near-surface and near-bottom salinities at 15-minute intervals in the late 1990s under an existing long-term contract with the Authority. Responding to comments and specific recommendations from the HBMP Scientific Review Panel, the Authority subsequently deployed three additional continuous floating, surface salinity recorders in December of 2005, two additional similar recorders again in May 2008, and recently three more recorders at the end of June 2011. In December 2009, USGS installed its third pair of near surface and near bottom continuous recorders immediately adjacent to the Facility’s river intake structure. Since provisional data from these USGS recorders are directly uploaded to the internet, they further provide the Authority with the ability to assess variations in river conductance in real time at both the downstream recorders and Facility under natural variations in flow and tide. The relative spatial distribution of the locations of the existing USGS/HBMP recorder array along the lower Peace River monitoring transect is depicted in Figure 4.2 and further summarized in Table 4.1.

Table 4.1

Summary of HBMP 2016 Array of Continuous Recorders on the Peace River

Gage ID, Location	From to Present (Unless noted)	River Kilometer
RK09 (Authority) – Navigation Marker south of I75 Bridge	Jun. 2011	RK 09.2
RK12 (Authority) - Manatee Zone Marker near Shell Creek (bottom)	May 2008 to Jun. 2011	RK 12.7
RK12 (Authority) - Manatee Zone Marker near Shell Creek (surface)	Jun. 2011	RK 12.7
HH (USGS - 02297460) – Dock at Harbour Heights *	Sep. 1996	RK 15.5
RK18 (Authority) – Channel Marker in Area of Power Lines	Jun. 2011	RK 18.5
RK18_HC (Authority) - Manatee Zone Marker on Hunter Creek	Jun. 2011	RK 18.7
RK20 (Authority) – Channel Marker downstream of Island	Jun. 2011	RK 20.8
RK21 (Authority) - Manatee Zone Marker near Liverpool area	Dec. 2005	RK 21.9
RK23 (Authority) - Manatee Zone Marker below Navigator Marina	Dec. 2005 to May 2008	RK 23.4
RK24 (Authority) - Manatee Zone Marker gage near Navigator Marina	Dec. 2005	RK 24.5
PRH (USGS - 02297350) – Dock at Peace River Heights gage *	Nov. 1997	RK 26.7
PRP (USGS – 02297345) – Peace River at Platt (Facility) *	Dec. 2009	RK 29.8
RK30 (Authority) - Manatee Zone Marker near SR 761 Bridge	May 2008 to June 2011	RK 30.6
RK31 (Authority) - Old Railroad Bridge upstream of Facility	May 2008	RK 31.7

* USGS Recorders measure near-surface and near-bottom salinities at fixed depths (while HBMP recorders measure sub-surface using floating recorders in stilling wells)

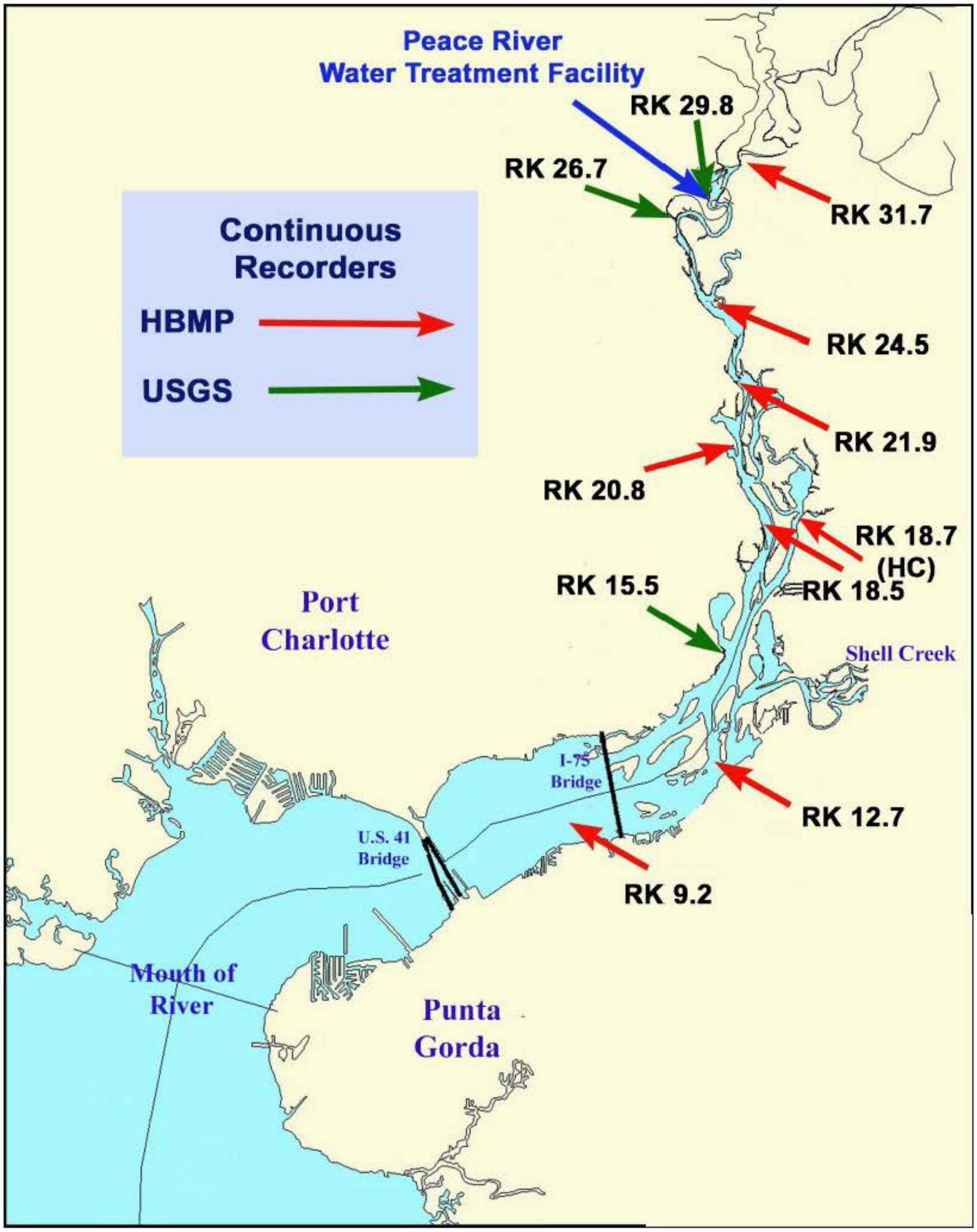

Figure 4.2 Locations of USGS and HBMP continuous recorders in 2016

4.1.3.1 USGS Recorders

The USGS began a cooperative water quality data collection program with the Authority in August 1996. An initial USGS continuous recorder (15-minute intervals) was installed later that month in the lower Peace River (**Figure 4.2**) at the end of an existing private dock at Harbour Heights (RK 15.5). This USGS gaging site (02297460) monitors water level, subsurface and near bottom specific conductance, and temperature.

The following month (September 1996) USGS installed an additional 15-minute recorder, which measured only water level at a site adjacent to Boca Grande. This site was located approximately near River Kilometer –31.8, and designated by USGS as 02293332. Tide stage data were collected by USGS for the Authority at this location between 1996 and 2004. The original purpose of this gage was to assess potential gradual increases in sea level. Rising sea level that might be expected to occur over time would subsequently result in natural increases in salinity in the tidal lower Peace River estuary. USGS staff however at a later date felt that any conclusions regarding sea level rises at this site would probably be compromised due to the gage's location near the mouth of the Boca Grande Pass. The Authority (after consultation with the Scientific Review Panel and District staff) decided to delete the continued collection of water level information at this location at the end of 2004.

The USGS added a second continuous conductivity recorder further upstream in the lower Peace River (RK 26.7) on a private dock near Peace River Heights (Figure 4.2) at the Authority's request in November 1997. This USGS site (02297350) also measures water level, near-surface and near-bottom specific conductance, and corresponding temperatures at 15-minute intervals. More recently, in December 2009, USGS installed near-surface and near-bottom recorders (02297345) at the Facility's intake (RK 29.8) near Platt.

Water level measurements at the two original USGS recording sites were initially made utilizing a floating sensor in a PVC stilling well for near surface measurements and a fixed sensor near the bottom of the water column for near bottom measurements. USGS combination temperature and specific conductance probes have been used to measure near-surface and near-bottom specific conductance and temperature. Readings are electronically averaged over two-minute intervals and recorded at 15-minute intervals using a Campbell Scientific CR-10 electronic data logger. Data are retrieved and the sensors recalibrated at approximately monthly intervals.

The near-surface sensors at the two original gaging sites were initially suspended one-foot below the surface using a float, while the near-bottom sensors were suspended about one-foot from the bottom in the same stilling well. However, following damage caused by Hurricane Charlie (August 2004), the Harbour Heights gage (02297460) was rebuilt on January 11, 2005. The upper sensor was set at a fixed depth (0.40 ft below NGVD 1929) below the water surface to measure the near-surface specific conductance and temperature and the lower sensor was fixed (3.5 ft below NGVD 1929) near the bottom. The sensors were subsequently lowered to a new elevation on Nov 21, 2006. The upper sensor was set at a fixed depth (1.40 below NGVD 1929) and the lower sensor was set at (4.4 ft below NGVD 1929) near the bottom. The Peace River Heights gage was also rebuilt at this time (January 6-7, 2005). The top sensor was set to a fixed elevation approximately 1.3 ft below NGVD 1929 and the bottom sensor at approximately 3.8 ft. below NGVD 1929.

In 2009, using both the extensive data collected before and after these changes, as well as corresponding field measurements made during the monthly "fixed" station monitoring, the Authority completed a series of statistical comparisons to determine if these changes in depth resulted in meaningful systematic differences in the measured data. The results of these analyses concluded that no such changes could be detected.

The USGS continuous recorders located at the Facility's river intake structure were installed in December 2009. The bottom YSI-600R water quality sensor is located inside 3 inch diameter pipe attached to the stilling well to record near bottom measurements (approximately 12.8 ft below NGVD 88). The top YSI-600R water quality sensor is located in a 2 ft section of 3 inch diameter PVC pipe attached to a float. This floating sonde system is attached to two guide cables that are fastened to both a bracket at the top of a 16 inch aluminum stilling well and to two eyebolts in the bottom. The float keeps the water quality sensor approximately 1.5 ft. from the water surface at all gage heights.

The particular locations of the USGS recorders on existing docks and structures were established in part due to the USGS's need to be able to have land-based access for the ease of routine maintenance and the downloading of data. The influences of tide, wind and antecedent flow conditions can individually and in combination result in extremely wide ranges of observed variation in daily averaged conductivity measurements. Installing the USGS recorder at the intake structure (RK 29.8) has provided the Authority with a far clearer real time view of tidal influences on the upstream movement of higher salinity waters, especially under prolonged low flow conditions. In addition, the USGS Peace River Heights and Platt recorders provide Facility staff the opportunity to closely follow tidal variations in conductivity near the low flow cutoff 130 cfs threshold and prevent adding higher conductivity water to the off-stream storage reservoirs.

4.1.3.2 Authority HBMP Recorders

The *2002 HBMP Comprehensive Report* (finalized in September 2004) recommended that an additional series of continuous conductivity gages be established by the Authority downstream of the USGS Peace River Heights recorder location. The primary objective of installing an additional series of HBMP continuous conductivity recorders, when combined with the existing long-term USGS sites, was to obtain greater resolution of the direct relationships among freshwater flow, stage height, and conductivity downstream of the Facility during periods of withdrawals. The addition of these gages was specifically designed to determine potential salinity changes during Facility withdrawals within the reach of the river characterized by the movement of the freshwater/saltwater interface at flows primarily above the 130 cfs threshold. The overall goal of the selected locations for these additional HBMP gages was, therefore, to assure and enhance the monitoring program's ability to directly measure salinity changes due to Facility withdrawals over a wider range of flow conditions.

A number of possible alternative sites and deployment methodologies were evaluated by the Authority to assure that these monitoring objectives were met by the additional HBMP continuous conductivity recorders. The first step in deploying these instruments was to determine the potential spatial distribution of arraying the recorders downstream of the Facility. Again, the primary objective was to spatially maximize the new recorders' ability to detect salinity changes (impacts) that could be directly attributed to Facility freshwater withdrawals. Existing statistical models and graphical analyses of salinity/flow relationships were reviewed from the long-term HBMP fixed stations and USGS continuous recorders along the lower Peace River HBMP monitoring transect. These results were next evaluated in relation to potential existing physical structures (docks, pilings, etc.) to which additional continuous recorders might be attached. A series of potential new monitoring sites located between the existing USGS continuous recorders were selected and evaluated. The placement by U.S. Fish and Wildlife (USFW) of a large number of Manatee Speed Zone markers along the lower river has provided a series of spatially distributed potential sites downstream of the Facility. The Authority received permission from USFW to establish continuous recorders using these markers. Three of these Manatee Speed Zone markers were chosen by the Authority for the initial deployment in December 2005 of HBMP continuous recorders measuring near surface conductivity.

- **RK 21.9** –The Manatee Speed Zone Marker located on the Peace River near the Liverpool side channel.
- **RK 23.4 –** The Manatee Speed Zone Marker located on the Peace River downstream of Navigator Marina.
- **RK 24.5 –** The Manatee Speed Zone Marker located on the Peace River just across from Navigator Marina (RK 24.5).

Based on comments and recommendations made by members of the HBMP Scientific Review Panel at its December 2007 meeting, the Authority added three additional continuous recorder locations in May 2008 by relocating the recorder previously at RK 23.4 to RK 31.7 and adding new recorders at RK 12.7 and RK 30.6 to extend upstream and downstream the area along the lower river covered by the continuous recorder array.

- **RK 12.7 –** A recorder was installed downstream of the USGS Harbour Heights gage on a Peace River Manatee Zone Marker (RK 12.7) below the confluence with Shell Creek. Unlike the other HBMP recorders, this instrument was installed near the bottom of the water column (~1.7 meters) and measures conductivity, temperature and dissolved oxygen levels continuously at 15-minute intervals.
- **RK 30.6 –** A recorder was also installed above the USGS Peace River Heights gage on a Manatee Zone Marker (RK 30.6) just upstream of the Facility's intake near the SR 761 Bridge. This recorder measures subsurface conductivity and temperature at 15-minute intervals.
- **RK 31.7 –** The HBMP recorder previously located at RK 23.4 was relocated upstream to the old railroad trestle (RK 31.7) above the Facility. This recorder also measures subsurface conductivity and temperature at 15-minute intervals.

The HBMP Scientific Review Panel met again in December 2010 and recommended the addition of an additional continuous recorder downstream of the I-75 Bridge, and that several new recorders be located between USGS Harbour Heights gage and the HBMP gage near the Liverpool area in order to better define the relationships between salinity and flow in that reach of the lower River. The following changes and additions to the HBMP continuous recorder array were made in June 2011.

- **RK 30.6 –** This recorder located just downstream of the SR 761 Bridge was discontinued since USGS had installed a third gaging location at the Facility intake (RK29.8) just downstream.

- **RK 09.2 –** A new recorder was located on a navigation marker between the I-75 and U.S. 41 Bridges. This recorder also measures subsurface conductivity and temperature at 15-minute intervals.

- **RK 12.7 –** This recorder and all probes (which also measures dissolved oxygen) was moved from the bottom of the water column to the surface so that its values would be comparable with those at the other HBMP recorder sites.

- **RK 18.5 –** A recorder measuring subsurface conductivity and temperature at 15-minute intervals was attached to a channel marker near the Power Line Crossing.

- **RK 18.7_HC –** A new subsurface conductivity and temperature recorder was located on the river's large Hunter Creek side-channel near the connection to Jim Long Lake. Located on a Manatee Zone marker, the objective of this site was to both determine if higher salinity water was moving upstream by way of this side channel and potential influences of ungaged freshwater inflows to this region of the lower river.

- **RK 20.8 –** This recorder was located on the navigation channel marker just downstream of an Island Thirty-Three (oddly named) in the lower river. The recorder measures subsurface conductivity and temperature at 15-minute intervals.

The locations, and period-of-records for each of the HBMP recorders are summarized in Table 4.1 and the current spatial distribution of the recorder array is shown in Figure 4.2. Data from these recorders are retrieved at approximately monthly intervals (or more often as needed during very dry periods when fouling may become an issue at the more downstream sampling sites). A complete cleaned, calibrated and checked replacement set of sondes are typically deployed each month. The sensors are considered calibrated if the temperature is within 0.2 °C and specific conductance is within five percent of the standard values.

4.2 Spatial Patterns in Salinity

This section presents longitudinal gradients in salinity along the Peace River monitoring transect as indicated by fixed-station data, as well as a summary of isohaline locations (river kilometer) as indicated by moving-station data. In general, surface salinity measurements are routinely lower than bottom salinity.

Many of the graphical analyses in this report involve box and whisker plots. A diagram explaining the features of these plots is shown in Figure 4.3. Additionally, notches (which illustrate the confidence interval around the median) have been added to many of the box and whisker plots. The endpoints of the notches are computed as

$$median \pm 1.58 \pm \left(IQR/\sqrt{N}\right)$$

Where IQR is the interquartile range and N is the number of values.

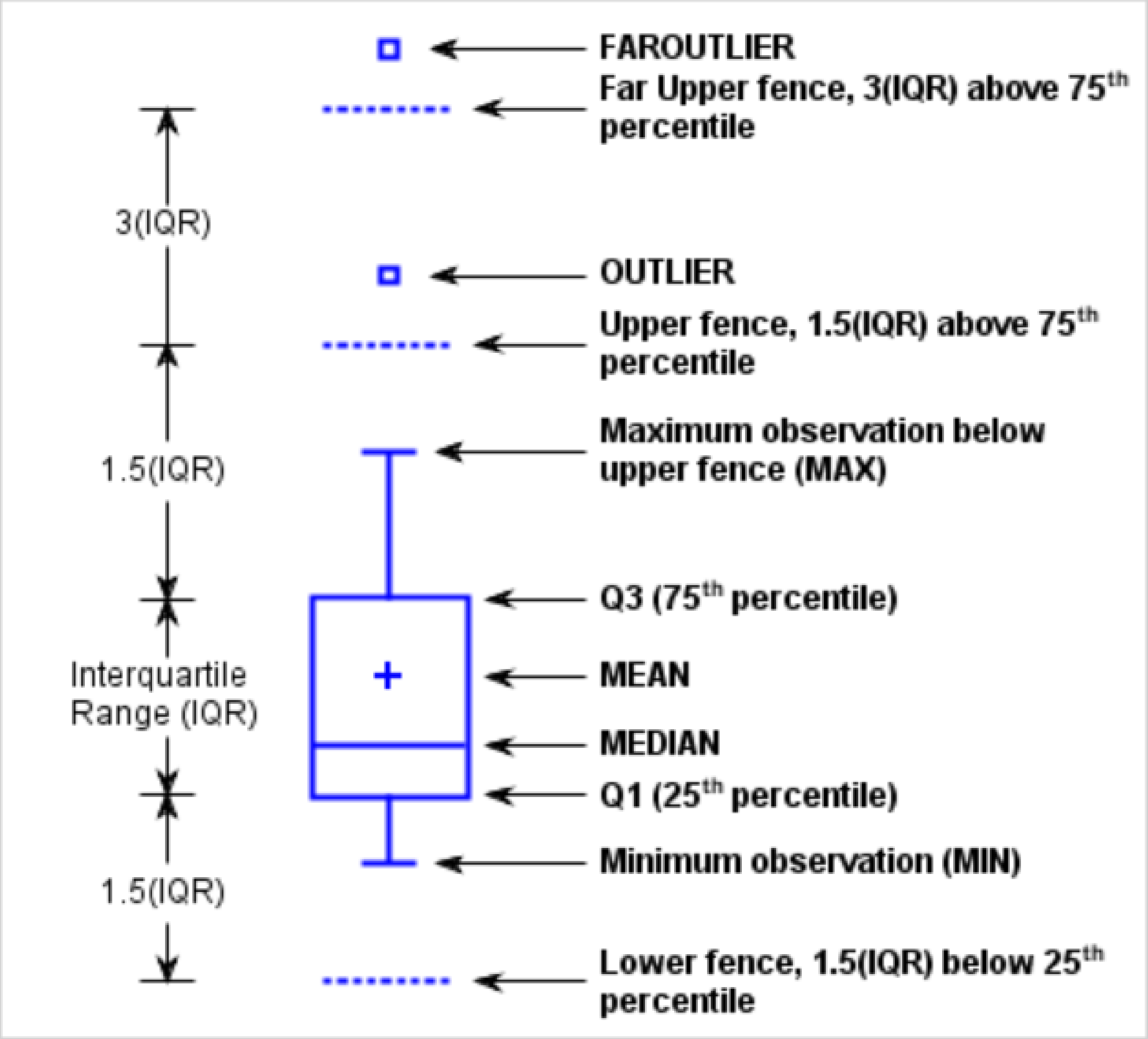

Figure 4.3 Features of a box and whisker plot. Note: the plus (+) has been replaced with other marker symbols (typically a circle) in this report. From SAS SGPLOT Box Plot Documentation.

Figure 4.4 provides box and whisker plots of salinity data sampled at the fixed-station locations. These plots exemplify the strong, distinct spatial salinity gradient along the lower Peace River monitoring transect. Salinity levels are much higher (often near Gulf water conditions) in the vicinity of the river mouth and are typically near freshwater levels just upstream of the Water Treatment Facility. Similar patterns are observed for both surface and bottom salinity levels, though, as expected, average/median salinity values are greater for bottom measurements than those taken at the surface.

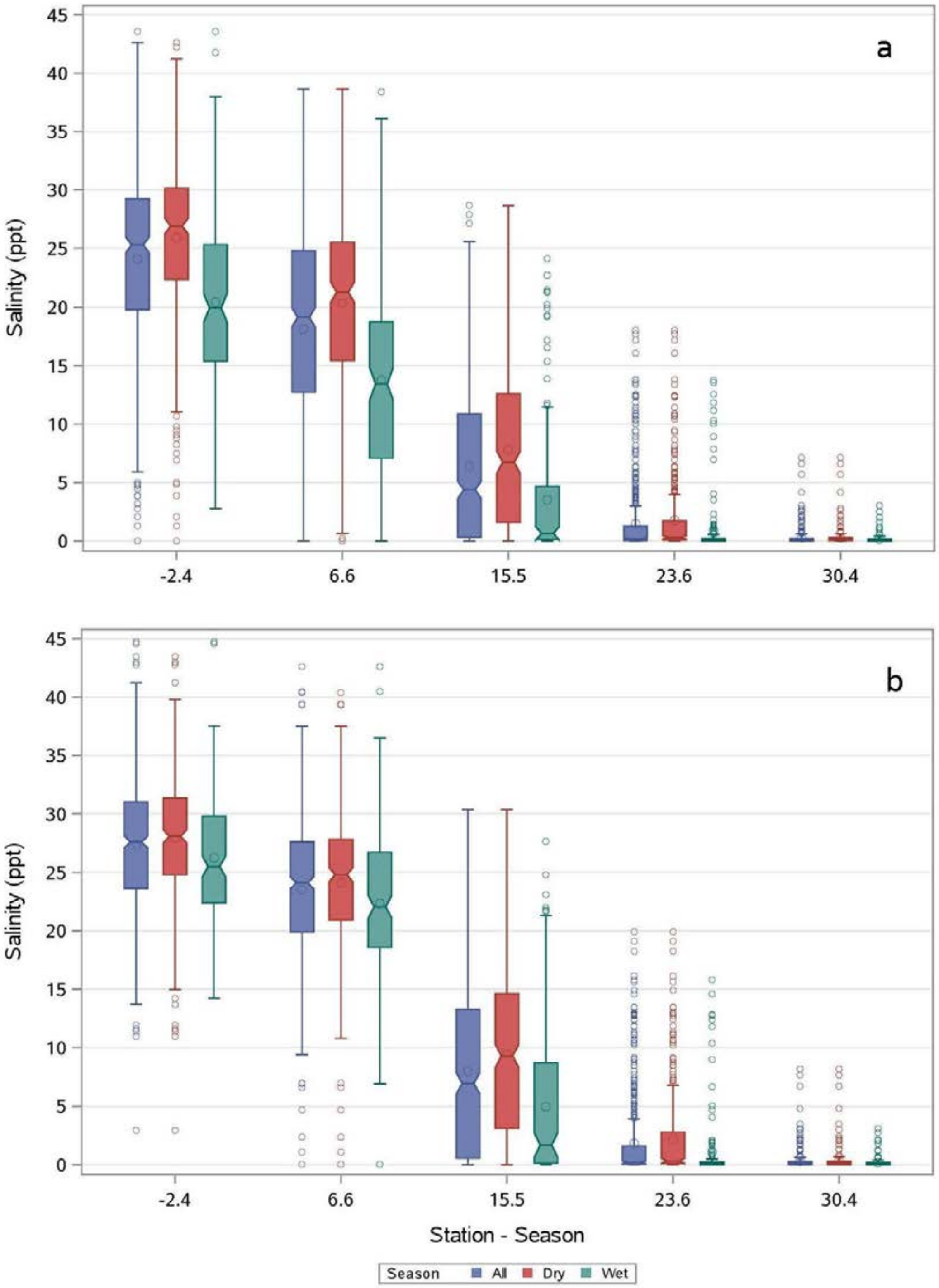

Figure 4.4 Box and whisker plots of a) Surface and b) Bottom salinity measured at fixed-station locations between 1976 and 2016. Boxes represent all data, dry season samples, and wet season samples.

Table 4.2 summarizes the historical statistical distributions of the locations (river kilometer) of the four isohalines along the HBMP Peace River monitoring transect. Figure 4.5 illustrates the historical range, mean and median of river kilometer location for each of the isohalines.

Table 4.2
Summary Statistics of the Four Isohaline Locations (River Kilometers) from the Peace River's Mouth for the Period 1983-2016

Isohaline	Minimum (Downstream)	Maximum (Upstream)	Mean	Median
0 psu	0.6	37.6	23.3	23.3
6 psu	-16.3	30.2	13.3	13.2
12 psu	-30.1	26.3	8.4	9.5
20 psu	-36.3	22.4	1.6	4.8

Note: previous older HBMP reports have used the units "o/oo", however, equivalent practical salinity units (psu) are currently used to distinguish between salinity determined by *in situ* conductivity rather than wet chemistry.

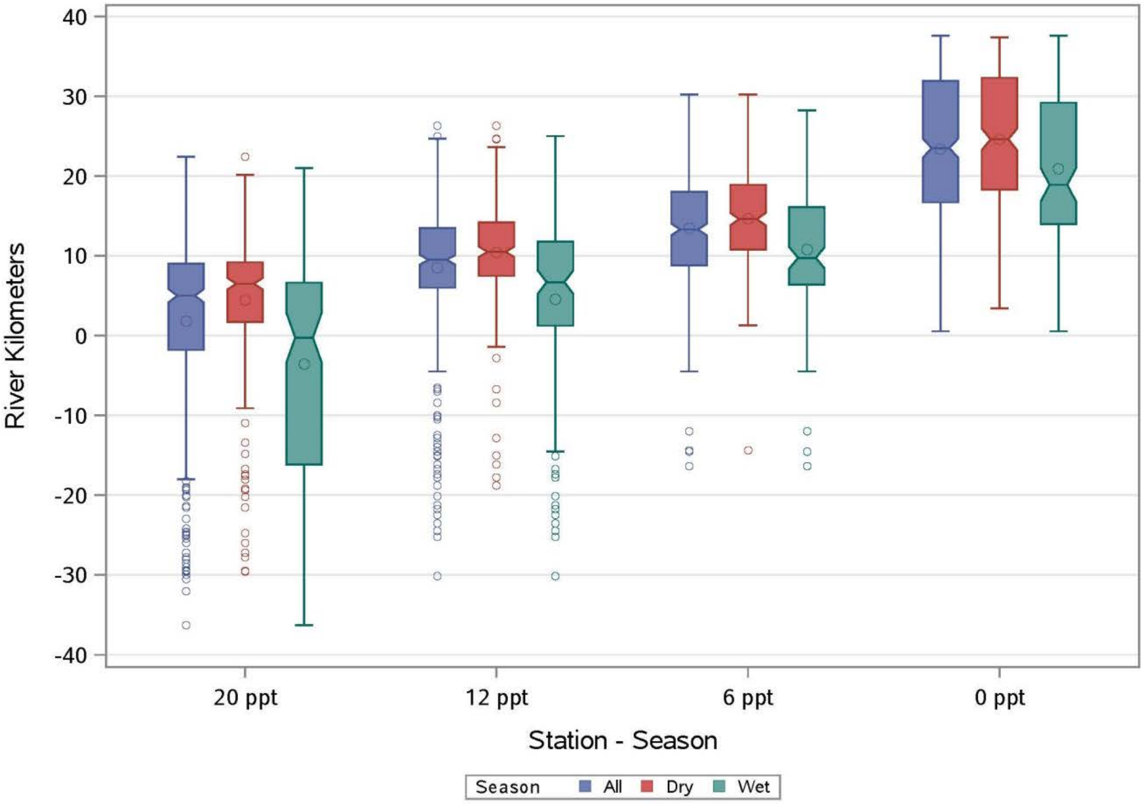

Figure 4.5 Box and whisker plots of isohaline location (river kilometer) of moving-station sampling between 1984 and 2016. Boxes represent all data, dry season samples, and wet season samples.

The Peace River Water Treatment Facility is located at approximately RK 29.9. To date, the most upstream occurrence of the 0 psu isohaline sampling location has been just over a quarter mile upstream of the point where Horse Creek joins the Peace River during June 2000. The most downstream occurrence of the 20 psu isohaline sampling location has been in the Gulf of Mexico just off Boca Grande during September 1988 (**Figure 4.6**).

4.3 Temporal Trends in Salinity

This section presents analyses of patterns and trends in intra-and inter-annual variation in salinity along the Peace River monitoring transect, as well as an investigation of long-term statistical trends in salinity.

4.3.1 Intra- and Inter-Annual Variability

Table 4.3 lists the time-series plots for salinity at each of the five "fixed" HBMP monitoring locations. Uniform vertical graphical scales are applied in Figures 4.7 through Figure 4.16 in order that direct comparisons can be readily made along the HBMP monitoring transect (i.e. time series graphics for salinity are plotted using a scale of 0 to 40 psu for all five fixed sampling locations).

Table 4.3
Monthly Time-Series Plots of Salinity at "Fixed" HBMP Stations

	River Kilometer -2.4	River Kilometer 6.6	River Kilometer 15.5	River Kilometer 23.6	River Kilometer 30.7
Surface Salinity	Figure 4.7	Figure 4.9	Figure 4.11	Figure 4.13	Figure 4.15
Bottom Salinity	Figure 4.8	Figure 4.10	Figure 4.12	Figure 4.14	Figure 4.16

Note: no data available 1990-1995.

The greatest inter-annual variability in salinity generally occurs in the surface waters at the most downstream monitoring sites where seasonal differences may reach 35 parts per thousand between extended periods of low and high freshwater inflow. However, even bottom salinity levels in the area of the US 41 Bridge (RK 6.6) exhibit similar large inter-annual variation. The influences of the high freshwater inflows during 1997/1998 El Niño event and the extended periods of lower flows during the 1999-2001 and 2006-2011droughts are evident in the time-series plots.

Box and whisker plots showing the relative locations (river kilometer) by year of each of the four monitored "moving" isohaline HBMP salinity zones are presented in Table 4.4. Corresponding box and whisker plots depicting the monthly variability of each of these salinity zones are also included in the table. These figures clearly indicate the large degree of both inter-and intra-annual variability that has occurred in the relative locations of the monitored isohalines along the established lower Peace River/upper Charlotte Harbor river kilometer transect. As shown above in Table 4.2, seasonal and long-term extreme variations in estuarine freshwater inflows have resulted in variations as much as 35 to 55 kilometers in the relative spatial distributions of the four isohalines.

Table 4.4
Inter- and Intra-Annual Variability of the Location of Estuarine Isohaline Zones

Isohaline	Box Plot of Inter-Annual Variability	Box Plot of Intra-Annual Variability
0 psu Salinity - First Upstream Occurrence	Figure 4.17	Figure 4.21
6 psu Salinity – First Downstream Occurrence	Figure 4.18	Figure 4.22
12 psu Salinity – First Downstream Occurrence	Figure 4.19	Figure 4.23
20 psu Salinity – First Downstream Occurrence	Figure 4.20	Figure 4.24

Continuous recorder data allow an examination of finer scale temporal patterns in salinity, including daily ranges. Salinity data have been recorded over periods up to fifteen years at two USGS longer term continuous recorders, which were installed in the late 1990s. Thus comparisons between the USGS Harbour Heights and Peace River Heights recorders provide an excellent basis for assessing the typical relative magnitude of salinity variability over a large portion (river kilometers 15.5 to 26.7) of the spatial extent of the current HBMP recorder array (Figure 4.2). Given the shorter periods of record for the most recently installed USGS gage, and those monitored by the Authority, these two USGS gages were used to make long term comparisons. The time interval captured by these gages is wide enough to fully characterize the normal range of variations in flows that characterize both extended wet and dry conditions. The two gages also allow an examination of the relative magnitudes of spatial and temporal variability along the lower Peace River recorder array during wetter and dryer time periods.

The continuous recorder data indicate that a specific location in the Peace River might see as much variation in salinity as it might also see in a given month or year. Table 4.5 provides summary comparative statistics (mean, median, minimum and maximum) of gage height, and surface and bottom salinities at the USGS continuous recorder at Harbour Heights (RK 15.5) and further upstream at Peace River Heights (RK 26.7) over the longer term 2000-2016 time interval. **Table 4.6** by contrast provides similar statistical comparisons between these two long-term gages annually over their periods-of-record. Minimum annual surface salinities at both sites were always near zero.

Table 4.5
Summary Statistics of Gage Height (Water Level) and Surface and Bottom Salinities over 2000-2016 Time Interval at the Two Longest Term USGS Continuous Recorders

	USGS Harbour Heights Gage (RK 15.5)			USGS Peace River Heights Gage (RK 26.7)		
Variable	Average	Minimum	Maximum	Average	Minimum	Maximum
Mean Gage Height	0.86	-1.51	3.69	0.90	-1.72	5.93
Median Gage Height	0.92	-1.59	3.82	0.95	-1.82	5.94
Daily Range Gage Height	2.18	0.00	5.15	2.12	0.12	4.81
Mean Surface Salinity	7.4	0.1	25.8	1.0	0.0	14.7
Median Surface Salinity	7.2	0.0	25.7	0.9	0.0	14.5
Daily Range in Surface Salinity	5.7	0.0	18.8	1.3	0.0	20.5

Table 4.5
Summary Statistics of Gage Height (Water Level) and Surface and Bottom Salinities over 2000-2016 Time Interval at the Two Longest Term USGS Continuous Recorders

Variable	USGS Harbour Heights Gage (RK 15.5)			USGS Peace River Heights Gage (RK 26.7)		
	Average	Minimum	Maximum	Average	Minimum	Maximum
Mean Bottom Salinity	7.7	0.1	26.8	1.0	0.0	15.1
Median Bottom Salinity	7.5	0.0	27.2	0.9	0.0	15.0
Daily Range in Bottom Salinity	6.1	0.0	18.3	1.3	0.0	19.2

The following summarizes some of the observed differences and patterns shown by the data presented in Tables 4.5 and 4.6 that compare the variability in measurements taken at these two sites along the lower Peace River HBMP monitoring transect.

- Minimum and maximum gage heights (water levels) indicate that the extremes between the highest and lowest annual levels can be as great as six to eight feet. Actual daily differences however are typically far lower. Differences between daily high and low water levels over the period between 2000 and 2016 at Harbour Heights averaged only 2.18 feet, while the greatest measured daily difference over the same period was 5.15 feet.

- Annual mean and median gage heights at the downstream Harbour Heights recorder are much more uniform than corresponding measurements upstream at the Peace River Heights location (**Table 4.6**). The results indicate that water levels further upstream are much more heavily influenced by higher flows during wet years, such as occurred during the interval between 2003 and 2005, than are corresponding measured gage heights further downstream. The implications of such observations are that seasonal differences in gage height need to be taken into account when developing statistical salinity models that rely on the interactions of flows and gage height (see Section 4.4.2). Higher gage heights during low river flows result in salinity tidally moving upstream, while higher gage heights with increasing flows reflect the combined influences of tide and the increasing resistance to downstream flow.

- Mean and median annual salinities at both USGS recorders were much higher during the extended 1999-2001 and more recent droughts. The largest relative observed differences were in the maximum salinities measured at the Peace River Heights site. Peak salinities measured at this upstream site during the drought years were at least four to six times higher than the maximum annual salinity levels observed during wetter years.

- Bottom salinity measurements were systematically higher than corresponding surface measurements, and as expected the differences were greater at the downstream Harbour Heights recorder location.

Table 4.7 provides similar statistical summary comparisons of surface salinities among the continuous recorders (USGS and HBMP) during both 2007 (a very dry year) and 2010 (a year with fairly typical rainfall). As expected, the average daily range in salinity progressively declines moving upstream. Somewhat surprising are the relatively large daily changes in surface salinities that can occur even well upstream given the right combinations of river flow, tides and wind.

Table 4.7
Seasonal and Daily Ranges of Surface Salinity at the USGS and Authority HBMP Continuous Recorders with a Complete Year of Data

Location	Annual Salinity Statistics				Daily Change (Δ) in Salinity			
	Mean Salinity (psu)	Median Salinity (psu)	Minimum Salinity (psu)	Maximum Salinity (psu)	Mean Salinity Change (psu)	Median Salinity Change (psu)	Minimum Salinity Change (psu)	Maximum Salinity Change (psu)
2007 – Drought Seasonal Rainfall Conditions								
USGS RK 15.5 Harbour Heights	13.1	13.6	0.5	30.6	13.0	8.0	2.3	15.8
HBMP RK 21.9	5.1	4.0	0.2	23.3	5.8	5.0	0.1	17.7
HBMP RK 23.4	3.9	2.6	0.2	25.1	5.0	3.7	0.0	21.5
HBMP RK 24.5	3.1	1.5	0.2	23.8	4.5	3.0	0.0	20.8
USGS RK 26.7 Peace River Heights	1.7	0.5	0.2	22.2	2.8	1.5	0.0	20.5
2010 – Generally Typical Seasonal Rainfall								
USGS RK 15.5 Harbour Heights	4.6	3.0	0.1	19.5	4.5	4.3	0.0	15.9
HBMP RK 21.9	1.0	0.3	0.1	11.5	0.9	0.9	0.0	9.8
HBMP RK 24.5	0.5	0.3	0.1	7.8	0.5	0.4	0.0	7.1
USGS RK 26.7 Peace River Heights	0.3	0.2	0.1	4.9	0.3	0.3	0.0	4.5
USGS RK29.8 at Facility	0.2	0.2	0.1	0.4	0.2	0.2	0.0	0.1
HBMP RK 30.6	0.2	0.2	0.1	0.7	0.2	0.2	0.0	0.3
HBMP RK 31.7	0.2	0.2	0.1	0.5	0.2	0.2	0.0	0.1

Further comparisons of the measured degree of annual variability in surface salinities along the HBMP monitoring transect are indicated by the series of box and whisker univariate plots presented blow. The general form of the information presented in these plots is as depicted in Figure 4.3. The "box" shows the range of annual values falling between the 25th and 75th percentiles, while the "whiskers" show the range from the minimum to the maximum values observed each year. Statistically rare events, those more than 1.5 times the range of the "box" are shown as individual points along the whiskers. These graphics further show annual means for surface salinities at each of the recorder locations by the addition of colored dots.

Comparative plots are included for the following series of years. Only those recorder locations with a complete year of data are included in each of these graphics. Plots for 2006-2010 were provided in the *2011 Comprehensive Summary Report* (Atkins 2013).

- 2011 – **Figure 4.25**
- 2012 – **Figure 4.26**
- 2013 – **Figure 4.27**
- 2014 – **Figure 4.28**
- 2015 – **Figure 4.29**
- 2016 – **Figure 4.30**

4.3.2 Statistical Analysis of Temporal Trends

Table 4.8 provides the results of tests for statistically significant changes in seasonally based mean annual salinity for these fixed lower Peace River sampling locations. Because of the gap in sampling from 1990-1995, a typical trend test (such as seasonal Kendall tau) is not valid. Therefore, to examine long-term changes at the fixed-stations, analyses were performed using methods developed by Coastal Environmental (1996) for the Florida Department of Environmental Protection using seasonally weighted yearly averages. In this instance the procedure was used to examine statistical differences between the two (1976-1989 and 1996-2016) disjunct periods of record. Details of these analyses are provided in **Appendix C** (including other water quality parameters discussed in **Section 5**). Individually scaled graphics by monitoring location are presented in Figure 4.24 through 4.33, which depict the results of seasonally based statistical tests for differences between the 1976-1989 and 1996-2016 time intervals.

Table 4.8
Tests for Differences between Periods
Peace River HBMP Estuary Sites Water Quality (1976-1989 and 1996-2016)

River Kilometer Parameter	Subsurface Values			
	Difference Test	Diff. Means	P Value of Diff.	Change
River Kilometer –2.4				
Salinity (Surface)	**Figure 4.31**	2.79	**0.000**	▲
Salinity (Bottom)	**Figure 4.32**	3.51	**0.000**	▲
River Kilometer 6.6				
Salinity (Surface)	**Figure 4.33**	1.23	0.112	
Salinity (Bottom)	**Figure 4.34**	2.73	**0.000**	▲
River Kilometer 15.5				
Salinity (Surface)	**Figure 4.35**	1.49	**0.022**	▲

Table 4.8
Tests for Differences between Periods
Peace River HBMP Estuary Sites Water Quality (1976-1989 and 1996-2016)

River Kilometer Parameter	**Subsurface Values**			
	Difference Test	**Diff. Means**	**P Value of Diff.**	**Change**
Salinity (Bottom)	**Figure 4.36**	1.86	**0.009**	▲
River Kilometer 23.6				
Salinity (Surface)	**Figure 4.37**	0.70	**0.019**	▲
Salinity (Bottom)	**Figure 4.38**	0.73	**0.040**	▲
River Kilometer 30.7				
Salinity (Surface)	**Figure 4.39**	0.24	**0.000**	▲
Salinity (Bottom)	**Figure 4.40**	0.26	**0.000**	▲

* Red ▼ denotes significance at the 0.05 level
* Blue ▼ denotes significance at the 0.10 level

The graphical and statistical analyses show that as a result of the extended periods of low flows during the droughts, both surface and bottom salinities were almost uniformly significantly higher during the 1996-2016 interval than between the 1976-1989 sampling period (on a seasonally averaged annual basis) along the entire lower river/upper harbor HBMP monitoring transect. These results further emphasize the profound influence of the recent intense seasonal drought conditions, especially since average annual freshwater inflows during the same recent sixteen year period have on average not been significantly different (see **Appendix C**). Alternatively, these differences may also in part reflect the very small changes in sea level that have occurred between the two time intervals.

The Coastal Environmental (1996) method of testing seasonally adjusted annual averages and the monthly Seasonal Kendall Tau statistical procedure (see complete description in **Section 3.2.3**) were both used to test for potential trends in the locations of each of the four monitored "moving" isohaline-based HBMP monitored salinity zones between 1984 and 2016. Summary results of these trend analyses are presented Table 4.9.

(Note: The presented time-series plots for the moving isohaline-based salinity zones start in June 1983 coinciding with the beginning of monitoring, while January 1984 was used as the starting point for all statistical trend analyses. The initial six months in 1983 were not included in order to incorporate twelve months of data having equal numbers of seasons within each of the subsequent twenty-eight years analyzed.)

Table 4.9
Trend Tests of Isohaline Locations 1984-2016

Salinity-Based Isohaline Location	Seasonally Adjusted Annual Means			Seasonal Kendall Tau of Monthly Means			
	Monthly Mean	Slope	P Value	Tau Value	Un- Adj. P	Adjusted P	Slope
0 psu Salinity - First Upstream Occurrence	**Figure 4.41**	0.23	**0.010**	0.18	0.000	**0.037**	0.200
6 psu Salinity – First Downstream Occurrence	**Figure 4.42**	0.09	**0.000**	0.09	0.009	0.227	0.079
12 psu Salinity – First Downstream Occurrence	**Figure 4.43**	0.10	**0.000**	0.11	0.002	0.171	0.879
20 psu Salinity – First Downstream Occurrence	**Figure 4.44**	0.18	**0.000**	0.17	0.000	**0.044**	0.153

* **Red** denotes significance at the 0.05 level
** **Blue** denotes significance at the 0.10 level

The results of the trend tests using the Coastal Environmental seasonally adjusted annual means method indicated statistically significant progressive increasing upstream movements in the relative spatial distributions of all four isohaline locations along the HBMP monitoring transect between 1984 and 2016. The somewhat more conservative Seasonal Kendall Tau procedure indicated that while all four isohalines showed upstream movements, only those of the 0 and 20 psu isohalines were statistically significant. Analyses completed as part of the *2011 HBMP Comprehensive Summary Report* yielded similar results. Both the extended 1999-2001 and 2006-2011 droughts affected rainfalls and river flows throughout southwest Florida. The influences of these droughts are evident in the observed changes in the relative locations of the HBMP isohalines. The relative overall degree of upstream movement of the freshwater/saltwater interface (0 psu) during these two droughts is especially noticeable in Figure 4.41.

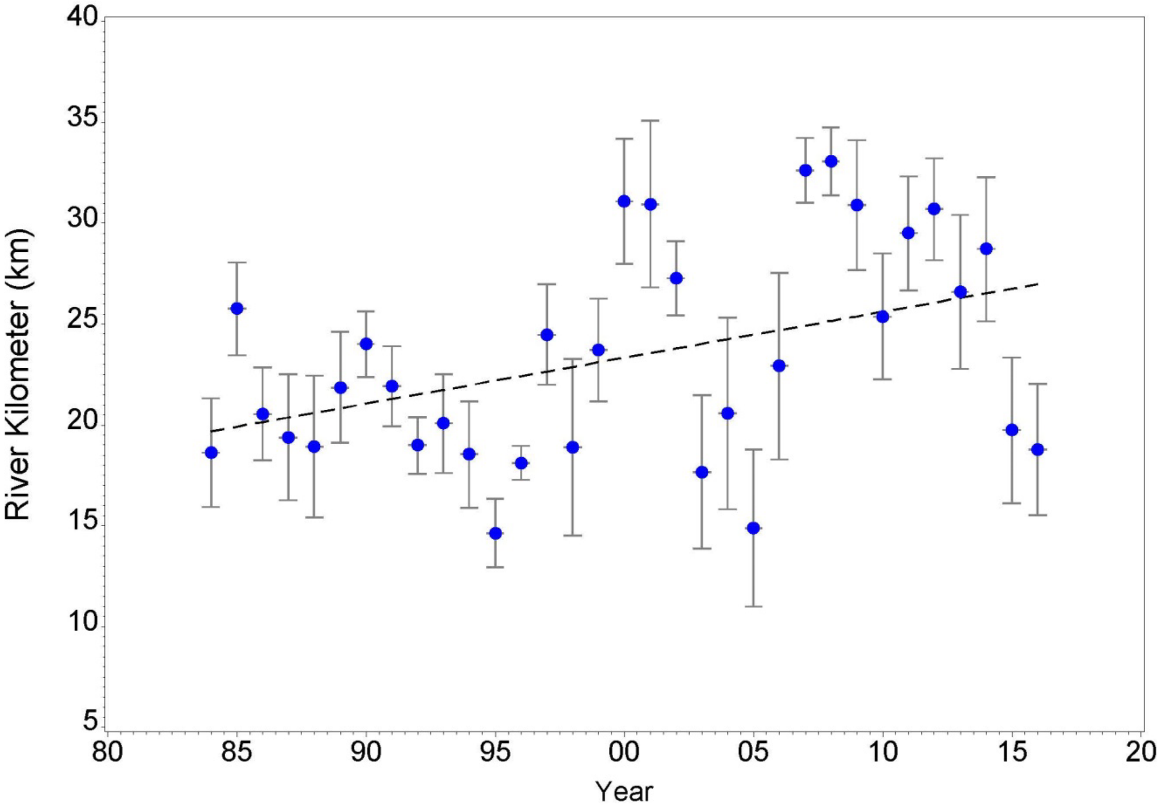

Figure 4.41 Mean (blue dots) and 95% confidence limits (grey bars) of 0 psu isohaline locations within each year (1984-2016)

4.4 Flow-Salinity Relationships

This section presents various analyses conducted using isohaline-based and fixed station sampling data, as well as data from the USGS and Authority continuous recorders to examine the relationship between salinity (or conductivity) and gaged flows.

4.4.1 Graphical and Correlation Analyses

Plots of sub-surface measurements of salinity versus the preceding seven-day average combined gaged flow upstream of the Facility (0 to 3000 cfs) are presented in Table 4.10. These graphical analyses provide additional support to the previously described responses of salinity to seasonal changes in freshwater inflow at each of the fixed sampling locations along the long-term HBMP monitoring transect.

Table 4.10
Relationships between Salinity and Freshwater Inflow

Water Quality Parameter	**Monitoring Station River Kilometer**				
	-2.4	**6.6**	**15.5**	**23.6**	**30.7**
Salinity (surface)	**Figure 4.45**	**Figure 4.46**	**Figure 4.47**	**Figure 4.48**	**Figure 4.49**
Salinity (Bottom)	**Figure 4.50**	**Figure 4.51**	**Figure 4.52**	**Figure 4.53**	**Figure 4.54**

Plots of the isohaline location for each of the four HBMP isohalines versus combined gaged flow upstream of the Facility (0 to 3000 cfs) are presented in Table 4.11. These analyses provide further support for the previously described response to seasonal changes in freshwater inflow at each of the salinity based sampling locations. As these figures indicate, large degrees of variation often occur at a given flow depending on the history of flows over both the immediate and longer-term preceding periods.

Table 4.11
Isohaline Sampling Location Versus Flow

Water Quality Parameter	**Estuarine Isohaline**			
	0 psu	**6 psu**	**12 psu**	**20 psu**
River Kilometer	**Figure 4.55**	**Figure 4.56**	**Figure 4.57**	**Figure 4.58**

Box and whisker graphical plots were used to depict spatial variations under different flow regimes of ambient salinity at each of the five fixed HBMP Peace River monitoring locations. These plots were compared by river kilometer among the sampling sites under a series of percentile flow based ranges of the preceding seven day average gaged flow (as measured by the three USGS gaging sites which combined contribute to the estimate of flow upstream of the Facility). Additionally, similar box and whisker plots were created to depict the spatial location of the four isohalines monitored by the moving station sampling under differing flow conditions. Flows were divided into the following series of categories based on percentiles relative to the long-term (1976-2016) record of HBMP monitoring. Note: Q values (percent exceedance) are equal to P values (percentiles) subtracted from 100.

- **Very Low Flows** (0 to 106 cfs) – representative of the lowest ten percent (P10) of river flows during the 1976-2016 time period;
- **Low Flows** (106-192 cfs) – or flows within the P10 to P25 interval;
- **Normal Low Flows** (192-477 cfs) – or flows characteristic of the long-term P25 to P50 (median) range;
- **Normal High Flows** (477 to 1,259 cfs) – representative of Peace River Arcadia flows within the P50 (median) to P75 statistical interval;
- **High Flows** (1259 to 3,063 cfs) – characterizing river flows in the P75 to P90 range.

- **Very High Flows** (above 3,063 cfs) – or the upper ten percent (P90) of all observed flows during the 1976-2016 time period; and
- **All Flows –** this final series of box and whisker plots depicts the overall spatial differences and the range of observed variation in each of the water quality parameters without regard to flow.

The graphical results of these analyses are summarized in Table 4.12.

Table 4.12
Box and Whisker Plots Of Salinity and Isohaline Locations (River Kilometer) Under Differing Flow Categories

Water Quality Parameter	Flow Category – Range in Cubic Feet/Second						
	0 to 106 cfs	106 to 189 cfs	189 to 466 cfs	466 to 1213 cfs	1213 to 2948 cfs	> 2948 cfs	All Flows
Salinity (Surface)	Figure 4.59	Figure 4.60	Figure 4.61	Figure 4.62	Figure 4.63	Figure 4.64	Figure 4.65
Salinity (Bottom)	Figure 4.66	Figure 4.67	Figure 4.68	Figure 4.69	Figure 4.70	Figure 4.71	Figure 4.72
River Kilometer	Figure 4.73	Figure 4.74	Figure 4.75	Figure 4.76	Figure 4.77	Figure 4.78	Figure 4.79

The following generalized patterns and overall observations can be drawn from the series of graphics presented in Table 4.12 for each of the selected water quality characteristics.

Surface Salinity (psu) – The series of figures clearly depicts the progressive changes that occur along the river kilometer based lower Peace River sampling transect as river flows increase. Under the lowest river flow conditions, brackish water conditions extend upstream well beyond the point of Facility water withdrawals. Conversely, freshwater at the surface can extend downstream to near the river's mouth under conditions of extended periods of freshwater inflow.

Bottom Salinity (psu) – The presented figures show that bottom salinity along the HBMP monitoring transect also declines as freshwater inflows increase. However, even under relatively higher flows (1000-3000 cfs combined gaged flow upstream of the Facility), bottom salinities downstream of the U.S. 41 Bridge (RK 6.6) are typically greater than 20 psu and brackish conditions extend well up into the lower river into the area near Harbour Heights (RK 15.5).

Isohaline Location (River Kilometer) – The series of plots indicate the effects of increased freshwater on the relative locations of each of the four HBMP isohalines along the lower Peace River/Charlotte Harbor monitoring transect. The presented series of figures show that under low flow conditions, all four isohalines are confined over limited ranges within the lower river. The spatial pattern of the locations of the isohalines changes with increasing flows. The relative spatial locations of each of the four isohaline-based salinity zones move more downstream and become much more variable as flows increase. This is especially true with regard to the relative spatial locations of the two highest salinity zones, since under high flows the positions of these isohalines are to a great extent dependent upon the length of the preceding period of high flows. Also, as flows increase, the water column at the higher salinity isohalines becomes more stratified, which further enhances their downstream movement. Overall, the variability of the relative locations of the four isohalines increases with salinity.

Correlations were further used to assess potential statistical differences in the relationships between differing rates of seven-day average combined gaged flow upstream of the Facility and salinity at each of the five fixed HBMP sampling sites spatially distributed along the lower river monitoring transect. The same seven statistically based river flow groupings described above were used to test for differences in correlations, and the summary results are presented in **Table 4.13**. Additionally, correlations were used to assess potential statistical differences in the relationships between differing rates of seven day average combined gaged flow upstream of the Facility and the river kilometer location of each of the four moving HBMP isohaline-based sampling salinity. **Table 4.14** presents the results of the isohaline location correlation analyses. Presented in Tables 4.13 and 4.14, for each location and flow category, are the number of available observations (N), the resulting correlation coefficient (R value), and the level of significance (P). In evaluating these results, it should be remembered that the relative degree of variability (percent) explained by changes in flow (the independent variable) is actually the correlation coefficient squared or R^2.

The following briefly summarizes some of the apparent patterns and primary conclusions resulting from the presented analytical comparisons between the measured variability of water quality characteristics in the lower river/upper harbor estuarine system and gaged freshwater inflows upstream of the Facility.

Salinity (psu) – There is a distinct inverse relationship between measured surface salinities and increases in gaged flow up to 3000 cfs at the most downstream fixed sampling site, located near the river's mouth. However, similar relationships increasingly break down further upstream with increasing flows as surface salinities along the HBMP lower river monitoring transect change from being tidally brackish to always being characteristically freshwater under conditions of increasing freshwater flows. Bottom salinities at the two most downstream monitoring sites show relationships with flows up to about 1000 cfs after which the water column becomes highly stratified and influences of further increases are highly reduced. Moving further upstream both surface and bottom salinities show similar relationships with increasing flows.

Isohaline Location (River Kilometer) – The relative locations of each of the four HBMP isohalines along the lower river/upper harbor monitoring transect show strong inverse relationships with freshwater inflows. Under very low flow conditions, the highest 20 psu salinity zone often extends up into the lower river. The freshwater/saltwater interface (0 psu), by comparison, can extend well downstream towards the mouth of the river during extended periods of high river flow. The graphical and statistical analyses indicate that the relative spatial locations of each of the isohalines initially move rapidly downstream with increasing flows. However, over higher ranges of flows the relative slope of change becomes less as do the relationships between flow and isohaline location along the monitoring transect. The observed relationships are confounded due to the importance of both short and long-term preceding conditions, as well as the often increasing physical stratification of the water column under conditions of higher flows.

4.4.2 Empirical Models of Flow versus Salinity Relationships at the Select Continuous Recorder Locations

The primary objective of the following series of presented analyses was to update and determine statistical relationships between the measured salinity variability at selected (Table 4.15) salinity recorder locations along the lower Peace River HBMP monitoring transect (Figure 4.2). The included analyses are intended to provide an understanding of the relationship between salinity and flow (and other explanatory factors) as well as to provide predictive modes. Specific ranges of flow were applied at each location to increase the resulting model's ability to be used specifically to assess salinity changes due to past and currently permitted withdrawals within the defined region of the lower river characterized by each individual recorders location. Combined gaged flows upstream of the Facility below 100 cfs were not included to assure that the empirical models were not unreasonably fitted to the rapidly increasing salinities under very low flows. The establishment of this lower threshold also guaranteed that the models would include conditions near, and slightly below, the Facility's 130 cfs permitted flow cutoff. Similar low flow cutoffs were previously applied in developing the specific flow models in conjunction with the evaluation of 2006-2007 HBMP "pump tests" (PBS&J 2007), and the *2006 HBMP Comprehensive Summary Report* (PBS&J 2009). The models developed in the *2011 HBMP Comprehensive Report* (Atkins 2013), as well as in this current report, also limited the model domain of flows at the high end. Unique high flow cutoffs were applied to the specific model for each recorder location based on the range of combined upstream flows at which segments of the lower river characterized by the recorder's location become predominantly distinguished by freshwater conditions (see Figures in Table 4.6 above). This again reduced the resulting statistical model's likelihood of unduly weighting its fit to the lower part of the salinity/flow relationship, beyond which withdrawals were extremely unlikely to be influenced by salinity levels in that region of the monitoring transect.

Empirical models using the more limited data available at that time, over a slightly wider range of flows, were previously developed for the two USGS continuous recorders as part of the *2002 HBMP Comprehensive Summary Report* (PBS&J 2004). These earlier models and those produced for the District (Janicki Environmental, 2003) were then used in this older (2002) HBMP Summary Document as predictive tools to assess the spatial extent and magnitude of possible salinity changes due to both historic and expected future potential permitted freshwater withdrawals. Updated and more spatially diverse data from the same two USGS and three new HBMP continuous recorders were subsequently used in the *2006 HBMP Comprehensive Summary Report* in developing statistical flow/salinity models used to further refine the potential spatial magnitude of potential salinity changes in the lower river due to Facility freshwater withdrawals. The *2011 HBMP Comprehensive Summary Report* added models for two newer sites at RK 29.8 and 30.6. These two newer locations both characterize conditions within the same general area of the lower river near the Facility's intake (which was why the gage at RK 30.6 was discontinued in June 2011). It should be noted that the Facility typically avoids withdrawing water from the river when there is indications of elevated salinity in this region of the lower river even if combined upstream gaged flows exceed 130 cfs. Thus, it is expected that any measureable effects of Facility withdrawals in this reach of the lower river will be quite small.

Table 4.15 lists the recorder sites used in this report to develop models using available data. This includes the seven sites previously used in the *2011 HBMP Comprehensive Summary Report*, as well as data from sites added in 2011 (Table 4.1).

The most upstream HBMP continuous recorder (RK 31.7) was excluded from these analyses even though data have been collected at this site since mid-2008. The reach of the lower river characterized by this recorder is typically characterized by freshwater conditions below the Facility's 130 cfs cutoff threshold. As such, conductivities (salinity) at the site are far more indicative of seasonal changes in the upstream watershed than the upstream movement of brackish harbor waters moving upstream that might be influenced by withdrawals.

Table 4.15

Selected Recorders with Sufficient Data to Provide Accurate Empirical Models

Gage ID, Location	Period of Record	River Kilometer
RK09 (Authority) – Navigation Marker south of I75 Bridge	Jun. 2011 – Dec. 2016	RK 09.2
RK12 (Authority) - Manatee Zone Marker near Shell Creek (surface)	Jun. 2011– Dec. 2016	RK 12.7
HH (USGS - 02297460) – Dock at Harbour Heights	Sep. 1996 – Dec. 2016	RK 15.5
RK18 (Authority) – Channel Marker in Area of Power Lines	Jun. 2011 – Dec. 2016	RK 18.5
RK18_HC (Authority) - Manatee Zone Marker on Hunter Creek	Jun. 2011 – Dec. 2016	RK 18.7
RK20 (Authority) – Channel Marker downstream of Island	Jun. 2011 – Dec. 2016	RK 20.8
RK21 (Authority) - Manatee Zone Marker near Liverpool area	Dec. 2005 – Dec. 2016	RK 21.9
RK24 (Authority) - Manatee Zone Marker gage near Navigator Marina	Dec. 2005 – Dec. 2016	RK 24.5
PRH (USGS - 02297350) – Dock at Peace River Heights gage	Nov. 1997 – Dec. 2016	RK 26.7
PRP (USGS – 02297345) – Peace River at Platt (Facility)	Dec. 2009 – Dec. 2016	RK 29.8

4.4.2.1 General Methodology for the Development of Empirical Models

The presented series of site specific empirical models were developed using averaged hourly surface conductivity data gathered during the periods-of-record for each of the selected continuous recording locations. The data were used to develop empirical models of salinity versus flow relationships using measured salinities as the dependent variables, and expressions of gaged freshwater inflows minus withdrawals as well as measured stage (water level) as independent variables. The following assumptions and criteria were applied during the development of the individual empirical models.

- The modeled flow terms used combined total daily gaged freshwater inflows measured by USGS at the Peace River at Arcadia, plus Horse Creek near Arcadia and Joshua Creek near Nocatee. Some enhancement of the model for the site at Harbor Heights (RK 15.5) would potentially have resulted from also including corresponding gaged flows from Shell Creek). However, this additional input was not included since a primary objective was to determine specific relationships relative to Peace River Facility withdrawals based on gaged flows upstream of the Peace River Facility.

- Actual daily Facility withdrawals were subtracted from the daily average combined upstream gaged flow for each observation in order to determine the final resultant flow terms.

- A second lagged, long-term cumulative flow term was then applied to the empirical models to establish some indication of background conditions and the "resident memory" associated with the characteristic of the longer-term salinity gradient within the lower river/upper harbor estuarine system. The length of the lag for this long-term cumulative flow was determined independently for each location.

- The 15-minute data from the continuous recorders were averaged over one-hour intervals to reduce the influences of short-term random events (such as boat wakes).

- Stage heights corresponding with the same interval of the measured salinity were added to the models to account for the daily variability in the influences of tides/wind on salinity. Water level heights were measured directly from the USGS Harbour Heights (RK 15.5), Peace River Heights (RK 26.7), and Platt (RK 29.8) recorder sites, with 15-minute stage data from the first two of these gages extending back to the late 1990s. Corresponding water levels for the HBMP surface salinity recorder locations were interpolated over their period-of-record based on their relative distances using lags in tide stage from the USGS recorder sites.

- A final term was tested for each model to account for the interactions of flow with stage and tidal influences. When freshwater inflows are low (such as during the spring dry-season), there are very close correlations between tidal stage and the observed daily variability in measured conductivities (salinity). However, as flow increases and overall conductivities decline, the influences of daily tidal variability on observed salinity patterns declines.

- As an initial step in the development of each empirical model, the Statistical Analysis Software (SAS) "Stepwise General Linear Model" and "RSREG" procedures were used to screen the potential significance of a number of possible applied linear, non-linear, and interactive terms. Log and square root flow terms were tested to account for the often-observed curvilinear response of salinity to increasing freshwater flow. Conversely, non-transformed variables were used within the models for those independent terms found to have more linear interactions. (All model parameters were tested and met the statistical requirements for normal distributions due to the very large number of observations.)

- Using an iterative process, surface salinity models were developed for each of the continuous recorder sites using the fewest number of independent variables that were both significant at the 0.05 level (or better) and added appreciably (at least one percent)

> to the overall explained error of the model. In developing the empirical models, enhancement of the explained variation (R-square) was considered secondary to increasing the relationships between estimated and observed salinities (model fit).

The developed models used to predict salinity levels at each of the continuous recorder locations initially utilized the following generalized form. Each model was then specifically modified to include only those significant terms that directly increase the overall fit using statistically significant terms. Only a single term was selected and applied to represent multiple significant terms that were themselves highly autocorrelated (i.e. one, five and seven day lag flow terms).

$$Salinity = \beta_\alpha + (\beta_1 \times Flow1) + (\beta_2 \times Flow2) + (\beta_3 \times Stage) + (\beta_4 \times (Stage/Flow))$$

where:

β_α = specific intercept

β_1 = "short-term" flow slopes (linear and/or non-linear)

β_2 = "long-term" flow slopes (linear and/or non-linear)

β_3 = gage height specific slope

β_4 = gage height/flow interaction specific slope

4.4.2.2 Results of Empirical Models

Table 4.16 summarizes the types of analyses undertaken during the development of the empirical models for each of the continuous recorder sites, which meet the established temporal and spatial selection criteria for selection.

Table 4.16
Surface Salinities at the USGS and HBMP Continuous Recorders

Continuous Recorder Location	Salinity vs. Flow (used to established high flow cutoff)	Developed Statistical Model	Example of Estimated vs. Observed Daily Average Salinity for 2016
RK 9.2 HBMP	Figure 4.80	Table 4.17	Figure 4.90
RK 12.7 HBMP	Figure 4.81	Table 4.18	Figure 4.91
RK 15.5 USGS Harbour Heights	Figure 4.82	Table 4.19	Figure 4.92
RK 18.5 HBMP	Figure 4.83	Table 4.20	Figure 4.93
RK 18.7 HBMP	Figure 4.84	Table 4.21	Figure 4.94
RK 20.8 HBMP	Figure 4.85	Table 4.22	Figure 4.95
RK 21.9 HBMP	Figure 4.86	Table 4.23	Figure 4.96
RK 24.5 HBMP	Figure 4.87	Table 4.24	Figure 4.97
RK 26.7 USGS Peace River Heights	Figure 4.88	Table 4.25	Figure 4.98
RK 29.8 USGS Platt	Figure 4.89	Table 4.26	Figure 4.99

Plots comparing the different salinity/flow relationships among the recorder locations using the combined gaged flows upstream of the Facility for the period-of-record for each recorder are shown in **Figures 4.80** through **4.89**. These graphics depict both average hourly measured salinity values as well as a fitted, smoothed line, plotted values using a SAS cubic spline method (which minimizes both the linear combination of the sums of squares of the residuals of the fit as well as the integral of the square of the second derivative). These figures clearly show the great degree of variability in salinity that can be observed at locations along the lower river even over a very narrow range of flows. As previously discussed, the high degree of observed salinity variability results primarily from the combined influences of normal daily tidal patterns, periodic strong wind's predominantly blowing from either the north or south, and differences in preceding seasonal flow patterns that result in either higher or lower background salinity levels in upper Charlotte Harbor. The vertical lines in these figures represent the selected low flow cutoff (130 cfs combined flow of the three USGS gages upstream of the Facility), while the depicted range of the X-axis indicates the unique high flow limit specifically used in establishing the domain of the empirical models for each recorder location.

Tables 4.17 through **4.26** provide the detailed results of the best-fit empirical models developed for each of the ten monitoring site locations. The resulting models for the more downstream stations ranged from explaining approximately 85 to 89 percent of the observed variation in salinity at the recorder locations. The best-fit empirical models for more upstream recorder sites by comparisons explain less of the observed hourly variability in salinity. This results both from the wide range of variability in salinity observed in comparison to the relatively much narrower range of flows in the models domain (see **Figures 4.80** through **4.89**). The presented tables of model results indicate the importance that both stage height and flows have, relative to their contribution in determining the observed variability in hourly averaged salinity at each of the recorder locations. Comparisons of the Type I and Type III error terms of the resulting best-fit empirical models shows the degree of importance of these two dominant variables, as well as the interactions with other factors in determining the natural range of variation in salinity observed along the lower river HBMP monitoring transect.

The relative degrees of fit of the empirical models developed for each recorder location are further shown in **Figures 4.90** through **4.99**. These figures indicate plots of estimated and observed daily averaged salinities over the last full year for which data were available at each of the recorder locations. Comparisons of estimated and observed salinities are only indicated in these figures when total gaged flow upstream of the Facility was within the selected range of flows applied in the developed empirical models for each site (**Figures 4.80** through **4.89**). Overall, these comparative plots of observed salinities with those estimated by the empirical models indicate that the models slightly over-predict salinities at low observed levels and correspondingly somewhat under-predict at higher observed salinity levels. However, over the typical range of salinities observed at each of the recorder sites, the models presented in Tables **4.17** through **4.26** provide a relatively good fit between observed and estimated values. This suggests that the models can be used to predict observed variations in salinity, even given the inherent natural variability resulting from the complex interactions of flows and tides within the lower reach of the Peace River characterized by the existing array of continuous recorders. As such, the models provide a fairly simple and straightforward method to analyze and predict the potential range and magnitude of potential salinity impacts of withdrawals along the lower river downstream of the Facility over the wide range of observed natural temporal and spatial fluctuations due to the combined influences of variations in upstream flows, tides and seasonal wind patterns.

4.5 Influence of Withdrawals on Salinity

4.5.1 Application of Empirical Models

The developed empirical models for surface salinities for the selected recorder locations in **Table 4.15** were used to estimate average hour salinities over the period 1998 through 2016. This corresponds with the interval of available complete annual 15-minute gage stage height data for the two older USGS recorder sites (**Figure 4.2**; note estimates were made for RK 29.8 for the period 2010-2016 as this USGS gage was installed in 2009). The availability of such data allows the estimation of corresponding stage data at other points (the HBMP recorder sites) along the lower river monitoring transect.

Estimated salinities were made using two separate modeling alternatives.

1. **“Actual Withdrawal” Scenario** – This condition was determined by applying the developed empirical models using directly measured stage heights at the three USGS gages. Corresponding calculated stage heights for the HBMP recorder locations were made based on estimated tidal lags relative to measured differences between the USGS recorders. The applied flow terms used in the models under this scenario are measured flow resulting from reduction due to withdrawals.

2. **“No Withdrawal” Scenario** – This condition was determined by applying the developed empirical models using directly measured stage heights at the three USGS gages. Corresponding calculated stage heights for the HBMP recorder locations were made based on estimated tidal lags relative to measured differences between the USGS recorders. The applied flow terms used in the models under this alternative have withdrawals made by the Facility added back in.

Summary graphical results of the modeled differences between the “No Withdrawal” and “Actual Withdrawal” alternative withdrawal scenarios are presented on an annual basis over the 1998 to 2016 time interval in Table 4.27. The depicted box and whisker plots show the estimated annual variability in surface salinities at each of the continuous recorder locations under the two alternative scenarios (annual mean salinities are shown as dots in the box and whisker plots; note that data for RK 29.8 begins in 2010).

More detailed summary statistics of calculated annual estimated salinity differences at each of the recorder sites between the “No” and “Actual” withdrawal scenarios are further summarized in **Table 4.28**.

Table 4.27
Box and Whisker Plots of Estimated Differences due to Withdrawals in Annual Average Salinities at Selected Recorder Locations along the HBMP Monitoring Transect

Year	Estimated Salinities
1998	**Figure 4.100**
1999	**Figure 4.101**
2000	**Figure 4.102**
2001	**Figure 4.103**
2002	**Figure 4.104**
2003	**Figure 4.105**
2004	**Figure 4.106**
2005	**Figure 4.107**
2006	**Figure 4.108**
2007	**Figure 4.109**
2008	**Figure 4.110**
2009	**Figure 4.111**
2010	**Figure 4.112**
2011	**Figure 4.113**
2012	**Figure 4.114**
2013	**Figure 4.115**
2014	**Figure 4.116**
2015	**Figure 4.117**
2016	**Figure 4.118**

The following summarizes some of the more apparent conclusions that can be drawn relative to the potential magnitude of salinity changes due to Facility withdrawals, as estimated by the empirical models developed for each of the continuous recorder locations along the HBMP lower river monitoring transect.

- The presented series of annual graphics emphasize the very high degree of seasonal and inter-annual temporal variability in salinity that naturally occurs spatially along the lower Peace River. These differences are especially dramatic when relative salinity comparisons are made among wetter years (such as took place in 1998, 2003, 2004, and 2005) and periods of comparatively much lower flows (such as occurred during the interval from late 1999 through early 2002, as well as over the extended period of drought between 2006 and 2011).

- The annual average (mean) estimated differences in salinities due to withdrawal were the greatest at the more downstream locations (RK 12.7 and 15.5) and became progressively smaller moving upstream, being the lowest near the Facility (RK 30.6). This result is as expected, since as flows increase the reaches of the river near and immediately downstream of the Facility become less and less influenced by higher salinity water moving tidally upstream. Facility withdrawals can only influence those segments of the lower river that are still tidally influenced by saltwater, and thus the further a location is downstream, the greater the percent of time that salinities can be influenced by withdrawals.

- Many of the calculated median differences in **Table 4.28** were zero (particularly at more upstream locations). A median of zero indicates that at least half the time Facility withdrawals have limited (if any) influence on the salinities. Obviously the Facility cannot affect salinity during the period of time when gage flows are below the District's low flow threshold. Conversely, when flows are high enough that a particular reach of the river is always characterized by freshwater conditions (**Figures 4.80 through 4.89**), Facility withdrawals also do not affect salinity in that portion of the lower river. A somewhat less intuitive finding of the series of "pump tests" (PBS&J 2007) was the observation that Facility withdrawals even during low to moderate flows, primarily only resulted in higher observed salinities during incoming tides. Withdrawals seemed to have very little directly measurable influence on salinities during the outgoing and low phases of the daily tidal cycle.

- Estimated annual average salinity changes due to actual Facility withdrawals for years following the 2009 Facility expansion range from approximately 0.1 psu upstream to 1.1 psu downstream. Estimated annual average salinity changes at upstream stations were greatest during 2000 and 2001 (with annual average change ~0.5-0.9 psu at RK 26.7), prior to Facility expansion. Similarly, the greatest estimated changes for more downstream stations occurred during this same drought period (annual average salinity change ~1.9 psu at RK 15.5).

- Estimated 95th percentile annual salinity differences due to Facility withdrawals are shown to have ranged from approximately 0.01 psu to 3.2 psu over the interval between 1998 and 2016. The estimated salinity changes due to withdrawals have varied both among wetter and drier periods, as well as with changes in the permitted withdrawal schedules. Interestingly, the greatest estimated salinity increases due to actual withdrawals have not always been calculated to have occurred at the most downstream locations, but rather spatially sometimes further upstream at the intermediate recorder locations along the HBMP monitoring transect. Again, these results are similar to the physical observations recorded during the HBMP Facility "pump tests." These results showed measurable salinity changes of similar magnitudes due to withdrawals that were temporally confined to the top end of incoming tides. Spatially, the maximum observed salinity changes during the "pump tests" were determined by the relative location of the saltwater/freshwater interface, which is a function of the interactions of both flows and tides.

The above models that estimate salinity for the period 1998-2016 incorporate the observed variability in two major factors that affect salinity. Freshwater flows are the primary factor affecting the salinity in the lower Peace River. These flows in turn are affected by variability in rainfall. As detailed in **Chapter 3**, there has been a notable increase in wet-season rainfall since approximately 1994, as well as marked declines in dry-season rainfall throughout the Peace River watershed. Salinities have increased in response to the decreased rainfall in this period. The permitted withdrawals also affect salinity in the river; the influence depends on the magnitude of the withdrawals, in combination with the variability in freshwater inflow. Prior to the development of the MFLs for the lower Peace River, Facility withdrawals had historically been fairly uniform throughout most of the year. Following their development, the annual pattern of withdrawals more closely follows a seasonal cycle that follows the natural variability in flow from the river.

To examine the changes in the effect of withdrawals on salinity as estimated by the model runs with and without withdrawals, the mean difference between the two model scenarios were computed for three periods: 2002-2006, 2007-2011, and 2012-2016 (Table 4.29. The estimated differences in salinity are slightly higher following the 2009 expansion and increased capacity of the Facility and the increase in permittable withdrawals. However, these estimated differences slightly declined in the most recent period examined likely due to the variation in freshwater flows in that period.

Table 4.29
Mean Annual Estimated Changes in salinity for the Three Most Recent 5-year Periods of the HBMP at the Selected Continuous Recorder Locations

Continuous Recorder Location	2002-2006	2007-2011	2012-2016
RK 9.2 HBMP	0.65	0.92	0.83
RK 12.7 HBMP	0.71	1.12	0.83
RK 15.5 USGS Harbour Heights	0.70	1.13	0.82
RK 18.5 HBMP	0.41	0.73	0.57
RK 18.7 HBMP	0.52	0.88	0.64
RK 20.8 HBMP	0.34	0.63	0.47
RK 21.9 HBMP	0.32	0.59	0.44
RK 24.5 HBMP	0.20	0.42	0.32
RK 26.7 USGS Peace River Heights	0.14	0.29	0.19

*note RK 29.8 (USGS Platt) was not included in this analyses as data were not available prior to 2010.

In assessing the potential magnitude of past actual withdrawals, it should be noted that historically the Facility has often not withdrawn the full daily amount allowed under its District permitted amounts. This can be due to a number of factors that include the physical limits to the Facility's withdrawal capacity, maintenance and other operational considerations, as well as poor water quality in the river (algal blooms, high conductivity, etc.). In other instances, withdrawals have sometimes slightly exceeded the permitted percentages, or the established low flow threshold. The reason for such discrepancies stems from the way that flow data are gathered. The Facility uses “provisional” real time preceding day flow data from the USGS water level recorders for withdrawal quantities allowed for the current day. “Provisional” real-time data are obtained by the Authority staff a number of times each day directly from the USGS Web Site. This is accomplished in order to determine an accurate working estimate of the preceding daily flow on which the current day’s withdrawal is scheduled. However, after the fact, the USGS checks and evaluates the data from both the gage stage recorder. USGS staff further periodically measures the river’s/creek’s cross section periodically over the year. Based on such quality assurance checks, USGS staff may make various revisions to the previously available real-time information before establishing finalized daily flow estimates for the preceding water year. Thus, the daily values used by the Facility are only “provisional” and can, and are often, changed as a result of ongoing USGS data quality assurance procedures weeks or even months later. It is therefore not uncommon for subsequent determinations of percent withdrawals, based on the finalized, revised USGS calculations of the initial “provisional” daily flows to sometimes indicate that daily withdrawals, based on initial real-time flow information, may have slightly exceeded the District’s permitted maximum percent and/or low flow cutoff. (Since corrected flows can be either increased or decreased, these changes can also result in the Facility having taken a somewhat lower percentage of flow than originally thought.)

4.5.2 Estimated Temporal and Spatial Magnitude of the Changes due to Facility Withdrawals

This section summarizes the estimated changes, as a result of Facility withdrawals, in salinity and isohaline location along the Lower Peace River.

4.5.2.1 Estimated Changes in Salinity, Spatially Along the Lower Peace River due to Facility Withdrawals (1998-2016)

The primary objective in this section is to provide similar, but more detailed, finer scale analyses indicating the recent historical effectiveness of the Facility’s withdrawal schedule in limiting salinity changes along the lower river. Specifically, this section presents two types of summary analyses of modeled, estimated salinity changes estimated to be due to freshwater withdrawals. Analyses were conducted over the 1998-2016 time interval at the selected spatial gaging locations along the lower river in Table 4.30. This included:

1. Modeled daily average estimated salinity increases relative to estimated daily average seasonal changes in salinity, and

2. Similar daily estimated spatial salinity increases relative to the estimated daily (hourly averaged) range of variability in salinity.

Table 4.30
USGS and HBMP Continuous Recorders Sites for which Empirical Salinity Models were Developed

Gage ID, Location	River Kilometer
RK09 (Authority) – Navigation Marker south of I75 Bridge	RK 09.2
RK12 (Authority) - Manatee Zone Marker near Shell Creek	RK 12.7
HH (USGS - 02297460) – Dock at Harbour Heights	RK 15.5
RK18 (Authority) – Channel Marker in Area of Power Lines	RK 18.5
RK18_HC (Authority) - Manatee Zone Marker on Hunter Creek	RK 18.7
RK20 (Authority) – Channel Marker downstream of Island	RK 20.8
RK21 (Authority) - Manatee Zone Marker near Liverpool area	RK 21.9
RK24 (Authority) - Manatee Zone Marker gage near Navigator Marina	RK 24.5
PRH (USGS - 02297350) – Dock at Peace River Heights gage	RK 26.7
PRP (USGS – 02297345) – Peace River at Platt (Facility)	RK 29.8

Modeled daily average estimated salinity increases relative to estimated daily average seasonal changes in salinities are depicted in the graphical summaries presented in Table 4.31 by year at the selected recorder sites along the lower Peace River.

Specific examples comparing modeled estimated average daily salinity increases due to Facility withdrawals corresponding projected daily averages in salinity, and the daily range in salinity are shown below for the gaging site at RK 15.5, during 1999 and 2011. This recorder location was selected for highlighting since the current and previous HBMP modeling efforts (PBS&J 2002, 2006 and 2009) showed that the expected largest changes in salinity due to withdrawals would occur in this region of the lower river. The year 1999 was selected for these comparisons since it represents a period of lower flows, prior to Facility expansions, when the Authority functioned completely under the original 1996 withdrawal schedule. By comparison, 2011 was also a relatively dry year, following the 2002 and 2009 major Facility expansions, and implementation in April 2011 of the current MFL based withdrawal schedule.

Table 4.31
A Comparison of Estimated Average Daily Differences in Salinity due to Withdrawals and Estimated Daily Salinity at Selected Recorder Sites along the Lower River

Year	RK 9.2	RK 12.7	RK 15.5	RK 18.5	RK 18.7	RK 20.8	RK 21.9	RK24.5	RK 26.7	RK 29.8
1998	Figure 4.119	Figure 4.120	Figure 4.121	Figure 4.122	Figure 4.123	Figure 4.124	Figure 4.125	Figure 4.126	Figure 4.127	
1999	Figure 4.128	Figure 4.129	Figure 4.130	Figure 4.131	Figure 4.132	Figure 4.133	Figure 4.134	Figure 4.135	Figure 4.136	
2000	Figure 4.137	Figure 4.138	Figure 4.139	Figure 4.140	Figure 4.141	Figure 4.142	Figure 4.143	Figure 4.144	Figure 4.145	
2001	Figure 4.146	Figure 4.147	Figure 4.148	Figure 4.149	Figure 4.150	Figure 4.151	Figure 4.152	Figure 4.153	Figure 4.154	
2002	Figure 4.155	Figure 4.156	Figure 4.157	Figure 4.158	Figure 4.159	Figure 4.160	Figure 4.161	Figure 4.162	Figure 4.163	
2003	Figure 4.164	Figure 4.165	Figure 4.166	Figure 4.167	Figure 4.168	Figure 4.169	Figure 4.170	Figure 4.171	Figure 4.172	
2004	Figure 4.173	Figure 4.174	Figure 4.175	Figure 4.176	Figure 4.177	Figure 4.178	Figure 4.179	Figure 4.180	Figure 4.181	
2005	Figure 4.182	Figure 4.183	Figure 4.184	Figure 4.185	Figure 4.186	Figure 4.187	Figure 4.188	Figure 4.189	Figure 4.190	
2006	Figure 4.191	Figure 4.192	Figure 4.193	Figure 4.194	Figure 4.195	Figure 4.196	Figure 4.197	Figure 4.198	Figure 4.199	
2007	Figure 4.200	Figure 4.201	Figure 4.202	Figure 4.203	Figure 4.204	Figure 4.205	Figure 4.206	Figure 4.207	Figure 4.208	
2008	Figure 4.209	Figure 4.210	Figure 4.211	Figure 4.212	Figure 4.213	Figure 4.214	Figure 4.215	Figure 4.216	Figure 4.217	
2009	Figure 4.218	Figure 4.219	Figure 4.220	Figure 4.221	Figure 4.222	Figure 4.223	Figure 4.224	Figure 4.225	Figure 4.226	
2010	Figure 4.227	Figure 4.228	Figure 4.229	Figure 4.230	Figure 4.231	Figure 4.232	Figure 4.233	Figure 4.234	Figure 4.235	Figure 4.236
2011	Figure 4.237	Figure 4.238	Figure 4.239	Figure 4.240	Figure 4.241	Figure 4.242	Figure 4.243	Figure 4.244	Figure 4.245	Figure 4.246
2012	Figure 4.247	Figure 4.248	Figure 4.249	Figure 4.250	Figure 4.251	Figure 4.252	Figure 4.253	Figure 4.254	Figure 4.255	Figure 4.256
2013	Figure 4.257	Figure 4.258	Figure 4.259	Figure 4.260	Figure 4.261	Figure 4.262	Figure 4.263	Figure 4.264	Figure 4.265	Figure 4.266
2014	Figure 4.267	Figure 4.268	Figure 4.269	Figure 4.270	Figure 4.271	Figure 4.272	Figure 4.273	Figure 4.274	Figure 4.275	Figure 4.276
2015	Figure 4.277	Figure 4.278	Figure 4.279	Figure 4.280	Figure 4.281	Figure 4.282	Figure 4.283	Figure 4.284	Figure 4.285	Figure 4.286
2016	Figure 4.287	Figure 4.288	Figure 4.289	Figure 4.290	Figure 4.291	Figure 4.292	Figure 4.293	Figure 4.294	Figure 4.295	Figure 4.296

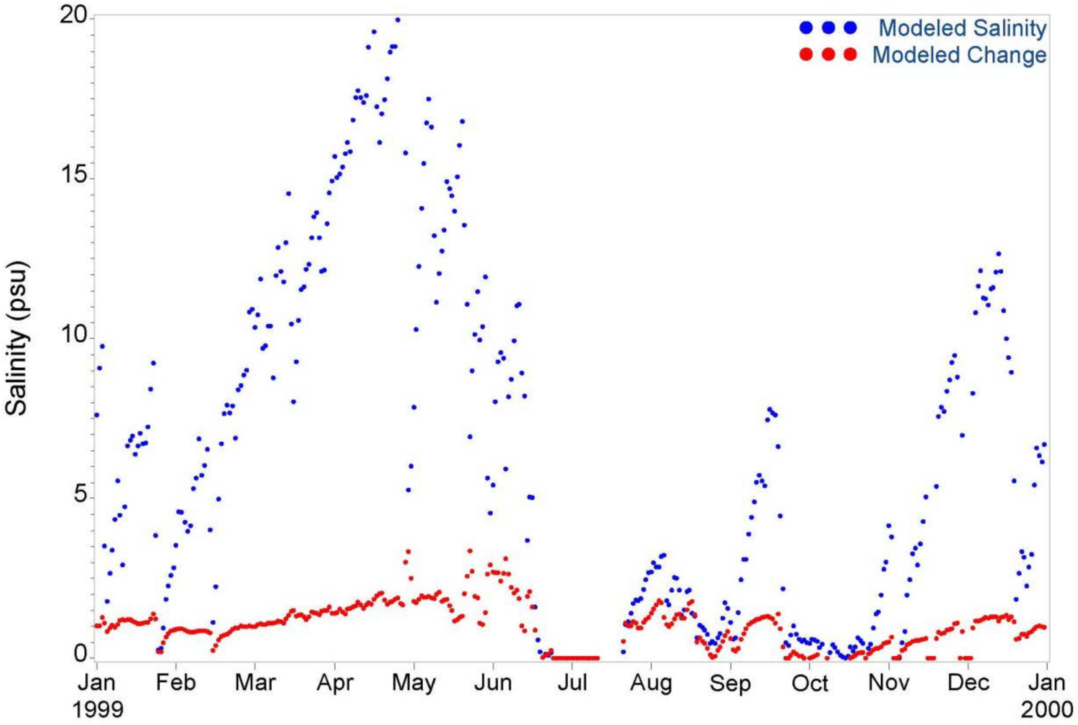

Figure 4.130 A comparison of average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 15.5 (1999)

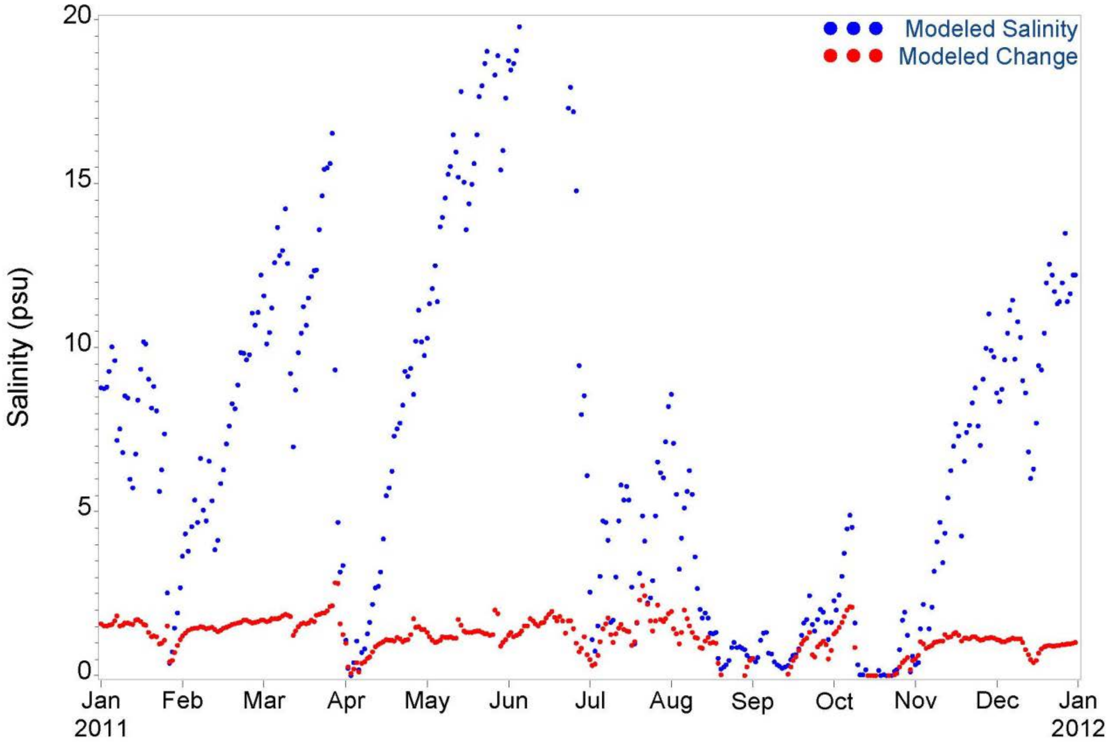

Figure 4.239 A comparison of average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 15.5 (2011)

Table 4.32 presents detailed statistical summaries of modeled estimates of each of these three comparative measures during 2016. **Table 4.33** provides a similar summary for the additional years over the 1998-2016 time interval. (Again, the modeled changes in all instances are based on "actual" daily withdrawals over the 1998-2016 period and not estimates of "potential maximum" change that might have occurred if the entire amounts of water under each of the withdrawal schedules had been withdrawn.)

Table 4.32

Comparison of Estimated Difference in Salinity due to Withdrawals to Daily Average and Range of Estimated Salinity Values at Selected Recorder Sites along the Lower River

Year	Site	Parameter	Mean	Min	P10	P25	P50	P75	P90	Max
2016	RK 9.2	Estimated Daily Average Salinity	9.6	0	0.5	4	8.9	15.1	20.2	22.5
2016	RK 9.2	Estimated Daily Range in Salinity	6	0	1.8	5.2	6.5	7.8	8.8	12.7
2016	RK 9.2	Estimated Change due to Withdrawals	0.7	0	0.3	0.5	0.7	0.9	1.1	1.2
2016	RK 12.7	Estimated Daily Average Salinity	4.6	0	0.1	0.6	2.7	7.9	12.6	14.9
2016	RK 12.7	Estimated Daily Range in Salinity	4	0	0.4	1.7	4.3	5.8	6.9	9.9
2016	RK 12.7	Estimated Change due to Withdrawals	0.5	-1	-0.1	0.1	0.6	0.9	1.2	1.5
2016	RK 15.5	Estimated Daily Average Salinity	3.5	0	0.1	0.4	1.3	5.6	10.7	13
2016	RK 15.5	Estimated Daily Range in Salinity	2.9	0	0.4	1.1	2.8	4.4	5.4	7.7
2016	RK 15.5	Estimated Change due to Withdrawals	0.4	-1.6	-0.4	0	0.4	0.9	1.3	1.5
2016	RK 18.5	Estimated Daily Average Salinity	2.5	0	0.1	0.3	1.6	4.3	7	9.1
2016	RK 18.5	Estimated Daily Range in Salinity	3.7	0	0.1	1.1	3.5	5.7	8	13.4
2016	RK 18.5	Estimated Change due to Withdrawals	-0.4	-8.8	-2.9	-0.2	0	0.5	1	1.3
2016	RK 18.7	Estimated Daily Average Salinity	1.9	0	0	0	0.2	3	7.1	9.2
2016	RK 18.7	Estimated Daily Range in Salinity	1.4	0	0	0	0.7	2.8	3.5	5.6
2016	RK 18.7	Estimated Change due to Withdrawals	0.3	-0.1	0	0	0.1	0.6	1	1.3
2016	RK 20.8	Estimated Daily Average Salinity	1.3	0	0	0	0.6	1.7	4.5	6.3
2016	RK 20.8	Estimated Daily Range in Salinity	2	0	0	0	1.5	3.6	5.2	8.3
2016	RK 20.8	Estimated Change due to Withdrawals	0.1	-1.9	-0.7	0	0	0.4	0.8	1.1
2016	RK 21.9	Estimated Daily Average Salinity	0.8	0	0	0	0	0.8	3.4	5.1
2016	RK 21.9	Estimated Daily Range in Salinity	1.1	0	0	0	0.2	1.8	3.8	6.3
2016	RK 21.9	Estimated Change due to Withdrawals	0.2	-0.4	0	0	0	0.3	0.8	1
2016	RK 24.5	Estimated Daily Average Salinity	0.4	0	0	0	0	0.4	1.4	2.6
2016	RK 24.5	Estimated Daily Range in Salinity	0.7	0	0	0	0	1.2	2.6	5.3
2016	RK 24.5	Estimated Change due to Withdrawals	0.1	-0.4	-0.1	0	0	0	0.6	1.1
2016	RK 26.7	Estimated Daily Average Salinity	0.2	0	0	0	0	0.2	0.7	1.3
2016	RK 26.7	Estimated Daily Range in Salinity	0.3	0	0	0	0	0.5	1.3	2.2
2016	RK 26.7	Estimated Change due to Withdrawals	0	-0.1	0	0	0	0	0.3	0.4
2016	RK 29.8	Estimated Daily Average Salinity	0.1	0	0	0	0	0	0.3	0.3
2016	RK 29.8	Estimated Daily Range in Salinity	0	0	0	0	0	0	0	0.1
2016	RK 29.8	Estimated Change due to Withdrawals	0	0	0	0	0	0	0	0.2

The following briefly summarizes some of the major observations and conclusions that can be drawn from the presented summary figures and tables of modeled results.

- The presented annually based graphics emphasize the very high degrees of long-term, annual, seasonal and daily salinity variability naturally occurring temporally and spatially along the lower river. These differences are especially notable when comparing wetter intervals (such as occurred in 1998, 2003, 2004, and 2005) with extended periods characterized by lower flows (such as happened from late 1999 through early 2002, and then again more recently during the extended period of drought between 2006 and 2011).

- The annually summarized statistical metrics of daily averaged salinity, the daily range in salinity, and the estimated daily average change in salinity due to withdrawals estimated by the developed empirical models were all larger at the three most downstream recorder locations (RK 9.2, RK 12.7 and RK 15.5). These metrics became progressively smaller moving upstream, being the lowest nearer the Facility (RK 29.8). These projected results were as expected, since as flows increase the reaches of the river near and immediately downstream of the Facility becomes less and less influenced by higher salinity water moving tidally upstream. Facility withdrawals can only influence those segments of the lower river that are still tidally influenced by saltwater moving upstream, and thus the further a location is downstream, the greater the potential duration that salinities can be influenced by withdrawals.

- The presented graphical and tabular results indicated increased changes in estimated salinities along the lower river following both the 2002 and 2009 Facility expansions. However, even following these expansions, and the more recent increased percentages under the new withdrawal schedule, estimated annual average salinity changes due to actual Facility withdrawals range from approximately 0.1 psu upstream to around 1.1 psu downstream.

- However, care should be taken in comparing the statistical summaries and especially in applying “mean” values. There are typically extended annual intervals when the Facility isn’t influencing salinity along extended regions of the lower river. Obviously the Facility is not affecting salinity during the often extended seasonal periods when gage flows are below the District’s low flow threshold. Conversely, when flows are high enough that a particular reach of the river is always characterized by freshwater conditions, Facility withdrawals again do not affect salinity in extended portions of the lower river. The findings of the Facility “pump tests” (PBS&J 2007) further indicated that withdrawals primarily only resulted in higher observed salinities during incoming tides and that withdrawal had less directly measurable influence on salinities during the outgoing and low phases of the daily tidal cycle. The common instances of “no” or “zero” influences needs to be taken into consideration when evaluating relative statistical metrics.

- The maximum daily estimated salinity changes due to withdrawals have varied both among wetter and drier periods, as well as with changes in the permitted withdrawal schedules. Interestingly, the estimated salinity increases due to actual withdrawals have not always been calculated to have been highest at the most downstream Harbour Heights recorder location, but rather spatially sometimes further upstream at the intermediate recorder locations along the HBMP monitoring transect. Again, these results are similar to the physical observations recorded during the recently completed HBMP Facility "pump tests." These results showed measurable salinity changes of similar magnitudes due to withdrawals that were temporally confined to the top end of incoming tides. Spatially, the maximum observed salinity changes during the "pump tests" were determined by the relative location of the saltwater/freshwater interface, which is a function of the interactions of flows, tides and withdrawals.

- In assessing the potential magnitude of past actual withdrawals, it should be noted that historically the Facility has often not withdrawn the full daily amount allowed under its District permitted amounts. This can be due to a number of factors that include the physical limits to the Facility's withdrawal capacity, maintenance and other operational considerations, as well as poor water quality in the river (algal blooms, high conductivity, etc.).

- The modeled results indicate that salinity changes due to Facility withdrawals have increased since the most recent expansion and change in the withdrawal schedule. These increases remain relatively small when compared to the range of naturally occurring daily, seasonal and longer term flow/tide related variation along the lower Peace River. The results further indicate that, by design, the largest increases in salinity resulting from the withdrawal schedule are focused into wetter periods, and occur in regions of the lower river that naturally experience relatively large salinity fluctuations. The components of the withdrawal schedule thus effectively reduce the relative potential influences of withdrawals.

4.5.2.2 Potential Isohaline Movement Due to Facility Withdrawals

The status and trends in the relative spatial locations of the four monthly monitored HBMP isohaline locations (0, 6, 12 and 20 psu) over the 1984-2016 time interval was discussed earlier in this chapter. Long-term differences and seasonal patterns in the relative monthly movement of these four isohalines were analyzed to changes in freshwater inflows. The analyses indicate the large degree of both inter- and intra-annual variability that occurs in the relative monthly locations along the established lower Peace River/upper Charlotte Harbor river kilometer transect in response to freshwater inflows, resulting in observed variations up to as much as 35 to 55 kilometers in the relative spatial distributions of the monthly based locations of the four monitored isohalines

In this section empirical models were developed to estimate the relative spatial location of each of the four isohalines along the HBMP monitoring transect utilized generalized forms similar to those used earlier in this chapter to estimate salinity at the continuous recorder sites. Each isohaline model incorporated only those significant terms that directly increase the overall fit using statistically significant terms, and only applying a single term to represent multiple significant terms that were themselves highly autocorrelated.

$$Salinity = \beta_{\alpha} + (\beta_1 x\ Flow1) + (\beta_2 \times Flow2)$$

where:

β_{α} = specific intercept

β_1 = “short-term” flow slopes (linear and/or non-linear)

β_2 = “long-term” flow slopes (linear and/or non-linear)

The following presents the results of the graphical and statistical analyses of the relationships between total gaged freshwater inflows upstream of the Facility and the spatial distributions of the four HBMP isohalines.

- 0 psu Isohaline – **Figure 4.297** and **Table 4.34**
- 6 psu Isohaline – **Figure 4.298** and **Table 4.35**
- 12 psu Isohaline – **Figure 4.299** and **Table 4.36**
- 20 psu Isohaline – **Figure 4.300** and **Table 4.37**

Figures 4.301 and 4.302 and **Table 4.38** summarize the modeled estimated isohaline movements due to actual withdrawals. Like the previous modeled changes in salinities, these results indicate that the movements of the isohalines increased as Facility capacity and storage have been enhanced, and the withdrawal schedule has been modified under the District’s lower Peace River MFL.

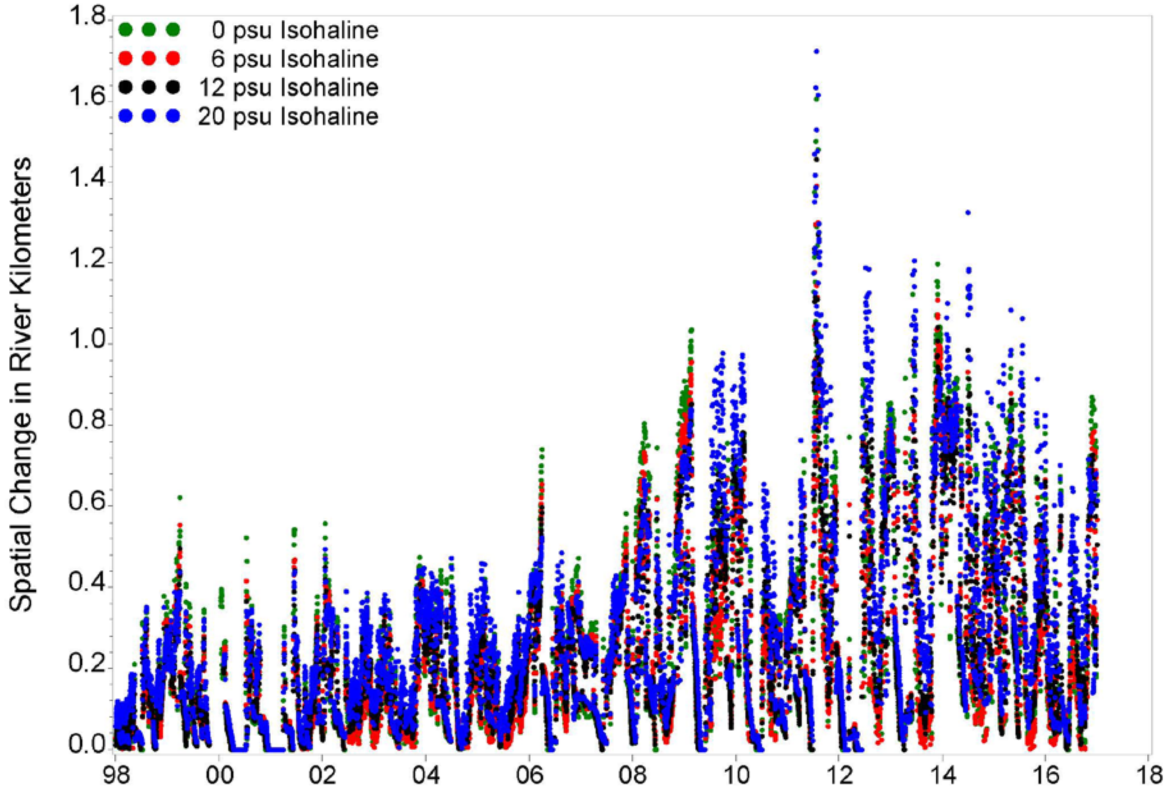

Figure 4.301 Estimated change in daily isohaline locations due to Facility withdrawals (1998-2016)

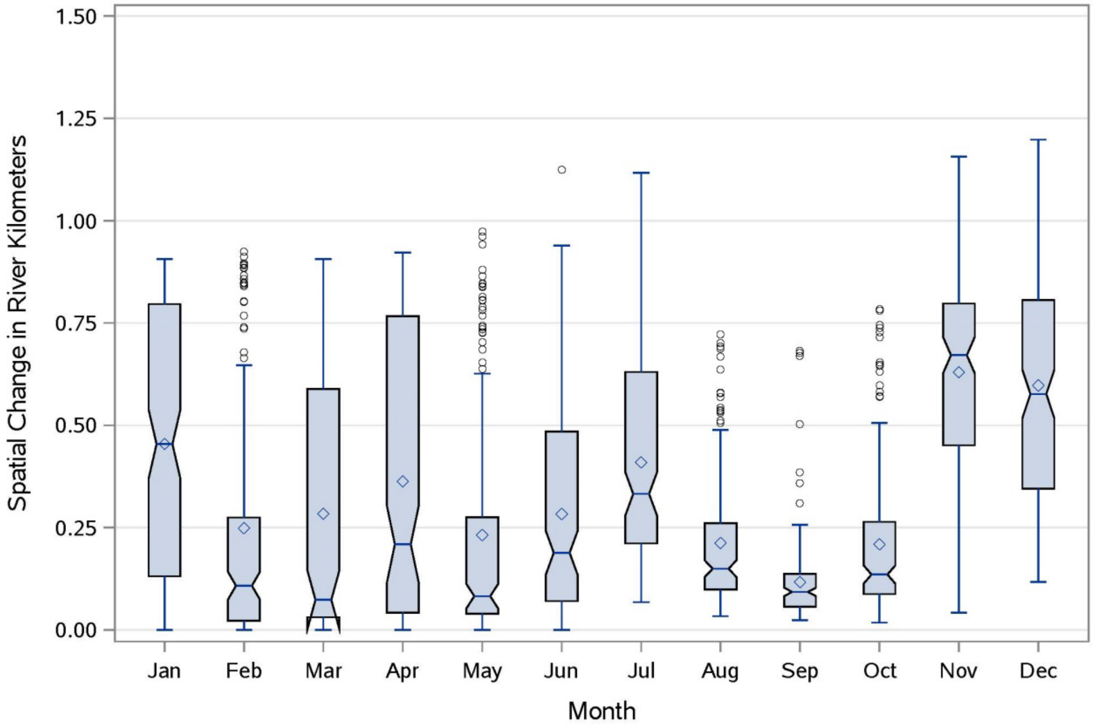

Figure 4.302a Monthly box plots of estimated changes in daily locations of the 0 psu isohaline due to Facility withdrawals

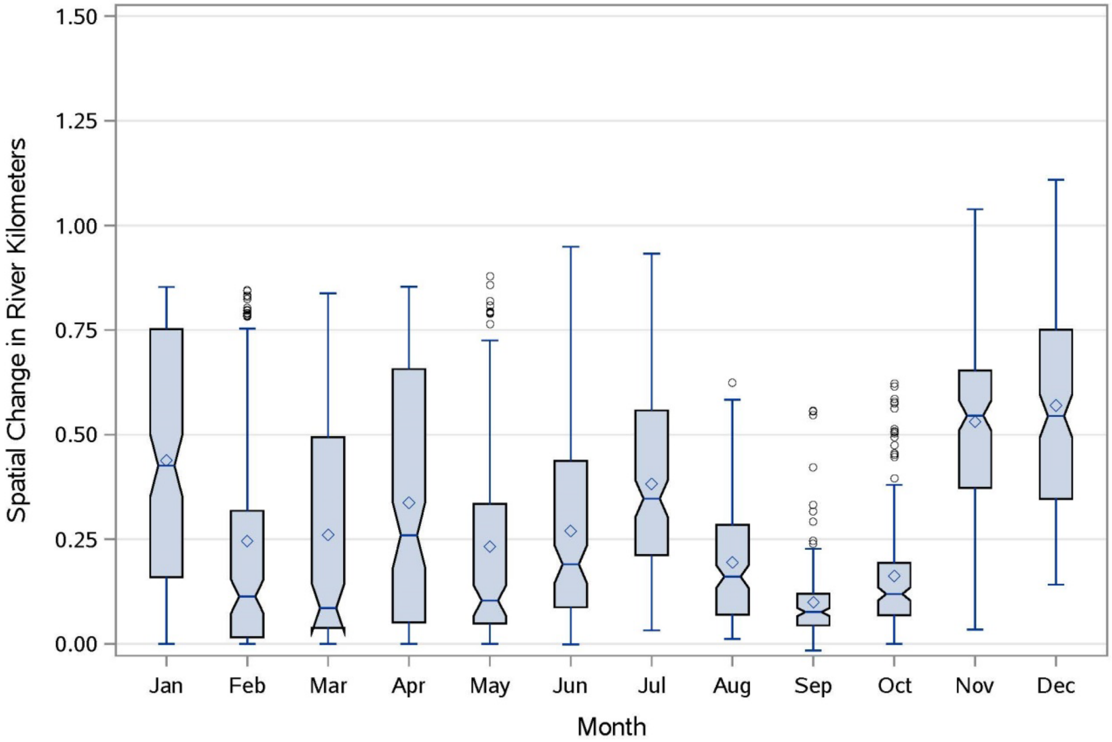

Figure 4.302b Monthly box plots of estimated changes in daily locations of the 6 psu isohaline due to Facility withdrawals

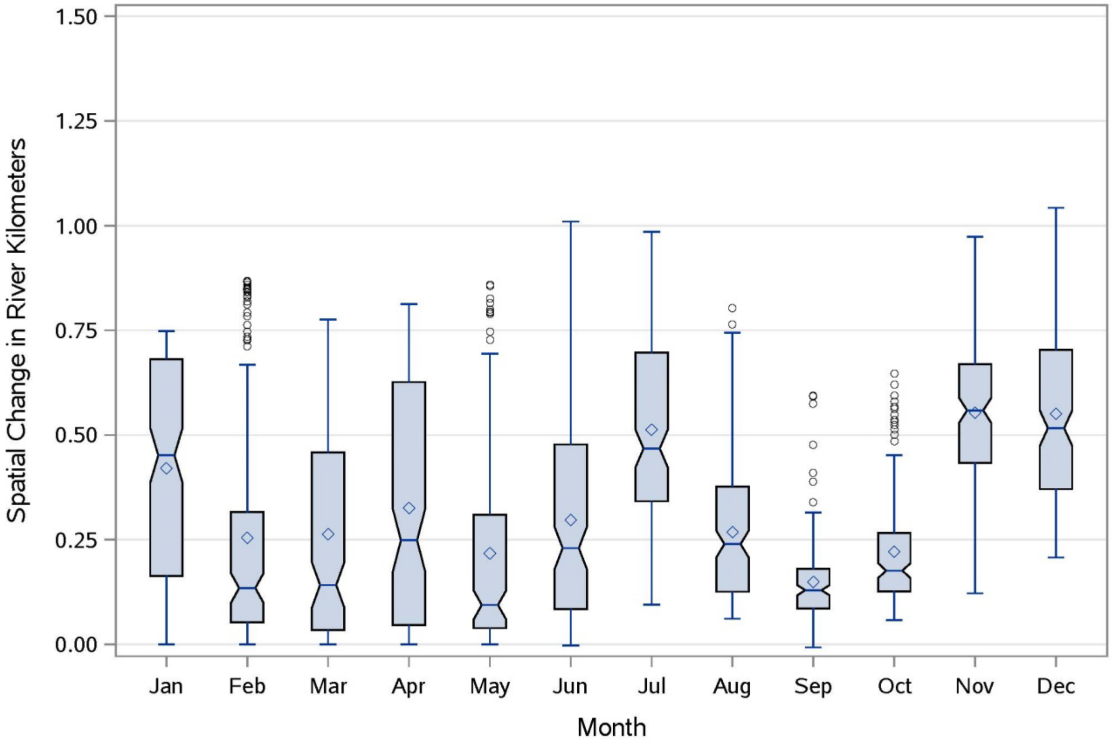

Figure 4. 302c Monthly box plots of estimated changes in daily locations of the 12 psu isohaline due to Facility withdrawals

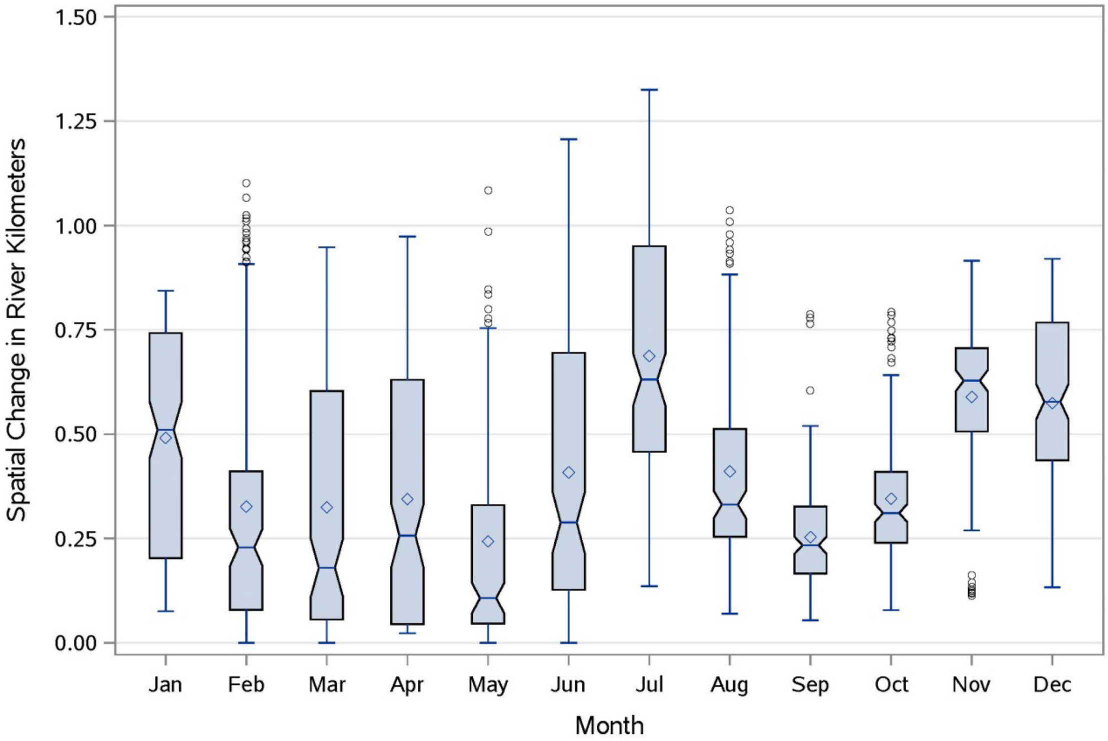

Figure 4. 302d Monthly box plots of estimated changes in daily locations of the 20 psu isohaline due to Facility withdrawals

Similar analyses presented in previous summary HBMP reports indicated that the maximum expected movement of the isohalines under the 1996 permit conditions would be seasonally limited to expected maximums of 0.1 to 0.5 kilometers, which was small given the normal daily range of tidal variation in the natural movement of the isohalines. The results of the current analyses suggest that under the Facility's revised withdrawal schedule such movement has increased to 0.7 to 1.3 kilometers. As shown in Figure 4.302, smaller changes in isohaline location due to withdrawals are estimated for the peak summer wet season months when flows are naturally higher. During such periods, the isohalines naturally, rapidly move further downstream (**Figures 4.297** through **4.300**). Thus the withdrawal schedule again functions to time the maximum changes due to withdrawals with the periods of highest natural change, limiting the magnitude of potential impacts.

4.6 Other Anthropogenic Influences on Salinity/Specific Conductivity in the Lower Peace River/Upper Charlotte Harbor

In addition to freshwater withdrawals for anthropogenic uses, there are at least two other explanatory factors for patterns and trends in salinity/conductivity in the Lower Peace river/Upper Charlotte Harbor. First, changes in land use in the watershed have influenced the amount of high conductivity water being used for irrigation and discharges related to mining. Secondly, in the future, rising sea level has the potential to move higher conductivity water further upstream.

4.6.1 Increasing Conductance Upstream of the Peace River Facility

The *Peace River Cumulative Impact Study* (PBS&J 2007) and *2011 HBMP Comprehensive Summary Report* (Atkins 2013) have identified anthropogenically related trends of increasing specific conductance within a number of the major upstream watershed tributaries to the lower Peace River (Figure 4.555). The observed changes in the lower portions of the Peace River watershed over recent decades have been primarily associated with increasing land conversions from less to more intense forms of agriculture, which increasingly relies on irrigation using higher conductivity ground water pumped from the upper Floridan aquifer. Both the *2006* and *2011 HBMP Comprehensive Summary Reports* evaluated patterns and historical trends in specific conductance and associated water quality characteristics measured at the Peace River at Arcadia gage, within both the upstream Joshua and Horse Creek tributaries, and at the fixed HBMP long-term monitoring site located at River Kilometer (RK) 30.7 located immediately upstream of the Peace River Facility's intake. The *2016 HBMP Annual Data Report* included analyses of the long-term data presented in the *2011 HBMP Comprehensive Summary Report*, updated with more recent data. The findings from the *2016 Annual Data Report* are included below.

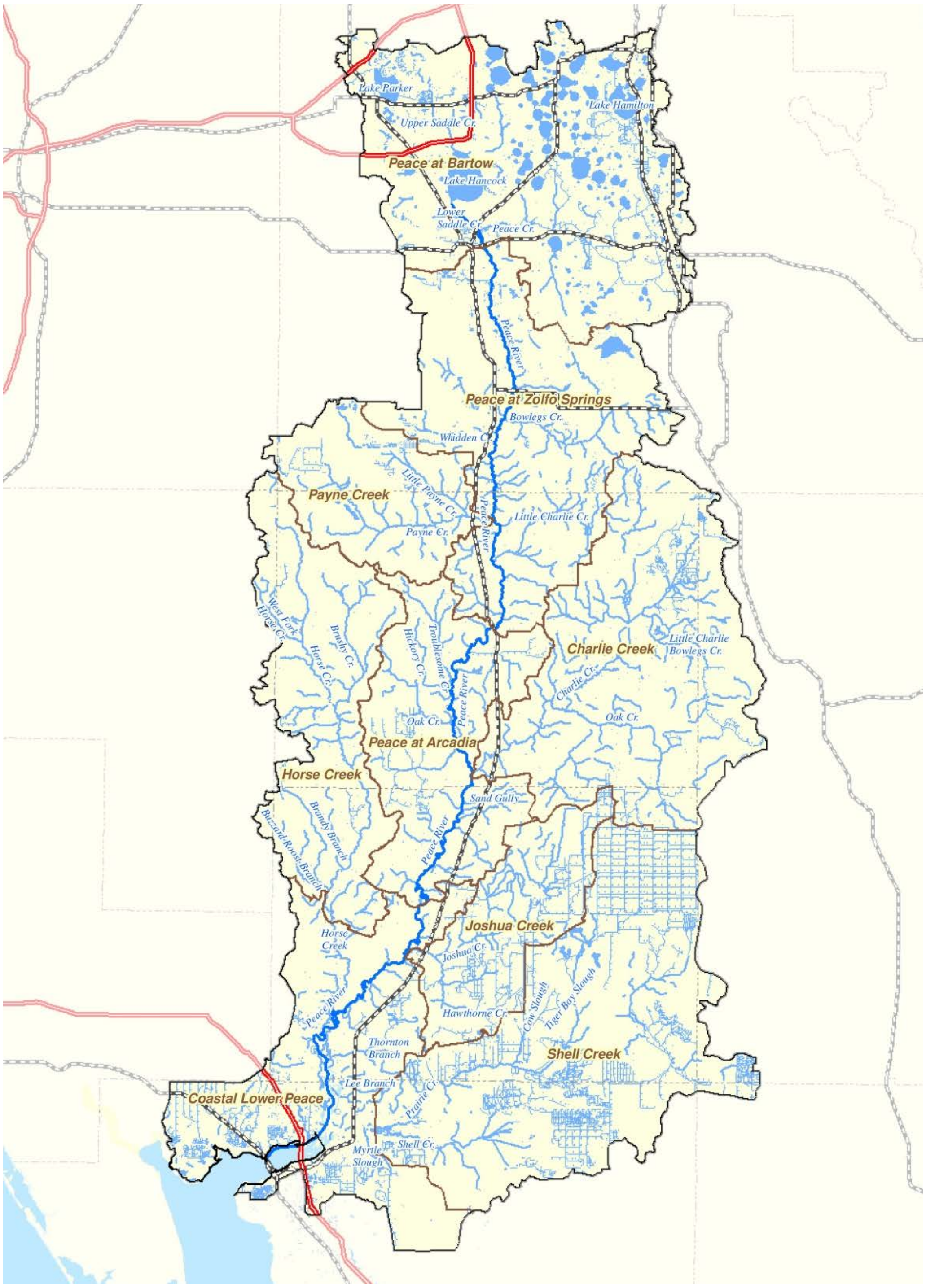

Figure 4.303 Major Hydrologic Features in the Peace River Watershed

4.6.1.1 Peace River at Arcadia

The Peace River at Arcadia USGS gage (2296750) has the longest historic flow record (1931–present) of any of the gages in the Peace River watershed. It is also the most downstream gage located along the main stem of the river and includes flows not only from the immediate basin, but also from the upstream Bartow and Zolfo Springs watershed basins, as well as the Payne, Whidden and Charlie Creek tributary basins. Historic loss of flows from springs and seeps has been one of the factors that has affected base flow to the upper portion of the Peace River. Base flows in both the upper and middle Peace River have also been affected by changes in discharges and drainage alterations associated with urbanization, phosphate mining, and more intense forms of agriculture. Specific conductance values historically measured by USGS and more recently by the District at the Peace River at Arcadia gage site have ranged from low levels measured in the 1960s to a high of nearly 1,400 uS/cm in 2011. Seasonally, the highest mean and median specific conductance values typically occur in May toward the end of the normal spring dry season, while the lowest mean and median levels are often observed toward the end the summer wet season. The analyses of long-term data presented in the *2011 HBMP Comprehensive Summary Report*, and updated with more recent data for the *2016 HBMP Annual Data Repor*t, clearly indicate that both specific conductance (see Figure 4.304) and chloride concentrations have increased over time during periods of lower flows. The observed patterns of water quality changes at the Arcadia gage clearly indicate seasonal contributions of higher conductivity groundwater into the middle portions of the Peace River. The largest increases in conductance occurred during the recent years of drought following the unusually high 2004-2005 flows. The more recent unusually high levels can be traced back to the closure of the phosphogypsum stacks in the Whidden Creek subbasin (see *2015 HBMP Annual Data Report* for more information).

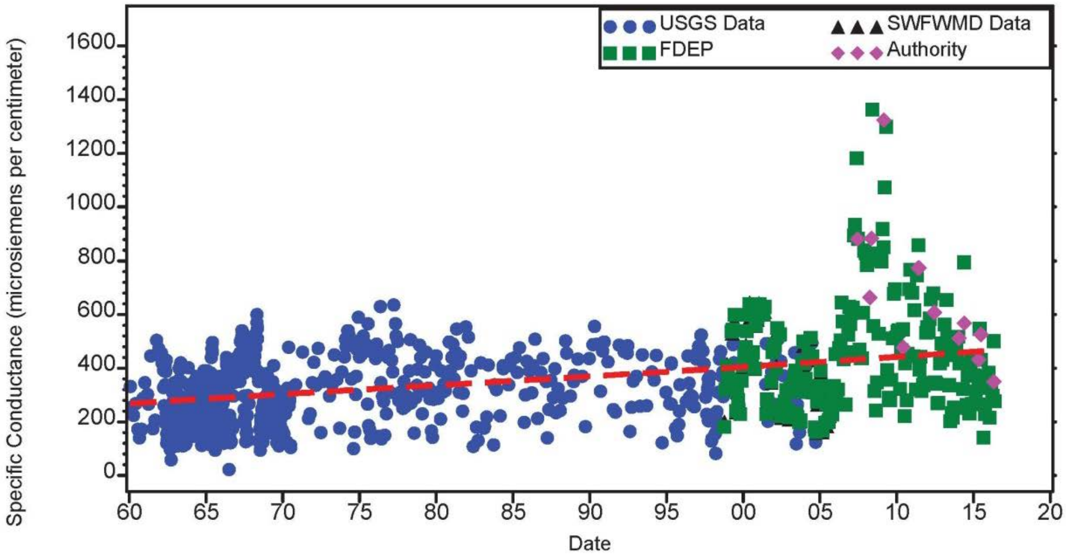

Figure 4.304 Specific conductance at USGS site 02296750/FDEP site 3556 – Peace River at Arcadia – Peace River at Arcadia Basin

4.6.1.2 Joshua Creek at Nocatee

Joshua Creek begins in northeastern DeSoto County and flows southwest to where it joins the Peace River downstream of the Peace River at Arcadia gage at a point slightly upstream from Nocatee in central DeSoto County. Land use in this basin has historically changed from predominantly native habitats and unimproved pasture in the 1940s to extensive areas of improved pasture and more intense forms of agriculture such as citrus and row crops by the late 1990s. Approximately three quarters of the land use in the Joshua Creek basin by 1999 was in agricultural uses, with 29 percent of the basin being utilized for citrus production (PBS&J 2007). These alterations to more intense forms of agriculture are reflected in the historic changes in the water chemistry of Joshua Creek, which over recent decades has seen large increases in concentrations of both specific conductance (see Figure 4.305) and total dissolved solids. These changes have been associated with increasing surface drainage of agricultural irrigation discharges of high conductivity groundwater pumped from the upper Floridan aquifer for irrigation, much of which ultimately flows into Joshua Creek. The augmentation of base flow resulting from agricultural discharges is particularly apparent during naturally occurring seasonal low flow periods, when irrigation is vital to agriculture. The available data indicate that water quality in Joshua Creek has undergone substantial chemical changes over time. These changes in conductivity and related water quality parameters stem from agricultural irrigation practices throughout the basin and have recently been particularly prevalent during drought conditions.

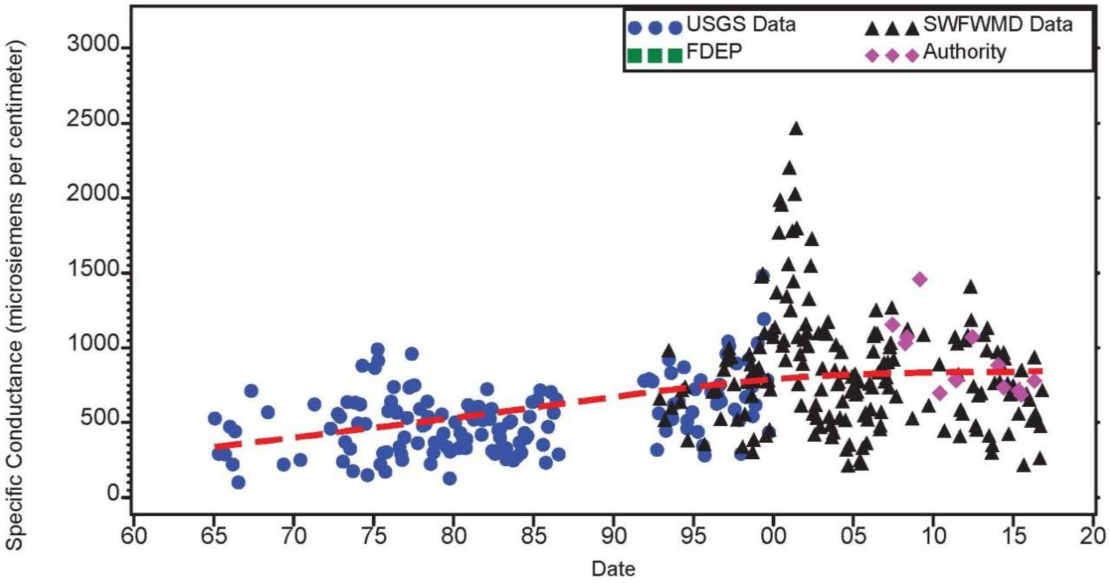

Figure 4.305 Specific conductance at USGS site 02297100/District site 24431 – Joshua Creek at Nocatee – Joshua Creek basin

The *Shell Creek and Prairie Creek Watersheds Management Plan* (SWFWMD 2004) addressed such water quality changes in Joshua Creek, acknowledging that the pumping of highly mineralized water from the upper Floridan aquifer for agricultural irrigation had been the primary contributing factor to the observed water quality degradation in Joshua Creek. The District's watershed management plan proposed that basin conductivity target levels (corresponding with the State standards for Class I waters) should not to be exceeded at any time by 2014. While progress has been made (see above graphic) in reducing levels below those observed during the 1999-2001 drought, dry-season levels remain above historic levels. Recently, FDEP extended the time-line to meet management plan goals by another five years.

4.6.1.3 Horse Creek near Arcadia

Over portions of the southern Horse Creek basin, the head of the intermediate aquifer is often higher than that of the surficial aquifer, resulting in intermediate aquifer groundwater moving upward into the surficial aquifer and then discharging into the creek (PBS&J 2007). In other portions of the basin, ground water use has historically reduced the potentiometric surface of the lower aquifers and much of Horse Creek base flow is seasonally, predominantly influenced by agricultural irrigation ground water discharges. There have been a number of land use changes in the Horse Creek basin that have influenced basin flows. Phosphate mining has moved farther south from the Payne Creek basin and continues to expand into the adjoining northern areas of the Horse Creek basin. Agriculture and urban development have both at the same time expanded in the more southern portions of the basin. Agriculture in 1999 accounted for just under half of the Horse Creek basin’s land use, with ten percent being in intense forms of agriculture (citrus and row crops).

Specific conductance levels are generally the highest in the southern part of the basin during the seasonal dry spring and other periods of low flow, such as during extended periods of drought (1999-2001 and 2006-2009). Again, the data (see Figure 4.306) indicate that specific conductance and chloride levels in southern Horse Creek have been increasing. This is primarily due to augmented base flow by surface discharges of highly mineralized deep aquifer ground water from agriculture irrigation. Specific conductance concentrations during dry periods exceed the protective levels set forth by the District in the *Shell Creek and Prairie Creek Watersheds Management Plan*.

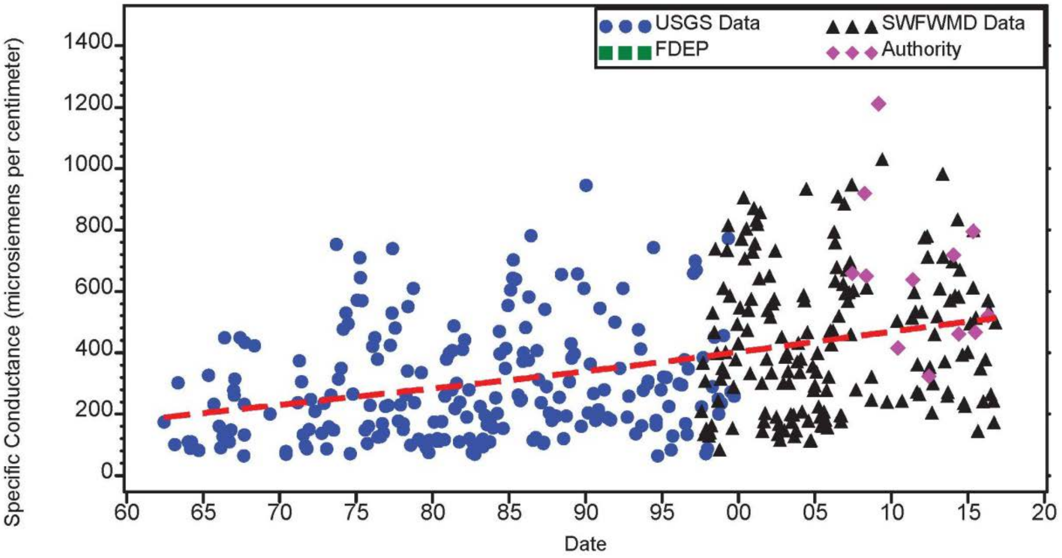

Figure 4.306 Specific conductance at USGS site 02297310/District site 24049 – Horse Creek near Arcadia – Horse Creek basin

4.6.1.4 Peace River Kilometer 30.7

Monthly samples have, and continue to be, taken as part of the fixed station HBMP water quality monitoring program just upstream of the Peace River Facility at RK 30.7 (old EQL monitoring Station 18). Monthly sampling at this "fixed" sampling site began in 1976, ceased in 1990, and then resumed in 1996 as part of both the HBMP "fixed" and "moving" station water quality monitoring in conjunction with the renewal of the Facility's 1996 water use permit. The data from this location have been of special interest due to its near upstream proximity to the Facility and thus the sampling frequency was increased in 1996 to twice monthly (by adding sample collection at RK 30.7 to the monthly "moving" HBMP sampling.) Table 4.39 provides statistical summaries of data collection between 1976-1990 in comparison to similar data from the more recent 1996-2016 time interval. In order to eliminate potential upstream influences of higher salinity estuarine waters, only samples collected when the preceding 7-day average flow exceeded 130 cfs were used in Table 4.39.

Table 4.39 Statistical Summaries for Sampling Upstream of the Facility (RK 30.7) for Historic 1976-1990 and more Recent 1996-2016 Time Intervals

Parameter	Mean	Median	Minimum	Maximum	# Samples
Statistical Summary 1976-1990					
Salinity (psu)	0.1	0.1	0	1.8	179
Conductivity (µS/cm)	375	400	100	3500	179
Total Dissolved Solids (mg/l)	264	242	99	3390	159
Chloride (mg/l)	23.3	22.2	3.5	126.0	167
Statistical Summary 1996-2016					
Salinity (psu)	0.2	0.2	0.0	1.1	395
Conductivity (µS/cm)	475	436	86	4,298	401
Total Dissolved Solids (mg/l)	291	276	0	1,024	125
Chloride (mg/l)	34.5	30.3	0.4	407.0	366

When the Peace River flows are low over an extended period of time, the reach of the lower Peace River near the Facility is tidally subject to intrusions of brackish waters from the harbor. However, beyond periods of such low flow occurrences, the primary seasonal influences on specific conductance (and other associated water quality parameters) measured immediately upstream of the Facility are constituents contained in combined flows moving downstream from the Peace River at Arcadia, Joshua Creek at Nocatee, and Horse Creek near Arcadia stations.

Dry-season conductance (Figure 4.307, as well as total dissolved solid and chloride concentrations, at RK 30.7 clearly show (Table 4.39) that measured levels immediately upstream of the Facility have been increasing over time (after having excluded the upstream movement of higher saline harbor waters). At the same time, the relative annual contributions of the upstream gages to flows at the Facility indicate that over time the proportion from the Peace River at Arcadia station has been decreasing, while the relative contributions from Horse and Joshua Creeks have been increasing. The increasing relative proportion of flows during dry periods has resulted from a decoupling of rainfall and basin flow due to agricultural augmentation of flow.

The upstream changes in water quality (conductance, chlorides, and TDS levels) originating from agricultural discharges during the dry-season have yet to be a serious hindrance to water supply. However, given these upstream changes, it is critical to continue the assessment of upstream changes in water quality as further changes may in fact impact the ability of the Authority to withdrawal water. Reducing agricultural groundwater pumping in these upstream basins would effectively decrease the potential for such impact to Facility operations. It would, however, also substantially reduce the total dry-season flows upstream of the Facility. To a great extent, the historic declines in base flow due to the anthropogenic losses of spring flows in the upper Peace River watershed have subsequently been replaced by agricultural discharges in the southern watershed basins. Future reductions of these artificially augmented flows without corresponding restoration of upper watershed base flows, when combined with projected future sea level rise, may have the unintended consequence of shifting the salt wedge further upriver and increasing the frequency of time during which the Facility is unable to withdraw river water during the dry season and put a higher premium on storing water during the wet season.

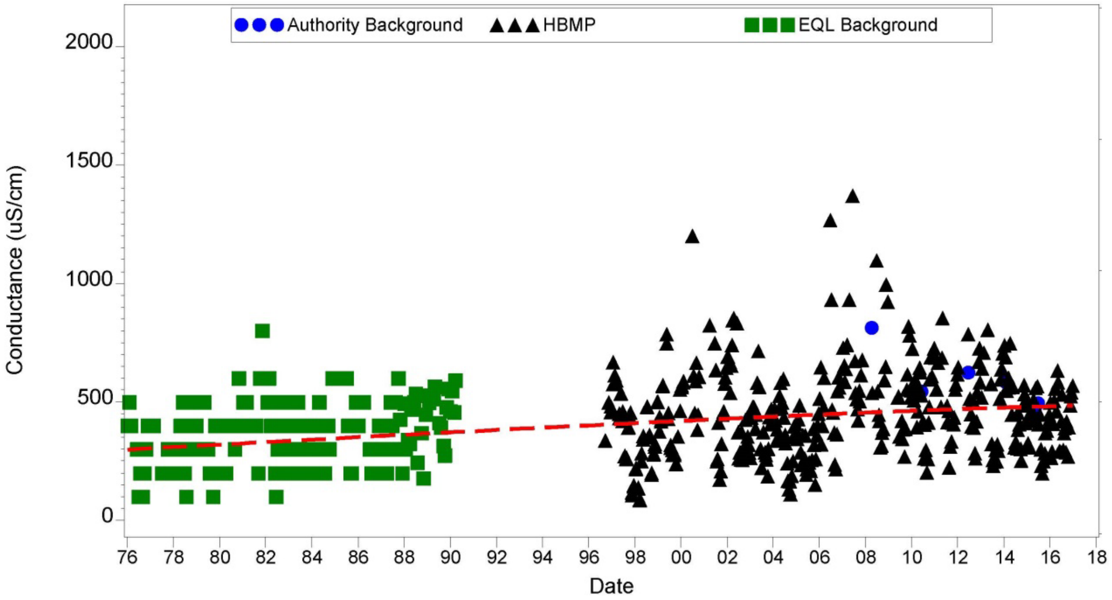

Figure 4.307 Monthly long-term surface conductivity at river kilometer 30.7 (S.R. 761)

4.6.2 Sea-Level Rise

The United Nations Intergovernmental Panel on Climate Change has projected that global temperatures are expected to increase by about 0.4°F per decade, resulting in about 2°F warmer temperatures by 2060 (International Panel on Climate Change 2007 in SFWMD 2009). According to the District's *2015 Regional Water Supply Plan Southern Planning Region* (RWSPSP, SWFWMD 2015), such increases are driving a slow but persistent increase in sea levels and are altering precipitation regimes. The District's RWSPSP states sea-level rise is likely to stress water resources in a variety of ways, including the inundation or upward migration of coastal wetlands, estuarine water encroachment in coastal rivers, and saltwater intrusion in aquifers.

As stated in the *Integrated Regional Water Supply Plan 2015* (Atkins et al. 2015), projected future sea-level rises are expected to influence future availability of lower Peace River water during seasonally lower flow conditions. At the current projected increase, impacts on Facility operations are expected to be relatively small for several decades. However, if future increases in sea-level rise are greater than projected, increasing conductance in the lower Peace River near the current Facility intake may begin by the middle of this century to limit the availability of water supplies to just seasonal high flow periods, resulting in a reduction in the frequency from past and current withdrawals.

In future analyses, empirical models, similar to those developed in this chapter to assess changes in salinity due to withdrawals, could be used to assess the effects of sea level rise. Additionally, hydrodynamic models have been developed for the Lower Peace River and could be used to discern the effects of sea level rise, independently from withdrawal effects. Specifically, those model simulations that have as their basis changes in sea leave rise and ambient salinity in Charlotte Harbor could be examined.

4.7 Summary

Overall, this chapter of the *2016 HBMP Comprehensive Summary Repor*t provides overviews and analyses relative to both the spatial and temporal patterns and trends for salinity/specific conductance in the lower Peace River/upper Charlotte Harbor estuarine system over the 1976-2016 time interval of HBMP monitoring. The chapter addresses spatial and temporal patterns and trends in salinity, the relationship(s) between salinity and freshwater flows, and anthropogenic influences on salinity in the Lower Peace River, including Facility withdrawals.

4.7.1 Spatial and Temporal Patterns and Trends in Salinity

There is a strong, distinct spatial salinity gradient along the lower Peace River monitoring transect. Salinity levels are much higher (often near Gulf water conditions) in the vicinity of the river mouth and are typically near freshwater levels just upstream of the Water Treatment Facility. Surface salinity values are routinely lower than those at the bottom of the water column.

The greatest inter-annual variability in salinity generally occurs in the surface waters at the most downstream monitoring sites where seasonal differences may reach 35 parts per thousand between extended periods of low and high freshwater inflow. However, even bottom salinity levels in the area of the US 41 Bridge (RK 6.6) exhibit similar large inter-annual variation. Both surface and bottom salinities at fixed-stations were almost uniformly significantly higher during the 1996-2016 interval than between the 1976-1989 sampling period along the entire lower river/upper harbor HBMP monitoring transect. Additionally, both the Coastal Environmental seasonally adjusted annual means test and the Seasonal Kendall Tau procedure indicated statistically significant progressive increasing upstream movements in the relative spatial distributions of isohaline locations along the HBMP monitoring transect (particularly for the 0 and 20 psu isohalines). Periods of extended drought since 1999, affecting rainfalls and river flows throughout southwest Florida, as well as upstream land use changes and small changes in sea level that have occurred over the monitoring period, may be reflected in these changes.

4.7.2 Flow – Salinity Relationships

Graphical and correlation analyses for isohaline-based and fixed-station sampling presented in this chapter support the following conclusions regarding isohalines movement and surface and bottom salinity levels:

Isohaline Location (River Kilometer) – The relative locations of each of the four HBMP isohalines along the monitoring transect show strong inverse relationships with freshwater inflows. The graphical and statistical analyses indicate that the relative spatial locations of each of the isohalines initially move rapidly downstream with increasing flows. However, over higher ranges of flows the relative slope of change becomes less as do the relationships between flow and isohaline location along the monitoring transect. The observed relationships are confounded due to the importance of both short and long-term preceding conditions, as well as the often increasing physical stratification of the water column under conditions of higher flows.

Salinity (psu) – Progressive changes occur along the sampling transect as flows increase. Under the lowest flow conditions, brackish water conditions at the surface extend upstream well beyond the point of Facility water withdrawals. Conversely, freshwater at the surface can extend downstream to near the river's mouth under conditions of extended periods of freshwater inflow. Bottom salinity along the HBMP monitoring transect also declines as freshwater inflow increase. However, even under relatively higher flows (1000-3000 cfs combined gaged flow upstream of the Facility), bottom salinities downstream of the U.S. 41 Bridge (RK 6.6) are typically greater than 20 psu and brackish conditions extend well up into the lower river into the area near Harbour Heights (RK 15.5). There is a distinct inverse relationship between measured surface salinities and increases in gaged flow up to 3000 cfs at the most downstream fixed sampling site, located near the river's mouth. However, similar relationships increasingly break down further upstream with increasing flows as surface salinities along the HBMP lower river monitoring transect change from being tidally brackish to always being characteristically freshwater under conditions of increasing freshwater flows. Bottom salinities at the two most downstream monitoring sites show relationships with flows up to about 1000 cfs after which the water column becomes highly stratified and influences of further increases are highly reduced. Moving further upstream both surface and bottom salinities show similar relationships with increasing flows.

A series of site specific empirical models were developed using averaged hourly surface conductivity, stage and gaged freshwater inflow data gathered during the periods-of-record for selected continuous recording locations. Overall, comparative plots of observed salinities with those estimated by the empirical models indicate that the models slightly over-estimate salinities at low observed levels and correspondingly somewhat under-estimate at higher observed salinity levels. However, over the typical range of salinities observed at each of the recorder sites, the models provide a relatively good fit between observed and estimated values. The models provide a fairly simple and straightforward method to analyze and estimate the potential range and magnitude of potential salinity impacts of withdrawals along the lower river downstream of the Facility over the wide range of observed natural temporal and spatial fluctuations due to the combined influences of variations in upstream flows, tides and seasonal wind patterns.

4.7.3 Anthropogenic Influences on Salinity/Specific Conductivity

Anthropogenic explanatory factors for patterns and trends in salinity were presented in this chapter. The effects of Facility withdrawals were assessed using the developed empirical models. Additionally, the influences of changes in land use in the upper watershed and potential impacts of sea-level rise were discussed.

4.7.3.1 Effects of Withdrawals on Salinity

The developed empirical models for surface salinities for the selected recorder locations were used to estimate salinities over the period 1998 through 2016 under two modeling alternatives: "No Withdrawal" Scenario and "Actual Withdrawal" Scenario. Additionally, empirical models were developed to estimate the relative spatial location of each of the four monthly monitored HBMP isohaline locations along the HBMP monitoring transect utilizing generalized forms similar to those used to estimate salinity at the continuous recorder sites. The following briefly summarizes some of the major observations and conclusions that can be drawn from the presented summary figures and tables of modeled results.

- The results emphasize the very high degrees of long-term, annual, seasonal and daily salinity variability naturally occurring temporally and spatially along the lower river. These differences are especially notable when comparing wetter intervals with extended periods characterized by lower flows.

- The annually summarized metrics of daily averaged salinity, the daily range in salinity, and the estimated daily average change in salinity due to withdrawals estimated by the developed empirical models were all larger at the three most downstream recorder locations (RK 9.2, RK 12.7 and RK 15.5). These metrics became progressively smaller moving upstream, being the lowest nearer the Facility (RK 29.8). These projected results were as expected, since as flows increase the reaches of the river near and immediately downstream of the Facility becomes less and less influenced by higher salinity water moving tidally upstream. Facility withdrawals can only influence those segments of the lower river that are still tidally influenced by saltwater moving upstream, and thus the further a location is downstream, the greater the potential duration that salinities can be influenced by withdrawals.

- The results indicated increased changes in estimated salinities along the lower river following both the 2002 and 2009 Facility expansions. However, even following these expansions, and the more recent increased percentages under the new withdrawal schedule, estimated annual average salinity changes due to actual Facility withdrawals range from approximately 0.1 psu upstream to around 1.1 psu downstream.

- However, care should be taken in comparing the statistical summaries and especially in applying “mean” values. There are typically extended annual intervals when the Facility isn’t influencing salinity along extended regions of the lower river. The Facility is not affecting salinity during the often extended seasonal periods when gage flows are below the District’s low flow threshold. Conversely, when flows are high enough that a particular reach of the river is always characterized by freshwater conditions, Facility withdrawals again do not affect salinity in extended portions of the lower river. The common instances of “no” or “zero” influences needs to be taken into consideration when evaluating relative statistical metrics.

- The daily estimated maximum salinity differences due to Facility withdrawals annually ranged from approximately 0.2 psu to 3.9 psu over the interval between 1998 and 2016. The maximum daily estimated salinity changes due to withdrawals have varied both among wetter and drier periods, as well as with changes in the permitted withdrawal schedules. Interestingly, the estimated salinity increases due to actual withdrawals have not always been calculated to have been highest at the most downstream Harbour Heights recorder location, but rather spatially sometimes further upstream at the intermediate recorder locations along the HBMP monitoring transect.

- The modeled results indicate that salinity changes due to Facility withdrawals have increased since the most recent expansion and change in the withdrawal schedule. These increases remain relatively small when compared to the range of naturally occurring daily, seasonal and longer term flow/tide related variation along the lower Peace River. The results further indicate that, by design, the largest increases in salinity resulting from the withdrawal schedule are focused into wetter periods, and occur in regions of the lower river that naturally experience relatively large salinity fluctuations. The components of the withdrawal schedule thus effectively reduce the relative potential influences of withdrawals.

- Previous summary HBMP reports indicated that the maximum expected movement of the isohalines under the 1996 permit conditions would be seasonally limited to expected maximums of 0.1 to 0.5 kilometers, which was small given the normal daily range of tidal variation in the natural movement of the isohalines. The results of the current analyses suggest that under the Facility's revised withdrawal schedule such movement has increased to 0.7 to 1.3 kilometers. Smaller changes in isohaline location due to withdrawals are estimated for the peak summer wet season months when flows are naturally higher. During such periods, the isohalines naturally, rapidly move further downstream. Thus the withdrawal schedule again functions to time the maximum changes due to withdrawals with the periods of highest natural change, limiting the magnitude of potential impacts.

4.7.3.2 Other Anthropogenic Influences on Salinity

Prior reports (PBS&K 2007, Atkins 2013) have identified anthropogenically related trends of increasing specific conductance within a number of the major upstream watershed tributaries to the lower Peace River. The observed changes in the lower portions of the Peace River watershed over recent decades have been primarily associated with increasing land conversions from less to more intense forms of agriculture, which increasingly relies on irrigation using higher conductivity ground water pumped from the upper Floridan aquifer. Additional increases may have occurred as a result of mining activities in the watershed. This chapter presents updates of earlier evaluations of patterns and historical trends in specific conductance and associated water quality characteristics measured at the Peace River at Arcadia gage, within both the upstream Joshua and Horse Creek tributaries, and at the fixed HBMP long-term monitoring site located at River Kilometer (RK) 30.7 located immediately upstream of the Peace River Facility's intake. These updated analyses indicate qualitatively that increased specific conductance (and related parameters) are still evident at the sites evaluated upstream of the Facility.

The upstream changes in water quality (conductance, chlorides, and TDS levels) originating from agricultural discharges during the dry-season have yet to be a serious hindrance to water supply. However, this is not to say that such changes may not become a problem in the future if trends in the contributing upstream basins continue. Reducing agricultural groundwater pumping in these upstream basins would effectively decrease the potential for such impact to Facility operations. It would, however, also substantially reduce the total dry-season flows upstream of the Facility. To a great extent, the historic declines in base flow due to the anthropogenic losses of spring flows in the upper Peace River watershed have subsequently been replaced by agricultural discharges in the southern watershed basins. Future reductions of these artificially augmented flows without corresponding restoration of upper watershed base flows, when combined with projected future sea level rise, may have the unintended consequence of shifting the salt wedge further upriver and increasing the frequency of time during which the Facility is unable to withdraw river water during the dry season and put a higher premium on storing water during the wet season.

5.0 Patterns and Trends of Hydrobiological Water Quality Indicators in the Lower Peace River/Upper Charlotte Harbor Estuarine System

The primary objectives of this section are to provide overviews and analyses of the patterns and trends in water quality in the lower Peace River/upper Charlotte Harbor estuarine system over the 1976-2016 interval of HBMP monitoring. This chapter addresses water quality parameters other than salinity, which was discussed in detail in **Chapter 4**. For a series of water quality parameters including dissolved oxygen (DO), chlorophyll *a*, nitrate/nitrite (NOX), total kjeldahl nitrogen (TKN), ortho-phosphorus (OP), silica, and color, this chapter focuses on:

- Depicting and describing the patterns and trends for HBMP data along the longitudinal monitoring transect (spatial comparison) for both fixed-station and isohaline-based sampling;
- Depicting and describing temporal trends in identified water quality parameters sampled through the HBMP for both isohaline-based and fixed-station sampling;
- Discussing changes in water quality upstream of the Peace River Facility as it pertains to patterns and trends observed in HBMP monitoring data; and
- Evaluating the effects of flow on the identified water quality parameters.

Analytical methods to investigate spatial and temporal patterns and trends for the identified water quality parameters for data from isohaline-based and fixed-station HBMP sampling follow those used in **Chapter 4** and **Appendix C** for salinity. Results are organized by each individual water quality parameter.

5.1 Dissolved Oxygen (DO)

This section presents the spatial and temporal patterns and trends in dissolved oxygen data collected by the HBMP at both isohaline-based and fixed-station locations. Additionally, the relationship between flow and dissolved oxygen is investigated.

5.1.1 Spatial Patterns in Dissolved Oxygen

This section assesses longitudinal gradients in dissolved oxygen along the Peace River monitoring transect. In general, surface dissolved oxygen measurements are routinely higher than bottom dissolved oxygen.

Figure 5.1 provides box and whisker plots of dissolved oxygen data sampled at the fixed-station locations. The features of a box and whisker plot were illustrated in **Figure 4.3**. When data collected throughout all months are compared, surface dissolved oxygen levels are similar along the lower Peace River monitoring transect. However, bottom dissolved oxygen levels are somewhat lower in the lower reaches of the monitoring transect than more upstream. This is particularly apparent during the summer periods of increased freshwater inflow due to increased stratification of the water column.

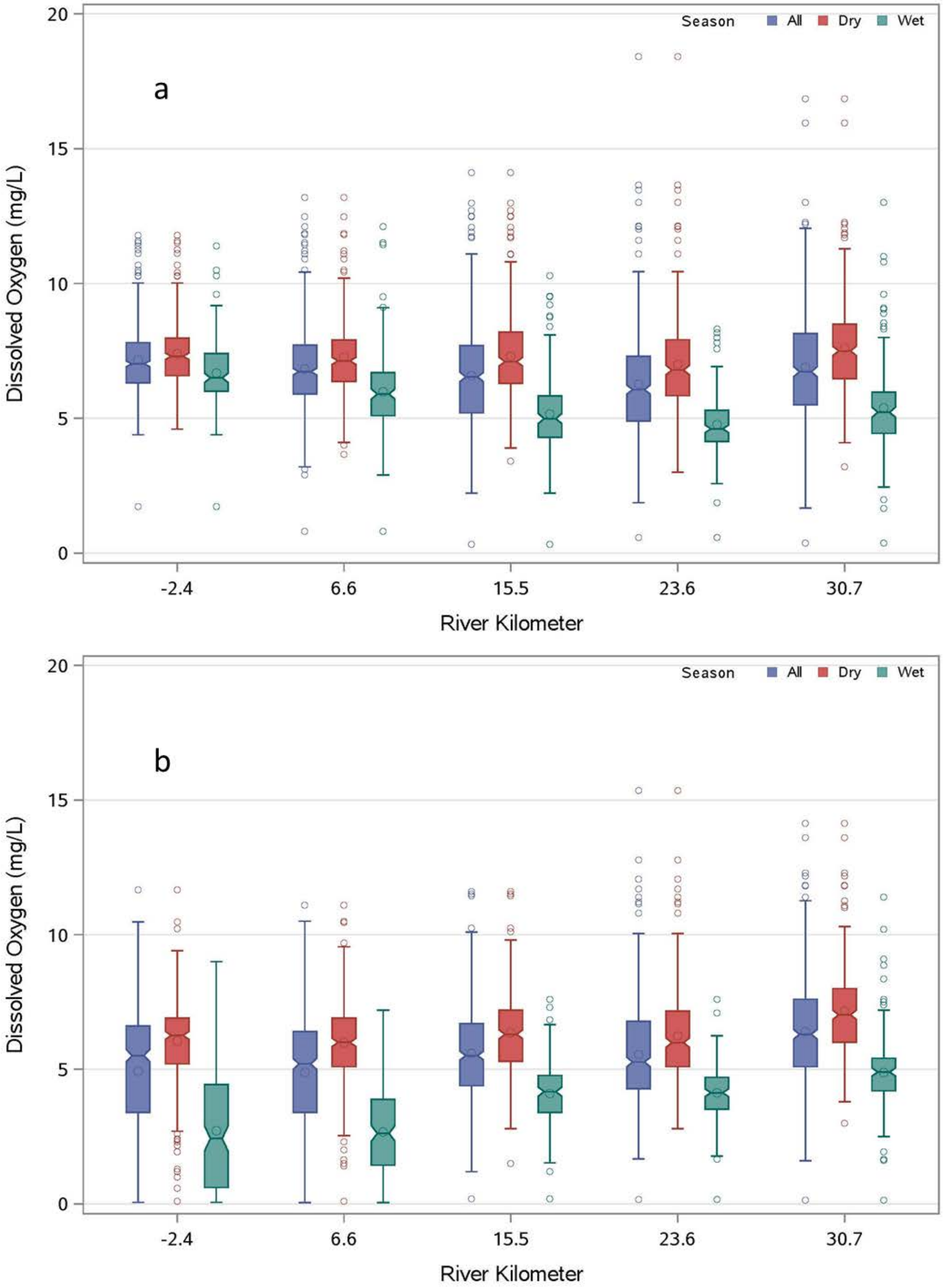

Figure 5.1 Fixed-station boxplots of a) surface and b) bottom dissolved oxygen levels for all samples and seasonally (1976-2016)

Data for the isohaline-basing "moving" station sampling also illustrate, that for all salinity ranges sampled, wet-season samples are typically lower in dissolved oxygen, even at the surface, than dry-season samples. However, freshwater stations (0 psu isohaline) tended to have slightly lower levels of dissolved oxygen at the surface during the summer than the other isohalines (Figure 5.2).

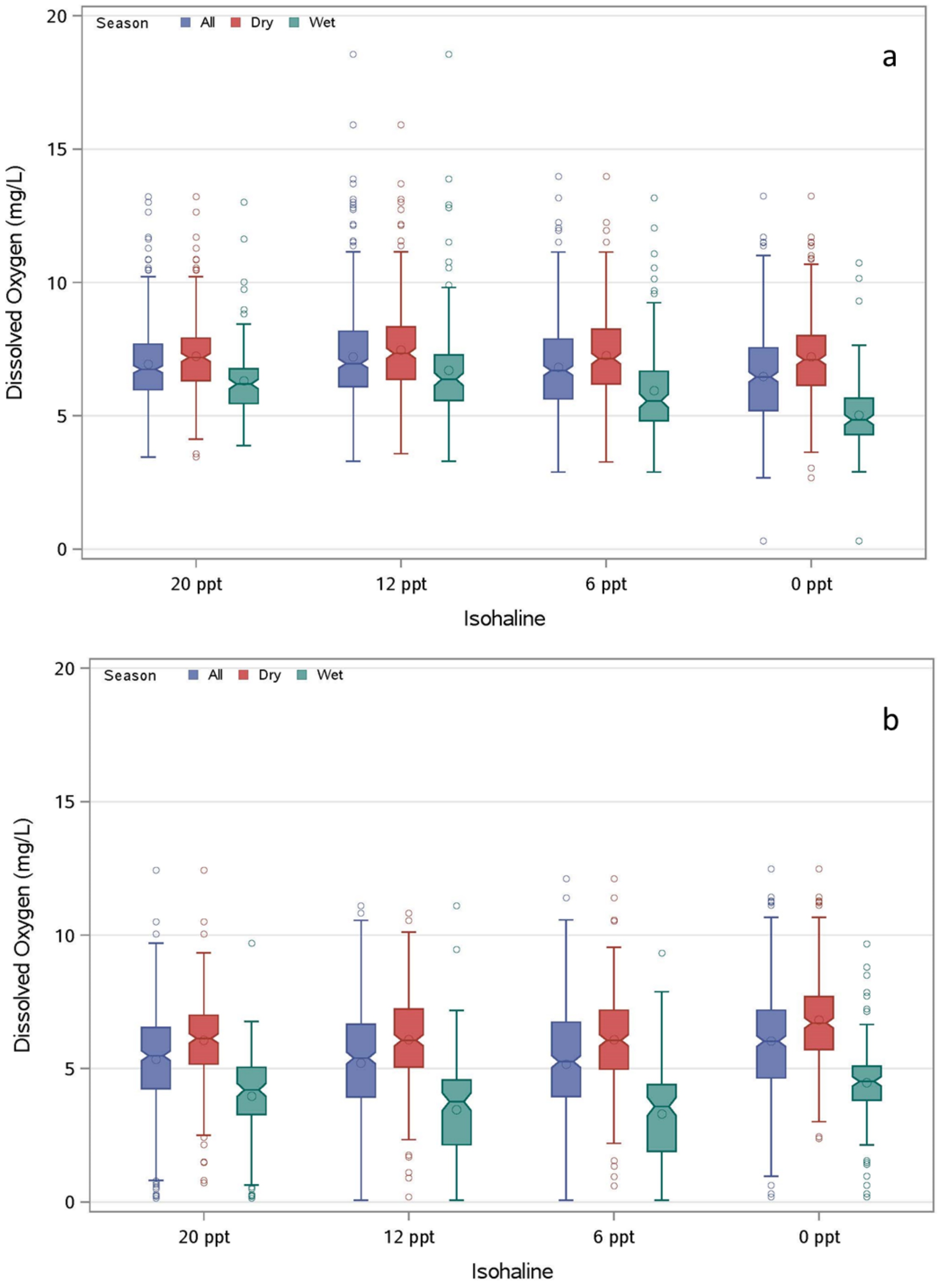

Figure 5.2 Boxplots of a)surface and b)bottom dissolved oxygen at each isohaline for all samples and seasonally (1984-2016)

5.1.2 Temporal Trends in Dissolved Oxygen

This section presents analyses of patterns and trends in inter- and intra-annual variation in dissolved oxygen along the Peace River monitoring transect. Time-series plots of dissolved oxygen data collected from surface and bottom samples at each of the selected fixed-station locations between 1976-1989 and 1996-2016 are summarized in Table 5.1. Uniform vertical graphical scales are applied in Figures 5.3 through Figure 5.12 in order that direct comparisons can be readily made along the HBMP monitoring transect. Box and whisker plots depicting inter- and intra-annual variability in dissolved oxygen at the isohaline-based stations for the period 1984-2016 are presented in Table 5.2. These graphical procedures provide overviews of the monthly ranges and long-term patterns for the HBMP dissolved oxygen measurements. The presented figures depict the relative degrees of both annual and inter-annual variability observed over the HBMP period along the lower Peace River/upper Charlotte Harbor estuarine monitoring transect.

Dissolved oxygen concentrations in the lower Peace River estuarine system show distinct seasonal patterns, with the lowest levels typically occurring during the summer wet-season. Even near the top of the water column dissolved oxygen concentrations are often below State of Florida standards (5 mg/L for freshwater and 4 mg/L for predominantly estuarine/marine). Measured levels are generally higher during cooler months, due to lower water temperatures (that increase the ability of the water to hold more dissolved gases) and seasonally increasing wind stress and mixing. Higher daytime values are also often associated with increases in phytoplankton production (chlorophyll *a*) and typically account for many of the unusually high observed values. Near-bottom dissolved oxygen concentrations show clear seasonal cycles in response to higher freshwater flows during the summer wet-season. The duration and magnitude of periods of low dissolved oxygen concentrations increase toward the river mouth as higher bottom salinities establish greater vertical stratification in the water column during high flows. Bottom dissolved oxygen concentrations at the two most downstream fixed-location monitoring stations, located at RK –2.4 and 6.6, are characterized by hypoxic (less than 2.0 mg/L) and even anoxic (less than 0.2 mg/L) conditions during extended periods of high flows during the summer wet-season.

Table 5.1
Time-Series Plots of Monthly Dissolved Oxygen at “Fixed” HBMP Stations

Water Quality Parameter	River Kilometer -2.4	River Kilometer 6.6	River Kilometer 15.5	River Kilometer 23.6	River Kilometer 30.7
Surface DO	Figure 5.3	Figure 5.5	Figure 5.7	Figure 5.9	Figure 5.11
Bottom DO	Figure 5.4	Figure 5.6	Figure 5.8	Figure 5.10	Figure 5.12

Note: no data available 1990-1995.

Table 5.2
Inter- and Intra-Annual Variability in Surface and Bottom Dissolved Oxygen at Isohaline-Based “Moving” HBMP Monitoring Salinity Zones (1984-2016)

Isohaline	Box Pot of Inter-Annual Variability	Box Plot of Intra-Annual Variability
0 psu Salinity	**Figure 5.13**	**Figure 5.17**
6 psu Salinity	**Figure 5.14**	**Figure 5.18**
12 psu Salinity	**Figure 5.15**	**Figure 5.19**
20 psu Salinity	**Figure 5.16**	**Figure 5.20**

Table 5.3 summarizes the results of tests for statistically significant changes in seasonally based mean annual dissolved oxygen for fixed lower Peace River sampling locations. Because of the gap in sampling from 1990-1995, a typical trend test (such as a seasonal Kendall tau) is not valid. Therefore, to examine long-term changes at the fixed-stations, analyses were performed using methods developed by Coastal Environmental (1996) for the Florida Department of Environmental Protection using seasonally weighted yearly averages. In this instance, the procedure was used to examine statistical differences between the two disjunct periods of record. Details of these analyses are provided in Appendix C. Individually scaled graphics by monitoring location are presented in Figure 5.21 through 5.30, which depict the results of seasonally based statistical tests for differences between the 1976-1989 and 1996-2016 time intervals. The results of these analyses suggest that more recent levels of dissolved oxygen in the downstream half of the monitoring area are lower than the earlier period of monitoring.

Table 5.3
Period Difference Tests
Peace River HBMP Estuary Sites Water Quality (1976-1989 and 1996-2016)

River Kilometer Parameter	Period Difference Test	Difference in Means	P Value	Change
River Kilometer –2.4				
Dissolved Oxygen (Surface)	**Figure 5.21**	-0.31	**0.025**	▼
Dissolved Oxygen (Bottom)	**Figure 5.22**	-0.24	0.137	
River Kilometer 6.6				
Dissolved Oxygen (Surface)	**Figure 5.23**	-0.32	**0.048**	▼
Dissolved Oxygen (Bottom)	**Figure 5.24**	-0.34	**0.030**	▼
River Kilometer 15.5				
Dissolved Oxygen (Surface)	**Figure 5.25**	-0.28	**0.072**	▼
Dissolved Oxygen (Bottom)	**Figure 5.26**	-0.28	**0.042**	▼
River Kilometer 23.6				
Dissolved Oxygen (Surface)	**Figure 5.27**	-0.11	0.467	
Dissolved Oxygen (Bottom)	**Figure 5.28**	-0.12	0.433	

Table 5.3
Period Difference Tests
Peace River HBMP Estuary Sites Water Quality (1976-1989 and 1996-2016)

River Kilometer Parameter	Period Difference Test	Difference in Means	P Value	Change
River Kilometer 30.7				
Dissolved Oxygen (Surface)	**Figure 5.29**	-0.19	0.266	
Dissolved Oxygen (Bottom)	**Figure 5.30**	-0.21	0.210	

* Red ▼ denotes significance at the 0.05 level
* Blue ▼ denotes significance at the 0.10 level

The Coastal Environmental (1996) method of testing seasonally adjusted annual averages and the monthly Seasonal Kendall Tau statistical procedure (See **Section 3.2.3** for complete description) were both used to test for the potential presence of long-term systematic changes in dissolved oxygen at each estuarine isohaline-based station locations between 1984 and 2016. Summary results of these trend analyses are presented in Table 5.4. The seasonally weighted annual average method identified statistically significant trends in dissolved oxygen at all isohalines, while the Seasonal Kendall Tau trend test method only indicated a significant trend for the 0 psu isohaline.

Table 5.4
Trend Tests of Isohaline Dissolved Oxygen Concentrations (1984-2016)

Salinity Based Isohaline Location	Seasonally Adjusted Annual Means			Seasonal Kendall Tau of Monthly Means		
	Yearly Mean	Slope	P Value	Tau Value	Slope	P Value
0 psu	**Figure 5.31**	0.01	**0.025**	0.09	0.015	**0.016**
6 psu	**Figure 5.32**	-0.02	**0.025**	-0.05	-0.01	0.316
12 psu	**Figure 5.33**	-0.02	**0.027**	-0.09	-0.018	0.121
20 psu	**Figure 5.34**	-0.01	**0.062**	-0.08	-0.013	0.192

* **Red** denotes significance at the 0.05 level
** **Blue** denotes significance at the 0.10 level

Observations from the moving, isohaline-based sites indicate that measured surface dissolved oxygen levels at the most upstream isohaline (0 psu) have increased over time. A potential mechanism that might explain the apparent increase may be related to the previously discussed recent periods of extensive drought resulting in lower freshwater inflows of highly colored water. Flows result in both higher average nutrient (inorganic and organic nitrogen) loadings to the upper reaches of the estuary, along with increased color which reduces the availability of light. Sufficient flow to stimulate phytoplankton production, while not being high enough flow to reduce light levels, may result in higher dissolved oxygen levels. Unfortunately, such relationships are confounded by a number of additional seasonal factors including temperature, nutrient recycling and residence time.

Other studies (CHNEP 1999, 2003 and PBS&J 2007, 2009) have noted apparent declines in dissolved oxygen concentrations in the lower river over time, but have been unable to clearly identify any cause. Proposed explanations have included: declines in the very high chlorophyll *a* concentrations that were frequently observed during the 1970s and 1980s; influences of higher average flows during more recent time periods; and potentially progressive changes associated with *in situ* dissolved membrane technology and measuring precision. The current analyses, based on a somewhat longer data set than these previous analyses, generally finds similar surface and bottom annual average dissolved oxygen concentrations in the upper portion of the HBMP monitoring transect when comparing the 1976-1989 and 1996-2016 time periods. However, small (<0.35 mg/L) statistically significant decreases between the two periods were observed for the lower reaches of the river (Table 5.3).

5.1.3 Relationship with Flow

Plots of dissolved oxygen at each of the fixed-stations versus combined gaged flow upstream of the Facility (0 to 3000 cfs) are presented in Table 5.5; and for each of the four HBMP isohalines in Table 5.6. Additionally, correlation analysis was used to assess potential statistical differences in the relationships between seven-day average combined gaged flow upstream of the Facility and surface dissolved oxygen at each of the five fixed-station and four moving HBMP isohaline-based sampling stations. Significant results are indicated below, and include the correlation coefficient (R value). The relative degree of variability (percent) explained for dissolved oxygen concentrations (the dependent variable) by changes in flow (the independent variable) is the correlation coefficient squared or R^2.

Table 5.5
Relationships between Surface and Bottom Dissolved Oxygen and Freshwater Inflow at Fixed Stations

Water Quality Parameter	Monitoring Station River Kilometer				
	-2.4	6.6	15.5	23.6	30.7
Dissolved Oxygen	Figure 5.35	Figure 5.36	Figure 5.37	Figure 5.38	Figure 5.39

Table 5.6
Dissolved Oxygen Versus Flow at Isohaline-Based Stations

Water Quality Parameter	Estuarine Isohaline			
	0 psu	6 psu	12 psu	20 psu
Dissolved Oxygen	Figure 5.40	Figure 5.41	Figure 5.42	Figure 5.43

As the figures indicate, large degrees of variation often occur at a given flow depending on the history of flows over both the immediate and longer-term preceding periods. Except under the very lowest flows, the intermediate isohalines typically exhibit the highest levels of dissolved oxygen along the HBMP monitoring transect. This result can be directly attributed to the seasonal interactions of flow (which delivers both nutrients and higher water color) with the spatial distribution of the zones of maximum phytoplankton production (resulting in higher daytime dissolved oxygen levels) along the HBMP salinity gradient.

As flows initially increase, upstream surface water dissolved oxygen concentrations slightly increase, and then concentrations decline under further increases in flow. As previously discussed, initially increasing flows deliver more nitrogen stimulating phytoplankton growth (which produces higher daytime dissolved oxygen levels). However, at some point further increasing freshwater inflows result in higher ambient water color, which results in reduced penetration of light into the water column and slows phytoplankton growth and consequently the production of oxygen. In addition, water column density stratification increases with increasing flow, especially in the lower reaches of the river. These phenomena, combined with the physical decrease in saturation levels with increasing summer wet-season temperatures, results in the observed declining levels in surface dissolved oxygen levels with increasing flows in the upper areas of the lower Peace River HBMP transect.

Under lower flows, near bottom dissolved oxygen levels typically exceed 4.0 mg/l. However, as flows increase and the water column downstream of approximately Harbour Heights (RK 15.5) begins to stratify bottom dissolved oxygen levels begin to be depressed. This is especially true downstream of the U.S. 41 Bridge (RK 6.6) where measured bottom concentrations during higher flows fall below 2.0 mg/l (generally indicating hypoxic conditions).

Many of the sampling locations exhibited significant negative correlations with seven-day average flow. A negative correlation indicates reduced dissolved oxygen levels with increasing flow. While the overall correlations were significant, the amount of variability explained for dissolved oxygen concentrations by changes in flow were generally less than 25%. The significant correlations (fixed-stations indicated by river kilometer [RK]; moving stations indicated by isohaline [psu]) were:

- RK 6.6 (R=-0.26)
- RK 15.5 (R=-0.34)
- RK 23.6 (R=-0.30)
- RK 30.7 (R=-0.38)
- 0 psu (R=-0.35)
- 6 psu (R=-0.15)

The relationship between dissolved oxygen concentrations and flow is confounded by the combined influences of seasonal changes in water temperature and salinity, as well as the interactions between nutrient stimulation and color inhibition mediated by flow.

5.2 Chlorophyll *a*

This section presents the spatial and temporal patterns and trends in chlorophyll *a* data collected by the HBMP at both isohaline-based and fixed-station locations. Additionally, the relationship between flow and chlorophyll *a* is investigated.

5.2.1 Spatial Patterns

This section assesses longitudinal gradients in chlorophyll *a* along the Peace River monitoring transect. Figure 5.44 provides box and whisker plots of chlorophyll *a* data sampled at the fixed-station locations. Concentrations of chlorophyll *a* exhibit slightly higher averages in the middle reach of the monitoring transect. In the lower reaches of the transect, average values tend to increase during the summer wet season, while those in the upper portion of the monitoring area show a slight decline.

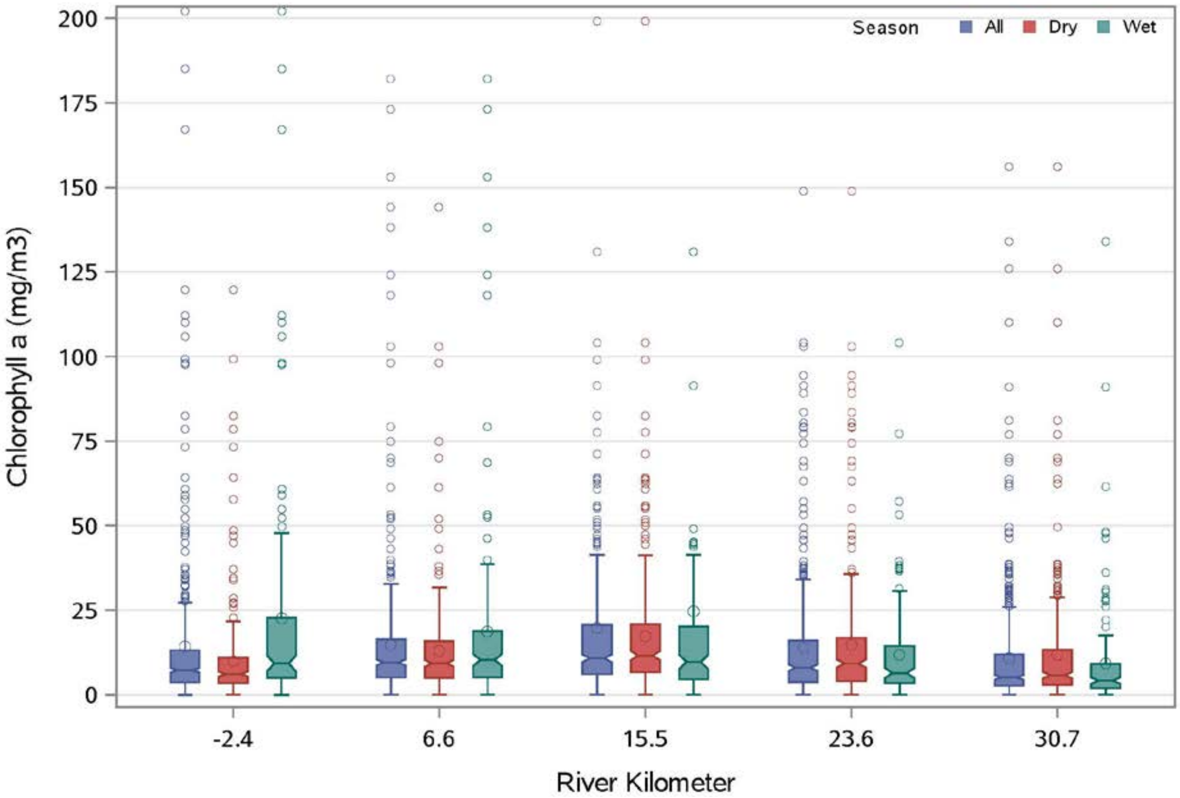

Figure 5.44 Fixed-station boxplots of surface Chlorophyll *a* concentrations for all samples and seasonally (1976-2016)

Data for the isohaline-based “moving” station sampling illustrate that chlorophyll *a* levels tend to always be relatively low in the freshwater end of the sampling range (0 psu isohaline, Figure 5.45). Levels at the two mid-range isohalines (6 and 12 psu) exhibit greater variability and averages during the wet season are somewhat higher.

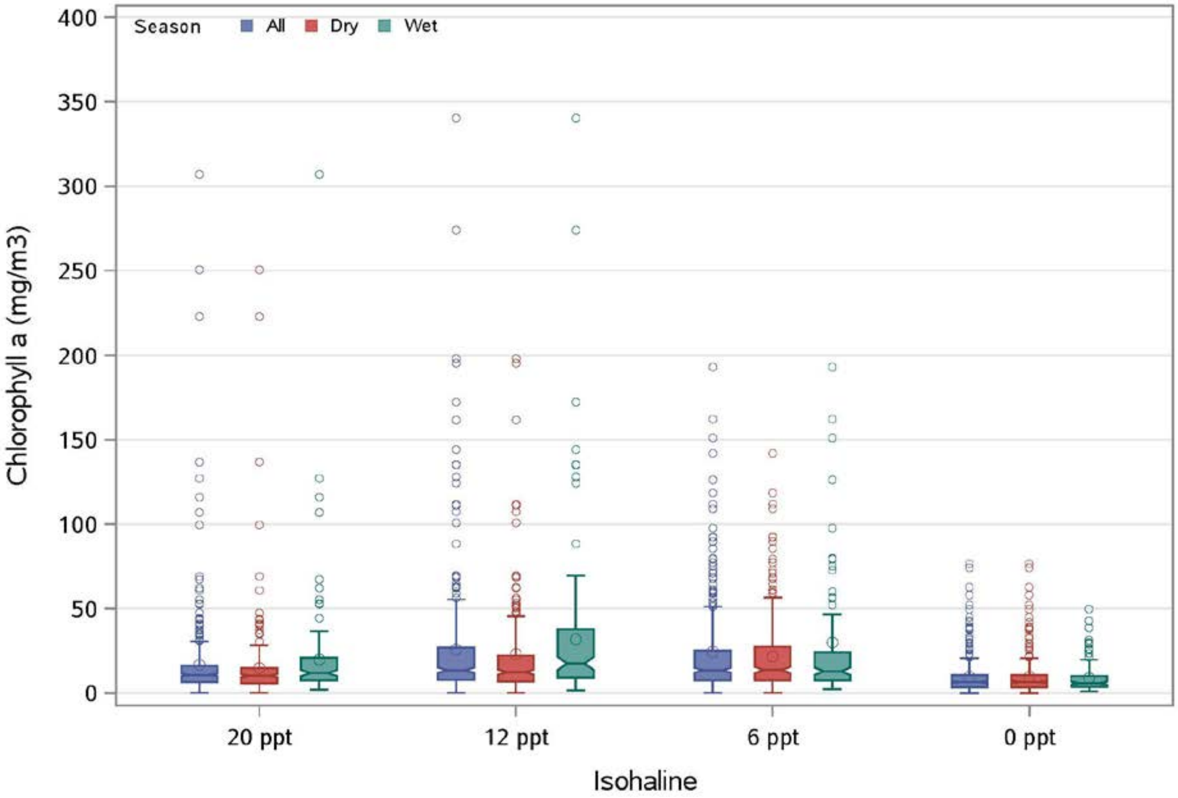

Figure 5.45 Boxplots of Chlorophyll *a* at each isohaline for all samples and seasonally (1984-2016)

5.2.2 Temporal Trends

This section presents analyses of patterns and trends in inter- and intra-annual variation in chlorophyll *a* along the Peace River monitoring transect. Time-series plots of chlorophyll *a* data collected from surface at each of the selected fixed-station locations between 1976-1989 and 1996-2016 are summarized in Table 5.7. Uniform vertical graphical scales are applied in Figures 5.46 through Figure 5.50 in order that direct comparisons can be readily made along the HBMP monitoring transect. Box and whisker plots depicting inter- and intra-annual variability in surface chlorophyll *a* at the isohaline-based stations for the period 1984-2016 are presented in Table 5.8. These graphical procedures provide overviews of the monthly ranges and long-term patterns for the HBMP chlorophyll *a* measurements. The presented figures depict the relative degrees of both annual and inter-annual variability observed over the HBMP period along the lower Peace River/upper Charlotte Harbor estuarine monitoring transect. In particular, Figures 5.51-5.54 illustrate the range of values that can occur within a year varies greatly from year to year, with the greatest ranges occurring at the intermediate isohalines (6 and 12 psu).

Table 5.7
Time-Series Plots of Monthly Chlorophyll a at “Fixed” HBMP Stations

Water Quality Parameter	River Kilometer -2.4	River Kilometer 6.6	River Kilometer 15.5	River Kilometer 23.6	River Kilometer 30.7
Chlorophyll *a*	Figure 5.46	Figure 5.47	Figure 5.48	Figure 5.49	Figure 5.50

Note: no data available 1990-1995.

Table 5.8
Inter- and Intra-Annual Variability in Chlorophyll *a* at Isohaline-Based “Moving” HBMP Monitoring Salinity Zones (June 1984-2016)

Isohaline	Box Pot of Inter-Annual Variability	Box Plot of Intra-Annual Variability
0 psu Salinity	Figure 5.51	Figure 5.55
6 psu Salinity	Figure 5.52	Figure 5.56
12 psu Salinity	Figure 5.53	Figure 5.57
20 psu Salinity	Figure 5.54	Figure 5.58

Table 5.9 summarizes the results of tests for statistically significant changes in seasonally based mean annual chlorophyll *a* for fixed lower Peace River sampling locations. Because of the gap in sampling from 1990-1995, a typical trend test (such as a seasonal Kendall tau) is not valid. Therefore, to examine long-term changes at the fixed-stations, analyses were performed using methods developed by Coastal Environmental (1996) for the Florida Department of Environmental Protection using seasonally weighted yearly averages. In this instance, the procedure was used to examine statistical differences between the two disjunct periods of record. Details of these analyses are provided in **Appendix C**. Individually scaled graphics by monitoring location are presented in Figure 5.59 through 5.63, which depict the results of seasonally based statistical tests for differences between the 1976-1989 and 1996-2016 time intervals. No significant differences were detected between the two monitoring periods at any station.

Table 5.9
Period Difference Tests
Peace River HBMP Estuary Sites Chlorophyll *a* (1976-1989 and 1996-2016)

River Kilometer Parameter	Period Difference Test	Difference in Means	P Value	Change
River Kilometer -2.4	Figure 5.59	2.74	0.279	
River Kilometer 6.6	Figure 5.60	-0.93	0.692	
River Kilometer 15.5	Figure 5.61	4.53	0.353	
River Kilometer 23.6	Figure 5.62	-0.53	0.790	

Table 5.9
Period Difference Tests
Peace River HBMP Estuary Sites Chlorophyll *a* (1976-1989 and 1996-2016)

River Kilometer Parameter	Period Difference Test	Difference in Means	P Value	Change
River Kilometer 30.7	**Figure 5.63**	0.69	0.719	

* Red ▼ denotes significance at the 0.05 level
* Blue ▼ denotes significance at the 0.10 level

The Coastal Environmental (1996) method of testing seasonally adjusted annual averages and the monthly Seasonal Kendall Tau statistical procedure (See **Section 3.2.3** for complete description) were both used to test for the potential presence of long-term systematic changes in chlorophyll *a* at each estuarine isohaline-based station locations between 1984 and 2016. Summary results of these trend analyses are presented in Table 5.10. The seasonally weighted annual average method and the Seasonal Kendall Tau trend test method only indicated a significant trend for the 20 psu isohaline.

Table 5.10
Trend Tests of Isohaline Chlorophyll *a* Concentrations (1984-2016)

Salinity Based Isohaline Location	Seasonally Adjusted Annual Means			Seasonal Kendall Tau of Monthly Means		
	Yearly Mean	Slope	P Value	Tau Value	Slope	P Value
0 psu	**Figure 5.64**	-0.03	0.509	0.04	0.022	0.540
6 psu	**Figure 5.65**	0.14	0.641	-0.03	-0.044	0.402
12 psu	**Figure 5.66**	0.07	0.712	0.00	0.004	0.930
20 psu	**Figure 5.67**	0.35	**0.007**	0.11	0.117	**0.041**

* **Red** denotes significance at the 0.05 level
** **Blue** denotes significance at the 0.10 level

While none of the tests for differences between the two sampling periods at fixed-station locations suggest significant differences in chlorophyll *a* concentrations, the applied statistical trend procedures suggest chlorophyll *a* phytoplankton levels increased within the 20 psu isohalines over the 1984-2016 time interval. Higher chlorophyll *a* levels are a reflection of the corresponding observed significant higher color levels (that can serve as a proxy for nutrient loadings; see Section 5.7 for analyses of color), and summer wet-season flows that have, on average, characterized portions of proposed warmer AMO phase since 1995. Spatially, the highest chlorophyll *a* levels occur within the two intermediate salinity zones. During the spring, high levels of phytoplankton biomass often are observed within the 6 psu isohaline, which characterizes the zone of the estuary where nutrient rich freshwater first mixes with low nutrient harbor water. A second, often smaller peak in phytoplankton chlorophyll a usually occurs within the 6 psu salinity zone during the fall, as water color (inflow) decreases. Conversely, an opposite seasonal pattern occurs in the more saline 12 psu salinity zone, where nutrients (nitrogen) are more limited and the spring phytoplankton bloom is smaller, and the fall increase in response to the reduction in light limitations is more pronounced. In the reaches of the estuary characterized by the 20 psu isohaline, phytoplankton production is reduced and shows less seasonal variability, with the highest concentrations often occurring at the end of the summer wet-season.

Previous studies (CHNEP 1999, 2003 and PBS&J 1999, 2004, 2007) observed marked declines in the periodic very high chlorophyll *a* concentrations (phytoplankton "blooms") that commonly occurred in the surface waters throughout the lower Peace River/upper Charlotte Harbor estuarine system during the late 1970s and early 1980s. The *2006 HBMP Comprehensive Summary Report* observed that between 2004 and 2006 "chlorophyll *a* levels in the lower river and upper harbor uniformly shown increases to annual average levels not seen in over twenty years". As previously noted, these observed increased chlorophyll a levels followed Hurricanes Charley, Francis and Jeanne in August and September of 2004. These events seem to correspond with the apparent relatively brief observed increase in chlorophyll a concentrations, since levels upstream and near the Facility declined in response to unusually dry conditions between 2006 and 2011. Since phosphorus levels in the lower Peace River/upper Charlotte Harbor Estuary are naturally high, and nutrient additions (Montgomery et al. 1991) have shown local estuarine phytoplankton populations to be seasonally nitrogen and not phosphorus limited, it is doubtful that the observed increases in phosphorus levels during 2004 and 2005 was directly the cause of the observed increases in chlorophyll *a* concentrations. It is more likely that other factors, including larger than normal Lake Hancock discharges, were responsible for the observed increases in phytoplankton levels. The consequences of historic excessive nutrient inputs have resulted in the hyper-eutrophication of Lake Hancock. Outflows from the lake subsequently caused increased nitrogen loadings that have stimulated chlorophyll production and depressed dissolved oxygen levels in the north portions of the upper Peace River.

Overall, the result of the observed historic declines, combined with the recent observed increases, is that there are no statistically significant differences in average annual seasonally weighted mean chlorophyll *a* concentrations between the 1976-1989 and 1996-2016 time intervals at any of the five fixed river kilometer based HBMP monitoring locations. This result demonstrates the inherent difficulty in using most commonly applied statistical trend procedures when evaluating long-term changes in water quality parameters having multiple non-seasonal increasing and decreasing patterns.

5.2.3 Relationship with Flow

Plots of chlorophyll *a* at each of the fixed stations versus combined gaged flow upstream of the Facility (0 to 3000 cfs) are presented in Table 5.11; and for the four HBMP isohalines in Table 5.12. Additionally, correlation analysis was used to assess potential statistical differences in the relationships between seven-day average combined gaged flow upstream of the Facility and chlorophyll *a* at each of the five fixed-station and four moving HBMP isohaline-based sampling stations. Significant results are indicated below, and include the correlation coefficient (R value). The relative degree of variability (percent) explained for chlorophyll *a* concentrations (the dependent variable) by changes in flow (the independent variable) is the correlation coefficient squared or R^2.

Table 5.11
Relationships between Chlorophyll *a* and Freshwater Inflow at Fixed Stations

Water Quality Parameter	**Monitoring Station River Kilometer**				
	-2.4	**6.6**	**15.5**	**23.6**	**30.7**
Chlorophyll *a*	**Figure 5.68**	**Figure 5.69**	**Figure 5.70**	**Figure 5.71**	**Figure 5.72**

Table 5.12
Chlorophyll *a* Versus Flow at Isohaline-Based Stations

Water Quality Parameter	**Estuarine Isohaline**			
	0 psu	**6 psu**	**12 psu**	**20 psu**
Chlorophyll *a*	**Figure 5.73**	**Figure 5.74**	**Figure 5.75**	**Figure 5.76**

As these figures indicate, large degrees of variation often occur at a given flow depending on the history of flows over both the immediate and longer-term preceding periods. The highest levels of phytoplankton chlorophyll *a* biomass spatially occur in the estuary within the two intermediate salinity zones. Chlorophyll *a* concentrations are typically slightly higher within the 6 psu isohaline as freshwater high in color and inorganic nitrogen mixes with low color, nutrient poor higher salinity water. However under conditions of higher flows the phytoplankton maximum often shifts to the 12 psu isohaline as increasing water color levels limit light levels in the two lower estuarine isohalines.

This general trend is also supported by the fixed-station sampling. Previous HBMP analyses have shown that chlorophyll *a* concentrations along the lower Peace River HBMP monitoring transect exhibits distinct spring and fall increases that are influenced by both the timing and amounts of freshwater inflow into the river estuarine system. The presented box and whisker plots indicate that normally there is a distinct chlorophyll *a* phytoplankton maxima that spatially occurs along the monitoring transect. The location of this maximum generally moves downstream as river flow increases. These seasonal patterns are the combined result of a number of factors associated with increasing freshwater flows. Higher flows reduce residence time and increase inorganic nitrogen loading that stimulates phytoplankton production, while at the same time higher color levels simultaneously reduce the ability of light to penetrate the water column and diminishes phytoplankton growth.

There were only two statistically significant correlations between chlorophyll *a* concentrations and seven-day average flow and they were opposite (one positive and one negative correlation); both explained less than 25% of the observed variation in chlorophyll *a*):

- RK -2.4 (R=0.19; explains less than 25% of variation)
- RK 23.6 (R=-0.12; explains less than 25% of variation)

Higher flows result in a number of interacting confounding factors that ultimately affect resultant phytoplankton biomass (chlorophyll *a* concentrations) within the lower river/upper harbor estuarine system. Higher rates of freshwater inflow increase inorganic nitrogen loading that stimulates phytoplankton production, while at the same time higher color levels simultaneously reduce the ability of light to penetrate the water column and reduces phytoplankton production. Higher rates of flow also reduce the physical hydraulic residence time within the lower river and effectively “flushes” phytoplankton populations further downstream, in effect limiting the buildup of higher chlorophyll concentrations. Chlorophyll concentrations within the 0 and 6 psu isohalines both show higher levels in response to low to moderate increases in gaged inflows and higher nitrogen inputs. However, as expected, measured chlorophyll *a* concentrations then decline as factors such as color and residence time become increasingly important. The direct relationships between chlorophyll a concentrations and flow are less distinct at the higher two salinity zones. As previously discussed, there are strong seasonal components associated with the interactions between rates of flow and phytoplankton biomass. Similar rates of flow in the spring and fall can have dramatically different influences on stimulating or inhibiting phytoplankton growth within each of the four different moving salinity zones. Chlorophyll *a* concentrations can therefore exhibit an extremely wide range of variability over a given range of flows as indicated by the results of correlations.

5.3 Nitrate/Nitrite

This section presents the spatial and temporal patterns and trends in nitrate/nitrite data collected by the HBMP at both isohaline-based and fixed-station locations. Additionally, the relationship between flow and nitrate/nitrite is investigated.

5.3.1 Spatial Patterns

This section assesses longitudinal gradients in nitrate/nitrite along the Peace River monitoring transect. Nitrate/nitrite levels at the most downstream fixed sampling location are typically near or at method detection limits (Figure 5.77). Inorganic nitrogen levels progressively increase moving upstream along the sampling transect, as dilution by low nutrient/high salinity harbor water declines and higher water color increasingly limits phytoplankton nitrogen uptake. This same spatial pattern was observed both for all data combined, and for the seasonal comparisons. Data for the isohaline-based “moving” station sampling also illustrate this longitudinal gradient in nitrate/nitrite concentrations (Figure 5.78).

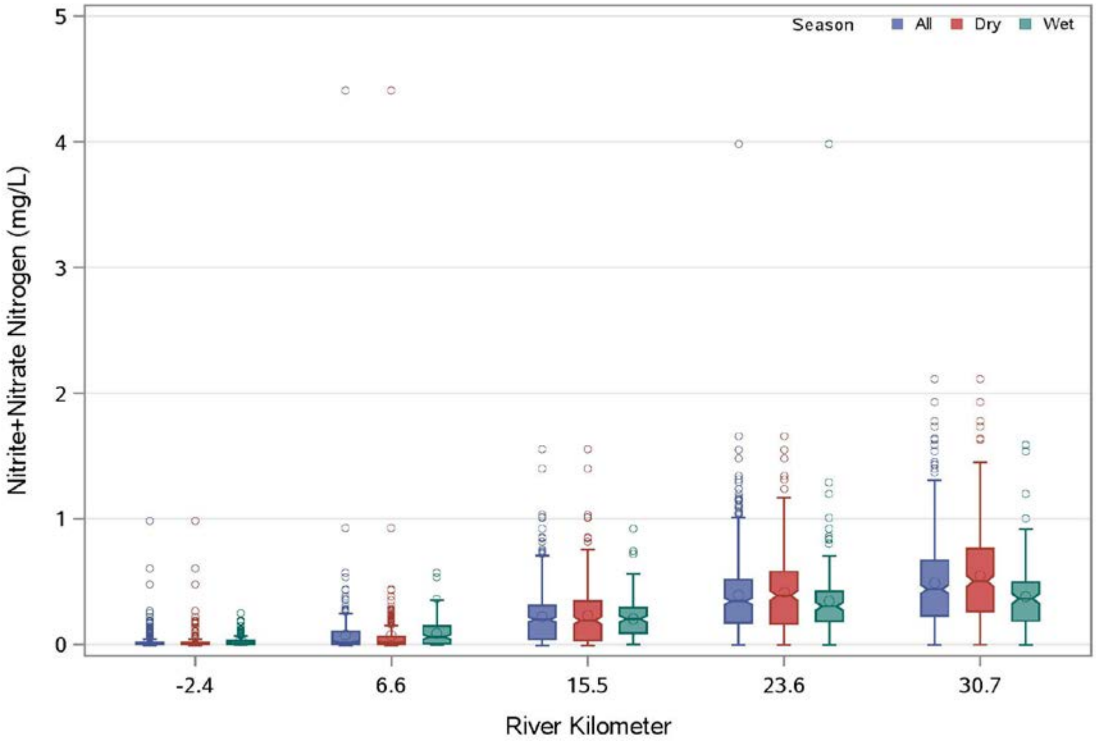

Figure 5.77 Fixed-station boxplots of surface nitrate/nitrite concentrations for all samples and seasonally (1976-2016)

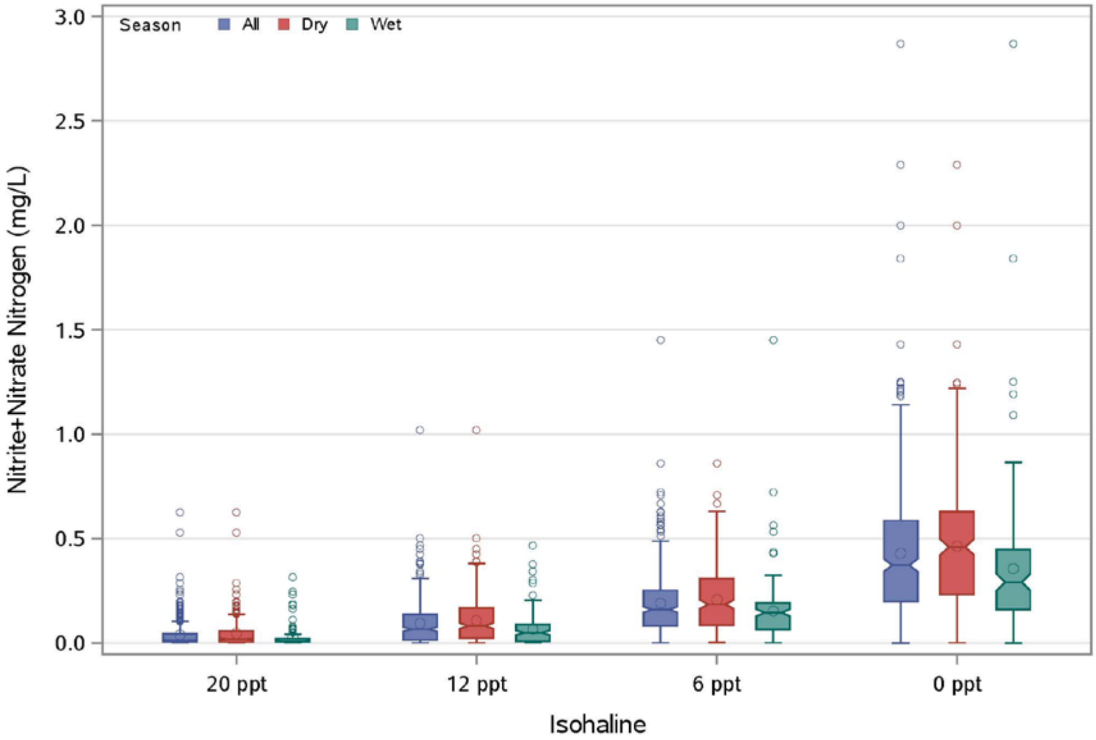

Figure 5.78 Boxplots of nitrate/nitrite concentrations at each isohaline for all samples and seasonally (1984-2016).

5.3.2 Temporal Trends

This section presents analyses of patterns and trends in inter- and intra-annual variation in concentrations of nitrate/nitrite along the Peace River monitoring transect. Time-series plots of nitrate/nitrite data collected from just below the water surface at each of the selected fixed-station locations between 1976-1989 and 1996-2016 are summarized in Table 5.13. Box and whisker plots depicting inter- and intra-annual variability in nitrate/nitrite at the isohaline-based stations for the period 1984-2016 are presented in Table 5.14. These graphical procedures provide overviews of the monthly ranges and long-term patterns for the HBMP nitrate/nitrite measurements. The presented figures depict the relative degrees of both annual and inter-annual variability observed over the HBMP period along the lower Peace River/upper Charlotte Harbor estuarine monitoring transect. In particular, Figures 5.84-5.87 indicate that inter-and intra-annual variability are more pronounced for the fresher end of the monitoring transect than for the more saline waters.

Table 5.13
Time-Series Plots of Monthly Nitrate/Nitrite at "Fixed" HBMP Stations

Water Quality Parameter	River Kilometer -2.4	River Kilometer 6.6	River Kilometer 15.5	River Kilometer 23.6	River Kilometer 30.7
Nitrate/Nitrite	**Figure 5.79**	**Figure 5.80**	**Figure 5.81**	**Figure 5.82**	**Figure 5.83**

Note: no data available 1990-1995.

Table 5.14
Inter- and Intra-Annual Variability in Nitrate/Nitrite at Isohaline-Based "Moving" HBMP Monitoring Salinity Zones (June 1984-2016)

Isohaline	Box Pot of Inter-Annual Variability	Box Plot of Intra-Annual Variability
0 psu Salinity	**Figure 5.84**	**Figure 5.88**
6 psu Salinity	**Figure 5.85**	**Figure 5.89**
12 psu Salinity	**Figure 5.86**	**Figure 5.90**
20 psu Salinity	**Figure 5.87**	**Figure 5.91**

Table 5.15 summarizes the results of tests for statistically significant changes in seasonally based mean annual nitrate/nitrite for fixed lower Peace River sampling locations. Because of the gap in sampling from 1990-1995, a typical trend test (such as a seasonal Kendall tau) is not valid. Therefore, to examine long-term changes at the fixed-stations, analyses were performed using methods developed by Coastal Environmental (1996) for the Florida Department of Environmental Protection using seasonally weighted yearly averages. In this instance, the procedure was used to examine statistical differences between the two disjunct periods of record. Details of these analyses are provided in **Appendix C**. Individually scaled graphics by monitoring location are presented in Figure 5.92 through 5.96, which depict the results of seasonally based statistical tests for differences between the 1976-1989 and 1996-2016 time

intervals. Seasonally averaged annual dissolved inorganic nitrate/nitrite concentrations at the three most upstream HBMP monitoring locations were statistically lower during the 1996-2016 period when compared with the earlier time period. The decrease appears to be heavily influenced by the period of drought beginning in 2006.

Table 5.15
Period Difference Tests
Peace River HBMP Estuary Sites Nitrate/Nitrite (1976-1989 and 1996-2016)

River Kilometer Parameter	Period Difference Test	Difference in Means	P Value	Change
River Kilometer -2.4	Figure 5.92	0.006	0.459	
River Kilometer 6.6	Figure 5.93	-0.016	0.605	
River Kilometer 15.5	Figure 5.94	-0.067	0.003	▼
River Kilometer 23.6	Figure 5.95	-0.111	0.001	▼
River Kilometer 30.7	Figure 5.96	-0.166	0.000	▼

* Red ▼ denotes significance at the 0.05 level
* Blue ▼ denotes significance at the 0.10 level

The Coastal Environmental (1996) method of testing seasonally adjusted annual averages and the monthly Seasonal Kendall Tau statistical procedure (See **Section 3.2.3** for complete description) were both used to test for the potential presence of long-term systematic changes in nitrate/nitrite at each estuarine isohaline-based station locations between 1984 and 2016. Summary results of these trend analyses are presented in Table 5.16. The seasonally weighted annual average method and the Seasonal Kendall Tau trend test method only indicated a significant trend for the 20 psu isohaline.

Table 5.16
Trend Tests of Isohaline Nitrate/Nitrite Concentrations (1984-2016)

Salinity Based Isohaline Location	Seasonally Adjusted Annual Means			Seasonal Kendall Tau of Monthly Means		
	Yearly Mean	Slope	P Value	Tau Value	Slope	P Value
0 psu	Figure 5.97	-0.03	0.509	0.04	0.022	0.540
6 psu	Figure 5.98	0.14	0.641	-0.03	-0.044	0.402
12 psu	Figure 5.99	0.07	0.712	0.00	0.004	0.930
20 psu	Figure 5.100	0.35	0.007	0.11	0.117	0.041

* **Red** denotes significance at the 0.05 level
** **Blue** denotes significance at the 0.10 level

Ambient inorganic nitrogen concentrations are typically at or near detection limits in the highest salinity reaches of the estuary throughout most of the spring and summer when light levels are high and phytoplankton production is greatest. Concentrations are conversely greater at all four measured isohalines during the fall and winter months. Overall, ambient inorganic nitrogen levels progressively increase moving upstream from high to low salinities. The results of the Seasonal Kendall Tau trend tests found that inorganic nitrite+nitrate concentrations within the most downstream 20 psu salinity zone have slightly statistically significantly increased over time. This result corresponds with both the observed periodic increases in flow (primarily during the summer wet-season) and the measured increased color levels.

5.3.3 Relationship with Flow

Plots of nitrate/nitrite at each of the fixed stations versus combined gaged flow upstream of the Facility (0 to 3000 cfs) are presented in Table 5.17; and for the four HBMP isohalines in Table 5.18. Additionally, correlation analysis was used to assess potential statistical differences in the relationships between seven-day average combined gaged flow upstream of the Facility and nitrate/nitrite at each of the five fixed-station and four moving HBMP isohaline-based sampling stations. Significant results are indicated below, and include the correlation coefficient (R value). The relative degree of variability (percent) explained for nitrate/nitrite concentrations (the dependent variable) by changes in flow (the independent variable) is the correlation coefficient squared or R^2.

Table 5.17

Relationships between Nitrate/Nitrite and Freshwater Inflow at Fixed Stations

Water Quality Parameter	Monitoring Station River Kilometer				
	-2.4	6.6	15.5	23.6	30.7
Nitrate/Nitrite	Figure 5.101	Figure 5.102	Figure 5.103	Figure 5.104	Figure 5.105

Table 5.18

Nitrate/Nitrite Versus Flow at Isohaline-Based Stations

Water Quality Parameter	Estuarine Isohaline			
	0 psu	6 psu	12 psu	20 psu
Nitrate/Nitrite	Figure 5.106	Figure 5.107	Figure 5.108	Figure 5.109

As the figures indicate, large degrees of variation often occur at a given flow depending on the history of flows over both the immediate and longer-term preceding periods. There were several statistically significant correlations between nitrate/nitrite concentrations and seven-day average flow. For more downstream stations, these correlations were positive indicating increasing concentrations with increasing flows. However, for the freshwater end of the spectrum, the correlations were negative, indicating decreasing concentrations with increasing flow. The statistically significant correlations explained less than 25% of the observed variation in nitrate/nitrite concentrations. The significant correlations were:

- RK -2.4 (R=0.30)
- RK 6.6 (R=0.19)

- RK 15.5 (R=0.12)
- RK 30.7 (R=-0.21)
- 0 psu (R=-0.20)

The relationships between dissolved inorganic nitrogen concentration and rates of freshwater inflow are complex. As flows gradually increase following the typical spring dry-season, increasing nitrogen loadings stimulate estuarine phytoplankton production and ambient inorganic nitrogen levels often remain near or at detection limits throughout much of the lower Peace River estuarine system. However, as flows further increase, upstream phytoplankton primary production become color rather than nitrogen limited and inorganic nitrogen levels rapidly rise with increasing flows. A third condition then occurs at the upstream HBMP sampling locations as both water color and nutrient levels start to decline with further increases in flow. Such changes again reflect seasonal changes in the water quality characteristic of sheet flow to the watershed’s major tributaries following longer (and/or higher) amounts of rainfall.

The observed changes in the patterns of inorganic dissolved nitrite+nitrate nitrogen concentrations among the four salinity zones show that, initially under conditions of increasing levels of freshwater inflow, inorganic nitrogen levels increase in the lower salinity estuarine waters. However, measured concentrations actually then decline during periods of very high river flow, when ground water levels are near the surface and sheetflow rapidly moves water from the land and into the estuary. These figures also show that dissolved inorganic nitrogen concentrations within the highest salinity zone are typically at or near detection limits except during periods of very highest freshwater inflow.

5.4 Total Kjeldahl Nitrogen

This section presents the spatial and temporal patterns and trends in Total Kjeldahl Nitrogen (TKN) data collected by the HBMP at both isohaline-based and fixed-station locations. Additionally, the relationship between flow and TKN is investigated.

5.4.1 Spatial Patterns

This section assesses longitudinal gradients in TKN along the Peace River monitoring transect. Figure 5.110 provides box and whisker plots of TKN data sampled at the fixed-station locations. Like inorganic nitrogen, this gross measurement of combined inorganic ammonia and organic water column nitrogen shows distinct seasonal and spatial patterns along the HBMP monitoring transect. Concentrations are typically lower in the more saline waters of the downstream stations, and are also more elevated during the summer wet-season than during the dry-season. Data for the isohaline-based “moving” station illustrate similar patterns in TKN concentrations (Figure 5.111).

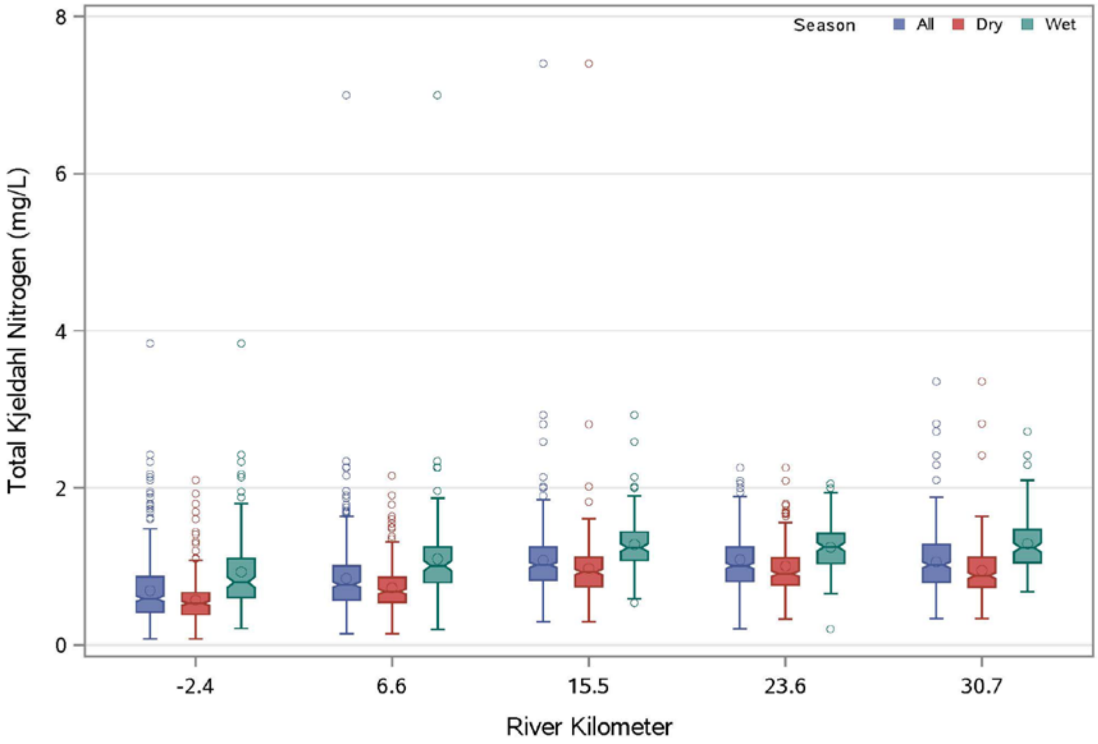

Figure 5.110 Fixed station boxplots of Total Kjeldahl Nitrogen concentrations for all samples and seasonally (1976-2016)

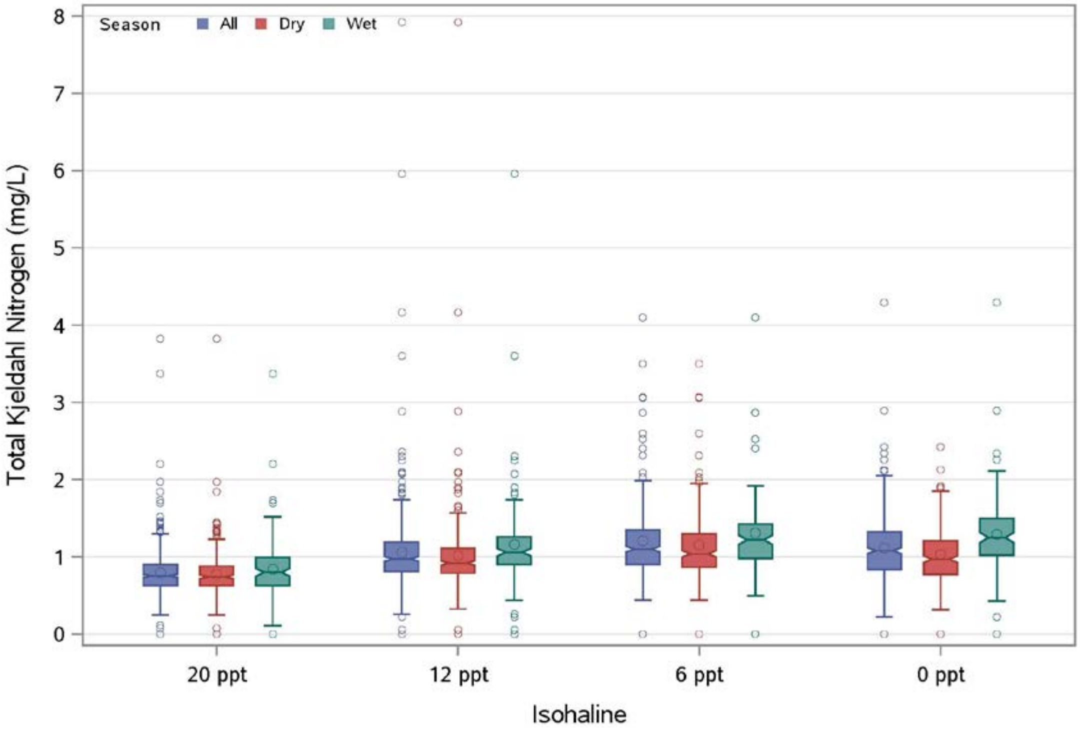

Figure 5.111 Boxplots of Total Kjeldahl Nitrogen concentration as each isohaline for all samples and seasonally (1984-2016)

5.4.2 Temporal Trends

This section presents analyses of patterns and trends in inter- and intra-annual variation in concentrations of TKN along the Peace River monitoring transect. Time-series plots of TKN data collected from just below the water surface at each of the selected fixed-station locations between 1976-1989 and 1996-2016 are summarized in Table 5.19. Box and whisker plots depicting inter- and intra-annual variability in TKN at the isohaline-based stations for the period 1984-2016 are presented in Table 5.20. These graphical procedures provide overviews of the monthly ranges and long-term patterns for the HBMP TKN measurements.

The presented figures depict the relative degrees of both annual and inter-annual variability observed over the HBMP period along the lower Peace River/upper Charlotte Harbor estuarine monitoring transect. Combined inorganic ammonia and organic nitrogen concentrations measured as TKN shows distinct seasonal/spatial patterns within the lower Peace River/upper Charlotte Harbor Estuary. The highest seasonal levels are typically observed throughout the estuarine system following the normal summer wet-season. The presented graphics indicate that measured total Kjeldahl nitrogen concentrations increase spatially from higher to lower salinities within the lower river/upper harbor estuarine system, directly reflecting the influences of freshwater inputs.

Table 5.19
Time-Series Plots of Monthly Total Kjeldahl Nitrogen at “Fixed” HBMP Stations

Water Quality Parameter	River Kilometer -2.4	River Kilometer 6.6	River Kilometer 15.5	River Kilometer 23.6	River Kilometer 30.7
Total Kjeldahl Nitrogen	Figure 5.112	Figure 5.113	Figure 5.114	Figure 5.115	Figure 5.116

Note: no data available 1990-1995.

Table 5.20
Inter- and Intra-Annual Variability in Total Kjeldahl Nitrogen at Isohaline-Based “Moving” HBMP Monitoring Salinity Zones (June 1984-2016)

Isohaline	Box Pot of Inter-Annual Variability	Box Plot of Intra-Annual Variability
0 psu Salinity	Figure 5.117	Figure 5.121
6 psu Salinity	Figure 5.118	Figure 5.122
12 psu Salinity	Figure 5.119	Figure 5.123
20 psu Salinity	Figure 5.120	Figure 5.124

Table 5.21 summarizes the results of tests for statistically significant changes in seasonally based mean annual TKN for fixed lower Peace River sampling locations. Because of the gap in sampling from 1990-1995, a typical trend test (such as a seasonal Kendall tau) is not valid. Therefore, to examine long-term changes at the fixed-stations, analyses were performed using methods developed by Coastal Environmental (1996) for the Florida Department of

Environmental Protection using seasonally weighted yearly averages. In this instance, the procedure was used to examine statistical differences between the two disjunct periods of record. Details of these analyses are provided in **Appendix C**. Individually scaled graphics by monitoring location are presented in Figure 5.125 through 5.129, which depict the results of seasonally based statistical tests for differences between the 1976-1989 and 1996-2016 time intervals. There were no statistically significant differences in seasonally averaged annual TKN concentrations at the fixed-station locations between the two time periods.

Table 5.21

Period Difference Tests Peace River HBMP Estuary Sites Total Kjeldahl Nitrogen (1976-1989 and 1996-2016)

River Kilometer Parameter	Period Difference Test	Difference in Means	P Value	Change
River Kilometer -2.4	**Figure 5.125**	-0.044	0.272	
River Kilometer 6.6	**Figure 5.126**	-0.0100	0.126	
River Kilometer 15.5	**Figure 5.127**	-0.010	0.810	
River Kilometer 23.6	**Figure 5.128**	-0.056	0.124	
River Kilometer 30.7	**Figure 5.129**	-0.061	0.196	

* Red ▼ denotes significance at the 0.05 level
* Blue ▼ denotes significance at the 0.10 level

The Coastal Environmental (1996) method of testing seasonally adjusted annual averages and the monthly Seasonal Kendall Tau statistical procedure (See **Section 3.2.3** for complete description) were both used to test for the potential presence of long-term systematic changes in TKN at each estuarine isohaline-based station locations between 1984 and 2016. Summary results of these trend analyses are presented in Table 5.22. None of the trend analyses indicated any statistically significant changes in TKN concentrations along the monitoring transect for the HBMP monitoring period.

Table 5.22

Trend Tests of Isohaline Total Kjeldahl Nitrogen Concentrations (1984-2016)

Salinity Based Isohaline Location	Seasonally Adjusted Annual Means			Seasonal Kendall Tau of Monthly Means		
	Yearly Mean	Slope	P Value	Tau Value	Slope	P Value
0 psu	**Figure 5.130**	-0.01	0.188	-0.03	-0.001	0.676
6 psu	**Figure 5.131**	-0.01	0.699	-0.05	-0.002	0.452
12 psu	**Figure 5.132**	-0.01	0.314	-0.04	-0.001	0.537
20 psu	**Figure 5.133**	0.01	0.431	0.02	0.552	0.767

* **Red** denotes significance at the 0.05 level
** **Blue** denotes significance at the 0.10 level

The applied statistical trend procedures did not indicate that total Kjeldahl nitrogen levels have systematically increased or decreased over the monitoring interval.

5.4.3 Relationship with Flow

Plots of TKN at each of the fixed stations versus combined gaged flow upstream of the Facility (0 to 3000 cfs) are presented in Table 5.23; and for the four HBMP isohalines in Table 5.24. Additionally, correlation analysis was used to assess potential statistical differences in the relationships between seven-day average combined gaged flow upstream of the Facility and TKN at each of the five fixed-station and four moving HBMP isohaline-based sampling stations. Significant results are indicated below, and include the correlation coefficient (R value). The relative degree of variability (percent) explained for TKN (the dependent variable) by changes in flow (the independent variable) is the correlation coefficient squared or R^2.

Table 5.23
Relationships between Total Kjeldahl Nitrogen and Freshwater Inflow at Fixed Stations

Water Quality Parameter	**Monitoring Station River Kilometer**				
	-2.4	**6.6**	**15.5**	**23.6**	**30.7**
Total Kjeldahl Nitrogen	**Figure 5.134**	**Figure 5.135**	**Figure 5.136**	**Figure 5.137**	**Figure 5.138**

Table 5.24
Total Kjeldahl Nitrogen Versus Flow at Isohaline-Based Stations

Water Quality Parameter	**Estuarine Isohaline**			
	0 psu	**6 psu**	**12 psu**	**20 psu**
Total Kjeldahl Nitrogen	**Figure 5.139**	**Figure 5.140**	**Figure 5.141**	**Figure 5.142**

As these figures indicate, large degrees of variation often occur at a given flow depending on the history of flows over both the immediate and longer-term preceding periods. TKN concentrations within the lower Peace River/upper Charlotte Harbor Estuary generally show spatial increases moving upstream, as well as increasing levels under higher freshwater inflows. This is supported both by the fixed-station as well as the isohaline-based station data. The following positive correlations of TKN with 7-day average flow were significant (and explained less than 25% of the observed variation in TKN):

- Rk -2.4 (R=0.43)
- RK 6.6 (R=0.38)
- RK 15.5 (R=0.23)
- RK 30.7 (R=0.34)
- 0 psu (R=0.25)

5.5 Ortho-phosphorus

This section presents the spatial and temporal patterns and trends in ortho-phosphorus data collected by the HBMP at both isohaline-based and fixed-station locations. Additionally, the relationship between flow and ortho-phosphorus is investigated.

5.5.1 Spatial Patterns

This section assesses longitudinal gradients in ortho-phosphorus concentrations along the Peace River monitoring transect. Figure 5.143 provides box and whisker plots of ortho-phosphorus data sampled at the fixed-station locations. The lower Peace River/upper Charlotte Harbor estuarine system is naturally high in phosphorus due to the extensive natural phosphate deposits in a number of the major upstream watershed basins. However, a longitudinal gradient, with lower values in more saline waters is observed in the fixed-station data, as well as the isohaline-based moving-station data (Figure 5.144). These figures also illustrate that, particularly for more upstream/freshwater stations, ortho-phosphorus levels are lower during the wet-season than the dry-season when the influences of ground water are more pronounced.

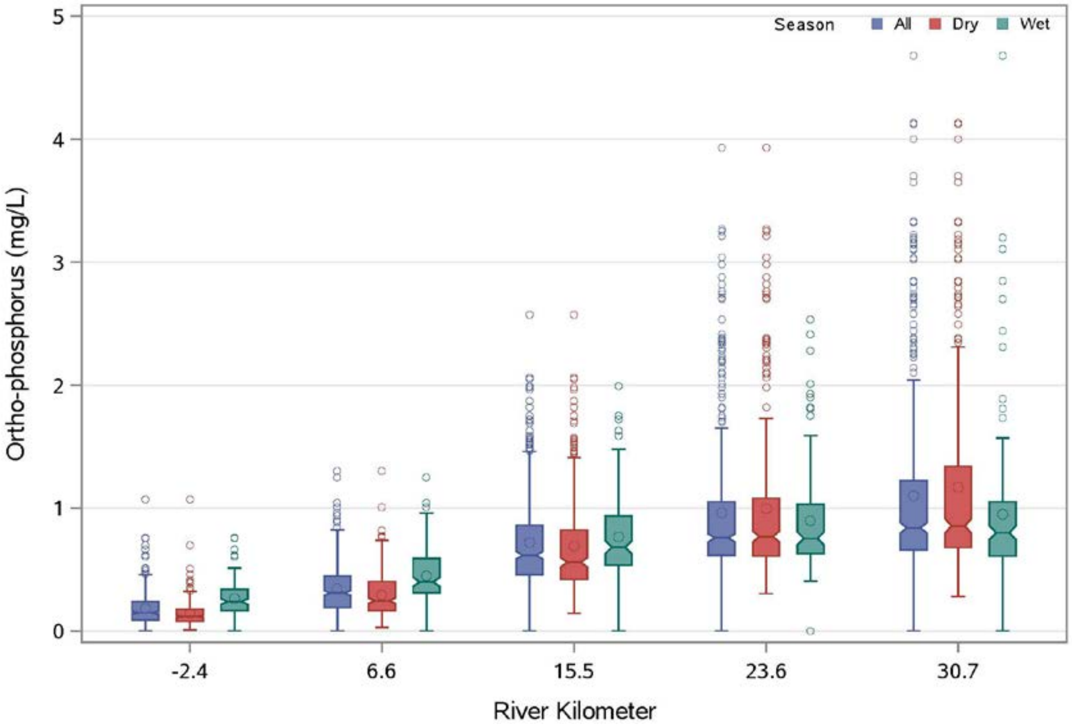

Figure 5.143 Fixed station boxplots of Ortho-phosphorus concentrations for all samples and seasonally (1976-2016)

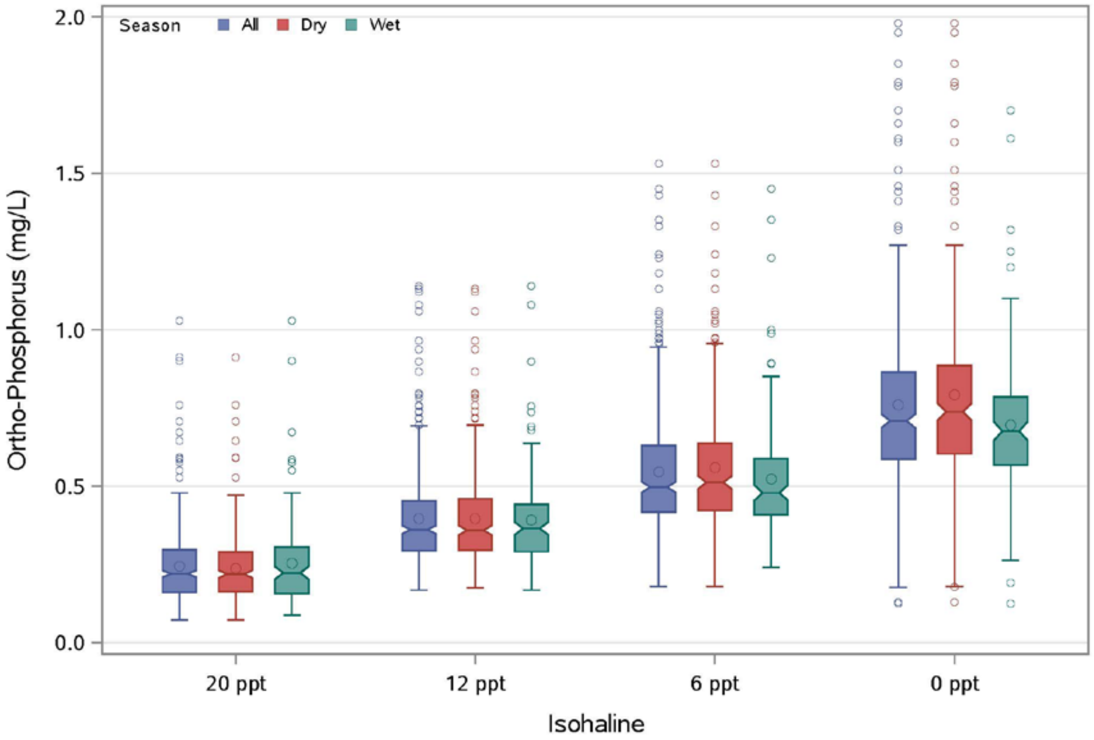

Figure 5.144 Boxplots of Total Kjeldahl Nitrogen concentration as each isohaline for all samples and seasonally (1984-2016)

5.5.2 Temporal Trends

This section presents analyses of patterns and trends in inter- and intra-annual variation in concentrations of ortho-phosphorus along the Peace River monitoring transect. Time-series plots of ortho-phosphorus data collected from just below the water surface at each of the selected fixed-station locations between 1976-1989 and 1996-2016 are summarized in Table 5.25. Box and whisker plots depicting inter- and intra-annual variability in ortho-phosphorus at the isohaline-based stations for the period 1984-2016 are presented in Table 5.26. These graphical procedures provide overviews of the monthly ranges and long-term patterns for the HBMP ortho-phosphorus measurements. The presented figures depict the relative degrees of both annual and inter-annual variability observed over the HBMP period along the lower Peace River/upper Charlotte Harbor estuarine monitoring transect.

Table 5.25
Time-Series Plots of Monthly Ortho-Phosphorus at “Fixed” HBMP Stations

Water Quality Parameter	River Kilometer -2.4	River Kilometer 6.6	River Kilometer 15.5	River Kilometer 23.6	River Kilometer 30.7
Ortho-phosphorus	Figure 5.145	Figure 5.146	Figure 5.147	Figure 5.148	Figure 5.149

Note: no data available 1990-1995.

Table 5.26
Inter- and Intra-Annual Variability in Ortho-Phosphorus at Isohaline-Based “Moving” HBMP Monitoring Salinity Zones (June 1984-2016)

Isohaline	Box Pot of Inter-Annual Variability	Box Plot of Intra-Annual Variability
0 psu Salinity	**Figure 5.150**	**Figure 5.154**
6 psu Salinity	**Figure 5.151**	**Figure 5.155**
12 psu Salinity	**Figure 5.152**	**Figure 5.156**
20 psu Salinity	**Figure 5.153**	**Figure 5.157**

Table 5.27 summarizes the results of tests for statistically significant changes in seasonally based mean annual ortho-phosphorus for fixed lower Peace River sampling locations. Because of the gap in sampling from 1990-1995, a typical trend test (such as a seasonal Kendall tau) is not valid. Therefore, to examine long-term changes at the fixed-stations, analyses were performed using methods developed by Coastal Environmental (1996) for the Florida Department of Environmental Protection using seasonally weighted yearly averages. In this instance, the procedure was used to examine statistical differences between the two disjunct periods of record. Details of these analyses are provided in **Appendix C**. Individually scaled graphics by monitoring location are presented in Figure 5.158 through 5.162, which depict the results of seasonally based statistical tests for differences between the 1976-1989 and 1996-2016 time intervals. For all fixed-station locations, the results indicate statistically significant decreases in seasonally averaged annual ortho-phosphorus from the 1976-1989 period to the 1996-2016 period.

Table 5.27
Period Difference Tests Peace River HBMP Estuary Sites Ortho-Phosphorus (1976-1989 and 1996-2016)

River Kilometer Parameter	Period Difference Test	Difference in Means	P Value	Change
River Kilometer -2.4	**Figure 5.158**	-0.07	**0.000**	▼
River Kilometer 6.6	**Figure 5.159**	-0.16	**0.000**	▼
River Kilometer 15.5	**Figure 5.160**	-0.45	**0.000**	▼
River Kilometer 23.6	**Figure 5.161**	-0.61	**0.000**	▼
River Kilometer 30.7	**Figure 5.162**	-0.70	**0.000**	▼

* Red ▼ denotes significance at the 0.05 level
* Blue ▼ denotes significance at the 0.10 level

The Coastal Environmental (1996) method of testing seasonally adjusted annual averages and the monthly Seasonal Kendall Tau statistical procedure (See **Section 3.2.3** for complete description) were both used to test for the potential presence of long-term systematic changes in ortho-phosphorus at each estuarine isohaline-based station locations between 1984 and 2016. Summary results of these trend analyses are presented in Table 5.28. For isohaline-based samples, the only significant difference over time was at the 20 psu isohaline, where the difference test on seasonally adjusted annual means indicated an increase in ortho-phosphorus.

Table 5.28
Trend Tests of Isohaline Ortho-Phosphorus Concentrations (1984-2016)

Salinity Based Isohaline Location	Seasonally Adjusted Annual Means			Seasonal Kendall Tau of Monthly Means		
	Yearly Mean	Slope	P Value	Tau Value	Slope	P Value
0 psu	Figure 5.163	-0.01	0.176	-0.13	-0.005	0.103
6 psu	Figure 5.164	0.01	0.130	-0.11	-0.002	0.192
12 psu	Figure 5.165	0.01	0.162	-0.05	-0.001	0.584
20 psu	Figure 5.166	0.01	0.000	0.08	0.012	0.001

* **Red** denotes significance at the 0.05 level
** **Blue** denotes significance at the 0.10 level

The lower Peace River/upper Charlotte Harbor estuarine system is naturally high in phosphorus due to the extensive natural phosphate deposits in a number of the major upstream watershed basins. Phosphorus concentrations generally reflect both the spatial and temporal variation in Peace River freshwater inputs. The highest phosphorus concentrations are typically associated with seasonal lower river flow, when the influences of ground water are more pronounced. Long-term temporal patterns indicate rapid declines in both the magnitude and variability in phosphorus levels (for example, see Figure 5.167) when compared with the initial first six years of HBMP monitoring.

This decline followed implementation in the late 1970s of stricter regulations and subsequent decreases of both point and nonpoint discharges to surface waters from phosphate mining and processing. Average annual mean phosphorus concentrations between 1976 and 1989 continued to decline at the HBMP river stations, even though the largest changes occurred prior to 1984. The presented graphical analyses indicate that inorganic phosphorus levels throughout the lower Peace River/upper Charlotte Harbor Estuary dramatically increased early in 2004 and again following Hurricanes Charley, Francis and Jeanne in August and September of 2004. The *2006 HBMP Comprehensive Summary Report* suggested “that the historically high flows that occurred in the upper Peace River watershed following this unusual series of events had at least temporarily increased phosphorus concentrations throughout the system to levels not seen for over twenty years”. However, more recent investigations (PBS&J 2009, 2010 and Atkins 2011, 2012) have concluded that the direct cause for the recent observed increase in phosphorus levels more likely seems to have been related to discharges of waters during the closure of the Ft. Meade phosphogypsum stack system in the upstream Whidden Creek subbasin. Phosphorus concentrations began again declining during 2009 and have continued through both 2010 and 2011. While slight increases in annually averaged ortho-phosphorus have occurred at some stations since 2011, overall inorganic phosphorus levels are significantly lower when compared to the previous historic period.

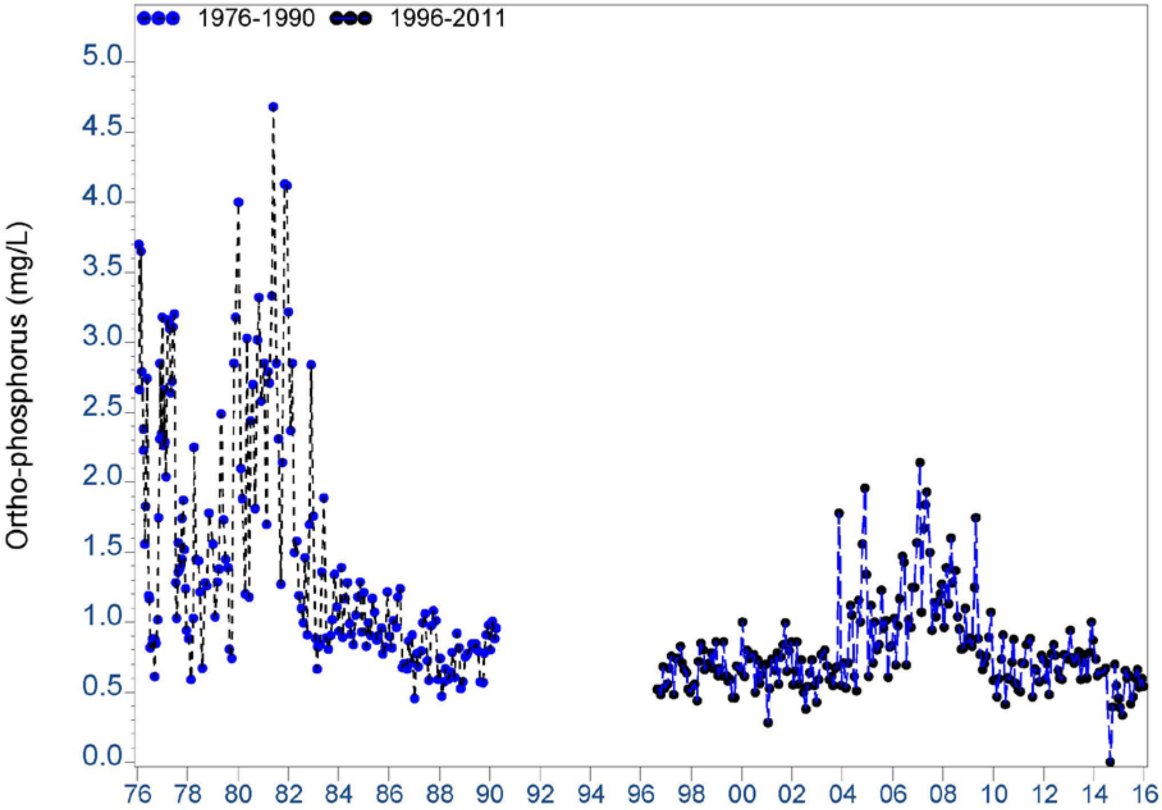

Figure 5.167 Monthly long-term surface ortho-phosphorus at river kilometer 30.7

5.5.3 Relationship with Flow

Plots of ortho-phosphorus at each of the fixed stations versus combined gaged flow upstream of the Facility (0 to 3000 cfs) are presented in Table 5.29; and for the four HBMP isohalines in Table 5.30. Additionally, correlation analysis was used to assess potential statistical differences in the relationships between seven-day average combined gaged flow upstream of the Facility and ortho-phosphorus at each of the five fixed-station and four moving HBMP isohaline-based sampling stations. Significant results are indicated below, and include the correlation coefficient (R value). The relative degree of variability (percent) explained for ortho-phosphorus (the dependent variable) by changes in flow (the independent variable) is the correlation coefficient squared or R^2.

Table 5.29
Relationships between Ortho-Phosphorus and Freshwater Inflow at Fixed Stations

Water Quality Parameter	Monitoring Station River Kilometer				
	-2.4	6.6	15.5	23.6	30.7
Ortho-phosphorus	Figure 5.168	Figure 5.169	Figure 5.170	Figure 5.171	Figure 5.172

Table 5.30
Ortho-Phosphorus Versus Flow at Isohaline-Based Stations

Water Quality Parameter	Estuarine Isohaline			
	0 psu	6 psu	12 psu	20 psu
Ortho-phosphorus	Figure 5.173	Figure 5.174	Figure 5.175	Figure 5.176

As the figures indicate, large degrees of variation often occur at a given flow depending on the history of flows over both the immediate and longer-term preceding periods. The data illustrate that the observed patterns and response of ortho-phosphorus to increasing flows in the lower Peace River estuarine system is very similar to that exhibited by inorganic nitrite/nitrate nitrogen. Concentrations progressively increase upstream towards the freshwater source, and initially rise in response to higher levels of freshwater inflow. However, as freshwater flows increase further and surface water runoff begins to provide an ever greater percentage of total river flow, the actual concentration of ortho-phosphorus (which is usually more than ninety percent total phosphorus) declines. Concentrations in the downstream more marine areas of the upper harbor generally show steady increasing levels with higher flows. However upstream, in the more freshwater reaches of the river, phosphorus concentrations are typically very high and then rapidly decline as freshwater flows increase and surface water runoff rather than ground water steadily provides an ever greater percentage of total river flow. Results of the correlation analyses support these trends observed in the presented figures. Significant correlations of ortho-phosphorus concentrations with seven-day average flow were identified at both fixed station (RK) and isohaline-based (psu) locations:

- RK -2.4 (R=0.56)
- RK 6.6 (R=0.47)
- RK 23.6 (R=-0.15)
- RK 30.7 (R=-0.21)
- 0 psu (R=-0.30)
- 6 psu (R=-0.28)
- 12 psu (R=-0.27)
- 20 psu (R=-0.16)

5.6 Silica

This section presents the spatial and temporal patterns and trends in silica data collected by the HBMP at both isohaline-based and fixed-station locations. Additionally, the relationship between flow and silica concentration is investigated.

5.6.1 Spatial Patterns

This section assesses longitudinal gradients in silica concentrations along the Peace River monitoring transect. Figure 5.177 provides box and whisker plots of Silica data sampled at the fixed-station locations; concentrations for isohaline-based stations are shown in Figure 5.178.

The box and whisker plots indicate that reactive silica levels spatially increase progressively upstream and that ambient concentrations are typically seasonally higher following the summer period of high freshwater inflows.

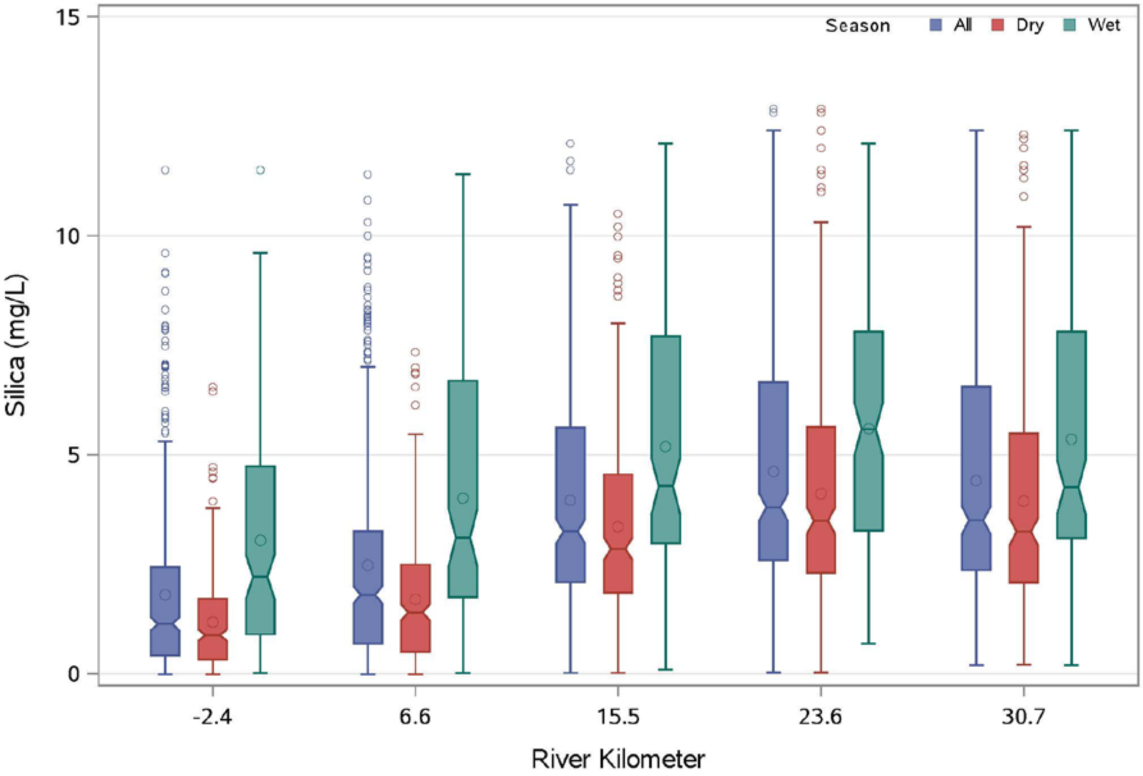

Figure 5.177 Fixed station boxplots of silica concentrations for all samples and seasonally (1976-2016)

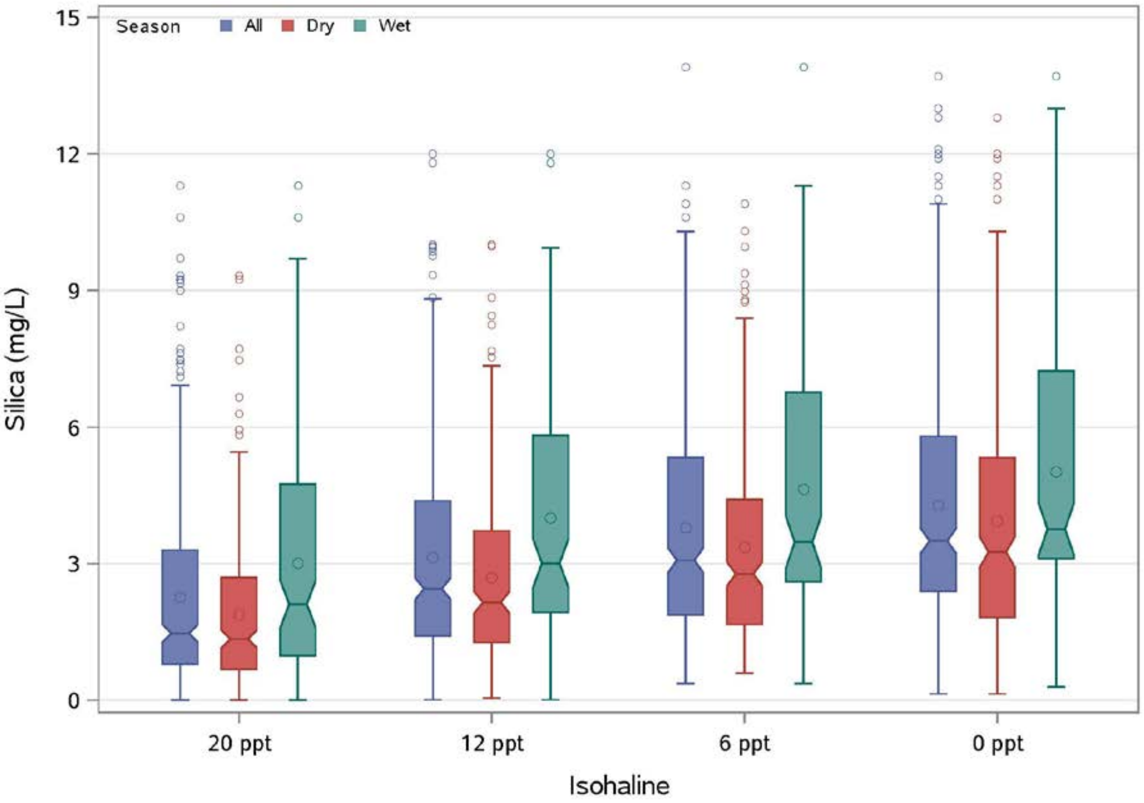

Figure 5.178 Boxplots of silica concentrations at each isohaline for all samples and seasonally (1984-2016)

5.6.2 Temporal Trends

This section presents analyses of patterns and trends in inter- and intra-annual variation in concentrations of silica along the Peace River monitoring transect. Time-series plots of silica data collected from just below the water surface at each of the selected fixed-station locations between 1976-1989 and 1996-2016 are summarized in Table 5.31. Box and whisker plots depicting inter- and intra-annual variability in silica at the isohaline-based stations for the period 1984-2016 are presented in Table 5.32. These graphical procedures provide overviews of the monthly ranges and long-term patterns for the HBMP silica measurements. The presented figures depict the relative degrees of both annual and inter-annual variability observed over the HBMP period along the lower Peace River/upper Charlotte Harbor estuarine monitoring transect.

Table 5.31
Time-Series Plots of Monthly Silica at "Fixed" HBMP Stations

Water Quality Parameter	River Kilometer -2.4	River Kilometer 6.6	River Kilometer 15.5	River Kilometer 23.6	River Kilometer 30.7
Silica	Figure 5.179	Figure 5.180	Figure 5.181	Figure 5.182	Figure 5.183

Note: no data available 1990-1995.

Table 5.32
Inter- and Intra-Annual Variability in Silica at Isohaline-Based “Moving” HBMP Monitoring Salinity Zones (June 1984-2016)

Isohaline	Box Pot of Inter-Annual Variability	Box Plot of Intra-Annual Variability
0 psu Salinity	**Figure 5.184**	**Figure 5.188**
6 psu Salinity	**Figure 5.185**	**Figure 5.189**
12 psu Salinity	**Figure 5.186**	**Figure 5.190**
20 psu Salinity	**Figure 5.187**	**Figure 5.191**

Table 5.33 summarizes the results of tests for statistically significant changes in seasonally based mean annual silica for fixed lower Peace River sampling locations. Because of the gap in sampling from 1990-1995, a typical trend test (such as a seasonal Kendall tau) is not valid. Therefore, to examine long-term changes at the fixed-stations, analyses were performed using methods developed by Coastal Environmental (1996) for the Florida Department of Environmental Protection using seasonally weighted yearly averages. In this instance, the procedure was used to examine statistical differences between the two disjunct periods of record. Details of these analyses are provided in **Appendix C**. Individually scaled graphics by monitoring location are presented in Figure 5.192 through 5.196, which depict the results of seasonally based statistical tests for differences between the 1976-1989 and 1996-2016 time intervals. For all fixed-station locations, the results indicate statistically significant increases in seasonally averaged annual silica from the 1976-1989 period to the 1996-2016 period.

Table 5.33
Period Difference Tests Peace River HBMP Estuary Sites Silica (1976-1989 and 1996-2016)

River Kilometer Parameter	Period Difference Test	Difference in Means	P Value	Change
River Kilometer -2.4	**Figure 5.192**	1.69	**0.000**	▲
River Kilometer 6.6	**Figure 5.193**	2.17	**0.000**	▲
River Kilometer 15.5	**Figure 5.194**	2.92	**0.000**	▲
River Kilometer 23.6	**Figure 5.195**	3.33	**0.000**	▲
River Kilometer 30.7	**Figure 5.196**	3.36	**0.000**	▲

* Red ▼ denotes significance at the 0.05 level
* Blue ▼ denotes significance at the 0.10 level

The Coastal Environmental (1996) method of testing seasonally adjusted annual averages and the monthly Seasonal Kendall Tau statistical procedure (See **Section 3.2.3** for complete description) were both used to test for the potential presence of long-term systematic changes in silica at each estuarine isohaline-based station locations between 1984 and 2016. Summary results of these trend analyses are presented in Table 5.34. With the exception of the Seasonal Kendall Tau test for the 20 psu isohaline, the trend test results indicate statistically significant increase in silica concentrations over time along the HBMP monitoring transect.

Table 5.34
Trend Tests of Isohaline Silica Concentrations (1984-2016)

Salinity Based Isohaline Location	Seasonally Adjusted Annual Means			Seasonal Kendall Tau of Monthly Means		
	Yearly Mean	Slope	P Value	Tau Value	Slope	P Value
0 psu	**Figure 5.197**	0.19	**0.000**	0.50	0.174	**0.000**
6 psu	**Figure 5.198**	0.17	**0.000**	0.55	0.150	**0.000**
12 psu	**Figure 5.199**	0.16	**0.000**	0.06	0.137	**0.000**
20 psu	**Figure 5.200**	0.14	**0.000**	0.53	0.000	0.114

* **Red** denotes significance at the 0.05 level
** **Blue** denotes significance at the 0.10 level

Seasonally, as freshwater inflows become greater, ambient reactive silica concentrations are shown to both increase and move further downstream into the upper Harbor. Both the long-term time-series plots and the statistical comparisons of mean annual average reactive silica concentrations indicate that silica levels have and continue to dramatically increase along the entire length of the lower Peace River monitoring transect (for example, see Figure 5.201. During the most recent twenty-one years of HBMP monitoring, silica concentrations at each of the five fixed sampling sites have increased and the range of variability has increased when compared with similar data from the 1976-1989 period. These increases are also reflected in the isohaline-based sampling data, see Figure 5.202 for example). Again the *2006 HBMP Comprehensive Summary Report* suggested "that the observed increases in ambient reactive silica levels in the Peace River estuarine system might reflect the cumulative influences of increased ground water use and the expansion of water intense agriculture in the Peace River watershed, or it may be associated with other land use changes occurring upstream in the watershed". In response to the observed increases in both silica and phosphorus, the Authority began collecting additional dry- season data at a number of locations throughout the upper watershed in order to be able to better identify potential sources of these apparent increasing concentrations. As with the observed increase in phosphorus levels the upstream data collected by the Authority showed very high silica levels in discharge waters associated with the Ft. Meade phosphogypsum stack system closure in the Whidden Creek subbasin. However, while phosphorus levels in the lower river/upper harbor appear to have again declined to more normal levels, silica levels continue to remain high.

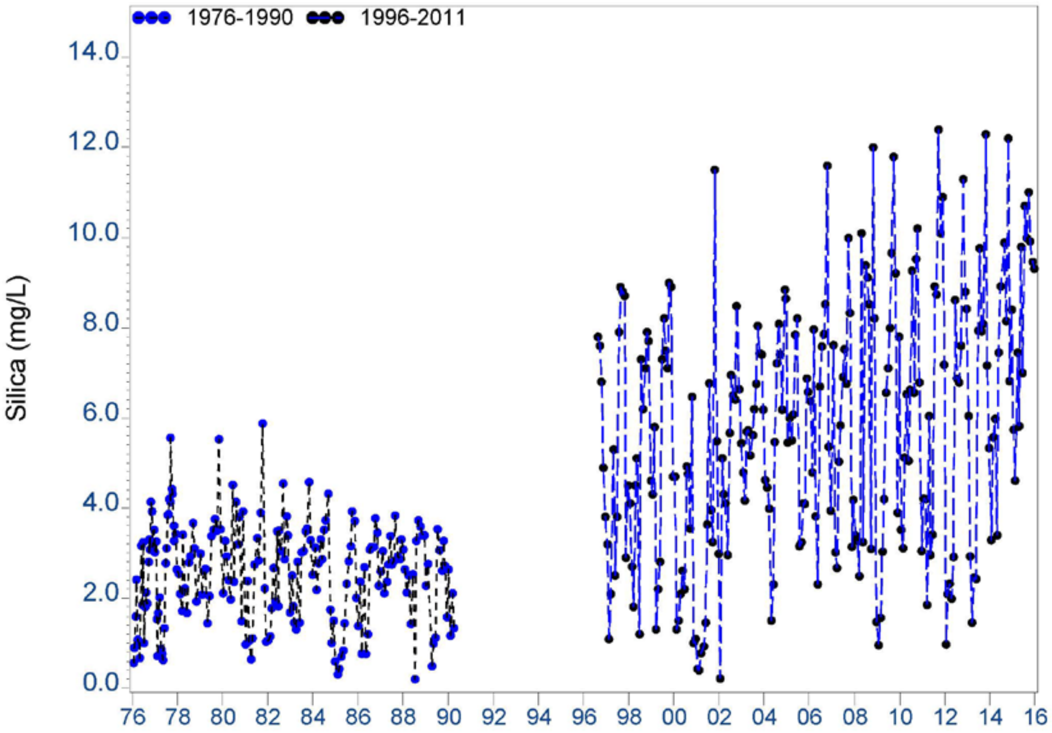

Figure 5.201 Monthly long-term surface silica at river kilometer 30.7

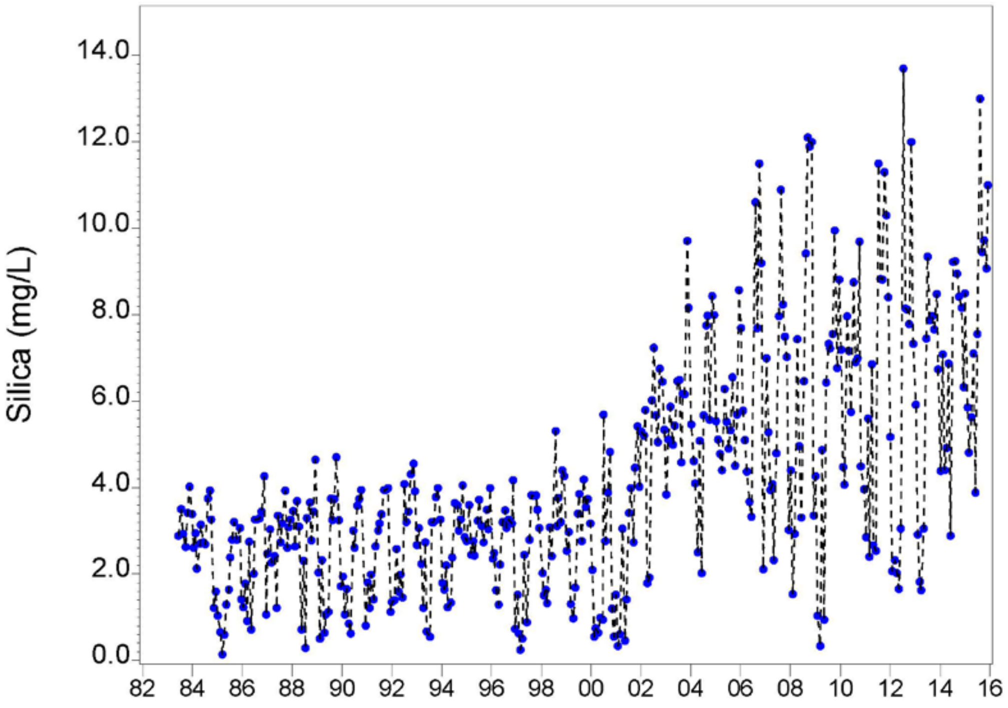

Figure 5.202 Monthly surface silica at 0 psu isohaline (1983-2016)

5.6.3 Relationship with Flow

Plots of silica at each of the fixed stations versus combined gaged flow upstream of the Facility (0 to 3000 cfs) are presented in Table 5.35; and for the four HBMP isohalines in Table 5.36. Additionally, correlation analysis was used to assess potential statistical differences in the relationships between seven-day average combined gaged flow upstream of the Facility and silica at each of the five fixed-station and four moving HBMP isohaline-based sampling stations. Significant results are indicated below, and include the correlation coefficient (R value). The relative degree of variability (percent) explained for silica (the dependent variable) by changes in flow (the independent variable) is the correlation coefficient squared or R^2.

Table 5.35
Relationships between Silica and Freshwater Inflow at Fixed Stations

Water Quality Parameter	**Monitoring Station River Kilometer**				
	-2.4	**6.6**	**15.5**	**23.6**	**30.7**
Silica	**Figure 5.203**	**Figure 5.204**	**Figure 5.205**	**Figure 5.206**	**Figure 5.207**

Table 5.36
Silica Versus Flow at Isohaline-Based Stations

Water Quality Parameter	**Estuarine Isohaline**			
	0 psu	**6 psu**	**12 psu**	**20 psu**
Silica	**Figure 5.208**	**Figure 5.209**	**Figure 5.210**	**Figure 5.211**

As the figures indicate, large degrees of variation often occur at a given flow depending on the history of flows over both the immediate and longer-term preceding periods. The observed spatial pattern of reactive silica within the lower Peace River estuarine system reflects the influences of freshwater inflows. Seasonally, as freshwater inflows become greater, ambient reactive silica concentrations are shown to both increase and move further downstream into the upper Harbor. Silica levels in the higher salinity waters of the upper harbor under low flows are often very low. Ambient concentrations initially rapidly rise throughout the lower river/upper harbor estuarine system as freshwater inflows increase. Following this marked initial rise however, silica concentrations then remain relatively similar as flows further increase.

The response of dissolved reactive silica concentrations within the four HBMP moving station isohalines to increases in gaged Peace River flows is somewhat similar to that of total Kjeldahl nitrogen. The concentration of dissolved reactive silica within the 0, 6 and 12 psu isohalines initially increase in response to higher freshwater inflows, and then quickly become asymptotic (and even decline) with further increases in flow. Concentrations within the 20 psu isohaline do not show the same clearly distinct, consistent patterns with changes in river flow.

Significant positive correlations of silica concentrations with seven-day average flow were identified at every station. The correlation coefficients indicate that seven-day average flow explains less than 25% of the observed variation in silica. The significant correlation coefficients, by station were:

- RK -2.4 (R=0.39)
- RK 6.6 (R=0.40)
- RK 15.5 (R=0.24)
- RK 23.6 (R=0.14)
- RK 30.7 (R=0.13)
- 0 psu (R=0.20)
- 6 psu (R=0.22)
- 12 psu (R=0.21)
- 20 psu (R=0.14)

5.7 Water Color

Humic compounds derived from the breakdown and subsequent leaching of vegetation into surface waters are the source of the high water color that characterizes the blackwater river systems of southwest Florida. This section presents the spatial and temporal patterns and trends in water color data collected by the HBMP at both isohaline-based and fixed-station locations. Additionally, the relationship between flow and water color is investigated.

5.7.1 Spatial Patterns

This section assesses longitudinal gradients in water color along the Peace River monitoring transect. Figure 5.212 provides box and whisker plots of water color data sampled at the fixed-station locations; data for isohaline-based stations are shown in Figure 5.213. These figures exemplify the longitudinal gradient in water color; levels are typically higher farther upstream than near the mouth of the river. However, very high water levels can extend well into the harbor during extended periods of high flows. The longitudinal gradient is observed during both the dry- and wet-seasons, but it is more pronounced with increasing levels during the wet-season.

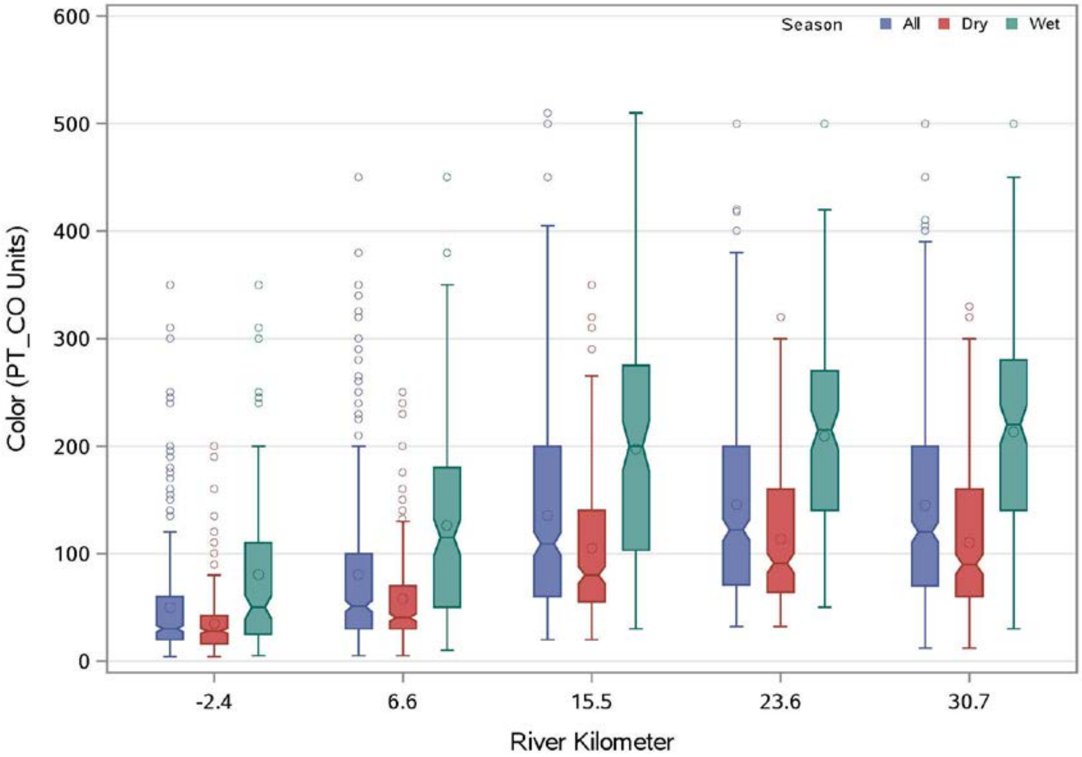

Figure 5.212 Fixed station boxplots of water color for all samples and seasonally (1976-2016)

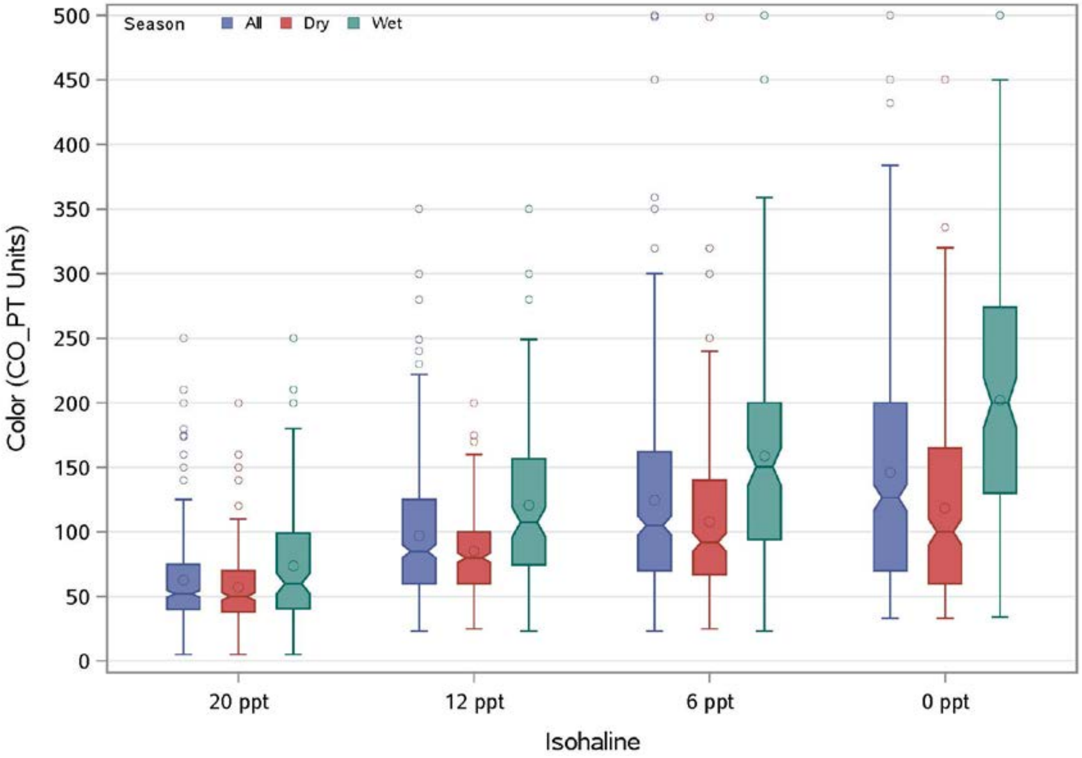

Figure 5.213 Boxplots of water color at each isohaline for all samples and seasonally (1984-2016)

5.7.2 Temporal Trends

This section presents analyses of patterns and trends in inter- and intra-annual variation in water color observed along the Peace River monitoring transect. Time-series plots of water color data collected from just below the water surface at each of the selected fixed-station locations between 1976-1989 and 1996-2016 are summarized in Table 5.37. Box and whisker plots depicting inter- and intra-annual variability in water color at the isohaline-based stations for the period 1984-2016 are presented in Table 5.38. These graphical procedures provide overviews of the monthly ranges and long-term patterns for the HBMP color measurements. The presented figures depict the relative degrees of both annual and inter-annual variability observed over the HBMP period along the lower Peace River/upper Charlotte Harbor estuarine monitoring transect.

Table 5.37
Time-Series Plots of Monthly Water Color at "Fixed" HBMP Stations

Water Quality Parameter	River Kilometer -2.4	River Kilometer 6.6	River Kilometer 15.5	River Kilometer 23.6	River Kilometer 30.7
Water Color	**Figure 5.214**	**Figure 5.215**	**Figure 5.216**	**Figure 5.217**	**Figure 5.218**

Note: no data available 1990-1995.

Table 5.38
Inter- and Intra-Annual Variability in Color at Isohaline-Based "Moving" HBMP Monitoring Salinity Zones (June 1984-2016)

Isohaline	Box Pot of Inter-Annual Variability	Box Plot of Intra-Annual Variability
0 psu Salinity	**Figure 5.219**	**Figure 5.223**
6 psu Salinity	**Figure 5.220**	**Figure 5.224**
12 psu Salinity	**Figure 5.221**	**Figure 5.225**
20 psu Salinity	**Figure 5.222**	**Figure 5.226**

Table 5.39 summarizes the results of tests for statistically significant changes in seasonally based mean annual water color for fixed lower Peace River sampling locations. Because of the gap in sampling from 1990-1995, a typical trend test (such as a seasonal Kendall tau) is not valid. Therefore, to examine long-term changes at the fixed-stations, analyses were performed using methods developed by Coastal Environmental (1996) for the Florida Department of Environmental Protection using seasonally weighted yearly averages. In this instance, the procedure was used to examine statistical differences between the two disjunct periods of record. Details of these analyses are provided in **Appendix C**. Individually scaled graphics by monitoring location are presented in Figure 5.227 through 5.231, which depict the results of seasonally based statistical tests for differences between the 1976-1989 and 1996-2016 time intervals.

Table 5.39
Period Difference Tests Peace River HBMP Estuary Sites Water Color (1976-1989 and 1996-2016)

River Kilometer Parameter	Period Difference Test	Difference in Means	P Value	Change
River Kilometer -2.4	Figure 5.227	11.79	0.008	▲
River Kilometer 6.6	Figure 5.228	19.23	0.002	▲
River Kilometer 15.5	Figure 5.229	7.67	0.281	
River Kilometer 23.6	Figure 5.230	11.40	0.092	▲
River Kilometer 30.7	Figure 5.231	11.76	0.099	▲

* Red ▼ denotes significance at the 0.05 level
* Blue ▼ denotes significance at the 0.10 level

Statistical analyses indicated significant increases at the 0.10 level between the average annual surface color levels for the two most upstream monitoring locations (RK 23.6 and 30.4) between the 1976-1989 and 1996-2016 sampling periods. Additionally, statistically significant increases at the 0.05 level between the two periods at the two most downstream monitoring locations (RK -2.4 and 6.6). These differences reflect the higher inflows of dark colored water farther down the river (ungaged lower mid river) somewhere between stations RK 23.6 and RK 6.6 and into the upper harbor during the recent period of high flows.

The Coastal Environmental (1996) method of testing seasonally adjusted annual averages and the monthly Seasonal Kendall Tau statistical procedure (See **Section 3.2.3** for complete description) were both used to test for the potential presence of long-term systematic changes in color at each estuarine isohaline-based station locations between 1984 and 2016. Summary results of these trend analyses are presented in Table 5.40.

Table 5.40
Trend Tests of Isohaline Water Color (1984-2016)

Salinity Based Isohaline Location	Seasonally Adjusted Annual Means			Seasonal Kendall Tau of Monthly Means		
	Yearly Mean	Slope	P Value	Tau Value	Slope	P Value
0 psu	Figure 5.232	0.94	0.003	0.09	0.696	0.075
6 psu	Figure 5.233	1.60	0.000	0.20	1.25	0.001
12 psu	Figure 5.234	1.59	0.000	0.288	1.300	0.000
20 psu	Figure 5.235	1.68	0.000	0.42	1.290	0.000

* **Red** denotes significance at the 0.05 level
** **Blue** denotes significance at the 0.10 level

Although a number of extensive droughts have characterized much of the more recent historical period, the data also suggests a number of wetter than usual summer wet-seasons have also occurred. The two applied statistical trend test procedures indicate that these increases in wet-season flows have resulted in statistically significant increases in average annual ambient water color within the estuarine salinity zones over the 1984 through 2016 time interval.

5.7.3 Relationship with Flow

Plots of water color at each of the fixed stations versus combined gaged flow upstream of the Facility (0 to 3000 cfs) are presented in Table 5.41; and for the four HBMP isohalines in Table 5.42. Additionally, correlation analysis was used to assess potential statistical differences in the relationships between seven-day average combined gaged flow upstream of the Facility and water color at each of the five fixed-station and four moving HBMP isohaline-based sampling stations. Significant results are indicated below, and include the correlation coefficient (R value). The relative degree of variability (percent) explained for water color (the dependent variable) by changes in flow (the independent variable) is the correlation coefficient squared or R^2.

Table 5.41
Relationships between Water Color and Freshwater Inflow at Fixed Stations

Water Quality Parameter	Monitoring Station River Kilometer				
	-2.4	6.6	15.5	23.6	30.7
Water Color	Figure 5.236	Figure 5.237	Figure 5.238	Figure 5.239	Figure 5.240

Table 5.42
Water Color Versus Flow at Isohaline-Based Stations

Water Quality Parameter	Estuarine Isohaline			
	0 psu	6 psu	12 psu	20 psu
Water Color	Figure 5.241	Figure 5.242	Figure 5.243	Figure 5.244

The graphics indicate that under low Peace River flows much of the water coming from the watershed originates from sources having low color levels, such as surficial base flows and discharges of deeper aquifer waters associated with agricultural pumping. Color levels under such low flow conditions are the highest near the reach of the lower river where drainage from the Lettuce Lake system enters the Peace River from the east, suggesting localized ungaged drainage may be an important source of color in this reach of the river when flows are low. The series of figures show that as flows increase, typical southwest Florida “blackwater” river inflows are a major influence on the lower Peace River/upper Charlotte Harbor estuarine system.

Color levels temporally increase quickly in response to increased freshwater inflows, with levels typically being higher farther upstream than near the mouth of the river. Very high color levels, however, can extend well into the harbor during extended periods of high freshwater flows such as occurred during the 1997/1998 El Niño or during the extremely high flows that occurred during 2001, 2003, 2004, an 2005. Somewhat analogous to the previously described spatially divergent responses of surface salinities to increases in freshwater flows, levels of water color at the downstream fixed monitoring sites show steady increases in color levels under ever higher rates of freshwater inflow. Further upstream, however, at some point additional increases in flow do not correspond to higher levels in ambient water color. Under conditions of extremely high flows, color levels actually in some regions of the lower river begin to decline as the contact time of sheet flow is reduced and previously built up humic compounds are increasingly flushed from the watershed by the direct addition of low color rainfall.

The moving-station data also illustrate that color levels in the freshwater and estuarine salinity zones rapidly increase throughout the lower Peace River/upper Charlotte Harbor system in response to higher seasonal summer freshwater inflows. Under conditions of lower flows, the intermediate salinities often have higher ambient color than the lowest or highest salinities. This suggests that during periods when ground water comprises the major source of water coming from the Peace River watershed, the wetlands immediately surrounding the lower river are the primary source (ungaged) of water color. However, as gaged freshwater flows from the watershed increase, the presented figures show the influences that “blackwater” river inflows have on the lower Peace River estuarine system.

Significant positive correlations of water color with seven-day average flow were identified at every station. The correlation coefficients were all positive and greater in magnitude than for many other parameters investigated above, in many cases indicating that flow explained more than 25% of the observed variation in water color. The significant correlation coefficients, by station were:

- RK -2.4 (R=0.75)
- RK 6.6 (R=0.79
- RK 15.5 (R=0.70)
- RK 23.6 (R=0.66)
- RK 30.7 (R=0.63)
- 0 psu (R=0.56)
- 6 psu (R=0.52)
- 12 psu (R=0.49)
- 20 psu (R=0.37)

5.8 Summary

Overall, this chapter of the *2016 HBMP Comprehensive Summary Repor*t provides overviews and analyses relative to both the spatial status and historic temporal trends in key water quality characteristics in the lower Peace River/upper Charlotte Harbor estuarine system over the 1976-2016 time interval of HBMP monitoring. For a series of water quality parameters, the following analyses are included:

- Depicting and describing the patterns and trends for HBMP data along the longitudinal monitoring transect (spatial comparison) for both isohaline-based and fixed-station sampling;
- Depicting and describing temporal trends in identified water quality parameters sampled through the HBMP for both isohaline-based and fixed-station sampling;

- Discussing changes in water quality upstream of the Peace River Facility and among Peace River watershed basins as it pertains to patterns and trends observed in HBMP monitoring data; and
- Evaluating the effects of flow on the identified water quality parameters.

It is important to note that concentrations of water quality constituents (such as nutrients) are not affected by freshwater withdrawals. However, the loads of such constituents may be. Other factors, such as changes in land use patterns, are more likely to affect changes in water quality. Analyses of period of record HBMP data have illustrated key findings relevant to water quality parameters, other than salinity, in the lower Peace River/upper Charlotte Harbor, and these are summarized below.

5.8.1 Dissolved Oxygen

Dissolved oxygen levels in the lower Peace River estuarine system show distinct seasonal patterns, with the lowest levels typically occurring during the summer wet-season. Even near the top of the water column dissolved oxygen concentrations are often low. Measured levels are generally higher during cooler months, due to lower water temperatures (that increase the ability of the water to hold more dissolved gases) and seasonally increasing wind stress and mixing. Higher daytime values are also often associated with increases in phytoplankton production (chlorophyll *a*) and typically account for many of the unusually high observed values.

The presented analyses generally found similar surface and bottom annual average dissolved oxygen concentrations in the upper portion of the HBMP monitoring transect when comparing the 1976-1989 and 1996-2016 time periods. However, small (<0.35 mg/L) statistically significant decreases between the two periods were observed for the lower reaches of the river. Observations from the moving, isohaline-based sites indicate that measured surface dissolved oxygen levels at the most upstream isohaline (0 psu) have increased over time. A potential mechanism that might explain these apparent increases may be related to the previously discussed recent periods of extensive drought resulting in lower freshwater inflows of highly colored water. Flows result in both higher average nutrient (inorganic and organic nitrogen) loadings to the upper reaches of the estuary, along with increased color which reduces the availability of light. Sufficient flow to stimulate phytoplankton production, while not being high enough to reduce light levels may result in higher dissolved oxygen levels. Unfortunately, such relationships are confounded by a number of additional seasonal factors including temperature, nutrient recycling and residence time.

The results generally show that surface dissolved oxygen concentrations along the monitoring transect initially increase slightly under increasing low to moderately levels of flow. However, above some level, further increases in flow tend to progressively depress ambient surface dissolved oxygen levels at each of the fixed locations along the HBMP monitoring transect. The relationship between surface dissolved oxygen concentrations and flow is confounded by the combined influences of seasonal changes in water temperature and salinity. Bottom dissolved oxygen levels at the more downstream sites decline with increasing flow in response to progressive density stratification of the water column. At the more upstream locations the responses of both surface and bottom dissolved oxygen concentrations are similar to increasing seasonal flows.

5.8.2 Chlorophyll *a*

Spatially, the highest chlorophyll *a* levels occur within the two intermediate salinity zones. During the spring, high levels of phytoplankton biomass often are observed within the 6 psu isohaline, which characterizes the zone of the estuary where nutrient rich freshwater first mixes with low nutrient harbor water. A second, often smaller peak in phytoplankton chlorophyll *a* usually occurs within the 6 psu salinity zone during the fall, as water color (inflow) decreases. Conversely, an opposite seasonal pattern occurs in the more saline 12 psu salinity zone, where nutrients (nitrogen) are more limited and the spring phytoplankton bloom is smaller, and the fall increase in response to the reduction in light limitations is more pronounced. In the reaches of the estuary characterized by the 20 psu isohaline, phytoplankton production is reduced and shows less seasonal variability, with the highest concentrations often occurring at the end of the summer wet-season.

The statistical trend procedures suggest chlorophyll *a* phytoplankton levels increased within the 20 psu isohalines over the 1984-2016 time interval. Higher chlorophyll *a* levels are a reflection of the corresponding observed significant higher color levels (that can serve as a proxy for nutrient loadings), and summer wet-season flows that have, on average, characterized portions of proposed warmer AMO phase since 1995. However analyses from the fixed-station data indicated that there are no statistically significant differences in average annual seasonally weighted mean chlorophyll *a* concentrations between the 1976-1989 and 1996-2016 time intervals at any of the five fixed river kilometer based HBMP monitoring locations.

Seasonally, initially higher flows increase inorganic nitrogen loading, which simulates phytoplankton production both in the lower river and upper harbor. However, further higher flows also increase color levels in the estuary reducing the ability of light to penetrate the water column, thus simultaneously diminishing phytoplankton growth rates. Residence time is also reduced as flows increase resulting in phytoplankton (chlorophyll) increasingly being “flushed out” of the lower river.

5.8.3 Nitrate/Nitrite

Ambient inorganic nitrogen concentrations are typically at or near detection limits in the highest salinity reaches of the estuary throughout most of the spring and summer when light levels are high and phytoplankton production is greatest. Concentrations are conversely greater during the fall and winter months. Overall, ambient inorganic nitrogen levels progressively increase moving upstream from high to low salinities. The results of the Seasonal Kendall Tau trend tests found that inorganic nitrite+nitrate concentrations within the most downstream 20 psu salinity zone have slightly statistically significantly increased over time. This result corresponds with both the observed periodic increases in flow (primarily during the summer wet-season) and the measured increased color levels.

The relationships between dissolved inorganic nitrogen concentration and rates of freshwater inflow are complex. As flows gradually increase following the typical spring dry-season, increasing nitrogen loadings stimulate estuarine phytoplankton production and ambient inorganic nitrogen levels often remain near or at detection limits throughout much of the lower Peace River estuarine system. However, as flows further increase, upstream phytoplankton primary production become color rather than nitrogen limited and inorganic nitrogen levels rapidly rise with increasing flows. A third condition then occurs at the upstream HBMP sampling locations as both water color and nutrient levels start to decline with further increases in flow. Such changes again reflect seasonal changes in the water quality characteristic of sheet flow to the watershed's major tributaries following longer (and/or higher) amounts of rainfall.

5.8.4 Total Kjeldahl Nitrogen

Like inorganic nitrogen, this gross measurement of combined inorganic ammonia and organic water column nitrogen shows distinct seasonal and spatial patterns along the HBMP monitoring transect. Concentrations are typically lower in the more saline waters of the downstream stations, and are also more elevated during the summer wet-season than during the dry-season. There were no statistically significant differences in seasonally averaged annual dissolved inorganic nitrate/nitrite concentrations at the fixed-station locations between the two time periods. Additionally, the applied statistical trend procedures did not indicate that TKN levels have systematically increased or decreased over the monitoring interval.

Large degrees of variation often occur at a given flow depending on the history of flows over both the immediate and longer-term preceding periods. TKN concentrations within the lower Peace River/upper Charlotte Harbor Estuary generally show spatial increases moving upstream, as well as increasing levels under higher freshwater inflows. This is supported both by the fixed-station as well as the isohaline-based station data. Several stations exhibited statistically significant, positive correlations of TKN with 7-day average flow.

5.8.5 Ortho-phosphorus

The lower Peace River/upper Charlotte Harbor estuarine system is naturally high in phosphorus due to the extensive natural phosphate deposits in a number of the major upstream watershed basins. However, a longitudinal gradient, with lower values in more saline waters is observed in the fixed-station data, as well as the isohaline-based moving-station data.

Long-term temporal patterns indicate rapid declines in both the magnitude and variability in phosphorus levels when compared with the initial first six years of HBMP monitoring. This decline followed implementation in the late 1970s of stricter regulations and subsequent decreases of both point and nonpoint discharges to surface waters from phosphate mining and processing. Average annual mean phosphorus concentrations between 1976 and 1989 continued to decline at the HBMP river stations, even though the largest changes occurred prior to 1984. Recent investigations (PBS&J 2009, 2010 and Atkins 2011, 2012) have concluded that the direct cause for the recent observed increase in phosphorus levels seems to have been related to discharges of waters during the closure of the Ft. Meade phosphogypsum stack system in the upstream Whidden Creek subbasin. Phosphorus concentrations began again declining during 2009 and have continued through both 2010 and 2011. While slight increases in annually averaged ortho-phosphorus have occurred at some stations since 2011, overall inorganic phosphorus levels are significantly lower when compared to the previous historic period.

Phosphorus concentrations generally reflect both the spatial and temporal variation in Peace River freshwater inputs. The highest phosphorus concentrations are typically associated with seasonal lower river flow, when the influences of ground water are more pronounced. Large degrees of variation often occur at a given flow depending on the history of flows over both the immediate and longer-term preceding periods. The data illustrate that the observed patterns and response of ortho-phosphorus to increasing flows in the lower Peace River estuarine system is very similar to that exhibited by inorganic nitrite/nitrate nitrogen. Concentrations progressively increase upstream towards the freshwater source, and initially rise in response to higher levels of freshwater inflow. However, as freshwater flows increase further and surface water runoff begins to provide an ever greater percentage of total river flow, the actual concentration of ortho-phosphorus (which is usually more than ninety percent total phosphorus) declines. Concentrations in the downstream more marine areas of the upper harbor generally show steady increasing levels with higher flows. However upstream, in the more freshwater reaches of the river, phosphorus concentrations are typically very high and then rapidly decline as freshwater flows increase and surface water runoff rather than ground water steadily provides an ever greater percentage of total river flow. Results of the correlation analyses support these trends observed in the presented figures.

5.8.6 Silica

Silica levels spatially increase progressively upstream. Seasonally, as freshwater inflows become greater, ambient reactive silica concentrations are shown to both increase and move further downstream into the upper Harbor. Ambient concentrations initially rapidly rise throughout the lower river/upper harbor estuarine system as freshwater inflows increase. Following this marked initial rise however, silica concentrations then remain relatively similar as flows further increase.

Both the long-term time-series plots and the statistical comparisons of mean annual average reactive silica concentrations indicate that silica levels have and continue to dramatically increase along the entire length of the lower Peace River monitoring transect. During the most recent twenty-one years of HBMP monitoring, silica concentrations at each of the five fixed sampling sites have increased and the range of variability has increased when compared with similar data from the 1976-1989 period. These increases are also reflected in the isohaline-based sampling data. The *2006 HBMP Comprehensive Summary Report* suggested “that the observed increases in ambient reactive silica levels in the Peace River estuarine system might reflect the cumulative influences of increased ground water use and the expansion of water intense agriculture in the Peace River watershed, or it may be associated with other land use changes occurring upstream in the watershed”. As with the observed increase in phosphorus levels the upstream data collected by the Authority showed very high silica levels in discharge waters associated with the Ft. Meade phosphogypsum stack system closure in the Whidden Creek subbasin. However, while phosphorus levels in the lower river/upper harbor appear to have again declined to more normal levels, silica levels continue to remain high.

5.8.7 Color

Water color levels exhibit a longitudinal gradient in the lower Peace River, with typically higher levels farther upstream than near the mouth of the river. However, very high water levels can extend well into the harbor during extended periods of high flows.

Statistical analyses indicated significant increases in the average annual surface color levels for multiple stations between the 1976-1989 and 1996-2016 sampling periods. These differences reflect the higher inflows of dark colored water farther down the river and into the upper harbor during the recent period of high flows. Although a number of extensive droughts have characterized much of the more recent historical period, the data also suggests a number of wetter than usual summer wet-seasons have also occurred. The applied statistical trend test procedures indicate that these increases in wet-season flows have resulted in statistically significant increases in average annual ambient water color within the estuarine salinity zones over the 1984 through 2016 time interval.

Under low Peace River flows much of the water coming from the watershed originates from sources having low color levels, such as surficial base flows and discharges of deeper aquifer waters associated with agricultural pumping. Color levels under such low flow conditions are the highest near the reach of the lower river where drainage from the Lettuce Lake system enters the Peace River from the east, suggesting localized ungaged drainage may be an important source of color in this reach of the river when flows are low. As flows increase, typical southwest Florida "blackwater" river inflows are a major influence on the lower Peace River/upper Charlotte Harbor estuarine system. Levels of water color at the downstream fixed monitoring sites show steady increases in color levels under ever higher rates of freshwater inflow. Further upstream, however, at some point additional increases in flow do not correspond to higher levels in ambient water color. Under conditions of extremely high flows, color levels actually in some regions of the lower river begin to decline as the contact time of sheet flow is reduced and previous built up humic compounds are increasingly flushed from the watershed.

6.0 Regulatory Influences on Water Withdrawals from the Lower Peace River

6.1 Introduction and Overview

Regulations implemented by various government agencies have the potential to impact permitted withdrawals by the Peace River/Manasota Regional Water Supply Authority's (Authority) Peace River Facility's water use permit. Such regulatory activity includes the adoption and potential revision of Minimum Flows and Levels (MFL) in the Peace River watershed, and any current or future water quality impairments and associated management actions occurring in the watershed. The primary objectives of this chapter are to:

1. Summarize the history of the Lower Peace River MFL, its relevancy to Authority operations, and its current status;
2. Summarize the history of the Facility and the Authority's water use permit; and
3. Summarize identified water quality impairments in the Peace River watershed and any associated management responses to such impairments.

6.2 Overview of the MFL for the Lower Peace River

The District is required to establish minimum flows and levels (MFLs) for surface water bodies, including rivers, streams and estuaries, to identify the limit at which further withdrawals would be significantly harmful to the water resources or the ecology of the area. District work on development of MFLs for the Lower Peace River was initiated in 2007, and was based on goals that included maintaining freshwater at the Authority's withdrawal facility on the Lower Peace River and biologically-relevant salinities throughout the Lower Peace River. After passing though many reviews, including independent scientific peer review, MFLs for the Lower Peace River were adopted into the District's Water Levels and Rates of Flow rules (specifically Rule 40D-8.041(8), Florida Administrative Code or F.A.C.) in July 2010 and became effective in August 2010. The approach utilized was to protect the flow regime, which is necessary to protect the ecology of the system.

As part of the process to determine the appropriate MFL and ensure protection of the flow regime, the District analyzed historic and current flow conditions to better understand the existing anthropogenic influence on the system. To better understand natural and anthropogenic influences on the system, climatic variability and long-term oscillations were accounted for in the review of historical hydrologic conditions. Seasonal blocks were defined based on typical low, medium and high flow periods of the year. The 'building block' approach which has been the preferred District method for determining minimum flows and levels was used in determining these MFLs. A low-flow threshold (below which withdrawal is not allowed) was determined, and the percent of flow method was used to determine allowable withdrawals when flows exceed the low-flow threshold.

The low-flow threshold for the Peace River was based on the operational capability of the Authority's Facility on the Peace River. Empirical analysis indicated that saline waters would be present at the withdrawal point when the combined flows of the Peace River at the Arcadia gauge, Joshua Creek at Nocatee, and Horse Creek near Arcadia are below 130 cfs. When the combined flow is below 130 cfs facility operations are limited by the presence of high-conductivity water, which is not suitable for water supply.

If flow is greater than 130 cfs the MFL protects the typical salinity distribution in the lower Peace River. Specifically, the MFL determined the acceptable percent of flow reduction to maintain the 2, 5 and 15 psu zones. Additionally, a portion of the lower Peace River has been shown to have high levels of fish abundance and diversity. The typical salinity levels in this portion of the river are 8 to 16 psu. Therefore an additional analysis based on maintaining the 8 to 16 psu salinity range within that portion of the river was conducted. Based upon the results of these analyses the allowable percent withdrawals from the lower Peace River are:

- Block 1 (April 20 to June 25): 16% of flow
- Block 2 (October 27 to April 19): 16% of flow when flow is at or below 625, 29% of flow when flow is above 625 cfs
- Block 3 (June 26 to October 26): 16% of flow when flow is at or below 625 cfs, 38% of flow when flow is above 625 cfs

The flow referenced in the above bullets is the combined flows of the Peace River at the Arcadia gauge, Joshua Creek at Nocatee, and Horse Creek near Arcadia. Additionally, a maximum flow withdrawal of 400 cfs was instituted. The analyses conducted indicate that surface water withdrawals at these levels are protective of the ecology of the lower Peace River.

The Lower Peace River MFL rule specified that the MFLs will be reevaluated to incorporate additional ecological data for the Lower Peace River within 5 years of rule adoption. In response to this timeline, the District prepared an initial MFLs reevaluation report and scheduled completion of a more comprehensive reevaluation for 2018 (SWFWMD 2015a). The timeline for the more comprehensive reevaluation was developed to allow for incorporation of additional ecological data that are expected to strengthen the technical basis for the reevaluation.

In the initial review, the District analysis shows that, in general, the Authority has been in compliance with their permit conditions except for some days during low and medium flow seasons when withdrawals slightly exceeded the permitted maximum flows. These minor exceedances were mostly associated with subsequent adjustments to provisional USGS flow data for the three gage sites that are used in real time by the Authority on a daily basis to calculate allowable percentages of flow that may be withdrawn from the Lower Peace River. Additionally, the initial review illustrated that the HBMP data collected in 2012, 2013 and 2014 do not show any substantial changes when compared to the pre-adopted MFLs (1983-2011) data. The initial review found that "in total, the analyses completed for this initial MFLs reevaluation indicate that the current withdrawals schedule included in the water use permit issued to the Authority for withdrawals from the Lower Peace river based on the currently adopted MFLs, has not and is not expected to significantly affect the Lower Peace River /Charlotte Harbor estuarine system" (SWFWMD 2015a).

A comprehensive Peace River MFLs reevaluation is scheduled for completion in the later part of 2018. Analyses to be incorporated into the reevaluation include: 1) running a hydrodynamic model for baseline and reduced flow scenarios, 2) characterization of floodplain features/habitats and how these habitats may be affected by changes in river flows, and 3) habitat suitability modeling for evaluation of the abundance and distribution of six fish species that are known to be responsive to freshwater inflows (SWFWMD personal communication August 2017).

6.3 Overview of the Peace River Facility's History and Permits

In the early 1970s, General Development Utilities (GDU) actively began searching for a major regional water supply that would support the projected population growth for a number of large communities in southwest Florida under construction or planned by its parent company, General Development Corporation (GDC). Projected population estimates at the time suggested that the number of new residents in these planned communities might well exceed a quarter of a million by the year 2020. The primary goal of GDU was to establish a reliable and expandable source of potable water to supply this projected future population growth. After reviewing a number of potential alternative sources, it was determined that the site of the current Peace River Facility in DeSoto County along the predominantly freshwater reach of the tidal lower Peace River provided the greatest opportunity for a sustainable, reliable water supply for the planned future population growth within the three (Charlotte, Sarasota, and DeSoto) county areas within which GDC communities were being constructed or planned for development.

General Development Corporation determined that an assessment study was needed to evaluate the feasibility of locating a regional water supply system on the Peace River in Desoto County near State Road No. 761. Staff from the Rosenstiel School of Marine and Atmospheric Science at University of Miami were contracted to assess the potential environmental impacts to the lower Peace River and upper Charlotte Harbor of projected future freshwater withdrawals.

The information on biological communities and salinity/flow relationships developed during these initial field investigations by University of Miami staff were based on data collected between 1973 and 1974 (Michel *et al.* 1975). During this period, Peace River flows (measured at the Arcadia gage) ranged from a low of 62 cubic feet per second (cfs) to more than 10,000 cfs. Fortuitously, the relationships between salinity and flow developed during this relatively short period of study, and subsequently used in calibrating the initial numerical models during this work, were characteristic of much of the normal range of variation in flows that have subsequently occurred during both extended wet and dry periods.

A series of numerical models were developed to predict changes in salinity at sites extending from near the mouth of the river upstream to the planned future location of the Peace River Facility. Changes in salinities were modeled under worst-case conditions assuming freshwater withdrawals during naturally occurring periods of low river flow. The report (Michel *et al.* 1975) concluded that "under these conditions of flow and withdrawal, biological data indicated that such slight salinity increases, above the naturally occurring values of low flow periods, should add little additional stress on the plants and animals of the study area." This conclusion was based on what was found to be the highly dynamic natural seasonal changes in salinity within portions of the lower Peace River due to difference in flows during wet and dry periods.

The final report also strongly recommended that an extensive monitoring program be implemented to assess the validity of the predicted results.

On December 10, 1975, the Consumptive Use Permit #7500016 for the Peace River Regional Water Supply Facility was signed between General Development Utilities, Inc. and the Southwest Florida Water Management District. Specific conditions of the District's initial and subsequent Consumptive Use Permits for the Peace River Facility have set forth requirements that the Regional Water Supply Authority implement a comprehensive HBMP. The District's continuing expressed purpose in mandating this requirement has been to ensure the continuing development of sufficient long-term data needed to establish and assess the responses of various physical, chemical and biological characteristics of the Charlotte Harbor Estuary to seasonal, long-term, and withdrawal related changes in Peace River flow. The long-term HBMP study elements have specifically been designed to evaluate the consequences and significance of natural changes in salinity, water quality and biological characteristics inherently associated with seasonal variations in freshwater input. In particular, a number of monitoring program elements have sought to establish the effects of natural long-term variations in river flow on the overall health of aquatic fauna and flora communities in the lower Peace River and upper Charlotte Harbor. Once having established the influences of natural variations, a corollary goal of the long-term monitoring program has been to determine if freshwater withdrawals by the Peace River Facility can be shown to have measurable impacts or result in quantifiable alterations of the biological communities of the lower Peace River/upper Charlotte Harbor Estuary. A history of the HBMP and descriptions of its major historic study elements are described below.

Construction of the Peace River Facility was completed and withdrawals began in the spring of 1980. As part of the initial construction, a relatively small off-stream surface water reservoir was constructed, and soon thereafter construction began on a series of underground Aquifer Storage Recovery (ASR) wells. Adequate storage was identified early in the initial evaluation and planning for the Peace River Facility as an important component in assuring a reliable source of water given the degree of natural variability in river flows. Unlike many other water treatment facilities that utilize surface waters, there is no in-stream barrier in the Peace River to impound water during the typically dry winter and spring months. The District mandated as an initial permit condition that no withdrawals could be made below certain river flow levels. As a result the Peace River Facility has always relied on off-stream storage to maintain water supplies during the dry season and/or drought conditions.

The first permit renewal occurred in 1982. At that time, actual Facility withdrawals had only begun in early 1980, and therefore only a limited number of minor changes were made to the initial HBMP monitoring design. By the second permit renewal in 1988, over a decade of data had been collected as part of the ongoing HBMP studies, and the findings from these data were assessed to make significant modifications to both the monitoring efforts and withdrawal schedule (a summary of the history of the Facility’s District Water Use permits is presented in Table 6.1 below).

Prior to 1988, the regulatory limit for maximum daily withdrawals from the Peace River was 22 mgd (34.0 cfs), which could be withdrawn as long as the measured stream flow at the Arcadia gage was above the regulatory minimum flows that had been established for each month of the year. These calculated individual minimum monthly flows were initially based on a general formula that had been established under the District's first "Water Use Rules" adopted in 1975. This formula used records of the previous twenty years of stream flow to establish a separate minimum flow for each calendar month. The monthly minimum flows for the Peace River used to establish the freshwater withdrawal schedule prior to 1988 ranged from 100 cfs in April and May, up to 664 cfs in September during the summer wet season. As a result, during low flow periods in the spring, maximum daily withdrawals of 34 cfs could reduce flows (as measured at the USGS Peace River at Arcadia gage) by as much as 25 percent on some days. Conversely, during September, no water could be taken from the river until flows exceeded 664 cfs.

When the permit was renewed in 1988, General Development Utility's consulting scientists and the District agreed that the existing withdrawal schedule caused the Peace River Facility to rely too heavily on periods of low to moderate flows. It was agreed that site-specific information should be used to establish regulatory minimum flows and daily withdrawal limits from the Peace River. Using the long-term data collected under the HBMP, statistical models were developed to analyze the location of the freshwater/saltwater boundary as a function of flow, and predicted salinity changes that might result from permitted withdrawals.

Based on these analyses, the District and GDU agreed that the withdrawal schedule should be modified. A minimum criterion was established with no withdrawals when flows at Arcadia were below 100 cfs during the three typically dry spring months (March through May) and 130 cfs during the remainder of the year. Beyond that, withdrawals could equal up to 10 percent of the daily measured gaged flow at Arcadia, up to a maximum not to exceed 22.0 mgd (34 cfs) as long as daily withdrawals did not reduce river flows below the minimum flow cut off. This schedule allowed withdrawals to more closely follow the natural variability of rainfall and flow.

In 1990 General Develop Utilities parent company GDC filed for bankruptcy protection. Charlotte County took control of GDU facilities within Charlotte County, and ownership of the Peace River Regional Water Supply Facility was transferred to the newly formed Peace River Manasota Regional Water Supply Authority in mid-1991. The Authority was formed in 1984 and functions through inter-local agreements made among Charlotte, Desoto, Manatee, and Sarasota counties. As owners of the Peace River Facility, the Authority soon began making plans for expansion of the treatment facilities to both increase reliability and provide additional water to the region beyond that originally envisioned by GDU. A further goal of the Authority has been to develop a series of interconnections among the member county's water supplies to reduce potential effects of natural disasters and other interruptions in supply and allow improved regional management of water sources. In 2002, the Authority completed a major expansion of the Peace River Facility and its interconnection with the Carlton Water Treatment Facility in Sarasota County as the first step toward this long-term goal.

A twenty-year renewal of the Facility's Water Use Permit (No. 20010420.0004) was issued by the District to the Authority in March 1996 (Table 6.1). The permit contained specific conditions for the continuation and enhancement of specific study elements for the ongoing lower Peace River/upper Charlotte Harbor Estuary HBMP and established a series of maximum withdrawal quantities. This permit increased the minimum flows measured at the upstream Arcadia gage, under which no withdrawal could occur, to 130 cfs during all months of the year. Beyond that,

Table 6.1
Summary of Previous Facility Permits

Year	December 1975	March 1979	May 1982	October 1988	March 1996
Water Use Permit Number	27500016	27602923	202923	2010420	2010420.02
Average Permitted River Withdrawal (mgd)	5.0	5.0	8.2	10.7	32.7
Maximum Permitted River Withdrawal (mgd)	12 & 18	12 & 18	22	22	90
Diversion Schedule Low Flow Cut off (cfs)	91 – 664 *	91 – 664 *	100 – 664 *	100 & 130 **	130 **
Maximum Percent Withdrawal of River Flow	5	5	n/a	10	10

* Withdrawals based on historic monthly averages

** Withdrawals are based on percent of actual daily flow from the preceding daily flow at the USGS at Arcadia gage

withdrawals were still not to exceed ten percent of the preceding day average daily Peace River at Arcadia gaged flow. This permit encouraged the Authority to withdraw, treat and store more river water under high flows while limiting withdrawals to ten percent, and not exceeding the daily pumpage 90 mgd (139 cfs).

These initial series of District permitted withdrawal schedules for the Peace River Facility were all far more conservative and well below the "safe" levels originally proposed by the University of Miami Study in the late 1970s. The magnitude of the predicted and observed changes in salinity and isohalines due to Facility freshwater withdrawals have indicated (the previous *HBMP Comprehensive Summary Reports* in 2002 and 2006, as well as the *2007 HBMP Low Flow Pump Test*) that the predicted influences of freshwater withdrawals under the Facility's 1996 withdrawal schedule typically impact the daily average salinity along the lower river in the range of 0.1-0.3 ppt. These modeling efforts suggested that any Facility salinity impacts probably could not easily be detected, other than by using continuous recorders, given the normal distributions and daily tidal ranges of salinity along the lower Peace River/upper Charlotte Harbor HBMP monitoring transect. Given the far greater natural daily and seasonal ranges of salinity variation in the lower Peace River/upper Charlotte Harbor estuary and the lack of information regarding the potential consequences of such small salinity changes on tidal estuarine processes, the ecological consequences of these small but predictable changes have been exceptionally difficult to evaluate and predict. Thus, while withdrawals have resulted in predictable changes in salinity, the normal daily and seasonal variability in estuarine salinity distributions indicate that the changes due to Facility withdrawals have not appeared to be of a magnitude likely to be easily measured directly. This suggests that evaluating and predicting the effects of withdrawals on the salinity distributions within the lower Peace River/upper Charlotte Harbor estuarine system might ultimately best be accomplished using hydrographic and statistical modeling approaches in assessing, comparing and quantifying the potential for significant adverse harm to the mechanisms by which Facility withdrawals might lead to significant adverse impacts.

Due to extended drought conditions during 2006 and concern about the upcoming 2007 dry season (Figure 6.1), the Authority asked and received permission from the District in December 2006 to reduce the low flow Peace River at Arcadia withdrawal threshold from 130 cfs to 90 cfs until the end of the drought while still using the 1996 permit's 10 percent criteria. However, due to the unexpected historic low Peace River flows during the summer of 2007, the District issued an additional series of Executive Orders that temporarily modified the Authority's Peace River Facility withdrawal schedule (Table 6.2). The series of District Executive Orders issued by the District in response to the severity of the extended drought modified the withdrawal schedule to include withdrawals based on the total gaged flows upstream of the Facility (Peace River at Arcadia, plus Horse Creek near Arcadia and Joshua Creek near Nocatee). These executive orders also modified the low flow threshold, and increased the allowable percent withdrawals all based on the District's initial draft proposed Lower Peace River MFL. The relative recent historic contributions of the USGS gaged freshwater sources to the lower Peace River, both upstream of the Facility and at the U.S. 41 Bridge (which further includes flows from Shell Creek), are presented in Table 6.3.

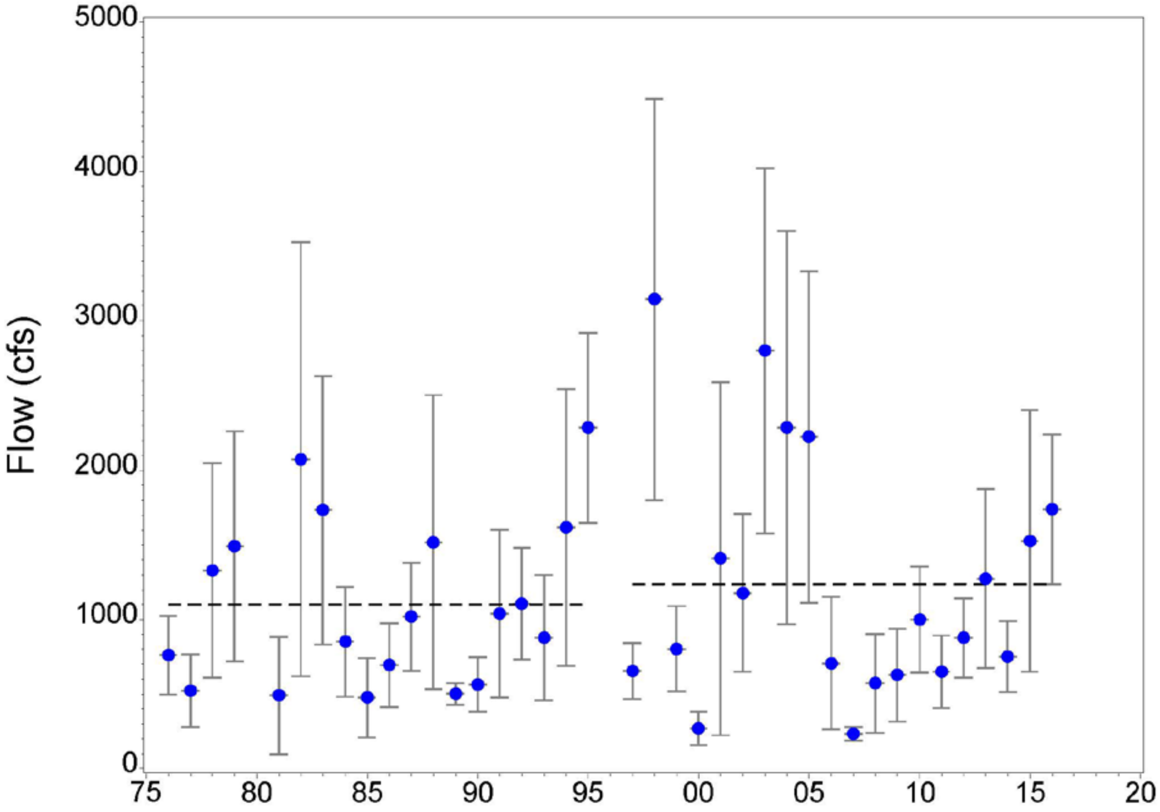

Figure 6.1 Annual monthly mean Peace River at Arcadia, plus Horse and Joshua Creeks gaged flows (with upper and lower 95% confidence intervals) between 1976 and 2016. The figure indicates that while total gaged flows upstream of the Facility since 1994 have been on average slightly higher (133 cfs) than during the previous 18 years of HBMP monitoring, much of the more recent period has been characterized by lower flows over extended periods.

The series of District Executive Orders were initially based on the draft criteria presented in the District's proposed Minimum Flow and Level (MFL) for the lower Peace River (Table 6.4). The District's initial draft MFL for the lower Peace River proposed that during seasonal Block 2 (October 27 to April 19) the maximum permitted Facility withdrawals should be 14 percent of all flows between 90 and 330 cfs based on the combined gaged flows upstream of the Facility.

Maximum withdrawals could then increase to 21 percent of the combined gaged flows above the long-term historic median flow of 330 cfs during the Block 2 time interval.

Table 6.2
Modifications to the Normal 1996 Permitted Withdrawal Schedule

Event	Effective Dates	Low Flow Threshold	Gages Used	Percent Withdrawal
Temporary WUP	12/1/06 to 8/12/07	90 cfs	Peace River at Arcadia	10%
Executive Order*	8/13/07 to 8/29/07	130 cfs	Three gages upstream of the Facility	12%
Executive Order*	8/30/07 – 10/31/07	90 cfs	Three gages upstream of the Facility	12%
Executive Order*	11/1/07 – 4/19/08	90 cfs	Three gages upstream of the Facility	14% to 330 cfs 21% above 330 cfs
Executive Order*	4/20/08 – 6/25/08	90 cfs	Three gages upstream of the Facility	10% to 221 cfs 26% above 221 cfs
Executive Order*	6/26/08 – 10/26/08	90 cfs	Three gages upstream of the Facility	12% to 1370 cfs 15% above 1370 cfs
Executive Order*	10/23/08 -7/15/09	90 cfs	Three gages upstream of the Facility	**4/20-6/25** 10% to 221 cfs 26% above 221 cfs **6/26-10/26** 12% to 1370 cfs 15% above1370 cfs **10/27-4/19** 14% to 330 cfs 15% above 330 cfs
Executive Order**	7/16/09 – March 2010	Same as above but increases maximum withdrawal from 90 to 120 mgd		
4/30/10 – Executive Orders ended and withdrawals returned to the original permit conditions				
Revised Permit Withdrawal Schedule Based on Adopted MFL	4/27/11 - Present	130 cfs	Three gages upstream of the Facility	**Block I** Apr 20th Jun 25th - 16% **Block II** Oct 27th – Apr 19th 16% if flow < 625 cfs 28% if flow > 625 cfs **Block III** Jun 26th – Oct 26th 16% if flow < 625 cfs 28% if flow > 625 cfs

* Note 1: The temp WUP was extended each month by the governing board until the first Executive Order was approved

** Note 2: Variable percent withdrawal based on District proposed MFL criteria

Table 6.3
Comparisons of Relative Contributions of Gaged Flows Over Recent Historic 1976-2016 Period

Time Period	Percent of Total Gaged Flow at Facility			Percent of Total Gaged Flow at U.S. 41 Bridge			
	Peace at Arcadia	Horse Creek	Joshua Creek	Peace at Arcadia	Horse Creek	Joshua Creek	Shell Creek
1976-2016	75.6	15.1	9.4	57.9	11.5	7.2	23.4

In April 2010 after evaluating comments received on the initial draft report covering both the lower Peace River and Shell Creek MFLs, the District revised its initial draft proposed MFL's by modifying the maximum withdrawals allowable. The District's revised MFL for the lower Peace River eliminated the criteria of adjusting withdrawals based on whether flows were above or below the calculated seasonal mean. The District's revised MFL's instead added a 625 cfs upper threshold prior to changing the allowable percent withdrawal to both Blocks II and III, and delayed determination of a final Shell Creek MFL. In August 2010 the District approved and implemented the final MFL for the lower Peace River (Table 6.5).

Table 6.4
Initial Daft District Proposed Lower Peace River MFL Schedule (based on combined USGS gaged flow at three upstream gages)

Block	Mean Flow	Allowable Percent Reduction if Flow:	
		Below the Median	Above the Median
Block 1 (April 20th – June 25th)	221	10	26
Block 2 (October 27th – April 19th)	330	14	21
Block 3 (June 26th – October 26th)	1370	12	15

Table 6.5
Final Adopted District Lower Peace River MFL Schedule (based on combined USGS gaged flow at three upstream gages)

Block	Allowable Percent Reduction in Flow	
Block 1 (April 20th – June 25th)	16%	
Block 2 (October 27th – April 19th)	16% if flow < 625 cfs	29% if flow > 625 cfs
Block 3 (June 26th – October 26th)	16% if flow < 625 cfs	38% if flow > 625 cfs

The temporary modifications to the Facility's 1996 Water Use Permit presented in Table 6.2 were in direct response to the severity of the 2006-2011 drought. These modifications were not permanent changes to the Authority's 1996 permitted 10 percent withdrawal of river flow based solely on Peace River at Arcadia gaged flows. In 2009, the Authority completed construction of the new 6 billion gallon reservoir, and expansion of maximum pumping capacity of the intake structure on the Peace River. Following the District's 2010 adoption of a final MFL for the lower Peace River, based on the combined flows of the three gaged flows upstream of the Facility (Table 6.5), the Authority requested a revised withdrawal schedule based on the District's adopted MFL. The Authority's goal in making this application was to provide for increased utilization of its recently increased off-stream storage during higher river flows, in order to improve system reliability for the same 32.7 mgd average day delivery of water permitted in the Facility's 1996 District permit conditions.

A revised withdrawal schedule (Table 6.6) based on the District's adopted MFL was issued by the District to the Authority on April 26, 2011, and was implemented the following day. This permit modification maintained the original 32.7 mgd yearly average withdrawal and the maximum monthly allowed withdrawal average of 38.1mgd. The maximum daily diversions from the river were increased from 90 mgd to 120 mgd, in order to allow greater flexibility with the Authority's recent Facility upgrades. While the District's adopted MFL allows seasonal maximum withdrawals of 16%, (Block 1), 29% (Block 2) and 38 % (Block 3), the Authority requested and received maximum withdrawals of 16% (Block 1) and 28 % (Blocks 2 and 3) in the permitted diversion schedule. Daily Facility withdrawals had previously been based on the preceding daily average flow measured at only the USGS Arcadia gage. The new District permitted withdrawal schedule instead utilizes the previous day's combined flow based on the readings from three gages upstream of the Facility located on the Peace River at Arcadia (USGS 02297310), Horse Creek (USGS 02297310), and Joshua Creek (USGS 02297100). The low flow cutoff for Facility withdrawals remained the same as previously permitted at 130 cfs, but was also changed to reflect the combined flow of the three upstream gages.

Table 6.6
April 2011 Revised Authority Lower Peace River Withdrawal Schedule (based on combined USGS gaged flow at three upstream gages)

Block	Allowable Percent Reduction in Flow	
Block 1 (April 20th – June 25th)	16% if flow is above 130 cfs	
Block 2 (October 27th – April 19th)	16% if flow is > 130 cfs	28% if flow > 625 cfs
Block 3 (June 26th – October 26th)	16% if flow is > 130 cfs	28% if flow > 625 cfs

Two additional modifications were made to the Facility's water use permit in 2011. The first occurred in October 2011 and made a small adjustment in the allowable annual average withdrawal increasing it from 32.7 mgd, to 32.855mgd. This permit modification also increased the allowable monthly maximum from 38.1 mgd to 38.3 mgd. The next permit modification occurred in November 2011and didn't change any of the permit conditions other than change the expiration date of the current water use permit from 2016 to 2037, in order to conform to the length of the Facility's existing bonds and to conform to new District rules allowing longer term water use permits.

Even with the District's revision of the withdrawal schedule based on the established MFL for the lower river, there continues to be a large number of days each year when the Peace River Facility does not withdraw water from the river. During 2016, the Facility didn't withdraw water from the river 32 percent (114 days) of the time. Reasons for the Facility not withdrawing water on a given day or time interval can be due to:

- The total USGS gaged stream flows upstream of the Facility being below the designated low flow threshold of 130 CFS for freshwater withdrawals
- Poor water quality (conductivity, taste/odor)
- Facility maintenance
- Insufficient storage capacity (full existing storage system) even with the 2009 completion of the new 6 billion gallon reservoir

Extensive analyses of long-term trends and changes in lower Peace River watershed flows and Facility withdrawals were presented and summarized in **Chapter 3**.

6.4 Water Quality Impairments in the Peace River Watershed

The Florida Department of Environmental Protection (FDEP) assesses waterbodies as units designated as waterbody IDs (WBIDs). The WBID containing the withdrawal point, the water treatment plant and reservoirs is WBID 1623A. This WBID was recently delisted (10/21/2016) for exceeding the historical chlorophyll *a* threshold. This historical chlorophyll *a* threshold is no longer valid as a numeric nutrient criterion at this location and the delisting of this location has been approved. The WBID was placed on the planning list for total phosphorus (TP), meaning the FDEP will be collecting additional information prior to the next assessment to determine its status regarding TP.

Several WBIDs upstream of the plant have been listed as impaired for the presence of the indicator bacteria, fecal coliform. Being listed as impaired is the first step in the restoration process that includes the development of Total Maximum Daily Loads (TMDLs) implemented through Basin Management Action Plans (BMAPs). Fecal coliform bacteria act as an indicator of the potential presence of pathogens associated with wastewater. Unfortunately, these bacteria are also naturally found within all warm-blooded creatures, i.e. mammal and birds, causing many false positive results. Many waterways flow through areas that can range from "natural" to rural to suburban/urban, making it difficult to identify the source of the bacteria except through expensive DNA analyses. These sources range from wildlife, to cattle and horses, to pets and humans across the range of landuses. This standard is meant to indicate the risk of the presence of pathogens and thus contact should be limited. It does not exclude these waters from being utilized as a potable water supply as fecal coliform are removed through the treatment process. The US Environmental Protection Agency and FDEP have recognized the disadvantages of using fecal coliform and have recently moved to *E. coli* in freshwaters and *Enterococci* in marine waters as the indicators of choice.

At this time, there are no verified impairments (exceedances of applicable water quality standards and designated uses based on the Impaired Waters Rule Chapters 62-303 and 62-302, Florida Administrative Code (F.A.C.)) that would hinder the operations of the Authority.

6.5 Summary

The capability of the Peace River/Manasota Regional Water Supply Authority to withdraw and utilized water from the Lower Peace River is controlled by many factors. Primarily, the limits of its capabilities are controlled by the water use permit granted by the District to the Authority. However, such limits in the water use permit are made in accordance with Minimum Flows and Levels also established by the District. Additionally, the ability of the Authority to withdraw and treat water from the Lower Peace River can be affected by the quality of the water in the vicinity of the withdrawal point. At this time, there are no verified impairments (exceedances of applicable water quality standards and designated uses based on the Impaired Waters Rule Chapters 62-303 and 62-302, Florida Administrative Code (F.A.C.)) that would hinder the operations of the Authority.

7.0 Water Demand and Supply

This chapter provides a synopsis of demand (historical and projected) in the region receiving water from the Peace River, and the related withdrawals from the Peace River. Additionally, this chapter includes a summary of the Authority's Master Water Supply Plan and alternate source studies.

7.1 Long-term Water Demand and Supply Projection

The purpose of this section is to provide a synopsis of historical demand in the region receiving water from the Peace River, and the related withdrawals from the Peace River. Included are a review of historical demand and projected demand, and comparisons of actual river withdrawals.

7.1.1 Major Facility Physical Expansions and Capabilities

In order to meet future projected increases in regional demands (see below), the Peace River Facility has undergone several expansions to enhance its potential ability to meet those projected future needs. The Peace River Facility's initial treatment capacity between 1980 through 1988 was just 6 mgd (9.3 cfs), while its ability to pump water from the river intake located on a side channel of the lower river was limited to 34.0 cfs (22 mgd). In 1989, General Development Utilities doubled the Facility's treatment capacity from 6 to 12 mgd (18.6 cfs), without making any changes to the intake.

Initially, the Facility's only storage capacity was the initial 625 million gallon (85 acre) off-stream, surface reservoir. Additional storage capacity was further added by GDU in 1985 with the development of a series of Aquifer Storage Recovery (ASR) wells. The initial three ASR wells added a further 1,080 million gallons of storage capacity by 1988, to give the Facility a total combined storage capacity of 1,705 million gallons. An additional expansion of three more ASR wells in 1989 by GDU again increased the Facility's total storage capacity to 2,785 million gallons. The storage capacity was again increased by the Authority in 1995 by further expansion of three additional ASR wells, providing for a total combined above and below ground Facility storage capacity of approximately 3,865 million gallons.

A further expansion of the Facility capacity became operational in December 2001. This expansion consisted of doubling the Facility's previous existing treatment capacity from 12 mgd to 24 mgd, as well as adding a further additional twelve ASR wells to the system's previously nine ASR wells. The 2001 expansion gave the Facility a total storage capacity of approximately 7,500 million gallons. At the same time, a total of 27 miles of new water transmission lines were completed providing additional potable water supply capacity to Charlotte, DeSoto and Sarasota Counties, as well as to the City of North Port. The Facility's 2001 increase in treatment capacity to 24 mgd (37.1 cfs) included expanding the original raw water river diversion station from its initial (1980) capability of 22 mgd to a maximum capacity of 44 mgd (68.0 cfs).

Figure 7.1 August 2010 aerial showing the side channel of the Peace River near S.R. 769 on which the Facility's intake is located, the expanded Treatment Facility, and both the original 0.625 and newer 6.0 billion gallon surface reservoirs.

In 2009 the Authority completed further expansions to the Peace River Facility. These were undertaken as part of the Authority's ongoing plans to meet projected future increasing water demands caused by previous estimates (which more recently have been reduced) of expected rapid regional growth in the member counties. These expansions included increasing the Facility's river designed pumping capacity from 44 to 90 mgd and construction that increased the Facility's treatment capacity from 24 mgd to 48 mgd. In addition, construction of a new regional off-stream reservoir with a capacity of approximately 6 billion gallons was completed (Figure 7.1), and additional system transmission pipe networks was started to expand and optimize water delivery throughout the region. The designed pumping capacity from the river was later re-rated to near 120 mgd in conjunction with the 2011 revision of permit withdrawal schedule under the District's adopted MFL for the lower Peace River. Further improvements as of late 2015 increased the Facility's treatment capacity and the Facility is now permitted to treat 51 mgd.

During periods of higher river flow (when permitted withdrawal exceed regional demands), raw river water is stored in the Facility's 6.625 billion gallon off-stream surface reservoirs, while any excess treated water is stored in the system's 21 aquifer storage/recovery (ASR) wells. Conversely, when water is unavailable from the Peace River due to the established low flow 130 cfs cutoff (or when demand exceeds permitted withdrawals), water can be pumped from the raw water reservoir to the Peace River Facility for treatment, and/or previously treated water can also be recovered from the ASR well system and re-treated to meet the water supply demands of the Authority's service area.

7.1.2 Regional Demand for Water

Demand is a direct function of (among other things) population. Since 1970, population levels have (and are expected to continue to) increase in each of the four counties (Charlotte, DeSoto, Manatee, and Sarasota) serviced by the Authority (**Figure 7.2**). The City of North Port, which also receives water from the Peace River Facility, is included in the Sarasota County census projections. The projected (Florida Office of Economic and Demographic Research) regional population is expected to reach more than 1.2 million by 2040. Such projections may ultimately be revised upward or downward depending on changing economic conditions. However, the projected increases suggest an expected significant increase from 1970.

Demands for water supplies from the Peace River Facility have progressively increased since it began operation in 1980 (Figure 7.3). There was a rapid increase in regional demands from the Facility following completion of the expansion in December 2001. Comparing annual average daily customer demands with Facility withdrawals indicates that river withdrawals have generally exceeded demands. The obvious exceptions being during the most severe phases (1999-2001and 2006-2008) of the recent extended periods of drought. During both the annual spring dry-season months and/or during drought conditions, the permit's low flow cutoff of 130 cfs often mandates that little (if any) river water is withdrawn by the Facility. Demands under these seasonally frequent, and rarer drought conditions far exceed permitted river water withdrawals, with the difference being made up from either available surface storage from the reservoirs or by previously treated and stored groundwater from the ASR wells. Generally, until completion of the 2009 expansion, the Facility had a much more relatively limited ability to quickly store water to meet future demands.

The Authority has developed projected estimated future demands based on available information from its member governments and other regional sources. When evaluating these demands it is important to note that the total water supplies for Charlotte, DeSoto, Manatee (in the future) and Sarasota counties (and the city of North Port) come from a variety of additional sources. Figure 7.4 shows the current potable water demands of each of the four member counties and their current sources.

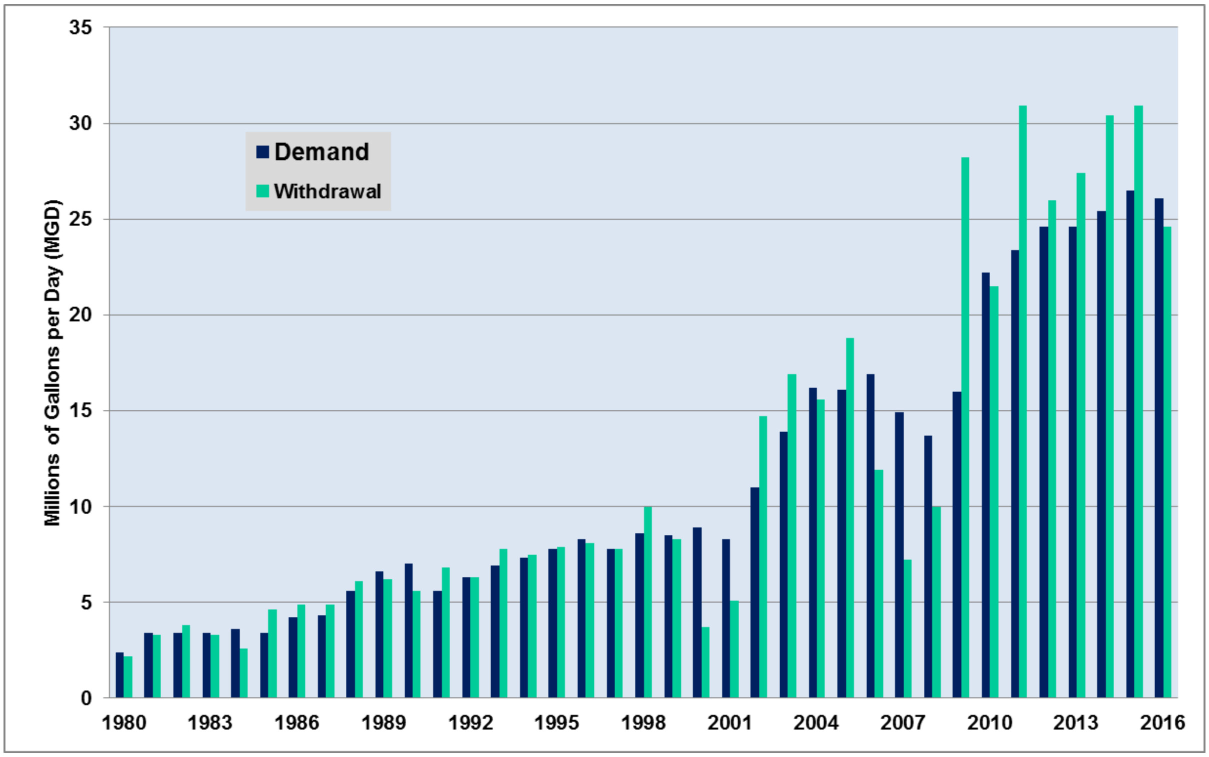

Figure 7.3 Comparison of annual average customer demands and Peace River Facility river withdrawals (1980-2016).

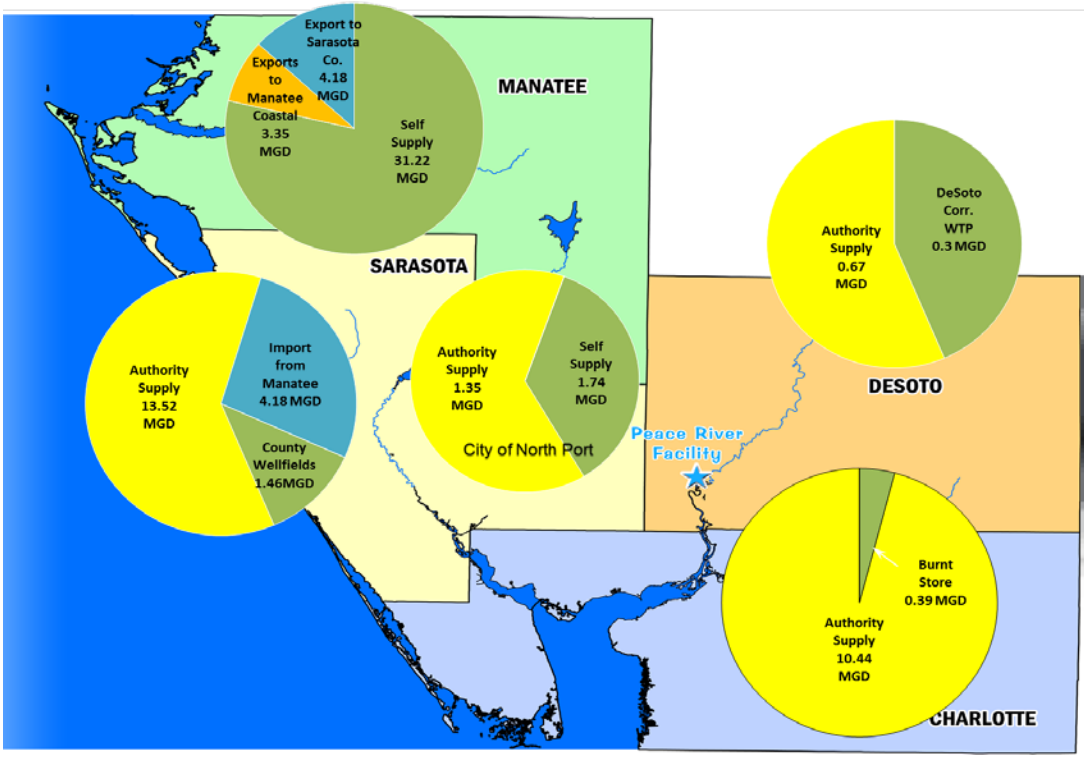

Figure 7.4 Summary of existing regional demands by each of the four county members relative to utilized sources.

7.2 Authority's Master Water Supply Plan and Alternate Source Studies

The Peace River Manasota Regional Water Supply Authority (Authority) provides drinking water in a four-county service area in southwest Florida. Customers now receiving water from the Authority include the counties of Charlotte, DeSoto, and Sarasota, and the city of North Port. By 2035 it is anticipated that Authority facilities will further serve a component of demand in Manatee County. In 2016 (Figure 7.4), the water demands supplied by the Authority were approximately 26 mgd.

The Authority withdraws water from the Peace River in DeSoto County. Withdrawals are limited by Water Use Permit to a percentage of the run-of-the-river, based on previous day flow at three U.S. Geological Survey flow gages upstream of the intake. Authority intake facilities on the river are capable of withdrawing up to about 120 mgd for conveyance to off-stream storage. Treatment, storage and transmission facilities include a 51 mgd conventional surface water treatment plant, 6.5 billion gallons of off-stream raw river water (reservoir) storage, a 6.3 billion gallon capacity treated water aquifer storage and recovery (ASR) system (Figure 7.5), about 65 miles of large diameter transmission pipelines, 25 mgd in remote booster pumping facilities and 22.5 million gallons of finished water storage.

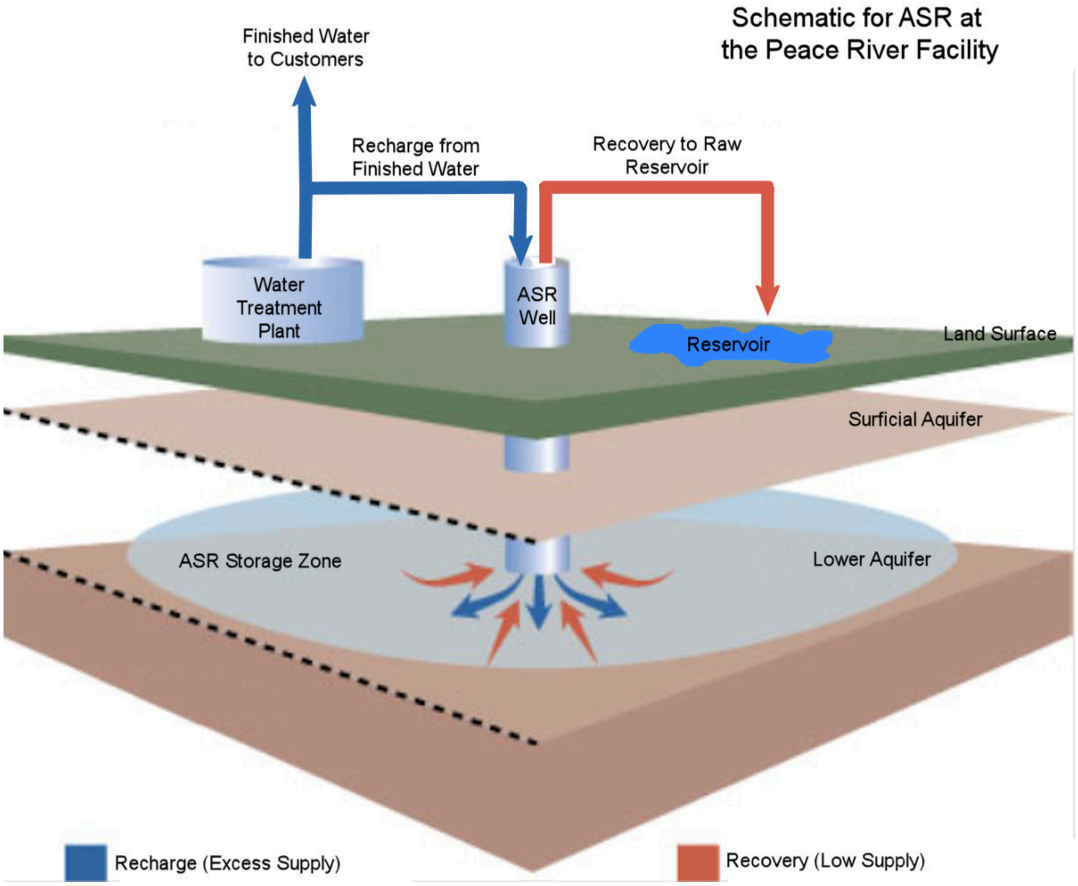

Figure 7.5 Schematic of use of ASR at Peace River Facility

Total supply capacity available from the Authority and its five Customers (Charlotte, DeSoto, Sarasota, and Manatee Counties and the City of North Port) is 102 mgd. This capacity is expected to increase to nearly 107 mgd in 2024 with the development of two wellfields in Manatee County and the City of North Port (Atkins et al 2015). As Figure 7.4 demonstrates, the Authority supplies a significant portion of this capacity. While currently supply exceeds demand, regional water demand is projected to grow resulting in a need for new supply development. The *2015 Regional Water Supply Plan* (Atkins et al 2015) projects that an additional 25 mgd of average annual permitted finished water capacity will need to be developed by the Authority and/or its Customers within the region by 2035. Multiple potential sources of supply were evaluated in the *2015 Regional Water Supply Plan* and include brackish wellfields, Peace River Facility surface water system expansion, and Cow Pen Slough surface water facility and expansion.

The Authority's Strategic Plan includes a focus on interconnecting the sources and demand areas throughout the region to improve system reliability and cost effectively meet current and future needs through optimal use of existing production facilities. Expansion of the regional pipeline system also improves resource management opportunities – enabling use of the right source at the right time, and expands the reach of the system improving opportunities to develop the most favorable new water supply sources. The Authority's Integrated Regional Water Supply Master Plan, adopted in April 2015, includes the Regional Vision for 2035 (Figure 7.6), recommending 72 miles of new pipelines interconnecting the region.

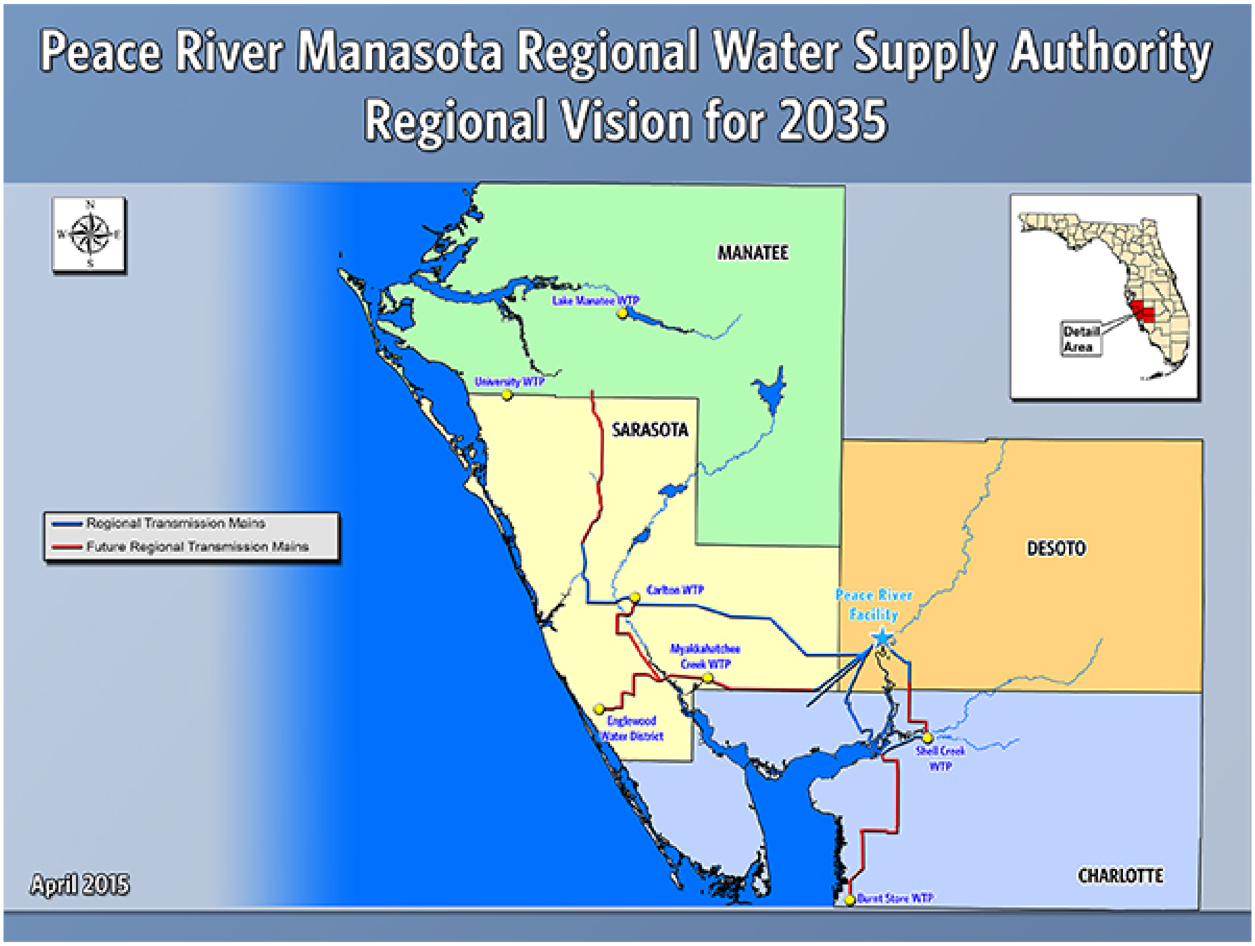

Figure 7.6 Peace River Manasota Regional Water Supply Authority Regional Vision for 2035 (from http://www.regionalwater.org/water-supply/peace-river-facility/pipelines/)

8.0 Assessing Environmental Change

Since its inception, the Hydrobiological Monitoring Program (HBMP) has incorporated numerous study elements directed toward assessing both the overall “health of the estuary” as well as determining impacts potentially associated with the Facility’s withdrawals. None of the extensive HBMP analyses completed to date have indicated changes resulting from either current or historic water withdrawals by the Facility have been of significant magnitude relative to the far greater natural degree of variation to have affected the long-term physical, chemical or biological characteristics of the lower Peace River/upper Charlotte Harbor estuarine system.

An approach for determining whether permitted surface withdrawals have or are causing adverse environmental impacts in the estuary, utilizing HBMP data, was proposed in the *2002 HBMP Comprehensive Summary Report*. Chapter 8 of the *2011 HBMP Comprehensive Summary Report* detailed the regulatory basis of review, the rationale for defining significant environmental change, and the hierarchy of management actions proposed under the HBMP to be implemented in response to detected changes that could forewarn of potential future adverse environmental impacts of sufficient magnitude that they would constitute an “adverse change”. Such management actions include data QA/QC audits, comparison of data correlates, redirected sampling efforts, District Governing Board hearings, and remediation. Additionally, the District may, at its discretion, convene a meeting of the HBMP Scientific Review Panel to evaluate detected changes or determine the appropriate regulatory course of action.

9.0 Monitoring Design and Modifications to the Existing Long-term HBMP Elements

9.1 Introduction and Overview

The primary objective of this section is to provide a final summary review of the overall effectiveness past and current HBMP study elements have had in assessing the relative magnitude of the impacts that Facility freshwater withdrawals have had, and potentially may have, to the downstream estuarine resources of the lower Peace River/upper Charlotte Harbor system. To this end, potential modifications to the current HBMP are addressed based on the results of the analyses and conclusions presented in previous sections of this document, as well as those contained within the series of preceding HBMP summary reports and documents submitted in compliance with the Facility 1996 water use permit.

- *2011 HBMP Comprehensive Summary Report* (Atkins 2013)
- *2006 HBMP Comprehensive Summary Report* (PBS&J 2009)
- *HBMP 2004 Midterm Interpretive Report* (PBS&J 2006)
- *2002 Comprehensive Summary Report* (PBS&J 2004)
- *2000 Midterm Interpretive Report* (PBS&J 2002)

The following series of topics are included in this chapter in conjunction with an overall review of the overall HBMP goals and objectives.

- An overview of the HBMP monitoring objectives;
- A review of established HBMP design criteria;
- Criteria for determining indicators of environmental change;
- An overview of previous HBMP elements;
- Summary of current HBMP study elements; and
- Recommendations regarding the reduction/elimination/enhancement of HBMP study elements.

9.2 HBMP Monitoring Objectives

The HBMP design needs to cost-effectively address the articulated goals and objectives delineated in the Southwest Florida Water Management District's (District) specific water use permit conditions. The combined elements of the program's design need to specifically meet the expectations and objectives set forth in the 1996 and previous water use permit's stated "specific conditions", as well as provide sufficient long-term information on which to base the development of answers to potential future questions that might be expected to arise.

The following summarizes the primary monitoring objectives of the HBMP study elements, as contained within the Authority's 1996 Water Use Permit's specific conditions.

- Monitor withdrawals from the Peace River Facility (Facility) and evaluate data as provided by the District for the gaged tributary flows from Joshua, Horse and Shell creeks, as well as the primary Peace River flows measured at Arcadia, and direct rainfall to the lower Peace River.

- Evaluate relationships between the ecology of the lower Peace River/upper Charlotte Harbor Estuary and freshwater inflows.

- Monitor selected water quality and biological variables in order to determine whether the ecological characteristics of the estuary related to freshwater inflows are changing over time.

- Determine the relative degree and magnitude of effects of Peace River withdrawals by the Facility on ecological changes that may be observed in the lower Peace River/upper Charlotte Harbor estuarine system.

- Evaluate whether consumptive freshwater withdrawals significantly contribute to any adverse ecological impacts to the estuary resulting from extended periods of low freshwater inflows.

- Evaluate whether the withdrawals have had any significant effects on the ecology of the estuary, based on related information such as nutrient loadings, fish abundance, or seagrass distributions data collected by other studies conducted by the District or other parties.

The overall goal of the HBMP continues to be to provide both the District and the Authority's governing Board with sufficient information to determine whether the water quality characteristics and biological communities of the lower Peace River/upper Charlotte Harbor estuarine system have been, are being, or may be significantly adversely impacted by permitted facility withdrawals. A secondary objective has historically been to develop an ongoing base of ecological information sufficient to provide the District with critical information regarding the overall status and relative "health" of the lower Peace River/upper Charlotte Harbor estuarine system, by evaluating the status and trends of selected water quality and biological parameters.

9.3 HBMP Design Criteria

In order to effectively meet these goals and objectives, the integrated design of HBMP elements should incorporate the following criteria.

- The program needs to identify those appropriate physical and biological indicators, and specific mechanisms of action, potentially subject to significant changes resulting from the Facility's permitted freshwater withdrawals from the lower Peace River/upper Charlotte Harbor estuarine system.

- The program should determine and predominantly focus it efforts in those geographical regions of the lower river/upper Harbor where naturally occurring and Facility induced changes in flows would be expected to result in the greatest potential observed changes in identified key estuarine characteristics.
- The design of the HBMP monitoring element should include sufficient spatial and temporal intensity to assure detection of measurable changes in selected physical/chemical/biological parameters resulting from changes in freshwater inflows.

It is therefore important that the following be clearly delineated for each of the HBMP study elements in order to meet these design criteria, and provide technically supportable data.

- The goals, objectives and specific sampling parameters need to be defined. This should include the specific purpose and application of each monitoring parameter.
- The sampling and analytical data gathering procedures need to be thoroughly described, specifically detailing the required temporal and spatial density of data collection.
- Data acquisition quality control and assurance methodologies need to be described, as well as potential methodologies and procedures for data analysis.

It is important that each HBMP study element, as well as the overall program, have specific clearly stated goals and objectives to cost-effectively meet the design criteria needed to accomplish the monitoring program's multiple expectations. These goals and objectives need to clearly establish the scientific basis needed to provide sufficient information to meet the District's criteria for required reasonable assurance. It is also essential that the HBMP study elements delineate the types and amounts of monitoring data necessary to construct, calibrate, and verify the quantitative models (see **Chapter 4.0**) needed to evaluate both current as well as possible future alternative withdrawal strategies under the District's established Minimum Flows and Levels (MFL) criteria.

Often a well-designed monitoring program results in unanswered questions concerning key environmental processes or potential impacts. It is therefore important that the HBMP design criteria provide for opportunities, where feasible, to include the incorporation of short-term, intensive monitoring elements needed to provide answers to specific questions or issues that may arise periodically during the review process. A clear example of such flexibility was the completed series of low flow "pump tests" (PBS&J 2009), which were used to confirm the predicted magnitude of temporal and spatial changes in salinity previously predicted by statistical models developed from data from the USGS and HBMP continuous recorders. The HBMP design elements further need to be sufficiently flexible to allow incorporation of modifications when and where changes in conditions, or new gathered information, suggest the need for specific monitoring program changes.

9.4 Indicators of Environmental Change

The following provides a brief overview of a number of the considerations and criteria associated with the selection of potential indicators (or parameters) that should be considered during the development and application of each HBMP study element. Possible monitoring parameters can generally be divided into three primary categories relative to their degree of overall importance in assessing the potential impacts of Facility withdrawals on the lower Peace River/upper Charlotte Harbor estuarine system.

- Those ***critical*** to the overall success of the monitoring program
- Parameters that would provide ***desirable*** additional information
- Indicators that may have some ***potential*** future application

Cost-effective HBMP elements need to incorporate key selected indicators that exhibit specific and robust direct (or indirect) quantifiable relationships with changes in freshwater inflows. Primary indicators that show direct relationships to temporal variations in freshwater inflows are typically physical or chemical in nature. Often, such parameters are characterized by rapid measurable responses to even relatively small changes in flows. In comparison, commonly utilized indicators characterized by indirect relationships with variations in flow are typically biological in nature. The relationships between changes in freshwater inflows and the distribution, structure and abundance of biological populations/communities within estuarine systems are mediated by preceding alterations of physical and chemical conditions. Thus, these indirect relationships generally exhibit much slower responses over time scales measured in days, months, seasons or even years. However, not only does the time scale potentially lengthen between variations in flow and observed responses with each trophic step up the food web, often the strength of the responses lessen relative to other seasonal factors associated with particular life-cycles and/or feeding-prey relationships.

A cost-effective HBMP monitoring design needs to focus on identifying and incorporating those *critical indicators* known to exhibit marked direct responses to variations in freshwater inflow, since it is these parameter measurements that present the greatest probability of both detecting and assessing the principle underlying causative factor(s) to observed environmental changes. To further incorporate accompanying *desirable indicators* within the HBMP, study elements should include those lower trophic level biological indicators that provide insight into the overall "health of the estuary," or those that afford insight into the integration of longer-term patterns. The utilization of *potential indicators* should be strictly limited to those few associated parameter measurements that can be quickly made with minimal additional effort or additional cost, and that may provide some further useful insight, without specifically being directly related to the study element's primary goals or objectives. The following basic criteria should be evaluated in assessing the relative efficacy of various potential indicators.

- **New Information** - provides specific fresh information and does not duplicate data already collected by other agencies or investigators.

- **Spatially Responsive** – the indicator should reflect changes in ecosystem conditions in response to an environmental stressor across a broad spatial range.

- **Anticipatory** - provides an accurate early warning of potential ecosystem changes.

- **Cost-Effective** - has low incremental cost relative to its information value.

- **Available Methodology** - should be generally accepted and standardized.

- **Unambiguously Interpretable** - must be indicative of either a direct or indirect pathway describing the structure and function within the context of an overall conceptual estuarine model.

- **Simple Quantification** – indicator measurements can be quantified relatively quickly with limited known variability among investigators.

- **Low Measurement Error** – parameter values should have known estimated levels of error than can be defined spatially and temporally.

- **Low Among Year Variability** – in order to detect ecologically significant changes within reasonable time frames, parameter values need to have low natural inter-annual variation relative to variables outside the environmental stressor of interest.

- **Sampling Stability** - measurements of the indicator should be spatially stable over the course of each sampling period.

- **Historical Record** – the availability of collaborative historical data from acceptable sources.

- **Retrospective** - can potentially be related to past conditions via retrospective analyses.

9.5 Previous HBMP Study Elements

Since the initiation of HBMP monitoring in 1976, the program has incorporated a number of differing physical, chemical, and biological study elements (see **Table 1.1**) that have been directed toward assessing both the overall "health of the harbor" as well as direct and indirect potential impacts that might be associated with Facility withdrawals. These HBMP studies have included the following program elements.

- A nine-year monthly study of the seasonal distribution of the sea star *Luidia clathrata* at twenty-six monitoring locations distributed between River Kilometers (RK) –28.0 and 8.0 throughout Charlotte Harbor and the lower Peace River was conducted.

- A benthic invertebrate ponar sampling program was conducted monthly. Between 1976 and1984 monitoring was done at nineteen sites distributed between the river's mouth (RK 0.0) and the point upstream of the Facility where Horse Creek enters the river (RK 34.0). This nine-year HBMP monitoring element was conducted to assess temporal and spatial responses of key benthic indicator invertebrates to both seasonal and long-term variations in freshwater inflows, salinity and dissolved oxygen.

- Monthly night-time otter trawls were performed around a fixed monitoring location in upper Charlotte Harbor (RK –2.4) over twelve years in order to determine the influences of freshwater inflows on the abundance and structure of juvenile fishes in the upper harbor.

- The HBMP program incorporated three long-term vegetation studies along the lower Peace River downstream of the Facility over the twenty-nine year period between 1976 and 2004. These vegetation HBMP elements include infra-red aerial photography, the first and last occurrences of indicator species, and the monitoring of emergent riparian community structure at selected transitional sites.

- The seasonal effects of freshwater inflows on phytoplankton primary production were assessed based on monthly measurements of radioactive carbon uptake rates at four isohalines between 1983 and 1998. Corresponding chlorophyll *a* measurements of phytoplankton biomass have continued since 1983 at the isohaline-based sampling sites. The associated composition of the phytoplankton communities at these locations was also determined between 1989 and 2004.

- A corollary study of zooplankton community structure was conducted monthly between 1989 and 1996 at each of the four monitored phytoplankton isohalines. The objectives of this eight-year HBMP study were to assess correlations among variations in freshwater inflow, phytoplankton production and biomass, and zooplankton populations.

- Since its inception, the HBMP has included extensive long-term monthly monitoring elements associated with both the physical and chemical water quality characteristics of the lower river and upper harbor at “fixed” monitoring locations. In 1983 corresponding monthly physical and water quality determinations were instituted at the four “moving” isohaline-based locations. These data have historically been utilized to assess both physical and chemical seasonal responses to changes in freshwater inflows, as well as long-term trends in water quality characteristics in the lower river and upper harbor estuary.

- The U.S. Geological Survey (USGS) began a cooperative water quality data collection program with the Peace River/Manasota Regional Water Supply Authority (Authority) in August 1996. An initial USGS continuous recorder (15-minute intervals) was installed later that month in the lower river at the end of an exiting private dock at Harbour Heights (River Kilometer (RK) 15.5). Since then, both USGS and the Authority have continued (Table 9.1), as recommended by the Scientific Review Panel, to expand the array of continuous recorder sites located along the lower Peace River (**Figure 6.1**).

Table 9.1

2016 Array of USGS and Authority Continuous Recorders Along the Lower Peace River

Gage ID, Location	Period of Record	River Kilometer
RK09 (Authority) – Navigation Marker south of I75 Bridge	Jun. 2011 to Present	RK 09.2
RK12 (Authority) - Manatee Zone Marker near Shell Creek (bottom)	May 2008 to Jun. 2011	RK 12.7
RK12 (Authority) - Manatee Zone Marker near Shell Creek (surface)	Jun. 2011 to Present	RK 12.7
HH (USGS - 02297460) – Dock at Harbour Heights *	Sep. 1996 to Present	RK 15.5
RK18 (Authority) – Channel Marker in Area of Power Lines	Jun. 2011 to Present	RK 18.5
RK18_HC (Authority) - Manatee Zone Marker on Hunter Creek	Jun. 2011 to Present	RK 18.7
RK20 (Authority) – Channel Marker downstream of Island	Jun. 2011 to Present	RK 20.8
RK21 (Authority) - Manatee Zone Marker near Liverpool area	Dec. 2005 to Present	RK 21.9
RK23 (Authority) - Manatee Zone Marker below Navigator Marina	Dec. 2005 to May 2008	RK 23.4
RK24 (Authority) - Manatee Zone Marker gage near Navigator Marina	Dec. 2005 to Present	RK 24.5
PRH (USGS - 02297350) – Dock at Peace River Heights gage *	Nov. 1997 to Present	RK 26.7
PRP (USGS – 02297345) – Peace River at Platt (Facility) *	Dec. 2009 to Present	RK 29.8
RK30 (Authority) - Manatee Zone Marker near SR 761 Bridge	May 2008 to June 2011	RK 30.6
RK31 (Authority) - Old Railroad Bridge upstream of Facility	May 2008 to Present	RK 31.7

* USGS Recorders measure near-surface and near-bottom salinities at fixed depths (while HBMP recorders measure sub-surface using floating recorders in stilling wells)

- A morphometric investigation of the river was undertaken in the late 1990s to establish a river kilometer-based centerline transect against which to standardize all historic and future HBMP monitoring data. Additional analyses were conducted to determine typical cross-sections, open-water areas, water volumes, shoreline lengths, and the areas/types of adjacent wetland habitat along 0.5 kilometer segments of the lower Peace River study area. (Note: More recently, the District has completed an updated morphometric investigation of the lower Peace River following Hurricane Charlie in 2004 in conjunction with its upcoming re-evaluation of the lower river's adopted MFL.)

- Intensive short-term investigations were conducted of the relative influences of variations in freshwater flows on the relative temporal/spatial distributions of both benthic macroinvertebrates and mollusks (1998-2000), and juvenile fishes and selected invertebrates (1997-2000). One of the objectives of both investigations was to determine potential monitoring strategies relating to future inclusions of additional HBMP study elements.

- Between December 2006 and May 2007, the Authority conducted a series of sixteen "pump test" events conducted under relatively low flow conditions. Graphical analyses of the relationships between average hourly gage heights and conductivities at the five continuous recorder locations downstream of the Facility showed that under ideal

> conditions of similar flows and tides, differences attributable to withdrawals were, as expected, relatively small given the normal daily range of variation. These analyses showed that salinity changes due to withdrawals were primarily confined to the peaks of incoming tides. The average salinity differences observed from these graphical analyses were well within those limits predicted by previous statistical models. In fact, when averaged over the entire range of the daily tidal cycles, these directly observed daily salinity changes were far less than those estimated from the previously developed statistical models.

The specific objectives, methods and results of these historic and ongoing HBMP study elements have been presented in the extensive series of HBMP Annual Data Reports and periodic Summary and mid-term Interpretive Reports submitted to the District since 1979. Comprehensive summaries of the objectives and conclusions of the major recent HBMP-related documents are presented in **Section 2.0**, and **Appendix B**. To date none of the extensive analyses conducted in conjunction with these HBMP study elements have indicated or suggested that there have been any major significant physical, chemical or biological changes within the lower Peace River/upper Charlotte Harbor estuarine system resulting from water withdrawals by the Peace River Regional Water Supply Facility. All modeling efforts of changes in either salinities or isohaline locations have concluded that the maximum expected changes potentially resulting from Facility withdrawals would be difficult to actually measure using only monthly monitoring given the range of the normal daily tidal and seasonal ranges of salinity variations.

9.6 HBMP Design Modifications

Modifications have been made to the monitoring elements of the HBMP throughout its history. While the overall cost (inflation adjusted) of the monitoring program has remained relatively constant, study elements have been added and deleted in order to enhance the overall knowledge base of the lower Peace River/upper Charlotte Harbor estuarine system. Historically, those major monitoring elements aimed at assessing direct relationships with variations in freshwater inflow have had the longest histories (vegetation and water quality – see **Table 1.1**). Other program elements, primarily those focused on assessing indirect biological indicators, have extended over a number of years and then ended once a sufficient baseline basis of information had been accumulated. Modifications recommended by the Scientific Review Panel were detailed in **Appendix A**. Overall the Panel continued to recommend that the HBMP should focus monitoring primarily on assessing long-term trends in key physical, chemical and biological characteristic directly related to the Facility's potential influences.

The only modification to the HBMP since the *2011 Comprehensive Summary Report* is the addition of a spatially intensive *in situ* chlorophyll monitoring program expected to provide additional information relative to a key biological process integrated to freshwater (nutrient) inflows, and directly linked to other estuarine food web components. The following provides a brief overview and rational for the addition of such monitoring to the HBMP which was initiated in 2013.

Both the "fixed" and "moving" HBMP water quality study elements include monthly monitoring of chlorophyll *a* levels along the lower river/upper harbor monitoring transect. As a common photosynthetic pigment among all major primary producers, chlorophyll *a* is widely used as an estimate of phytoplankton biomass in both freshwater and estuarine systems. The spatial and temporal variability of phytoplankton chlorophyll *a* concentrations is widely applied in estuarine ecology as a relative indicator of overall integrated levels of primary production.

The development of a comprehensive understanding of phytoplankton production (biomass) is a fundamental component in developing an integrated understanding of the interrelated physical/chemical systems and biological processes within the lower Peace River estuarine system, and a key component of the developed Peace River HBMP Conceptual Model (**Figure 9.1**). Phytoplankton production represents a large, immediately available food resource directly accessible to many lower rivers' grazing, filter and detrital feeding estuarine organisms. Phytoplankton production further represents a basic, integrated estuarine component directly influenced by variations in freshwater inflows. Due to the very short generation times involved (hours/days), phytoplankton production, when compared with many other potential biological indicators, can potentially be more directly quantitatively linked to changes in freshwater inflows. The observed numbers and spatial distributions of other potential biological estuarine indicators are subject to the confounding additional influences associated with longer generation times, intricate life-cycles, and the increasing complexity of predatory/prey interactions with each additional trophic level.

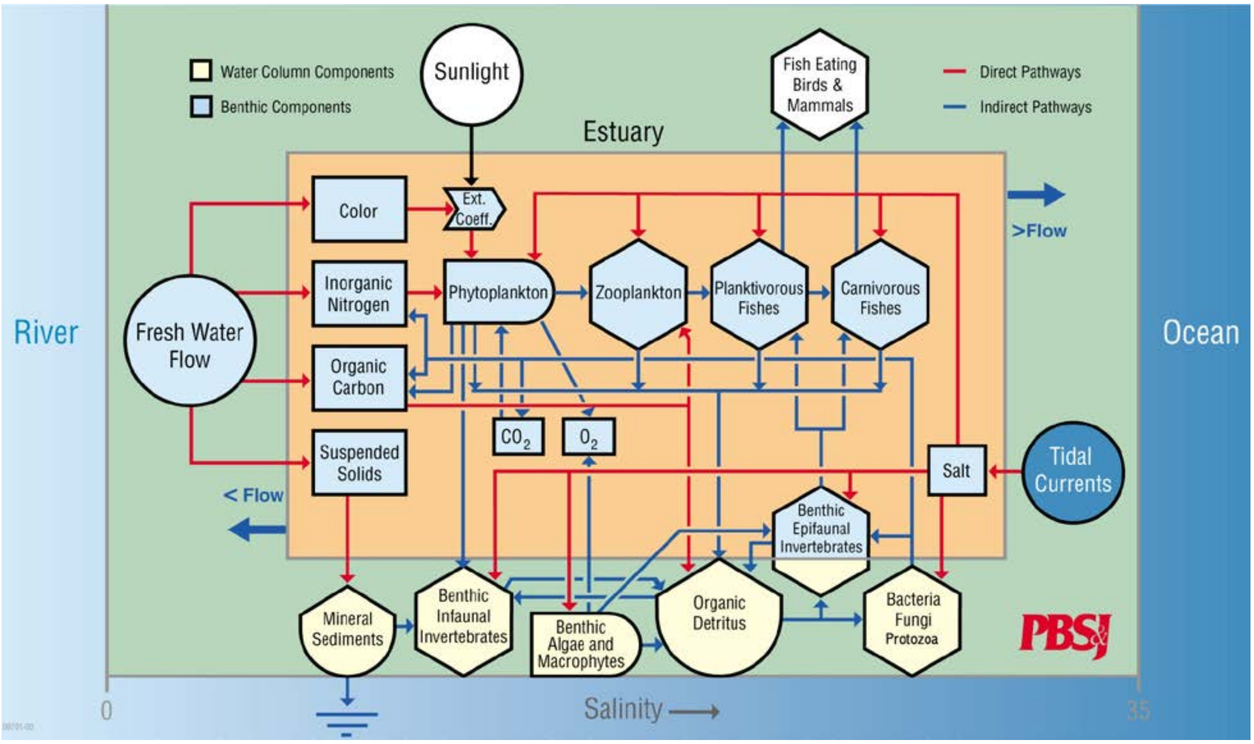

Figure 9.1 Conceptual model of the Peace River estuarine system

The existing "fixed" and "moving" HBMP study elements, have indicated the existence of a distinct, seasonally-variable chlorophyll *a* maxima along the lower Peace River/upper Charlotte Harbor monitoring transect. Including a new HBMP study element employing *in situ* fluorometer chlorophyll *a* methodology could provide the fine-grained spatial information needed to accurately define, on a monthly basis, both the magnitude and spatial extent of variations in chlorophyll *a* patterns within the lower Peace River/upper Charlotte Harbor Estuary. Accurate spatial determinations of the relative intensity and location of monthly chlorophyll *a* maxima patterns were expected to provide additional information regarding the known seasonal interactions between changes in freshwater flow (relative to additions of both nutrients and color) and the seasonal movement of important estuarine zones of primary (and secondary) production. The resulting high resolution data could then be graphically analyzed using standardized GIS kriging procedures and relative weighted centers of abundance determined using Spatial Analyst routines. Calculated metrics of observed spatial patterns could then be statistically seasonally analyzed relative to natural variations in flow and measured water quality parameters obtained from other HBMP study elements. The *2016 HBMP Annual Data Report* provides an overview of the sampling methodology utilized for this recently added HBMP element.

Ultimately, such determination of the seasonal influences of changes in river flow may be used to assess any potential influences of Facility withdrawals on estuarine production under the existing established MFL criteria. The information may further be applied to assess (and potentially refine) the existing and future spatial locations of the HBMP continuous recorder array (see **Section 4**). It is recommended that an analysis of the utility of this HBMP study element, and recommendations for its future continuance, be made now that several years of data have been collected. Should the assessment indicate this HBMP element be continued, then continued assessment and reporting should be done at specific intervals as part of future major summary monitoring program reports.

9.7 Summary

The combined elements of the program’s design need to meet the specific expectations and objectives set forth in the permit as well as provide sufficient long-term information on which to base the development of answers to potential future questions that might be expected to arise.

In order to effectively meet these goals and objectives, the integrated design of HBMP elements should incorporate the following criteria.

- The program needs to identify appropriate physical and biological indicators, and specific mechanisms of action, potentially subject to significant changes resulting from permitted freshwater withdrawals from the lower Peace River/upper Charlotte Harbor estuarine system.

- The program should determine and predominantly focus it efforts in those geographical regions of the lower river where naturally occurring and Facility induced changes in river flow would be expected to result in the greatest potential observed changes in identified key estuarine characteristics.

- The design of the HBMP monitoring element should include sufficient spatial and temporal intensity to assure detection of measurable changes in selected physical/chemical/biological parameters resulting from changes in freshwater inflows.

It is important that each HBMP study element, as well as the overall program, have specific clearly stated goals and objectives to effectively meet the design criteria needed to accomplish the monitoring program's multiple expectations. These goals and objectives need to clearly establish the scientific basis needed to provide sufficient information to meet the District's criteria for required reasonable assurance, as well as provide meaningful information to both the public and the members of the HBMP Scientific Review Panel. The HBMP design elements further need to be sufficiently flexible to allow incorporation of modifications when and where changes in conditions, or new gathered information, suggest the need for specific monitoring program changes.

The HBMP monitoring design needs to be primarily focused on identifying and incorporating those *critical indicators* known to exhibit marked direct responses to variations in freshwater inflow, since it is these parameter measurements that present the greatest probability of both detecting and assessing the principle underlying causative factor(s) to observed environmental changes.

Since the initiation of HBMP monitoring in 1976, the program has incorporated a number of differing physical, chemical, and biological study elements. Modifications have been made to the elements of the HBMP throughout its history. Historically, those major monitoring elements aimed at assessing direct relationships with variations in freshwater inflow have had the longest histories. Other program elements, primarily those focused on assessing indirect biological indicators, have extended over a number of years and then ended once a sufficient baseline basis of information had been accumulated.

9.7.1 HBMP Study Element Recommendations

Both the "fixed" and "moving" HBMP water quality study elements currently include monthly monitoring of chlorophyll *a* levels along the lower river/upper harbor monitoring transect. However, advances in fluorescence technology have resulted in the recent capability of semi-quantitatively measuring of *in situ* phytoplankton chlorophyll estimates. *In situ* fluorometer chlorophyll measurement procedures present the potential of synoptically identifying spatial phytoplankton biomass patterns at a very fine scale along the lower river/upper harbor salinity gradient.

Results from both the "fixed" and "moving" HBMP study elements have indicated the presence of a distinct, seasonally-variable chlorophyll *a* maxima along the lower Peace River/upper Charlotte Harbor monitoring transect. Inclusion of a new HBMP study element employing *in situ* fluorometer chlorophyll methodology could provide the fine-grained spatial information needed to accurately define on a monthly basis both the magnitude and spatial extent of variations in chlorophyll patterns within the lower Peace River/upper Charlotte Harbor Estuary. Accurate spatial determinations of the relative intensity and location of monthly chlorophyll maxima patterns would provide additional information regarding the known seasonal interactions between changes in freshwater flow (relative to additions of both nutrients and color) and the seasonal movement of important estuarine zones of primary (and secondary) production.

Based on previous discussions and Scientific Review Panel recommendations, such a monitoring element was added to the HBMP and sampling begun in April 2013. It is recommended that an analysis of the utility of this HBMP study element, and recommendations for its future continuance, be made now that several years of data have been collected. Should the assessment indicate this HBMP element be continued, then continued assessment and reporting should be done at specific intervals as part of future major summary monitoring program reports.

9.7.2 Facilities Withdrawal Schedule

None of the extensive HBMP analyses done to date have indicated that either measured or modeled changes resulting from Facility withdrawals have been of sufficient magnitude (relative to the far greater natural degree of variation in freshwater inflows) to have affected the long-term physical, chemical or biological characteristics of the lower Peace River/upper Charlotte Harbor estuarine system. Historically, the estimated changes due to Facility withdrawals have been such that they would have been difficult to physically measure given the far greater magnitudes of daily, seasonal and annual naturally occurring variation. The Facility however has undergone two major recent expansions (in 2002 and 2009), which have substantially increased its ability to withdraw, store and treat water from the river and increased overall reliability. In addition, the District completed a review and adopted a final MFL for the lower Peace River in 2010, and the Authority's withdrawal schedule was subsequently modified in 2011. This modification seasonally increased the maximum allowed withdrawal percentages. The results of statistical models presented in this report (**Chapter 4**) indicate commensurate increases in the projected salinity changes and movement of isohaline locations under the recent higher actual Facility withdrawals. While the annual averages (mean and median) of these projected changes still would remain hard to directly measure, the estimated maximum annual changes in these indicators have increased to detectable levels. However, the estimated maximum changes due to actual Facility withdrawals remain small in comparison to the relative far greater magnitudes of typical naturally occurring seasonal and annual variations. The withdrawal schedule by design results in the maximum expected withdrawal changes to occur with the periods of highest natural change (wet season flows), thus limiting the magnitude of potential impacts.

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Appendix A – Scientific Review Panel

A Peace River HBMP Scientific Review Panel (Panel) was implemented in conjunction with the 1996 Water Use Permit renewal. The Panel's primary objective was to provide guidance and recommendations to both the District and Authority regarding ongoing monitoring, reports and studies associated with overall lower Peace River/upper Charlotte Harbor Hydrobiological Monitoring Program. The Panel was comprised of regional and outside experts with specific knowledge and experience in assessing the potential influences and impacts of anthropogenic modifications of natural freshwater inflows to estuarine systems. Panel members were selected by and represent the following entities:

- Two representatives were selected by the District
- One representative was chosen by the Florida Department of Environmental Regulation
- One was selected by Charlotte County
- Two were chosen by the Authority

Fortunately, through 2011 Panel membership remained stable with only one replacement since its initial meeting in July 1999. The primary focus of the initial Panel meeting was to provide the members with an overview of the purpose and objectives of the HBMP, as well as summarize the history of monitoring, reports and conclusions reached since the initiation of the HBMP in 1976. Presentations were also made regarding the findings of the recently completed larval fish (USF) and benthic invertebrate (Mote Marine) special studies that had been funded jointly by the Authority and District. One of the Panels initial recommendations was with regard to the Annual and Summary HBMP Reports. Up until that time, the Annual Data Reports primarily focused on simply summarizing the data collected over the previous year, often without providing comparative context regarding how the most recent year's data compared with historically collected similar information. Even the Summary Reports (produced at 3 and 5 year intervals), often assumed that the reader had an extensive knowledge of the results and conclusions presented in previous historic HBMP reports. The Panel members found going through the large volume of previously compiled HBMP related documents difficult and strongly recommended changes to all future reports. They recommended that:

- The Annual Data Reports continue, but that individual reports include a brief overview of the history of the HBMP, as well as comparisons between the annually collected HBMP data, and similar historically collected information. The Panel further recommended that the individual document sections provide summaries of the presented results and conclusions, and that the most important of these be further included in a concise initial Executive Summary at the front of the document.

- Similarly, the Panel strongly recommended that future HBMP Summary Documents provide sufficient background information that readers (or new Panel members) would be able to obtain a comprehensive overview of the Facility's history, permits, and HBMP elements without necessarily having to refer back to older HBMP reports. Again, they recommended summary conclusions be provided within each major portion of the summary reports and that an overall comprehensive much less technical Executive Summary be included for more general readers.

- Overall, it was suggested that such changes would make it easier for individuals (and reviewers) not having an extensive previous history with the program to be able to read the most recent reports to obtain an adequate overview of the HBMPs history and status, as well as assess long-term temporal and spatial patterns in the collected data.

The Panel met again in November 2002 and reviewed the monitoring program modifications recommended in the *1998 Mid-term Interpretive Report*. The Panel recommended a number of changes to the monitoring program study elements. The Panel agreed that both the “fixed” and “moving” water quality monitoring programs were important, and that if a water chemistry parameter was not providing useful information relative to seasonal variations in freshwater inflows and potential Facility impacts, it should be deleted from the HBMP.

Other suggestions and recommendations made by the Scientific Review Panel regarding the monitoring program included:

- Continue collecting non-size fractioned phytoplankton biomass estimates at both the “fixed” and “moving” physical/chemical water quality monitoring locations.

- Continue enumeration of phytoplankton taxonomic composition at the “moving” isohalines for at least major taxonomic groupings (blue greens, diatoms, flagellates, dinoflagellates, etc.).

- Determine if either the benthic invertebrate/mollusk investigations conducted by Mote Marine Laboratory, or the juvenile fish/zooplankton study undertaken by the University of South Florida should be incorporated in part into HBMP study elements.

- Evaluate the need to continue monitoring at the existing spatial and temporal intensity.

Overall the Panel recommended that the HBMP should focus monitoring primarily on assessing long-term trends in key physical, chemical and biological characteristic directly related to the Facility’s potential influences and less on “health of the estuary” issues that should be the task of other District monitoring efforts.

The third meeting of the Peace River HBMP Scientific Review Panel was in September 2004, with the primary objective being to review and make additional recommendations based on the *2002 Peace River HBMP Comprehensive Summary Report*. The Panel made a series of further recommendations to the District and Authority with regard to what they believed were needed changes to the ongoing monitoring program’s study elements.

Recommended Deletions to the Existing Monitoring Program – the Scientific Review Panel recommended in 2004 that a number of the study elements be deleted from further study.

- Data had been collected since the inception of the HBMP program with regard to the first and last occurrence of riparian vegetation along the lower Peace River. Extensive analysis of the data over the 1976-2002 time interval found that although there had been extended periods of both high and low river flows' the relative spatial distributions of the major vegetation communities had remained virtually unchanged. Based on these finding the review Panel recommended deletion of this HBMP study element.

- Aerial photography of vegetation along the lower river had also been taken at periodic intervals since 1976. Analyses failed to indicate any systematic spatial changes in the major communities that could be tied to known changes in river flows, and the panel again recommended that this element of the HBMP be discontinued.

- Vegetation data had further been collected since 1979 at selected fixed transitional vegetation sites along the lower river and the Panel recommended that this monitoring also be deleted.

- Expansion of the HBMP monitoring program had included the collection by USGS of 15-minute tide stage near Boca Grande pass. However, subsequent discussions with USGS staff revealed that the location of this gage was inappropriate for its intended use of determining potential long-term changes in sea levels. All parties recommended that this gage be deleted from the array of HBMP continuous recorders and the Panel agreed.

- Monthly phytoplankton taxonomy had been conducted in conjunction with measurements of chlorophyll *a* biomass at the moving isohaline-based monitoring locations. The Scientific Review Panel recommended that chlorophyll *a* concentrations continue to be measured monthly at these locations, while phytoplankton species composition should be deleted from further consideration.

Recommended Additions to the Monitoring Program – the Scientific Review Panel recommended several additional sources of information be added to the HBMP.

- The Panel recommended that the Authority investigate adding wind velocity to the data being collected, in order to provide a possible source of data to further explain flow/salinity relationships being developed from the 15-minute conductivity data being collected at the two USGS recorders in the lower Peace River.

- The Panel also recommended that the Authority look into installing a series of additional continuous recorders between the two initially established in 1996 by the USGS as part of the expanded HBMP program under the District's permit renewal.

- The Panel suggested that the Authority evaluate and report back on the technical merit of implementing monthly *in situ* chlorophyll *a* monitoring along the HBMP monitoring transect to determine potential spatial peaks in chlorophyll biomass relative to seasonal changes in freshwater inflows.

- The Panel supported the Authority's intention to run a series of "pump tests" using data from the continuous recorders to experimentally determine the relative spatial magnitude of Facility withdrawals on salinities over a number of tidal cycles given different flow conditions.

Proposed Additions not Recommended – the *2002 Peace River HBMP Comprehensive Summary Report* suggested several additional potentially new study elements for the program. The Scientific Review Panel felt that given the already available existing information and the relative added costs, three of these proposed additional studies should be deleted from consideration at the current time.

- Addition of a limited stratified random monitoring design for *in situ* water quality parameters.
- Additional dry and wet season larval fish sampling.
- A continued limited ongoing benthic mollusk study.

The next meeting of the Peace River HBMP Scientific Review Panel was held in December 2007 to review the findings in the draft Authority report on the initial series of Facility "low flow pump tests" run between December 2006 and April 2007. At this meeting the Panel also reviewed and provided comments to the District on its proposed draft Minimum Flows and Levels (MFL) for both the lower Peace River and Shell Creek.

- The Panel recommended that the Authority install at least two more continuous recorders above the upstream Peace River Heights USGS recorder. In response to this recommendation, the Authority installed additional continuous recorders at two locations upstream of the Facility and at a third location downstream near the mouth of Shell Creek (see **Table 1.2** and **Figure 1.2**) in May of 2008.
- Based on the findings of the initial series of pump tests conducted by the Authority, the panel recommended that no further river pump tests be conducted until after the upcoming Facility expansion is completed.

The most recent meeting of the HBMP Scientific Review Panel was conducted in December 2010. At that meeting, a number of presentations were made to the Panel members regarding both recent and ongoing Authority and District activities, as well as a general discussion of ongoing and future HBMP monitoring.

- The District made a presentation on the methodology being incorporated in its updating of the District's Regional Water Supply Plan. The Panel suggested that the District treat savings due to conservation as a reduction in demand rather than as "found water" in meeting demand projections. While mathematically the numbers are the same, the panel felt this would provide a more consistent public message regarding water conservation.
- The Authority made a presentation on current future projected regional demands, which have declined substantially due the recession and associated marked decline in regional growth. These changes have shifted the previously estimated timelines for the need for additional water further into the future. Atkins (PBS&J) staff made a presentation summarizing the finding and conclusions of the recently completed Alternative Sources Study, which evaluated possible future regional surface water sources in the Shell Creek, Myakka River and Donna Bay watersheds. The study estimated potential environmentally

safe yields and relative costs, as well as the potential conjunctive use of brackish groundwater desalinization during seasonally drier periods.

- District staff presented an overview of its recently adopted MFL for the lower Peace River. The presentation reviewed previous draft, and changes that had been made between the draft and final versions of the MFL document in response to received comments. The Panel had a number of comments regarding the MFL in light that the District plans a further review within the next five years.
  - Panel Members noted that while the median habitat change might be less than 15 percent, the District provided graphics showed a large number of instances (especially at lower flows) where the change was greater than 15 percent. The panel questioned how the 15 percent change in habitat under the MFL was determined, and based on the graphics presented by District staff, asked during how many days (percent of the time) 15 percent was violated in 100 cfs increments.
  - The Panel asked if there were continuous periods (during lower flows) when the 15 percent was violated and if it was proper to average these with periods of no withdrawal or very high flows.
  - The Panel suggested that if the habitat was changed by 15 percent wasn't it likely that there would be far greater impacts than 15 percent on the biology of the system (fish, invertebrates, benthic communities, etc) since changes usually seem to be magnified up the food chain?
  - The Panel suggested that there were items under the HBMP that the Authority should be doing, while a great deal of any additional biological monitoring in support of the MFL would probably be the District's responsibility.
  - The Panel pointed out that special emphasis should be given to the braided portions of the lower river, especially concerning changes in salinity influencing estuarine production during seasonally important periods (spring and fall).
  - The Panel pointed out that the existing MFL basically ignored those portions of the estuary below the mouth of the river, and that changes over much of the upper and middle portions of the harbor during higher flows could be critically important to a number of species that use freshwater flows as specific signals for movement and spawning. The Panel suggested using the State's independent fisheries monitoring data to determine potential changes within the middle and lower harbor.

- The Panel agreed that juvenile and adult species of recreationally/economically important species are subject to too many outside variables to be useful as indicators of water withdrawals.

- The Panel also questioned whether high reductions of flows during the wet-season might influence natural patterns of hypoxia, and questioned if the District had considered the relative importance of such events.

- The Panel agreed that the District's later changes to the draft MFL had improved the MFL considerably, but that some fine-tuning of higher withdrawals was still probably appropriate. Specifically, the District's use of blocks versus actual flows might lead to seemingly unjustified large changes in withdrawals between the end of one block and the beginning of the next. The Panel suggested using some means of average flow over the preceding period to eliminate this problem, and that some further consideration of changes under unusually dry conditions might be warranted.

- The Panel questioned whether the planned interconnection with the City of Punta Gorda would help the Authority to possibly supply water to the City during the spring dry-season. The panel asked if the withdrawal schedule based on the MFL would potentially limit any new upstream users.

- The Panel felt that there were some studies that the District should fund prior to its re-evaluation of the MFL and other enhancements of the HBMP that were probably the Authority's responsibility.

- The Panel felt that since the morphological study used in the District's hydrodynamic model had taken place prior to the passage of Hurricane Charley (August 2004) that it might be wise for the District to repeat the morphological study prior to the District's upcoming review of the MFL. It was suggested that during this process that dual beam transponders be used to determine the spatial extent/depth of organic material in the lower river since these areas would be expected to be important zones of benthic production and foraging habitat for fish species.

o Atkins (PBS&J) made a short presentation reviewing the existing HBMP elements, their adequacy in assessing potential changes due to withdrawals, and potential future program modifications. The Panel's comments included:

- Suggesting that it would be important to collect more detailed synoptic data of the spatial distributions of salinity (and possibly chlorophyll) seasonally under different seasonal flow conditions that could be used to verify the District's hydrodynamic model. The Panel felt that Shell Creek should be included in these spatial studies.

- The Panel discussed how conductivities at the Facility intake might be influenced over the very long-term by progressive changes in salinity due to sea level changes and agriculture/industry discharges from upstream. It was suggested that this would reduce the Authority's ability to withdraw water near the low flow cutoff and increase the reliance on higher flow periods, and a greater use of storage. The panel suggested that the Authority continue and where appropriate increase monitoring upstream of the Facility to monitor water quality changes from upstream land use changes.

- The Panel supported the recommendations to decrease the time taken between draft and finalized reports.

- The Panel asked how the data being collected by the Shell Creek HBMP were being incorporated with the Peace River HBMP data. They encouraged coordination between the two programs.

- The Panel felt it would be appropriate to move the next Year Five Comprehensive Summary Report forward such that it coincides with the end of the current withdrawal schedule once the District has issued revisions under the MFL. Then re-start the reporting schedule to align with the new MFL based diversion schedule.

- The Panel agreed that the movement and addition of more continuous recorders would provide enhanced information with regard to changes in the braided portions of the river and the deep channel side of the river at Harbor Heights. The results of the detailed synoptic study might be used to further adjust the locations of these recorders.

- The Panel suggested the area between the I-75 and US 41 bridges as an important area for any expanded continuous monitoring.

- Again, it was reiterated that it might be important to continue monitoring at the same location but near the surface at the downstream continuous recorder located near Shell Creek.

Appendix B – Previous Summaries of Relevant Reports

The following summarizes reports and studies relative to the Peace River watershed, lower river and upper harbor that were presented in previous HBMP summary reports.

1.0 Summary from the *2002 HBMP Comprehensive Summary Report*

The following series of documents and reports were summarized in the *2002 HBMP Comprehensive Summary Report*.

- Upper Peace River: An Analysis of Minimum Flows and Levels (SWFWMD, 2002)
- A Review of "Upper Peace River: An Analysis of Minimum Flows and Levels" (Gore et al. 2002)
- Effects of Phosphate Mining and Other Land Uses on Peace River Flows (Ardaman & Associates 2002)
- Cumulative Risk of Decreasing Stream Flows in the Peace River Watershed (SDI Environmental Services, Inc. 2003)
- Predicted Change in Hydrologic Conditions along the Upper Peace River due to a Reduction in Ground-Water Withdrawals (Basso, SWFWMD 2003)
- Long-term Variation in Rainfall and its Effect on Peace River Flow in West-Central Florida (Basso and Schultz, SWFWMD 2003)
- Water Quality Data Analysis and Report for the Charlotte Harbor National Estuary Program (Janicki Environmental, Inc. 2003)
- An Evaluation of Stream Flow Loss during Low Flow Conditions in the Upper Peace River (draft, Basso, SWFWMD 2004)
- Development of Hydrologic Model to Assess Phosphate Mining on the Ona Fort Green Extension (SDI Environmental Services, Inc. 2004)
- 2003 HBMP Annual Data Report (PBS&J 2004)
- Florida River Flow Patterns and the Atlantic Multidecadal Oscillation (Kelley, SWFWMD 2004)
- Shell Creek and Prairie Creek Watersheds Management Plan – Reasonable Assurance Documentation (Shell, Prairie, and Joshua Creeks Watershed Management Plan Stakeholders Group 2004)
- Proposed Minimum Flows and Levels for the Middle Segment of the Peace River, from Zolfo Springs to Arcadia (Kelly et al. 2005)
- 2004 HBMP Annual Data Report (PBS& J 2005)
- Impact of Phosphate Mining on Streamflow (Schreuder et al. 2006)
- 2005 HBMP Annual Data Report (PBS&J 2006)

- Assessment of Potential Shell Creek Impacts Resulting from Changes in City of Punta Gorda Facility Withdrawals (PBSJ 2006)
- Peace River Cumulative Impact Study (PBSJ 2007)
- 2006 HBMP Annual Data Report (PBS&J 2007)

1.1 *Summary of Historical Information Relevant to the Hydrobiological Monitoring of the Lower Peace River and Upper Charlotte Harbor Estuarine System* (PBS&J, July 1999)

The *Summary* document presented a synopsis of previous studies relevant to freshwater flow relationships in the lower Peace River and upper Charlotte Harbor.

Hydrology – Gages on four tributaries to the lower Peace River measured streamflows from approximately 89 percent of the Peace River watershed. Streamflow is seasonal and typically highest during the summer wet-season. Long-term declines in streamflows during the late-1950s to the 1980s in the upper reaches of the river were attributed primarily to corresponding rainfall deficits, while streamflow increases during the 1990s corresponded with increased rainfall.

In the upper river basin, decreased flows were also attributed to aquifer drawdown and watershed alterations due to phosphate mining. However, groundwater withdrawals for the phosphate industry decreased dramatically in the mid-1970s, and some recovery in groundwater levels has occurred. In the southern portion of the watershed, declines in streamflow have not occurred since 1965 and may be a result of combined hydrogeologic and human factors.

Since 1980, withdrawals from the river by the Facility averaged 5.8 mgd (0.6 percent) of the total measured streamflow. The largest withdrawal occurred during 1996 and made up 1.42 percent of the total gaged streamflow. Facility withdrawals were limited to 10 percent of the previous day’s streamflow above 100 cfs (measured at Arcadia) since 1988 and have not been permitted below 130 cfs since 1996. Records since 1965 indicated that streamflows at Arcadia fall below 130 cfs about 12.6 percent of the time. The Arcadia gage is located 17 miles upstream of the Facility and measured flow from about 58 percent of the watershed. Consequently, a ten percent reduction in withdrawals based on flows at Arcadia was a ten percent reduction in only about half the flows at the river mouth.

Salinity – Long-term monthly salinity data collected between 1976 and 1990 indicated brackish water upstream of the Peace River Facility intake during extended periods of drought such as occurred during 1981, 1985, and 1986. Analyses of surface and bottom salinity data at fixed points located along the HBMP monitoring transect from upper Charlotte Harbor to above the Facility indicated no long-term trends.

Four “moving” salinity stations (0, 6, 12, and 20 ppt) were monitored monthly in the lower river and harbor since 1983. These stations shift upstream and downstream as a result of seasonal changes in freshwater flows. Typical seasonal, within year shifts ranged from about 15 to 16 kilometers for the 0, 6, and 12 ppt salinity zones to about 27 kilometers for the 20 ppt zone. Trend analyses indicated no net upstream or downstream movements of the salinity zones.

Salinity in the lower Peace River was monitored as part of the current HBMP using three methods:

- Monthly salinity measurements at fixed-stations from 1976-1990 and resumed in 1997
- Monthly measurements at four moving salinity stations
- Measurements of specific conductance at 15-minute interval at two USGS recorders

Water Quality – Comprehensive, long-term water quality data collections began in 1975 and indicated that water quality in the lower Peace River and upper Charlotte Harbor remained good with the exception of phosphorus. Although dissolved inorganic phosphorus concentrations were extremely high when compared with other estuaries, peak levels declined by as much as an order of magnitude since the early 1980s following the implementation of new environmental regulations that restrict phosphate mining discharges and other point source discharges. Water quality declined markedly upstream and water quality degradation was both more frequent and severe toward the headwaters of the Peace River near Lake Hancock.

While water quality in the upper harbor was good, high freshwater inflows during the summer wet-season resulted in salinity stratification in upper Charlotte Harbor. This in turn resulted in the development of large areas of hypoxia over the bottom of the harbor. Monthly water quality monitoring under the current HBMP will continue at six fixed stations located in the river from the upper harbor to upstream of the Facility and at four moving stations.

Plankton/Phytoplankton – Phytoplankton production and biomass in the lower Peace River were low, regardless of water temperature, during periods of low freshwater inflow. As freshwater inflows increased during the wet-season, phytoplankton production and biomass increased at intermediate salinities. The magnitude of the increase was temperature-dependent.

As river flows increased, available light in the water column decreased due to the high color of the freshwater. Consequently, light limitation quickly reduced the initial increase in productivity that resulted from nutrient increases associated with higher freshwater inflows. As a result, the highest carbon-uptake rates and chlorophyll *a* levels often occurred at 6 and 12 ppt salinity, during periods of lower freshwater inputs, higher temperatures, and higher light availability. Higher peaks in phytoplankton biomass and production often occurred in the upper harbor in the fall, at the end of the wet-season, when nitrogen levels were high and water color was declining.

Monthly measurements of phytoplankton primary production and biomass at 0, 6, 12, and 20 ppt salinity and species composition were scheduled to continue until the end of the first five years of the new monitoring program.

Zooplankton – Specific taxonomic groups of zooplankton characterized each of the four salinity zones sampled, although many of the taxa were observed in large numbers over a wide range of salinities. Seasonally, fluctuations in zooplankton densities were more than four orders of magnitude within each of the four salinity zones sampled. The few patterns observed with regard to species numbers, densities, or diversity measurements among seasons or salinity zone are listed below.

- The greatest number of high salinity taxa was observed during high freshwater inflow.
- The number of taxa generally increased with increased salinity.
- Phytoplankton biomass was positively correlated with zooplankton densities for dominant zooplankton taxa within each of the salinity zones.
- The measured variation in freshwater inflows alone could not account for the variation in zooplankton species numbers, density, or diversity.

A limited number of studies of benthic invertebrate communities have included the lower Peace River and upper Charlotte Harbor. Early studies conducted as part of the HBMP were among the first to quantify the conditions, magnitude, and influences of hypoxia/anoxia in upper Charlotte Harbor resulting from density stratification due to high freshwater flows. Consequently, additional macroinvertebrate study elements were included in the 1996 permit renewal to investigate the characteristics and magnitude of changes in community structure resulting from seasonal variations in freshwater flows in the lower Peace River and to determine the value of including future benthic study elements.

Fishes – A long-term monitoring program was undertaken in June 1975 by Environmental Quality Laboratory (EQL) to address species composition and abundance of fish communities in upper Charlotte Harbor. The program included collection of monthly trawl samples and associated water quality data at a single sampling location, but was terminated in May 1988.

Fish assemblages occurred in distinct “wet” or “dry” season modes, which were defined as a function of freshwater inflow. No quantitative relationships were developed that were successful in identifying thresholds or critical levels of freshwater inflows, either for individual or groups of species. In addition, fish community responses to variation in freshwater inflow appeared to occur over several years.

Florida Marine Research Institute (FMRI) conducted quantitative monitoring of fish populations in Charlotte Harbor, as well as the tidal reaches of the Peace and Myakka rivers, since 1989 as a component of the Fisheries Independent Monitoring Program. To date, these data had not been analyzed with respect to changes in freshwater inflow and related variables in the lower Peace River. The sampling program is expected to continue indefinitely.

A two-year collaborative study by the SWFWMD, the Authority, University of South Florida Department of Marine Science, and FMRI to study freshwater inflow effects on habitat use by estuarine dependent fishes began in 1997. Systematic monitoring of habitat use was being used to develop regression models for evaluating impacts of proposed freshwater withdrawals and, in the process, contribute to baseline data. This study is part of the current HBMP for the Facility.

Vegetation – Emergent and submerged aquatic vegetation were and continue to be monitored along the lower Peace River as part of the HBMP using first and last species occurrence, changes in plant community composition at fixed transition sites, and periodic interpretation of aerial imagery. Data indicated there was little change in the upstream and downstream distributions of freshwater and estuarine plant species along the lower Peace River over the past 20 years, although there was variability between years.

Open water increased along the Peace and Myakka rivers between 1950 and 1994 by five and ten percent, respectively, with the construction of finger canals along the lower reaches of both rivers. Similarly, changes to upland, bottomland hardwood, and mixed hardwood plant communities resulted in decreases in marsh vegetation by 520 acres (22 percent) along the lower Peace River between 1950 and 1994, primarily between 1950 and 1970.

Seagrass coverage in Charlotte Harbor increased by a total of approximately six percent between 1982 and 1996, which included a loss of 600 acres from 1988 to 1992 followed by a gain of 718 acres from 1992 to 1994. Seagrass coverage in the harbor appeared to vary as a function of water temperature, salinity, and water clarity, which in turn were functions of season, rainfall, and freshwater inflow. Seagrass mapping in the harbor will continue on a bi-annual basis as part of the District's Surface Water Improvement and Management Plan.

1.2 *2000 Midterm Interpretive Report* (PBS&J, February 2002)

This report was the first *Midterm Interpretive Report* and, pursuant to the Water Use Permit conditions, examined monitoring progress and changes in streamflow, salinity, and other variables. Issues of the effectiveness of the current HBMP design in meeting program objectives were addressed and recommendations were made regarding the evaluation, modification, and potential removal of certain variables from the current HBMP design.

Conceptual Model – A conceptual model was developed to illustrate the qualitative relationships between river discharges or freshwater inflow and other water quality and biota variables in the lower Peace River/ upper Charlotte Harbor system. The variables that were most effective in modeling these relationships were those linked most directly to flow variations (e.g. salinity, inorganic nitrogen concentrations, color) and those that were closely associated with directly affected variables (e.g. chlorophyll *a* as a measure of nutrient assimilation). Variables related to, but not directly or solely driven by, freshwater inflows (e.g. organic carbon) were not successful in evaluating potential impacts of withdrawals.

Rainfall – No consistent patterns of increasing or decreasing rainfall were identified during the historic period of record (1966-1998) or during the time frame of the HBMP (1976-1998) in the upper Peace River watershed. However, more recent increases in rainfall were significant, due to unusually heavy rains of 1995, and the 1997/1998 El Niño event.

Rainfall to Flow Relationship – Results of "double mass" curve analyses indicated no conspicuous changes in the general relationships between flow and rainfall in the Peace River basin or its three tributary sub-basins (Horse, Joshua and Shell creeks) since 1966, although small differences occurred during extended wet and dry periods. However, statistically significant increases in base flow in several tributaries during normally dry periods, in combination with similar increases in mineralization, were reported. These patterns suggested that increased dry-season flows were directly linked to increased agricultural irrigation in these watersheds.

Freshwater Inflow – During approximately the last thirty years, gaged freshwater flows in all of the major Peace River tributaries have increased or showed no significant trends.

Withdrawals – Freshwater withdrawals by the Authority steadily and progressively increased in response to public demand. However, withdrawals remained extremely small when compared with the natural seasonal variability of freshwater flows and currently comprised less than one percent of total freshwater inflow at the mouth of the Peace River.

Salinity – No long-term trends in salinity were detected using trend analyses for the period 1976-1989 at a series of fixed stations in the lower Peace River. A single exception occurred at River Kilometer (RK) 30.4 (upstream of the point of withdrawal) and was attributed to drought conditions that followed the 1983 El Niño rather than a long-term change. Even with the effects of the 1997/1998 El Niño, the distribution pattern of median salinities along the lower Peace River during the most recent three year period (1996-1998) was not substantially different than the long-term average.

Impact of Withdrawals on Salinity – As part of the *Midterm Interpretive Report,* predictive statistical models were developed for the influence of withdrawals on downstream salinities. Model results indicated that, on average, past withdrawals historically resulted in maximum changes of less than 0.3 ppt along the lower Peace River between the US 41 Bridge and the Facility and that the greatest changes occurred between RK 14 and 18.

Salinity changes under the maximum permitted daily withdrawals for flows between 200 and 1,000 cfs, measured at Arcadia, were also modeled. Results predicted a maximum salinity change of < 0.5 ppt between RK 14 and 18 for flows between 400 and 1000 cfs. Arcadia flows of 200 cfs resulted in similar changes in salinity (< 0.5 ppt) farther upstream.

Water Quality – Surface dissolved oxygen concentrations tended to increase from the Peace River by the Facility downstream to river's mouth. On average, dissolved oxygen concentrations between the Facility and the river mouth were above the State Class III 24 hour average standard of 5.0 mg/L (the instantaneous standard is 4.0 mg/L). In comparison, near bottom dissolved oxygen concentration measurements progressively downstream indicated the seasonal occurrences of hypoxic summer events as high flows result in salinity stratification of the water column.

Except for slightly elevated levels of phosphorus and color, water quality characteristics of the lower river were similar to those of other southwest Florida rivers, despite the fact that the watershed area of the Peace River is much larger than that of most comparable rivers.

Recent water quality measures in the lower river indicated only small differences between these and the longer-term averages (1976-1998). The most notable exception was a long-term reduction in phosphorus for the period 1984-1998 that probably reflects more stringent regulatory requirements for the treatment of point and non-point discharges in the upper Peace River basin.

Vegetation – Long-term comparisons of upstream and downstream occurrences of selected indicator plant species along the lower Peace River indicated that the distribution of most species changed very little over time.

Evaluation of the Current HBMP Design – Physical, chemical, and biological parameters that were measured as part of the existing HBMP were evaluated with respect to their continued relevance to the program objectives. Extinction coefficient and vegetation were recommended for further evaluation regarding continued inclusion in the program. The following variables were recommended for removal from the program:

- Turbidity
- Alkalinity
- Chlorides
- Ammonia/ammonium
- Total phosphorus
- Silica
- Inorganic carbon
- Dissolved organic carbon
- Total organic carbon
- Phytoplankton species counts
- Carbon uptake
- Chorophyll *a* size fractions

The current design sampling strategies for the HBMP included: 1) fixed, continuous sampling at two stations and two depths; 2) fixed, monthly sampling at seventeen stations, and 3) "moving station" monthly sampling at four selected salinities. Under this design, the portion of the river where the relationship between river flow, withdrawals, and salinity were most pronounced, between RK 15.3 and RK 21.1, was under sampled when compared with the portion of the river above RK 21.1. Further evaluation of sampling design as it pertains to the sampling of these areas was recommended.

1.3 *2002 HBMP Annual Data Report* (PBS&J, May 2003)

This document represented the seventh *Annual Data Report* submitted under the expanded HBMP, initiated in 1996 in compliance with Water Use Permit (WUP) 2010420.03. Yearly data reports to the District provide statistical and graphical analyses of data from the current reporting period, comparisons with data from previous years, as well as long-term analyses of flow, water quality and biological measurements for the period of record. This report provided an updated analysis of pre- and post- water withdrawal data collected as part of the HBMP. Comprehensive summary report findings reported in the *2002 Annual Data Report* are listed below.

- The magnitude of withdrawals (by the Facility) was small when compared to the natural seasonal variability in the river. Current withdrawals comprised less than 1 percent of total freshwater flow at the mouth of the Peace River.

- Based on salinity models, past withdrawals from the lower Peace River between the US 41 Bridge and the Facility resulted in maximum changes of less than 0.3 ppt. in salinities and the greatest changes occurred between RK 14 and 18.

- Model results predicted a maximum salinity change of < 0.5 ppt would occur between RK 14 and 18 when Arcadia flows were in the range of 400 to1000 cfs. With Arcadia flows of 200 cfs, similar changes in salinity (< 0.5 ppt) were predicted farther upstream.

- Long-term comparisons of upstream and downstream occurrences of selected indicator plant species along the lower Peace River indicated that the distribution of most species changed very little over time.

Comparisons – Data collected during 2002 were compared with data from previous years' monitoring events. In comparisons of the 2002 data with averages of similar data collected over the preceding nineteen-year period (1983-2001), it should be noted that the very wet winter/spring El Niño of 1997/1998 was followed by very dry La Niña conditions that influenced southwest Florida and the entire Peace River watershed between 1999 and mid-2002. Comparisons of freshwater inflows, Facility withdrawals, relevant physical and biological parameters are presented in Table 3.1.

Table 3.1
Comparisons Between 2002 and Long-term Averages for the Selected Physical, Chemical, and Biological Water Quality Factors

Factor	Summary of Comparison Results
2.1.1.1 Flows	Average 2002 mean daily flow at Arcadia were more than eight times that for 2000, which was its lowest during 27 years of HBMP monitoring. Combined flows for the lower river in 2002 were roughly 150 perecent of 1976-2001 flows.
Facility Withdrawals	Facility withdrawals reached 10 percent of the gaged Arcadia flows over 130 cfs on 4.6 percent days of the year in 2002. Total withdrawals in 2002 equaled 1.93 percent of Arcadia flows and 1.04 percent of the lower Peace River flow. Maximum withdrawals increased during the second half of 2002 due to the recently completed Facility expansion.
Temperature	Lower than average water temperatures in January 2002 were followed by average temperatures until temperatures increased following the 2002 El Niño. Summer wet-season temperatures were lower in the freshwater reaches than in the harbor.
Salinity	Record high salinities occurred during the 2000/2002 drought. Salinities at the two most upstream sampling sites were generally higher during the recent drought than during the 1984-1985 drought that followed the 1983 El Niño.
Dissolved Oxygen	Near-bottom concentrations were low in response to summer wet-season inflows. The duration and magnitude of periods of depressed DO increased towards the river's mouth.
Water Color	Low flows during the first half of 2002 resulted in lower water color, followed by higher water color during the El Niño. Water color was higher upstream than near the mouth of the river, although color increased in the harbor during extended high flow.
Extinction Coefficient	Light attenuation was influenced by water color and phytoplankton biomass. Low light extinction coefficients during the first half of 2002 reflected low, long-term freshwater inflows.
NO_2/NO_3 Nitrogen	During 2002, average concentrations were similar or above average at monitoring stations. Inorganic nitrogen increased upstream with decreasing salinity. Ambient concentrations were typically lowest during the late spring dry season, in response to phytoplankton changes.
Ortho-Phosphorus	Average concentrations during 2002 were similar to long-term averages. Differences among monitored isohalines reflected dilution by seawater. Previously reported declines in concentrations prior to 1985 showed fairly consistent seasonal patterns.
N to P ratios	Long-term data indicated nitrogen was the limiting macronutrient throughout the lower Peace River and Charlotte Harbor.

Table 3.1
Comparisons Between 2002 and Long-term Averages for the Selected Physical, Chemical, and Biological Water Quality Factors

Factor	Summary of Comparison Results
Silica	Concentrations during 2002 reflected a continued pattern of higher values at all HBMP monitoring locations, interrupted by the recent drought. Silica levels were higher at the upstream sampling sites, and showed strong seasonal patterns.
Chlorophyll *a*	In general, phytoplankton association with isohalines was similar to long-term averages. However, there was a decline in chlorophyll *a* concentrations and blooms that commonly occurred during the late 1970s and early 80s.

Conclusions – Results and analyses presented in this document indicated no substantial changes in the physical or biological characteristics based on data collected during 2002 and previous years. Limited analyses did not indicate any long-term changes resulting due to current or historic water withdrawals by the Facility. Atypical events noted during this study are listed below.

- An extended drought through the first half of 2002 resulted in near or historically high salinity levels upstream into the lower Peace River.
- The onset of a strong El Niño at the end of the year.
- A continued long-term increase in reactive silica concentrations in the lower river.

Permanent Data – All historic water quality and *in situ* data collected during the fixed and moving station elements of the HBMP used in the preparation of the document were provided on the *2002 Annual Data Report* CD in the directory labeled 2002 Data Sets, as ASCII files and/or SAS format. Table 3.2 provides summary descriptions of the variables within each of the SAS data sets.

Table 3.2
Description of Data Sets

Data Set	Time Period	Brief Description
HBMP SAS Data Sets		
Flwd02.sd2	1931-2002	Historic daily flow data for: Peace at Arcadia; Horse Creek near Arcadia; Joshua Creek near Nocatee; and Shell Creek near Punta Gorda.
Cmov8302.sd2	1983-2002	Water quality and phytoplankton biomass and uptake measurements from monthly surface samples collected at each of the four moving isohalines.
Hymov02.sd2	1983-2002	Monthly hydrolab *in situ* water quality measurements taken at 0.5-meter intervals at each of the four moving isohalines.
Hyfix02.sd2	1996-2002	Monthly *in situ* hydrolab water column profile data at 0.5 meter intervals from fixed sample locations from near the river mouth to upstream of the Facility.

Table 3.2
Description of Data Sets

Data Set	Time Period	Brief Description
Cfix9602.sd2	1996-2002	Monthly surface and bottom chemical water quality at five intervals from fixed sample locations from near the river mouth to upstream of the Facility.
Efix9602.sd2	1996-2002	Water column extinction coefficients collected at the fixed sampling locations.
Boca02.sd2	1996-2002	Water level at 15-minute intervals from the continuous recording gage near Boca Grande.
Ph02.sd2	1996-2002	Water level, surface and bottom conductivity, and temperature at 15-minute intervals from the continuous recorder near Harbor Heights (RK 15.5).
Pr02.sd2	1997-2002	Water level, surface and bottom conductivity, and temperature at 15-minute intervals from the continuous recorder near Peace River Heights (RK 26.7).
Environmental Quality Laboratory Background Data Sets		
Chall_2.sd2	1976-1990	EQL Charlotte Harbor background water chemistry data.
Hydroall.sd2	1976-1990	EQL Charlotte Harbor hydrolab water column profile data.

Problems during 2002 – Some of the problems and errors encountered during data collection for various elements of the 2002 HBMP monitoring program were related to loss of phytoplankton material due to a broken sample bottle, differences in water quality analysis methods between laboratories that invalidated comparisons, and a change in laboratories that resulted in no analysis of some samples for February and March. Also, an instrument failure resulted in the loss of some light profile measurements during the November "fixed" station monitoring, and due to instrument failures, gage height data were unavailable for the Peace River Heights location during two periods, January to March and June to September. Conductivity and temperature data for portions of these two periods were also lost for the Peace River Heights gage.

1.4 *Morphometric Habitat Analysis of the Lower Peace River* (PBS&J, January 2000)

The goal of this effort was to develop maps and describe the river and adjacent wetland habitat along the lower Peace River. The final report was submitted to the District in January 2000. A key component of this study was the development of a standardized spatial reference system for the lower Peace River/Charlotte Harbor Estuary so that historic, recent, and ongoing HBMP monitoring efforts could be compared more easily. Sampling stations were previously established without a permanent reference system, and stations were located "at the mouth of the harbor near Boca Grande" and "near Horse Creek upstream of the future Water Treatment Facility."

A standard reference centerline was established using the previously established USGS imaginary "mouth" of the Peace River as the initial zero reference point. All HBMP "fixed" monitoring locations were then designated in River Kilometers either upstream (positive) or downstream (negative) of the river mouth. All previous “moving” station locations were converted to the standardized reference system. The results were reference points for HBMP sampling stations and EQL station locations, as well as a means of referencing USGS stations.

Field measurements were made for forty-nine typical cross-sections and a morphometric analysis along segments of the lower Peace River from RK 10.0, between the I-75 and US 41 Bridge, to a location upstream of Horse Creek and the Facility. Data for each 0.5 kilometer river segment along the lower Peace River centerline were then used to develop:

- Typical river cross-section profiles along each of the 49 transect lines
- Total river segment shoreline length
- Areas of open-water within each river segment
- The volume of water in each segment
- Areas of shoreline vegetation habitat type within each river segment

Summary graphics illustrating the spatial distribution of key morphometric river characteristics and shoreline vegetation patterns along the lower Peace River were prepared and findings are listed below.

- There was a high degree of variation in morphometry among typical river cross-sections.

- The lower river had a “funnel like” shape, based on cross-sectional length and area, segment surface and bottom area, and segment volume.

- The largest areas of shallow (0 to 0.9 meters) benthic habitat occurred between RK 7 and 12.

- Shoreline habitat was abundant as a result of islands and a sinuous river bank, ranging between three and seven kilometers of shoreline per one-half kilometer distance along the centerline in many reaches of the tidal river, particularly between RK 11 and 25

- Spatial distributions of freshwater and estuarine vegetation were distinct along the lower river

1.5 *Regression Analysis of Salinity-Streamflow Relationships in the Lower Peace River/Upper Charlotte Harbor Estuary* (Janicki Environmental, March 2002)

This report presented salinity models for “fixed” sampling stations along the lower Peace River, and the “moving” isohaline sampling locations using HBMP data updated to 1999. This report supplemented previous analyses presented in the HBMP *Midterm Interpretive Report*, where spatial statistical models were developed as predictive tools in assessing the magnitude of potential salinity changes due to both historic and potential maximum freshwater withdrawals under the existing permit conditions along the lower Peace River and upper Charlotte Harbor Estuary.

Salinity at "Fixed" Station Locations – Updated models predicted salinities at seven "fixed" sampling stations along the lower Peace River, from RK 2.4 (downstream of the river mouth) to RK 25.9 (downstream of the Facility). Previous efforts relied on sub-surface and near-bottom salinity, and/or the relative locations of isohalines with respect to gaged freshwater inflows. Models developed for this report also addressed water column depths of one and two meters (where available) at the "fixed" monitoring location. Regression models were then used to predict salinities at four water column depths, at each station for:

- Twenty-one flow scenarios corresponding to percentiles for the range of flow conditions for the historic period 1981-1999.

- Three withdrawal scenarios based on daily freshwater withdrawals *minus*:
  - "no withdrawals"
  - "actual historical withdrawals"
  - "maximum theoretical withdrawals" per 1996 permit schedule.

Location of Surface Isohalines – Regression models were updated using data through 1999 to predict spatial locations of four near-surface monitored "moving" isohalines (0, 6, 12 and 20 ppt) relative to freshwater inflows. Isohalines were predicted under the same three withdrawal scenarios described above.

Summary of Study Findings – Findings of this study were comparable to previous analyses and HBMP reports. Predicted salinities under maximum permitted withdrawals differed from salinities predicted with no withdrawals by 0.1 to 0.3 ppt. Isohaline locations under maximum permitted withdrawals varied from locations predicted with no withdrawals varying by 0.1 to 0.3 kilometer.

1.6 *HBMP Supplemental Analysis* (PBS&J, June 2002)

Eleven supplemental analyses of HBMP data through 2001 requested by the District and completed in conjunction with supplemental analyses performed by the District are listed below.

1. Vertical bar chart of the number of samples by River Kilometer (RK) for the fixed stations only.
2. Vertical bar chart of the number of samples in 2 km intervals for all the moving stations combined (X-axis scale of -20 to 35 RK).
3. Vertical bar charts of the distribution of four moving stations separately, all four plotted on one page using the same X-axis (scale of -20 to 35 RK).
4. Time series plots for the following variables for each fixed location station: surface and bottom salinity, surface and bottom DO, chlorophyll *a*, color, total Kjeldahl nitrogen (TKN), dissolved inorganic nitrogen (DIN), ortho-P, silica and turbidity.

5. In support of the time series plots in 4 above, produced tables that show the mean concentrations of these variables for the preceding period (1976-1990) and the recent period (1996-2001).
6. Box and whisker plots for the fixed stations for the variables mentioned above, plus total organic carbon, dissolved organic carbon, and total suspended solids.
7. Box and whisker plots for the moving stations for the variables mentioned above, plus total organic carbon, dissolved organic carbon, and total suspended solids.
8. Plots of the flow vs. concentrations of the variables listed in Table 5.19 of the *Midterm Interpretive Report*, plus TSS and chlorophyll *a*. Plots were prepared for each of the fixed location and moving stations separately. Flows were combined flows for Arcadia, Horse and Joshua Creeks for fixed stations at RK 15.5 and above and the 0 ppt isohaline. The sum of these flows plus Shell Creek was used for all other stations.
9. A correlation table of the Pearson product-moment correlations of each variable at each station with the log transformed (ln) flow. The correlation coefficient and the significance of the test were reported for each case.
10. Plots of mean and maximum daily salinity vs. date for the period of record for the two continuous recorders in the lower Peace River Estuary.
11. A plot that shows the percent of flow comprised by withdrawals each month for the period of record. The mean flow and mean withdrawal for each year/month combination were used as percent of gaged Arcadia flow and as percent of total gaged freshwater inflows to the lower Peace River.

1.7 *Peace River Benthic Macroinvertebrate and Mollusk Indicators* (Mote Marine Laboratory, July 2001)

Mote Marine Laboratory conducted this special study element of the HBMP and a final report was submitted in April 2002. The final report incorporated the major findings and provided summaries of major considerations for any future long-term HBMP benthic sampling elements. The primary objectives of the two investigations conducted as part of this effort were to:

- Describe the distribution of major macroinvertebrate habitats and communities in the lower Peace River

- Determine whether benthic organisms and/or their community structure can be used to assess natural variations in freshwater inflows and, measure potential influences caused by the diversions of the Facility

The time period during which these benthic investigations were conducted (November 1998 - February 2000) was preceded by very wet, high flow conditions associated with the 1997/1998 El Niño and historically dry, low flow environment characterized by the following intense La Niña. During this period, the locations of measured near-surface isohalines in the estuary varied across 20 and 40 kilometers, while near-bottom salinities in the lower river ranged from freshwater conditions to more than 20 ppt.

Benthic Macroinfauna Investigations – The macroinfaunal study was comprised of a stratified river interval design, based on historical HBMP data for the seasonal distribution of characteristic near-bottom salinity regimes in the lower Peace River. The experimental sampling design incorporated: 1) sample collections within both intertidal and deeper areas, along four intervals of the lower river; 2) samples from three of the primary oxbow systems; and 3) samples taken near the river's mouth in an area of submerged aquatic vegetation (SAV). Samples were collected during five events (one wet and four dry periods) using cores to obtain quantitative measurements, and both artificial substrates and sweep nets for qualitative measurements. The primary findings of these investigations were summarized as follows.

- More than 60,000 animals were identified, representing 314 specific taxa. Of these, 78 taxa were observed in the core samples, while 86 taxa were found only in the sweep samples.
- During the single moderately wet sampling event, upstream benthic species diversity was lower than the other four drier sample collection periods.
- During each sampling event, relatively distinct faunal zones were observed.
- Inflection points, representing step-wise jumps in species richness, within specific regions along the lower river, were conspicuous.
- Analysis showed that the benthic communities were more longitudely stratified during high flow periods, with the upper and lower river communities exhibiting the greatest distinctions. The middle river zones were transitional and representative of mixed faunal assemblages.
- Microcrustaceans, an important fisheries food source, were important motile components of the river fauna. Amphipods and cumaceans comprised the most abundant macroinfauna.
- Changes in distribution patterns for five polychaete species (segmented worms) and eight abundant micromollusks were distinct in relation to natural seasonal changes in salinity.

Benthic Infauna Conclusions – Most of the observed species survived over broad salinity ranges, and therefore generally reflect shifts among opportunistic euryhaline taxa. However, approximately 30 of the over three hundred observed species were both relatively abundant and exhibited spatial changes in response to variations in freshwater inflows. Of these, crustaceans merited consideration as potential long-term indicators because they are also important fish prey. However, measurements of changes in benthic macoinfauna community structure solely for the purpose of detecting potential impacts of freshwater withdrawals was not recommended due to the salinity tolerances of these taxa and the variability in tidal cycle that exceeds potential salinity changes predicted as a result of freshwater withdrawals at the Facility.

Macromollusk Investigations – The spatial distributions of mollusk communities sampled in the lower Peace River/upper Charlotte Harbor estuarine system reflected antecedent conditions of many weeks and/or months. Patterns of both living and dead organisms were also influenced by differential reproductive periods, larval development rates, recruitment/life history characteristics, and selective mortality to both biological and physical factors. The literature supported the use of comparisons between living and dead assemblages in interpreting historical changes in distribution patterns and indicated that taxonomic composition (species richness) was more informative than abundance or diversity/evenness indices.

Two surveys (in 1999 and 2000) of sixty-one sampling locations distributed between the river mouth and the point of confluence with Horse Creek were also conducted. The primary findings of these investigations are summarized below.

- Over 70,000 specimens, representing 32 mollusk taxa were identified.
- The introduced Asiatic clam *Corbicula* accounted for two-thirds of all individuals collected.
- *Corbicula* and another 14 taxa accounted for more than 98 percent of the samples. Most of the numerically rare taxa were observed in higher salinity reaches near the river mouth.
- Except for four taxa, the dead (relict) shell footprints differed between 1999 and 2000 samplings and may have been a result of juvenile recruitment and subsequent mortality.
- Few strong relationships were observed between salinity and macromollusk distributions, although higher richness of dead mollusks was generally associated with greater salinity variation.
- As the drought persisted and salinities increased farther upstream, spatial patterns of living mollusk species aligned with historic “footprints” of relict shells, and suggested that freshwater inflows control the long term, upstream/downstream shell patterns in the lower river.

Macromollusks Conclusions – Live and dead mollusks can generally be collected, identified and enumerated quickly in the field. In the lower Peace River Estuary, the overall dynamics and spatial distribution of these benthic mollusk assemblages could be understood as estuarine (salt tolerant) taxa “trying to invade” a tidal river, the upstream reaches of which had already been invaded by an exotic (*Corbicula*) freshwater taxa. Very dry periods characterized by extended periods of low freshwater inflows strongly influenced the relict “footprint” of the mollusk assemblages in the tidal river reaches. These patterns were matched by living populations only during periods of low freshwater inflows.

- Macromollusk ranges were imprecise salinity indicators *per se*, but rather were indicative of long-term, flow related changes in salinity patterns.

- Any future HBMP monitoring element should focus on no more than ten subtidal taxa, over no more than a 20-kilometer river reach, sampled once during the height of the dry season each year.

1.8 *An Assessment of the Effects of Fresh Water Inflow on Fish and Invertebrate Habitat Use in the Peace River and Shell Creek Estuaries* (University of South Florida College of Marine Science, September 2002)

The University of South Florida College of Marine Science conducted this special short-term, two-year study, which was jointly funded by the Authority and the District. The goal was to define seasonal and spatial patterns of fish nursery use within the lower Peace River/upper Charlotte Harbor Estuary and to determine the potential influences/relationships freshwater inflows have had on such observed patterns. Stratified estimates of the relative distribution and abundance of fishes and selected invertebrate taxa were made from two randomly selected, five minute, three-step (bottom-midwater-surface) oblique tows collected during night, with flood tide conditions using a weighted, flowmeter-equipped plankton net. Monthly samples were collected at seven zones within the lower Peace River. A comprehensive report summarizing the findings of this investigation was submitted in June 2002.

Quantitative ecological criteria were needed to establish minimum flows and levels for rivers and streams within the District, as well as for the more general purpose of improving overall management of aquatic ecosystems. As part of the approach to obtaining these criteria, the ecological relationships between freshwater inflows and downstream estuaries were assessed. A 26-month study of freshwater inflow effects on habitat use by estuarine organisms in the tidal Peace River and Shell Creek began in April 1997, using funds provided by SWFWMD and the Peace River/Manasota Regional Water Supply Authority. The general objective of the study was to identify patterns of estuarine habitat use and organism abundance under variable freshwater inflow conditions. Systematic monitoring was used to develop a predictive capability for evaluating potential impacts of proposed freshwater withdrawals and to contribute to baseline data. The predictive aspect involved development of regressions that described variation in organism distribution and abundance as a function of natural variation in inflows and salinity. These regressions can be applied to any proposed alterations of freshwater inflow or salinity that fall within the range of natural variation documented during the collection period.

For sampling purposes, the lengthwise axes of the tidal Peace River and Shell Creek were divided into seven and four zones, respectively. Monthly sampling of aquatic organisms implemented three gear types: a plankton net deployed in the channel during nighttime flood tides; seines deployed at the shoreline during the day under variable tide conditions; and trawls deployed in the channel during the day under variable tide conditions. Two plankton net tows, two seine hauls and one trawl were made each month in each zone. Salinity, water temperature, dissolved oxygen and pH measurements were taken in association with each gear deployment. Daily freshwater inflow estimates for the Peace/Shell Estuary were derived by summing the flows at the Shell Creek, Horse Creek, Joshua Creek, and the Peace River at Arcadia gages.

The fish assemblage sampled with plankton net gear was dominated by bay anchovy, gobies, menhaden, sand seatrout, rainwater killifish, silversides, and hogchoker. The invertebrate catch was dominated by larval crabs, arrow worms, copepods, mysids, amphipods, isopods, cumaceans, larvacean *Oikopleura dioica*, larval and juvenile bivalves, and ctenophores. Water released by the Shell Creek dam was distinctive in having large numbers of phantom midge larvae and freshwater cyclopoid copepods. Higher salinities near the mouth of the Peace River included *O. dioca*, chaetogaths, *Penilia avirostsris*, the cumacean *Cyclaspis varians*, the planktonic shrimp *Lucifer faxoni*, and the copepods *Acartia tonsa* and *Labidocera aestiva*. Shoreline seine collections were dominated by the bay anchovy, menhaden, silversides, mojarras, eastern mosquitofish, several killifish, striped mullet, and hogchoker. The trawl catch from the channel was dominated by the bay anchovy, sand seatrout, southern kingfish, hogchoker, and blue crab.

A large body of descriptive habitat-use information was generated and presented in tabular form. In general, observed habitat-use patterns were consistent with findings from other tidal rivers on Florida’s west coast. The three gear types documented the distributions of egg, larval, juvenile, and adult stages of estuarine-dependent, estuarine-resident, and freshwater fishes. Estuarine-dependent fishes were spawned at seaward locations and invaded tidal rivers during the late larval or early juvenile stage, whereas estuarine-resident fishes were present within tidal rivers through out their life cycles. Comparisons of life-stage-specific distributions demonstrated the ingress of estuarine-dependent fishes in the Peace River. For example, the mean salinity at capture for the bay anchovy decreased during development, starting at 22 ppt during the egg stage and decreasing from 21 to 14 ppt during various larval stages and finally to 6 ppt as the fish occupied its estuarine nursery habitat during the juvenile stage. Similar patterns of ingress were found for other estuarine-dependent species. Seine data indicated that juvenile snook, red drum, and striped mullet were common within the tidal rivers even though the eggs and larvae of these species were not. Larval ingress, as measured by age-related reduction in salinity at capture, was not as apparent in Shell Creek for two reasons: (1) larvae were relatively uncommon in Shell Creek because anchovies, seatrout, and other species that broadcast their eggs tended to spawn in the bay-like reaches of the tidal Peace River (below I-75) and not in the characteristically riverine portions of the Peace River and Shell Creek, and (2) salinities in Shell Creek were consistently low during most of the survey period, which interfered with the use of salinity-at-capture as a tracking method.

In addition to collecting the early stages of coastal fishes, the plankton net collected large numbers of freshwater and estuarine invertebrate plankton and hyperbenthos, which consisted of substrate-associated invertebrates that rise into the water column at night. These organisms were of particular interest because many serve as important prey for the estuarine-dependent fishes that seek out tidal rivers as nursery habitat. The survey data were used to develop regressions that described shifts in fish and invertebrate distribution as inflow rates and salinities change. It was found that the distributions of more than 20 types of fishes and invertebrates shifted as freshwater inflows fluctuated, moving upstream during low-inflow periods and downstream during high-inflow periods. Some species appeared to be more reluctant to change position than others. There was, however, no strong indication that prey distributions were offset from fish nursery habitats by this distributional response to inflow. Some predator-prey pairs appeared to move upstream and downstream in synchrony as inflows fluctuated (e.g. the sand seatrout and mysid shrimps). Another significant finding was that total numbers of some estuarine and estuarine-dependent fishes and invertebrates were reduced during low inflow periods. Regressions were developed to predict decreases in organism number as a function of freshwater inflow. Many organisms exhibited a pronounced peak in abundance several months after the end of the high inflow 1997/1998 El Niño period.

The number of fish taxa in the plankton-net catch increased during spring and decreased during fall, and was generally highest from April through October. However, the fall decrease observed for larval fishes was not observed in the seine catch because older juveniles remained in the tidal river long after larval recruitment diminished. The period from April to June appeared to have had the highest potential for impact due to the coupling of naturally low inflows with increasing nursery habitat use in the estuary. Some species, such as red drum and menhaden, spawn in fall or winter. There was, therefore, no time of year when potential for impacting economically or ecologically important species was absent.

Distribution responses to freshwater inflow were found for >20 taxa of fishes and invertebrates collected by the plankton net. Almost all taxa (94 percent) moved downstream with increasing inflow. Same day inflow and the location of a reference isohaline (7 ppt isohaline) both served as good indicators of organism position in the tidal river. Although most responses were in the same direction, the species distributions were staggered in the river, such that some were generally farther upstream than others.

Positive and negative abundance responses to freshwater inflow were documented for 18 taxa of fishes and invertebrates in the Peace River and 10 taxa in Shell Creek. Most positive responses to high inflow were found for freshwater organisms that shifted downstream during high-inflow periods, increasing their total numbers in the tidal river. Negative responses were found for high-salinity organisms that left the tidal rivers during high inflow periods. Positive responses were also found for sand seatrout and naked goby juveniles and mysids. These organisms congregate within the middle reaches of the tidal river as a characteristic part of their life histories. The positive responses by these organisms were also evident in regressions against referenced isohaline location. Most estuarine and estuarine-dependent organisms, however, appeared to have had a positive response to freshwater inflow that was delayed by 3-6 months. The very high inflows during the 1997/1998 El Niño period were followed several months later by large peaks in abundance of a diversity of estuarine and estuarine-dependent organisms. Many of these taxa had been displaced into the harbor, but later returned to the tidal river in large numbers.

Mysids were important prey for many juvenile estuarine-dependent fishes in tidal river nursery habitat. Reductions in mysid numbers during low-inflow periods likely reduced the carrying capacities of the Peace River and Shell Creek for snook, red drum, sand seatrout, spotted seatrout, and other species.

A second, potentially negative response to reduced inflows was predator-prey offset. Inflow-induced movement of keystone prey groups relative to the fixed structural habitats preferred by certain fishes could cause prey distributions to become offset upstream or downstream of their fish predators, reducing the carrying capacity of the tidal river for these fishes. In the Peace River, mysids appeared to be frequently offset upstream of the principal juvenile red drum habitat. A more detailed analysis supported the possibility that mysids in Shell Creek were favored as an alternative food supply, causing the red drum to remain downstream of the Peace River's mysid peak. Juvenile spotted seatrout and sand seatrout were more spatially coordinated with their prey in the Peace River, and often congregated upstream of the Shell Creek confluence.

1.9 *An Analysis of Vegetation-Salinity Relationships in Tidal Rivers on the Coast of West Central Florida* (SWFWMD, Draft 2002)

The purpose of this study was to identify ecological relationships between plant species distributions and salinity along the tidal portions of seven rivers on the coast of west central Florida. Four northern rivers, the Withlacoochee, Crystal, Chassahowitzka, and Weekiwachee, and three southern rivers, the Little Manatee, Myakka, and Peace, were included in the study and surveys were limited to the river banks.

Four emergent herbaceous species, sawgrass (*Cladium jamaicense),* needlerush (*Juncus roemerianus),* southern cattail (*Typha domingensis),* and one tree species, sabal palm (*Sabal palmetto),* occurred along all seven rivers. A total of 118 different species were identified along the river banks of the rivers. The total number of species was similar for the Peace, Myakka, and Withlacoochee rivers and ranged from 52 to 59 difference species in more than 60 sample sites along each river. Total numbers of species in the remaining four rivers ranged from 19 on the Weekiwachee (41 sample sites) to 42 on the Chassahowitzka (84 sample sites).

There appeared to be differences in plant species distributions between the northern and the southern rivers. The red mangrove (*Rhizophora mangle)* occurred nearest to the Gulf. Saltmarsh cordgrass (*Spartina alterniflora*) was more abundant along the northern four rivers than the southern three rivers, which were characterized more by *R. mangle*. Leather fern (*Acrostichum danaefolium*) was also more apparent along the three southern rivers. Needlerush tended to occur in more saline habitats in the northern rivers and less saline habitats in southern rivers, likely a result of displacement by mangroves that were absent in the northern rivers.

Water column salinity data were collected along the length of each river to examine the distribution of plant species in relation to salinity regimes. Histograms for the median salinity value and 95th percentile (P95) salinity were graphed for each site and river for all species. Median salinity was considered the typical salinity experienced by a species population and the range in median salinities at a site was assumed to describe the normal salinity regime for that species. The P95 salinity may be ecologically important because it represents the highest salinity experienced on a regular basis.

Co-occurrence of needlerush with four other species (sawgrass, southern cattail, giant bulrush (*Scirpus californicus*), and red mangrove) along river banks was used to evaluate potential "critical positions" that could be used to indicate a change in salinity regime. Shifts in vegetation occurred from mangrove- or cordgrass-dominated shorelines to needlerush-dominated shorelines, needlerush-dominated shorelines to mixed species, e.g. sawgrass and cattails, and from mixed species to freshwater species such as *Pontedaria cordata* (pickerel weed) and *Zizania aquatica* (wild rice). The study concluded the following findings.

- Highest mean salinities varied tremendously among several species and central tendencies were better indicators than extremes for interpretation of salinity regimes associated with plant species.

- Breakpoints in vegetation were not always clear due to narrow river bank, and vegetation landward of river bank may be more indicative of vegetation patterns associated with salinity.

- P95 values for the *Juncus/Cladium* vegetation class (16-18 ppt), median salinities for the *Juncus/Typha* class (8-10 ppt), and P95 for the *Juncus/Scirpus* class (14-16 ppt) may prove useful in detecting temporal changes in salinity regimes for rivers.

1.10 *Development of GIS-Based Maps to Determine the Status and Trends of Oligohaline Vegetation in the Tidal Peace and Myakka Rivers* (Florida Marine Research Institute, 1998)

The objective of this study was to assess possible upstream movement of salt marshes over time as an indicator of long-term salinity changes in the Peace and Myakka rivers. Color infra-red (CIR) and black and white (B&W) aerial photography were used to classify vegetation based on species dominance and co-dominance. Field verification was conducted by boat and truck. A comprehensive plant list was compiled for the report. Spatial analysis was used to evaluate change in distribution of marshes along the rivers from 1950 to 1994.

Aerial Photography – Changes in vegetation must be of sufficient size (0.25 acres) and may occur over three to four years to be of sufficient size to be mapped and interpreted. Historical change analyses were difficult due to variability in photography, and post-photography field verification. Consequently, conclusions regarding species-level changes in the oligohaline marshes could not be made using the scale and resolution of available aerial photography. However, larger scale changes were apparent.

Digital imagery and larger-scale photography was recommended. Bottomland hardwoods, mixed forests, salt marsh and mangroves were readily discernible on CIR aerial photography when acquired during optimal periods (leaf-off), during which differences in vegetation communities were more conspicuous, thereby improving the accuracy of interpretations and delineations. Identifications were conducted to Florida Land Use, Cover and Forms Classification System (FLUCFCS) Level 3 classifications and Level 4 where possible.

Historic Changes – Vegetation transitions in the Peace and Myakka rivers were similar and marsh habitat in both rivers decreased from the 1950s to the 1990s. Almost half of the change was due to conversion of marshes to uplands. Changes after 1970 appeared smaller. Marshes along the Peace River decreased from 2,390 acres in 1950 to 1,940 acres in 1985 and to 1,870 acres in 1994, for a total decrease of 541 acres. Along the Myakka River, marshes decreased from 1,040 in 1950 to 880 acres in 1970, to 850 acres in 1994 and amounted to a total loss of 233 acres of marshes.

Historic changes along the Peace River during the last 40 years occurred primarily in salt marshes from river mile (RM) 7 to RM 11, and in bottomland hardwoods and mixed forests between RM 13.5 and RM 16.5 prior to the 1970s. The most dramatic change was the displacement of marshes by woody vegetation during the 1950s to 1970. The minimal loss of marshes that have occurred along the Peace River since the 1970s was documented during this study. These conclusions were consistent with those made from earlier EQL studies, in which little change in vegetation was identified during a 17-year study.

Changes in vegetation distributions along the Myakka River were similar to those described for the Peace River. Changes during the past 40 years were primarily conversions to development, mangroves, and mixed hardwoods. Conversion of salt marsh to mangroves was minimal in comparison to other changes. Changes in the Myakka River appeared more gradual when compared with those for the Peace River.

1.11 *Peace River/Manasota Regional Surface Water Supply, Storage, and Interconnect Project. Final Environmental Impact Statement (EIS),* 2003.

This EIS was prepared to evaluate environmental impacts due to the proposed expansion of the existing Peace River Regional Water Supply Facility by the Peace River/Manasota Regional Water Supply Authority, as well as to compare and assess potential alternatives. The lead agency for the EIS was the USEPA. The purpose of the proposed project was to increase the reliable water supply to meet the growing water supply demand in the local four-county area in an environmentally acceptable manner.

The existing Facility has a treatment capability of a maximum 12 mgd. Under the proposed alternative, a maximum withdrawal of 90 mgd would be allowed, as permitted under the existing Water Use Permit. The water would be delivered to the off-stream reservoir and stored for future treatment. Following subsequent treatment, water would be distributed to water users, treated, and stored in the Aquifer Storage and Recovery (ASR) system, or some combination of these. The proposed project included the expansion of the existing Facility and the commensurate increase in the withdrawal, transport, storage, and treatment of water, as well as construction of new ASR wells and transmission facilities. Consequently, the Authority would be able to meet established 2015 water supply demands.

Initially, 20 alternatives were screened to eliminate those with engineering and/or economic constraints, and a potential seawater desalination facility was eliminated. The remaining 19 alternatives were evaluated for potentially significant environmental constraints (e.g. wetlands, protected species, critical habitat, cultural resources), and seven groundwater alternatives were subsequently eliminated. After additional analyses regarding the potential to provide an additional 20 mgd of potable water by 2015, three alternatives remained in addition to the *No Action* alternative. The four alternatives are briefly described below.

- Peace River alternative (Preferred Alternative). Expand existing facility to accommodate large withdrawals and greater ASR capabilities.

- Shell Creek alternative. Expand the existing Shell Creek Reservoir to increase freshwater diversions, transport up to 10 mgd of raw water to the Peace River Facility via a new pipeline, and expansion of the Peace River Facility to treat additional water.

- Myakka River alternative. Diversion of water from the Myakka River for storage in a newly constructed offstream reservoir or in ASR for use during low flows periods. Requires construction of 120 mgd diversion, treatment, and storage facilities and a 1,500 acre reservoir and/or ASR facilities.

- No Action alternative. No use of federal funding to construct and implement the preferred alternative, which would be developed using other non-federal funding sources.

The alternative preferred by the EPA and the Authority was the Peace River alternative. The proposed plan would be developed in two phases and provide the means for a quality source of water during both wet and dry seasons, allowing the Authority to meet the demands of the member counties with fewer impacts than either of the other two alternatives. The document provided tables that list acres of impacts to wetlands, open water, land use and land cover categories, and habitat edges anticipated as a result of each alternative.

Based on the analysis presented in this document, the proposed project would not affect flows downstream from the intake facility during times of low flows because water would be withdrawn following District guidelines. The Facility is permitted a maximum withdrawal of 90 mgd that may not exceed 10 percent of the flows from the Peace River. The proposed project would allow this withdrawal. Water would be sent to an off-stream reservoir and treated or stored for future treatment, or stored in the ASR system. Under this alternative, the Authority would meet projected annual average water demands of 32.76 mgd by storing excess water during high flows for use during low flows. The Myakka River alternative would impact larger quantities of undeveloped land and impacts due to freshwater withdrawals would be greater. The Shell Creek alternative would require pipeline construction and the amount of terrestrial habitat impacted would be greater than that for the proposed alternative.

2.0 Summary from the *2006 HBMP Comprehensive Summary Report*

The following series of documents and reports were summarized in the *2006 HBMP Comprehensive Summary Report*.

- Upper Peace River: An Analysis of Minimum Flows and Levels (SWFWMD, 2002)
- A Review of “Upper Peace River: An Analysis of Minimum Flows and Levels” (Gore et al. 2002)
- Effects of Phosphate Mining and Other Land Uses on Peace River Flows (Ardaman & Associates 2002)

- Cumulative Risk of Decreasing Stream Flows in the Peace River Watershed (SDI Environmental Services, Inc. 2003)
- Predicted Change in Hydrologic Conditions along the Upper Peace River due to a Reduction in Ground-Water Withdrawals (Basso, SWFWMD 2003)
- Long-term Variation in Rainfall and its Effect on Peace River Flow in West-Central Florida (Basso and Schultz, SWFWMD 2003)
- Water Quality Data Analysis and Report for the Charlotte Harbor National Estuary Program (Janicki Environmental, Inc. 2003)
- An Evaluation of Stream Flow Loss during Low Flow Conditions in the Upper Peace River (draft, Basso, SWFWMD 2004)
- Development of Hydrologic Model to Assess Phosphate Mining on the Ona Fort Green Extension (SDI Environmental Services, Inc. 2004)
- 2003 HBMP Annual Data Report (PBS&J 2004)
- Florida River Flow Patterns and the Atlantic Multidecadal Oscillation (Kelley, SWFWMD 2004)
- Shell Creek and Prairie Creek Watersheds Management Plan – Reasonable Assurance Documentation (Shell, Prairie, and Joshua Creeks Watershed Management Plan Stakeholders Group 2004)
- Proposed Minimum Flows and Levels for the Middle Segment of the Peace River, from Zolfo Springs to Arcadia (Kelly et al. 2005)
- 2004 HBMP Annual Data Report (PBS& J 2005)
- Impact of Phosphate Mining on Streamflow (Schreuder et al. 2006)
- 2005 HBMP Annual Data Report (PBS&J 2006)
- Assessment of Potential Shell Creek Impacts Resulting from Changes in City of Punta Gorda Facility Withdrawals (PBSJ 2006)
- Peace River Cumulative Impact Study (PBSJ 2007)
- 2006 HBMP Annual Data Report (PBS&J 2007)

2.1 Upper Peace River: An Analysis of Minimum Flows and Levels (SWFWMD, 2002)

This report was published as a draft in August 2002. It was subsequently used to develop a provisional minimum flows and levels (MFL) for the upper Peace River (from the Zolfo Springs gage to the Bartow gage located immediately downstream from the Lake Hancock discharge) which was adopted by the Southwest Florida Water Management District (District) Governing Board. The document was peer reviewed by a Scientific Peer Review Panel (Panel) established by the District (see Gore et al. below).

This document was the first produced by the District to articulate the concept that the protection of a river's ecology is dependent on maintaining minimum flows across the entire flow regime not just a low flow threshold. Furthermore, this document outlined both a general methodological and policy approach to MFL evaluations.

The determination of minimum flows for the upper Peace River first involved an assessment of the historic and current flow regime and the factors that have shaped flow regimes. The upper Peace River has experienced declining baseflows over the past three decades. It has been hypothesized that phosphate mining and agricultural irrigation are the primary anthropogenic causes. In recent years, climate change, specifically the Atlantic Multi-decadal Oscillation, has been shown to have a significant effect on flows in Florida rivers. The District utilized various statistical and hydrologic modeling tools to conduct flow analyses including various trend analysis techniques and the Index of Hydrologic Alteration developed by the Nature Conservancy Sustainable Waters Program.

This was followed by a consideration of the absolute minimum instream flow needs, or the flow which historically has been most often equated with the idea of a “minimum flow.” In the case of the upper Peace River, this flow was the lowest acceptable flow under the lowest anticipated flow conditions. A flow that would ensure fish passage or maintain the desirable wetted perimeter was considered the lowest acceptable minimum flow.

Certain instream habitats (“snags and roots”) provide substrate for the development and colonization of food organisms, and cover for various aquatic species, but occur at elevations above that which would allow for fish passage and a minimum acceptable wetted perimeter. It was therefore considered desirable to evaluate how often these habitats are inundated each year in an effort to determine when significant harm will occur to the resource.

It is expected that riparian hardwood and cypress swamp systems require flooding on at least a seasonal basis to maintain their biological integrity, and if historic flow records indicate a fairly sustained period of inundation, their flow needs can be assessed on the basis of the inundation requirements of certain associated biota (e.g. frog life histories).

To quantify the flow requirements of both instream and floodplain habitats, topographic survey transects were conducted at various locations perpendicular to the river channel to determine the elevations of desirable habitats. Then the USGS hydrologic model HEC-RAS was used to determine what flows would be necessary to ensure the desired inundation period of those habitats.

In summary, the resource management goals established for the upper Peace River included the following:

- Maintain minimum depths for fish passage and canoeing in the upper river
- Maintain depths above the inflection point in the wetted perimeter of the stream bottom
- Inundate woody habitats in the stream channel
- Meet the hydrologic requirements of floodplain biological communities

Following the completion of the MFL evaluation, DISTRICT staff recommended the adoption of only a minimum low flow at each of the three gage locations covering this segment based solely on the fish passage and wetted perimeter criteria. It was recommended that the minimum low flow, as a 95 percent annual exceedance value, not be allowed to go below 17 cfs at Bartow, 27 cfs at Ft. Meade, and 45 cfs at Zolfo Springs.

Furthermore, it was concluded that the flow regime in the upper Peace River was such that medium and high flows were not adequate to protect ecological resources (e.g. riparian swamps) across the entire flow regime. Because District staff could not adequately partition among the various controlling factors (rainfall, structural alterations and changes, withdrawals) the causes for the altered flow regime, no medium and high minimum flow criteria were proposed for adoption.

Two management standards were proposed for consideration that, if met, would provide some measure of improvement to the riverine ecosystem in the medium to medium-high flow range. To ensure that exposed root habitat in the uppermost reaches of the river (upstream of Ft. Meade) is inundated so that the habitat can be used long enough for dominant macroinvertebrates (dipterans, predominately chironomids) to colonize and reach maturity, it was recommended that the highest root indicator site measured in the upper river be inundated to its mean elevation for a minimum of 45 consecutive days annually. In order for the majority of anuran (frogs and toads) species expected to occur in association with the river and its floodplain to have access to and reproduce in riverine wetlands, it was proposed that periods of 90 consecutive days of inundation are needed in lower floodplain habitats at a three-year average recurrence interval.

The findings for habitats requiring medium and high flows were considered to be applicable to other District strategies to restore the full flow regime in the upper river through a combination of physical, regulatory, and management approaches. As such, the District is pursuing a recovery strategy for the upper Peace River.

2.2 A Review of "Upper Peace River: An Analysis of Minimum Flows and Levels" (Gore *et al*. 2002)

As stated above, the District convened a panel of experts – referred to as the MFL Scientific Peer Review Panel - to provide a peer review of the upper Peace River MFL evaluation report. The panel report was published in November 2002. The objectives of the panel review were to: 1) provide a critical review of the methods, data, and conclusions of the District with regard to the upper Peace River MFL; and 2) recommend improvements and guidelines for future decisions on the restoration and/or rehabilitation of the upper Peace River. The findings and conclusions of the MFL Scientific Peer Review Panel can be summarized as follows.

- The proposed MFLs for the upper Peace River are a good first step in the management process but cannot be the only step.

- The resource management goals represent a reasonable subset of potential goals for an improved biotic community in the degraded upper basin. The rationale for choosing these goals was clearly presented and scientifically justified.

- In general, the wetted perimeter approach does an adequate job to predict levels that will address the management goals, as described. As an initial step, maintaining fish passage, or the hydrologic connectivity of the system, is a necessary goal. The assumption of a desired elevation of the channel at its deepest point being 0.6 feet above minimum elevation for fish passage is reasonable. The application of the HEC-RAS model to generate a wetted perimeter versus flow plot for each transect also is a justifiable scientific approach.

- In order to complete an effective program of rehabilitation of the upper Peace River, the current management goals may not adequately address the linkages between instream flow-related (hydraulic) habitat requirements of resident biota and discharge conditions over the range of life-stages and functions of various species within the community. Future efforts to enhance the integrity of the upper Peace River may require that these linkages be established.

- The District should frequently revisit this study and view the establishment of MFLs and rehabilitation goals as a dynamic process that results in improved flow criteria as new data and techniques are acquired.

- The approach the District adopted to investigate the relationship between floodplain systems and hydrologic patterns were reasonable and appropriate, based on the relationships presented in most of the published literature. However, in this system, the methods and analyses were not adequate to produce information that could be used to formulate recommendations regarding medium and high flow regimes on those surfaces. The District was, therefore, correct in declining to recommend specific flow criteria for that purpose. Recommendations for future studies of this nature include collection of more detailed data and the adoption of a broader perspective regarding options for ecosystem management and restoration, including actions other than flow regulation.

- No specific quality assurance measures are described in the report. In hindsight, it might have been a good idea to apply the “peer review panel” concept to the study plan development phase. This might have produced a more streamlined and more narrowly focused study plan.

- The District completed a comprehensive data set for application to the wetted perimeter method for minimum flow analysis. However, the question of “best available data to establish minimum flows” cannot be entirely evaluated. There are many alternative techniques for predicting or analyzing minimum flows in fluvial systems. Some of these techniques would require more comprehensive instream physical data than reported in this study.

- One of the weaknesses of the District report is the ability to link maintenance of medium and high flows to the maintenance of riparian floodplains. This linkage is a critical component for the maintenance of the integrity of the upper Peace River basin. We suggest that the ultimate goal for restoration of that integrity will necessarily be the recreation of the medium and high flows that establish these linkages.

The panel reviewed several techniques that it considered to be alternatives to the evaluation procedures employed by the District. All of these techniques would require a greater effort in data collection and analysis; however, the panel felt that such an analysis would lead to more sound management strategies to maintain the integrity of riverine ecosystems. Specifically, the panel suggested that the instream flow incremental approach be considered as the next management step as a means of connecting physical habitat requirements and availability to MFLs already established.

The panel further stated that instream flow analysts consider a loss of more than 15 percent of the habitat of a particular population or assemblage, as compared to the undisturbed or current conditions, to be a significant impact on that population or assemblage. In addition, the panel recommended that the District utilize a so-called building block approach in future MFL evaluations.

2.3 Effects of Phosphate Mining and Other Land Uses on Peace River Flows (Ardaman & Associates 2002)

The objective of this study was to assess the potential impact of phosphate mining on observed reductions in flows in the lower Peace River. Addressed issues included reductions in base flow, decreased stream flow at Arcadia, the lower potentiometric surface in the Floridan aquifer, and changes in evapotranspiration (ET) rates. Average annual water budgets were developed for the Peace River above Arcadia for the two periods 1934-1963 and 1969-1988 shown below.

Average Annual Water Budgets for Peace River above Arcadia

Parameter	Quantity (in/year)	
	1934 - 1963	1969 - 1998
Rainfall	54.75	50.90
Evapotranspiration	38.8	37.8
Deep recharge	3.37	6.3
Return Flow	0.5	1.95
Δ Storage	0.0	0.0
Stream flow	13.08	8.75

The results of the study attributed most of the observed reduction following 1963 in Peace River flows at the USGS Arcadia gage to natural changes in rainfall, with smaller contributions caused by the lowering of potentiometric ground water surfaces, and changes in evapotranspiration. Overall, the report suggested that phosphate mining has had relatively minimal impacts on Peace River flows, concluding that:

- 88 percent of the reduction in Peace River flows at Arcadia after 1963 was caused by lower natural rainfall.

- That only 8.5 percent of the 45-foot drawdown of the Floridan aquifer potentiometric surface at Kissengen Spring south of Bartow was related to phosphate mining.

- That higher evapotranspiration rates on the order of 0.5–1.0 inch/year in mined versus unmined areas due to increased evapotranspiration from wetlands, lakes and clay settling areas (CSAs) resulting from mining and reclamation.

- The study found that approximately 89 percent (387 out of 436 cfs) of the observed Peace River at Arcadia flow reductions can be attributed to rainfall declines and that phosphate mining is responsible for a relatively small fraction of the remaining 11 percent. Specifically, the study attributes a flow loss due to phosphate mining at 8.5–17 cfs (~1 percent).

- The reduction in stream flow from increased evapotranspiration rates is more than offset by the increased runoff, estimated at 160 cfs, resulting from urban development.

- Mining has not significantly reduced base flow to the Peace River; and that evidence suggests that base flow may be higher in tributary basins that have been mined.

2.4 Cumulative Risk of Decreasing Stream Flows in the Peace River Watershed (SDI Environmental Services, Inc. 2003)

This report presents an analysis of the impacts of phosphate mining on stream flows in the Peace River and predictions of future stream flow reductions based on projected increases of mined areas. The analysis is based on a statistical regression between monthly rainfall and stream flow for the period of 1933 – 1962. Rainfall was the average of rainfall records at Bartow, Wauchula and Arcadia, and the stream flow data was taken from the Arcadia gage. Having developed the regression model, the authors then applied it to estimate how much of the observed stream flow reductions from 1963 onward can be attributed to anthropogenic factors (i.e. land uses changes), versus climatic factors (i.e. reductions in rainfall). In order to separate mining impacts from other land use changes, the study examined stream flow reductions in the South Prong Alafia watershed. This watershed was primarily impacted by mining, with minimal impacts from other land use changes. The study used South Prong data for the periods 1963-1977 and 1978-2000 to develop a relationship between the mined area fraction of the watershed and stream flow reductions. Extrapolation of this relationship to the Peace River watershed allowed the authors to estimate how much of the stream flow reduction above Arcadia could be attributed to mining as compared to other land use changes. The same methodology was also used to estimate future stream flow reductions resulting from expansion of the area mined in the Peace River watershed. Findings from this study are:

- Average annual rainfall in the Peace River watershed for 1963 – 2002 decreased by 8 percent (55.48 to 51.02 inches) compared to the 1933 – 1962 period.

- Average annual stream flow decreased by 34 percent (13.25 to 8.78 inches) over the same time periods.

- Primary contributing factors to the stream flow reductions are: rainfall (55.3 percent), mining (17.5 percent), and other anthropogenic (27.2 percent).

- The unit rate of stream flow (inches of stream flow per unit area of watershed) under ‘natural’ conditions is 2.13 times higher than the unit stream flow for mined areas.
- Mining impacts on stream flow are similar for reclaimed areas as they are for active mining areas.

The conclusions of this study regarding the contribution of mining to Peace River stream flow reductions contradict findings in the 2002 report of Ardaman and Associates on “*Effects of Phosphate Mining and Other Land Uses on Peace River Flows.*” Ardaman and Associates argue that 89 percent (387 out of 436 cfs) of the observed stream flow reductions above Arcadia can be attributed to rainfall reductions and that phosphate mining is responsible for a relatively small fraction of the remaining 11 percent. Specifically, Ardaman and Associates attribute a flow loss of 8.5 – 17 cfs (~ 1 percent of the pre-1963 flow at Arcadia) to increased evapotranspiration from wetlands, lakes and CSAs resulting from mining and reclamation.

The rainfall – stream flow regression model developed in this study provides a way to separate natural and anthropogenic influences on observed Peace River stream flow reductions. In applying their mining analysis to the South Prong Alafia River watershed, the authors assumed that all factors other than the area mined (i.e. including average rainfall) remained constant during the period of 1963 – 2000. The study is based on a statistical analysis of stream flow data, and does not address the mechanisms through which mining impacts stream flow. As a result, the projections of future impacts are based on the tacit assumption that mining and reclamation practices that cause the stream flow reductions have and will remain the same. For example, this study does not address how changes in water use by mines (historically based on ground water pumping, but currently based on capture of stormwater) impact Peace River flows.

2.5 Predicted Change in Hydrologic Conditions along the Upper Peace River due to a Reduction in Ground-Water Withdrawals (Basso, SWFWMD 2003)

This study examined the interaction between the Peace River and surrounding groundwater from Lake Hancock to the Zolfo Springs gage station. Decreases in Peace River flow due to the effect of groundwater pumpage have been discussed in the literature since the 1950s. Surface drainage to the upper portion of the river is largely phosphate mine releases and reclaimed stream channels. There are 25 facilities with Florida Department of Environmental Protection (FDEP) permits to discharge effluent, the total volume of which is about 20 mgd.

The major groundwater users have traditionally been the phosphate mining industry and agriculture. Current groundwater withdrawals average between 300-400 mgd from Hardee and Polk counties.

Kissengen Spring is the only major spring in the upper Peace River basin. This spring, which had averaged ~19 mgd of discharge ceased continuous discharge in 1950, and has not flowed at all since 1960. Peek (1951) attributed the cessation in flow largely to a decline in the potentiometric surface of the intermediate and Upper Floridan (UF) aquifers. This attribution is supported by analysis of estimated (by regression) and observed data from the late 1940s to 1975. These data indicate that the decline in water level of the UF aquifer removed the potential for discharge at Kissengen Spring.

There are very few groundwater monitoring sites with data that predate 1970. Thus models have been produced to estimate the impact of groundwater withdrawals on the potentiometric surface of the Upper Floridan aquifer. These estimates generally show a steep decline in potentiometric surface from about 1960 to the mid-1970s, after which a more gradual increase has occurred. These analyses indicate that as of 2000 the potentiometric surface is still much lower than the pre-1960 condition.

The two major contributing factors to changes in potentiometric surface are groundwater withdrawals and rainfall. In periods of high rainfall water is naturally available and irrigation needs decrease (both agricultural and residential), allowing for a decrease in groundwater withdrawal. In dry periods this feedback loop reverses, as irrigation needs increase.

In addition to the loss of flow from Kissengen Spring, there have been several documented sinks/subsidences between Bartow and Ft. Meade, which may have caused a loss of as much as 11 mgd of river flow. Despite these losses baseflow can still provide a positive input to the upper Peace River from the surficial aquifer and possibly a unit of the intermediate aquifer system (IAS) below Ft. Meade.

Groundwater Reduction Scenarios

In order to restore positive flow at Kissengen Spring during the spring dry season it is estimated that groundwater withdrawals in Polk County and the surrounding area would have to be reduced by 60 percent. In order to increase Kissengen Spring flow to near 15 cfs, withdrawals would have to be reduced by more than 80 percent. Overall, reducing dry season withdrawal by 20 percent should increase upward flow along 5 additional river miles. Reducing withdrawal by 40 percent allows for upward flow along 10 additional river miles, and an 80 percent reduction should create upward flow along an additional 30 river miles, in conjunction with initiating positive flow from Kissengen Spring.

A second modeled approach was to reduce withdrawals in the 676 square mile region surrounding Kissengen Springs. In this scenario a 50 percent withdrawal reduction was estimated to create upward flow over an additional 8.5 river miles, but flow would not be initiated at Kissengen Spring. A 100 percent cessation of withdrawals in this region would create upward flow over an additional 28 miles of the river, and initiate flow from Kissengen Spring.

2.6 Long-term Variation in Rainfall and its Effect on Peace River Flow in West-Central Florida (Basso and Schultz, SWFWMD 2003)

Flow reductions in the Peace River have been largely attributed to anthropogenic factors, however the role of long-term, multi-decadal variation in rainfall toward flow changes has only recently received close attention. This report examines long-term changes in rainfall, focusing on decadal variations and its impacts on streamflow. Various analytical methods and models are utilized to demonstrate the hydrologic significance of these changes.

Data from 27 long-term rainfall stations in central Florida were examined, with six of these stations considered within the Peace River basin specifically. Based on simple linear regression of annual rainfall data, five-year running mean rainfall, and median rainfall by decade, the report indicates that regional multi-decadal cycles of above-or-below average rainfall appear to closely follow the Atlantic Multidecadal Oscillation (AMO).

Averaging the six stations within the Peace River basin indicated that the change in rainfall was about five inches per year between 30-year periods (partitioned at either 1965 or 1970, ± 30 years). Additionally, the five-year running average rainfall for the six Peace River basin stations was similar to the 27-station average for the region. Cumulative departure analyses also indicated that the 1930s to 1960s were wetter than the more recent three decades.

Based on monthly averages over the period of record from the six Peace River basin stations, about 80 percent of the 5 inches/year change between 30 year periods was due to a decline in wet season rainfall. Single mass plots and running 5-year means of wet season rainfall illustrate that the change in wet season rainfall emanated around 1970. Single mass analysis and 5-year running mean of dry season rainfall indicate a slight decline in dry season rainfall beginning in the mid-to-late 1960s.

The AMO is strongly associated with variation in tropical cyclone activity. The report questions whether the AMO cooler mode from 1970-1994 leading to a lull in tropical cyclone activity compared to the previous 45 years accounts for all of the decline in annual rainfall between the two periods. The frequency of cyclones was greater during the warmer AMO phase than the cooler AMO phase. Additionally, tropical cyclone mean rainfall declined between 30 year periods. Tropical cyclone frequency was found to account for up to one-third of the 5 inch/year decline in rainfall.

In general, statistical tests of significant differences (two-sample t-test, Wilcoxon Rank Sum) between two 30 year periods support the hypothesis that the post-1965 period was drier than the pre-1965 period. The authors note that statistical significance does not necessarily equate to physical significance (in terms of aquifer recharge or streamflow).
Empirical and surface water model results were utilized to calculate estimates of streamflow decline due to rainfall changes. The estimated minimum annual rainfall values needed for the Peace River to remain a perennial system differed between methods, and the magnitude of flow decline associated with a 5 inch/ year rainfall change varied from 22 to 35 percent, expressed as a percentage of mean flow. Single mass plots combined with regression analyses of empirical data indicated that 75 to 90 percent of observed streamflow decline can be related to long-term changes in rainfall.

The authors note that a warmer ocean phase of the AMO mode began in 1995 and the wetter cycle is expected to last another 20 to 50 years.

2.7 Water Quality Data Analysis and Report for the Charlotte Harbor National Estuary Program (Janicki Environmental, Inc. 2003)

The results of the status and trends analysis of surface water quality indicated that although there have been many areas of unchanging or improving water quality in the Peace River watershed, there have also been declines in some water quality parameters in a number of basins. Relatively consistent problems regarding selected water quality constituents were found across much of the Charlotte Harbor study area. Florida surface water standards were frequently exceeded in many basins for both dissolved oxygen (instantaneous and daily average) and ammonia, and to a lesser extent for chlorophyll *a* and bacteria.

Similar results were observed for the 1996 to 2000 status period with the approach being applied by FDEP for the Florida Impaired Waters Rule (FAC 62-303.100). The results of the comparison of current water quality conditions to three candidate nutrient criteria suggested that these criteria may not be appropriate for all of the basins in the study area. Nutrient criteria were frequently exceeded for chlorophyll, phosphorus, and nitrogen. The Secchi disk depth criterion was also exceeded in a number of basins, while the turbidity criterion was only rarely exceeded.

Overall, it was suggested that the presented results of the integrated status and trend analyses provide useful information to the Charlotte Harbor National Estuary Program in addressing watershed goals. Brief descriptions of the water quality analysis for each basin are provided here.

- **Peace River at Bartow –** Significant declines in ammonia, total nitrogen, and total phosphorus were observed at several locations and concentrations exceeded five percent of the median value for a station per year. Significant, but smaller, declines were also detected for Total Kjeldahl Nitrogen (TKN) and nitrogen at several stations. Both increasing and decreasing trends in Secchi disk depth trends were identified. With respect to surface water quality standards, water quality at stations in this basin frequently exceeded the standard for ammonia, and some stations frequently exceeded the chlorophyll *a*, total coliform bacteria, and dissolved oxygen standards. With respect to the Impaired Water Rule (IWR) criteria, this basin indicated unacceptable conditions for dissolved oxygen, ammonia, and chlorophyll *a*.

- **Payne Creek –** The Payne Creek basin is relatively small and drains to the Peace River upstream of the USGS Zolfo Springs gage. Streams in this basin were ranked high among the groups of stations with respect to total phosphorus and dissolved oxygen, and were ranked low with respect to Secchi disk depth, chlorophyll *a*, and turbidity. With respect to water quality standards, ammonia and total coliform bacteria criteria were frequently exceeded. Application of the IWR criteria identified acceptable conditions for dissolved oxygen, chlorophyll *a*, and fluoride, and unacceptable conditions for ammonia.

- **Peace River at Zolfo Springs –** This basin receives direct discharge upstream at its confluence with Payne Creek. Significant declines in Secchi disk depths (deteriorating water clarity) at a rate of greater than five percent of the median value per year were observed at 12 stations in the basin. Significant increases in total nitrogen and total phosphorus concentrations were also observed at a number of locations. State surface water quality standards at sampling stations were frequently exceeded for ammonia, dissolved oxygen, total coliform bacteria, and annual chlorophyll *a*. Relative to IWR criteria, total coliform bacteria and fluoride conditions were acceptable, while dissolved oxygen, ammonia, and chlorophyll *a* annual means were not.

- **Charlie Creek –** The Charlie Creek basin is one of the larger basins and discharges freshwater into the Peace River upstream of the USGS Peace River at Arcadia gage and downstream of the Zolfo Springs gage. No differences in water quality were found in comparisons between historical and current time periods. Water quality at basin stations were ranked among the best for Secchi disk conditions, total phosphorus, turbidity, and total nitrogen values. With respect to IWR criteria, this basin was also identified as having unacceptable conditions for ammonia. The EPA nutrient criteria for total phosphorus and total nitrogen were frequently exceeded at some stations, although the EPA criteria for chlorophyll *a*, Secchi disk depth, and turbidity were not.

- **Peace River at Arcadia –** The Peace River at Arcadia basin receives flow from below the Peace River at Zolfo Springs USGS stream flow gage and receives additional flows from the upstream confluence with Charlie Creek. A trend of increasing nitrite+nitrate at a rate greater than five percent of the median value per year was reported. A decreasing trend of similar magnitude was detected for total phosphorus. The stream stations in the Peace River at Arcadia basin were ranked highest with respect to color, total phosphorus, ammonia and nitrite+nitrate. The stations were ranked among the lowest with respect to conductivity, pH, turbidity, and Secchi disk depth. Florida standards for ammonia and dissolved oxygen standards were frequently exceeded. Chloride, annual chlorophyll *a*, and conductivity standards were not found to be frequently exceeded. With respect to the IWR criteria, the basin has acceptable conditions for dissolved oxygen, total coliform bacteria, and mean annual chlorophyll *a* values. Unacceptable conditions occurred for ammonia. EPA nutrient criteria were frequently exceeded for all parameters except Secchi depth and turbidity.

- **Joshua Creek –** This relatively small basin discharges freshwater into the Coastal Lower Peace basin upstream of the confluences of the Peace River with Horse Creek. Significant increasing trends were observed for nitrite+nitrate, chloride, and sulfate. The stream stations in the basin were ranked high with respect to the median nitrite+nitrate value, and ranked among the lowest stations for turbidity. State standards for ammonia, dissolved oxygen and total coliform bacteria were exceeded. Relative to IWR criteria, water quality was acceptable for dissolved oxygen and fluoride, and unacceptable for ammonia.

- **Horse Creek –** This relatively large basin discharges freshwater into the tidal area of the Coastal Lower Peace basin downstream of the Peace River at Arcadia gage. Two Horse Creek stations frequently exhibited exceedances of the state ammonia standard and IWR criteria. EPA phosphorus criteria were also frequently exceeded.

- **Shell Creek –** This basin discharges to the tidal Coastal Lower Peace River watershed and is characterized by an extensive estuary at its confluence with the Peace River estuary. Significant trends in increasing conductivity were observed at the HBMP Prairie Creek monitoring site upstream of the City’s reservoir. Since 1991, this trend appears to be influenced by a recent shift towards slightly higher values. Higher TKN values were also detected in comparisons of historical and current time periods. Overall, observed water quality was relatively good in comparison to the other basins. However, with respect to surface water quality standards, there were frequent exceedances of ammonia and dissolved oxygen. Relative to IWR standards, the basin was identified as having acceptable conditions for fluoride and mean annual chlorophyll *a*, and unacceptable conditions for dissolved oxygen and ammonia.

- **Coastal Lower Peace –** The basin includes the Peace River watershed, beginning downstream of the Arcadia USGS gage, and continuing to the wider, tidal portions of the Peace River at its confluence with Charlotte Harbor. A number of significant water quality trends were detected for the stations in the Coastal Lower Peace basin. Notably Total Suspended Solids (TSS) trends were detected for five stations at rates of increase of greater than five percent of median values per year, and slight, significant trends in pH were detected for 20 stations. The pH trends appear to be gradual rather than sudden, which might be expected if the change was due to a change in a metering device. Ammonia, chlorophyll *a*, and dissolved oxygen values frequently exceeded water quality standards. Relative to IWR criteria, fecal coliform bacteria, total coliform bacteria, and annual chlorophyll *a* means in the stream stations were acceptable, while dissolved oxygen, ammonia, and annual chlorophyll *a* means for estuary stations were not.

2.8 An Evaluation of Stream Flow Loss during Low Flow Conditions in the Upper Peace River (draft, Basso, SWFWMD 2004)

Prior to significant groundwater withdrawals (predevelopment), the potentiometric surface of the Upper Floridan aquifer was much higher than the stage of the Peace River throughout its entire length. Increasing groundwater withdrawals for phosphate mining, agriculture, and public supply use has resulted in a 30 to 40 foot decline of the potentiometric surface of the Upper Floridan aquifer since predevelopment in the upper Peace River Basin. This long-term decline has reversed the hydraulic gradient between the Peace River and the underlying aquifers, resulting in occasional loss of perennial flow between Bartow and Homeland during the spring dry season. At the time of this study, the United States Geological Survey (USGS) was engaged in a cooperative study with the District to map karst features in the riverbed and adjacent floodplain and determine stream flow loss to the underlying aquifer(s). For the planning stages of the District water resource development projects, however, an immediate estimate of stream flow loss was needed so that potential augmentation quantities could be established. This paper examines the flow history between the Bartow and Ft. Meade stations and uses statistical analysis to provide an estimate of anticipated augmentation quantities necessary to overcome losses between the two stations. It was intended to be a preliminary analysis until more quantitative results could be obtained by the USGS.

The stream flow record from the Bartow and Ft Meade stations was examined from 1975 through 2003 to summarize hydrologic conditions and determine durations of flow that fell below the proposed minimum flows and levels. To assess river leakage during the dry part of the year, statistics were generated on the difference in daily flow between each station when Ft. Meade was at or below its recommended MFL.

The study concluded that during low flow conditions, defined as 27 cfs or lower at Ft. Meade, the average daily stream flow loss between Bartow and Ft. Meade was about 7 cfs, and less than 16 cfs, 95 percent of the time. This estimate assumes that the runoff characteristics are the same for the watershed between Ft. Meade and Bartow as they are for the watershed above Bartow. The report acknowledges the uncertainty in the estimated loss by not accounting for permitted mining discharges. Based on further examination of stream flow records at Homeland, located in between Bartow and Ft. Meade, the study concluded that nearly all of the in-stream leakage to the ground water system occurs along the river segment between Bartow and Homeland.

The study provided conservative estimates of augmentation quantities to meet MFLs. Expected augmentation schedules were derived based on regressions of historical flow differences and taking into account flow history at Ft. Meade over a 29 year period. The maximum projected capacity for in-stream augmentation to meet the MFL was 52 cfs (MFL at Ft. Meade plus 25 cfs). This capacity was required to assure that the MFL be met 99 percent of the time. The author stressed that the augmentation schedules should be considered preliminary and subject to revision until the detailed assessment conducted by the USGS could be completed.

2.9 Development of Hydrologic Model to Assess Phosphate Mining on the Ona Fort Green Extension (SDI Environmental Services, Inc. 2004)

This study was conducted in support of the administrative hearing process for the proposed Ona Mine extension in the Horse Creek basin. It involved the development of an integrated hydrologic model to evaluate the proposed reclamation technique and design that was part of the permit application. The model was first calibrated against stream flow and surficial aquifer water level data for the period 1978 – 1988, and was then applied to compare post-reclamation to pre-mining conditions in terms of various hydrologic watershed characteristics, including stream flow quantities, flow duration curves, and wetland hydroperiod. The study also provided an average water budget for Horse Creek for the 1978-1988 period. The average annual water budget had the following components:

- Rainfall + irrigation = 49.8 inches
- Evapotranspiration = 36.9 inches
- Stream flow (runoff+base flow) = 9.8 inches
- Net ground water recharge = 3.1 inches

2.10 2003 HBMP Annual Data Report (PBS&J 2004)

Between 1979 and 2003, an ongoing series of individual reports have been submitted to the District, documenting the results of the HBMP during the period from January 1976 through December 2002. This data report represents the fourteenth year of data collection for the Peace River/Manasota Regional Water Supply Authority (Authority), the owner/operator of the Peace River Regional Water Supply Facility.

This report compares data collected during 2003 with similar average values for key parameters previously compiled during various elements of the ongoing long-term monitoring programs. In making comparisons of the 2003 data with averages of similar data collected over the preceding twenty-year period (1983-2002), it should be noted that the very wet winter/spring El Niño of 1997/1998 was followed by very dry La Niña conditions that influenced southwest Florida and the entire Peace River watershed between 1999 and mid-2002. A weaker El Niño at the end of 2002 and a wetter than average wet-season resulted in freshwater flows during 2003 being well above average.

- **Flows** – Overall, gaged Peace River at Arcadia freshwater inflows during 2003 were approximately double the average daily flow for the preceding long-term period 1976-2002. The sum of average daily flows from the Peace River at Arcadia, Horse Creek, Joshua Creek, and Shell Creek during 2003 was roughly one hundred and ninety percent of the average daily flows for the period 1976-2002.

- **Withdrawals** – Facility withdrawals only reached levels of ten percent of the gaged Peace River at Arcadia flows (those over 130 cfs) on three percent of the days of the year. Facility withdrawals during 2003 comprised 1.41 percent of the annual Arcadia gaged flow, and 0.89 percent of the combined lower Peace River gaged flow (Peace River at

Arcadia, Horse Creek, Joshua Creek and Shell Creek). During 2003, the facility did not withdraw any water approximately eleven percent of the time. Maximum withdrawals increased notably during the later half of 2002 due to the recently completed facility expansion, which resulted in an increase in the Authority's ability to treat larger daily amounts of freshwater when river flows are within the existing permit schedule.

- **Temperature –** Average water temperatures throughout most of the year were generally above the long-term annual averages, even though surface water temperatures during the summer months were slightly below recent years (probably reflecting increased wet-season rainfall). Water temperatures at the end of the year (November and December 2003) were much warmer than average. As in previous years, during the summer wet-season (June through October), water temperatures in the freshwater isohaline were slightly below those observed at the other three monitored salinity zones.

- **Water Color –** The average color levels throughout the estuary were markedly different than those recently observed during the preceding years of drought. Color levels were well above the long-term averages as a result of the higher than average flows during much of 2003. Comparatively, the greatest difference in color levels during 2003 when compared to the long-term averages occurred within the higher salinity reaches of the estuary.

- **Extinction Coefficient –** Comparisons among the mean 2003 extinction values indicated divergent patterns. Light extinction coefficients within the freshwater reaches of the lower river were below historical annual averages, while at the same time extinction coefficients were at or above average within the higher estuarine salinity zones. It is suggested that the higher than average flows that occurred through the first half of 2003 suppressed normal spring levels of phytoplankton production (chlorophyll *a*), resulting in lower than average measurements of extinction coefficients within the lower river.

- **Nitrite/Nitrate Nitrogen** - During 2003, the average concentrations of this major inorganic form of nitrogen were similar to the long-term averages in the lower river, and slightly above average in the higher salinity reaches of the estuary. Spatially concentrations typically decreased rapidly with increasing salinity, while temporally ambient inorganic nitrogen concentrations in the estuary usually declined to their lowest levels during the relatively drier, late spring as phytoplankton populations responded to increasing water temperatures and light, and increased primary production removed available inorganic nitrogen.

- **Ortho-phosphorus** - Average inorganic phosphorus concentrations during 2003 were generally lower than the long-term averages (1983-2002). Since ambient inorganic phosphorus concentrations are heavily influenced by the unusually "very" high natural levels found in the Peace River watershed, the observed differences in concentrations among the four monitored HBMP isohalines simply reflect conservative dilution by Gulf waters. Unlike inorganic nitrogen, observed changes in phosphorus concentrations are for the most part unaffected by biological uptake. Ambient inorganic phosphorus concentrations entering the estuary system from the Peace River watershed are typically lower during wetter periods, when a higher proportion of flow results from surface flow (rather than coming from groundwater, which is naturally richer in phosphorus). Since the late 1970s there has been a marked decline in inorganic phosphorus levels in the lower Peace River/upper Charlotte Harbor estuarine system due to declines in the influences of phosphate mining in the upper reaches of the basin.

- **Nitrogen to Phosphorus Atomic Ratios** – Calculated atomic inorganic nitrogen to phosphorus ratios for ambient measured concentrations showed nitrogen to always be the inorganic macronutrient limiting phytoplankton production within the lower Peace River/upper Charlotte Harbor estuarine system.

- **Silica** - Concentrations during 2003 reflected a continuation of the previously noted increasing pattern of higher dissolved silica concentrations. This increasing pattern was slightly interrupted by the recent extended drought, but average reactive silica concentrations during 2003 were more than double the long-term means throughout the lower river and upper harbor.

- **Chlorophyll *a*** – The pattern of freshwater inflows during 2003 reflected the influences of the much wetter than usual 2002/2003 winter, followed by wetter than average conditions during the typically very dry spring, and a wetter than average summer wet-season. The result was both higher than average inputs of inorganic nutrients, and higher than average ambient water color (low light). This was fairly typical of relatively lower levels of phytoplankton production in the more highly color-influenced lower salinity reaches of the estuary, combined with higher than average phytoplankton production (chlorophyll *a*) within the higher salinity zones. The 2003 data indicated the occurrences of a number of instances of high phytoplankton chlorophyll *a* biomass. Corresponding species identifications found that either increases in dinoflagellates or diatoms often characterized these “blooms.”

The graphical and summary analyses presented in this document do not indicate any substantial changes, or atypical events in either the physical or biological data collected during 2003, other than those previously noted. These include:

- Higher than usual winter freshwater inflows associated with the winter 2002/2003 El Niño event.

- A wetter than average summer wet-season.

- A resumption of the previously noted long-term increase in reactive silica concentrations in the lower Peace River.

These “limited” analyses also do not suggest that there have been any long-term changes resulting from either current or historic water withdrawals by the Peace River Regional Water Supply Facility.

2.11 Florida River Flow Patterns and the Atlantic Multidecadal Oscillation (Kelley, SWFWMD 2004)

The purpose of this paper was to discuss the influence of the Atlantic Multidecadal Oscillation (AMO) on stream flow patterns throughout Florida, including the Peace River. This broader climatic influence was placed in the context of geographic and seasonal differences in rainfall patterns in Florida, and a number of waterbodies are specifically examined. There is a seasonal/geographic divergence in rainfall pattern within the state of Florida. North Florida receives its highest rainfall in the spring, while South Florida receives the majority of its rainfall through the summer monsoon. The Wacasassa and Steinhatchee Rivers are located in a range that is influenced by both rainfall patterns. These rivers exhibit a seasonally bimodal flow pattern (summer and winter peaks in flow). The AMO is now widely accepted among climatologists. There has been an assumption that the long term rainfall and flow are distributed in a random independent and identical manner. The presence of predictable periodic changes in rainfall counters this assumption. Due to the affect of the AMO on rainfall, and the relationship between rainfall and stream flow, the author believes that there should be a distinct step trend, rather than a monotonic trend, in temporal flow evaluations.

The relationship between mean annual flow and total annual rainfall was developed further to examine seasonal and monthly flow and rainfall relationships. In doing so, median daily flows were normalized by creating a ratio of flow per unit area of drainage basin. Flow conditions in many Florida Rivers changed sometime around 1970, the time of an AMO shift. Prior to 1970 the flow peaks in South Florida were larger, and flow peaks in North Florida were smaller. The rivers with bimodal flow distribution exhibited these changes as apparent shifts in seasonal rainfall volume. In the Peace River Basin, despite the impact of the regional lowering of the potentiometric surface of the Upper Floridan Aquifer it is believed that the recent decline in flow is attributable to natural variation in climatic condition (the AMO) rather than anthropogenic sources. This attribution is based on the similarity in flow trend between the Peace River and Charlie and Horse Creeks, despite the fact that Charlie and Horse Creeks have not undergone anthropogenic landscape alteration to the extent of the Peace River.

2.12 Shell Creek and Prairie Creek Watersheds Management Plan – Reasonable Assurance Documentation (Shell, Prairie, and Joshua Creeks Watershed Management Plan Stakeholders Group 2004)

The Shell, Prairie, and Joshua creek watersheds account for 20 percent of the Peace River basin. Shell and Prairie creeks are designated Class I waterways, while Joshua Creek is a Class III waterway. Currently three of the eight waterbody identifications (WBIDs) that comprise the Shell and Prairie creek watersheds are classified as impaired. WBID #1962 in the Prairie Creek watershed is impaired for specific conductance and total dissolved solids (TDS). WBIDs #2040 and #2041 in the Shell Creek watershed are impaired for specific conductance, TDS, and chloride. The identified predominant source of these pollutants is mineralized groundwater withdrawn for agricultural use. The presence of these contaminants affects the ability of the City of Punta Gorda to meet secondary drinking water standards.

The goal of the reasonable assurance plan is to improve the water quality of the Praire and Shell creek waterbodies to meet Class I Standards at all times. The Joshua Creek watershed is included because of its proximity to Shell and Prairie creeks and due to identification of similar water quality issues.

A number of management activities, including but not limited to well back plugging, well construction and water use permitting, Facilitating Agricultural Resource Management Systems (FARMS) projects, land acquisition, and best management practices manuals will be utilized to reduce pollutant loads to the impaired waterbodies. The results of these management activities will be monitored by:

- Specific Conductance Reconnaissance Network (SWFWMD)
- In-Stream Data Sonde – Conductance Logging Network (SWFWMD and USGS)
- SPJC – Water Quality Monitoring Networks
- Pre- and Post- Back Plug Well Monitoring Network (SWFWMD)
- Surface Water Quality Monitoring Networks (SWFWMD and FDEP)
- Habitat Assessment and Stream Condition Index Monitoring (SWFWMD and FDEP)
- Coastal Ground Water Quality Monitoring Network (SWFWMD)
- Water Use Permitting Ground Water Quality Monitoring Network (SWFWMD)
- Shell Creek Hydrobiological Monitoring Program (City of Punta Gorda)

As the cause of impairment is a known point source of highly mineralized groundwater used for agricultural purpose, it is believed that no corrective action will be needed beyond controlling this point source. It is acknowledged that, due to the buildup of salts in the sediments, it may be some time before the full benefit of the corrective actions is recognized. While it is believed that a ten year time period will be sufficient, additional time may be necessary to achieve the Class I waterway standards.

2.13 Proposed Minimum Flows and Levels for the Middle Segment of the Peace River, from Zolfo Springs to Arcadia (Kelly *et al*. 2005)

This report was published as a draft in February 2005. The methods used in this MFL evaluation were significantly more sophisticated than those employed in the upper Peace River evaluation, largely following the recommendations of the MFL Scientific Peer Review Panel. The report was subsequently used to develop MFLs for the middle Peace River which were adopted by the District Governing Board.

The middle segment of the Peace River is defined as the stretch of the river from the USGS gage sites at Zolfo Springs and at Arcadia (approximately 35 km, not tidally influenced). The watershed of this segment of the Peace River is relatively unimpacted by mining activities and urban development compared to the upper Peace River. The intake for the Peace River/Manasota Regional Water Supply Authority potable water supply is located approximately twenty-five kilometers downstream from the Arcadia gage.

Building on the approach used for the upper Peace River segment, an analysis of historic versus current flow conditions was conducted to assess the extent withdrawals or other anthropogenic factors have affected flows. The District assessed for the first time the effects of climatic oscillations on regional river flows, and identified two benchmark periods for evaluating flows in the middle segment of the Peace River. Furthermore, they concluded that "…flow declines in the middle Peace River which have been ascribed to human causes by some investigators, are largely a function of climatic variation."

For development of the MFLs, the District identified three seasonal blocks corresponding to periods of low, medium and high flows. Short-term minimum flow compliance standards for the Zolfo Springs and Arcadia gage sites were developed for each of these seasonal periods using a "building block" approach recommended by the Panel. Prescribed flow reductions were based on limiting potential changes in aquatic and wetland habitat availability that may be associated with seasonal changes in flow. Low flow thresholds were based on fish passage depth and wetted perimeter inflection points, and were also incorporated into the short-term compliance standards. The low flow threshold was defined to be a flow that serves to limit withdrawals, with no withdrawals permitted unless the threshold is exceeded.

A prescribed flow reduction for the low flow period (Block 1, April 20 - June 24) was based on review of limiting factors developed using the Physical Habitat Simulation Model (PHABSIM) to model potential changes in habitat availability for several fish species and macroinvertebrate diversity. Simulated reductions in historic flows greater than 10 percent resulted in more than a 15 percent loss of available habitat as sites upstream from the Arcadia and the Zolfo Springs gages. Using this limiting factor, the prescribed flow reduction for both gage sites during the low flow period was defined as a 10 percent reduction in flow, with the exception that withdrawals should not be allowed to reduce the flow to less than 45 cfs at the Zolfo Springs site and 67 cfs at the Arcadia site.

For the high flow season of the year (Block 3, June 25 - October 27), prescribed flow reduction was based on review of limiting factors developed using the HEC-RAS floodplain model and frequency statistical analyses to evaluate percent of flow reductions associated with changes in the number of days of inundation of floodplain features. It was determined that a stepped flow reduction of 13 percent and 8 percent of historic flows, with the step occurring at the 25 percent exceedance flow (1,362 cfs) resulted in a decrease of 15 percent or more in the number of days that flows would inundate floodplain features at the Arcadia gage. A stepped flow reduction of 11 percent and 8 percent of historic flows, with the step occurring at the 25 percent exceedance flow (783 cfs) was established at the Zolfo Springs gage. Using these limiting factors, prescribed flow reductions consistent with the stepped flow reductions described above were established, with the exception that withdrawals should not be allowed to reduce the flow to less than 45 and 67 cfs at the Zolfo Springs and Arcadia gage sites, respectively.

For the medium flow period (Block 2, October 28 - April 19), both PHABSIM and HEC-RAS were utilized to evaluate prescribed flow reductions. PHABSIM was deemed to be the more conservative approach for both gages and was utilized to define the percent flow reduction. It was determined that more then 15 percent of historically available habitat would be lost for specific species life-stages if flows were reduced by more than 18 percent at Arcadia or more the

10 percent at Zolfo Springs during the medium flow period. Thus, prescribed flow reductions during the medium flow period were set at these levels, with the exception that withdrawals would not be allowed to reduce flow at the Zolfo Springs site below 45 cfs.

Because minimum flows are intended to protect the water resources or ecology of an area, and because climatic variation can influence river flow regimes, the District developed long-term compliance standards for the middle Peace River gage sites at Arcadia and Zolfo Springs. The standards are hydrologic statistics that represent flows that may be expected to occur during long-term periods when short term-compliance standards are being met. The long-term compliance standards were generated using gage-specific historic flow records and the short-term compliance standards. For the analyses, the entire flow record for each site was altered by the maximum allowable flow reductions in accordance with the prescribed flow reductions and the low flow threshold. Hydrologic statistics for the resulting altered flow data sets, including five and ten-year mean and median flows were determined and identified as long-term compliance standards. Because these long-term compliance standards were developed using the short-term compliance standards and the historic flow records, it may be expected that the long-term standards will be met if compliance with short-term standards is achieved.

Collectively, the short and long-term compliance standards proposed for the USGS gage sites at Zolfo Springs and Arcadia comprised the District's proposed minimum flows and levels for the middle segment of the Peace River. The standards are intended to prevent significant harm to the water resources or ecology of the river that may result from water use. The building block approach and resulting compliance standards encompass the full flow regime for this segment, and are substantially more comprehensive than the low flow threshold developed for the upper Peace River segment.

2.14 2004 HBMP Annual Data Report (PBS& J 2005)

This data report represents the fifteenth year of data collection for the Peace River/Manasota Regional Water Supply Authority (Authority), the owner/operator of the Peace River Regional Water Supply Facility. The report compares data collected during 2004 with similar average values for key parameters previously compiled during various elements of the ongoing long-term monitoring programs. In making comparisons of the 2004 data with averages of similar data collected over the preceding twenty-one year period, it should be noted that the very wet winter/spring El Niño of 1997/1998 was followed by very dry La Niña conditions that influenced the entire Peace River watershed between 1999 and mid-2002. A weaker El Niño occurred at the end of 2002, and freshwater flows during both 2003and 2004 were well above average.

- **Flows** – Overall, gaged Peace River at Arcadia freshwater inflows during 2004 were approximately one hundred and ninety-five percent the average daily flow for the preceding long-term period 1976-2003. The sum of average daily flows from the Peace River at Arcadia, Horse Creek, Joshua Creek, and Shell Creek during 2004 was roughly one hundred and eighty-two percent of the average daily flows for the period 1976-2003.

- **Withdrawals** – Overall withdrawals comprised 1.39 percent of the annual Arcadia gaged flow, and 0.87 percent of the combined lower Peace River gaged flow (Peace River at Arcadia, Horse Creek, Joshua Creek and Shell Creek). Facility withdrawals exceeded ten percent of the gaged Peace River at Arcadia flows approximately four and a half percent of the time. Such ascendances result from subsequent revisions by USGS of the provisional daily flow information available to the Authority at the time of actual withdrawals. During 2004, the facility did not withdraw any water approximately twenty percent of the time.

- **Temperature** – Median water temperatures during 2004 were slightly lower than corresponding values measured over the preceding twenty-one year period. Such results may reflect differences in cloud cover resulting from the overall wetter than usual conditions and three hurricanes that passed near (or over) the area. Measured water temperatures in the freshwater isohaline during the spring of 2004 were slightly higher than those observed at the other three monitored salinity zones, possibly reflecting the increased heating of the more highly colored water. The water temperatures measured during December 2004 were the warmest December values measured during the 1983-2004 period.

- **Water Color –** Color levels, as in 2003, were well above the long-term averages as a result of the higher than average freshwater inflows during much of 2004.

- **Extinction Coefficient –** The rates of measured light attenuation reflect both ambient color and phytoplankton biomass. Comparisons among the mean 2004 extinction values indicate that even though water color throughout the estuary was slightly higher than average during 2004, light extinction coefficients were below historical annual averages. It is possible that higher than average freshwater inflows resulted in higher than average water color, which in turn suppressed normal spring levels of phytoplankton production (chlorophyll *a*), resulting in lower than average measurements of extinction coefficients.

- **Nitrite/Nitrate Nitrogen** - During 2004, the average concentrations of this major inorganic form of nitrogen were slightly lower than the long-term historical annual averages. Monthly comparisons show unusual marked declines in the freshwater flows entering the estuary following the hurricanes in August and September. Typically, monthly comparisons indicate nitrite/nitrate inorganic nitrogen concentrations in the lower Peace River/upper Charlotte Harbor Estuary are characterized by a distinct spatial gradient. Concentrations typically decrease rapidly with increasing salinity, with inorganic nitrogen levels within the 20 o/oo isohaline being near method detection limits throughout much of the year. Normally, estuarine inorganic nitrogen concentrations usually decline to their lowest levels during the relatively drier, late spring as phytoplankton populations respond to increasing water temperatures and light, and increased primary production removes available inorganic nitrogen. However, the higher than normal freshwater flows during the spring of 2004 also resulted in differences in the characteristic annual patterns of inorganic nitrogen concentrations in the upper reaches of the estuary.

- **Ortho-phosphorus** - Estuarine inorganic phosphorus concentrations in the lower Peace River and upper Charlotte Harbor are heavily influenced by the unusually "very" high natural levels found in the Peace River watershed. As a result, the observed differences in concentrations among the four isohalines simply reflect conservative dilution by Gulf waters. Unlike inorganic nitrogen, seasonal observed changes in phosphorus concentrations in the estuary are for the most part unaffected by biological uptake. Since the late 1970s there has been marked historical declines in inorganic phosphorus levels in the lower Peace River/upper Charlotte Harbor estuarine system due to declines in the influences of phosphate mining in the upper reaches of the basin. Inorganic phosphorus concentrations entering the estuary system from the Peace River watershed are typically lower during wetter periods, when a higher proportion of flow results from surface flow (rather than coming from groundwater, which is naturally richer in phosphorus). However, average concentrations during 2004 were higher than the long-term averages. This was the result of unusually high phosphorus levels in the freshwater entering the estuary following Hurricanes Charley Frances and Jeanne.

- **Nitrogen to Phosphorus Atomic Ratios** – Calculated atomic inorganic nitrogen to phosphorus ratios for ambient measured concentrations in 2004, as indicated by the long-term averages, show nitrogen to always be the limiting macronutrient at each of four isohalines sampled.

- **Silica** – Measured concentrations of dissolved reactive silica in the lower Peace River/upper Charlotte Harbor estuarine system during 2004 reflected a continuation of the previously noted increasing pattern of higher values. Comparisons of long-term annual average silica concentrations indicated that 2004 levels were approximately double the long-term historic levels.

- **Chlorophyll *a*** – The seasonal patterns of freshwater inflows during 2004 were influenced by both much wetter than average conditions during the typically very dry early spring, and a wetter than average late summer wet-season. The resulting seasonal flow patterns combined to produce both higher than average inputs of inorganic nutrients, as well as higher than average levels of water color (resulting in greater light attenuation). Overall, phytoplankton production (chlorophyll *a*) levels in the lower Peace River/upper Charlotte Harbor Estuary were slightly above the long-term (1983-2003) averages within each of the four salinity zones. Phytoplankton blooms within both the 6 and 12 o/oo isohalines occurred periodically during 2004.

The analyses presented in this document do not indicate any substantial changes, or atypical events in either the physical or biological data collected during 2004, other than those previously noted. These include:

- A series of somewhat unusual periods of increased freshwater inflow during the typically dry early spring.

- High late summer/fall freshwater inflows following the rainfall events associated with Hurricane Charlie in August and Frances, Ivan and Jeanne in September.
- A continuation of the previously noted long-term increase in reactive silica concentrations in the lower Peace River.

- Marked increases in inorganic phosphorus concentrations in the freshwater entering the estuary following the hurricanes.

These "limited" analyses also do not suggest that there have been any long-term changes resulting from either current or historic water withdrawals by the Peace River Regional Water Supply Facility.

2.15 Impact of Phosphate Mining on Streamflow (Schreuder *et al*. 2006)

This study combined analyses of both double-mass rainfall/flow plots and best-fit trend lines to assess the potential impacts of phosphate mining on stream flow. Double-mass rainfall/flow plots were developed for the Peace River and its tributaries: Bowlegs, Charlie, Joshua, Payne and Horse creeks, as well as the South Prong of the Alafia River, the Alafia at Lithia, the Little Manatee River at Wimauma, the Manatee River at Myakka Head, the Myakka River near Sarasota, and the Withlacoochee River at Holder. Annual low flow (P10), median flow (P50) and high flow (P90) exceedance values for each of these systems were plotted against cumulative annual rainfall. The conclusions of the study based on these analyses indicated:

- Approximately 70 percent of the Payne Creek basin has been impacted by phosphate mining. However, results indicated that total stream flow from the Payne Creek basin was higher than from the similarly sized Joshua Creek basin.

- Overall, standardized (flow per unit area) mean stream flow was found to be consistently higher from basins in the Alafia River and Peace River watersheds where phosphate mining is a dominant land use.

- In the Southern Water Use Caution Area (SWUCA), agricultural irrigation pumpage from the Floridan aquifer has caused a significant decline in the potentiometric surface of the Floridan aquifer. This decline represents the transfer of large volumes of ground water from the deeper Floridan aquifer to the shallow surficial aquifer that is in direct contact with surface water streams.

- As a result, mean stream flow was found to be higher in the coastal river basins than either the Alafia or the Peace River watersheds.

- Stream flows from Payne Creek were found to significantly increase the unit mean flow in the Peace River from 0.40 cfs/m at the Ft. Meade gaging station to 0.58 cfs/m at the Zolfo Springs gage. The study concluded that this demonstrates that additional surface water flow from tributary basins, where pumpage from the underlying confined aquifer system(s) or salvage of evapotranspiration losses is taking place, augments the surface water flow in the Peace River.

- Polynomial trendlines of the double-mass plots of area standardized mean stream flow versus rainfall for the 20 year period from 1980 through 2000 indicate increased stream flow in the studied streams, with the exceptions of upper Horse Creek, Bowlegs Creek and the Withlacoochee River.

- The results of the double-mass analyses indicated that stream flows from predominantly mined/reclaimed areas have not been declining, but during the 1980-2000 period have been increasing at rates greater than unmined areas with irrigated agricultural land uses..
- There was a distinctly different distribution of stream flows between the mined (reclaimed) basins and other basins. The analyses indicated mined areas tend to retain flood flows (P90) for later release as median (Q50) and base flows (P10).

- The magnitude and seasonal distribution of stream flow were observed to be similar among the mined basins, but distinctly different from unmined agriculture-dominated basins. Gains in streamflow resulting from phosphate mining were related to reduced evapotranspiration (ET) losses associated with vegetation changes on reclaimed land compared to more mature pre-mining vegetation. In agriculture-dominated basins, gains in stream flow were due to ground water pumpage from the underlying confined aquifer and subsequent discharges to surface waters.

2.16 2005 HBMP Annual Data Report (PBS&J 2006)

This data report represents the sixteenth year of data collection for the Peace River/Manasota Regional Water Supply Authority (Authority), the owner/operator of the Peace River Regional Water Supply Facility and the tenth Annual Data Report submitted under the expanded Hydrobiological Monitoring Program (HBMP) initiated in 1996.

The report summarizes and compares data collected during 2005 with similar HBMP information previously compiled during various elements of the ongoing long-term monitoring programs. In making comparisons of the 2005 data with averages of similar data collected over the preceding twenty-two year period (1983-2004), it should be noted that the very wet winter/spring El Niño of 1997/1998 was followed by very dry La Niña conditions that influenced southwest Florida and the entire Peace River watershed between 1999 and mid-2002. A weaker El Niño occurred at the end of 2002, and freshwater flows during 2003, 2004 and 2005 were generally above average.

- **Flows** – Overall, gaged Peace River at Arcadia freshwater mean flows during 2005 were approximately two hundred and two percent the average daily flow for the preceding long-term period 1976-2004. The sum of average daily flows from the Peace River at Arcadia, Horse Creek, Joshua Creek, and Shell Creek during 2005 was roughly one hundred and eighty-seven percent of the average daily flows for the period 1976-2004.

- **Withdrawals** – Overall withdrawals comprised 1.01 percent of the annual Arcadia gaged flow, and 0.64 percent of the combined lower Peace River gaged flow (Peace River at Arcadia, Horse Creek, Joshua Creek and Shell Creek). Facility withdrawals during 2005 never exceeded ten percent of the gaged Peace River at Arcadia flows. During 2005, the facility did not withdraw any water approximately nine percent of the time.

- **Temperature** – Median water temperatures at each of the three higher salinity isohalines were slightly greater than corresponding values measured over the preceding twenty-two year period. The warm water temperatures in the freshwater isohaline during the spring of 2005 were slightly higher than those observed at the other three salinity zones, possibly reflecting the increased heating of the more highly colored water. Water temperatures measured in January and December 2005 were much warmer than usual.

- **Water Color –** Color levels in 2005 were well above the long-term averages as a result of the higher than average freshwater inflows. The peak very high color levels typically observed during the summer wet-season within the freshwater isohaline was not observed during 2005. This may reflect the higher than usual flows during both the winter and spring of 2005 and that the washout of tannins from uplands and wetlands were distributed over a much longer period.

- **Extinction Coefficient –** The rates of measured light attenuation reflect both ambient color and phytoplankton biomass. Comparisons among the mean 2005 extinction values indicate that even though water color throughout the estuary was higher than average during 2005 due to greater than average freshwater inflows, light extinction coefficients were below historical annual averages. It is possible that in 2003 - 2005 higher than average inflows resulted in higher than average water color, which in turn suppressed normal spring levels of phytoplankton production, yielding lower than average extinction coefficients.

- **Nitrite/Nitrate Nitrogen** - During 2005, average concentrations of this major inorganic form of nitrogen were lower in the upper freshwater reach of the estuary than the long-term, historical annual average and higher at the three higher salinity isohalines. This is unlike the typical spatial gradient where concentrations decrease rapidly with increasing salinity, with inorganic nitrogen levels within the 20 o/oo isohaline often being near method detection limits. Normally, estuarine inorganic nitrogen concentrations usually decline to their lowest levels during the relatively drier, late spring as phytoplankton populations increase. However, the higher than normal freshwater flows during winter and spring of 2005 resulted in differences in the characteristic annual patterns of inorganic nitrogen concentrations in the estuary.

- **Ortho-phosphorus** - Estuarine inorganic phosphorus concentrations are heavily influenced by the unusually “very” high natural levels found in the Peace River watershed. As a result, the observed differences in concentrations among isohalines simply reflect conservative dilution by Gulf waters. Seasonal observed changes in phosphorus concentrations in the estuary are for the most part unaffected by biological uptake. Inorganic phosphorus concentrations entering the estuary system from the Peace River watershed are typically lower during wetter periods, when a higher proportion of flow results from surface flow (rather than coming from groundwater, which is naturally richer in phosphorus). Average inorganic phosphorus concentrations during 2005 were higher than the long-term averages, reflecting the overall results of higher than average freshwater inflows.

- **Nitrogen to Phosphorus Atomic Ratios –** Calculated atomic inorganic nitrogen to phosphorus ratios for ambient measured concentrations in 2005, as indicated by the long-term averages, show nitrogen to always be the limiting macronutrient at each of the four isohalines.

- **Silica –** Although the observed seasonal peaks of dissolved reactive silica in the lower Peace River/upper Charlotte Harbor estuarine system during 2005 were below those observed in 2003 and 2004, overall concentrations reflected a continuation of the previously noted increasing pattern of higher values at all four isohalines.

- **Chlorophyll *a* –** The seasonal patterns of freshwater inflows to the estuary during 2005 reflect both much wetter than average conditions during the typically dry winter/spring and wetter than average conditions both during the early and late summer wet-season. The resulting seasonal flow patterns combined to produce both higher than average inputs of inorganic nutrients, as well as higher than average levels of water color (resulting in greater light attenuation). Overall, phytoplankton production (chlorophyll *a*) levels in the lower Peace River/upper Charlotte Harbor Estuary were above the long-term averages within each of the four salinity zones. As in previous years, phytoplankton blooms were more common within the intermediate (6 and 12 o/oo) isohalines. Somewhat surprisingly, the highest chlorophyll level ever recorded by any of the HBMP monitoring programs occurred during October 2005 at the 12 o/oo isohaline. The actual recorded value was based on a calculation using a very high dilution and therefore represents only a relative estimate. However, this isolated unusual estimated level was nearly double the previous highest measurement.

The graphical and summary analyses presented in this document do not indicate any substantial changes, or atypical events in either the physical or biological data collected during 2005, other than those previously noted. These include:

- Freshwater inflows during 2005 were characterized by much wetter than normal flows during the winter (January and February), unusually high flows during the typical spring dry-season (especially during March and May), much higher than normal flow through the first part of the summer wet-season (June, July and August), and seasonally very high flows from the end of October through mid-November.

- A continuation of the previously noted long-term increase in reactive silica concentrations in the lower Peace River.

- Some indications that inorganic phosphorus concentrations in the freshwater entering the estuary has increased slightly in recent years, following decades of major declines that began in the late 1970s.

The "limited" analyses presented in the annual data report do not suggest that there have been any long-term changes resulting from either current or historic water withdrawals by the Peace River Regional Water Supply Facility. To date, none of the conducted HBMP data analyses have shown that facility withdrawals have had, or are expected to cause, measurable negative physical or biological adverse impacts within the lower Peace River estuarine system.

2.17 Assessment of Potential Shell Creek Impacts Resulting from Changes in City of Punta Gorda Facility Withdrawals (PBSJ 2006)

The Authority and the City of Punta Gorda (City) submitted a conjunctive water use permit application to the Southwest Florida Water Management District, including a request to increase the permitted maximum monthly Shell Creek Reservoir water withdrawals from 8 to 10 million gallons per day (mgd) to accommodate a projected “gap” between water supply demands and permitted withdrawals. This document was prepared to provide data and analyses requested by the District in order to evaluate whether the biological communities of the Shell Creek/lower Peace River estuarine system might be adversely impacted as a result of the proposed increased permitted freshwater withdrawals.

Data sources for the report included seasonal and long-term water quality data from the Shell Creek Hydrobiological Monitoring Program (HBMP) which began in 1991. Additionally, information from a number of other sources was utilized including USGS flow data, rainfall data from the District and water quality data from the USGS and City monitoring programs.
A number of technical analyses and summaries of existing available information were undertaken in conjunction with evaluating potential impacts of the proposed “Gap” increase in withdrawals from the Shell Creek Reservoir.

Characterization of Historical Shell Creek Flow Regime

Daily USGS flow data for the period 1966-2004 were used to develop a comprehensive overview of both annual and seasonal variability in Shell Creek freshwater flows.
Graphical analyses indicated freshwater flows over the Hendrickson Dam (Dam) vary seasonally and annually. Flows during the drier and cooler historic AMO period (1966-1994) were lower when compared with a wetter and warmer recent AMO period (1995-2004). Higher flows occurred primarily in wet-season months.

Results of the USGS Seasonal Kendall Tau analysis were consistent with other studies, indicating that long-term increases in base flows in Shell Creek during winter/spring flows are a result of agricultural groundwater augmentation. However, analyses of variance (ANOVA) results indicated no significant differences in flows between the previously described AMO periods.

Influences of Withdrawals on Flow Characteristics

The greatest changes in flows were predicted during the lowest monthly flows, and changes decreased in magnitude as flows increased. Differences between the current maximum capacity and alternative withdrawals indicate that the proposed “Gap” permit increase from 8 to 10 mgd would result in relatively small changes in the range, minimum, maximum, and other statistics associated with flows. While changes in flows due to withdrawals are most conspicuous during the spring dry season, withdrawals could potentially reduce flows significantly on a percentage basis during any month as a result of the wide seasonal variability.

Influences of Flow on Salinity, Dissolved Oxygen, and Chlorophyll *a*

Under no-flow conditions, surface salinities near the dam can reach nearly 15 psu. As flows increase, salinities can decrease to zero, although the effect of flow on salinity decreases downstream. Variability increases in the salinity flow relationship moving downstream as a result of the combined effects of tidal volume and Peace River flows. Unusually high tides or extended periods of southerly winds may move higher salinity water upstream increasing salinities beyond those predicted using typical salinity/flow relationships.

Bottom Dissolved Oxygen (DO) values are generally lower than surface values, although differences become less distinct under very high flows. DO levels at the dam are low at low flows, but differences are less apparent downstream. A pattern of declining DO values with high flows occurs during the summer, and may be related to higher water temperatures.

Data analyses indicate that chlorophyll *a* levels decline with decreasing flows. This is probably due to the combined influences of increases in water color and a decrease in residence time.

Analyses were performed to evaluate spatial and temporal differences in salinity, DO and chlorophyll *a* along the Shell Creek monitoring transect. Results indicate spatial gradients in surface and bottom salinity levels, but not DO or chlorophyll *a*. Temporal differences are apparent from salinity data in the tidal portion of Shell Creek.

Potential Influences of Facility Freshwater Withdrawals on Salinity

Modeling and analyses indicated that potential increases in surface and bottom salinities along Shell Creek due to a proposed increase in withdrawals from 8 to 10 mgd would be very small when compared to both the short and longer term seasonal variations occurring naturally in this reach of the creek.

Comparisons of Flows with and without Proposed Withdrawals

Log-Pearson Type III distributions were utilized to assess potential changes in flow-duration and lowest mean-discharges for various consecutive-day periods. The results of these analyses indicated only small differences between the current maximum 8 mgd withdrawal and the proposed “Gap” increase to 10 mgd.

Characterization of Major Freshwater Ions

Relevant long-term monitoring data from a number of sources were utilized to characterize trends in water quality characteristics and major ion constituents of Shell and Prairie creeks, as well as within the City of Punta Gorda’s reservoir. While most of the analyses indicate no significant trends in water quality, some changes were likely associated with increases in groundwater use and “tail water” agricultural discharges to natural surface waters. For example, there has been an increase in chloride levels over time at both Prairie Creek and Shell Creek sites. Data for a Prairie Creek site indicate increases in specific conductance, hardness, total dissolved solids, and chlorides. Shell Creek Reservoir data indicate increases in specific conductance, hardness, chloride, sulfate and silica levels over time. Increases in surface DO levels also suggest that the reservoir may be more eutrophic due to increased agricultural development in the upstream watersheds.

Within the reservoir, concentrations of most parameters, including specific conductance, hardness, DO, pH, total dissolved solids, total Kjeldahl nitrogen, total phosphorus, ortho-phosphorus, total organic carbon, and alkalinity increased with increasing flows, while color, sulfate, and chloride decreased.

Riparian Vegetation

The spatial distribution of riparian vegetation along estuarine Shell Creek below the Dam was evaluated and compared with previous GIS vegetation information developed by Florida Marine Research Institute (FMRI) for the District from field verified 1994 aerials. Vegetation along the creek transitions downstream from a larger mix of low-salinity and freshwater species, to fewer species tolerant of a larger range in salinities, to species such as mangroves and needle rush, which are tolerant of salinities much greater than that of sea water.
Within a given salinity regime, other factors become more important in affecting marsh species distributions. For example, under freshwater conditions, species competition influences distributions. Under higher salinity conditions, elevation becomes more important, as does proximity to wave energy.

Mapping data from 1994 (FMRI 1998) and this 2006 “Gap” report indicate a spatial shift to a larger number of freshwater species, specifically giant cutgrass, upstream of the Myrtle Slough confluence. In addition, the distribution of at least one species, bulrush, appears to have increased along the river channel since 1994. Salinity data indicate lower salinities during 2002 – 2004, compared with 1991 – 2001, and changes in salinity could cause a slow shift to larger numbers of more typically freshwater species. Bulrushes are tolerant of a wide range of salinities and may easily expand into gaps where other species are absent.

However, the resolution of the digital orthophoto quadrangle (DOQQs) used may limit the ability to make this comparison and, as noted by the authors of the FMRI report, better resolution photographs would have been helpful in making more accurate observations. Finally, although not addressed in this study, the impact of recent hurricanes cannot be disregarded when considering possible spatial and temporal changes in vegetation along Shell Creek.

Evaluation of Information of Flow Influences on Biological Community Structure

Biological information gathered as part of the Peace River HBMP and the District minimum flow studies were evaluated and summarized in order to provide a general overview of the relationships between historical seasonal and long-term variations in Shell Creek flow and the structure and composition of biological communities in the Shell Creek/lower Peace River estuarine system. The information, graphics and conclusions contained in previous studies conducted for the District were reviewed and summarized as part of this report with regard to evaluating the salinity tolerances of key groups of estuarine species and assessing potential responses to predicted levels of salinity increase potentially resulting from proposed “Gap” withdrawals.

2.18 Peace River Cumulative Impact Study (PBSJ 2007)

Changes in both land and water uses in the Peace River watershed have cumulatively impacted both the hydrology and ecology of the watershed. In recognition of these impacts, the Florida Legislature enacted Senate Bill 18-E during the 2003 legislative session. The bill directed the Florida Department of Environmental Protection to conduct a Cumulative Impact Study (CIS) and prepare a Resource Management Plan for the Peace River watershed. The purpose of this study was to conduct an objective assessment of the individual and cumulative impacts of certain anthropogenic and natural stressors in the Peace River watershed with respect to historical changes in stream flow, ambient water quality, and various ecological indicators.

The Resource Management Plan prepared by FDEP will identify regulatory and non-regulatory means to minimize future impacts and mitigate past impacts to the Peace River watershed. In support of the Resource Management Plan, the primary goal and specific task of the CIS was to document and evaluate the historic hydrologic and land use changes in the Peace River watershed. The CIS objectives presented below were established to evaluate the potential cumulative impacts of the observed changes on the natural resources of the watershed and downstream estuarine system.

- Assess historical changes in the watershed with respect to the following indicators:

    1. Acres of wetlands lost
    2. Acres of native upland habitats lost
    3. Miles of streambed lost
    4. Changes in rainfall
    5. Changes in stream flows
    6. Changes in ground water elevations
    7. Changes in the concentrations of indicator water quality constituents
    8. Changes in the abundance, distribution, and diversity of indicator fish communities.

- Discern, and quantify where possible, the relative and absolute contribution of each of the four stressors to documented historical changes in each of the nine major basins in the Peace River watershed.

- Develop a scientific foundation for the subsequent preparation and adoption of a Resource Management Plan for the Peace River watershed.

A variety of analytical techniques were used to determine and quantify, where feasible, the relative cause and effect relationships between the primary stressors and key indicators. Temporal changes in land uses and cover types associated with the anthropogenic stressors were directly assessed and quantified using various GIS spatial analytical methods. Temporal changes in hydrology attributable to the anthropogenic stressors and recent climate variability were assessed and quantified where possible using appropriate multivariate statistical procedures and modeling techniques.

A historical timeline of policy and regulatory programs implemented in the Peace River watershed from the benchmark period to the present was prepared. An attempt was made to relate historical changes in state and water management district policy and regulatory programs with documented temporal changes in key watershed indicators. From this analysis, inferences were developed regarding the effectiveness of current policy and regulatory programs. In addition, proposed changes to current regulatory and management programs were developed to reduce or reverse documented cumulative impacts.

The goal of the CIS report was to summarize the major findings of the study in a manner that provides a comprehensive overview to a wide audience. The general findings and conclusions presented in the report were then supported through a series of technical appendices constructed around specific project tasks.

2.19 2006 HBMP Annual Data Report (PBS&J 2007)

This document represents the eleventh Annual Data Report submitted under the expanded Hydrobiological Monitoring Program (HBMP) initiated in 1996. The report compares data collected during 2006 with similar average values for key parameters previously compiled during various elements of the ongoing long-term monitoring programs. In making comparisons of the 2006 data with averages of similar data collected over the preceding twenty-three year period (1983-2005), it should be noted that the very wet winter/spring El Niño of 1997/1998 was followed by very dry La Niña conditions that influenced southwest Florida and the entire Peace River watershed between 1999 and early 2002. A weaker El Niño occurred at the end of 2002, and freshwater flows during 2003, 2004 and 2005 were generally above average. Rainfall in the Peace River watershed during 2006 by comparison was well below average, especially during the usually wet summer months. The summer 2006 wet-season was often characterized by afternoon summer thunder storms building along the coast rather than inland, and few tropical storms in comparison to the recent preceding years.

- **Flows** – Overall, gaged Peace River at Arcadia freshwater mean flow (376 cfs) during 2006 was approximately forty percent of the average daily flow for the preceding long-term period 1976-2005. In comparison, the sum of average daily flows from the Peace River at Arcadia, Horse Creek, Joshua Creek, and Shell Creek during 2006 was roughly fifty-one percent of the average daily flows over the longer term 1976-2005 HBMP monitoring period.

- **Withdrawals** – Combined total freshwater withdrawals by the Peace River and the City of Punta Gorda facilities accounted for approximately 3.2 percent of total freshwater flows to the estuary. In comparison with previous years, there were a number of days during 2006 when Peace River Facility withdrawals exceeded ten percent of the gaged Peace River at Arcadia flows. Such exceedances of the permitted ten percent withdrawals result from subsequent revisions by USGS of the provisional daily flow information available to the Authority at the time of actual withdrawals. During 2006, the facility did not withdraw any water from the river approximately thirty-two percent of the time.

- **Salinity Spatial Distribution** – The influences of the much drier than usual conditions that characterized 2006 were reflected in the seasonal and average spatial distributions of each of four sampled, moving isohalines along the HBMP monitoring transect. Overall, the relative spatial distributions of each of the isohalines during 2006 reflected upstream movements of 4-7 kilometers when compared with their previous long-term 1983-2005 averages.

- **Temperature** – Mean water temperatures during 2006 at each of the salinity isohalines were similar to one another, as well as to corresponding values measured over the preceding twenty-thee year period (1983-2005). It should, however, be noted that the water temperatures measured during both January and December 2006 were, as during the previous three years (2003-2005), much warmer than usual in comparison to values measured over the longer term period-of-record.

- **Water Color** – Color levels in 2006 were below long-term averages as a result of the lower than average freshwater inflows. Somewhat surprisingly was the very high peak in color level observed within the most upstream freshwater isohaline toward the end of the summer wet-season in September 2006 following tropical storm Ernesto. This unusually high peak in color level may have reflected higher flows following the storm event washing-out tannins and humic compounds from uplands and wetlands that had accumulated over the much drier than usual summer period.

- **Extinction Coefficient** – Comparisons among the mean 2006 extinction values indicate that lower than average freshwater inflows resulted in diminished water color throughout the estuary during most of 2006. This combined with fairly typical chlorophyll *a* phytoplankton biomass levels resulted in light extinction coefficients being well below long-term historical annual averages. As with color, light extinction coefficients seasonally peaked during September-October as a result of the high flows following tropical storm Ernesto.

- **Nitrite/Nitrate Nitrogen** - During 2006, average concentrations of this major inorganic form of nitrogen were much lower when compared with the long-term, historical annual averages. Monthly comparisons among the isohalines indicate concentrations typically decrease rapidly with increasing salinity, with inorganic nitrogen levels within the 20 psu isohaline often being near or at method detection limits over much of the year. Normally, estuarine inorganic nitrogen concentrations decline to their lowest levels during the relatively drier spring as phytoplankton populations respond to increasing water temperatures and light, and increased primary production removes available inorganic nitrogen. However, during 2006 there was a marked decline to near detection limits of inorganic nitrogen in the most upstream freshwater isohaline during March. This somewhat unusual event was associated with a corresponding early peak in phytoplankton chlorophyll *a* biomass upstream of the freshwater/saltwater interface.

- **Ortho-phosphorus** - Estuarine inorganic phosphorus concentrations in the lower Peace River and upper Charlotte Harbor are heavily influenced by the characteristically “very” high natural levels found in the Peace River watershed. As a result, the observed difference in concentrations among the four isohalines primarily reflects conservative dilution by Gulf waters. Seasonal observed changes in phosphorus concentrations in the estuary are for the most part unaffected by biological uptake. Inorganic phosphorus concentrations entering the estuary system from the Peace River watershed are typically lower during wetter periods, when a higher proportion of flow results from surface flow (rather than coming from groundwater, which is naturally richer in phosphorus). Historically, since the late 1970s, there had been marked declines in inorganic phosphorus levels in the lower Peace River/upper Charlotte Harbor estuarine system due to declines in the combined influences of phosphate mining and processing in the upper reaches of the basin. However, following Hurricane Charley and the subsequent influences of Hurricanes Francis and Jean during the late summer of 2004, inorganic phosphorus concentrations have dramatically increased throughout the lower Peace River/upper Charlotte Harbor estuarine system. Ortho-phosphorus concentrations during 2006 were well above both historic and recent levels. Currently, the direct cause for these increased levels remains unclear.

- **Nitrogen to Phosphorus Atomic Ratios** – Calculated atomic inorganic nitrogen to phosphorus ratios for ambient measured concentrations in 2006, as indicated by the long-term averages, show nitrogen to always be the limiting macronutrient at each of the four isohalines.

- **Silica** – Seasonally, silica levels in the lower Peace River/upper Charlotte Harbor estuarine system typically peak following periods of high freshwater inflows. Although silica levels also seem to be positively correlated with higher water temperatures (possibly reflecting recycling from riverine/estuarine sediments), historically lower silica concentrations in higher salinity zones of the estuary have often occurred during corresponding periods of combined low spring freshwater inflow and spring increases in phytoplankton diatom numbers. Between 1983 and the late 1990s these seasonal patterns of increasing and decreasing reactive silica concentrations remained relatively stable with no indications of any consistent systematic changes over time. However, as discussed in previous HBMP reports, silica levels started showing increasing concentrations during the late 1990s. Then, as flows declined during the 1999-2002 extended drought, silica levels also declined. However, following the return of higher than average flows during 2003-2005 measured silica levels in the estuary again began rapidly increasing. Even though flows during 2006 were below normal, silica levels throughout the lower river/upper harbor estuary reached historically high levels during the summer wet-season. The immediate cause of these fairly recent increases is unknown. However, studies in other areas have found that increases in dissolved silica concentrations have been associated with land use changes and clearing of natural vegetation. In many of these systems, changes in silica concentrations have also been found to be associated with changes in both calcium and magnesium levels.

- **Chlorophyll *a*** – The seasonal patterns of freshwater inflows to the estuary during 2006 were characterized by much drier than average conditions. Seasonally, there was an unusually high peak in flow during February, and then conditions were unusually dry until the much higher peak in flows during September following tropical storm Ernesto.

> Such periods of high seasonal flows combine to produce both higher than average inputs of limiting inorganic nutrients (nitrogen), as well as higher than average levels of water color (resulting in greater light attenuation). The early high flows in February were followed in March by a spike in chlorophyll *a* levels in the upper freshwater reach of the estuary, while the high flows in the late summer were followed by increases in phytoplankton biomass in November in the 6 psu zone, and then in the downstream 12 psu in December. Overall, phytoplankton production (chlorophyll *a*) levels in the lower Peace River/upper Charlotte Estuary were similar to the long-term (1983-2005) averages within the three higher salinity zones. The relatively low flows and reduced water color during 2006 resulted in chlorophyll *a* levels in the upper freshwater reach of the estuary being higher than the corresponding long-term average. As in previous years, phytoplankton levels were generally higher within the intermediate (6 and 12 psu) isohalines, reflecting a balance between stimulation due to increased nitrogen inputs, and light inhibition resulting from higher water color.

The graphical and summary analyses presented in this document do not indicate any substantial changes, or atypical events in either the physical or biological data collected during 2006, other than those previously noted. These include:

- Freshwater inflows during 2006 were characterized by a much drier than normal flows, especially during the normal summer wet-season.

- There has been a continuation of the previously noted long-term increase in reactive silica concentrations in the lower Peace River.

- There are strong indications that inorganic phosphorus concentrations in the freshwater entering the estuary has increased in recent years, following decades of major declines that began in the late 1970s.

The “limited” analyses presented in the Annual Data Report do not suggest that there have been any long-term changes resulting from either current or historic water withdrawals by the Peace River Regional Water Supply Facility.

3.0 Summary from the *2011 HBMP Comprehensive Summary Report*

The following series of documents and reports were summarized in the *2011 HBMP Comprehensive Summary Report*.

- *Distribution and Fluctuations in the Fish Fauna of the Charlotte Harbor Estuary, Florida*. (Wang and Raney, 1971)
- *Enrichment of a subtropical estuary with nitrogen, phosphorus and silica. In: Estuaries and Nutrients*. (Fraser and Wilcox, 1981)
- *The Lower Peace River and Horse Creek: Flow and Water Quality Characteristics, 1976-1986*. (Fraser, 1991)

- *Abundance, seasonality, community indices, trends and relationships with physic chemical factors of trawled fish in upper Charlotte Harbor, Florida*. (Fraser, 1997)
- *The Atlantic multidecadal oscillation and its relation to rainfall and river flows in the continental U.S.* (Enfield et al, 2001)
- *Late Holocene Sea Level Rise in Southwest Florida: Implications for Estuarine Management and Coastal Evolution.* (Saverese et al., 2002)
- *Sedimentary Evidence of Coastal Response to Holocene Sea-Level Change, Blackwater Bay, Southwest Florida.* (Lowery, 2002)
- *The Influence of Sea Level Rise on the History of Estuarine Environments in Southwest Florida.* (Obley, 2002)
- *The Effects of Season and Proximity to Fringing Mangroves on Seagrass-Associated Fish Communities in Charlotte Harbor*. (Poulakis et al., 2003)
- *Fishes of the Charlotte Harbor Estuarine System, Florida*. (Poulakis et al., 2004)
- *Assessment of relationships between freshwater inflow and populations of fish and selected macroinvertebrates in the peace river and shell creek, Florida*. (Greenwood, et al., 2004)
- *Water Quality Assessment Report: Charlotte Harbor*. (FDEP, 2005)
- *Seasonal Variation in Fish Assemblages within the Estuarine Portions of the Myakka and Peace Rivers, Southwest Florida*. (Idelberger and Greenwood, 2005)
- *Feeding Habitats of Common Snook, Centropomus undecimalis¸in Charlotte Harbor, Florida.* (Blewett et al., 2005)
- *Proposed Minimum Flows and Levels for the Middle Segment of the Peace River, from Zolfo Springs to Arcadia*. (SWFWMD, 2005)
- *A Review of "Proposed Minimum Flows and Levels for the Middle Segment of the Peace River, from Zolfo Springs to Arcadia"*. (Shaw et al 2005)
- *Development of a Fluorescence Method to Detect Optical Brighteners in the Presence of Varying Concentrations of Fluorescent Humic Substances: Identifying Regions Influenced by OSTDS in the Estuarine Waters of Charlotte Harbor.* (Dixon et al, 2005)
- *Effects of Hurricane Charley on Smalltooth Sawfish (Pristis pectinata) nursery habitats in Charlotte Harbor, Florida.* (Simpfendorfer et al., 2005)
- *Dissolved Oxygen Dynamics in Charlotte Harbor and Its Contributing Watershed, in Response to Hurricanes Charley, Frances, and Jeanne – Impacts and Recover.* (Tomasko et al., 2006)
- *A Multivariate Statistical Analysis of Relationships between Freshwater Inflows and Mollusk Distributions in Tidal Rivers in Southwest Florida.* (Montagna, 2006)
- *Red Mangrove (Rhizophora mangle) Reproduction and Seedling Colonization after Hurricane Charley: Comparisons of Charlotte Harbor and Tampa Bay.* (Proffitt et al., 2006)

- *Anthropogenic effects on the Smalltooth Sawfish (Pristis pectinata) in the United States.* (Seitz and Poulakis, 2006)
- *Short-term Effects of a Low Dissolved Oxygen Event on Estuarine Fish Assemblages Following the Passage of Hurricane Charley.* (Stevens et al., 2006)
- *Development of Water Quality Targets for Charlotte Harbor, Florida Using Seagrass Light Requirements.* (Corbett and Hale, 2006)
- *Southern Water Use Caution Area Recovery Strategy*. (SWFWMD 2006)
- *Colored Dissolved Organic Matter (CDOM) Workshop Summary.* (Corbett, 2007)
- *Variable Habitat Use by Juvenile Common Snook, Centropomus undecimalis (Pisces: Centropomidae): Applying a Life-History Model in a Southwest Florida Estuary.* (Stevens et al., 2007)
- *Habitat Use by Juvenile Gag, Mycteroperca microlepis (Pisces: Serranidae), in Subtropical Charlotte Harbor, Florida (USA).* (Casey et al., 2007)
- *Recruitment and Essential Habitat of Juvenile Sand Seatrout (Cynoscion arenarius) in Four Estuaries along the West Coast of Florida.* (Purtlebaugh and Rogers, 2007)
- *Long-term increase in Karenia brevis abundance along the Southwest Florida Coast.* (Brand and Compton, 2007)
- *National Estuary Program Coastal Condition Report, Chapter 5: Gulf of Mexico National Estuary Program Coastal Condition, Charlotte Harbor National Estuary Program.* (June, 2007)
- *Relative Abundance and Distribution of Sand Seatrout (Cynoscion arenarius) in Relation to Environmental Conditions, Habitat, and River Discharge in Two Florida Estuaries.* (Knapp and Purtlebaugh, 2008)
- *Scientific Peer Review of the Proposed Minimum Flows and Levels for the Lower Peace River and Shell Creek.* (Montagna et al 2008)
- *Comparison of Fish Community Metrics to Assess Long-term Changes and Hurricane Impacts at Peace River, Florida.* (Champeau et al., 2009)
- *Use of Rivers by Common Snook Centropomus undecimalis in Southwest Florida: A First Step in Addressing the Overwintering Paradigm.* (Blewett et al., 2009).
- *Trends and explanatory variables for the major phytoplankton groups of two southwestern Florida estuaries, U.S.A.* (Dixon et al, 2009)
- *Hydrodynamic and Water Quality Modeling Report for Peace River and Charlotte Harbor, Florida.* (USEPA, 2009)
- *The Effects of Climate Change on Florida's Ocean and Coastal Resources. A special report to the Florida Energy and Climate Commission and the people of Florida.* (Florida Oceans and Coastal Council, 2009)
- *City of Punta Gorda Adaptation Plan.* (SWFRPC and CHNEP, 2009)
- *Hydrologic Conditions that Influence Streamflow Losses in a Karst Region of the Upper Peace River, Polk County, Florida* (Metz and Lewelling, 2009)

- *Modeling water quality and hypoxia dynamics in Upper Charlotte Harbor, Florida, U.S.A. during 2000.* (Kim et al, 2010)
- *City of Punta Gorda Shell Creek HBMP Year Five Comprehensive Summary Report.* (PBS&J 2010)
- *Proposed Minimum Flows and Levels for the Lower Peace River and Shell Creek.* (SWFWMD 2010)
- *Relative Abundance and Distribution of Common Snook along Shoreline Habitats of Florida Estuaries.* (Winner et al., 2010)
- *2010 Regional Water Supply Plan Southern Planning Region.* (SWFWMD, 2011)
- *Tracking the Multidecadal Oscillation through the last 8,000 years.* (Knudsen et al, 2011)
- *A Regional Modeling Framework of Phosphorus Sources and Transport in Streams of the Southeastern United States.* (Garćia et al., 2011)
- *Distribution and Abundance of Introduced Fishes in Florida's Charlotte Harbor Estuary.* (Idelberger et al., 2011)
- *Effect of Groundwater Levels and Headwater Wetlands on Streamflow in the Charlie Creek Basin, Peace River Watershed, West-Central Florida* (Lee et al., 2010)
- *A Presumptive Standard for Environmental Flow Protection (Richter et al., 2011)*
- *Peace River fish community assessment. (Call, et al., 2011)*

3.1 Distribution and Fluctuations in the Fish Fauna of the Charlotte Harbor Estuary, Florida. (Wang and Raney, 1971)

This report was published in Charlotte Harbor Estuarine Studies by the Mote Marine Laboratory in June 1971. The study describes the distribution, diversity and abundance of fish fauna throughout the Charlotte Harbor estuarine system in 1968 and 1969. Reconnaissance efforts, including a total of 485 trawling events, in addition to seine surveys, were conducted from February–May 1968 throughout the Charlotte Harbor estuarine system, resulting in the collection of over 38,000 specimens. Through these efforts, sampling locations were eliminated typically based upon species compositions being similar to those in other areas or very small collections.

The random sampling component of the study used a combination of a 16-foot semi-balloon trawl, two-sized seines, and a dipnet to sample fish fauna at 33 stations during 131 daytime collecting trips over approximately 120,000 acres of Charlotte Harbor and contiguous waters. All fish were preserved and measured. Small or young fish, representing limited portions of life histories, were typically collected due to the mesh size of the sampling equipment and the trawl speed; larger, fast-swimming fishes (e.g., mullet, sharks) were not collected despite their presence in the estuary. Rocky areas or other inaccessible habitats were not sampled. Air and water temperature readings and water samples were collected at all stations; salinity measurements were taken in the laboratory. Water samples were also collected at five additional sites.

The effect of dilution resulting from freshwater contributions into Charlotte Harbor from the Myakka and Peace Rivers, especially during the wet season, was demonstrated using 11 stations along the length of the estuary. Results also showed the effect of Hurricane Abby and associated rainfall on salinities as far as Cape Haze. Similarly, patterns of freshwater flow out of the estuary were demonstrated using 17 stations distributed throughout the Intracoastal Waterway adjacent to passes. With the exception of July and August, 1968, there was little variation in salinities at these stations.

For comparative purposes, stations within the bay area, with the exception of the Peace River and Matlacha Pass, were divided into three geographical subareas: 1) the Charlotte Harbor area; 2) Pine Island Sound area; and 3) the Lemon Bay/Gasparilla Sound area. Bay anchovy (*Anchoa mitchilli*) was the most abundant species in all areas except Lemon Bay/Gasparilla Sound where pinfish (*Lagodon rhomboids*) was most abundant. Silver perch (*Bairdiella chrysura*), pigfish (*Orthopristis chrysopterus*) silver jenny (*Eucinostomus gula*), and the sand seatrout (*Cynoscion arenarius*) were the next most common species collected. The highest number and greatest species diversity of fish were observed in the Lemon Bay/ Gasparilla Sound area. Although the northern portion of Pine Island Sound is very productive, abundance decreases considerably by the mouth of the Caloosahatchee River. With the exception of near the mouths of the Peace and Myakka Rivers, the Charlotte Harbor area resulted in a relatively small fish population.

Fish abundance in the bay followed trends in both salinity and temperature. Highest fish catches occurred in June and November. When salinity levels dropped during the rainy season in July, fish catch also decreased. This was likely the result of the departure from the bay of those high abundance fish species with preferences for higher salinities during the summer months. As salinities increased in October with the end of the wet season, fish catches within the bay also increased. Another, more drastic decline in fish catch was observed in the winter when water temperatures dropped to approximately 20°C.

A long-term study would be helpful to understand the differences in relative abundance and composition of fish species obtained from this investigation as compared to that by Finucane in 1965.

3.2 Enrichment of a subtropical estuary with nitrogen, phosphorus and silica. In: Estuaries and Nutrients. (Fraser and Wilcox, 1981)

This study looked at nutrients and chlorophyll levels at eight sampling sites distributed spatially in Charlotte Harbor and the lower Peace River, over the three year interval between 1975 and 1978. Seasonal pulses of nutrients delivered to Charlotte Harbor from the Peace River and its tributaries were evaluated relative to gaged freshwater inflows, with the greatest loadings occurring during the summer wet season. Observed phosphate and nitrate values were higher coming from the Peace River watershed than in adjacent southwest Florida riverine systems, while ammonium and silica were seasonally similar to other streams. Phosphate dilution curves in the estuary suggest that changing concentrations along the chloride gradient are conservative and dependent on the result of mixing processes. Inorganic nitrogen and silica dilution curves suggest non-conservative processes occurring, since their concentrations decrease faster along the chloride gradient than can be explained by dilution alone. Thus, both inorganic nitrogen and silica could become limiting factors in different parts of Charlotte Harbor during portions of the annual cycle, while phosphorus is always abundant. Phytoplankton populations were observed to respond positively to seasonal pulses of nutrients with higher productivity occurring during or just after high river flow. Productivity levels were observed to increase from the lower harbor toward near the river mouth in all seasons. General population level and productivity are similar to other Florida estuaries, with diatoms dominating the phytoplankton (blue-green algae being less than 1 percent) community even with the systems generally observed higher nutrient levels.

3.3 The Lower Peace River and Horse Creek: Flow and Water Quality Characteristics, 1976-1986. (Fraser, 1991)

This study compared freshwater inflows and water quality characteristics over the 1976-1986 time interval at a series of long-term monitoring sites in the lower Peace River upstream of the U.S. 41 Bridge, and at the Horse Creek and Peace River Arcadia USGS gauging locations. Water quality for 16 constituents and water quantity characteristics are reported for six stations in the Peace River basin.

Comparisons were further made relative to the water quality characteristics in the Horse Creek (where phosphate mining had yet to occur) and the lower Peace River basin. The report identifies both long-and short-term trends in selected water quality constituents and makes comparisons related to both flow and estimated areal fluxes. A long-term decline of approximately .27 m3s-1 (9.53 ft3s-1) per year since 1959 in the annual Peace River discharge at Arcadia, Florida was identified. Deficient rainfall in the wet season was determined to be the primary reason for the observed long-term trend. The "No Name" storm of June 1982 produced the highest discharges from the Peace Basin since Hurricane Donna in 1960 and had long-lasting effects on water quality constituents.

The report identifies sharp contrast for phosphate and fluoride levels between the relatively unmined Horse Creek watershed and the Peace River watershed which had notoriously been affected by the phosphate industry discharges. The report suggest that other water quality characteristics may have indicated the influences of other basin landuse characteristics. There were some significant differences among stations. The Peace River at Arcadia generally had the highest median concentrations for the majority of constituents, while median concentrations in Horse Creek were lowest for a majority of constituents, with the exceptions being color and total organic carbon. All the tidally influences stations indicated the seasonal influences of mixing with seawater.

The report found the lower Peace River (and associated tidal portions) to be eutrophic according to observed nutrient and chlorophyll *a* characteristics. Inorganic nitrogen was observed to be rapidly reduced to analytical detection limits in the tidal river, with nitrogen being considered to be the limiting macronutrient for phytoplankton primary production. Long-term trends of decreasing concentration were identified for phosphate industry-related constituents in the Peace River at Arcadia. The tidal Peace River has mostly declining nutrient trends and a declining trend for surface dissolved oxygen levels.

3.4 Abundance, seasonality, community indices, trends and relationships with physic chemical factors of trawled fish in upper Charlotte Harbor, Florida. (T. H. Fraser. 1997)

Seasonal and longer term patterns in habitat use (by size) of mostly juvenile fishes were described for upper Charlotte Harbor based on 13 years of monthly otter trawl sampling. Wet (June-September) and dry (October-May) seasonal groupings were identified for the most abundant fishes.

Dissolved oxygen levels below 2mg/liter near the bottom were found to result in sharp decreases in both the relative abundance and number of species present in the upper harbor. The13-year study encompassed the driest 10 years in terms of freshwater inflow from the Peace River for the preceding period-of-record (57 years), with record droughts during both the 1980-81 and 1984-85 intervals. In comparison, the study period also included 1982, which was the second highest wet-season flow since 1960.

Over the 13-year study, a total of sixty-two species were caught by ottertrawl. Thirteen of these species were common enough in the sampling to further analyze for relationships with dissolved oxygen, salinity (freshwater inflow) and temperature. Principal components analysis was performed using 13 environmental variables. This reduced variability and provided factors which accounted for 75% of the observed environmental variation. These factors were then analyzed relative to the occurances of the more common species. The two most abundant species, Anchoa mitchilli and Cynoscion arenarius showed significant long-term declines in relative abundances. Less common species, particularly those in the rare category increased in relative abundances. Trends of relative abundance by species, community indices and standardized estimates of species number supported the idea that decreasing flows result in a more diverse group of fishes using the upper harbor. Overall, total annual abundances were observed to vary by as much as a factor of four.

3.5 The Atlantic multidecadal oscillation and its relation to rainfall and river flows in the continental U.S. (Enfield et al, 2001)

This paper, published in the journal Geophysical Research Letters, describes the impact of the Atlantic multidecadal oscillation (AMO) on the hydrology of the United States. The study examines patterns of precipitation in the US as they relate to the phases of the AMO. The authors used singular spectrum analysis on the dataset of temperatures beginning in the 1850’s. North Atlantic SST exhibited a 65-80 year cycle with a 0.4 °C temperature range during the 1856-1999 period. The AMO index is correlated with sea surface temperatures (SST) in the north Atlantic, and to a lesser degree the north Pacific. The oscillation appears to be driven primarily by factors in the Atlantic, including Atlantic thermohaline circulation. The correlations between AMO index and rainfall are largely negative. In the northeast US, Pacific Northwest, and in Florida there are regional clusters of positive correlations. Based on a review of the seasonality, these correlations appear to be driven by summer rainfall events.

The connectivity between El Nino/Southern Oscillation (ENSO) cycles and US rainfall was reviewed to determine whether this pattern was affected by the AMO cycle. It has been shown that the Pacific Decadal Oscillation (PDO) affects the ENSO related rainfall. Florida is wetter during El Nino events than it is otherwise, regardless of the AMO cycle. After correcting the data for ENSO effects the correlation pattern was similar but the regionality of the clusters changed. During AMO warm phase the positive correlations were limited to Florida and the southwest US border region. During AMO cool phase the positive correlations were distributed throughout the southern states. This analysis indicates that Mississippi basin rainfall is lower during El Nino events when the AMO is in warm phase, but not when AMO is in cool phase.

The AMO index has been increasing since 1990 and became positive in 1995, indicating that we are currently in a warm AMO phase, similar to 1930-1960. The effect of this AMO warming should be a reduction of annual rainfall in most of the US, especially the eastern Mississippi basin, and an increase in rainfall in Florida.

3.6 Late Holocene Sea Level Rise in Southwest Florida: Implications for Estuarine Management and Coastal Evolution. (Saverese et al., 2002)

This paper, published in the Fifteenth Keck Research Symposium in Geology Proceedings, discusses the environmental and water management impacts associated with sea level rise in southwest Florida. For example, the mangrove-rimmed estuaries unique to the southern tip of the Florida peninsula may be in jeopardy if sea level rise far exceeds the sedimentation rate necessary for this geomorphology to persist. Currently, these habitats persist despite increasing sea levels with the help of sedimentation associated with the production of leaf litter and root mass by mangroves, shoaling, and oyster reef development. If coastal mangrove and wetland habitats in southwest Florida degrade, impacts to those flora and fauna dependent upon them would be likely. In addition, although coastal mangrove and wetland habitats are typically left undeveloped, the land immediately inshore of this fringe is not typically protected. As a result, there is little room for the landward migration of mangrove and wetland habitats as a response to sea level rise. In those areas where development would not hinder the landward migration of coastal habitats, topography and distance from the coast would determine the distribution of freshwater and brackish water wetlands. As a result, urban planning associated with these areas would need to be reassessed.

In order to effectively manage the implications associated with sea level rise, the last few thousand years of southwest Florida’s history of coastal systems should be well understood. Insights and data gained from the last 3,000 – 5,000 years would help plan responses for the future and would provide vast temporal databases to increase the accuracy of model predictions. Paleoenvironmental changes in the region can be monitored though coring of estuarine unconsolidated sediments, radiocarbon AMS and standard counting techniques, and the use of amino acid racemization on subfossil oysters. The results of a number of student projects aimed at increasing our understanding of the impacts of sea level rise on the coastal evolution and environmental management of southwest Florida will be submitted to regional entities to help better manage the area's environmental needs.

3.7 Sedimentary Evidence of Coastal Response to Holocene Sea-Level Change, Blackwater Bay, Southwest Florida. (Lowery, 2002)

This paper, published in the Fifteenth Keck Research Symposium in Geology Proceedings, discusses the sedimentary sequences observed in sediment cores extracted from across Blackwater Bay in southwest Florida. These cores were collected from a low energy, low relief system that provides the perfect conditions for the deposition and preservation of sedimentary layers indicative of changes in sea level.

Four cores were taken from across Blackwater Bay using a boat-mounted vibracore in June 2001 and analyzed in the lab for percent carbonate, organic content, and grain size. Three layers reflecting the Holocene record (Units B, C, and D), and one layer representing the upper Pleistocene (Unit A), were recovered from all four cores. Each of the three layers within the Holocene record indicates a different phase of relative sea-level change in the area within a time of eustatic rise. Unit A, the base layer in each of the cores, was composed of Pliocene limestone overlain by Pleistocene aged clayey sand, suggesting transition from a terrestrial environment to a salt water marsh. The drastic change to Unit B in each of the cores indicates the introduction of fluvial deposits of the ancestral Blackwater River. The thick peat sequences comprising Unit C in the cores characterizes the growth and landward migration of coastal mangroves as an intertidal habitat was formed by increasing sea level. The defined transition to Unit D, composed of shelly carbonate muds, signifies a deepening phase followed by a shallowing phase. The relatively abrupt deepening in the area and inundation of the mangroves characterized by a fine mud component in the cores, likely brought on by a significant storm event or series of storms, eventually resulted in the current condition of Blackwater Bay.

According to area and global tidal gauges, sea level is rising at a rate of 10 to 40 cm/100 years. If this continues, Blackwater Bay would continue to deepen and the intertidal mangroves will be slowly inundated.

3.8 The Influence of Sea Level Rise on the History of Estuarine Environments in Southwest Florida. (Obley, 2002)

This paper, published in the Fifteenth Keck Research Symposium in Geology Proceedings, discusses the sedimentary sequences observed in sediment cores extracted from within Estero Bay and Estero River and how they compare to changes seen in the Ten Thousand Islands area.
Ten, three-inch diameter cores were extracted from along an offshore to onshore transect from within the study area using both manual and vibracore methods. Five cores were collected from inside the bay and five were taken from various distances from and beyond the mangrove fringe. This study design was selected in an effort to gain an understanding of sea level changes throughout the river and estuary system. Each core was analyzed in the lab for radiocarbon

dating and standard counting, grain size, percent carbonate, percent organics, and fossil identification. The cores represent a maximum of 4,345 years.

Although each of the ten cores included a layer of interlaminated white fine sand with few, if any, shells or other marine indicators, the sequences overlying these layers were unique to the area sampled. For those cores closest to the Gulf, the white fine sand was found in the lower portion of the core with fine or very fine sand and marine or brackish mollusks above it. The upper portions of these cores were comprised of coarse silts and shoal sediments, and some had vermetids and oysters. This indicates deeper water and a marginal environment that never extended to the locations of the other cores. Similarly, the white fine sand sequence was also found in the lower portion of those cores taken from along the river or near the mouth; however, this layer was topped by mangrove peat. Those cores taken from the river mouth had very fine sand with numerous mollusks topping the core suggesting a mangrove forest that was degraded and never re-established. In contrast, the core taken from along the river was topped by peat, characteristic of the current mangrove condition at this location. Unlike the others, two cores extracted from the river's mangrove fringe showed bedrock at the bottom and the white fine sand layer near the top of the core, overlying estuarine sediments with oysters; the tops of the cores were comprised of mangrove peat or detrital mud.

The patterns within the cores suggest a transgression through approximately 2,400 to 2,880 ybp followed by a regression. The rate of sea level rise calculated by this study is 5.2 cm/100 years. These results are consistent with results of prior studies. If the sea level rise rate increases to historical levels, the current mangrove habitats may not be able to keep pace and could be degraded.

3.9 The Effects of Season and Proximity to Fringing Mangroves on Seagrass Associated Fish Communities in Charlotte Harbor, Florida. (Poulakis et al., 2003)

This paper, published in the journal Gulf of Mexico Science, uses Florida Fish and Wildlife Conservation Commission (FWC) Florida Marine Research Institute's Fisheries-Independent Monitoring (FIM) program data to examine the spatial and seasonal patterns of habitat use by fishes in Charlotte Harbor. The two predominant habitats in Charlotte Harbor, mangrove-seagrass shoreline and offshore seagrass flats, were used for comparison. Fish abundance, hydrologic, and habitat data collected through the FIM program from 1996 to 2000 were evaluated for this study. A monthly stratified-random sampling design based on a predefined grid system was used to collect samples using center-bag seines at sampling sites selected randomly from along mangrove shorelines and offshore flats. All fishes were identified to the lowest possible taxon, measured, and enumerated. Hydrologic data (i.e., water temperature, salinity, dissolved oxygen), and environmental parameters (e.g., water depth, seagrass coverage, shoreline characteristics) were recorded at each site. Two seasons (dry season: December through May; wet season: June through November) were defined for analysis.

Over 100 taxa and 406,155 individuals were collected and used for analysis, the majority (82%) of which included six species. Lowest fish abundance indices were typically found near the mouths of the Peace and Myakka rivers during the dry season. Although some species were plentiful in both habitats, several consistently differentiated between the two habitats as well as the area of the harbor. Factors (e.g., tidal stage, time of day, seagrass blade density, structural complexity, predator-prey interactions) not examined in this study may be responsible for these trends. The abundance of many taxa also varied seasonally. This is likely related to spawning and recruitment periods.

Four environmental parameters (i.e., water temperature, salinity, water depth, and dissolved oxygen levels) were found to influence fish abundance in Charlotte Harbor either individually or in combination. The role of dissolved oxygen in the shallow-water areas was likely related to the influential role of temperature. In addition, while the range of salinities encountered by fish in the estuary was important, mean salinity levels were not a major factor. Water depth, likely related to tidal influences, was also a significant contributing factor in determining distribution of fish species across habitats. While fish may prefer the mangrove-seagrass shoreline during higher tides, they are forced out to the offshore seagrass habitat during lower tides.
Results of this study will help resource managers predict future impacts on fishes due to anthropogenic activities (e.g., freshwater withdrawals, seagrass loss).

3.10 Fishes of the Charlotte Harbor Estuarine System, Florida. (Poulakis et al., 2004)

This paper, published in the journal Gulf of Mexico Science, presents a comprehensive list of fish species known to occur within the Charlotte Harbor estuarine system defined as Charlotte Harbor proper, Gasparilla Sound, Pine Island Sound, Matlacha Pass, San Carlos Bay, and the watersheds of the Myakka, Peace, and Caloosahatchee rivers. Additions to the icthyofauna of the system were determined using Florida Fish and Wildlife Conservation Commission (FWC) Fish and Wildlife Research Institute's (FWRI) ongoing Fisheries-Independent Monitoring (FIM) program collections and previously unpublished data at the Florida Museum of Natural History (FMNH). Records within the published literature of species reported from the estuarine system were deemed erroneous or questionable, as appropriate.

The addition of 39 recorded fish species resulting from this study brings the total number of species documented within the Charlotte Harbor estuarine system to 255; 22 previously reported species were not included in this species list based on the more recent evaluation. Although the FIM program provides the most comprehensive sampling effort focused on the Charlotte Harbor icthyofauna, data gaps reflecting the presence of some species (e.g., large active fish and small cryptic species) and habitat types (e.g., high structured habitats) likely exist due to the types of sampling gear used.

3.11 Assessment of relationships between freshwater inflow and populations of fish and selected macroinvertebrates in the peace river and shell creek, Florida. (Greenwood, et al, 2004)

This study, by the Independent Monitoring Program (FIM) of the Florida Fish and Wildlife Conservation Commission's Fish and Wildlife Research Institute (FWC/FWRI), used seine and trawl data collected from January 1996 to December 2003 in nearshore and channel habitats of the main stems of Peace River and Shell Creek. The purpose of the study was to assess relationships between freshwater inflow and biotic populations and communities to be used by the Southwest Florida Water Management District (SWFWMD) in conjunction with establishing minimum flows and levels for the Peace River and Shell Creek.

The study's main objectives of the study were to:

- Assess composition of the nekton community (finfish and selected macroinvertebrates)
- Examine habitat use for selected economically or ecologically important species
- Analyze movement and relative abundance of nekton populations in relation to magnitude of freshwater inflow
- Examine nekton community composition in relation to magnitude of freshwater inflow.

In the Peace River, above its confluence with Shell Creek (RK 15.40–29.0), a total of 65,386 animals from 73 taxa were collected nearshore in 171 seine hauls. Bay anchovies, Anchoa mitchilli, were the most abundant animals, comprising 61.2% of the total catch. Hogchoker, Trinectes maculatus, were the most frequently occurring taxon, being present in 80.1% of all samples. The ten most abundant taxa comprised 95.8% of the total catch. Thirty-one taxa were represented by less than ten individuals. A total of 11,894 animals from 42 taxa were collected in 359 trawl hauls in the channel. Hogchoker were the most abundant animals, comprising 39.8% of the total catch, and also were the most frequently occurring taxon, being present in 76.2% of all samples. The ten most abundant taxa comprised 98.8% of the total catch. Twenty-seven taxa were represented by less than ten individuals.

In the Peace River below its confluence with Shell Creek (RK -2.26–15.39), a total of 200,397 animals from 96 taxa were collected nearshore in 520 seine hauls. Bay anchovies were the most abundant animals, comprising 67.0% of the total catch. Silversides, Menidia spp., were the most frequently occurring taxon, being present in 72.7% of all samples. The ten most abundant taxa comprised 90.4% of the total catch. Thirty-five taxa were represented by less than ten individuals. A total of 56,719 animals from 69 taxa were collected in 80 trawl hauls in the channel of the below-confluence Peace River. Bay anchovies were the most abundant animals, comprising 46.7% of the total catch. Blue crabs, Callinectes sapidus, were the most frequently occurring taxon, being present in 69.9% of all samples. The ten most abundant taxa comprised 96.3% of the total catch. Thirty-three taxa were represented by less than ten individuals.

In Shell Creek (RK12.9–23.1), a total of 282,507 animals from 77 taxa were collected nearshore in 255 seine hauls. Bay anchovies were the most abundant animals, comprising 59.4% of the total catch. Silversides and rainwater killifish, Lucania parva, were the most frequently occurring taxa, being present in 83.5% of all samples. The ten most abundant taxa comprised 97.0% of the total catch. Twenty-three taxa were represented by less than ten individuals. A total of 21,199 animals from 51 taxa were collected in 123 trawl hauls in the channel of Shell Creek. Bay anchovies were the most abundant animals, comprising 41.8% of the total catch. Hogchoker were the most frequently occurring taxon, being present in 85.4% of all samples. The ten most abundant taxa comprised 97.7% of the total catch. Twenty-eight taxa were represented by less than ten individuals.

Thirty-four taxa were selected for detailed analysis on the basis of overall abundance (i.e., an Index of Relative Importance > 0.3). These taxa included pink shrimp (Farfantepenaeus duorarum), blue crab, striped anchovy (Anchoa hepsetus), bay anchovy, menhaden (Brevoortia spp.), white catfish (Ameiurus catus), channel catfish (Ictalurus punctatus), striped mullet (Mugil cephalus), marsh killifish (Fundulus confluentus), Gulf killifish (Fundulus grandis), striped killifish (Fundulus majalis), Seminole killifish (Fundulus seminolis), rainwater killifish, bluefin killifish (Lucania goodei), eastern mosquitofish (Gambusia holbrooki), sailfin molly (Poecilia latipinna), least killifish (Heterandria formosa), rough silverside (Membras martinica), brook silverside (Labidesthes sicculus), bighead searobin (Prionotus tribulus), sunfishes (Lepomis spp.), leatherjack (Oligoplites saurus), striped mojarra (Diapterus plumieri), silver jenny (Eucinostomus gula), tidewater mojarra (Eucinostomus harengulus), pinfish (Lagodon rhomboides), silver perch (Bairdiella chrysoura), sand seatrout (Cynoscion arenarius), spotted seatrout (Cynoscion nebulosus), southern kingfish (Menticirrhus americanus), red drum (Sciaenops ocellatus), naked goby (Gobiosoma bosc), clown goby (Microgobius gulosus), and hogchoker. For all 34 taxa, we generated plots of abundance by segment of the study area, month, river stratum (nine 3.5-km divisions along the length of the study area), modified Venice salinity classification, dominant shore type, and size class. Detailed species accounts are presented for pink shrimp, blue crab, bay anchovy, Seminole killifish, rainwater killifish, eastern mosquitofish, sailfin molly, tidewater mojarra, pinfish, sand seatrout, spotted seatrout, southern kingfish, red drum, clown goby, and hogchoker.

Comparisons of the relationship of freshwater inflow to population center- of-abundance (kmU comparisons) and overall population relative abundance (abundance comparisons) indicated that many species move upstream during periods of low inflow and that many species reach their maximum abundance at intermediate levels of inflow. Apparently, there are complex relationships between relative importance of freshwater inflow and the life histories of species found in the river.

Long-term inflow patterns have stronger relationships to the distribution and abundance of nekton species than do short-term inflow patterns. Nekton community structure in the Peace River and Shell Creek was generally separated into assemblages above and below the confluence between the two systems. There was relatively little difference in structure between the community in the Peace River above the confluence with Shell Creek and that in Shell Creek, whereas the community in these two segments differed greatly from that in the Peace River below the confluence.

Significant annual cycles in community structure were evident in all three segments of the study area. These cycles were most pronounced in the Peace River below the confluence with Shell Creek and were comparatively poorly defined in the Peace River above the confluence and in Shell Creek. This is due to the below-confluence segment being an important nursery area for transient species with well-defined seasonal patterns of recruitment.

The correlation between patterns of monthly change in community structure and magnitude of inflow was moderate in each of the three segments of the study area. Patterns of community change in the above-confluence Peace River and in Shell Creek correlated to a far greater extent with changes in salinity than with magnitude of inflow, whereas correlations with community change were similar for both salinity and inflow in the Peace River below the confluence. The relatively high correlation of community structure in the below-confluence Peace River with temperature may be more indicative of regular seasonal change in community rather than a direct link to the physical environment, because the correlation was less than that shown when testing for presence of annual cycles (see above). The relatively high correlation of salinity with change in community structure in the two more upstream segments of the study area suggests that salinity is an important determinant of community structure in these areas. Moderate correlation of inflow patterns with community structure may be partly due to the fact that inflow data used in analyses were from gauges generally well upstream of the study area, while temperature and salinity data were collected in situ. Salinity is undoubtedly determined by magnitude of freshwater inflow, so results demonstrating associations with salinity also indirectly illustrate the importance of inflow in structuring the nekton community.

There was little evidence for magnitude of inflow being related to longitudinal pattern of community change from upstream to downstream in any of the three segments of the study area when data from each season were compared.

3.12 Water Quality Assessment Report: Charlotte Harbor. (FDEP, 2005)

This report, published by the Florida Department of Environmental Protection (FDEP), is part of the FDEP management approach for restoring and protecting water resources and addressing total maximum daily load (TMDL) related issues. A TMDL represents the maximum amount of a given pollutant that a water body can assimilate and still support its designated use. If a water body fails to meet its designated use it is categorized as impaired. This report contains a list of verified impaired water bodies to be approved by USEPA. Water bodies on this list must have TMDLs developed, unless the failure to meet the designated use can be attributed to naturally occurring conditions. Regional stakeholders share responsibility for the achievement of water quality goals, and provide FDEP with data and information on activities in the watershed. At the time of the publication of this report TMDLs had not been developed for impaired water bodies in the Charlotte Harbor basin.

Charlotte Harbor is the second largest open water estuary in Florida, with an area of ~270 square miles. The primary issues in the waters of Charlotte Harbor identified by FDEP are:

- Altered freshwater inflows
- Excessive nutrient inputs
- Hypoxia (dissolved oxygen levels <2.0 mg/l)
- Red tide
- Protection of mangroves and seagrass
- Impacts of boating on water quality and submerged aquatic vegetation

The primary issues in the Charlotte Harbor watershed identified by FDEP are:

- Conversion of natural lands to:
    - Agriculture
    - Mining
    - Urban
- Overpumping of groundwater
- Ditching and draining of wetlands
- Reduced rainfall

This report identifies 13 water body segments (WBIDs) that are impaired and thus require the development of TMDLs. These are divided into planning units for the assessment of water quality improvement activities. The planning units identified are:

- Lemon Bay (6 impaired WBIDs)
- Charlotte Harbor Proper (4 impaired WBIDs)
- Pine Island (3 impaired WBIDs)

It was determined that there are no high priority areas for TMDL development within the Charlotte Harbor Basin. The surface water quality assessment describes the data sources and FDEP findings in detail. The TMDL development chapter provides additional information on the development, allocation, and implementation of TMDLs.

3.13 Seasonal Variation in Fish Assemblages within the Estuarine Portions of the Myakka and Peace Rivers, Southwest Florida. (Idelberger and Greenwood, 2005)

This paper, published in the journal Gulf of Mexico Science, describes seasonal patterns in the structure of fish assemblages in the estuarine portions of the Myakka and Peace Rivers in Southwest Florida and evaluates the potential for relationships between these assemblages and environmental factors.

Monthly samples were collected during the day from February 1996 through December 2002 from both shallow habitats close to shore and deeper waters. In each estuary, a 21.3-m nylon bag seine was used to collect the shallow samples four times per month and a 6.1-m otter trawl was used to collect samples in the deeper areas three times per month. This combination of equipment types provided the ability to sample a large portion of the estuarine fish fauna with a focus on smaller fishes. Sampling sites were determined randomly using a pre-determined grid system. All specimens were identified to the lowest possible taxon and enumerated. The standard length (SL) of up to 40 randomly chosen individuals was determined. Hydrologic data, date, location, depth, and bottom and shoreline descriptors were recorded at each sampling location. Data from seine and trawl samples were analyzed separately.

Over 620,000 fish were collected from 1,174 samples. Fish collection and hydrologic data revealed similar conditions and fish assemblages across the two estuaries. In addition, in both rivers, a weak relationship was identified between seasonal fish assemblages and environmental factors.

Anchoa mitchilli was, by far, the most abundant species collected (81.6 % of total catch); *Menidia* spp. represented the next most abundant fish population (4.2%). Temporal changes in the abundance of these dominant species, primarily due to peak spawning in warmer months, were prime factors in defining seasonal fish assemblages in the two systems. Another defining factor was the influx of young-of-the-year species that enter the estuary from higher salinity areas as part of their regular life cycle. As a result, well-defined fish assemblages were observed in both rivers during the summer wet season from May/June to September/October. Another group of estuary-dependent fish species were observed to spawn in the fall and recruit into the estuary in the winter. These patterns were regularly observed over the entire study period suggesting that they will remain stable over the long-term if left undisturbed by external environmental changes.

3.14 Feeding Habitats of Common Snook, Centropomus undecimalis¸ in Charlotte Harbor, Florida. (Blewett et al., 2005)

This paper, published in the journal Gulf and Caribbean Research, examines the feeding habits of common snook, *Centropomus undecimalis,* in Charlotte Harbor, Florida through stomach contents analysis. This investigation builds upon the findings of previous studies that were more limited in sample size and duration. Authors of this study focused on assessing 1) variation in prey consumption due to ontogeny, location within the estuary, or time of year, 2) predator size-prey size relationships, and 3) size-selective feeding patterns.

Florida Fish and Wildlife Conservation Commission (FWC) Florida Marine Research Institute’s Fisheries-Independent Monitoring (FIM) program data collected between March 2000 and February 2002 were used in this study. Samples were collected from ≤ 2.5 m depth with a 183-m center-bag seine during daylight hours using a standardized random sampling design. Samples were typically collected from mangrove and seagrass habitats as they are predominant within the estuary. Common snook were transported on ice to the laboratory where the standard length (SL) was measured and the stomachs were removed and frozen. Within one month of collection, stomach contents were sorted, identified to the lowest possible taxon, and measured (if whole). Percent numerical abundance, percent weight, and percent frequency of occurrence of prey species were calculated from the stomach contents. Potential prey within the estuary were collected from 12 random sites along the shorelines of Charlotte Harbor using 21.3-m and 183-m center-bag seines and compared to prey found within the stomachs of common snook to evaluate changes in availability, size and seasonality.

A total of 694 stomachs were extracted from common snook ranging from 300 to 822 mm SL; 432 of which contained prey items. Fishes and crustaceans were the most common prey items by number and weight, though a wide variety of prey was observed. This investigation shows that common snook feed on pelagic, demersal, and burrowing species located among mangrove shorelines, seagrass beds, and unvegetated substrates. Although common snook appear to exploit prey by availability, they are selective in the size prey consumed throughout their ontogeny; prey size increases with size of the predator snook. These selective feeding habits were also influenced by season and associated recruitment and growth patterns of prey.

Results of this study differed from those of previous investigations. This is most likely due to the methods and times of sample collection. Additional trophic studies are needed to better understand the factors influencing the diet of common snook.

3.15 Proposed Minimum Flows and Levels for the Middle Segment of the Peace River, from Zolfo Springs to Arcadia. (SWFWMD, 2005)

This report was published in October 2005. It was subsequently used to develop a provisional minimum flows and levels (MFL) for the middle Peace River (from the Zolfo Springs gage to the Arcadia gage) which was adopted by the Southwest Florida Water Management District (District) Governing Board. The document was peer reviewed by a Scientific Peer Review Panel (Panel) established by the District (see Shaw et al. below).

The determination of minimum flows for the upper Peace River first involved an assessment of the historic and current flow regime and the factors that have shaped flow regimes. The Peace River has experienced declining baseflows over the past three decades. It has been hypothesized that phosphate mining and agricultural irrigation are the primary anthropogenic causes. In recent years, climate change, specifically the Atlantic Multi-decadal Oscillation, has been shown to have a significant effect on flows in Florida rivers. The District reviewed the effects of climatic oscillations on regional river flows and identified benchmark periods for the Peace River.

The resource management goals established for the upper Peace River included the following:

- Maintain minimum depths for fish passage and canoeing in the upper river
- Maintain depths above the inflection point in the wetted perimeter of the stream bottom
- Inundate woody habitats in the stream channel
- Meet the hydrologic requirements of floodplain biological communities

The low flow threshold defines the flow rate below which no withdrawals are allowed. For the middle Peace River the low flow thresholds were determined to be 67 cubic feet per second (cfs) at the Arcadia gage, and 45 cfs at the Zolfo Springs gage. The allowed flow reduction for the low flow period was determined to be 10% (above the low flow cutoff). This value was generated using the Physical Habitat Simulation Model (PHABSIM), and is based on habitat requirements for some common freshwater fishes. For the medium flow period the allowed flow reduction was determined to be 18% at the Arcadia gage or 10% at the Zolfo gage. These values were reached using PHABSIM to evaluate habitat availability for several species of fish and for macroinvertebrate diversity. In addition Regional and Long Term Positional Hydrographic (RALPH) analyses and HEC-RAS modeling was used to evaluate inundation periods for instream woody habitat. The PHABSIM analyses provided the more conservative values. The allowed flow reduction during the high flow period was determined to be a stepped reduction of 11% and 8% with the step occurring at 783 cfs at the Zolfo gage, and a stepped reduction of 13%

and 8% with the step occurring at 1,362 cfs at the Arcadia gage. These values were determined using both RALPH and HEC-RAS analyses.

3.16 A Review of “Proposed Minimum Flows and Levels for the Middle Segment of the Peace River, from Zolfo Springs to Arcadia”. (Shaw et al 2005)

The District convened a panel of experts, referred to as the MFL Scientific Peer Review Panel, to provide a peer review of the upper Peace River MFL evaluation report. The panel review was published in June 2005. The purpose of the report is to provide a critical review of the methods, data, and conclusions in the report.

The panel strongly endorsed some of the innovative techniques used in the report, including:

- Using two benchmark periods based on AMO phase
- Using multiple independent approaches to identify the most protective flow regimes
- Specifying the minimum flow with percent of flow reduction allowed on a seasonal basis

In addition the panel found that:

- The District has integrated the climate-streamflow interactions into the development of this MFL recommendation by analyzing multiple climatic cycles and using the most conservative scenarios. The District presents a compelling argument that the recently observed trends in flow are the result of climate rather than being anthropogenically derived.
- The building block approach is a rigorous and defensible approach, which ensures that the existing hydrologic regime is not disrupted. The weakness of the approach is that it may not provide protection during periods of unusual hydrologic conditions.
- The use of PHABSIM and RALPH analyses in conjunction with HEC-RAS modeling provided a more robust platform for determining MFLs than the use of HEC-RAS alone. There should have been a discussion of the precision and accuracy of the HEC-RAS model output.
- The District should focus on evaluating additional biotic indicators for their PHABSIM modeling. It has been shown that the use of invertebrate taxa can lead to substantially different results than the use of fish taxa.
- RALPH analysis enhanced the presentation of the MFLs for the middle Peace River, and should be utilized in future MFL development.
- The use of the 0.6 foot fish passage standard represents the best available information. However this standard was derived for the passage of salmonids in environmental conditions drastically different to those present in southwest Florida. It is recommended that the District engage the research community to evaluate the validity of this standard in southwest Florida.

- The report failed to discuss the ‘recreational use’ aspect of the minimum flow from the perspective of boat passage. Analysis of this use would be helpful in justifying the 0.6 foot standard.
- The use of floodplain inundation analysis is commendable. The presentation of methods and the definitions of plant/ecological communities could use refinement. Additionally the analysis does not consider depth of inundation, which has an effect on fish passage to seasonally inundated areas and an effect on floodplain productivity. Using a minimum inundation depth would strengthen the defensibility of the analyses. Finally a discussion of sources of model uncertainty would aid in report interpretation.
- The snag and root inundation analysis is an effective use of critical habitat analysis. Discussion of model uncertainty would aid in interpretation of the results.
- The panel strongly endorses the proposed minimum flows for the middle Peace River, finding them to be based on sound science and the best available information.

3.17 Development of a Fluorescence Method to Detect Optical Brighteners in the Presence of Varying Concentrations of Fluorescent Humic Substances: Identifying Regions Influenced by OSTDS in the Estuarine Waters of Charlotte Harbor. (Dixon et al, 2005)

This report, published in September 2005, describes the development of techniques to detect optical brighteners (OBs), which are additives to laundry detergents. The objective of developing this technique is to provide a method to understand where on-site sewage treatment and disposal systems (OSTDS) in the residential canals of Charlotte County, FL may be failing.

Two approaches were taken to measuring OBs. Absorbent dye-free cotton pads were placed in the canals for 2-3 day periods. After recovery the pads were analyzed for fluorescence (visually and with a spectroradiometer) under 254 nm illumination. Alternatively, paired flow-through fluorometers were used to obtain a continuous record of fluorescence along the length of the canals. Multiple wavelength bands were monitored to allow for the separation of fluorescence by humic substances versus fluorescence by OBs. Under laboratory conditions both techniques responded to the presence of OBs. The pad method was less sensitive and displayed greater variation in the results than the flow-through method. Due to the accumulation of natural organic matter in the field (biofouling and pad degradation) the pads in the field study displayed lower fluorescence than the pads in the laboratory study. Due to this interference the pads were judged not to allow for quantification of OBs. The flow-through method showed promise in field deployment, but required extensive work in data processing and analysis. This method is conservative and does not produce false positive results. This survey method may not capture the presence of OBs if the plumes are intermittent and the OBs are short lived in the environment.
The results of the field studies were mapped and canals were identified for further evaluation. Agreement between the two methods of evaluation was mixed.

3.18 Effects of Hurricane Charley on Smalltooth Sawfish (Pristis pectinata) nursery habitats in Charlotte Harbor, Florida. (Simpfendorfer et al., 2005)

This report, published by the Mote Marine Laboratory in 2005, evaluated the potential impact of Hurricane Charley (Category 4) on the endangered smalltooth sawfish (*Pristis pectinata*) in Charlotte Harbor. Given observations by the public, it is apparent that the fringing mangrove habitats in Charlotte Harbor are important nursery grounds for smalltooth sawfish.

Damage to the shoreline mangrove habitat was assessed at 75 sites in Charlotte Harbor in February and March 2005, and 25 sites in the Ten Thousand Islands (used as a control) in August 2005; samples were selected using a grid system. A 100-meter section of mangrove shoreline was visually assessed at each sampling location and damage was rated using a five-point qualitative index. Within each site, a single measure of mangrove damage (the mangrove damage index) was determined by calculating the mean of the damage scores, weighted by the proportion of each. The proportion of trees that appeared to be dead or completely defoliated within each site was also estimated. All values were plotted on maps and compared to the track of Hurricane Charley. At each site, abundance of trash was also determined and plotted on maps of the area.

Although mangrove damage was apparent at all sampling locations, results of a t-test indicate that the mean mangrove damage index was significantly higher in Charlotte Harbor than in the Ten Thousand Islands. As expected, the worst of the damage was observed closest to the hurricane's track and decreased with distance. Greatest degree of death or complete defoliation occurred mostly to the east, and within 15 km, of the hurricane's track where the strongest winds were present. Notably, additional mortality may be observed as observations were taken less than a year after the storm.

Unlike mangrove damage, trash levels were higher in the control site. This may be due to a greater potential for trash to come ashore from the Gulf of Mexico. It is also possible that observations of trash may not be accurate as a result of cleanup operations or the natural breakdown of materials.

Although this study provides results as to mangrove habitat damage, it does not indicate the impacts on smalltooth sawfish. The impacts on sawfish nursery habitat resulting from the extent and type of damage observed will be better known once the habitat use patterns of *P. pectinata* are better understood.

3.19 Dissolved Oxygen Dynamics in Charlotte Harbor and Its Contributing Watershed, in Response to Hurricanes Charley, Frances, and Jeanne – Impacts and Recover. (Tomasko et al., 2006)

This paper, published in the journal Estuaries and Coasts, discusses the effect of Hurricanes Charley, Frances, and Jeanne on dissolved oxygen conditions throughout the Charlotte Harbor watershed. Within six weeks, the three hurricanes directly impacted the Charlotte Harbor watershed through wind damage, high rainfall, and flooding. Existing water quality monitoring programs in the Peace River watershed were supplemented and water quality sampling efforts in Charlotte Harbor were continued with the objective of identifying the basis and extent of hypoxic conditions in the Peace River.

Existing monthly sampling frequencies were increased to weekly visits eight days after the landfall of Hurricane Charley at locations along the Peace River and contributing tributaries. Distances between sampling sites and the track of the hurricane's eyewall were estimated. Standard water quality parameters were measured in the field at all sampling sites. Water samples were collected from each site for the measurement of additional parameters (i.e., turbidity, total suspended solids [TSS], color, and biological oxygen demand [BOD] in the laboratory. Dissolved oxygen (DO) data collected as part of the Florida Fish and Wildlife Conservation Commission's (FFWCC) existing sampling program was also used in this investigation. The data selected for analysis were collected from 0.2 and 2.0 m below the surface at five randomly selected sites each month within the strata Upper Charlotte Harbor.
The rainy season (July to September) in Charlotte Harbor is typically characterized by hypoxic conditions due to warm water temperatures and increased freshwater inputs and associated stratification of the water column compounded by the increased influx of organic loads over time. In contrast, hypoxia is normally limited in the Peace River to the upper reaches, likely a result of the input of highly polluted water from Lake Hancock. After the passage of Hurricane Charley, widespread hypoxic conditions were observed in Charlotte Harbor and much of the Peace River watershed. Data suggest that high levels of dissolved organic matter (measured by color) and TSS were associated with the elevated BOD values observed at the same locations and the overall drastic reduction in DO in the Peace River watershed. While pre-disturbance levels of DO were attained in Charlotte Harbor within approximately one month, 2-3 months were needed for the Peace River stations to recover. This difference in recovery time likely reflects the higher rate of flushing in Charlotte Harbor by Gulf of Mexico waters.

The considerable reductions in DO were observed at those locations within the Peace River watershed that were within 20 km of Hurricane Charley's eyewall track. While defoliation and tree mortality was also observed only in this area and likely contributed to the elevated BOD levels, other factors were also important. Elevated freshwater inflows to Charlotte Harbor resulted in salinity stratifications and the input of water with high BOD.

3.20 A Multivariate Statistical Analysis of Relationships between Freshwater Inflows and Mollusk Distributions in Tidal Rivers in Southwest Florida. (Montagna, 2006)

This report was submitted to the SWFWMD in December 2006. The report describes an inter-river multivariate comparison of the relationships between freshwater inflows, physicochemical variables, and the distribution of mollusks in the Peace River, Alafia River, Myakka River, Weeki Wachee River, Shell Creek, and Shakett Creek/Dona and Roberts Bay. The purpose of the project was to understand the physical and chemical requirements of the mollusk communities found in Southwest Florida tidal rivers. Improved understanding of these communities is intended to improve the evaluation of freshwater inflow requirements. In these analyses salinity is used as a surrogate measure of flow.

The invertebrate and sediment data for this study were provided by Mote Marine Laboratory, and have been previously published in a number of reports by Mote Marine Laboratory staff, which were focused on individual river systems. Water quality data were provided by the SWFWMD. The findings of the study are:

- The dominant mollusk was the Asian clam, *Corbicula fluminea*, an exotic species
- The dominance patterns were different in each of the river systems analyzed
- The similarity between 2 km river segments was low, and was driven by the relatively dominant mollusk taxa
- Water quality data had higher correlations with mollusk community data than did sediment data, and salinity had the highest correlation among water quality variables

3.21 Red Mangrove (Rhizophora mangle) Reproduction and Seedling Colonization after Hurricane Charley: Comparisons of Charlotte Harbor and Tampa Bay. (Proffitt et al., 2006)

This paper, published in the journal Estuaries and Coasts, examines the role of life history traits of the red mangrove in its ability to recover after considerable destruction of mangroves from Hurricane Charley in Charlotte Harbor. This is very important given that hurricane season and the presence of mature red mangrove propagules co-occur. Data on the reproductive effort of red mangroves from mangrove-dominated shorelines of Charlotte Harbor before and after the hurricane are compared to those from Tampa Bay. The outcrossing rate of the studied mangroves and preliminary data on seedling colonization in heavily and lightly damaged areas in Charlotte Harbor are also presented.

Charlotte Harbor forest stands sampled in this study were located in Tarpon Bay, east Pine Island, Patricio Island, Part Island, Ding Darling, and northern Estero Bay. Ten sites along the eastern shoreline and four sites along the western shoreline of Tampa Bay were studied; two additional sites in upper Boca Ceiga Bay were included. The number of reproducing trees (those with at least 10 propagules) within roughly 10 m of open water was counted in July and August (during peak season of maturing propagules) in Charlotte Harbor (2002, 2003, and 2005) and Tampa Bay (2001, 2002, 2003, and 2005) and divided by the length of shoreline assessed to calculate density. Tree size, including a visual estimate of height and rank diameter at breast height (DBH) for sentinel trees was recorded. The degree of outcrossing in a forest stand was determined by calculating the deviance from the 3:1 ratio of green:albino propagules expected from selfing trees in sentinel trees (those heterozygotic for albinism) observed at surveyed sites. Data were grouped into three categories for statistical analysis: 1) Charlotte Harbor pre-Charley (2002 and 2003) sites; 2) Charlotte Harbor post-Charley (2005) sites; and 3) Tampa Bay sites.
After Hurricane Charley, the density of reproducing trees in Charlotte Harbor decreased by an order of magnitude; a similar trend was not apparent in Tampa Bay though only one site was surveyed. As a result, the length of shoreline evaluated in Charlotte Harbor was increased in an effort to locate enough reproducing trees to obtain a reliable sample. Notably, this reduction in density of reproducing trees was likely the result of stress related to mangrove damage and

associated shifts in resources to recover and grow rather than tree mortality. Trees were larger in Charlotte Harbor than in Tampa Bay but did not differ before and after the storm.

Outcrossing rates in Charlotte Harbor were significantly higher than those in Tampa Bay; however, while outcrossing increased with density of reproducing trees in Tampa, no correlation was observed in Charlotte Harbor. Whether or not these trends are related to seedling survival and growth is unknown.

A randomly positioned permanent quadrat placed within each of 24 circular plots at four sites in April 2005 within the Ding Darling National Wildlife Refuge on Sanibel Island was used to measure seedling recruitment. The number of new seedlings established after the reproductive season (December 2005) within each quadrat was counted. Measurements of living fallen and broken trees were used to calculate canopy loss.

Seedlings in Charlotte Harbor plots generally survived Hurricane Charley though new recruitment in the year following the storm was low; recruitment was higher in plots with larger numbers of pre-storm established seedlings. This is likely the result of reduced reproduction and loss of floating propagules during the storm. This suggests that red mangroves have a one-year lag in significant reproduction following a major disturbance and that new recruitment is generally from local trees.

3.22 Anthropogenic effects on the Smalltooth Sawfish (Pristis pectinata) in the United States. (Seitz and Poulakis, 2006)

This paper, published in the journal Marine Pollution Bulletin, documents non-net anthropogenic factors that continue to affect smalltooth sawfish in Florida and summarizes literary accounts of these effects on sawfishes worldwide. Information regarding encounters with smalltooth sawfish was obtained by soliciting information through local media outlets, circulation of posters, and a website. Posters were distributed between January 1999 and April 2001 throughout south and southwest Florida. Information collected for each sawfish included date and location of encounter, estimated total length, and general health of the fish; photographs or video were obtained when possible.

Nearly 1000 interviews were conducted through November 2005, documenting over 3200 smalltooth sawfish encounters throughout the United States, most of which were in south Florida since 1998. Fifty of these fish were reported entangled, injured, or dead and 82% were reported to be impacted by anthropogenic activities. Interactions with sharks accounted for other reported effects. Pollution-related injuries, including entanglement in various types of marine litter, were reported. Other injuries included those caused directly and intentionally by humans (e.g., rostrum removal, shooting) as well as those by accident. Documented examples of reasons for reduced sawfish populations include human consumption, leather production, and use in traditional medicine or for religious purposes.

Smalltooth sawfish are protected by state and federal laws in the United States but impacts to these fish by marine pollution and human interaction continue. The extent to which these impacts have affected the population of sawfish and what the long-term effects are on the recovery of the fish is unknown. However, because these fish produce small numbers of young and are characterized by slow growth and later maturity, their populations were reduced quickly and are replaced slowly. In addition, sawfishes are commonly in coastal habitats, making them even more vulnerable to anthropogenic impacts. Proper disposal of debris and use of ecologically friendly fishing materials would help and can be communicated by including fisher education into the conservation and management process. In addition, international protection and enforcement together with the elimination of markets for sawfish products are necessary to improve worldwide populations.

3.23 Short-term Effects of a Low Dissolved Oxygen Event on Estuarine Fish Assemblages Following the Passage of Hurricane Charley. (Stevens et al., 2006)

This paper, published in Estuaries and Coasts, describes the short term impact on fish communities of the reductions in dissolved oxygen throughout the estuarine Peace River and Charlotte Harbor after the passage of Hurricane Charley. Hypoxia is defined as dissolved oxygen less than 2 mg/l, and can lead to fish kills and deteriorated fish condition. Within one week of the passage of Hurricane Charley dissolved oxygen levels dropped to less than 1 mg/l in some parts of the Peace River, and in an area of Charlotte Harbor estimated to be greater than 75 square miles.

Fish community monitoring in the study area is part of a long term monitoring effort by the Florida Fish and Wildlife Conservation Commission (FWC). Data from these existing programs were analyzed to determine the effects of the hypoxic conditions. Hypoxic conditions occurred and abated within weeks of the hurricane passage. Approximately one month after the hurricane passage dissolved oxygen levels had recovered to average levels near 4 mg/l. There were widespread reports of fish kills in the first two weeks following passage of the storm. Samples taken immediately following the storm were drastically different than those taken just prior to the storm, and were comprised exclusively of fishes that are known to be tolerant of hypoxic conditions. Approximately one month after storm passage the fish community had returned to a near normal composition. It is apparent that the fish communities of the Peace River and Charlotte Harbor are able to recover quickly from relatively short lived and infrequent widespread hypoxic conditions.

3.24 Development of Water Quality Targets for Charlotte Harbor, Florida Using Seagrass Light Requirements. (Corbett and Hale, 2006)

This paper was written by staff at the Charlotte Harbor Estuary Program and at the Charlotte Harbor Environmental Center and was published in the Florida Scientist in 2006. In order to facilitate the recovery and maintenance of seagrass in the Charlotte Harbor estuary it is necessary to have sufficient light reaching the seagrass community. In neighboring areas (Tampa and Sarasota Bays) seagrass communities have recovered after nutrient loading reductions led to reduced phytoplankton density and therefore less water column light attenuation. In Charlotte

Harbor greater than 30% reductions in seagrass coverage have been documented. Water quality data have indicated significant increases in total suspended solids in upper and lower Charlotte Harbor, and increased turbidity and nutrient concentrations in lower Charlotte Harbor. This paper presents an optical model which aims to provide goals that will maintain the present seagrass distribution into the future.

The data from the dry season sampling typically met or exceeded the proposed criteria, however approximately half of the wet season samples did not meet the criteria. The three major constituents affecting light transmissivity identified in the paper are color, chlorophyll-a, and turbidity. The authors contend that the proposed targets are necessary to understand the acceptable concentration of a component of light attenuation relative to the other components. The concept being that any concentration of any of the constituents (below their target) is acceptable so long as sufficient light reaches the target seagrass depth. There are times during which these targets are not met, but seagrass may still be supported, particularly if the area is shallower than the target depth. Seagrass bed coverage has been stable in upper Charlotte Harbor since 1988, resource management should focus on the long term maintenance of this coverage through water clarity targets. If future research indicates that the current extent of seagrass beds in Charlotte Harbor is substantially less than the historic condition then targets should be developed to promote restoration.

3.25 Southern Water Use Caution Area Recovery Strategy. (SWFWMD 2006)

This report, published in March 2006, describes the strategy for the hydrologic recovery of the Southern Water Use Caution Area (SWUCA). The SWUCA covers ~5,100 square miles including part or all of 8 counties in the southern portion of the Southwest Florida Water Management District (SWFWMD). In this region groundwater has been utilized as the primary source for drinking water supply, causing declines in aquifer levels. Changes to aquifer management have resulted in stabilization of the aquifer level; however regional problems persist due to the decreased aquifer level. Florida law requires regional water supply planning in areas where it is determined that existing sources are not adequate for all existing and projected future uses, and to sustain natural systems. Regional water supply plans also include the implementation of minimum flows and levels (MFLs) for priority waterways. If the existing flow is below, or is projected to fall below, the minimum level, then as part of the regional water supply plan the SWFWMD will implement a recovery strategy. This strategy will include a timetable, allowing for the provision of sufficient water supply, while developing alternative water supply sources and implementing conservation and other efficiency strategies. This report contains the SWUCA recovery strategy. It is designed to restore minimum flows to the upper Peace River and minimum levels to lakes in Highlands and Polk counties, and to slow the inland movement of saltwater intrusion such that there will be minimum risk of contamination to the existing water supply.

The specific goals are:

- Restore minimum levels to lakes in the Ridge area by 2025
- Restore minimum flows to the upper Peace River by 2025

- Reduce rate of saltwater intrusion in coastal Hillsborough, Manatee, and Sarasota counties by achieving the proposed minimum aquifer level for saltwater intrusion by 2025
- Ensure that there are sufficient water supplies for all existing and projected reasonable-beneficial uses

The two major components to the recovery strategy are, management of groundwater withdrawals, and implementation of alternative source water projects. There are six major elements to the strategy:

- Development of a regional water supply plan
- Apply existing rules when considering water use applications
- Enhance existing rules (net benefit concept)
- Provide incentives for conservation and the development of alternative supplies
- Develop/implement water resource development projects that will restore lake and floodplain storage to enhance recharge
- Perform monitoring, reporting, and cumulative impact analysis

The remainder of the report provides detail and examples for each of these elements. The document describes how these proposed actions will be monitored, reviewed, and how the need for further action will be evaluated.

3.26 Colored Dissolved Organic Matter (CDOM) Workshop Summary. (Corbett, 2007)

This report, published in September 2007, contains information from a workshop conducted in May 2007, related to understanding CDOM. CDOM is the largest reservoir of organic carbon in aquatic environments. It contributes to light absorption in the water column, and may fuel bacterial respiration. CDOM contributes large quantities of carbon, nitrogen and phosphorus to estuaries. In Charlotte Harbor CDOM can account for the majority of light attenuation at times, and is a major component of water clarity targets. Despite its apparent importance, CDOM dynamics are not well understood. The two day workshop described in this document was intended to further the understanding and conversation regarding CDOM dynamics and its importance to the health and ecology of estuaries.

There were multiple conclusions reached regarding CDOM in the Charlotte Harbor region, among them were:

- It is important to better understand CDOM composition due to its effects on seagrass and benthic communities
- Results from analyses of existing CDOM data demonstrate that CDOM is positively associated with flow until a level of flow is achieved such that the CDOM is ‘washed out’

- A better understanding of the spatial-temporal variability of CDOM concentration and composition is needed before it can be properly managed for
- A CDOM working group should be created to coordinate research and monitoring as well as data sharing, and that the CHNEP should facilitate this group

3.27 Variable Habitat Use by Juvenile Common Snook, *Centropomus undecimalis* (Pisces: Centropomidae): Applying a Life-History Model in a Southwest Florida Estuary. (Stevens et al., 2007)

This paper, published in the journal Bulletin of Marine Science, evaluates whether the general life history model for common snook, *Centropomus undecimalis*, derived primarily from the Indian River Lagoon (IRL) and Tampa Bay, is applicable to Charlotte Harbor. This comparison is important given the considerable differences among estuaries. Unlike the IRL and Tampa Bay, coastal wetland habitat in Charlotte Harbor remains intact and much of the shoreline is designated as Aquatic Buffer Preserves. In addition, the distance from major tributaries to spawning grounds is greater in Charlotte Harbor than in the IRL and Tampa Bay. The authors of this study focused on three objectives: 1) determine where juvenile snook habitat is located in Charlotte Harbor; 2) describe habitat affinities through early ontogeny; and 3) compare findings to those from IRL and Tampa Bay.

A combination of fixed site and stratified-random sampling (SRS) designs were used to collect juvenile common snook throughout Charlotte Harbor. Fixed sites (Bokeelia Pond, Key Point Canal, Peace River, and Cape Haze) were identified using results of preliminary surveys to maximize collection efforts in multiple habitat types. Monthly sampling at these locations, with the exception of Cape Haze, was performed from 1991 – 1995 using a 21.3-m or 6.1-m seine. A bayward pond and a landward pond site were established for quarterly sampling at Cape Haze; when surrounding marshes were not flooded, the landward pond was isolated from nearby waters. A 21.3-m seine was used at both locations within Cape Haze while a 6.1-m seine was also pulled through a small creek connecting the landward pond to the nearby marsh. SRS sites were located throughout the bay system, also characterizing a variety of habitat types. Sites were randomly selected from zones dividing the estuary and a variety of gear, including a 21.3-m seine and 183-m haul seine, were used to collect monthly samples from 1996 to 2002. Juvenile snook were designated as “small” (≤ 150 mm standard length (SL)) or “large” (151-350 mm SL). One thousand six hundred and sixty-seven common snook were collected from the monthly fixed sites and 157 additional fish were sampled at Cape Haze. Forty small juvenile common snook were collected from 16 SRS sites while 435 large juvenile common snook were sampled from 168 SRS sites. Juvenile common snook were found in lower densities from the passes to the upper estuary in Charlotte Harbor despite the presence of similar habitat. This is likely explained by the proximity to larval sources near the passes.

Interestingly, small juvenile common snook appear to make more use of coastal wetland habitats than freshwater tributaries in Charlotte Harbor as compared to the IRL and Tampa Bay. While only one small juvenile fish was collected from a river in Charlotte Harbor, most of the 1835 small common snook were sampled from riverine habitats in the IRL and Tampa Bay during the same period. More research using SRS design is needed to determine if 1) this pattern is due to high river flows and greater distances to passes that may hinder dispersal of small juveniles into the upper estuary of Charlotte Harbor or 2) sampling limitations used with the SRS design may have negatively influenced collections in the more prevalent coastal wetland habitats in Charlotte Harbor due to inaccessibility. This is supported by the high density of small juvenile common snook collected from fixed sites in remote wetland ponds. Once these fish reach 150 mm SL, observations indicate that they move more bayward. This movement may be prompted by physiological changes in tolerance to environmental conditions or pursuit of larger prey. This movement appears to be complicated by changes in water levels responsible for establishing connectivity of remote pond areas to adjacent habitats; however, juvenile common snook show the ability to adapt to various conditions and habitats.

3.28 Habitat Use by Juvenile Gag, *Mycteroperca microlepis* (Pisces: Serranidae), in Subtropical Charlotte Harbor, Florida (USA). (Casey et al., 2007)

This paper, published in the journal Gulf of Mexico Science, uses Florida Fish and Wildlife Conservation Commission (FWC) Fish and Wildlife Research Institute’s (FWRI) ongoing Fisheries-Independent Monitoring (FIM) program data from Charlotte Harbor to examine the importance of subtropical estuaries on the distribution, seasonality, habitat use, and relative abundance of juvenile gag (*Mycteroperca microlepis*). Although the importance of temperate estuarine systems on the juvenile stages of gag is well documented, the role of subtropical estuaries has not been well studied. This information can be used as a baseline to help predict how natural or anthropogenic changes to the water quality and habitat of Charlotte Harbor will affect the species.

Fish abundance and habitat data collected through the FIM program from January 1996 to December 2002 were evaluated for this study. A monthly stratified-random sampling design was used to collect gag using three different seines (each focused in a specific habitat type) at sampling sites selected randomly by using a predefined grid system. All fishes were identified to the lowest possible taxon and enumerated and the standard length (SL) of up to 40 individuals per sample was measured. General water quality parameters, location, bottom type, seagrass species, shoreline vegetation species, and coverage (%) of each sample were qualitatively measured.

Over 700 juvenile gag, between 30 to 489 mm SL, were collected from the estuary; 95% of which were collected in polyhaline Gasparilla and Pine Island sounds. Evaluation of specific habitat use and relative abundance focused on gag collected in the haul seine from May to December in Gasparilla and Pine Island Sounds because these samples accounted for 78% of all gag captured.

As observed in temperate environments, juvenile gag moved into and settled in subtropical Charlotte Harbor during April and May. In temperate estuaries, gag appear to leave estuaries for open waters in September and October during the passage of cold fronts. Although the abundance of juvenile gag throughout Charlotte Harbor began to decrease between October and December, this appeared to be the result of moving to deeper open waters within the estuary in

October and November. This extended time spent within the estuary accounts for the larger sizes attained before egressing to open waters. A difference in habitat use was also observed between gag in temperate and subtropical estuaries. While seagrass beds are a common habitat for juvenile gag in both environments, fringing mangroves also provide structure and large areas of suitable habitat not previously reported for this species.

3.29 Recruitment and Essential Habitat of Juvenile Sand Seatrout (*Cynoscion arenarius*) in Four Estuaries along the West Coast of Florida. (Purtlebaugh and Rogers, 2007)

This paper, published in the journal Gulf of Mexico Science, analyzes the relationships between spatial and temporal distributions of juvenile sand seatrout to various habitat parameters along the gulf coast of Florida. A stratified-random sampling design was used to sample and estimate the relative abundance of juvenile sand seatrout in Apalachicola Bay and the Suwannee River estuary (the northernmost estuaries) and Tampa Bay and Charlotte Harbor (the southernmost estuaries). A bag seine was used to sample “shoreline”, “offshore”, and “river” habitats while otter trawls were utilized in both bay and riverine habitats. Sand seatrout samples were counted and the standard length (SL) of up to 40 individuals per sample was measured; length measurements were extrapolated to the unmeasured remainder of the sample. General water quality parameters, location, bottom type, bottom vegetation and shore type were recorded at all sample sites. Only fish ≤ 100 mm SL, generally less than one year old, were included in the analyses.

Over 25,000 sand seatrout were collected from the four estuaries; the vast majority of which (79%) were collected with trawls. May-October was the primary recruitment period in all estuaries except Tampa Bay, where recruitment began in April. Although an initial increase in abundance of sand seatrout associated with increased water temperatures was observed, there was no synchronous change between water temperature and number of sand seatrout between months. Notably, smaller individuals (<25 mm SL) were captured earlier (March) and later (Nov. and Dec.) in the two southern estuaries than in the two northern estuaries. This suggests the occurrence of some year-round spawning in the region.

Freshwater discharge, together with available suitable habitat, appeared to be significant factors influencing spatial distribution of sand seatrout among the sampled estuaries. For example, the highest densities of sand seatrout were in the small rivers and tidal creeks as opposed to the larger Apalachicola and Suwannee Rivers. Similarly, within the bays and estuaries themselves, highest abundances were observed adjacent to discharge areas. These areas of abundant sand seatrout were also characterized by unvegetated mud bottom, often associated with salt marsh vegetation. The proximity to freshwater discharge is likely a function of feeding as areas near freshwater inputs generally have higher levels of nutrients to support a greater abundance of plankton, larval fishes, and nekton. Interestingly, in each studied estuary, as individuals >70mm SL grew, they moved to areas of higher salinity.

Further study is needed to confirm optimal salinity necessary for the growth and survival of juvenile sand seatrout. This information would help to define essential habitat and help to predict the potential effects of changes in salinity on this ecologically and economically important fishery.

3.30 Long-term increase in *Karenia brevis* abundance along the Southwest Florida Coast. (Brand and Compton, 2007)

This paper, published in the journal Harmful Algae, examines spatial and temporal patterns of the toxic dinoflagellate *Karenia brevis* along the southwest coast of Florida between Tampa Bay and Sanibel Island from 1954 to 2002. Although *K. brevis* occurs naturally within the Gulf of Mexico in relatively low concentrations, major fish kills, death of marine mammals, respiratory problems in humans and marine mammals, and bioaccumulation in shellfish consumed by humans, have been attributed to larger and denser blooms. This investigation evaluated the possibility that *K. brevis* blooms have increased over the last 50 years throughout the study area. Raw data, collected by a variety of people and organizations, between January 1954 to May 2002 from Tampa Bay to Sanibel Island were assessed for sampling bias. A potential for bias was observed between 1964 and 1993 when a considerably lower monthly sampling effort was observed. As a result, data from within this time range was excluded from analysis. Using normalized data to reduce a possible “observer effect”, *K. brevis* was found to be significantly more abundant along the shoreline than offshore. After binning the data by month to avoid the potential effect of increased sampling efforts during observed blooms, an 18-fold increase was identified in *K. brevis* abundance from the 1954 – 1963 period to 1994 – 2002 period. Lastly, any potential bias introduced in more recent years by remote sensing used for detection of *K. brevis* blooms was deemed insufficient to explain the large increase in the dinoflagellate concentration over time and the change in the seasonal pattern of *K. brevis* occurrence. Similarly, no known long-term changes or oscillations in the ecosystem have been identified to predict an increase in *K. brevis* over time.

The maximum biomass of *K. brevis* that can develop is defined by the availability of nutrients. As a result, the increased abundance and highest achieved concentrations of *K. brevis* over time suggests an increase in nutrient availability. Land-based sources of nutrient-rich water are likely factors contributing to higher concentrations of the dinoflagellate nearshore rather than offshore. As there has not been a natural increase in sources of nutrients to the magnitude needed to support the higher abundance of *K. brevis*, the large increase is likely related to the rising human population and related activities of South Florida and the associated effects (e.g., increased sewage output and high-nutrient surface runoff, reduced ability of remaining ecosystems to sequester nutrients, release of buried nutrients). Authors of this study hypothesize that nutrients resulting from a combination of anthropogenic-related sources introduced to the inshore system and associated nutrient pool through river flow, non-point source inputs, and groundwater are the major factor contributing to increased dinoflagellate blooms.

3.31 National Estuary Program Coastal Condition Report, Chapter 5: Gulf of Mexico National Estuary Program Coastal Condition, Charlotte Harbor National Estuary Program. (June, 2007)

In June, 2007 EPA issued the National Estuary Program (NEP) Coastal Condition Report, the third in a series of coastal environmental assessments. The report includes results from estuarine monitoring conducted by EPA, and estuarine monitoring conducted by individual NEPs. The primary concerns identified for Charlotte Harbor are hydrologic alteration, water quality degradation, and habitat loss. Among the challenges identified for the estuary were securing new water supply sources for the region's growing population, protecting wetlands for water retention, groundwater recharge, and wildlife, and improving the efficiency of freshwater usage. The population of the 10 county area designated as part of the CHNEP coastal region increased from 0.8 to 3.0 million people between 1960 and 2000. This growth rate was approximately double the rate found over the entire Gulf Coast.

The report rates the overall condition of Charlotte Harbor as fair. Water quality was rated poor, while sediment quality was rated good, and benthic communities were rated fair. In the water quality subcategories Charlotte Harbor rated good for dissolved inorganic nitrogen, fair for dissolved oxygen, and poor for dissolved inorganic phosphorous, water clarity, and chlorophyll-a. No data were available to assess sediment or fish tissue contamination.

In general water quality problems are attributed to population growth, stormwater runoff, and agriculture/industry. Seagrass habitat is considered the key indicator of habitat quality, and seagrass in the northern portion of the estuary is considered to be in a stable condition. Seagrass habitat in the southern portion of the estuary was being analyzed at the time of this publication.

3.32 Relative Abundance and Distribution of Sand Seatrout (*Cynoscion arenarius*) in Relation to Environmental Conditions, Habitat, and River Discharge in Two Florida Estuaries. (Knapp and Purtlebaugh, 2008)

This paper, published in the journal Gulf of Mexico Science, examines the relative abundance and habitat preferences of sand seatrout >100 mm standard length (SL) in the Tampa Bay (1997-2004) and Charlotte Harbor (1999-2004) estuaries on Florida's west coast. Existing long-term fishery-independent monitoring data, collected by the Florida Fish and Wildlife Conservation Commission (FFWCC), Fish and Wildlife Research Institute's Fisheries-Independent Monitoring Program, were used to evaluate factors including physical habitat, environmental conditions, and freshwater discharge rates on the relative abundance and distribution of sand seatrout. A monthly stratified-random sampling design was used to collect sand seatrout using a terminal-bag purse seine in water depths ranging from 1.0 to 3.3 m at sampling sites selected randomly by using a predefined grid system. Sand seatrout samples were counted and the standard length (SL) of up to 40 individuals per sample was measured; length measurements were extrapolated proportionally to the unmeasured remainder of the sample. General water quality parameters, location, bottom type, and bottom vegetation were recorded at all sample sites.

Nearly 9,000 sand seatrout, between 101 to 343 mm SL, were collected from Tampa Bay and Charlotte Harbor; relative abundance in Charlotte Harbor was nearly twice that in Tampa Bay. Pearson correlation analysis comparing results from this study to annual recreational and commercial harvest data for sand seatrout from the west coast of Florida (1997-2004) indicate that 1) the methods used in this study were effective for sampling sand seatrout entering the fishery and 2) the results are relevant to the future management of this species.

Bottom substrate, depth, and month were all important factors influencing relative abundance of sand seatrout in both estuaries. Relative abundance was at least 1.5 times greater over mud substrate than sand bottom and increased in February/March and decreased in July/August; seventy-five percent of all sand seatrout were collected from >2.0 m deep. The preference for unvegetated mud habitat may be related to salinity levels, high availability of prey, low competition for space and food, and optimal conditions for metabolic rate, growth, and survival of the species. The seasonal trend may be due to responses to changes in water temperature to avoid extremes but may also reflect the movement of reproductively active fish or spawning activity.

As suggested in Purtlebaugh and Rogers (2007) (summary above), as fish increased in length, they trended toward areas of higher salinity. In this study, while individuals of 145-175 mm SL were present in the lower-salinity waters near river mouths, those >175 mm SL occupied higher salinity, seaward areas of the estuaries. This movement may be related to changes in feeding preferences, the search for deeper spawning habitat, or the need to reduce osmoregulatory stress. In both Tampa Bay and Charlotte Harbor, sand seatrout 155 to 255 mm SL also declined with increasing freshwater discharge. This decrease may be the result of higher mortality, migration out of the estuary, or the search for higher salinities in deeper waters (not sampled in this study).
Management of sand seatrout along the west coast of Florida would benefit from additional studies to better understand reproduction, mortality and movement of the species.

3.33 Scientific Peer Review of the Proposed Minimum Flows and Levels for the Lower Peace River and Shell Creek. (Montagna et al 2008)

The District convened a panel of experts – referred to as the MFL Scientific Peer Review Panel (the Panel)- to provide a peer review of the lower Peace River MFL evaluation report. This panel review was published in April 2008. The purpose of the report is to provide a critical review of the methods, data, and conclusions in the report. After the peer review committee submitted their findings the report was revised substantially, with a final report being submitted in April 2010. The changes made to that final report are not reflected in the comments contained in this review.
The issue on which the reviewers place most emphasis is the conceptual model linking ecological resources to salinity criteria to salinity models to the MFL recommendations. It is noted that errors in any of these linkages will cause errors in the MFL recommendations, and that there are two apparent sources of error. One is in the large variability of ecological responses to salinity and the other is in the often large error in the salinity prediction models. The Panel recommended performing error analysis on the salinity models to further explore these sources of error.

The Panel found that the data and information used to generate the MFL recommendations were appropriate and technically sound, and that the data used was the best available data. The Panel found that the report made reasonable effort to describe the assumptions that were made during the course of data analysis. The analyses that were most heavily burdened with these assumptions were the hydrodynamic and conservative mass transport salinity models. The assumptions used in these efforts did appear to be based on the best available information. In general the analyses used were found to be technically appropriate and based on the best available information.

The Panel offered six questions that still needed to be answered to further validate the MFL recommendations. These questions were:

1. Does the biological analysis support using salinity zones to define habitats?
2. Does the hydrodynamic model (or regression model) adequately predict the salinity regimes under a variety of flow rates for the purposes of the CDF analysis?
3. Are the divisions used (Blocks, low/high flow, salinity ranges) appropriate for the critical habitat?
4. Is the conflating of space and time in the CDF curve reasonable for habitat prediction?
5. Does the difference between the areas under the CDF curve reasonably predict the habitat loss expected?
6. Is a 15% measure of habitat loss appropriate and supported by the uncertainty of the method?

The Panel concluded that there were three principal deficiencies in the proposed MFL. First, the error in the hydrodynamic model predictions had not been adequately quantified, so the underlying foundation of the MFL was still open to question. Second the relationship of the hydrodynamic model error to the error in the cumulative distribution function curves had not been reviewed. Third, there was no analysis of the error in the modeled area of lost habitat. This error could be large as it is a compound function of error in the three models which contribute to the lost habitat projection.

3.34 Comparison of Fish Community Metrics to Assess Long-term Changes and Hurricane Impacts at Peace River, Florida. (Champeau et al., 2009)

This paper, published in the journal Florida Scientist, compares the size and structure of Peace River fish communities assessed in 2005 – 2006 (post-hurricane) to those evaluated in 1983 – 1992. Although two years of data is not sufficient to compare to historical records after 13 years without data, results from this study provide a new baseline on which to build upon for future comparisons.

Standardized boat electrofishing was used to collect fish from 0.5 to 2.5 m depth at four sites along the Peace River. Fish were collected from a variety of habitats along the river edge. All fish were measured prior to release and location. GPS coordinates, river stage, flow rate and specific conductivity were recorded for each sample. Community metrics used to evaluate ecological stability of the system, including species richness, species diversity, numeric abundance and biomass indices for native and exotic species, and fish community composition, were calculated.

Although differences were detected, significant trends in abundance and biomass of native and exotic fishes and species richness were not identified among years. Fish community composition, however, differed between the post-hurricane sampling events of 2005 – 2006 and the historic period (1983 – 1992). For example, some rare native species documented in the river's mainstem during the historic period were not observed in 2005 – 2006. This is likely due to the recent reduced sampling effort. In contrast, few native species collected during the recent sampling were not included in the historic record. This observation is likely the result of 2004 flood conditions associated with hurricanes that led to high reproduction and disruptions in the fish community. At least four exotic species were also newly documented in the 2005 – 2006 sampling. Some of these species may be underrepresented due to their low vulnerability to electrofishing gear. In contrast, percent composition of other exotic species appears to have decreased over time. Additional studies are needed to understand the role and interaction of exotic fish species in the Peace River.

This study suggests ecological stability of the Peace River despite an increase in exotic fish species after the flooding and hypoxia resulting from the 2004 hurricanes. However, chronic low-flow conditions are the current and future threats to the Peace River fishes. As a result, investigations focusing on the impacts of such conditions are needed and could help to improve water management practices.

3.35 Use of Rivers by Common Snook *Centropomus undecimalis* in Southwest Florida: A First Step in Addressing the Overwintering Paradigm. (Blewett et al., 2009)

This paper, published in the journal Florida Scientist, examines the seasonal abundances and size distribution of common snook, *Centropomus undecimalis*, in the Charlotte Harbor estuary and three contributing tidal rivers (Peace River, Myakka River, and Caloosahatchee River) with various developmental and environmental characteristics. The paradigm for common snook was believed to entail movement from open estuary shorelines to warmer rivers, creeks, and canals for purposes of overwintering; however, information on the use of rivers by common snook is limited.

Common snook and largemouth bass were sampled seasonally in the Peace and Myakka rivers from November 2004 to August 2006 and in the Caloosahatchee River from May 2005 to August 2006 using electrofishing transects at >0.9 m and >1.7 m depths. Standardized fixed and stratified-random seasonal sampling sites were chosen by dividing each of the three rivers into zones to ensure adequate sampling coverage; angler knowledge was used to select fixed sites to ensure adequate abundance of common snook. Only natural shorelines were sampled in the Peace and Myakka rivers while both natural and dredged shorelines and areas surrounding man-made structures were sampled in the Caloosahatchee River. Total length (TL) measurements were taken for common snook before live release.

Common snook size and abundance data for the Charlotte Harbor estuary was obtained from the Fish and Wildlife Research Institute's Fisheries-Independent Monitoring program from January 1997 through December 2007. These data represent monthly captures of common snook using a standardized random sampling protocol along shorelines throughout the Charlotte Harbor estuary. Samples were collected using a 183-m center-bag haul seine at depths at or above 2.5 m. Standard length (SL) measurements were converted to TL. Surface and bottom temperature and salinity were noted.

A total of 1,144 common snook were collected from fixed and random sampling locations across the three rivers. Similar catch rates were observed within each season at both site types with the exception of greater numbers during winter at the deeper fixed locations. Although depth at fixed sites was greater than that at random sites, there was no difference in temperature observed. A study using an array of temperature loggers would be needed to better assess the role of temperature in these areas.

In each of the three rivers, greatest numbers of common snook were typically observed in fall, followed by winter and spring and summer, respectively. This is not consistent with the overwintering paradigm. There was no observed seasonal change in the size distribution of common snook in the rivers.

Data from Charlotte Harbor estuary included measurements for 7,761 common snook. Generally, greatest abundance was observed in the summer and lowest abundance in the winter. As with the observations in the rivers, there was no observed change in the size distribution of common snook in the open estuary by season.

Average seasonal temperatures from the rivers and open estuary were similar while salinities were expectedly higher in the estuary. These data suggest movement of the common snook population between rivers and the open estuary that is not related to fish size. The significant decrease in abundance in the open estuary during the winter may be due to the use of nearby warm water sites outside of the sampling area as well as larger-scale movements into rivers. The movement of common snook between the open estuary and rivers across seasons may be related to reproductive success and the use of a protracted spawning season.

3.36 Trends and explanatory variables for the major phytoplankton groups of two southwestern Florida estuaries, U.S.A. (Dixon et al, 2009)

This paper, published in the Journal of Sea Research, analyzes the relationships between nutrient concentrations and phytoplankton communities in Tampa Bay (1995-2004) and Charlotte Harbor (1989-2001). Phytoplankton samples collected in Tampa Bay and in Charlotte Harbor were enumerated, identified to the lowest practical level, and biomass was estimated by concentration of chlorophyll-a. Water quality data were gathered from long term monitoring programs in each estuary.

Tampa Bay was generally more saline than was Charlotte Harbor. There is substantial phosphorus loading in both systems, such that both systems are nitrogen limited. Phosphorus loading to Tampa Bay had been higher than to Charlotte Harbor, however loading to Tampa Bay has declined and the two systems are now similar. Color in Charlotte Harbor was approximately twice the color in Tampa Bay. Water temperature exhibited a significant increasing trend in

Tampa Bay, but not in Charlotte Harbor, likely due to the low temperatures occurring in the early 1980’s. Chlorophyll-a declined at all stations in Tampa Bay, and for the least saline stations in Charlotte Harbor. Concentrations of all nitrogen and phosphorus species declined in nearly all Tampa Bay stations, but declines in nitrogen were less substantial than declines in phosphorus resulting in an increased nitrogen to phosphorus ratio. In Charlotte Harbor nitrogen increased at all stations, while phosphorus decreased, resulting in an increased nitrogen to phosphorus ratio at most stations.

There were 230 species of phytoplankton observed in Tampa Bay, versus 131 in Charlotte Harbor. This difference is likely due to the differences in salinity between the two systems. At stations with comparable salinities richness between the two systems was very similar. In both systems diatoms were the dominant taxonomic group, followed by dinoflagellates and then by cyanobacteria. When similar stations were compared between the two systems, Tampa Bay had relatively high counts of diatoms and flagellates, while Charlotte Harbor had higher dinoflagellates and cyanobacteria. In Tampa Bay, nearly all stations experienced a significant decline in cyanobacteria. The trends in both Tampa Bay and Charlotte Harbor were primarily decreasing, however the decrease in cyanobacteria in Tampa Bay was the strongest trend observed. Seasonality played a significant role in determining phytoplankton community composition. Group community structure alone was not a good predictor of nutrient loads or eutrophication. The phytoplankton community responded gradually to decrease nutrient loading due to the reservoir of nutrients present in the systems.

3.37 Hydrodynamic and Water Quality Modeling Report for Peace River and Charlotte Harbor, Florida. (USEPA, 2009)

This document, published in September 2009, documents the development and calibration of a hydrodynamic model and a water quality model to simulate the fate and transport of nutrients, organic materials, and dissolved oxygen (DO) in the impaired water bodies flowing to Charlotte Harbor. The Environmental Fluid Dynamics Code (EFDC) model was selected for use. EDFC has 1-D, 2-D, and 3-D functionality, and models transport and biogeochemical processes. It is supported by the USEPA and is used extensively in Total Maximum Daily Load (TMDL) development throughout the United States. The water quality model selected is the USEPA Water Quality Analysis Simulation Program (WASP) 7.3. WASP utilizes user specified parameters, and considers the processes of advection, dispersion, point and non-point loading, and boundary exchange. The parameters simulated for the analysis of the waters flowing to Charlotte Harbor were ammonia, nitrate+nitrite, organic nitrogen, orthophosphate, organic phosphorus, CBODu, phytoplankton, and dissolved oxygen. In addition to the WASP model a spreadsheet model was used to establish a link between loads versus sediment oxygen demand for Little Charlie Creek and Bear Branch. The hydrodynamic model simulated circulation, water temperature, and salinity under the watershed freshwater inflows with open boundaries. Watershed inflows were considered pure freshwater with salinity set to 0 psu. Tide data at Port Boca Grande were used as the elevation boundary condition. Water temperature at the open boundary was assumed to be the same as temperature at USGS station 0229700. Salinity boundary conditions were set to a constant 35 psu.

The hydrodynamic model was calibrated based on 2003-2004 data. This was considered sufficient to remove the need for additional model validation, as it was stated that 2003-2004 encompassed both wet and dry conditions. The model captured the magnitude and phases of elevation changes caused by tide and freshwater inflows. Discrepancies in water level were attributed to the open boundary location being inside Charlotte Harbor while the tide data used was not open ocean tide data. Generally, modeled water temperature agreed well with data at all stations. Temperature at upstream stations was influenced significantly by inflows. Discrepancies with modeled salinity were attributed to uncertainty with modeled watershed inflows, and lack of an observed open boundary salinity.

Charlotte Harbor was divided into 858 segments (429 surface, 429 bottom) for the WASP model. WASP cannot deal with open boundary conditions, therefore the elevation boundary conditions generated from the hydrodynamic model were used. The WASP model simulated conditions for the 2003-2004 period. The model requires the input of boundary conditions, the modeled concentrations of ammonia nitrate+nitrite, organic nitrogen, orthophosphate, organic phosphorus, and CBODu from the LSPC (Load Simulation Program in C++) model were used for inflow conditions, while observed data were used for the tidal flows (it is noted that the availability of these data was very limited). WASP requires that initial concentrations of simulated constituents be specified. For these simulations all nutrients were set to 0.01 mg/L, dissolved oxygen was set to 8 mg/l, chlorophyll a was set to 1 ug/l, and CBODu was set to 1 mg/l. These concentrations changed quickly after responding to the boundary conditions. Model validation was combined with calibration for the same reasons stated in the hydrodynamic model section. Discrepancies in the modeled results were attributed to uncertainties in the estimations of watershed loading. Scenarios were run for the developed watershed and for the natural condition (developed lands replaced with forested land in the simulation). The results of these two scenarios were compared to quantify the impacts of development. The results of these comparisons were not interpreted, only presented in raw graphical form.

3.38 The Effects of Climate Change on Florida’s Ocean and Coastal Resources. A special report to the Florida Energy and Climate Commission and the people of Florida. (Florida Oceans and Coastal Council, 2009)

This report was produced in order to provide a basis for discussions on the impacts to Florida due to global climate change. It provides information for legislators, policymakers, agencies and the public. The report is intended to be updated periodically. The report states that global climate change is a reality, and concludes that most of the observed temperature increase since the mid-20th century is very likely caused by increased concentration of greenhouse gases from human activities. The issue for Florida is what the long term effects of this climate change will be. Florida has over 1,200 miles of coastline, nearly 4,500 square miles of estuaries and bays, more than 6,700 square miles of other coastal waters, low elevation topography, and most Floridians live within 60 miles of the coast. The state’s economy depends on preserving coastal and marine resources for the long term.

The report identifies four main components (referred to as drivers) of climate change:

- Increasing concentration of greenhouse gases
- Increase air temperature and water vapor
- Increasing ocean temperature
- Increasing sea level

None of the effects of climate change are predicted to be a benefit to Florida's natural resources or human population. The potential impacts on the state's infrastructure, human health, and economy are significant. The report lists a number of known and probable impacts of climate change. The report states that some of these impacts are already affecting Florida, and the time will come when Florida is simultaneously and continuously challenged by many of these effects. The long term extent of these impacts is said to be governed by the ability of human society to reduce or eliminate sources of greenhouse gases.

3.39 City of Punta Gorda Adaptation Plan. (SWFRPC and CHNEP, 2009)

This technical report, authored by The Charlotte Harbor National Estuary Program (CHNEP) and, its host agency, the Southwest Florida Regional Planning Council (SWFRPC), identifies and discusses the adaptation alternatives that could be implemented in south Florida to address climate change vulnerabilities in the City of Punta Gorda. These alternatives, developed with the help of the City of Punta Gorda and their citizen stakeholder group, Team Punta Gorda, provide options from which the City could select from for implementation, adaptive management, and subsequent monitoring.

The process of developing this Adaptation Plan began with an assessment of vulnerability which was based upon the City's sensitivity to climate changes and its ability to adapt to these changes. As part of this process, a risk analysis was conducted to 1) identify those hazards most likely to impact the City of Punta Gorda (e.g., flooding, coastal storms and erosion), 2) profile hazard events in terms of causes, characteristics, past impacts, and areas of vulnerability, 3) create an asset inventory for each identified hazard area, and 4) estimate potential loss. In addition, in an effort to balance the risk and vulnerability assessments with the goals and objectives of the City, several factors were considered when assessing management priorities (e.g., timing and severity of projected impacts, probability of occurrence of different impacts, constraints).

One of the key components in developing this adaptation plan was to gain the input and consensus of the stakeholder community throughout the process. Outreach and organization of stakeholders was accomplished with the help of Team Ponte Gorda and various media outlets. Three public meetings were held over a period of five months. The first meeting began with the distribution of a questionnaire to gain background on the attendees and their thoughts and opinions. Presentations were given and group activities were performed resulting in 1) the selection of the most important climate change vulnerabilities of the City, 2) the generation of alternative adaptation strategies, and 3) a sense of agreement by the participants for each of the identified adaptation measures previously identified. The second workshop focused on reviewing the previously developed adaptation strategies and allowed participants the opportunity to recommend locations where possible adaptations should be implemented.

A total of 54 vulnerabilities that addressed eight major areas of climate change vulnerability for the City were identified through the public workshops. In order of priority, the eight major vulnerabilities include: 1) fish and wildlife habitat degradation; 2) inadequate water supply; 3) flooding; 4) unchecked or unmanaged growth; 5) water quality degradation; 6) education and economy and lack of funds; 7) fire; and 8) availability of insurance. The potential impacts associated with each of these categories of vulnerability are discussed in the report and the critical areas for adaptation planning and implementation are identified.

There were also 104 acceptable and 34 unacceptable climate change adaptations identified during the public workshops that could be used to address the different vulnerabilities for the area. These actions focus on four basic strategies for preventing or minimizing impacts of climate change - avoidance, mitigation, minimization, and adaptation. Only the most favored adaptation for each vulnerability area is discussed in detail. These priority adaptations are recommended as the basis for development of the first implementation plans by the City of Punta Gorda. Summary tables of selected and undesirable adaptations are provided for each of the eight categories of vulnerability.

As a progressive city that has already begun implementing actions to lessen impacts from climate change and improve the overall standard of living for its citizens, all of the adaptations that have been identified in this document can be easily incorporated into the City of Punta Gorda’s envisioned 2025 Comprehensive Plan. An adaptive management strategy, based upon the lessons learned from the monitoring and evaluation of results, will be used to continually update and maintain the Adaptation Plan as a living document. It is recommended that this plan be revisited to evaluate success and to determine the next set of priority adaptations for implementation.

3.40 Hydrologic Conditions that Influence Streamflow Losses in a Karst Region of the Upper Peace River, Polk County, Florida. (Metz and Lewelling, 2009)

This document, prepared as a U.S. Geological Survey Scientific Investigations Report, evaluates hydrologic, lithologic, geophysical, and water-chemistry data to assess influences of streamflow losses in a karst region of the upper Peace River from 2002-2007 (water years). Historically, artesian wells and springs discharged water into the Peace River; however, as a result of extensive groundwater withdrawals beginning in the 1930s, flow from the upper Peace River, from Bartow to Fort Meade, now moves from the river to the underlying aquifers. Although streamflow appeared to have stabilized in the 1970s, significant declines were observed in the 1940s – 1960s and again between the 1970s and 2003.

Declines in streamflow have been affected by rainfall, significant groundwater withdrawals, changes in natural drainage patterns contributing to the river, changes in surface sediments, and the presence of numerous karst features in the upper basin. Notably, phosphate mining and agricultural activities throughout the upper Peace River basin have substantially altered the landscape and associated drainage system. Meandering tributaries with sloping gradients that once contributed large volumes of water to the upper Peace River were replaced by flat ditches and clay-settling ponds that store large quantities of water available to evaporation.

A combination of hydrogeologic techniques was used to gather information about the hydraulic connection between the upper Peace River and the underlying aquifers. Wells were drilled in the surficial aquifer, intermediate aquifer system, and Upper Floridan aquifer at three sites along the Peace River floodplain to define rock formations and aquifer properties. Geologic cores were collected at the three well sites in an effort to define the hydrogeologic framework. Aquifer performance tests, geophysical logging, and downhole video analyses were also conducted at the three well sites to better understand the hydraulic properties of the rock-bearing formations below the upper Peace River basin. In addition, borehole geophysical surveys were used at these locations to assist in determining aquifer properties. The numerous karst features and fractured carbonbates and cavernous zones observed suggest use of a well-connected groundwater flow system with large transport and storage capacities.

Groundwater flow patterns along the Upper Peace River were studied with 12 continuous monitoring wells used to identify water-level trends in the underlying aquifers. Additional wells extending into the Upper Floridan aquifer were located throughout the upper Peace River basin and used to create potentiometric-surface maps of the area. Although these maps show a rise in aquifer water levels since 1975 when groundwater usage associated with mining peaked, 2007 levels were still up to 30 ft below the Peace River floodplain elevation due to pumping stresses associated with increased population and agricultural expansion. The hydrologic relationship between Dover and Gator sinks, two significant karst features, and streamflow losses, was studied using continuous water-level recorders. Because of the current groundwater head gradient, these features, as well as numerous others in the area, are responsible for large amounts of streamflow loss. Selected wells in the intermediate aquifer system and the Upper Floridan aquifer were used to collect water-quality and stable isotopic samples to assist in understanding the relationship and flow paths between the river water and the underlying groundwater system. Using these analyses, water from the Peace River was distinctly identifiable in the upper Floridan aquifer.

Seasonal flow measurements were collected at 10 USGS continuous gauging-stations located along the upper Peace River and adjoining tributaries. During the study period, river discharge peaked in 2005 due to high rainfall amounts in 2003-2005. In contrast, river discharge dropped to its lowest levels in 2007 after a two-year cumulative rainfall deficit. In addition, the largest streamflow losses were observed at the beginning of the summer wet season after groundwater levels dropped and large volumes of water were needed to fill the voids in the underlying aquifers. Seepage runs were performed along a 13-mile segment of the river in an effort to determine where streamflow losses and gains were occurring. The size and locations of major karst features were recorded and streamflow losses associated with each feature was quantified. The greatest observed losses resulted from 10 karst features, most importantly Ledges Sink and Dover Sink, located within a two-mile section of the Peace River approximately one mile south of the Bartow gauging station. In Reach 1, along the upper part of this two-mile section, the intermediate aquifer and the river are hydraulically connected. As a result, streamflow losses were proportional to changes in the aquifer water level. In contrast, Reach 2 of the Peace River, located along the end of the two-mile section, is connected to both the intermediate aquifer system and the Floridan aquifer through a large conduit system associated with Dover Sink that accommodates large volumes of water from the river at multiple stages.

3.41 Effect of Groundwater Levels and Headwater Wetlands on Streamflow in the Charlie Creek Basin, Peace River Watershed, West-Central Florida. (Lee et al., 2010)

This document, prepared as a U.S. Geological Survey Scientific Investigations Report, evaluates streamflow, groundwater elevation, and rainfall data to characterize how seasonal-flooding of headwater wetlands and groundwater interactions with Charlie Creek, its tributaries, and headwater wetlands affect streamflow in the Charlie Creek Basin. Although the Charlie Creek basin is a relatively undeveloped area of the Peace River watershed with modest groundwater withdrawals, pumping efforts in the adjacent regions are considerably higher and can lead to decreased Upper Floridan aquifer heads in the Charlie Creek basin.

Data used in this study were collected from April 2004 through January 2006; existing lithologic logs were also utilized. Results of the numerical MIKE SHE model used to simulate the integrated surface and groundwater flows in the sub-basins of Charley Creek and resulting water budgets for the entire 330-squre mile basin and five individual sub-basins are also presented. Seepage runs were performed along the main channel of Charlie Creek to determine areas where groundwater was entering or leaving the stream along six reaches within the Lower Charlie Creek sub-basin. In the lower half of the basin, the presence of fractured carbonate rocks that crop out in the streambed may provide preferential flow paths for groundwater. Stream discharge and specific conductance (used to interpret the concentration of dissolved minerals in the basin stream waters) were also measured. Results indicate that agricultural land-use practices, particularly citrus land use, in the basin have increased the specific conductance of the stream waters.

The hydrogeologic units and land-surface elevations of the basin were characterized using well logs from the Florida Geological Survey and Southwest Florida Water Management District (SWFWMD) and LIDAR data provided by the SWFWMD, respectively. A great deal of attention was focused on the intermediate aquifer system because of the high variability of permeable and non-permeable layers within this unit and the resulting interactions with the overlying surficial aquifer or stream channels; two extensive permeable zones, Zones 2 (the upper Arcadia aquifer) and 3 (the lower Arcadia aquifer), were evaluated in this study. A digital elevation model (DEM), used for several analyses in the study, was also developed. Twenty-nine shallow monitoring wells were drilled to collect water-table elevation data; data were supplemented using existing wells and stratigraphic logs. Shallow wells were also drilled along two transects, approximately 14 river miles apart, crossing Charlie Creek. Existing wells maintained and monitored by the SWFWMD as part of the Regional Observation and Monitor-well Program (ROMP) were used to examine vertical head differences between the surficial aquifer, the intermediate aquifer system, and the Upper Floridan aquifer.

Data collected from the monitoring wells were used to create potentiometric surface maps that, together with the DEM, allowed for determinations of where aquifer heads exceeded land surface (and streambed) elevations. The maps demonstrated that downward recharge of groundwater between the surficial aquifer, the intermediate aquifer system, and the Upper Floridan aquifer dominated throughout much of the Charlie Creek basin. In two areas of the basin, the higher volume of groundwater pumped from the intermediate aquifer resulted in upward movement of groundwater from the Upper Floridan aquifer. When artesian head conditions in the intermediate aquifer system were high, upward flow into the surficial aquifer was observed and waters in associated wetlands did not recharge downward. This resulted in increased streamflow in the Charlie Creek basin. In contrast, when artesian head conditions in the intermediate aquifer system were decreased or non-existent, the magnitude of streamflow also decreased. This is especially important in the upper part of the basin where headwater wetlands and stream channels are located. These wetlands and depressions within the upper half of the basin also provide storage capacity which causes less generation of streamflow per unit area than the lower half of the basin.

Artesian head conditions in the intermediate aquifer system within the Lower Charlie Creek sub-basin caused upward movement of water into the surficial aquifer below the stream and appeared to be more vulnerable to groundwater pumping effects than the other sub-basins during the study period.

The dynamic balance between wetland storage, rainfall-runoff processes, and groundwater-level differences in the upper half of the basin, allow this area to generate approximately half of the streamflow from the Charlie Creek basin. Modification of the wetland landscape during high flow conditions or reduction of groundwater levels could cause significant decreases in streamflow in Charlie Creek and possibly the Peace River. In addition, increased groundwater withdrawals from the Upper Floridan aquifer would likely change artesian head conditions resulting in an increased potential for downward groundwater flow and less upward discharge into the surficial aquifer.

3.42 Modeling water quality and hypoxia dynamics in Upper Charlotte Harbor, Florida, U.S.A. during 2000. (Kim et al, 2010)

This paper, published in the journal Estuarine, Coastal, and Shelf Science, describes the results of modeling the water quality dynamics of Upper Charlotte Harbor. Hypoxia (dissolved oxygen < 2.0 mg/l) is known to occur in the bottom waters of Upper Charlotte Harbor. Upper Charlotte Harbor is the receiving water body for both the Peace and Myakka rivers. During periods of high flow vertical stratification occurs in the waters of Upper Charlotte Harbor. The presence of this stratification allows for sediment oxygen demand (SOD) and other processes to deplete the available oxygen. Organic carbon loads to the sediments of Upper Charlotte Harbor have increased over the past two centuries, increasing SOD. It is expected that increased future nutrient loading will lead to increased organic deposits and further increases in oxygen demand.
This study used data from 2000 and a three dimensional model to study the dynamics of bottom water hypoxia and water quality in Upper Charlotte Harbor. The results of the model indicated that this model was comparable or better than previous models. As this model run used monthly SWFWMD data in Upper Charlotte Harbor, it would have benefitted from a more robust data set. Hypoxia was predicted in the areas in which it was observed in the field data, primarily nearer the river mouths where stratification is highest. Stratification and SOD, as well as nutrient loading were primary factors driving hypoxia in the model. In order to alleviate the occurrence of

hypoxic conditions it would be necessary to reduce stratification (increase vertical mixing), reduce SOD (reduced nutrient loading, lower temperatures, reduced organic material), and reduce nutrient loading.

3.43 City of Punta Gorda Shell Creek HBMP Year Five Comprehensive Summary Report. (PBS&J 2010)

This report, published in October 2010, serves to provide the SWFWMD with sufficient information to verify that Shell Creek and the lower Peace River have not been and will not be adversely impacted by the City of Punta Gorda's (the City) freshwater withdrawals. In addition to a summary of the history of the facility and associated withdrawals and monitoring, the results of the following analyses are described:

- The status and trends of hydrologic conditions within the Prairie/Shell Creek Watersheds
- Temporal and spatial patterns of water quality characteristics measured upstream of the Hendrickson Dam (Dam), summarizing water quality differences between the Prairie and Shell Creek systems and relationships with changes in flow
- Changes in key water quality parameters in the tidal reach of Shell Creek downstream of the Dam, relative to variations in flow
- Comparison of the magnitude of predicted changes in salinity below the Dam associated with the City's withdrawals from Shell Creek relative to natural variations in seasonal and annual flows

Recommendations are also made relating to possible modifications to the monitoring program elements associated with withdrawals from Shell Creek.

There is a wide range of flows over the Dam, both seasonally and interannually, but clear long-term patterns are apparent in the data. Minimum flows increased from the mid-1960s through the mid-1990s, and have since declined. There were severe droughts in 1999-2002 and 2006-2008. The period since 1995 has actually been wetter than the 1966-1994 period, however dry season flows have been exceptionally low in recent years due to drought conditions. There have been no statistically significant trends over the entire period of record. The differences in flow between no-withdrawal and withdrawal scenarios are very small relative to the natural variability in the system. Historic withdrawals have predominately influenced only the lowest 20% of flows, with appreciable changes confined to the lowest 10% of flows. Under the maximum withdrawal scenario the lowest 40% of flows would have been influenced, with the most appreciable changes occurring in the lowest 20% of flows.

Specific conductance and chloride are inversely related to flow, and specific conductance is usually higher than the required level for drinking water standards (based on the relationship between specific conductance and TDS). Statistical models were developed to assess the magnitude and duration of potential salinity changes downstream of the Dam. It is estimated that withdrawals increase salinity approximately 50% of the time, with increases ranging from 0.1 to 1.6 psu.

The Shell Creek HBMP has remained relatively unchanged since it began in 1991. Initially the Shell Creek HBMP was designed to match with the parts of the Peace River HBMP. Since that time, the effort in the Peace River HBMP has been reduced and refocused. It is recommended that the Shell Creek HBMP consider a similar redistribution of effort. Specifically the following items should be considered:

- Maintain the ongoing close monthly timing between the Shell Creek and Peace River HBMP sampling to allow for future analyses using data from both programs
- Discontinue some of the background Shell Creek HBMP lower Peace River monitoring sites that are similar to those already being monitored by the Peace River HBMP. Reduce the water quality parameters being monitored downstream of the dam to match the parameters being monitored in the Peace River HBMP
- Assess the cost effectiveness of continuous recorders to provide higher resolution data for directly assessing the impacts of freshwater withdrawals
- Determine whether the parameters being monitored above the Dam are providing the City with sufficient data relative to seasonal changes in upstream water quality

3.44 Proposed Minimum Flows and Levels for the Lower Peace River and Shell Creek. (SWFWMD 2010)

This report was published in April 2010. It was subsequently used to develop provisional minimum flows and levels (MFL) for the lower Peace River (from the Arcadia gage to Charlotte Harbor) and Shell Creek which was adopted by the Southwest Florida Water Management District (District) Governing Board. The earlier draft document was peer reviewed by a Scientific Peer Review Panel (Panel) established by the District (see Montagna et al. below). A second report (April 2009) was published, after which additional analysis and discussions with stakeholders resulted in this final document. The modifications from the 2009 iteration to this report are:

- Change in the low flow threshold from 90 cfs to 130 cfs of combined flow to the lower Peace River
- Establishment of a flow trigger (625 cfs) in seasonal blocks 2 and 3 which must be exceeded before higher withdrawal rates are initiated
- Establishment of a maximum diversion capacity (400 cfs) which limits the total amount of water which is allowed to be taken from the river
- A provision calling for re-evaluation of the MFLs within 5 years of rule adoption

In this report, minimum flows are proposed for the lower Peace River (downstream of the Arcadia gauge, including Joshua Creek, and Horse Creek), and Shell Creek below the City of Punta Gorda Dam. The approach utilized was to protect the flow regime, which is necessary to protect the ecology of the system. In order to ensure protection of the flow regime the district analyzed historic and current flow conditions to better understand the existing anthropogenic influence on the system. In order to better understand anthropogenic influences, climatic variability and long term oscillations were accounted for in the review of historical hydrologic conditions. Seasonal blocks were defined based on typical low, medium and high flow periods of the year. The ‘building block’ approach which has been the preferred SWFWMD method for determining minimum flows and levels was used in determining these MFLs. A low flow threshold (below which withdrawal is not allowed) was determined, and the percent of flow method was used to determine allowable withdrawals when flows exceed the low flow threshold. For Shell Creek, despite analysis of salinity, chlorophyll a, and dissolved oxygen no clear and easily defensible low flow threshold was identified. It was determined that the most protective criterion for Shell Creek was the maintenance of the 2 psu salinity zone. This criterion was used to determine the percent of flow which would be permissible for withdrawal from Shell Creek during each seasonal block. It was also determined that if there is no flow into the reservoir, then there is no flow required below the dam. The results of the analysis were:

- Block 1 (April 20 to June 25): 16% of flow
- Block 2 (October 27 to April 19): 29% of flow
- Block 3 (June 26 to October 26): 38% of flow

The low flow threshold for the Peace River was based on the operational capacity of the PRMRWSA facility on the Peace River. Empirical analysis indicated that saline waters would be present at the withdrawal point when the combined flows of the Peace River at the Arcadia gauge, Joshua Creek at Nocatee, and Horse Creek near Arcadia are below 130 cfs. When the combined flow is below 130 cfs facility operations are limited by the presence of high salinity water, which is not suitable for water supply. The salinity zones selected for the analysis to determine the acceptable percent of flow for withdrawal were the 2, 5, and 15 psu zones. Additionally, a portion of the lower Peace River has been shown to have high levels of fish abundance and diversity. The typical salinity levels in this portion of the river are 8 to 16 psu. Therefore an additional analysis based on maintaining the 8 to 16 psu salinity range within that portion of the river was conducted. Based upon the results of these analyses the allowable percent withdrawals from the lower Peace River are:

- Block 1 (April 20 to June 25): 16% of flow
- Block 2 (October 27 to April 19): 16% of flow when flow is at or below 625, 29% of flow when flow is above 625 cfs
- Block 3 (June 26 to October 26): 16% of flow when flow is at or below 625 cfs, 38% of flow when flow is above 625 cfs

The flow referenced in the above bullets is the combined flows of the Peace River at the Arcadia gauge, Joshua Creek at Nocatee, and Horse Creek near Arcadia. Additionally, a maximum withdrawal cap of 400 cfs was instituted. The analyses conducted indicate that surface water withdrawals at these levels are protective of the ecology of the lower Peace River.

3.45 Relative Abundance and Distribution of Common Snook along Shoreline Habitats of Florida Estuaries. (Winner et al., 2010)

This paper, published in the journal Transactions of the American Fisheries Society, describes the relative abundances, spatial and temporal distributions, and habitats of common snook in Tampa Bay, Charlotte Harbor, and the Indian River Lagoon. The fisheries-independent dataset provided by this study can assist fisheries managers in modeling fish populations on coastal and regional scales and documenting and managing critical habitats needed to support this fish species into the future.

Monthly stratified random sampling was used to collect common snook using a center-bag haul seine from each of the three estuaries from January 1997 to December 2000. Each estuary was divided into zones with similar biological and hydrological characteristics and then further divided into grids. For the west coast of Florida, the presence or absence of overhanging shoreline vegetation was used to further stratify sampling; overhanging shoreline vegetation was not commonly found in the northern Indian River Lagoon and was therefore not used to stratify sampling throughout the Lagoon.

All fish, blue crab and panaeid shrimp were identified to the lowest practical taxon and enumerated in the field as prey species. The relative abundance (catch per unit effort) of common snook was calculated, all common snook and 20-40 individuals/sample of selected invertebrates were measured. The quantity of potential prey in each haul was categorized. Location, date time, hydrologic data (i.e., water temperature, salinity, pH dissolved oxygen), and environmental parameters (e.g., water depth, bottom vegetation type and coverage,) were recorded at each site. The Indian River Lagoon was divided into northern and southern estuaries for all analyses.

Nearly 13,000 common snook were collected from over 3,000 seine hauls throughout the four estuarine areas. The longest common snook were found in Charlotte Harbor, followed by the northern Indian River Lagoon. More small common snook were collected from the Atlantic coast than the Gulf coast and in close proximity to nursery habitats. As common snook grew and reached maturity, they generally expanded their distribution across habitats.

The greatest relative abundance of common snook was found in the southern Indian River Lagoon and within the lower portions of the estuaries and near ocean inlets. This difference may be due to habitat differentiations between estuaries (e.g., bay versus coastal lagoon, available habitat) as well as more localized variables (e.g., degree of coastal development, red tide effects, local fishing pressure). Peak relative abundance was typically in the spring and early summer with considerable declines when monthly water temperatures dropped below 20°C. With the exception of the northern Indian River Lagoon, relative abundance increased with increasing temperature and salinity; salinity was negatively correlated with relative abundance in the northern Indian River Lagoon. The relationship between abundance and salinity may be explained by aggregations of pre-spawning or spawning fish that are known to group in high salinity waters.

Common snook were collected in greater numbers in Tampa Bay, Charlotte Harbor, and the southern Indian River Lagoon when overhanging shoreline vegetation and bottom vegetation were present and were mainly collected along mangrove shorelines. This suggests the importance of mangrove and seagrass habitats for this species. Catch per unit effort of common snook also increased with prey species abundance.

3.46 2010 Regional Water Supply Plan Southern Planning Region. (SWFWMD, 2011)

The Regional Water Supply Plan (RWSP) for the Southern Planning Region (SPR) details an assessment of projected water demand and available supply sources for the period 2005 through 2030, providing a framework for future water supply management decision making. The Southern Planning Region includes DeSoto, Manatee, Sarasota, and Charlotte (the portion within SWFWMD jurisdiction) Counties. This document is an update to previous versions published in 2001 and 2006. The RWSP identifies hundreds of potential options for possible future water supply development, including both groundwater sources and alternative sources. During the period since the 2006 document update the District has accomplished the expansion of alternative water supplies, increased efforts for water conservation, and expansion of reclaimed water usage. The District has also continued with the establishment of minimum flows and levels (MFLs) on a number of water bodies in the SPR.

Land use in the SPR covers a wide spectrum of uses, from industrial and mining, to various residential and agricultural classifications. The population of the SPR is projected to increase approximately 40% in the next 25 years, most of which will be due to migration. Topography in the SPR is fairly flat, with a high point of 136 ft occurring in Manatee County. Much of the SPR was drained by the construction of canals, and most of the undeveloped lands are pine flatwoods, saw palmetto, and prairie grasslands. There are seven major watersheds in the SPR, three of which have been developed to provide public water supply. There are no first order springs in the SPR. All or part of three estuaries of national significance, Tampa Bay, Sarasota Bay, and Charlotte Harbor, occur within the SPR. Also a variety of wetlands occur in the SPR, with the most extensive systems occurring in the Myakka River Watershed.

There are three aquifer systems in the SPR which have been developed for water supply, the surficial, intermediate, and Upper Floridan aquifers. The Upper Floridan is the most important source of groundwater for water supply in the SPR. There is no recharge in the Upper Floridan along the coast as this is the discharge area. Inland the recharge rate increases up to a few inches per year. In the southern portions of the SPR the Upper Floridan is highly mineralized. In these areas the intermediate has been developed for water supply.

This 2010 RWSP builds on previous work which began in the 1970’s and included collaboration with other agencies, primarily the USGS. This data allows for the complex linkages between human activities, hydrologic cycles, climatic cycles, and water quality to be better understood. These studies included:

- understanding the relationships between hydrology, groundwater usage, and lake levels

- long term cooperative studies with the USGS to improve understanding of cause and effect relationships and produce analytical tools for resource evaluation, typically focused on hydrogeology, water quality, and data collection
- a U.S. Army Corps of Engineers assessment of regional water resources, prepared to identify sources which might be used to alleviate regional water supply problems

One result of these data collection and analysis efforts has been the designation of three Water Use Caution Areas (WUCAs) due to the impacts of groundwater withdrawals. Additionally, the need for alternative supply sources was identified, and surface water sources were developed. The resulting data have also been used in analyses in support of MFL development, and various modeling efforts, including groundwater modeling, saltwater intrusion modeling, integrated surface/groundwater modeling, and regulation modeling.

The document describes in various levels of detail:

- the purpose and implementation of resource protection programs, including the Southern Water Use Caution Area and minimum flows and levels
- the applied strategies for preventing further degradation and for recovery
- the concept of reserving water for the protection of fish and wildlife or public health and safety
- the effects of climate change on regional water supplies
- current management strategies to address climate change
- future adaptive management strategies

Demand projections were made based on those reasonable uses of water anticipated to occur through 2030. Under ‘normal’ hydrologic conditions public water supply demand is projected to increase by 45 mgd in the SPR, a projection consistent with the 2006 RWSP. Under drought conditions public water supply demand was projected to increase by 47.8 mgd. Overall demand (projections for all uses) is projected to increase by 84.1 mgd under normal conditions, or 92.3 under drought conditions.

Water sources were evaluated in terms of the volume which is potentially available for development. In 2006 78 percent of the regional water supply was harvested from groundwater sources. It is assumed in the document that new water supply will be developed from alternative sources. Potential sources for large volumes of water supply include the Dona Bay/Shakett Creek system (up to 32.9 mgd, based on MFL criteria), Myakka River (up to 41.7 mgd, based on preliminary MFL criteria), Peace River (up to 80.4 mgd, based on MFL criteria), and Shell Creek (up to 14.6 mgd, based on MFL criteria). Additionally the District has set a goal to achieve 75 percent utilization of reclaimed wastewater treatment plant flows. This will offset the need for potable water supply in some industrial and landscaping uses. The document further discusses the potential for using desalination technology and aquifer storage and recovery technology to meet future demand, and the use of conservation for reducing future demand.

Comparison of the available potential supply and the projected future demand indicates that sufficient potential supply exists to meet projected future demands through 2030. The supply source with the greatest potential to meet this need is surface waters. The estimated costs per unit of supply are provided for each of the major surface water supply options, as well as for other potential water supply development projects. Additional water resource development projects are continuing, and sufficient funding mechanisms exist to support future supply.

3.47 Tracking the Multidecadal Oscillation through the last 8,000 years. (Knudsen et al, 2011)

This report was published in the journal Nature Communications in January 2011. The Atlantic Multidecadal Oscillation (AMO) describes a pattern of periodic changes in the sea surface temperature (SST) in the Northern Atlantic Ocean. In general these periods last from 60 to 90 years. The AMO is believed to affect patterns of rainfall through large portions of the northern hemisphere, leading to periods of either abundant rainfall or drought. The authors of this paper use spectral analysis of high resolution climate proxies (ice core and geologic records) from regions bounding the north Atlantic to analyze the AMO through the preceding 8,000 years.

The authors find that the duration of periods varied over time, between 55-70 years per period. When the periods were shorter the oscillations were less well defined. A comparison of the AMO record with the solar radiation cycle indicates that the AMO is not being driven by variability in solar intensity cycles. The AMO response pattern exhibits a general shift within the last 8,000 years. The signal was strongest in the Arctic latitudes during the Holocene Thermal Maximum, whereas it was strongest in the tropics after that. The AMO that is known from modern instrumentation records has a narrower band than previously believed. The variability in AMOs appears to be driven by internal ocean-atmosphere variability, atmospheric circulation patterns, and sea ice cover. The analysis suggests that during periods of higher SST in the north Atlantic the AMO influence was stronger at more northern latitudes. Given the current and expected future increase in the North Atlantic SST it is expected that the AMO will play a larger role in climate variations in the northern latitudes. The AMO shifted into a warm phase in the 1990's which may have accentuated the global warming in the period. The variability of AMOs need to be taken into account when future temperature modeling is undertaken.

3.48 A Regional Modeling Framework of Phosphorus Sources and Transport in Streams of the Southeastern United States. (Garćia et al., 2011)

This paper, published in the Journal of the American Water Resources Association, discusses the results of applying the Spatially Referenced Regression On Watershed (SPARROW) attributes model to assess the sources and transport of phosphorus to streams and downstream receiving waters in the Southeastern United States. Model results will serve to better understand and assess the regional phosphorus budget and improve load-reduction strategies.

Spatial data incorporated into the SPARROW model included those from 8,321 catchments. The temporal framework used long-term mean annual phosphorus loads calculated at 370 water-quality monitoring sites. Load estimation methods were applied to water quality and streamflow data collected between 1975 and 2004 by state and federal agencies, allowing for model inputs and outputs representative of long-term hydrologic variability. In an effort to make estimated loads compatible with source data, 2002 was established as the baseline year. A regional phosphorus index was developed using the SPARROW model.

Six of the seven source variables evaluated were determined to be statistically significant in explaining variations in phosphorus loads throughout the southeastern US. The six variables include point sources, urban land, manure, agricultural land, soil-parent rock, and phosphate mines. While manure and phosphate mines were the least significant of the variables, this is likely due to limitations in the input data. Fertilizer applied to agricultural land was not a statistically significant variable. This is likely the result of nutrient management practices and variations in the application of phosphorus fertilizer in agricultural areas underlain and not underlain by phosphate-rich limestone.

Five of the eleven land-to-water variables evaluated were statistically significant in model estimation. These variables included soil erodibility factor, precipitation, organic matter, depth to water table, and soil pH; all of these factors, with the exception of organic matter content, are included in the set of transport variables in existing P-indices of states in the Southeast. The land-to-water variables determined to be significant predictors of variability of instream phosphorus include those associated with erosion, soluble phosphorus transport, and phosphorus absorption. Most notably, those associated with absorption (percentage of organic matter, water table depth, and soil pH) are unexpected predictors of instream phosphorus load at the regional scale as they are not included in the P-indices for the majority of the Southeast. In addition, it appears that coastal wetlands, as areas with high water tables and high organic matter, have an important buffering role.

The model indicated that catchments with high background levels of phosphorus (i.e., soils naturally rich in phosphorus) and that have been impacted by human activity have the highest total yields in the Southeast. The model predictions of yield from soil parent material provided helpful baseline levels with which to compare water quality standards in the different areas throughout the Southeast.

Incorporation of additional and updated data into the model would provide more accurate results.

3.49 A Presumptive Standard for Environmental Flow Protection. (Richter et al., 2011)

This paper, published in the River Research and Applications journal, presents benefits to implementing a presumptive standard derived from a “percent of flow” (POF) approach. This approach is used to express environmental flow requirements across broad areas when the “Ecological Limits of Hydrologic Alteration” method or site-specific environmental flow determinations cannot be applied in the near future. Examples from around the world of efforts to apply such requirements based on POF expressions are described to demonstrate the feasibility of applying standards consistent with the suggested approach. These case studies include approaches taken by, or incorporated into, the Southwest Florida Water Management

District, The Great Lakes – St. Lawrence River Water Resources Compact, the European Union Water Framework Directive as applied by the UK, and the Maine Sustainable Water Use Rule. Management implications in applying this technique are also discussed.

Large-scale environmental flow standards have typically been developed using three approaches: 1) minimum flow thresholds; 2) statistically based standards; and 3) POF approaches. Minimum flow thresholds have been recognized to be insufficient in protecting aquatic habitats and can lead to the “flat-lining” of flow variability. While statistically based standards are generally more protective of flow regimes, they usually involve complex hydrologic models that are difficult to implement. In contrast, POF approaches allow for natural flow variability and implementation can be relatively straightforward. Allowing for a range of allowable water flows has been used in the case studies described with minimal, if any, harm resulting to aquatic ecosystems and species. In addition, the POF approach considers optimization of three main factors: 1) desired upstream consumption or regulation of water; 2) desired downstream uses of water; and 3) desired ecological conditions and environmental services to be maintained.

The sustainability boundary approach (SBA) was derived from a POF approach, but unlike other methods, it uses risk bands placed around natural flow variability. The natural flow conditions for a specific point of interest are estimated daily and sustainability boundaries, expressed as percentage-based deviations from natural flows, are set. The proposed presumptive standard (±20%) is based on thresholds of ecological protection supported by environmental flow assessments conducted by the authors as well as the case study review. Although this limitation is thought to be conservative, seasonal adjustments that narrow the bands of allowable alteration for smaller or intermittent streams may be required. In other instances when flows are highly fluctuating (e.g., when influenced by hydropower dams) the presumptive standard may need to be applied on an hourly basis.

In order for the presumptive standard to be properly applied, water managers will need to develop a modeling tool to estimate daily natural or baseline flow and determine whether any proposed changes would cause a violation of the standard. Daily flows at key locations would need to be monitored to verify and refine model results and allow for regulatory enforcement. If a monthly allocation is desired, the system must be modeled at a daily time step to check for compatibility with the standard. Although developing the necessary hydrologic modeling tools and implementing this type of water monitoring may be expensive and require adequate technology and expertise, the authors strongly suggest giving priority to this type of investment in water management. The result will prove useful for initial water planning that requires less technological investment.

3.50 Distribution and Abundance of Introduced Fishes in Florida’s Charlotte Harbor Estuary. (Idelberger et al., 2011)

This paper, published in the journal Gulf and Caribbean Research, builds upon the comprehensive list of fish species known to occur within the Charlotte Harbor estuarine system (including the Caloosahatchee River, southern Matlacha Pass, and southern Pine Island Sound) earlier described by Poulakis et al. (2004). Updates to the list of icthyofauna present within the system were determined using Florida Fish and Wildlife Conservation Commission (FWC) Fish and Wildlife Research Institute's (FWRI) ongoing Fisheries-Independent Monitoring (FIM) program data from 1989 to 2007.

Samples were collected generally during the day in spring and fall from 1989 to 1995 and then monthly to 2007 throughout a study area that varied slightly over the years. A variety of sampling gear, including a 21.3 nylon bag seine, a 6.1 m otter trawl, 183 m center-bag haul seines, 183 m center-bag purse nets, and 180 m gill nets were used to sample a wide range of fish sizes and types. Sampling locations were selected using a stratified-random design. All fish and selected invertebrates were identified to the lowest possible taxon and enumerated. The standard length (SL) of up to 40 randomly chosen individuals of each taxon was determined. Hydrologic data, date, location, depth, and bottom and shoreline descriptors were recorded.

While the former study by Poulakis et al. included five introduced species, the 7,459,363 individuals belonging to over 260 taxa of fishes and commercially important crustaceans assessed in this study, included eight species of introduced fishes. While six of these taxa were relatively abundant in the study area, the grass carp and walking catfish were only represented by one and two specimens, respectively. The other introduced species collected included 197 African jewelfish, 284 blue tilapia, 29 brown hoplos, 462 Mayan cichlid, 29 sailfin catfish, and 1,038 spotted tilapia. While other invasive species have been reported in Charlotte Harbor, they were not represented in this study.

This investigation indicates that the number of introduced fish species in Charlotte Harbor estuary is considerably fewer than those of the surrounding areas. This is likely due to the relatively low level of development that may help to facilitate the establishment of non-native species, and the small number of aquaculture facilities that are often sources of introduced species, in the Charlotte Harbor area.

3.51 Peace River fish community assessment. (Call, et al., 2011)

In conjunction with the Southwest Florida Water Management District's (SWFWMD) legislatively mandated development of minimum flows and levels (MFLs), the Florida Marine Research Institute (FMRI) investigated the edifice of assessing long-term changes in fish communities and species-specific abundances to assess changes in environmental conditions (flows and water quality) in the lower Peace River. The objectives were to:

1. Update the fish database using historical sampling approaches in the Peace River and compare metrics with previous data
2. Initiate new sampling strategies and analyses that compare fish abundance and community structure with quantified habitat
3. Characterize fish abundance and community structure in Horse and Charlie Creeks
4. Document fish abundance and composition in the oligohaline zone

Ultimately the objective of the study was to assess whether long-term monitoring of fish assemblages may reveal seasonal, annual, and decadal changes associated with natural and anthropogenic influences in the riverine/estuarine systems. During the late fall/winter periods of 2005, 2006, and 2009, fish were collected via electrofishing to update previously collected data and compare fish community metrics with similar data collected over the 1983-1988 and 1989-1992 intervals. Concurrently, water quality parameters were measured and river stage and flow rates were obtained from the regional array of USGS gages. Fish population characteristics (e.g., diversity) and non-metric multidimensional scaling (MDS) plots were used to determine whether fish community structure differed among years.

Overall, fish species richness, diversity, and evenness were found to have decreased in the lower Peace River over the long-term sampling interval, with the exception of a slight increase in evenness from 2006 to 2009. Non-metric multidimensional scaling indicated that fish assemblages associated with the two sampling events following (2005 and 2006) Hurricane Charley were separate from sampling in other years. Record low flows were recorded in the river in 2007. Despite these events, the 2009 fish assemblage was similar to previous historic data. These results suggest that overall, fish assemblages in the Peace River appear to be resilient to extreme natural environmental changes. The authors advocate continued long-term monitoring of fish communities in the Peace River in helping document biological changes due to anthropogenic impacts and/or management actions, to ensure further degradation and meet resource demands.

In adition to the study describe above, fish assemblages in the Peace River were also determined via electrofishing bi-annually from fall (September-December) 2007 through spring (February-May) 2010. Physical (woody debris counts, macrophyte coverage) and chemical (salinity, temperature) microhabitat parameters were quantified from each electrofishing transect for comparison with fish assemblage data. Fish population characteristics , and calculated habitat suitability indices and curves were assessed to determine whether fish assemblages differed across river section, season, year, and with physical and chemical parameters. During all years the top five gamefish (largemouth bass, bluegill, redear sunfish, spotted sunfish, and common snook), exotic fish (blue tilipia and Pterygoplichthys spp.), and other abundant fish species (brook silversides, Notropis spp., and Seminole killifish) were all found to utilize similar moderately-complex riverine habitats. Fish assemblages differed ($p=0.05$, $R=0.42$) in each section of the river but not across seasons or years. In addition, the strongest correlations ($\rho>0.745$) of community structure with physiochemical variables and habitat metrics occurred for the lower and middle sections of the river. The middle section of the river appears to be the least dynamic in regards to flow rates and conductivity when compared to the upper and lower sections, respectively.

Similar electrofishing techniques were also used to determine fish population characteristics and habitat suitability curves, and the similarities of fish assemblages in two tributaries of the Peace River, Charlie and Horse Creeks. Sampling occurred during the spring and fall of 2008-2010. Water quality parameters, substrate, and habitat measurements were recorded at each transect for comparison with fish community structure.

- In Charlie Creek, species richness decreased from 2008-2009, but increased in 2010. Species diversity increased across all years while evenness remained the same for 2008-2009, but decreased in 2010.

- In Horse Creek, species richness and diversity decreased across all years while evenness decreased in 2009 and then increased in 2010.

An important finding in this study was zero catch rates of non-native species as well as common snook in 2010 due to extreme cold winter conditions. Community analyses showed that fish assemblages associated with each sampling event were dissimilar to one another across the two tributaries. However, habitat suitability curves indicate that popular gamefish and the most commonly sampled species used similar habitats in Charlie and Horse creeks.

Due to the unique physical, chemical, and biological processes occurring in the low salinity, oligohaline zone (0.5-5 psu), the third part of this study was to compare fish community structure and species-specific abundances in the oligohaline zone during periods of varying freshwater inflow. The abundances of several estuarine and coastal shelf transient fishes were assessed by capture using a 21.3-m seine.

1. Sand seatrout (Cynoscion arenarius), tidewater mojarra (Eucinostomus harengulus), red drum (Sciaenops ocellatus), and spot (Leiostomus xanthurus) were observed to be similar between the designated river sections, which is consistent with the premise that the oligohaline zone is an extension of the juvenile habitat known to be important for transient fish in lower rivers.

2. Estuary residents such as mosquitofish (Gambusia holbrooki), rainwater killifish (Lucania parva), and sailfin molly (Poecilia latipinna) were at least an order of magnitude more abundant in the oligohaline zone, likely the result of higher production at low salinity, greater marsh area, or less competition.

3. Large-bodied fish assemblages of the oligohaline zone captured by 61-m seine included several piscivores (such as S. ocellatus), common snook (Centropomus undecimalis), ladyfish (Elops saurus), gray snapper (Lutjanus griseus), and Florida gar (Lepisosteus platyrhincus). The abundance of piscivores was similar to that of estuarine shorelines downstream. During a severe drought, the oligohaline fish assemblages became more similar to assemblages of the lower river mouth, and the abundances of the species that define the oligohaline zone were reduced. These results indicated that large changes in the position of the freshwater-saline interface can lead to measurable biological changes.

A number of estuarine and marine species not only occupy the oligohaline zone of the Peace River but penetrate well into the freshwater zone, where they become a natural component of the riverine system. The euryhaline common snook (Centropomus undecimalis) extends up to 100 km upriver and its abundance can exceed that of common freshwater predators. This study further assessed the abundance, distribution, habitat, and diet of common snook relative to other freshwater apex predators:

- Largemouth bass (Micropterus salmoides)
- Florida gar (Lepisosteus platyrhincus)
- Longnose gar (Lepisosteus osseus)

- Bowfin (Amia calva)

Large predators were electrofished in the mainstem of the Peace River over the 2007-2010 time interval and gastric lavage was used to acquire stomach contents. Common snook habitat and diet (predominantly brown hoplo Hoplosternum littorale and crayfish Procamburus spp.) were found to be similar to other resident freshwater predators, usage of the river differed over time and space. Common snook were present throughout the entire river during summer and fall, moving upriver in response to high water levels, but were absent from the upper river during winter, when low water levels and cold temperatures prompted downriver movements. In contrast, resident freshwater predators were most abundant in the upper river and during winter. Seasonal rates of prey consumption between estuarine and freshwater predators was also observed to differ. Common snook ate more prey during summer, whereas largemouth bass ate more prey during winter. A longer time record was available for common snook and largemouth bass in the lower river where electrofishing also occurred during 2004-2006. Analyses of these data clearly indicated that environmental events affect abundance patterns. The abundance of largemouth bass was low after the extensive hypoxic event following Hurricane Charley (2004). Common snook, by comparison, were up to three times more abundant during 2004-2006 than in 2007-2010. Increased flow, abundance of prey, or lack of interspecific competition may have contributed to the observed higher snook abundances. In comparison, a catastrophic cold event occurred in winter 2010, which initially reduced the abundance of the cold-sensitive common snook, but had no effect on largemouth bass abundance.

Appendix C Tests for Differences in Flow and Water Quality Parameters between Two Periods

This appendix describes the results of statistical tests of flow and water quality data collected by the HBMP at fixed station sampling locations between the periods 1976-1989 and 1996-2016. Analyses were performed using methods developed by Coastal Environmental (1996) for the Florida Department of Environmental Protection using seasonally weighted yearly averages.

Gaged Peace River Flow Over 1976-1989 and 1996-2016 Time Intervals

The following analyses were conducted in order to provide comparisons of freshwater inflows over the same two time intervals for which physical and water chemistry are available from the lower river fixed HBMP monitoring locations. Graphical depictions presented in Table C.1 of differences in daily, monthly mean, and monthly median gaged Peace River flows at three different river locations were selected to incorporate and account for cumulative differences in the major gaged river tributaries. A more extensive discussion of seasonal and long-term hydrological patterns in rainfall and flow were previously presented in **Chapter 3**.

Table C.1
Gaged Peace River Flow

Gaged Peace River Flow	Daily	Monthly Mean	Monthly Median
Peace River at Arcadia	**Figure C.1**	**Figure C.2**	**Figure C.3**
Total Gaged Flow Upstream of Facility	**Figure C.4**	**Figure C.5**	**Figure C6**
Total Gaged Flow Upstream of US 41 Bridge	**Figure C.7**	**Figure C.8**	**Figure C.9**

Statistical tests were used to determine seasonally adjusted annual mean and median differences in total gaged flow at each of the three selected Peace River locations over the 1976-1989 and 1996-2016 time intervals. These results are summarized in Table C.2, and indicate relatively small (170-270 cfs), non-statistically significant (at the 0.05 level) increases in annual mean and median flows at these locations during the recent twenty-one-year 1996-2016 time period, when compared to the previous fourteen-year 1976-1990 time interval. Both of the 1976-1989 and 1996-2016 time intervals where characterized by highly variable seasonal and yearly differences in gaged freshwater inflows. Both intervals had extended periods of very high flows during El Niño climatic events, followed by extended unusually dry La Niña rainfall conditions. The differences in flows between the two time intervals, as previously discussed in **Chapter 3.4**, correspond to some degree with the proposed Atlantic Multidecadal Oscillation (AMO) theory of differences in average summer rainfall resulting from small cycling differences in North Atlantic Ocean average surface temperatures. The 1976-1990 time interval is within the AMO cool/dry phase proposed to have extended from 1969 to 1994, while the 1996-2016 interval lies totally within the more recent, ongoing warm/wet AMO phase proposed to have initially begun in 1995. Similar analyses presented in the *2006 HBMP Comprehensive Summary Report* indicated larger, statistically significant differences in flows between the two 1976-1990 and 1996-2006 intervals. The smaller observed differences between the two time intervals from the current analyses extending through 2016 directly reflect the influences of the recent 2006-2012 extended period of unusually low flows, which was characterized by extended intervals of drought during the normally drier months (see discussion in **Chapter 3.4**).

Table C.2
Trend Tests Gaged Peace River Flow (1976-1990 & 1996-2011)

Gaged Peace River Flow	Monthly Mean	Diff. Means	P Value of Diff.	Monthly Median	Diff. Means	P Value of Diff.
Peace River at Arcadia	**Figure C.10**	177.3	0.086	**Figure C.11**	172.6	0.053
Total Gaged Flow at Facility	**Figure C.12**	200.6	0.178	**Figure C.13**	185.6	0.138
Total Gaged Flow at US 41 Bridge	**Figure C.14**	267.5	0.146	**Figure C.15**	241.3	0.129

* All tests were not statistically significant at the 0.05 level

Water Quality Comparisons between 1976-1989 and 1996-2016

Table C.3 (containing links to Figures C.16 through C.115) summarizes both the time-series plots as well as the results of the statistical tests used to determine seasonally adjusted mean annual differences in selected water quality parameters from samples collected monthly at each of the five “fixed” HBMP monitoring locations between the 1976-1989 and 1996-2016 time periods (since there is only a partial year of water chemistry data for 1990 it wasn’t used in testing for trends). The results of these analyses depict both observed shorter-term seasonal patterns as well as longer-term variations for each of the selected water quality parameters between the two temporal monitoring periods. It should be noted that all of the water quality data over the 1976-1989 time period were analyzed by EQL, while similar data from the most recent sixteen-years were sequentially analyzed by the USGS, EQL and Benchmark Laboratories (PBS&J 2004). The time-series and trend test analyses summarized in Table C.3 were only conducted for the current, ongoing water quality parameters included through 2016 as part of the existing HBMP. Not included in these analyses were those additional water quality characteristics that had previously been deleted from the monitoring program after consultation with District staff and the Scientific Review Panel. Previous parameters deleted from these ongoing analyses include Turbidity, Total Phosphorus, Total Suspended Solids (TSS), Total Organic Carbon (TOC), Dissolved Organic Carbon (DOC) and Total Inorganic Carbon (IOC).

Uniform vertical graphical scales for each parameter from each fixed station river kilometer are applied in Figures C.16 through Figure C.65 in order that direct comparisons can be readily made along the HBMP monitoring transect for a given water quality characteristic (i.e. time series graphics for salinity are plotted using a scale of 0 to 40 psu for all five fixed sampling locations). Individually scaled graphics by parameter and monitoring location are presented in Figure C.66 through C.115, which depict the results of seasonally based statistical tests for differences between the 1976-1989 and 1996-2016 time intervals. The depicted results are directly associated with changes in upstream watershed land uses and/or extended periods of higher and wetter rainfall/flow, and not Facility withdrawals. Historically, there were large observed declines in phosphorus concentrations in the lower river and upper harbor as a result of changes in the phosphate mining practice of direct wastewater discharges. The more recent increase in phosphorus concentrations (Figure C.63) detected by the HBMP monitoring can be directly linked to discharges to Whidden Creek in the upper Peace River watershed during closure of phosphogypsum stacks. Discharges from these stacks are also probably the major cause of the recent (Figure C.64) marked observed increases in silica levels in the lower Peace River.

Table C.3
Time-Series and Trend Tests
Peace River HBMP Estuary Sites Water Quality (1976-1989 and 1996-2016)

River Kilometer Parameter	**Subsurface Values**				
	Time-Series	**Trend Test**	**Diff. Means**	**P Value of Diff.**	**Change**
River Kilometer –2.4					
Salinity (Surface)	**Figure C.16**	**Figure C.66**	2.79	**0.000**	▲
Salinity (Bottom)	**Figure C.17**	**Figure C.67**	3.51	**0.000**	▲
Dissolved Oxygen (Surface)	**Figure C.18**	**Figure C.68**	-0.31	**0.025**	▼
Dissolved Oxygen (Bottom)	**Figure C.19**	**Figure C.69**	-0.24	0.137	
Color	**Figure C.20**	**Figure C.70**	11.79	**0.008**	▲
Nitrite + Nitrate Nitrogen	**Figure C.21**	**Figure C.71**	0.006	0.459	
Total Kjeldahl Nitrogen	**Figure C.22**	**Figure C.72**	-0.042	0.280	
Ortho-Phosphorus	**Figure C.23**	**Figure C.73**	-0.07	**0.000**	▼
Silica	**Figure C.24**	**Figure C.74**	1.69	**0.000**	▲
Chlorophyll a	**Figure C.25**	**Figure C.75**	2.74	0.279	
River Kilometer 6.6					
Salinity (Surface)	**Figure C.26**	**Figure C.76**	1.23	0.112	
Salinity (Bottom)	**Figure C.27**	**Figure C.77**	2.73	**0.000**	▲
Dissolved Oxygen (Surface)	**Figure C.28**	**Figure C.78**	-0.32	**0.048**	▼
Dissolved Oxygen (Bottom)	**Figure C.29**	**Figure C.79**	-0.34	**0.030**	▼
Color	**Figure C.30**	**Figure C.80**	19.23	**0.002**	▲
Nitrite + Nitrate Nitrogen	**Figure C.31**	**Figure C.81**	-0.016	0.605	
Total Kjeldahl Nitrogen	**Figure C.32**	**Figure C.82**	-0.090	0.142	
Ortho-Phosphorus	**Figure C.33**	**Figure C.83**	-0.16	**0.000**	▼
Silica	**Figure C.34**	**Figure C.84**	2.17	**0.000**	▲
Chlorophyll *a*	**Figure C.35**	**Figure C.85**	-0.93	0.692	
River Kilometer 15.5					
Salinity (Surface)	**Figure C.36**	**Figure C.86**	1.49	**0.022**	▲

Table C.3
Time-Series and Trend Tests
Peace River HBMP Estuary Sites Water Quality (1976-1989 and 1996-2016)

River Kilometer Parameter	Subsurface Values				
	Time-Series	Trend Test	Diff. Means	P Value of Diff.	Change
Salinity (Bottom)	Figure C.37	Figure C.87	1.86	0.009	▲
Dissolved Oxygen (Surface)	Figure C.38	Figure C.88	-0.28	0.072	▼
Dissolved Oxygen (Bottom)	Figure C.39	Figure C.89	-0.28	0.042	▼
Color	Figure C.40	Figure C.90	7.67	0.281	
Nitrite + Nitrate Nitrogen	Figure C.41	Figure C.91	-0.067	0.003	▼
Total Kjeldahl Nitrogen	Figure C.42	Figure C.92	0.008	0.864	
Ortho-Phosphorus	Figure C.43	Figure C.93	-0.45	0.000	▼
Silica	Figure C.44	Figure C.94	2.92	0.000	▲
Chlorophyll *a*	Figure C.45	Figure C.95	4.53	0.353	
River Kilometer 23.6					
Salinity (Surface)	Figure C.46	Figure C.96	0.70	0.019	▲
Salinity (Bottom)	Figure C.47	Figure C.97	0.73	0.040	▲
Dissolved Oxygen (Surface)	Figure C.48	Figure C.98	-0.11	0.467	
Dissolved Oxygen (Bottom)	Figure C.49	Figure C.99	-0.12	0.433	
Color	Figure C.50	Figure C.100	11.40	0.092	▲
Nitrite + Nitrate Nitrogen	Figure C.51	Figure C.101	-0.111	0.001	▼
Total Kjeldahl Nitrogen	Figure C.52	Figure C.102	-0.159	0.209	
Ortho-Phosphorus	Figure C.53	Figure C.103	-0.61	0.000	▼
Silica	Figure C.54	Figure C.104	3.33	0.000	▲
Chlorophyll *a*	Figure C.55	Figure C.105	-0.53	0.790	
River Kilometer 30.4					
Salinity (Surface)	Figure C.56	Figure C.106	0.24	0.000	▲
Salinity (Bottom)	Figure C.57	Figure C.107	0.26	0.000	▲
Dissolved Oxygen (Surface)	Figure C.58	Figure C.108	-0.19	0.266	
Dissolved Oxygen (Bottom)	Figure C.59	Figure C.109	-0.21	0.210	
Color	Figure C.60	Figure C.110	11.76	0.099	▲
Nitrite + Nitrate Nitrogen	Figure C.61	Figure C.111	-0.166	0.000	▼
Total Kjeldahl Nitrogen	Figure C.62	Figure C.112	-0.044	0.338	
Ortho-Phosphorus	Figure C.63	Figure C.113	-0.70	0.000	▼
Silica	Figure C.64	Figure C.114	3.36	0.000	▲
Chlorophyll *a*	Figure C.65	Figure C.115	0.69	0.719	

- * Red ▼ denotes significance at the 0.05 level
- * Blue ▼ denotes significance at the 0.10 level

Table C.4 further summarizes the overall results of the trend tests presented in Table C.3 by parameter and location (river kilometer) along the HBMP monitoring transect (**Figure 1.1**). Brief descriptions of the overall results of the graphical and trend analyses for each of the water quality parameters currently monitored in the lower river and upper harbor are further provided below.

Table C. 4
Trend Tests Peace River HBMP Estuary Sites Water Quality
(1976-1989 and 1996-2011)

Parameter	**River Kilometer**				
	-2.3	**6.6**	**15.5**	**23.6**	**30.4**
Salinity (Surface)	▲		▲	▲	▲
Salinity (Bottom)	▲	▲	▲	▲	▲
Dissolved Oxygen (Surface)	▼	▼	▼		
Dissolved Oxygen (Bottom)		▼	▼		
Color	▲	▲		▲	▲
Nitrite + Nitrate Nitrogen			▼	▼	▼
Total Kjeldahl Nitrogen					
Total Phosphorus	▼	▼	▼	▼	▼
Silica	▲	▲	▲	▲	▲
Chlorophyll *a*					

- * Red ▲ denotes significance at the 0.05 level
- * Blue ▲ denotes significance at the 0.10 level

Salinity (psu) – There is a strong, distinct spatial salinity gradient along the lower Peace River monitoring transect. Salinity levels are much higher (often near Gulf water conditions) in the vicinity of the river mouth and are typically near freshwater levels just upstream of the Water Treatment Facility. The greatest inter-annual variability in salinity generally occurs in the surface waters at the most downstream monitoring sites where seasonal differences may reach 35 parts per thousand between extended periods of low and high freshwater inflow. However, even bottom salinity levels in the area of the US 41 Bridge (RK 6.6) exhibit similar large inter-annual variation. The influences of the high freshwater inflows during 1997/1998 El Niño event and the extended periods of lower flows during the 1999-2001 and 2006-2011droughts are evident in the time-series plots. The graphical and trend analyses show that as a result of the extended periods of low flows during the droughts, both surface and bottom salinities were almost uniformly significantly higher during the 1996-2016 interval than between the 1976-1989 sampling period (on a seasonally averaged annual basis) along the entire lower river/upper harbor HBMP monitoring transect. These results further emphasize the profound influence of the recent intense seasonal drought conditions. Especially, since average annual freshwater inflows during the same recent sixteen year period have on average not been significantly different (see Table C.2

above). (Alternatively, these differences may also in part reflect the very small changes in sea level that have occurred between the two time intervals).

Dissolved Oxygen (mg/L) – Near-bottom dissolved oxygen concentrations show clear seasonal cycles in response to higher freshwater flows during the summer wet-season. The duration and magnitude of periods of low dissolved oxygen concentrations increase toward the river mouth as higher bottom salinities establish greater vertical stratification in the water column during high flows. Bottom dissolved oxygen concentrations at the two most downstream monitoring stations, located at RK –2.4 and 6.6, are characterized by hypoxic (less than 2.0 mg/L) and even anoxic (less than 0.2 mg/L) conditions during extended periods of high flows during the summer wet-season. Other studies (CHNEP 1999, 2003 and PBS&J 2007, 2009) have noted apparent declines in dissolved oxygen concentrations in the lower river over time, but have been unable to clearly identify any cause. Proposed explanations have included: declines in the very high chlorophyll *a* concentrations that were frequently observed during the 1970s and 1980s; influences of higher average flows during more recent time periods; and potentially progressive changes associated with *in situ* dissolved membrane technology and measuring precision. The current analyses, based on a somewhat longer data set than these previous analyses, generally finds similar surface and bottom annual average dissolved oxygen concentrations in the upper portion of the HBMP monitoring transect when comparing the 1976-1989 and 1996-2016 time periods. However, small (<0.35 mg/L) statistically significant decreases between the two periods were observed for the lower reaches of the river (Table C.3).

Water Color (Pt-Co Units) – Humic compounds derived from the breakdown and subsequent leaching of vegetation into surface waters are the source of the high water color that characterizes the blackwater river systems of southwest Florida. The presented time-series graphs indicate that color levels temporally increase quickly in response to increased freshwater inflows, with levels typically being higher farther upstream than near the mouth of the river. Very high color levels, however, can extend well into the harbor during extended periods of high freshwater flows such as occurred during the 1997/1998 El Niño or recently during the extremely high flows that occurred during 2001, 2003, 2004, 2005 and 2008. Statistical analyses indicated significant increases at the 0.10 level between the average annual surface color levels for the two most upstream monitoring locations (RK 23.6 and 30.4) between the 1976-1989 and 1996-2016 sampling periods.. Additionally, statistically significant increases at the 0.05 level between the two periods at the two most downstream monitoring locations (RK -2.3 and 6.6). These differences reflect the higher inflows of dark colored water farther down the river and into the upper harbor during the recent period of high flows.

Nitrite+Nitrate Nitrogen (mg/L) – Concentration levels and seasonal patterns of dissolved inorganic nitrite+nitrate nitrogen are spatially different among the five HBMP lower Peace River monitoring locations. The time-series plots indicate that inorganic nitrite+nitrate nitrogen levels at the most downstream fixed sampling station (located near the arbitrarily defined river mouth) are typically near or at method detection limits. Salinities are typically high in this region of the estuary and, except during periods of very high river flow, phytoplankton primary production is limited by the availability of inorganic nitrogen (Montgomery et al. 1991). Conversely, during extended periods of high freshwater river flows, surface salinities decline, bringing increased nutrient loading and higher levels of water color that limit the penetration of light into the water column and subsequently reduces phytoplankton growth and nitrogen uptake. By comparison, inorganic nitrogen levels progressively increase moving upstream along the HBMP sampling transect, as dilution by low nutrient/high salinity harbor water declines and higher water color increasingly limits phytoplankton nitrogen uptake. Only during periods of extended low freshwater flow, such as during the spring dry-season, are ambient inorganic nitrogen levels low at the upstream river sampling sites. Differences between seasonally averaged annual surface dissolved inorganic nitrite+nitrate nitrogen concentrations at the three most upstream HBMP monitoring locations were statistically significantly lower during the recent 1996-2016 time interval when compared with the previous 1976-1989 time period. The decrease appears to be heavily influenced by the period of drought beginning in 2006.

Total Kjeldahl Nitrogen (mg/L) – Like inorganic nitrogen, this gross measurement of combined inorganic ammonia and organic water column nitrogen shows distinct seasonal and spatial patterns along the HBMP monitoring transect. However, the applied time series analyses indicated that measured total Kjeldahl nitrogen levels along the monitoring transect were not statistically significantly different between the 1976-1989 time period and the 1996-2016 period.

Ortho-Phosphorus (mg/L) – One of the most dramatic long-term change in water quality in the lower Peace River is the marked, observed statistically significant long-term decline in dissolved inorganic (and total) phosphorus concentrations (CHNEP 1999, 2003 and PBS&J 1999, 2004, 2007, 2009). The lower Peace River/upper Charlotte Harbor estuarine system is naturally high in phosphorus due to the extensive natural phosphate deposits in a number of the major upstream watershed basins. Phosphorus concentrations generally reflect both the spatial and temporal variation in Peace River freshwater inputs. The highest phosphorus concentrations are typically associated with seasonal lower river flow, when the influences of ground water are more pronounced. Long-term temporal patterns indicate rapid declines in both the magnitude and variability in phosphorus levels when compared with the initial first six years of HBMP monitoring.

This decline followed implementation in the late 1970s of stricter regulations and subsequent decreases of both point and nonpoint discharges to surface waters from phosphate mining and processing. Average annual mean phosphorus concentrations between the 1976 and 1989 continued to decline at the HBMP river stations, even though the largest changes occurred prior to 1984. The presented graphical analyses indicate that inorganic phosphorus levels throughout the lower Peace River/upper Charlotte Harbor Estuary dramatically increased early in 2004 and again following Hurricanes Charley, Francis and Jeanne in August and September of 2004. The *2006 HBMP Comprehensive Summary Report* suggested "that the historically high flows that occurred in the upper Peace River watershed following this unusual series of events had at least temporarily increased phosphorus concentrations throughout the system to levels not seen for over twenty years". However, more recent investigations (PBS&J 2009, 2010 and Atkins 2011, 2012) have concluded that the direct cause for the recent observed increase in phosphorus levels more likely seems to have been related to discharges of waters during the closure of the Ft. Meade phosphogypsum stack system in the upstream Whidden Creek subbasin. Phosphorus concentrations began again declining during 2009 and have continued through both 2010 and 2011. While slight increases in annually averaged ortho-phosphorus have occurred at some stations since 2011, overall inorganic phosphorus levels are significantly lower when compared to the previous historic period.

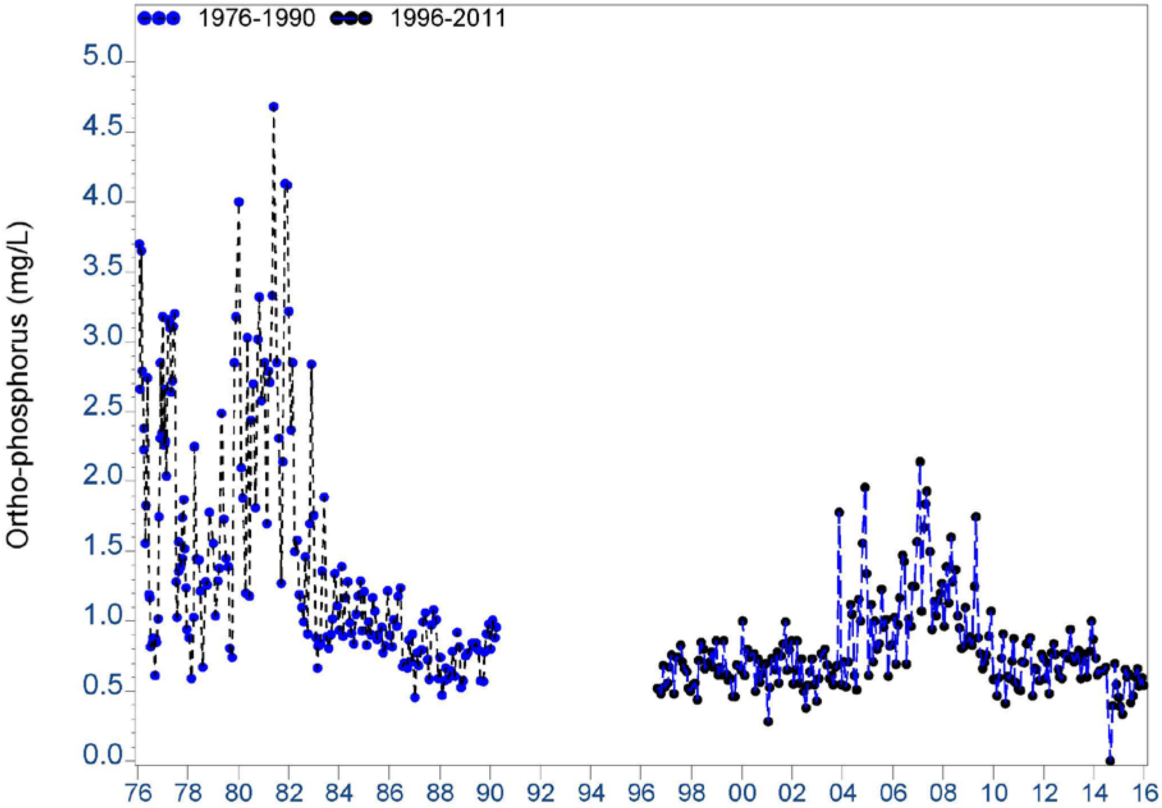


Figure C.63 Monthly long-term surface ortho-phosphorus at river kilometer 30.7

Silica (mg/L) – Both the long-term time-series plots and the statistical comparisons of mean annual average reactive silica concentrations indicate that silica levels have and continue to dramatically increase along the entire length of the lower Peace River monitoring transect. During the most recent twenty-one years of HBMP monitoring, silica concentrations at each of the five fixed sampling sites have increased and the range of variability has increased when compared with similar data from the 1976-1989 period. Again the *2006 HBMP Comprehensive Summary Report* suggested "that the observed increases in ambient reactive silica levels in the Peace River estuarine system might reflect the cumulative influences of increased ground water use and the expansion of water intense agriculture in the Peace River watershed, or it may be associated with other land use changes occurring upstream in the watershed". In response to the observed increases in both silica and phosphorus, the Authority began collecting additional dry-season data at a number of locations throughout the upper watershed in order to be able to better identify potential sources of these apparent increasing concentrations. As with the observed increase in phosphorus levels the upstream data collected by the Authority showed very high silica levels in discharge waters associated with the Ft. Meade phosphogypsum stack system closure in the Whidden Creek subbasin. However, while phosphorus levels in the lower river/upper harbor appear to have again declined to more normal levels, silica levels continue to remain high.

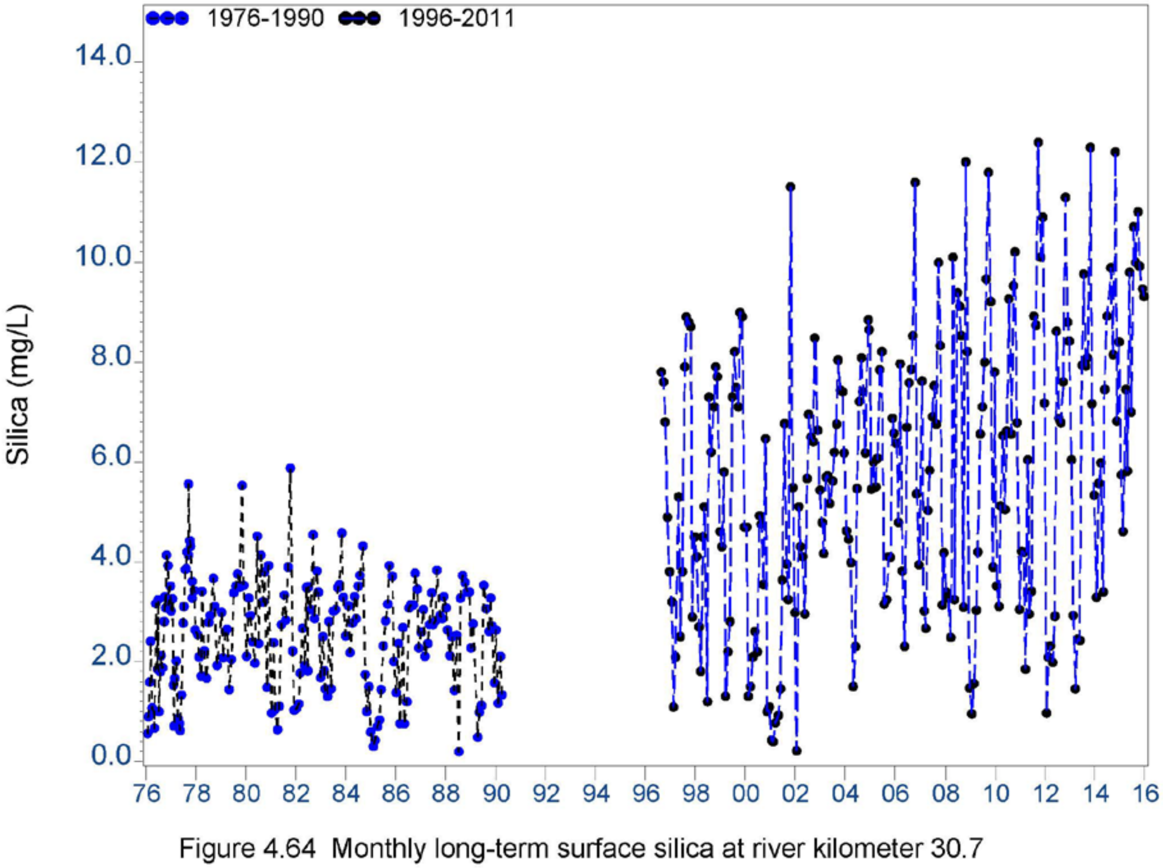


Figure C.64 Monthly long-term surface silica at river kilometer 30.7

Chlorophyll *a* (ug/L) – Previous studies (CHNEP 1999, 2003 and PBS&J 1999, 2004, 2007) observed marked declines in the periodic very high chlorophyll *a* concentrations (phytoplankton "blooms") that commonly occurred in the surface waters throughout the lower Peace River/upper Charlotte Harbor estuarine system during the late 1970s and early 1980s. The *2006 HBMP Comprehensive Summary Report* observed that between 2004 and 2006 "chlorophyll *a* levels in the lower river and upper harbor uniformly shown increases to annual average levels not seen in over twenty years". As previously noted, these observed increased followed Hurricanes Charley, Francis and Jeanne in August and September of 2004. These events seem to correspond with the apparent relatively brief observed increase in chlorophyll a concentrations, since levels upstream and near the Facility declined in response to unusually dry conditions between 2006 and 2011. Since phosphorus levels in the lower Peace River/upper Charlotte Harbor Estuary are naturally high, and nutrient additions (Montgomery et al. 1991) have shown local estuarine phytoplankton populations to be seasonally nitrogen and not phosphorus limited, it is doubtful that the observed increases in phosphorus levels during 2004 and 2005 was directly the cause of the observed increases in chlorophyll *a* concentrations. It is more likely that other factors, including larger than normal Lake Hancock discharges, were responsible for the observed increases in phytoplankton levels. Overall, the result of the observed historic declines, combined with the recent observed increases, is that there are no statistically significant differences in average annual seasonally weighted mean chlorophyll *a* concentrations between the 1976-1989 and 1996-2016 time intervals at any of the five fixed river kilometer based HBMP monitoring locations. This result demonstrates the inherent difficulty in using most commonly applied statistical trend procedures when evaluating long-term changes in water quality parameters having multiple non-seasonal increasing and decreasing patterns.

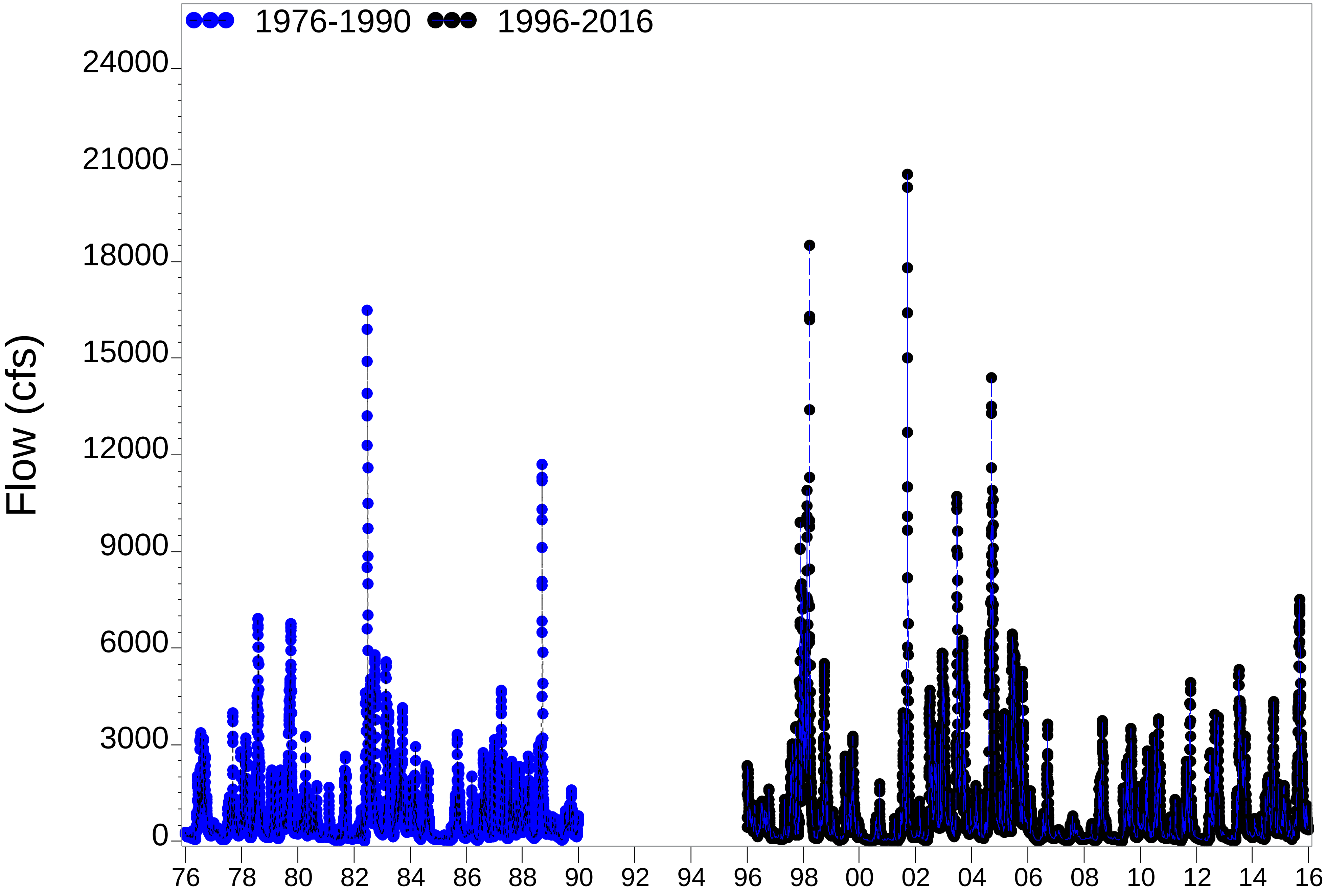


Figure C.1. Daily Peace River at Arcadia Gaged Flow

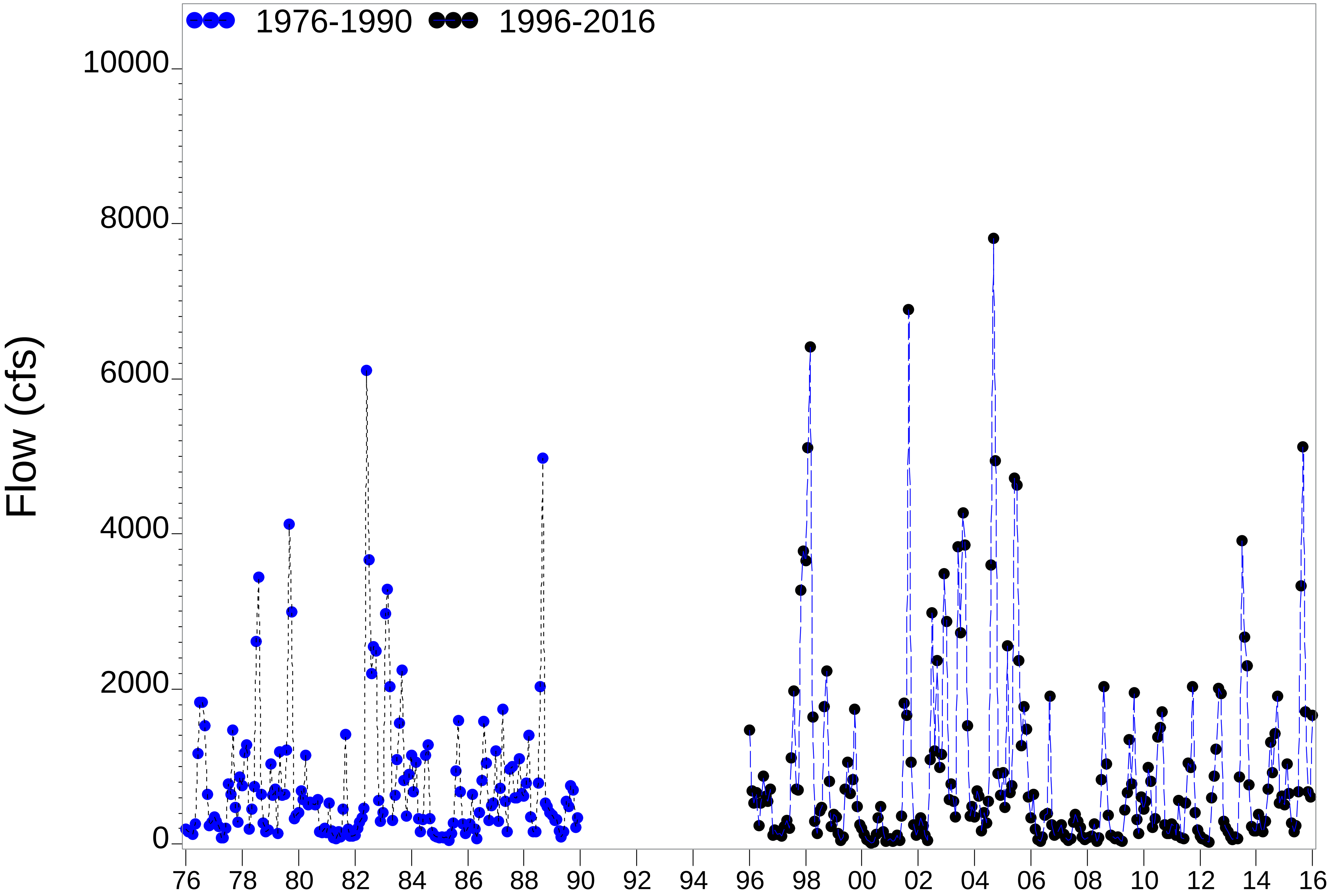


Figure C.2. Mean Monthly Peace River at Arcadia Gaged Flow

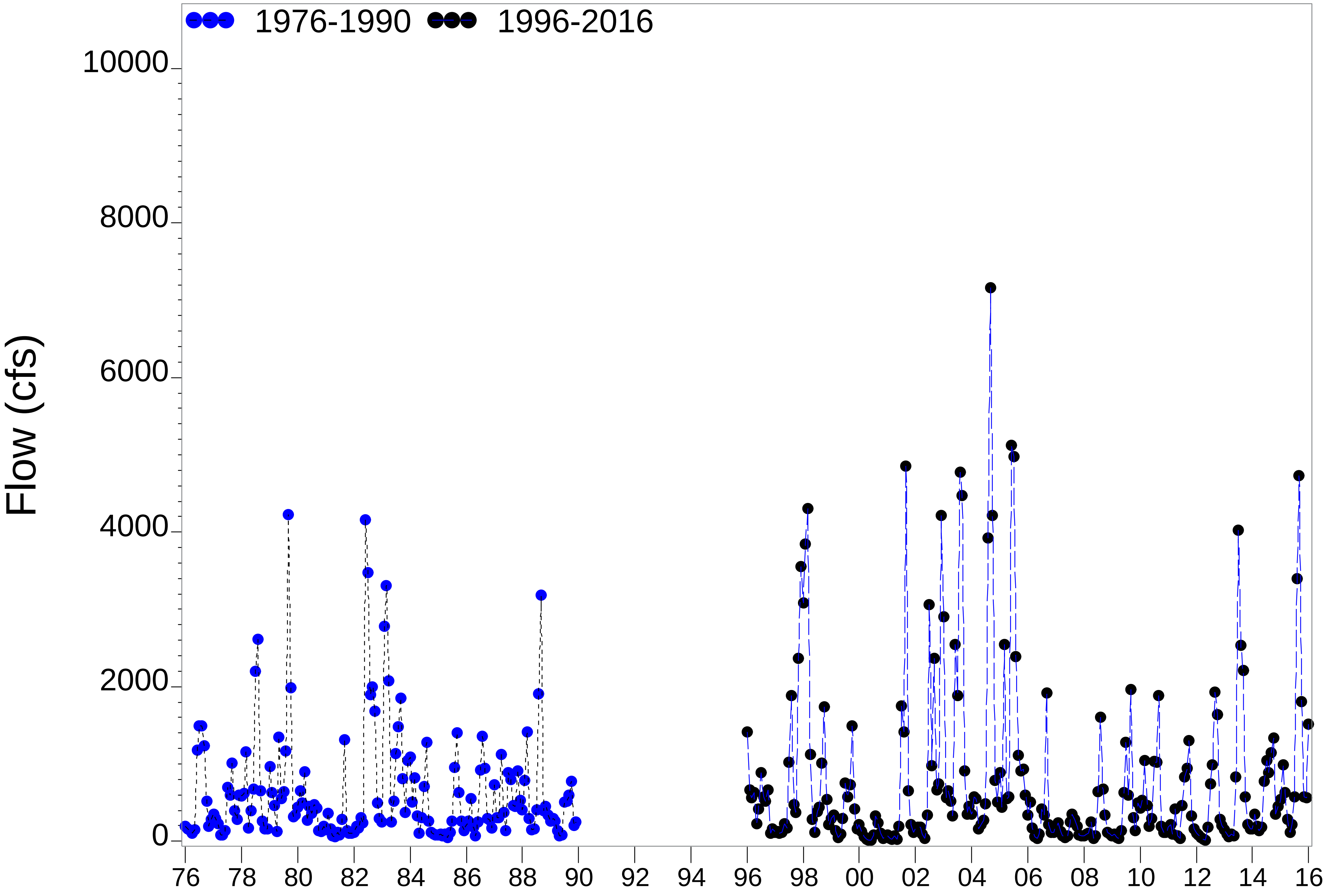


Figure C.3. Median Monthly Peace River at Arcadia Gaged Flow

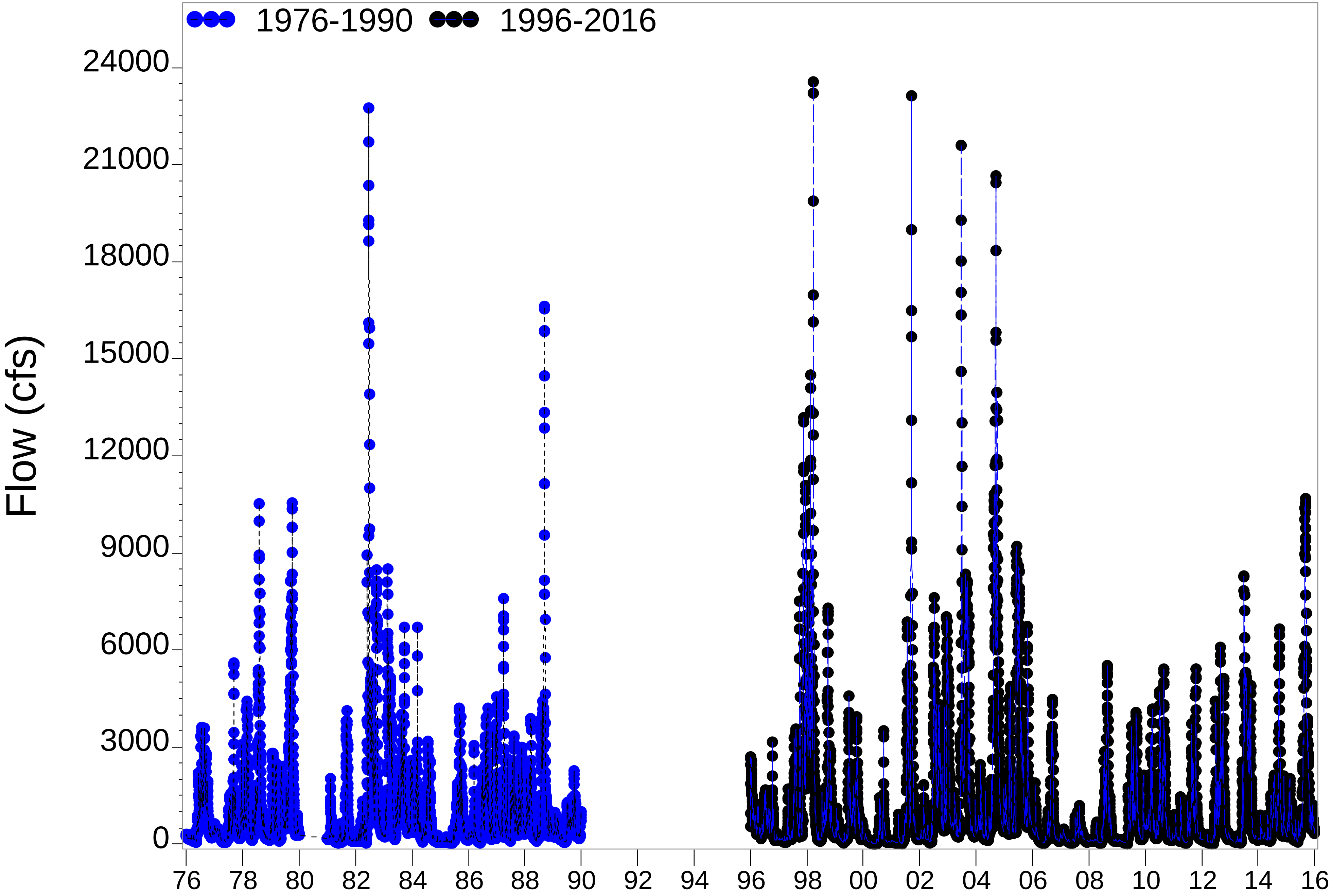


Figure C.4. Peace River at Arcadia plus Horse and Joshua Creeks Gaged Flows

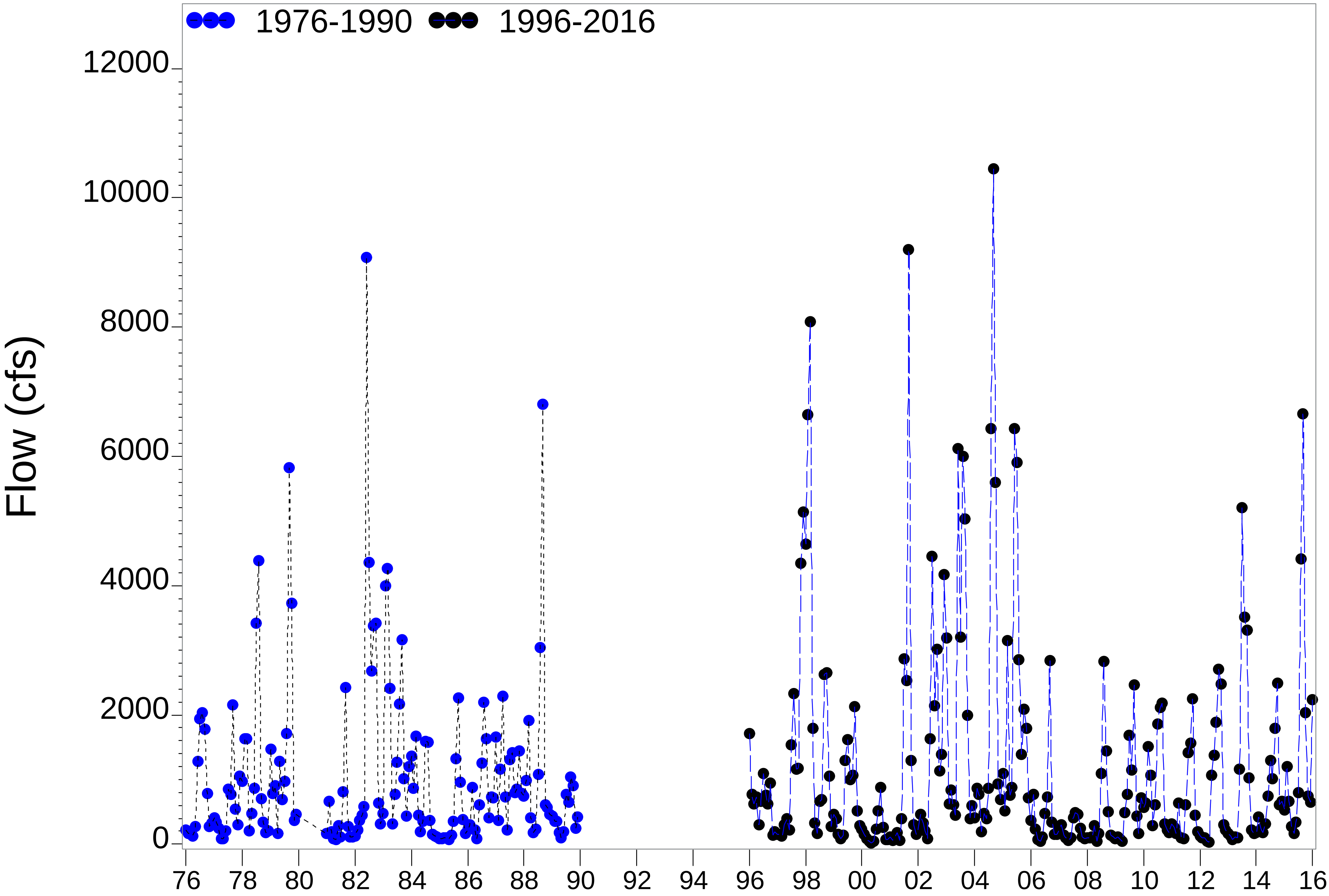


Figure C.5. Mean Monthly Peace River at Arcadia plus Horse and Joshua Creeks Gaged Flows

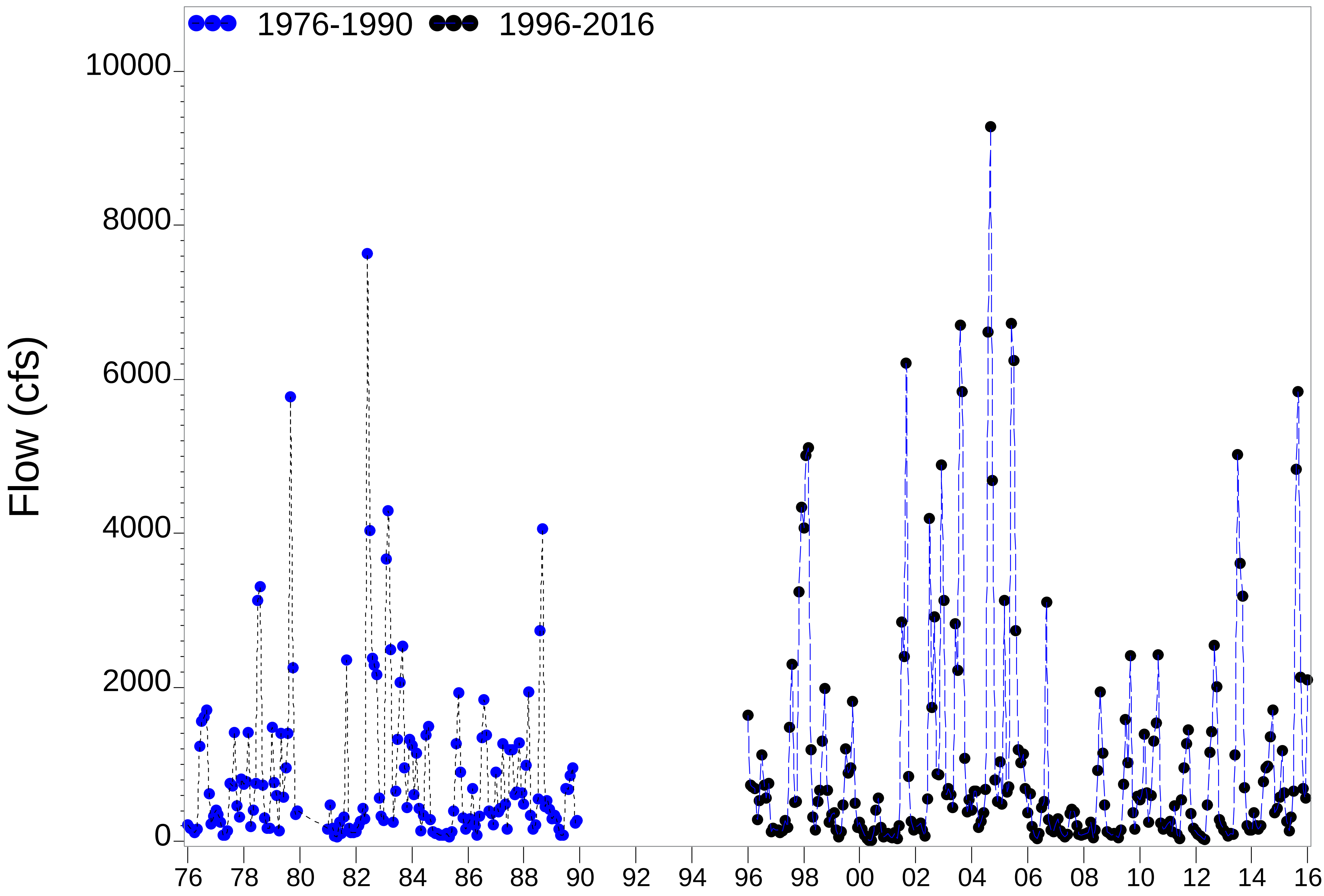


Figure C.6. Median Monthly Peace River at Arcadia plus Horse and Joshua Creeks Gaged Flows

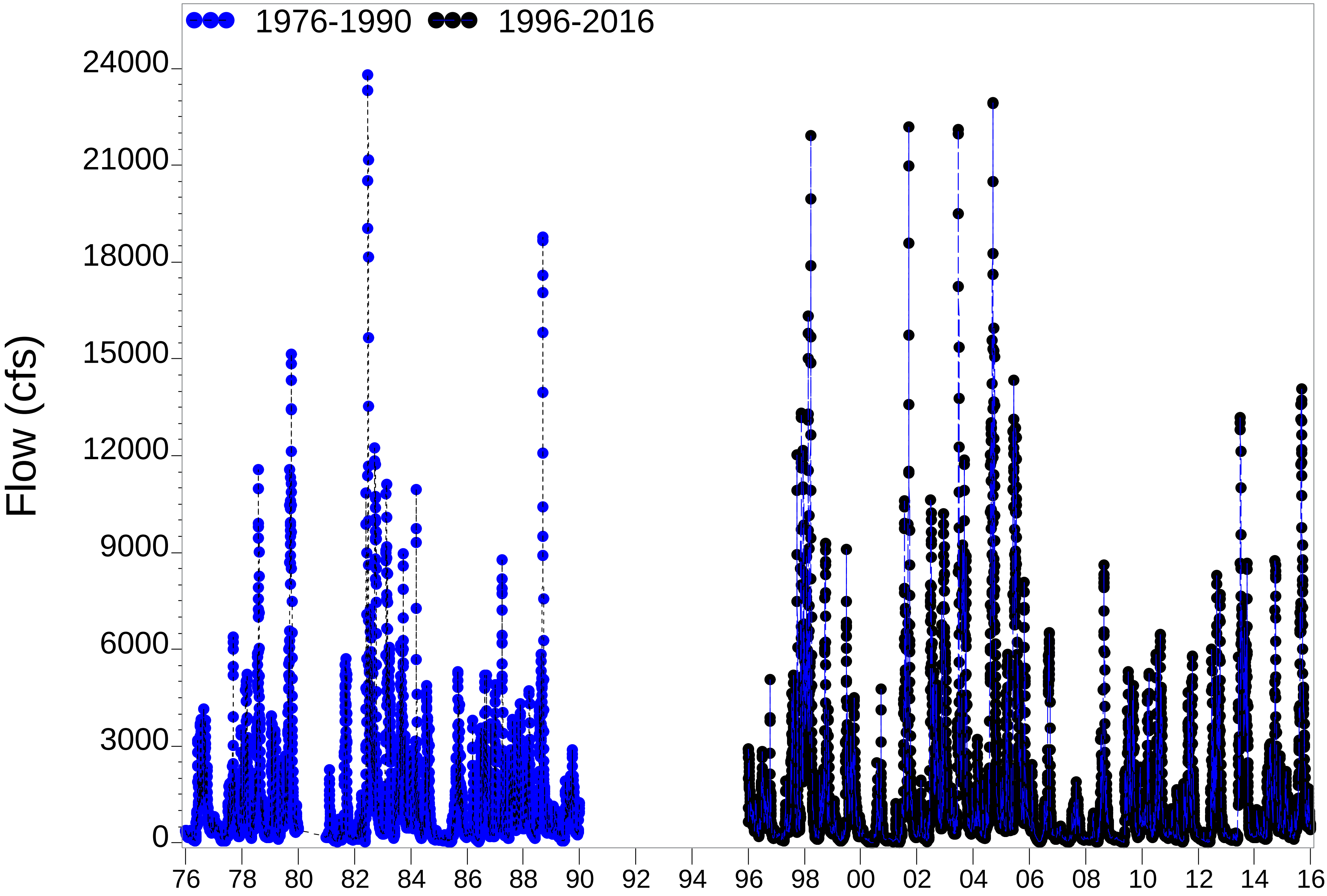


Figure C.7. Peace River at Arcadia plus Horse Joshua and Shell Creeks Gaged Flows

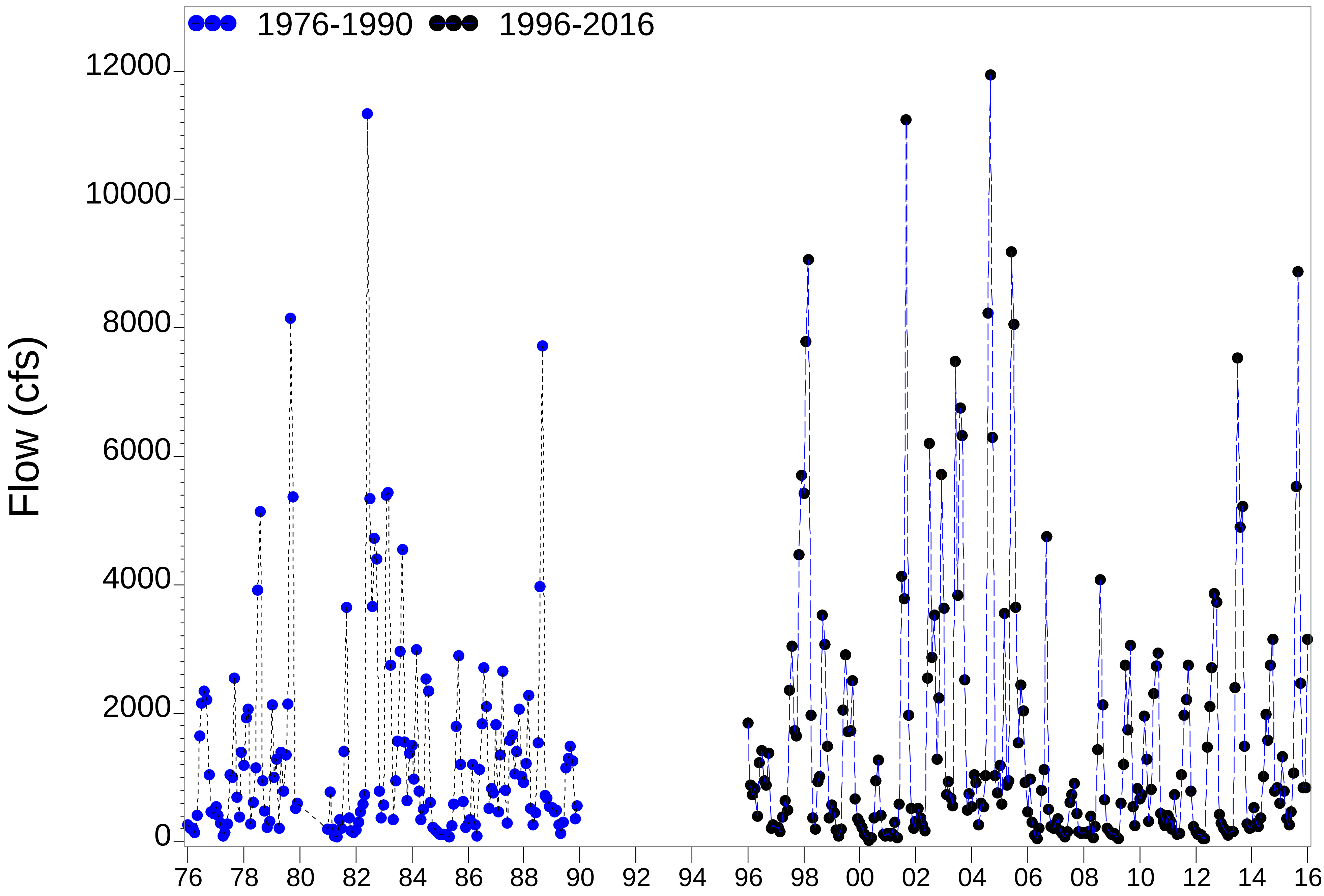


Figure C.8. Mean Monthly Peace River at Arcadia plus Horse Joshua and Shell Creeks Gaged Flows

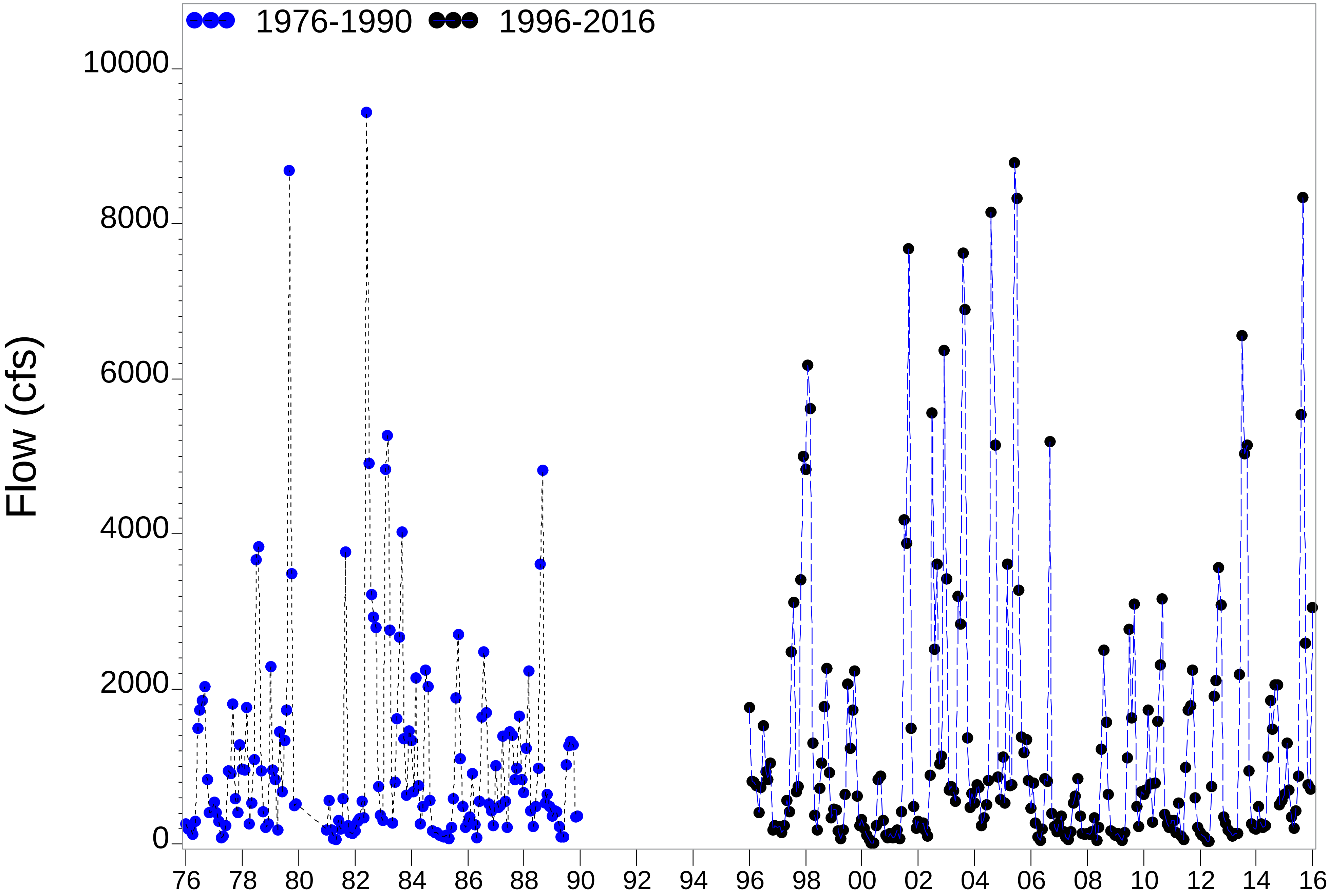


Figure C.9. Median Monthly Peace River at Arcadia plus Horse Joshua and Shell Creeks Gaged Flows

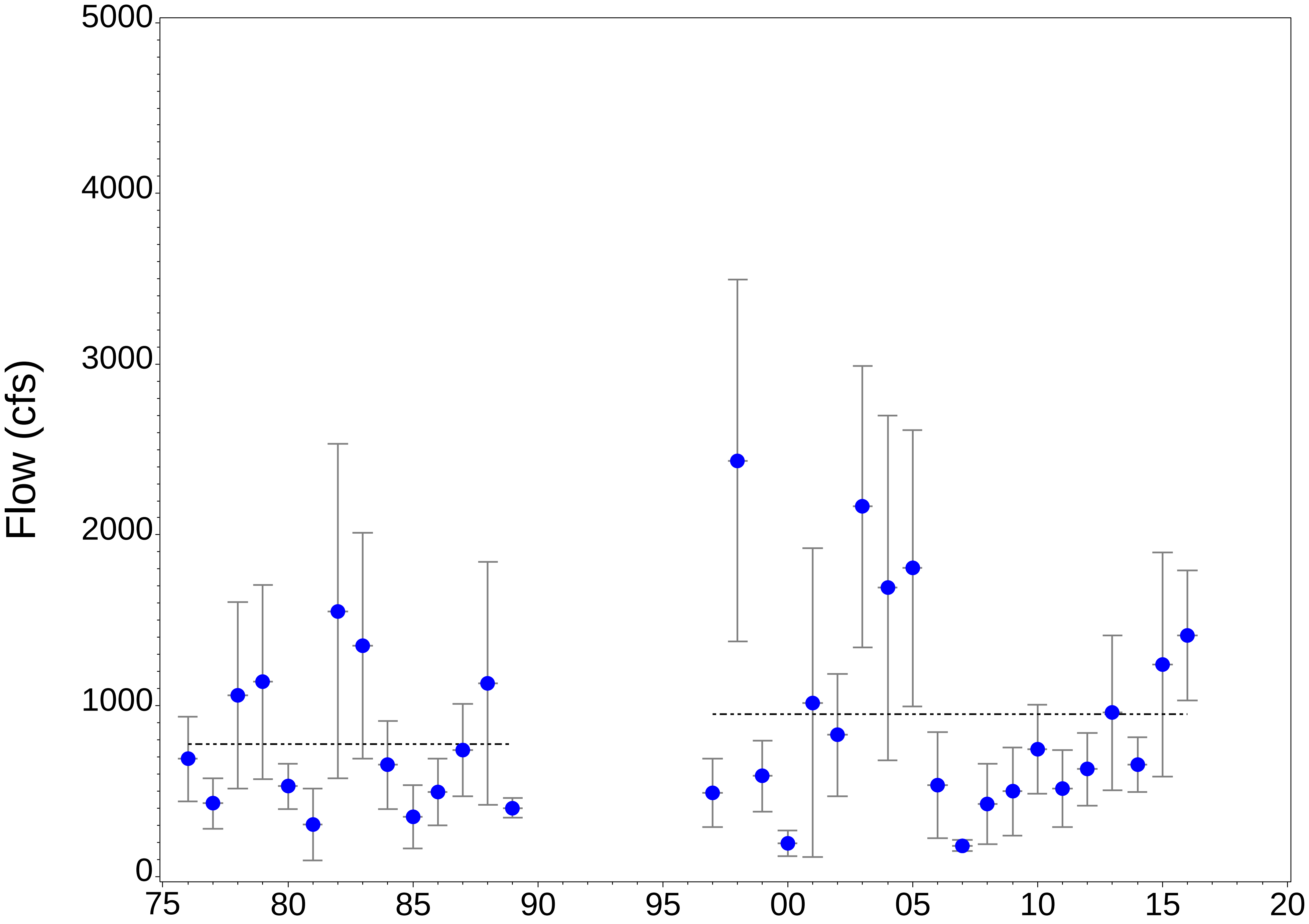


Figure C.10. Annual monthly mean Peace River at Arcadia gaged flow

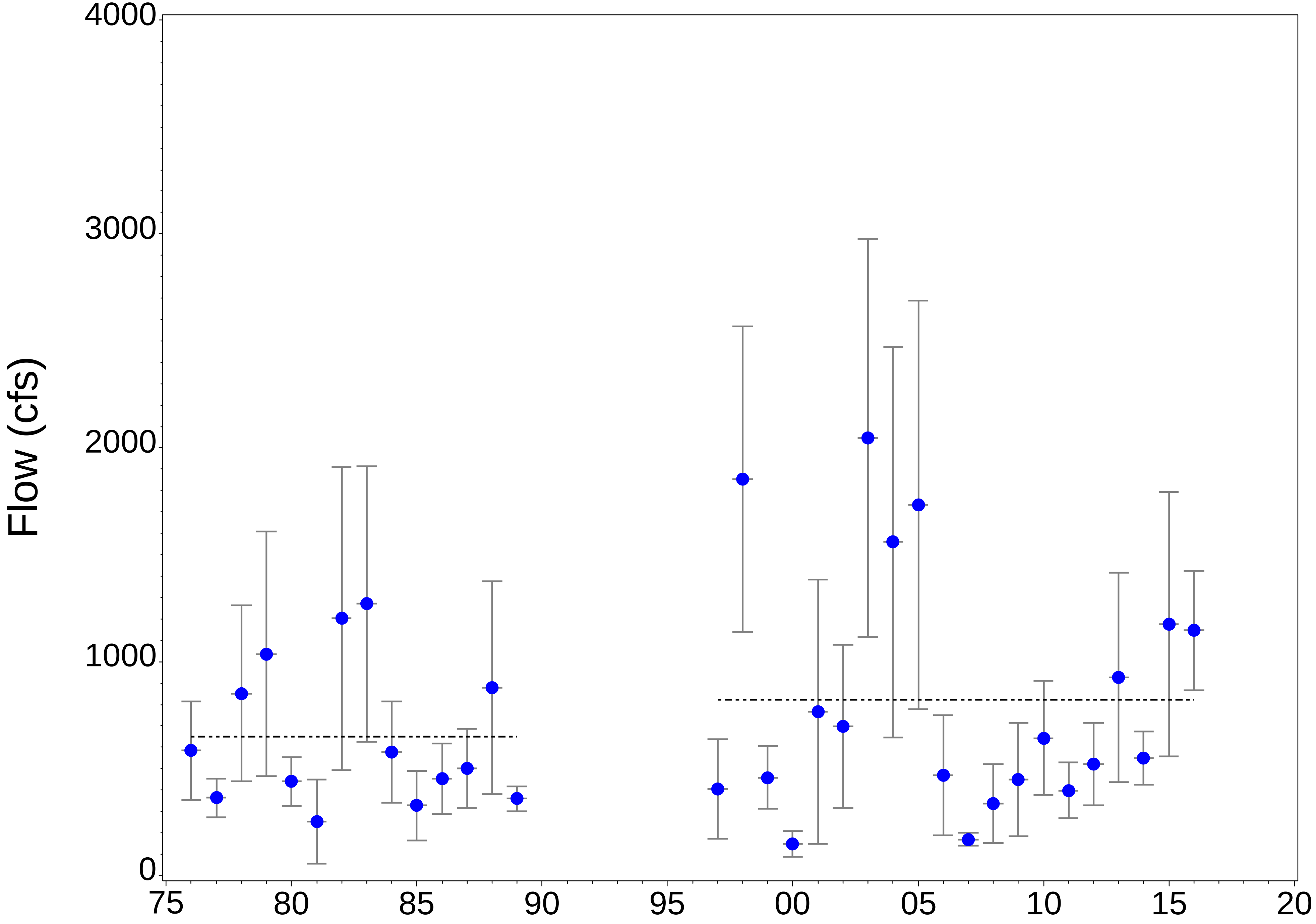


Figure C.11. Annual monthly median Peace River at Arcadia gaged flow

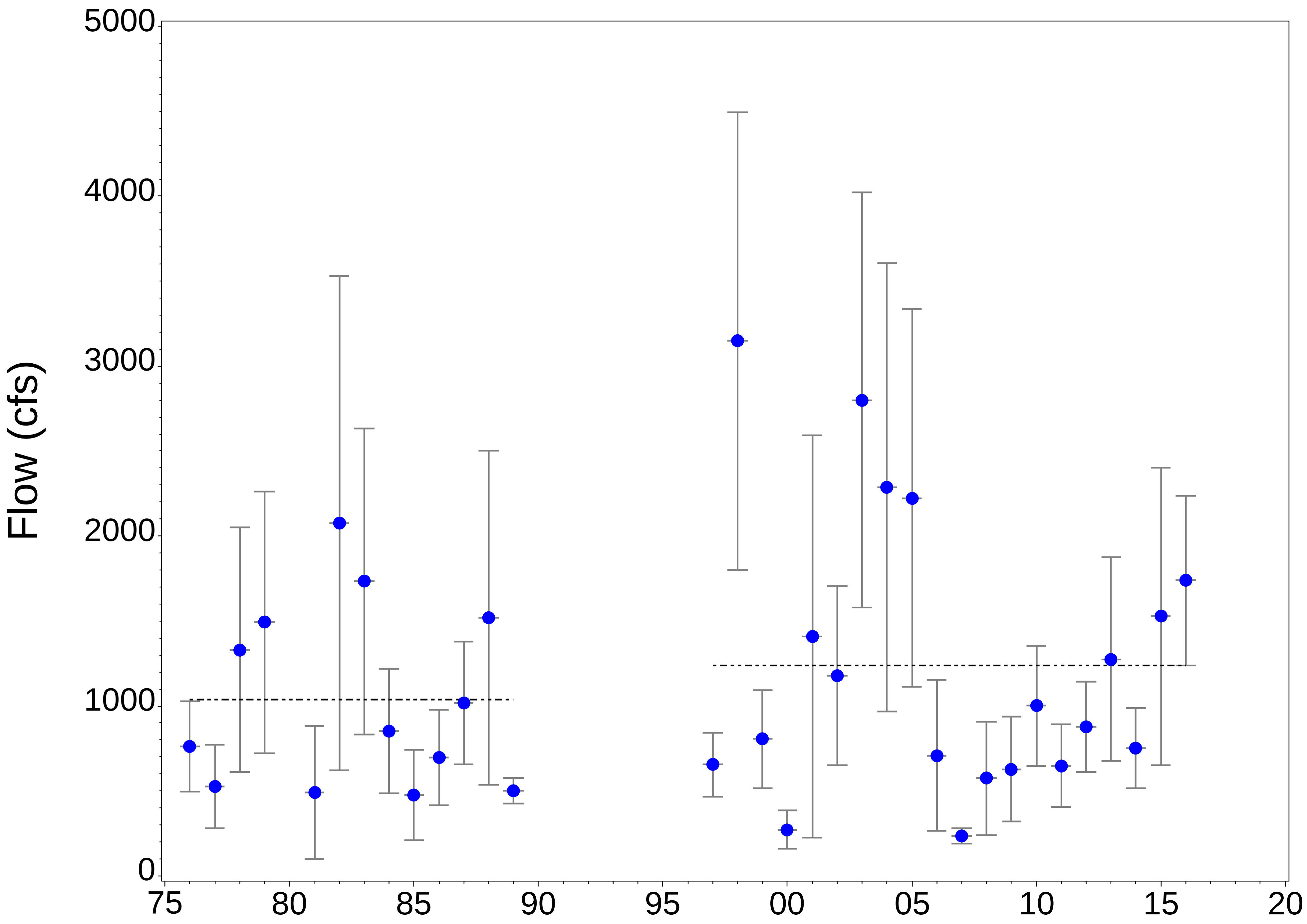


Figure C.12. Annual monthly mean Peace River at Arcadia plus Horse and Joshua Creeks gaged flows

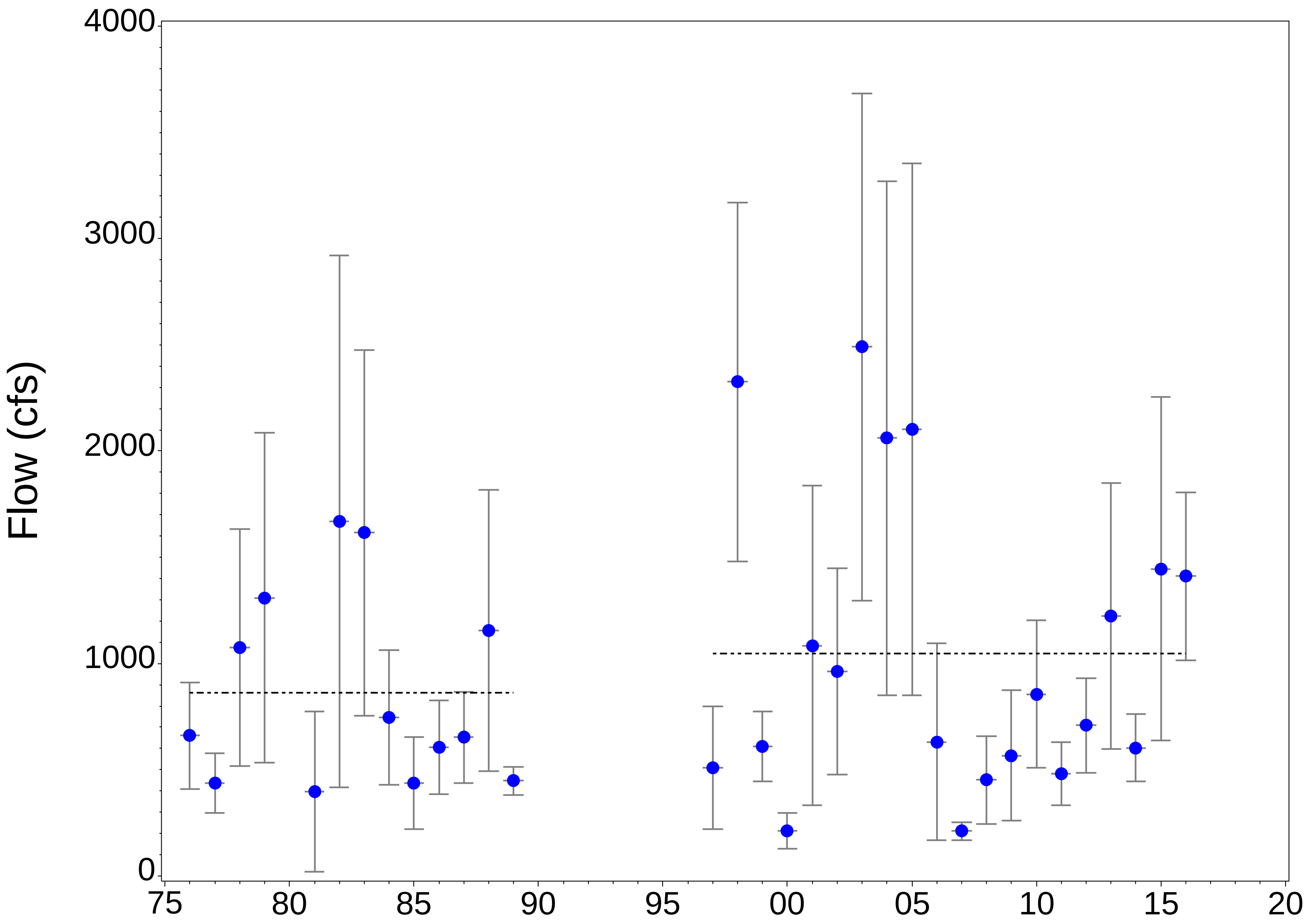


Figure C.13. Annual monthly median Peace River at Arcadia plus Horse and Joshua Creeks gaged flows

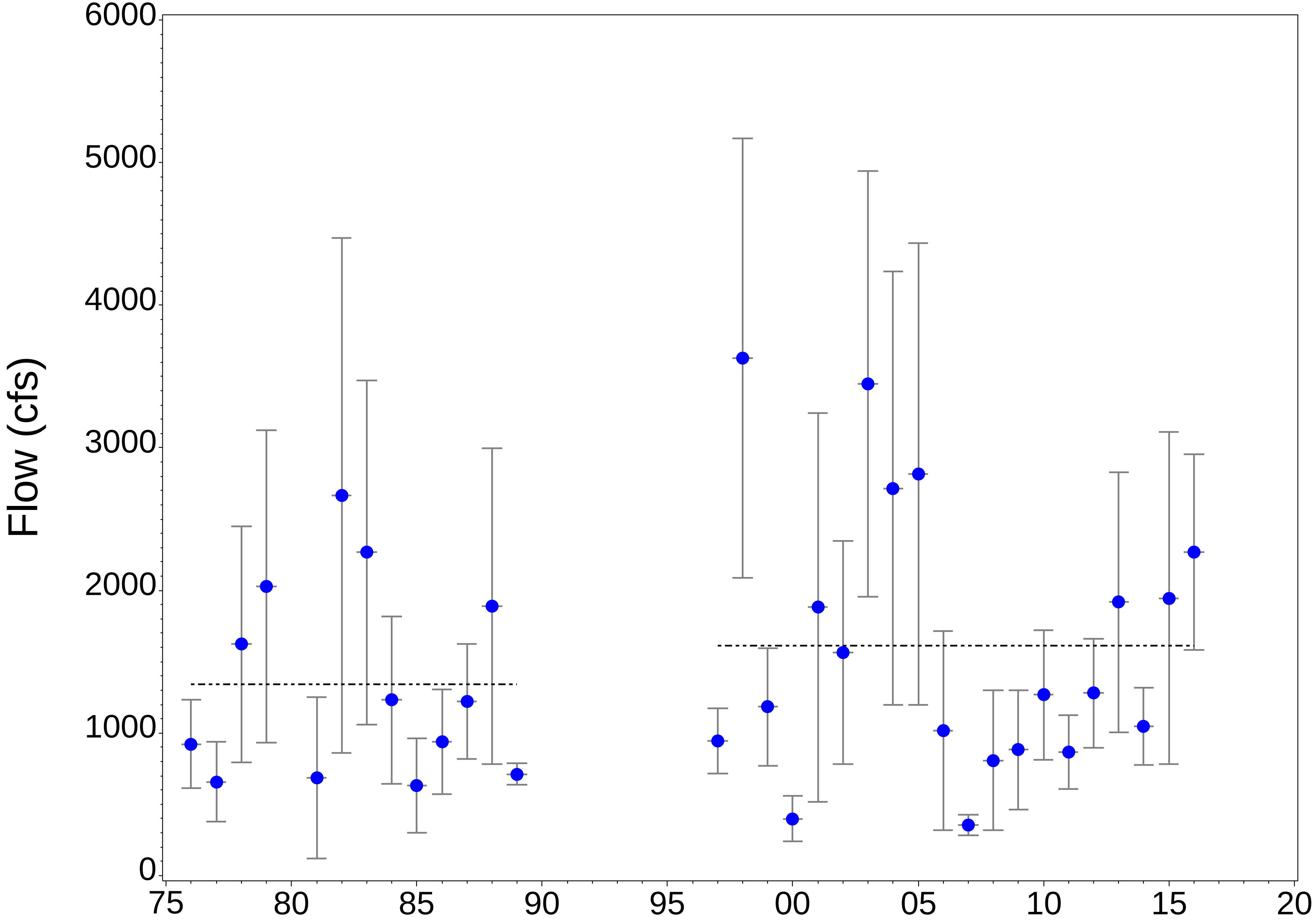


Figure C.14. Annual monthly mean Peace River at Arcadia plus Horse, Joshua and Shell Creeks gaged flows

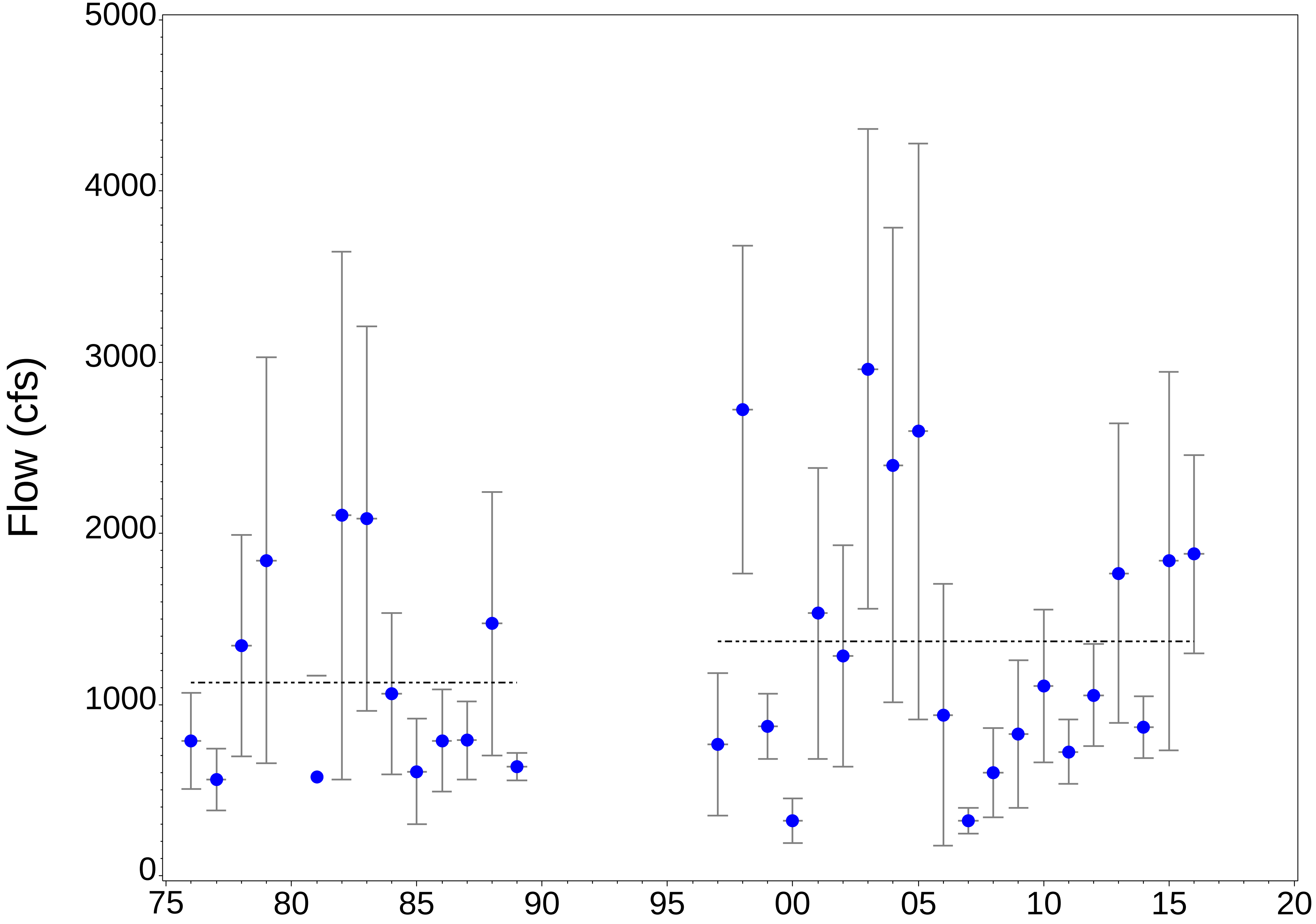


Figure C.15. Annual monthly median Peace River at Arcadia plus Horse, Joshua and Shell Creeks gaged flows

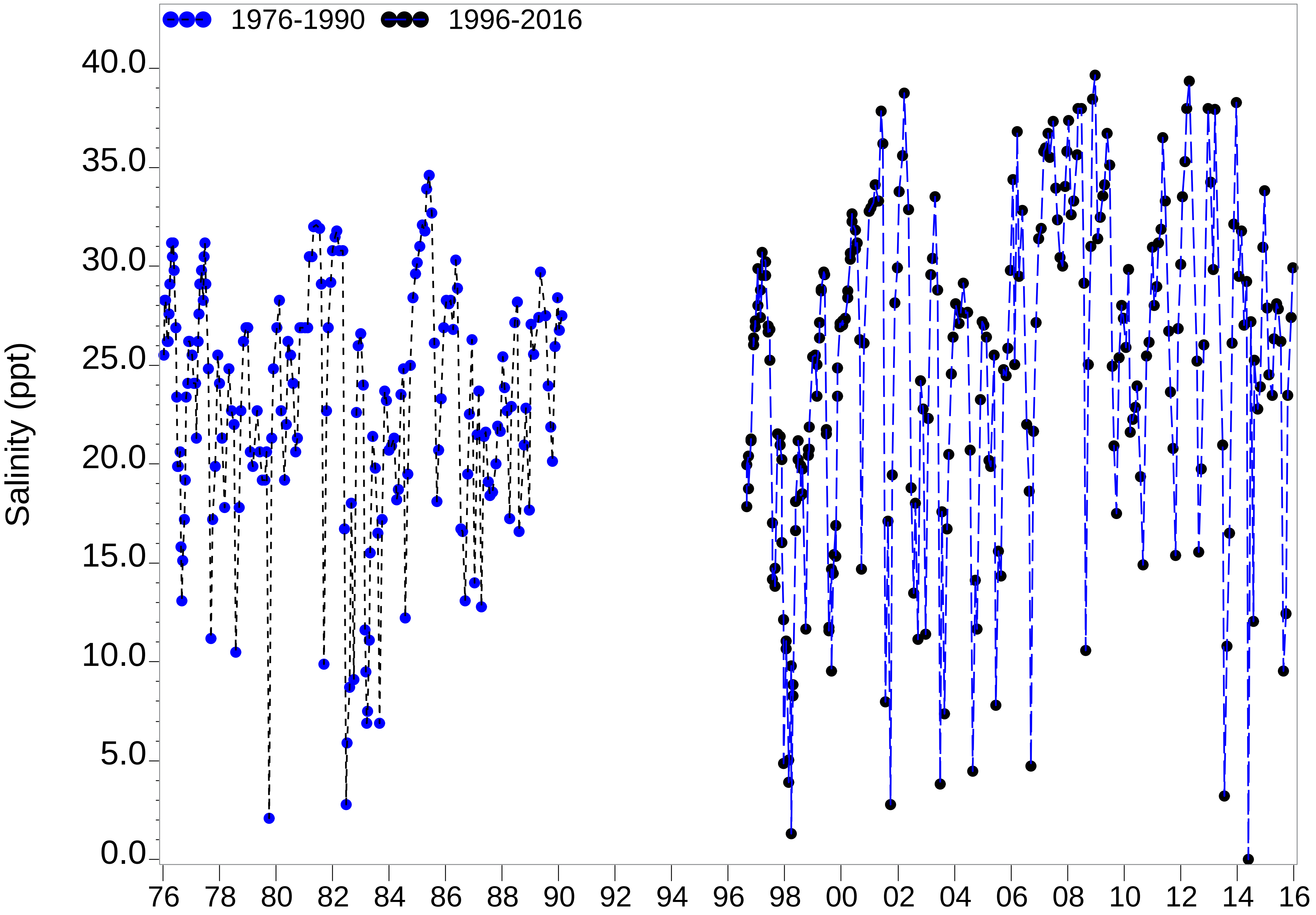


Figure C.16. Monthly long-term Surface Salinity at river kilometer -2.4

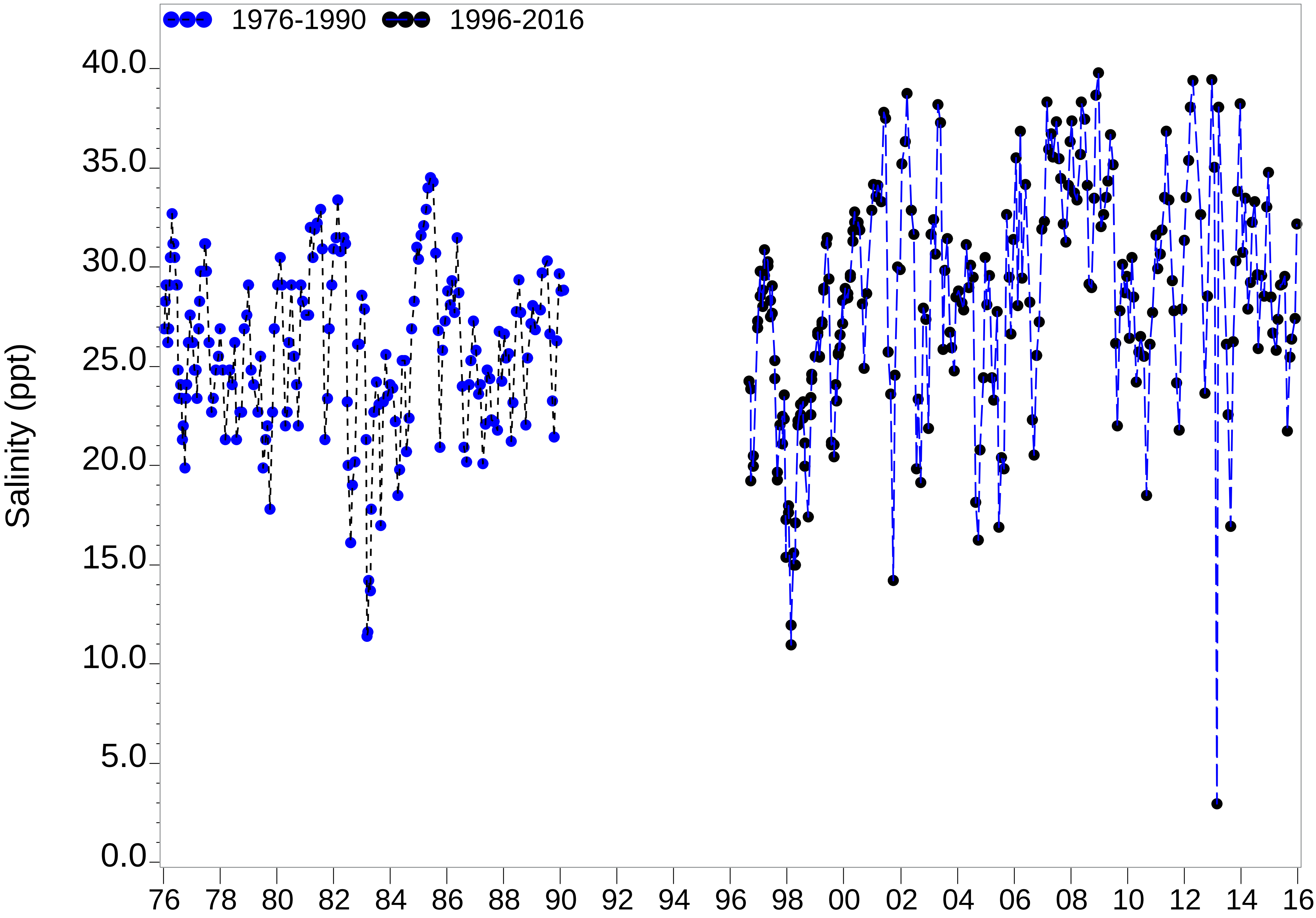


Figure C.17. Monthly long-term Bottom Salinity at river kilometer -2.4

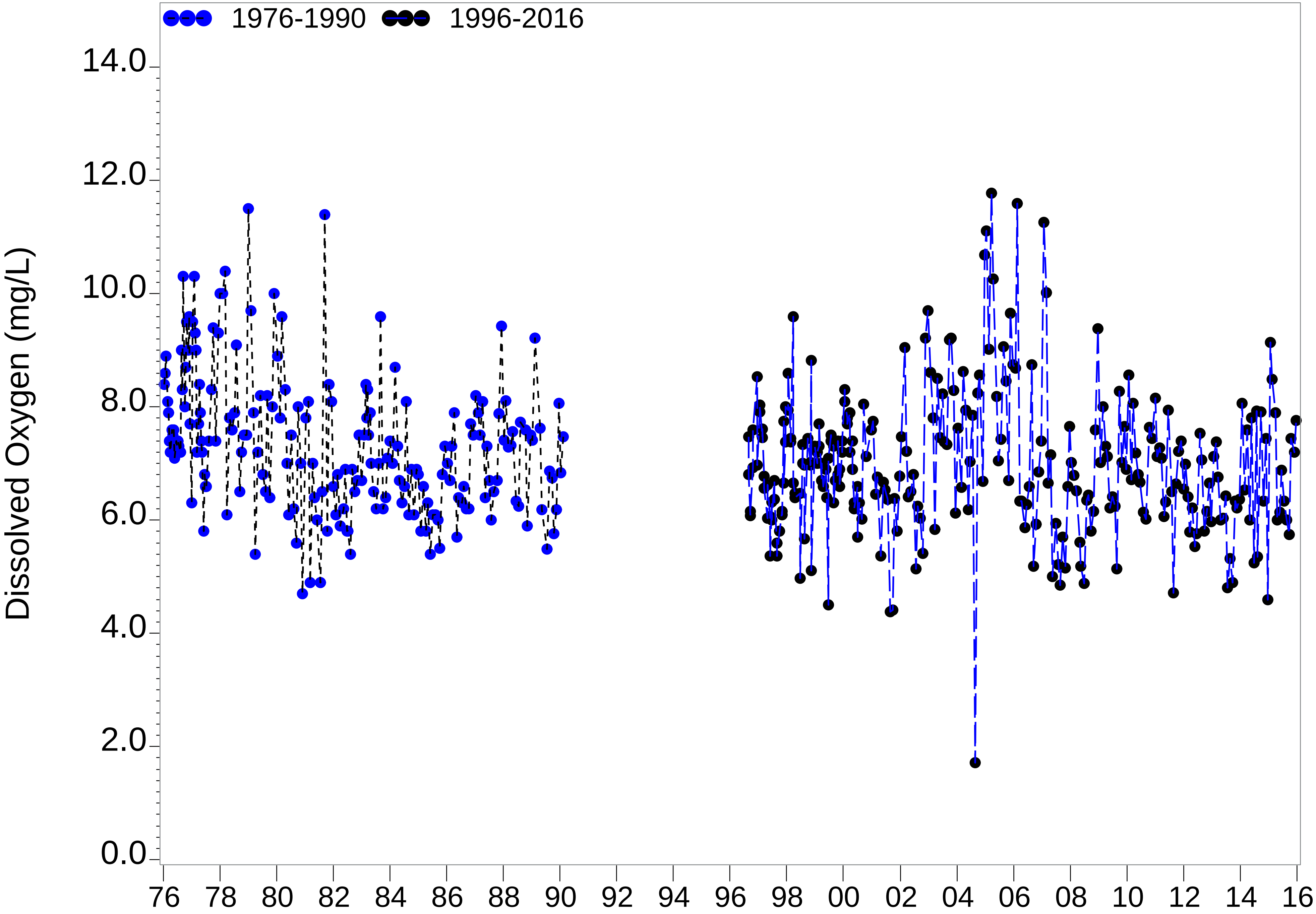


Figure C.18. Monthly long-term Surface Dissolved Oxygen Levels at river kilometer -2.4

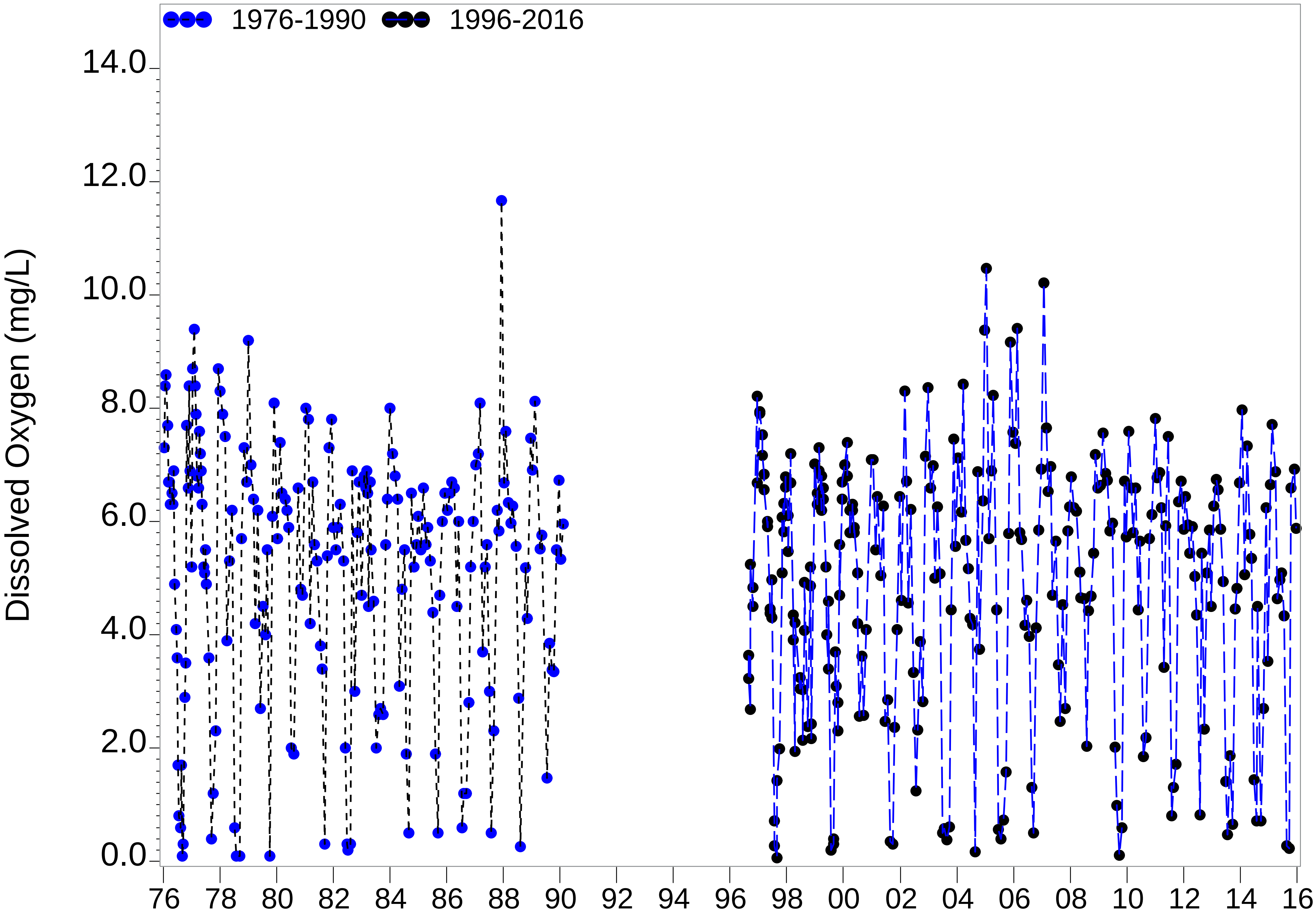


Figure C.19. Monthly long-term Bottom Dissolved Oxygen Levels at river kilometer -2.4

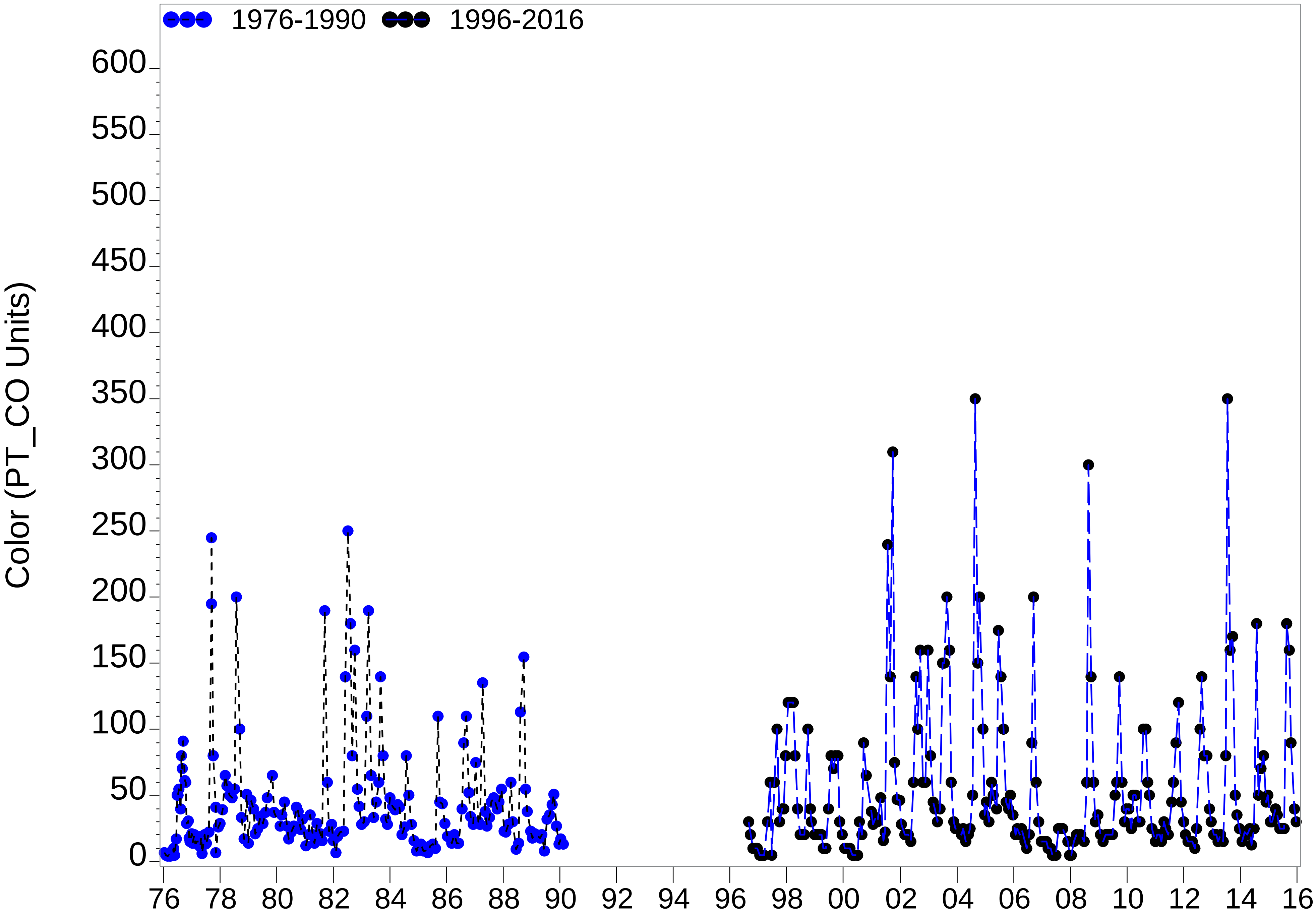


Figure C.20. Monthly long-term Surface Water Color at river kilometer -2.4

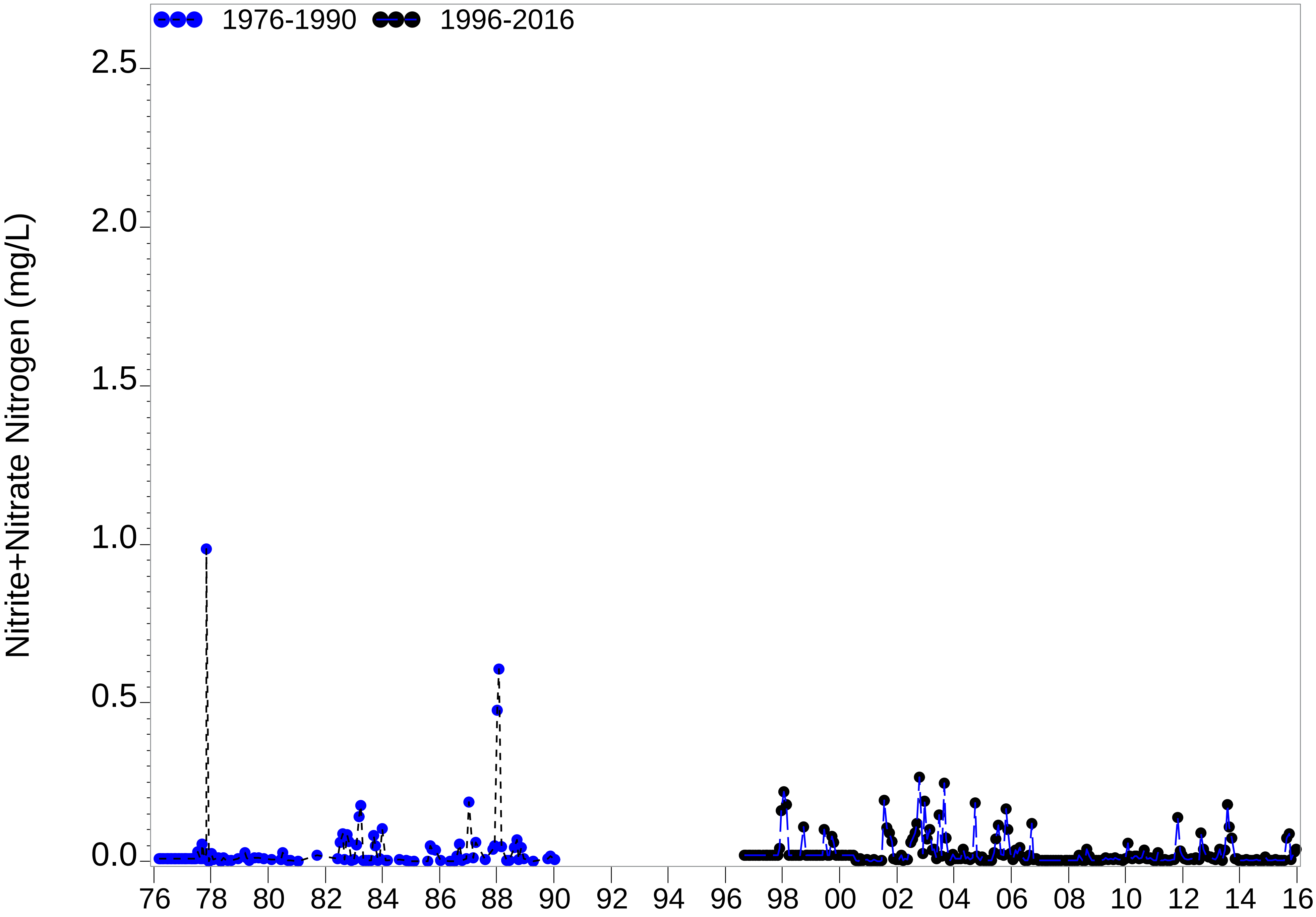


Figure C.21. Monthly long-term Surface Nitrite/Nitrate Nitrogen Concentrations at river kilometer -2.4

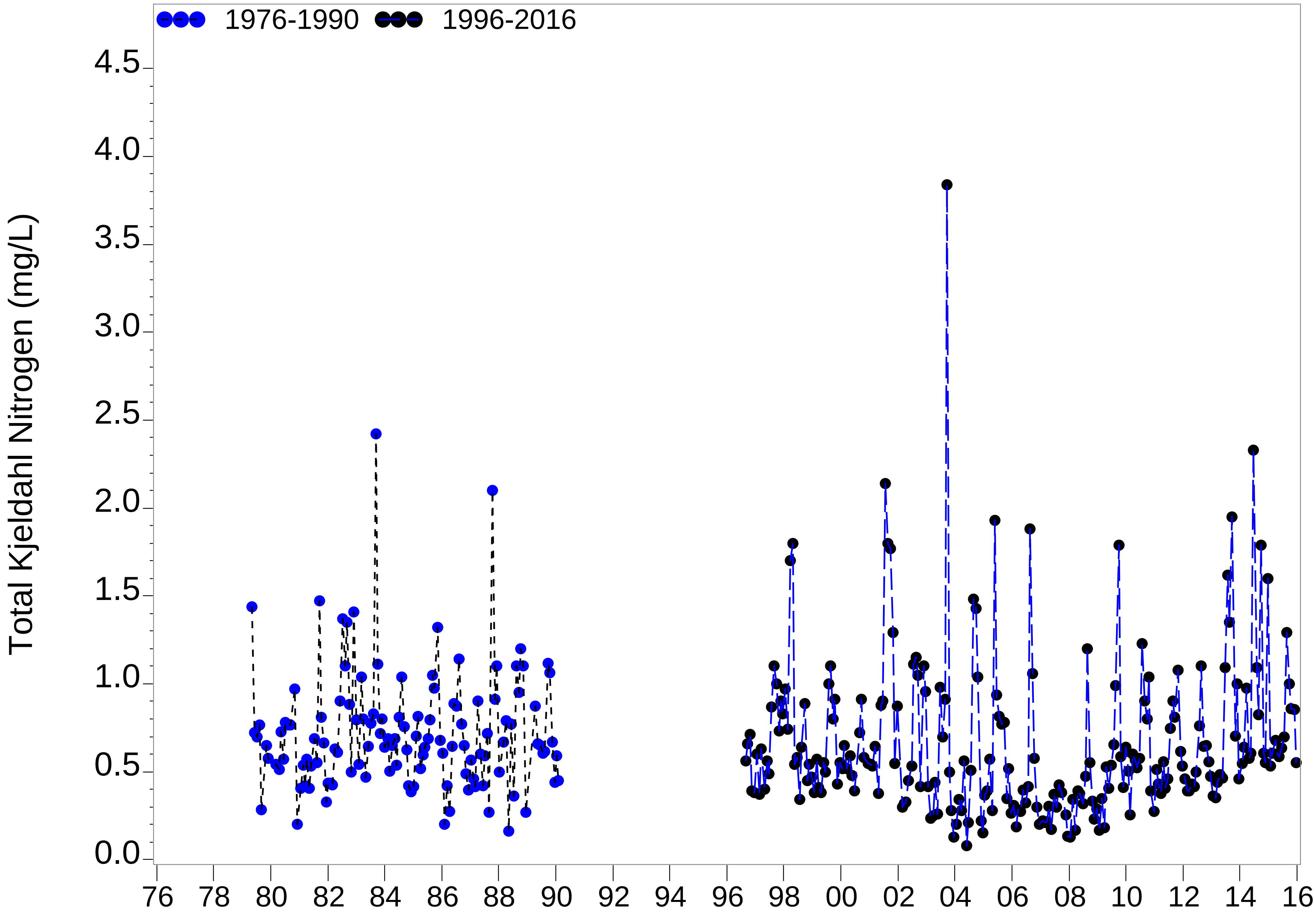


Figure C.22. Monthly long-term Surface Total Kjeldahl Nitrogen Concentrations at river kilometer -2.4

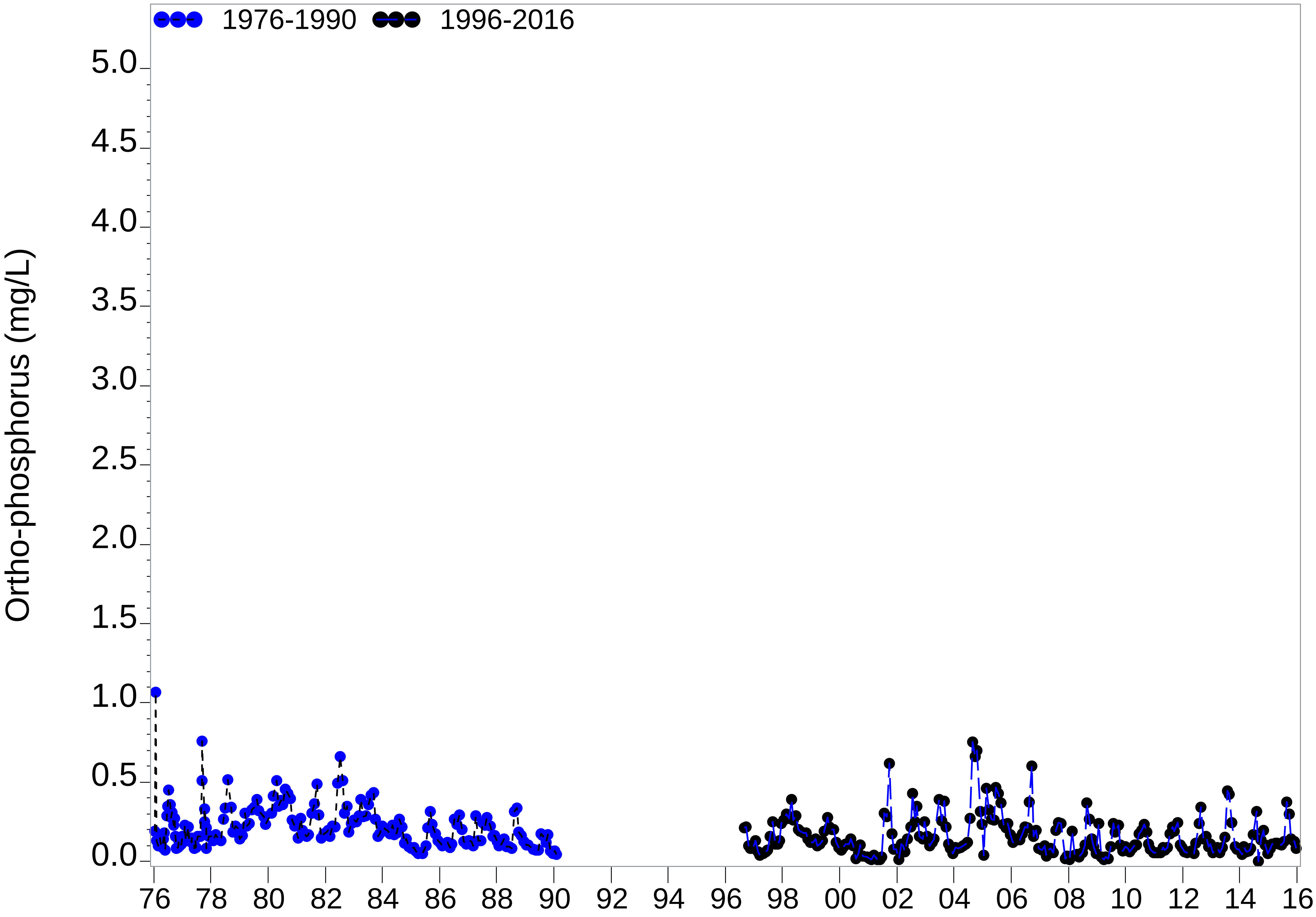


Figure C.23. Monthly long-term Surface Ortho-phosphorus Concentrations at river kilometer -2.4

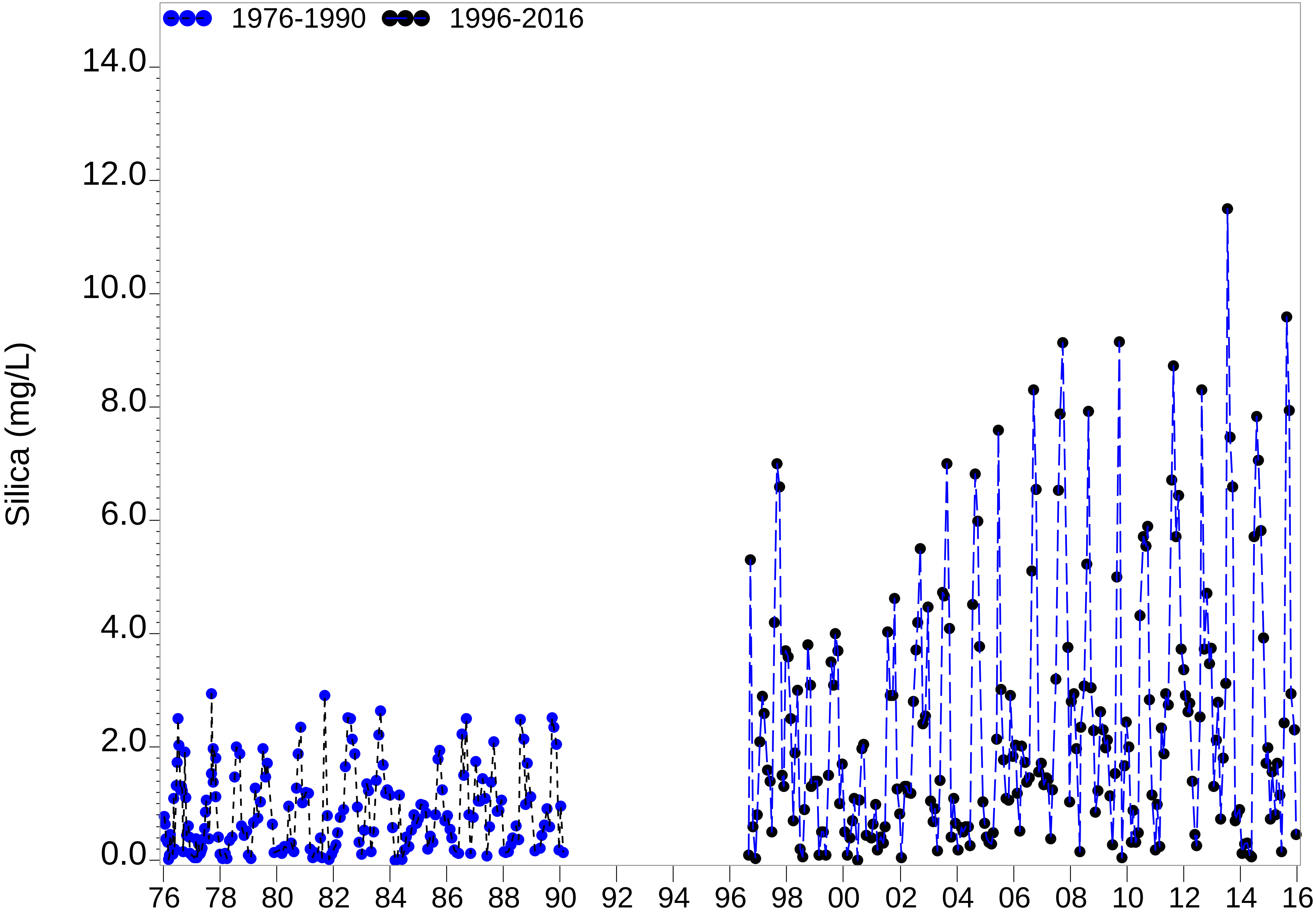


Figure C.24. Monthly long-term Surface Silica Concentrations at river kilometer -2.4

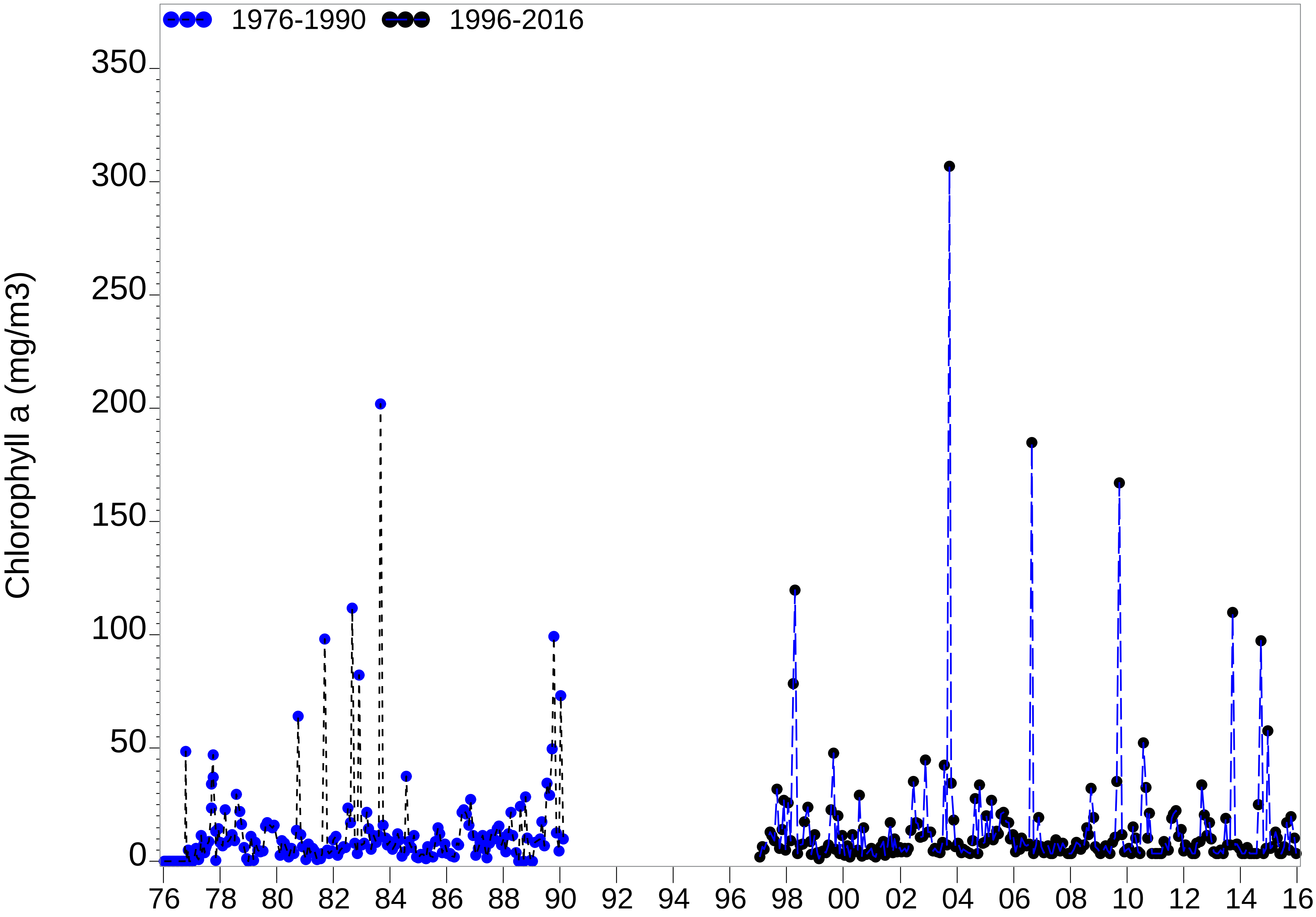


Figure C.25. Monthly long-term Surface Chlorophyll a Concentrations at river kilometer -2.4

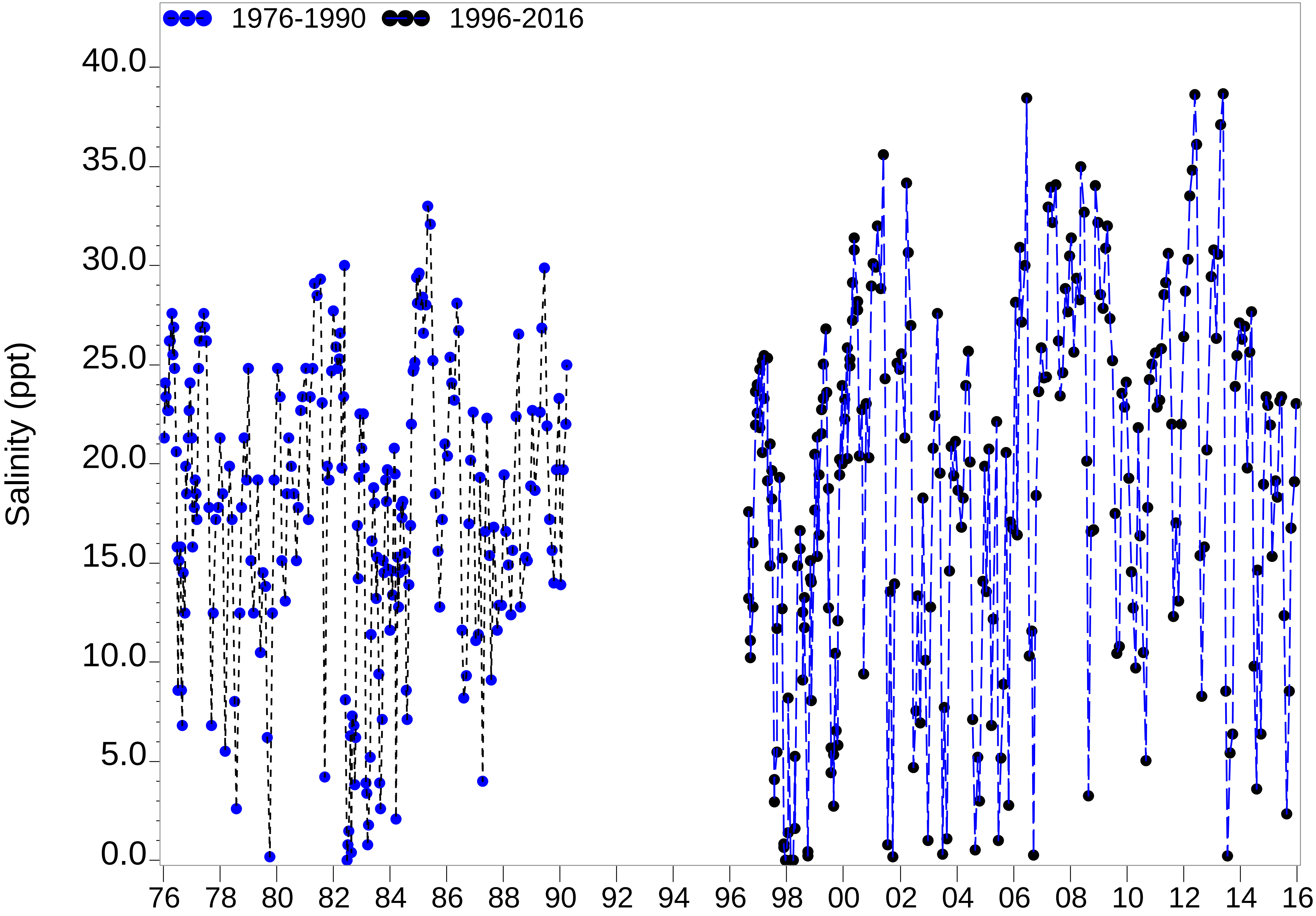


Figure C.26. Monthly long-term Surface Salinity at river kilometer 6.6

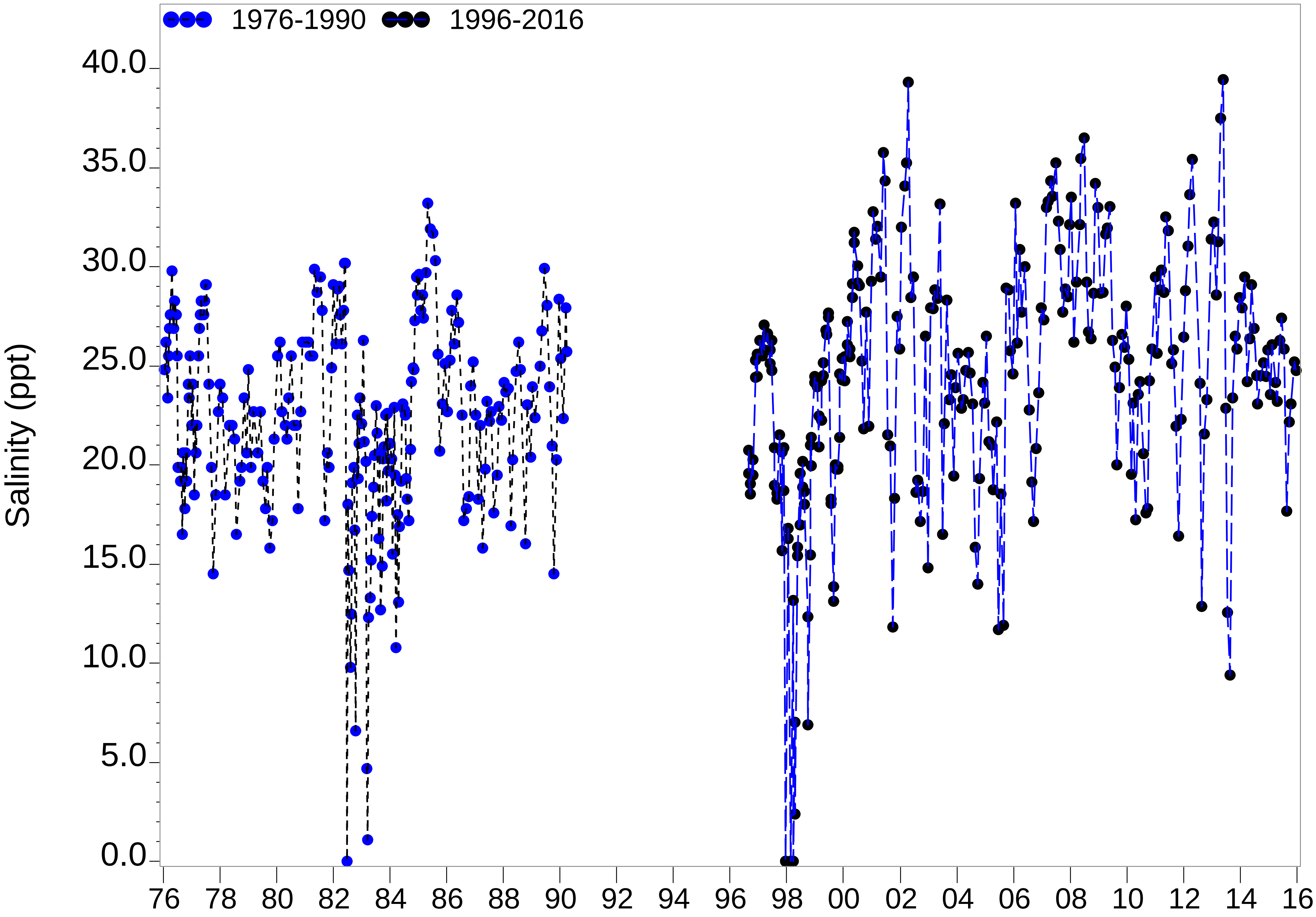


Figure C.27. Monthly long-term Bottom Salinity at river kilometer 6.6

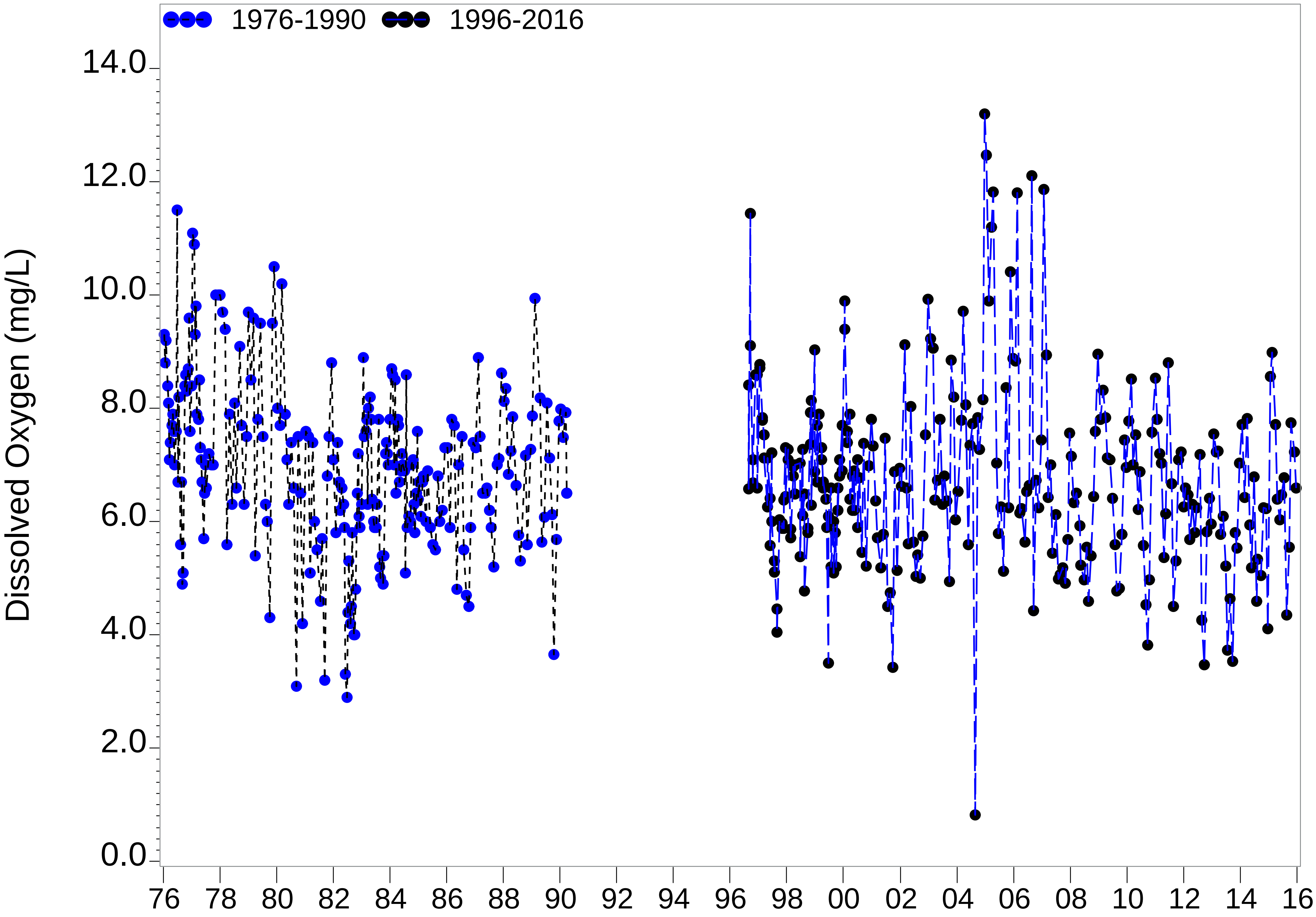


Figure C.28. Monthly long-term Surface Dissolved Oxygen Levels at river kilometer 6.6

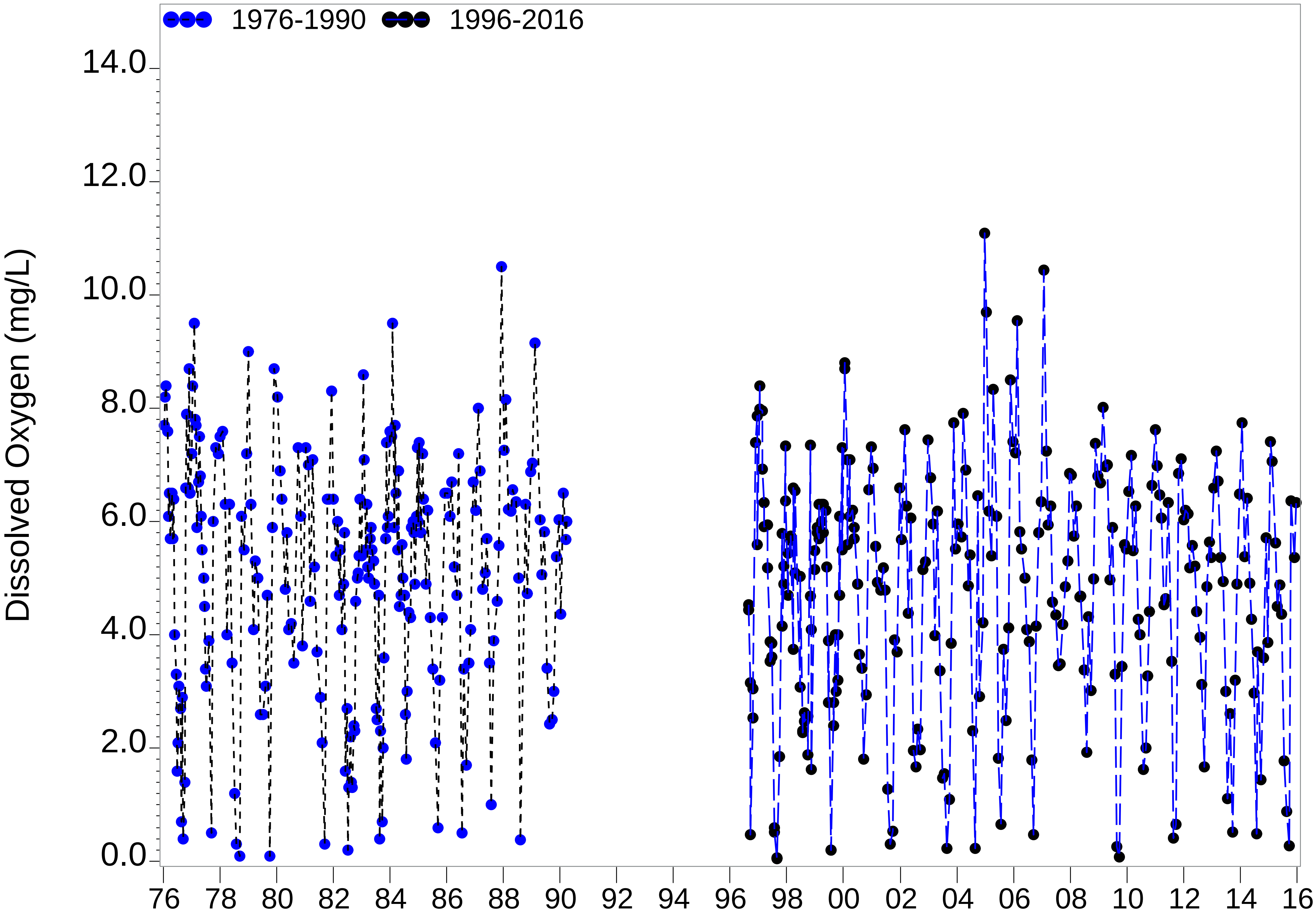


Figure C.29. Monthly long-term Bottom Dissolved Oxygen Levels at river kilometer 6.6

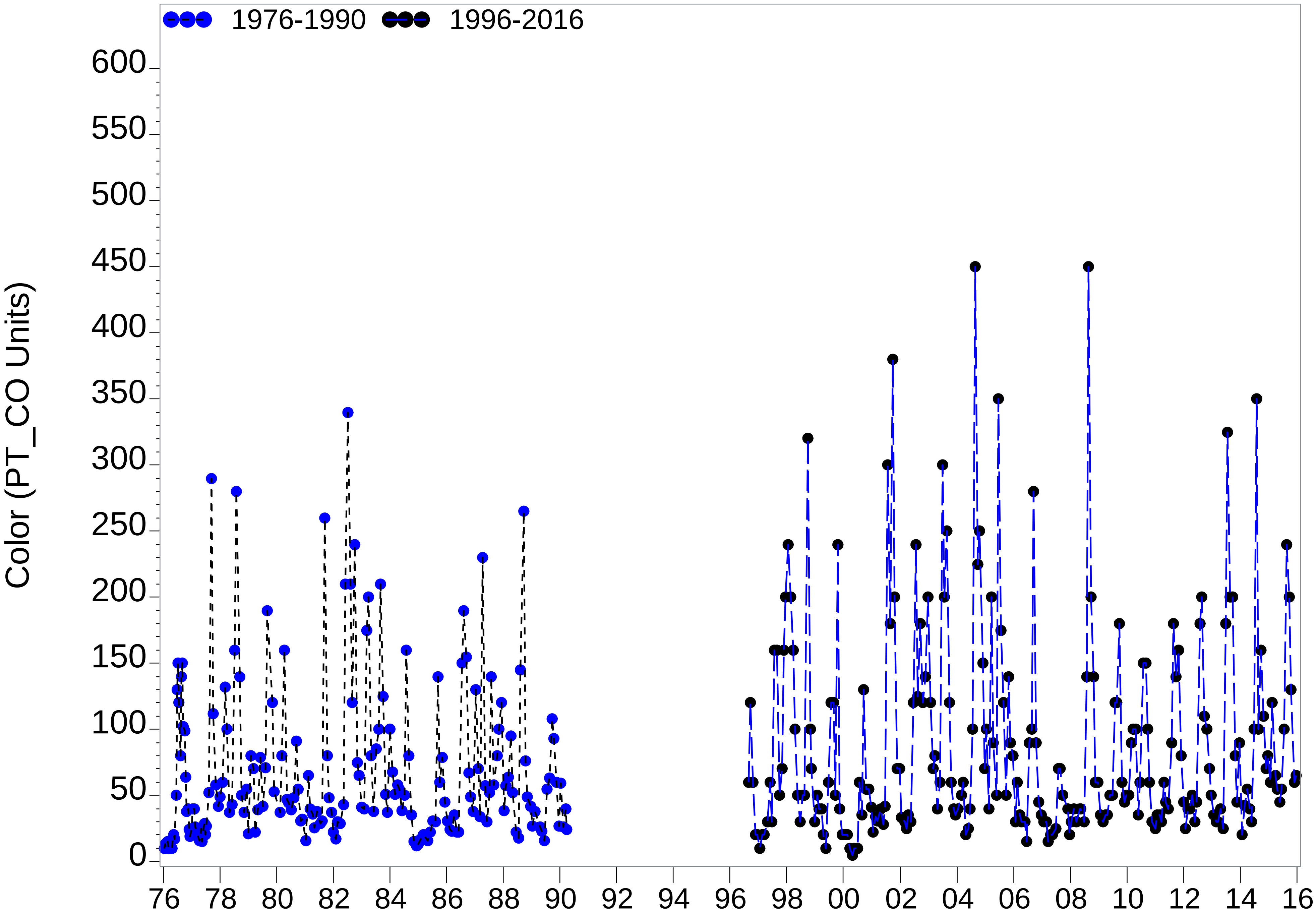


Figure C.30. Monthly long-term Surface Water Color at river kilometer 6.6

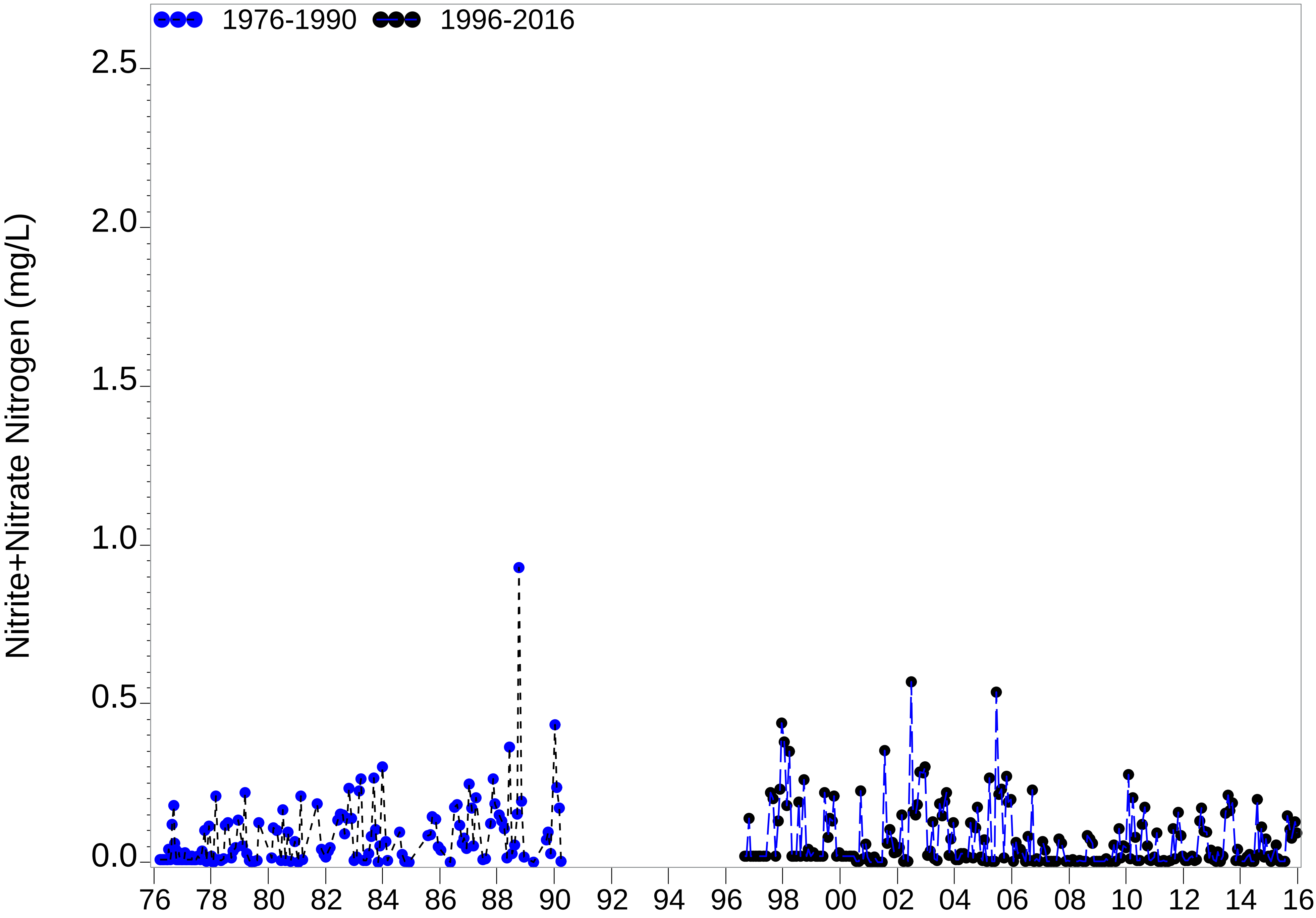


Figure C.31. Monthly long-term Surface Nitrite/Nitrate Nitrogen Concentrations at river kilometer 6.6

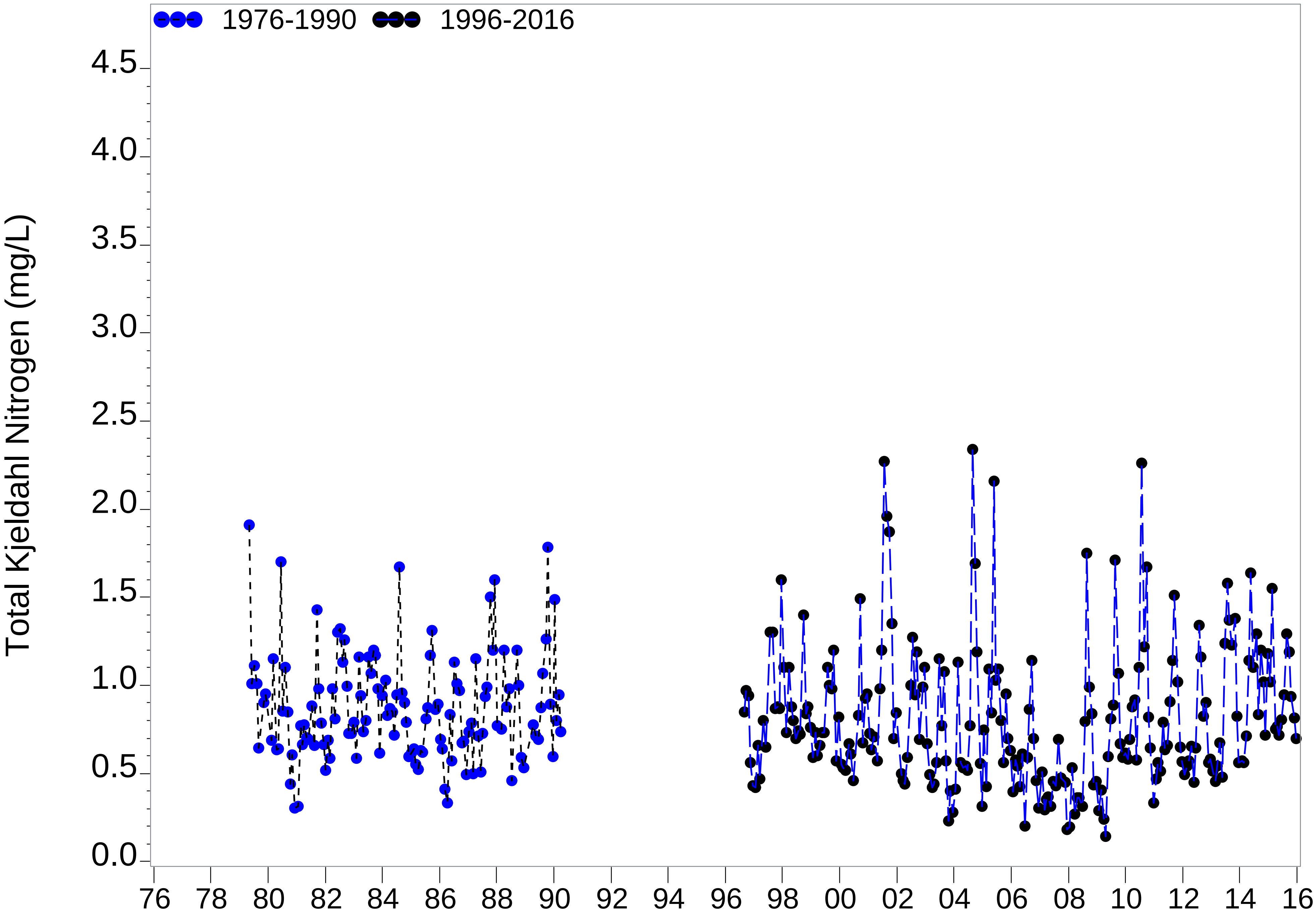


Figure C.32. Monthly long-term Surface Total Kjeldahl Nitrogen Concentrations at river kilometer 6.6

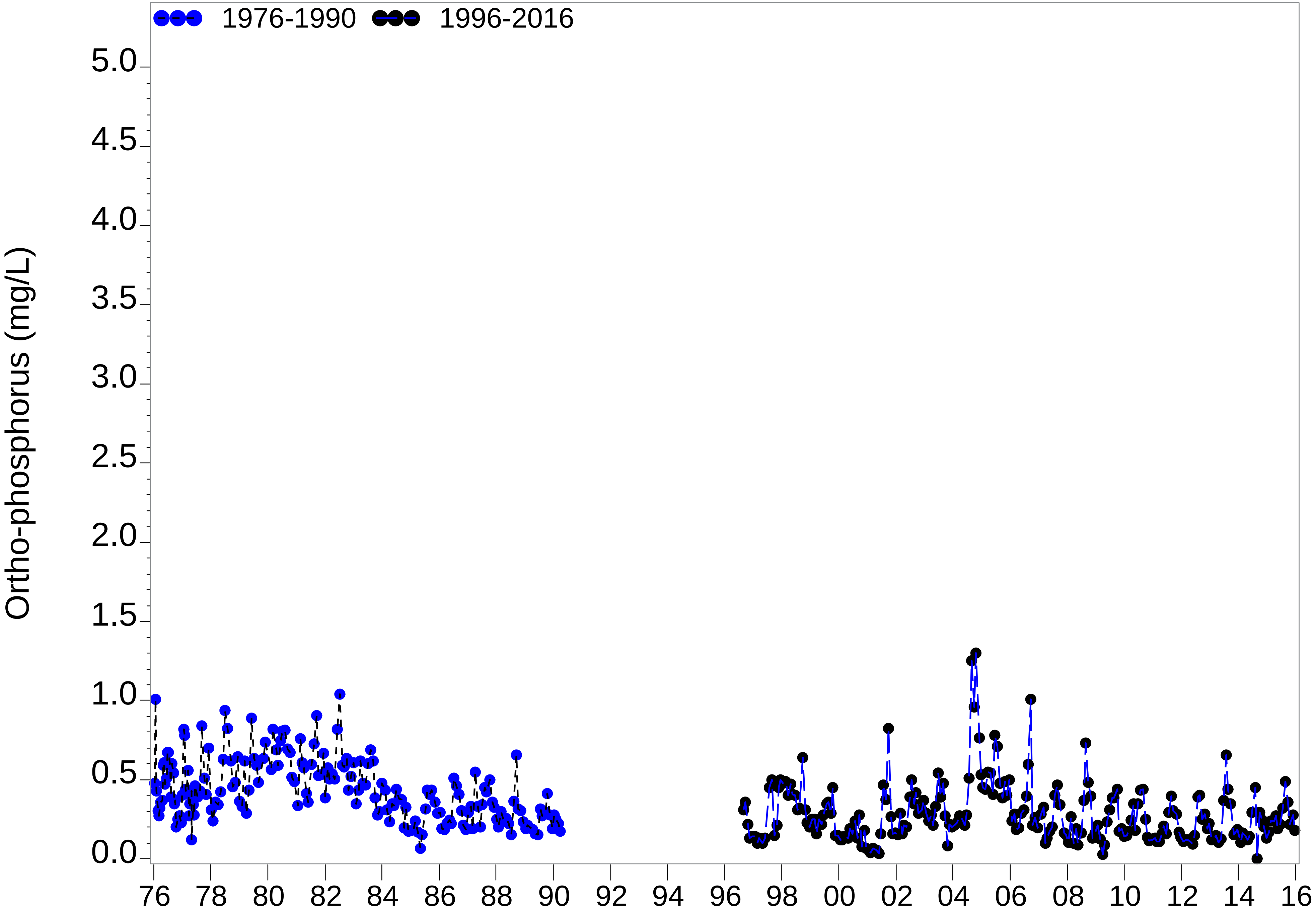


Figure C.33. Monthly long-term Surface Ortho-phosphorus Concentrations at river kilometer 6.6

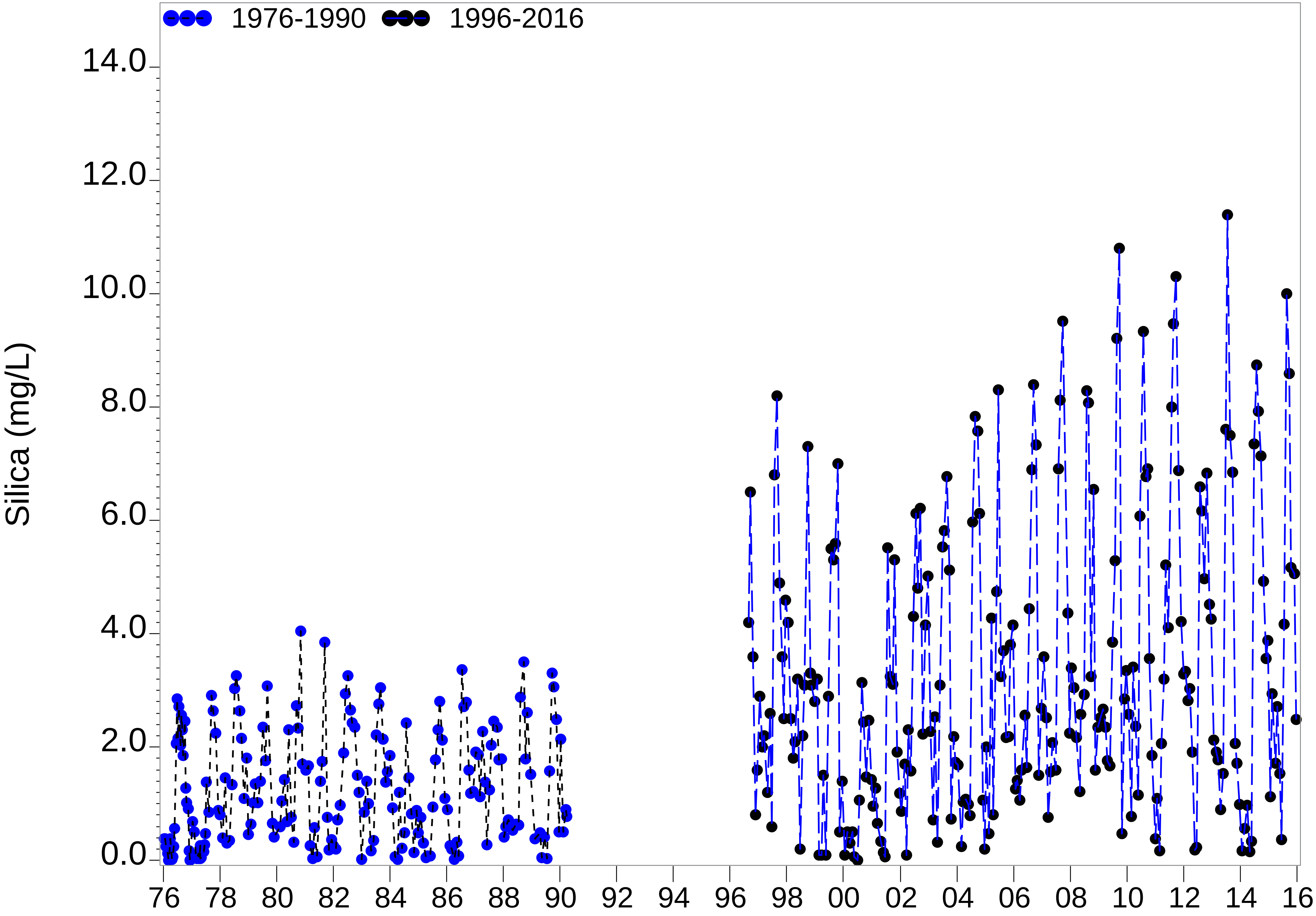


Figure C.34. Monthly long-term Surface Silica Concentrations at river kilometer 6.6

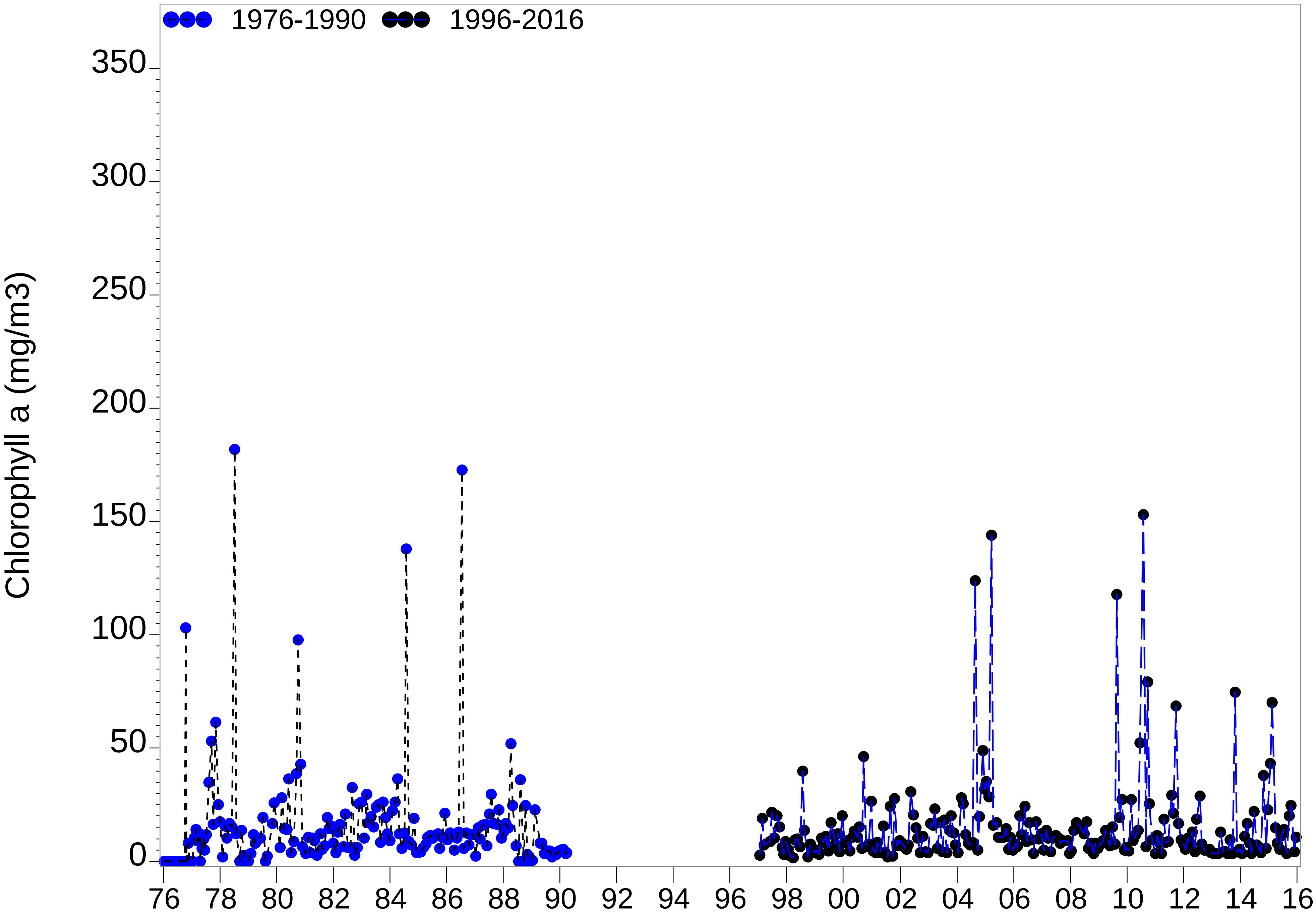


Figure C.35. Monthly long-term Surface Chlorophyll a Concentrations at river kilometer 6.6

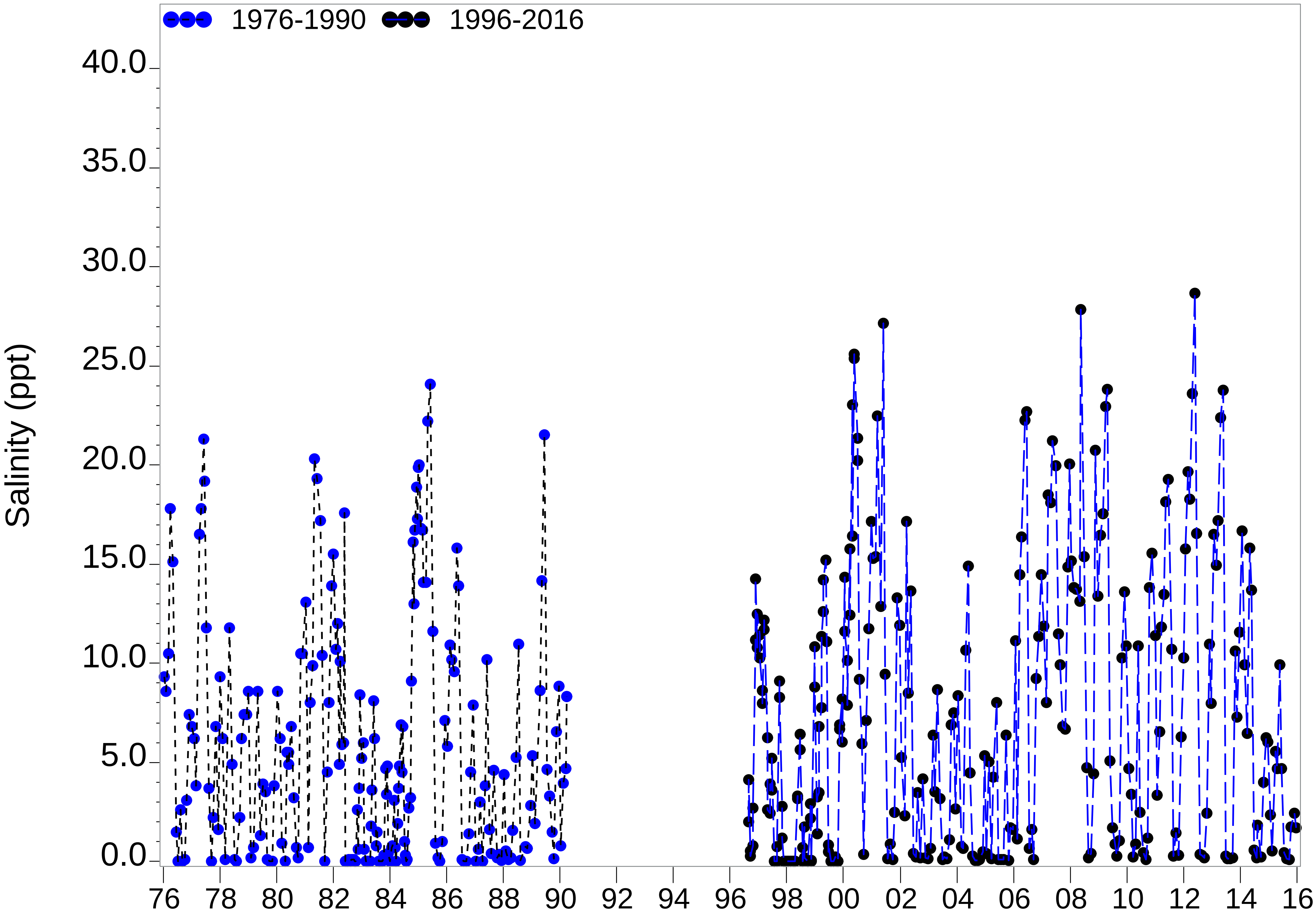


Figure C.36. Monthly long-term Surface Salinity at river kilometer 15.5

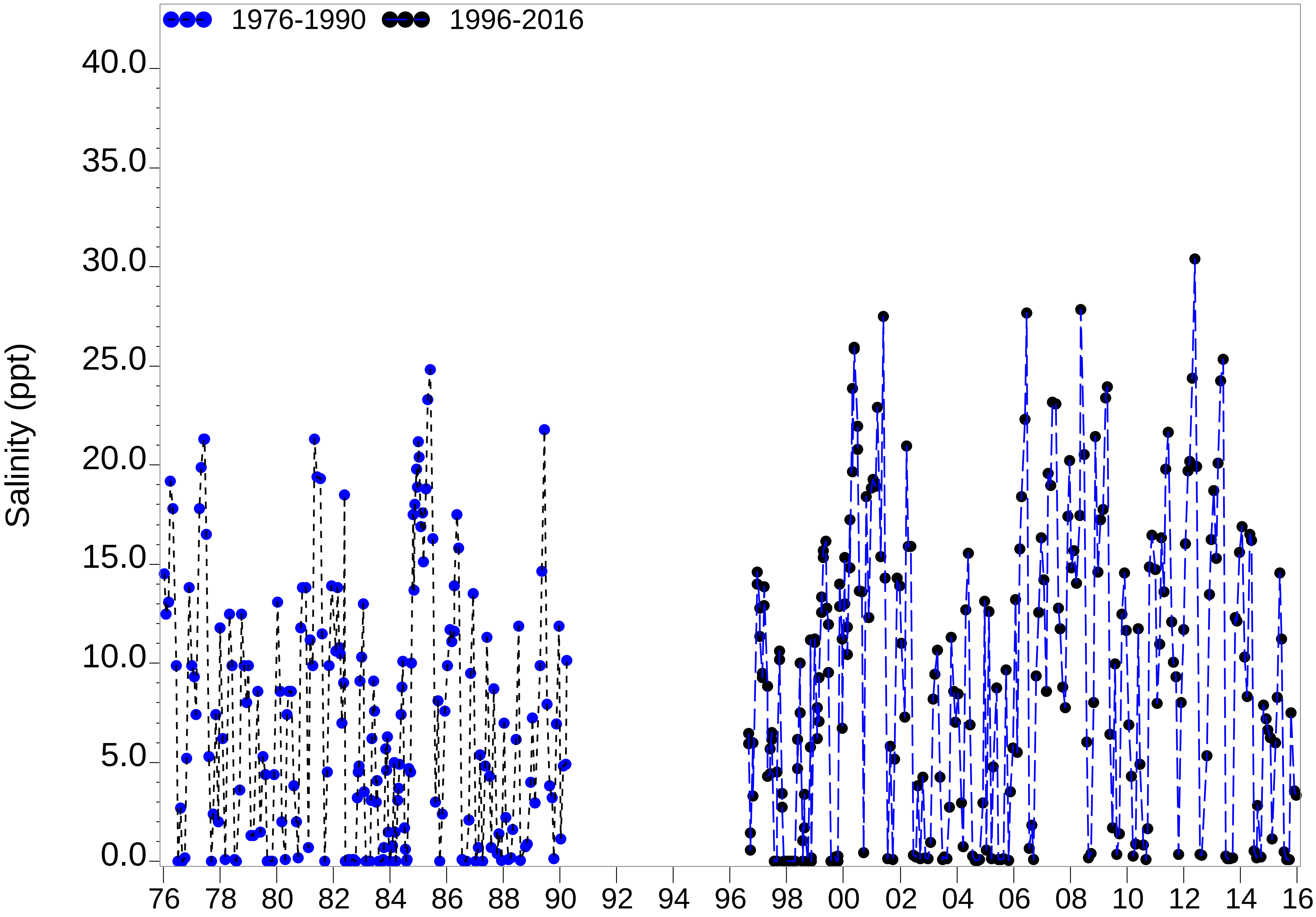


Figure C.37. Monthly long-term Bottom Salinity at river kilometer 15.5

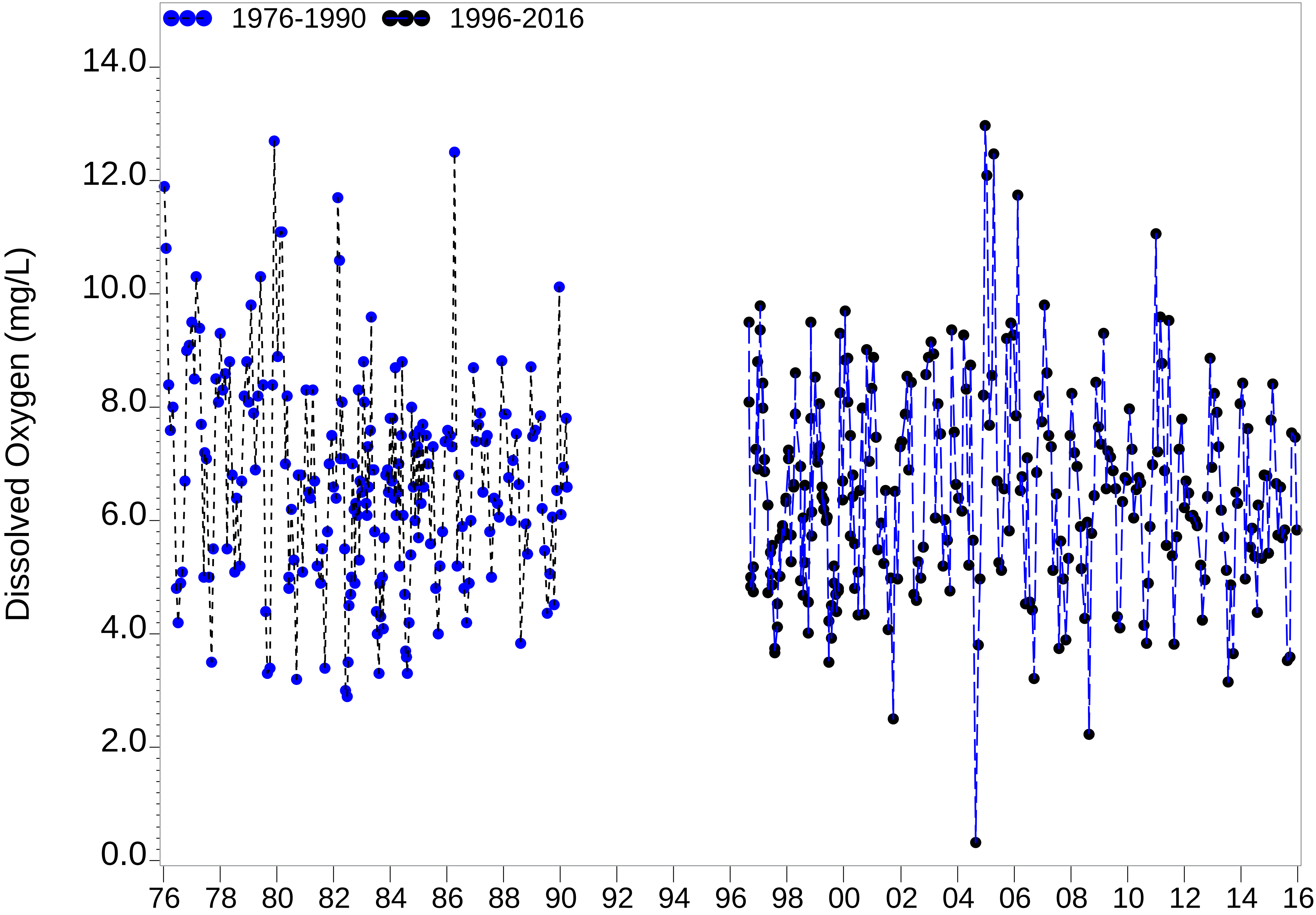


Figure C.38. Monthly long-term Surface Dissolved Oxygen Levels at river kilometer 15.5

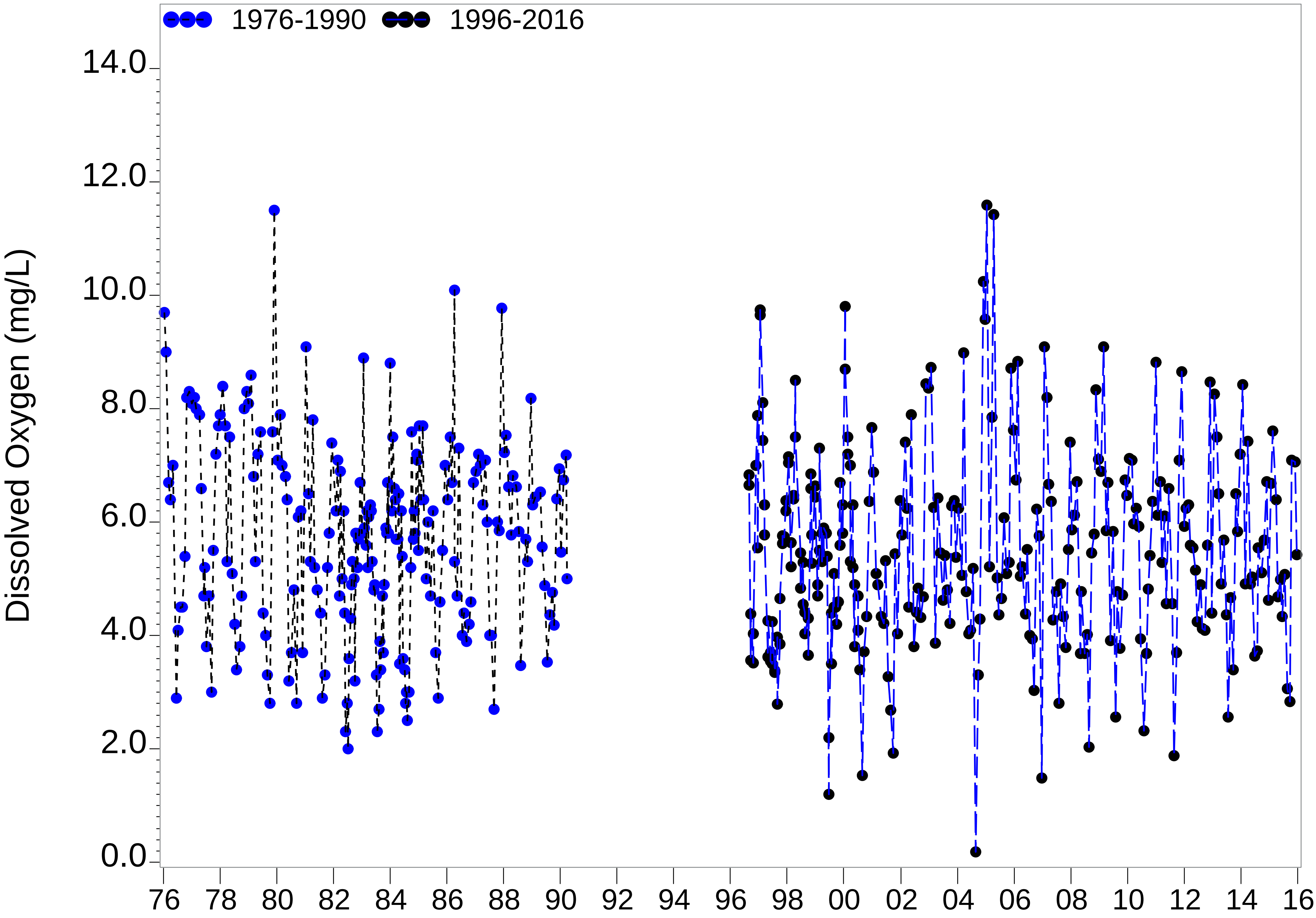


Figure C.39. Monthly long-term Bottom Dissolved Oxygen Levels at river kilometer 15.5

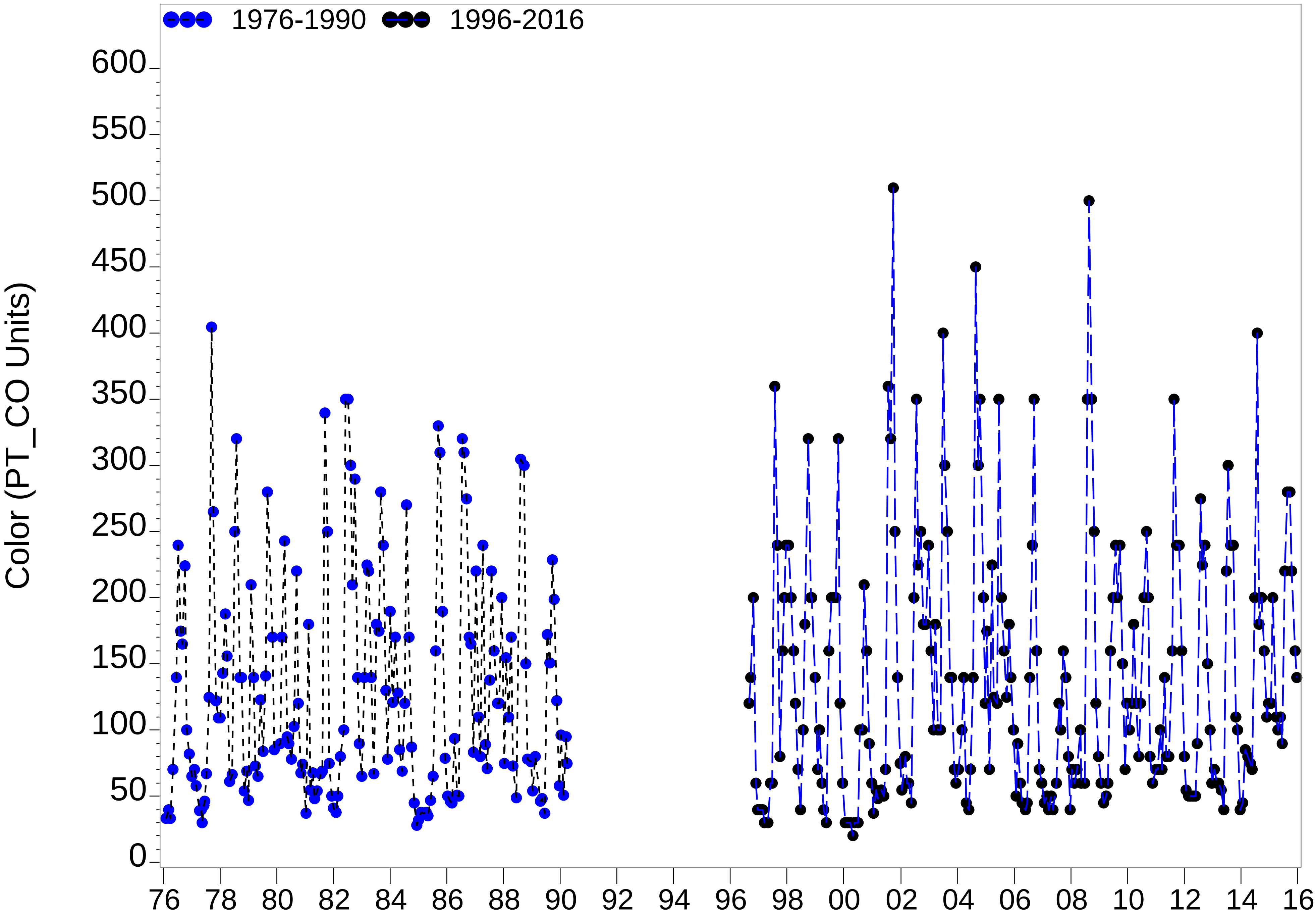


Figure C.40. Monthly long-term Surface Water Color at river kilometer 15.5

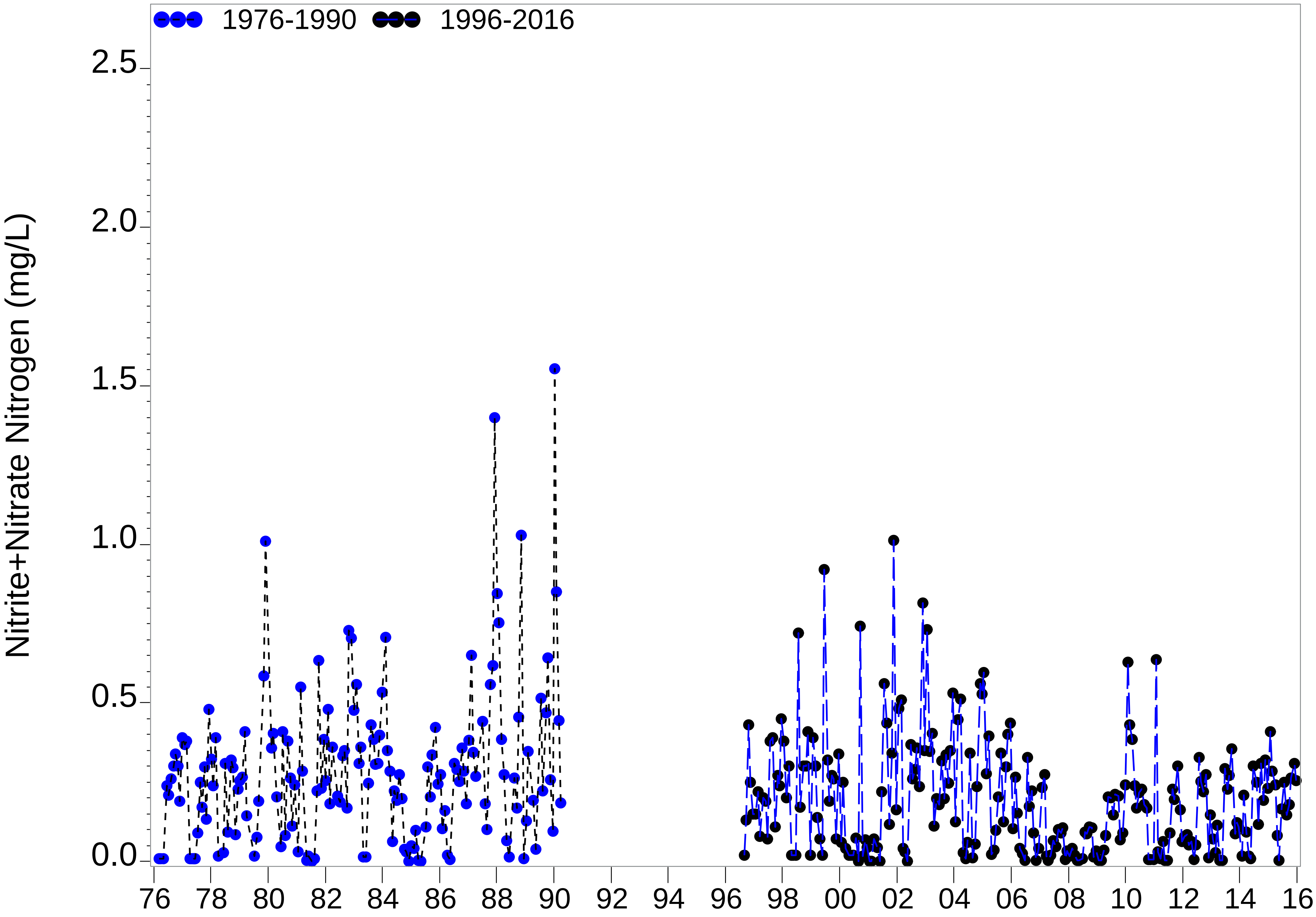


Figure C.41. Monthly long-term Surface Nitrite/Nitrate Nitrogen Concentrations at river kilometer 15.5

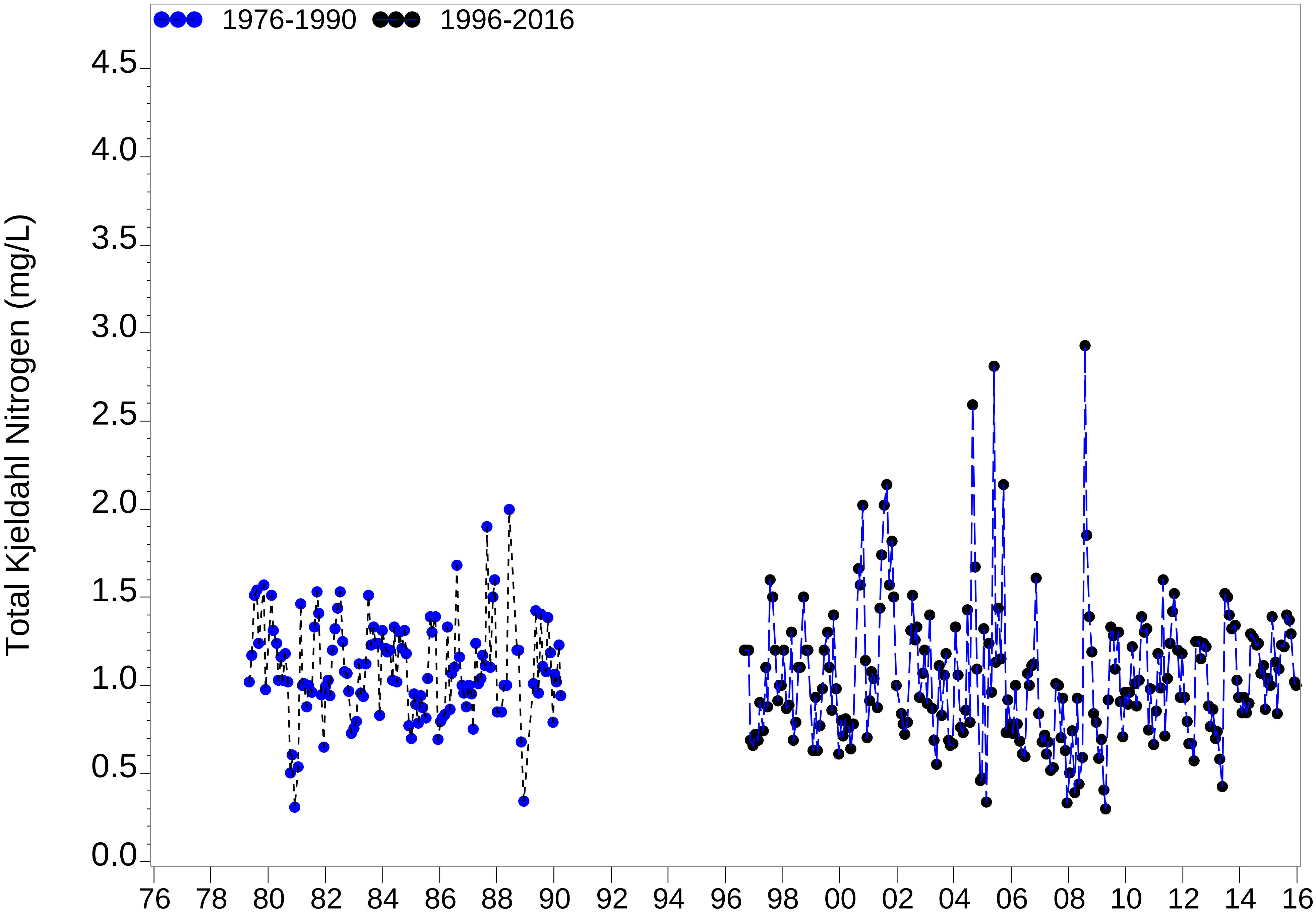


Figure C.42. Monthly long-term Surface Total Kjeldahl Nitrogen Concentrations at river kilometer 15.5

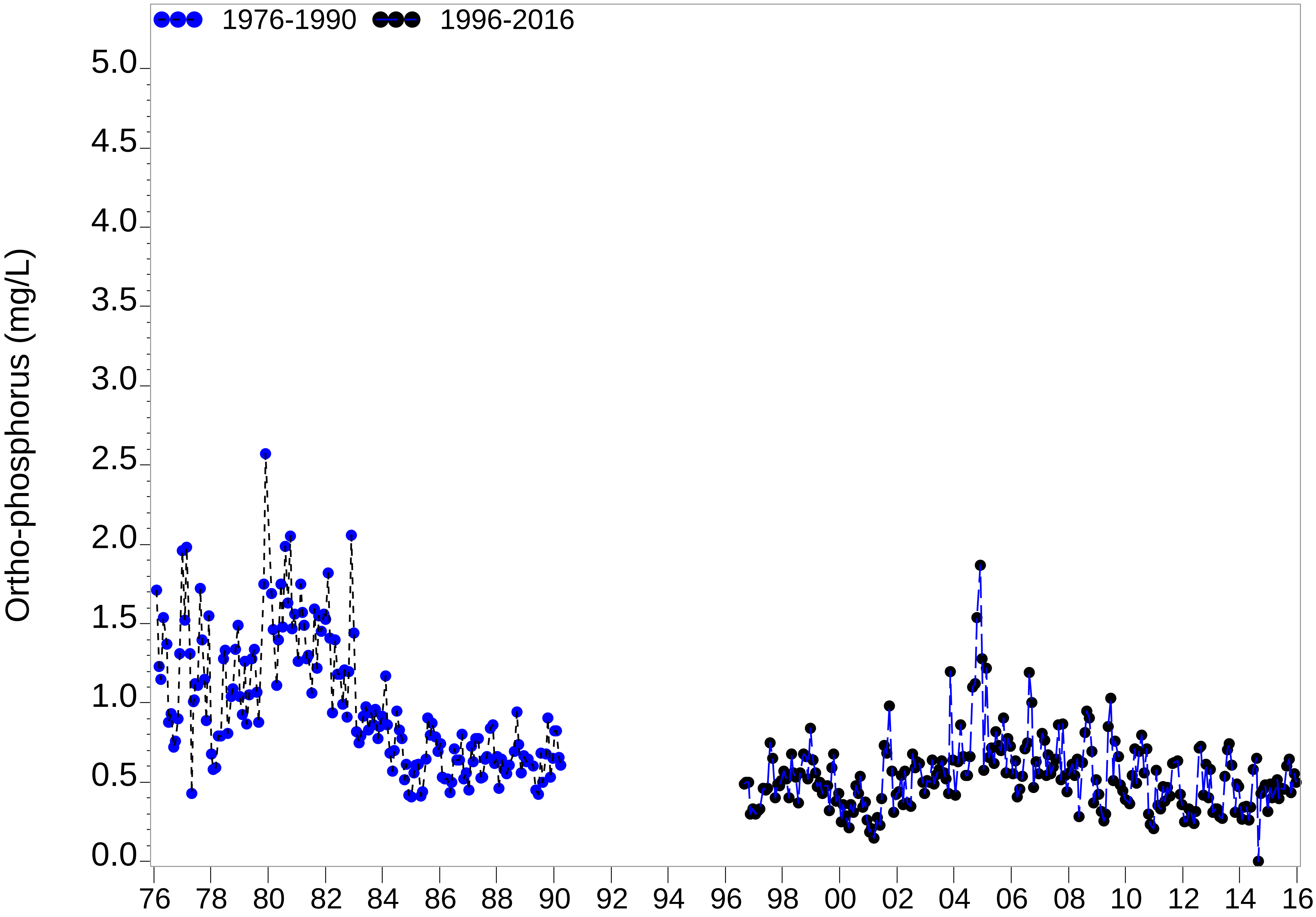


Figure C.43. Monthly long-term Surface Ortho-phosphorus Concentrations at river kilometer 15.5

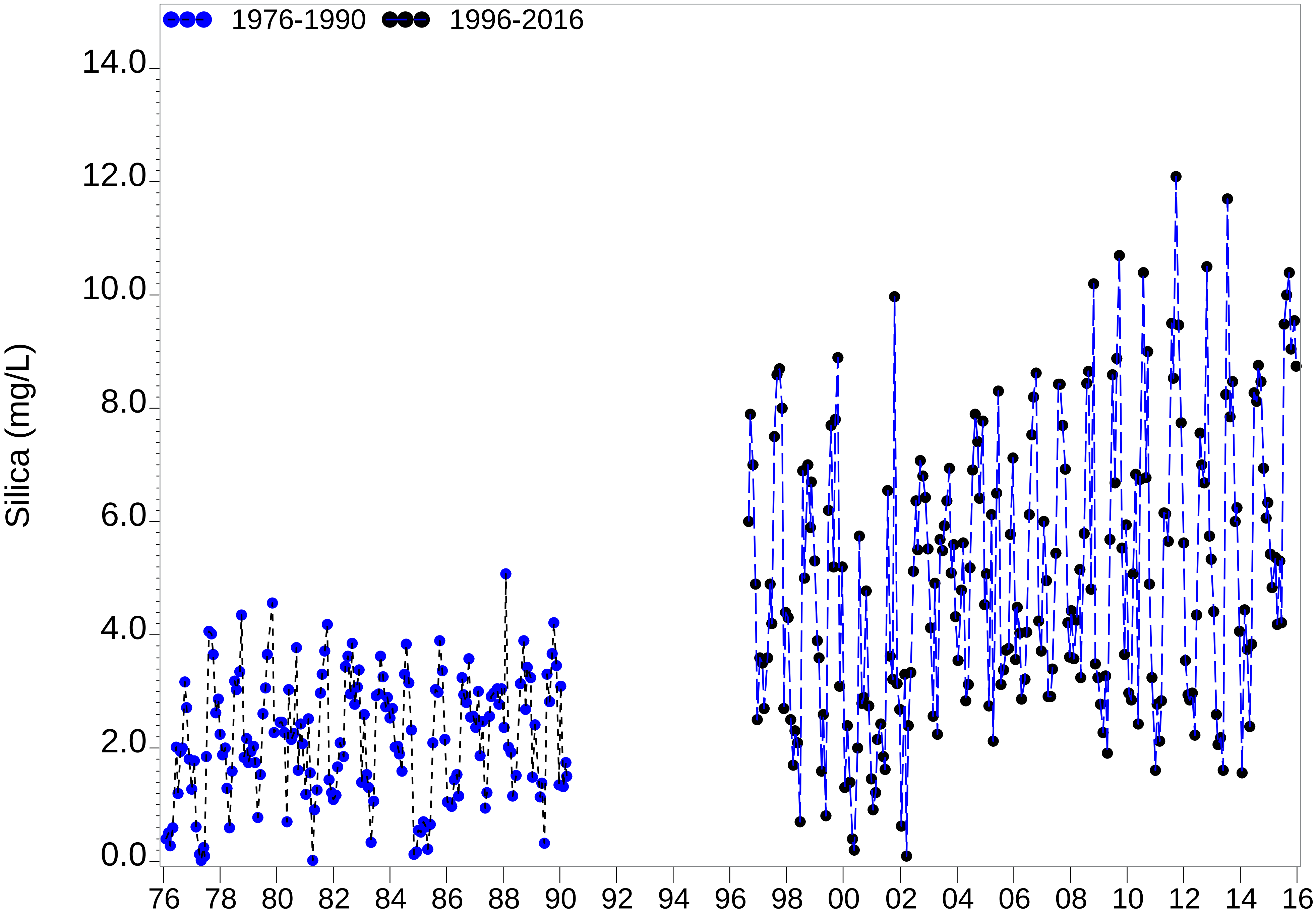


Figure C.44. Monthly long-term Surface Silica Concentrations at river kilometer 15.5

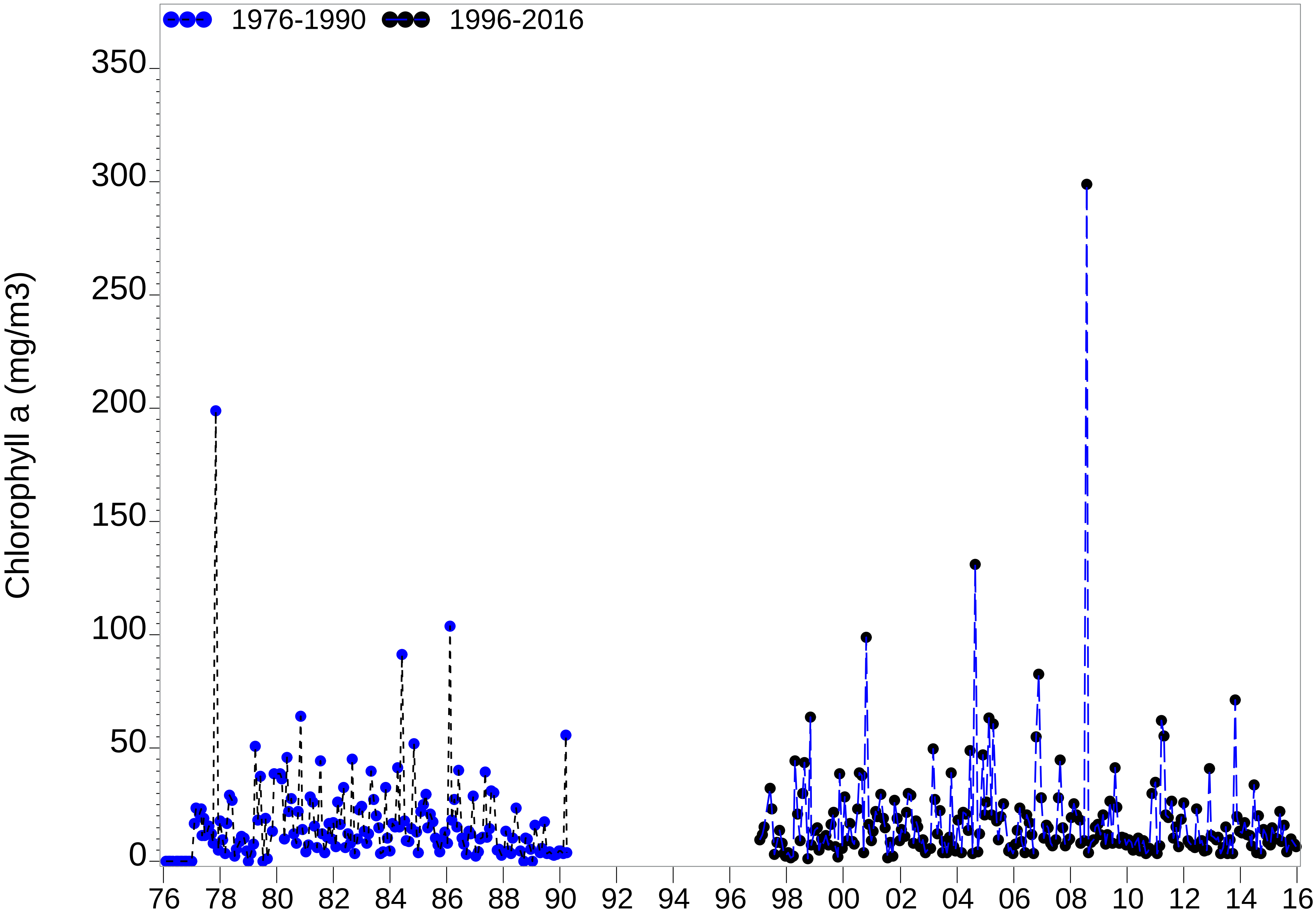


Figure C.45. Monthly long-term Surface Chlorophyll a Concentrations at river kilometer 15.5

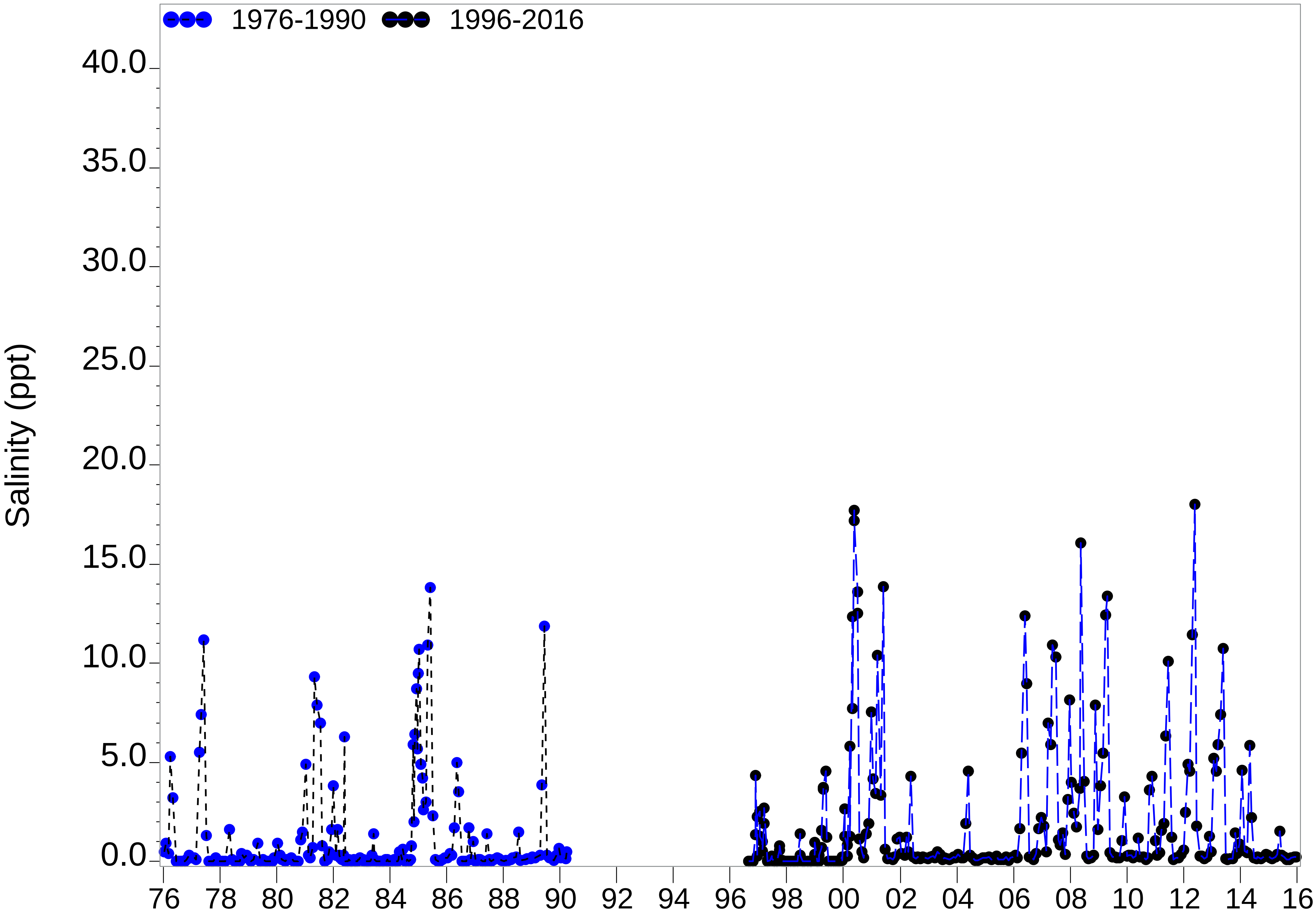


Figure C.46. Monthly long-term Surface Salinity at river kilometer 23.6

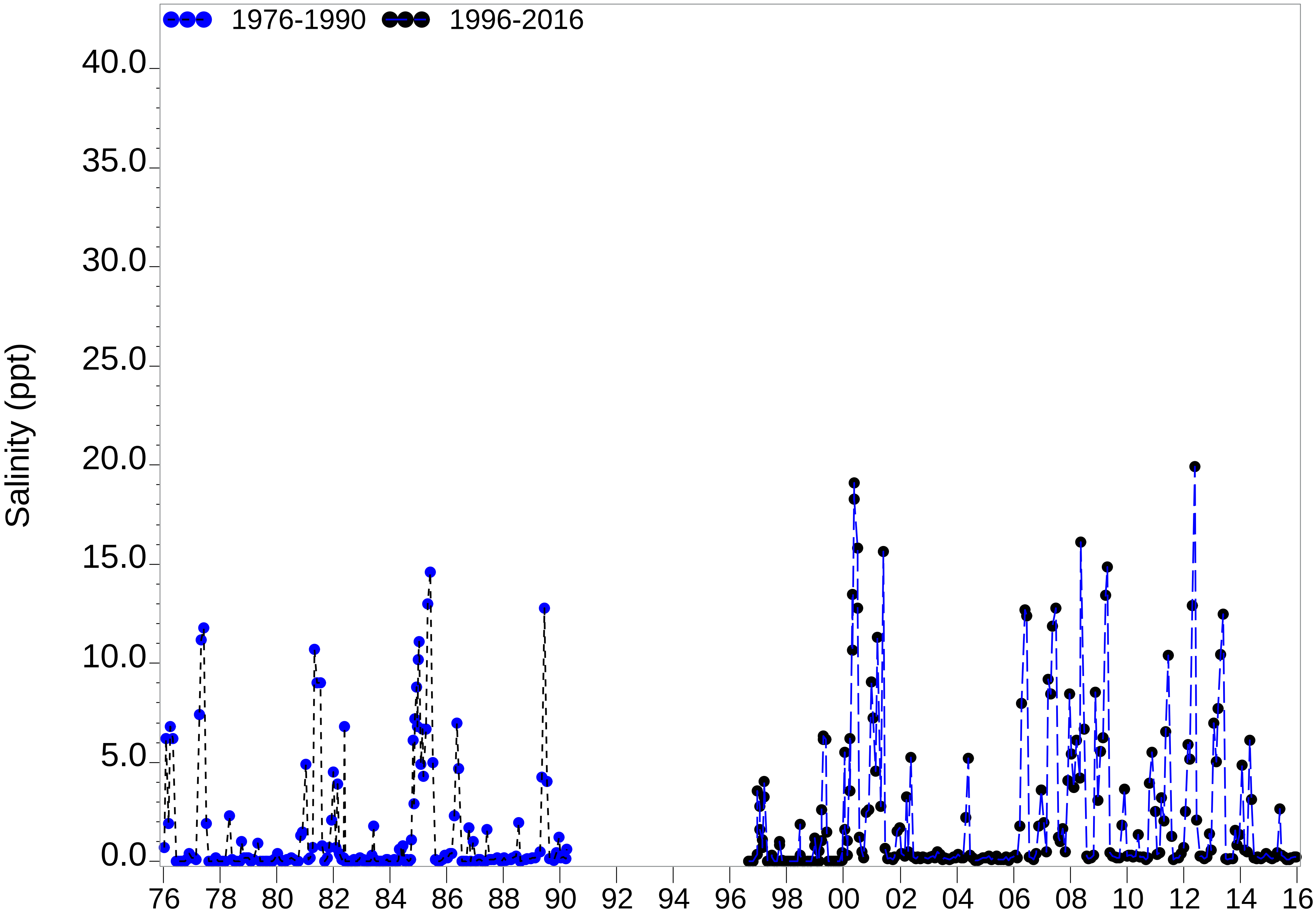


Figure C.47. Monthly long-term Bottom Salinity at river kilometer 23.6

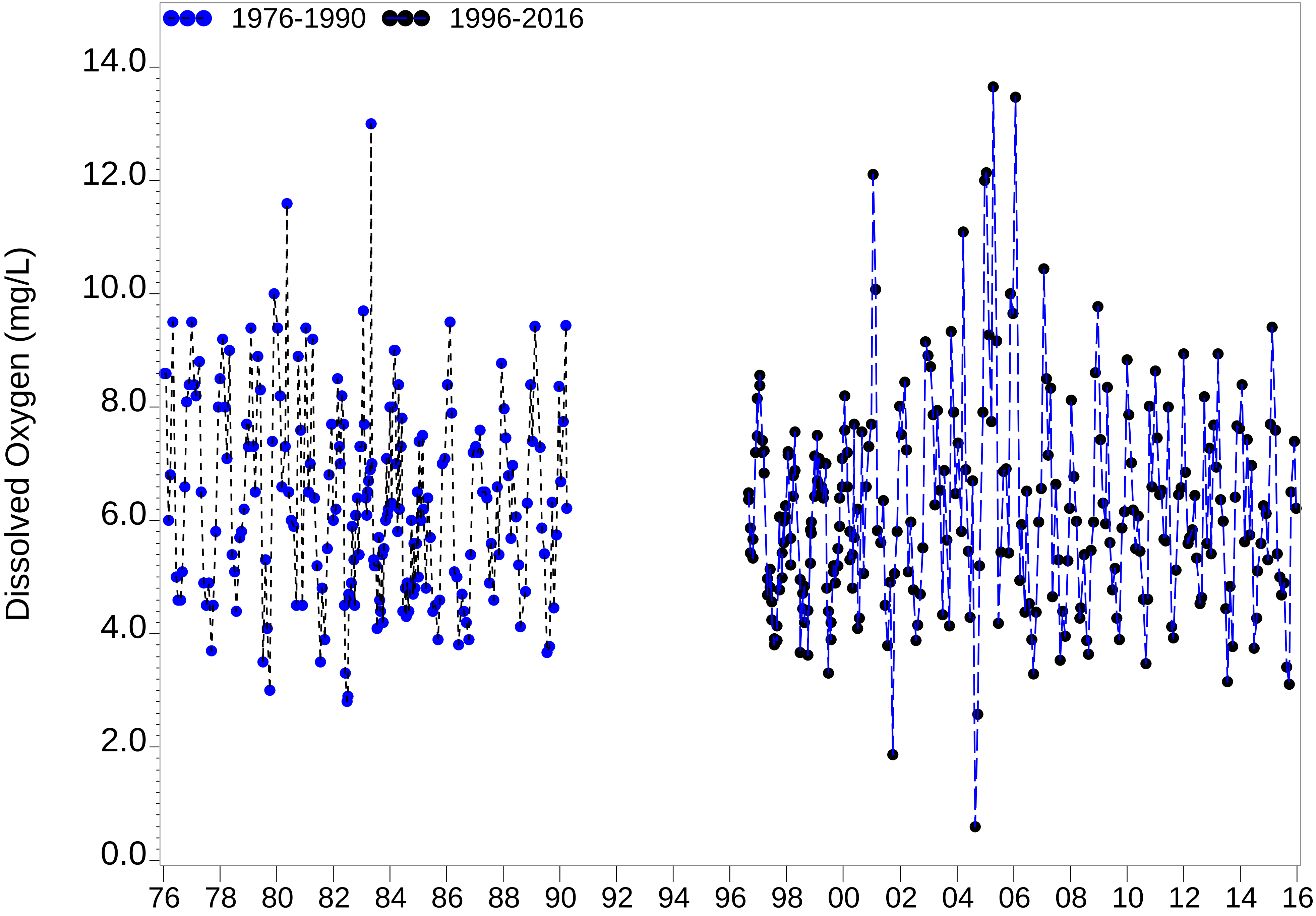


Figure C.48. Monthly long-term Surface Dissolved Oxygen Levels at river kilometer 23.6

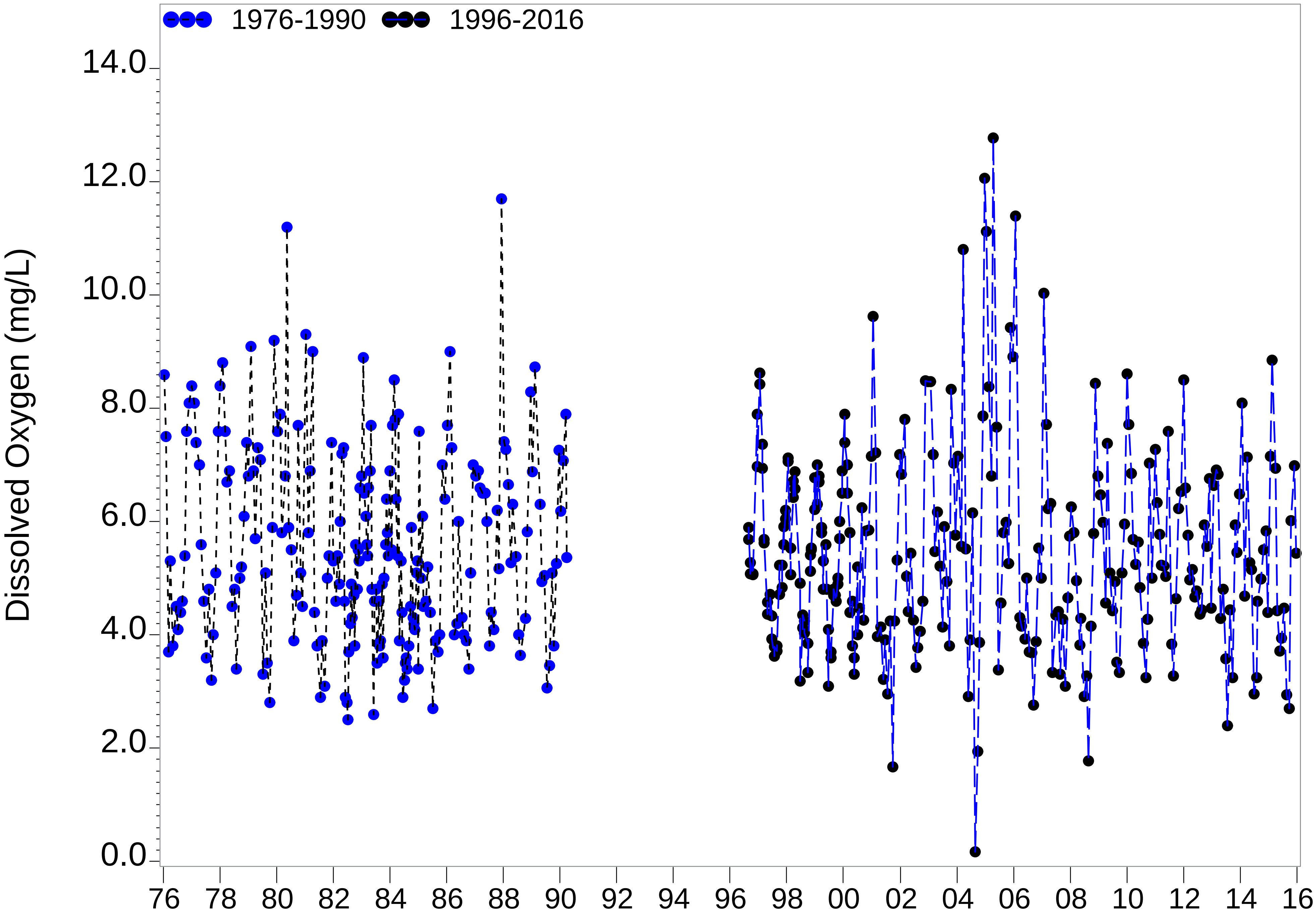


Figure C.49. Monthly long-term Bottom Dissolved Oxygen Levels at river kilometer 23.6

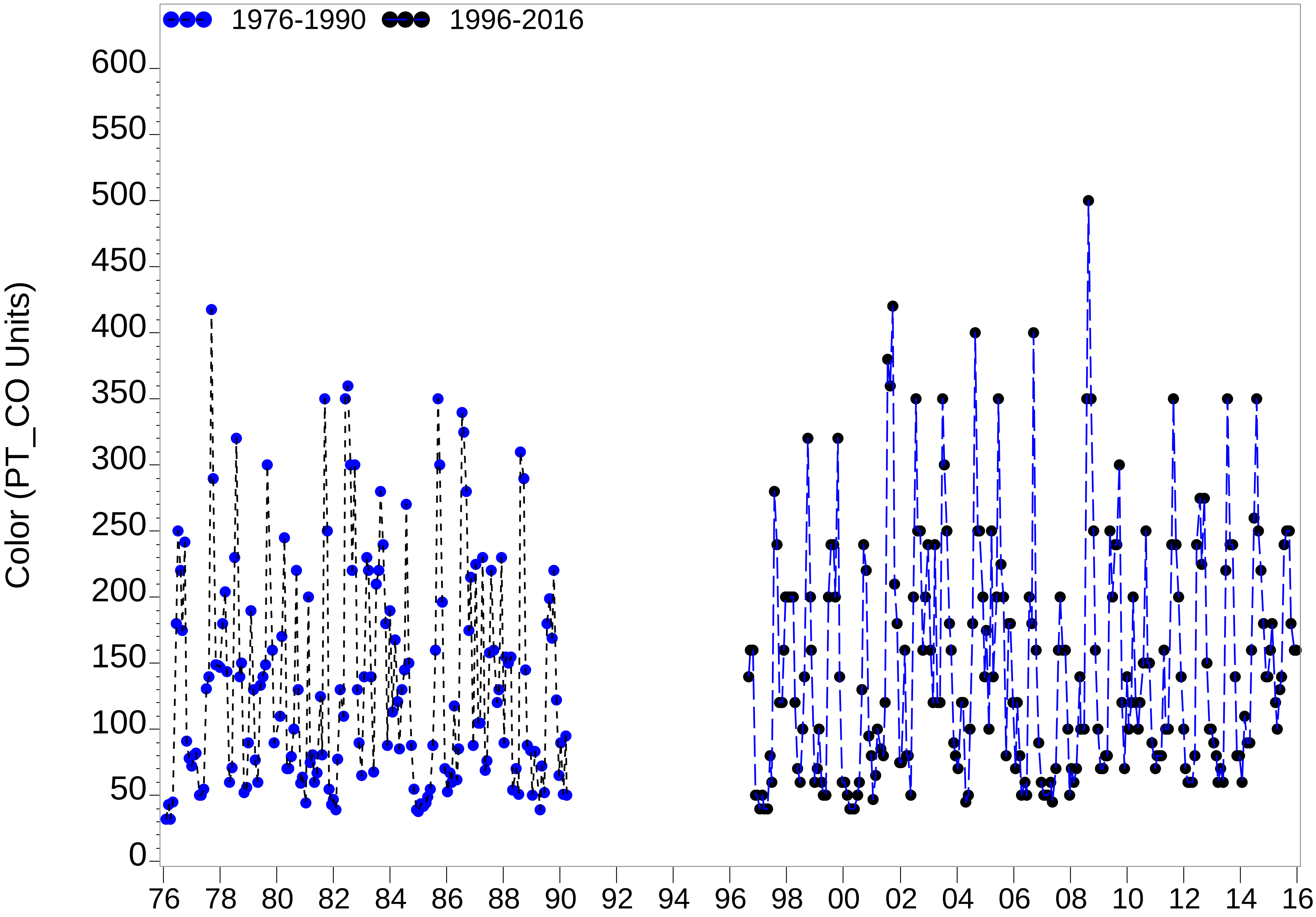


Figure C.50. Monthly long-term Surface Water Color at river kilometer 23.6

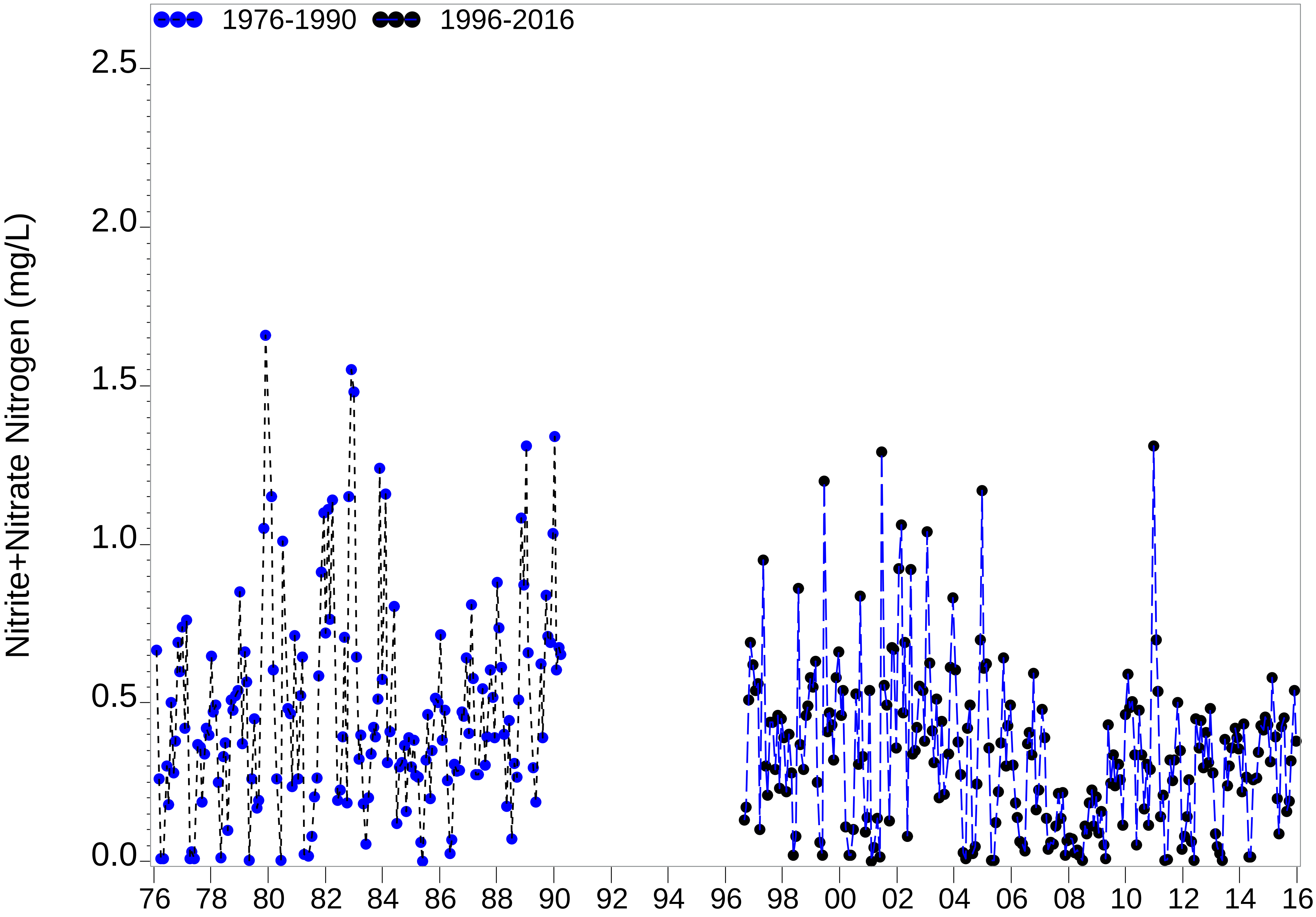


Figure C.51. Monthly long-term Surface Nitrite/Nitrate Nitrogen Concentrations at river kilometer 23.6

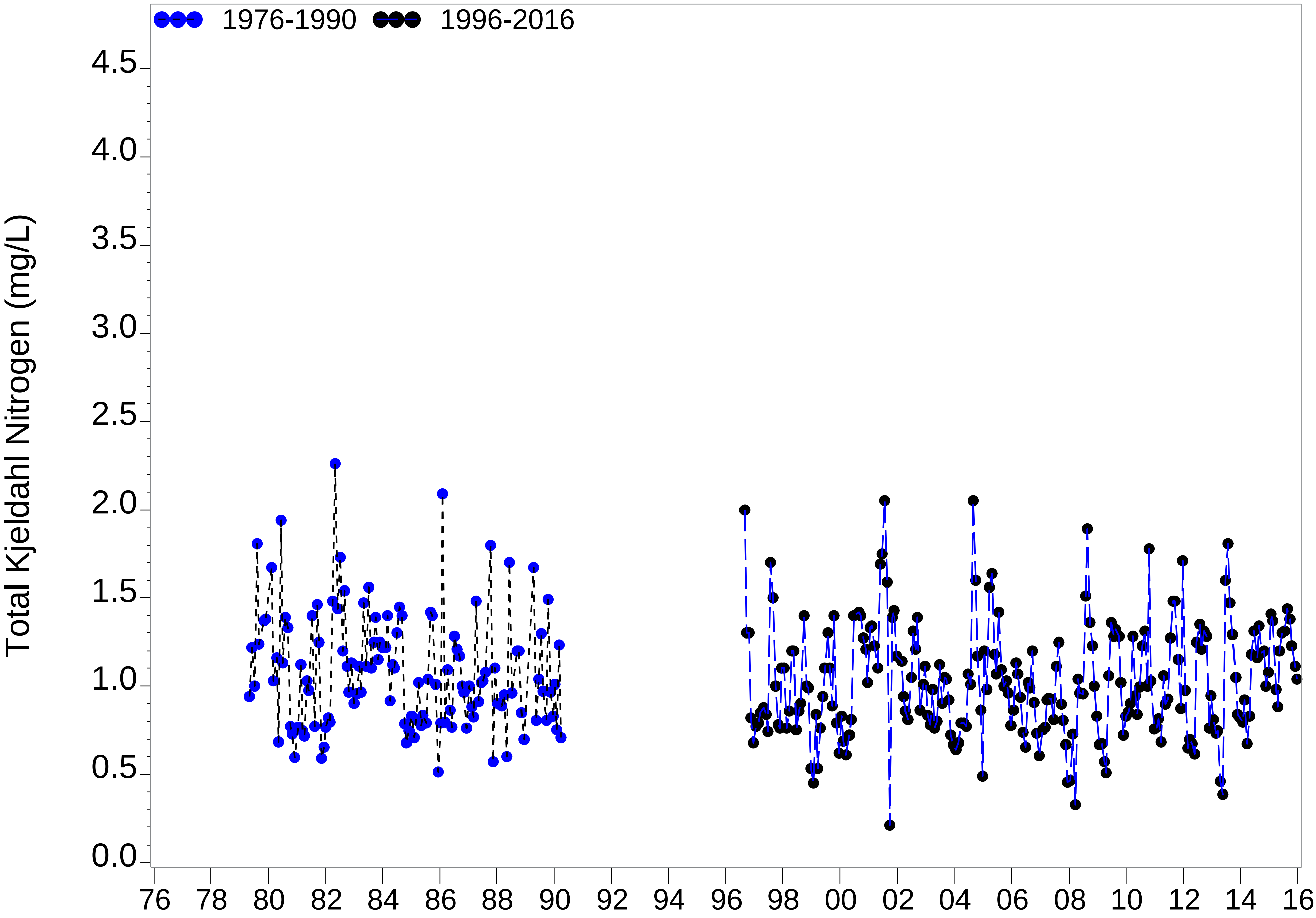


Figure C.52. Monthly long-term Surface Total Kjeldahl Nitrogen Concentrations at river kilometer 23.6

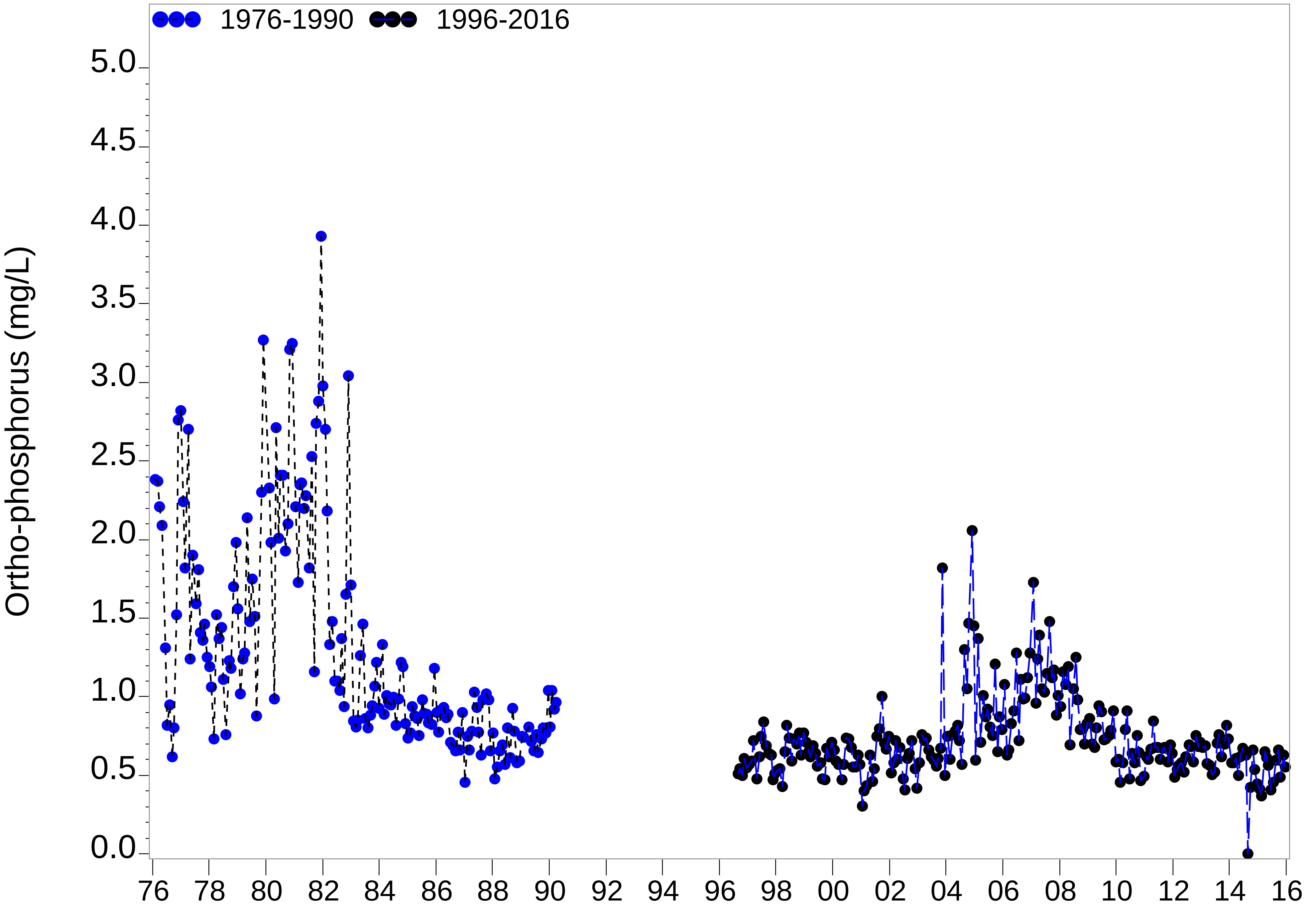


Figure C.53. Monthly long-term Surface Ortho-phosphorus Concentrations at river kilometer 23.6

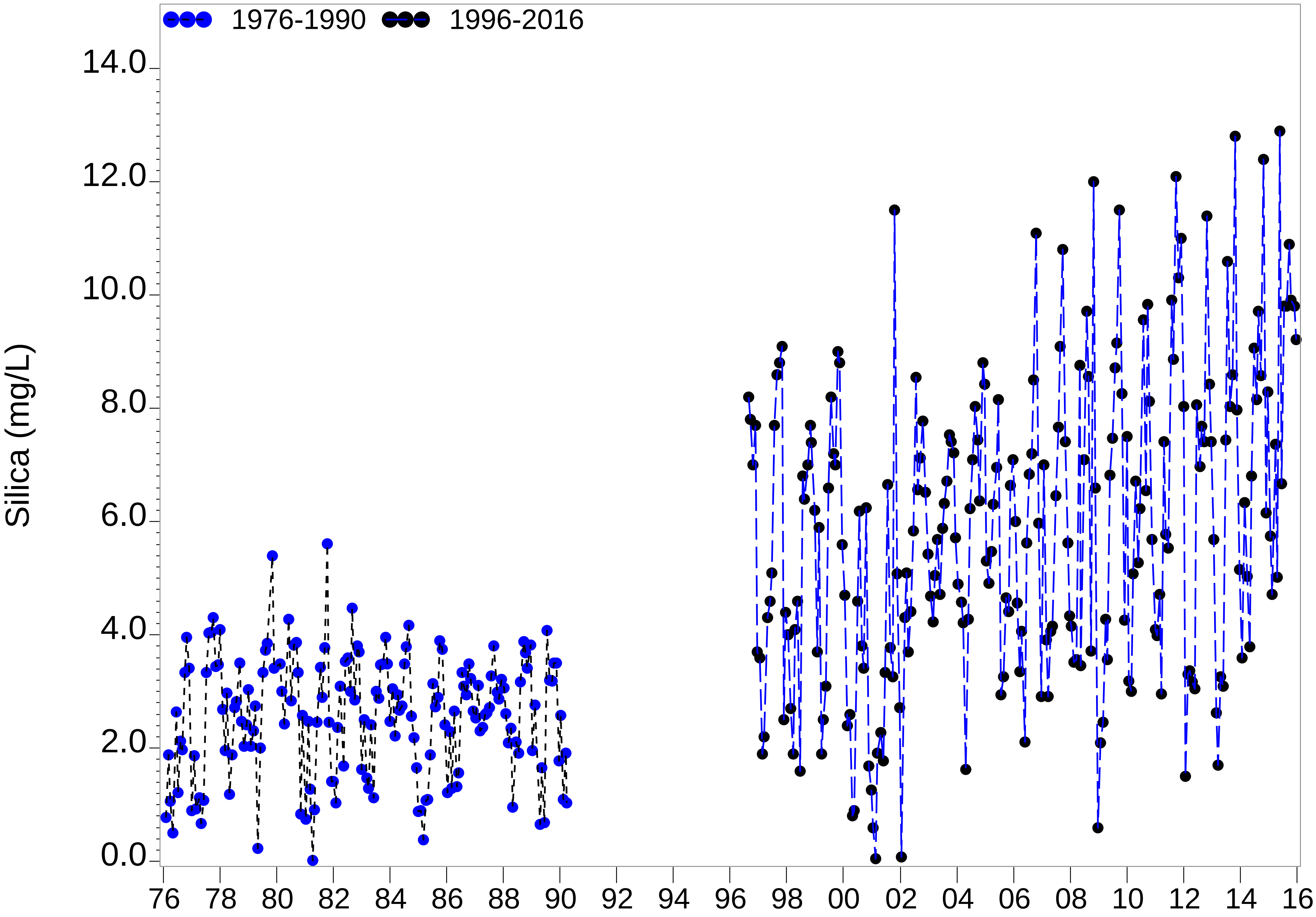


Figure C.54. Monthly long-term Surface Silica Concentrations at river kilometer 23.6

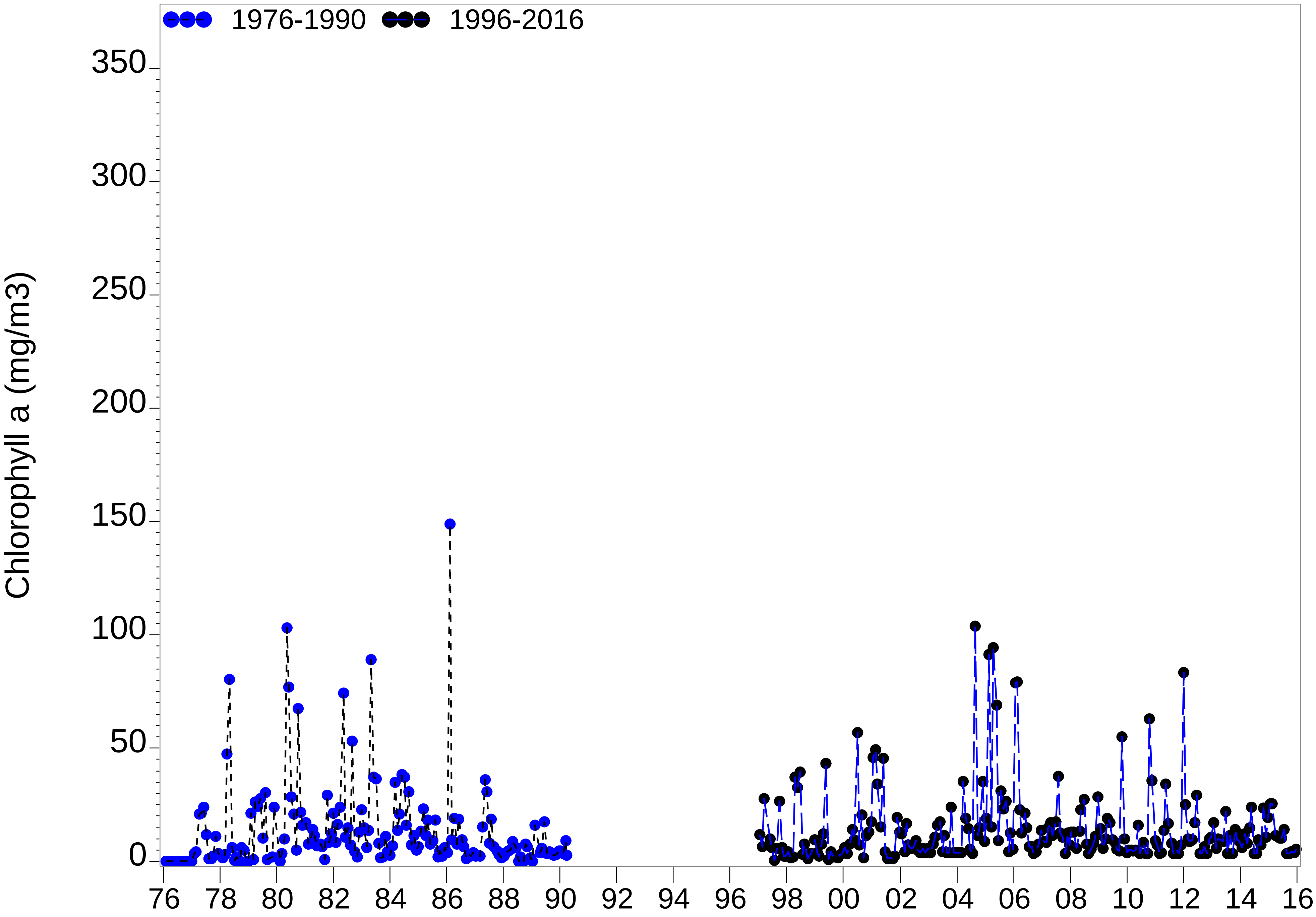


Figure C.55. Monthly long-term Surface Chlorophyll a Concentrations at river kilometer 23.6

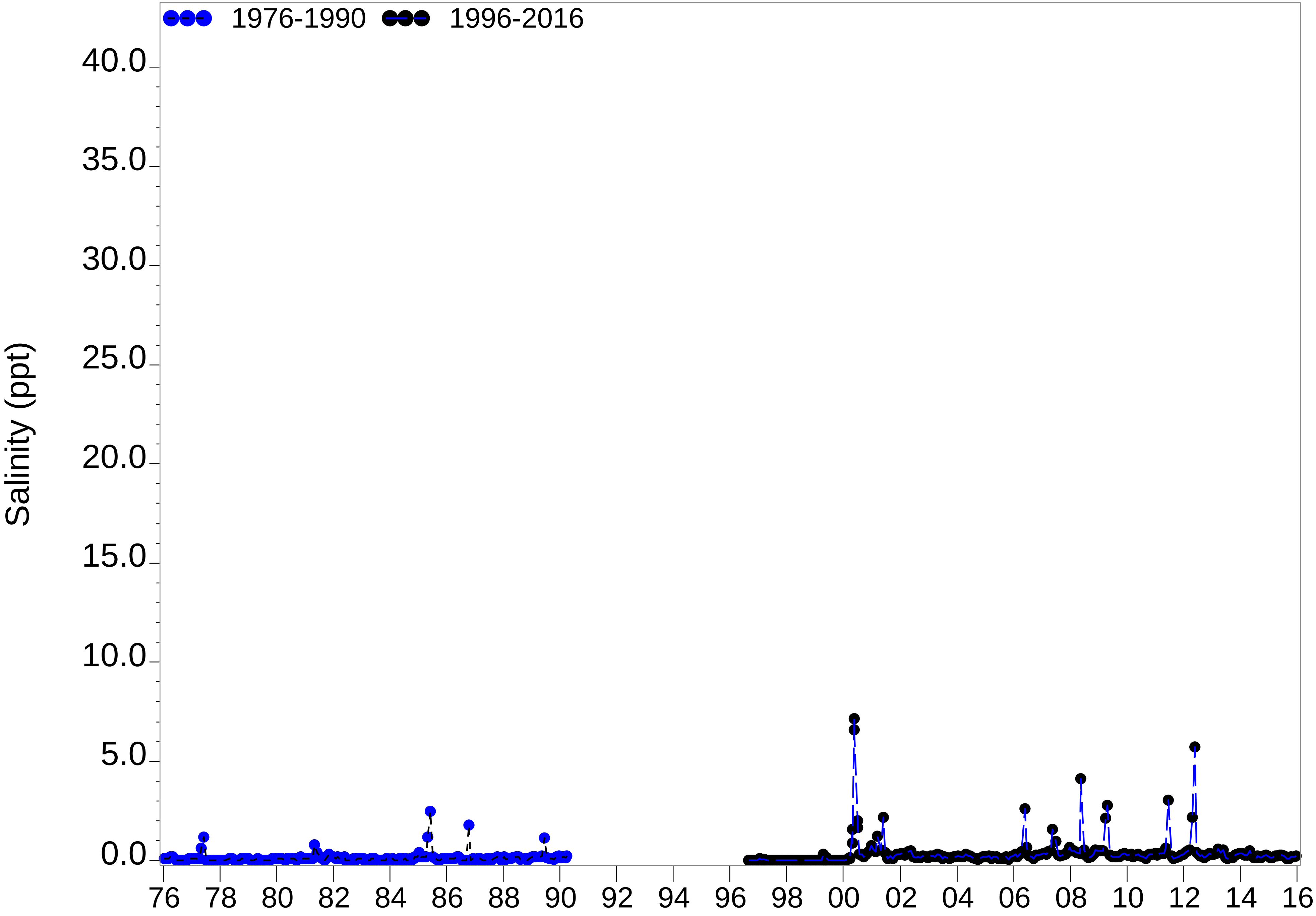


Figure C.56. Monthly long-term Surface Salinity at river kilometer 30.7

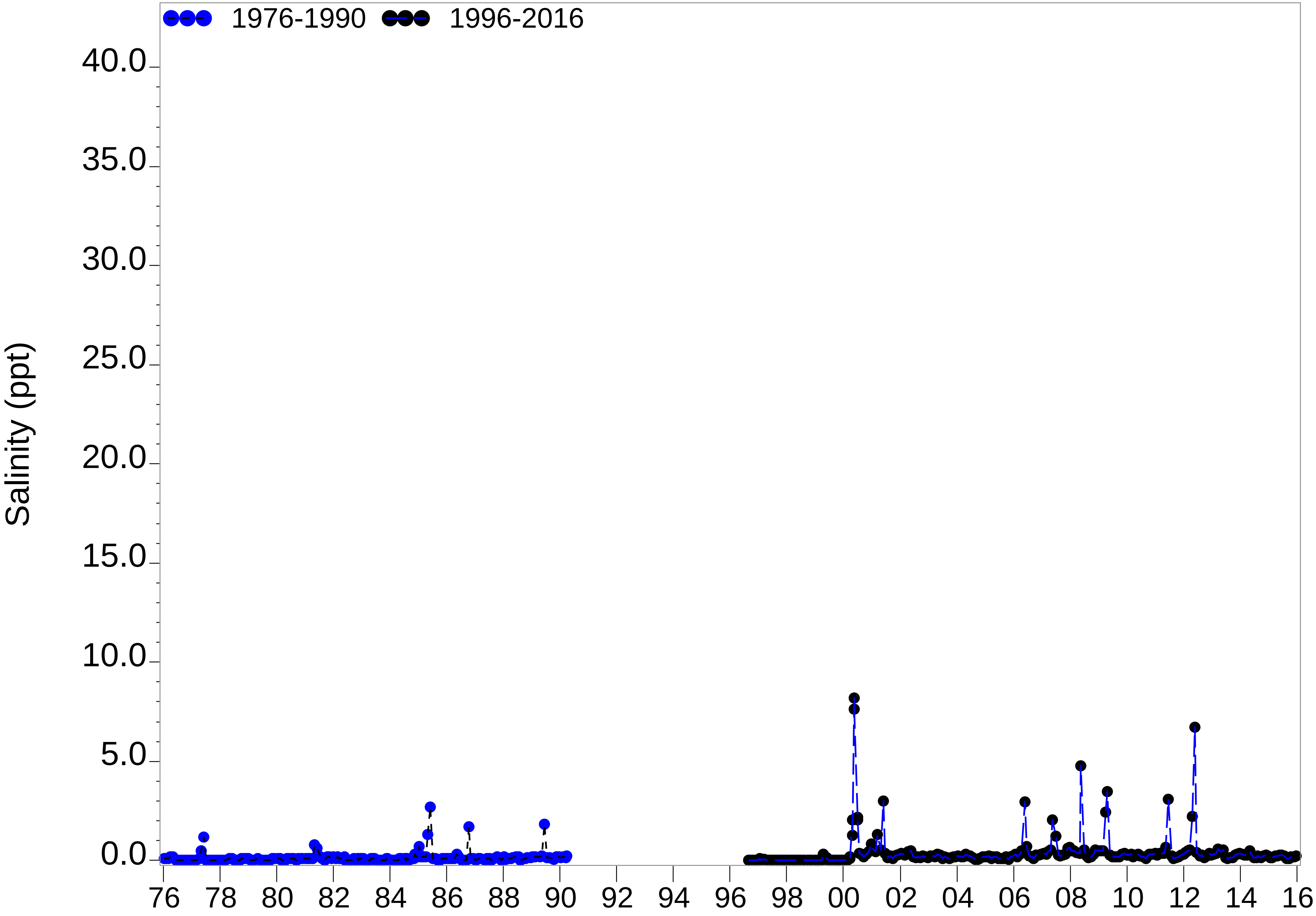


Figure C.57. Monthly long-term Bottom Salinity at river kilometer 30.7

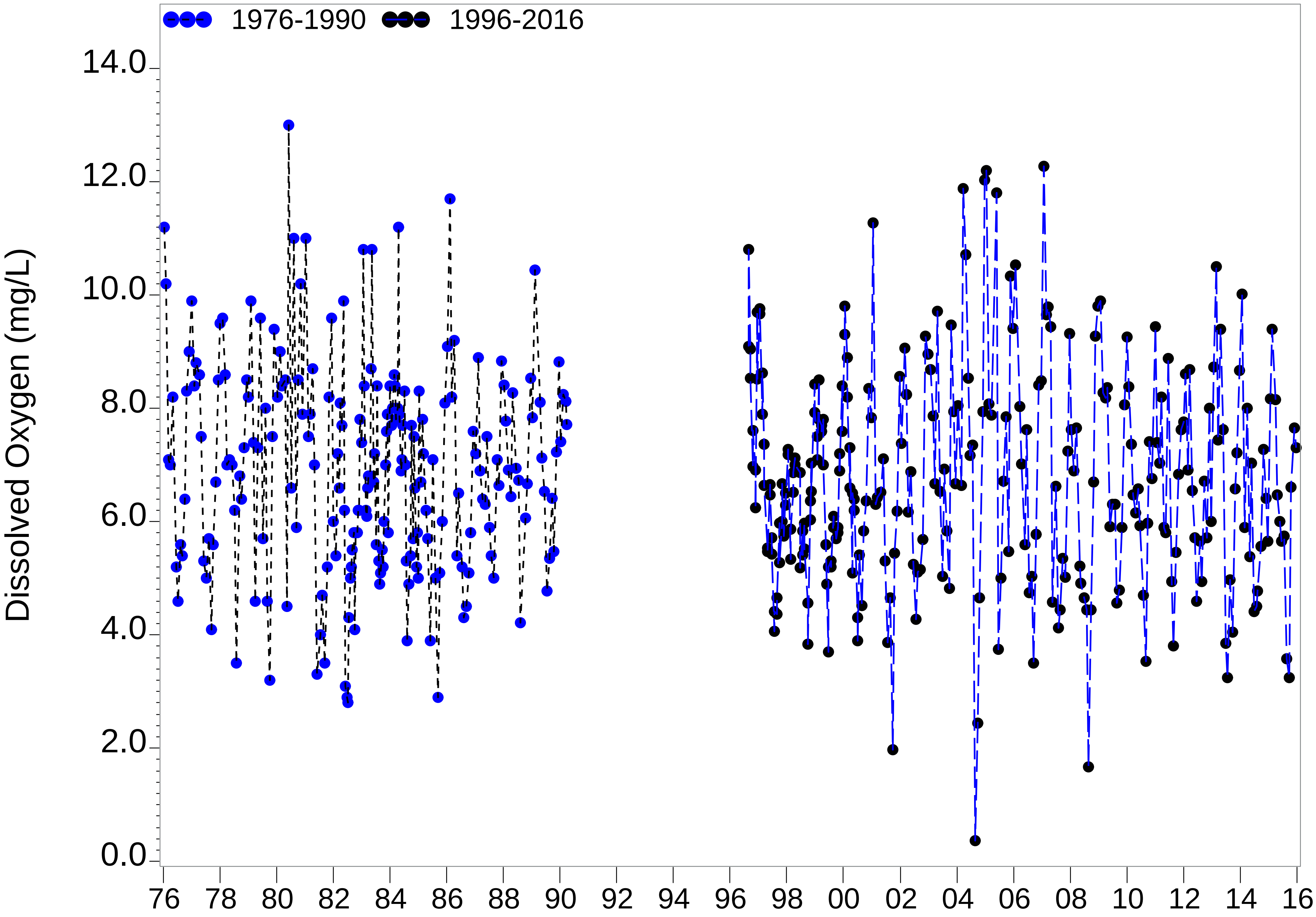


Figure C.58. Monthly long-term Surface Dissolved Oxygen Levels at river kilometer 30.7

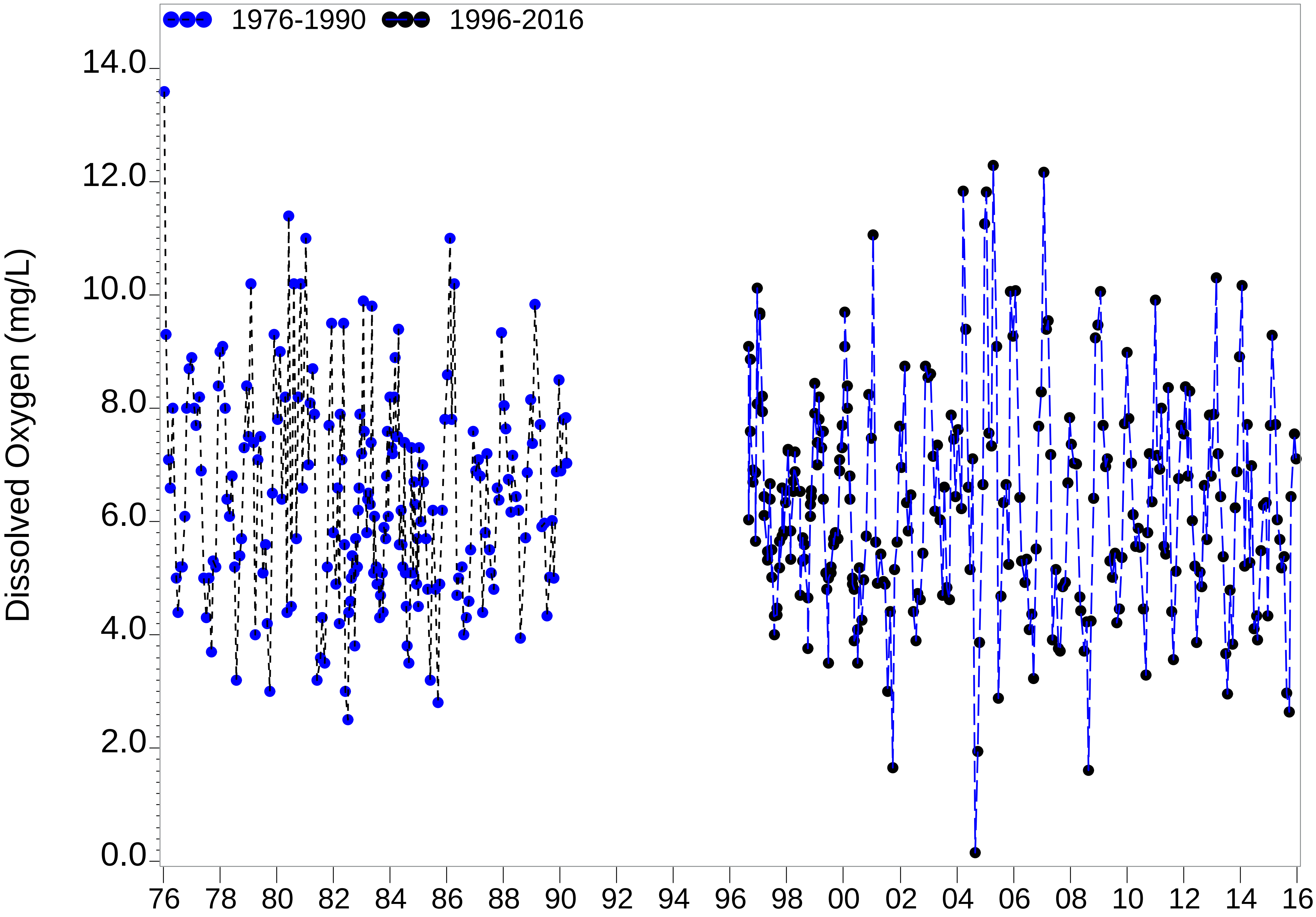


Figure C.59. Monthly long-term Bottom Dissolved Oxygen Levels at river kilometer 30.7

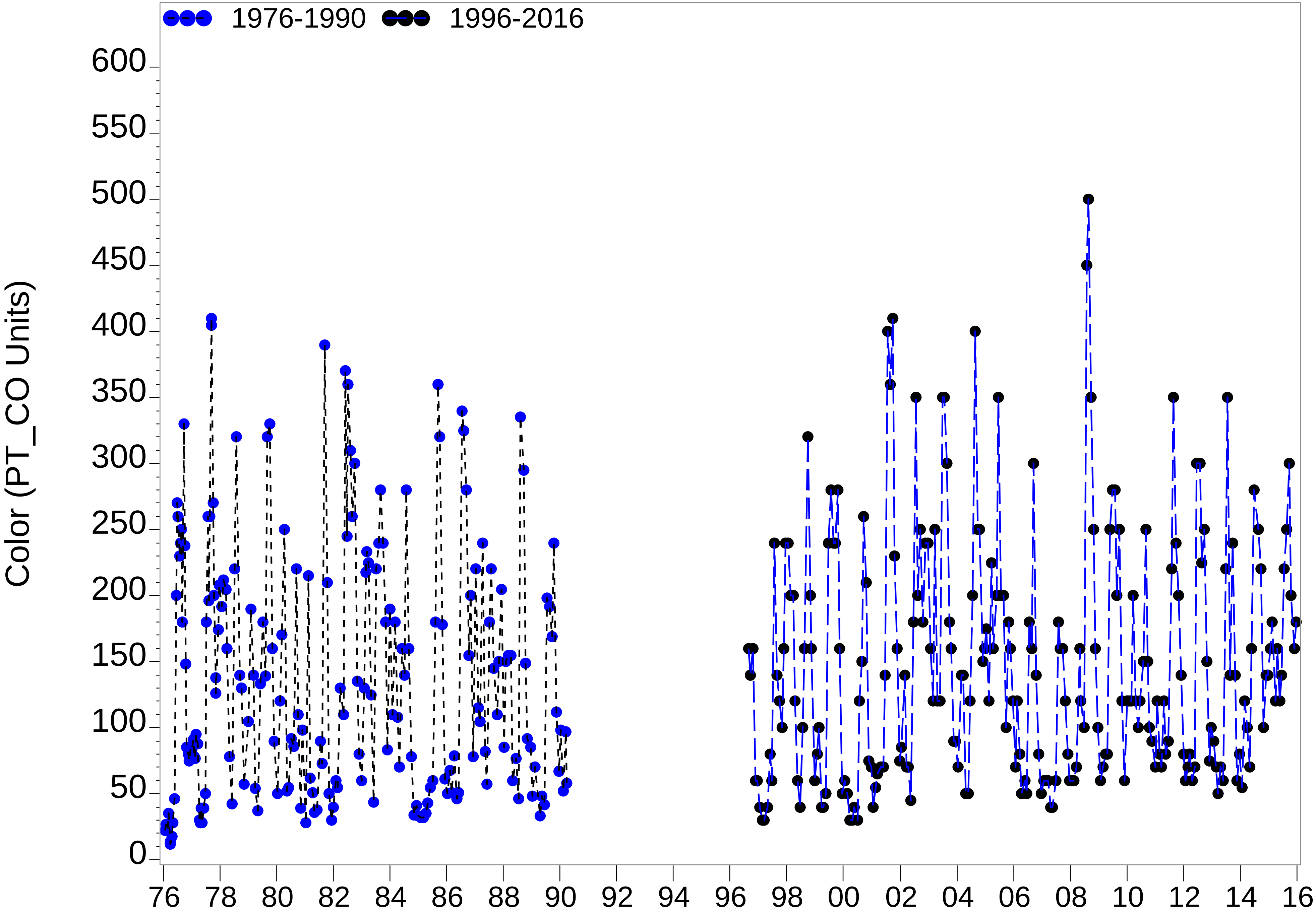


Figure C.60. Monthly long-term Surface Water Color at river kilometer 30.7

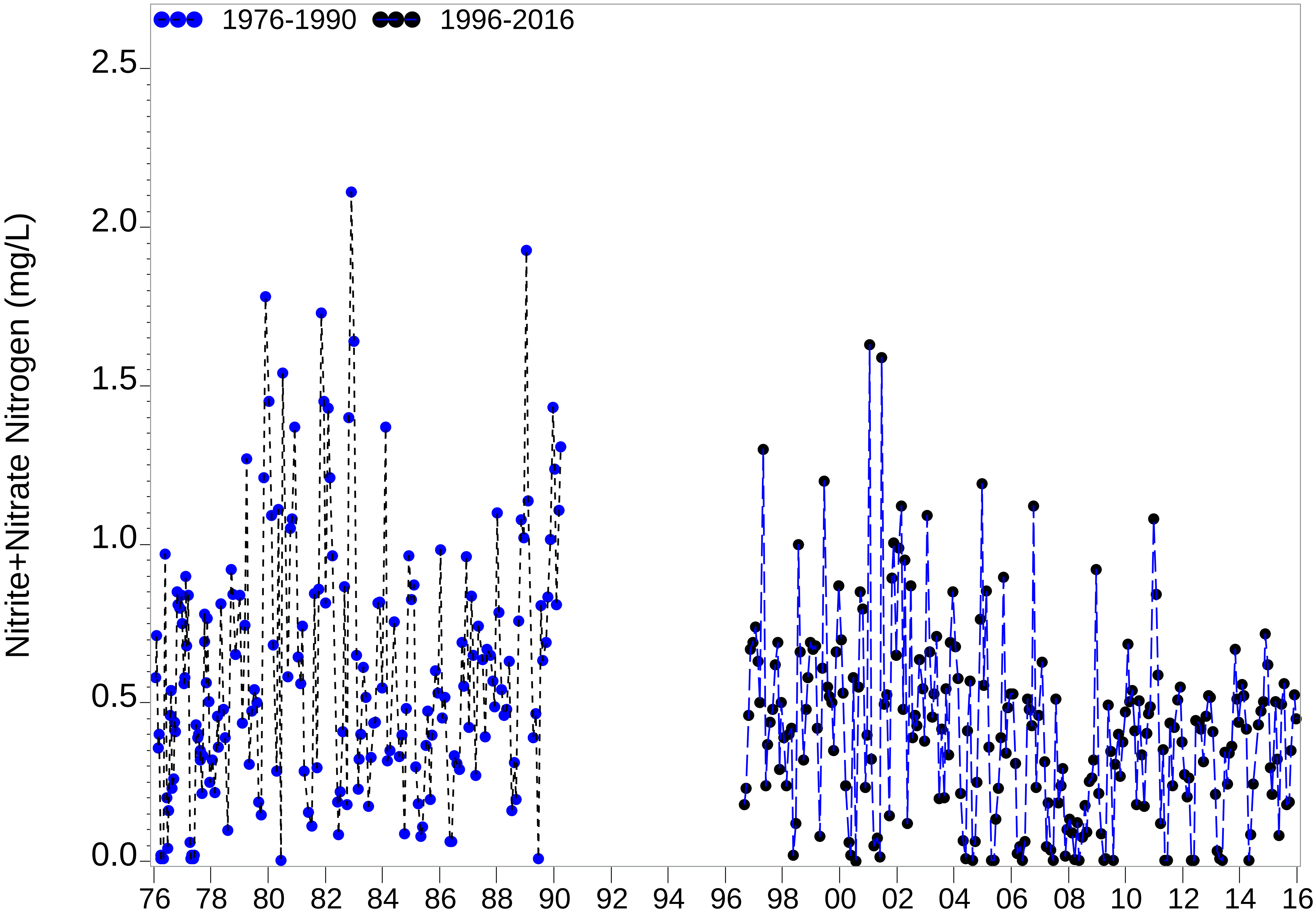


Figure C.61. Monthly long-term Surface Nitrite/Nitrate Nitrogen Concentrations at river kilometer 30.7

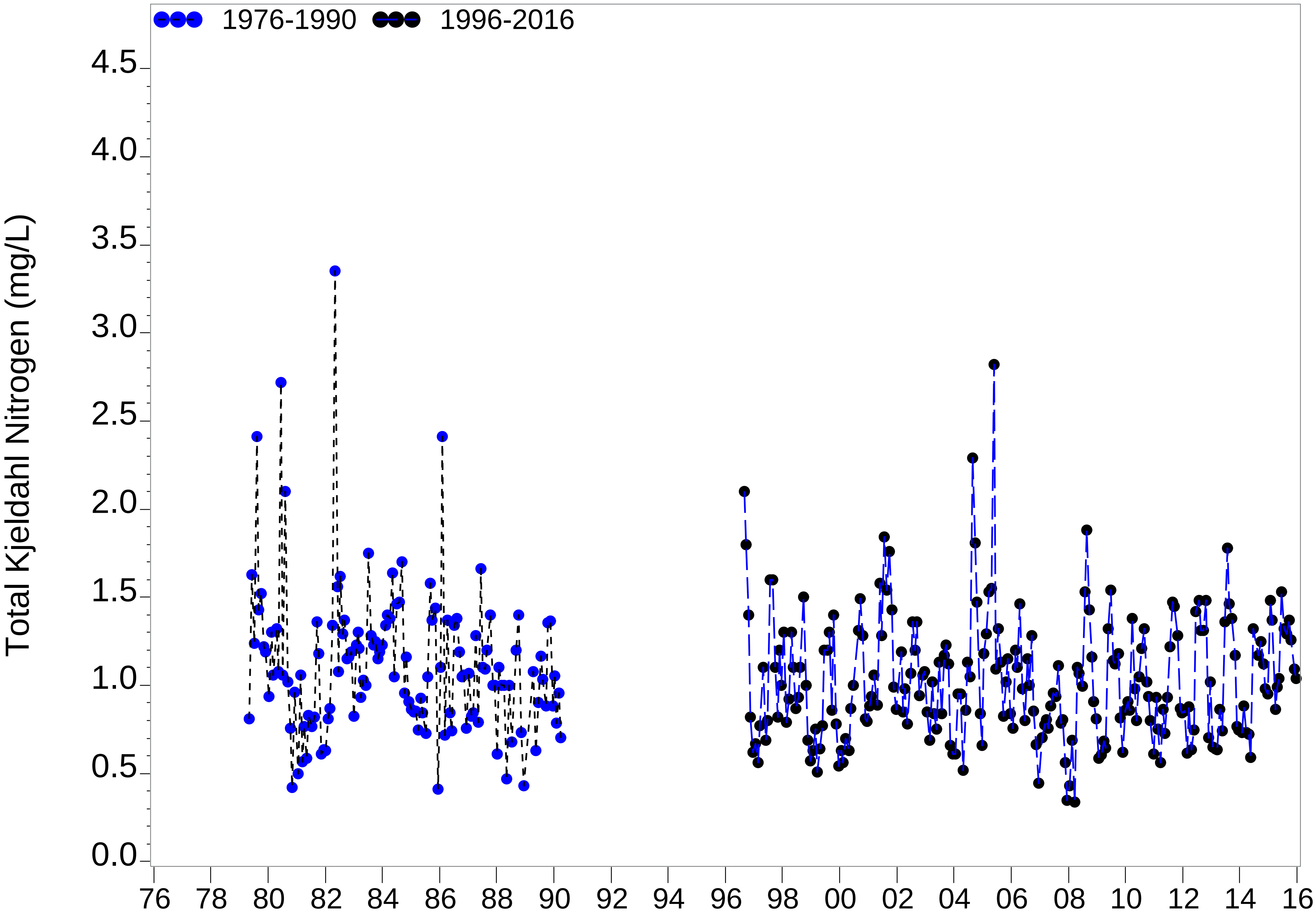


Figure C.62. Monthly long-term Surface Total Kjeldahl Nitrogen Concentrations at river kilometer 30.7

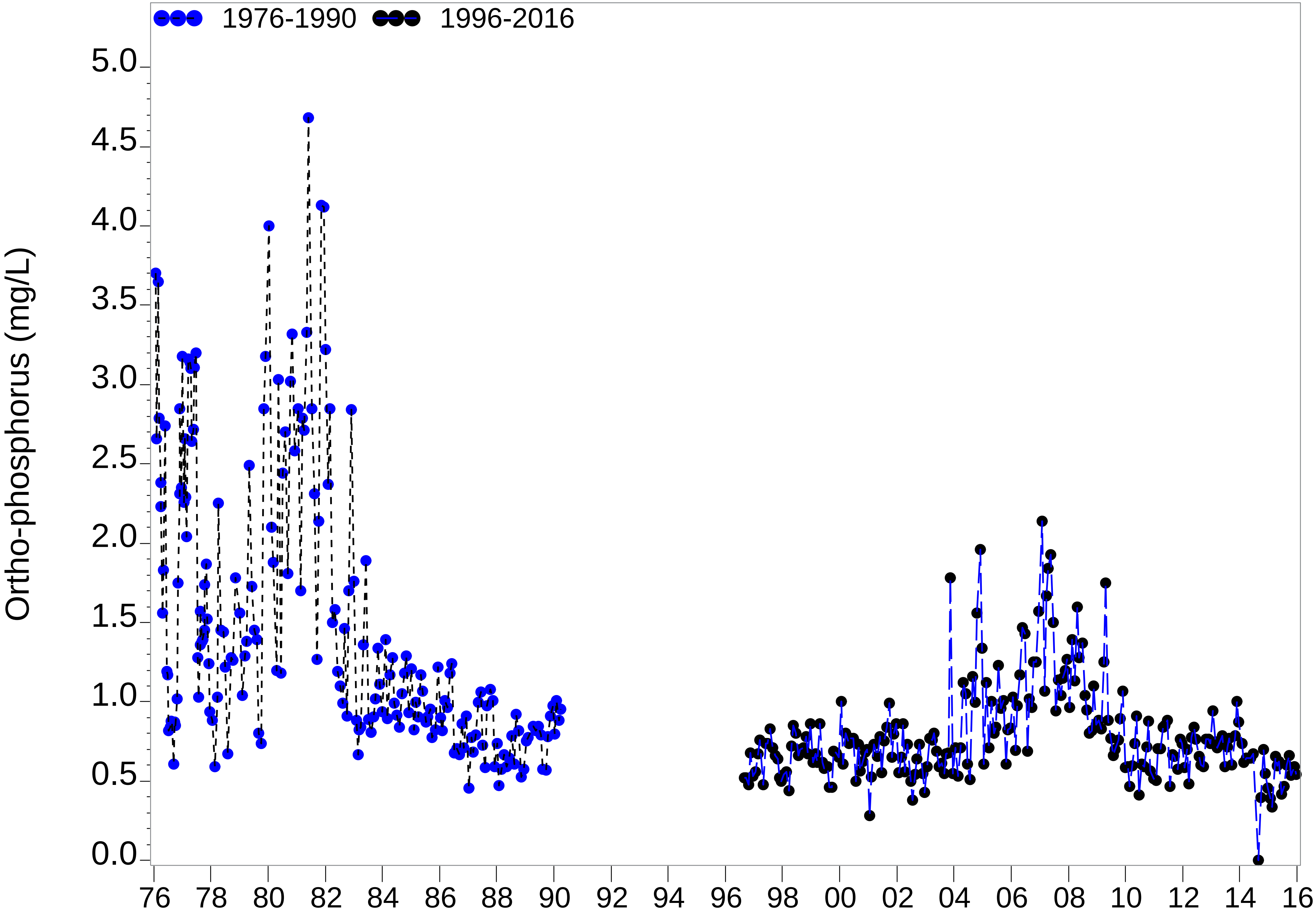


Figure C.63. Monthly long-term Surface Ortho-phosphorus Concentrations at river kilometer 30.7

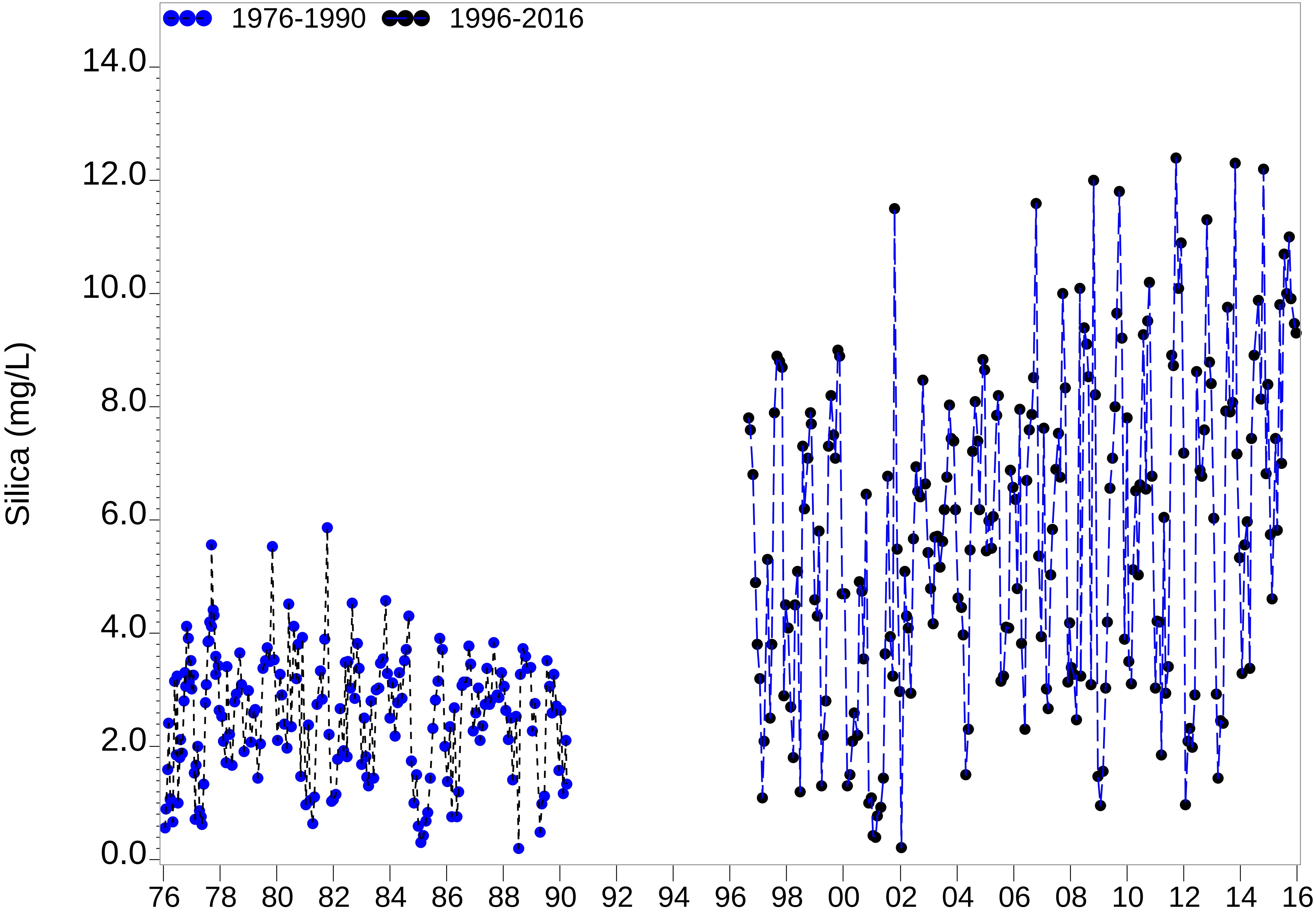


Figure C.64. Monthly long-term Surface Silica Concentrations at river kilometer 30.7

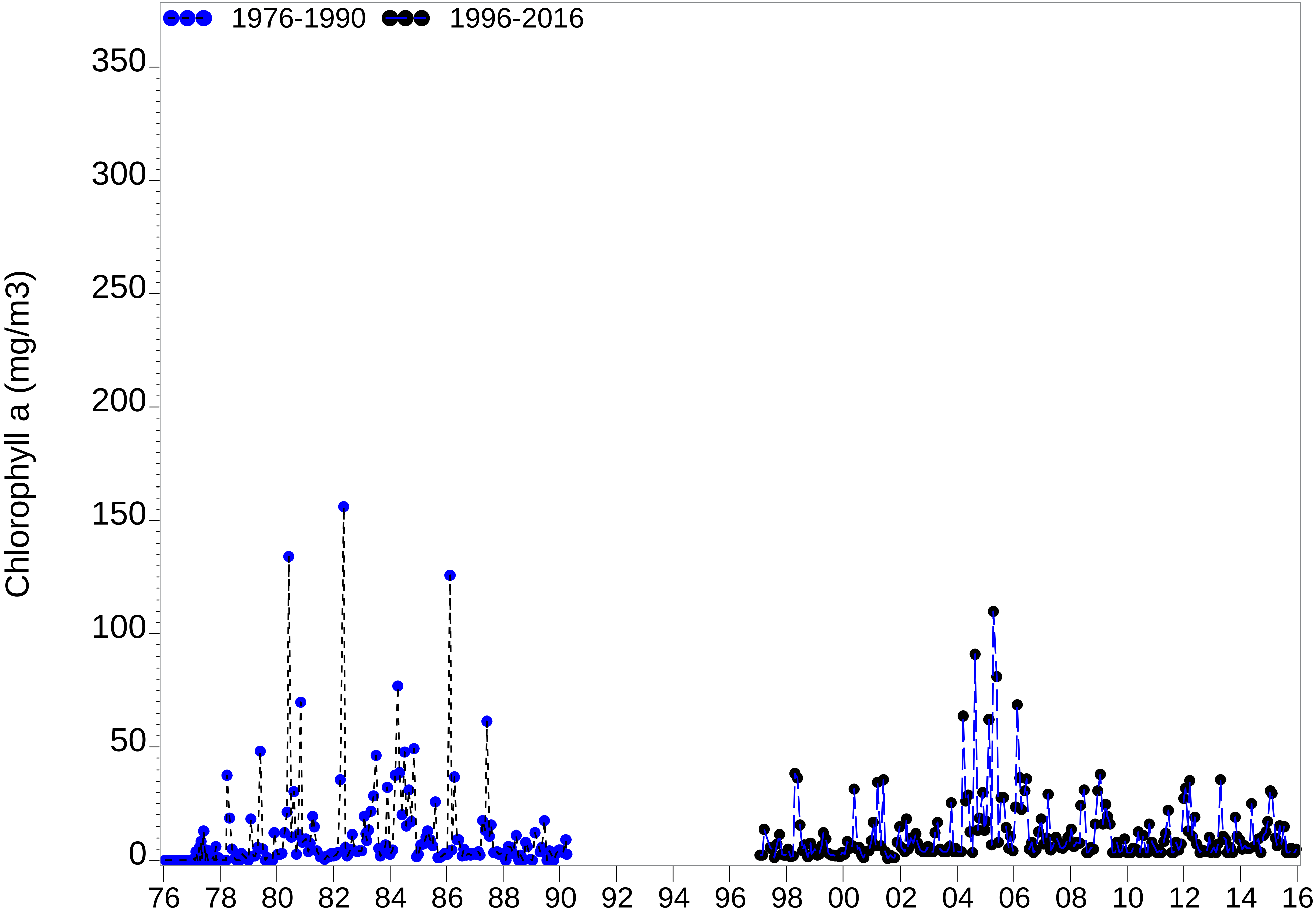


Figure C.65. Monthly long-term Surface Chlorophyll a Concentrations at river kilometer 30.7

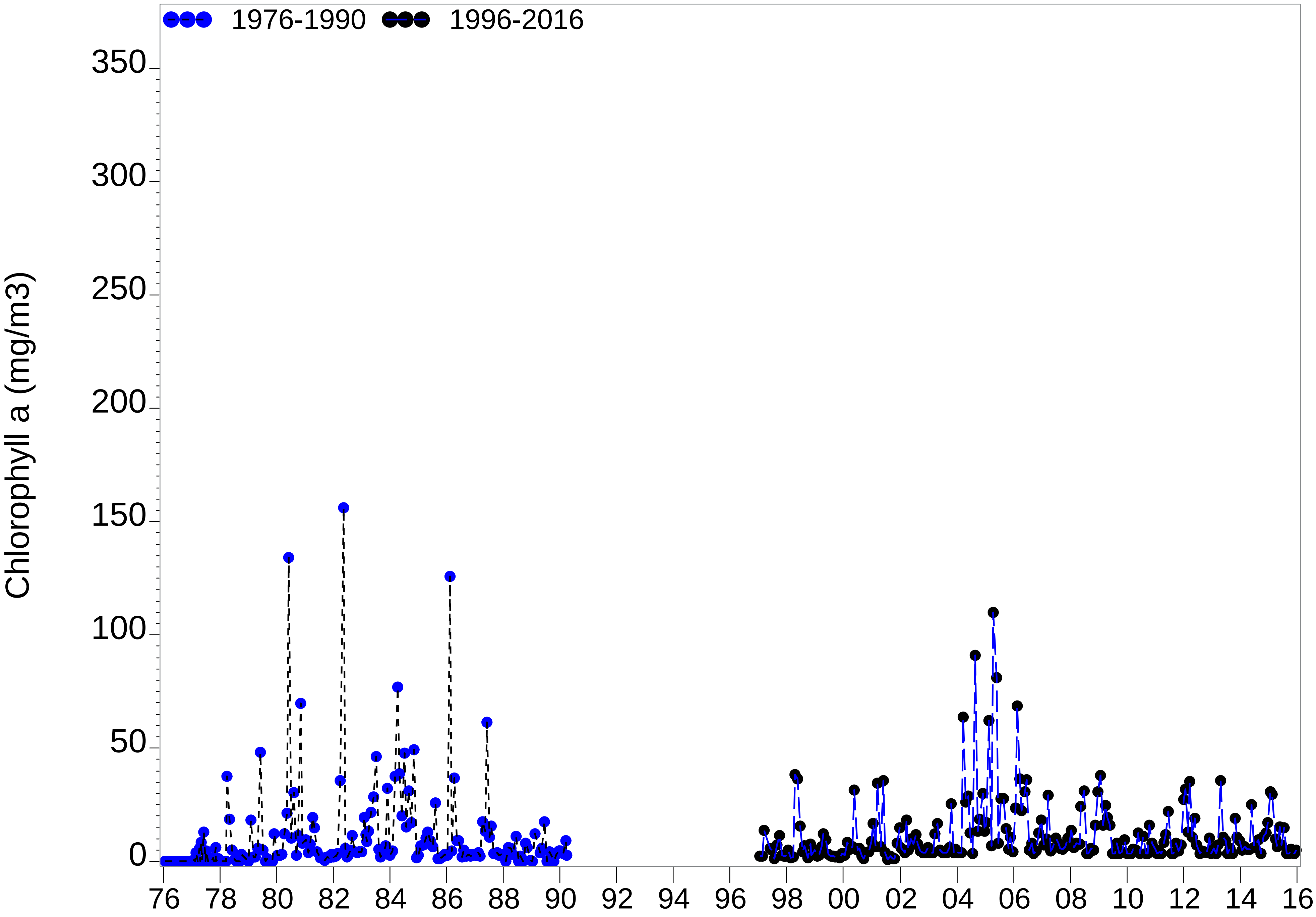


Figure C.65. Monthly long-term Surface Chlorophyll a Concentrations at river kilometer 30.7

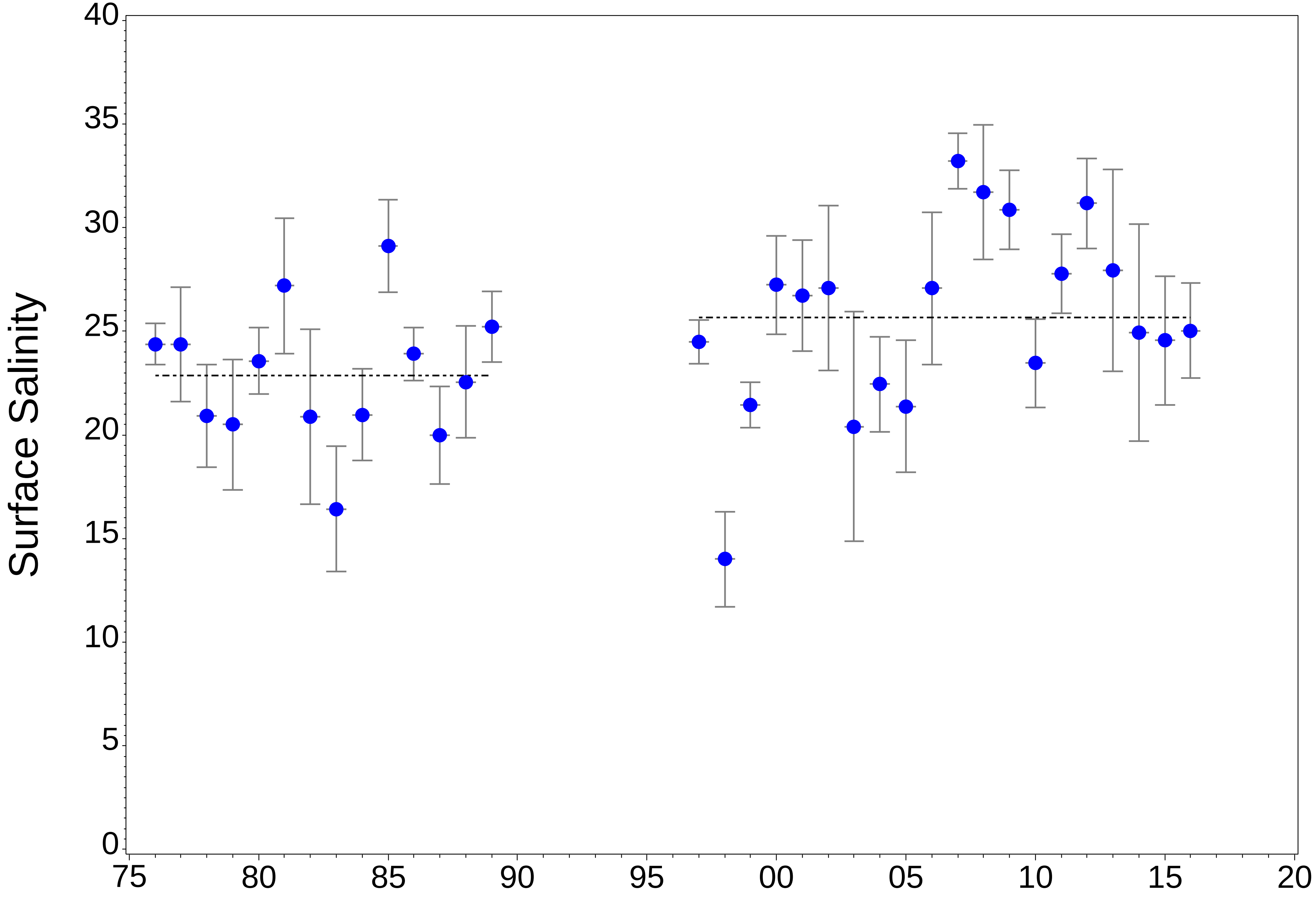


Figure C.66. Long-term Surface Salinity at river kilometer -2.4

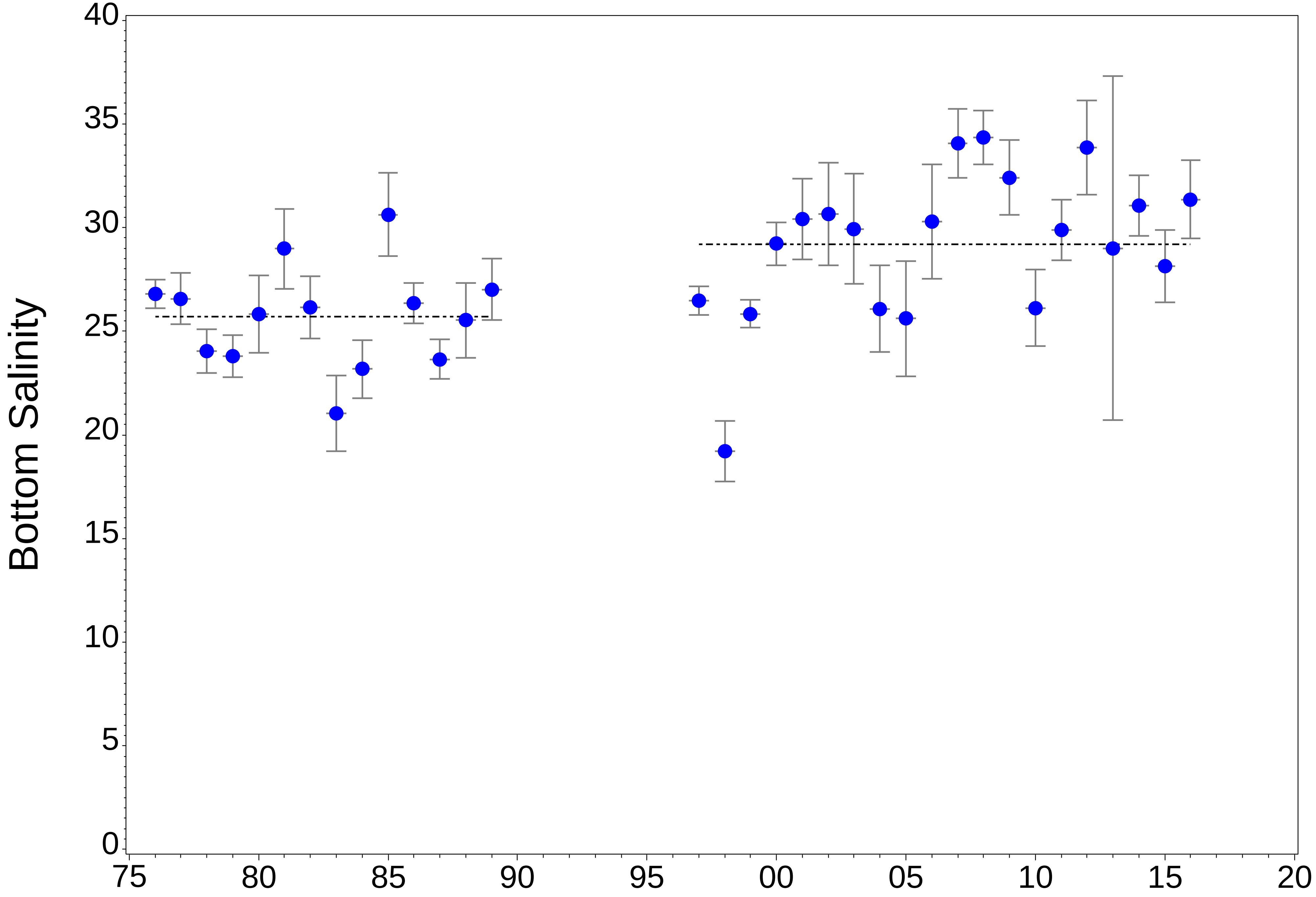


Figure C.67. Long-term Bottom Salinity at river kilometer -2.4

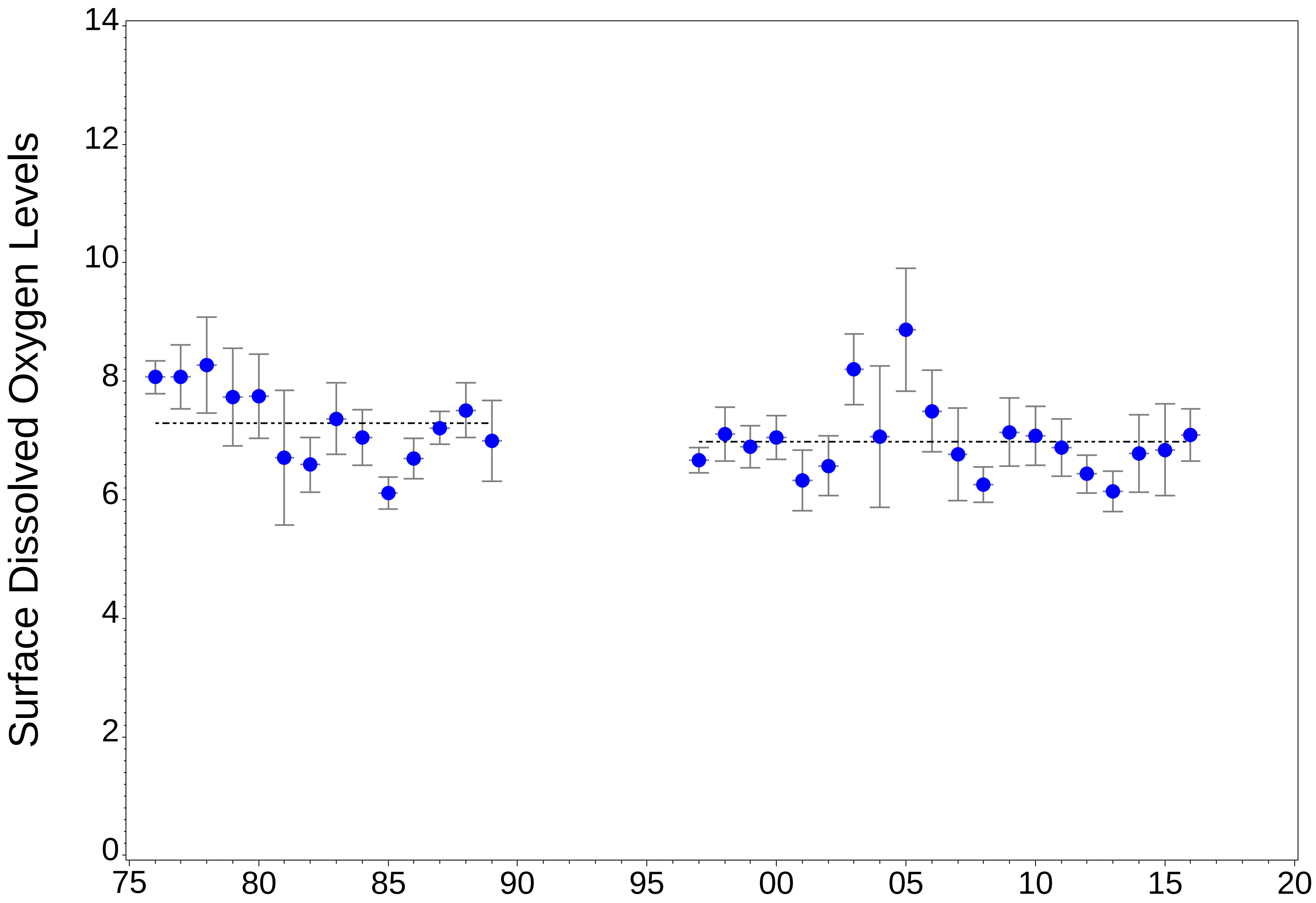


Figure C.68. Long-term Surface Dissolved Oxygen Levels at river kilometer -2.4

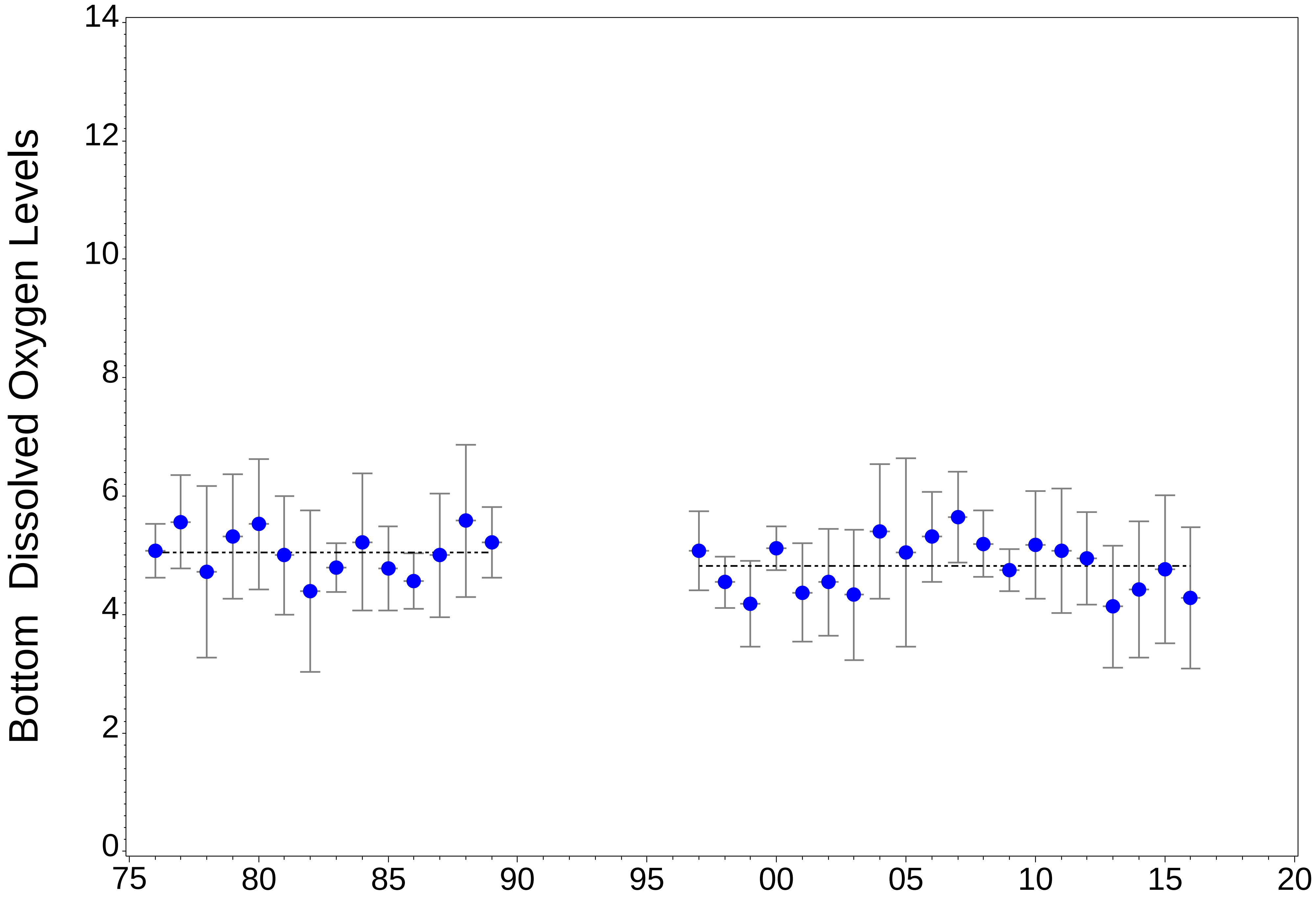


Figure C.69. Long-term Bottom Dissolved Oxygen Levels at river kilometer -2.4

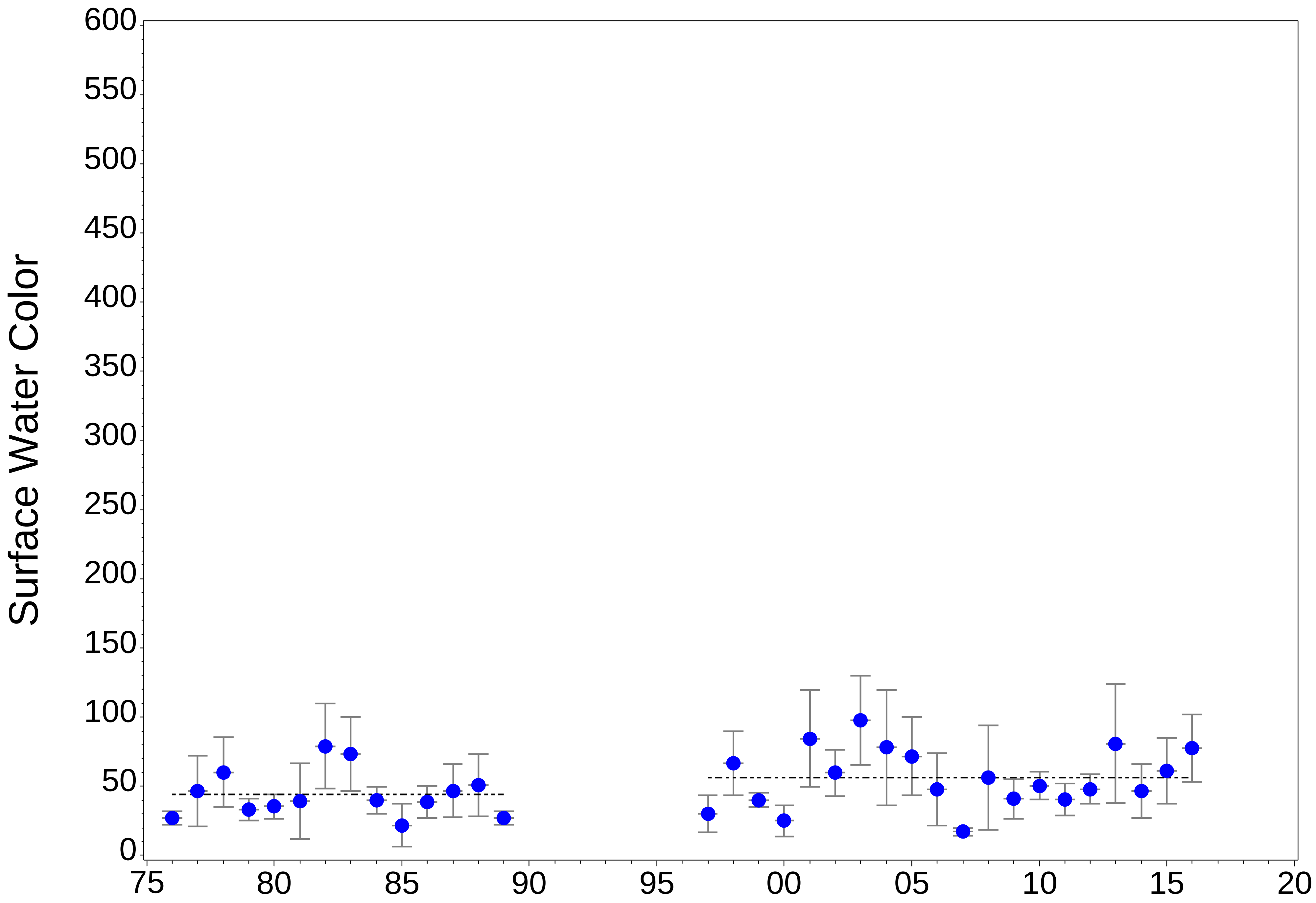


Figure C.70. Long-term Surface Water Color at river kilometer -2.4

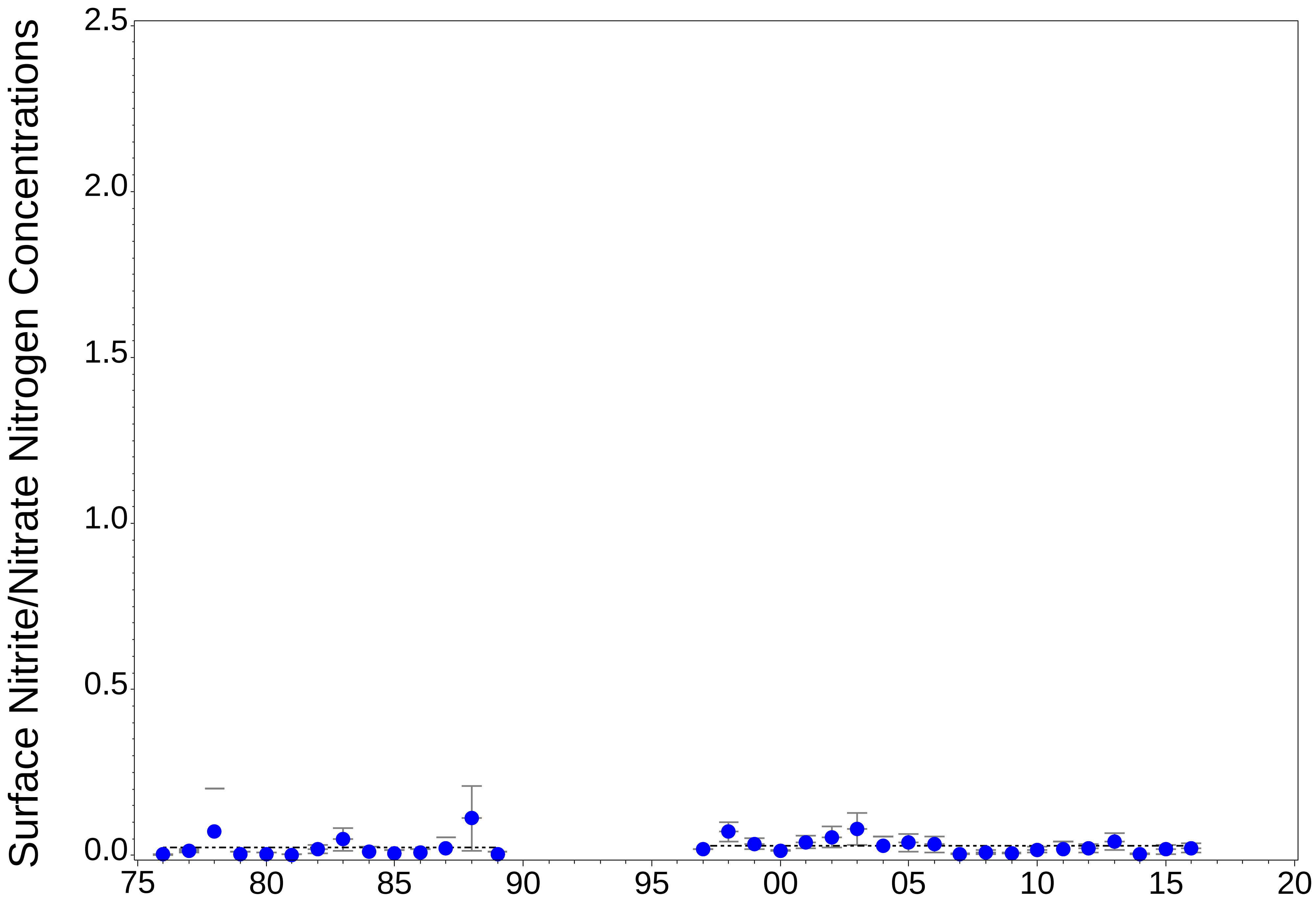


Figure C.71. Long-term Surface Nitrite/Nitrate Nitrogen Concentrations at river kilometer -2.4

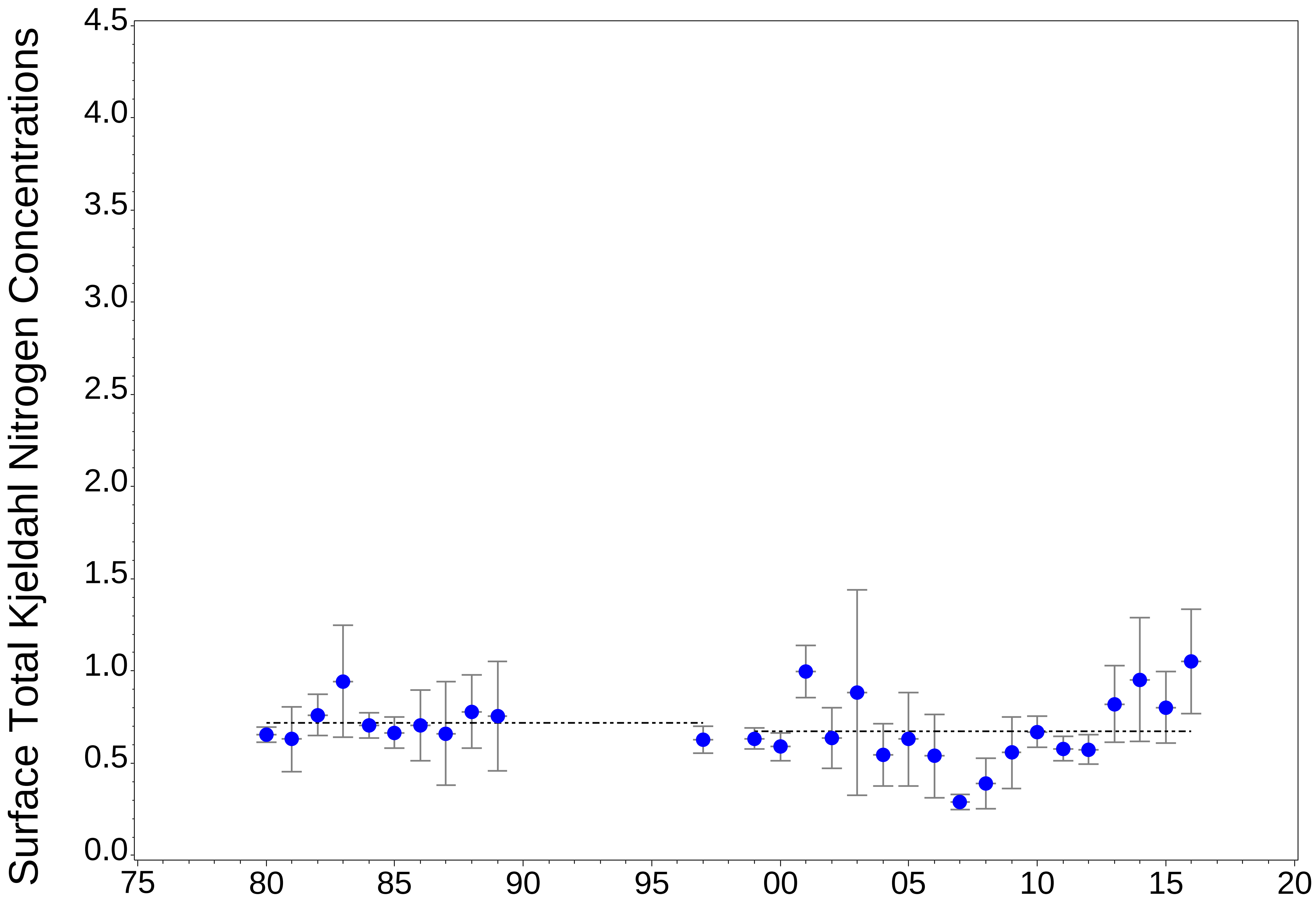


Figure C.72. Long-term Surface Total Kjeldahl Nitrogen Concentrations at river kilometer -2.4

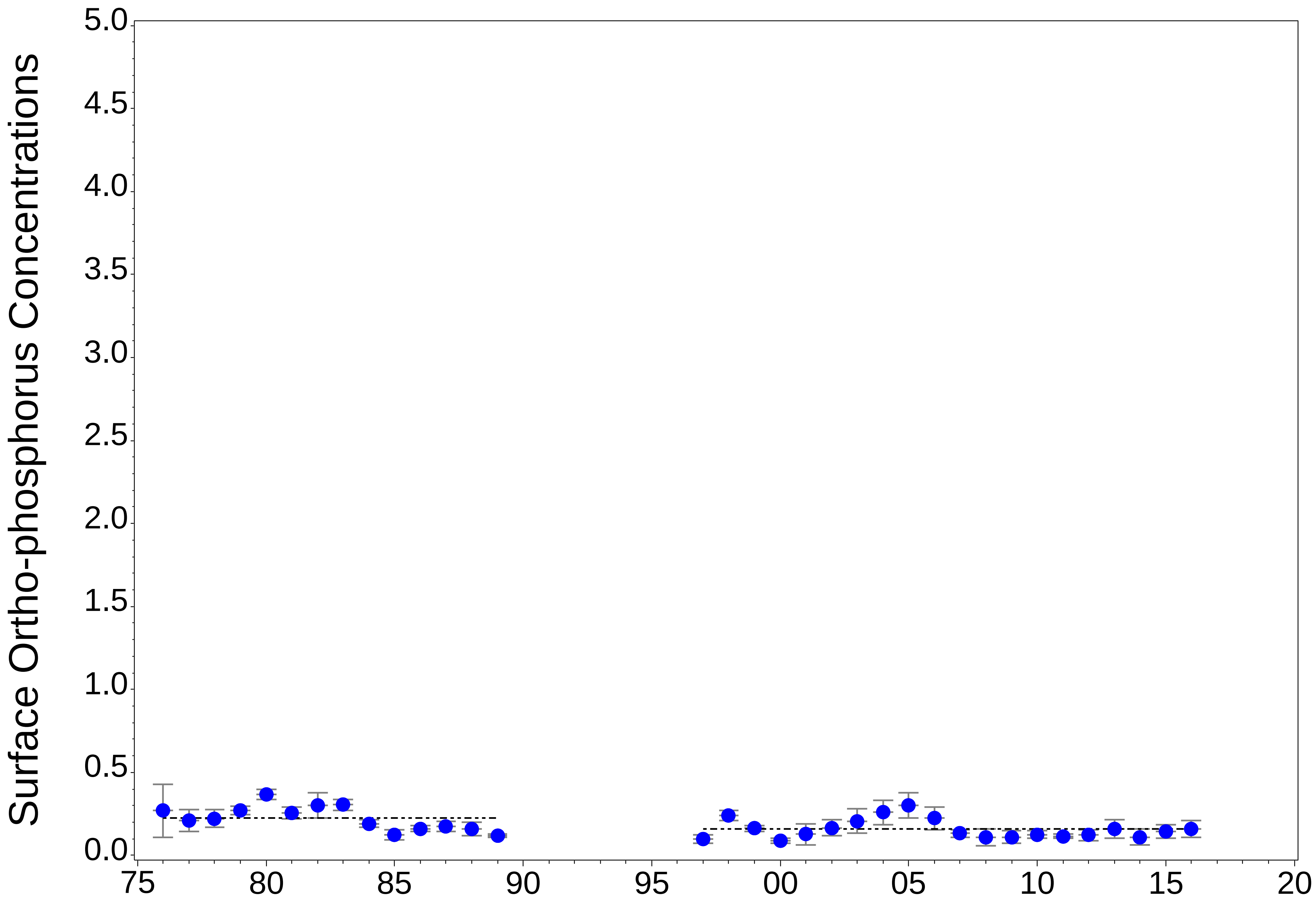


Figure C.73. Long-term Surface Ortho-phosphorus Concentrations at river kilometer -2.4

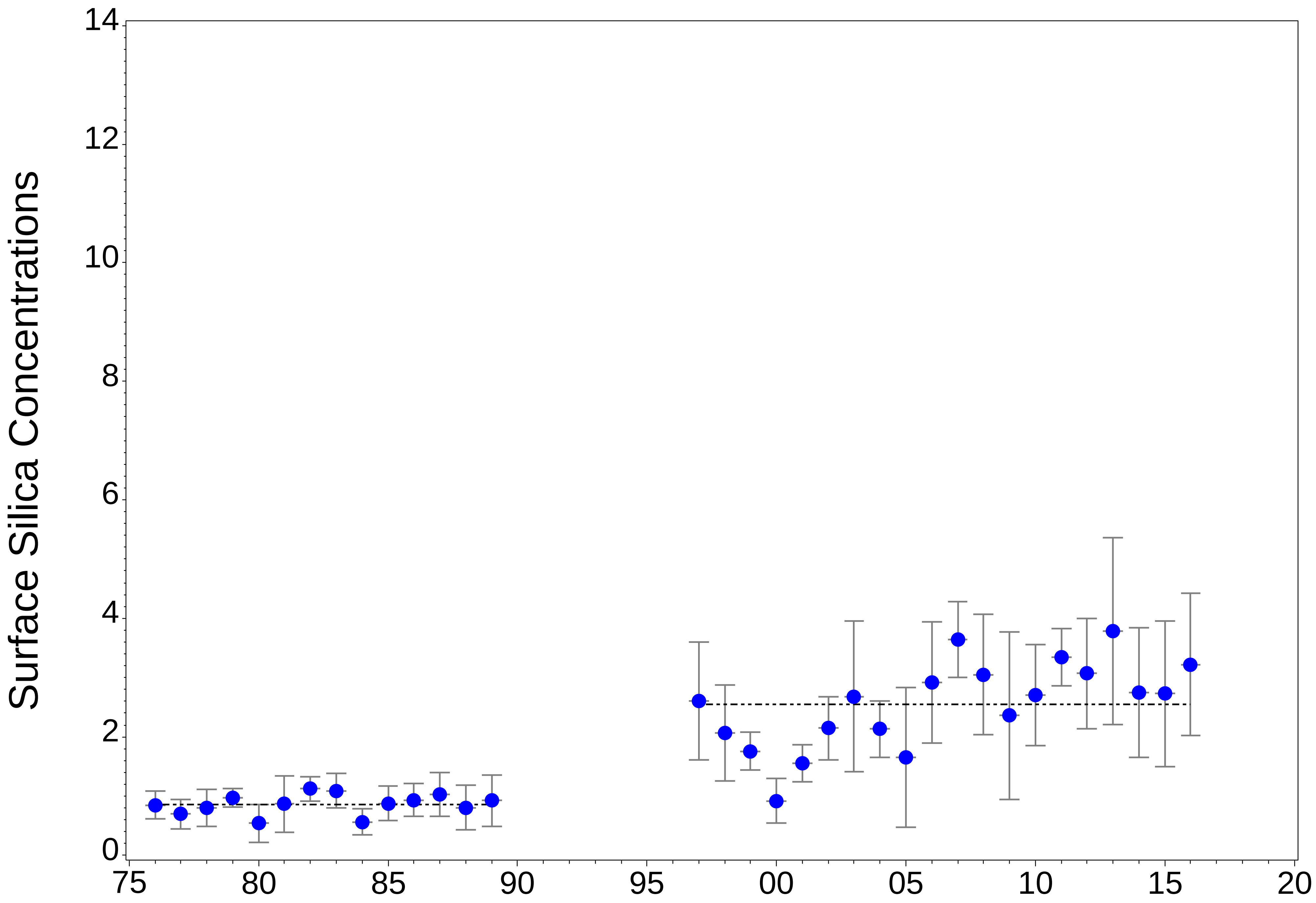


Figure C.74. Long-term Surface Silica Concentrations at river kilometer -2.4

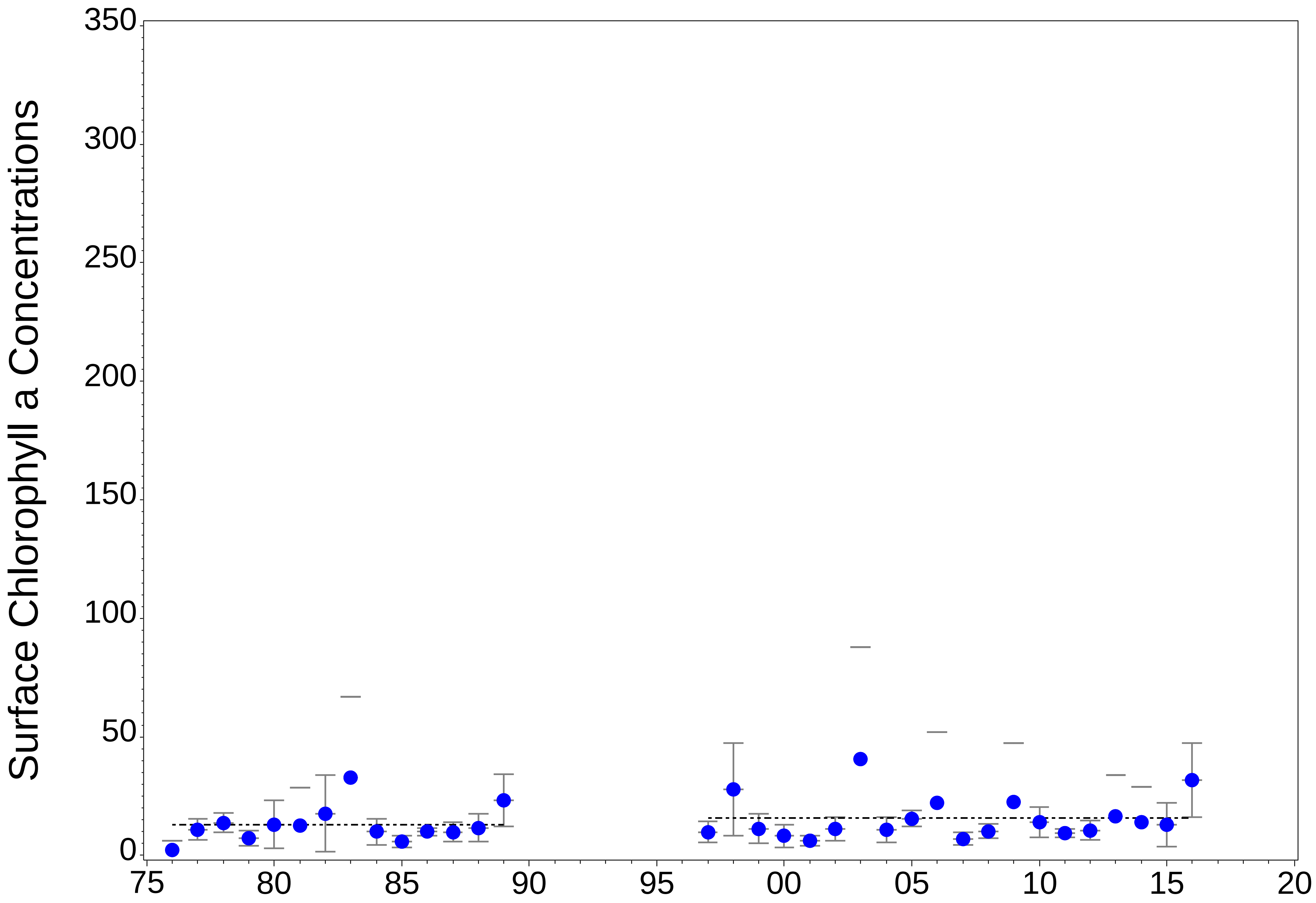


Figure C.75. Long-term Surface Chlorophyll a Concentrations at river kilometer -2.4

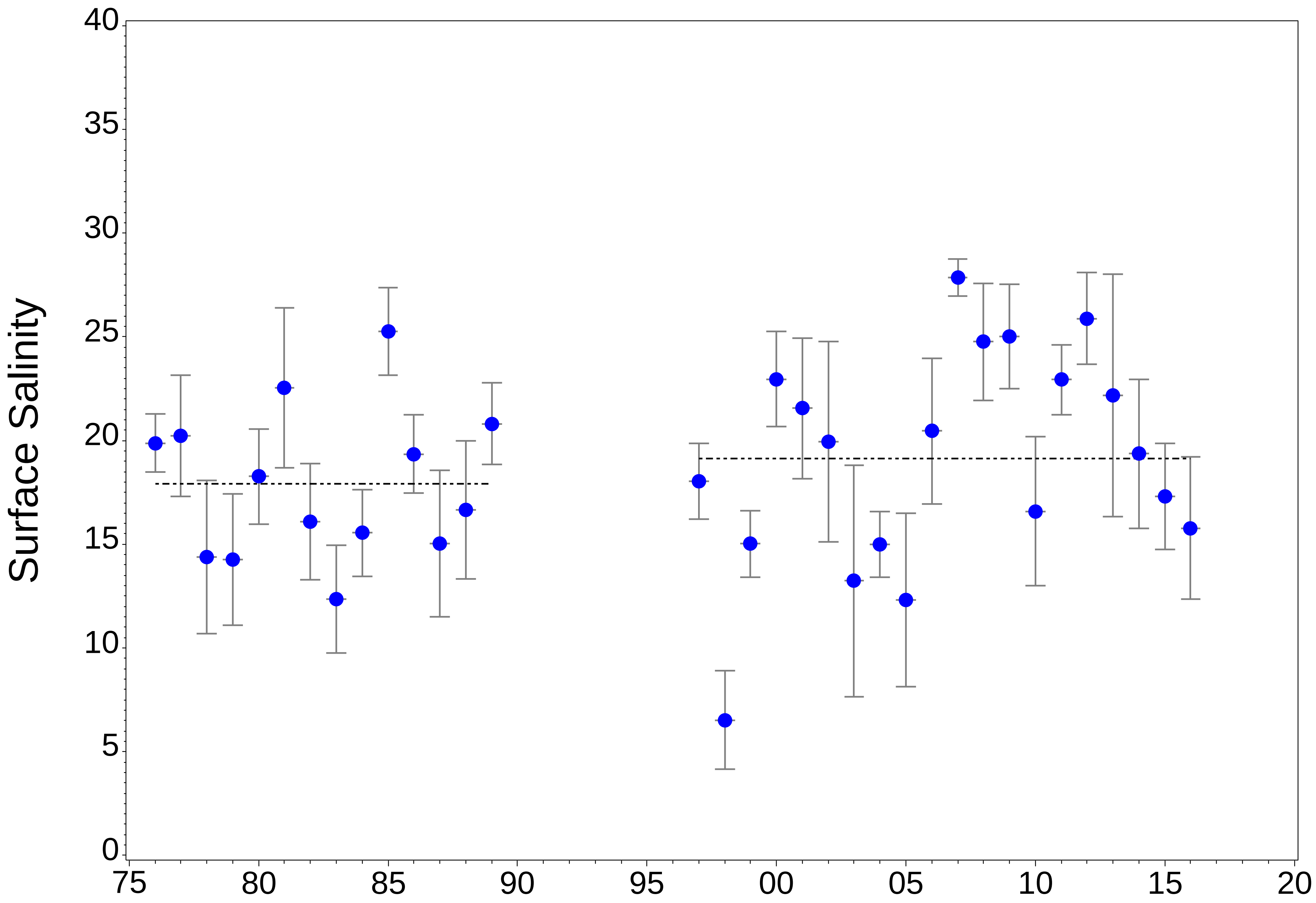


Figure C.76. Long-term Surface Salinity at river kilometer 6.6

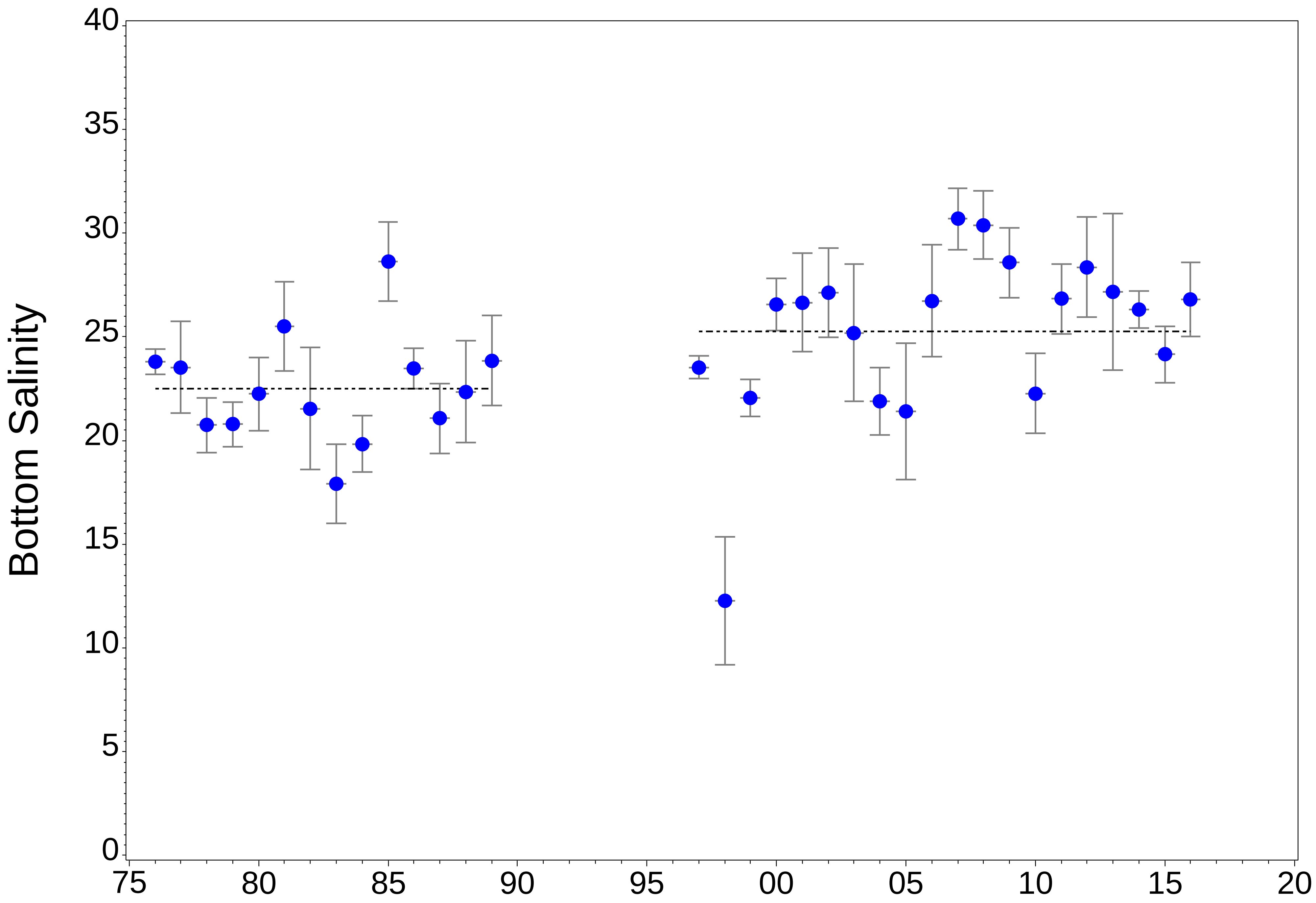


Figure C.77. Long-term Bottom Salinity at river kilometer 6.6

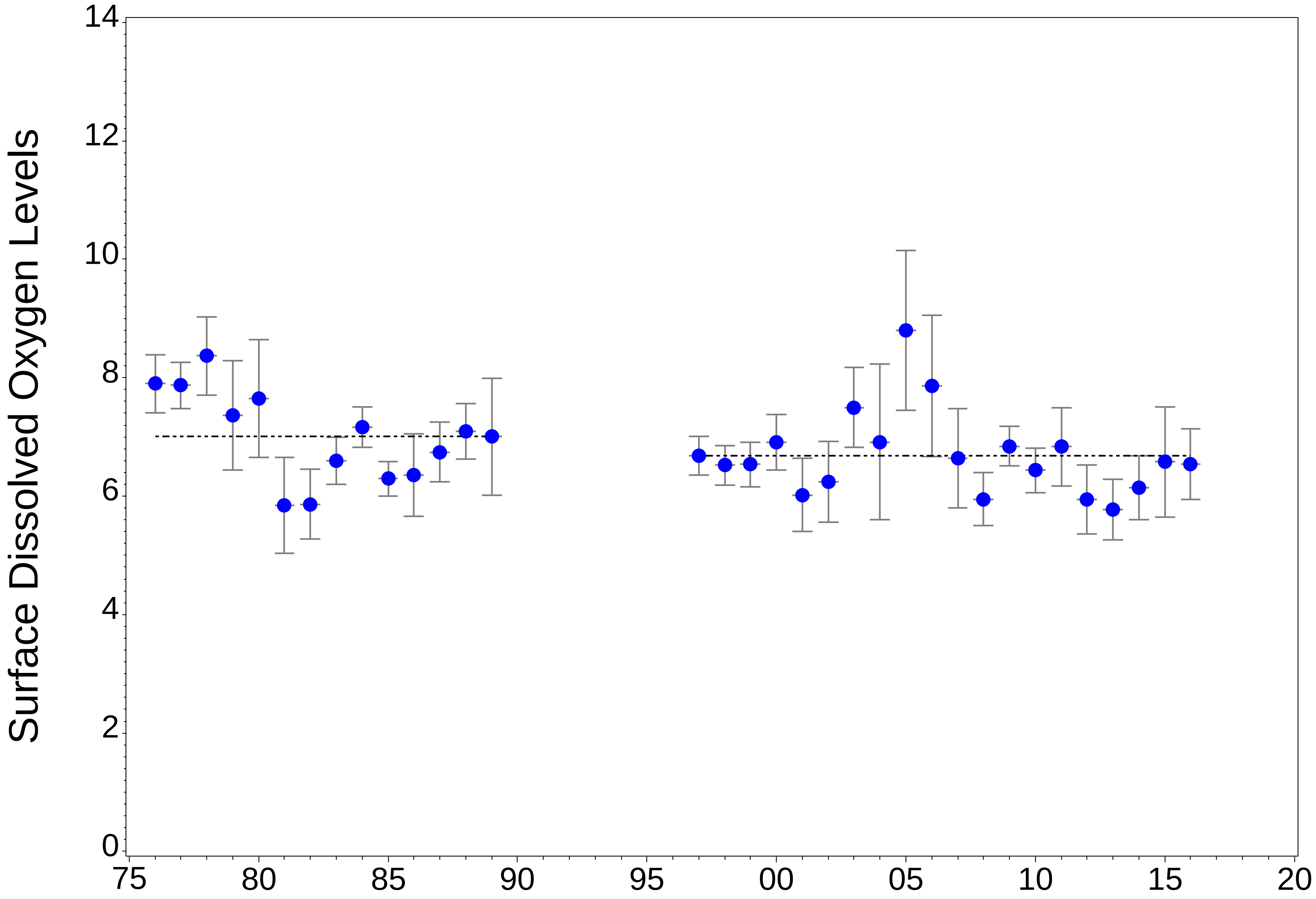


Figure C.78. Long-term Surface Dissolved Oxygen Levels at river kilometer 6.6

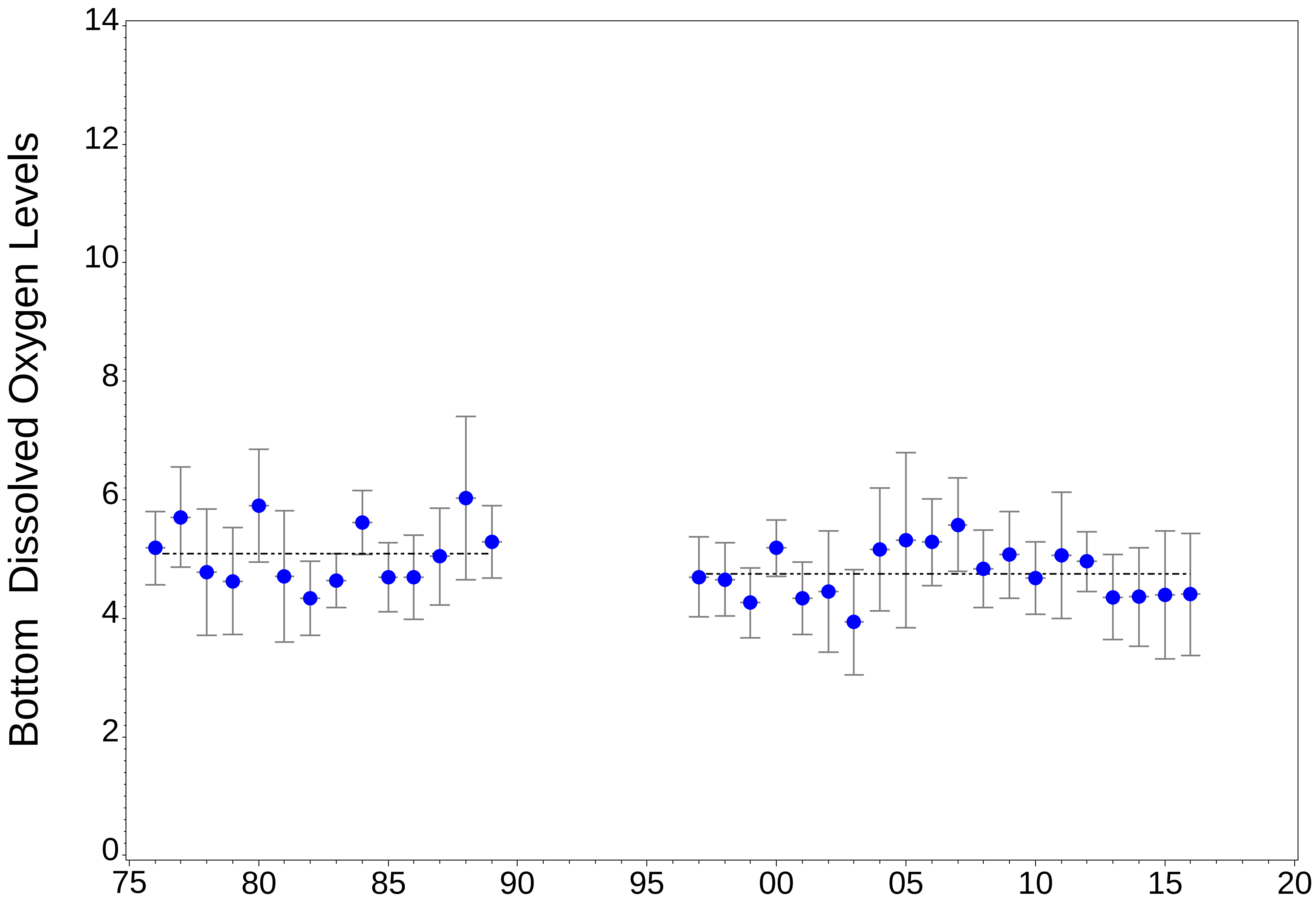


Figure C.79. Long-term Bottom Dissolved Oxygen Levels at river kilometer 6.6

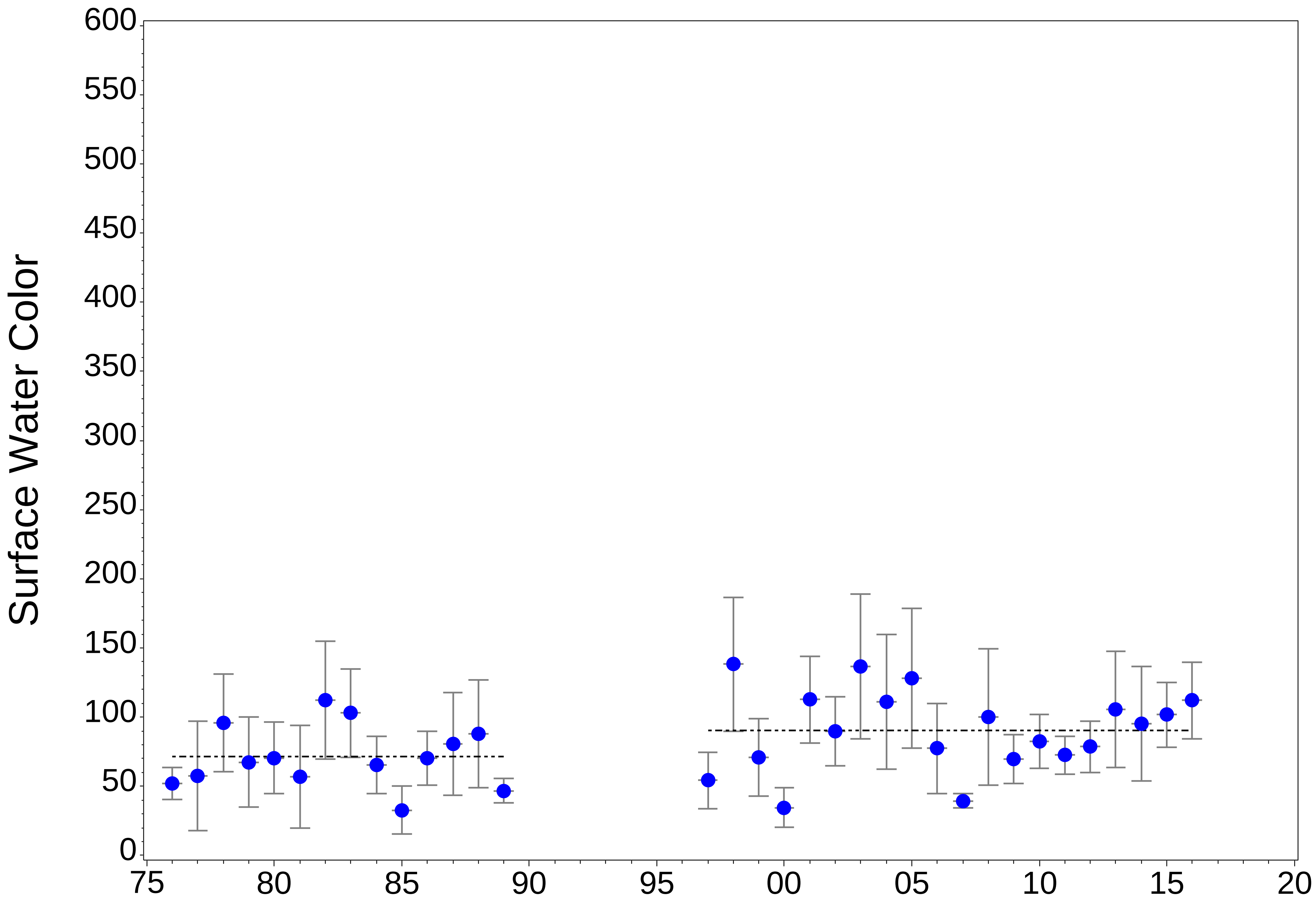


Figure C.80. Long-term Surface Water Color at river kilometer 6.6

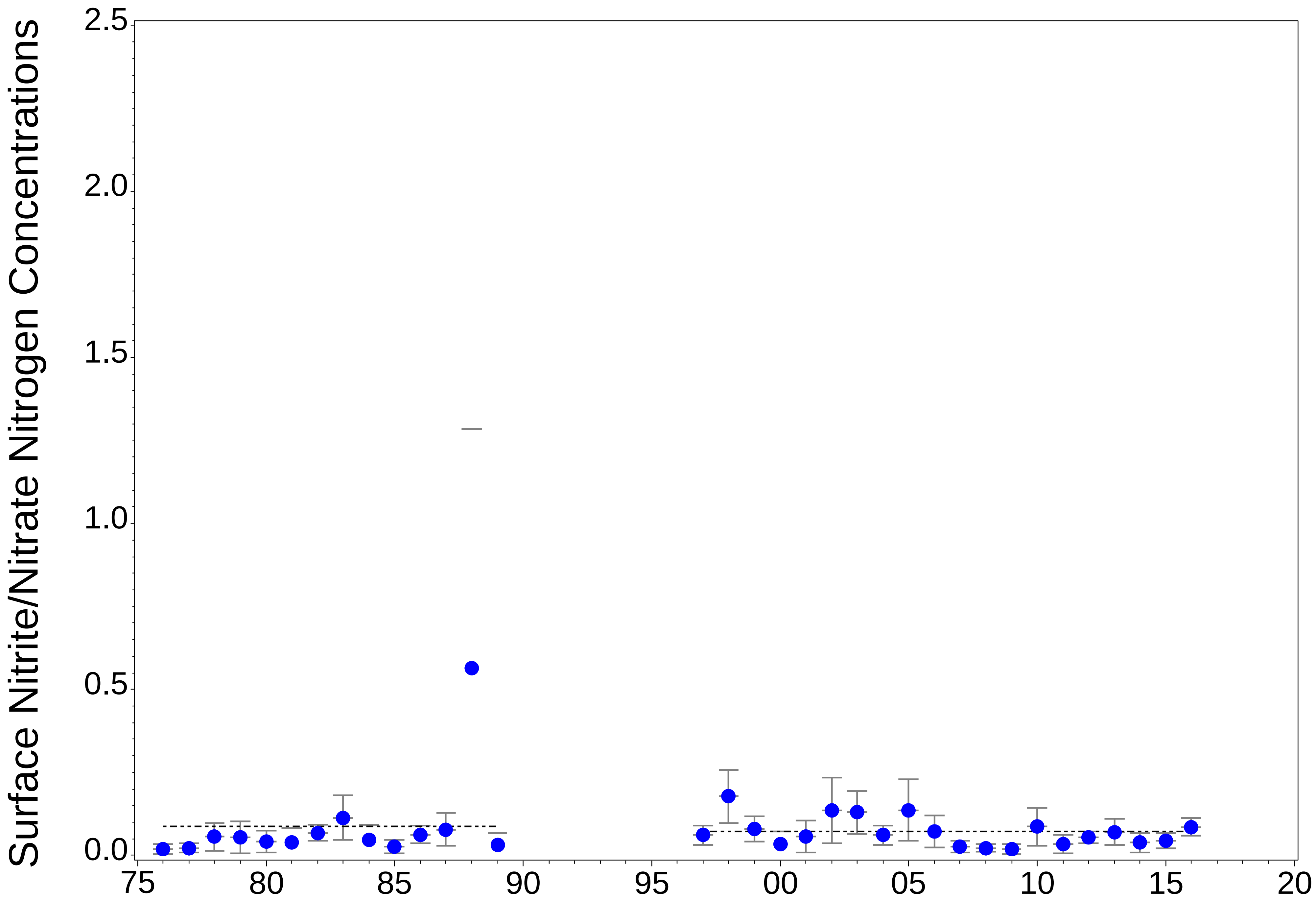


Figure C.81. Long-term Surface Nitrite/Nitrate Nitrogen Concentrations at river kilometer 6.6

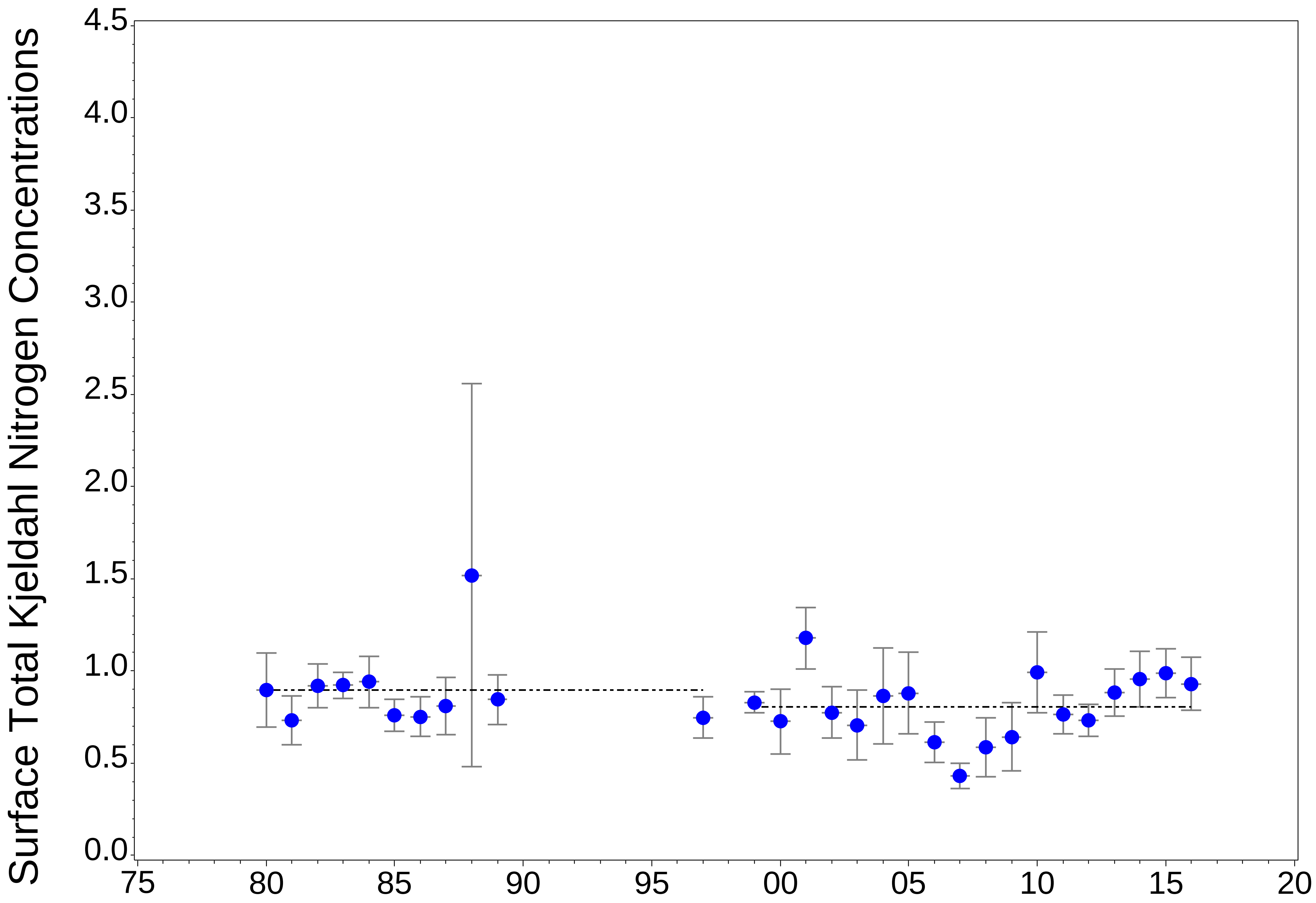


Figure C.82. Long-term Surface Total Kjeldahl Nitrogen Concentrations at river kilometer 6.6

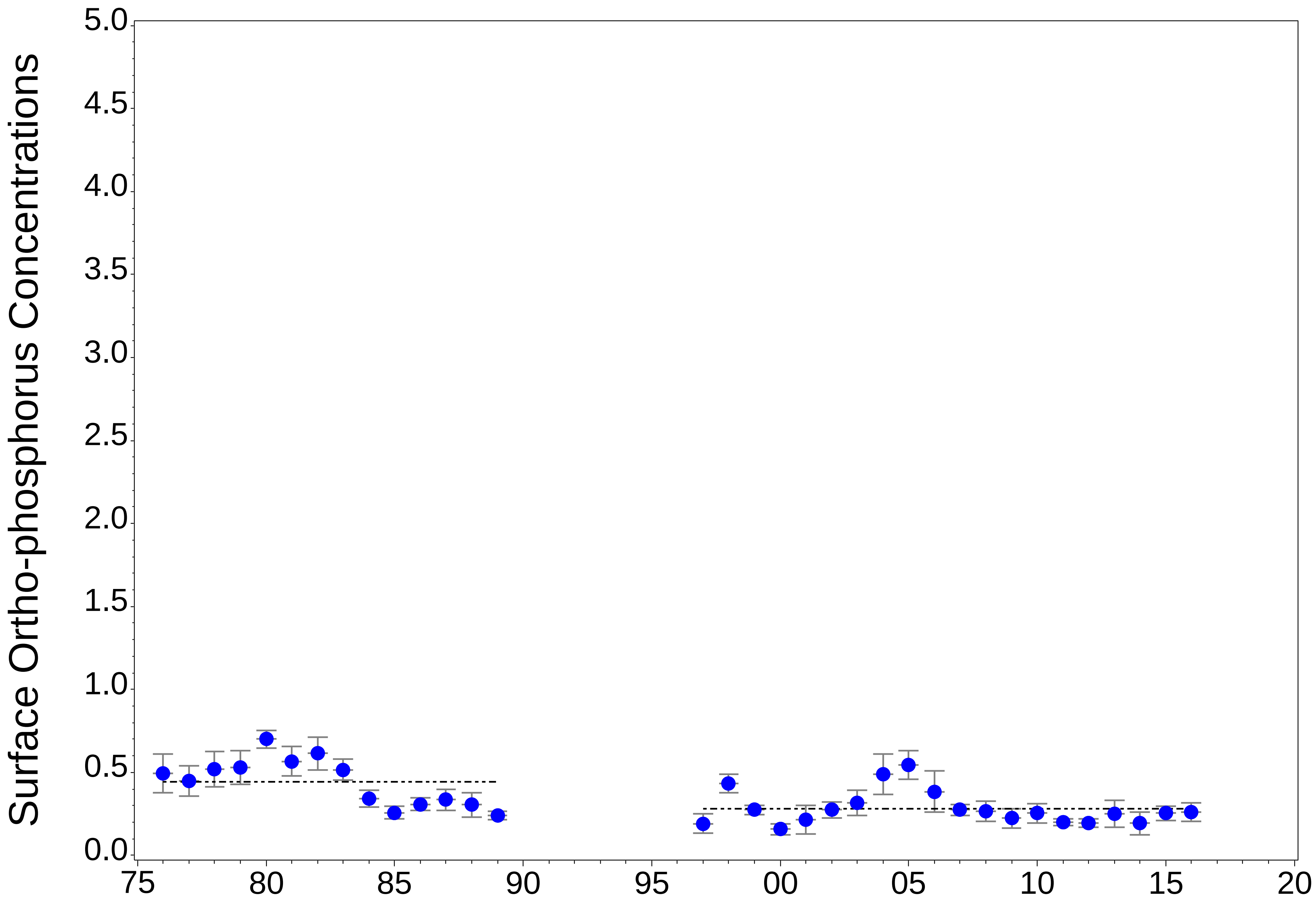


Figure C.83. Long-term Surface Ortho-phosphorus Concentrations at river kilometer 6.6

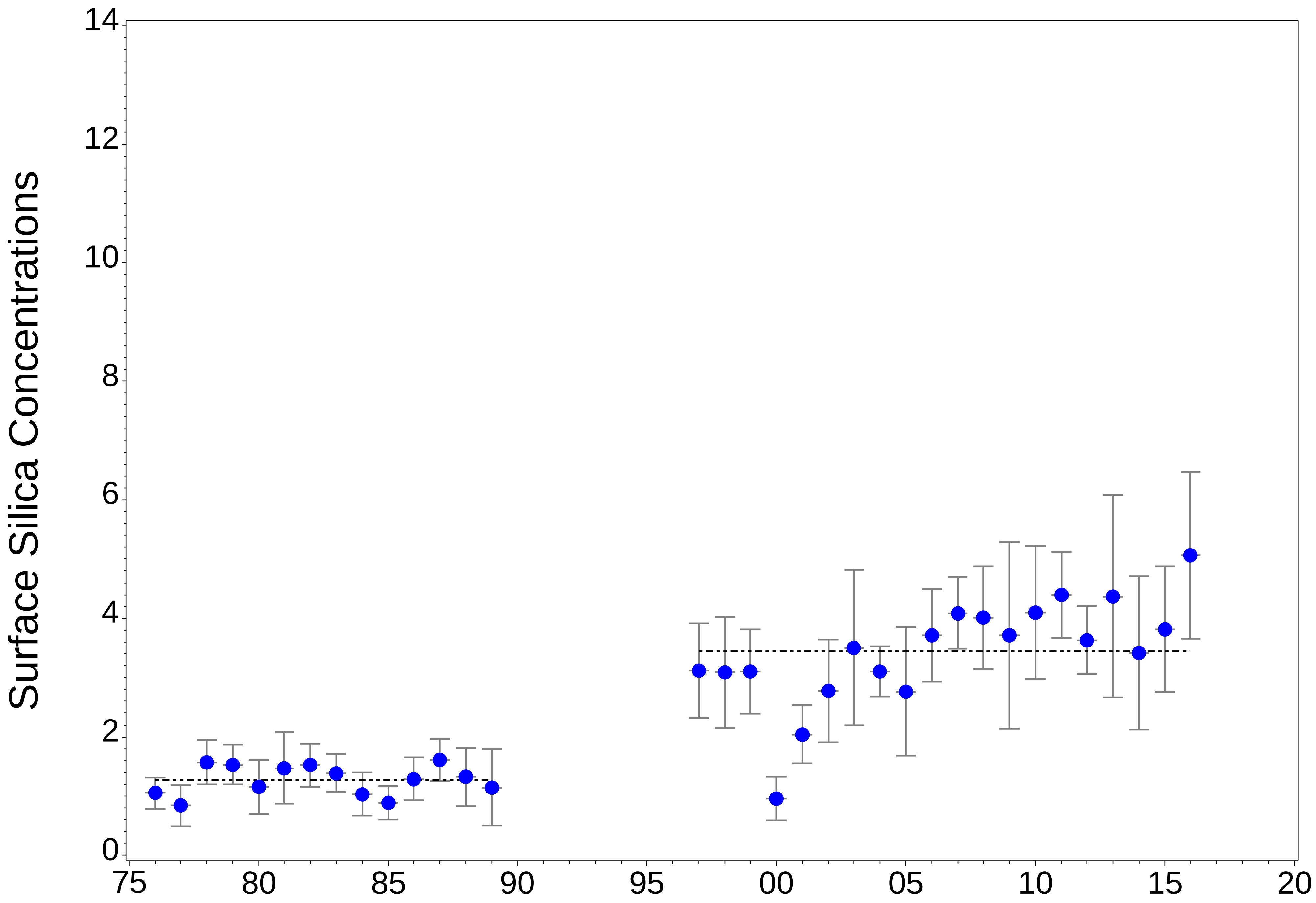


Figure C.84. Long-term Surface Silica Concentrations at river kilometer 6.6

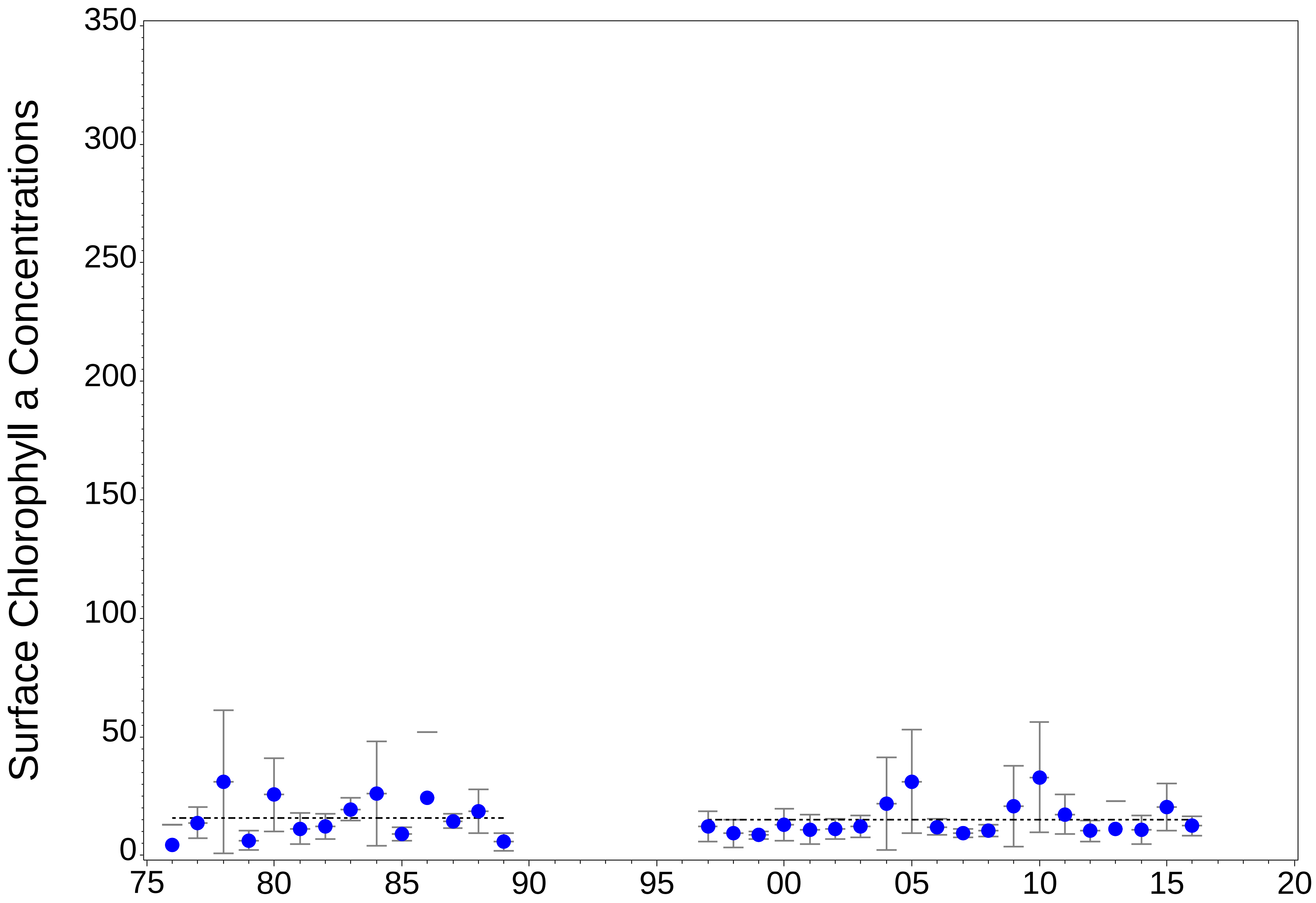


Figure C.85. Long-term Surface Chlorophyll a Concentrations at river kilometer 6.6

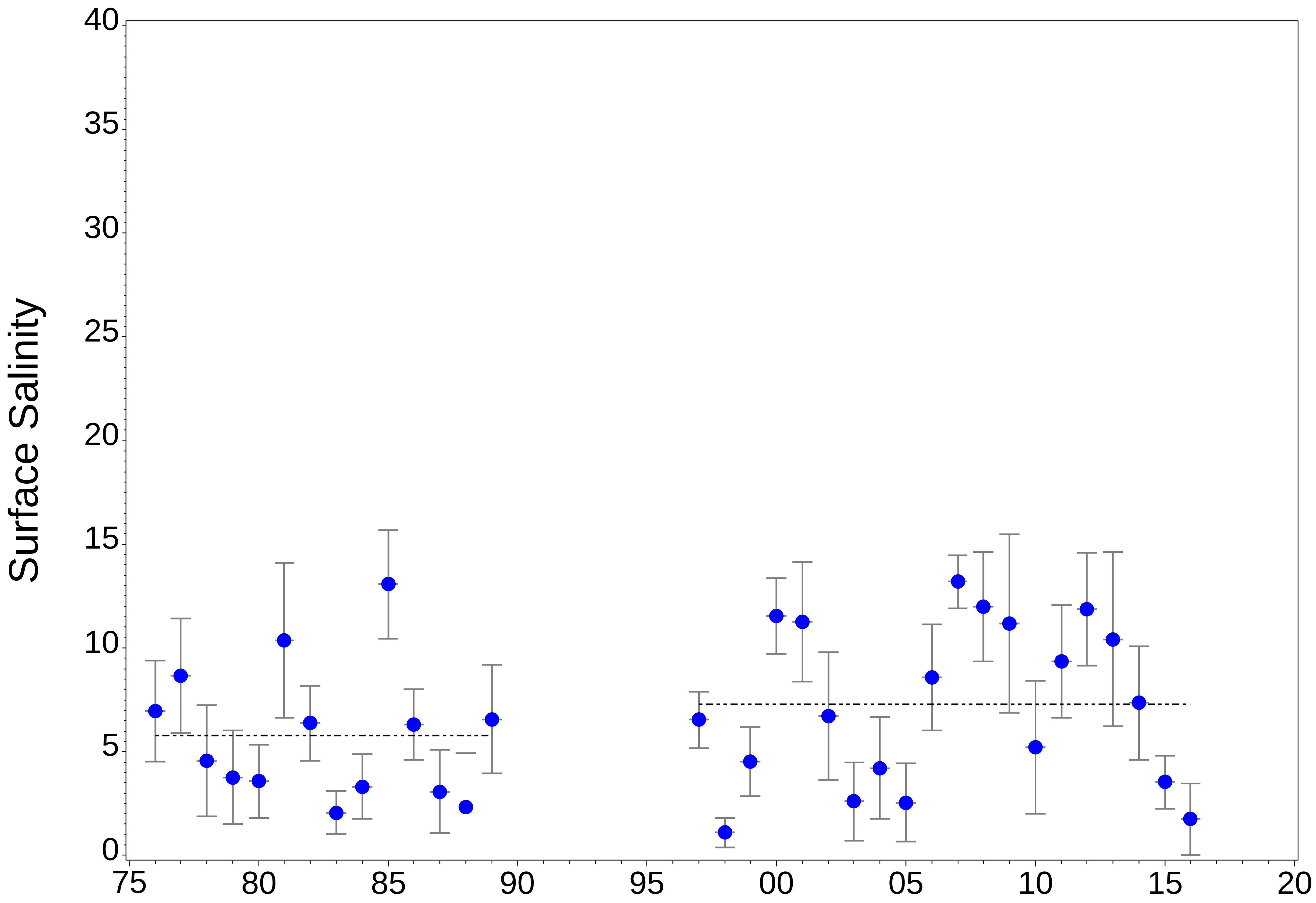


Figure C.86. Long-term Surface Salinity at river kilometer 15.5

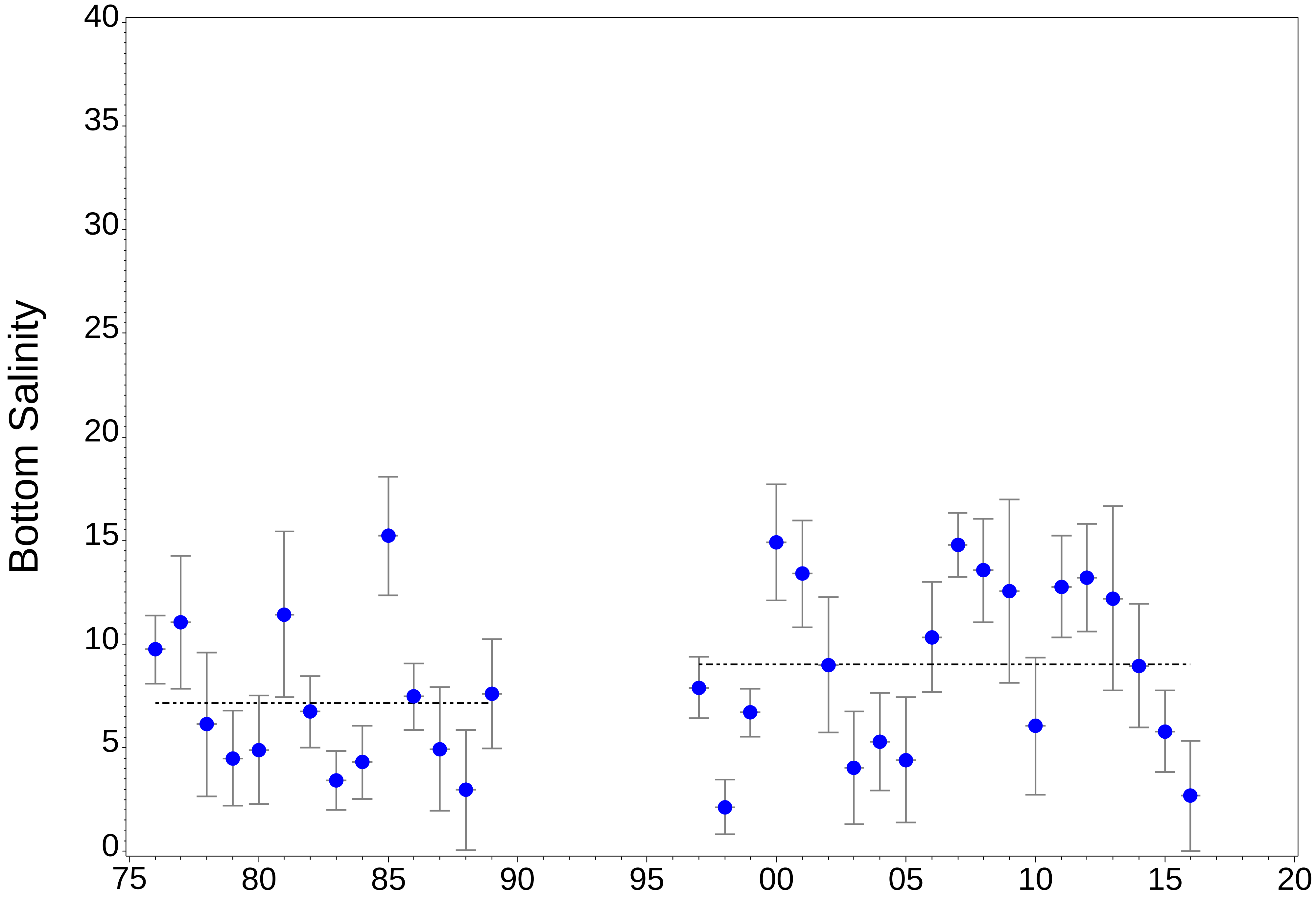


Figure C.87. Long-term Bottom Salinity at river kilometer 15.5

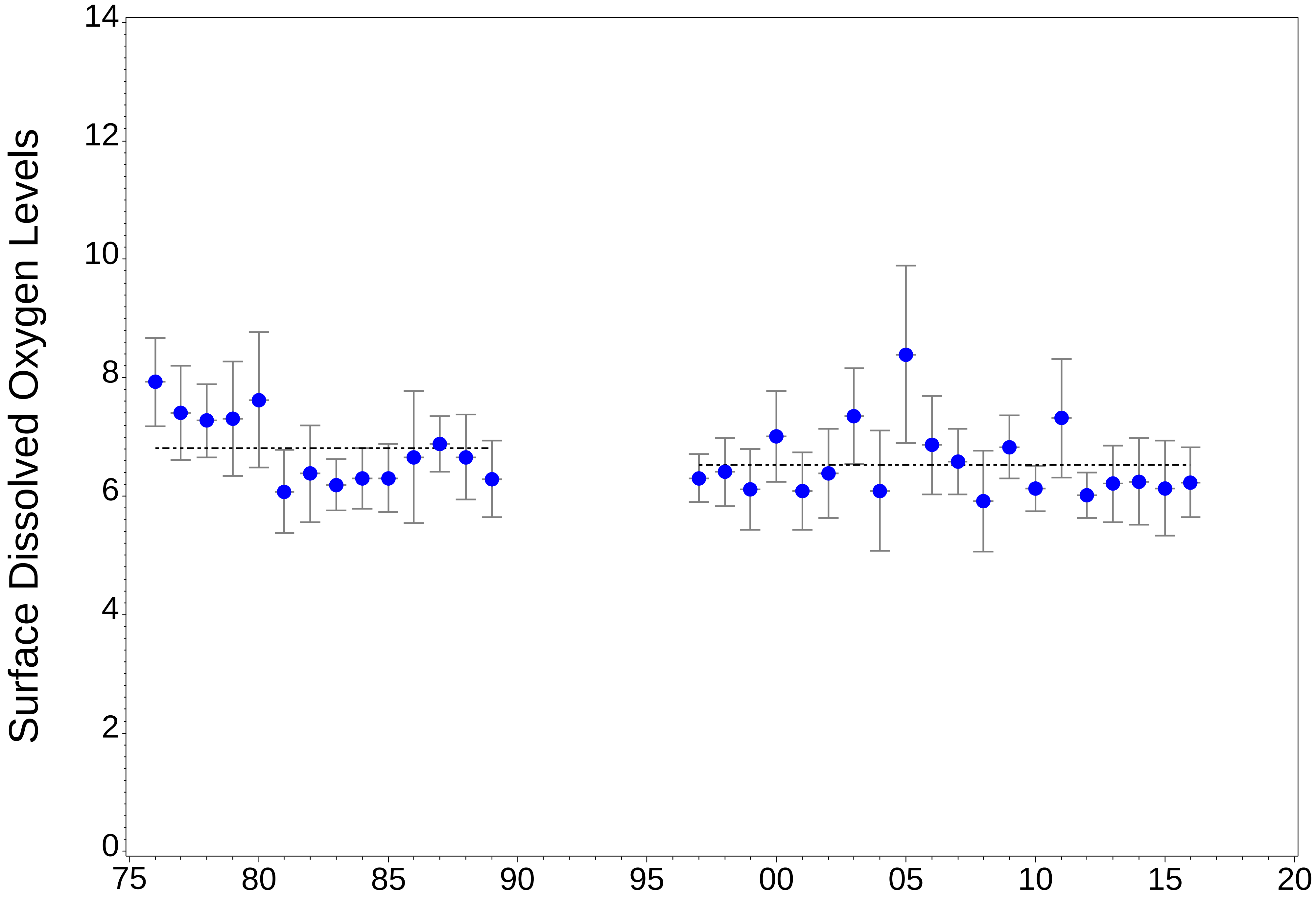


Figure C.88. Long-term Surface Dissolved Oxygen Levels at river kilometer 15.5

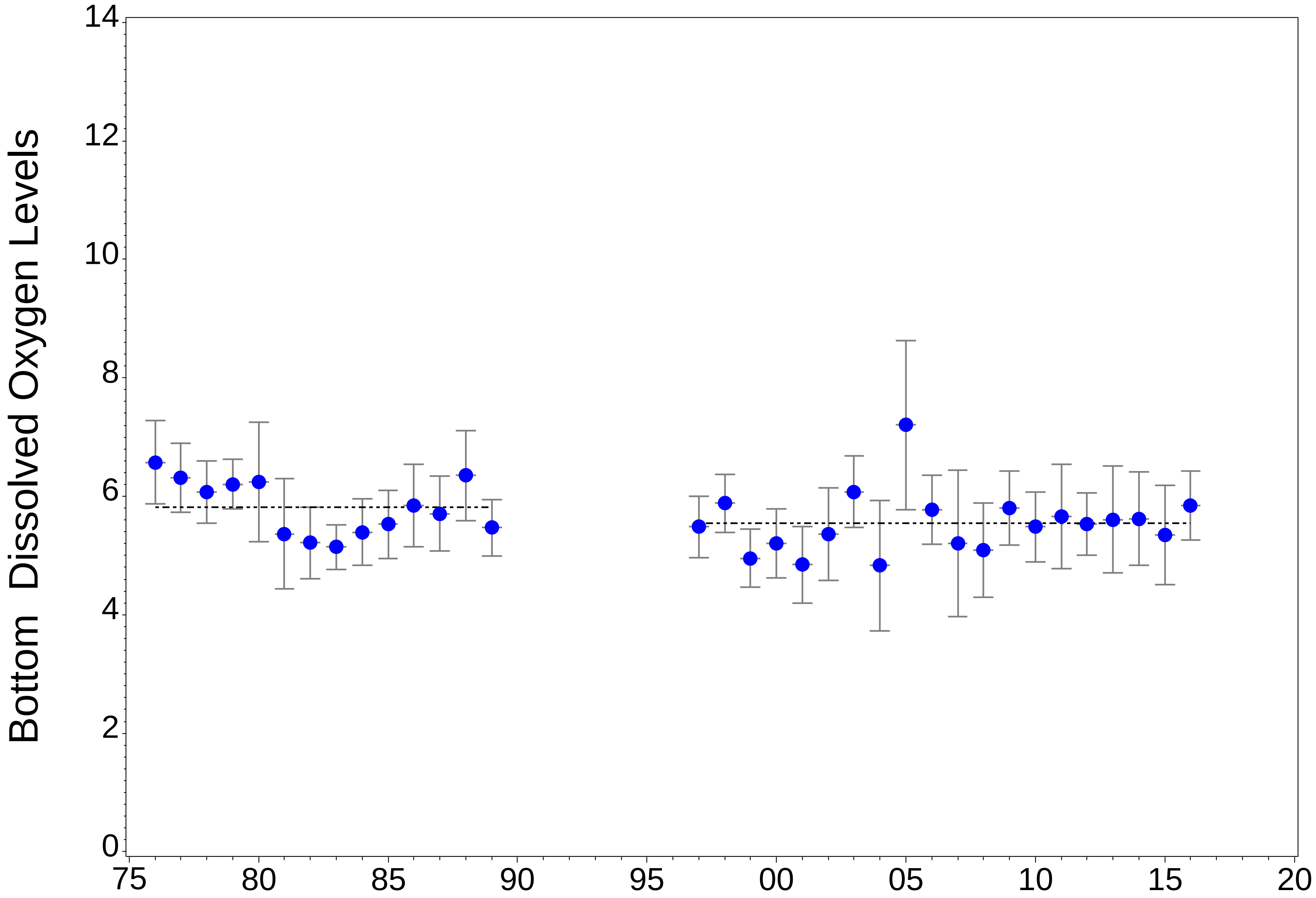


Figure C.89. Long-term Bottom Dissolved Oxygen Levels at river kilometer 15.5

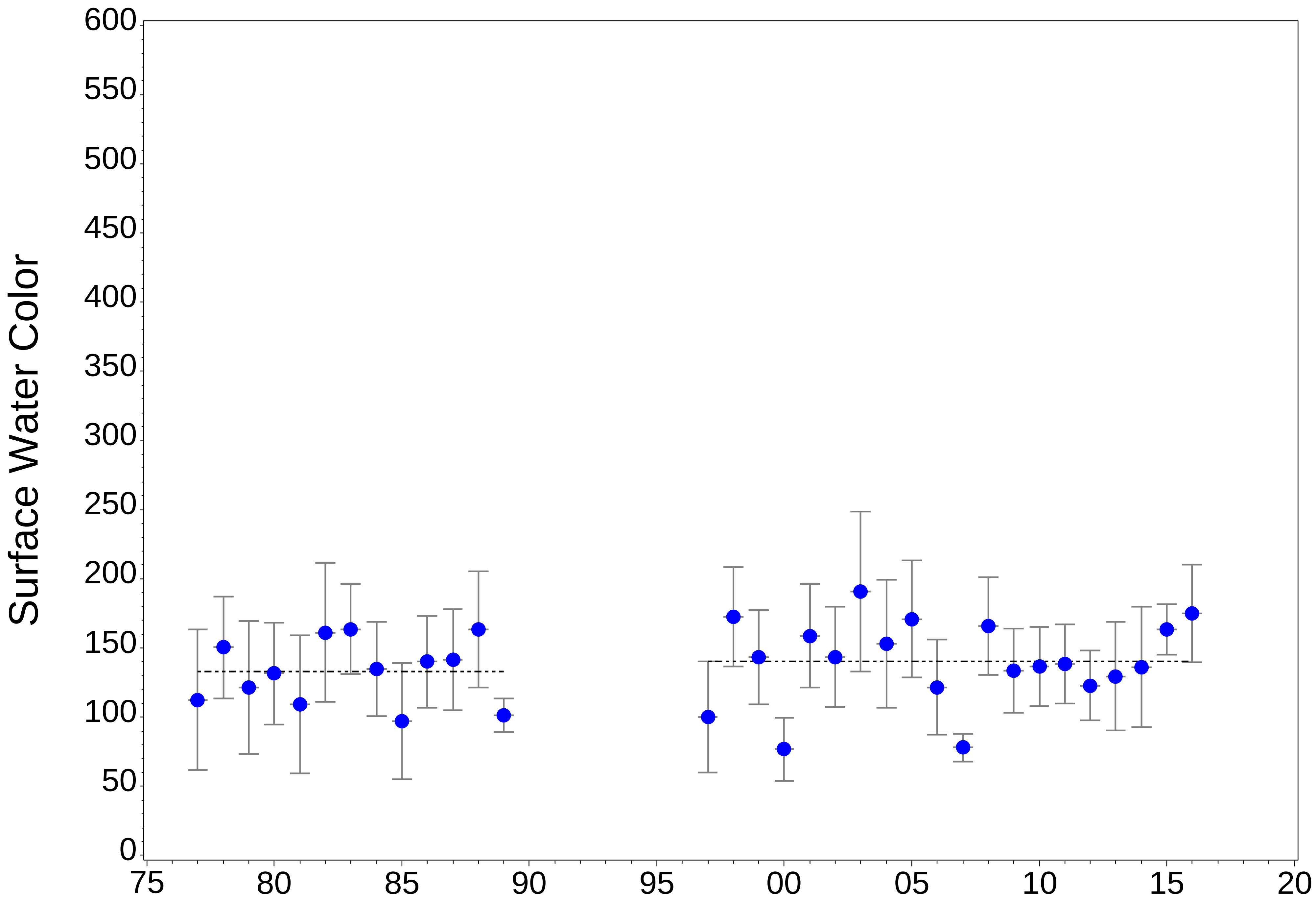


Figure C.90. Long-term Surface Water Color at river kilometer 15.5

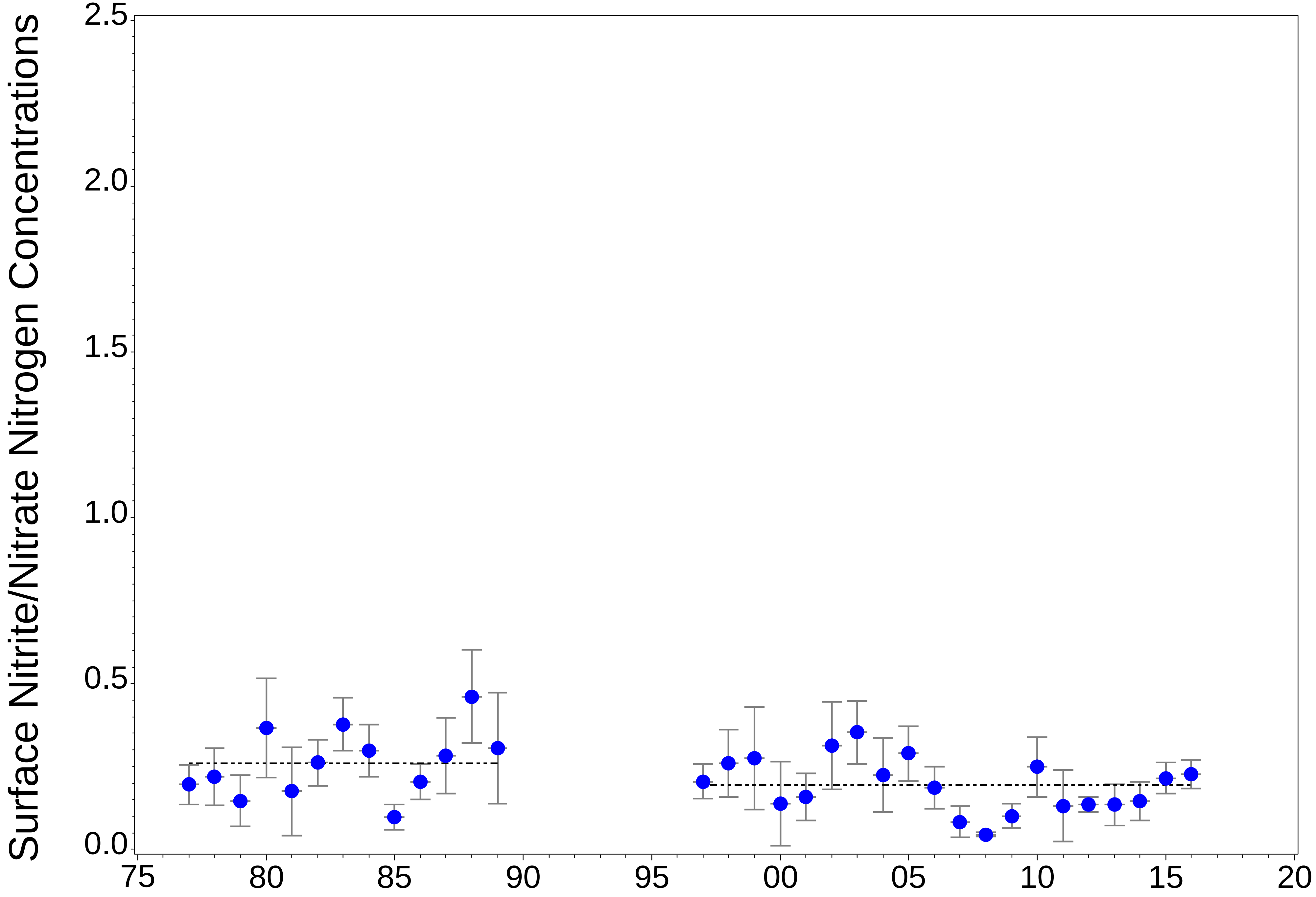


Figure C.91. Long-term Surface Nitrite/Nitrate Nitrogen Concentrations at river kilometer 15.5

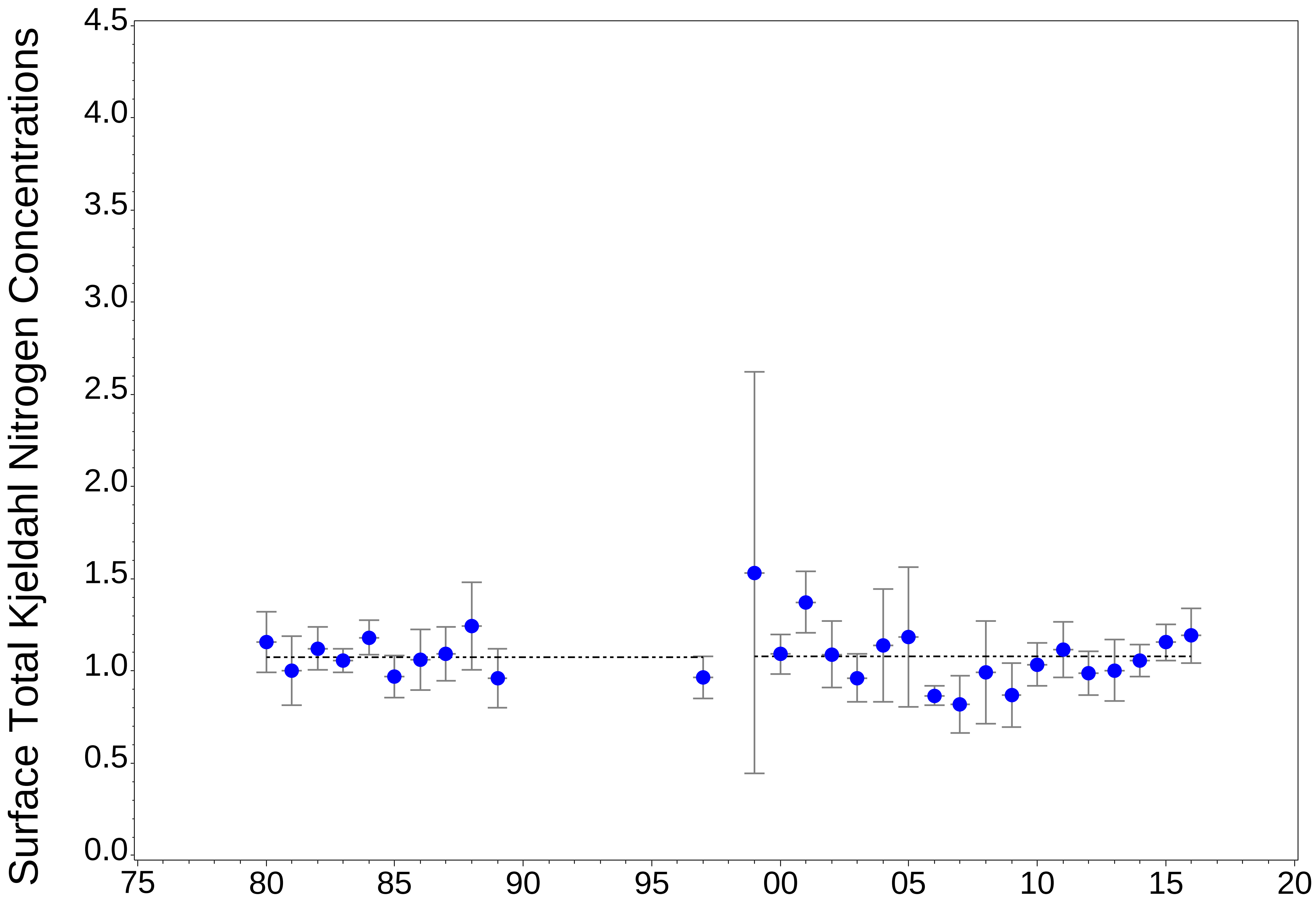


Figure C.92. Long-term Surface Total Kjeldahl Nitrogen Concentrations at river kilometer 15.5

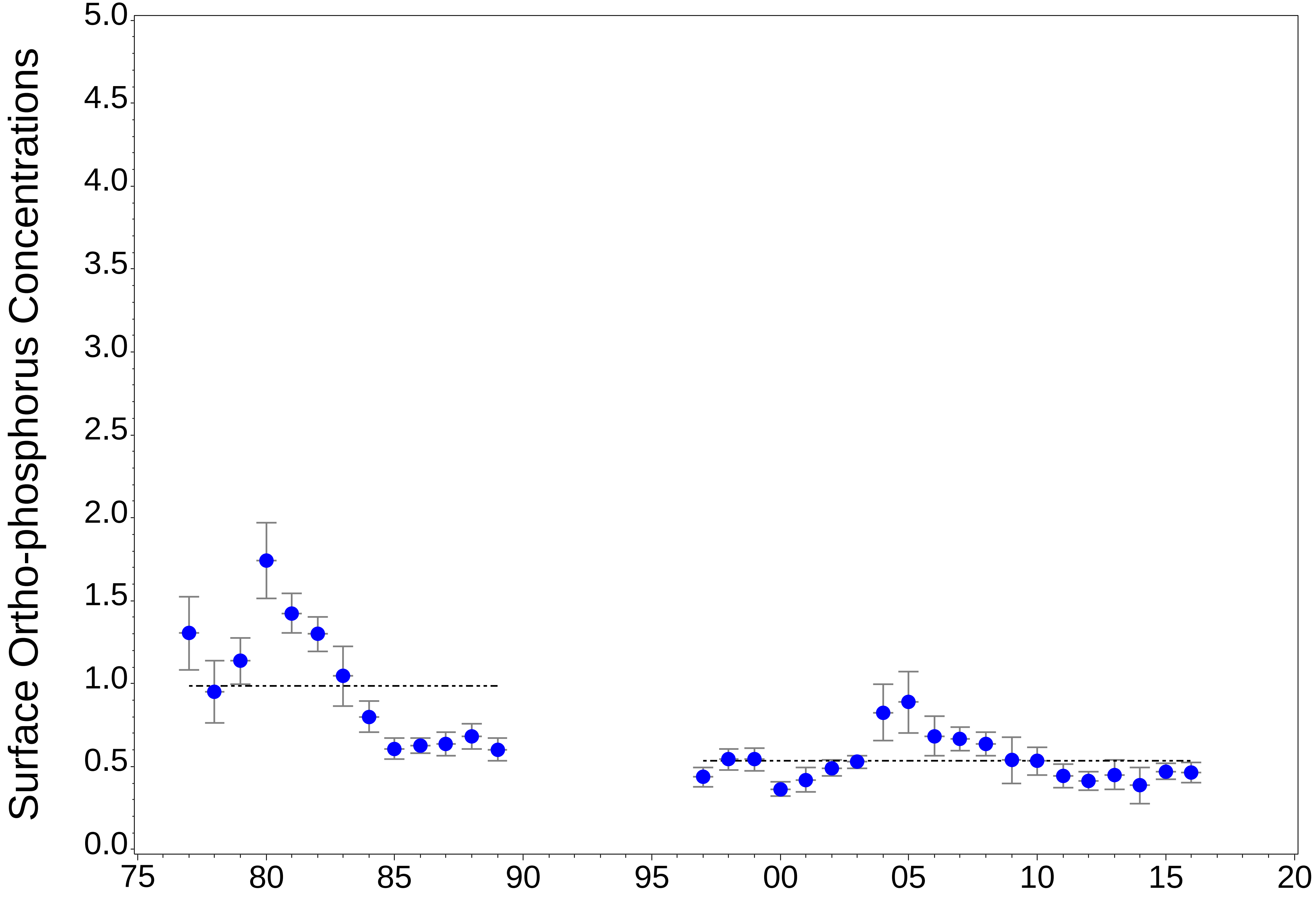


Figure C.93. Long-term Surface Ortho-phosphorus Concentrations at river kilometer 15.5

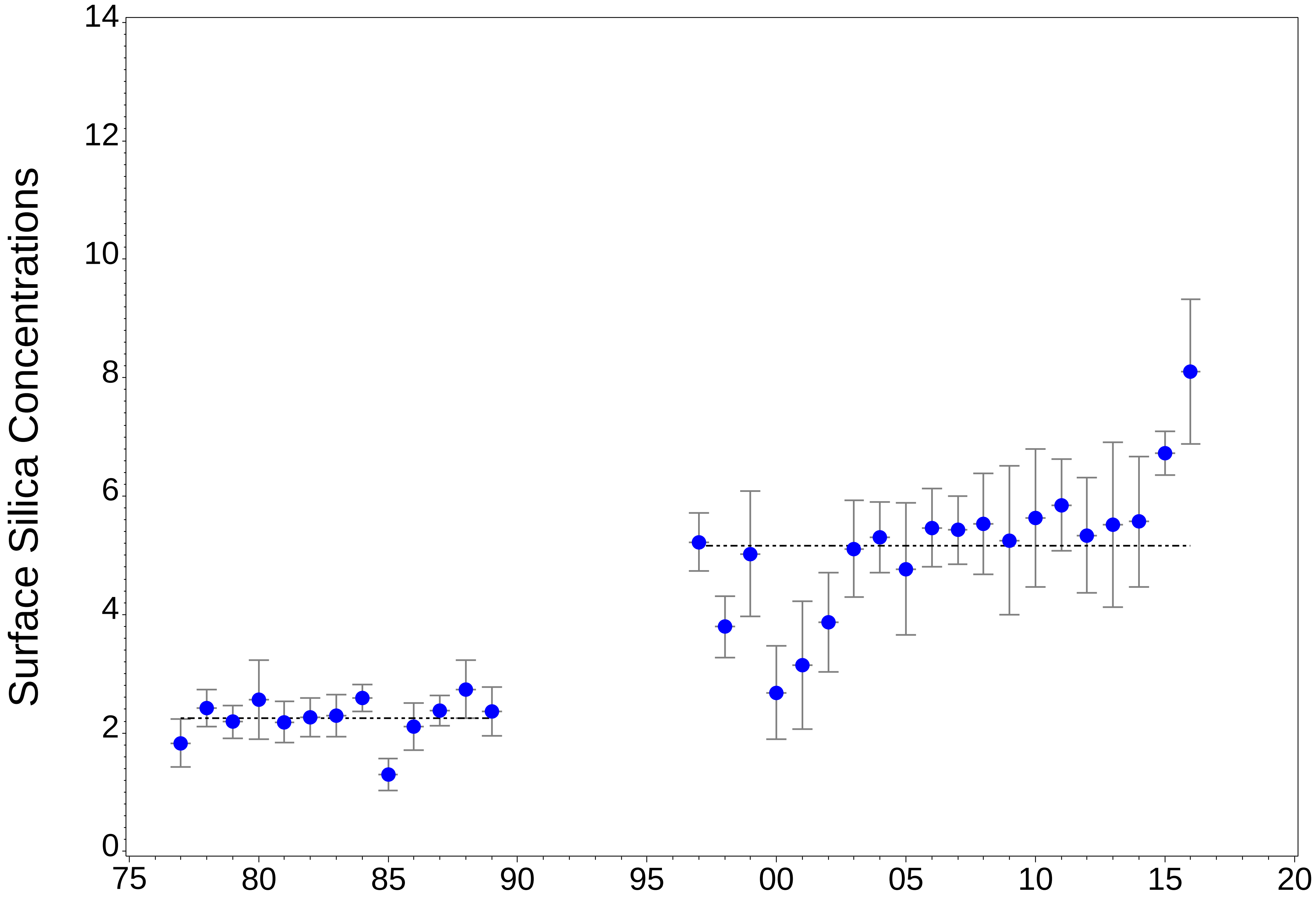


Figure C.94. Long-term Surface Silica Concentrations at river kilometer 15.5

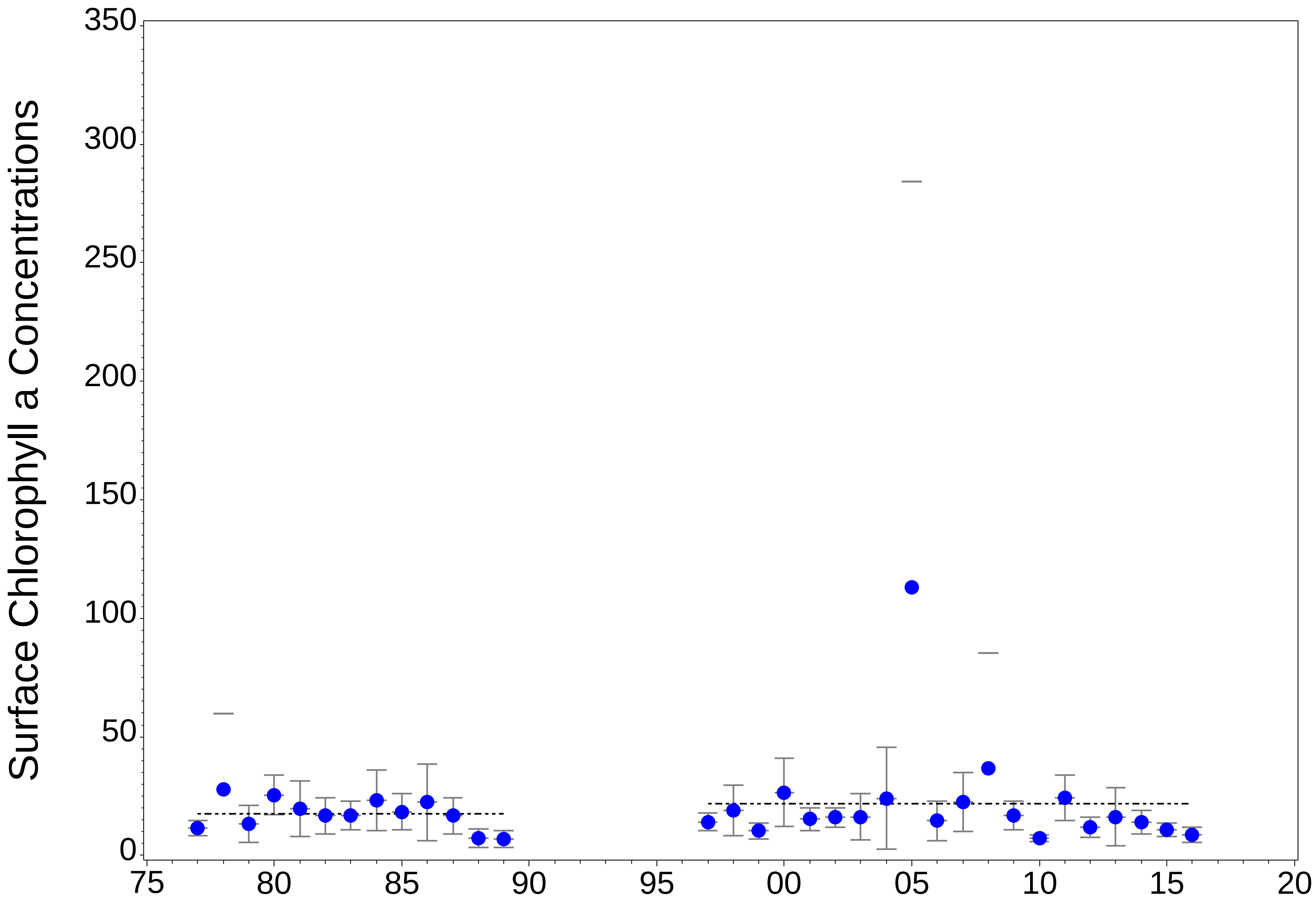


Figure C.95. Long-term Surface Chlorophyll a Concentrations at river kilometer 15.5

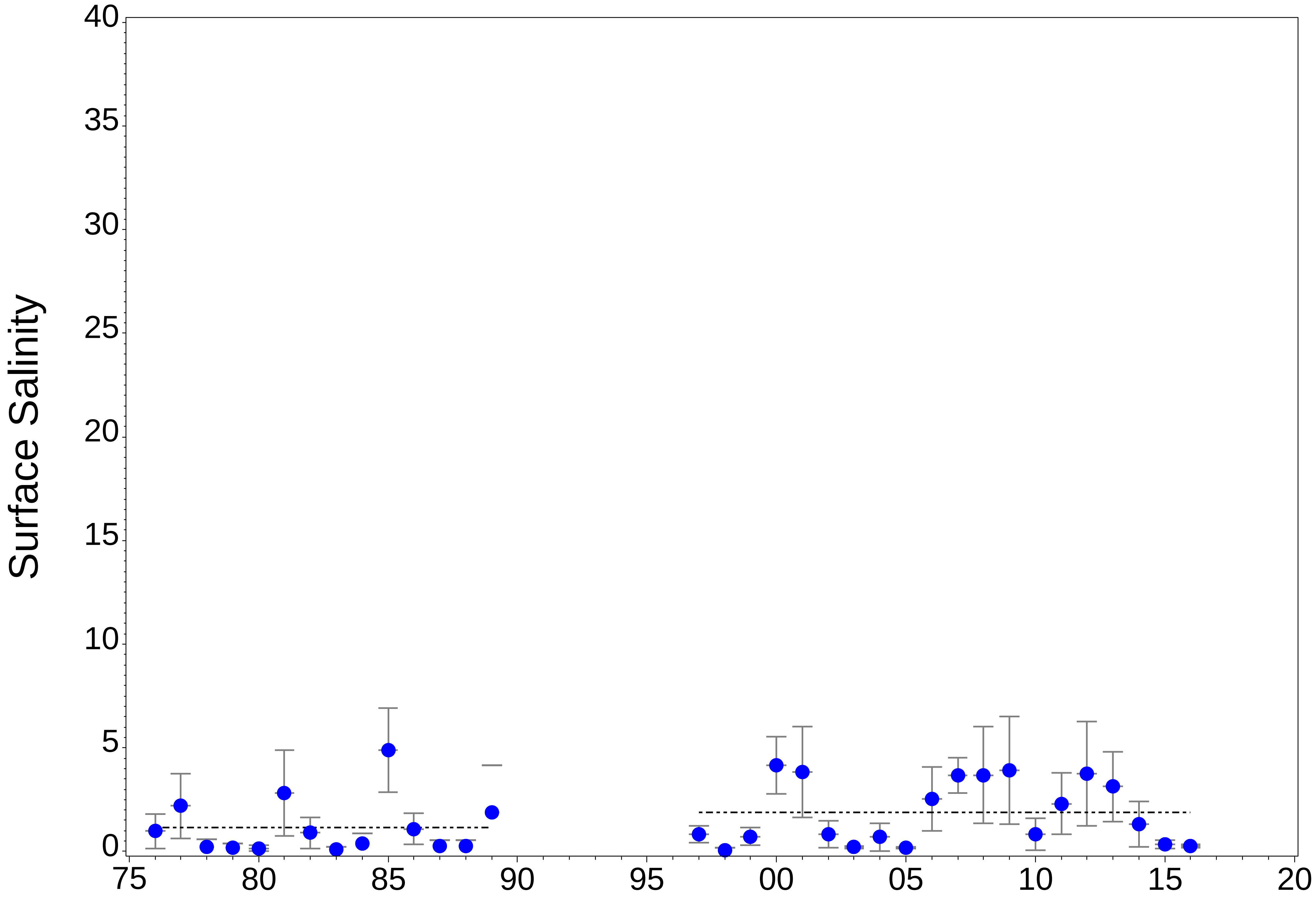


Figure C.96. Long-term Surface Salinity at river kilometer 23.6

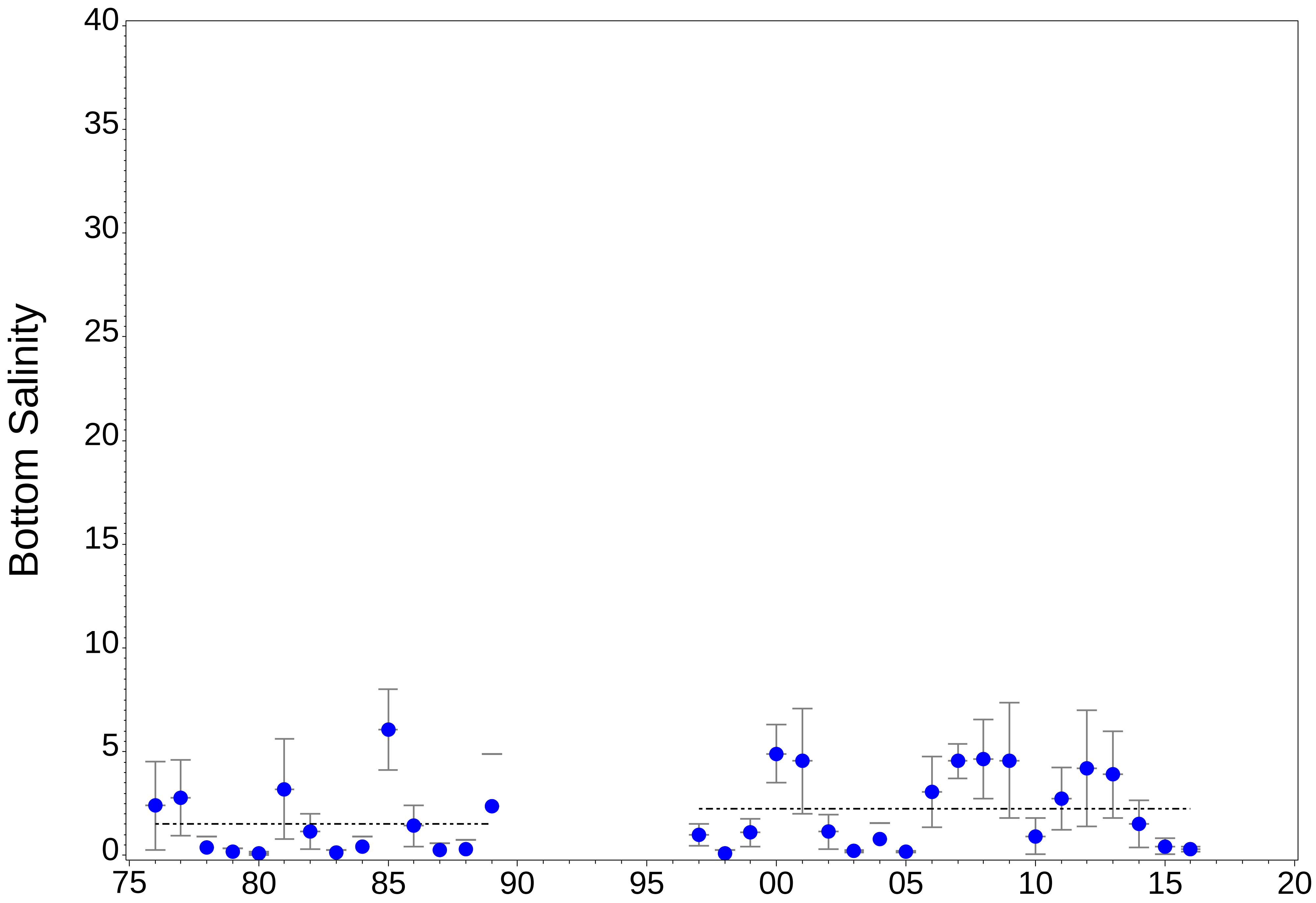


Figure C.97. Long-term Bottom Salinity at river kilometer 23.6

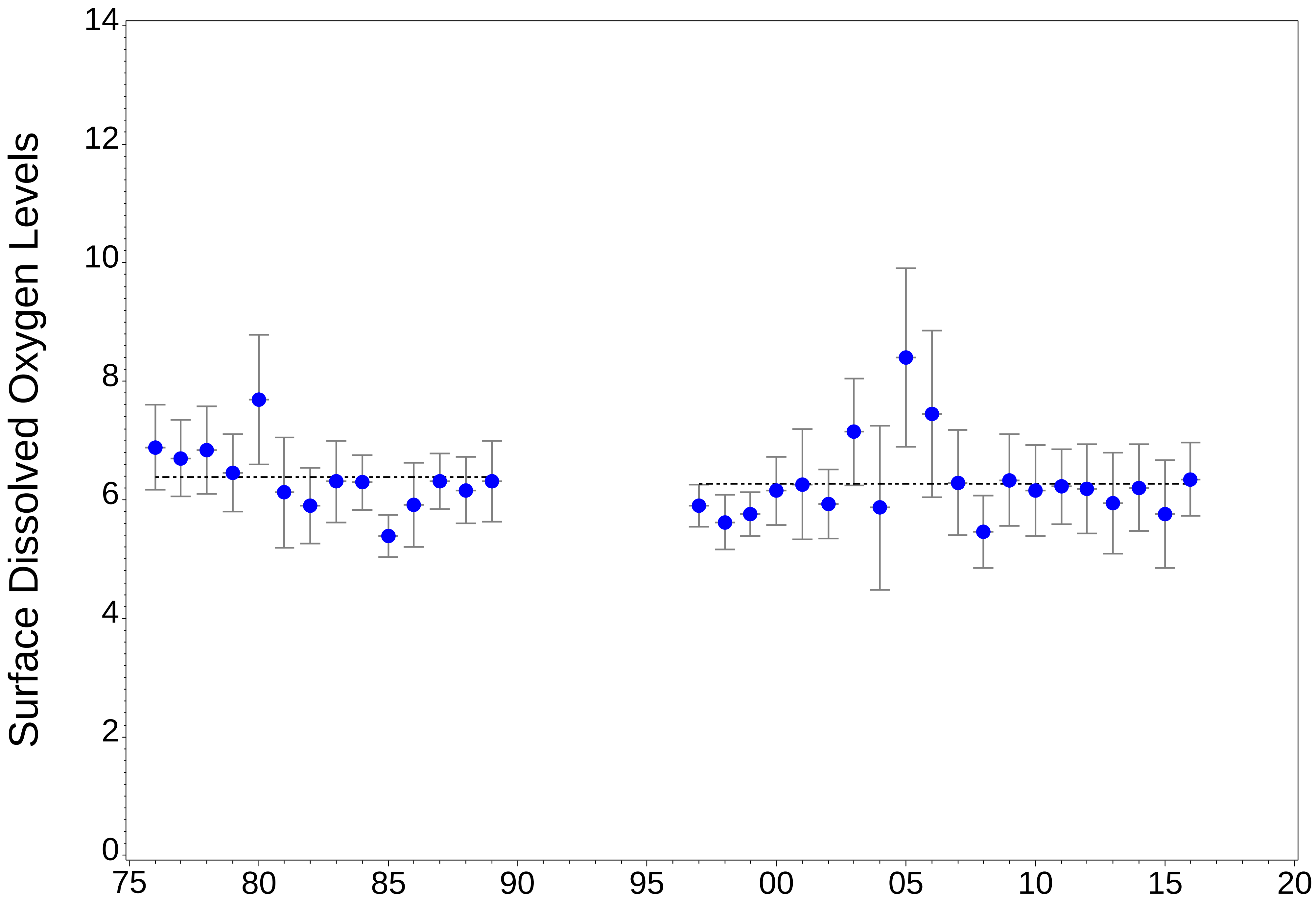


Figure C.98. Long-term Surface Dissolved Oxygen Levels at river kilometer 23.6

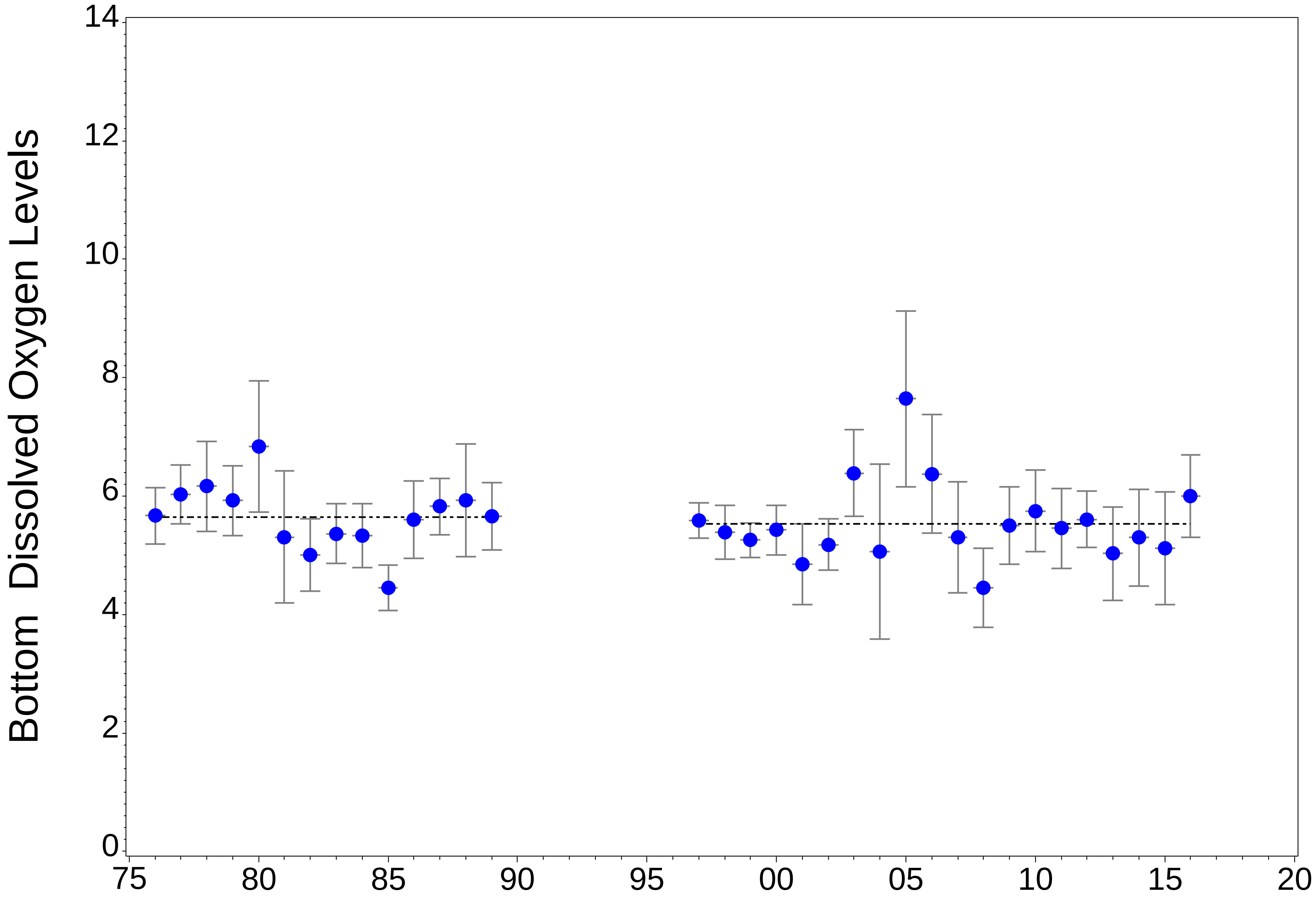


Figure C.99. Long-term Bottom Dissolved Oxygen Levels at river kilometer 23.6

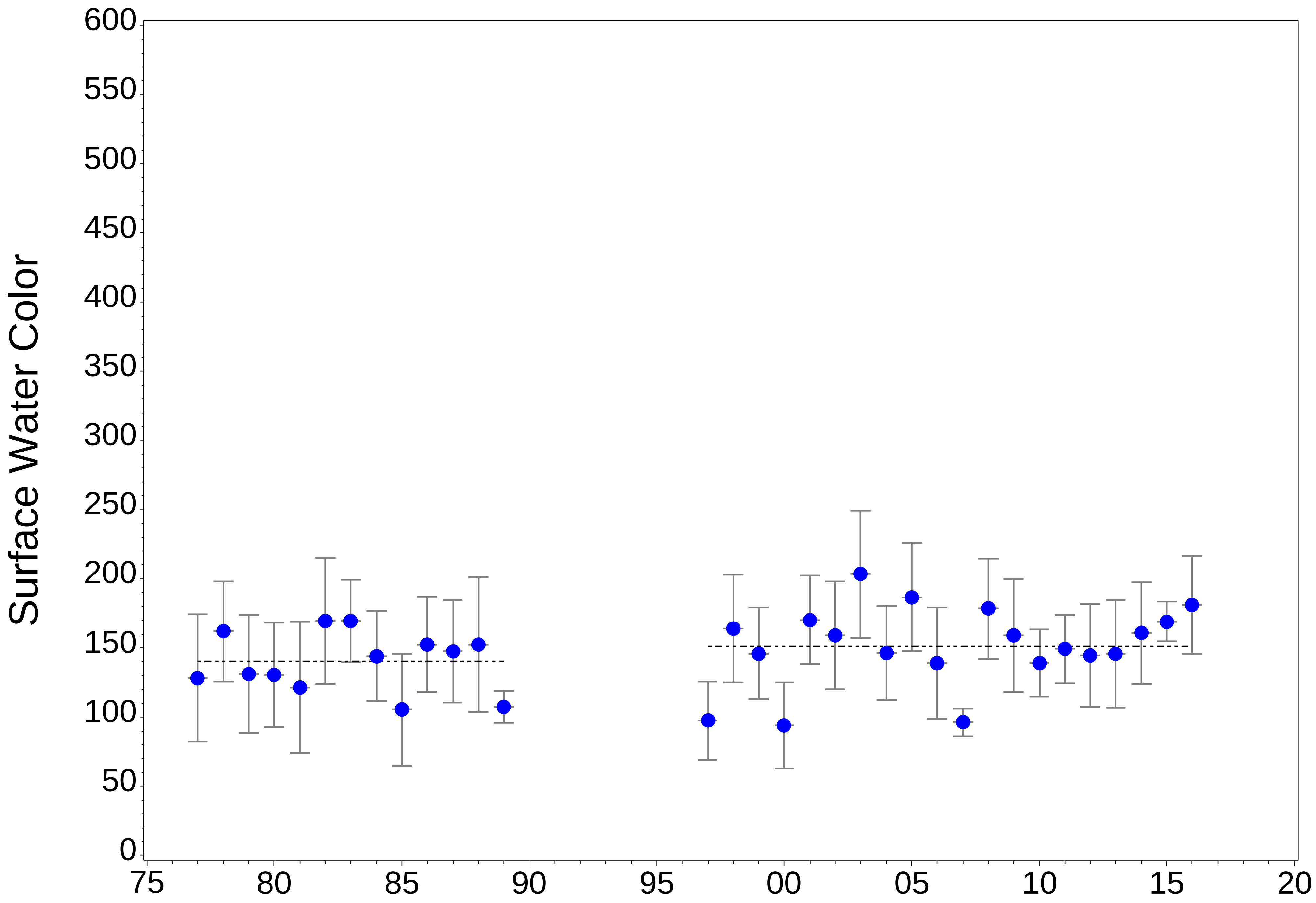


Figure C.100. Long-term Surface Water Color at river kilometer 23.6

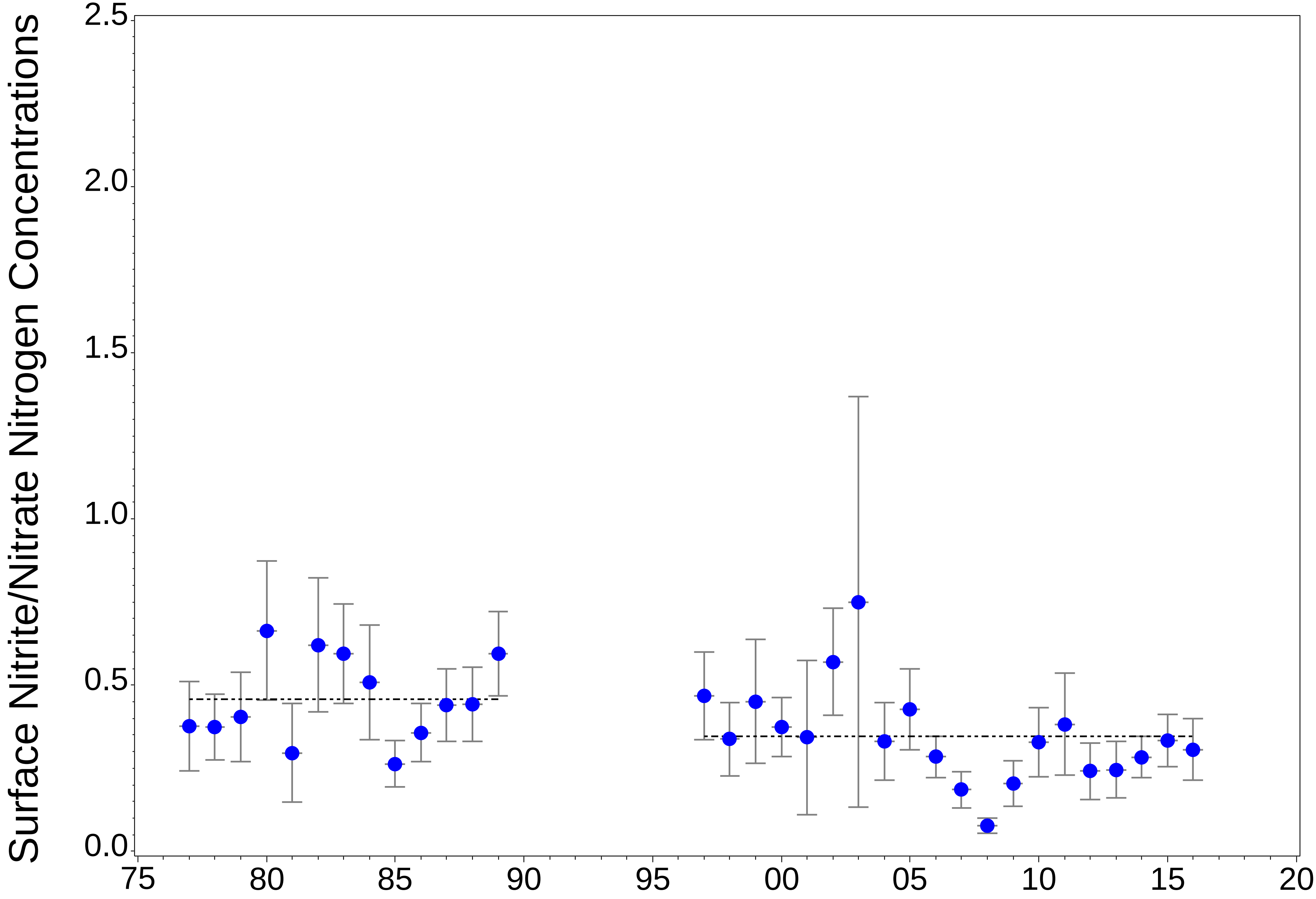


Figure C.101. Long-term Surface Nitrite/Nitrate Nitrogen Concentrations at river kilometer 23.6

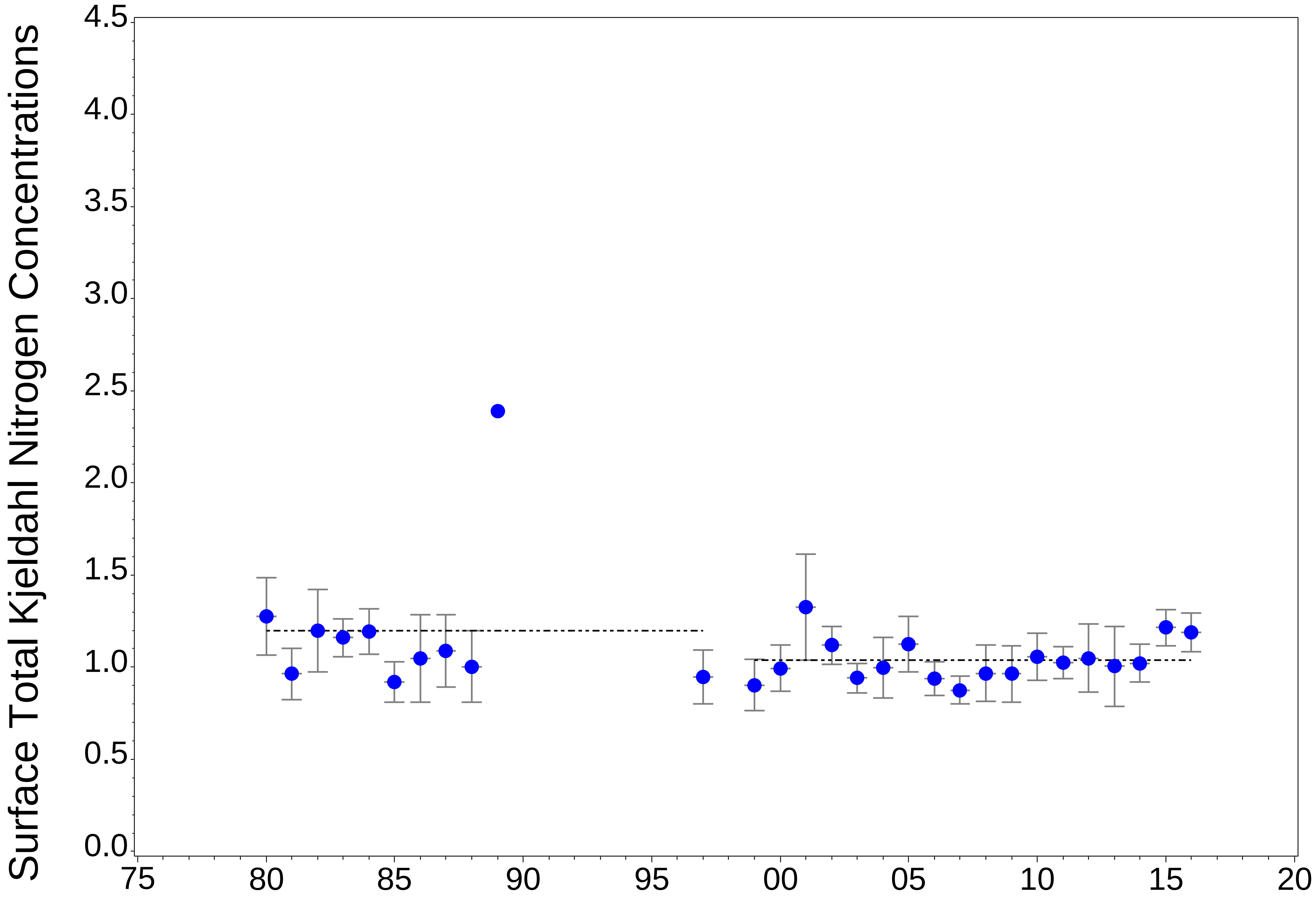


Figure C.102. Long-term Surface Total Kjeldahl Nitrogen Concentrations at river kilometer 23.6

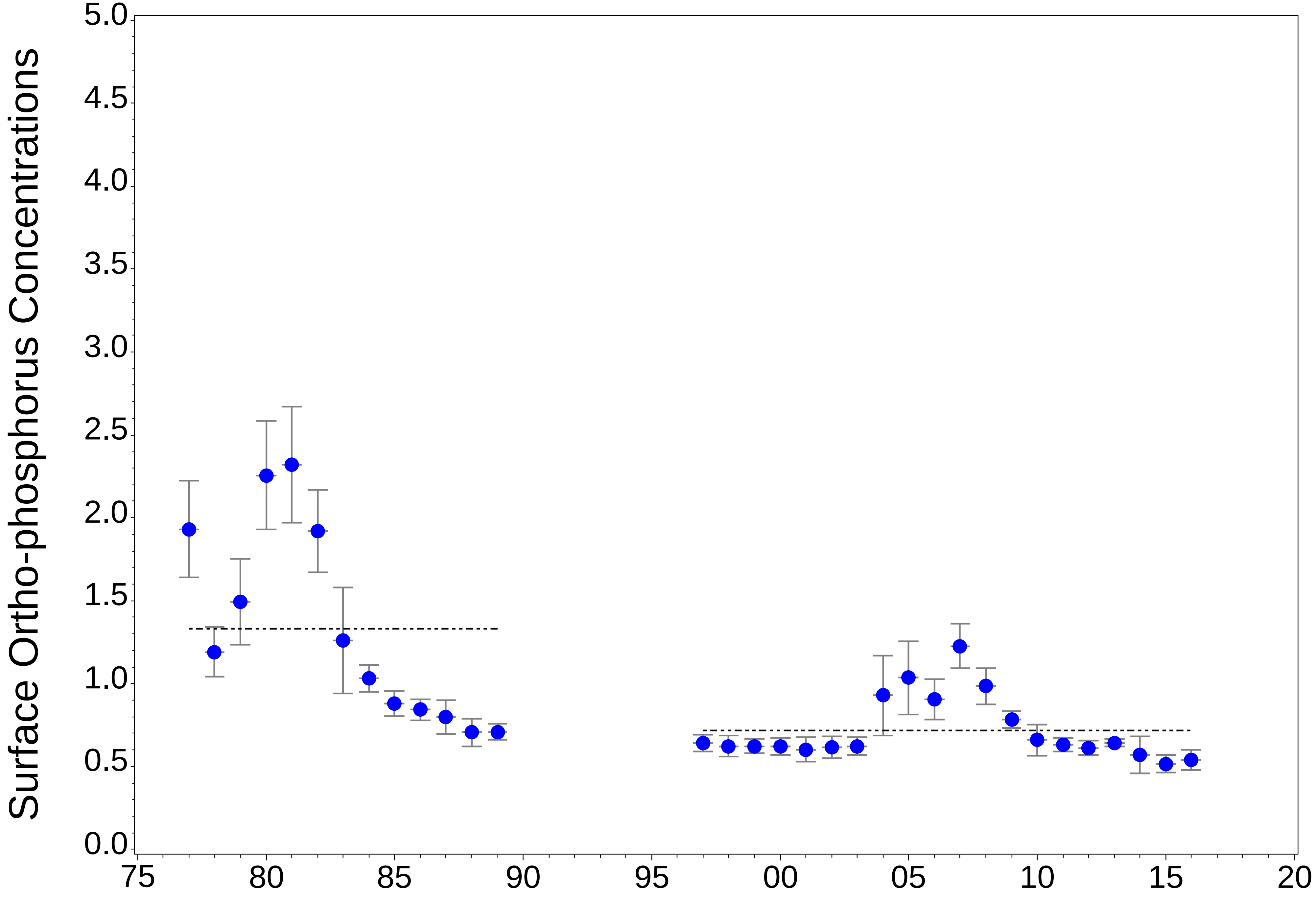


Figure C.103. Long-term Surface Ortho-phosphorus Concentrations at river kilometer 23.6

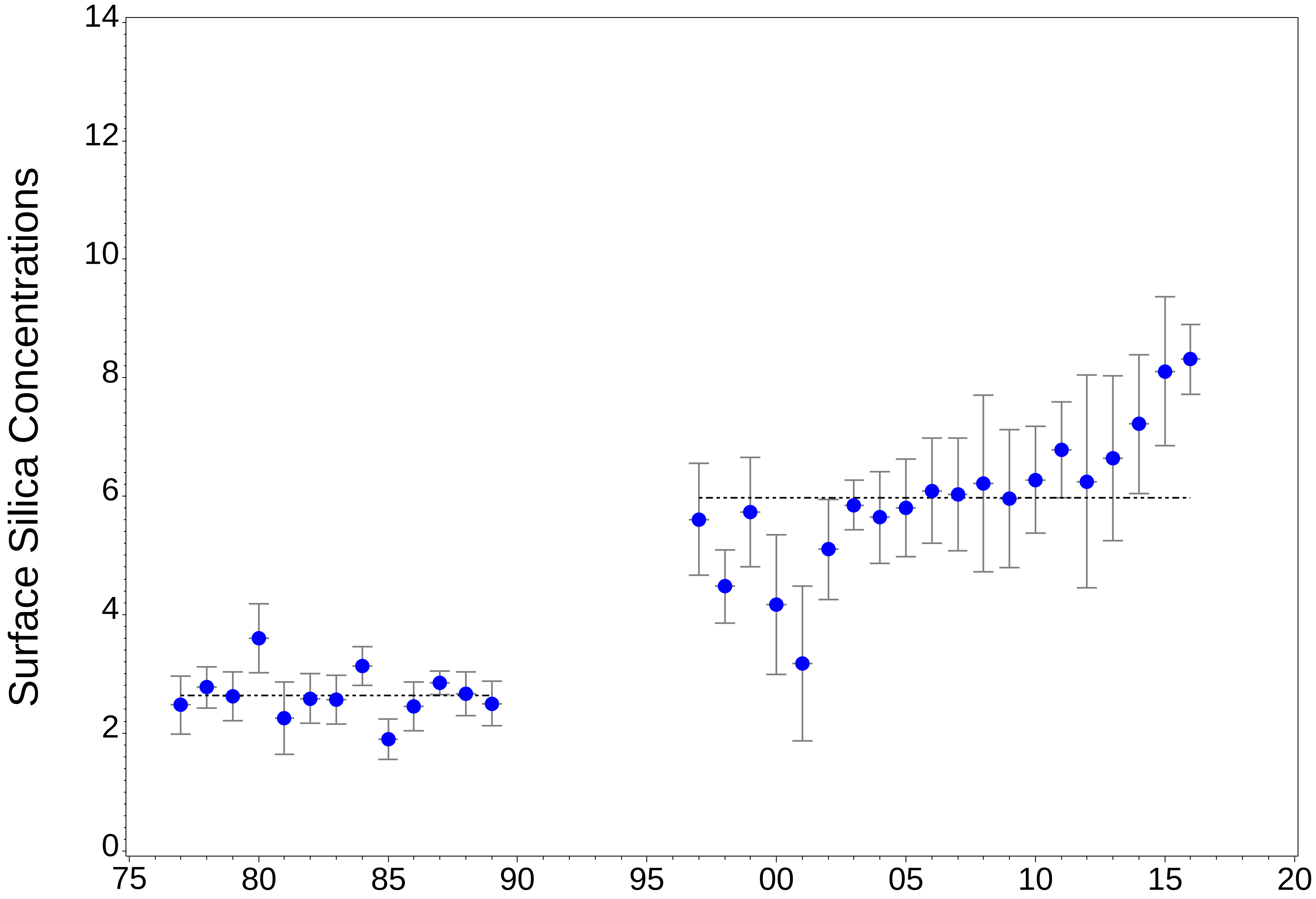


Figure C.104. Long-term Surface Silica Concentrations at river kilometer 23.6

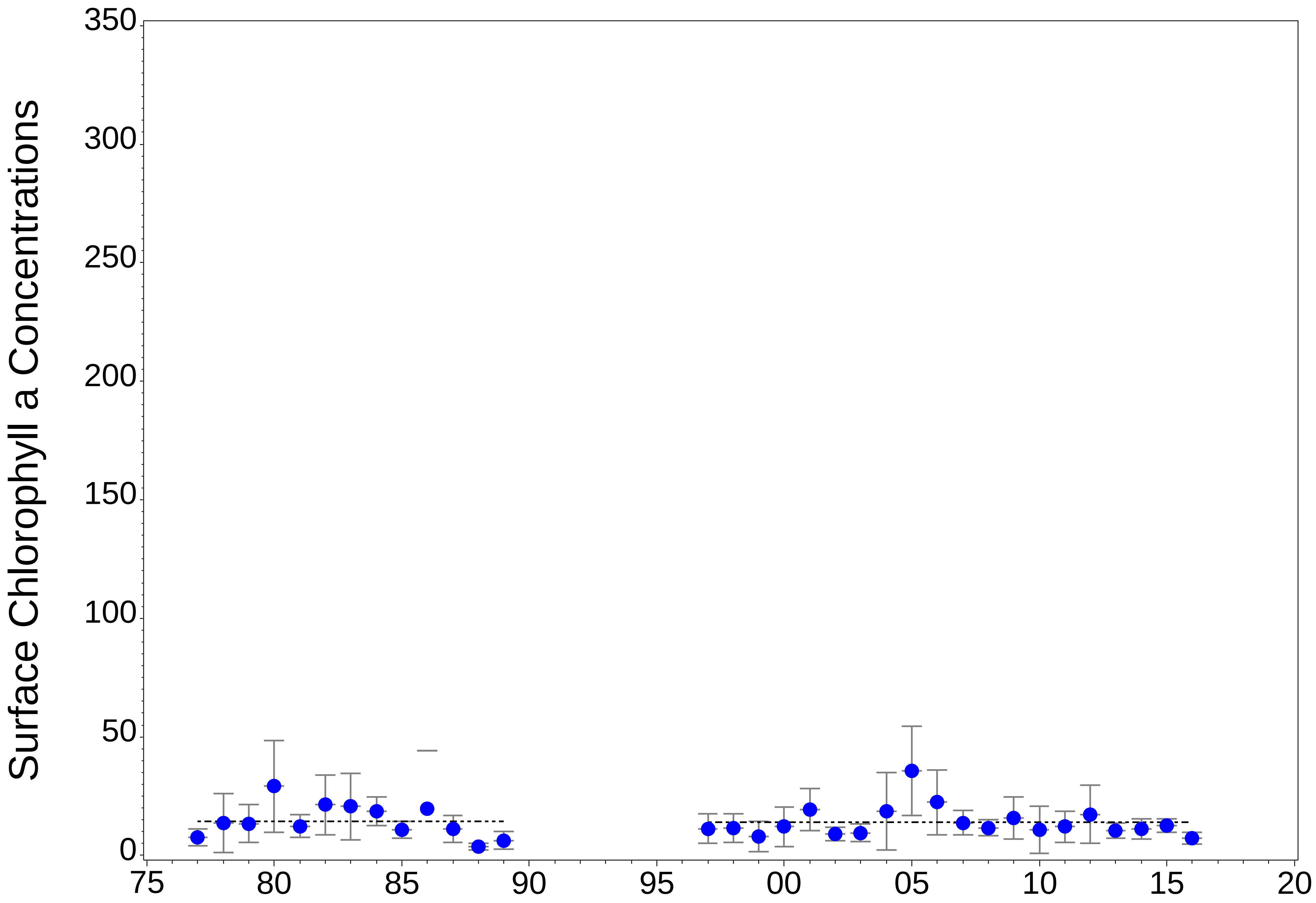


Figure C.105. Long-term Surface Chlorophyll a Concentrations at river kilometer 23.6

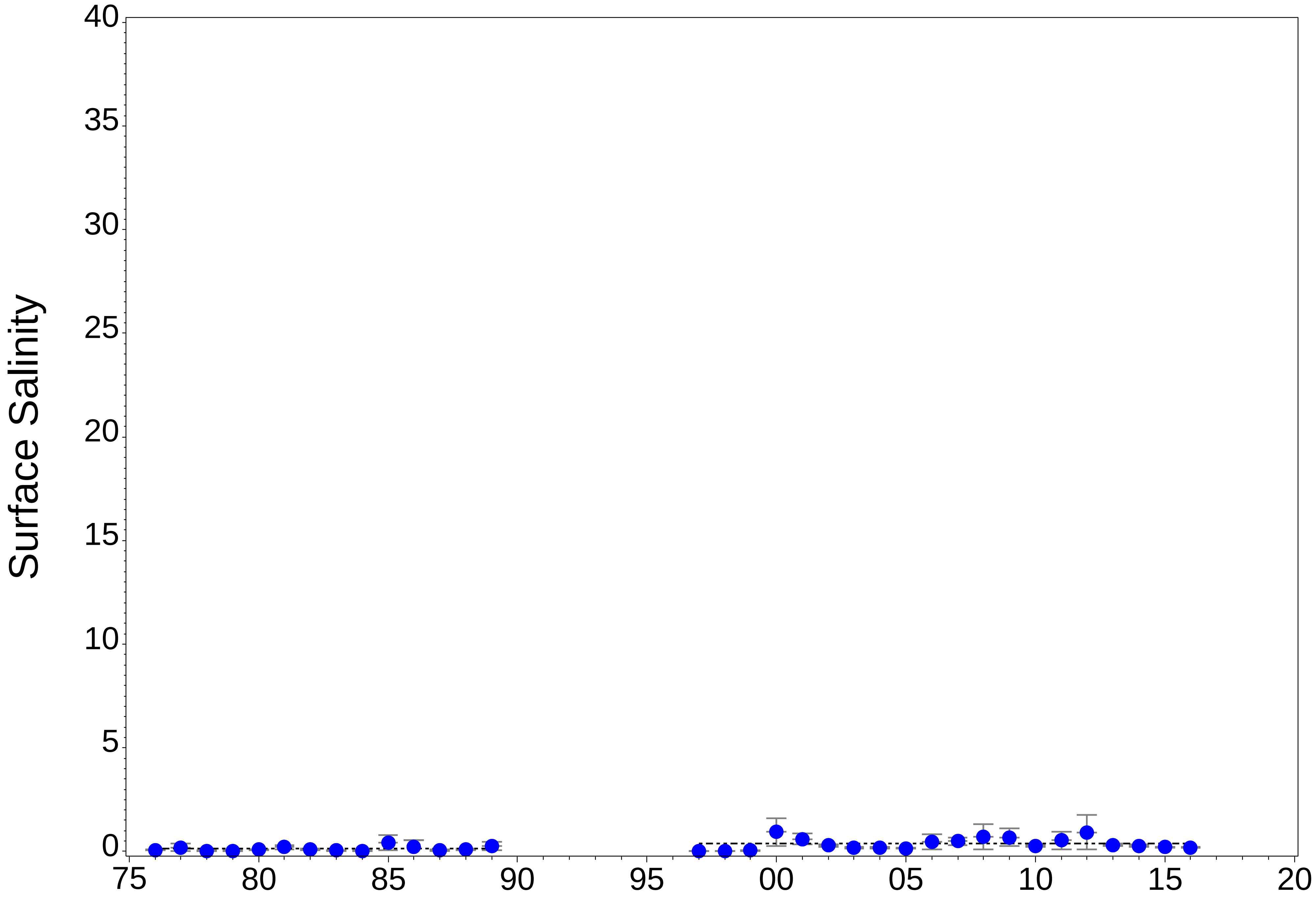


Figure C.106. Long-term Surface Salinity at river kilometer 30.7

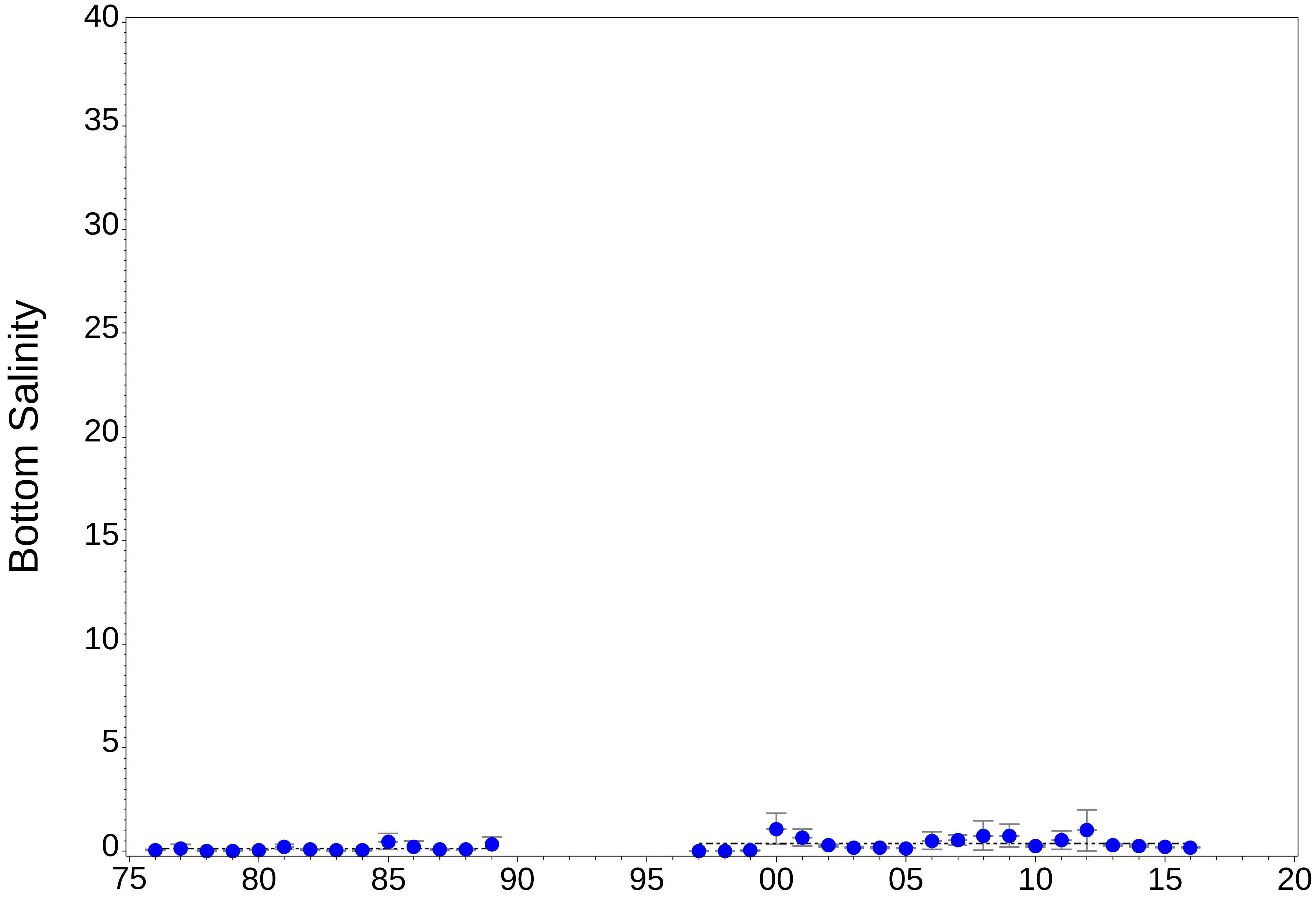


Figure C.107. Long-term Bottom Salinity at river kilometer 30.7

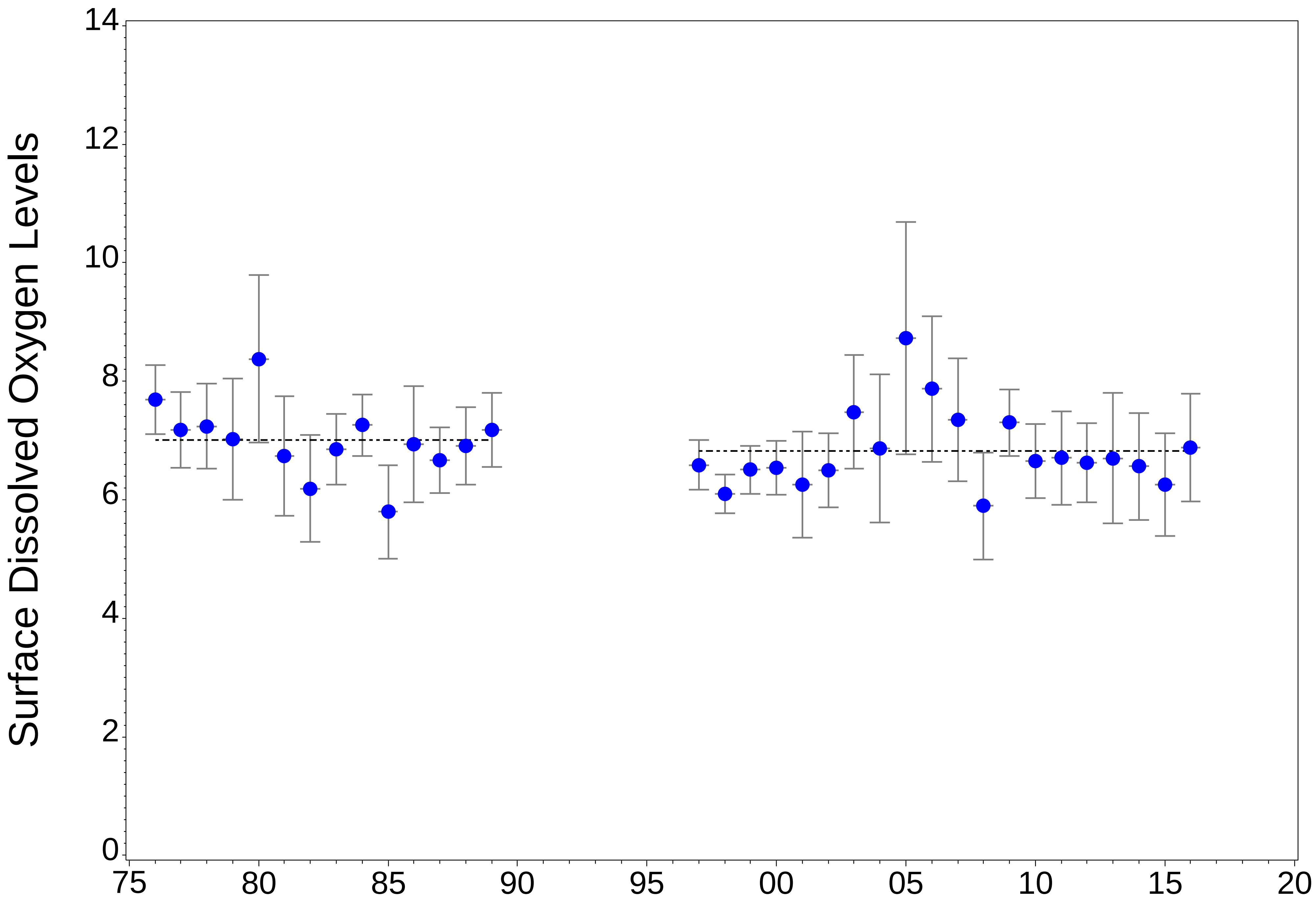


Figure C.108. Long-term Surface Dissolved Oxygen Levels at river kilometer 30.7

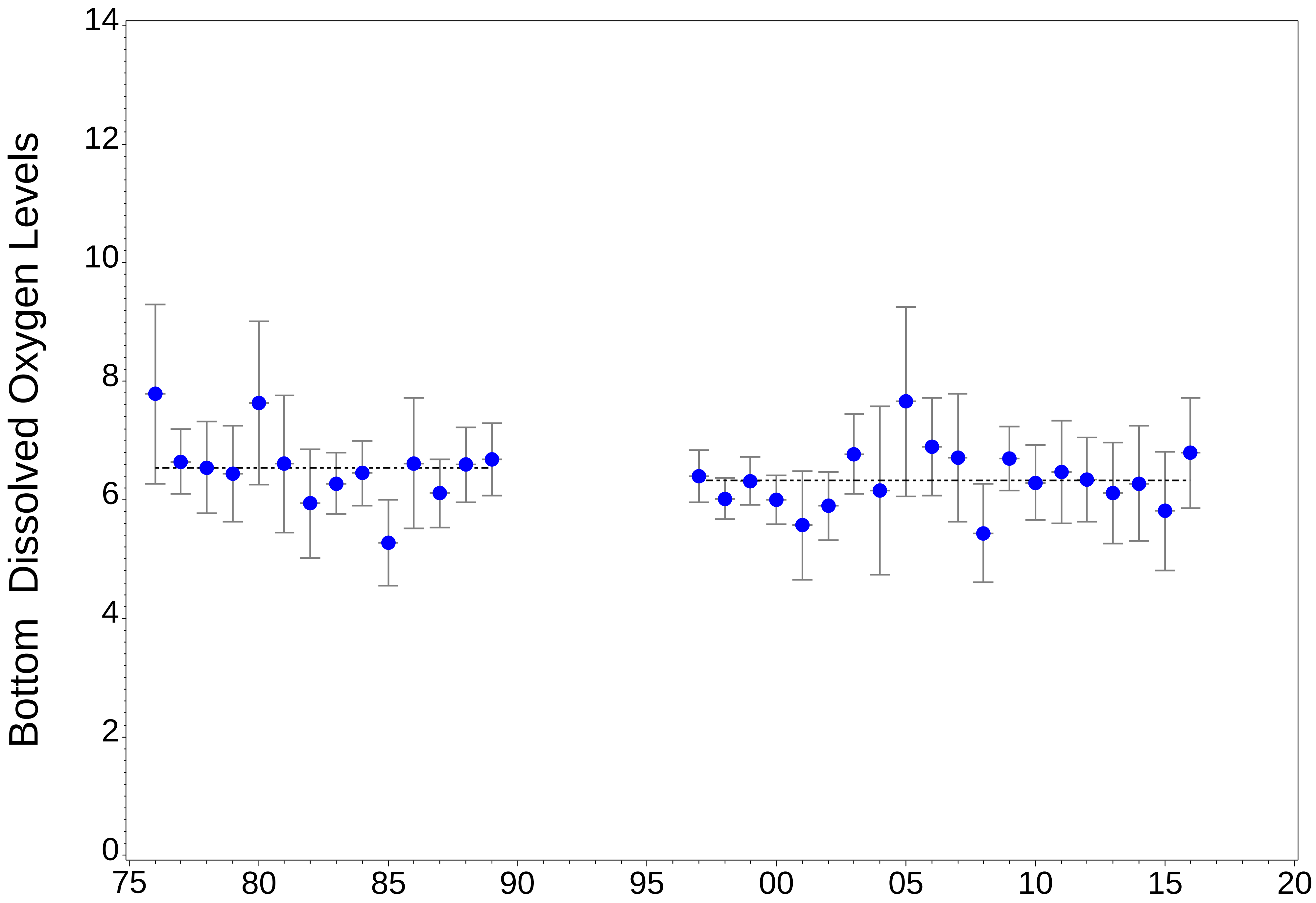


Figure C.109. Long-term Bottom Dissolved Oxygen Levels at river kilometer 30.7

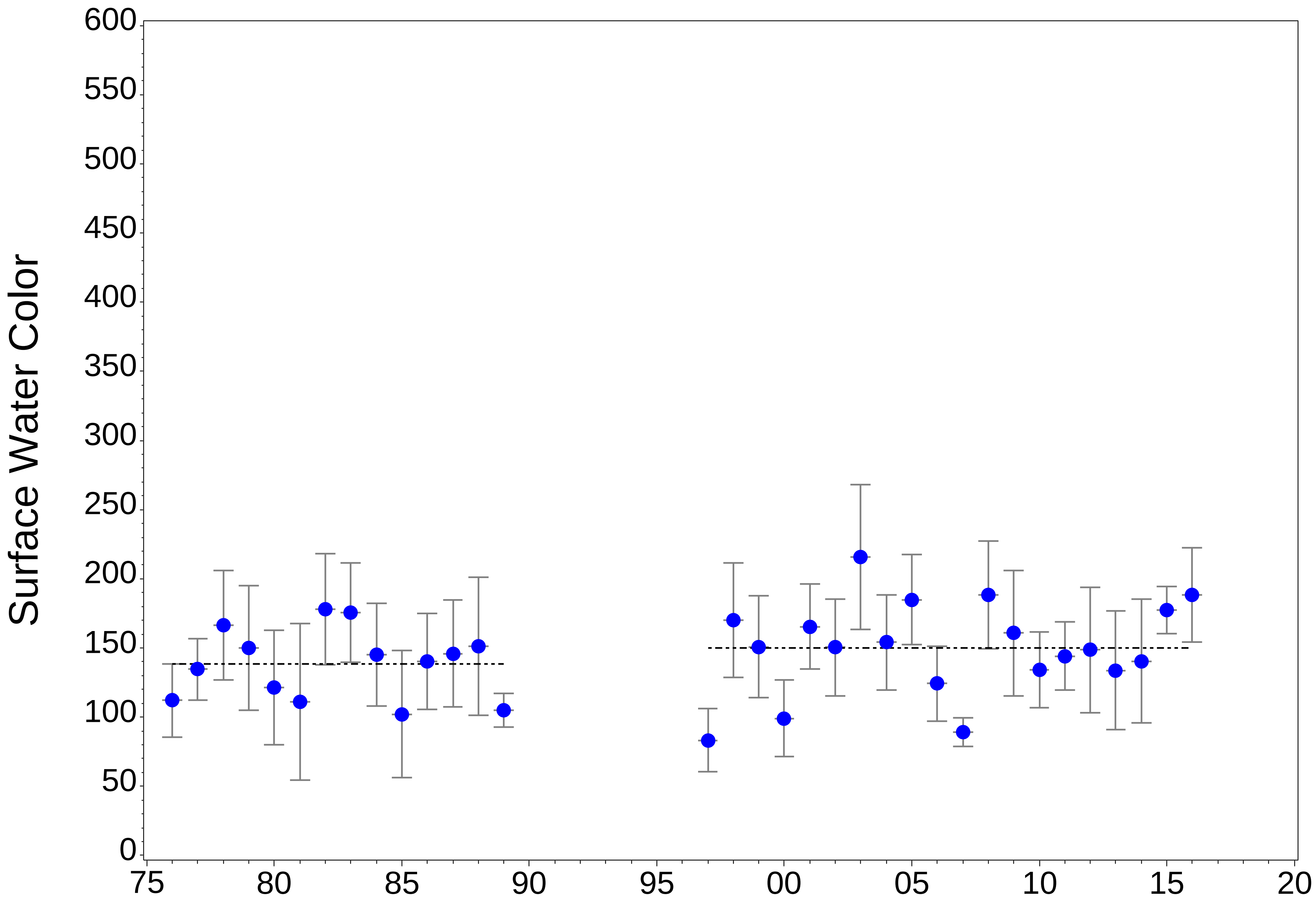


Figure C.110. Long-term Surface Water Color at river kilometer 30.7

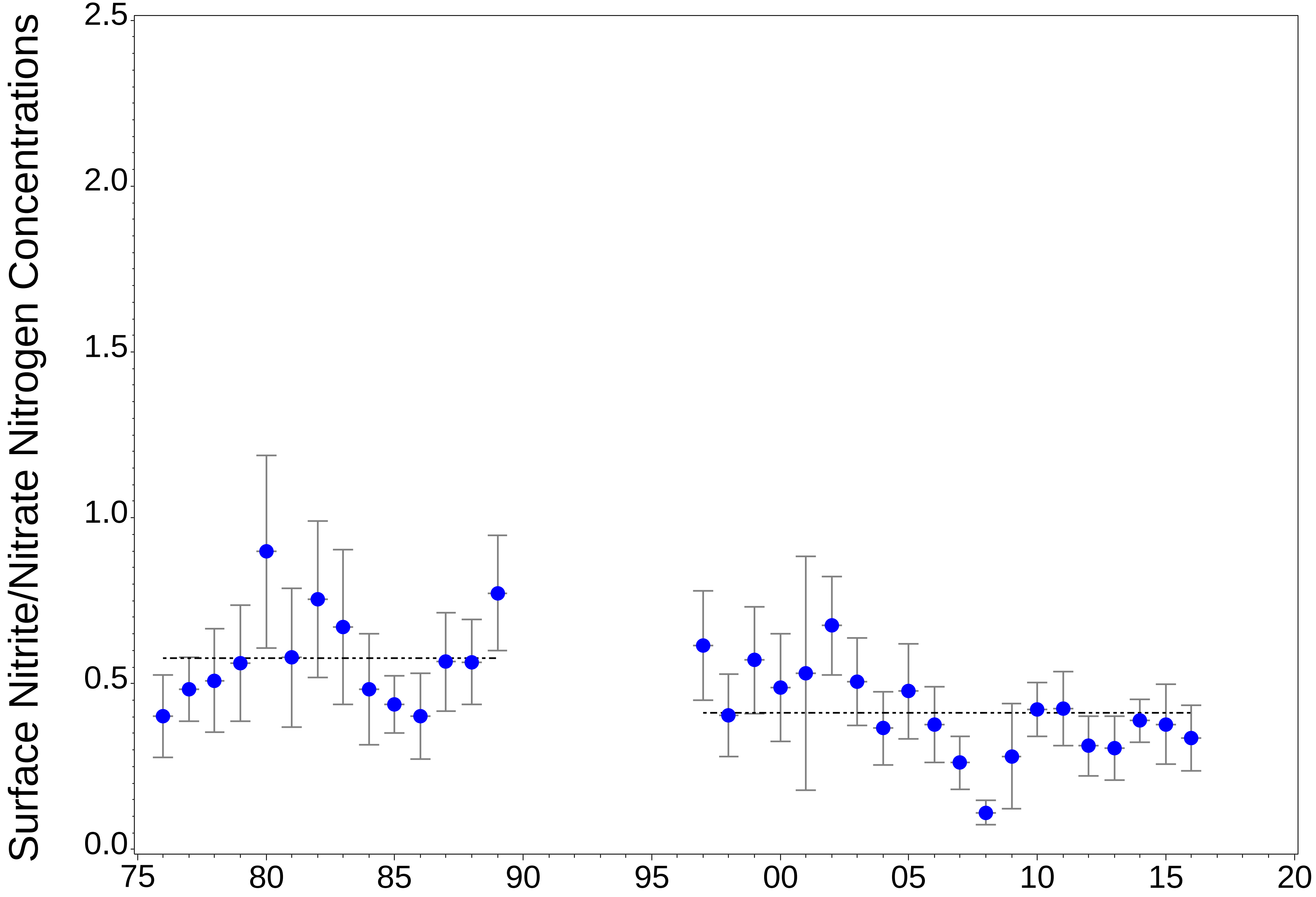


Figure C.111. Long-term Surface Nitrite/Nitrate Nitrogen Concentrations at river kilometer 30.7

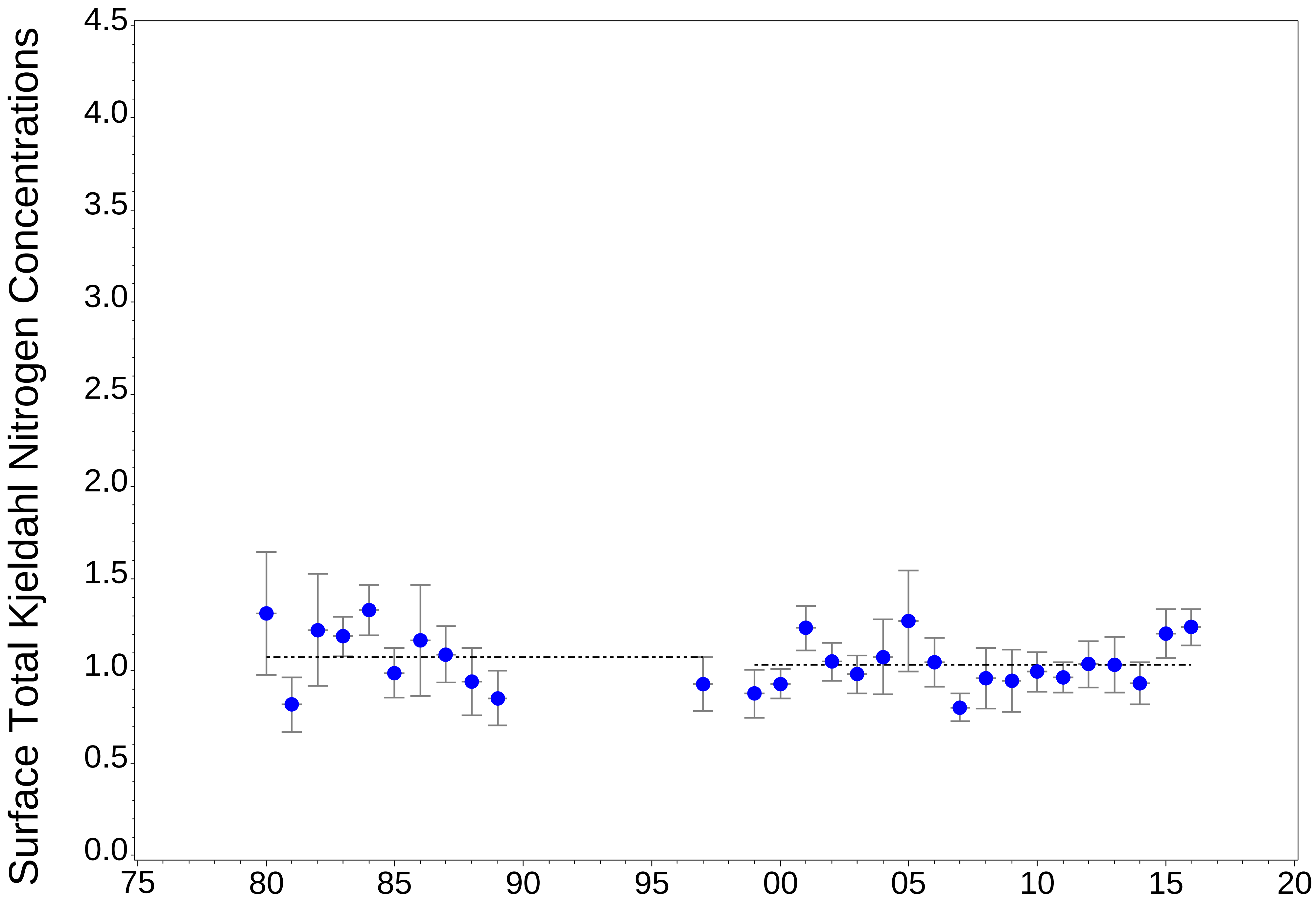


Figure C.112. Long-term Surface Total Kjeldahl Nitrogen Concentrations at river kilometer 30.7

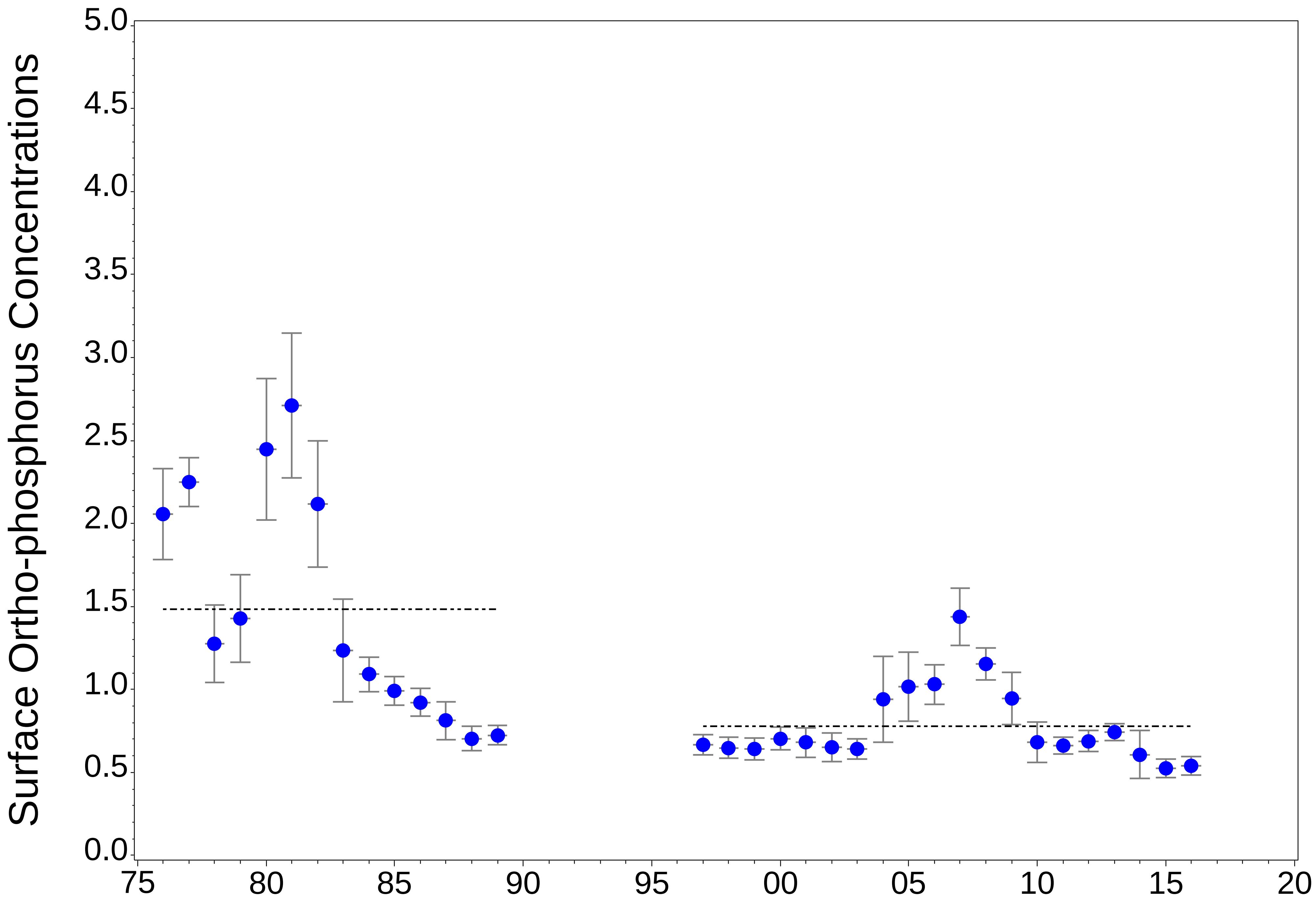


Figure C.113. Long-term Surface Ortho-phosphorus Concentrations at river kilometer 30.7

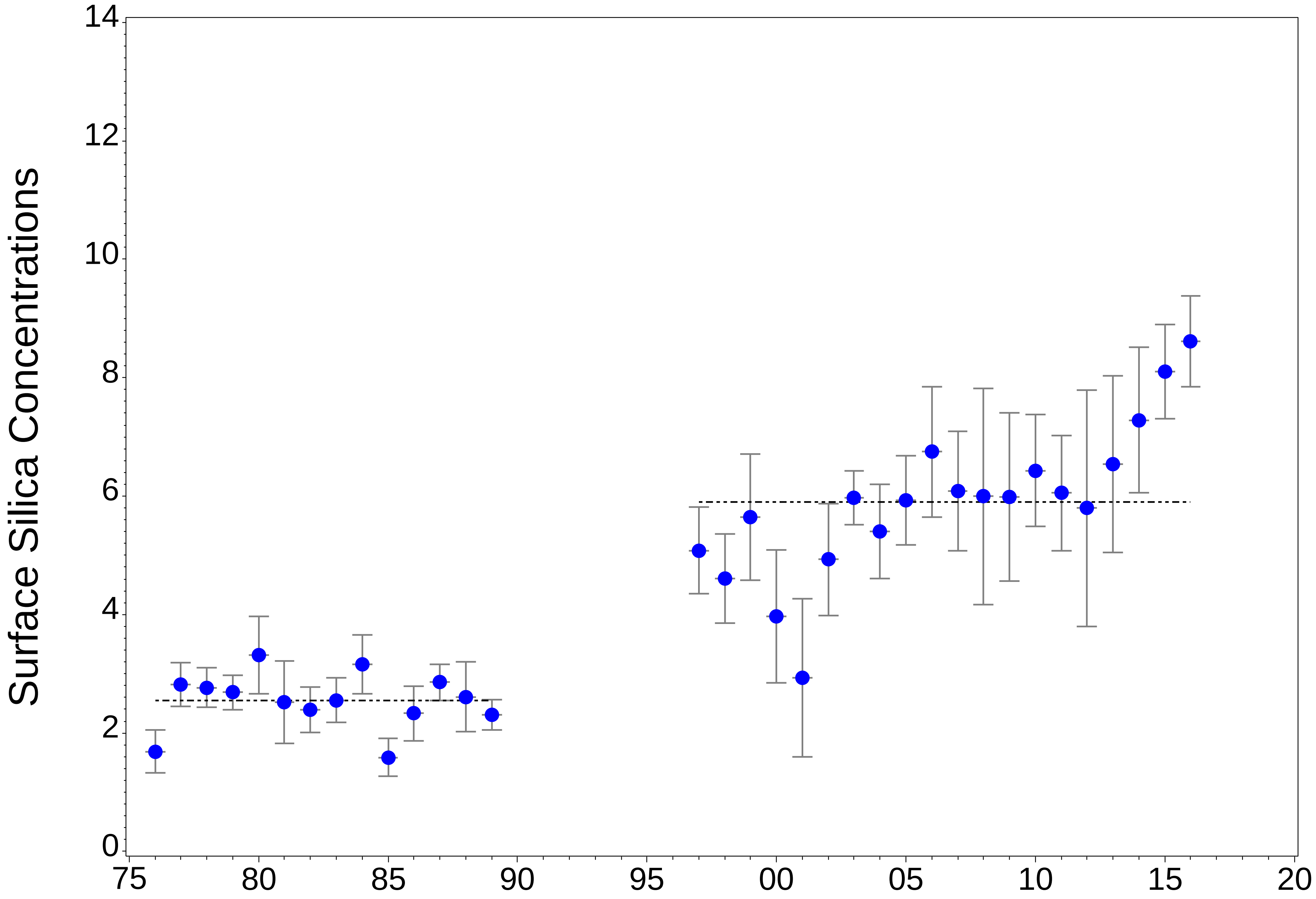


Figure C.114. Long-term Surface Silica Concentrations at river kilometer 30.7

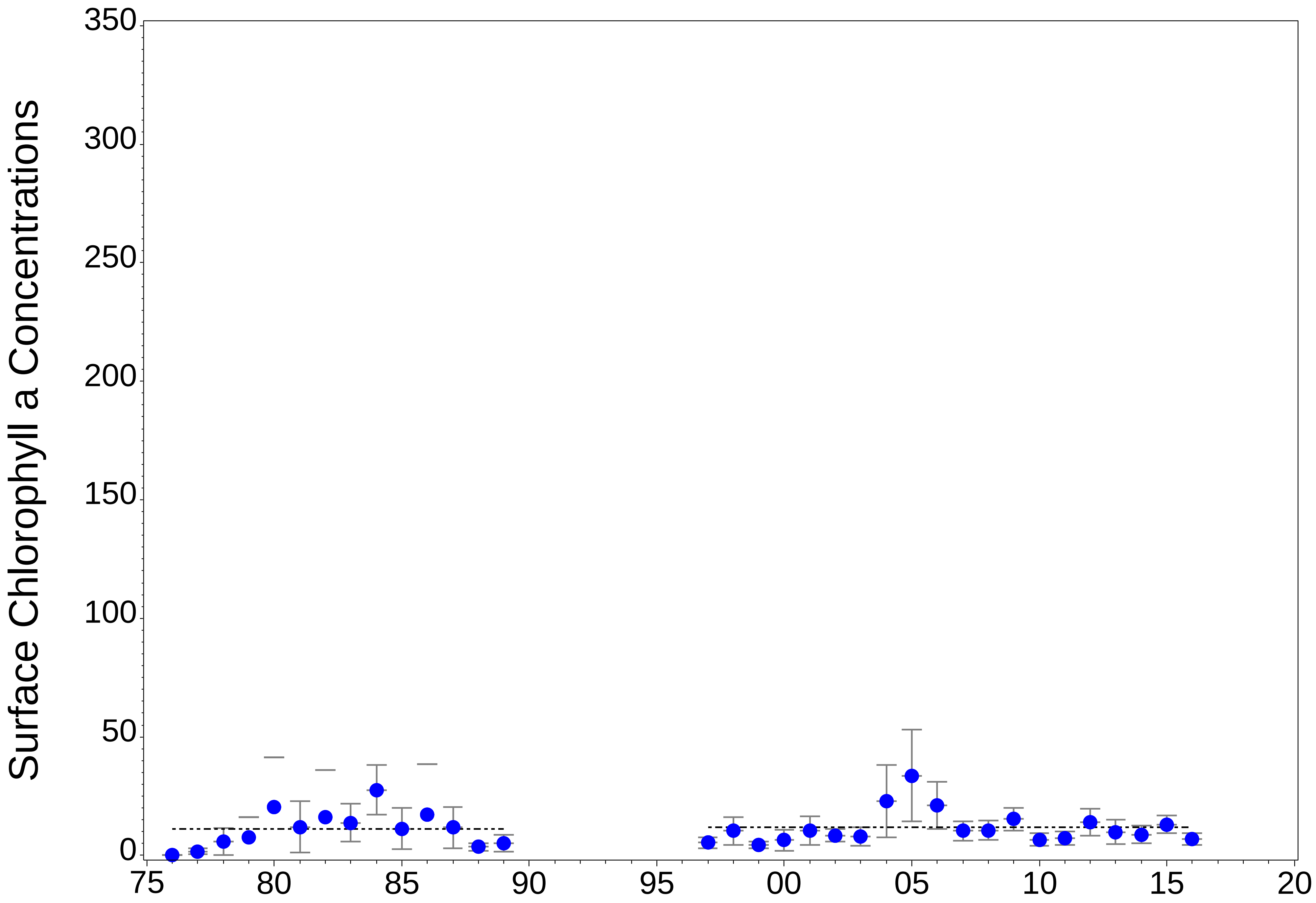


Figure C.115. Long-term Surface Chlorophyll a Concentrations at river kilometer 30.7

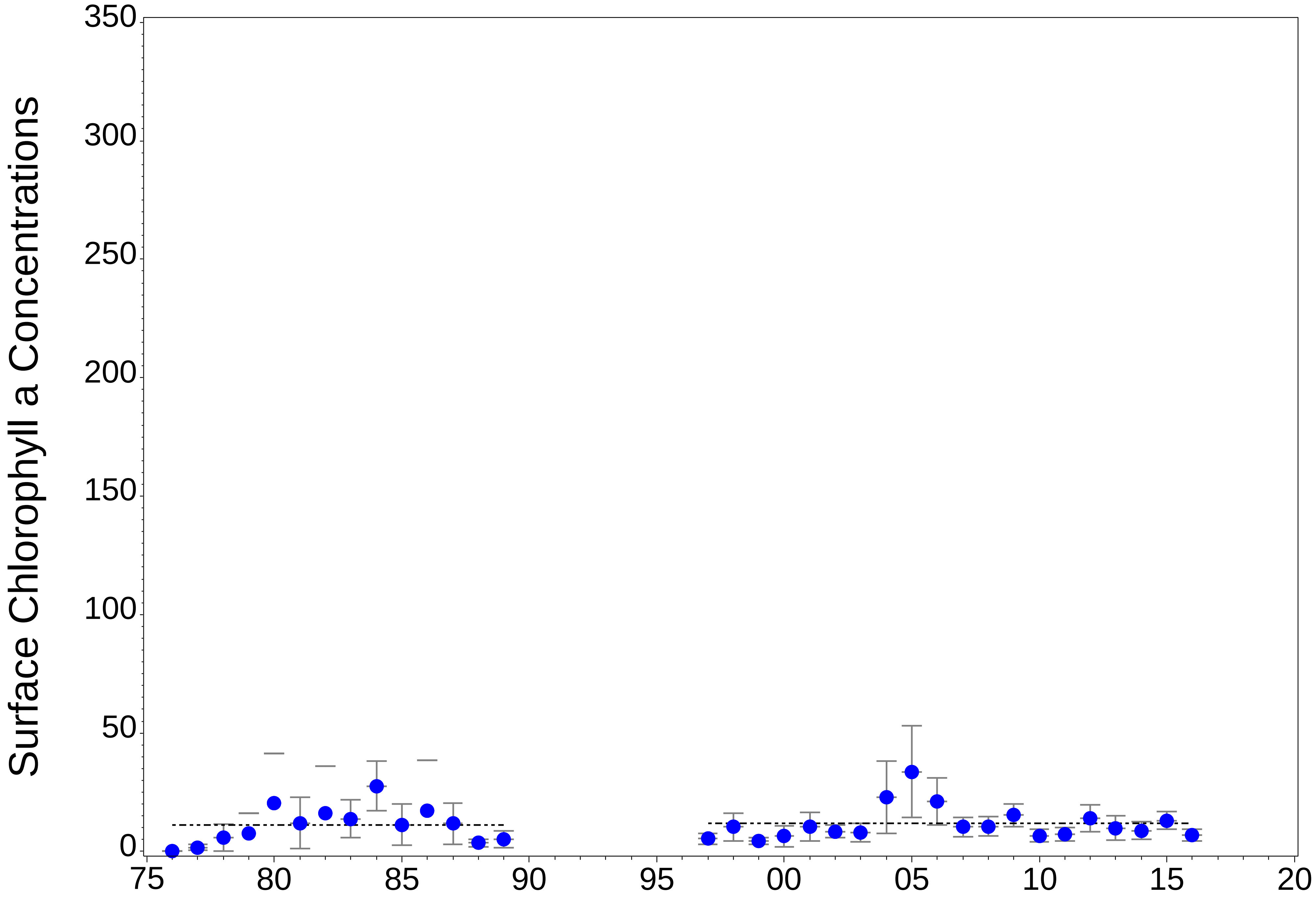


Figure C.115. Long-term Surface Chlorophyll a Concentrations at river kilometer 30.7

2016 HBMP
Comprehensive Summary Report
Tables

This section contains tables not included directly in the text for each section.

* Denotes chapters without additional tables

Table 1.7
Historic Time Lines for both Ongoing and Previous Major HBMP Study Elements

	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
Indicator Benthic Species	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦											
Sea Star	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦											
Upper Harbor Juvenile Fishes	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦								
Vegetation - Aerial Photography	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	
Vegetation - First and Last		🟦				🟦	🟦	🟦	🟦				🟦		🟦	🟦		🟦		🟦
Vegetation - Transect Sites		🟦				🟦	🟦	🟦	🟦				🟦		🟦	🟦		🟦		🟦
Isohaline Phytoplankton Primary Production								🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Isohaline Phytoplankton Species Identification														🟦	🟦	🟦	🟦	🟦	🟦	🟦
Zooplankton (Isohalines)														🟦	🟦	🟦	🟦	🟦	🟦	🟦
Water Quality **↓ (0, 6, 12, 20 ppt Isohalines)**								🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Water Quality Lower /Middle Harbor																				
Stations 1, 3, 5, 6	🟦	🟦	🟦	🟦	🟦	🟦														
↓↓ Stations 2, 4, 7	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦											
Water Quality Upper Harbor																				
↓↓ Station 9	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦					
Water Quality Lower River																				
↓↓ Stations 10, 12, 14, 18	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦					
↓↓ Stations 16, 20	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦					
Stations 11, 13, 15, 17, 19	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦											
Stations 21, 22, 23, 24, 25							🟦	🟦	🟦											
Continuous Recorders																				
Benthic Invertebrates & Mollusc																				
Larval Fish/Plankton																				

Note: The station locations used in this table refer to the historically used numerical identifications, since not all of the sites in the lower/upper harbor were sampled along the current river kilometer centerline. Table 1.4 provides conversions to the currently used centerline identification system for stations 9 through 25.

↓ Includes *in situ* water column profile and surface water chemistry

↓↓ Includes both *in situ* water column profile, and top and bottom water chemistry

Table 1.7
Historic Time Lines for both Ongoing and Previous Major HBMP Study Elements

	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16
Indicator Benthic Species																					
Sea Star																					
Upper Harbor Juvenile Fishes																					
Vegetation - Aerial Photography	■		■		■		■		■			■				■					
Vegetation - First and Last		■	■		■		■		■												
Vegetation - Transect Sites		■	■		■		■		■												
Isohaline Phytoplankton Primary Production	■	■	■	■																	
Isohaline Phytoplankton Species Identification	■	■	■	■	■	■	■	■	■												
Zooplankton (Isohalines)	■																				
Water Quality (0, 6, 12, 20 ppt Isohalines)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Water Quality Lower /Middle Harbor																					
Stations 1, 3, 5, 6																					
↓↓ **Stations 2, 4, 7**																					
Water Quality Upper Harbor																					
↓↓ **Station 9**	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Water Quality Lower River																					
↓↓ **Stations 10, 12, 14, 18**	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
↓↓ **Stations 16, 20**																					
Stations 11, 13, 15, 17, 19	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Stations 21, 22, 23, 24, 25	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Continuous Recorders	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Benthic Invertebrates & Mollusc			■	■																	
Larval Fish/Plankton		■	■																		

Note: The station locations used in this table refer to the historically used numerical identifications, since not all of the sites in the lower/upper harbor were sampled along the current river kilometer centerline. Table 1.4 provides conversions to the currently used centerline identification system for stations 9 through 25.

↓ **Includes *in situ* water column profile and surface water chemistry**

↓↓ **Includes both *in situ* water column profile, and top and bottom water chemistry**

Table 1.8

River Kilometer Designations of Present and Past HBMP Fixed Locations

2011 Ongoing *In Situ* Water Column Profile Sampling Locations				
Previous USGS River Mile	**USGS Location Number**	**Previous EQL Station Number**	**Additional Surface/Bottom Sampling**	**New River Kilometer designation based on Morphometric Study**
CH6	265355082075500	9	Water Quality	**-2.4**
RM3.95	265640082033500	10	Water Quality	**6.6**
RM4.88	265724082024400	21		**8.4**
RM6.25	265727082012800	11		**10.5**
RM8.61	265711081595500	Shell Creek 9 (92)		**12.7**
RM8.6B	265819082003200	22		**12.8**
RM10.2	2297460	12	Water Quality	**15.5**
RM11.2	270022081591000	23		**17.5**
RM 12.55	270124081592500	13		**20.1**
RM13.95	270235081592400	24		**21.9**
RM14.82	270318081593100	14	Water Quality	**23.6**
RM15.45	270337081595800	25		**24.7**
RM16.29	270418082001600	15		**25.9**
N/A	2297350	N/A	Tide Gage/ Conductivity	**26.7**
RM18.25	270451081595100	17		**29.5**
RM18.95	2297330	18	Water Quality	**30.7**
RM19.5	270537081585800	19		**32.3**
Previous EQL (non HBMP) Water Column and Chemistry Sampling Sites				
N/A	N/A	16		**27.1**
N/A	N/A	20		**34.1**
2011 USGS Continuous 15-minute Recorders (conductivity/temperature/stage) (simultaneous subsurface and near bottom)				
Name	**Gage ID**	**Starting Date**	**Ending Date**	**River Kilometer**
Harbour Heights	02297460	Sept. 1996	Ongoing	**RK 15.5**
Peace River Heights	02297350	Nov. 1997	Ongoing	**RK 26.7**
Peace River at Platt (Facility)	02297345	Dec. 2009	Ongoing	**RK 29.8**

Table 1.8

River Kilometer Designations of Present and Past HBMP Fixed Locations

2011 Authority Continuous 15-minute Recorders (conductivity/temperature) (subsurface)				
Gage ID	**Location**	**Starting Date**	**Ending Date**	**River Kilometer**
RK09	Lower Peace River	Jun. 2011	Ongoing	**RK 09.2**
RK12 (bottom)	Lower Peace River	May 2008	Jun. 2011	**RK 12.7**
RK12 (surface)	Lower Peace River	Jun. 2011	Ongoing	**RK 12.7**
RK18	Lower Peace River	Jun. 2011	Ongoing	**RK 18.5**
RK_HC	Hunter Creek	Jun. 2011	Ongoing	**RK 18.7**
RK20	Lower Peace River	Jun. 2011	Ongoing	**RK 20.8**
RK21	Lower Peace River	Dec. 2005	Ongoing	**RK 21.9**
RK23	Lower Peace River	Dec. 2005	May 2008	**RK 23.4**
RK24	Lower Peace River	Dec. 2005	Ongoing	**RK 24.5**
RK30	Lower Peace River	May 2008	Jun. 2011	**RK 30.6**
RK31	Lower Peace River	May 2008	Ongoing	**RK 31.7**

Previous Fixed Vegetation Transect Locations	
EQL Vegetation Site ID	**River Kilometer**
I	**15.6**
II	**22.3**
III	**20.4**

Table 1.10
HBMP Chemical Water Quality Parameters

Ongoing Long-term Analytes	Analytes Deleted Starting March 2003
Salinity	Alkalinity
Chloride	Turbidity
Color	Total Phosphorus
Silica	Inorganic Carbon
Ortho-Phosphorus	Total Organic Carbon
Nitrate + Nitrite Nitrogen	Dissolved Organic Carbon
Ammonia/Ammonium Nitrogen	
Total Kjeldahl Nitrogen	
Total Nitrogen	
Suspended Solids	
Volatile Solids	
Chlorophyll *a*	

Table 3.4
Statistical Summary of Results of Seasonal Kendall Tau Trend Analyses of Total Monthly Rainfall (Recent 1932-2016 Historic Period)

SWFWMD ID	NOAA Gage Identification	Time Interval	Number of Years	Tau Statistic	P-Value Without Serial Correlation	P-Value With Serial Correlation	Slope Statistic
Peace River Watershed							
R142	Peace River at Bartow (ATM0274)	1932-2016	85	-0.05	0.022	**0.033**	-0.006
R148	Arcadia (ATM007)	1932-2016	85	-0.01	0.624	0.672	-0.001
R255	Punta Gorda (ATM0117)	1932-2016	85	0.00	0.840	0.857	0.001
Reference Watershed							
R336	Myakka River State Park (ATM0101)	1944-2016	73	0.05	0.050	**0.096**	0.006

(1976-2016 Period of HBMP Monitoring)

SWFWMD ID	NOAA Gage Identification	Time Interval	Number of Years	Tau Statistic	P-Value Without Serial Correlation	P-Value With Serial Correlation	Slope Statistic
Peace River Watershed							
R142	Peace River at Bartow (ATM0274)	1976-2016	41	-0.003	0.298	0.324	-0.007
R148	Arcadia (ATM007)	1976-2016	41	0.02	0.439	0.478	0.006
R255	Punta Gorda (ATM0117)	1976-2016	41	0.01	0.850	0.863	0.001
Reference Watershed							
R336	Myakka River State Park (ATM0101)	1976-2016	41	0.01	0.846	0.849	0.001

* Red values denote significant trend at p=0.05 level, while blue indicates trends significant at p=0.10

** Positive Tau statistic and slope values indicate increasing trend over time, negative values correspond to declining changes in flow over time

P-Values corrected for serial autocorrelations are applicable for rainfall data where values in preceding/following months are often similar seasonally.

Table 3.5
Statistical Summary of Results of Seasonal Kendall Tau Trend Analyses of Total Annual Rainfall
(Recent 1932-2016 Historic Period)

SWFWMD ID	NOAA Gage Identification	Time Interval	Number of Years	Tau Statistic	P-Value Without Serial Correlation	P-Value With Serial Correlation	Slope Statistic
Peace River Watershed							
R142	Peace River at Bartow (ATM0274)	1932-2016	85	-0.16	**0.035**	NA	-0.085
R148	Arcadia (ATM007)	1932-2016	85	0.01	0.982	NA	0.002
R255	Punta Gorda (ATM0117)	1932-2016	85	0.03	0.676	NA	0.017
Reference Watershed							
R336	Myakka River State Park (ATM0101)	1944-2016	73	0.16	**0.047**	NA	0.121

(1976-2016 Period of HBMP Monitoring)

SWFWMD ID	NOAA Gage Identification	Time Interval	Number of Years	Tau Statistic	P-Value Without Serial Correlation	P-Value With Serial Correlation	Slope Statistic
Peace River Watershed							
R142	Peace River at Bartow (ATM0274)	1976-2016	40	-0.03	0.779	NA	-0.041
R148	Arcadia (ATM007)	1976-2016	40	0.16	0.132	NA	0.240
R255	Punta Gorda (ATM0117)	1976-2016	40	0.17	0.113	NA	0.147
Reference Watershed							
R336	Myakka River State Park (ATM0101)	1976-2016	40	0.05	0.645	NA	0.073

* Red values denote significant trend at p=0.05 level, while blue indicates trends significant at p=0.10

** Positive Tau statistic and slope values indicate increasing trend over time, negative values correspond to declining changes in flow over time

NA – Correlations are not applicable when analyzing data based on annual values

Table 3.7
Summary of Time Series Graphics for Flows over the Period of Record for each Gage

USGS ID	Gage Identification	Time Period of Data		P0 (Minimum)	P10	P25	P50 (Median)
Peace River Watershed							
2294650	Peace River at Bartow	10/01/39	12/31/16	**Figure 3.58**	**Figure 3.71**	**Figure 3.84**	**Figure 3.97**
2294898	Peace River at Fort Meade	06/01/74	12/31/16	**Figure 3.59**	**Figure 3.72**	**Figure 3.85**	**Figure 3.98**
2295420	Payne Creek near Bowling Green	10/01/63	12/31/16	**Figure 3.60**	**Figure 3.73**	**Figure 3.86**	**Figure 3.99**
2295637	Peace River at Zolfo Springs	09/01/33	12/31/16	**Figure 3.61**	**Figure 3.74**	**Figure 3.87**	**Figure 3.100**
2296500	Charlie Creek near Gardner	05/01/50	12/31/16	**Figure 3.62**	**Figure 3.75**	**Figure 3.88**	**Figure 3.101**
2296750	Peace River at Arcadia	04/01/31	12/31/16	**Figure 3.63**	**Figure 3.76**	**Figure 3.89**	**Figure 3.102**
2297100	Joshua Creek at Nocatee	05/01/50	12/31/16	**Figure 3.64**	**Figure 3.77**	**Figure 3.90**	**Figure 3.103**
2297310	Horse Creek near Arcadia	05/01/50	12/31/16	**Figure 3.65**	**Figure 3.78**	**Figure 3.91**	**Figure 3.104**
	Total Gaged Flow at Facility	05/01/50	12/31/16	**Figure 3.66**	**Figure 3.79**	**Figure 3.92**	**Figure 3.105**
2298123	Prairie Creek near Fort Ogden	10/01/63	12/31/16	**Figure 3.67**	**Figure 3.80**	**Figure 3.93**	**Figure 3.106**
2298202	Shell Creek near Punta Gorda	01/01/65	12/31/16	**Figure 3.68**	**Figure 3.81**	**Figure 3.94**	**Figure 3.107**
	Total Gaged Flow to Harbor	01/01/65	12/31/16	**Figure 3.69**	**Figure 3.82**	**Figure 3.95**	**Figure 3.108**
Reference Watershed							
2298830	Myakka River near Sarasota	9/1/1936	12/31/16	**Figure 3.70**	**Figure 3.83**	**Figure 3.96**	**Figure 3.109**

Table 3.7 (continued)

Summary of Time Series Graphics of Flows over the Period of Record for each Gage

USGS ID	Gage Identification	Time Period of Data		P75	P90	P100 (Maximum)	Mean
Peace River Watershed							
2294650	Peace River at Bartow	10/01/39	12/31/16	**Figure 3.110**	**Figure 3.123**	**Figure 3.136**	**Figure 3.149**
2294898	Peace River at Fort Meade	06/01/74	12/31/16	**Figure 3.111**	**Figure 3.124**	**Figure 3.137**	**Figure 3.150**
2295420	Payne Creek near Bowling Green	10/01/63	12/31/16	**Figure 3.112**	**Figure 3.125**	**Figure 3.138**	**Figure 3.151**
2295637	Peace River at Zolfo Springs	09/01/33	12/31/16	**Figure 3.113**	**Figure 3.126**	**Figure 3.139**	**Figure 3.152**
2296500	Charlie Creek near Gardner	05/01/50	12/31/16	**Figure 3.114**	**Figure 3.127**	**Figure 3.140**	**Figure 3.153**
2296750	Peace River at Arcadia	04/01/31	12/31/16	**Figure 3.115**	**Figure 3.128**	**Figure 3.141**	**Figure 3.154**
2297100	Joshua Creek at Nocatee	05/01/50	12/31/16	**Figure 3.116**	**Figure 3.129**	**Figure 3.142**	**Figure 3.155**
2297310	Horse Creek near Arcadia	05/01/50	12/31/16	**Figure 3.117**	**Figure 3.130**	**Figure 3.143**	**Figure 3.156**
	Total Gaged Flow at Facility	05/01/50	12/31/16	**Figure 3.118**	**Figure 3.131**	**Figure 3.144**	**Figure 3.157**
2298123	Prairie Creek near Fort Ogden	10/01/63	12/31/16	**Figure 3.119**	**Figure 3.132**	**Figure 3.145**	**Figure 3.158**
2298202	Shell Creek near Punta Gorda	01/01/65	12/31/16	**Figure 3.120**	**Figure 3.133**	**Figure 3.146**	**Figure 3.159**
	Total Gaged Flow to Harbor	01/01/65	12/31/16	**Figure 3.121**	**Figure 3.134**	**Figure 3.147**	**Figure 3.160**
Reference Watershed							
2298830	Myakka River near Sarasota	9/1/1936	12/31/16	**Figure 3.122**	**Figure 3.135**	**Figure 3.148**	**Figure 3.161**

Table 3.8
Summary of Time Series Graphics of Flows over the 1976-2016 Period for each Gage

USGS ID	Gage Identification	Time Period of Data		P0 (Minimum)	P10	P25	P50 (Median)
Peace River Watershed							
2294650	Peace River at Bartow	11/01/76	12/31/16	**Figure 3.162**	**Figure 3.175**	**Figure 3.188**	**Figure 3.201**
2294898	Peace River at Fort Meade	11/01/76	12/31/16	**Figure 3.163**	**Figure 3.176**	**Figure 3.189**	**Figure 3.202**
2295420	Payne Creek near Bowling Green	11/01/76	12/31/16	**Figure 3.164**	**Figure 3.177**	**Figure 3.190**	**Figure 3.203**
2295637	Peace River at Zolfo Springs	11/01/76	12/31/16	**Figure 3.165**	**Figure 3.178**	**Figure 3.191**	**Figure 3.204**
2296500	Charlie Creek near Gardner	11/01/76	12/31/16	**Figure 3.166**	**Figure 3.179**	**Figure 3.192**	**Figure 3.205**
2296750	Peace River at Arcadia	11/01/76	12/31/16	**Figure 3.167**	**Figure 3.180**	**Figure 3.193**	**Figure 3.206**
2297100	Joshua Creek at Nocatee	11/01/76	12/31/16	**Figure 3.168**	**Figure 3.181**	**Figure 3.194**	**Figure 3.207**
2297310	Horse Creek near Arcadia	11/01/76	12/31/16	**Figure 3.169**	**Figure 3.182**	**Figure 3.195**	**Figure 3.208**
	Total Gaged Flow at Facility	11/01/76	12/31/16	**Figure 3.170**	**Figure 3.183**	**Figure 3.196**	**Figure 3.209**
2298123	Prairie Creek near Fort Ogden	11/01/76	12/31/16	**Figure 3.171**	**Figure 3.184**	**Figure 3.197**	**Figure 3.210**
2298202	Shell Creek near Punta Gorda	11/01/76	12/31/16	**Figure 3.172**	**Figure 3.185**	**Figure 3.198**	**Figure 3.211**
	Total Gaged Flow to Harbor	11/01/76	12/31/16	**Figure 3.173**	**Figure 3.186**	**Figure 3.199**	**Figure 3.212**
Reference Watershed							
2298830	Myakka River near Sarasota	11/01/76	12/31/16	**Figure 3.174**	**Figure 3.187**	**Figure 3.200**	**Figure 3.213**

Table 3.8 (continued)

Summary of Time Series Graphics of Flows over the 1976-2016 for each Gage

USGS ID	Gage Identification	Time Period of Data		P75	P90	P100 (Maximum)	Mean
Peace River Watershed							
2294650	Peace River at Bartow	11/01/76	12/31/16	**Figure 3.214**	**Figure 3.227**	**Figure 3.240**	**Figure 3.253**
2294898	Peace River at Fort Meade	11/01/76	12/31/16	**Figure 3.215**	**Figure 3.228**	**Figure 3.241**	**Figure 3.254**
2295420	Payne Creek near Bowling Green	11/01/76	12/31/16	**Figure 3.216**	**Figure 3.229**	**Figure 3.242**	**Figure 3.255**
2295637	Peace River at Zolfo Springs	11/01/76	12/31/16	**Figure 3.217**	**Figure 3.230**	**Figure 3.243**	**Figure 3.256**
2296500	Charlie Creek near Gardner	11/01/76	12/31/16	**Figure 3.218**	**Figure 3.231**	**Figure 3.244**	**Figure 3.257**
2296750	Peace River at Arcadia	11/01/76	12/31/16	**Figure 3.219**	**Figure 3.232**	**Figure 3.245**	**Figure 3.258**
2297100	Joshua Creek at Nocatee	11/01/76	12/31/16	**Figure 3.220**	**Figure 3.233**	**Figure 3.246**	**Figure 3.259**
2297310	Horse Creek near Arcadia	11/01/76	12/31/16	**Figure 3.221**	**Figure 3.234**	**Figure 3.247**	**Figure 3.260**
	Total Gaged Flow at Facility	11/01/76	12/31/16	**Figure 3.222**	**Figure 3.235**	**Figure 3.248**	**Figure 3.261**
2298123	Prairie Creek near Fort Ogden	11/01/76	12/31/16	**Figure 3.223**	**Figure 3.236**	**Figure 3.249**	**Figure 3.262**
2298202	Shell Creek near Punta Gorda	11/01/76	12/31/16	**Figure 3.224**	**Figure 3.237**	**Figure 3.250**	**Figure 3.263**
	Total Gaged Flow to Harbor	11/01/76	12/31/16	**Figure 3.225**	**Figure 3.238**	**Figure 3.251**	**Figure 3.264**
Reference Watershed							
2298830	Myakka River near Sarasota	11/01/76	12/31/16	**Figure 3.226**	**Figure 3.239**	**Figure 3.252**	**Figure 3.265**

Table 3.9

Summary of Results of Seasonal Kendall Trend Analyses of Flows
Period-of-Record Through 2016 - Monthly Minimum Values (P0 or Q100)

USGS ID	Gage Identification	Time Period of Data	Number of Years	Tau Statistic	P-Value Without Serial Correlation	P-Value With Serial Correlation	Slope Statistic (cfs/yr)
Peace River Watershed							
2294650	Peace River at Bartow	1940	77	-0.31	0.000	**0.000**	-0.792
2295420	Payne Creek near Bowling Green	1980	37	-0.02	0.621	0.834	-0.042
2295637	Peace River at Zolfo Springs	1934	83	-0.24	0.000	**0.000**	-1.583
2296500	Charlie Creek near Gardner	1951	66	-0.02	0.379	0.662	-0.018
2296750	Peace River at Arcadia	1932	85	-0.14	0.000	**0.003**	-1.217
2297100	Joshua Creek at Nocatee	1951	66	0.37	0.000	**0.000**	0.257
2297310	Horse Creek near Arcadia	1951	66	0.03	0.166	0.491	0.022
	Total Gaged Flow Upstream of the Facility	1951	66	-0.15	0.000	**0.006**	-1.909
2298123	Prairie Creek near Fort Ogden	1978	39	0.15	0.000	**0.023**	0.3667
2298202	Shell Creek near Punta Gorda	1965	52	0.05	0.058	0.332	0.125
	Total Gaged Peace River Flow to the Harbor	1965	52	-0.03	0.248	0.583	-0.613
Reference Watershed							
2298830	Myakka River near Sarasota	1937	80	0.18	0.000	**0.000**	0.180

* Red values denote significant trend at p=0.05 level, while blue indicates trends significant at p=0.10

** Positive Tau statistic and slope values indicate increasing trend over time, negative values correspond to declining changes in flow over time

P-Values corrected for serial autocorrelations are applicable for rainfall data where values in preceding/following months are often similar seasonally

Table 3.10

Summary of Results of Seasonal Kendall Trend Analyses of Flows Period-of-Record Through 2016 - P10 (or Q90)

USGS ID	Gage Identification	Time Period of Data	Number of Years	Tau Statistic	P-Value Without Serial Correlation	P-Value With Serial Correlation	Slope Statistic (cfs/yr)
Peace River Watershed							
2294650	Peace River at Bartow	1940	77	-0.30	0.000	**0.000**	-0.866
2295420	Payne Creek near Bowling Green	1980	37	-0.01	0.675	0.856	-0.042
2295637	Peace River at Zolfo Springs	1934	83	-0.23	0.000	**0.000**	-1.708
2296500	Charlie Creek near Gardner	1951	66	-0.02	0.326	0.621	-0.028
2296750	Peace River at Arcadia	1932	85	-0.13	0.000	**0.005**	-1.293
2297100	Joshua Creek at Nocatee	1951	66	0.34	0.000	**0.000**	0.277
2297310	Horse Creek near Arcadia	1951	66	0.03	0.213	0.528	0.025
	Total Gaged Flow Upstream of the Facility	1951	66	-0.14	0.000	**0.009**	-2.086
2298123	Prairie Creek near Fort Ogden	1978	39	0.14	0.000	**0.034**	0.384
2298202	Shell Creek near Punta Gorda	1965	52	0.04	0.131	0.424	0.125
	Total Gaged Peace River Flow to the Harbor	1965	52	-0.04	0.260	0.540	-0.757
Reference Watershed							
2298830	Myakka River near Sarasota	1937	80	0.16	0.000	**0.000**	0.188

* Red values denote significant trend at p=0.05 level, while blue indicates trends significant at p=0.10

** Positive Tau statistic and slope values indicate increasing trend over time, negative values correspond to declining changes in flow over time

P-Values corrected for serial autocorrelations are applicable for rainfall data where values in preceding/following months are often similar seasonally

Table 3.11

Summary of Results of Seasonal Kendall Trend Analyses of Flows Period-of-Record Through 2016 - P25 (or Q75)

USGS ID	Gage Identification	Time Period of Data	Number of Years	Tau Statistic	P-Value Without Serial Correlation	P-Value With Serial Correlation	Slope Statistic (cfs/yr)
Peace River Watershed							
2294650	Peace River at Bartow	1940	77	-0.29	0.000	**0.000**	-1.021
2295420	Payne Creek near Bowling Green	1980	37	-0.02	0.551	0.792	-0.077
2295637	Peace River at Zolfo Springs	1934	83	-0.21	0.000	**0.000**	-1.837
2296500	Charlie Creek near Gardner	1951	66	-0.03	0.158	0.468	-0.058
2296750	Peace River at Arcadia	1932	85	-0.13	0.000	**0.005**	-1.522
2297100	Joshua Creek at Nocatee	1951	66	0.29	0.000	**0.000**	0.286
2297310	Horse Creek near Arcadia	1951	66	0.02	0.346	0.631	0.025
	Total Gaged Flow Upstream of the Facility	1951	66	-0.13	0.000	**0.011**	-2.317
2298123	Prairie Creek near Fort Ogden	1978	39	0.12	0.000	**0.058**	0.429
2298202	Shell Creek near Punta Gorda	1965	52	0.01	0.596	0.774	0.016
	Total Gaged Peace River Flow to the Harbor	1965	52	-0.03	0.289	0.603	-0.781
Reference Watershed							
2298830	Myakka River near Sarasota	1937	80	0.14	0.000	**0.001**	0.209

* Red values denote significant trend at p=0.05 level, while blue indicates trends significant at p=0.10

** Positive Tau statistic and slope values indicate increasing trend over time, negative values correspond to declining changes in flow over time

P-Values corrected for serial autocorrelations are applicable for rainfall data where values in preceding/following months are often similar seasonally

Table 3.12

Summary of Results of Seasonal Kendall Trend Analyses of Flows
Period-of-Record Through 2016 - Monthly Median Values (P50 or Q50)

USGS ID	Gage Identification	Time Period of Data	Number of Years	Tau Statistic	P-Value Without Serial Correlation	P-Value With Serial Correlation	Slope Statistic (cfs/yr)
Peace River Watershed							
2294650	Peace River at Bartow	1940	77	-0.25	0.000	**0.000**	-1.170
2295420	Payne Creek near Bowling Green	1980	37	-0.02	0.626	0.824	-0.087
2295637	Peace River at Zolfo Springs	1934	83	-0.17	0.000	**0.000**	-2.097
2296500	Charlie Creek near Gardner	1951	66	-0.05	0.045	0.290	-0.128
2296750	Peace River at Arcadia	1932	85	-0.10	0.000	**0.021**	-1.648
2297100	Joshua Creek at Nocatee	1951	66	0.22	0.000	**0.000**	0.305
2297310	Horse Creek near Arcadia	1951	66	0.00	0.911	0.983	0.000
	Total Gaged Flow Upstream of the Facility	1951	66	-0.11	0.000	**0.026**	-2.830
2298123	Prairie Creek near Fort Ogden	1978	39	0.10	0.003	0.105	0.500
2298202	Shell Creek near Punta Gorda	1965	52	0.01	0.762	0.868	0.040
	Total Gaged Peace River Flow to the Harbor	1965	52	-0.03	0.354	0.643	-0.884
Reference Watershed							
2298830	Myakka River near Sarasota	1937	80	0.10	0.000	**0.010**	0.240

* Red values denote significant trend at p=0.05 level, while blue indicates trends significant at p=0.10

** Positive Tau statistic and slope values indicate increasing trend over time, negative values correspond to declining changes in flow over time

P-Values corrected for serial autocorrelations are applicable for rainfall data where values in preceding/following months are often similar seasonally

Table 3.13

Summary of Results of Seasonal Kendall Trend Analyses of Flows Period-of-Record Through 2016 - P75 (or Q25)

USGS ID	Gage Identification	Time Period of Data	Number of Years	Tau Statistic	P-Value Without Serial Correlation	P-Value With Serial Correlation	Slope Statistic (cfs/yr)
Peace River Watershed							
2294650	Peace River at Bartow	1940	77	-0.21	0.000	**0.000**	-1.451
2295420	Payne Creek near Bowling Green	1980	37	0.01	0.708	0.860	0.119
2295637	Peace River at Zolfo Springs	1934	83	-0.16	0.000	**0.001**	-2.750
2296500	Charlie Creek near Gardner	1951	66	-0.04	0.082	0.354	-0.207
2296750	Peace River at Arcadia	1932	85	-0.09	0.000	**0.039**	-2.102
2297100	Joshua Creek at Nocatee	1951	66	0.13	0.000	**0.004**	0.308
2297310	Horse Creek near Arcadia	1951	66	-0.03	0.304	0.589	-0.083
	Total Gaged Flow Upstream of the Facility	1951	66	-0.10	0.000	**0.044**	-3.789
2298123	Prairie Creek near Fort Ogden	1978	39	0.06	0.071	0.311	0.500
2298202	Shell Creek near Punta Gorda	1965	52	0.01	0.835	0.902	0.053
	Total Gaged Peace River Flow to the Harbor	1965	52	-0.01	0.595	0.783	-0.864
Reference Watershed							
2298830	Myakka River near Sarasota	1937	80	0.07	0.001	**0.070**	0.244

* Red values denote significant trend at p=0.05 level, while blue indicates trends significant at p=0.10

** Positive Tau statistic and slope values indicate increasing trend over time, negative values correspond to declining changes in flow over time

P-Values corrected for serial autocorrelations are applicable for rainfall data where values in preceding/following months are often similar seasonally

Table 3.14

Summary of Results of Seasonal Kendall Trend Analyses of Flows Period-of-Record Through 2016 - P90 (or Q10)

USGS ID	Gage Identification	Time Period of Data	Number of Years	Tau Statistic	P-Value Without Serial Correlation	P-Value With Serial Correlation	Slope Statistic (cfs/yr)
Peace River Watershed							
2294650	Peace River at Bartow	1940	77	-0.19	0.000	**0.000**	-1.714
2295420	Payne Creek near Bowling Green	1980	37	0.00	0.970	0.985	0.000
2295637	Peace River at Zolfo Springs	1934	83	-0.16	0.000	**0.000**	-3.421
2296500	Charlie Creek near Gardner	1951	66	-0.04	0.069	0.319	-0.320
2296750	Peace River at Arcadia	1932	85	-0.09	0.000	**0.036**	-2.750
2297100	Joshua Creek at Nocatee	1951	66	0.09	0.000	**0.047**	0.304
2297310	Horse Creek near Arcadia	1951	66	-0.03	0.203	0.494	-0.155
	Total Gaged Flow Upstream of the Facility	1951	66	-0.10	0.001	**0.046**	-4.927
2298123	Prairie Creek near Fort Ogden	1978	39	0.04	0.243	0.503	0.4589
2298202	Shell Creek near Punta Gorda	1965	52	-0.1	0.797	0.882	-0.111
	Total Gaged Peace River Flow to the Harbor	1965	52	-0.01	0.656	0.814	-0.848
Reference Watershed							
2298830	Myakka River near Sarasota	1937	80	0.05	0.022	0.200	0.218

* Red values denote significant trend at p=0.05 level, while blue indicates trends significant at p=0.10

** Positive Tau statistic and slope values indicate increasing trend over time, negative values correspond to declining changes in flow over time

P-Values corrected for serial autocorrelations are applicable for rainfall data where values in preceding/following months are often similar seasonally

Table 3.15

Summary of Results of Seasonal Kendall Trend Analyses of Flows Period-of-Record Through 2016 - Monthly Maximum Values (P100 or Q0)

USGS ID	Gage Identification	Time Period of Data	Number of Years	Tau Statistic	P-Value Without Serial Correlation	P-Value With Serial Correlation	Slope Statistic (cfs/yr)
Peace River Watershed							
2294650	Peace River at Bartow	1940	77	-0.19	0.000	**0.001**	-2.000
2295420	Payne Creek near Bowling Green	1980	37	-0.01	0.823	0.912	-0.125
2295637	Peace River at Zolfo Springs	1934	83	-0.14	0.000	**0.001**	-4.118
2296500	Charlie Creek near Gardner	1951	66	-0.05	0.031	0.235	-0.556
2296750	Peace River at Arcadia	1932	85	-0.09	0.000	**0.030**	-3.580
2297100	Joshua Creek at Nocatee	1951	66	0.05	0.34	0.230	0.250
2297310	Horse Creek near Arcadia	1951	66	-0.04	0.116	0.396	-0.291
	Total Gaged Flow Upstream of the Facility	1951	66	-0.10	0.000	**0.043**	-6.923
2298123	Prairie Creek near Fort Ogden	1978	39	0.02	0.537	0.724	0.352
2298202	Shell Creek near Punta Gorda	1965	52	-0.01	0.626	0.783	-0.264
	Total Gaged Peace River Flow to the Harbor	1965	52	-0.02	0.553	0.756	-1.393
Reference Watershed							
2298830	Myakka River near Sarasota	1937	80	0.04	0.072	0.310	0.194

* Red values denote significant trend at p=0.05 level, while blue indicates trends significant at p=0.10

** Positive Tau statistic and slope values indicate increasing trend over time, negative values correspond to declining changes in flow over time

P-Values corrected for serial autocorrelations are applicable for rainfall data where values in preceding/following months are often similar seasonally

Table 3.16

Summary of Results of Seasonal Kendall Trend Analyses of Flows Period-of-Record Through 2016 - Monthly Mean Values

USGS ID	Gage Identification	Time Period of Data	Number of Years	Tau Statistic	P-Value Without Serial Correlation	P-Value With Serial Correlation	Slope Statistic (cfs/yr)
Peace River Watershed							
2294650	Peace River at Bartow	1940	77	-0.23	0.000	**0.000**	-1.313
2295420	Payne Creek near Bowling Green	1980	37	0.00	0.994	0.997	0.004
2295637	Peace River at Zolfo Springs	1934	83	-0.17	0.000	**0.000**	-2.449
2296500	Charlie Creek near Gardner	1951	66	-0.05	0.59	0.317	-0.189
2296750	Peace River at Arcadia	1932	85	-0.10	0.000	**0.024**	-1.933
2297100	Joshua Creek at Nocatee	1951	66	0.14	0.000	**0.003**	0.279
2297310	Horse Creek near Arcadia	1951	66	-0.02	0.466	0.703	-0.047
	Total Gaged Flow Upstream of the Facility	1951	66	-0.11	0.000	**0.003**	-3.365
2298123	Prairie Creek near Fort Ogden	1978	39	0.07	0.042	0.270	0.450
2298202	Shell Creek near Punta Gorda	1965	52	0.01	0.722	0.844	0.068
	Total Gaged Peace River Flow to the Harbor	1965	52	-0.02	0.466	0.714	-0.864
Reference Watershed							
2298830	Myakka River near Sarasota	1937	80	0.07	0.007	**0.063**	0.203

* Red values denote significant trend at p=0.05 level, while blue indicates trends significant at p=0.10
** Positive Tau statistic and slope values indicate increasing trend over time, negative values correspond to declining changes in flow over time

P-Values corrected for serial autocorrelations are applicable for rainfall data where values in preceding/following months are often similar seasonally

Table 3.18
Summary of Results of Seasonal Kendal Trend Analyses of Flows Percentiles over Period of Record - 2016
(With Corrections for Serial Correlations)

USGS ID	Gage Identification	First Year	P0 (Min)	P10	P25	P50 (Median)	P75	P90	P100 (Max)	Mean
Peace River Watershed										
2294650	**Peace River at Bartow**	1940	🔻	🔻	🔻	🔻	🔻	🔻	🔻	🔻
2295420	**Payne Creek near Bowling Green**	1980								
2295637	**Peace River at Zolfo Springs**	1934	🔻	🔻	🔻	🔻	🔻	🔻	🔻	🔻
2296500	**Charlie Creek near Gardner**	1951								
2296750	**Peace River at Arcadia**	1932	🔻	🔻	🔻	🔻	🔻	🔻	🔻	🔻
2297100	**Joshua Creek at Nocatee**	1951	🔺	🔺	🔺	🔺	🔺	🔺		🔺
2297310	**Horse Creek near Arcadia**	1951								
	Total Gaged Flow at Facility	1951	🔻	🔻	🔻	🔻	🔻	🔻	🔻	🔻
2298123	**Prairie Creek near Fort Ogden**	1978	🔺	🔺	▲					
2298202	**Shell Creek near Punta Gorda**	1965								
	Total Gaged Peace River Flow to Harbor	1965								
Reference Watershed										
2298830	**Myakka River near Sarasota**	1937	🔺	🔺	🔺	🔺	▲			▲

Note: Direction of arrow denotes significant increasing or decreasing trend. Red arrows are significant at p=0.05 level, while blue show trends significant at p=0.10, and blanks indicate no significant trends in Seasonal Kendall Tau test corrected for serial correlations.

The values are shown as flow percentiles (P values), percent exceedances (Q values) are simply the (100% - the percentile)

Table 3.19
Summary of Results of Seasonal Kendall Trend Analyses of Monthly Flow Percentiles over Different Selected Periods of Time Through 2016

USGS Gaging Site	Flow Percentile	1935 to 2016	1940 to 2016	1945 to 2016	1950 to 2016	1955 to 2016	1960 to 2016	1965 to 2016	1970 to 2016	1975 to 2016	1980 to 2016	1985 to 2016	1990 to 2016	1995 to 2016	2000 to 2016	2005 to 2016
Peace River Watershed																
Peace River at Bartow	Low (P10)	▨	🔻	🔻	🔻	🔻	🔻	🔻	🔽							
	Median (P50)	▨	🔻	🔻	🔻	🔻	🔻	🔻								
	High (P90)	▨	🔻	🔻	🔻	🔻	🔻									
Payne Creek near Bowling Green	Low (P10)	▨	▨	▨	▨	▨	▨	▨	▨	▨						
	Median (P50)	▨	▨	▨	▨	▨	▨	▨	▨	▨						
	High (P90)	▨	▨	▨	▨	▨	▨	▨	▨	▨						
Peace River at Zolfo Springs	Low (P10)	🔻	🔻	🔻	🔻	🔻	🔻	🔻	🔻							
	Median (P50)	🔻	🔻	🔻	🔻	🔻	🔻	🔻	🔽							
	High (P90)	🔻	🔻	🔻	🔻	🔻	🔻	🔽								
Charlie Creek near Gardner	Low (P10)	▨	▨	▨	▨											
	Median (P50)	▨	▨	▨	▨											
	High (P90)	▨	▨	▨	▨											
Peace River at Arcadia	Low (P10)	🔻	🔻	🔻	🔻	🔻	🔻	🔽								
	Median (P50)	🔻	🔻	🔻	🔻	🔻	🔻									
	High (P90)	🔻	🔻	🔻	🔻	🔻	🔽									
Joshua Creek at Nocatee	Low (P10)	▨	▨	▨	▨	🔺	🔺	🔺	🔺	🔺	🔺					
	Median (P50)	▨	▨	▨	▨	🔺	🔺	🔺	🔺	🔺	🔼					
	High (P90)	▨	▨	▨	▨	🔼	🔺	🔼	🔼							

* Note: Direction of arrow denotes significant increasing or decreasing trend. Red arrows are significant at p=0.05 level, blue show trends significant at p=0.10, and blanks indicate no significant trends in Seasonal Kendall Tau tests corrected for serial correlations. Dashed lines indicate periods prior to USGS gaging at each location.

Table 3.19 (continued)
Summary of Results of Seasonal Kendall Trend Analyses of Monthly Flow Percentiles over Different Selected Periods of Time Through 2016

USGS Gaging Site	Flow Percentile	1935 to 2016	1940 to 2016	1945 to 2016	1950 to 2016	1955 to 2016	1960 to 2016	1965 to 2016	1970 to 2016	1975 to 2016	1980 to 2016	1985 to 2016	1990 to 2016	1995 to 2016	2000 to 2016	2005 to 2016
Horse Creek near Arcadia	Low (P10)	▨	▨	▨	▨				▲							
	Median (P50)	▨	▨	▨	▨											
	High (P90)	▨	▨	▨	▨											
Total Gaged Flow Upstream of the Facility	Low (P10)	▨	▨	▨	▨	🔻	▼									
	Median (P50)	▨	▨	▨	▨	▼										
	High (P90)	▨	▨	▨	▨											
Prairie Creek near Fort Ogden	Low (P10)	▨	▨	▨	▨	▨	▨	▨	▨	▨	🔺					
	Median (P50)	▨	▨	▨	▨	▨	▨	▨	▨	▨						▲
	High (P90)	▨	▨	▨	▨	▨	▨	▨	▨	▨						
Shell Creek near Punta Gorda	Low (P10)	▨	▨	▨	▨	▨	▨						🔻			
	Median (P50)	▨	▨	▨	▨	▨	▨						🔻			
	High (P90)	▨	▨	▨	▨	▨	▨									
Total Gaged Peace River Flow to Upper Harbor	Low (P10)	▨	▨	▨	▨	▨	▨									
	Median (P50)	▨	▨	▨	▨	▨	▨									
	High (P90)	▨	▨	▨	▨	▨	▨									
Reference Watershed																
Myakka River near Sarasota	Low (P10)	▨	🔺	🔺	🔺		▲									
	Median (P50)	▨	🔺	▲												
	High (P90)	▨														

* Note: Direction of arrow denotes significant increasing or decreasing trend. Red arrows are significant at p=0.05 level, blue show trends significant at p=0.10, and blanks indicate no significant trends in Seasonal Kendall Tau tests corrected for serial correlations. Dashed lines indicate periods prior to continuous USGS gaging at each location.

The values are shown as flow percentiles (P values), percent exceedances (Q values) are simply the (100% - the percentile)

Table 3.20

Summary of Results of Seasonal Kendall Trend Analyses of Flows 1976 Through 2016 - Monthly Minimum Values (P0)

USGS ID	Gage Identification	Time Interval	Tau Statistic	P-Value Without Serial Correlation	P-Value With Serial Correlation	Slope Statistic (cfs/yr)
Peace River Watershed						
2294650	Peace River at Bartow	1976-2016	-0.09	0.006	0.246	-0.208
2295420	Payne Creek near Bowling Green	1976-2016	-0.02	0.621	0.834	-0.041
2295637	Peace River at Zolfo Springs	1976-2016	-0.08	0.012	0.306	-0.809
2296500	Charlie Creek near Gardner	1976-2016	0.08	0.013	0.211	0.105
2296750	Peace River at Arcadia	1976-2016	-0.02	0.584	0.809	-0.237
2297100	Joshua Creek at Nocatee	1976-2016	0.27	0.000	**0.000**	0.375
2297310	Horse Creek near Arcadia	1976-2016	0.10	0.001	0.103	0.116
	Total Gaged Flow Upstream of the Facility	1976-2016	0.01	0.795	0.906	0.133
2298123	Prairie Creek near Fort Ogden	1976-2016	0.15	0.000	**0.023**	0.367
2298202	Shell Creek near Punta Gorda	1976-2016	0.01	0.815	0.905	0.000
	Total Gaged Peace River Flow to the Harbor	1976-2016	0.01	0.851	0.930	0.130
Reference Watershed						
2298830	Myakka River near Sarasota	1976-2016	-0.06	0.044	0.310	-0.166

* Red values denote significant trend at p=0.05 level, while blue indicates trends significant at p=0.10

** Positive Tau statistic and slope values indicate increasing trend over time, negative values correspond to declining changes in flow over time

P-Values corrected for serial autocorrelations are applicable for rainfall data where values in preceding/following months are often similar seasonally

Table 3.21

Summary of Results of Seasonal Kendall Trend Analyses of Flows
1976 Through 2016 - Monthly P10 Value (Q90)

USGS ID	Gage Identification	Time Interval	Tau Statistic	P-Value Without Serial Correlation	P-Value With Serial Correlation	Slope Statistic (cfs/yr)
Peace River Watershed						
2294650	Peace River at Bartow	1976-2016	-0.07	0.017	0.318	-0.205
2295420	Payne Creek near Bowling Green	1976-2016	-0.014	0.675	0.856	-0.042
2295637	Peace River at Zolfo Springs	1976-2016	-0.081	0.009	0.284	-1.000
2296500	Charlie Creek near Gardner	1976-2016	0.07	0.020	0.233	0.117
2296750	Peace River at Arcadia	1976-2016	-0.01	0.669	0.848	-0.232
2297100	Joshua Creek at Nocatee	1976-2016	0.25	0.000	**0.001**	0.400
2297310	Horse Creek near Arcadia	1976-2016	0.09	0.004	0.149	0.123
	Total Gaged Flow Upstream of the Facility	1976-2016	0.01	0.738	0.877	0.247
2298123	Prairie Creek near Fort Ogden	1976-2016	0.14	0.000	0.034	0.384
2298202	Shell Creek near Punta Gorda	1976-2016	0.01	0.858	0.927	0.000
	Total Gaged Peace River Flow to the Harbor	1976-2016	0.00	0.961	0.982	0.034
Reference Watershed						
2298830	Myakka River near Sarasota	1976-2016	-0.06	0.056	0.326	-0.183

* Red values denote significant trend at p=0.05 level, while blue indicates trends significant at p=0.10

** Positive Tau statistic and slope values indicate increasing trend over time, negative values correspond to declining changes in flow over time

P-Values corrected for serial autocorrelations are applicable for rainfall data where values in preceding/following months are often similar seasonally

Table 3.22

Summary of Results of Seasonal Kendall Trend Analyses of Flows 1976 Through 2016 - Monthly P25 Value (Q75)

USGS ID	Gage Identification	Time Interval	Tau Statistic	P-Value Without Serial Correlation	P-Value With Serial Correlation	Slope Statistic (cfs/yr)
Peace River Watershed						
2294650	Peace River at Bartow	1976-2016	-0.06	0.051	0.414	-0.190
2295420	Payne Creek near Bowling Green	1976-2016	-0.02	0.551	0.792	-0.077
2295637	Peace River at Zolfo Springs	1976-2016	-0.07	0.017	0.315	-1.111
2296500	Charlie Creek near Gardner	1976-2016	0.06	0.040	0.281	0.140
2296750	Peace River at Arcadia	1976-2016	-0.02	0.473	0.743	-0.458
2297100	Joshua Creek at Nocatee	1976-2016	0.22	0.000	**0.001**	0.400
2297310	Horse Creek near Arcadia	1976-2016	0.09	0.006	0.156	0.167
	Total Gaged Flow Upstream of the Facility	1976-2016	0.01	0.917	0.961	0.072
2298123	Prairie Creek near Fort Ogden	1976-2016	0.12	0.001	**0.058**	0.429
2298202	Shell Creek near Punta Gorda	1976-2016	-0.01	0.659	0.818	-0.055
	Total Gaged Peace River Flow to the Harbor	1976-2016	-0.01	1.000	1.000	0.000
Reference Watershed						
2298830	Myakka River near Sarasota	1976-2016	-0.04	0.207	0.498	-0.157

* Red values denote significant trend at p=0.05 level, while blue indicates trends significant at p=0.10

** Positive Tau statistic and slope values indicate increasing trend over time, negative values correspond to declining changes in flow over time

P-Values corrected for serial autocorrelations are applicable for rainfall data where values in preceding/following months are often similar seasonally

Table 3.23

Summary of Results of Seasonal Kendall Trend Analyses of Flows 1976 Through 2016 - Monthly Median Values (P50)

USGS ID	Gage Identification	Time Interval	Tau Statistic	P-Value Without Serial Correlation	P-Value With Serial Correlation	Slope Statistic (cfs/yr)
Peace River Watershed						
2294650	Peace River at Bartow	1976-2016	-0.04	0.186	0.571	-0.176
2295420	Payne Creek near Bowling Green	1976-2016	-0.02	0.626	0.824	-0.087
2295637	Peace River at Zolfo Springs	1976-2016	-0.05	0.097	0.467	-1.160
2296500	Charlie Creek near Gardner	1976-2016	0.04	0.155	0.451	0.150
2296750	Peace River at Arcadia	1976-2016	-0.01	0.726	0.871	-0.356
2297100	Joshua Creek at Nocatee	1976-2016	0.17	0.000	0.007	0.408
2297310	Horse Creek near Arcadia	1976-2016	0.07	0.025	0.246	0.196
	Total Gaged Flow Upstream of the Facility	1976-2016	0.01	0.843	0.925	0.239
2298123	Prairie Creek near Fort Ogden	1976-2016	0.10	0.003	0.105	0.500
2298202	Shell Creek near Punta Gorda	1976-2016	-0.01	0.899	0.945	-0.014
	Total Gaged Peace River Flow to the Harbor	1976-2016	0.01	0.820	0.912	0.483
Reference Watershed						
2298830	Myakka River near Sarasota	1976-2016	-0.03	0.418	0.654	-0.146

* Red values denote significant trend at p=0.05 level, while blue indicates trends significant at p=0.10

** Positive Tau statistic and slope values indicate increasing trend over time, negative values correspond to declining changes in flow over time

P-Values corrected for serial autocorrelations are applicable for rainfall data where values in preceding/following months are often similar seasonally

Table 3.24

Summary of Results of Seasonal Kendall Trend Analyses of Flows 1976 Through 2016 - Monthly P75 Values (Q25)

USGS ID	Gage Identification	Time Interval	Tau Statistic	P-Value Without Serial Correlation	P-Value With Serial Correlation	Slope Statistic (cfs/yr)
Peace River Watershed						
2294650	Peace River at Bartow	1976-2016	-0.03	0.392	0.713	-0.168
2295420	Payne Creek near Bowling Green	1976-2016	0.01	0.709	0.860	0.119
2295637	Peace River at Zolfo Springs	1976-2016	-0.04	0.163	0.524	-1.329
2296500	Charlie Creek near Gardner	1976-2016	0.05	0.121	0.407	0.339
2296750	Peace River at Arcadia	1976-2016	-0.01	0.808	0.907	-0.364
2297100	Joshua Creek at Nocatee	1976-2016	0.10	0.001	**0.086**	0.400
2297310	Horse Creek near Arcadia	1976-2016	0.05	0.120	0.423	0.231
	Total Gaged Flow Upstream of the Facility	1976-2016	0.01	0.736	0.868	0.732
2298123	Prairie Creek near Fort Ogden	1976-2016	0.06	0.071	0.311	0.500
2298202	Shell Creek near Punta Gorda	1976-2016	-0.01	0.951	0.972	0.000
	Total Gaged Peace River Flow to the Harbor	1976-2016	0.01	0.697	0.845	0.978
Reference Watershed						
2298830	Myakka River near Sarasota	1976-2016	-0.02	0.436	0.670	-0.193

* Red values denote significant trend at p=0.05 level, while blue indicates trends significant at p=0.10

** Positive Tau statistic and slope values indicate increasing trend over time, negative values correspond to declining changes in flow over time

P-Values corrected for serial autocorrelations are applicable for rainfall data where values in preceding/following months are often similar seasonally

Table 3.25

Summary of Results of Seasonal Kendall Trend Analyses of Flows 1976 Through 2016 - Monthly P90 Values (Q10)

USGS ID	Gage Identification	Time Interval	Tau Statistic	P-Value Without Serial Correlation	P-Value With Serial Correlation	Slope Statistic (cfs/yr)
Peace River Watershed						
2294650	Peace River at Bartow	1976-2016	-0.01	0.699	0.869	-0.130
2295420	Payne Creek near Bowling Green	1976-2016	-0.01	0.970	0.985	0.000
2295637	Peace River at Zolfo Springs	1976-2016	-0.04	0.242	0.584	-1.207
2296500	Charlie Creek near Gardner	1976-2016	0.04	0.244	0.527	0.379
2296750	Peace River at Arcadia	1976-2016	0.01	0.887	0.944	0.235
2297100	Joshua Creek at Nocatee	1976-2016	0.07	0.025	0.220	0.428
2297310	Horse Creek near Arcadia	1976-2016	0.04	0.251	0.543	0.229
	Total Gaged Flow Upstream of the Facility	1976-2016	0.02	0.573	0.778	1.396
2298123	Prairie Creek near Fort Ogden	1976-2016	0.04	0.243	0.503	0.459
2298202	Shell Creek near Punta Gorda	1976-2016	-0.01	0.899	0.943	-0.067
	Total Gaged Peace River Flow to the Harbor	1976-2016	0.02	0.564	0.770	1.658
Reference Watershed						
2298830	Myakka River near Sarasota	1976-2016	-0.02	0.622	0.791	-0.135

* Red values denote significant trend at p=0.05 level, while blue indicates trends significant at p=0.10

** Positive Tau statistic and slope values indicate increasing trend over time, negative values correspond to declining changes in flow over time

P-Values corrected for serial autocorrelations are applicable for rainfall data where values in preceding/following months are often similar seasonally

Table 3.26

Summary of Results of Seasonal Kendall Trend Analyses of Flows 1976 Through 2016 - Monthly Maximum Values (P100)

USGS ID	Gage Identification	Time Interval	Tau Statistic	P-Value Without Serial Correlation	P-Value With Serial Correlation	Slope Statistic (cfs/yr)
Peace River Watershed						
2294650	Peace River at Bartow	1976-2016	-0.01	0.923	0.967	-0.034
2295420	Payne Creek near Bowling Green	1976-2016	-0.01	0.827	0.912	-0.125
2295637	Peace River at Zolfo Springs	1976-2016	-0.02	0.454	0.718	-1.261
2296500	Charlie Creek near Gardner	1976-2016	0.03	0.392	0.643	0.384
2296750	Peace River at Arcadia	1976-2016	-0.01	0.961	0.981	-0.036
2297100	Joshua Creek at Nocatee	1976-2016	0.04	0.158	0.416	0.367
2297310	Horse Creek near Arcadia	1976-2016	0.02	0.525	0.732	0.200
	Total Gaged Flow Upstream of the Facility	1976-2016	0.02	0.622	0.808	1.400
2298123	Prairie Creek near Fort Ogden	1976-2016	0.02	0.536	0.724	0.352
2298202	Shell Creek near Punta Gorda	1976-2016	0.01	0.990	0.994	0.000
	Total Gaged Peace River Flow to the Harbor	1976-2016	0.01	0.638	0.814	1.809
Reference Watershed						
2298830	Myakka River near Sarasota	1976-2016	-0.01	0.659	0.810	-0.152

* Red values denote significant trend at p=0.05 level, while blue indicates trends significant at p=0.10
** Positive Tau statistic and slope values indicate increasing trend over time, negative values correspond to declining changes in flow over time

P-Values corrected for serial autocorrelations are applicable for rainfall data where values in preceding/following months are often similar seasonally

Table 3.27

Summary of Results of Seasonal Kendall Trend Analyses of Flows 1976 Through 2016 - Monthly Mean Values

USGS ID	Gage Identification	Time Interval	Tau Statistic	P-Value Without Serial Correlation	P-Value With Serial Correlation	Slope Statistic (cfs/yr)
Peace River Watershed						
2294650	Peace River at Bartow	1976-2016	-0.03	0.261	0.636	-0.184
2295420	Payne Creek near Bowling Green	1976-2016	-0.01	0.994	0.997	-0.004
2295637	Peace River at Zolfo Springs	1976-2016	-0.04	0.153	0.527	-1.060
2296500	Charlie Creek near Gardner	1976-2016	0.04	0.164	0.463	0.239
2296750	Peace River at Arcadia	1976-2016	-0.01	0.853	0.931	-0.292
2297100	Joshua Creek at Nocatee	1976-2016	0.11	0.000	**0.066**	0.377
2297310	Horse Creek near Arcadia	1976-2016	0.05	0.089	0.388	0.221
	Total Gaged Flow Upstream of the Facility	1976-2016	0.01	0.734	0.870	0.471
2298123	Prairie Creek near Fort Ogden	1976-2016	0.07	0.042	0.270	0.449
2298202	Shell Creek near Punta Gorda	1976-2016	0.01	0.874	0.933	0.054
	Total Gaged Peace River Flow to the Harbor	1976-2016	0.01	0.662	0.831	0.754
Reference Watershed						
2298830	Myakka River near Sarasota	1976-2016	-0.03	0.371	0.633	-0.163

* Red values denote significant trend at p=0.05 level, while blue indicates trends significant at p=0.10

** Positive Tau statistic and slope values indicate increasing trend over time, negative values correspond to declining changes in flow over time

P-Values corrected for serial autocorrelations are applicable for rainfall data where values in preceding/following months are often similar seasonally

Table 3.28
Summary of Results of Seasonal Kendal Trend Analyses of Flows over the 1976 – 2016 Period (With Corrections for Serial Correlations)

USGS ID	Gage Identification	First Year	P0 (Min)	P10	P25	P50 (Median)	P75	P90	P100 (Max)	Mean
Peace River Watershed										
2294650	**Peace River at Bartow**	1976								
2295420	**Payne Creek near Bowling Green**	1976								
2295637	**Peace River at Zolfo Springs**	1976								
2296500	**Charlie Creek near Gardner**	1976								
2296750	**Peace River at Arcadia**	1976								
2297100	**Joshua Creek at Nocatee**	1976	🔺	🔺	🔺	🔺	▲			▲
2297310	**Horse Creek near Arcadia**	1976								
	Total Gaged Flow at Facility	1976								
2298123	**Prairie Creek near Fort Ogden**	1976	🔺		▲					
2298202	**Shell Creek near Punta Gorda**	1976								
	Total Gaged Peace River Flow to Harbor	1976								
Reference Watershed										
2298830	**Myakka River near Sarasota**	1976								

Note: Direction of arrow denotes significant increasing or decreasing trend. Red arrows are significant at p=0.05 level, while blue show trends significant at p=0.10, and blanks indicate no significant trends in Seasonal Kendall Tau test corrected for serial correlations.

The values are shown as flow percentiles (P values), percent exceedances (Q values) are simply the (100% - the percentile)

Table 3.38
Historic Overview of Facility Capacity and Demand

Year	Facility Treatment Capacity (MGD)	River Intake Pumping Capacity (MGD)	Surface Water Reservoir Capacity (BG)	Aquifer Storage Recovery Well Capacity (MG)	Annual Avg. Permitted River Diversion (MGD)	Annual Avg. Public Demand (MGD)	Annual Avg. River Diversion (MGD)
1980	6	22	.625	0	5.0	2.4	2.2
1981	6	22	.625	0	5.0	3.4	3.3
1982	6	22	.625	0	8.2	3.4	3.8
1983	6	22	.625	0	8.2	3.4	3.3
1984	6	22	.625	0	8.2	3.6	2.6
1985	6	22	.625	720	8.2	3.4	4.6
1986	6	22	.625	720	8.2	4.2	4.9
1987	6	22	.625	1080	8.2	4.3	4.9
1988	6	22	.625	1080	10.7	5.6	6.1
1989	12	22	.625	2160	10.7	6.6	6.2
1990	12	22	.625	2160	10.7	7.0	5.6
1991	12	22	.625	2160	10.7	5.6	6.8
1992	12	22	.625	2160	10.7	6.3	6.3
1993	12	22	.625	2160	10.7	6.9	7.8
1994	12	22	.625	2160	10.7	7.3	7.5
1995	12	22	.625	3240	10.7	7.8	7.9
1996	12	22	.625	3240	32.7	8.3	8.1
1997	12	22	.625	3240	32.7	7.8	7.8
1998	12	22	.625	3240	32.7	8.6	10.0
1999	12	22	.625	3240	32.7	8.5	8.3
2000	12	22	.625	3240	32.7	8.9	3.7
2001	12	22	.625	3240	32.7	8.3	5.1
2002	24	42	.625	7560	32.7	11.0	14.7
2003	24	42	.625	7560	32.7	13.9	16.9
2004	24	42	.625	7560	32.7	16.2	15.6
2005	24	42	.625	7560	32.7	16.1	18.8
2006	24	42	.625	7560	32.7	16.9	11.9
2007	24	42	.625	7560	32.7	14.9	7.2
2008	24	42	.625	7560	32.7	13.7	10.0
2009	48	120	6.625	7560	32.7	16.0	28.2
2010	48	120	6.625	7560	32.7	22.2	21.5
2011	48	120	6.625	7560	32.855	23.4	30.9
2012	48	120	6.625	7560	32.855	24.6	26.0
2013	48	120	6.625	7560	32.855	24.6	27.4
2014	48	120	6.625	7560	32.855	25.4	30.4

Table 3.38
Historic Overview of Facility Capacity and Demand

Year	Facility Treatment Capacity (MGD)	River Intake Pumping Capacity (MGD)	Surface Water Reservoir Capacity (BG)	Aquifer Storage Recovery Well Capacity (MG)	Annual Avg. Permitted River Diversion (MGD)	Annual Avg. Public Demand (MGD)	Annual Avg. River Diversion (MGD)
2015	48	120	6.625	7560	32.855	26.5	30.9
2016	54	120	6.625	7560	32.855	26.1	24.6

Notes:
- Facility treatment capacity is physical capacity to treat water.
- Reservoir capacity is the capacity of the reservoir when full. The actual volume in the reservoir varies depending on public demand and river diversion.
- ASR wellfield capacity is calculated by taking the number of individual wells times 360 MG to equal a full well. Actual volume in the wells varies depending on public demand and river diversions and time well has existed.
- Public demand is total public demand from the Facility.
- Annual average river diversion is the total diversion from the river no matter whether the water is stored in the reservoir, stored in ASR or met public demand.
- Permitted river diversion by the Peace River Facility.

Table 3.39
Long-Term Yearly Mean Measurements of Peace River Flows and Facility Withdrawals during HBMP Monitoring Period

Year	Annual Mean Peace River Total Gaged Flow (cfs) at:			Annual Mean Withdrawals (cfs)		Peace River Facility Withdrawals as Percentages of Total Gaged Flows at:			Total of Authority and City of Punta Gorda Withdrawals as Percent of Total Gaged Flow as US 41 Bridge
	Arcadia	Peace River Facility	US 41 Bridge	Peace River Facility	City of Punta Gorda from Shell Creek	Arcadia	Facility	US 41 Bridge	
1976	703.3	782.9	959.7	No Withdrawals	2.5	No Withdrawals			0.3
1977	478.7	588.0	732.0		3.0				0.4
1978	997.3	1254.6	1525.8		3.0				0.2
1979	1171.5	1532.7	2080.5		3.2				0.2
1980	495.2	578.2	726.3	3.9	3.4	0.7	0.6	0.5	0.9
1981	288.4	442.3	629.7	5.1	3.7	1.8	1.2	0.8	1.4
1982	1610.5	2141.9	2746.9	5.9	3.9	0.4	0.3	0.2	0.4
1983	1371.4	1778.7	2319.9	5.1	3.8	0.4	0.3	0.2	0.4
1984	567.0	742.9	1102.7	4.1	4.2	0.7	0.6	0.4	0.8
1985	369.0	510.6	680.8	7.2	3.9	2.0	1.4	1.1	1.6
1986	549.0	781.3	1013.7	7.5	3.8	1.4	1.0	0.7	1.1
1987	802.8	1095.5	1357.8	7.6	3.8	1.0	0.7	0.6	0.8
1988	1054.1	1425.2	1738.4	9.5	5.0	0.9	0.7	0.6	0.8
1989	373.6	481.9	699.0	9.6	5.2	2.6	2.0	1.4	2.1
1990	402.4	544.5	741.4	8.7	5.3	2.2	1.6	1.2	1.9
1991	771.2	1063.7	1567.6	10.4	4.7	1.4	1.0	0.7	1.0
1992	784.6	1143.0	1543.7	9.4	5.0	1.2	0.8	0.6	0.9
1993	698.5	903.1	1249.3	12.0	4.9	1.7	1.3	1.0	1.4
1994	1365.9	1788.6	2259.0	11.7	5.0	0.9	0.7	0.5	0.7
1995	1708.1	2250.4	3071.6	12.2	4.9	0.7	0.5	0.4	0.6
1996	598.2	725.6	928.8	12.5	5.2	2.1	1.7	1.3	1.9
1997	1059.9	1439.0	1777.6	12.1	5.0	1.1	0.8	0.7	1.0
1998	1916.0	2459.9	2921.3	15.4	5.1	0.8	0.6	0.5	0.7
1999	565.0	781.3	1142.2	12.8	5.5	2.3	1.7	1.2	1.7
2000	138.7	220.8	335.3	5.7	6.1	4.1	2.6	1.7	3.5
2001	1038.4	1442.0	1936.9	7.9	6.1	0.8	0.6	0.4	0.7

Table 3.39
Long-Term Yearly Mean Measurements of Peace River Flows and Facility Withdrawals during HBMP Monitoring Period

Year	Annual Mean Peace River Total Gaged Flow (cfs) at:			Annual Mean Withdrawals (cfs)		Peace River Facility Withdrawals as Percentages of Total Gaged Flows at:			Total of Authority and City of Punta Gorda Withdrawals as Percent of Total Gaged Flow as US 41 Bridge
	Arcadia	Peace River Facility	US 41 Bridge	Peace River Facility	City of Punta Gorda from Shell Creek	Arcadia	Facility	US 41 Bridge	
2002	1191.8	1635.8	2202.6	22.8	6.5	1.9	1.4	1.0	1.3
2003	1856.3	2454.3	2921.9	26.1	6.8	1.4	1.1	0.9	1.1
2004	1746.5	2363.3	2788.1	24.2	6.9	1.4	1.0	0.9	1.1
2005	1859.9	2338.7	2955.3	29.1	6.9	1.6	1.2	1.0	1.2
2006	375.6	537.7	818.4	18.4	7.5	4.9	3.4	2.2	3.2
2007	173.1	237.6	353.2	11.2	5.0	6.5	4.7	3.2	4.6
2008	430.8	597.1	832.6	15.4	6.6	3.6	2.6	1.9	2.7
2009	544.8	727.0	990.1	43.6	6.9	8.0	6.0	4.4	5.1
2010	703.8	994.8	1262.3	33.3	7.1	4.7	3.4	2.6	3.2
2011	542.0	720.4	957.6	47.8	7.3	8.8	6.6	5.0	5.8
2012	622.2	910.0	1297.3	41.5	7.7	6.7	4.6	3.2	3.8
2013	956.6	1315.9	1953.7	42.8	7.9	4.5	3.3	2.2	2.6
2014	721.1	875.3	1193.6	47.0	7.7	6.5	5.4	3.9	4.6
2015	1247.6	1583.7	1994.9	47.8	7.8	3.8	3.0	2.4	2.8
2016	1333.5	1689.5	2198.3	38.0	7.7	2.9	2.3	1.7	2.1

Table 4.6
Annual Summary Statistics of Gage Height (Water Level) and Surface and Bottom Salinities over the Period-of-Record at the Two Longest Term USGS Continuous Recorders

Year	Gage Height (feet)				Surface Salinity (psu)				Bottom Salinity (psu)			
	Mean	Median	Minimum	Maximum	Mean	Median	Minimum	Maximum	Mean	Median	Minimum	Maximum
River Kilometer 15.5 (Harbour Heights)												
1997	0.72	0.73	-1.91	3.3	5.5	3.8	0.0	22.9	6.0	4.3	0.0	25.0
1998	0.77	0.79	-2.12	3.6	2.0	0.3	0.0	17.6	2.1	0.3	0.0	18.2
1999	0.80	0.84	-1.81	3.3	6.7	6.6	0.1	23.1	6.8	6.8	0.1	22.9
2000	0.72	0.77	-2.46	4.2	12.6	13.8	0.2	28.8	13.2	14.3	0.2	29.8
2001	0.60	0.61	-1.98	5.6	11.0	11.8	0.0	28.6	11.2	12.2	0.0	29.5
2002	0.75	0.78	-2.09	3.0	6.0	2.6	0.1	24.8	6.2	2.8	0.1	24.1
2003	0.77	0.84	-2.09	3.2	2.6	1.2	0.0	19.1	3.0	1.4	0.0	19.9
2004	0.83	0.87	-2.38	5.4	4.6	3.1	0.0	20.0	4.6	3.1	0.0	19.4
2005	0.89	0.94	-1.59	3.4	2.1	0.5	0.0	20.0	2.4	0.6	0.1	20.8
2006	0.77	0.81	-1.94	3.5	8.1	7.6	0.1	24.7	8.6	8.2	0.1	25.3
2007	0.79	0.84	-1.62	3.8	13.1	13.6	0.5	30.6	13.9	14.5	0.6	32.0
2008	0.81	0.85	-2.42	3.4	11.7	13.7	0.1	27.5	12.2	14.3	0.1	28.2
2009	1.01	1.06	-1.49	3.2	9.9	7.0	0.1	29.6	10.5	8.3	0.1	30.0
2010	0.84	0.89	-1.83	3.0	4.6	3.0	0.1	19.5	4.6	3.3	0.1	19.3
2011	0.77	0.80	-1.97	3.7	7.5	6.9	0.1	25.8	7.8	7.2	0.1	25.5
2012	0.97	1.00	-2.20	4.3	10.2	11.0	0.1	28.4	10.5	11.6	0.1	29.0
2013	0.95	0.98	-1.57	3.6	8.0	9.8	0.1	22.6	8.3	10.2	0.1	22.9
2014	1.00	1.04	-1.50	3.1	6.1	5.5	0.1	22.2	6.3	5.9	0.1	22.8
2015	1.09	1.12	-1.36	3.4	4.3	3.2	0.1	19.4	4.5	3.5	0.1	19.9
2016	1.09	1.13	-1.37	3.9	3.6	0.6	0.1	20.4	3.8	0.7	0.1	21.1
River Kilometer 26.7 (Peace River Heights)												
1998	1.05	1.01	-1.69	5.6	0.2	0.1	0.0	1.6	0.2	0.1	0.0	1.7
1999	0.78	0.84	-1.88	3.2	0.4	0.2	0.1	11.5	0.4	0.2	0.1	11.4
2000	0.62	0.67	-2.55	4.1	2.9	0.9	0.1	19.8	3.0	0.9	0.1	20.5
2001	0.73	0.68	-2.10	6.0	1.5	0.4	0.0	15.4	1.6	0.4	0.0	15.9
2002	0.78	0.85	-2.02	3.0	0.6	0.2	0.0	9.2	0.6	0.2	0.1	9.5

Table 4.6
Annual Summary Statistics of Gage Height (Water Level) and Surface and Bottom Salinities over the Period-of-Record at the Two Longest Term USGS Continuous Recorders

Year	Gage Height (feet)				Surface Salinity (psu)				Bottom Salinity (psu)			
	Mean	Median	Minimum	Maximum	Mean	Median	Minimum	Maximum	Mean	Median	Minimum	Maximum
2003	1.12	1.17	-1.69	5.1	0.2	0.2	0.0	1.8	0.2	0.2	0.0	2.0
2004	1.14	1.07	-1.98	5.6	0.2	0.2	0.1	6.8	0.2	0.2	0.1	6.7
2005	1.10	1.19	-1.47	3.8	0.1	0.1	0.1	3.3	0.1	0.1	0.1	3.4
2006	0.75	0.79	-2.10	3.5	1.1	0.3	0.1	14.1	1.2	0.3	0.1	14.1
2007	0.72	0.77	-1.77	3.6	1.7	0.5	0.2	22.2	1.7	0.5	0.2	20.8
2008	0.71	0.77	-2.68	3.4	1.7	0.6	0.1	13.7	1.7	0.6	0.1	13.9
2009	0.84	0.91	-2.33	3.1	2.0	0.3	0.1	18.8	2.0	0.3	0.1	18.6
2010	0.80	0.87	-2.01	2.9	0.3	0.2	0.1	4.9	0.3	0.2	0.1	4.9
2011	0.73	0.77	-2.16	3.7	0.8	0.3	0.1	11.6	0.8	0.3	0.1	11.8
2012	0.96	1.03	-1.76	4.5	2.1	0.3	0.1	17.4	2.1	0.3	0.1	17.3
2013	0.95	1.03	-1.88	3.4	0.6	0.3	0.1	8.8	0.7	0.3	0.1	9.0
2014	0.93	0.99	-1.80	2.9	0.3	0.2	0.1	6.8	0.3	0.2	0.1	6.8
2015	1.12	1.17	-2.11	3.3	0.2	0.2	0.1	4.8	0.2	0.2	0.1	4.8
2016	1.17	1.24	-1.56	4.0	0.2	0.1	0.1	3.6	0.2	0.1	0.1	3.7

Table 4.13

Correlation of Surface Water Salinity with 7-Day Average Flow by Category at Fixed Stations

Water Quality Parameter	Overall	<106 cfs	106-192 cfs	192-477 cfs	477-1259 cfs	1259-3063 cfs	> 3063 cfs
River Kilometer -2.4							
Correlation Coefficient (R)	**-0.69338**	-0.16997	**-0.33007**	-0.09415	**-0.26293**	**-0.32890**	**-0.54609**
Probability	**<.0001**	0.2534	**0.0056**	0.2983	**0.0062**	**0.0045**	**<.0001**
Number of Observations	**471**	47	**69**	124	**107**	**73**	**51**
River Kilometer 6.6							
Correlation Coefficient (R)	**-0.67554**	**-0.35277**	**-0.27469**	**-0.27162**	**-0.31195**	**-0.47182**	**-0.49466**
Probability	**<.0001**	**0.0077**	**0.0179**	**0.0013**	**0.0006**	**<.0001**	**0.0002**
Number of Observations	**519**	**56**	**74**	**138**	**117**	**83**	**51**
River Kilometer 15.5							
Correlation Coefficient (R)	**-0.44974**	**-0.51860**	**-0.39959**	**-0.48743**	**-0.24028**	**-0.35983**	-0.22143
Probability	**<.0001**	**<.0001**	**0.0007**	**<.0001**	**0.0091**	**0.0011**	0.1184
Number of Observations	**504**	**54**	**68**	**135**	**117**	**79**	51
River Kilometer 23.6							
Correlation Coefficient (R)	**-0.25168**	**-0.60145**	**-0.32898**	**-0.38868**	**-0.25932**	-0.10981	-0.12457
Probability	**<.0001**	**<.0001**	**0.0070**	**<.0001**	**0.0048**	0.3354	0.3838
Number of Observations	**500**	**54**	**66**	**133**	**117**	79	51
River Kilometer 30.7							
Correlation Coefficient (R)	**-0.16444**	**-0.66554**	-0.20703	-0.03970	**-0.24473**	-0.07115	-0.13286
Probability	**0.0002**	**<.0001**	0.0953	0.6501	**0.0081**	0.5386	0.3527
Number of Observations	**497**	**54**	66	133	**116**	77	51

* **Blue** highlights statistically significant relationships

** **Red** highlights statistically significant relationships explaining more than twenty-five percent of the observed variation

Table 4.14

Correlation of Isohaline Location (River Kilometer) with 7-Day Average Flow by Category

Water Quality Parameter	Overall	<106 cfs	106-192 cfs	192-477 cfs	477-1259 cfs	1259-3063 cfs	> 3063 cfs
0 psu Salinity Zone							
Correlation Coefficient (R)	**-0.60476**	-0.29649	-0.24114	**-0.27018**	**-0.27443**	-0.15494	-0.26869
Probability	**<.0001**	0.0707	0.0790	**0.0096**	**0.0031**	0.2498	0.0648
Number of Observations	**402**	38	54	**91**	**114**	57	48
6 psu Salinity Zone							
Correlation Coefficient (R)	**-0.68689**	**-0.73000**	**-0.50187**	**-0.36392**	-0.13990	-0.15819	**-0.36857**
Probability	**<.0001**	**<.0001**	**0.0001**	**0.0004**	0.1377	0.2399	**0.0099**
Number of Observations	**403**	**38**	**54**	**92**	114	57	**48**
12 psu Salinity Zone							
Correlation Coefficient (R)	**-0.76063**	**-0.68442**	**-0.46419**	**-0.28454**	-0.08441	**-0.26194**	**-0.45990**
Probability	**<.0001**	**<.0001**	**0.0005**	**0.0063**	0.3698	**0.0490**	**0.0010**
Number of Observations	**403**	**39**	**53**	**91**	115	**57**	**48**
20 psu Salinity Zone							
Correlation Coefficient (R)	**-0.74000**	**-0.66769**	**-0.36063**	**-0.28915**	-0.07566	**-0.34634**	**-0.45562**
Probability	**<.0001**	**<.0001**	**0.0080**	**0.0054**	0.4216	**0.0083**	**0.0011**
Number of Observations	**403**	**39**	**53**	**91**	115	**57**	**48**

* **Blue** highlights statistically significant relationships

** **Red** highlights statistically significant relationships explaining more than twenty-five percent of the observed variation

Table 4.17. Best Fit GLM Model of Surface Salinity at HBMP recorder at RK 9.2

The GLM Procedure

Number of Observations Read	156956
Number of Observations Used	43913

Table 4.17. Best Fit GLM Model of Surface Salinity at HBMP recorder at RK 9.2

The GLM Procedure

Dependent Variable: SAL_T

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	2378916.296	475783.259	53341.3	<.0001
Error	43907	391633.362	8.920		
Corrected Total	43912	2770549.658			

R-Square	Coeff Var	Root MSE	SAL_T Mean
0.858644	21.84889	2.986572	13.66921

Source	DF	Type I SS	Mean Square	F Value	Pr > F
LFLOW	1	1978529.132	1978529.132	221818	<.0001
FGH	1	49826.769	49826.769	5586.20	<.0001
LF5	1	59135.498	59135.498	6629.83	<.0001
GHEIGHT	1	228146.556	228146.556	25578.1	<.0001
LF30	1	63278.341	63278.341	7094.29	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LFLOW	1	29871.7825	29871.7825	3349.00	<.0001
FGH	1	13157.2415	13157.2415	1475.09	<.0001
LF5	1	4998.5321	4998.5321	560.40	<.0001
GHEIGHT	1	252462.5275	252462.5275	28304.2	<.0001
LF30	1	63278.3411	63278.3411	7094.29	<.0001

Table 4.17. Best Fit GLM Model of Surface Salinity at HBMP recorder at RK 9.2

The GLM Procedure

Dependent Variable: SAL_T

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	49.45943556	0.10600346	466.58	<.0001
LFLOW	-2.63443139	0.04552283	-57.87	<.0001
FGH	-0.00047635	0.00001240	-38.41	<.0001
LF5	-1.23206034	0.05204556	-23.67	<.0001
GHEIGHT	3.82346358	0.02272644	168.24	<.0001
LF30	-2.28312277	0.02710658	-84.23	<.0001

Table 4.18. Best Fit GLM Model of Surface Salinity at HBMP recorder at RK 12.7

The GLM Procedure

Number of Observations Read	43983
Number of Observations Used	41479

Table 4.18. Best Fit GLM Model of Surface Salinity at HBMP recorder at RK 12.7

The GLM Procedure

Dependent Variable: SAL_T

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	1540335.991	308067.198	50601.5	<.0001
Error	41473	252491.858	6.088		
Corrected Total	41478	1792827.849			

R-Square	Coeff Var	Root MSE	SAL_T Mean
0.859166	31.62997	2.467408	7.800855

Source	DF	Type I SS	Mean Square	F Value	Pr > F
FGH	1	362355.6481	362355.6481	59518.7	<.0001
F5	1	448837.2344	448837.2344	73723.7	<.0001
LF52	1	550923.2663	550923.2663	90491.8	<.0001
GHEIGHT	1	151276.9413	151276.9413	24848.0	<.0001
LF30	1	26942.9007	26942.9007	4425.50	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
FGH	1	26470.2169	26470.2169	4347.86	<.0001
F5	1	55556.0446	55556.0446	9125.35	<.0001
LF52	1	157016.0513	157016.0513	25790.6	<.0001
GHEIGHT	1	161449.7249	161449.7249	26518.9	<.0001
LF30	1	26942.9007	26942.9007	4425.50	<.0001

Table 4.18. Best Fit GLM Model of Surface Salinity at HBMP recorder at RK 12.7

The GLM Procedure

Dependent Variable: SAL_T

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	45.30665628	0.11464794	395.18	<.0001
FGH	-0.00076377	0.00001158	-65.94	<.0001
F5	0.00228495	0.00002392	95.53	<.0001
LF52	-2.55553924	0.01591298	-160.59	<.0001
GHEIGHT	3.24837617	0.01994751	162.85	<.0001
LF30	-1.57018858	0.02360318	-66.52	<.0001

Table 4.19. Best Fit GLM Model of Surface Salinity at Harbour Heights (RK 15.5)

The GLM Procedure

Number of Observations Read	155976
Number of Observations Used	145157

Table 4.19. Best Fit GLM Model of Surface Salinity at Harbour Heights (RK 15.5)

The GLM Procedure

Dependent Variable: SAL_T SALINITY

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	5014605.227	716372.175	133643	<.0001
Error	145149	778046.470	5.360		
Corrected Total	145156	5792651.697			

R-Square	Coeff Var	Root MSE	SAL_T Mean
0.865684	34.43906	2.315239	6.722711

Source	DF	Type I SS	Mean Square	F Value	Pr > F
FGH	1	905445.664	905445.664	168916	<.0001
F5	1	1218033.165	1218033.165	227231	<.0001
GHEIGHT	1	210029.831	210029.831	39182.3	<.0001
F402	1	18.995	18.995	3.54	0.0598
LF52	1	2474596.296	2474596.296	461650	<.0001
F40	1	38486.472	38486.472	7179.87	<.0001
LF402	1	167994.805	167994.805	31340.4	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
FGH	1	69521.0487	69521.0487	12969.5	<.0001
F5	1	116804.1624	116804.1624	21790.5	<.0001
GHEIGHT	1	374544.5803	374544.5803	69873.4	<.0001
F402	1	21260.3414	21260.3414	3966.24	<.0001
LF52	1	461579.3878	461579.3878	86110.3	<.0001
F40	1	46886.8128	46886.8128	8747.00	<.0001
LF402	1	167994.8046	167994.8046	31340.4	<.0001

Table 4.19. Best Fit GLM Model of Surface Salinity at Harbour Heights (RK 15.5)

The GLM Procedure

Dependent Variable: SAL_T SALINITY

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	49.36268243	0.07373284	669.48	<.0001
FGH	-0.00071696	0.00000630	-113.88	<.0001
F5	0.00197839	0.00001340	147.62	<.0001
GHEIGHT	2.58285730	0.00977112	264.34	<.0001
F402	-0.00000018	0.00000000	-62.98	<.0001
LF52	-2.22080253	0.00756802	-293.45	<.0001
F40	0.00245395	0.00002624	93.53	<.0001
LF402	-1.64776415	0.00930771	-177.03	<.0001

Table 4.20. Best Fit GLM Model of Surface Salinity at HBMP recorder at RK 18.5

The GLM Procedure

Number of Observations Read	37214
Number of Observations Used	35447

Table 4.20. Best Fit GLM Model of Surface Salinity at HBMP recorder at RK 18.5

The GLM Procedure

Dependent Variable: SAL_T

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	731850.1886	91481.2736	34759.9	<.0001
Error	35438	93265.9473	2.6318		
Corrected Total	35446	825116.1359			

R-Square	Coeff Var	Root MSE	SAL_T Mean
0.886966	35.00206	1.622284	4.634826

Source	DF	Type I SS	Mean Square	F Value	Pr > F
FLOW2	1	192557.9941	192557.9941	73165.7	<.0001
LFLOW	1	325896.3943	325896.3943	123830	<.0001
FGH	1	18886.4230	18886.4230	7176.22	<.0001
GHEIGHT	1	104287.8844	104287.8844	39626.0	<.0001
F10	1	4958.8979	4958.8979	1884.22	<.0001
F102	1	9921.8901	9921.8901	3769.99	<.0001
LF102	1	70000.5152	70000.5152	26597.9	<.0001
LF302	1	5340.1896	5340.1896	2029.10	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
FLOW2	1	7279.5216	7279.5216	2765.98	<.0001
LFLOW	1	3658.4306	3658.4306	1390.08	<.0001
FGH	1	26373.3027	26373.3027	10021.0	<.0001
GHEIGHT	1	117336.6662	117336.6662	44584.1	<.0001
F10	1	18017.3509	18017.3509	6846.00	<.0001
F102	1	7283.9696	7283.9696	2767.67	<.0001

Table 4.20. Best Fit GLM Model of Surface Salinity at HBMP recorder at RK 18.5

The GLM Procedure

Dependent Variable: SAL_T

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LF102	1	34313.0439	34313.0439	13037.8	<.0001
LF302	1	5340.1896	5340.1896	2029.10	<.0001

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	42.61303280	0.14479691	294.30	<.0001
FLOW2	0.00000122	0.00000002	52.59	<.0001
LFLOW	-1.10457112	0.02962601	-37.28	<.0001
FGH	-0.00232876	0.00002326	-100.10	<.0001
GHEIGHT	3.58141250	0.01696151	211.15	<.0001
F10	0.00784817	0.00009485	82.74	<.0001
F102	-0.00000106	0.00000002	-52.61	<.0001
LF102	-2.73728635	0.02397273	-114.18	<.0001
LF302	-0.45392090	0.01007694	-45.05	<.0001

Table 4.21. Best Fit GLM Model of Surface Salinity at HBMP recorder at RK 18.7

The GLM Procedure

Number of Observations Read	37000
Number of Observations Used	35365

Table 4.21. Best Fit GLM Model of Surface Salinity at HBMP recorder at RK 18.7

The GLM Procedure

Dependent Variable: SAL_T

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	714696.9673	119116.1612	48312.4	<.0001
Error	35358	87176.5273	2.4655		
Corrected Total	35364	801873.4945			

R-Square	Coeff Var	Root MSE	SAL_T Mean
0.891284	31.38480	1.570203	5.003070

Source	DF	Type I SS	Mean Square	F Value	Pr > F
FGH	1	132953.0332	132953.0332	53924.5	<.0001
GHEIGHT	1	112790.5223	112790.5223	45746.8	<.0001
F10	1	117871.3115	117871.3115	47807.5	<.0001
F102	1	179123.4162	179123.4162	72650.8	<.0001
LF102	1	166386.8656	166386.8656	67485.0	<.0001
LF302	1	5571.8185	5571.8185	2259.88	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
FGH	1	10007.95821	10007.95821	4059.14	<.0001
GHEIGHT	1	42380.12145	42380.12145	17189.0	<.0001
F10	1	21239.38478	21239.38478	8614.50	<.0001
F102	1	5975.97004	5975.97004	2423.80	<.0001
LF102	1	81594.08271	81594.08271	33093.8	<.0001
LF302	1	5571.81847	5571.81847	2259.88	<.0001

Table 4.21. Best Fit GLM Model of Surface Salinity at HBMP recorder at RK 18.7

The GLM Procedure

Dependent Variable: SAL_T

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	44.49261722	0.13870807	320.76	<.0001
FGH	-0.00115371	0.00001811	-63.71	<.0001
GHEIGHT	1.95297327	0.01489605	131.11	<.0001
F10	0.00817427	0.00008807	92.81	<.0001
F102	-0.00000096	0.00000002	-49.23	<.0001
LF102	-3.30585466	0.01817232	-181.92	<.0001
LF302	-0.45613803	0.00959519	-47.54	<.0001

Table 4.22. Best Fit GLM Model of Surface Salinity at HBMP recorder at RK 20.8

The GLM Procedure

Number of Observations Read	37214
Number of Observations Used	35443

Table 4.22. Best Fit GLM Model of Surface Salinity at HBMP recorder at RK 20.8

The GLM Procedure

Dependent Variable: SAL_T

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	433487.0451	61926.7207	29114.0	<.0001
Error	35435	75371.8167	2.1270		
Corrected Total	35442	508858.8618			

R-Square	Coeff Var	Root MSE	SAL_T Mean
0.851881	48.63481	1.458439	2.998756

Source	DF	Type I SS	Mean Square	F Value	Pr > F
FLOW2	1	84267.0641	84267.0641	39617.0	<.0001
FGH	1	15.3787	15.3787	7.23	0.0072
GHEIGHT	1	89992.7648	89992.7648	42308.8	<.0001
F10	1	41748.0852	41748.0852	19627.3	<.0001
F102	1	87130.7831	87130.7831	40963.3	<.0001
LF102	1	127606.1008	127606.1008	59992.2	<.0001
LF402	1	2726.8683	2726.8683	1282.00	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
FLOW2	1	5461.29952	5461.29952	2567.55	<.0001
FGH	1	24323.29851	24323.29851	11435.3	<.0001
GHEIGHT	1	86096.97808	86096.97808	40477.3	<.0001
F10	1	27156.32996	27156.32996	12767.2	<.0001
F102	1	12415.55344	12415.55344	5837.00	<.0001
LF102	1	76685.63479	76685.63479	36052.7	<.0001
LF402	1	2726.86835	2726.86835	1282.00	<.0001

Table 4.22. Best Fit GLM Model of Surface Salinity at HBMP recorder at RK 20.8

The GLM Procedure

Dependent Variable: SAL_T

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	35.61670700	0.12956331	274.90	<.0001
FLOW2	0.00000091	0.00000002	50.67	<.0001
FGH	-0.00221749	0.00002074	-106.94	<.0001
GHEIGHT	3.06221269	0.01522053	201.19	<.0001
F10	0.00948081	0.00008391	112.99	<.0001
F102	-0.00000139	0.00000002	-76.40	<.0001
LF102	-3.05037473	0.01606514	-189.88	<.0001
LF402	-0.25228128	0.00704598	-35.81	<.0001

Table 4.23. Best Fit GLM Model of Surface Salinity at HBMP recorder at RK 21.9

The GLM Procedure

Number of Observations Read	78271
Number of Observations Used	74420

Table 4.23. Best Fit GLM Model of Surface Salinity at HBMP recorder at RK 21.9

The GLM Procedure

Dependent Variable: SAL_T

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	773398.7382	96674.8423	48109.8	<.0001
Error	74411	149526.1426	2.0095		
Corrected Total	74419	922924.8808			

R-Square	Coeff Var	Root MSE	SAL_T Mean
0.837987	53.15141	1.417555	2.667014

Source	DF	Type I SS	Mean Square	F Value	Pr > F
FLOW2	1	120012.6570	120012.6570	59723.7	<.0001
FGH	1	1504.5513	1504.5513	748.73	<.0001
GHEIGHT	1	128203.9185	128203.9185	63800.1	<.0001
F10	1	73117.3343	73117.3343	36386.5	<.0001
F102	1	153744.8366	153744.8366	76510.4	<.0001
LF102	1	284380.4623	284380.4623	141521	<.0001
F60	1	2571.6317	2571.6317	1279.76	<.0001
LF602	1	9863.3467	9863.3467	4908.45	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
FLOW2	1	7418.4118	7418.4118	3691.74	<.0001
FGH	1	32470.6110	32470.6110	16158.9	<.0001
GHEIGHT	1	113253.7471	113253.7471	56360.2	<.0001
F10	1	55281.6692	55281.6692	27510.7	<.0001
F102	1	29220.3119	29220.3119	14541.4	<.0001
LF102	1	148838.7648	148838.7648	74068.9	<.0001

Table 4.23. Best Fit GLM Model of Surface Salinity at HBMP recorder at RK 21.9

The GLM Procedure

Dependent Variable: SAL_T

Source	DF	Type III SS	Mean Square	F Value	Pr > F
F60	1	3112.5731	3112.5731	1548.96	<.0001
LF602	1	9863.3467	9863.3467	4908.45	<.0001

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	35.84306008	0.08489729	422.19	<.0001
FLOW2	0.00000079	0.00000001	60.76	<.0001
FGH	-0.00188888	0.00001486	-127.12	<.0001
GHEIGHT	2.28796242	0.00963746	237.40	<.0001
F10	0.01025512	0.00006183	165.86	<.0001
F102	-0.00000168	0.00000001	-120.59	<.0001
LF102	-2.89215147	0.01062681	-272.16	<.0001
F60	0.00063102	0.00001603	39.36	<.0001
LF602	-0.48505034	0.00692332	-70.06	<.0001

Table 4.24. Best Fit GLM Model of Surface Salinity at HBMP recorder at RK 24.5

The GLM Procedure

Number of Observations Read	55073
Number of Observations Used	53088

Table 4.24. Best Fit GLM Model of Surface Salinity at HBMP recorder at RK 24.5

The GLM Procedure

Dependent Variable: SAL_T

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	316240.8383	35137.8709	27085.5	<.0001
Error	53078	68857.6952	1.2973		
Corrected Total	53087	385098.5336			

R-Square	Coeff Var	Root MSE	SAL_T Mean
0.821195	56.02187	1.138988	2.033112

Source	DF	Type I SS	Mean Square	F Value	Pr > F
FLOW2	1	67774.14318	67774.14318	52242.8	<.0001
FGH	1	6641.60150	6641.60150	5119.59	<.0001
GHEIGHT	1	81810.29986	81810.29986	63062.3	<.0001
F10	1	28856.22199	28856.22199	22243.4	<.0001
F102	1	52978.88974	52978.88974	40838.0	<.0001
LF102	1	72186.44154	72186.44154	55643.9	<.0001
F40	1	580.61976	580.61976	447.56	<.0001
F402	1	762.78819	762.78819	587.98	<.0001
LF402	1	4649.83257	4649.83257	3584.26	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
FLOW2	1	2609.74470	2609.74470	2011.69	<.0001
FGH	1	22009.61252	22009.61252	16965.8	<.0001
GHEIGHT	1	61269.66719	61269.66719	47228.9	<.0001
F10	1	11225.08527	11225.08527	8652.70	<.0001
F102	1	5355.54019	5355.54019	4128.24	<.0001
LF102	1	26765.40535	26765.40535	20631.7	<.0001

Table 4.24. Best Fit GLM Model of Surface Salinity at HBMP recorder at RK 24.5

The GLM Procedure

Dependent Variable: SAL_T

Source	DF	Type III SS	Mean Square	F Value	Pr > F
F40	1	2112.38378	2112.38378	1628.30	<.0001
F402	1	1303.18909	1303.18909	1004.55	<.0001
LF402	1	4649.83257	4649.83257	3584.26	<.0001

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	34.98648063	0.13265775	263.73	<.0001
FLOW2	0.00000527	0.00000012	44.85	<.0001
FGH	-0.00579072	0.00004446	-130.25	<.0001
GHEIGHT	2.61304978	0.01202386	217.32	<.0001
F10	0.02236941	0.00024048	93.02	<.0001
F102	-0.00000902	0.00000014	-64.25	<.0001
LF102	-2.89556847	0.02015886	-143.64	<.0001
F40	0.00381304	0.00009449	40.35	<.0001
F402	-0.00000088	0.00000003	-31.69	<.0001
LF402	-0.85386941	0.01426237	-59.87	<.0001

Table 4.25. Best Fit GLM Model of Surface Salinity at Peace River Heights (RK 26.7)

The GLM Procedure

Number of Observations Read	87495
Number of Observations Used	83147

Table 4.25. Best Fit GLM Model of Surface Salinity at Peace River Heights (RK 26.7)

The GLM Procedure

Dependent Variable: SAL_T

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	176878.1892	19653.1321	21804.0	<.0001
Error	83137	74935.7824	0.9014		
Corrected Total	83146	251813.9716			

R-Square	Coeff Var	Root MSE	SAL_T Mean
0.702416	92.10223	0.949396	1.030807

Source	DF	Type I SS	Mean Square	F Value	Pr > F
FGH	1	2061.99584	2061.99584	2287.67	<.0001
F5	1	46920.83049	46920.83049	52056.0	<.0001
F52	1	32389.36586	32389.36586	35934.2	<.0001
LFLOW2	1	2165.23642	2165.23642	2402.21	<.0001
GHEIGHT	1	34131.42511	34131.42511	37866.9	<.0001
F402	1	20.18852	20.18852	22.40	<.0001
LF52	1	47571.17686	47571.17686	52777.5	<.0001
F40	1	998.83520	998.83520	1108.15	<.0001
LF402	1	10619.13489	10619.13489	11781.3	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
FGH	1	18940.14792	18940.14792	21013.0	<.0001
F5	1	13613.76041	13613.76041	15103.7	<.0001
F52	1	6946.13579	6946.13579	7706.34	<.0001
LFLOW2	1	2301.18006	2301.18006	2553.03	<.0001
GHEIGHT	1	40546.46102	40546.46102	44984.0	<.0001
F402	1	1799.54158	1799.54158	1996.49	<.0001

Table 4.25. Best Fit GLM Model of Surface Salinity at Peace River Heights (RK 26.7)

The GLM Procedure

Dependent Variable: SAL_T

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LF52	1	26544.40615	26544.40615	29449.5	<.0001
F40	1	4630.71470	4630.71470	5137.52	<.0001
LF402	1	10619.13489	10619.13489	11781.3	<.0001

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	24.52510194	0.10558736	232.27	<.0001
FGH	-0.00382005	0.00002635	-144.96	<.0001
F5	0.02656791	0.00021618	122.90	<.0001
F52	-0.00001470	0.00000017	-87.79	<.0001
LFLOW2	0.35336816	0.00699358	50.53	<.0001
GHEIGHT	1.60472767	0.00756610	212.09	<.0001
F402	-0.00000021	0.00000000	-44.68	<.0001
LF52	-2.51835768	0.01467501	-171.61	<.0001
F40	0.00183152	0.00002555	71.68	<.0001
LF402	-0.61913294	0.00570410	-108.54	<.0001

Table 4.26. Best Fit GLM Model of Surface Salinity at Peace River Heights (RK 29.8)

The GLM Procedure

Number of Observations Read	20352
Number of Observations Used	19699

Table 4.26. Best Fit GLM Model of Surface Salinity at Peace River Heights (RK 29.8)

The GLM Procedure

Dependent Variable: SAL_T

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	895.923082	99.547009	2669.23	<.0001
Error	19689	734.286658	0.037294		
Corrected Total	19698	1630.209740			

R-Square	Coeff Var	Root MSE	SAL_T Mean
0.549575	65.66430	0.193117	0.294098

Source	DF	Type I SS	Mean Square	F Value	Pr > F
F5	1	101.7737416	101.7737416	2728.94	<.0001
F52	1	103.9213803	103.9213803	2786.52	<.0001
GHeight	1	6.9443278	6.9443278	186.20	<.0001
F602	1	0.0457184	0.0457184	1.23	0.2682
LF52	1	538.2832347	538.2832347	14433.4	<.0001
F30	1	16.2706077	16.2706077	436.28	<.0001
LF402	1	50.6928352	50.6928352	1359.27	<.0001
F60	1	19.1057751	19.1057751	512.30	<.0001
LF602	1	58.8854613	58.8854613	1578.94	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
F5	1	271.4571611	271.4571611	7278.79	<.0001
F52	1	208.8682522	208.8682522	5600.55	<.0001
GHeight	1	3.7614327	3.7614327	100.86	<.0001
F602	1	56.3280114	56.3280114	1510.37	<.0001
LF52	1	335.9789055	335.9789055	9008.86	<.0001
F30	1	5.9187915	5.9187915	158.71	<.0001

Table 4.26. Best Fit GLM Model of Surface Salinity at Peace River Heights (RK 29.8)

The GLM Procedure

Dependent Variable: SAL_T

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LF402	1	12.5510931	12.5510931	336.54	<.0001
F60	1	77.9448300	77.9448300	2090.00	<.0001
LF602	1	58.8854613	58.8854613	1578.94	<.0001

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	13.93020575	0.10719055	129.96	<.0001
F5	0.02414887	0.00028305	85.32	<.0001
F52	-0.00002292	0.00000031	-74.84	<.0001
GHeight	0.01727424	0.00172006	10.04	<.0001
F602	-0.00000036	0.00000001	-38.86	<.0001
LF52	-1.41440145	0.01490176	-94.92	<.0001
F30	0.00019716	0.00001565	12.60	<.0001
LF402	-0.06892069	0.00375690	-18.35	<.0001
F60	0.00133371	0.00002917	45.72	<.0001
LF602	-0.20410608	0.00513657	-39.74	<.0001

Table 4.28
Modeled Differences Between "No Withdrawal" and "Actual Withdrawals" Annual Statistics based on Daily Averages of Hourly Estimates

Year	River Kilometer	Modeled Differences (Increases) Between No-Withdrawals and Actual Facility Withdrawals			
		Mean (psu)	Median (psu)	5th Percentile (psu)	95th Percentile (psu)
1998	RK 9.2	0.47	0.47	0.00	1.02
	RK 12.7	0.53	0.39	0.00	1.35
	RK 15.5	0.52	0.27	0.00	1.41
	RK 18.5	0.29	0.00	0.00	1.04
	RK 18.7	0.38	0.00	0.00	1.22
	RK 20.8	0.24	0.00	0.00	0.96
	RK 21.9	0.23	0.00	0.00	0.95
	RK 24.5	0.13	0.00	0.00	0.78
	RK 26.7	0.07	0.00	0.00	0.51
1999	RK 9.2	0.79	0.79	0.00	1.51
	RK 12.7	1.01	1.02	0.00	2.00
	RK 15.5	1.00	1.06	0.00	2.11
	RK 18.5	0.62	0.58	0.00	1.61
	RK 18.7	0.76	0.74	0.00	1.89
	RK 20.8	0.54	0.42	0.00	1.54
	RK 21.9	0.51	0.30	0.00	1.52
	RK 24.5	0.34	0.00	0.00	1.35
	RK 26.7	0.20	0.00	0.00	1.00
2000	RK 9.2	1.09	1.07	0.67	1.69
	RK 12.7	1.77	1.70	0.90	2.88
	RK 15.5	1.94	1.90	0.54	3.24
	RK 18.5	1.39	1.42	0.00	2.52
	RK 18.7	1.68	1.71	0.00	2.99
	RK 20.8	1.33	1.42	0.00	2.56
	RK 21.9	1.31	1.42	0.00	2.59
	RK 24.5	1.07	1.06	0.00	2.63
	RK 26.7	0.88	0.86	0.00	2.09
2001	RK 9.2	0.89	0.93	0.00	1.43
	RK 12.7	1.38	1.40	0.00	2.64
	RK 15.5	1.50	1.53	0.00	3.01
	RK 18.5	1.07	1.12	0.00	2.38
	RK 18.7	1.30	1.34	0.00	2.82
	RK 20.8	1.04	1.09	0.00	2.45
	RK 21.9	1.03	1.07	0.00	2.49
	RK 24.5	0.89	0.76	0.00	2.49
	RK 26.7	0.55	0.12	0.00	1.89
2002	RK 9.2	0.87	0.94	0.00	1.50

Table 4.28
Modeled Differences Between “No Withdrawal” and “Actual Withdrawals” Annual Statistics based on Daily Averages of Hourly Estimates

Year	River Kilometer	Modeled Differences (Increases) Between No-Withdrawals and Actual Facility Withdrawals			
		Mean (psu)	Median (psu)	5th Percentile (psu)	95th Percentile (psu)
	RK 12.7	0.98	0.99	0.00	2.54
	RK 15.5	0.98	0.79	0.00	2.81
	RK 18.5	0.64	0.22	0.00	2.16
	RK 18.7	0.79	0.37	0.00	2.58
	RK 20.8	0.58	0.00	0.00	2.18
	RK 21.9	0.56	0.00	0.00	2.17
	RK 24.5	0.38	0.00	0.00	1.96
	RK 26.7	0.29	0.00	0.00	1.60
2003	RK 9.2	0.36	0.41	0.00	0.90
	RK 12.7	0.36	0.21	0.00	1.22
	RK 15.5	0.33	0.00	0.00	1.25
	RK 18.5	0.15	0.00	0.00	0.73
	RK 18.7	0.21	0.00	0.00	0.86
	RK 20.8	0.11	0.00	0.00	0.62
	RK 21.9	0.09	0.00	0.00	0.58
	RK 24.5	0.03	0.00	0.00	0.26
	RK 26.7	0.02	0.00	0.00	0.17
2004	RK 9.2	0.61	0.63	0.00	1.38
	RK 12.7	0.67	0.66	0.00	1.63
	RK 15.5	0.64	0.47	0.00	1.57
	RK 18.5	0.34	0.02	0.00	1.12
	RK 18.7	0.44	0.26	0.00	1.30
	RK 20.8	0.26	0.00	0.00	1.00
	RK 21.9	0.23	0.00	0.00	0.97
	RK 24.5	0.11	0.00	0.00	0.75
	RK 26.7	0.05	0.00	0.00	0.45
2005	RK 9.2	0.45	0.56	0.00	0.84
	RK 12.7	0.37	0.37	0.00	0.96
	RK 15.5	0.31	0.01	0.00	0.90
	RK 18.5	0.11	0.00	0.00	0.56
	RK 18.7	0.17	0.00	0.00	0.62
	RK 20.8	0.07	0.00	0.00	0.44
	RK 21.9	0.05	0.00	0.00	0.38
	RK 24.5	0.04	0.00	0.00	0.05
	RK 26.7	0.00	0.00	0.00	0.01
2006	RK 9.2	0.94	0.86	0.52	1.51
	RK 12.7	1.17	1.23	0.00	1.97

Table 4.28
Modeled Differences Between "No Withdrawal" and "Actual Withdrawals" Annual Statistics based on Daily Averages of Hourly Estimates

Year	River Kilometer	Modeled Differences (Increases) Between No-Withdrawals and Actual Facility Withdrawals			
		Mean (psu)	Median (psu)	5th Percentile (psu)	95th Percentile (psu)
2006	RK 15.5	1.22	1.31	0.00	2.05
	RK 18.5	0.81	0.90	0.00	1.50
	RK 18.7	0.98	1.05	0.00	1.78
	RK 20.8	0.70	0.79	0.00	1.37
	RK 21.9	0.66	0.72	0.00	1.34
	RK 24.5	0.44	0.27	0.00	1.29
	RK 26.7	0.32	0.14	0.00	0.95
2007	RK 9.2	0.87	0.84	0.43	1.32
	RK 12.7	1.30	1.26	0.79	1.90
	RK 15.5	1.39	1.37	0.86	1.93
	RK 18.5	0.98	1.00	0.44	1.41
	RK 18.7	1.17	1.16	0.69	1.66
	RK 20.8	0.88	0.93	0.00	1.38
	RK 21.9	0.84	0.91	0.00	1.39
	RK 24.5	0.57	0.65	0.00	1.23
	RK 26.7	0.37	0.37	0.00	0.90
2008	RK 9.2	0.90	0.87	0.00	1.66
	RK 12.7	1.14	1.22	0.00	2.00
	RK 15.5	1.18	1.31	0.00	2.19
	RK 18.5	0.84	1.00	0.00	1.65
	RK 18.7	0.97	1.16	0.00	1.92
	RK 20.8	0.74	0.95	0.00	1.55
	RK 21.9	0.72	0.95	0.00	1.51
	RK 24.5	0.57	0.68	0.00	1.29
	RK 26.7	0.39	0.45	0.00	0.95
2009	RK 9.2	0.82	0.79	0.00	1.73
	RK 12.7	0.92	0.98	0.00	1.84
	RK 15.5	0.88	0.99	0.00	1.86
	RK 18.5	0.53	0.49	0.00	1.36
	RK 18.7	0.64	0.66	0.00	1.60
	RK 20.8	0.46	0.24	0.00	1.37
	RK 21.9	0.43	0.01	0.00	1.38
	RK 24.5	0.37	0.00	0.00	1.30
	RK 26.7	0.33	0.12	0.00	0.96
2010	RK 9.2	1.00	1.00	0.63	1.44
	RK 12.7	1.14	1.27	0.00	1.98
	RK 15.5	1.09	1.23	0.00	2.09

Table 4.28
Modeled Differences Between “No Withdrawal” and “Actual Withdrawals” Annual Statistics based on Daily Averages of Hourly Estimates

Year	River Kilometer	Modeled Differences (Increases) Between No-Withdrawals and Actual Facility Withdrawals			
		Mean (psu)	Median (psu)	5th Percentile (psu)	95th Percentile (psu)
	RK 18.5	0.56	0.52	0.00	1.36
	RK 18.7	0.75	0.79	0.00	1.68
	RK 20.8	0.44	0.17	0.00	1.32
	RK 21.9	0.39	0.00	0.00	1.30
	RK 24.5	0.21	0.00	0.00	0.99
	RK 26.7	0.11	0.00	0.00	0.64
	RK 29.8	0.04	0.00	0.00	0.21
2011	RK 9.2	0.99	0.97	0.42	1.74
	RK 12.7	1.12	1.16	0.00	1.80
	RK 15.5	1.13	1.18	0.00	1.92
	RK 18.5	0.74	0.87	0.00	1.47
	RK 18.7	0.88	0.96	0.00	1.70
	RK 20.8	0.62	0.70	0.00	1.43
	RK 21.9	0.58	0.66	0.00	1.40
	RK 24.5	0.39	0.07	0.00	1.40
	RK 26.7	0.24	0.01	0.00	1.04
	RK 29.8	0.09	0.00	0.00	0.42
2012	RK 9.2	1.00	0.93	0.28	2.06
	RK 12.7	1.15	1.13	0.00	2.57
	RK 15.5	1.15	1.18	0.00	2.67
	RK 18.5	0.81	0.92	0.00	1.92
	RK 18.7	0.94	0.96	0.00	2.30
	RK 20.8	0.74	0.78	0.00	1.87
	RK 21.9	0.72	0.74	0.00	1.89
	RK 24.5	0.58	0.45	0.00	1.79
	RK 26.7	0.41	0.19	0.00	1.44
	RK 29.8	0.16	0.04	0.00	0.67
2013	RK 9.2	0.86	0.89	0.00	1.60
	RK 12.7	0.86	1.01	0.00	1.87
	RK 15.5	0.90	1.09	0.00	1.87
	RK 18.5	0.69	0.87	0.00	1.42
	RK 18.7	0.76	0.91	0.00	1.66
	RK 20.8	0.61	0.72	0.00	1.37
	RK 21.9	0.59	0.71	0.00	1.35
	RK 24.5	0.46	0.48	0.00	1.14
	RK 26.7	0.28	0.19	0.00	0.78
	RK 29.8	0.08	0.00	0.00	0.30

Table 4.28
Modeled Differences Between "No Withdrawal" and "Actual Withdrawals" Annual Statistics based on Daily Averages of Hourly Estimates

Year	River Kilometer	Modeled Differences (Increases) Between No-Withdrawals and Actual Facility Withdrawals			
		Mean (psu)	Median (psu)	5th Percentile (psu)	95th Percentile (psu)
2014	RK 9.2	0.84	0.84	0.26	1.37
	RK 12.7	0.87	0.88	0.00	1.66
	RK 15.5	0.87	0.93	0.00	1.70
	RK 18.5	0.62	0.69	0.00	1.37
	RK 18.7	0.68	0.74	0.00	1.41
	RK 20.8	0.49	0.48	0.00	1.16
	RK 21.9	0.45	0.40	0.00	1.12
	RK 24.5	0.27	0.00	0.00	0.91
	RK 26.7	0.13	0.00	0.00	0.51
	RK 29.8	0.04	0.00	0.00	0.18
2015	RK 9.2	0.74	0.78	0.00	1.41
	RK 12.7	0.71	0.75	0.00	1.55
	RK 15.5	0.67	0.69	0.00	1.60
	RK 18.5	0.42	0.31	0.00	1.12
	RK 18.7	0.48	0.44	0.00	1.27
	RK 20.8	0.31	0.05	0.00	0.98
	RK 21.9	0.26	0.00	0.00	0.94
	RK 24.5	0.15	0.00	0.00	0.74
	RK 26.7	0.07	0.00	0.00	0.46
	RK 29.8	0.03	0.00	0.00	0.17
2016	RK 9.2	0.69	0.72	0.00	1.20
	RK 12.7	0.56	0.57	0.00	1.26
	RK 15.5	0.49	0.40	0.00	1.36
	RK 18.5	0.29	0.00	0.00	1.20
	RK 18.7	0.33	0.05	0.00	1.18
	RK 20.8	0.22	0.00	0.00	0.99
	RK 21.9	0.20	0.00	0.00	0.95
	RK 24.5	0.12	0.00	0.00	0.73
	RK 26.7	0.05	0.00	0.00	0.35
	RK 29.8	0.01	0.00	0.00	0.08

Table 4.33
Average Daily Estimated Salinity, Range and Difference due to Withdrawals at Selected Recorder Sites along the Lower River

Year	Site	Parameter	Mean	Min	P10	P25	P50	P75	P90	Max
1998	RK 9.2	Estimated Daily Average Salinity	8.2	0.0	0.0	0.0	8.0	15.1	19.5	23.6
1998	RK 9.2	Estimated Daily Range in Salinity	4.9	0.0	0.0	0.0	5.7	7.7	9.2	28.0
1998	RK 9.2	Estimated Change due to Withdrawals	0.5	0.0	0.0	0.0	0.5	0.8	0.9	1.9
1998	RK 12.7	Estimated Daily Average Salinity	4.3	0.0	0.0	0.0	2.3	8.2	12.2	16.1
1998	RK 12.7	Estimated Daily Range in Salinity	3.5	0.0	0.0	0.1	4.0	5.9	7.6	19.7
1998	RK 12.7	Estimated Change due to Withdrawals	0.5	-1.6	-0.1	0.0	0.4	1.0	1.2	2.9
1998	RK 15.5	Estimated Daily Average Salinity	3.4	0.0	0.0	0.0	1.4	6.2	10.7	15.0
1998	RK 15.5	Estimated Daily Range in Salinity	2.6	0.0	0.0	0.1	2.3	4.6	6.0	17.6
1998	RK 15.5	Estimated Change due to Withdrawals	0.4	-1.6	-0.3	0.0	0.2	1.0	1.3	3.1
1998	RK 18.5	Estimated Daily Average Salinity	2.5	0.0	0.0	0.0	0.9	4.6	7.5	12.8
1998	RK 18.5	Estimated Daily Range in Salinity	3.4	0.0	0.0	0.0	2.3	6.2	8.3	14.7
1998	RK 18.5	Estimated Change due to Withdrawals	-0.4	-13.0	-3.4	0.0	0.0	0.5	0.9	2.0
1998	RK 18.7	Estimated Daily Average Salinity	2.0	0.0	0.0	0.0	0.2	3.5	7.2	11.1
1998	RK 18.7	Estimated Daily Range in Salinity	1.5	0.0	0.0	0.0	0.9	2.8	4.0	12.7
1998	RK 18.7	Estimated Change due to Withdrawals	0.4	-0.4	0.0	0.0	0.0	0.7	1.1	2.4
1998	RK 20.8	Estimated Daily Average Salinity	1.1	0.0	0.0	0.0	0.2	1.6	4.0	7.4
1998	RK 20.8	Estimated Daily Range in Salinity	1.7	0.0	0.0	0.0	0.5	3.4	5.5	10.6
1998	RK 20.8	Estimated Change due to Withdrawals	0.2	-2.8	0.0	0.0	0.0	0.4	0.9	1.8
1998	RK 21.9	Estimated Daily Average Salinity	0.8	0.0	0.0	0.0	0.0	0.9	3.4	6.6
1998	RK 21.9	Estimated Daily Range in Salinity	1.1	0.0	0.0	0.0	0.0	2.2	4.0	8.8
1998	RK 21.9	Estimated Change due to Withdrawals	0.2	-0.6	0.0	0.0	0.0	0.3	0.9	1.8
1998	RK 24.5	Estimated Daily Average Salinity	0.4	0.0	0.0	0.0	0.0	0.5	1.3	3.8
1998	RK 24.5	Estimated Daily Range in Salinity	0.8	0.0	0.0	0.0	0.0	1.3	3.0	6.0
1998	RK 24.5	Estimated Change due to Withdrawals	0.1	-0.3	-0.1	0.0	0.0	0.1	0.5	1.6
1998	RK 26.7	Estimated Daily Average Salinity	0.2	0.0	0.0	0.0	0.0	0.2	0.6	1.8
1998	RK 26.7	Estimated Daily Range in Salinity	0.4	0.0	0.0	0.0	0.0	0.6	1.4	3.2
1998	RK 26.7	Estimated Change due to Withdrawals	0.1	-0.2	0.0	0.0	0.0	0.0	0.3	0.8
1999	RK 9.2	Estimated Daily Average Salinity	13.9	0.0	1.7	9.0	14.6	19.6	23.6	30.9
1999	RK 9.2	Estimated Daily Range in Salinity	6.8	0.0	3.1	6.0	7.1	8.4	9.3	22.5
1999	RK 9.2	Estimated Change due to Withdrawals	0.8	0.0	0.4	0.6	0.8	1.0	1.3	2.0
1999	RK 12.7	Estimated Daily Average Salinity	7.7	0.0	0.1	2.5	7.2	12.2	16.3	23.1
1999	RK 12.7	Estimated Daily Range in Salinity	5.2	0.0	0.5	4.1	5.6	6.7	7.8	15.1
1999	RK 12.7	Estimated Change due to Withdrawals	1.0	-0.1	0.0	0.6	1.0	1.4	1.7	3.2
1999	RK 15.5	Estimated Daily Average Salinity	6.3	0.0	0.1	1.1	5.3	10.5	14.9	21.6
1999	RK 15.5	Estimated Daily Range in Salinity	3.9	0.0	0.3	2.8	4.3	5.2	6.1	12.9
1999	RK 15.5	Estimated Change due to Withdrawals	1.0	-0.5	0.0	0.5	1.0	1.4	1.9	3.4
1999	RK 18.5	Estimated Daily Average Salinity	4.0	0.0	0.0	0.6	2.5	6.5	10.8	18.1
1999	RK 18.5	Estimated Daily Range in Salinity	4.1	0.0	0.2	1.6	4.5	6.5	7.6	10.6
1999	RK 18.5	Estimated Change due to Withdrawals	0.5	-6.0	-0.1	0.0	0.6	1.0	1.5	2.3

Table 4.33
Average Daily Estimated Salinity, Range and Difference due to Withdrawals at Selected Recorder Sites along the Lower River

Year	Site	Parameter	Mean	Min	P10	P25	P50	P75	P90	Max
1999	RK 18.7	Estimated Daily Average Salinity	4.1	0.0	0.0	0.3	2.7	7.1	11.0	16.7
1999	RK 18.7	Estimated Daily Range in Salinity	2.4	0.0	0.0	1.1	2.7	3.6	4.2	8.7
1999	RK 18.7	Estimated Change due to Withdrawals	0.8	-0.6	0.0	0.1	0.7	1.2	1.7	2.8
1999	RK 20.8	Estimated Daily Average Salinity	2.5	0.0	0.0	0.3	1.1	4.1	7.6	13.7
1999	RK 20.8	Estimated Daily Range in Salinity	3.0	0.0	0.0	1.0	2.8	5.1	6.0	8.0
1999	RK 20.8	Estimated Change due to Withdrawals	0.5	-1.9	-0.2	0.0	0.4	1.0	1.4	2.4
1999	RK 21.9	Estimated Daily Average Salinity	2.0	0.0	0.0	0.0	0.6	3.3	6.6	12.0
1999	RK 21.9	Estimated Daily Range in Salinity	2.0	0.0	0.0	0.3	1.6	3.7	4.5	6.0
1999	RK 21.9	Estimated Change due to Withdrawals	0.5	-0.9	0.0	0.0	0.3	0.9	1.4	2.4
1999	RK 24.5	Estimated Daily Average Salinity	1.1	0.0	0.0	0.0	0.3	1.3	3.9	9.3
1999	RK 24.5	Estimated Daily Range in Salinity	1.5	0.0	0.0	0.0	0.8	2.9	4.0	6.0
1999	RK 24.5	Estimated Change due to Withdrawals	0.3	-0.3	-0.1	0.0	0.0	0.7	1.1	2.1
1999	RK 26.7	Estimated Daily Average Salinity	0.5	0.0	0.0	0.0	0.2	0.5	1.9	5.2
1999	RK 26.7	Estimated Daily Range in Salinity	0.8	0.0	0.0	0.0	0.4	1.3	2.4	3.7
1999	RK 26.7	Estimated Change due to Withdrawals	0.2	-0.1	0.0	0.0	0.0	0.3	0.7	1.5
2000	RK 9.2	Estimated Daily Average Salinity	20.7	0.0	11.7	16.0	21.3	25.6	29.8	35.7
2000	RK 9.2	Estimated Daily Range in Salinity	7.7	0.0	5.6	6.6	7.7	8.7	9.7	36.3
2000	RK 9.2	Estimated Change due to Withdrawals	1.1	0.0	0.7	0.8	1.1	1.3	1.6	2.0
2000	RK 12.7	Estimated Daily Average Salinity	13.5	0.0	4.7	8.6	13.6	18.1	22.4	28.4
2000	RK 12.7	Estimated Daily Range in Salinity	6.4	0.0	4.5	5.4	6.5	7.4	8.2	28.9
2000	RK 12.7	Estimated Change due to Withdrawals	1.8	-1.0	1.0	1.3	1.7	2.3	2.6	3.4
2000	RK 15.5	Estimated Daily Average Salinity	12.4	0.0	2.7	7.0	12.2	17.0	22.1	28.9
2000	RK 15.5	Estimated Daily Range in Salinity	4.9	0.0	3.4	4.2	5.1	5.8	6.6	13.4
2000	RK 15.5	Estimated Change due to Withdrawals	1.9	-1.5	1.0	1.3	1.9	2.6	2.9	3.8
2000	RK 18.5	Estimated Daily Average Salinity	8.7	0.0	0.9	3.2	8.1	12.7	17.4	24.2
2000	RK 18.5	Estimated Daily Range in Salinity	6.0	0.0	2.8	5.0	6.3	7.6	8.5	11.3
2000	RK 18.5	Estimated Change due to Withdrawals	1.4	-1.9	0.4	0.9	1.4	1.9	2.2	3.0
2000	RK 18.7	Estimated Daily Average Salinity	9.1	0.0	1.1	4.3	8.5	13.0	17.8	24.2
2000	RK 18.7	Estimated Daily Range in Salinity	3.5	0.0	2.2	2.8	3.6	4.2	4.8	9.0
2000	RK 18.7	Estimated Change due to Withdrawals	1.7	-0.3	0.8	1.1	1.7	2.3	2.7	3.5
2000	RK 20.8	Estimated Daily Average Salinity	6.1	0.0	0.5	1.6	5.2	9.1	13.1	18.9
2000	RK 20.8	Estimated Daily Range in Salinity	4.8	0.0	1.2	3.7	5.2	6.4	7.2	9.0
2000	RK 20.8	Estimated Change due to Withdrawals	1.3	-0.8	0.2	0.7	1.4	1.9	2.3	3.1
2000	RK 21.9	Estimated Daily Average Salinity	5.4	0.0	0.2	1.1	4.4	8.2	12.4	18.1
2000	RK 21.9	Estimated Daily Range in Salinity	3.5	0.0	0.7	2.7	3.8	4.7	5.4	6.8
2000	RK 21.9	Estimated Change due to Withdrawals	1.3	-0.7	0.1	0.7	1.4	1.9	2.3	3.1
2000	RK 24.5	Estimated Daily Average Salinity	3.5	0.0	0.1	0.5	2.0	5.4	9.5	15.5
2000	RK 24.5	Estimated Daily Range in Salinity	3.1	0.0	0.3	1.3	3.5	4.6	5.5	15.6
2000	RK 24.5	Estimated Change due to Withdrawals	1.1	-0.4	-0.1	0.2	1.1	1.7	2.1	3.4

Table 4.33

Average Daily Estimated Salinity, Range and Difference due to Withdrawals at Selected Recorder Sites along the Lower River

Year	Site	Parameter	Mean	Min	P10	P25	P50	P75	P90	Max
2000	RK 26.7	Estimated Daily Average Salinity	2.4	0.0	0.1	0.3	1.2	3.2	8.0	10.1
2000	RK 26.7	Estimated Daily Range in Salinity	2.0	0.0	0.2	0.9	2.2	3.0	3.6	4.8
2000	RK 26.7	Estimated Change due to Withdrawals	0.9	-0.2	0.0	0.1	0.8	1.4	1.9	2.7
2001	RK 9.2	Estimated Daily Average Salinity	17.1	0.0	3.9	11.7	19.3	22.8	26.5	35.5
2001	RK 9.2	Estimated Daily Range in Salinity	7.0	0.0	4.3	6.1	7.3	8.5	9.5	11.7
2001	RK 9.2	Estimated Change due to Withdrawals	0.9	0.0	0.4	0.7	0.9	1.2	1.3	1.7
2001	RK 12.7	Estimated Daily Average Salinity	10.7	0.0	0.6	4.7	12.0	15.5	19.0	28.3
2001	RK 12.7	Estimated Daily Range in Salinity	5.6	0.0	1.9	4.9	6.0	7.1	8.0	10.2
2001	RK 12.7	Estimated Change due to Withdrawals	1.4	-1.0	0.2	0.9	1.4	2.0	2.4	2.9
2001	RK 15.5	Estimated Daily Average Salinity	9.7	0.0	0.4	2.7	10.6	14.8	18.5	28.6
2001	RK 15.5	Estimated Daily Range in Salinity	4.3	0.0	1.1	3.8	4.7	5.5	6.3	8.4
2001	RK 15.5	Estimated Change due to Withdrawals	1.5	-1.3	0.0	0.7	1.5	2.2	2.7	3.3
2001	RK 18.5	Estimated Daily Average Salinity	6.6	0.0	0.2	1.1	6.5	10.1	13.8	24.0
2001	RK 18.5	Estimated Daily Range in Salinity	5.2	0.0	0.6	3.0	5.9	7.4	8.3	10.6
2001	RK 18.5	Estimated Change due to Withdrawals	0.9	-10.0	0.0	0.2	1.1	1.7	2.1	2.6
2001	RK 18.7	Estimated Daily Average Salinity	7.0	0.0	0.0	1.0	7.2	11.2	14.5	23.9
2001	RK 18.7	Estimated Daily Range in Salinity	2.9	0.0	0.0	2.0	3.2	4.0	4.5	6.1
2001	RK 18.7	Estimated Change due to Withdrawals	1.3	-0.1	0.0	0.4	1.3	2.0	2.5	3.1
2001	RK 20.8	Estimated Daily Average Salinity	4.4	0.0	0.0	0.5	3.9	6.8	10.0	18.8
2001	RK 20.8	Estimated Daily Range in Salinity	4.0	0.0	0.0	1.7	4.7	6.1	6.9	8.8
2001	RK 20.8	Estimated Change due to Withdrawals	1.0	-1.6	0.0	0.1	1.1	1.7	2.2	2.7
2001	RK 21.9	Estimated Daily Average Salinity	3.9	0.0	0.0	0.1	3.3	6.3	9.4	17.9
2001	RK 21.9	Estimated Daily Range in Salinity	2.8	0.0	0.0	0.6	3.5	4.5	5.1	6.5
2001	RK 21.9	Estimated Change due to Withdrawals	1.0	-0.5	0.0	0.0	1.1	1.7	2.2	2.8
2001	RK 24.5	Estimated Daily Average Salinity	2.4	0.0	0.0	0.3	1.3	3.5	6.4	15.4
2001	RK 24.5	Estimated Daily Range in Salinity	2.6	0.0	0.0	0.7	2.9	4.1	4.9	6.8
2001	RK 24.5	Estimated Change due to Withdrawals	0.9	-0.4	-0.1	0.0	0.7	1.6	2.2	3.0
2001	RK 26.7	Estimated Daily Average Salinity	1.0	0.0	0.0	0.0	0.3	1.3	3.3	9.4
2001	RK 26.7	Estimated Daily Range in Salinity	1.2	0.0	0.0	0.0	0.9	2.4	2.9	4.1
2001	RK 26.7	Estimated Change due to Withdrawals	0.5	-0.1	0.0	0.0	0.2	1.0	1.7	2.4
2002	RK 9.2	Estimated Daily Average Salinity	10.9	0.0	0.0	2.5	11.3	17.6	22.1	27.9
2002	RK 9.2	Estimated Daily Range in Salinity	5.9	0.0	0.1	4.5	6.5	7.9	8.9	11.6
2002	RK 9.2	Estimated Change due to Withdrawals	0.9	0.0	0.1	0.6	0.9	1.2	1.4	1.9
2002	RK 12.7	Estimated Daily Average Salinity	5.9	0.0	0.1	0.6	4.2	10.2	14.2	19.9
2002	RK 12.7	Estimated Daily Range in Salinity	4.3	0.0	0.5	1.5	4.8	6.5	7.4	11.2
2002	RK 12.7	Estimated Change due to Withdrawals	0.9	-1.8	-0.3	0.0	1.0	1.6	2.2	3.3
2002	RK 15.5	Estimated Daily Average Salinity	4.9	0.0	0.0	0.5	2.4	8.9	12.7	18.9
2002	RK 15.5	Estimated Daily Range in Salinity	3.2	0.0	0.2	1.0	3.6	5.0	5.9	8.8
2002	RK 15.5	Estimated Change due to Withdrawals	0.8	-1.9	-0.6	0.0	0.7	1.7	2.4	3.7

Table 4.33
Average Daily Estimated Salinity, Range and Difference due to Withdrawals at Selected Recorder Sites along the Lower River

Year	Site	Parameter	Mean	Min	P10	P25	P50	P75	P90	Max
2002	RK 18.5	Estimated Daily Average Salinity	3.3	0.0	0.0	0.5	2.5	4.9	8.9	14.8
2002	RK 18.5	Estimated Daily Range in Salinity	4.3	0.0	0.0	1.2	4.7	6.8	8.2	15.5
2002	RK 18.5	Estimated Change due to Withdrawals	0.1	-12.0	-2.5	-0.1	0.3	1.1	1.8	2.9
2002	RK 18.7	Estimated Daily Average Salinity	3.1	0.0	0.0	0.0	0.9	5.7	8.9	14.6
2002	RK 18.7	Estimated Daily Range in Salinity	1.9	0.0	0.0	0.0	2.0	3.4	4.2	5.8
2002	RK 18.7	Estimated Change due to Withdrawals	0.8	-0.3	0.0	0.0	0.4	1.3	2.1	3.5
2002	RK 20.8	Estimated Daily Average Salinity	1.8	0.0	0.0	0.0	0.7	2.7	5.7	10.8
2002	RK 20.8	Estimated Daily Range in Salinity	2.5	0.0	0.0	0.0	1.9	4.6	6.1	9.0
2002	RK 20.8	Estimated Change due to Withdrawals	0.5	-3.8	-0.4	0.0	0.1	1.0	1.8	3.0
2002	RK 21.9	Estimated Daily Average Salinity	1.4	0.0	0.0	0.0	0.1	2.0	4.8	9.7
2002	RK 21.9	Estimated Daily Range in Salinity	1.6	0.0	0.0	0.0	0.6	3.4	4.5	6.6
2002	RK 21.9	Estimated Change due to Withdrawals	0.5	-0.7	0.0	0.0	0.0	1.0	1.8	3.0
2002	RK 24.5	Estimated Daily Average Salinity	0.7	0.0	0.0	0.0	0.0	0.8	2.5	6.9
2002	RK 24.5	Estimated Daily Range in Salinity	1.2	0.0	0.0	0.0	0.2	2.1	3.6	7.1
2002	RK 24.5	Estimated Change due to Withdrawals	0.4	-0.6	-0.1	0.0	0.0	0.5	1.5	2.9
2002	RK 26.7	Estimated Daily Average Salinity	0.4	0.0	0.0	0.0	0.0	0.4	1.3	3.6
2002	RK 26.7	Estimated Daily Range in Salinity	0.6	0.0	0.0	0.0	0.0	1.0	2.1	4.6
2002	RK 26.7	Estimated Change due to Withdrawals	0.3	-0.1	0.0	0.0	0.0	0.3	1.2	2.1
2003	RK 9.2	Estimated Daily Average Salinity	6.3	0.0	0.0	0.0	4.8	12.2	15.7	19.8
2003	RK 9.2	Estimated Daily Range in Salinity	4.5	0.0	0.0	0.0	5.7	7.6	8.9	20.3
2003	RK 9.2	Estimated Change due to Withdrawals	0.4	0.0	0.0	0.0	0.4	0.6	0.8	1.0
2003	RK 12.7	Estimated Daily Average Salinity	2.7	0.0	0.0	0.0	0.8	5.3	8.3	12.4
2003	RK 12.7	Estimated Daily Range in Salinity	3.0	0.0	0.0	0.0	2.4	5.7	6.9	12.8
2003	RK 12.7	Estimated Change due to Withdrawals	0.3	-1.2	0.0	0.0	0.2	0.6	1.1	1.7
2003	RK 15.5	Estimated Daily Average Salinity	1.9	0.0	0.0	0.0	0.4	3.4	6.1	10.3
2003	RK 15.5	Estimated Daily Range in Salinity	2.1	0.0	0.0	0.0	1.1	4.2	5.3	10.6
2003	RK 15.5	Estimated Change due to Withdrawals	0.3	-0.9	0.0	0.0	0.0	0.6	1.0	1.8
2003	RK 18.5	Estimated Daily Average Salinity	1.3	0.0	0.0	0.0	0.5	1.9	4.2	11.4
2003	RK 18.5	Estimated Daily Range in Salinity	2.5	0.0	0.0	0.0	1.5	3.8	6.6	12.8
2003	RK 18.5	Estimated Change due to Withdrawals	-0.4	-11.0	-1.9	0.0	0.0	0.2	0.6	1.2
2003	RK 18.7	Estimated Daily Average Salinity	0.9	0.0	0.0	0.0	0.0	1.5	3.2	6.6
2003	RK 18.7	Estimated Daily Range in Salinity	1.1	0.0	0.0	0.0	0.3	2.3	3.3	6.8
2003	RK 18.7	Estimated Change due to Withdrawals	0.2	-0.4	0.0	0.0	0.0	0.4	0.7	1.5
2003	RK 20.8	Estimated Daily Average Salinity	0.5	0.0	0.0	0.0	0.0	0.7	1.8	4.3
2003	RK 20.8	Estimated Daily Range in Salinity	1.2	0.0	0.0	0.0	0.3	2.0	3.9	6.5
2003	RK 20.8	Estimated Change due to Withdrawals	0.0	-3.7	-0.1	0.0	0.0	0.1	0.4	1.1
2003	RK 21.9	Estimated Daily Average Salinity	0.2	0.0	0.0	0.0	0.0	0.1	1.0	3.2
2003	RK 21.9	Estimated Daily Range in Salinity	0.6	0.0	0.0	0.0	0.0	0.7	2.1	4.8
2003	RK 21.9	Estimated Change due to Withdrawals	0.1	-0.6	0.0	0.0	0.0	0.1	0.3	1.0

Table 4.33

Average Daily Estimated Salinity, Range and Difference due to Withdrawals at Selected Recorder Sites along the Lower River

Year	Site	Parameter	Mean	Min	P10	P25	P50	P75	P90	Max
2003	RK 24.5	Estimated Daily Average Salinity	0.2	0.0	0.0	0.0	0.0	0.4	0.9	2.4
2003	RK 24.5	Estimated Daily Range in Salinity	0.6	0.0	0.0	0.0	0.0	1.0	2.0	4.7
2003	RK 24.5	Estimated Change due to Withdrawals	0.0	-0.4	-0.2	0.0	0.0	0.0	0.0	2.8
2003	RK 26.7	Estimated Daily Average Salinity	0.1	0.0	0.0	0.0	0.0	0.2	0.3	1.2
2003	RK 26.7	Estimated Daily Range in Salinity	0.2	0.0	0.0	0.0	0.0	0.3	0.8	1.7
2003	RK 26.7	Estimated Change due to Withdrawals	0.0	-0.1	0.0	0.0	0.0	0.0	0.1	0.8
2004	RK 9.2	Estimated Daily Average Salinity	9.7	0.0	0.0	2.4	10.9	14.6	19.3	23.5
2004	RK 9.2	Estimated Daily Range in Salinity	6.0	0.0	0.0	4.4	6.8	8.6	9.6	13.9
2004	RK 9.2	Estimated Change due to Withdrawals	0.6	0.0	0.0	0.3	0.6	0.9	1.2	1.7
2004	RK 12.7	Estimated Daily Average Salinity	4.7	0.0	0.0	0.4	4.3	7.3	12.2	15.8
2004	RK 12.7	Estimated Daily Range in Salinity	4.4	0.0	0.0	1.2	5.1	6.6	7.8	10.3
2004	RK 12.7	Estimated Change due to Withdrawals	0.6	-2.8	0.0	0.0	0.7	1.1	1.4	2.2
2004	RK 15.5	Estimated Daily Average Salinity	3.5	0.0	0.0	0.2	2.6	5.3	10.5	14.1
2004	RK 15.5	Estimated Daily Range in Salinity	3.2	0.0	0.0	0.6	3.8	5.1	6.0	8.1
2004	RK 15.5	Estimated Change due to Withdrawals	0.6	-2.4	0.0	0.0	0.5	1.1	1.4	2.2
2004	RK 18.5	Estimated Daily Average Salinity	2.0	0.0	0.0	0.1	1.0	2.6	6.7	10.3
2004	RK 18.5	Estimated Daily Range in Salinity	3.1	0.0	0.0	0.4	2.7	4.9	6.9	14.0
2004	RK 18.5	Estimated Change due to Withdrawals	0.1	-6.8	-0.1	0.0	0.2	0.7	1.0	1.4
2004	RK 18.7	Estimated Daily Average Salinity	2.0	0.0	0.0	0.0	1.0	2.8	7.0	10.1
2004	RK 18.7	Estimated Daily Range in Salinity	1.8	0.0	0.0	0.0	2.0	3.1	3.8	5.5
2004	RK 18.7	Estimated Change due to Withdrawals	0.4	-0.4	0.0	0.0	0.3	0.8	1.1	1.6
2004	RK 20.8	Estimated Daily Average Salinity	1.1	0.0	0.0	0.0	0.4	1.3	4.1	7.1
2004	RK 20.8	Estimated Daily Range in Salinity	1.9	0.0	0.0	0.0	1.4	3.2	5.1	8.4
2004	RK 20.8	Estimated Change due to Withdrawals	0.2	-4.1	-0.1	0.0	0.1	0.4	0.9	1.3
2004	RK 21.9	Estimated Daily Average Salinity	0.7	0.0	0.0	0.0	0.1	0.6	3.2	6.0
2004	RK 21.9	Estimated Daily Range in Salinity	1.1	0.0	0.0	0.0	0.5	1.7	3.7	6.1
2004	RK 21.9	Estimated Change due to Withdrawals	0.2	-0.7	0.0	0.0	0.0	0.4	0.9	1.3
2004	RK 24.5	Estimated Daily Average Salinity	0.4	0.0	0.0	0.0	0.1	0.6	1.4	3.4
2004	RK 24.5	Estimated Daily Range in Salinity	0.9	0.0	0.0	0.0	0.2	1.5	3.0	5.4
2004	RK 24.5	Estimated Change due to Withdrawals	0.1	-0.5	-0.2	-0.1	0.0	0.0	0.6	2.0
2004	RK 26.7	Estimated Daily Average Salinity	0.2	0.0	0.0	0.0	0.0	0.2	0.6	1.7
2004	RK 26.7	Estimated Daily Range in Salinity	0.3	0.0	0.0	0.0	0.0	0.5	1.3	3.0
2004	RK 26.7	Estimated Change due to Withdrawals	0.0	-0.2	0.0	0.0	0.0	0.0	0.3	0.6
2005	RK 9.2	Estimated Daily Average Salinity	6.6	0.0	0.0	0.1	6.6	11.1	14.3	17.8
2005	RK 9.2	Estimated Daily Range in Salinity	5.3	0.0	0.0	0.9	6.3	8.0	9.2	16.5
2005	RK 9.2	Estimated Change due to Withdrawals	0.5	0.0	0.0	0.2	0.5	0.6	0.7	1.1
2005	RK 12.7	Estimated Daily Average Salinity	2.6	0.0	0.0	0.1	1.5	4.4	7.1	10.4
2005	RK 12.7	Estimated Daily Range in Salinity	3.4	0.0	0.0	0.5	3.4	5.8	7.0	10.0
2005	RK 12.7	Estimated Change due to Withdrawals	0.3	-1.8	0.0	0.0	0.4	0.7	0.8	1.4

Table 4.33
Average Daily Estimated Salinity, Range and Difference due to Withdrawals at Selected Recorder Sites along the Lower River

Year	Site	Parameter	Mean	Min	P10	P25	P50	P75	P90	Max
2005	RK 15.5	Estimated Daily Average Salinity	1.7	0.0	0.0	0.1	0.9	2.4	5.0	8.2
2005	RK 15.5	Estimated Daily Range in Salinity	2.4	0.0	0.0	0.4	2.0	4.2	5.2	7.0
2005	RK 15.5	Estimated Change due to Withdrawals	0.2	-1.2	-0.3	0.0	0.2	0.6	0.7	1.4
2005	RK 18.5	Estimated Daily Average Salinity	1.3	0.0	0.0	0.0	0.6	2.0	3.9	12.0
2005	RK 18.5	Estimated Daily Range in Salinity	2.7	0.0	0.0	0.0	1.7	4.2	6.7	17.8
2005	RK 18.5	Estimated Change due to Withdrawals	-0.6	-12.0	-3.3	0.0	0.0	0.2	0.4	0.8
2005	RK 18.7	Estimated Daily Average Salinity	0.7	0.0	0.0	0.0	0.1	0.9	2.5	4.9
2005	RK 18.7	Estimated Daily Range in Salinity	1.1	0.0	0.0	0.0	0.5	2.0	3.0	4.5
2005	RK 18.7	Estimated Change due to Withdrawals	0.2	-0.8	0.0	0.0	0.0	0.3	0.5	1.0
2005	RK 20.8	Estimated Daily Average Salinity	0.4	0.0	0.0	0.0	0.1	0.7	1.5	2.9
2005	RK 20.8	Estimated Daily Range in Salinity	1.1	0.0	0.0	0.0	0.5	1.8	3.4	6.0
2005	RK 20.8	Estimated Change due to Withdrawals	-0.1	-2.5	-0.3	0.0	0.0	0.1	0.2	0.6
2005	RK 21.9	Estimated Daily Average Salinity	0.2	0.0	0.0	0.0	0.0	0.1	0.6	1.9
2005	RK 21.9	Estimated Daily Range in Salinity	0.4	0.0	0.0	0.0	0.0	0.5	1.5	4.1
2005	RK 21.9	Estimated Change due to Withdrawals	0.0	-0.6	0.0	0.0	0.0	0.0	0.2	0.5
2005	RK 24.5	Estimated Daily Average Salinity	0.2	0.0	0.0	0.0	0.0	0.1	1.0	2.7
2005	RK 24.5	Estimated Daily Range in Salinity	0.5	0.0	0.0	0.0	0.0	0.5	2.2	4.5
2005	RK 24.5	Estimated Change due to Withdrawals	0.0	-0.5	-0.2	0.0	0.0	0.0	0.0	2.2
2005	RK 26.7	Estimated Daily Average Salinity	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.6
2005	RK 26.7	Estimated Daily Range in Salinity	0.1	0.0	0.0	0.0	0.0	0.0	0.4	1.5
2005	RK 26.7	Estimated Change due to Withdrawals	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.3
2006	RK 9.2	Estimated Daily Average Salinity	16.3	0.0	5.5	12.2	16.8	21.0	23.7	30.8
2006	RK 9.2	Estimated Daily Range in Salinity	7.7	0.0	5.1	6.4	7.7	9.0	9.9	30.7
2006	RK 9.2	Estimated Change due to Withdrawals	0.9	0.0	0.6	0.7	0.9	1.1	1.4	1.8
2006	RK 12.7	Estimated Daily Average Salinity	9.7	0.0	1.1	5.4	9.3	13.7	16.5	23.6
2006	RK 12.7	Estimated Daily Range in Salinity	6.0	0.0	2.5	5.1	6.3	7.4	8.2	21.9
2006	RK 12.7	Estimated Change due to Withdrawals	1.2	-0.9	0.4	0.9	1.2	1.4	1.8	2.6
2006	RK 15.5	Estimated Daily Average Salinity	8.3	0.0	0.8	3.5	7.6	12.2	15.2	23.0
2006	RK 15.5	Estimated Daily Range in Salinity	4.6	0.0	1.5	3.9	4.8	5.8	6.5	21.2
2006	RK 15.5	Estimated Change due to Withdrawals	1.2	-1.6	0.2	0.9	1.3	1.6	1.9	2.7
2006	RK 18.5	Estimated Daily Average Salinity	5.4	0.0	0.5	1.6	4.1	8.1	10.8	18.6
2006	RK 18.5	Estimated Daily Range in Salinity	5.4	0.0	1.8	4.0	5.6	7.1	8.3	16.8
2006	RK 18.5	Estimated Change due to Withdrawals	0.7	-4.3	-0.1	0.4	0.9	1.2	1.4	1.7
2006	RK 18.7	Estimated Daily Average Salinity	5.6	0.0	0.0	1.6	4.7	8.5	11.2	18.4
2006	RK 18.7	Estimated Daily Range in Salinity	3.1	0.0	0.2	2.3	3.2	4.1	4.6	16.7
2006	RK 18.7	Estimated Change due to Withdrawals	1.0	-0.2	0.0	0.7	1.1	1.4	1.6	2.1
2006	RK 20.8	Estimated Daily Average Salinity	3.5	0.0	0.1	0.6	2.1	5.3	7.7	14.3
2006	RK 20.8	Estimated Daily Range in Salinity	3.8	0.0	0.2	1.9	3.9	5.7	7.0	12.6
2006	RK 20.8	Estimated Change due to Withdrawals	0.7	-1.7	0.0	0.3	0.7	1.1	1.3	1.6

Table 4.33
Average Daily Estimated Salinity, Range and Difference due to Withdrawals at Selected Recorder Sites along the Lower River

Year	Site	Parameter	Mean	Min	P10	P25	P50	P75	P90	Max
2006	RK 21.9	Estimated Daily Average Salinity	2.9	0.0	0.0	0.3	1.4	4.4	6.7	13.1
2006	RK 21.9	Estimated Daily Range in Salinity	2.7	0.0	0.0	0.9	2.8	4.1	5.1	11.7
2006	RK 21.9	Estimated Change due to Withdrawals	0.6	-0.8	0.0	0.2	0.7	1.1	1.3	1.6
2006	RK 24.5	Estimated Daily Average Salinity	1.7	0.0	0.0	0.1	0.7	2.1	4.0	10.3
2006	RK 24.5	Estimated Daily Range in Salinity	2.0	0.0	0.0	0.3	1.8	3.5	4.6	8.7
2006	RK 24.5	Estimated Change due to Withdrawals	0.4	-0.5	-0.2	0.0	0.3	0.9	1.1	2.7
2006	RK 26.7	Estimated Daily Average Salinity	1.2	0.0	0.0	0.1	0.4	1.4	4.5	6.2
2006	RK 26.7	Estimated Daily Range in Salinity	1.3	0.0	0.0	0.2	0.9	2.3	3.1	4.1
2006	RK 26.7	Estimated Change due to Withdrawals	0.3	-0.2	0.0	0.0	0.2	0.6	0.8	1.1
2007	RK 9.2	Estimated Daily Average Salinity	19.9	7.0	14.0	16.3	19.5	23.8	25.9	30.7
2007	RK 9.2	Estimated Daily Range in Salinity	7.7	4.2	5.6	6.6	7.7	8.9	9.7	16.0
2007	RK 9.2	Estimated Change due to Withdrawals	0.9	0.4	0.6	0.7	0.8	1.0	1.2	1.8
2007	RK 12.7	Estimated Daily Average Salinity	12.6	1.5	6.7	9.0	12.2	16.4	18.7	23.7
2007	RK 12.7	Estimated Daily Range in Salinity	6.4	3.3	4.7	5.4	6.4	7.4	8.0	13.1
2007	RK 12.7	Estimated Change due to Withdrawals	1.3	0.7	0.9	1.1	1.3	1.5	1.7	2.3
2007	RK 15.5	Estimated Daily Average Salinity	11.1	0.6	4.6	7.0	10.6	15.2	17.8	23.3
2007	RK 15.5	Estimated Daily Range in Salinity	5.0	1.9	3.6	4.2	5.0	5.8	6.4	9.3
2007	RK 15.5	Estimated Change due to Withdrawals	1.4	0.6	1.0	1.2	1.4	1.6	1.8	2.3
2007	RK 18.5	Estimated Daily Average Salinity	7.3	0.0	1.9	3.6	6.5	10.8	13.3	18.7
2007	RK 18.5	Estimated Daily Range in Salinity	6.1	0.0	3.8	5.0	6.3	7.3	8.2	14.3
2007	RK 18.5	Estimated Change due to Withdrawals	1.0	-0.1	0.6	0.8	1.0	1.2	1.3	1.7
2007	RK 18.7	Estimated Daily Average Salinity	7.7	0.3	2.3	4.0	7.1	11.2	13.6	18.8
2007	RK 18.7	Estimated Daily Range in Salinity	3.5	0.8	2.4	2.9	3.5	4.1	4.6	7.7
2007	RK 18.7	Estimated Change due to Withdrawals	1.2	-0.1	0.8	1.0	1.2	1.4	1.5	2.0
2007	RK 20.8	Estimated Daily Average Salinity	4.9	0.0	0.8	1.9	4.0	7.6	9.7	14.4
2007	RK 20.8	Estimated Daily Range in Salinity	4.9	0.0	2.4	3.8	5.0	6.1	7.0	12.5
2007	RK 20.8	Estimated Change due to Withdrawals	0.9	-0.4	0.5	0.7	0.9	1.1	1.3	1.7
2007	RK 21.9	Estimated Daily Average Salinity	4.1	0.0	0.4	1.2	3.3	6.7	8.7	13.4
2007	RK 21.9	Estimated Daily Range in Salinity	3.5	0.0	1.3	2.7	3.6	4.5	5.2	9.2
2007	RK 21.9	Estimated Change due to Withdrawals	0.8	-0.7	0.4	0.6	0.9	1.1	1.3	1.7
2007	RK 24.5	Estimated Daily Average Salinity	2.4	0.0	0.1	0.4	1.2	4.0	5.9	10.6
2007	RK 24.5	Estimated Daily Range in Salinity	2.6	0.0	0.4	1.0	2.5	4.1	5.2	9.5
2007	RK 24.5	Estimated Change due to Withdrawals	0.6	-0.3	0.0	0.2	0.6	0.9	1.2	1.4
2007	RK 26.7	Estimated Daily Average Salinity	1.2	0.0	0.1	0.3	0.6	1.9	3.1	6.2
2007	RK 26.7	Estimated Daily Range in Salinity	1.6	0.0	0.1	0.6	1.4	2.5	3.2	5.6
2007	RK 26.7	Estimated Change due to Withdrawals	0.4	-0.2	0.0	0.0	0.3	0.7	0.8	1.0
2008	RK 9.2	Estimated Daily Average Salinity	16.3	0.0	2.2	10.9	18.2	22.4	27.1	32.0
2008	RK 9.2	Estimated Daily Range in Salinity	7.0	0.0	3.4	6.0	7.4	8.7	9.8	25.8
2008	RK 9.2	Estimated Change due to Withdrawals	0.9	0.0	0.5	0.7	0.9	1.2	1.3	2.2

Table 4.33
Average Daily Estimated Salinity, Range and Difference due to Withdrawals at Selected Recorder Sites along the Lower River

Year	Site	Parameter	Mean	Min	P10	P25	P50	P75	P90	Max
2008	RK 12.7	Estimated Daily Average Salinity	10.2	0.0	0.7	4.0	11.2	15.3	20.1	24.8
2008	RK 12.7	Estimated Daily Range in Salinity	5.6	0.0	1.8	4.4	6.0	7.3	8.2	18.0
2008	RK 12.7	Estimated Change due to Withdrawals	1.1	-1.4	0.0	0.8	1.2	1.5	1.7	3.4
2008	RK 15.5	Estimated Daily Average Salinity	9.0	0.0	0.3	2.1	9.9	14.0	18.9	24.1
2008	RK 15.5	Estimated Daily Range in Salinity	4.3	0.0	0.9	3.3	4.6	5.8	6.6	16.1
2008	RK 15.5	Estimated Change due to Withdrawals	1.1	-1.3	0.0	0.7	1.3	1.6	1.8	3.7
2008	RK 18.5	Estimated Daily Average Salinity	6.0	0.0	0.2	1.0	5.5	9.7	14.7	19.9
2008	RK 18.5	Estimated Daily Range in Salinity	5.0	0.0	0.2	2.2	5.5	7.4	8.7	14.4
2008	RK 18.5	Estimated Change due to Withdrawals	0.8	-3.8	-0.1	0.1	1.0	1.3	1.5	2.8
2008	RK 18.7	Estimated Daily Average Salinity	6.3	0.0	0.0	0.8	6.7	10.2	14.8	19.3
2008	RK 18.7	Estimated Daily Range in Salinity	2.8	0.0	0.0	1.5	3.1	4.1	4.8	11.9
2008	RK 18.7	Estimated Change due to Withdrawals	1.0	-0.2	0.0	0.3	1.2	1.4	1.6	3.2
2008	RK 20.8	Estimated Daily Average Salinity	4.1	0.0	0.0	0.6	3.2	6.7	10.9	15.4
2008	RK 20.8	Estimated Daily Range in Salinity	3.9	0.0	0.0	1.4	4.4	6.1	7.3	10.8
2008	RK 20.8	Estimated Change due to Withdrawals	0.7	-1.3	-0.1	0.0	0.9	1.2	1.4	2.6
2008	RK 21.9	Estimated Daily Average Salinity	3.5	0.0	0.0	0.2	2.7	5.8	9.8	14.1
2008	RK 21.9	Estimated Daily Range in Salinity	2.8	0.0	0.0	0.5	3.1	4.5	5.4	8.9
2008	RK 21.9	Estimated Change due to Withdrawals	0.7	-0.8	0.0	0.0	0.9	1.2	1.4	2.6
2008	RK 24.5	Estimated Daily Average Salinity	2.1	0.0	0.0	0.0	1.0	3.1	7.0	11.3
2008	RK 24.5	Estimated Daily Range in Salinity	2.4	0.0	0.0	0.0	2.4	4.1	5.1	7.1
2008	RK 24.5	Estimated Change due to Withdrawals	0.5	-0.5	-0.1	0.0	0.6	1.0	1.2	2.0
2008	RK 26.7	Estimated Daily Average Salinity	1.1	0.0	0.0	0.0	0.7	1.6	3.8	6.7
2008	RK 26.7	Estimated Daily Range in Salinity	1.5	0.0	0.0	0.0	1.7	2.6	3.1	4.3
2008	RK 26.7	Estimated Change due to Withdrawals	0.4	-0.1	0.0	0.0	0.4	0.7	0.8	1.5
2009	RK 9.2	Estimated Daily Average Salinity	14.0	0.0	0.0	7.1	12.1	22.1	28.0	34.3
2009	RK 9.2	Estimated Daily Range in Salinity	6.4	0.0	0.0	5.4	7.0	8.6	9.7	11.6
2009	RK 9.2	Estimated Change due to Withdrawals	0.8	0.0	0.0	0.5	0.8	1.1	1.5	2.1
2009	RK 12.7	Estimated Daily Average Salinity	8.4	0.0	0.0	1.8	5.1	14.9	20.5	27.9
2009	RK 12.7	Estimated Daily Range in Salinity	4.8	0.0	0.0	3.2	5.5	6.9	7.9	9.6
2009	RK 12.7	Estimated Change due to Withdrawals	0.9	-0.4	0.0	0.4	1.0	1.4	1.6	2.2
2009	RK 15.5	Estimated Daily Average Salinity	7.3	0.0	0.0	0.8	3.1	13.5	19.5	28.5
2009	RK 15.5	Estimated Daily Range in Salinity	3.6	0.0	0.0	1.8	4.1	5.3	6.2	7.7
2009	RK 15.5	Estimated Change due to Withdrawals	0.8	-1.0	0.0	0.2	1.0	1.3	1.7	2.1
2009	RK 18.5	Estimated Daily Average Salinity	5.2	0.0	0.0	0.4	2.0	9.2	15.2	23.3
2009	RK 18.5	Estimated Daily Range in Salinity	4.1	0.0	0.0	1.2	4.2	6.8	8.3	11.6
2009	RK 18.5	Estimated Change due to Withdrawals	0.3	-5.7	-0.3	0.0	0.4	0.9	1.3	1.7
2009	RK 18.7	Estimated Daily Average Salinity	5.2	0.0	0.0	0.0	1.2	9.8	15.1	23.9
2009	RK 18.7	Estimated Daily Range in Salinity	2.1	0.0	0.0	0.1	2.2	3.6	4.5	5.5
2009	RK 18.7	Estimated Change due to Withdrawals	0.6	-0.1	0.0	0.0	0.6	1.1	1.5	1.8

Table 4.33
Average Daily Estimated Salinity, Range and Difference due to Withdrawals at Selected Recorder Sites along the Lower River

Year	Site	Parameter	Mean	Min	P10	P25	P50	P75	P90	Max
2009	RK 20.8	Estimated Daily Average Salinity	3.6	0.0	0.0	0.2	0.7	6.3	11.4	18.5
2009	RK 20.8	Estimated Daily Range in Salinity	3.0	0.0	0.0	0.4	2.1	5.4	6.8	8.5
2009	RK 20.8	Estimated Change due to Withdrawals	0.4	-2.1	-0.1	0.0	0.2	0.8	1.3	1.5
2009	RK 21.9	Estimated Daily Average Salinity	3.1	0.0	0.0	0.0	0.3	5.3	10.2	17.8
2009	RK 21.9	Estimated Daily Range in Salinity	2.0	0.0	0.0	0.0	0.9	4.1	5.1	6.6
2009	RK 21.9	Estimated Change due to Withdrawals	0.4	-0.6	-0.1	0.0	0.1	0.8	1.3	1.6
2009	RK 24.5	Estimated Daily Average Salinity	2.1	0.0	0.0	0.0	0.2	2.8	7.3	15.2
2009	RK 24.5	Estimated Daily Range in Salinity	1.8	0.0	0.0	0.0	0.5	4.0	4.9	6.7
2009	RK 24.5	Estimated Change due to Withdrawals	0.3	-0.9	-0.1	0.0	0.0	0.9	1.2	1.7
2009	RK 26.7	Estimated Daily Average Salinity	1.3	0.0	0.0	0.0	0.3	1.7	4.0	9.6
2009	RK 26.7	Estimated Daily Range in Salinity	1.3	0.0	0.0	0.0	0.9	2.5	3.1	4.2
2009	RK 26.7	Estimated Change due to Withdrawals	0.3	-0.2	0.0	0.0	0.1	0.8	0.9	1.1
2010	RK 9.2	Estimated Daily Average Salinity	12.0	0.0	3.0	7.9	11.9	16.9	20.4	24.0
2010	RK 9.2	Estimated Daily Range in Salinity	7.4	0.0	4.8	6.1	7.5	8.9	10.1	12.2
2010	RK 9.2	Estimated Change due to Withdrawals	1.0	0.0	0.7	0.8	1.0	1.2	1.4	1.8
2010	RK 12.7	Estimated Daily Average Salinity	5.8	0.0	0.6	1.9	4.8	9.2	12.8	16.0
2010	RK 12.7	Estimated Daily Range in Salinity	5.4	0.1	1.4	4.0	5.6	7.2	8.2	10.2
2010	RK 12.7	Estimated Change due to Withdrawals	1.1	-1.3	0.0	0.9	1.3	1.5	1.7	2.3
2010	RK 15.5	Estimated Daily Average Salinity	4.4	0.0	0.4	1.0	3.0	7.3	11.0	14.4
2010	RK 15.5	Estimated Daily Range in Salinity	3.9	0.0	0.9	2.3	4.3	5.5	6.3	8.3
2010	RK 15.5	Estimated Change due to Withdrawals	1.0	-1.5	-0.1	0.6	1.2	1.6	1.8	2.4
2010	RK 18.5	Estimated Daily Average Salinity	2.7	0.0	0.2	0.6	1.6	4.1	7.3	10.6
2010	RK 18.5	Estimated Daily Range in Salinity	4.1	0.0	0.6	2.0	4.0	6.0	7.8	11.6
2010	RK 18.5	Estimated Change due to Withdrawals	0.2	-7.5	-1.4	0.0	0.5	1.0	1.3	1.6
2010	RK 18.7	Estimated Daily Average Salinity	2.5	0.0	0.0	0.2	1.2	4.3	7.4	10.4
2010	RK 18.7	Estimated Daily Range in Salinity	2.2	0.0	0.0	0.7	2.3	3.5	4.3	5.5
2010	RK 18.7	Estimated Change due to Withdrawals	0.7	-0.1	0.0	0.1	0.8	1.2	1.6	1.9
2010	RK 20.8	Estimated Daily Average Salinity	1.5	0.0	0.0	0.2	0.7	2.1	4.6	7.3
2010	RK 20.8	Estimated Daily Range in Salinity	2.6	0.0	0.0	0.8	2.0	4.1	6.1	8.1
2010	RK 20.8	Estimated Change due to Withdrawals	0.3	-2.4	-0.3	0.0	0.2	0.9	1.2	1.5
2010	RK 21.9	Estimated Daily Average Salinity	1.0	0.0	0.0	0.0	0.3	1.3	3.7	6.2
2010	RK 21.9	Estimated Daily Range in Salinity	1.6	0.0	0.0	0.1	0.9	2.7	4.4	6.1
2010	RK 21.9	Estimated Change due to Withdrawals	0.4	-0.7	0.0	0.0	0.1	0.8	1.2	1.5
2010	RK 24.5	Estimated Daily Average Salinity	0.6	0.0	0.0	0.0	0.3	0.8	1.7	3.6
2010	RK 24.5	Estimated Daily Range in Salinity	1.2	0.0	0.0	0.0	0.7	2.2	3.2	5.3
2010	RK 24.5	Estimated Change due to Withdrawals	0.1	-1.0	-0.3	-0.1	0.0	0.3	0.8	2.2
2010	RK 26.7	Estimated Daily Average Salinity	0.2	0.0	0.0	0.0	0.0	0.4	0.7	1.7
2010	RK 26.7	Estimated Daily Range in Salinity	0.5	0.0	0.0	0.0	0.0	0.8	1.5	3.1
2010	RK 26.7	Estimated Change due to Withdrawals	0.1	-0.3	-0.1	0.0	0.0	0.1	0.4	0.7

Table 4.33
Average Daily Estimated Salinity, Range and Difference due to Withdrawals at Selected Recorder Sites along the Lower River

Year	Site	Parameter	Mean	Min	P10	P25	P50	P75	P90	Max
2010	RK 29.8	Estimated Daily Average Salinity	0.1	0.0	0.0	0.0	0.0	0.2	0.3	0.4
2010	RK 29.8	Estimated Daily Range in Salinity	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
2010	RK 29.8	Estimated Change due to Withdrawals	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3
2011	RK 9.2	Estimated Daily Average Salinity	15.3	0.0	5.0	10.2	15.6	19.7	25.1	33.2
2011	RK 9.2	Estimated Daily Range in Salinity	7.5	0.0	5.2	6.3	7.6	9.1	10.0	11.2
2011	RK 9.2	Estimated Change due to Withdrawals	1.0	0.0	0.5	0.8	1.0	1.2	1.6	2.7
2011	RK 12.7	Estimated Daily Average Salinity	8.8	0.0	0.9	3.5	8.4	12.5	17.7	26.0
2011	RK 12.7	Estimated Daily Range in Salinity	5.8	0.0	2.6	4.7	6.0	7.5	8.3	9.5
2011	RK 12.7	Estimated Change due to Withdrawals	1.1	-0.3	0.4	0.9	1.1	1.4	1.6	2.7
2011	RK 15.5	Estimated Daily Average Salinity	7.5	0.0	0.5	1.8	6.5	11.1	16.5	25.6
2011	RK 15.5	Estimated Daily Range in Salinity	4.4	0.0	1.3	3.4	4.7	5.8	6.6	7.8
2011	RK 15.5	Estimated Change due to Withdrawals	1.1	-1.0	0.0	0.9	1.2	1.5	1.7	2.8
2011	RK 18.5	Estimated Daily Average Salinity	4.8	0.0	0.3	0.8	3.3	6.8	12.2	21.2
2011	RK 18.5	Estimated Daily Range in Salinity	5.0	0.0	0.8	2.3	5.3	7.2	8.5	11.9
2011	RK 18.5	Estimated Change due to Withdrawals	0.6	-6.8	-0.1	0.2	0.9	1.1	1.3	2.1
2011	RK 18.7	Estimated Daily Average Salinity	5.0	0.0	0.0	0.6	3.8	7.5	12.4	20.9
2011	RK 18.7	Estimated Daily Range in Salinity	2.8	0.0	0.1	1.5	3.2	4.0	4.7	5.7
2011	RK 18.7	Estimated Change due to Withdrawals	0.9	-0.1	0.0	0.4	1.0	1.3	1.6	2.5
2011	RK 20.8	Estimated Daily Average Salinity	3.1	0.0	0.1	0.3	1.6	4.2	8.8	16.5
2011	RK 20.8	Estimated Daily Range in Salinity	3.6	0.0	0.2	1.0	3.8	5.7	7.0	8.7
2011	RK 20.8	Estimated Change due to Withdrawals	0.6	-2.6	0.0	0.1	0.7	1.0	1.3	2.0
2011	RK 21.9	Estimated Daily Average Salinity	2.5	0.0	0.0	0.0	1.0	3.6	7.8	15.4
2011	RK 21.9	Estimated Daily Range in Salinity	2.4	0.0	0.0	0.3	2.5	4.1	5.2	6.4
2011	RK 21.9	Estimated Change due to Withdrawals	0.6	-0.7	0.0	0.0	0.6	1.0	1.3	2.0
2011	RK 24.5	Estimated Daily Average Salinity	1.5	0.0	0.0	0.0	0.4	1.5	5.0	12.7
2011	RK 24.5	Estimated Daily Range in Salinity	1.8	0.0	0.0	0.0	1.3	3.1	4.6	7.0
2011	RK 24.5	Estimated Change due to Withdrawals	0.3	-0.7	-0.2	0.0	0.2	0.6	1.1	2.1
2011	RK 26.7	Estimated Daily Average Salinity	0.8	0.0	0.0	0.0	0.2	0.6	2.5	7.7
2011	RK 26.7	Estimated Daily Range in Salinity	1.0	0.0	0.0	0.0	0.6	1.5	2.8	4.4
2011	RK 26.7	Estimated Change due to Withdrawals	0.2	-0.1	0.0	0.0	0.1	0.3	0.8	1.4
2011	RK 29.8	Estimated Daily Average Salinity	0.3	0.0	0.0	0.0	0.2	0.3	0.8	3.0
2011	RK 29.8	Estimated Daily Range in Salinity	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2
2011	RK 29.8	Estimated Change due to Withdrawals	0.1	0.0	0.0	0.0	0.0	0.1	0.3	0.7
2012	RK 9.2	Estimated Daily Average Salinity	16.9	0.0	3.3	7.8	18.3	23.4	30.8	35.5
2012	RK 9.2	Estimated Daily Range in Salinity	7.1	0.0	4.5	5.8	7.4	8.7	9.6	12.0
2012	RK 9.2	Estimated Change due to Withdrawals	1.0	0.0	0.5	0.7	0.9	1.1	1.8	2.8
2012	RK 12.7	Estimated Daily Average Salinity	10.7	0.0	0.7	2.0	11.0	16.1	23.4	28.6
2012	RK 12.7	Estimated Daily Range in Salinity	5.4	0.0	1.4	3.8	5.9	7.3	8.1	12.1
2012	RK 12.7	Estimated Change due to Withdrawals	1.1	-1.7	0.0	0.8	1.1	1.5	2.0	3.7

Table 4.33
Average Daily Estimated Salinity, Range and Difference due to Withdrawals at Selected Recorder Sites along the Lower River

Year	Site	Parameter	Mean	Min	P10	P25	P50	P75	P90	Max
2012	RK 15.5	Estimated Daily Average Salinity	9.7	0.0	0.4	1.1	9.2	15.0	22.9	28.5
2012	RK 15.5	Estimated Daily Range in Salinity	4.2	0.0	1.0	2.3	4.6	5.8	6.4	10.7
2012	RK 15.5	Estimated Change due to Withdrawals	1.1	-1.7	-0.2	0.5	1.2	1.5	2.2	3.9
2012	RK 18.5	Estimated Daily Average Salinity	7.1	0.0	0.3	1.1	5.6	10.5	18.5	24.0
2012	RK 18.5	Estimated Daily Range in Salinity	5.3	0.0	0.6	2.6	6.1	7.6	8.5	11.3
2012	RK 18.5	Estimated Change due to Withdrawals	0.5	-9.8	-1.0	0.0	0.9	1.1	1.6	2.8
2012	RK 18.7	Estimated Daily Average Salinity	7.0	0.0	0.0	0.2	5.8	11.3	18.3	23.5
2012	RK 18.7	Estimated Daily Range in Salinity	2.7	0.0	0.0	0.5	3.2	4.1	4.7	6.5
2012	RK 18.7	Estimated Change due to Withdrawals	0.9	-0.2	0.0	0.0	1.0	1.3	1.9	3.2
2012	RK 20.8	Estimated Daily Average Salinity	4.9	0.0	0.0	0.5	3.2	7.4	14.0	19.0
2012	RK 20.8	Estimated Daily Range in Salinity	4.0	0.0	0.0	1.4	4.6	6.1	7.1	9.0
2012	RK 20.8	Estimated Change due to Withdrawals	0.6	-1.9	-0.4	0.0	0.7	1.1	1.6	2.6
2012	RK 21.9	Estimated Daily Average Salinity	4.3	0.0	0.0	0.1	2.4	6.6	13.0	17.8
2012	RK 21.9	Estimated Daily Range in Salinity	2.7	0.0	0.0	0.2	3.3	4.6	5.2	6.8
2012	RK 21.9	Estimated Change due to Withdrawals	0.7	-0.7	0.0	0.0	0.7	1.1	1.6	2.6
2012	RK 24.5	Estimated Daily Average Salinity	2.8	0.0	0.0	0.0	0.8	3.8	10.2	15.2
2012	RK 24.5	Estimated Daily Range in Salinity	2.3	0.0	0.0	0.0	1.9	4.3	5.2	7.4
2012	RK 24.5	Estimated Change due to Withdrawals	0.6	-0.7	0.0	0.0	0.4	0.9	1.6	2.4
2012	RK 26.7	Estimated Daily Average Salinity	1.6	0.0	0.0	0.0	0.4	1.9	5.9	9.5
2012	RK 26.7	Estimated Daily Range in Salinity	1.3	0.0	0.0	0.0	1.0	2.6	3.2	4.4
2012	RK 26.7	Estimated Change due to Withdrawals	0.4	-0.1	0.0	0.0	0.2	0.7	1.2	1.9
2012	RK 29.8	Estimated Daily Average Salinity	0.6	0.0	0.0	0.0	0.3	0.6	2.3	4.3
2012	RK 29.8	Estimated Daily Range in Salinity	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4
2012	RK 29.8	Estimated Change due to Withdrawals	0.2	0.0	0.0	0.0	0.0	0.2	0.6	0.9
2013	RK 9.2	Estimated Daily Average Salinity	14.7	0.0	0.3	4.2	18.2	22.0	24.9	29.4
2013	RK 9.2	Estimated Daily Range in Salinity	6.4	0.0	1.5	5.4	7.0	8.4	9.6	11.4
2013	RK 9.2	Estimated Change due to Withdrawals	0.9	0.0	0.4	0.6	0.9	1.1	1.3	2.5
2013	RK 12.7	Estimated Daily Average Salinity	9.3	0.0	0.3	0.8	11.5	14.9	17.8	22.1
2013	RK 12.7	Estimated Daily Range in Salinity	4.9	0.0	0.8	1.9	5.7	7.1	8.1	10.2
2013	RK 12.7	Estimated Change due to Withdrawals	0.8	-1.9	-0.2	0.2	1.0	1.2	1.4	3.0
2013	RK 15.5	Estimated Daily Average Salinity	8.3	0.0	0.3	1.0	9.8	13.5	16.9	21.5
2013	RK 15.5	Estimated Daily Range in Salinity	3.8	0.0	0.4	1.6	4.4	5.6	6.4	8.3
2013	RK 15.5	Estimated Change due to Withdrawals	0.8	-1.7	-0.6	0.0	1.1	1.4	1.5	3.2
2013	RK 18.5	Estimated Daily Average Salinity	5.8	0.0	0.1	1.9	5.7	9.1	12.3	16.9
2013	RK 18.5	Estimated Daily Range in Salinity	5.5	0.0	0.1	4.2	6.3	7.4	8.4	12.6
2013	RK 18.5	Estimated Change due to Withdrawals	0.2	-5.6	-2.2	0.0	0.9	1.1	1.3	2.5
2013	RK 18.7	Estimated Daily Average Salinity	5.7	0.0	0.0	0.0	6.3	9.7	12.7	17.2
2013	RK 18.7	Estimated Daily Range in Salinity	2.5	0.0	0.0	0.0	3.0	4.0	4.6	6.1
2013	RK 18.7	Estimated Change due to Withdrawals	0.8	-0.1	0.0	0.0	0.9	1.2	1.3	2.8

Table 4.33

Average Daily Estimated Salinity, Range and Difference due to Withdrawals at Selected Recorder Sites along the Lower River

Year	Site	Parameter	Mean	Min	P10	P25	P50	P75	P90	Max
2013	RK 20.8	Estimated Daily Average Salinity	3.7	0.0	0.0	0.0	3.5	6.3	8.9	12.8
2013	RK 20.8	Estimated Daily Range in Salinity	3.6	0.0	0.0	0.0	4.5	5.9	6.8	8.8
2013	RK 20.8	Estimated Change due to Withdrawals	0.6	-1.5	0.0	0.0	0.7	1.0	1.1	2.3
2013	RK 21.9	Estimated Daily Average Salinity	3.1	0.0	0.0	0.0	2.8	5.4	8.1	11.9
2013	RK 21.9	Estimated Daily Range in Salinity	2.6	0.0	0.0	0.0	3.3	4.3	5.0	6.5
2013	RK 21.9	Estimated Change due to Withdrawals	0.6	-0.6	0.0	0.0	0.7	1.0	1.1	2.2
2013	RK 24.5	Estimated Daily Average Salinity	1.7	0.0	0.0	0.0	0.8	2.8	5.2	9.0
2013	RK 24.5	Estimated Daily Range in Salinity	2.0	0.0	0.0	0.0	2.0	3.6	4.6	6.6
2013	RK 24.5	Estimated Change due to Withdrawals	0.5	-0.7	0.0	0.0	0.5	0.8	1.0	1.9
2013	RK 26.7	Estimated Daily Average Salinity	0.8	0.0	0.0	0.0	0.4	1.2	2.6	5.1
2013	RK 26.7	Estimated Daily Range in Salinity	1.2	0.0	0.0	0.0	1.1	2.2	2.9	4.1
2013	RK 26.7	Estimated Change due to Withdrawals	0.3	-0.1	0.0	0.0	0.2	0.5	0.7	1.3
2013	RK 29.8	Estimated Daily Average Salinity	0.3	0.0	0.0	0.0	0.3	0.4	0.9	2.0
2013	RK 29.8	Estimated Daily Range in Salinity	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3
2013	RK 29.8	Estimated Change due to Withdrawals	0.1	0.0	0.0	0.0	0.0	0.2	0.3	0.5
2014	RK 9.2	Estimated Daily Average Salinity	14.0	0.0	6.2	9.7	14.8	18.4	21.5	25.9
2014	RK 9.2	Estimated Daily Range in Salinity	7.1	0.0	5.1	6.1	7.2	8.4	9.1	13.3
2014	RK 9.2	Estimated Change due to Withdrawals	0.8	0.0	0.4	0.6	0.8	1.2	1.3	1.5
2014	RK 12.7	Estimated Daily Average Salinity	7.5	0.0	1.3	3.2	7.8	11.4	14.2	18.1
2014	RK 12.7	Estimated Daily Range in Salinity	5.5	0.0	2.7	4.5	5.7	6.8	7.7	11.0
2014	RK 12.7	Estimated Change due to Withdrawals	0.9	-1.2	0.2	0.4	0.9	1.2	1.4	2.6
2014	RK 15.5	Estimated Daily Average Salinity	5.9	0.0	0.4	1.5	5.7	9.6	12.4	16.2
2014	RK 15.5	Estimated Daily Range in Salinity	4.1	0.0	1.3	3.1	4.4	5.3	6.0	8.7
2014	RK 15.5	Estimated Change due to Withdrawals	0.9	-0.9	0.1	0.3	0.9	1.3	1.5	2.8
2014	RK 18.5	Estimated Daily Average Salinity	3.4	0.0	0.2	0.6	2.7	5.6	8.5	12.6
2014	RK 18.5	Estimated Daily Range in Salinity	4.2	0.0	0.5	1.6	4.5	6.5	7.7	11.4
2014	RK 18.5	Estimated Change due to Withdrawals	0.5	-4.3	-0.1	0.0	0.7	1.1	1.3	1.9
2014	RK 18.7	Estimated Daily Average Salinity	3.6	0.0	0.0	0.4	3.0	6.2	8.6	11.8
2014	RK 18.7	Estimated Daily Range in Salinity	2.4	0.0	0.0	1.0	2.7	3.6	4.2	6.3
2014	RK 18.7	Estimated Change due to Withdrawals	0.7	-0.2	0.0	0.1	0.7	1.1	1.3	2.3
2014	RK 20.8	Estimated Daily Average Salinity	2.1	0.0	0.1	0.3	1.4	3.4	5.7	9.2
2014	RK 20.8	Estimated Daily Range in Salinity	3.1	0.0	0.3	1.0	3.1	4.9	6.3	9.7
2014	RK 20.8	Estimated Change due to Withdrawals	0.4	-3.2	-0.2	0.0	0.5	0.9	1.0	1.8
2014	RK 21.9	Estimated Daily Average Salinity	1.5	0.0	0.0	0.0	0.7	2.6	4.6	7.7
2014	RK 21.9	Estimated Daily Range in Salinity	2.0	0.0	0.0	0.2	1.8	3.5	4.6	7.2
2014	RK 21.9	Estimated Change due to Withdrawals	0.4	-0.4	0.0	0.0	0.4	0.8	1.0	1.7
2014	RK 24.5	Estimated Daily Average Salinity	0.7	0.0	0.0	0.0	0.2	0.9	2.2	4.9
2014	RK 24.5	Estimated Daily Range in Salinity	1.2	0.0	0.0	0.0	0.6	2.3	3.3	5.0
2014	RK 24.5	Estimated Change due to Withdrawals	0.2	-0.8	-0.1	0.0	0.1	0.5	0.8	1.4

Table 4.33
Average Daily Estimated Salinity, Range and Difference due to Withdrawals at Selected Recorder Sites along the Lower River

Year	Site	Parameter	Mean	Min	P10	P25	P50	P75	P90	Max
2014	RK 26.7	Estimated Daily Average Salinity	0.3	0.0	0.0	0.0	0.1	0.4	1.0	2.5
2014	RK 26.7	Estimated Daily Range in Salinity	0.6	0.0	0.0	0.0	0.3	1.0	1.9	3.0
2014	RK 26.7	Estimated Change due to Withdrawals	0.1	-0.1	0.0	0.0	0.0	0.2	0.4	1.0
2014	RK 29.8	Estimated Daily Average Salinity	0.1	0.0	0.0	0.0	0.0	0.3	0.3	0.5
2014	RK 29.8	Estimated Daily Range in Salinity	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
2014	RK 29.8	Estimated Change due to Withdrawals	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3
2015	RK 9.2	Estimated Daily Average Salinity	11.2	0.0	0.0	5.5	12.0	16.2	20.3	26.5
2015	RK 9.2	Estimated Daily Range in Salinity	6.2	0.0	0.0	5.3	6.9	8.1	9.0	10.5
2015	RK 9.2	Estimated Change due to Withdrawals	0.7	0.0	0.0	0.5	0.8	1.0	1.2	1.8
2015	RK 12.7	Estimated Daily Average Salinity	5.7	0.0	0.3	1.0	5.2	8.6	13.1	19.2
2015	RK 12.7	Estimated Daily Range in Salinity	4.6	0.0	1.0	2.3	5.2	6.4	7.4	8.8
2015	RK 12.7	Estimated Change due to Withdrawals	0.7	-1.4	0.0	0.2	0.7	1.1	1.4	2.3
2015	RK 15.5	Estimated Daily Average Salinity	4.2	0.0	0.0	0.4	3.1	6.4	11.1	18.0
2015	RK 15.5	Estimated Daily Range in Salinity	3.3	0.0	0.0	1.1	3.8	4.9	5.7	6.9
2015	RK 15.5	Estimated Change due to Withdrawals	0.6	-1.1	-0.1	0.1	0.7	1.1	1.4	2.5
2015	RK 18.5	Estimated Daily Average Salinity	2.5	0.0	0.0	0.3	1.6	3.4	7.3	13.7
2015	RK 18.5	Estimated Daily Range in Salinity	3.5	0.0	0.0	1.1	3.5	5.5	7.0	10.9
2015	RK 18.5	Estimated Change due to Withdrawals	0.2	-3.7	-1.0	0.0	0.3	0.8	1.0	1.8
2015	RK 18.7	Estimated Daily Average Salinity	2.4	0.0	0.0	0.0	1.2	3.6	7.4	13.8
2015	RK 18.7	Estimated Daily Range in Salinity	1.8	0.0	0.0	0.0	1.9	3.0	3.8	5.0
2015	RK 18.7	Estimated Change due to Withdrawals	0.5	0.0	0.0	0.0	0.4	0.8	1.0	2.0
2015	RK 20.8	Estimated Daily Average Salinity	1.4	0.0	0.0	0.0	0.6	1.8	4.8	10.1
2015	RK 20.8	Estimated Daily Range in Salinity	2.2	0.0	0.0	0.1	1.7	3.7	5.5	7.6
2015	RK 20.8	Estimated Change due to Withdrawals	0.3	-1.5	0.0	0.0	0.1	0.6	0.8	1.5
2015	RK 21.9	Estimated Daily Average Salinity	1.0	0.0	0.0	0.0	0.1	1.0	3.7	9.0
2015	RK 21.9	Estimated Daily Range in Salinity	1.3	0.0	0.0	0.0	0.6	2.3	4.0	5.7
2015	RK 21.9	Estimated Change due to Withdrawals	0.3	-0.5	0.0	0.0	0.1	0.4	0.8	1.4
2015	RK 24.5	Estimated Daily Average Salinity	0.5	0.0	0.0	0.0	0.1	0.4	1.6	6.2
2015	RK 24.5	Estimated Daily Range in Salinity	0.9	0.0	0.0	0.0	0.2	1.3	3.0	5.2
2015	RK 24.5	Estimated Change due to Withdrawals	0.1	-0.6	-0.2	0.0	0.0	0.2	0.6	1.5
2015	RK 26.7	Estimated Daily Average Salinity	0.2	0.0	0.0	0.0	0.0	0.2	0.7	3.3
2015	RK 26.7	Estimated Daily Range in Salinity	0.4	0.0	0.0	0.0	0.0	0.5	1.4	3.2
2015	RK 26.7	Estimated Change due to Withdrawals	0.1	-0.2	0.0	0.0	0.0	0.1	0.3	0.7
2015	RK 29.8	Estimated Daily Average Salinity	0.1	0.0	0.0	0.0	0.0	0.2	0.3	1.0
2015	RK 29.8	Estimated Daily Range in Salinity	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
2015	RK 29.8	Estimated Change due to Withdrawals	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3
2016	RK 9.2	Estimated Daily Average Salinity	9.6	0.0	0.5	4.0	8.9	15.1	20.2	22.5
2016	RK 9.2	Estimated Daily Range in Salinity	6.0	0.0	1.8	5.2	6.5	7.8	8.8	12.7
2016	RK 9.2	Estimated Change due to Withdrawals	0.7	0.0	0.3	0.5	0.7	0.9	1.1	1.2

Table 4.33
Average Daily Estimated Salinity, Range and Difference due to Withdrawals at Selected Recorder Sites along the Lower River

Year	Site	Parameter	Mean	Min	P10	P25	P50	P75	P90	Max
2016	RK 12.7	Estimated Daily Average Salinity	4.6	0.0	0.1	0.6	2.7	7.9	12.6	14.9
2016	RK 12.7	Estimated Daily Range in Salinity	4.0	0.0	0.4	1.7	4.3	5.8	6.9	9.9
2016	RK 12.7	Estimated Change due to Withdrawals	0.5	-1.0	-0.1	0.1	0.6	0.9	1.2	1.5
2016	RK 15.5	Estimated Daily Average Salinity	3.5	0.0	0.1	0.4	1.3	5.6	10.7	13.0
2016	RK 15.5	Estimated Daily Range in Salinity	2.9	0.0	0.4	1.1	2.8	4.4	5.4	7.7
2016	RK 15.5	Estimated Change due to Withdrawals	0.4	-1.6	-0.4	0.0	0.4	0.9	1.3	1.5
2016	RK 18.5	Estimated Daily Average Salinity	2.5	0.0	0.1	0.3	1.6	4.3	7.0	9.1
2016	RK 18.5	Estimated Daily Range in Salinity	3.7	0.0	0.1	1.1	3.5	5.7	8.0	13.4
2016	RK 18.5	Estimated Change due to Withdrawals	-0.4	-8.8	-2.9	-0.2	0.0	0.5	1.0	1.3
2016	RK 18.7	Estimated Daily Average Salinity	1.9	0.0	0.0	0.0	0.2	3.0	7.1	9.2
2016	RK 18.7	Estimated Daily Range in Salinity	1.4	0.0	0.0	0.0	0.7	2.8	3.5	5.6
2016	RK 18.7	Estimated Change due to Withdrawals	0.3	-0.1	0.0	0.0	0.1	0.6	1.0	1.3
2016	RK 20.8	Estimated Daily Average Salinity	1.3	0.0	0.0	0.0	0.6	1.7	4.5	6.3
2016	RK 20.8	Estimated Daily Range in Salinity	2.0	0.0	0.0	0.0	1.5	3.6	5.2	8.3
2016	RK 20.8	Estimated Change due to Withdrawals	0.1	-1.9	-0.7	0.0	0.0	0.4	0.8	1.1
2016	RK 21.9	Estimated Daily Average Salinity	0.8	0.0	0.0	0.0	0.0	0.8	3.4	5.1
2016	RK 21.9	Estimated Daily Range in Salinity	1.1	0.0	0.0	0.0	0.2	1.8	3.8	6.3
2016	RK 21.9	Estimated Change due to Withdrawals	0.2	-0.4	0.0	0.0	0.0	0.3	0.8	1.0
2016	RK 24.5	Estimated Daily Average Salinity	0.4	0.0	0.0	0.0	0.0	0.4	1.4	2.6
2016	RK 24.5	Estimated Daily Range in Salinity	0.7	0.0	0.0	0.0	0.0	1.2	2.6	5.3
2016	RK 24.5	Estimated Change due to Withdrawals	0.1	-0.4	-0.1	0.0	0.0	0.0	0.6	1.1
2016	RK 26.7	Estimated Daily Average Salinity	0.2	0.0	0.0	0.0	0.0	0.2	0.7	1.3
2016	RK 26.7	Estimated Daily Range in Salinity	0.3	0.0	0.0	0.0	0.0	0.5	1.3	2.2
2016	RK 26.7	Estimated Change due to Withdrawals	0.0	-0.1	0.0	0.0	0.0	0.0	0.3	0.4
2016	RK 29.8	Estimated Daily Average Salinity	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.3
2016	RK 29.8	Estimated Daily Range in Salinity	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
2016	RK 29.8	Estimated Change due to Withdrawals	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2

Table 4.34. Best Fit GLM Model for 0 psu ishaline

The GLM Procedure

Number of Observations Read	402
Number of Observations Used	400

Table 4.34. Best Fit GLM Model for 0 psu ishaline

The GLM Procedure

Dependent Variable: DIS Distance (km)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	16567.01618	8283.50809	317.38	<.0001
Error	397	10361.58996	26.09972		
Corrected Total	399	26928.60614			

R-Square	Coeff Var	Root MSE	DIS Mean
0.615220	21.94311	5.108789	23.28197

Source	DF	Type I SS	Mean Square	F Value	Pr > F
LFLOW	1	16014.22764	16014.22764	613.58	<.0001
LF40	1	552.78855	552.78855	21.18	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LFLOW	1	2280.891001	2280.891001	87.39	<.0001
LF40	1	552.788547	552.788547	21.18	<.0001

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	56.06719630	1.38260763	40.55	<.0001
LFLOW	-3.39373183	0.36303058	-9.35	<.0001
LF40	-1.82062424	0.39560225	-4.60	<.0001

Table 4.35. Best Fit GLM Model for 6 psu ishaline

The GLM Procedure

Number of Observations Read	403
Number of Observations Used	400

Table 4.35. Best Fit GLM Model for 6 psu ishaline

The GLM Procedure

Dependent Variable: DIS Distance (km)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	14978.23921	3744.55980	326.10	<.0001
Error	395	4535.77329	11.48297		
Corrected Total	399	19514.01250			

R-Square	Coeff Var	Root MSE	DIS Mean
0.767563	25.39744	3.388653	13.34250

Source	DF	Type I SS	Mean Square	F Value	Pr > F
FLOW2	1	5058.229603	5058.229603	440.50	<.0001
LFLOW2	1	9224.305153	9224.305153	803.30	<.0001
F602	1	5.429664	5.429664	0.47	0.4921
LF402	1	690.274787	690.274787	60.11	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
FLOW2	1	166.291470	166.291470	14.48	0.0002
LFLOW2	1	1137.167427	1137.167427	99.03	<.0001
F602	1	99.746573	99.746573	8.69	0.0034
LF402	1	690.274787	690.274787	60.11	<.0001

Table 4.35. Best Fit GLM Model for 6 psu ishaline

The GLM Procedure

Dependent Variable: DIS Distance (km)

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	44.46413255	1.09713900	40.53	<.0001
FLOW2	-0.00000005	0.00000001	-3.81	0.0002
LFLOW2	-1.32475184	0.13312188	-9.95	<.0001
F602	0.00000008	0.00000003	2.95	0.0034
LF402	-1.14364905	0.14750573	-7.75	<.0001

Table 4.36. Best Fit GLM Model for 12 psu ishaline

The GLM Procedure

Number of Observations Read	403
Number of Observations Used	400

Table 4.36. Best Fit GLM Model for 12 psu ishaline

The GLM Procedure

Dependent Variable: DIS Distance (km)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	22896.10307	5724.02577	257.01	<.0001
Error	395	8797.21903	22.27144		
Corrected Total	399	31693.32210			

R-Square	Coeff Var	Root MSE	DIS Mean
0.722427	56.10489	4.719263	8.411500

Source	DF	Type I SS	Mean Square	F Value	Pr > F
LFLOW2	1	20515.79667	20515.79667	921.17	<.0001
F10	1	1873.61305	1873.61305	84.13	<.0001
F602	1	17.67015	17.67015	0.79	0.3736
LF402	1	489.02319	489.02319	21.96	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LFLOW2	1	765.096595	765.096595	34.35	<.0001
F10	1	1556.874507	1556.874507	69.90	<.0001
F602	1	157.242430	157.242430	7.06	0.0082
LF402	1	489.023193	489.023193	21.96	<.0001

Table 4.36. Best Fit GLM Model for 12 psu ishaline

The GLM Procedure

Dependent Variable: DIS Distance (km)

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	36.79852666	1.68795281	21.80	<.0001
LFLOW2	-1.14729362	0.19574497	-5.86	<.0001
F10	-0.00197464	0.00023618	-8.36	<.0001
F602	0.00000011	0.00000004	2.66	0.0082
LF402	-0.94224665	0.20108238	-4.69	<.0001

Table 4.37. Best Fit GLM Model for 20 psu ishaline

The GLM Procedure

Number of Observations Read	403
Number of Observations Used	400

Table 4.37. Best Fit GLM Model for 20 psu ishaline

The GLM Procedure

Dependent Variable: DIS Distance (km)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	35957.99041	7191.59808	185.54	<.0001
Error	394	15271.57002	38.76033		
Corrected Total	399	51229.56043			

R-Square	Coeff Var	Root MSE	DIS Mean
0.701899	400.5391	6.225779	1.554350

Source	DF	Type I SS	Mean Square	F Value	Pr > F
FLOW	1	27450.82281	27450.82281	708.22	<.0001
FLOW2	1	4514.04424	4514.04424	116.46	<.0001
LFLOW	1	1998.40966	1998.40966	51.56	<.0001
F20	1	1222.81417	1222.81417	31.55	<.0001
LF60	1	771.89953	771.89953	19.91	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
FLOW	1	550.8362077	550.8362077	14.21	0.0002
FLOW2	1	287.1828662	287.1828662	7.41	0.0068
LFLOW	1	353.1114250	353.1114250	9.11	0.0027
F20	1	421.4820908	421.4820908	10.87	0.0011
LF60	1	771.8995339	771.8995339	19.91	<.0001

Table 4.37. Best Fit GLM Model for 20 psu ishaline

The GLM Procedure

Dependent Variable: DIS Distance (km)

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	31.42157742	2.87664133	10.92	<.0001
FLOW	-0.00329739	0.00087469	-3.77	0.0002
FLOW2	0.00000019	0.00000007	2.72	0.0068
LFLOW	-1.91618073	0.63485467	-3.02	0.0027
F20	-0.00123181	0.00037355	-3.30	0.0011
LF60	-2.08722266	0.46771589	-4.46	<.0001

Table 4.38
Statistical Summary of Daily Estimated Changes in Isohaline Locations along the HBMP Monitoring Transect due to Facility Withdrawals
(By Year and Isohaline)

Year	Isohaline	Summary Statistical Metrics							
		Mean	Min	P10	P25	P50	P75	P90	Max
1998	0 psu	0.1	0.0	0.0	0.0	0.1	0.1	0.2	0.4
1998	6 psu	0.1	0.0	0.0	0.0	0.0	0.1	0.2	0.3
1998	12 psu	0.1	0.0	0.0	0.0	0.1	0.1	0.2	0.3
1998	20 psu	0.1	0.0	0.0	0.0	0.1	0.2	0.2	0.3
1999	0 psu	0.2	0.0	0.0	0.1	0.1	0.3	0.4	0.6
1999	6 psu	0.1	0.0	0.0	0.0	0.1	0.2	0.3	0.5
1999	12 psu	0.1	0.0	0.0	0.1	0.1	0.2	0.3	0.4
1999	20 psu	0.2	0.0	0.0	0.1	0.2	0.3	0.3	0.5
2000	0 psu	0.1	0.0	0.0	0.0	0.0	0.2	0.2	0.4
2000	6 psu	0.1	0.0	0.0	0.0	0.0	0.1	0.2	0.3
2000	12 psu	0.1	0.0	0.0	0.0	0.0	0.1	0.2	0.3
2000	20 psu	0.1	0.0	0.0	0.0	0.1	0.2	0.3	0.4
2001	0 psu	0.1	0.0	0.0	0.0	0.0	0.1	0.2	0.6
2001	6 psu	0.1	0.0	0.0	0.0	0.0	0.1	0.2	0.5
2001	12 psu	0.1	0.0	0.0	0.0	0.0	0.1	0.2	0.4
2001	20 psu	0.1	0.0	0.0	0.0	0.1	0.1	0.2	0.5
2002	0 psu	0.1	0.0	0.0	0.0	0.1	0.2	0.3	0.5
2002	6 psu	0.1	0.0	0.0	0.0	0.1	0.2	0.3	0.5
2002	12 psu	0.1	0.0	0.0	0.1	0.1	0.2	0.3	0.4
2002	20 psu	0.2	0.0	0.1	0.1	0.2	0.2	0.3	0.5
2003	0 psu	0.1	0.0	0.0	0.0	0.1	0.2	0.3	0.5
2003	6 psu	0.1	0.0	0.0	0.0	0.1	0.2	0.3	0.4
2003	12 psu	0.1	0.0	0.0	0.1	0.1	0.2	0.3	0.4
2003	20 psu	0.2	0.0	0.1	0.1	0.1	0.2	0.3	0.5
2004	0 psu	0.2	0.0	0.0	0.0	0.2	0.3	0.3	0.5
2004	6 psu	0.2	0.0	0.0	0.0	0.2	0.2	0.3	0.4
2004	12 psu	0.2	0.0	0.0	0.1	0.2	0.2	0.3	0.4
2004	20 psu	0.2	0.0	0.0	0.1	0.2	0.3	0.4	0.4
2005	0 psu	0.1	0.0	0.0	0.0	0.1	0.2	0.3	0.4
2005	6 psu	0.1	0.0	0.0	0.1	0.1	0.2	0.2	0.4
2005	12 psu	0.1	0.0	0.1	0.1	0.1	0.2	0.2	0.3
2005	20 psu	0.2	0.0	0.1	0.1	0.2	0.2	0.3	0.4
2006	0 psu	0.2	0.0	0.0	0.1	0.3	0.4	0.4	0.7

Table 4.38
Statistical Summary of Daily Estimated Changes in Isohaline Locations along the HBMP Monitoring Transect due to Facility Withdrawals
(By Year and Isohaline)

Year	Isohaline	Summary Statistical Metrics							
		Mean	Min	P10	P25	P50	P75	P90	Max
2006	6 psu	0.2	0.0	0.0	0.1	0.2	0.3	0.4	0.6
2006	12 psu	0.2	0.0	0.0	0.1	0.2	0.3	0.4	0.5
2006	20 psu	0.3	0.0	0.0	0.2	0.3	0.4	0.4	0.7
2007	0 psu	0.2	0.0	0.0	0.1	0.2	0.3	0.4	0.6
2007	6 psu	0.2	0.0	0.0	0.1	0.2	0.3	0.4	0.5
2007	12 psu	0.2	0.0	0.0	0.1	0.2	0.3	0.3	0.4
2007	20 psu	0.2	0.0	0.0	0.1	0.3	0.3	0.4	0.5
2008	0 psu	0.3	0.0	0.0	0.1	0.2	0.6	0.7	0.9
2008	6 psu	0.3	0.0	0.0	0.1	0.2	0.5	0.6	0.8
2008	12 psu	0.3	0.0	0.0	0.1	0.2	0.4	0.5	0.7
2008	20 psu	0.3	0.0	0.1	0.1	0.3	0.5	0.7	0.8
2009	0 psu	0.4	0.0	0.0	0.1	0.3	0.6	0.8	1.0
2009	6 psu	0.3	0.0	0.0	0.1	0.3	0.5	0.7	0.9
2009	12 psu	0.3	0.0	0.0	0.1	0.3	0.5	0.7	0.8
2009	20 psu	0.4	0.0	0.0	0.2	0.5	0.7	0.8	1.0
2010	0 psu	0.2	0.0	0.0	0.0	0.1	0.3	0.6	0.8
2010	6 psu	0.2	0.0	0.0	0.0	0.1	0.3	0.5	0.7
2010	12 psu	0.2	0.0	0.0	0.0	0.2	0.3	0.6	0.7
2010	20 psu	0.3	0.0	0.0	0.1	0.2	0.4	0.7	0.9
2011	0 psu	0.4	0.0	0.1	0.1	0.4	0.5	0.9	1.2
2011	6 psu	0.3	0.0	0.1	0.1	0.3	0.4	0.7	1.1
2011	12 psu	0.4	0.0	0.1	0.2	0.3	0.5	0.8	1.1
2011	20 psu	0.5	0.0	0.1	0.2	0.4	0.6	1.0	1.4
2012	0 psu	0.3	0.0	0.0	0.0	0.1	0.5	0.7	0.9
2012	6 psu	0.2	0.0	0.0	0.0	0.1	0.5	0.6	0.8
2012	12 psu	0.3	0.0	0.0	0.0	0.1	0.5	0.7	0.9
2012	20 psu	0.3	0.0	0.0	0.0	0.3	0.6	0.9	1.2
2013	0 psu	0.4	0.0	0.0	0.1	0.2	0.7	1.0	1.2
2013	6 psu	0.3	0.0	0.0	0.1	0.2	0.6	0.9	1.1
2013	12 psu	0.4	0.0	0.0	0.1	0.2	0.7	0.8	1.0
2013	20 psu	0.4	0.0	0.1	0.2	0.3	0.7	0.9	1.2
2014	0 psu	0.5	0.0	0.1	0.2	0.5	0.8	0.9	1.1
2014	6 psu	0.4	0.0	0.1	0.2	0.4	0.7	0.8	0.9

Table 4.38
Statistical Summary of Daily Estimated Changes in Isohaline Locations along the HBMP Monitoring Transect due to Facility Withdrawals
(By Year and Isohaline)

Year	Isohaline	Summary Statistical Metrics							
		Mean	Min	P10	P25	P50	P75	P90	Max
2014	12 psu	0.5	0.1	0.2	0.2	0.4	0.7	0.8	1.0
2014	20 psu	0.6	0.1	0.2	0.3	0.6	0.8	0.9	1.3
2015	0 psu	0.4	0.0	0.1	0.1	0.3	0.6	0.8	1.0
2015	6 psu	0.3	0.0	0.0	0.1	0.3	0.5	0.7	0.9
2015	12 psu	0.4	0.0	0.1	0.1	0.4	0.5	0.7	0.9
2015	20 psu	0.4	0.1	0.1	0.3	0.4	0.6	0.8	1.1
2016	0 psu	0.2	0.0	0.0	0.1	0.1	0.3	0.7	0.9
2016	6 psu	0.2	0.0	0.0	0.1	0.1	0.3	0.6	0.8
2016	12 psu	0.2	0.0	0.0	0.1	0.2	0.3	0.6	0.7
2016	20 psu	0.3	0.0	0.1	0.1	0.3	0.5	0.6	0.7

2016 HBMP
Comprehensive Summary Report
Figures, Maps & Photos

This section contains figures, maps and photos not included directly in the text for each section.

Chapter 1	Introduction
Chapter 2*	Summaries of Recent Relevant Reports
Chapter 3	Status and Trends in Regional Rainfall, Flows and Facility Withdrawals
Chapter 4	Salinity in the Lower Peace River/Upper Charlotte Harbor Estuarine System
Chapter 5	Patterns and Trends of Hydrobiological Water Quality Indicators in the Lower Peace River/Upper Charlotte Harbor Estuarine System
Chapter 6*	Regulatory Influences on Water Withdrawals from the Lower Peace River
Chapter 7	Water Demand and Supply
Chapter 8*	Significant Environmental Change
Chapter 9*	Monitoring Design and Modifications to the Existing Long-term HBMP Elements

* Denotes chapters without additional figures

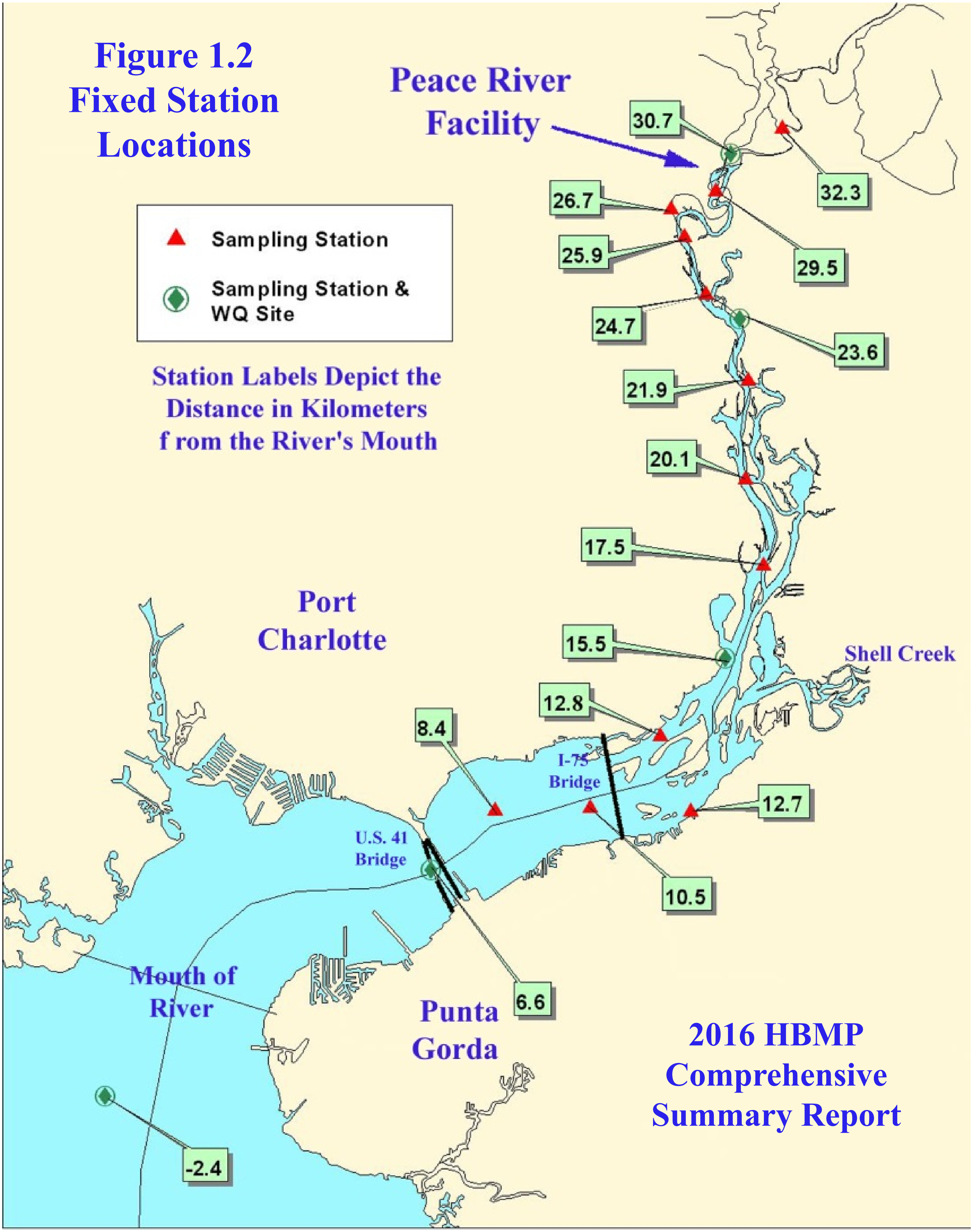


Figure 1.2 Fixed Station Locations

2016 HBMP Comprehensive Summary Report

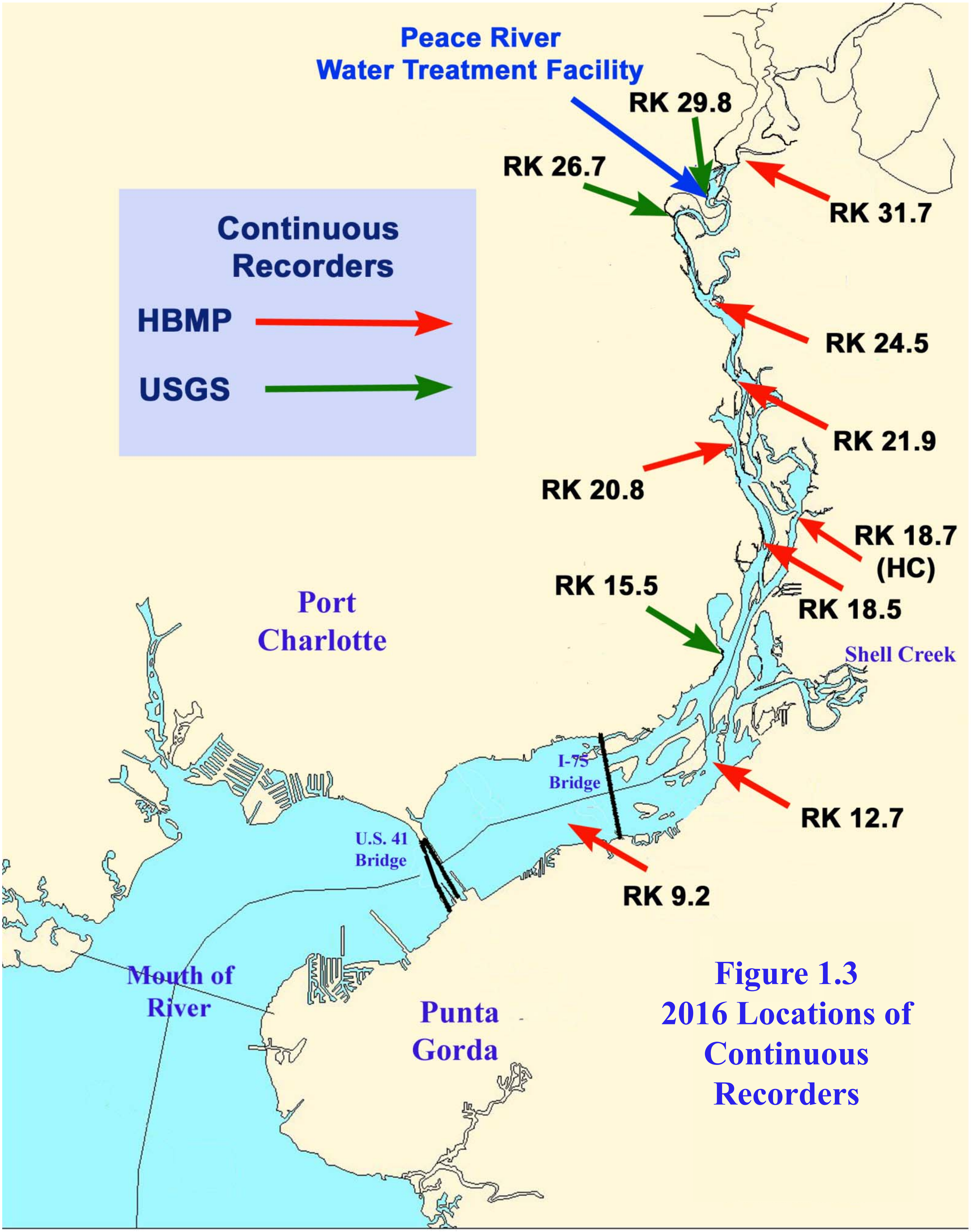


Figure 1.3
2016 Locations of Continuous Recorders

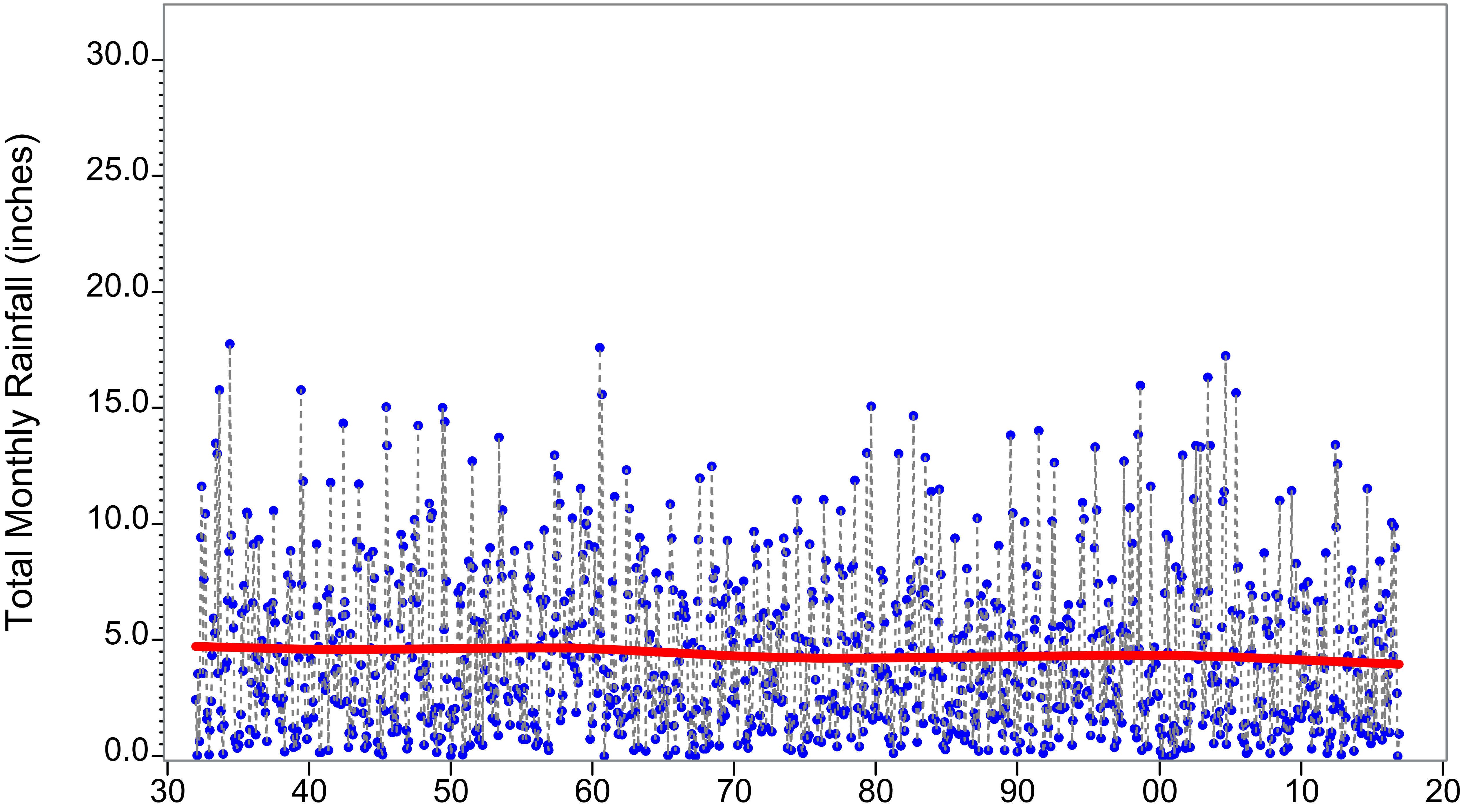


Figure 3.8 Monthly rainfall at long-term Bartow NOAA gage (District #25164/R142), 1932-2016

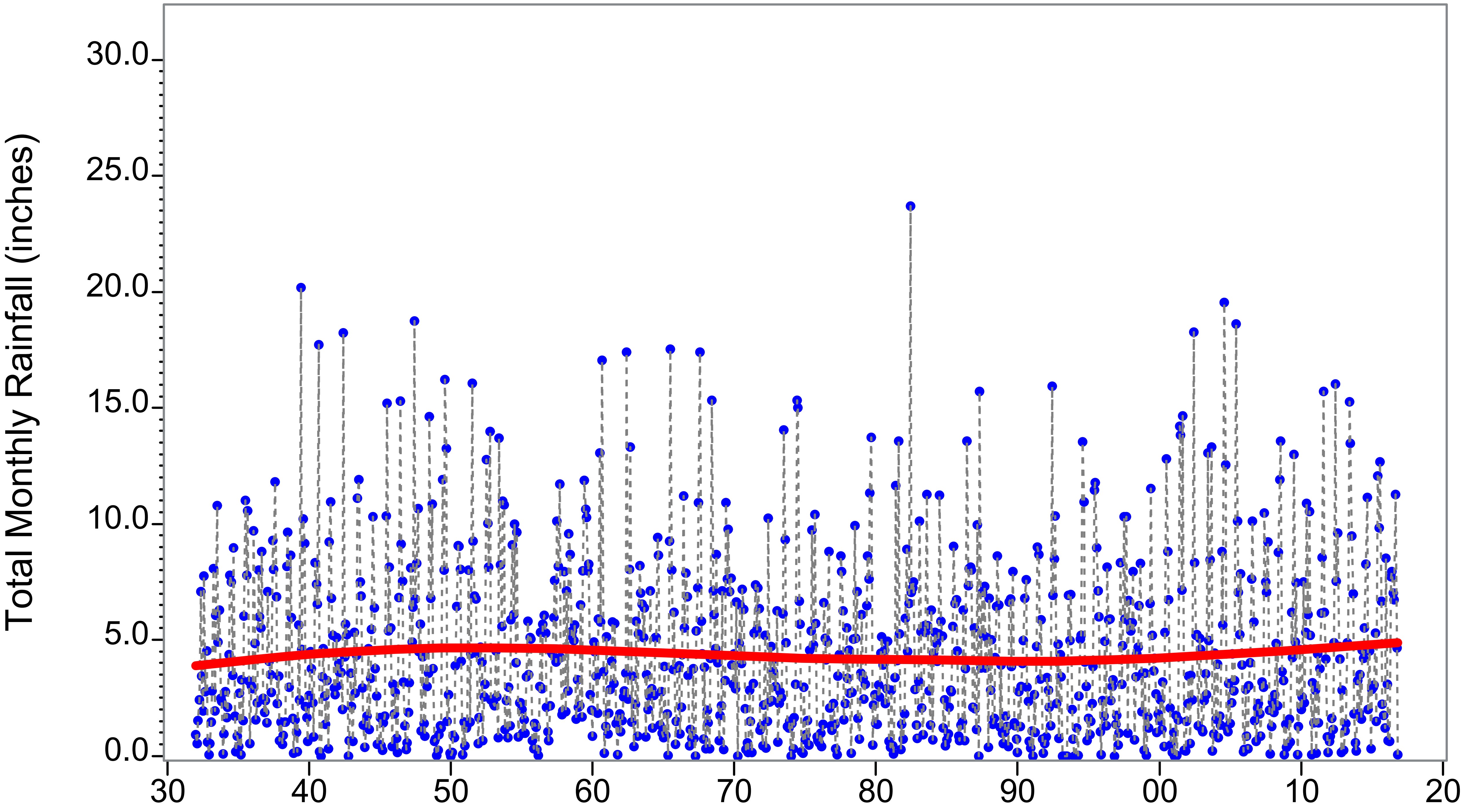


Figure 3.9 Monthly rainfall at long-term Arcadia NOAA gage (District #24570/R148), 1932-2016

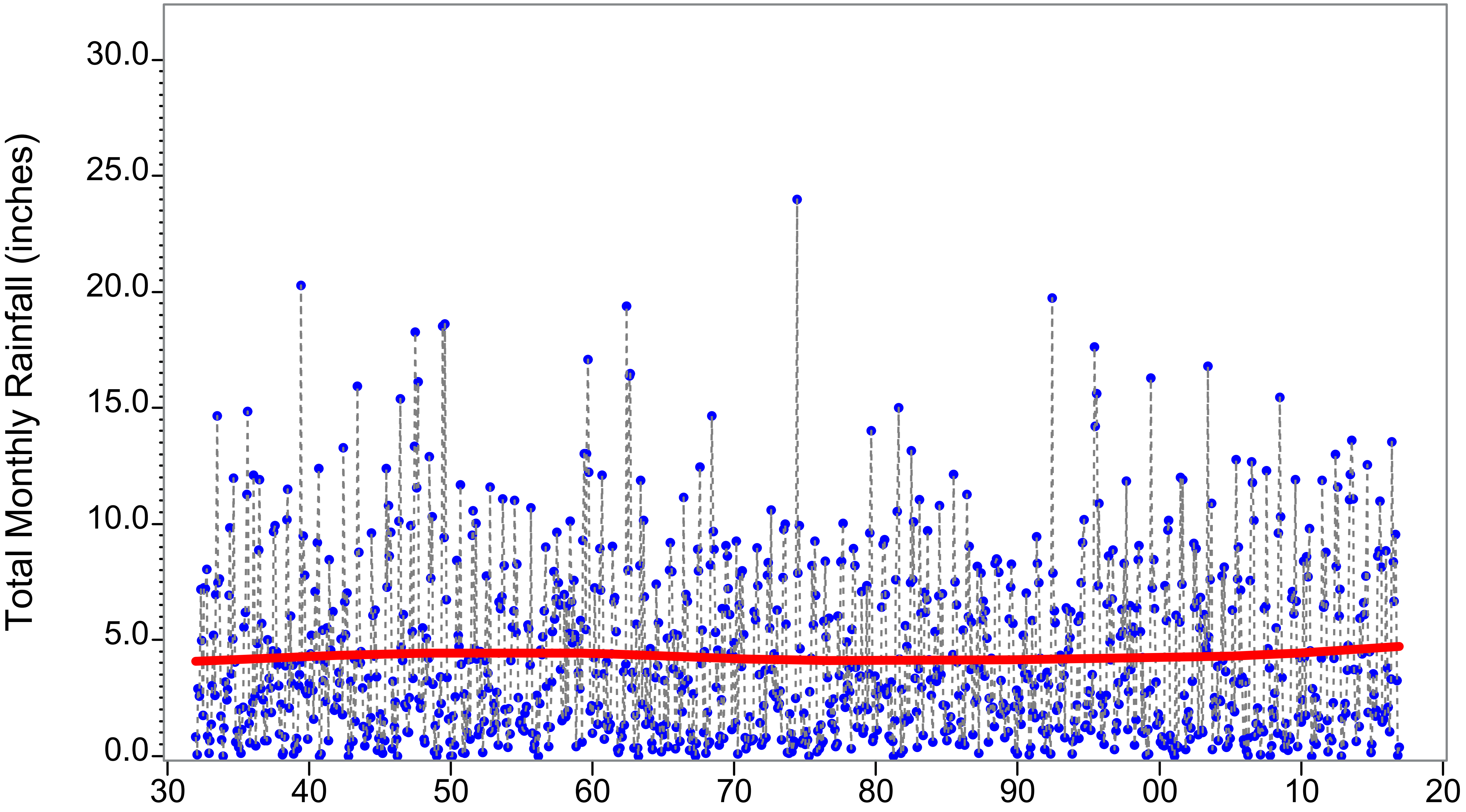


Figure 3.10 Monthly rainfall at long-term Punta Gorda NOAA gage (District #25105/R255), 1932-2016

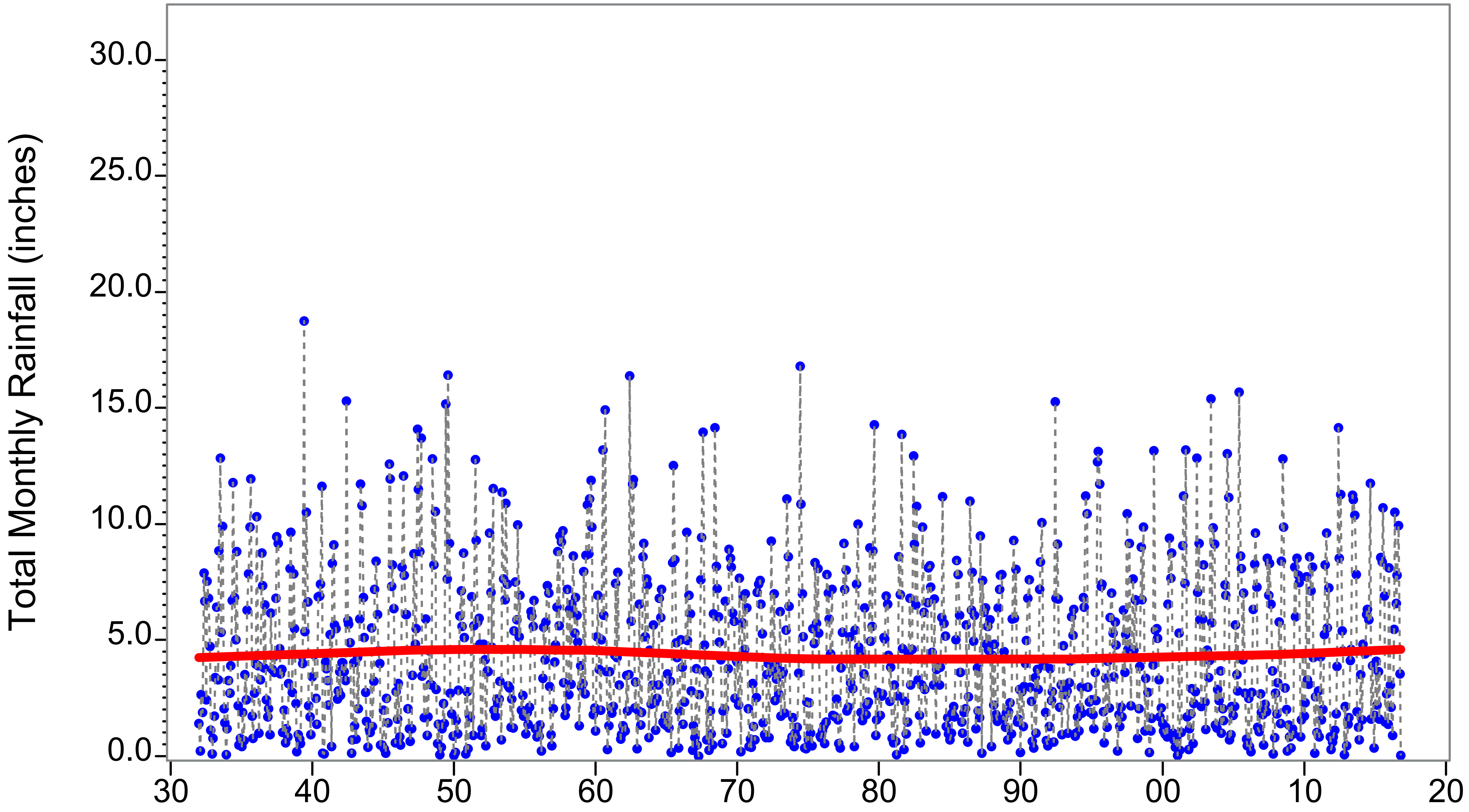


Figure 3.11 Monthly rainfall for the average of the three Peace River watershed basin gages, 1932-2016

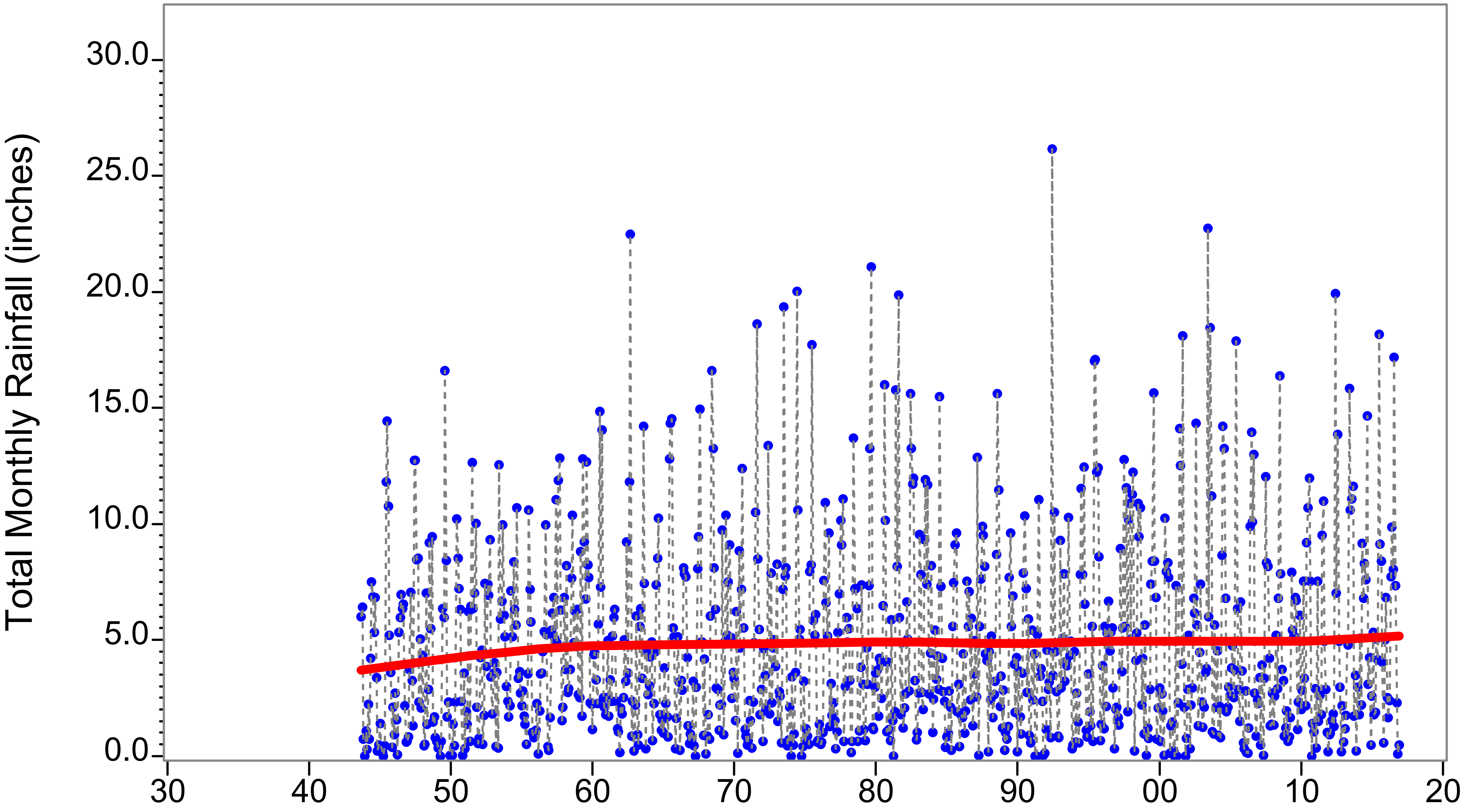


Figure 3.12 Monthly rainfall at long-term Myakka NOAA gage (District #25793/R336), 1943-2016

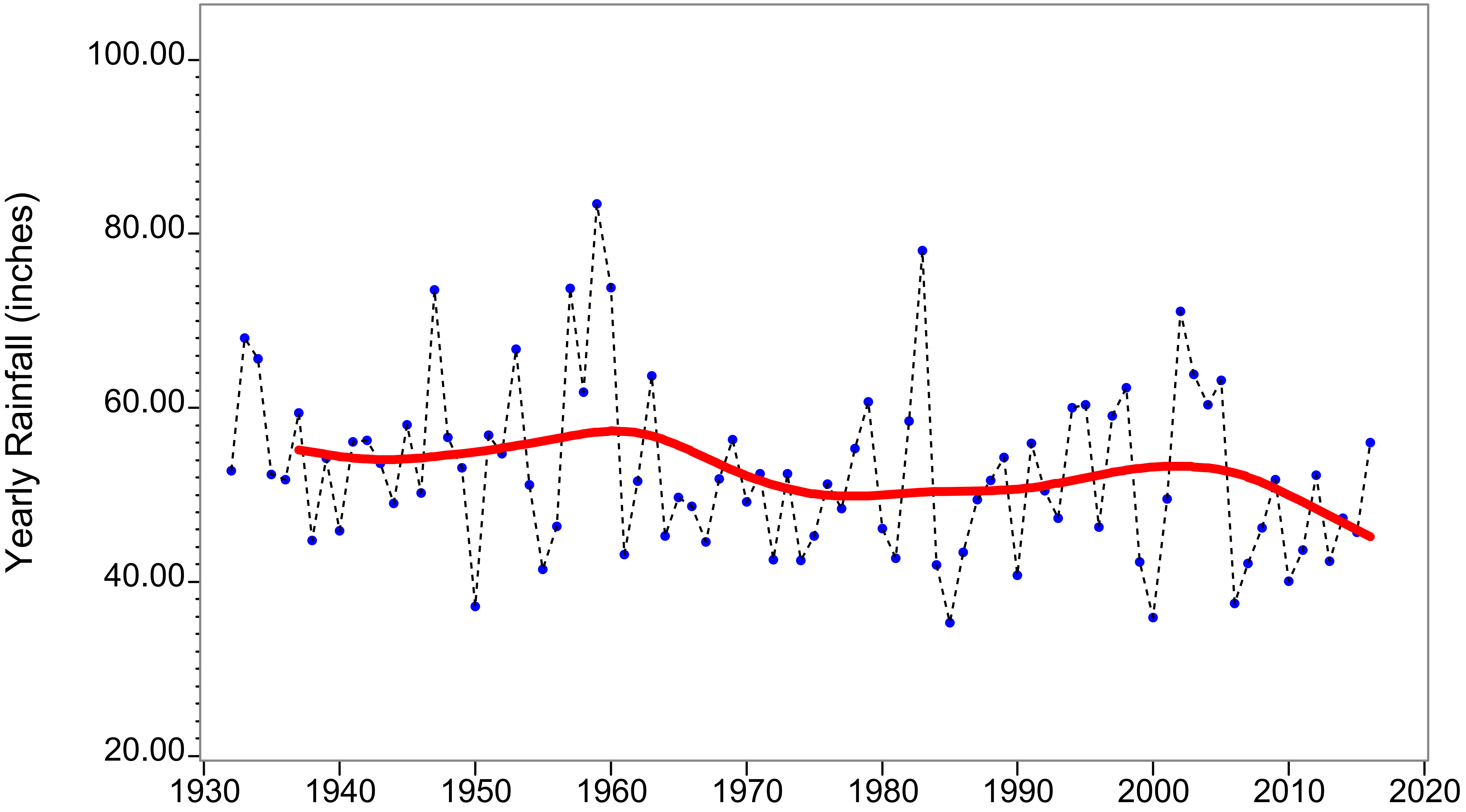


Figure 3.13 Yearly total and 5-year moving average rainfall at long-term Bartow NOAA gage (District #25164/R1422), 1932-2016

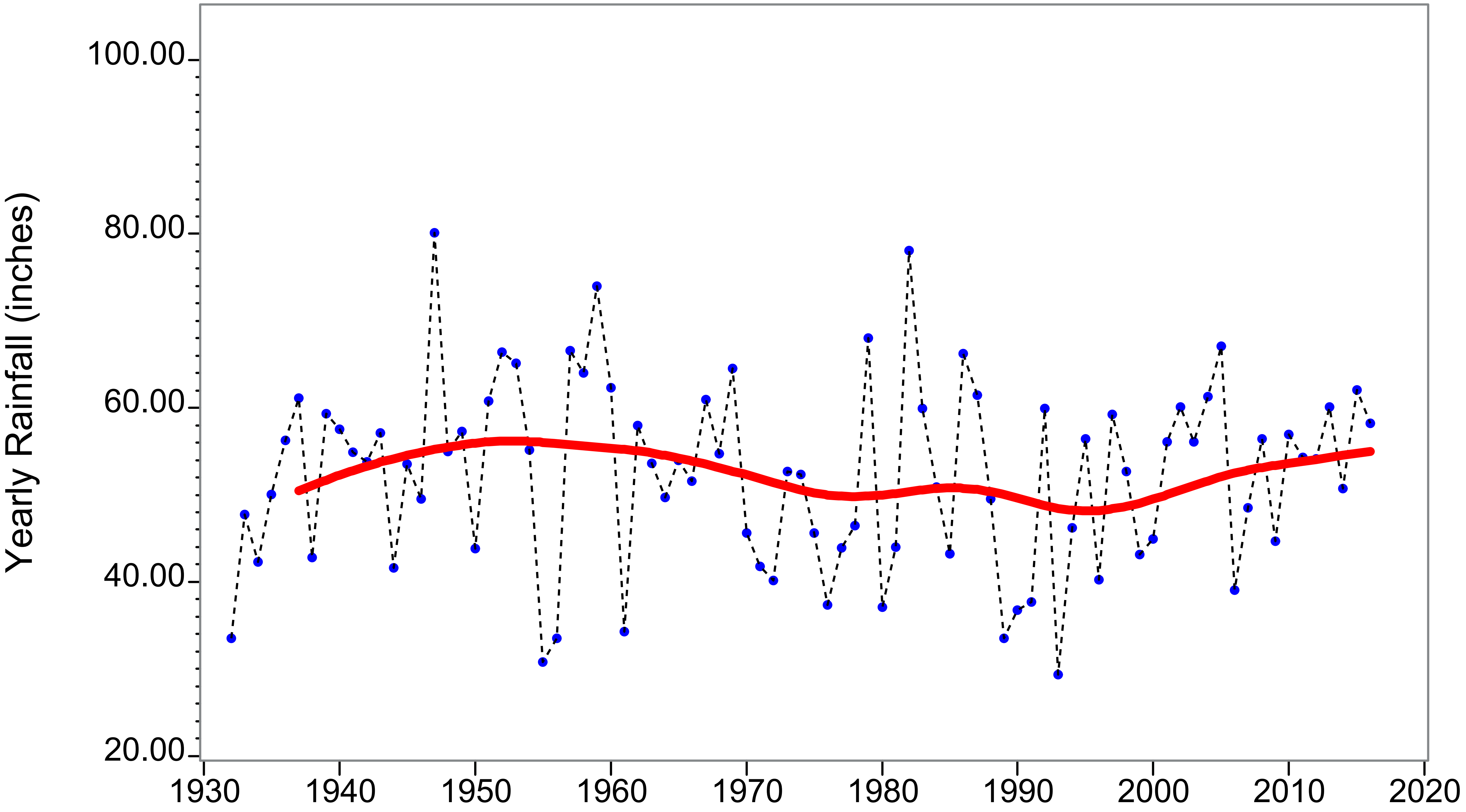


Figure 3.14 Yearly total and 5-year moving average rainfall at long-term Arcadia NOAA gage (District #24570/R148), 1932-2016

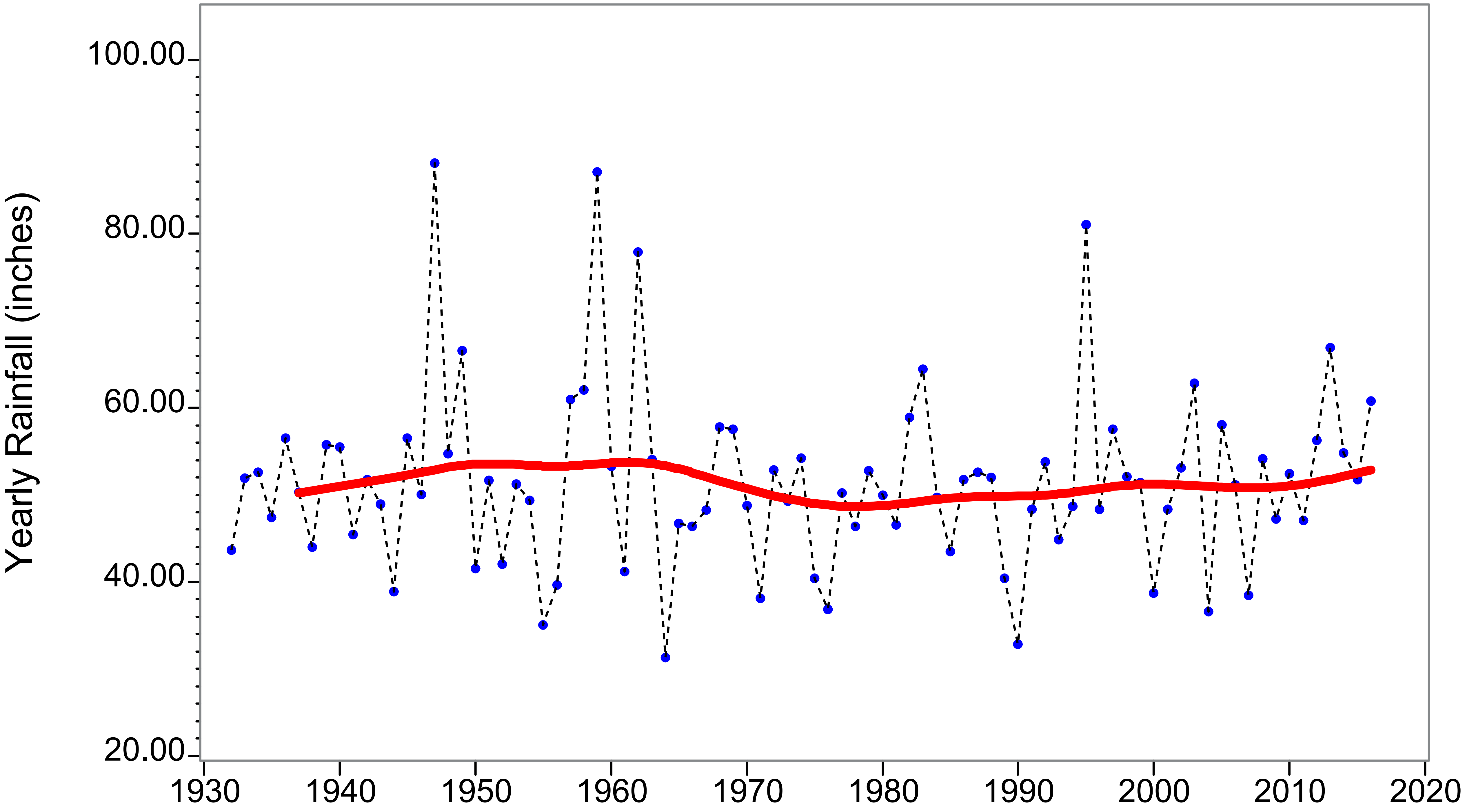


Figure 3.15 Yearly total and 5-year moving average rainfall at long-term Punta Gorda NOAA gage (District #25105/R255), 1932-2016

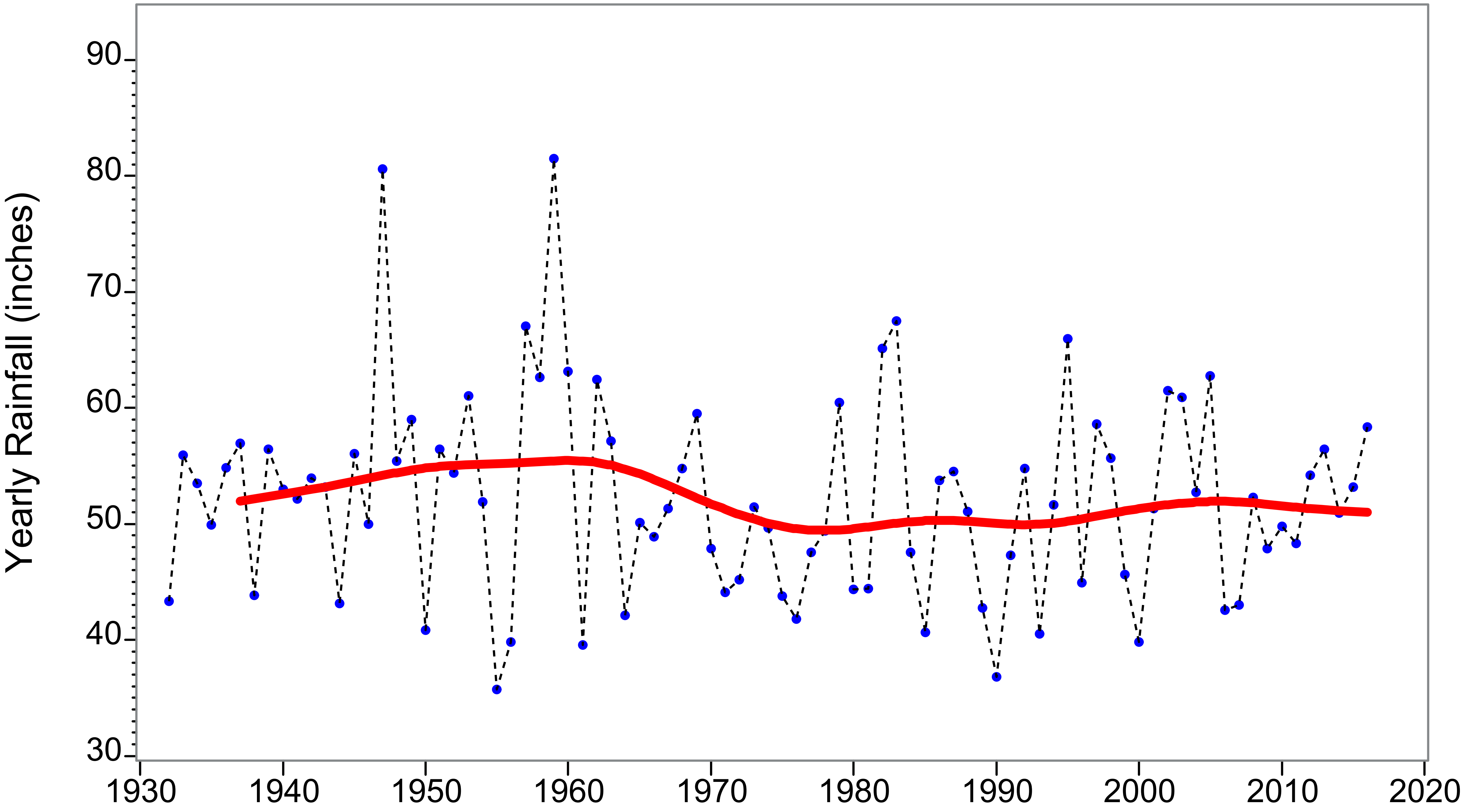


Figure 3.16 Yearly total and 5-year moving average rainfall for the average of the three Peace River watershed basin gages, 1932-2016

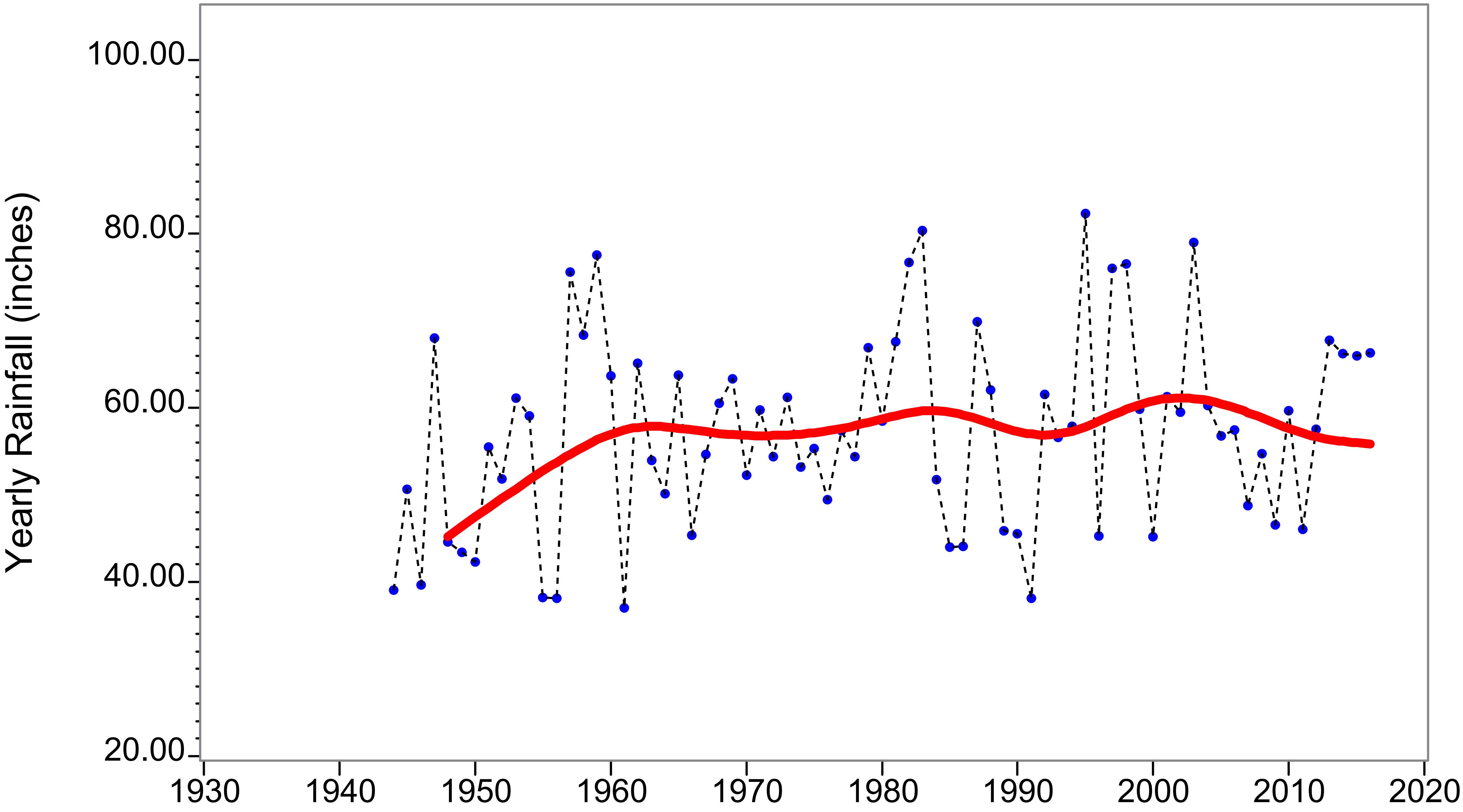


Figure 3.17 Yearly total and 5-year moving average rainfall at long-term Myakka NOAA gage (District #25793/R336), 1943-2016

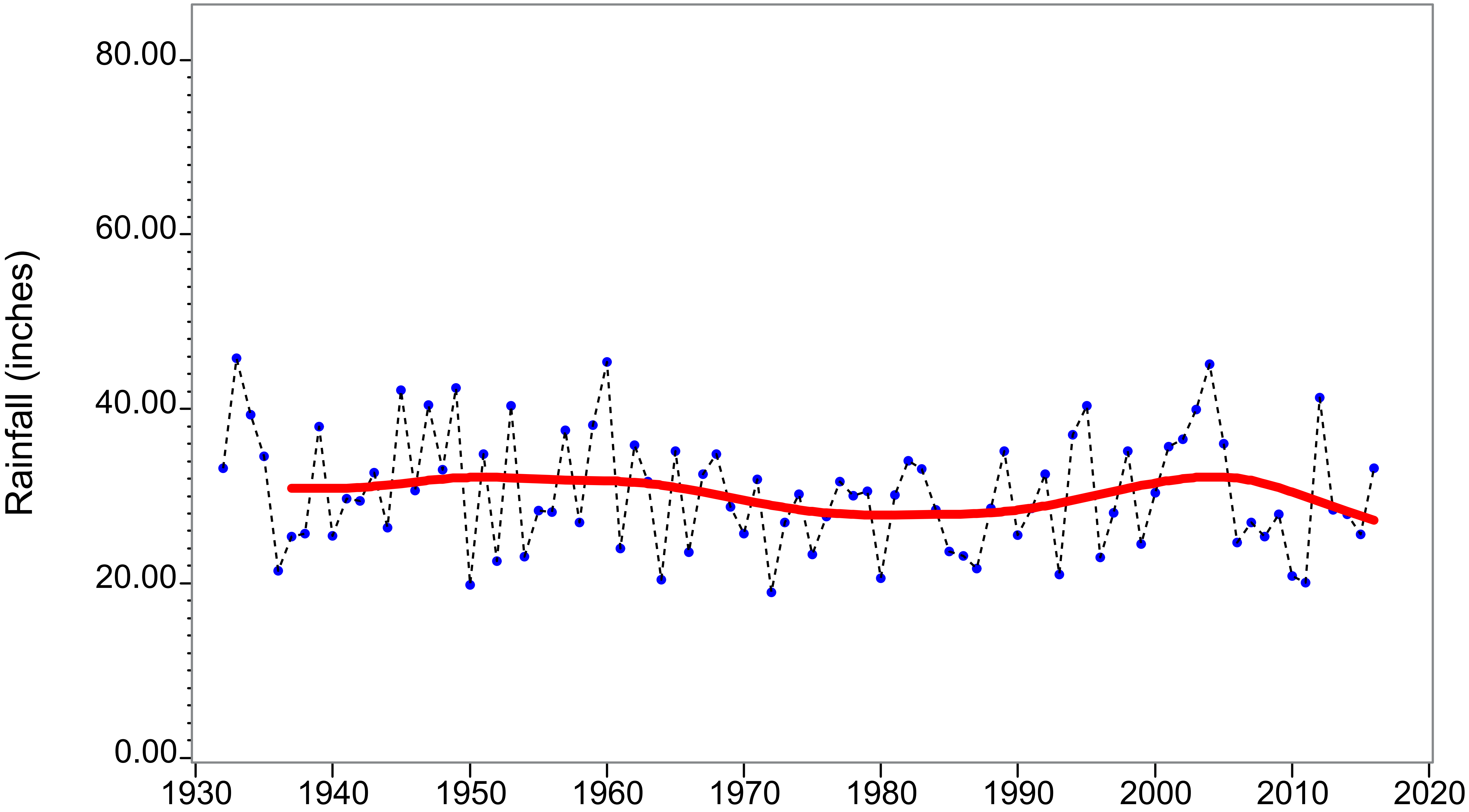


Figure 3.18 Yearly wet-season and 5-year moving average rainfall at long-term Bartow NOAA gage (District #25164/R1422), 1932-2016

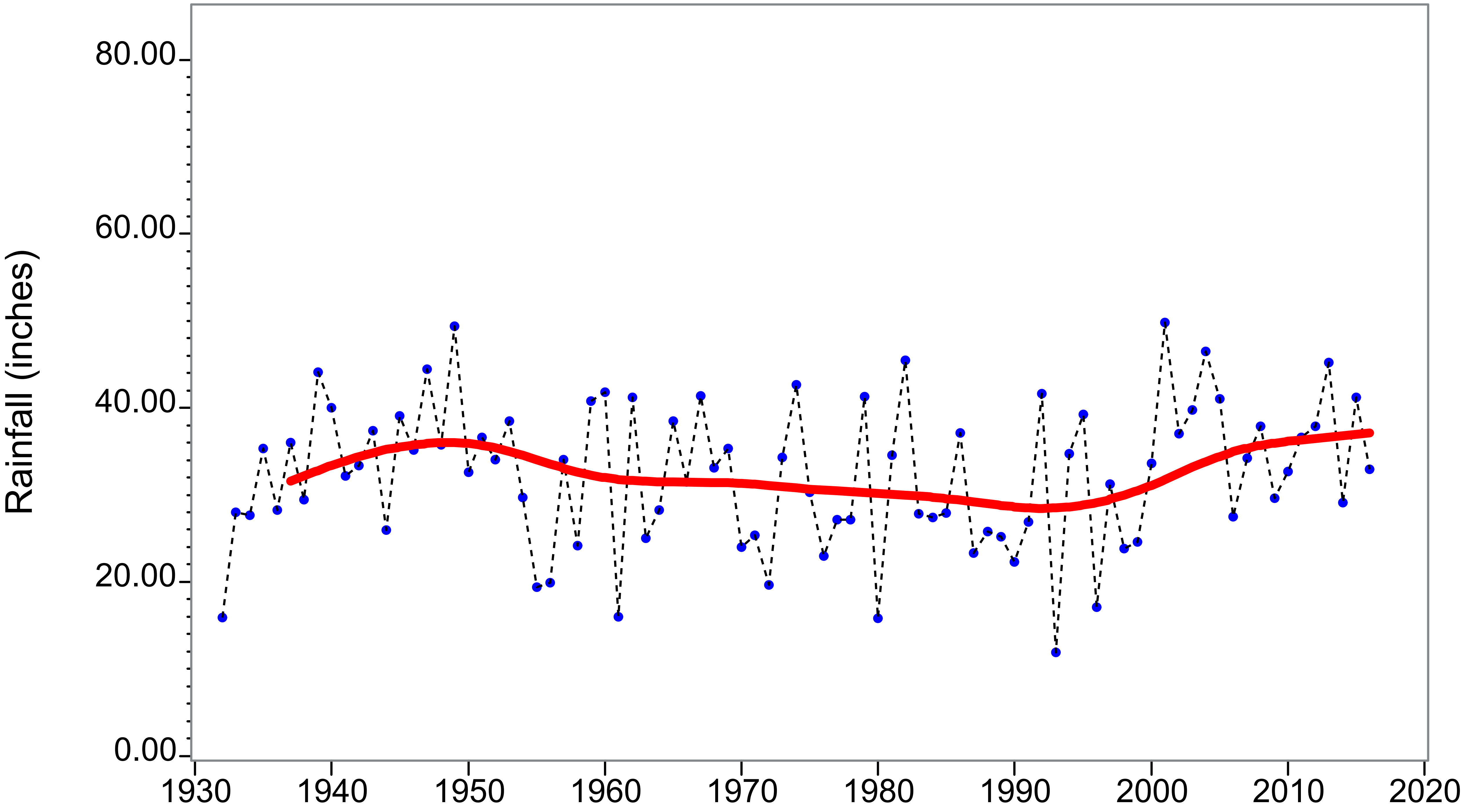


Figure 3.19 Yearly wet-season and 5-year moving average rainfall at long-term Arcadia NOAA gage (District #24570/R148), 1932-2016

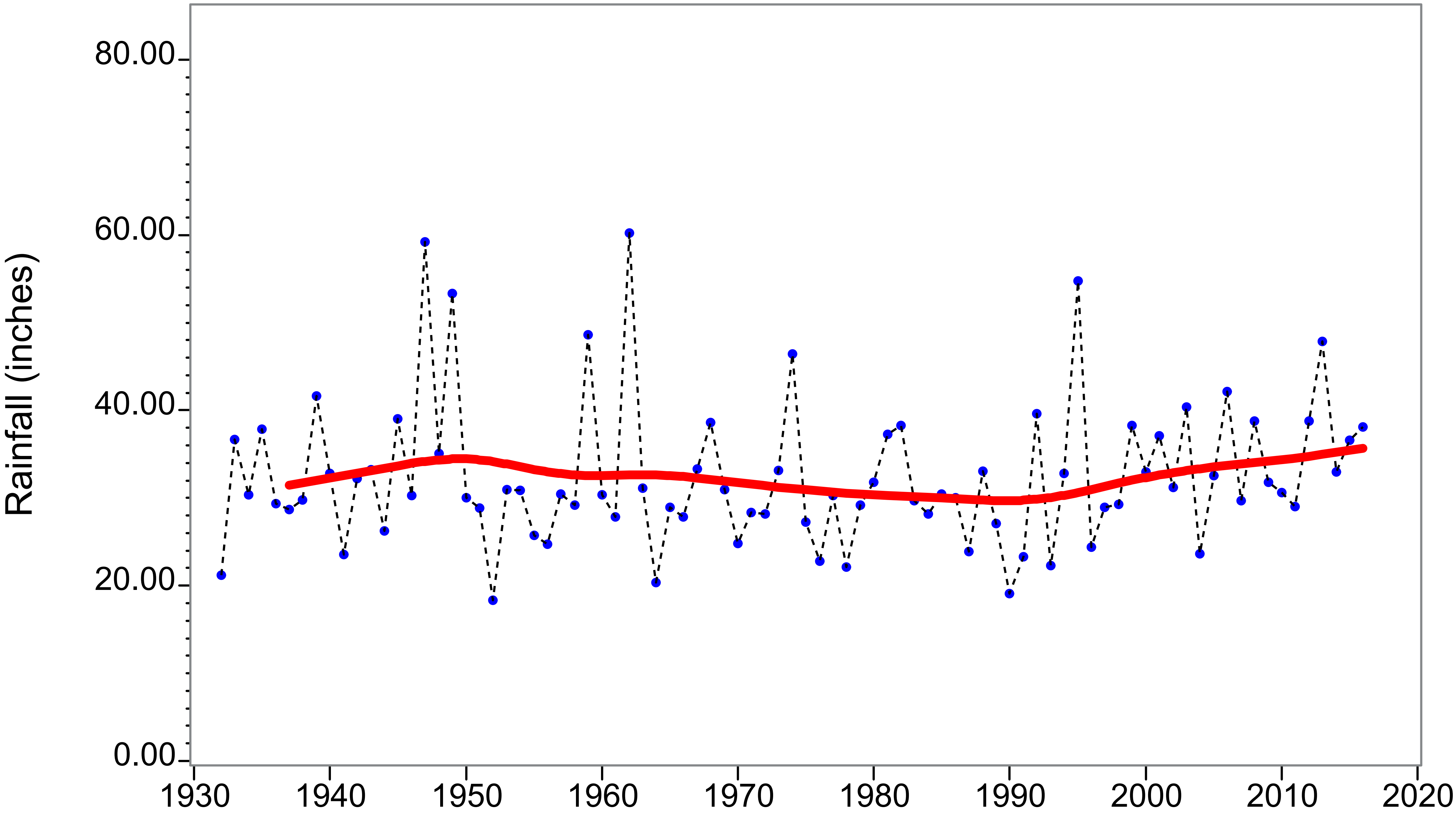


Figure 3.20 Yearly wet-season and 5-year moving average rainfall at long-term Punta Gorda NOAA gage (District #25105/R25), 1932-2016

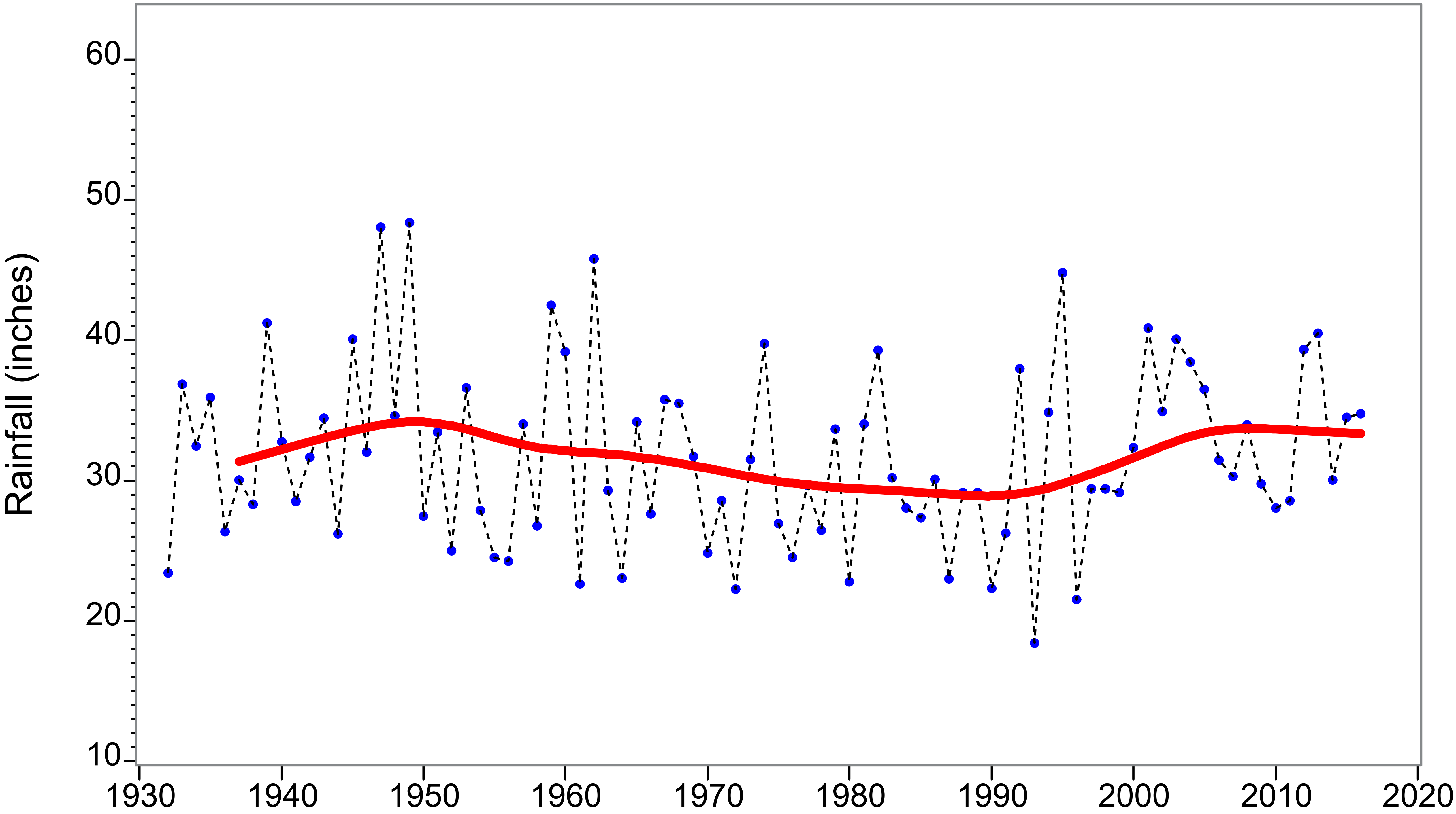


Figure 3.21 Yearly wet-season and 5-year moving average rainfall for the average of the three Peace River watershed basin gages, 1932-2016

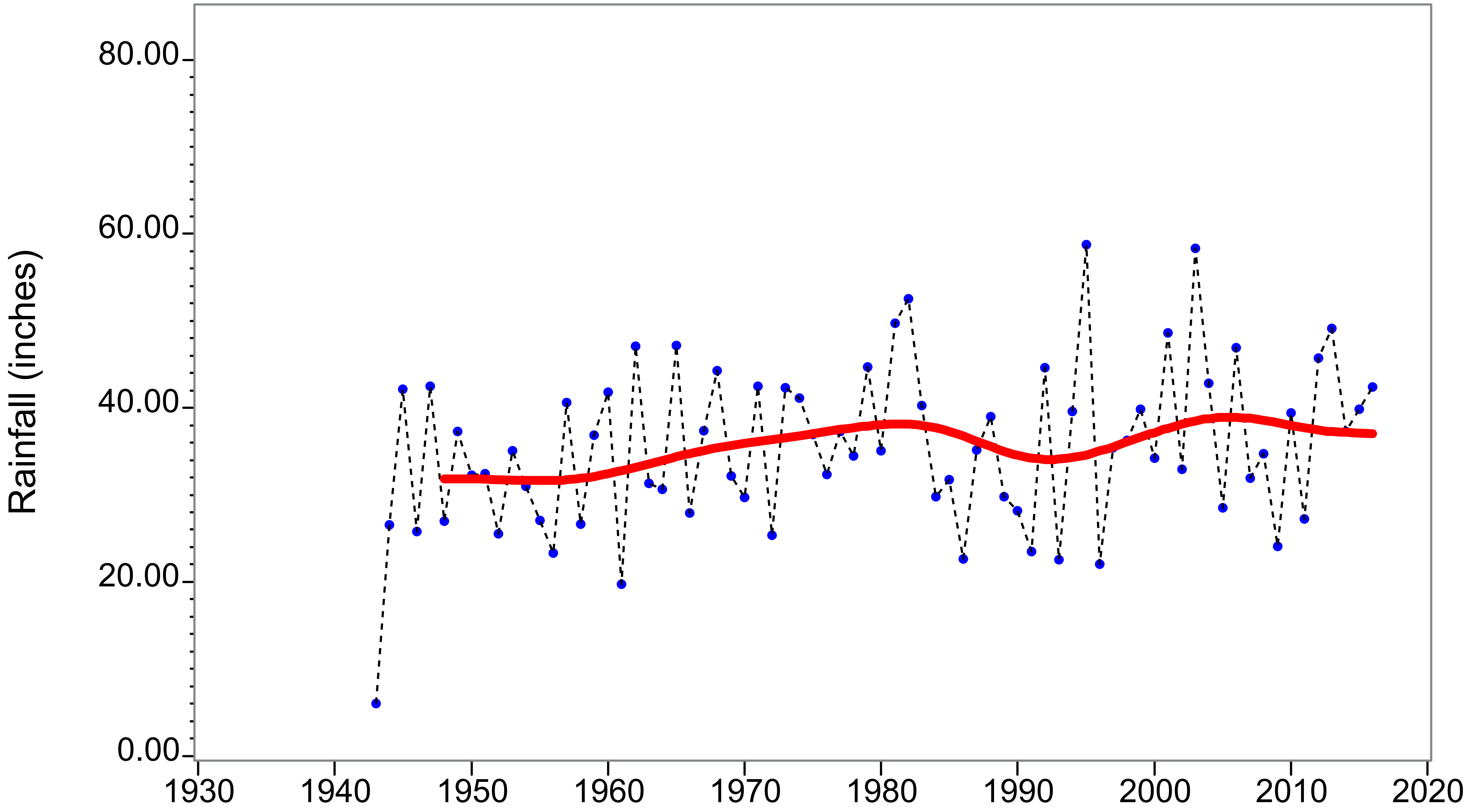


Figure 3.22 Yearly wet-season and 5-year moving average rainfall at long-term Myakka NOAA gage (District #25793/R336), 1943-2016

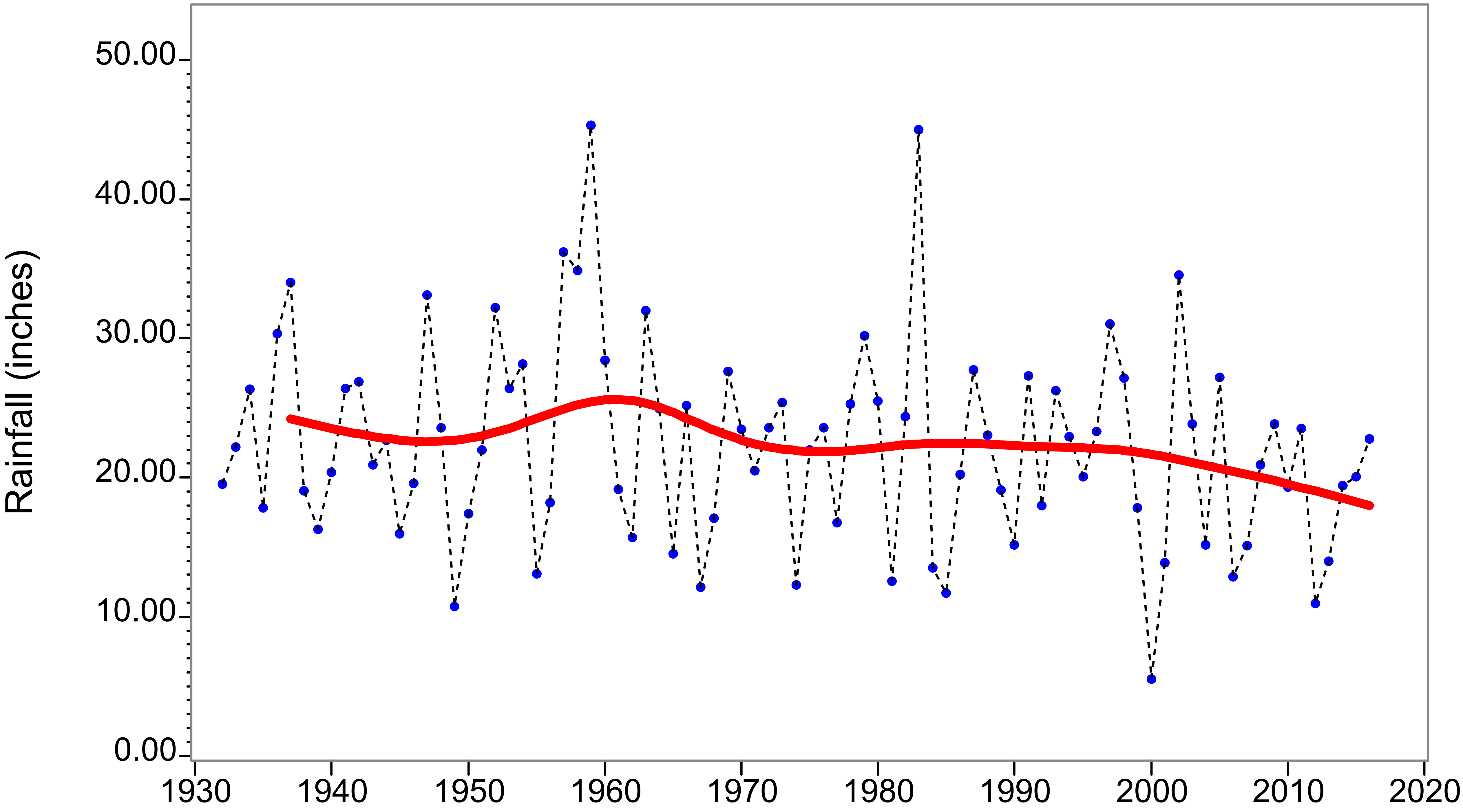


Figure 3.23 Yearly dry-season and 5-year moving average rainfall at long-term Bartow NOAA gage (District #25164/R1422), 1932-2016

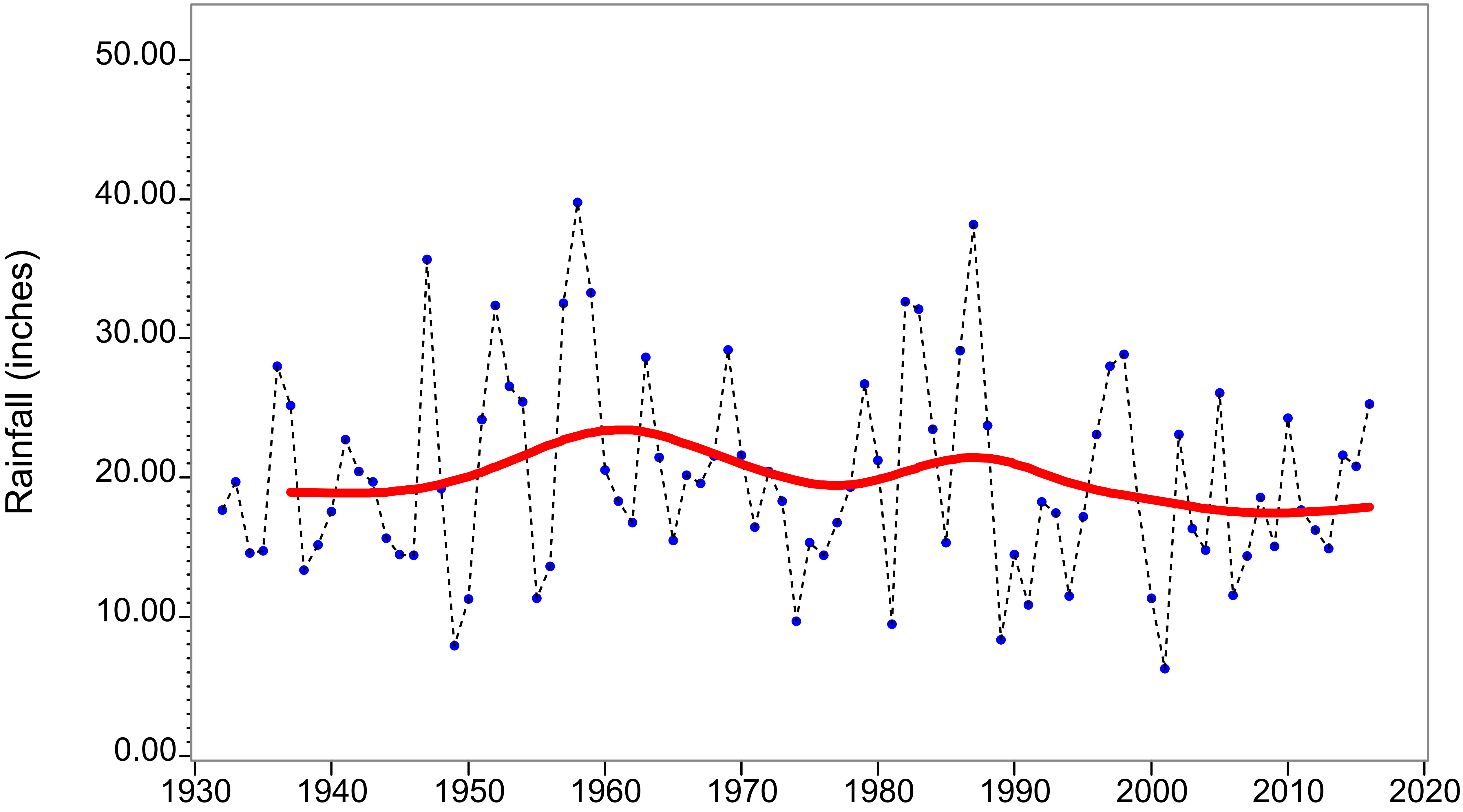


Figure 3.24 Yearly dry-season and 5-year moving average rainfall at long-term Arcadia NOAA gage (District #24570/R148), 1932-2016

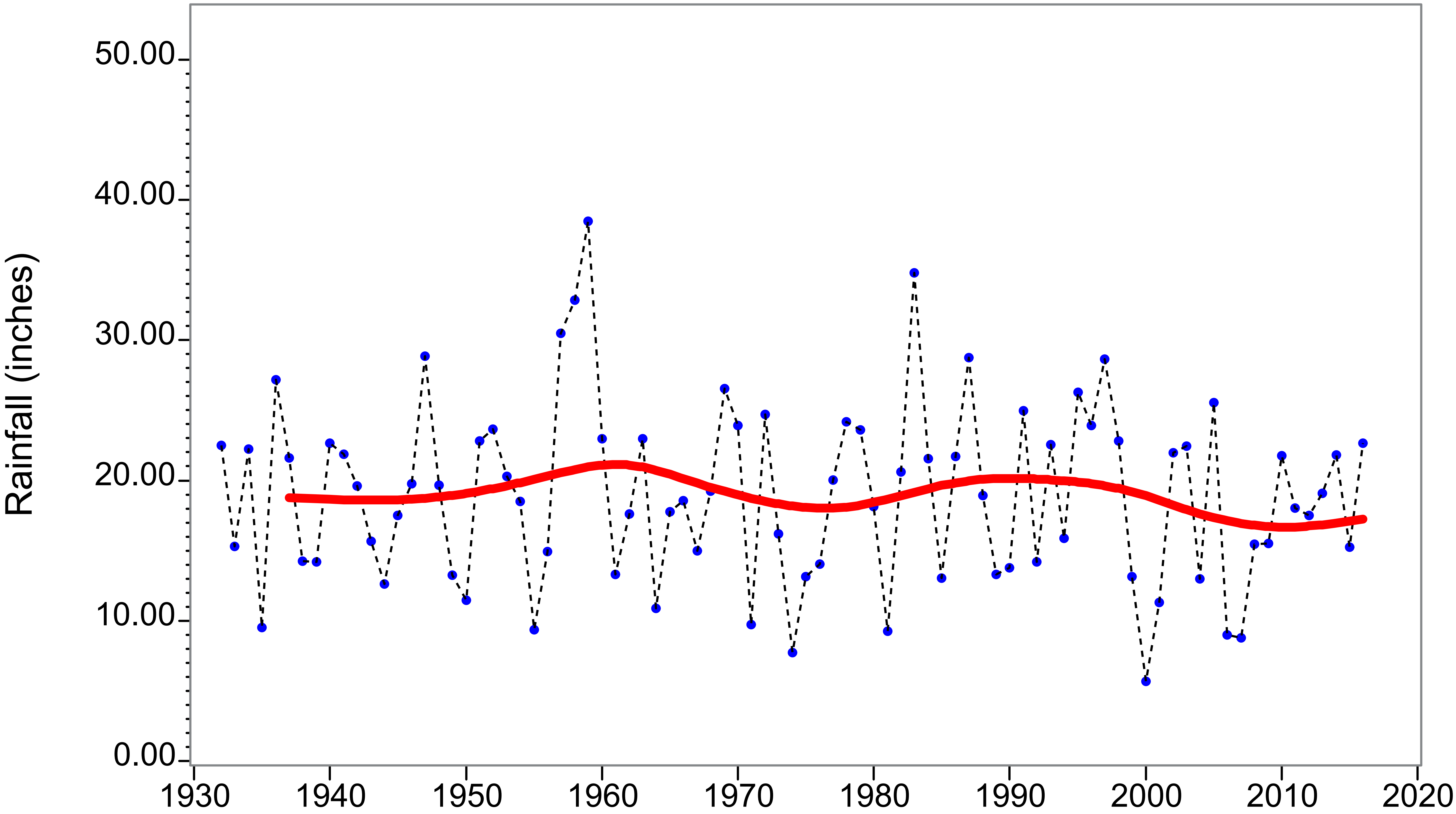


Figure 3.25 Yearly dry-season and 5-year moving average rainfall at long-term Punta Gorda NOAA gage (District #25105/R255), 1932-2016

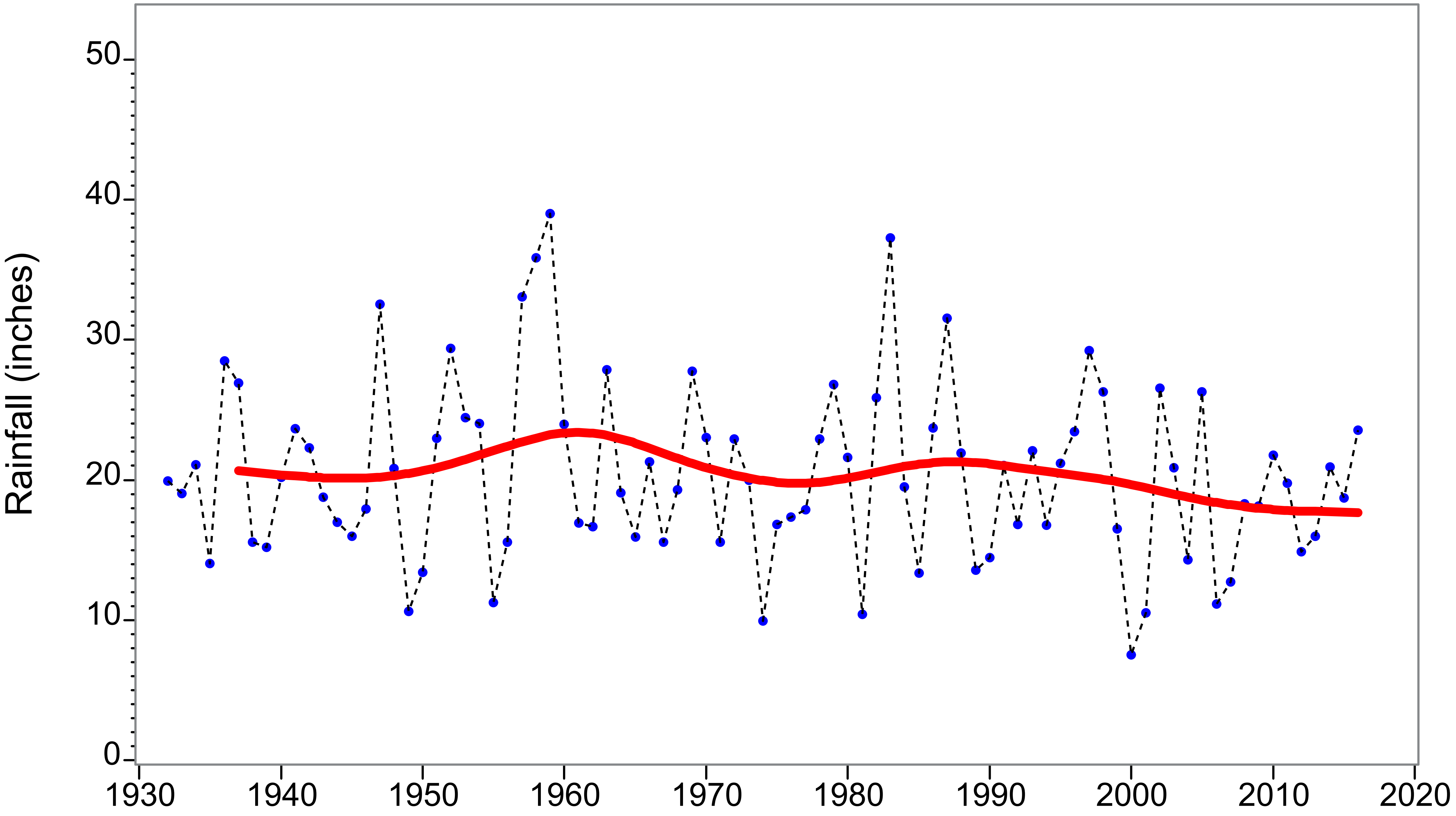


Figure 3.26 Yearly dry-season and 5-year moving average rainfall for the average of the three Peace River watershed basin gages, 1943-2016

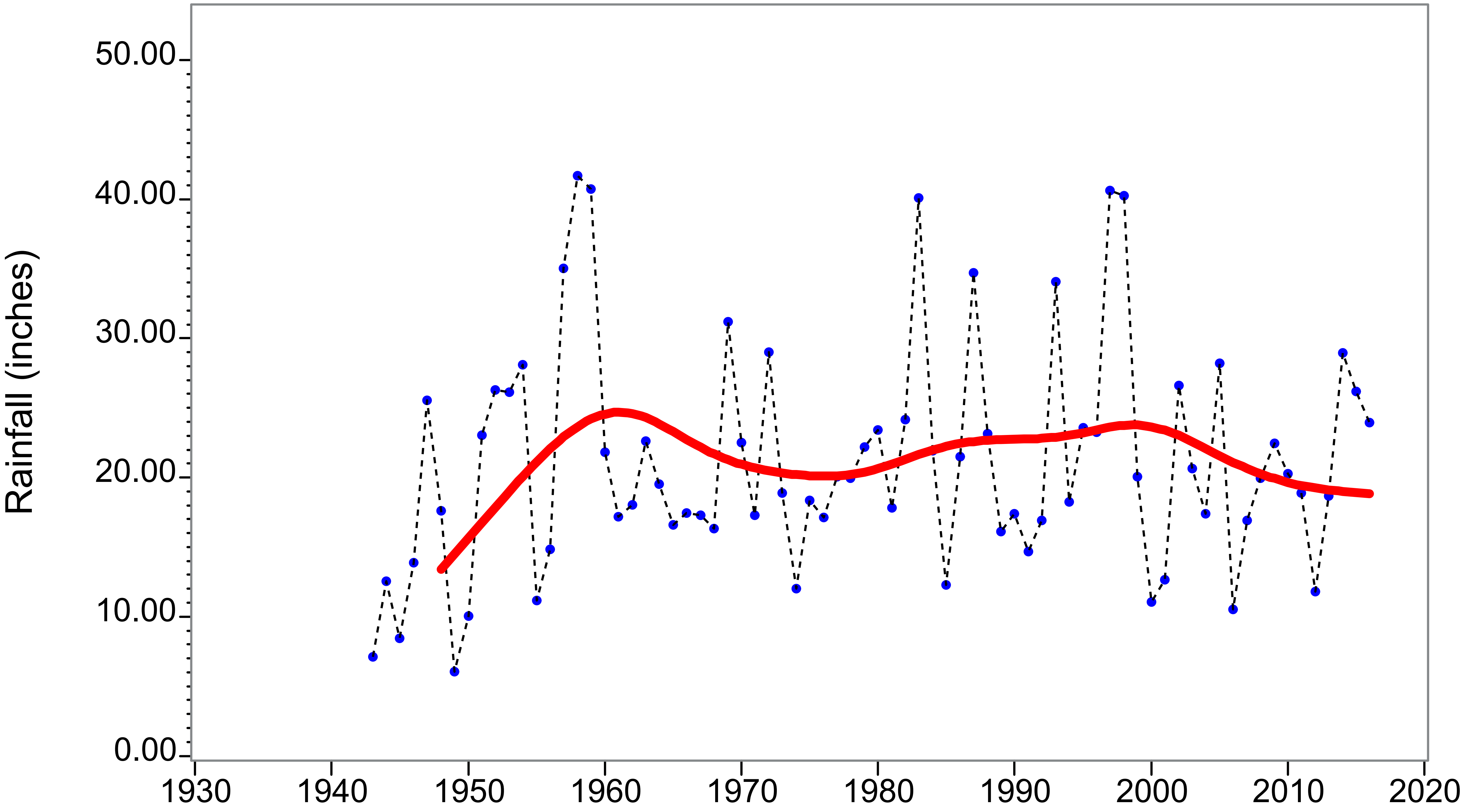


Figure 3.27 Yearly dry-season and 5-year moving average rainfall at long-term Myakka NOAA gage (District #25793/R336), 1943-2016

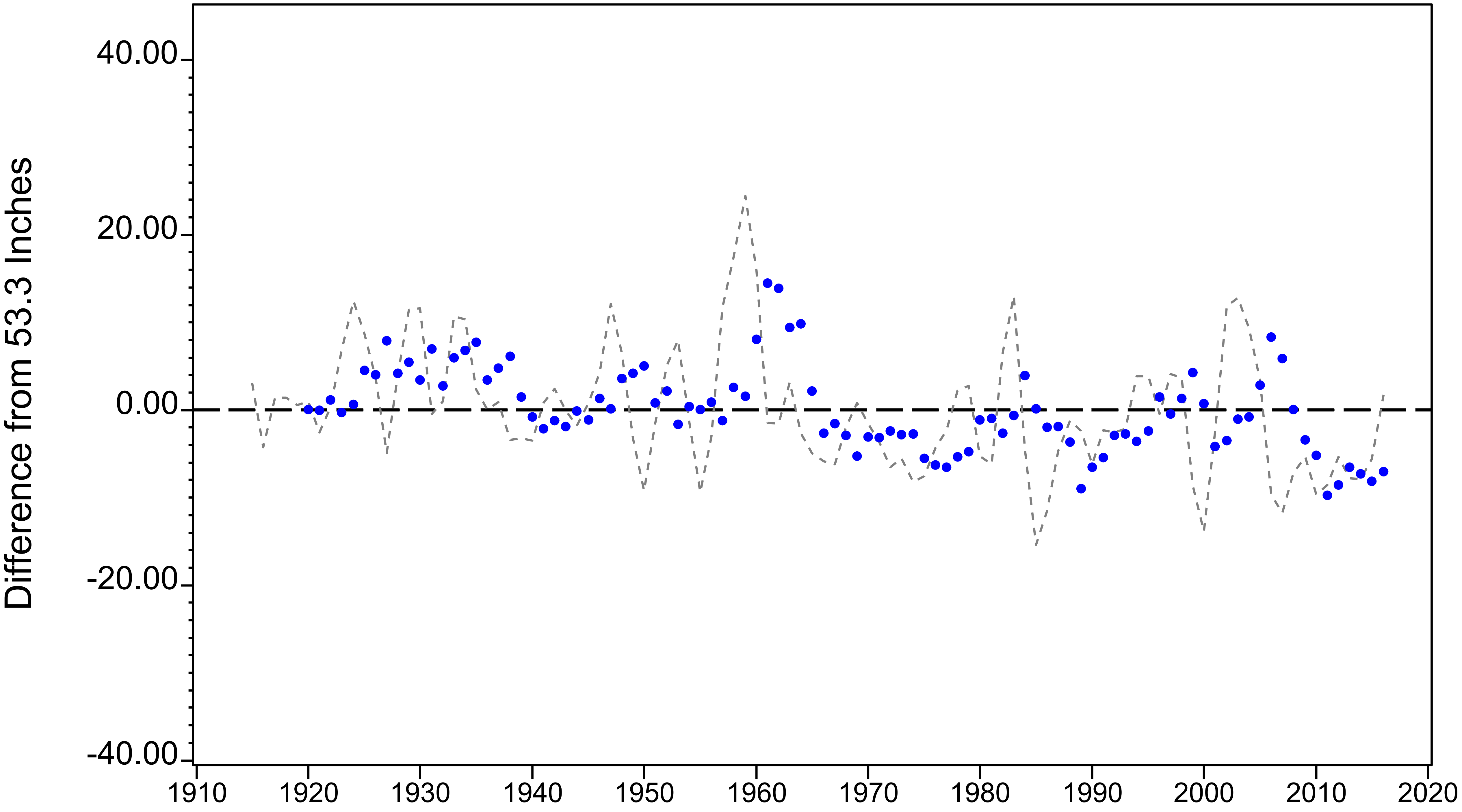


Figure 3.28 Yearly and 5-year moving average annual rainfall at long-term Bartow NOAA gage (District #25164/R142) 1915-2016

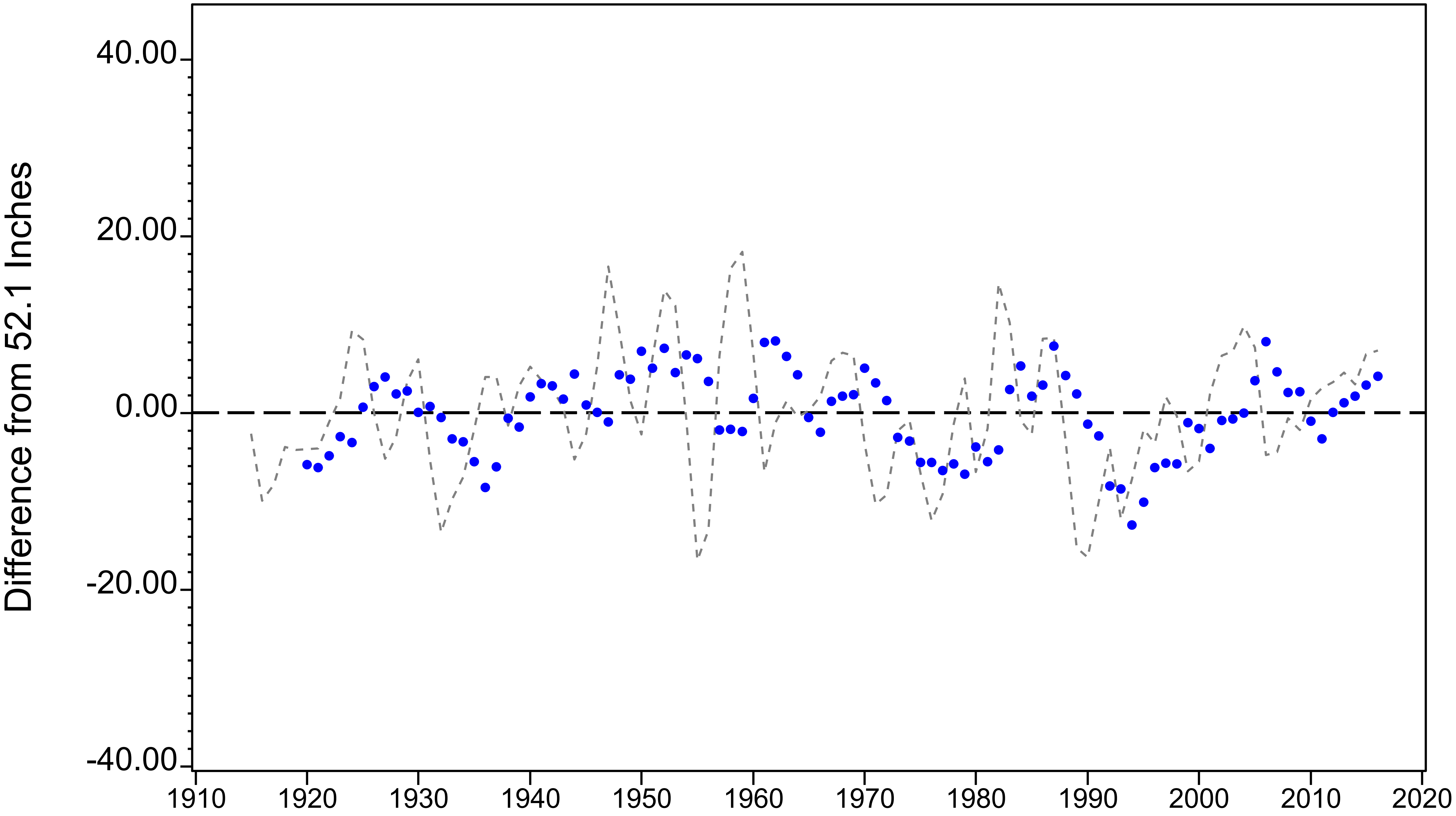


Figure 3.29 Yearly and 5-year moving average annual rainfall at long-term Arcadia NOAA gage (District #24570/R148) 1915-2016

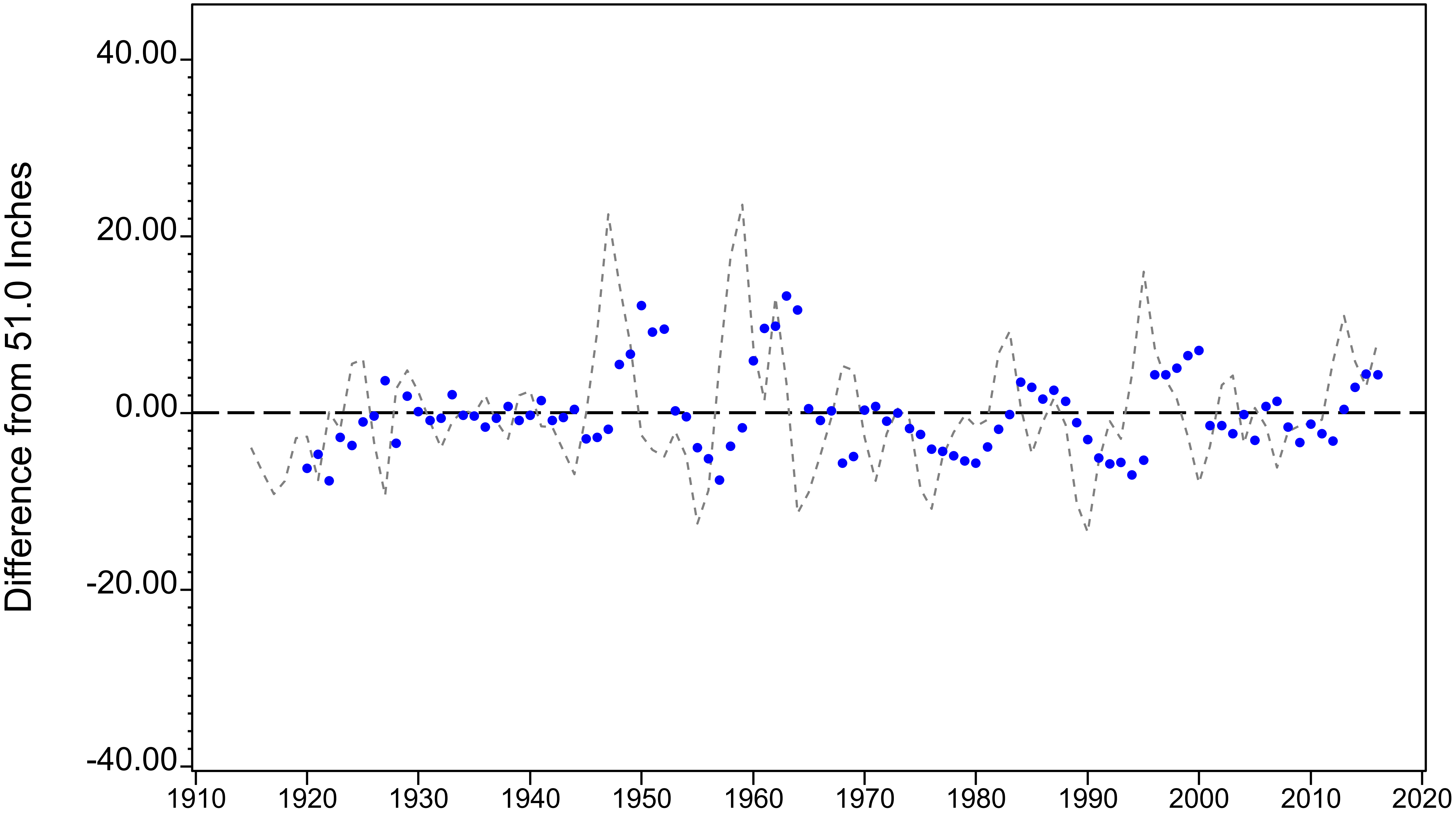


Figure 3.30 Yearly and 5-year moving average annual rainfall at long-term Punta Gorda NOAA gage (District #25105/R255) 1915-2016

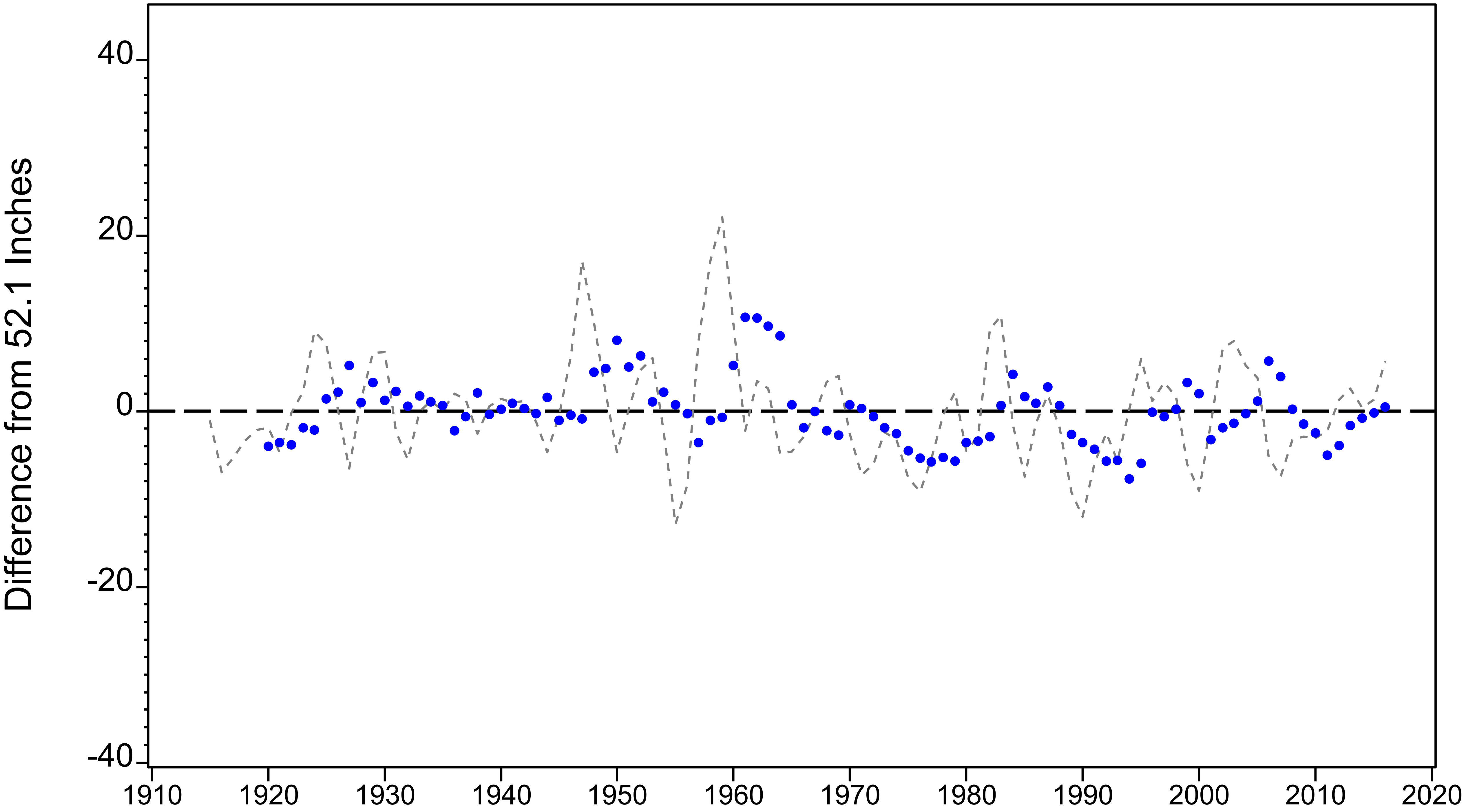


Figure 3.31 Yearly and 5-year moving average of Bartow, Arcadia and Punta Gorda average anual rainfall (1915-2016)

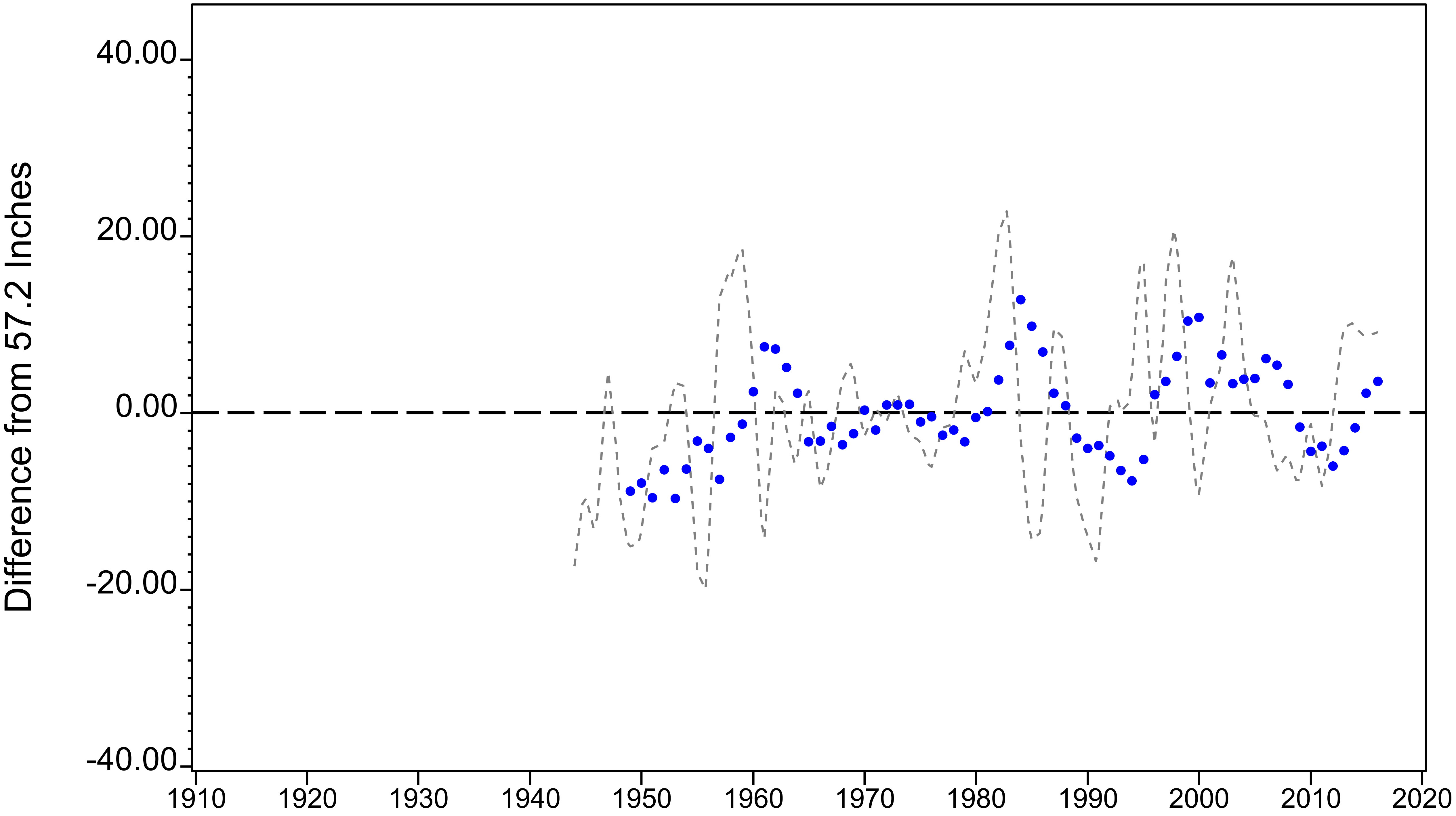


Figure 3.32 Yearly and 5-year moving average annual rainfall at long-term Myakka NOAA gage (District #25793/R336) 1943-2016

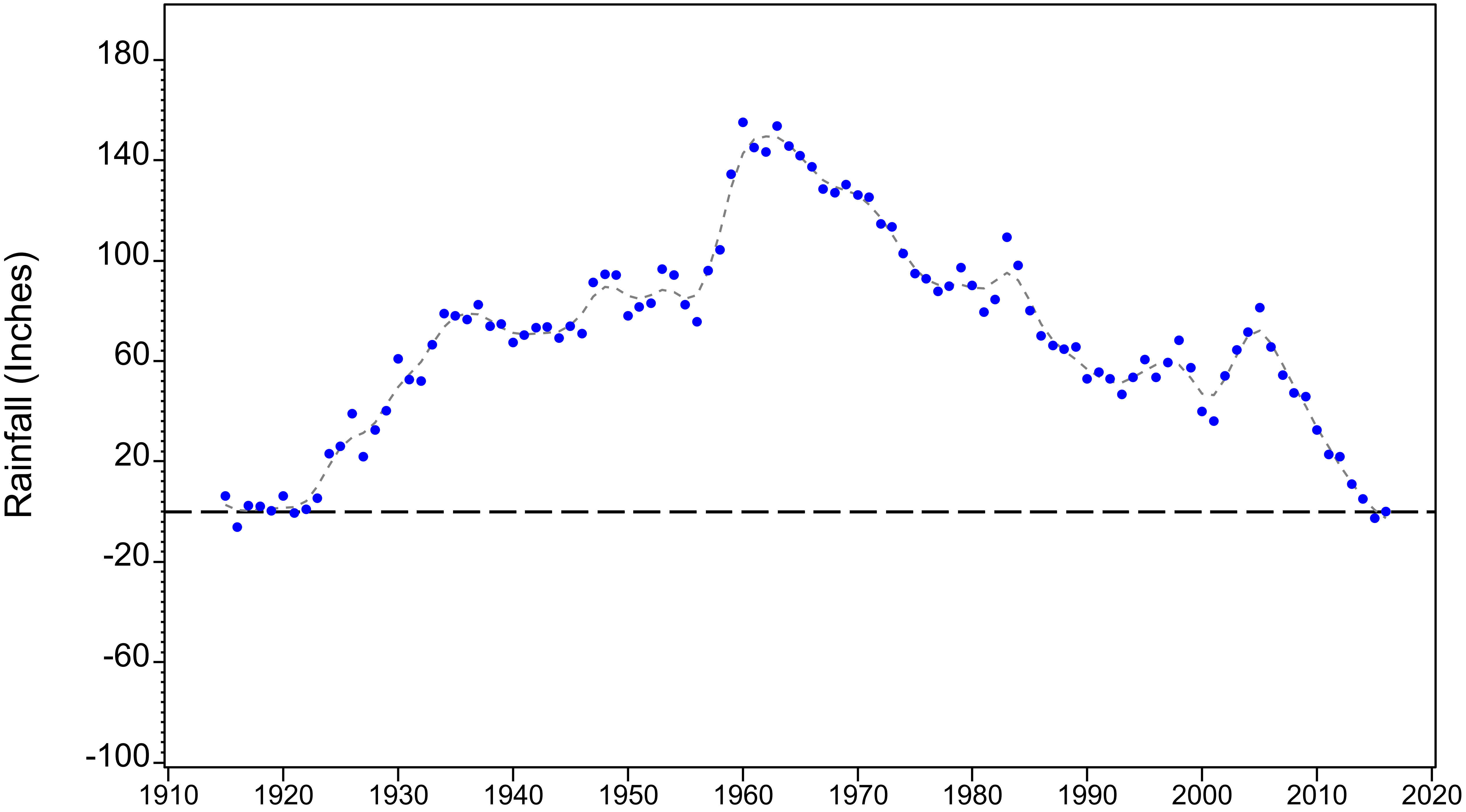


Figure 3.33 Long-term cumulative annual rainfall above 53.3 inches at Bartow NOAA gage (District #25164/R142) 1915-2016

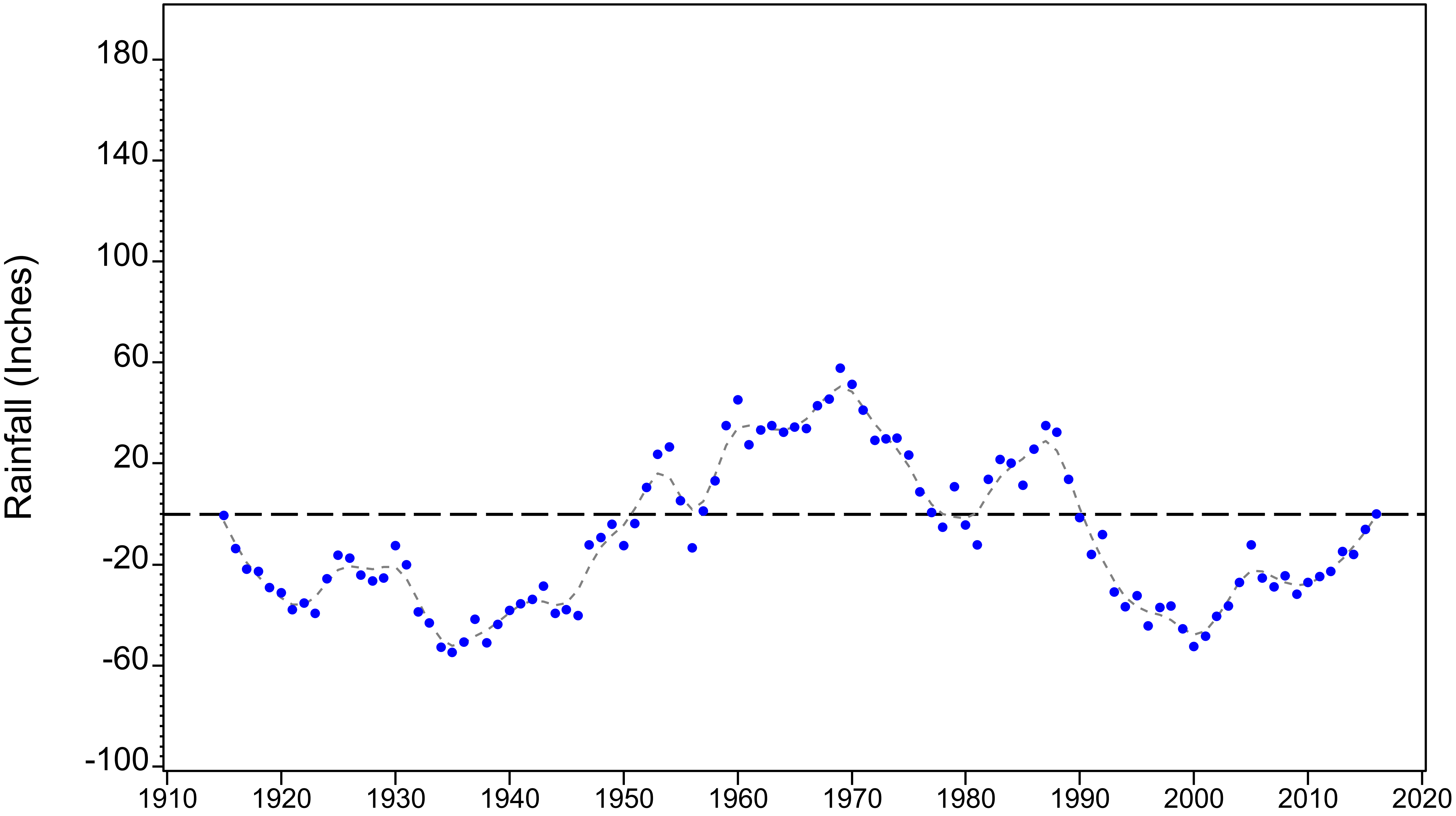


Figure 3.34 Long-term cumulative annual rainfall above 52.1 inches at long-term Arcadia NOAA gage (District #24570/R148) 1915-2016

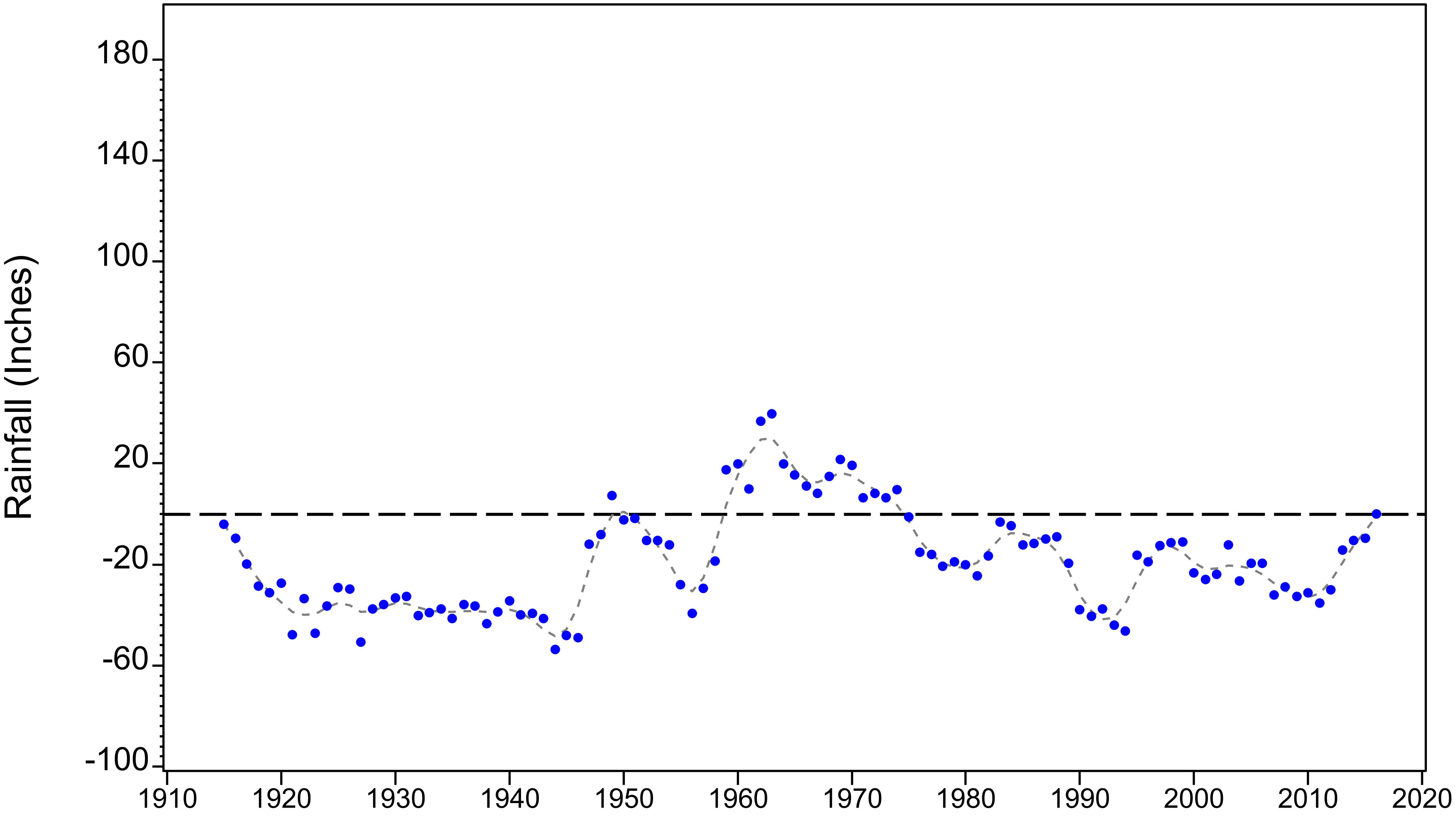


Figure 3.35 Long-term cumulative annual rainfall above 51.0 inches at long-term Punta Gorda NOAA gage (District #25105/R255) 1915-2016

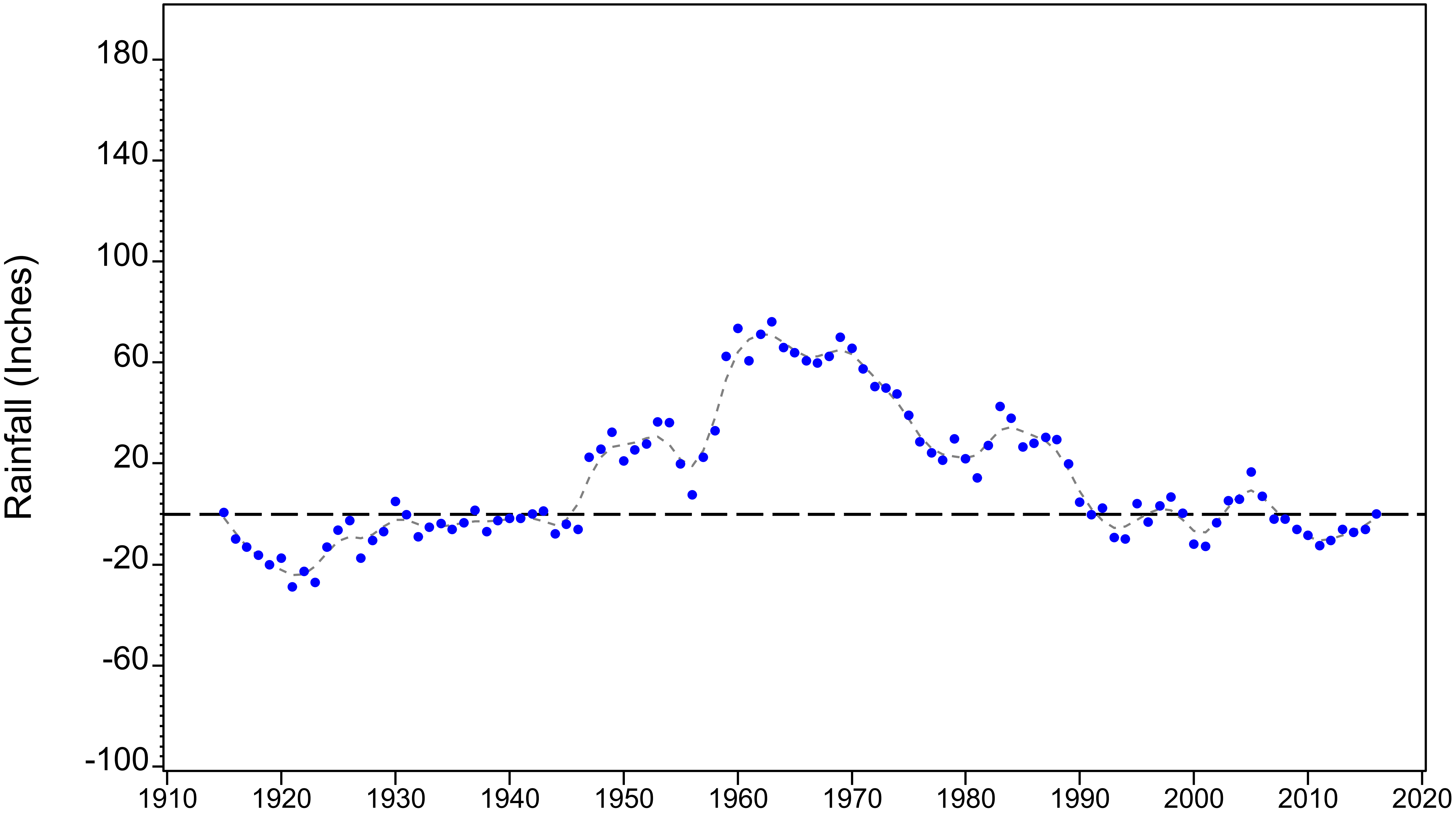


Figure 3.36 Long-term cumulative annual rainfall above 52.1 inches of Bartow, Arcadia and Punta Gorda average rainfall (1915-2016)

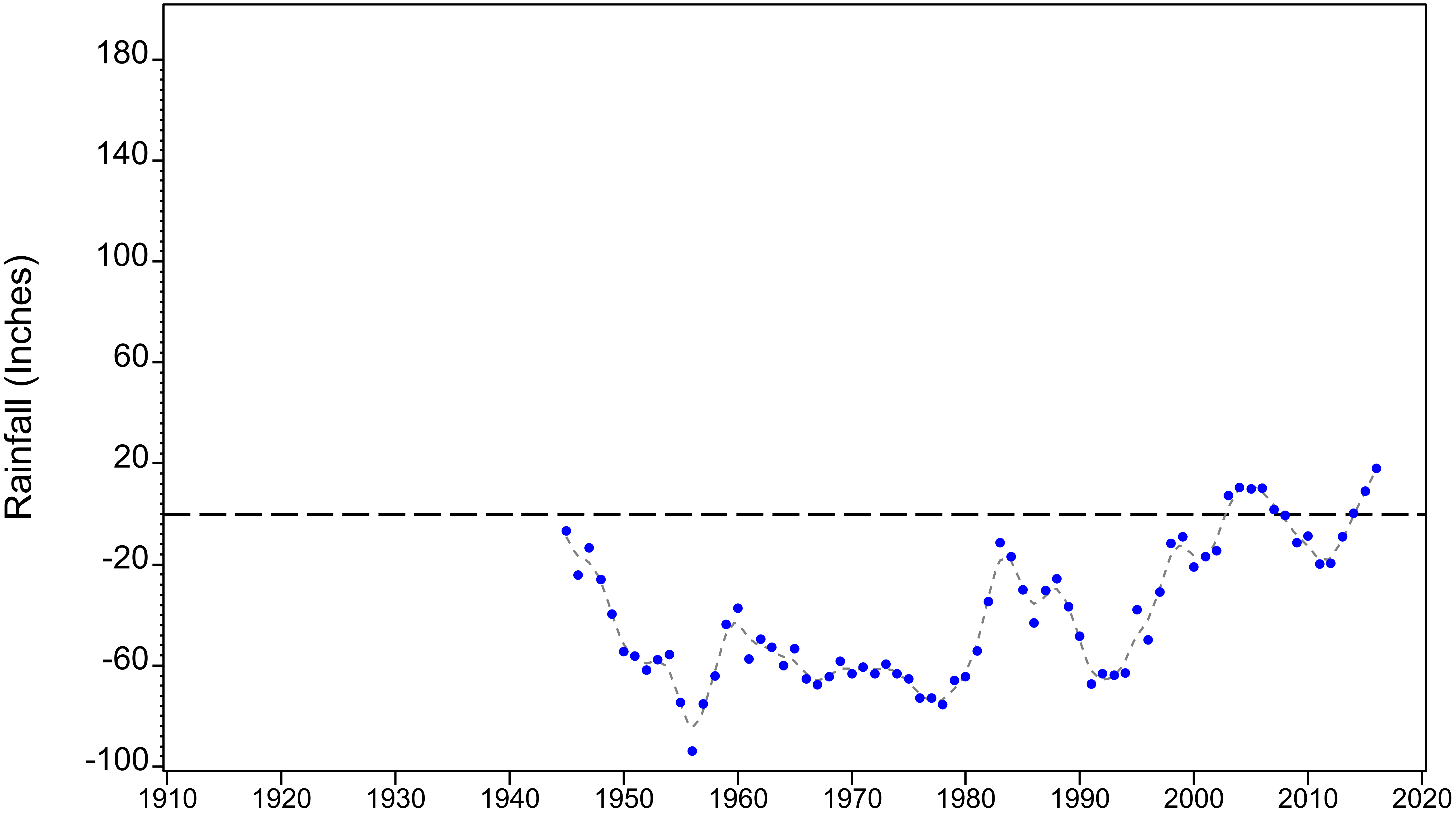


Figure 3.37 Long-term cumulative annual rainfall above 57.1 inches at long-term Myakka NOAA gage (District #25793/R336) 1943-2016

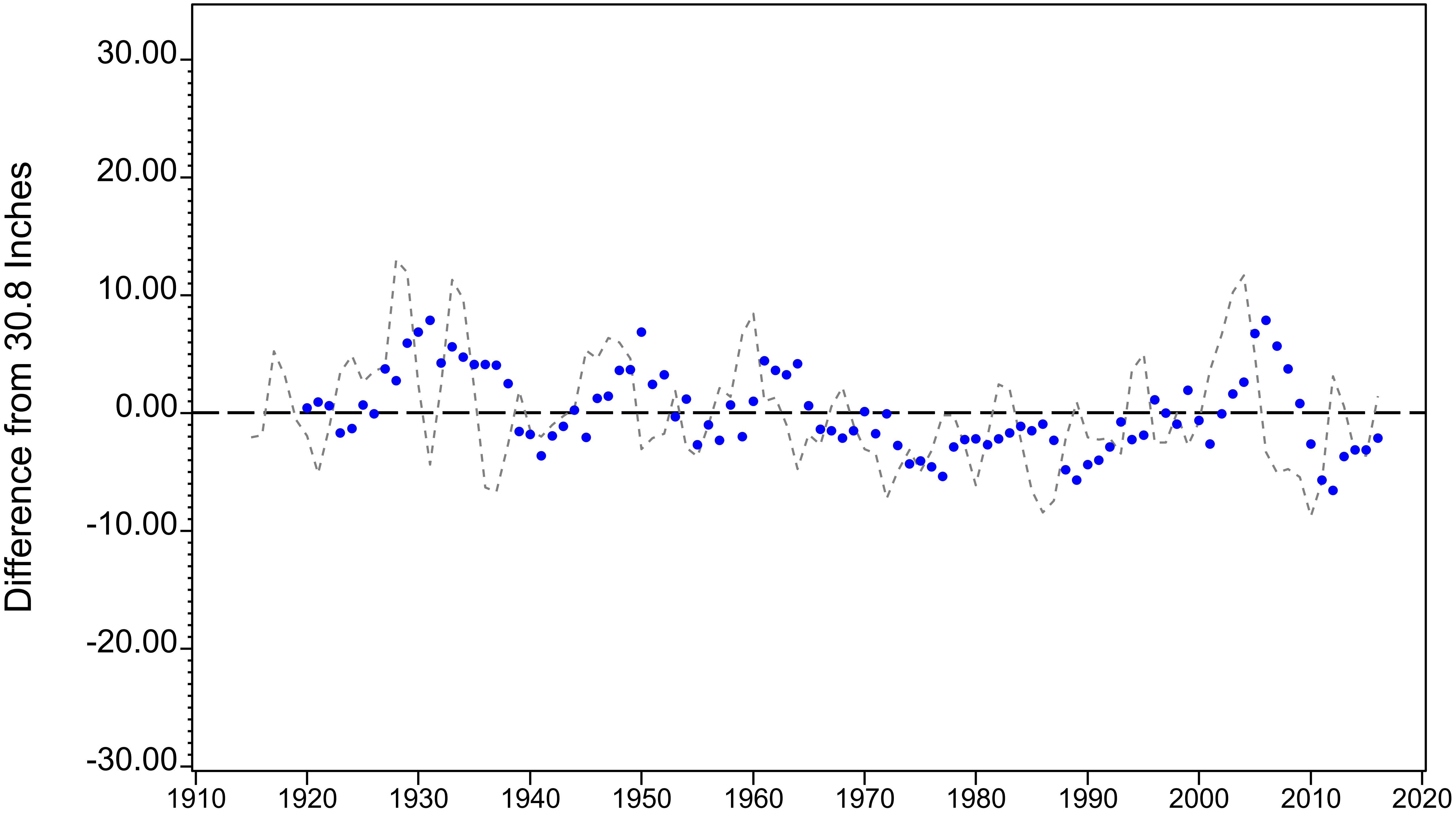


Figure 3.38 Yearly and 5-year moving average annual wet-season rainfall at long-term Bartow NOAA gage (District #25164/R142) 1915-2016

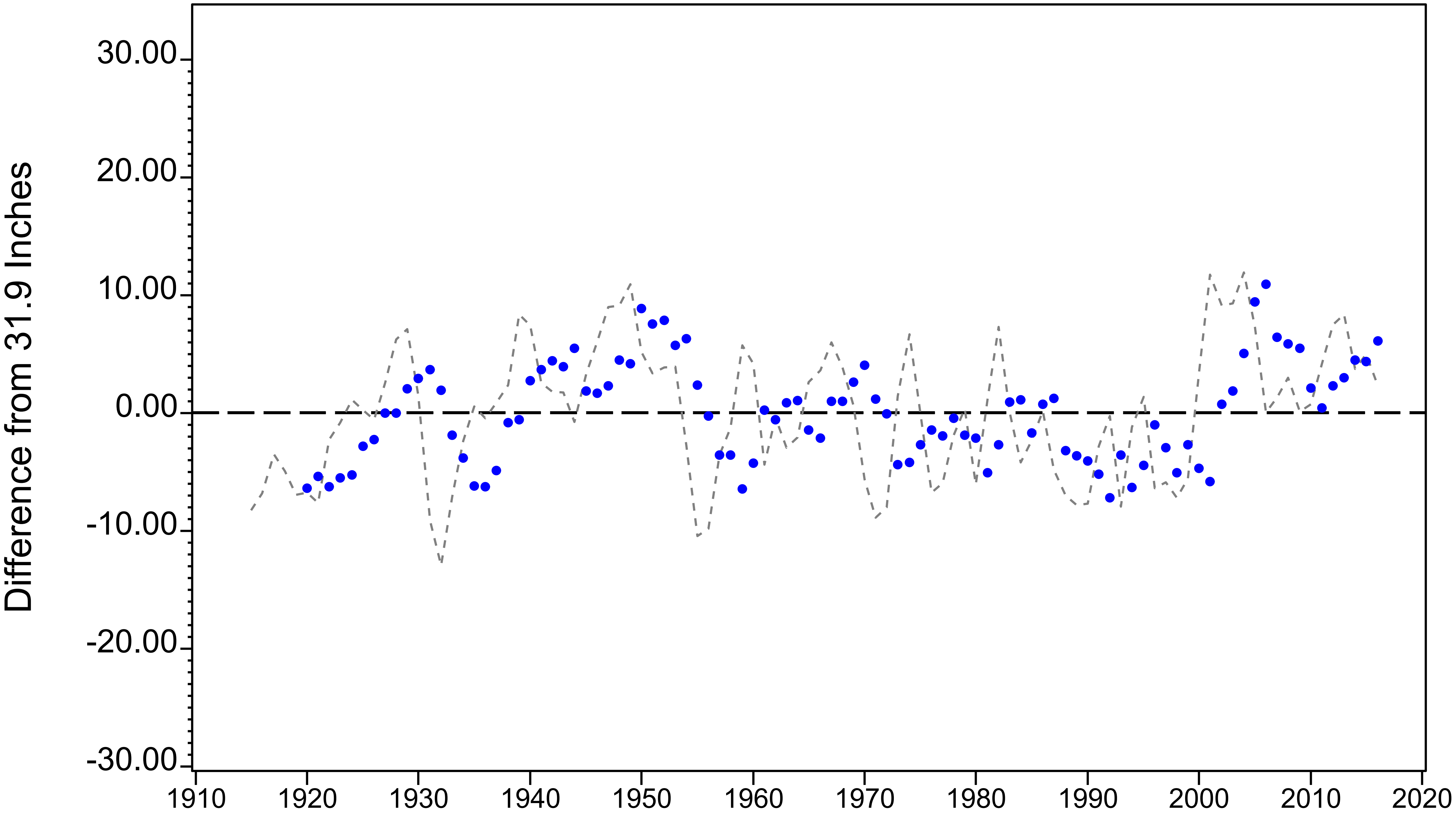


Figure 3.39 Yearly and 5-year moving average annual wet-season rainfall at long-term Arcadia NOAA gage (District #24570/R148) 1915-2016

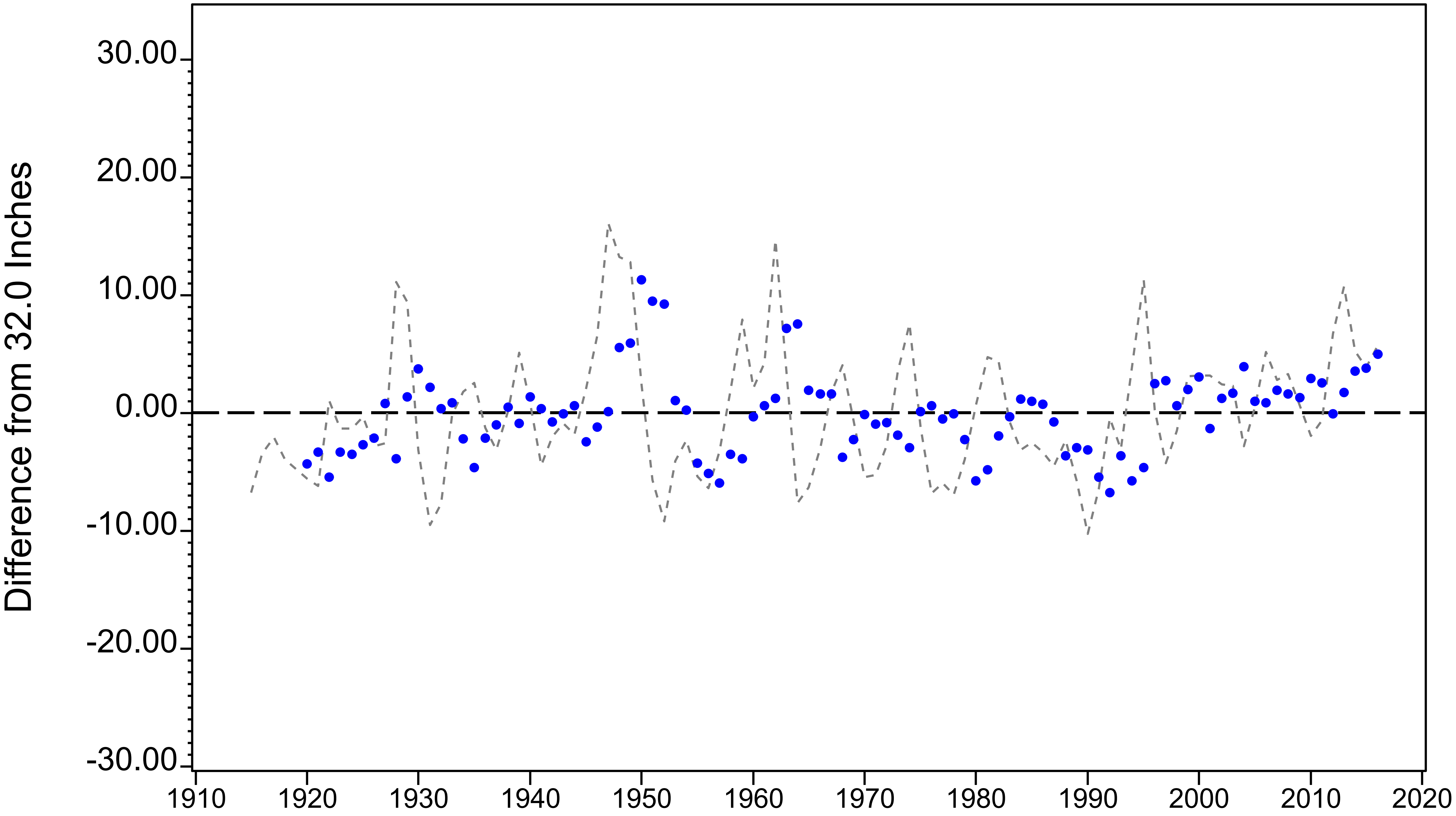


Figure 3.40 Yearly and 5-year moving average annual wet-season rainfall at long-term Punta Gorda NOAA gage (District #25105/R255) 1915-2016

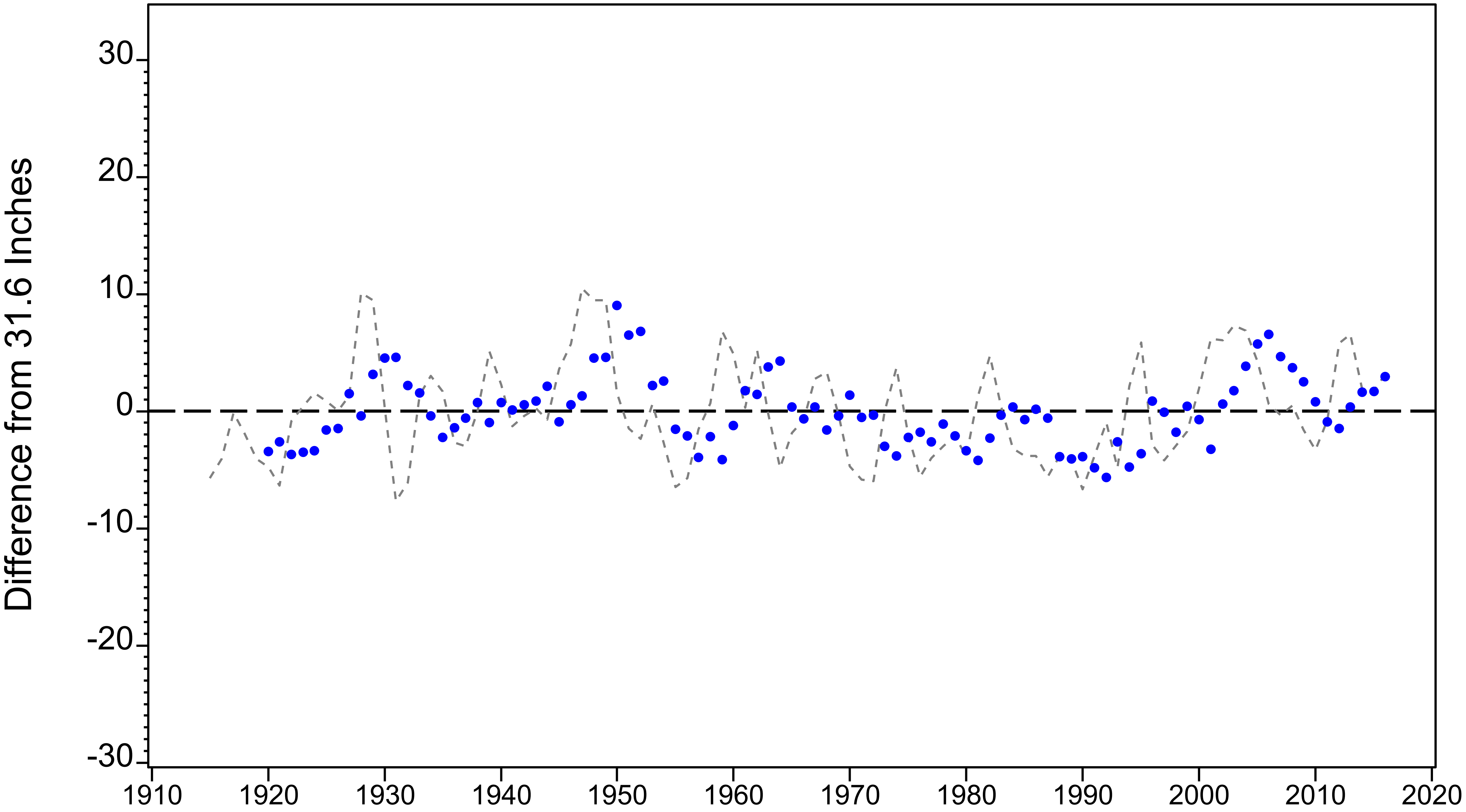


Figure 3.41 Yearly and 5-year moving average anuual wet-season Bartow, Arcadia and Punta Gorda average rainfall 1915-2016

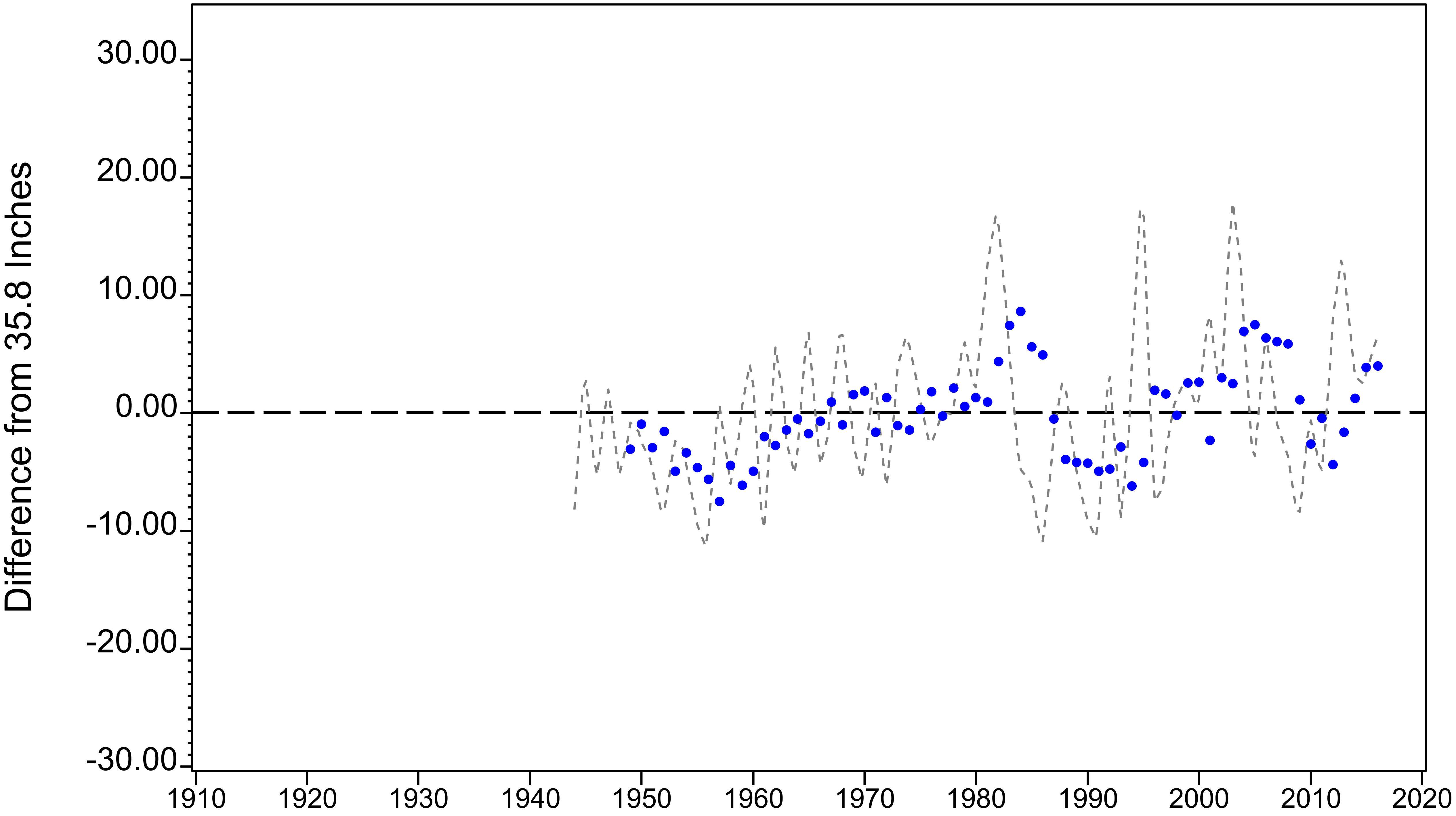


Figure 3.42 Yearly and 5-year moving average annual wet-season rainfall at long-term Myakka NOAA gage (District #25793/R336) 1943-2016

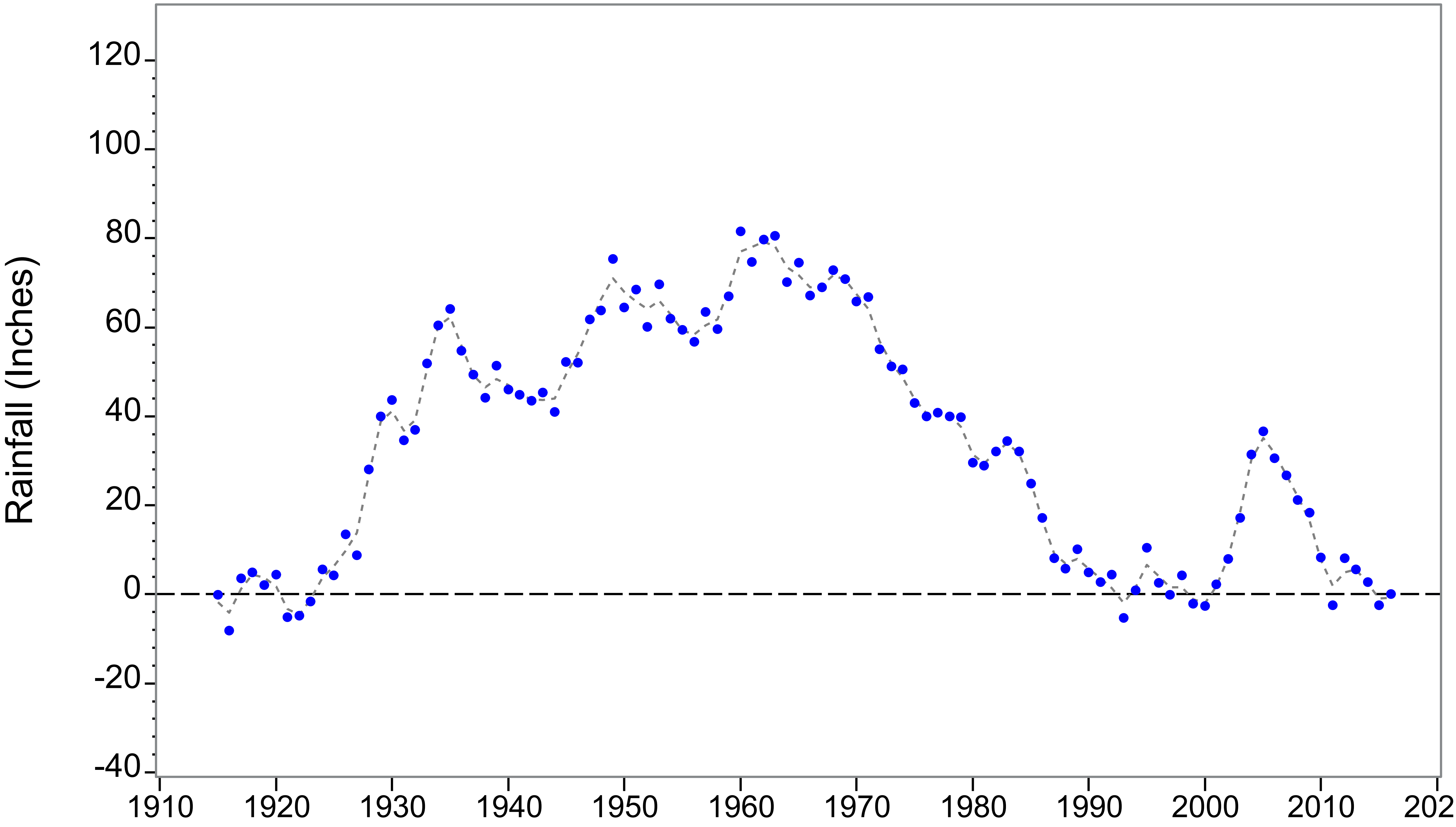


Figure 3.43 Long-term cumulative annual wet-season rainfall above 30.8 inches at Bartow NOAA gage (District #25164/R142) 1915-2016

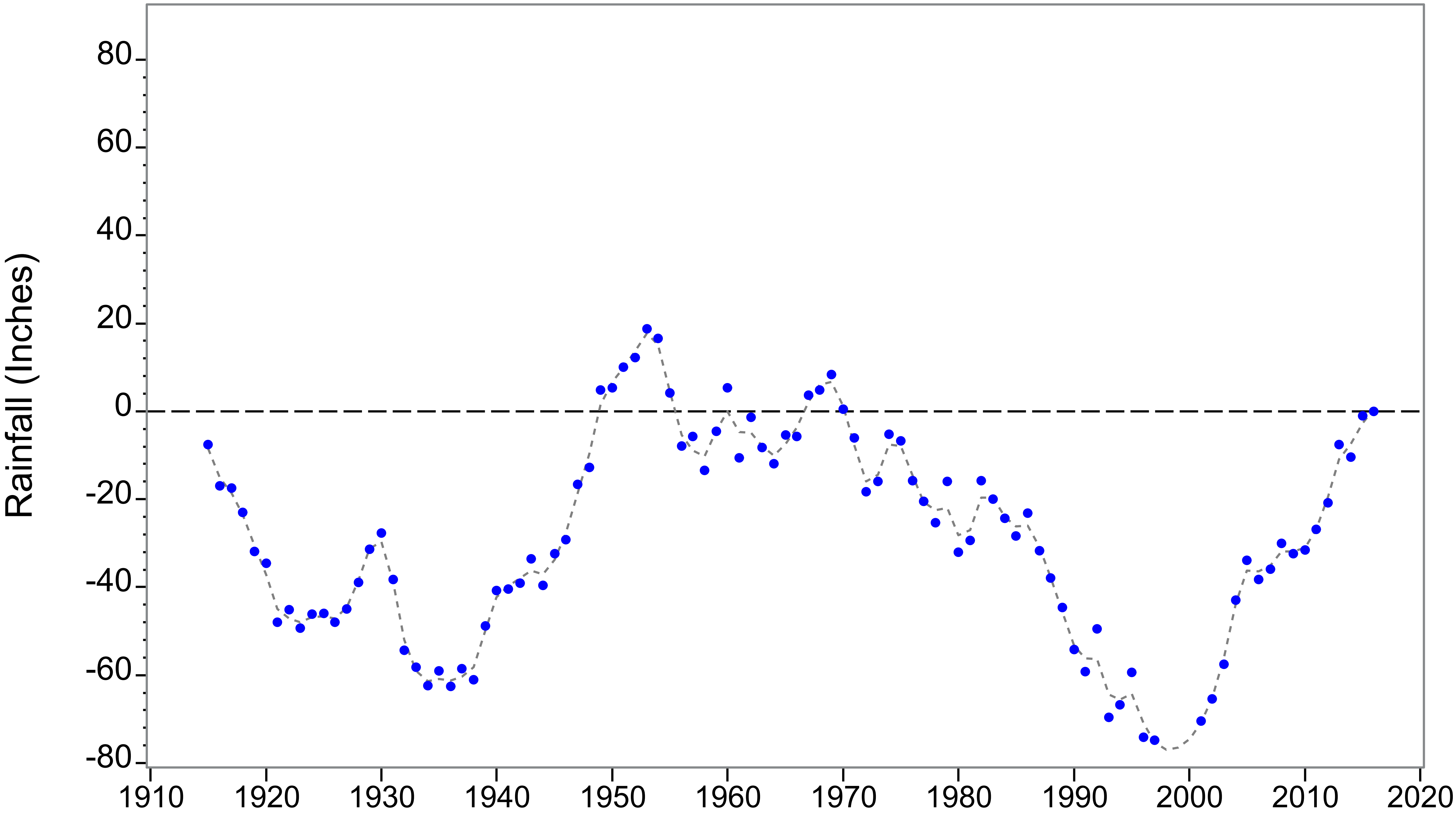


Figure 3.44 Long-term cumulative annual wet-season rainfall above 31.9 inches at long-term Arcadia NOAA gage (District #24570/R148) 1915-2016

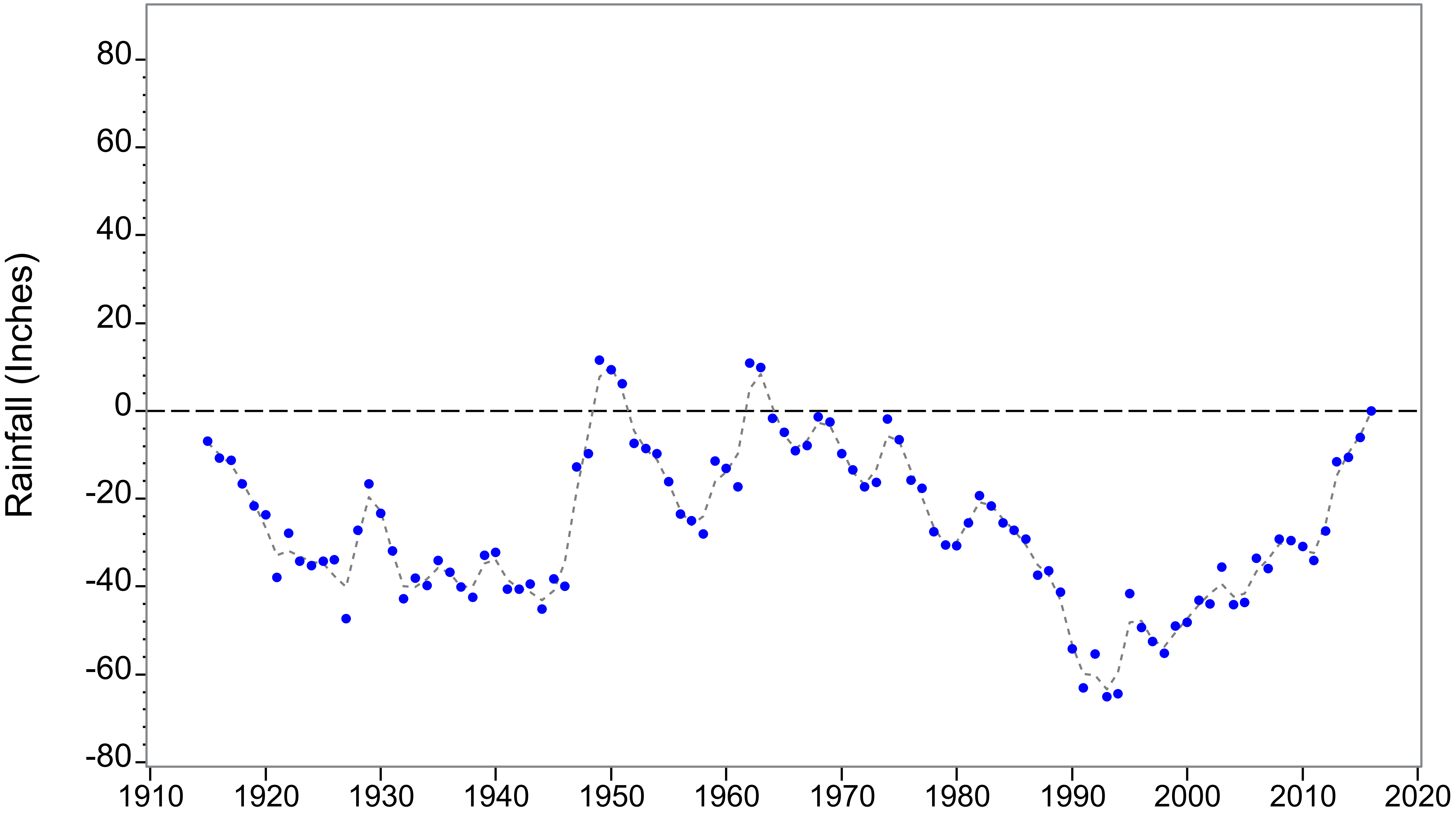


Figure 3.45 Long-term cumulative annual wet-season rainfall above 32.0 inches at long-term Punta Gorda NOAA gage (District #25105/R255) 1915-2016

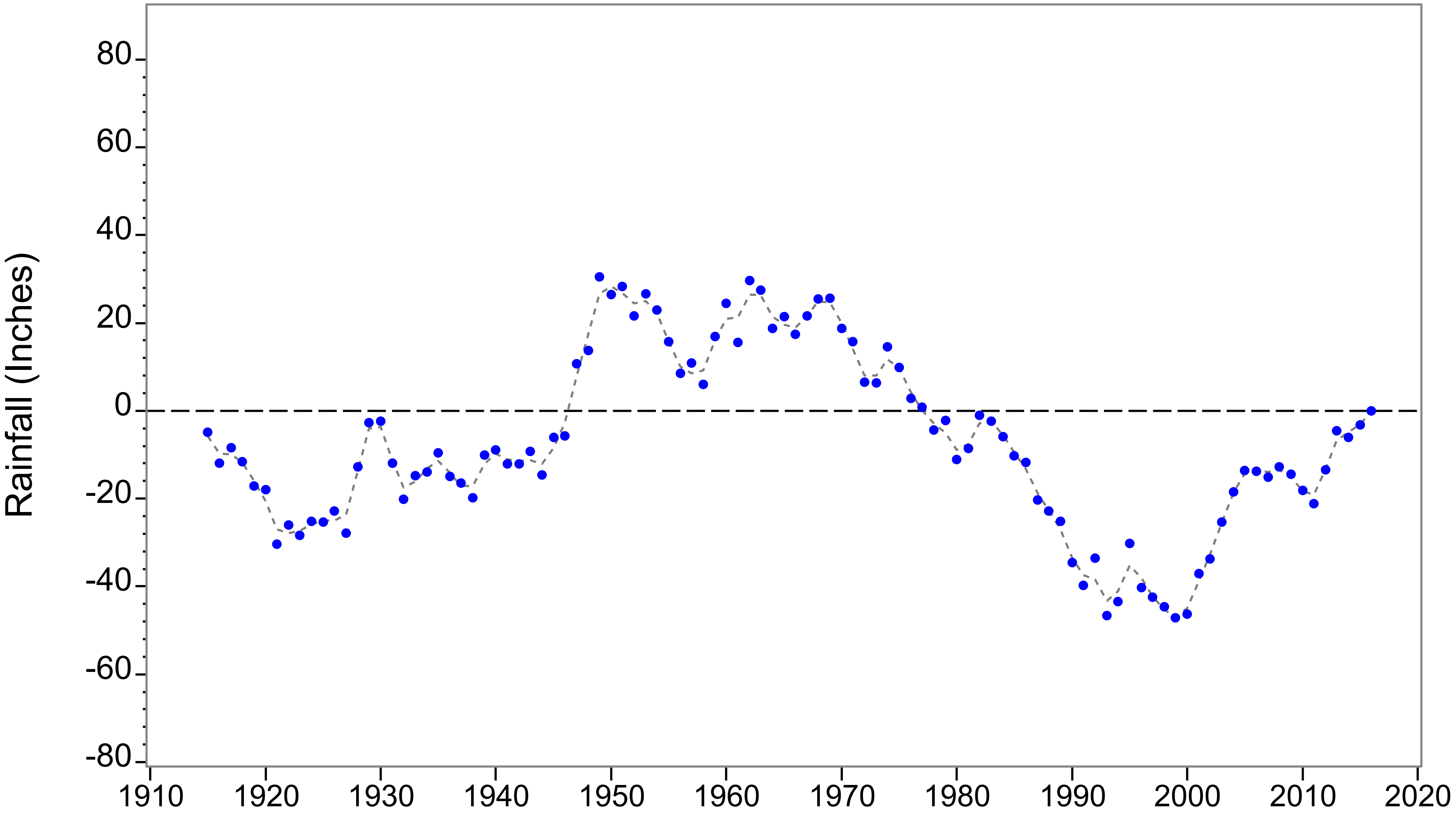


Figure 3.46 Long-term cumulative annual wet-season rainfall above 31.6 inches of Bartow, Arcadia and Punta Gorda average rainfall (1915-2016)

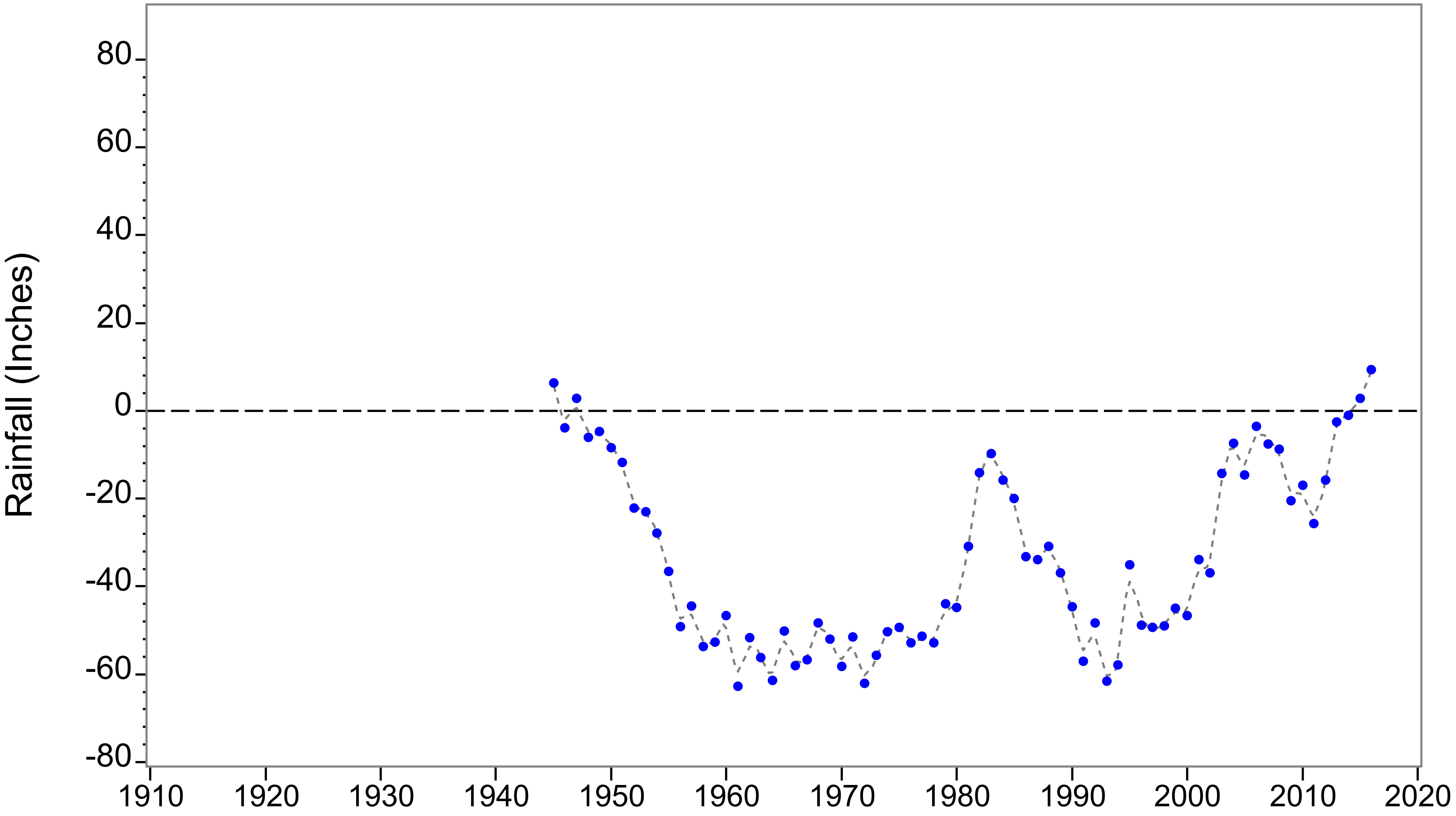


Figure 3.47 Long-term cumulative annual wet-season rainfall above 35.9 inches at long-term Myakka NOAA gage (District #25793/R336) 1943-2016

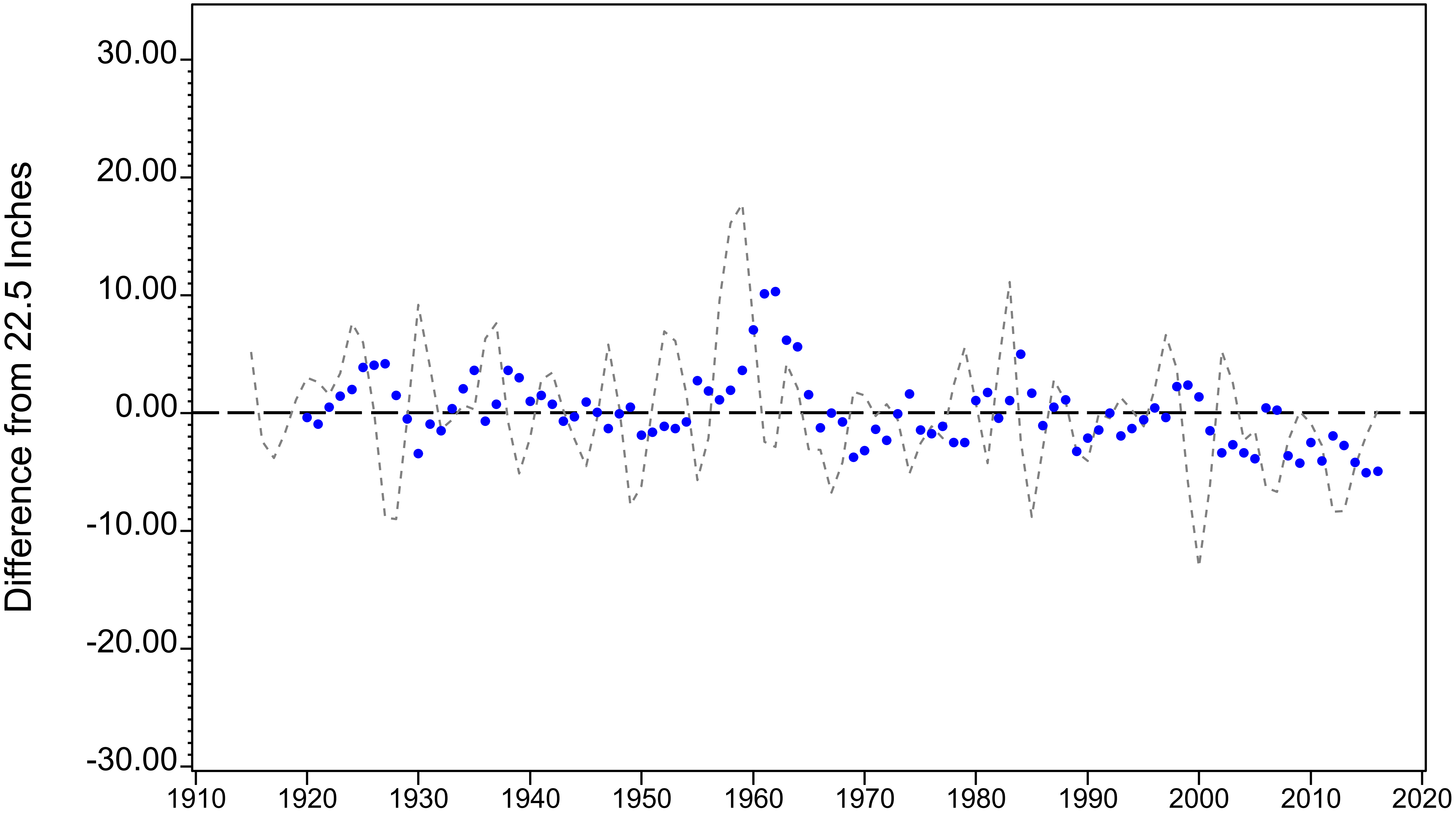


Figure 3.48 Yearly and 5-year moving average annual dry-season rainfall at long-term Bartow NOAA gage (District #25164/R142) 1915-2016

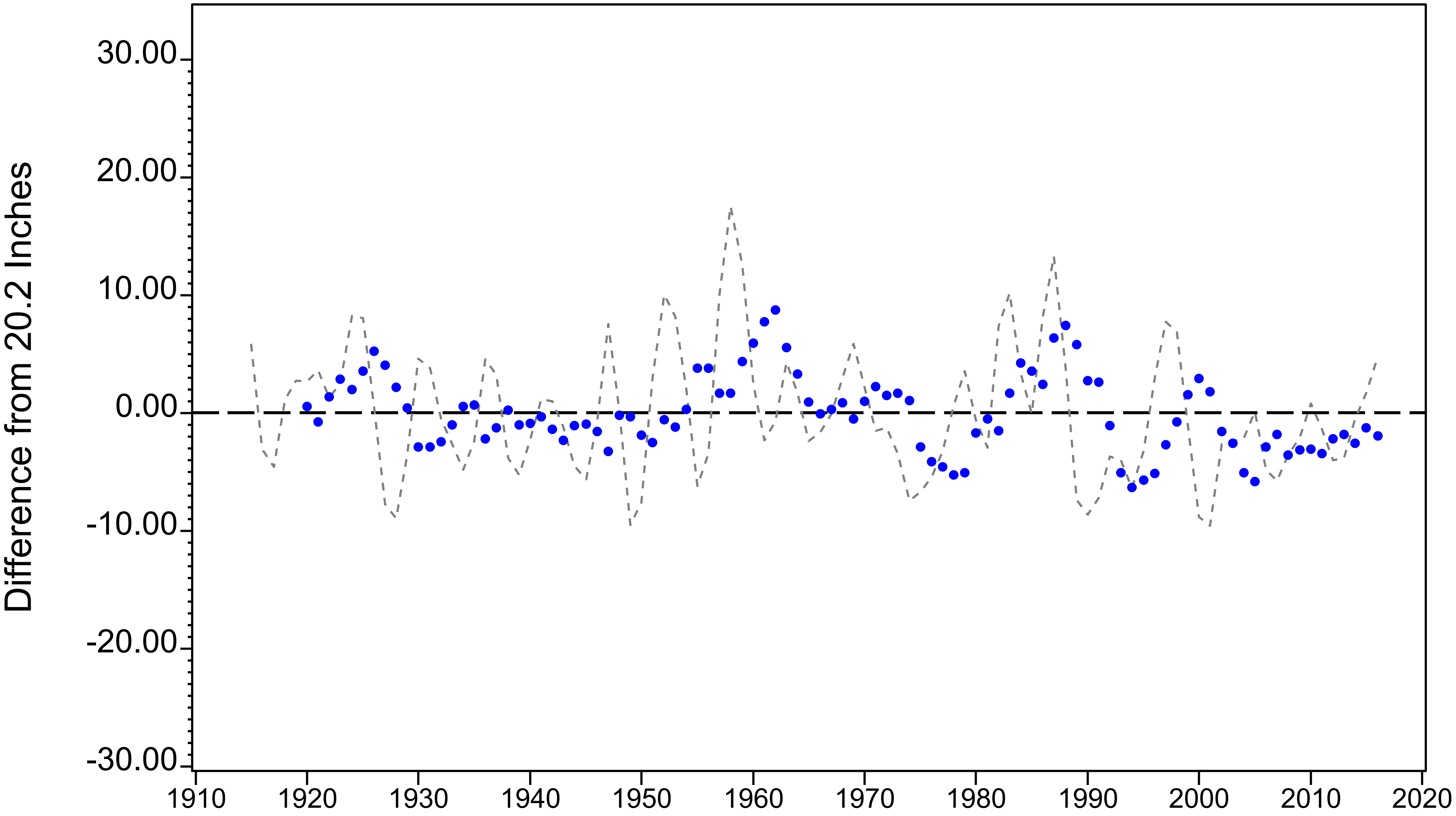


Figure 3.49 Yearly and 5-year moving average annual dry-season rainfall at long-term Arcadia NOAA gage (District #24570/R148) 1915-2016

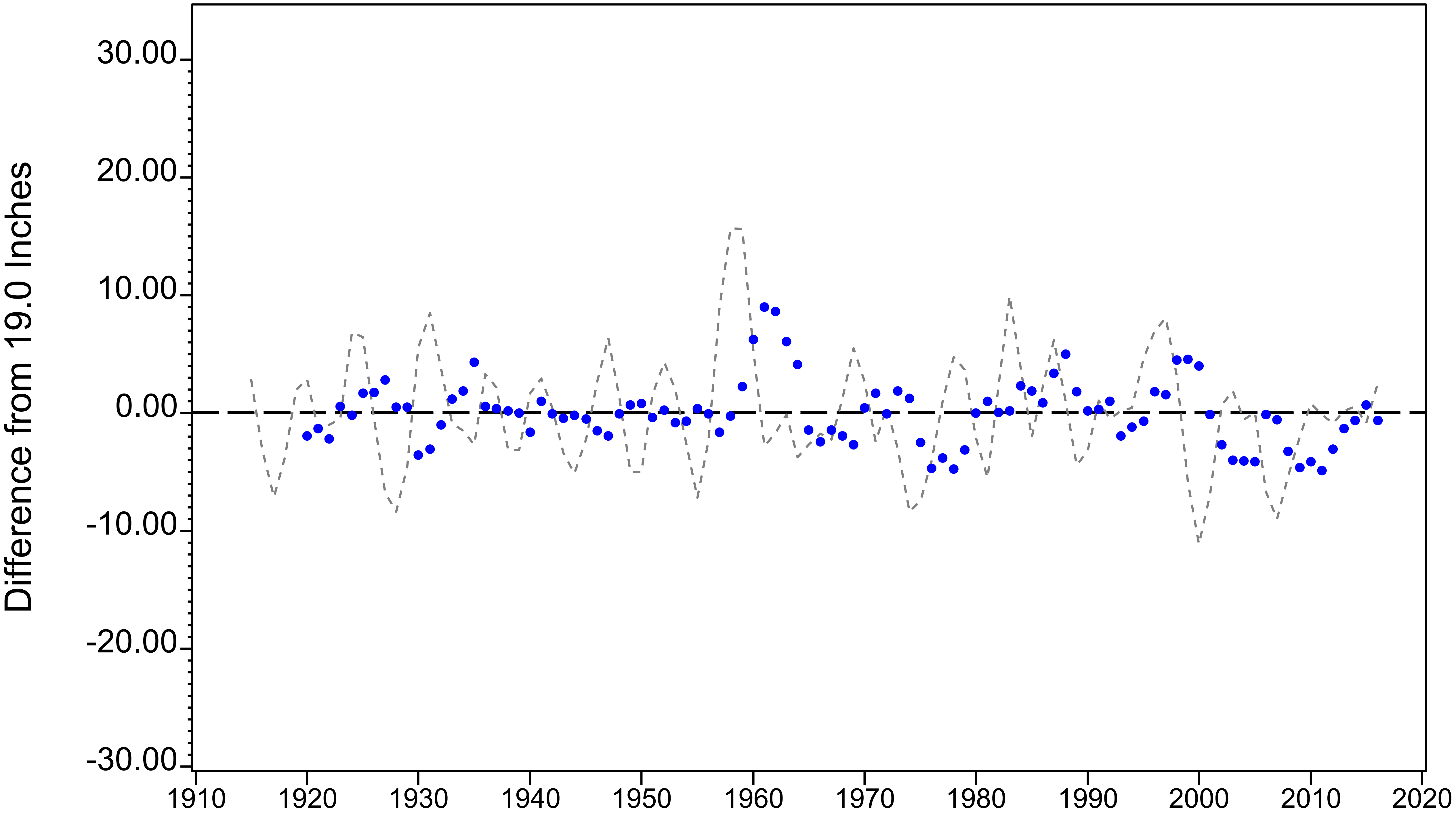


Figure 3.50 Yearly and 5-year moving average annual dry-season rainfall at long-term Punta Gorda NOAA gage (District #25105/R255) 1915-2016

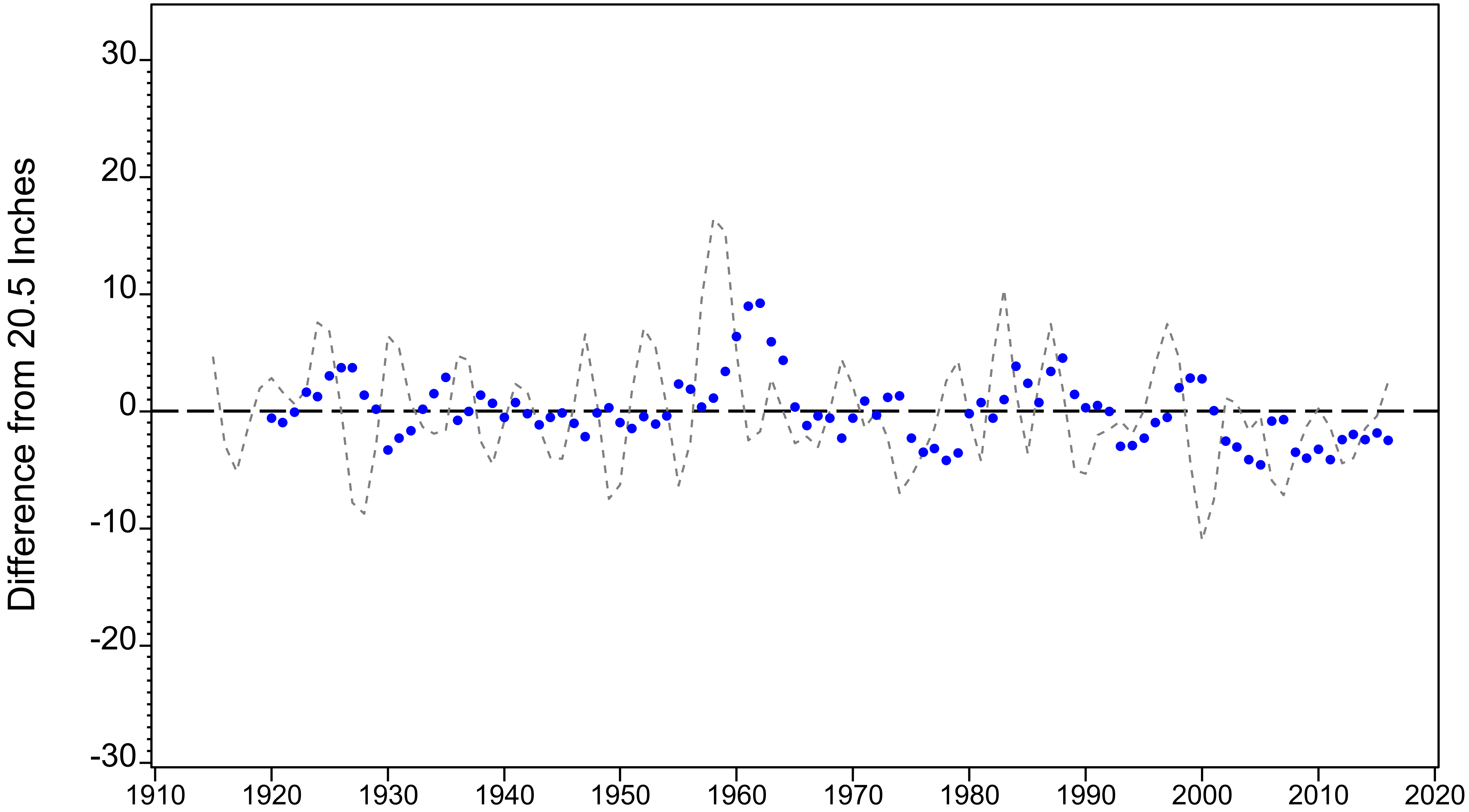


Figure 3.51 Yearly and 5-year moving average anuual dry-season average Bartow, Arcadia and Punta Gorda rainfall 1915-2016

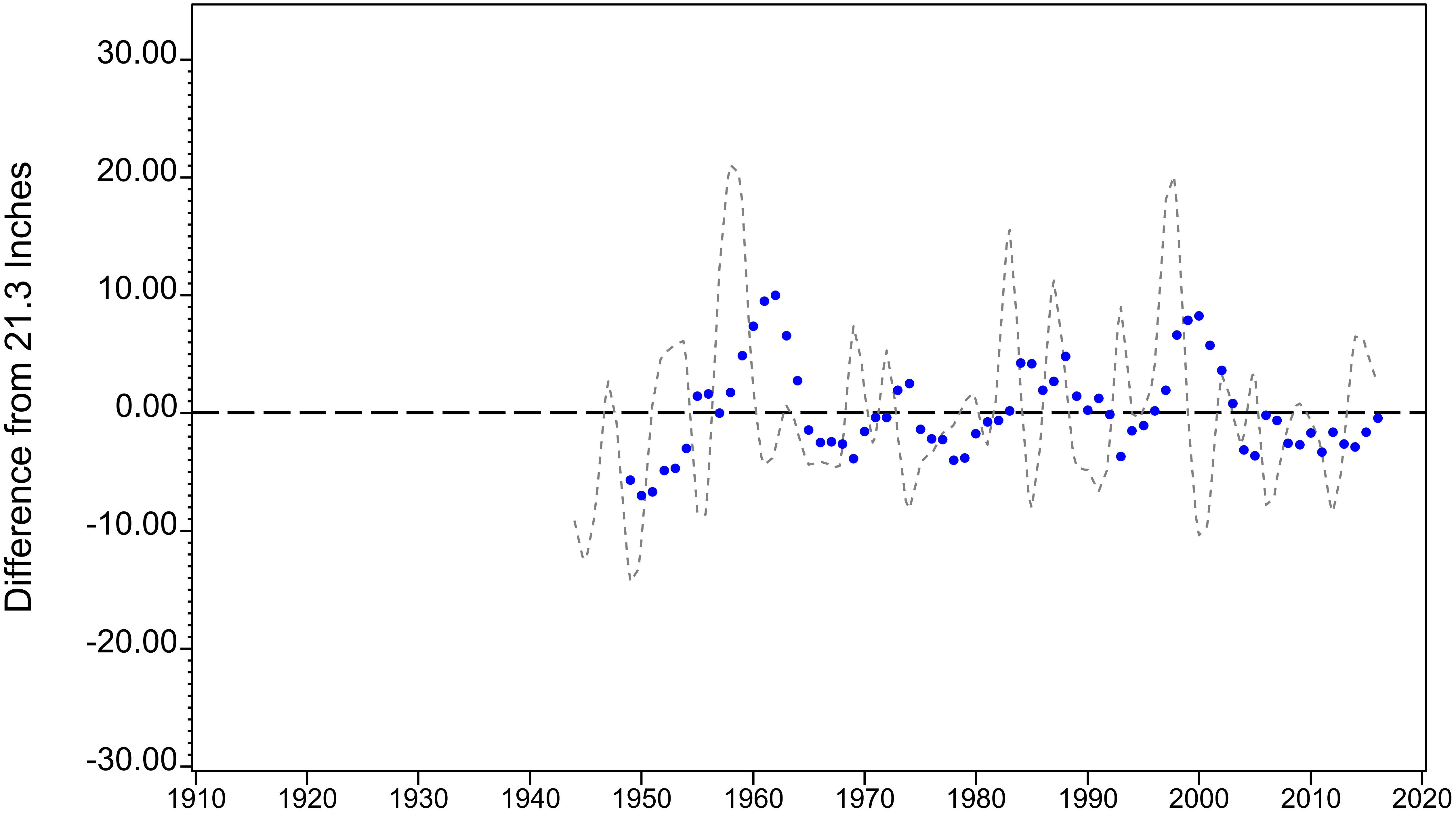


Figure 3.52 Yearly and 5-year moving average annual dry-season rainfall at long-term Myakka NOAA gage (District #25793/R336) 1943-2016

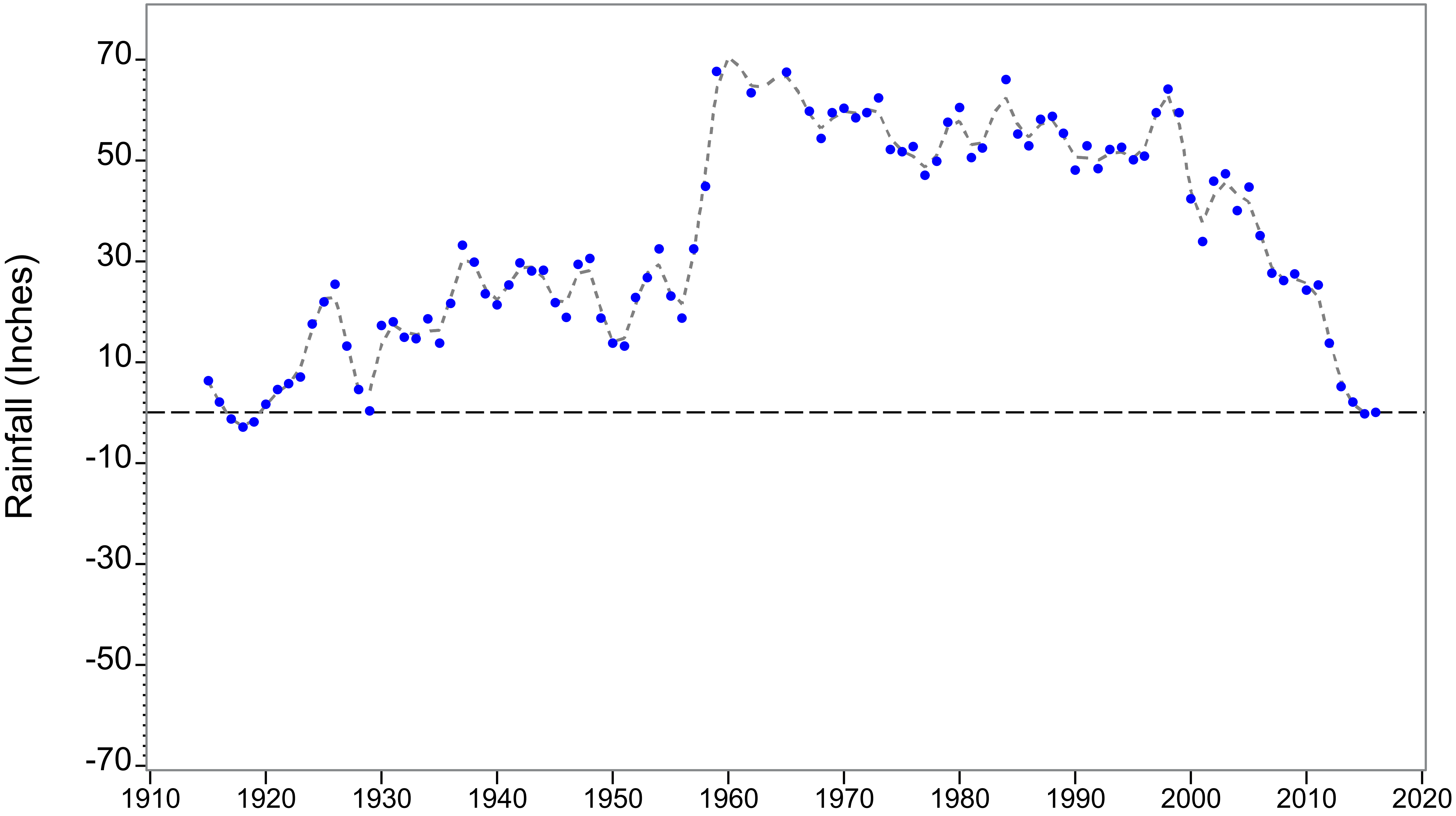


Figure 3.53 Long-term cumulative annual dry-season rainfall above 22.5 inches at Bartow NOAA gage (District #25164/R142) 1915-2016

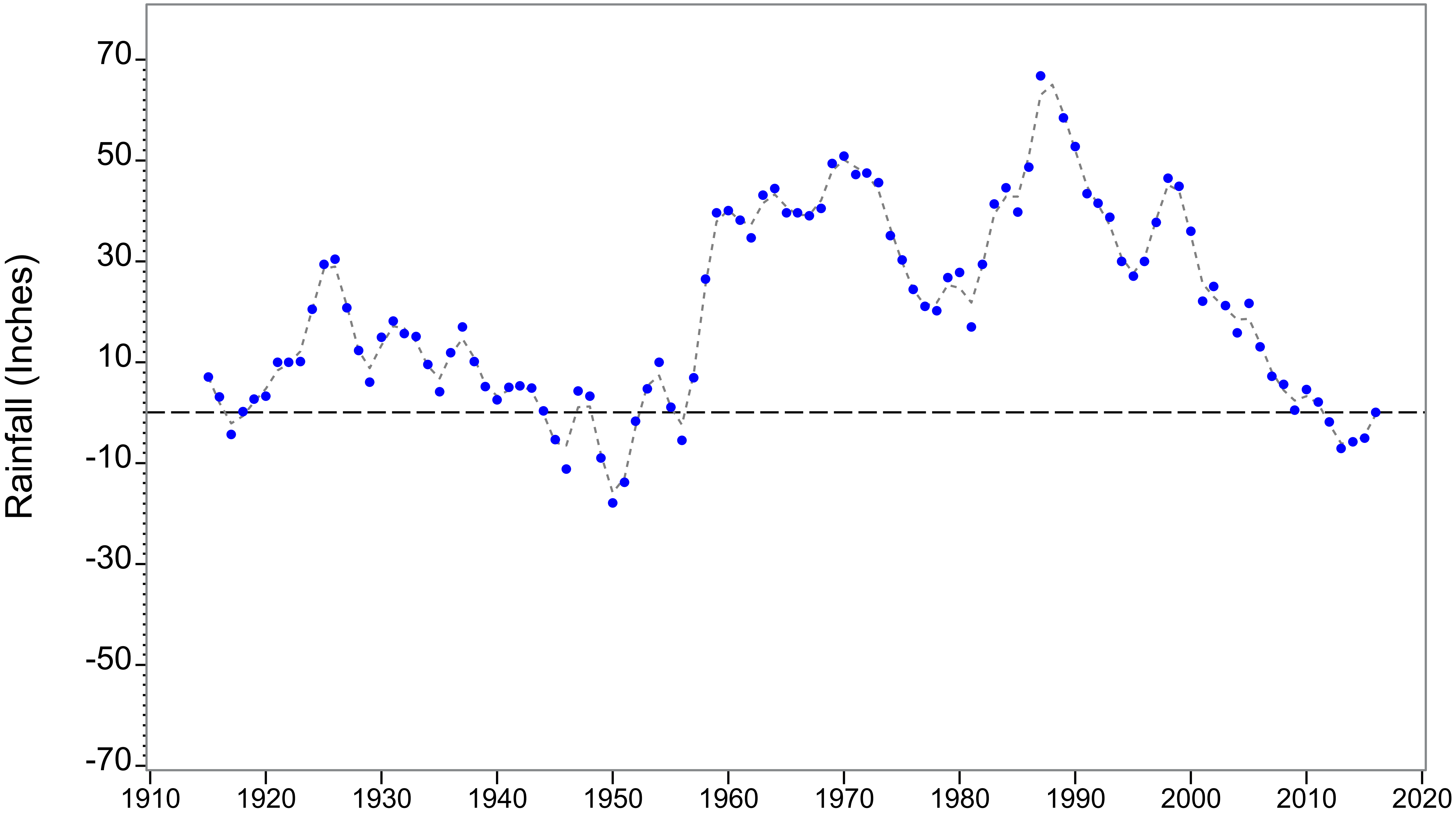


Figure 3.54 Long-term cumulative annual dry-season rainfall above 20.2 inches at long-term Arcadia NOAA gage (District R148) 1915-2016

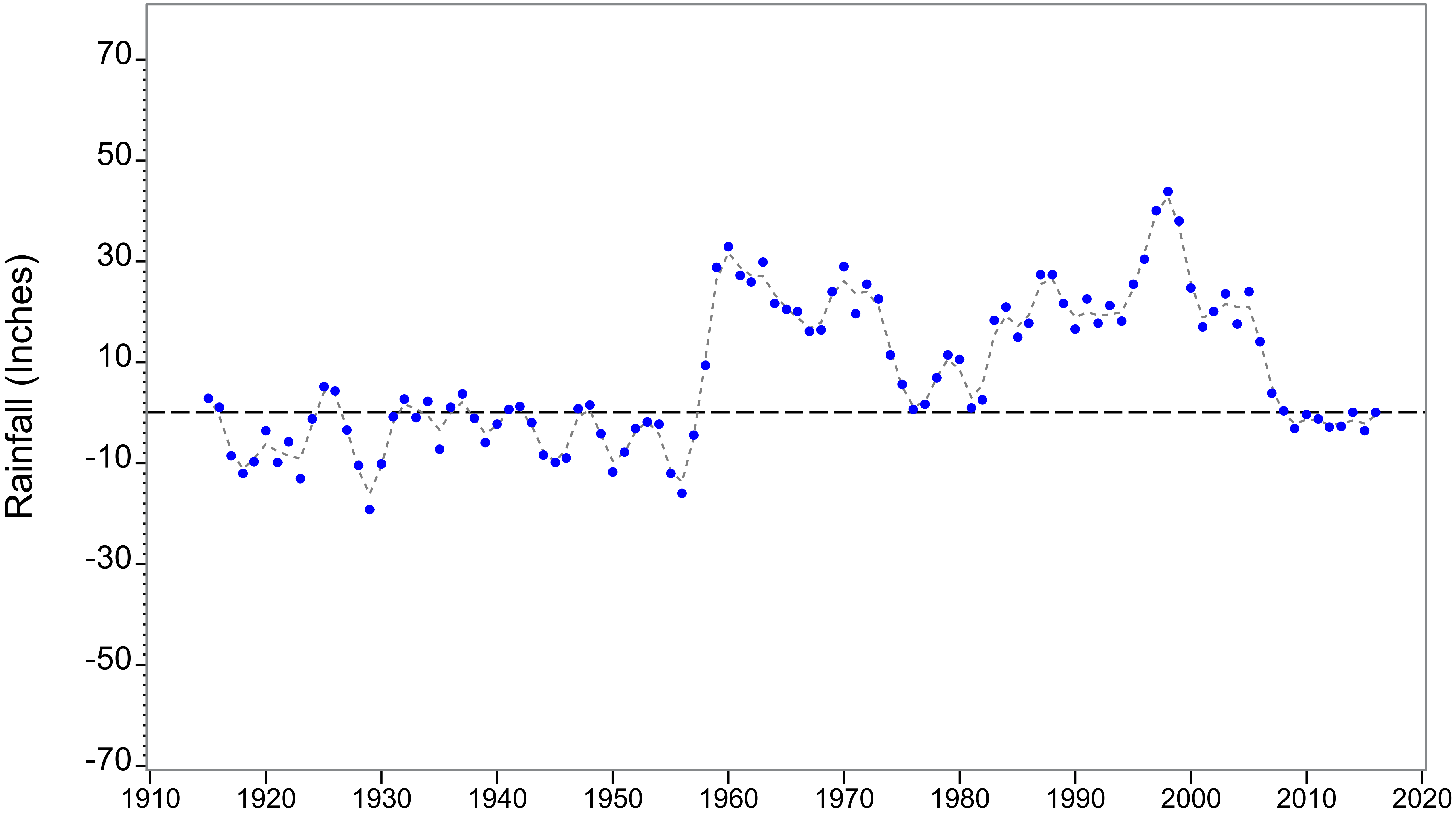


Figure 3.55 Long-term cumulative annual dry-season rainfall above 19.0 inches at long-term Punta Gorda NOAA gage (District R255) 1915-2016

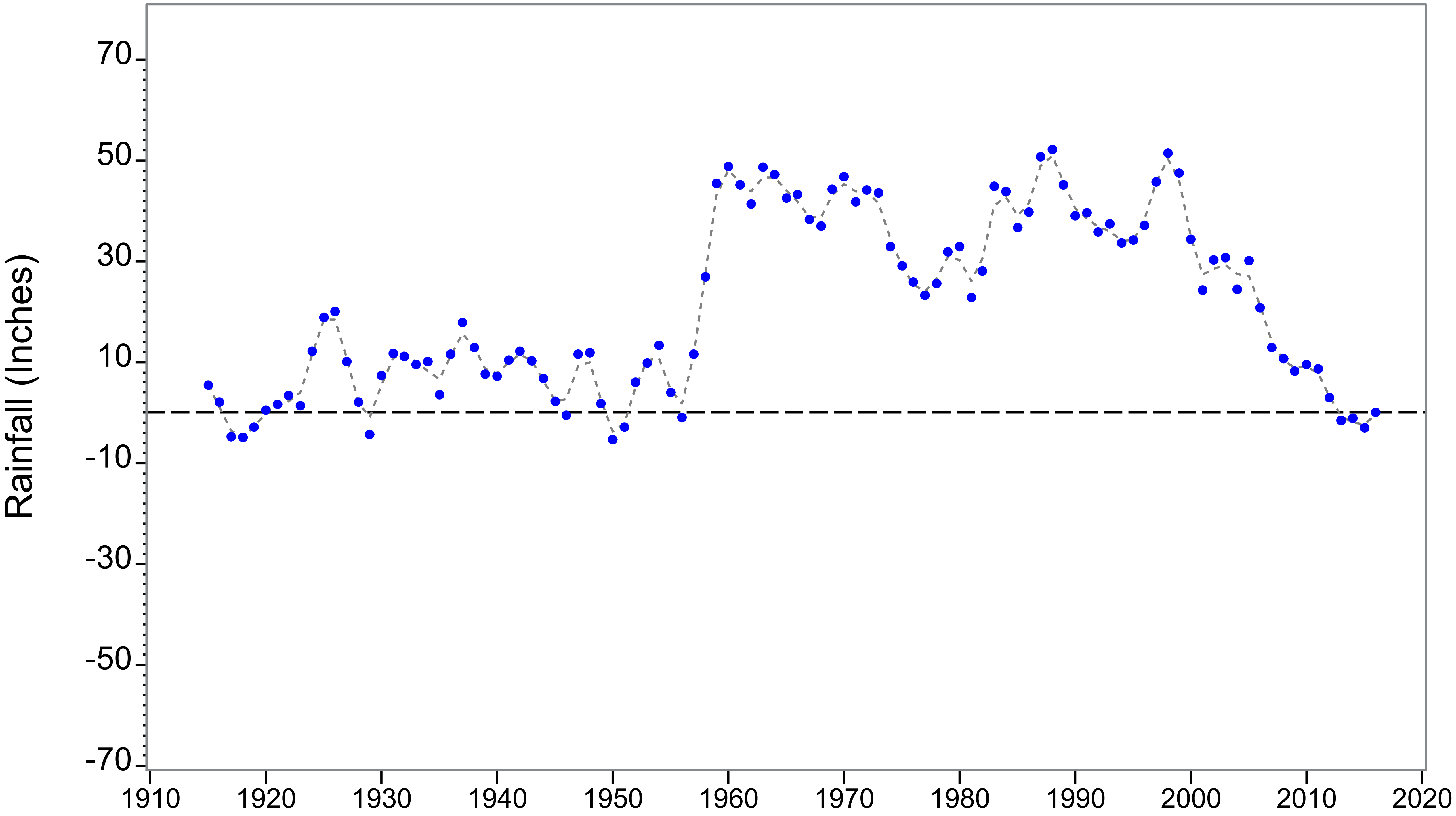


Figure 3.56 Long-term cumulative annual dry-season rainfall above 20.5 inches of Bartow, Arcadia and Punta Gorda average rainfall (1915-2016)

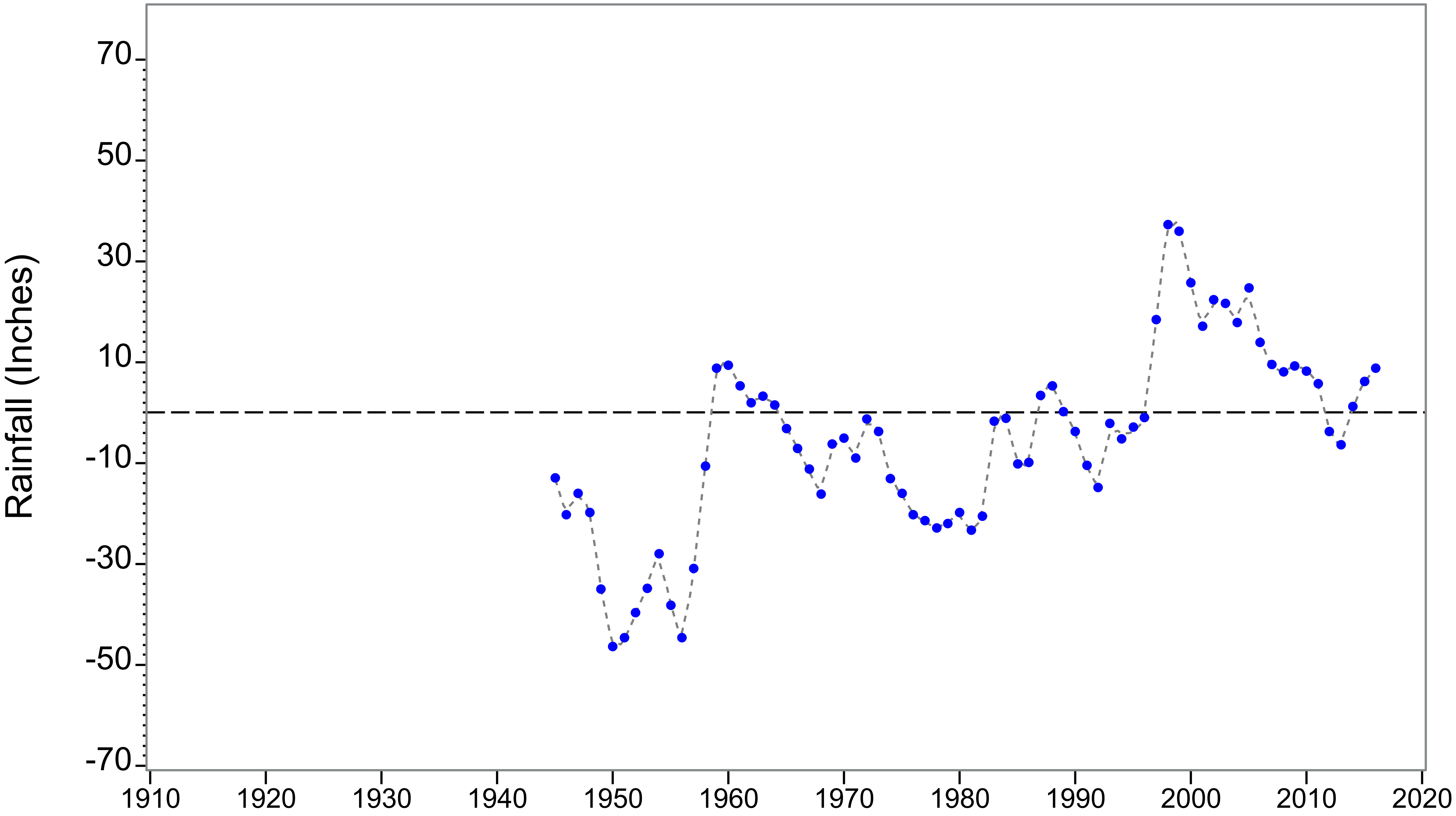


Figure 3.57 Long-term cumulative annual dry-season rainfall above 21.3 inches at long-term Myakka NOAA gage (District R336) 1915-2016

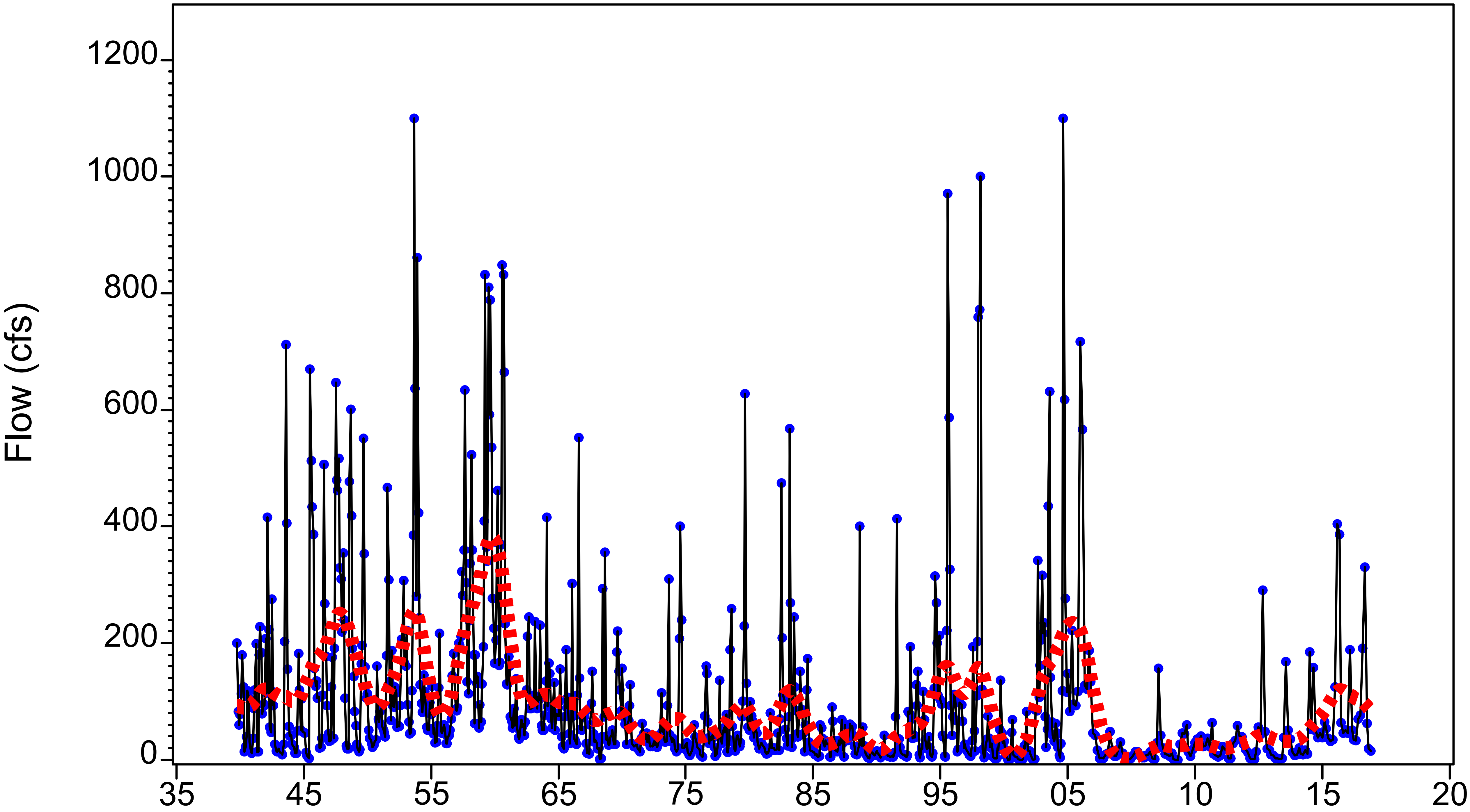


Figure 3.58 Monthly minimum flow at long-term Peace River at Bartow (2294650) gage (1939-2016)

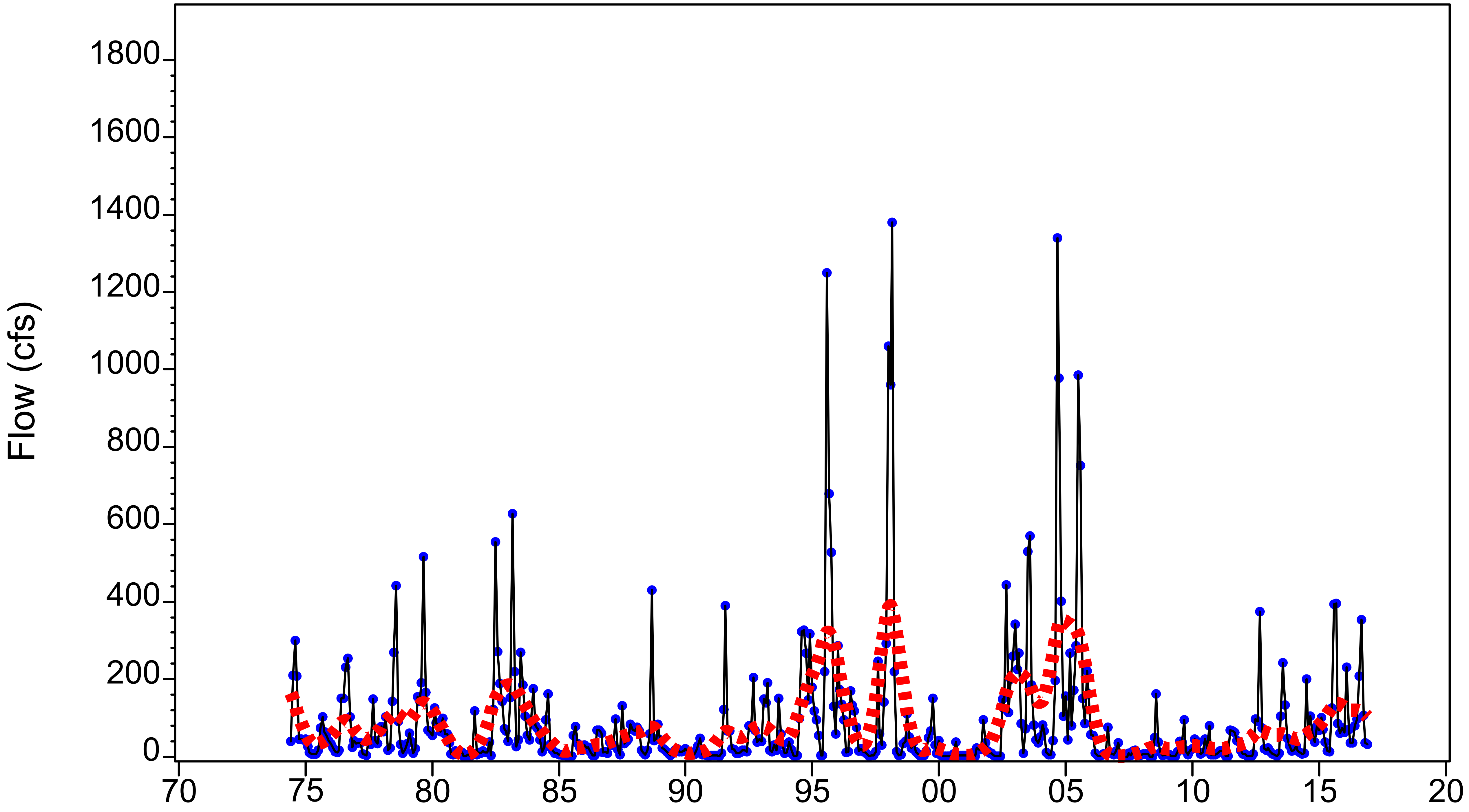


Figure 3.59 Monthly minimum flow at long-term Peace River at Ft. Meade (2294898) gage (1974-2016)

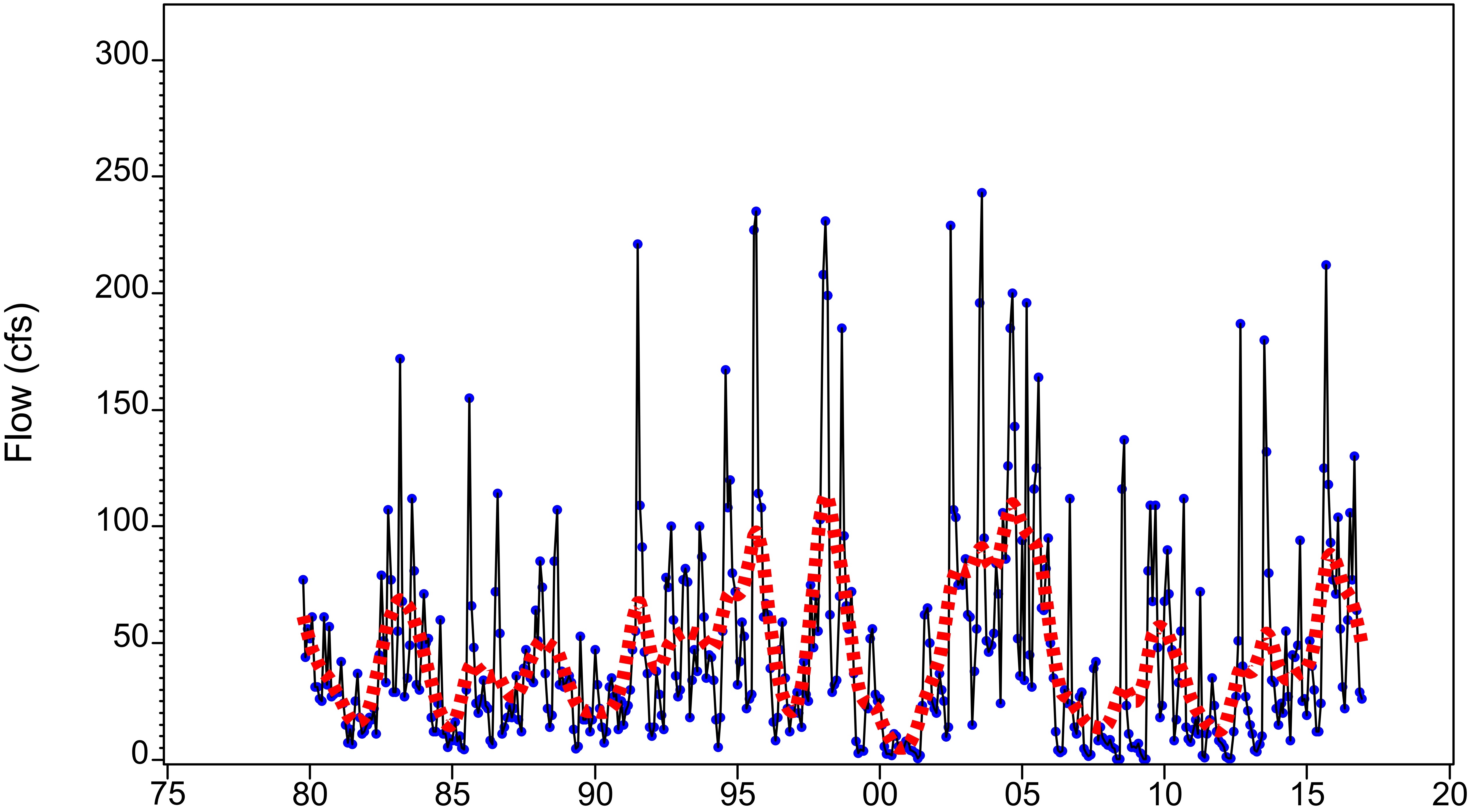


Figure 3.60 Monthly minimum flow at long-term Payne Creek (2295420) gage (1979-2016)

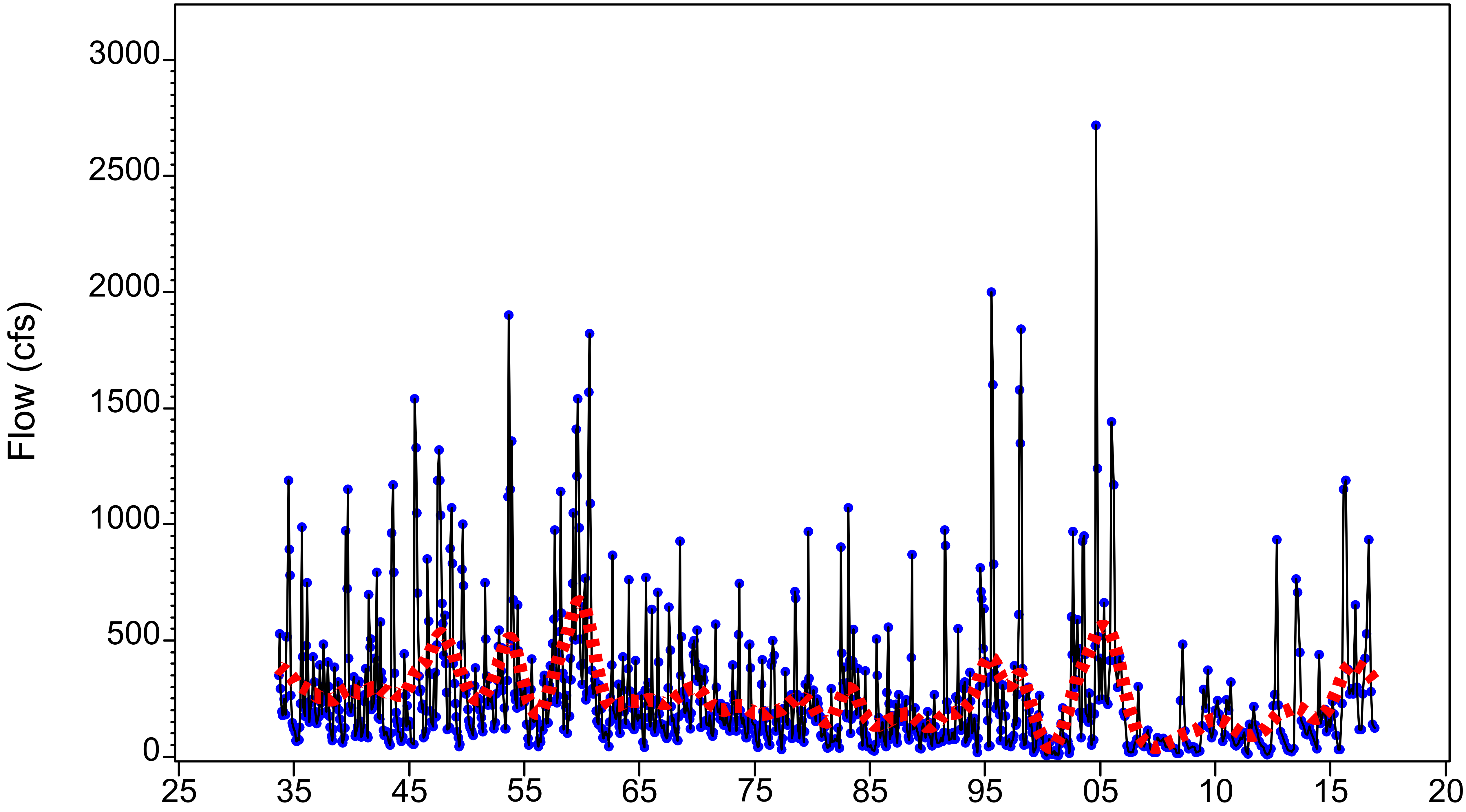


Figure 3.61 Monthly minimum flow at long-term Peace River at Zolfo (2295637) gage (1933-2016)

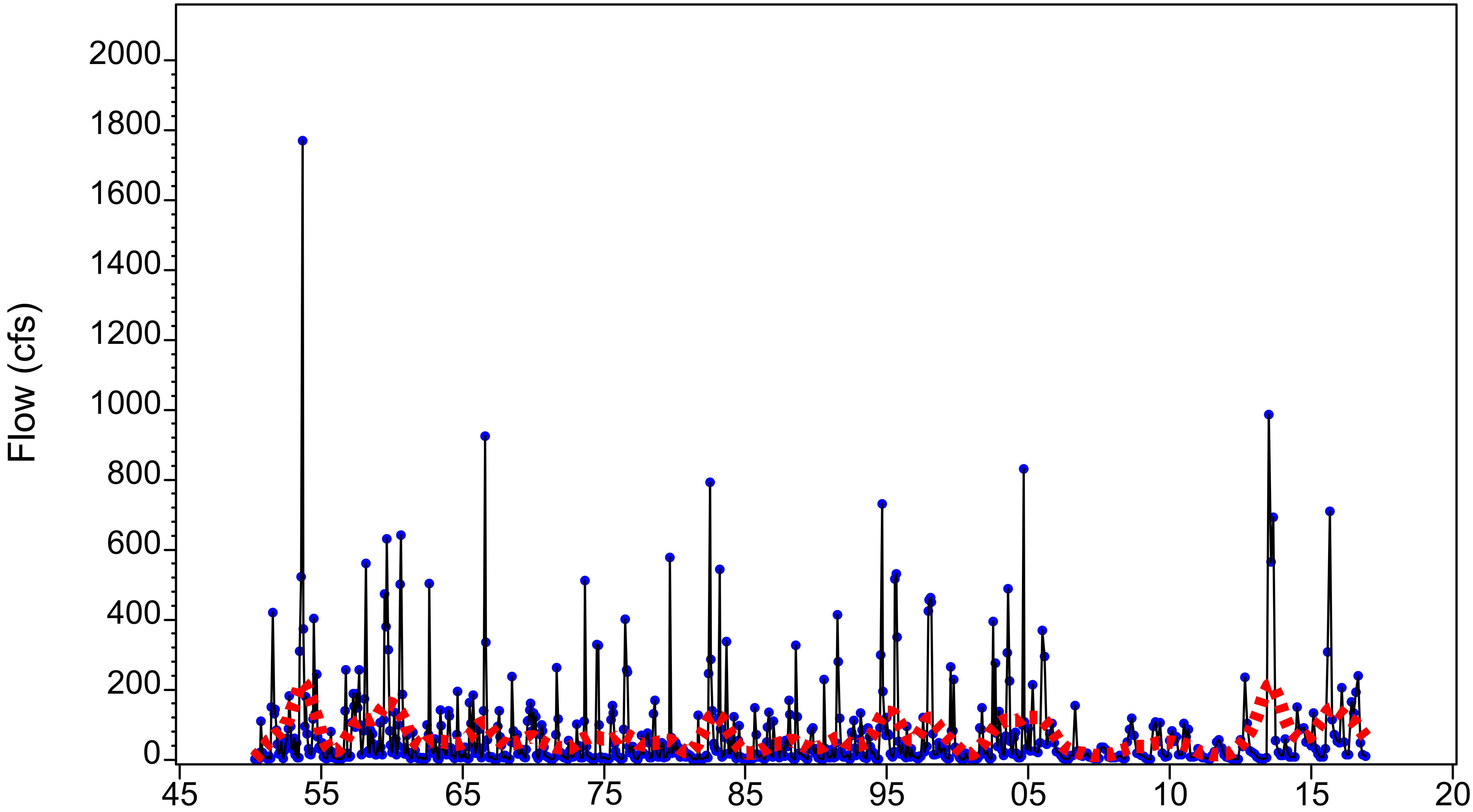


Figure 3.62 Monthly minimum flow at long-term Charlie Creek (2296500) gage (1950-2016)

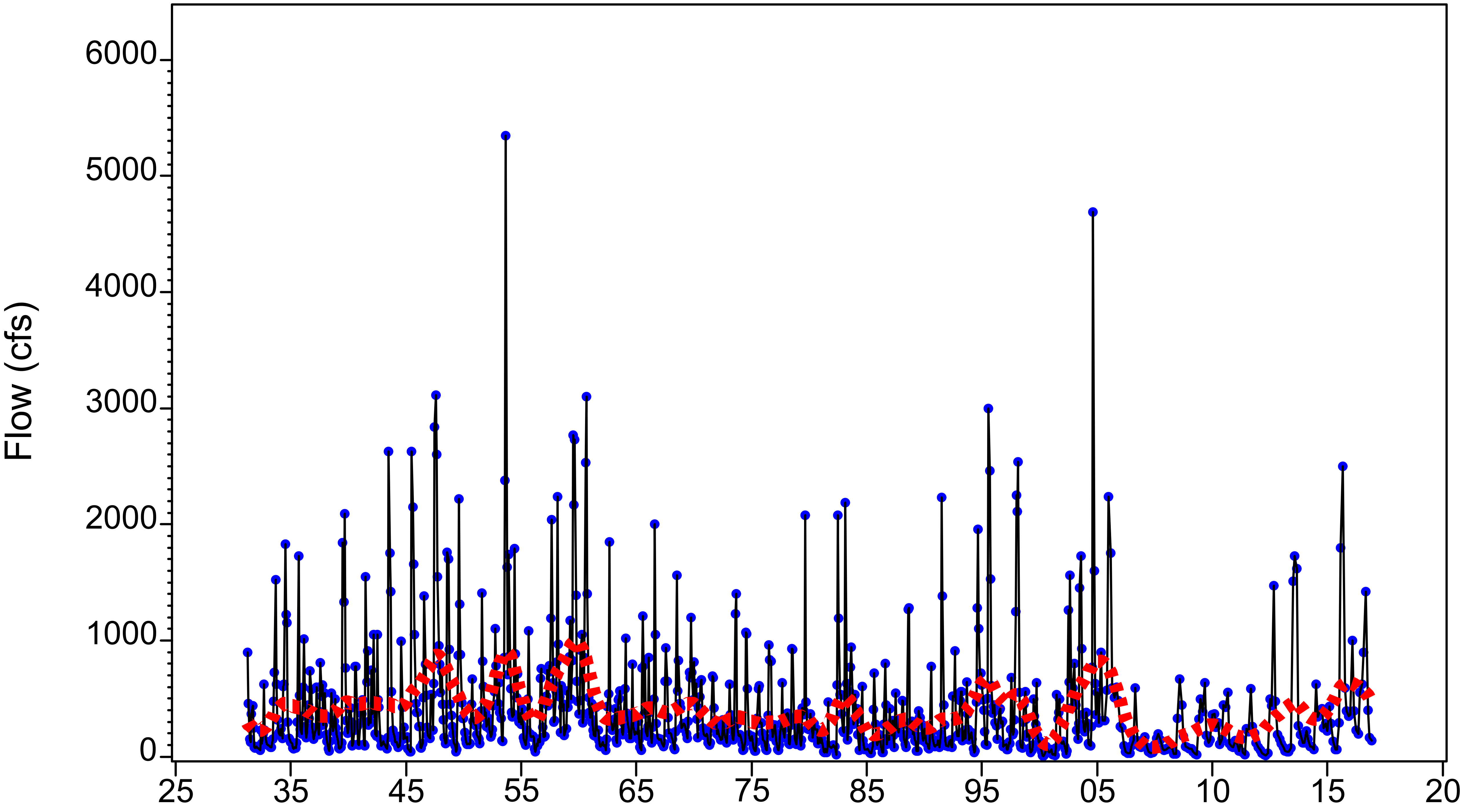


Figure 3.63 Monthly minimum flow at long-term Peace River at Arcadia (2296750) gage (1931-2016)

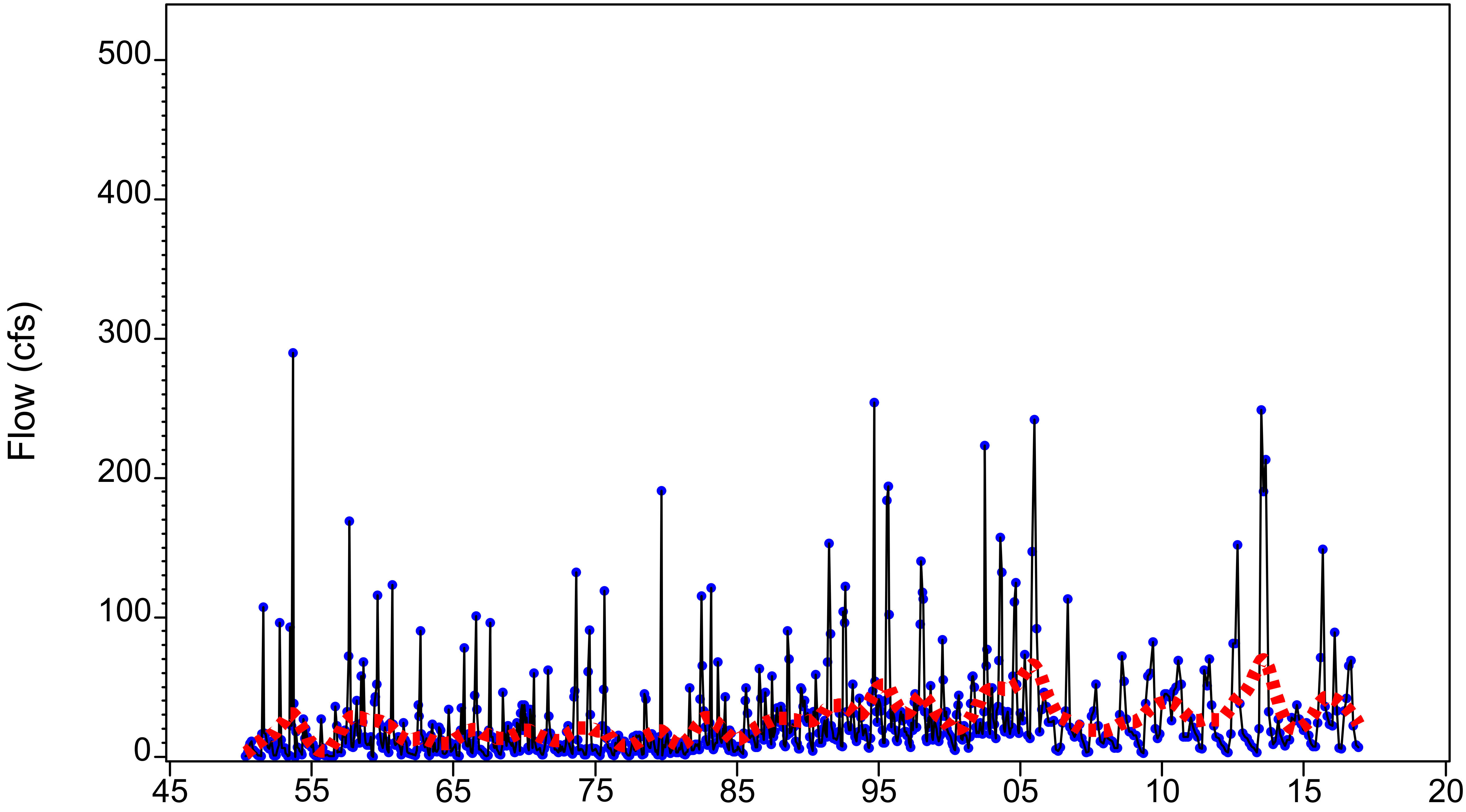


Figure 3.64 Monthly minimum flow at long-term Joshua Creek at Nocatee (2297100) gage (1950-2016)

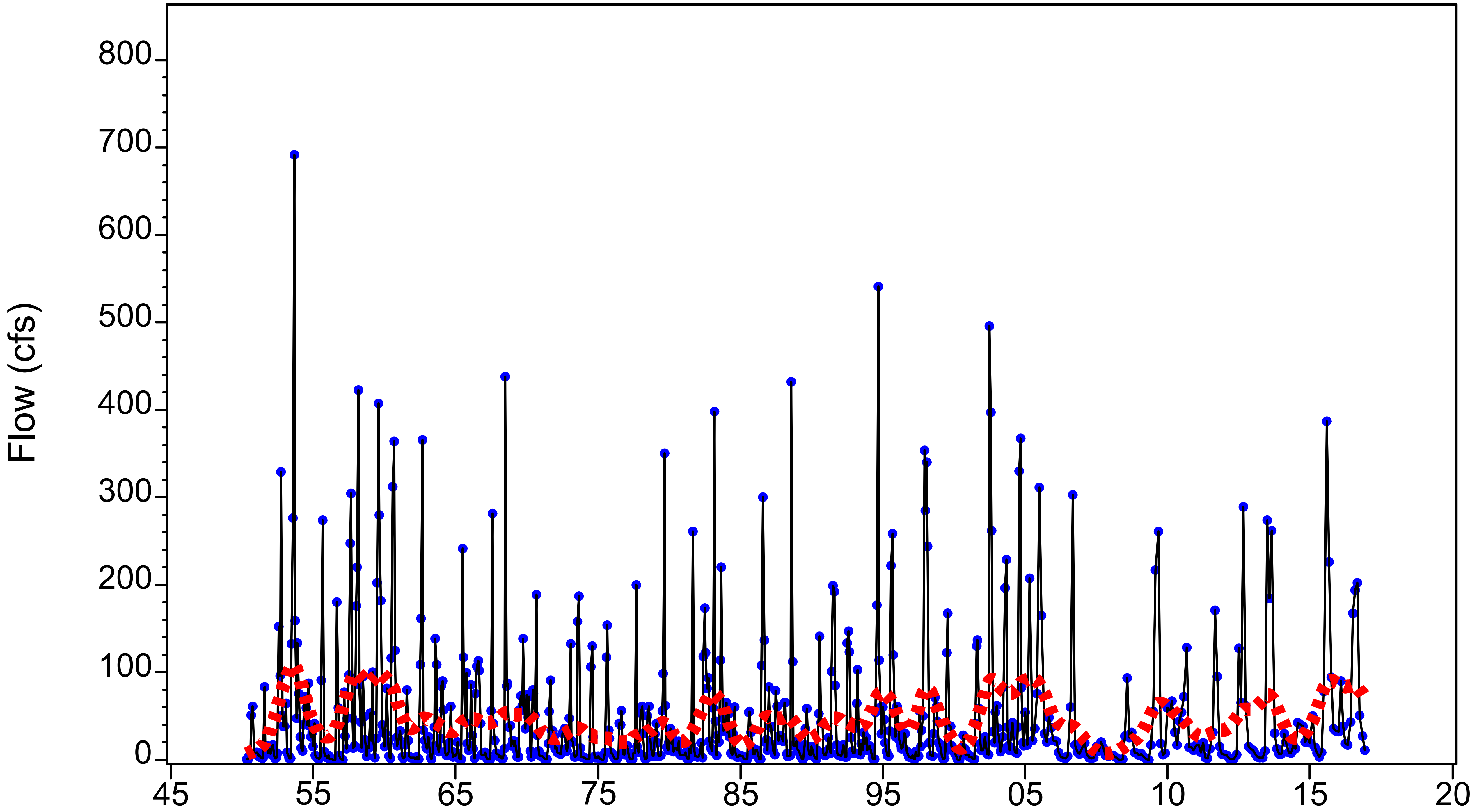


Figure 3.65 Monthly minimum flow at long-term Horse Creek near Arcadia(2297310) gage (1950-2016)

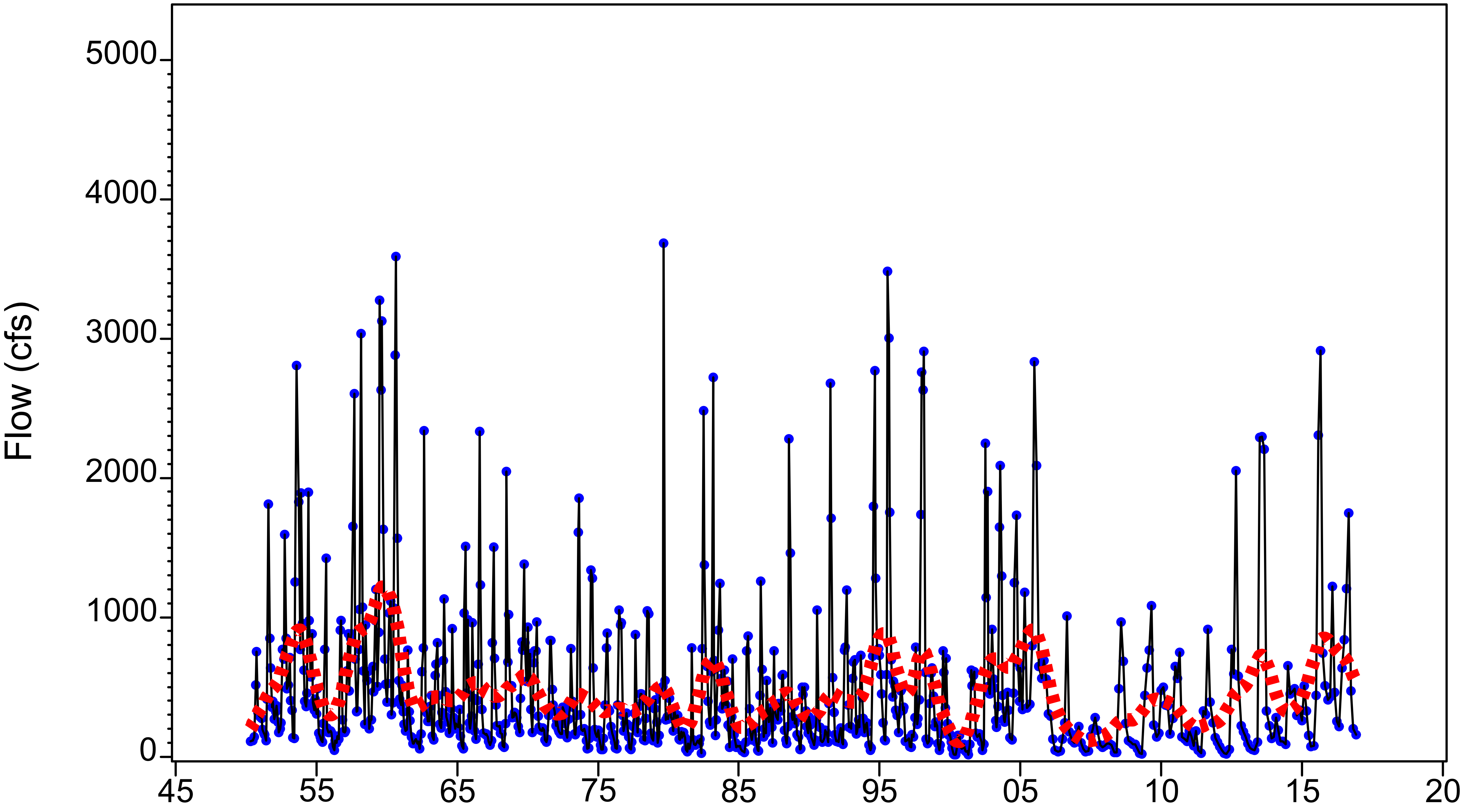


Figure 3.66 Monthly minimum flow at long-term for total gaged flow upstream of the Facility (1950-2016)

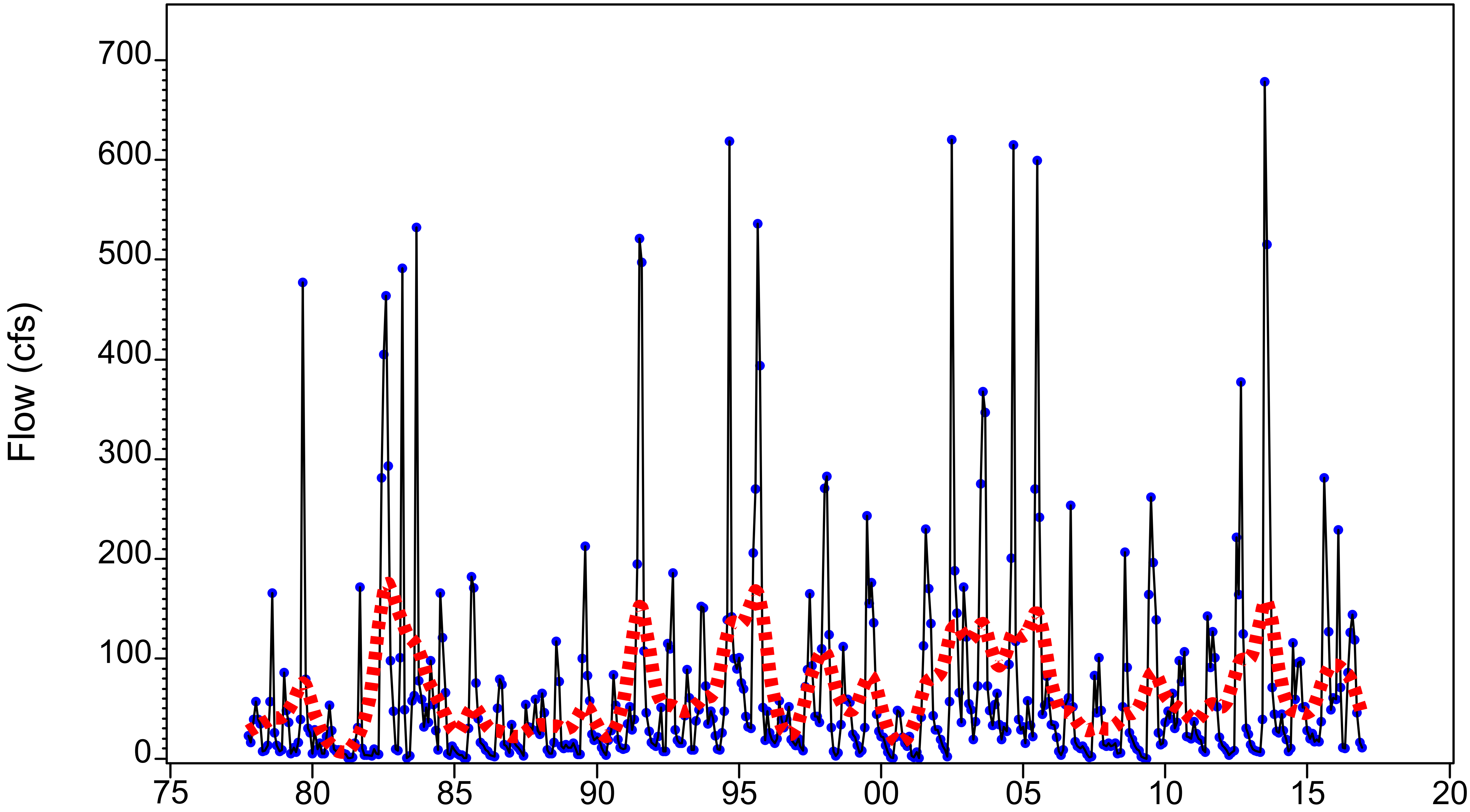


Figure 3.67 Monthly minimum flow at long-term Prairie Creek (2298123) gage (1977-2016)

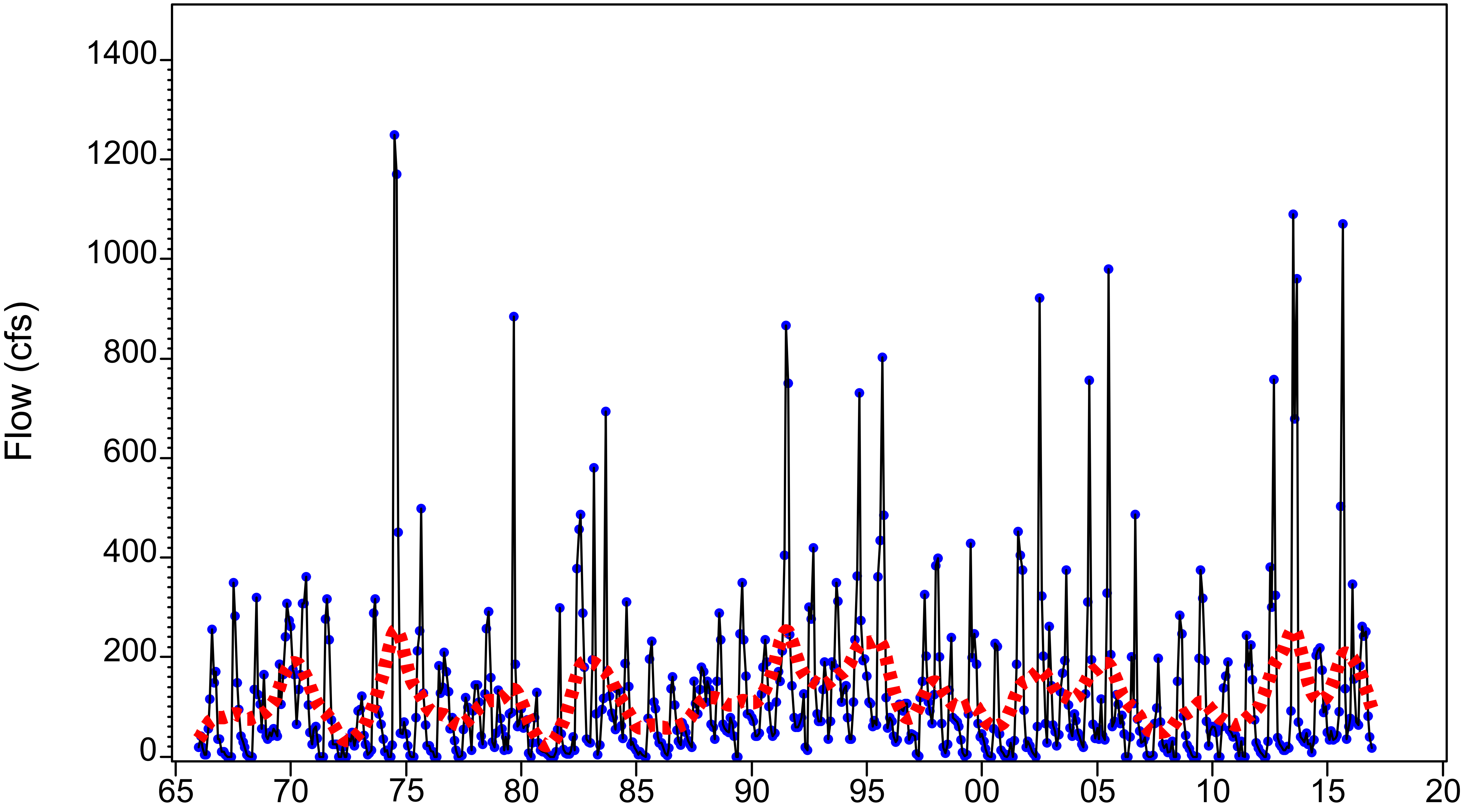


Figure 3.68 Monthly minimum flow at long-term Shell Creek gage (1965-2016)

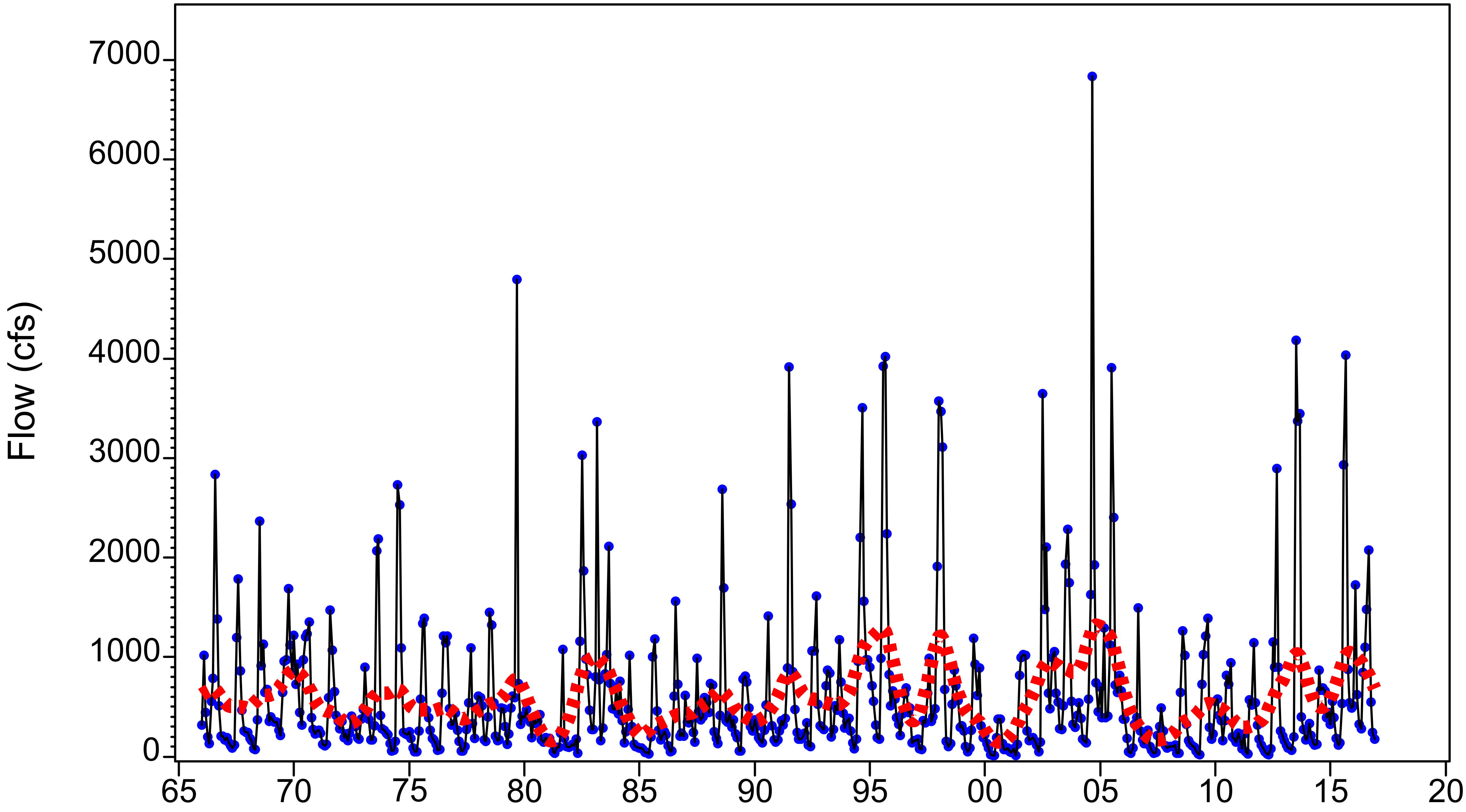


Figure 3.69 Monthly minimum flow of total gaged Peace River flow to the Upper Harbor (1965-2016)

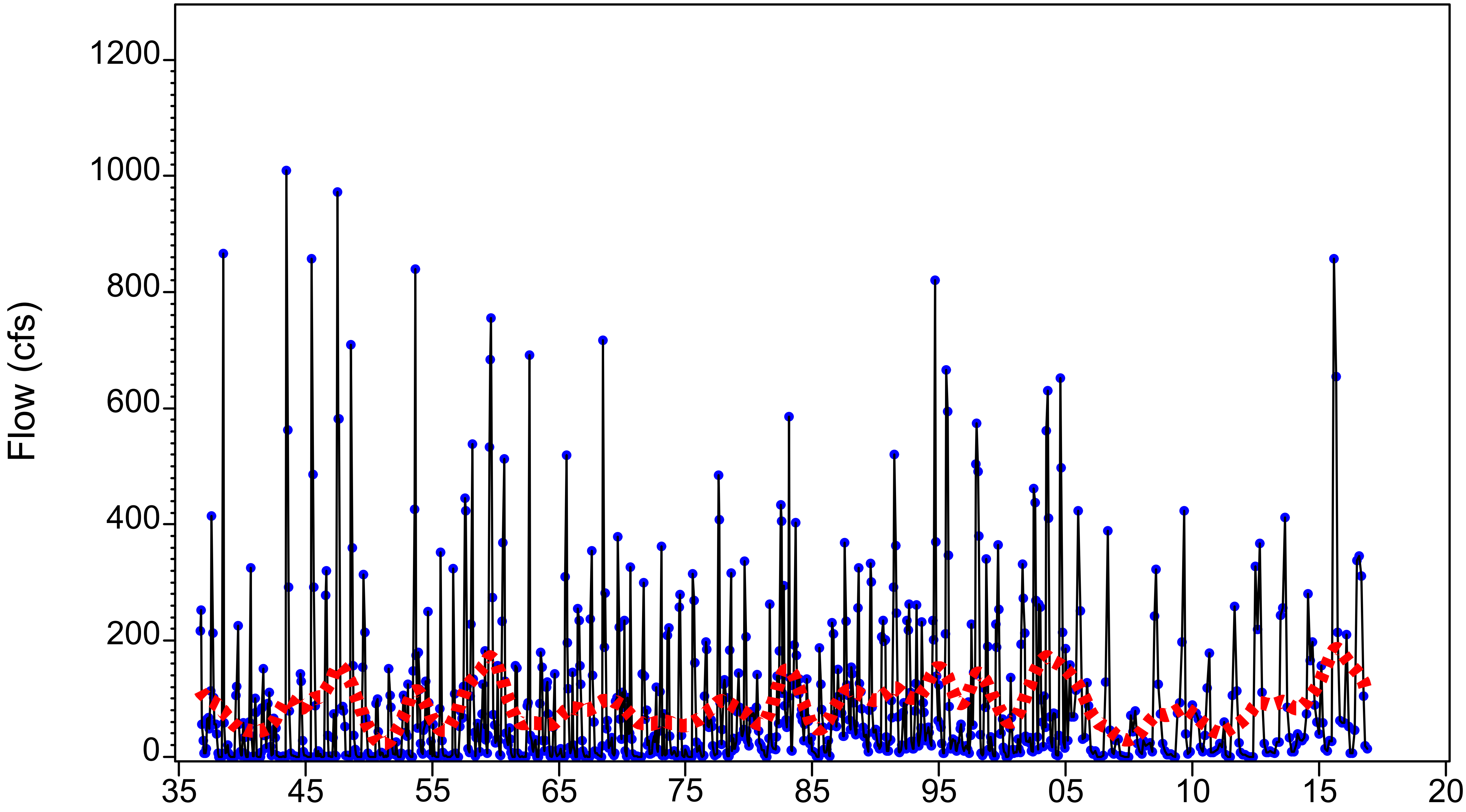


Figure 3.70 Monthly minimum flow at long-term Myakka River near Sarasota (2298830) gage (1936-2016)

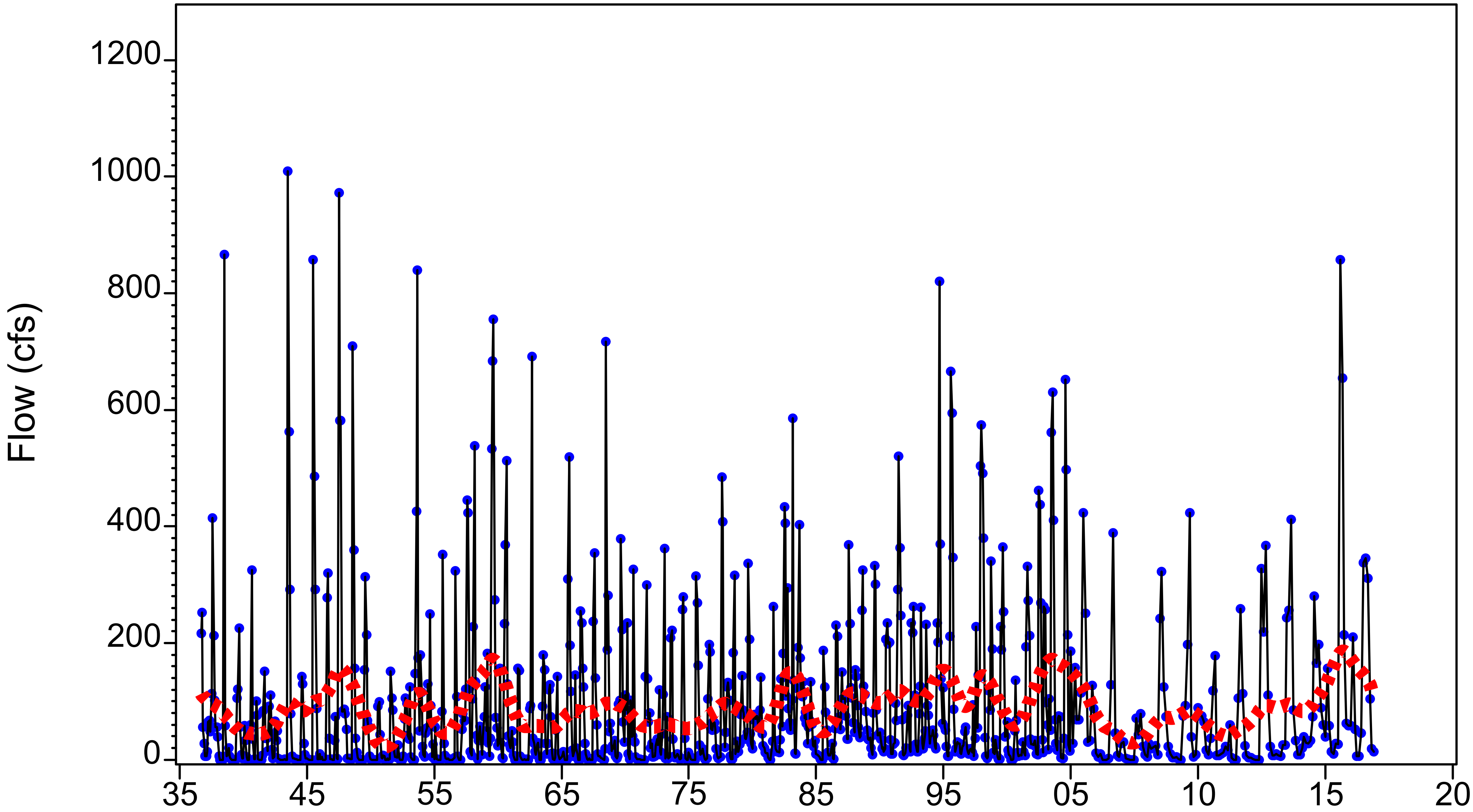


Figure 3.70 Monthly minimum flow at long-term Myakka River near Sarasota (2298830) gage (1936-2016)

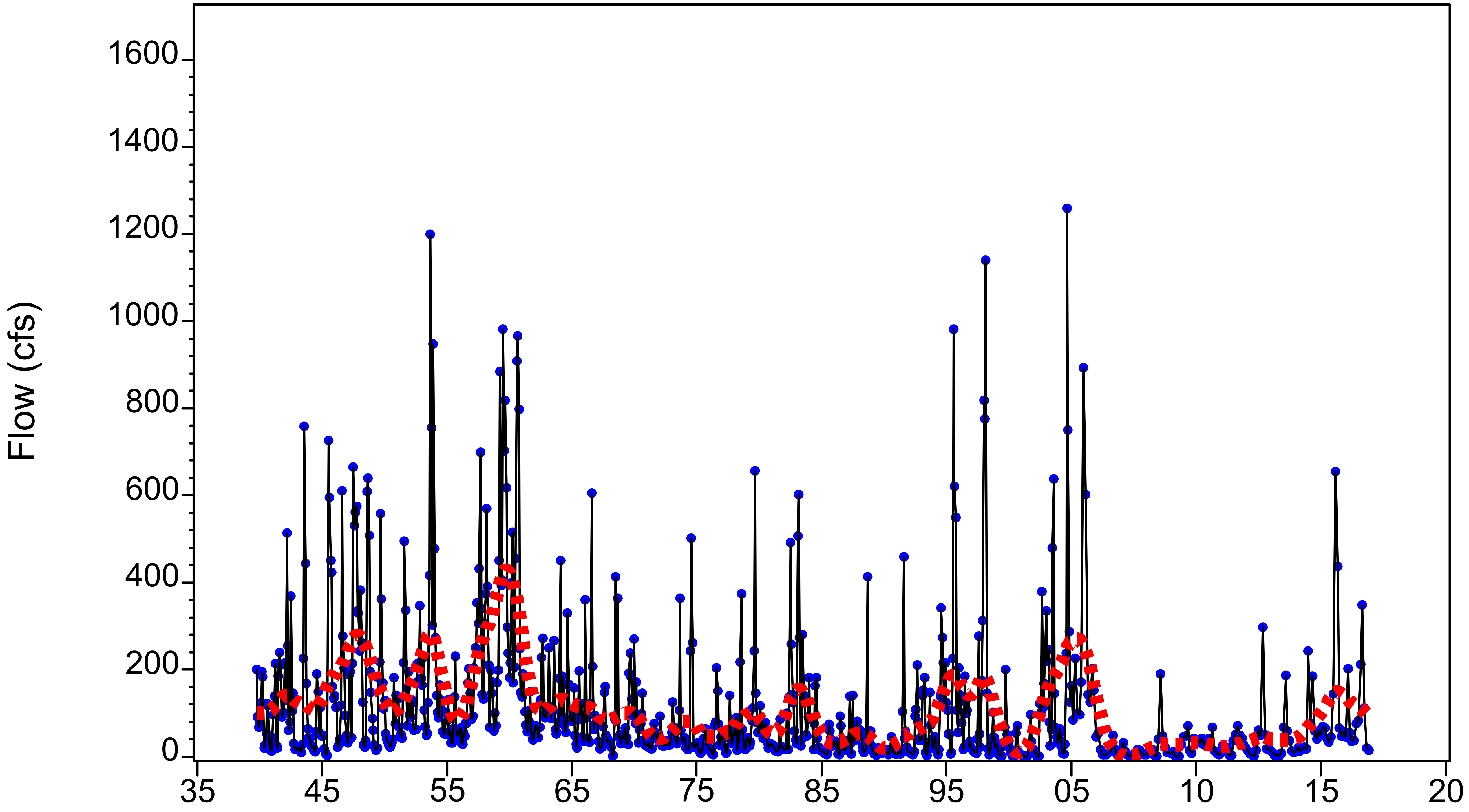


Figure 3.71 Monthly P10 flow at long-term Peace River at Bartow (2294650) gage (1939-2016)

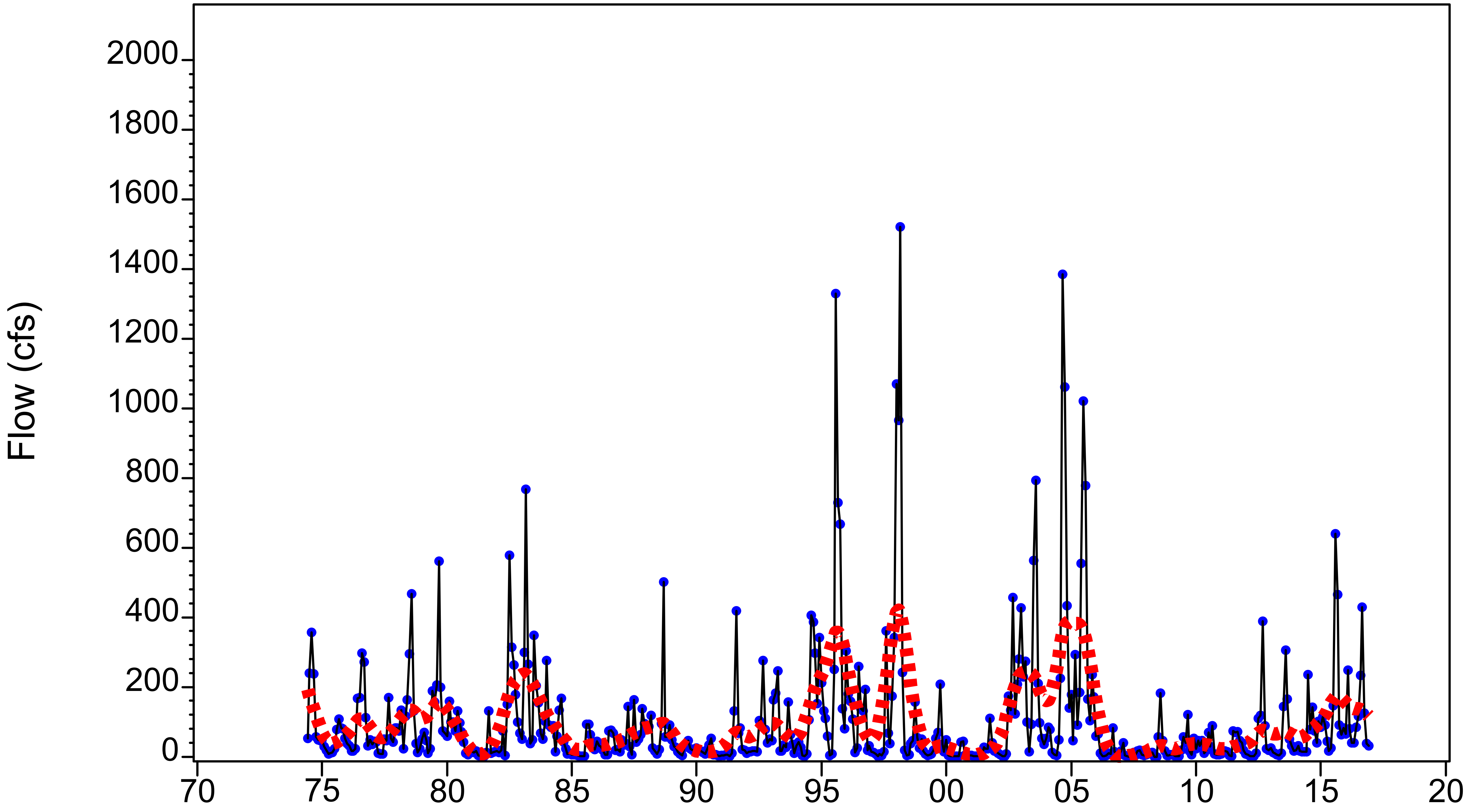


Figure 3.72 Monthly P10 flow at long-term Peace River at Ft. Meade (2294898) gage (1974-2016)

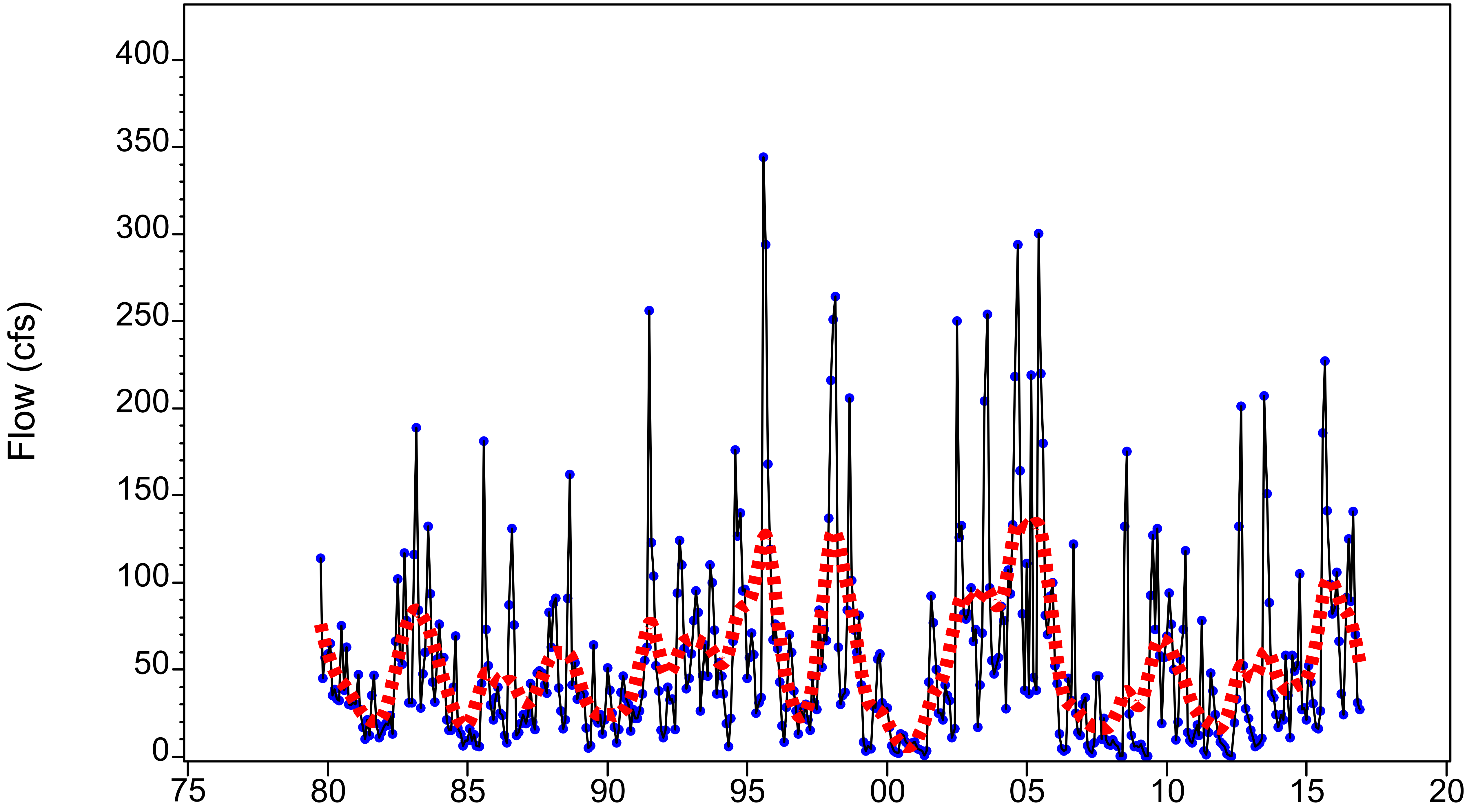


Figure 3.73 Monthly P10 flow at long-term Payne Creek (2295420) gage (1979-2016)

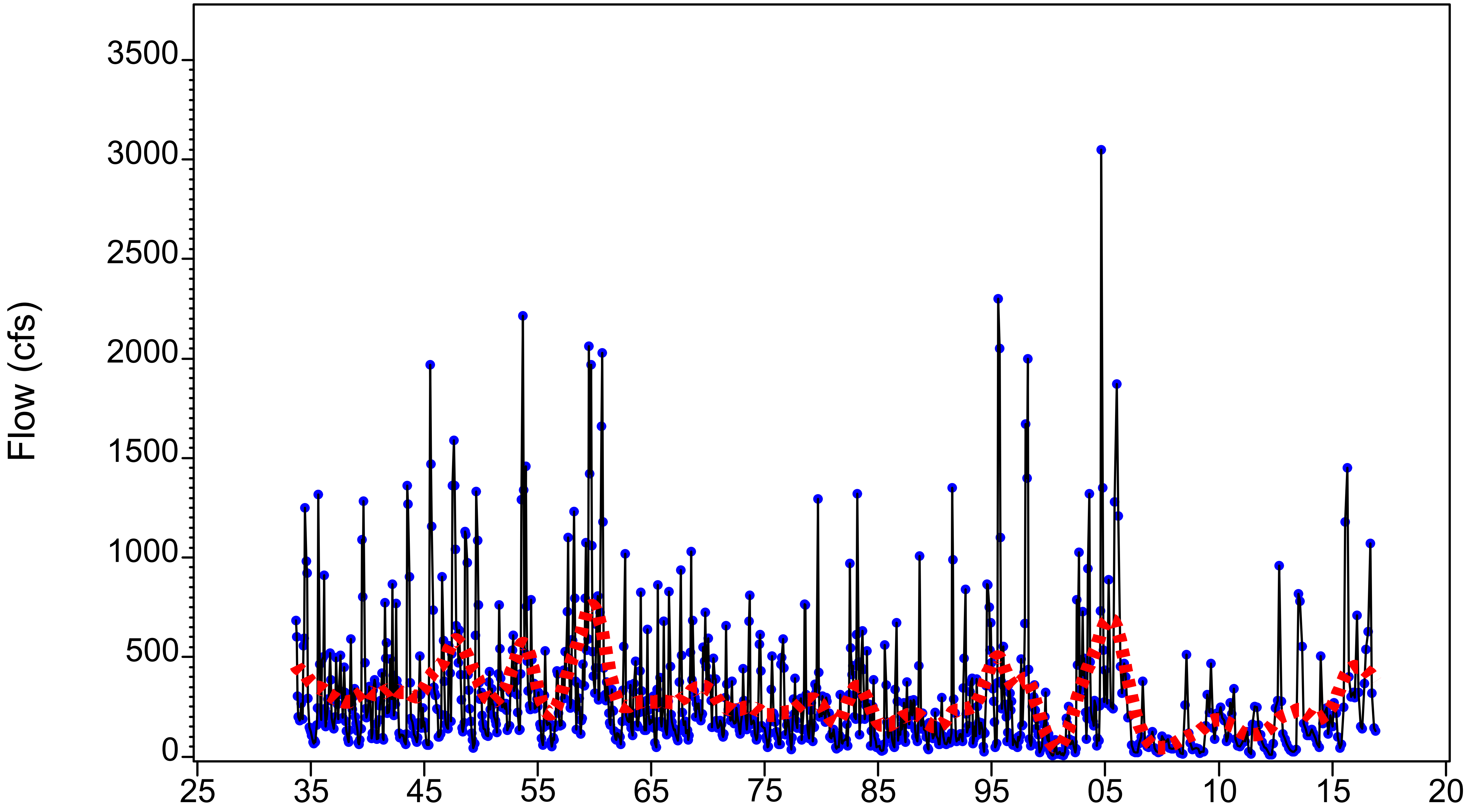


Figure 3.74 Monthly P10 flow at long-term Peace River at Zolfo (2295637) gage (1933-2016)

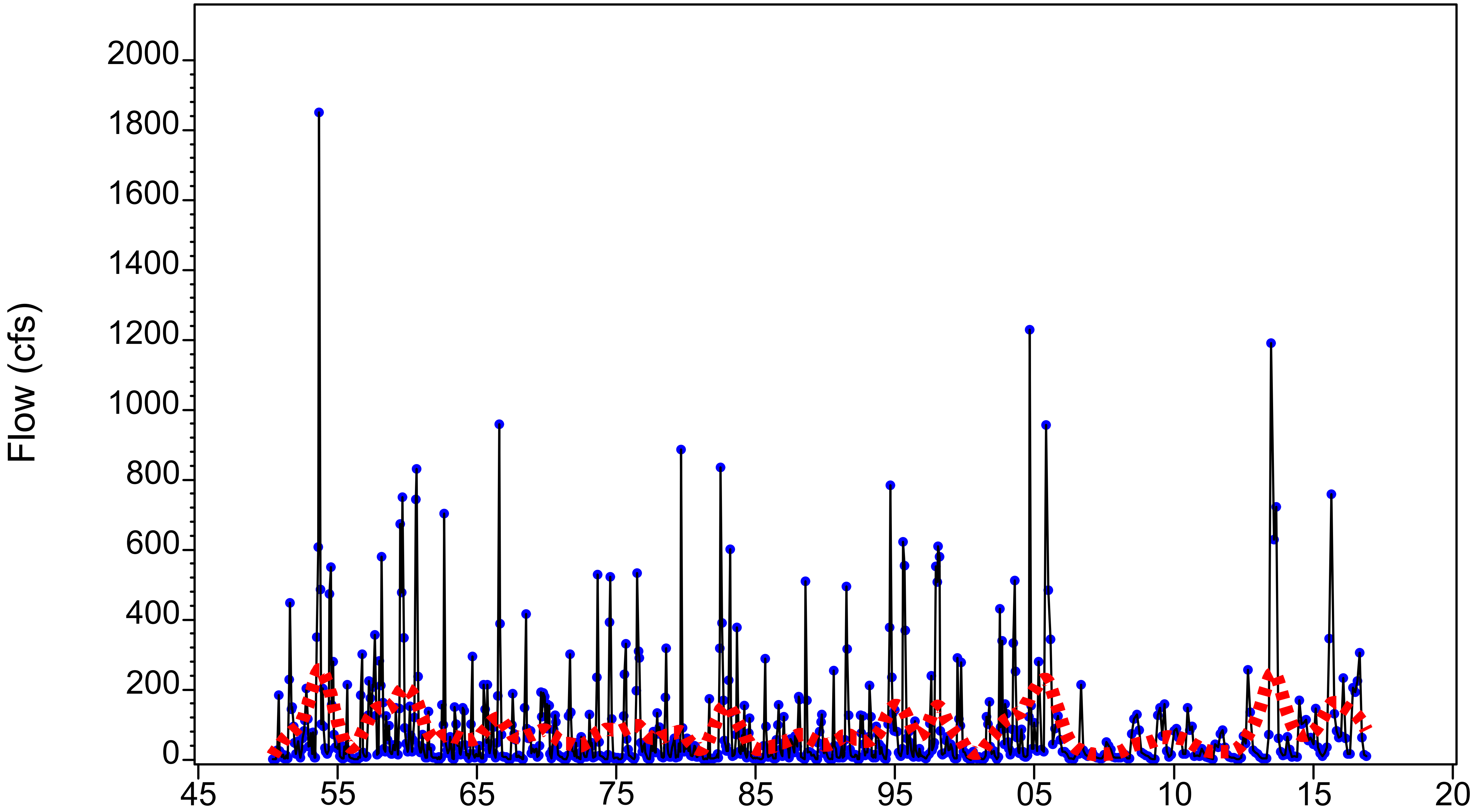


Figure 3.75 Monthly P10 flow at long-term Charlie Creek (2296500) gage (1950-2016)

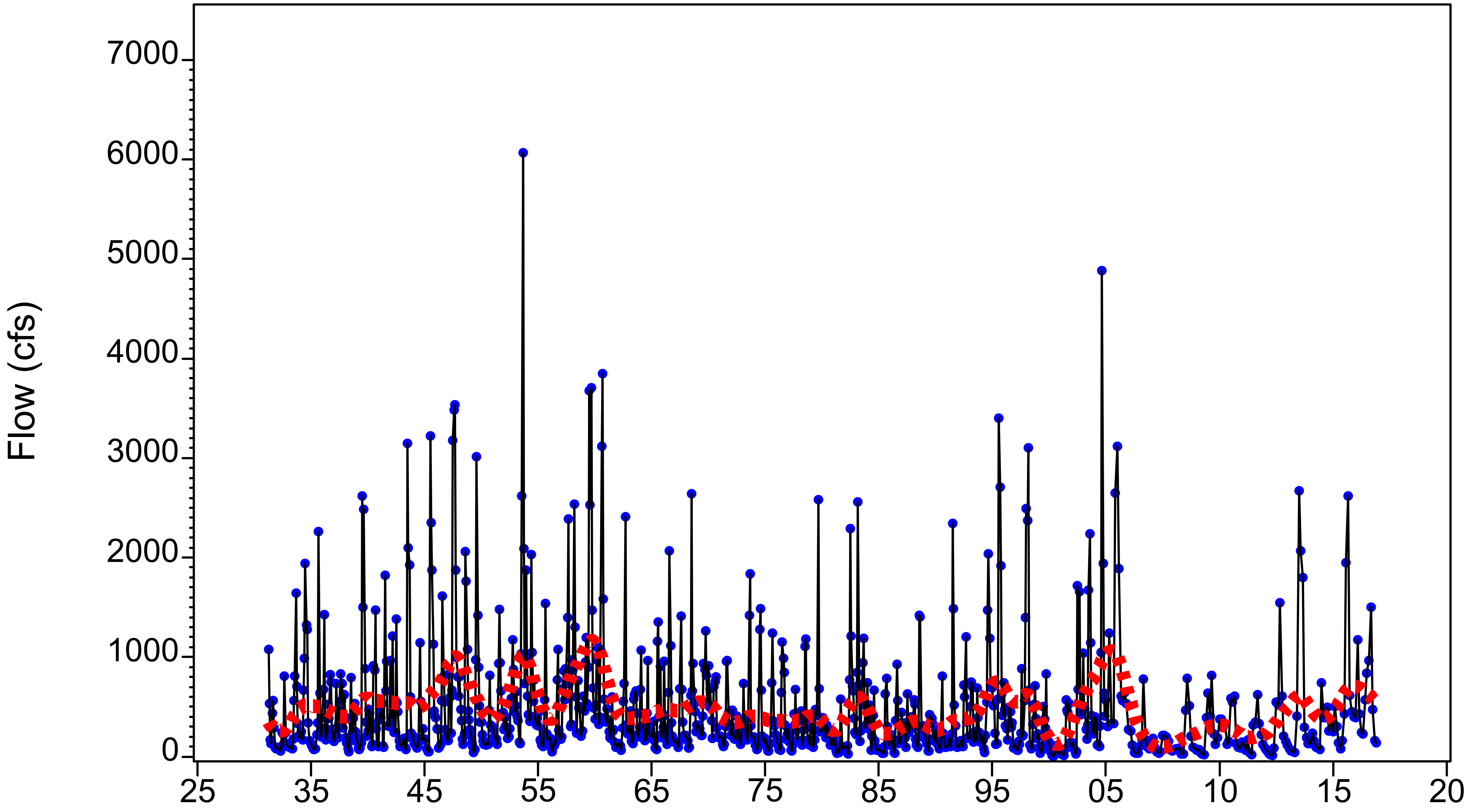


Figure 3.76 Monthly P10 flow at long-term Peace River at Arcadia (2296750) gage (1931-2016)

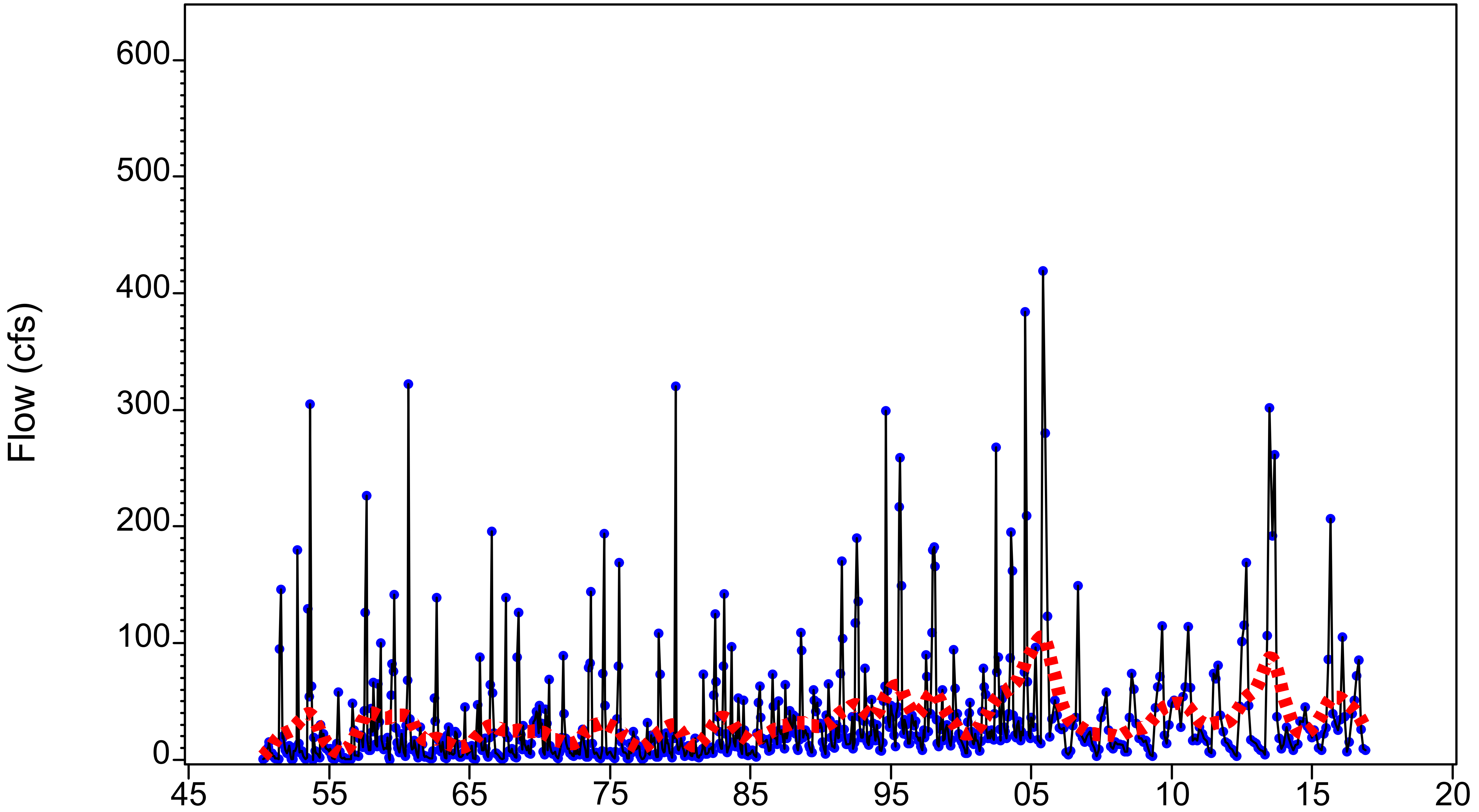


Figure 3.77 Monthly P10 flow at long-term Joshua Creek at Nocatee (2297100) gage (1950-2016)

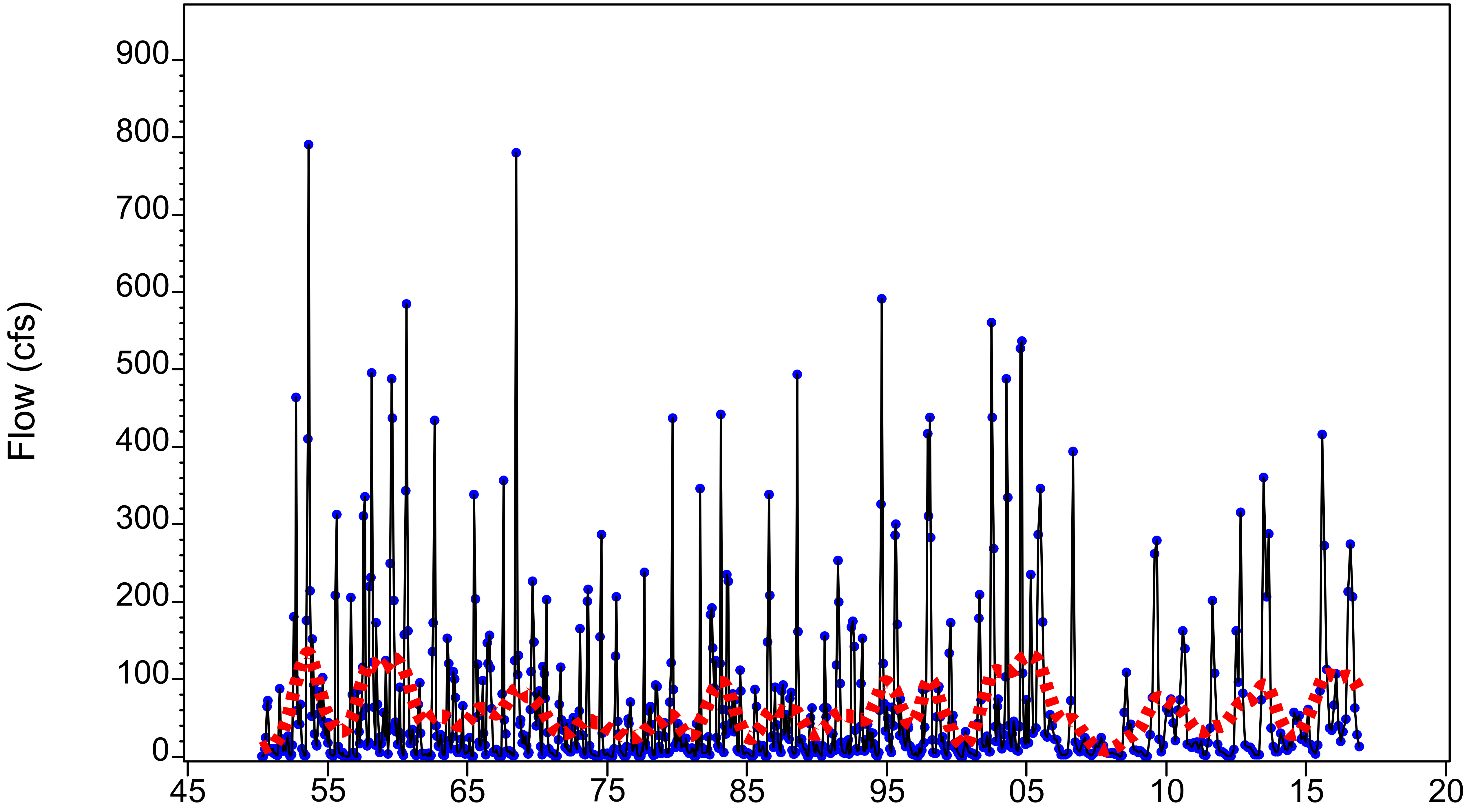


Figure 3.78 Monthly P10 flow at long-term Horse Creek near Arcadia(2297310) gage (1950-2016)

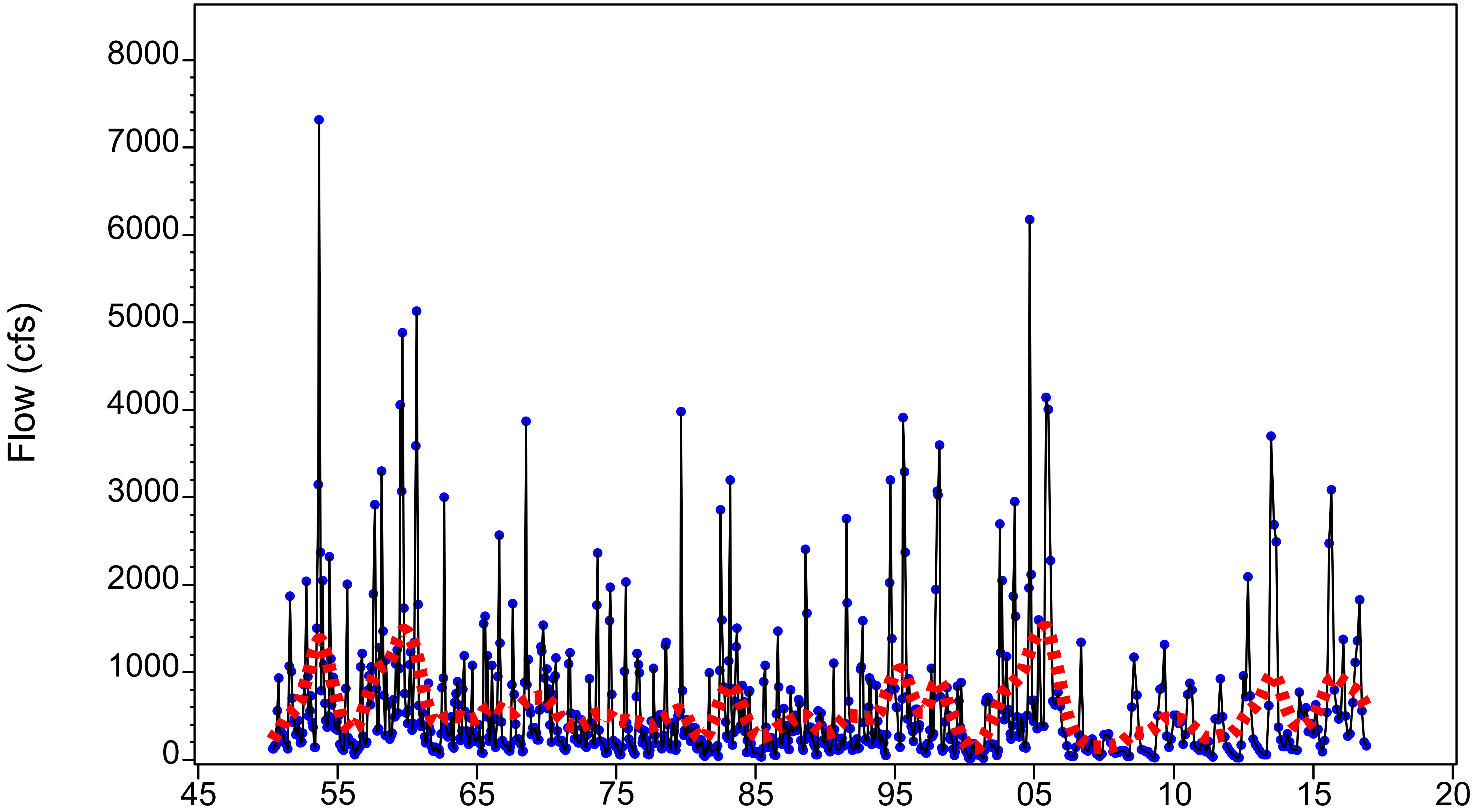


Figure 3.79 Monthly P10 flow at long-term for total gaged flow upstream of the Facility (1950-2016)

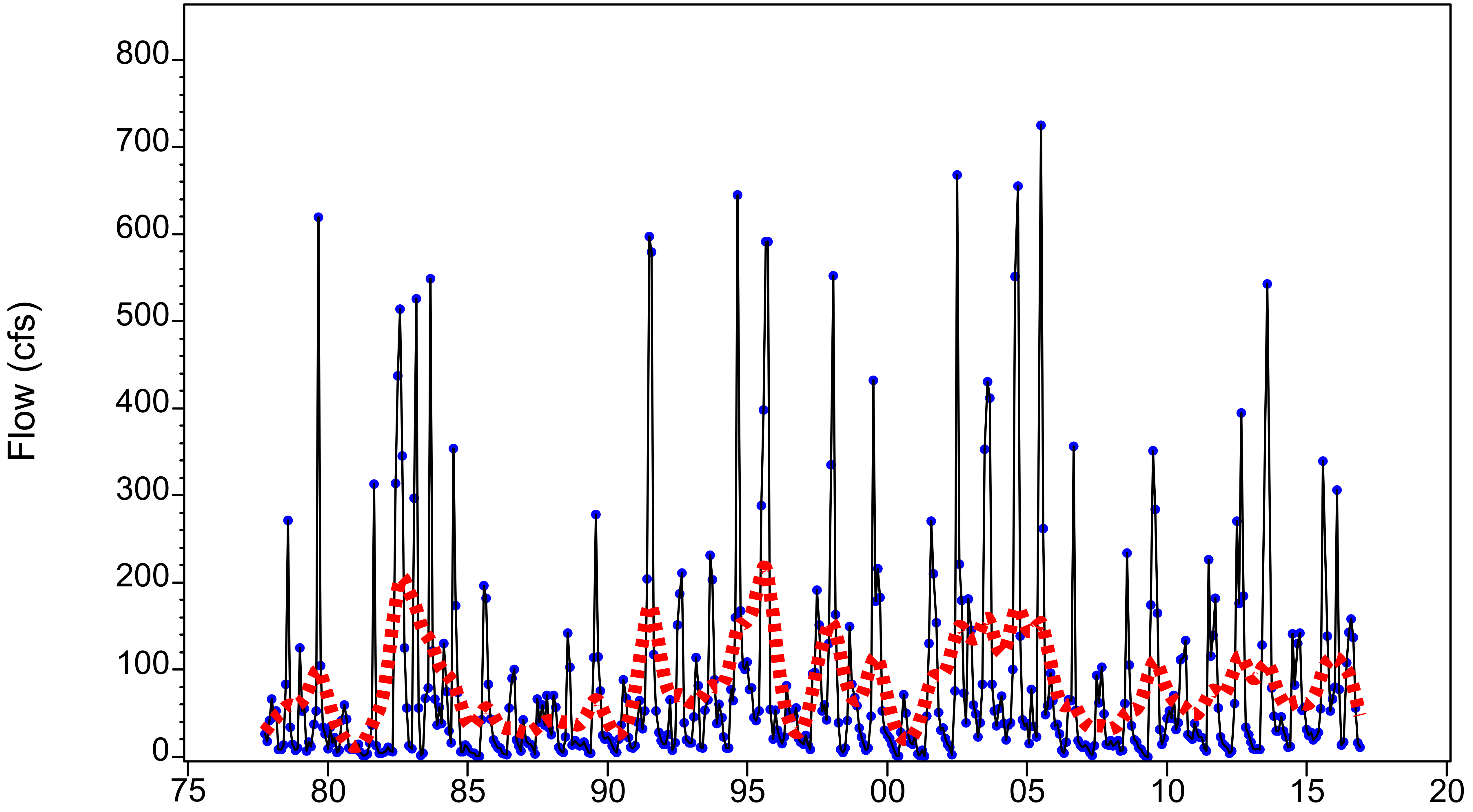


Figure 3.80 Monthly P10 flow at long-term Prairie Creek (2298123) gage (1977-2016)

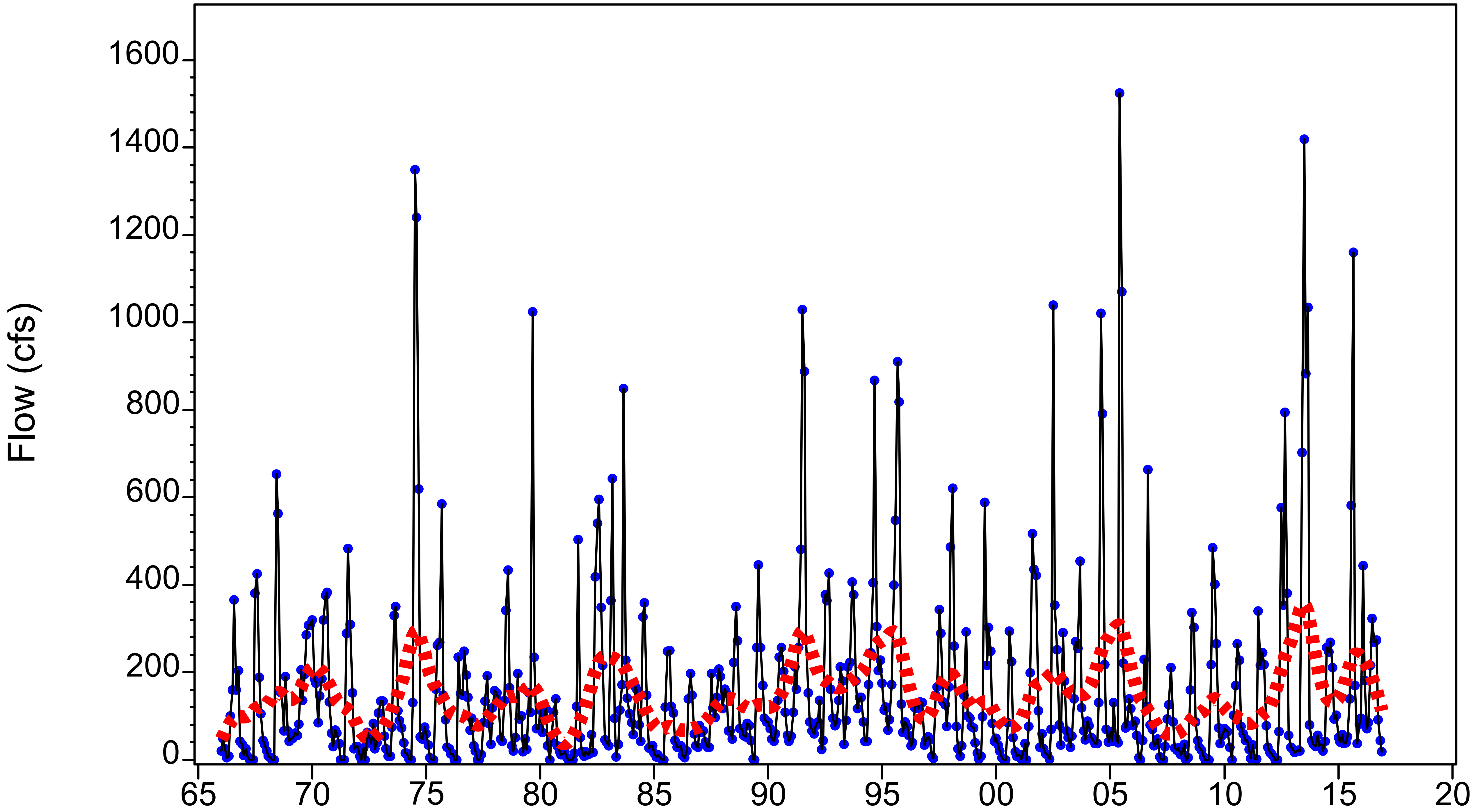


Figure 3.81 Monthly P10 flow at long-term Shell Creek gage (1965-2016)

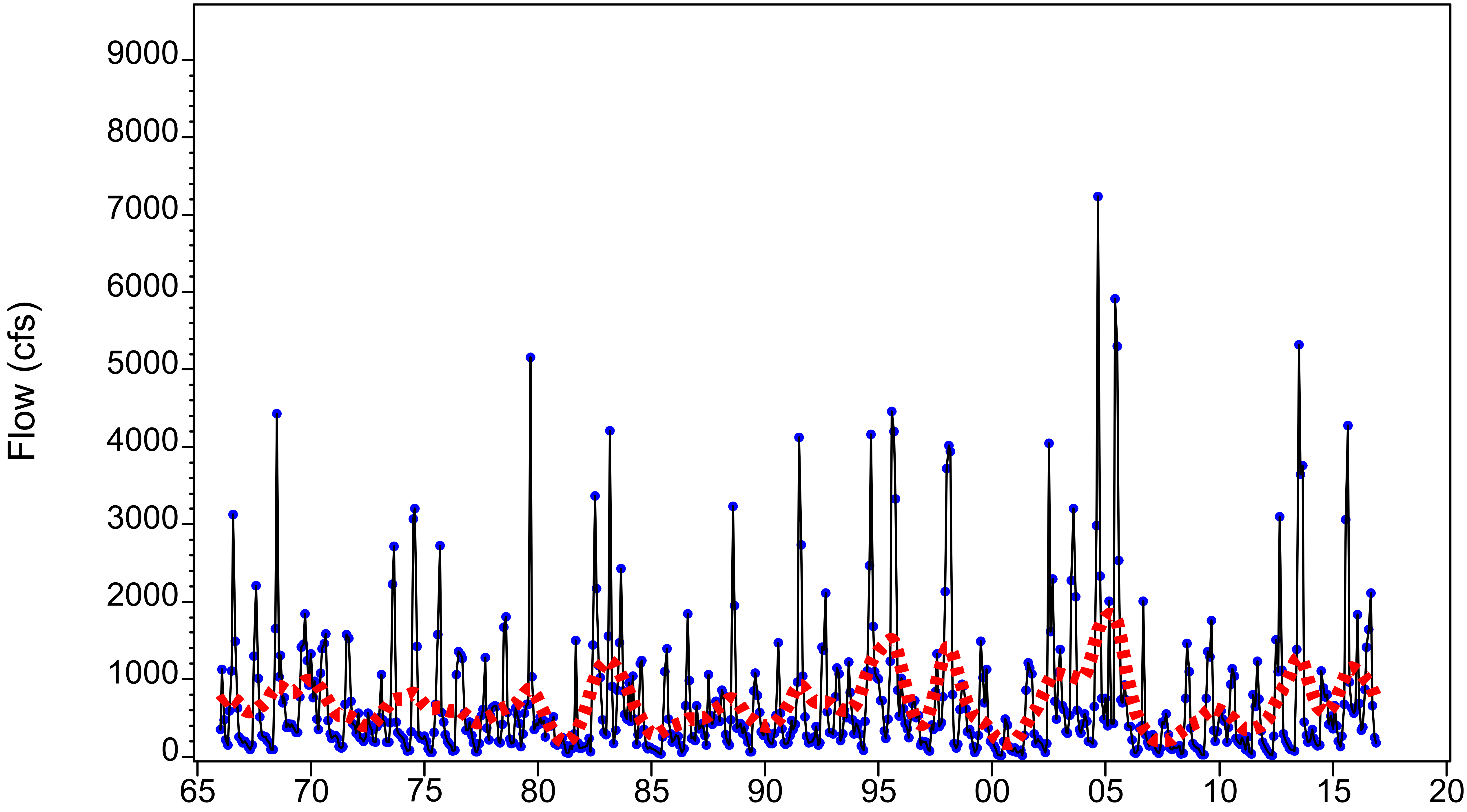


Figure 3.82 Monthly P10 flow of total gaged Peace River flow to the Upper Harbor (1965-2016)

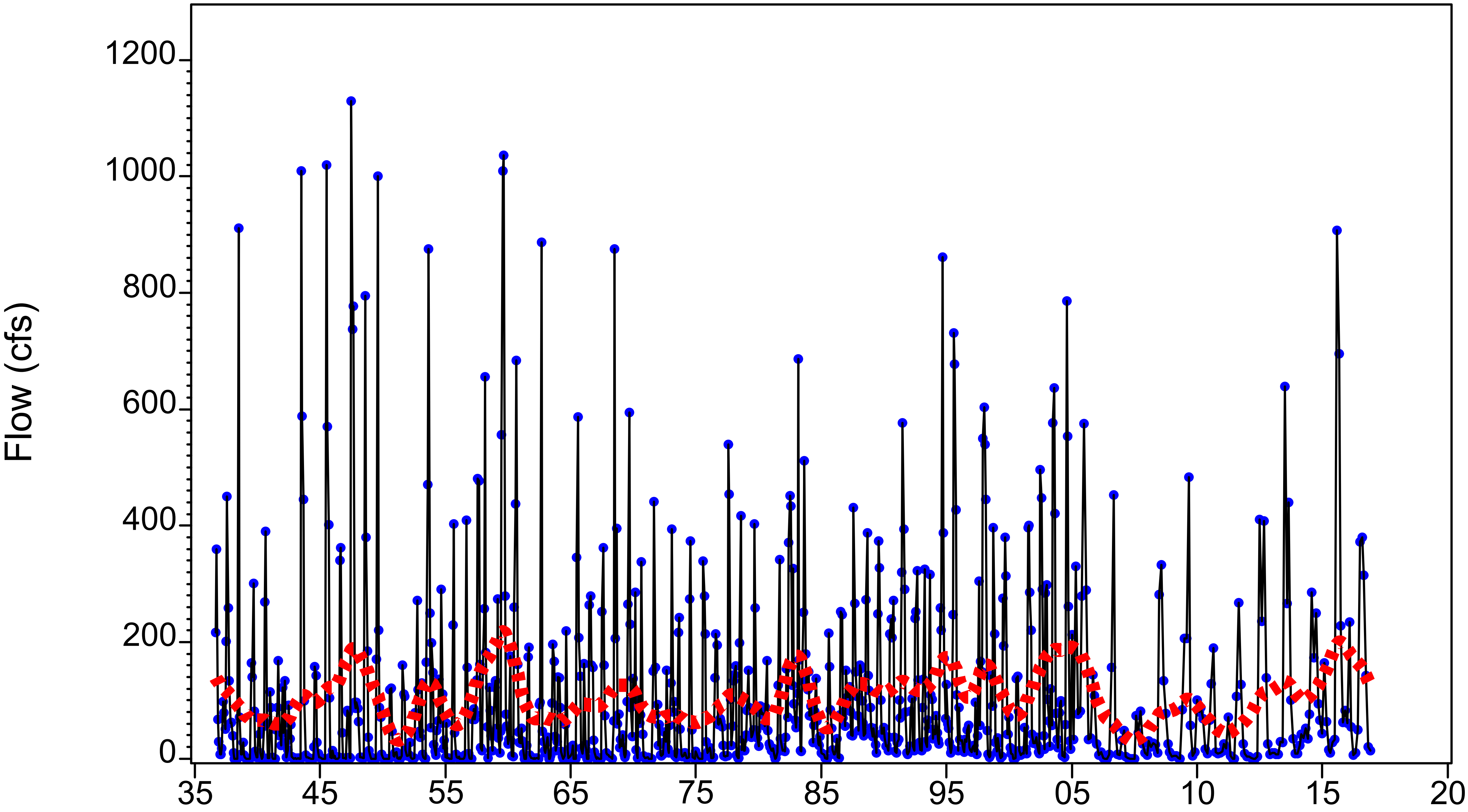


Figure 3.83 Monthly P10 flow at long-term Myakka River near Sarasota (2298830) gage (1936-2016)

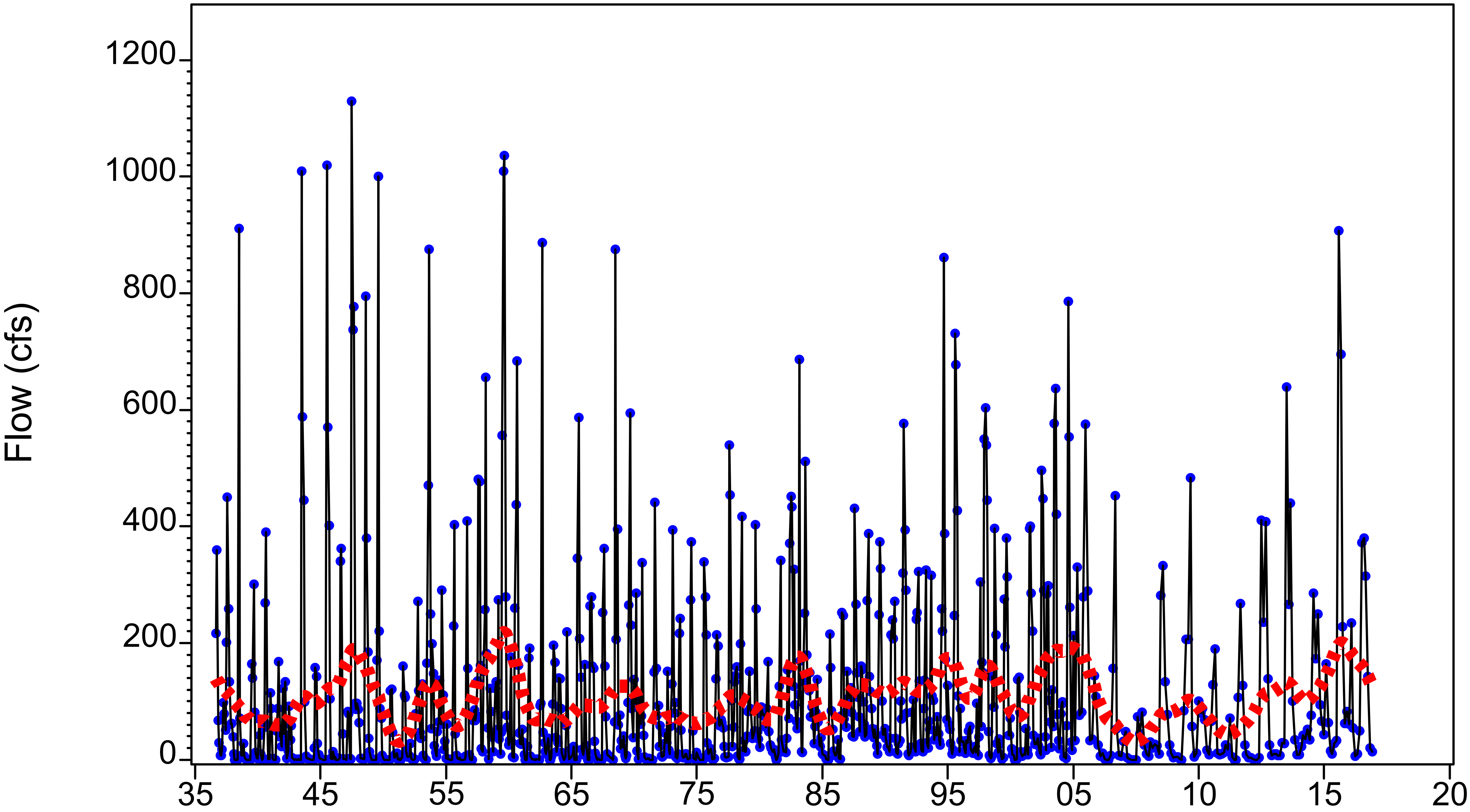


Figure 3.83 Monthly P10 flow at long-term Myakka River near Sarasota (2298830) gage (1936-2016)

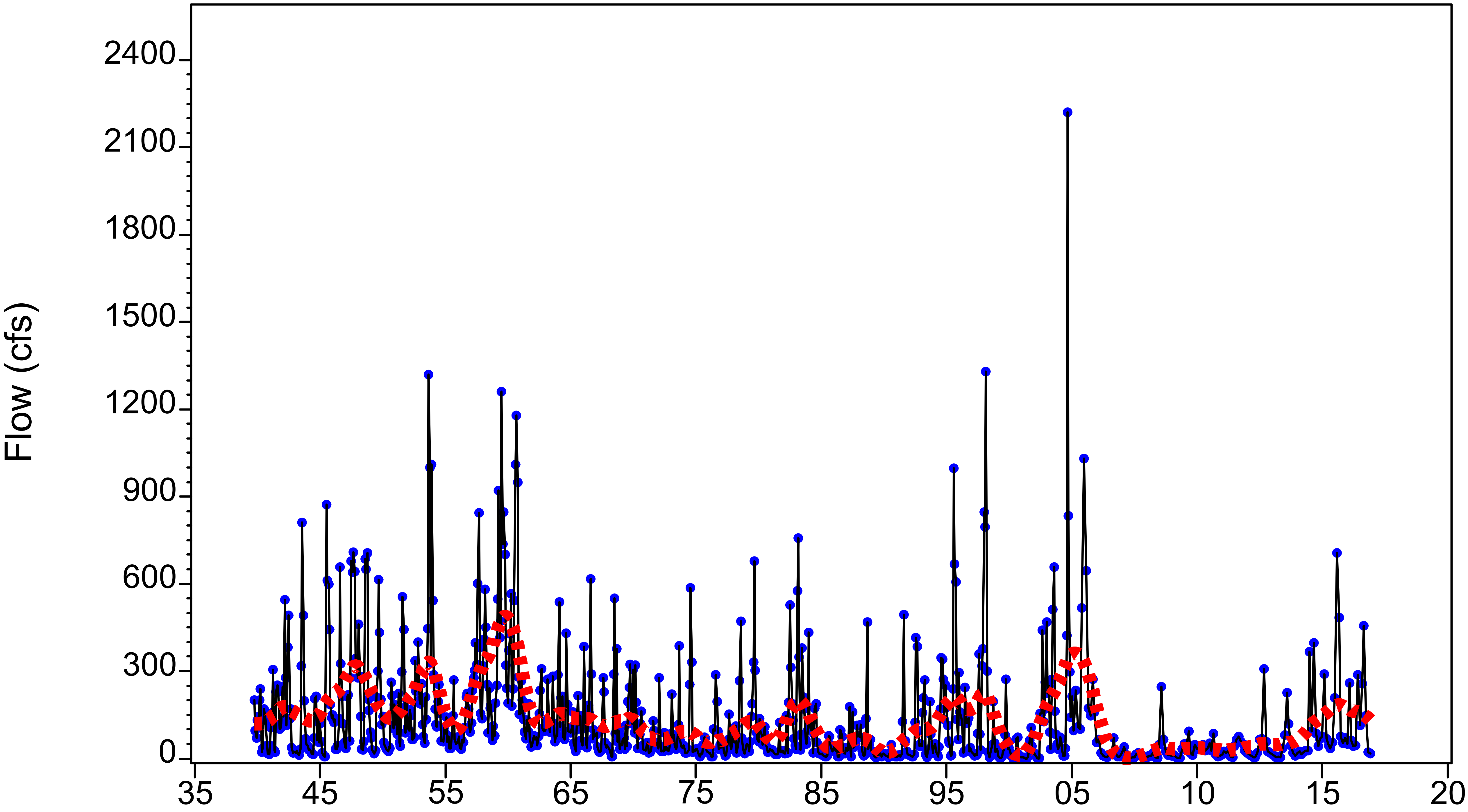


Figure 3.84 Monthly P25 flow at long-term Peace River at Bartow (2294650) gage (1939-2016)

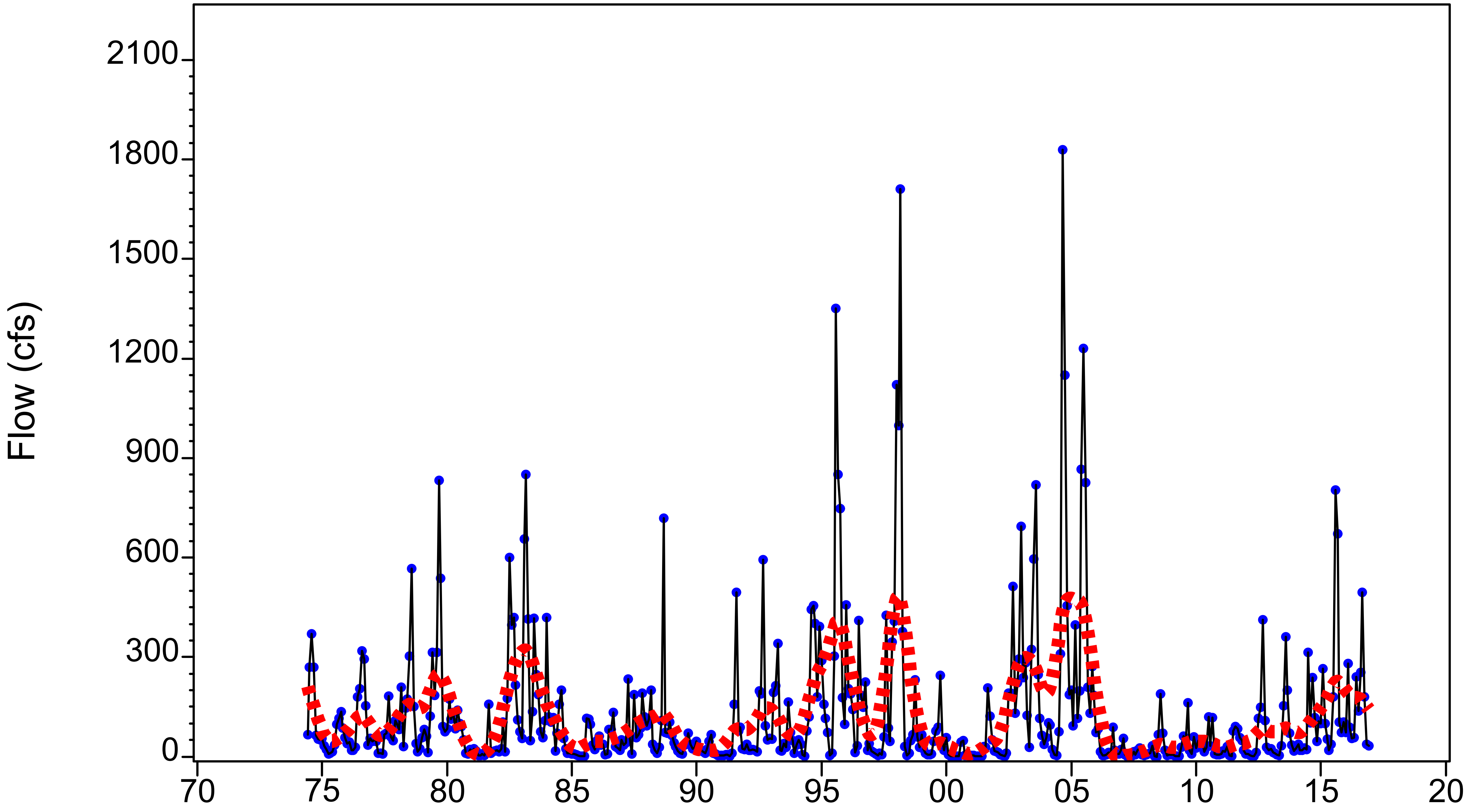


Figure 3.85 Monthly P25 flow at long-term Peace River at Ft. Meade (2294898) gage (1974-2016)

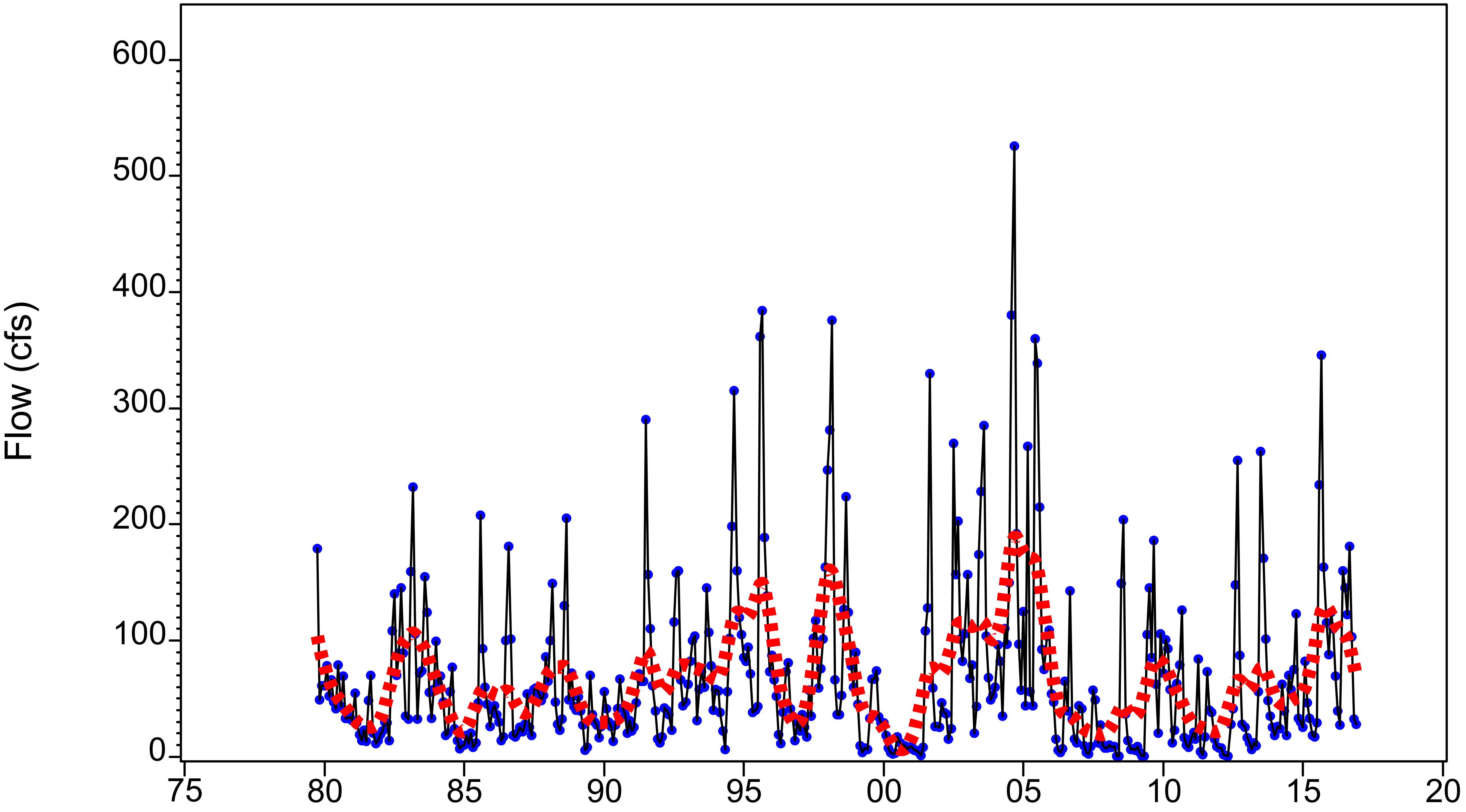


Figure 3.86 Monthly P25 flow at long-term Payne Creek (2295420) gage (1979-2016)

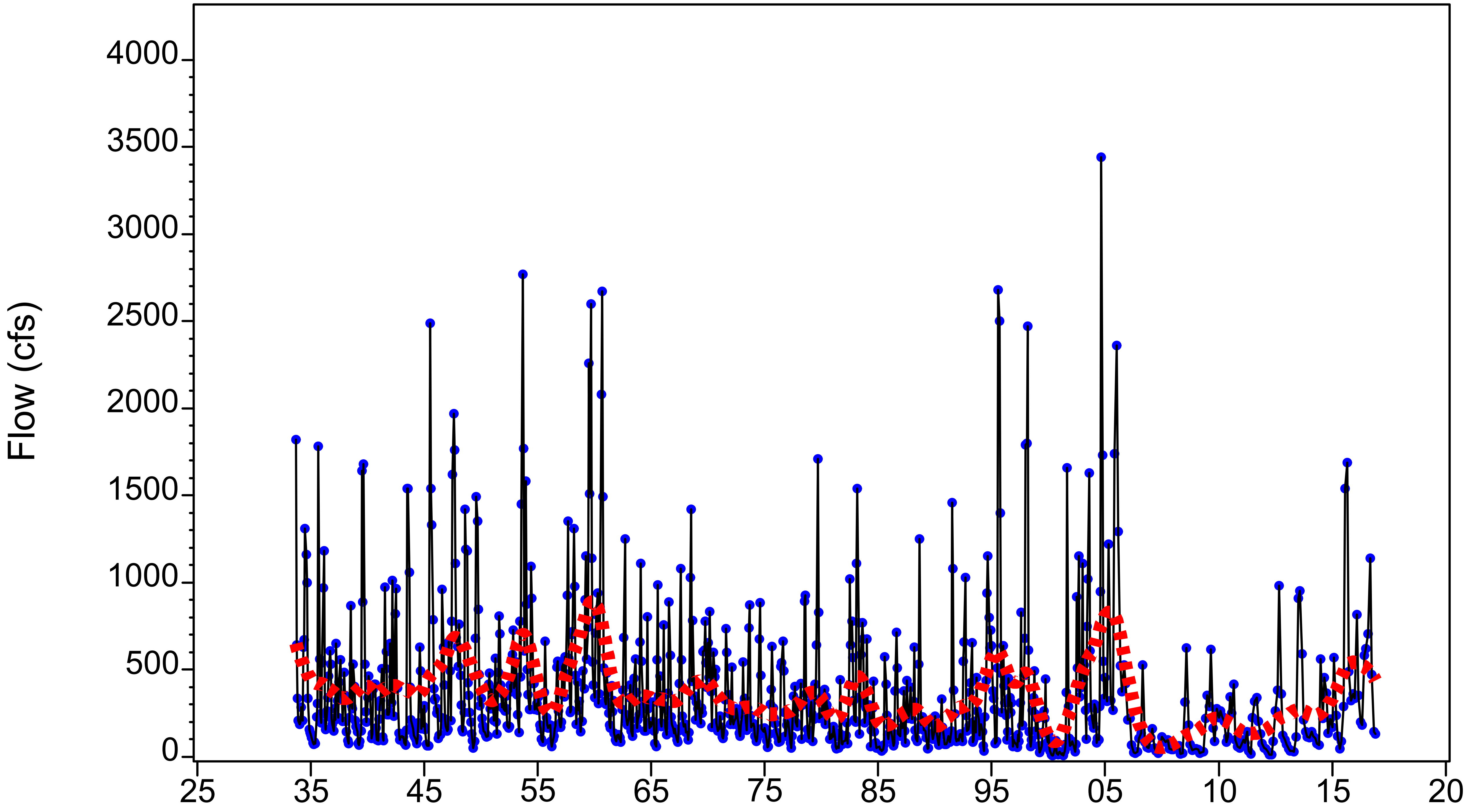


Figure 3.87 Monthly P25 flow at long-term Peace River at Zolfo (2295637) gage (1933-2016)

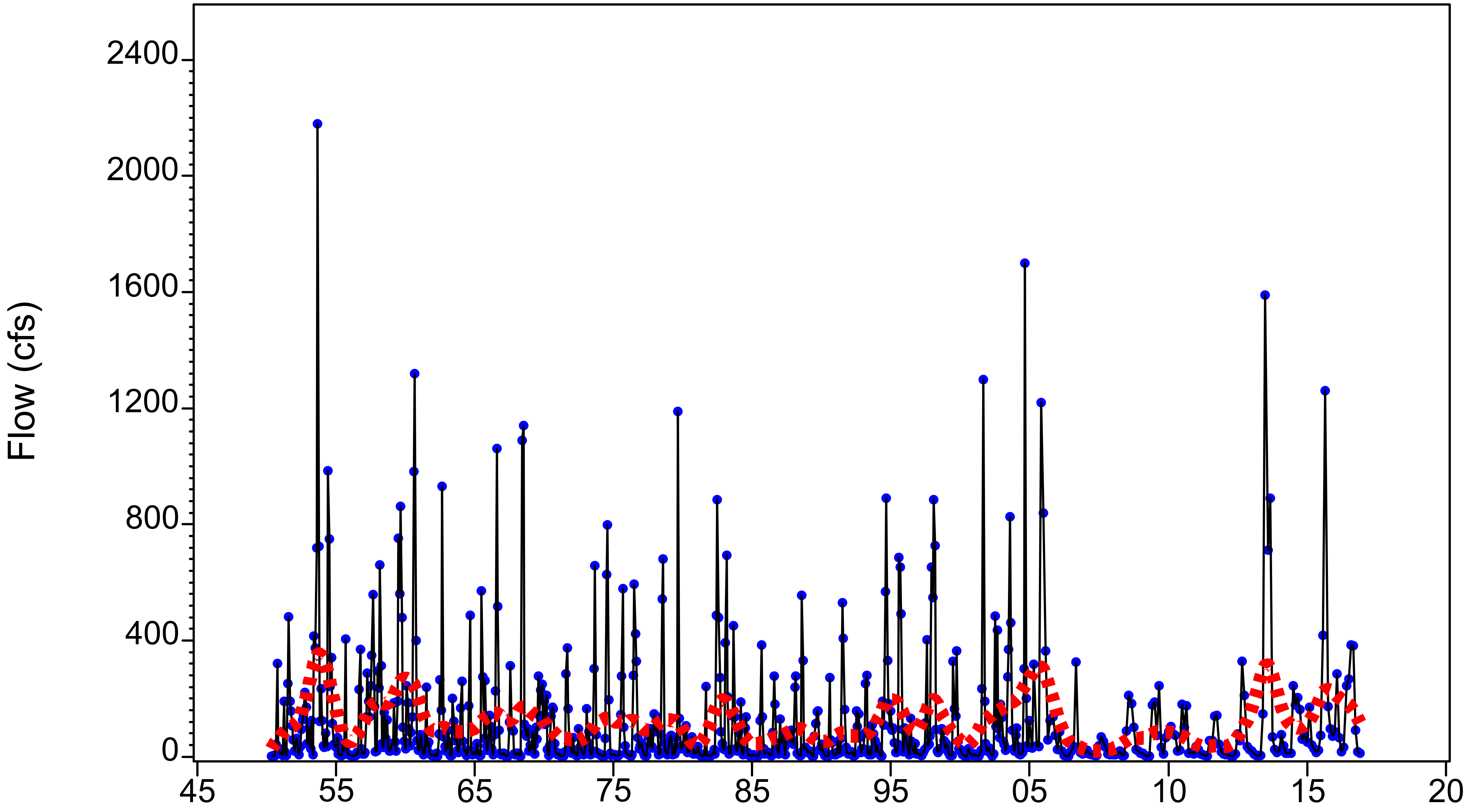


Figure 3.88 Monthly P25 flow at long-term Charlie Creek (2296500) gage (1950-2016)

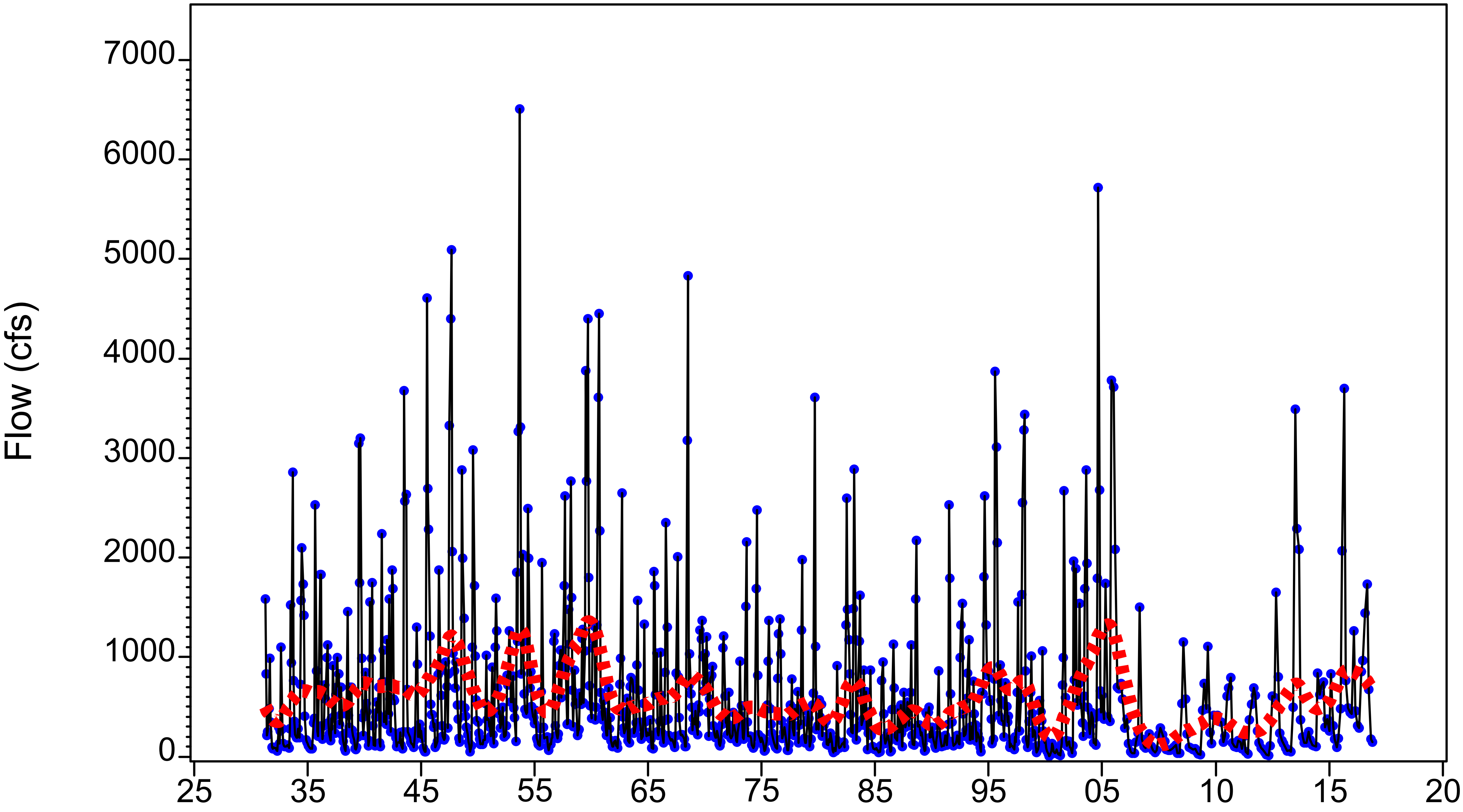


Figure 3.89 Monthly P25 flow at long-term Peace River at Arcadia (2296750) gage (1931-2016)

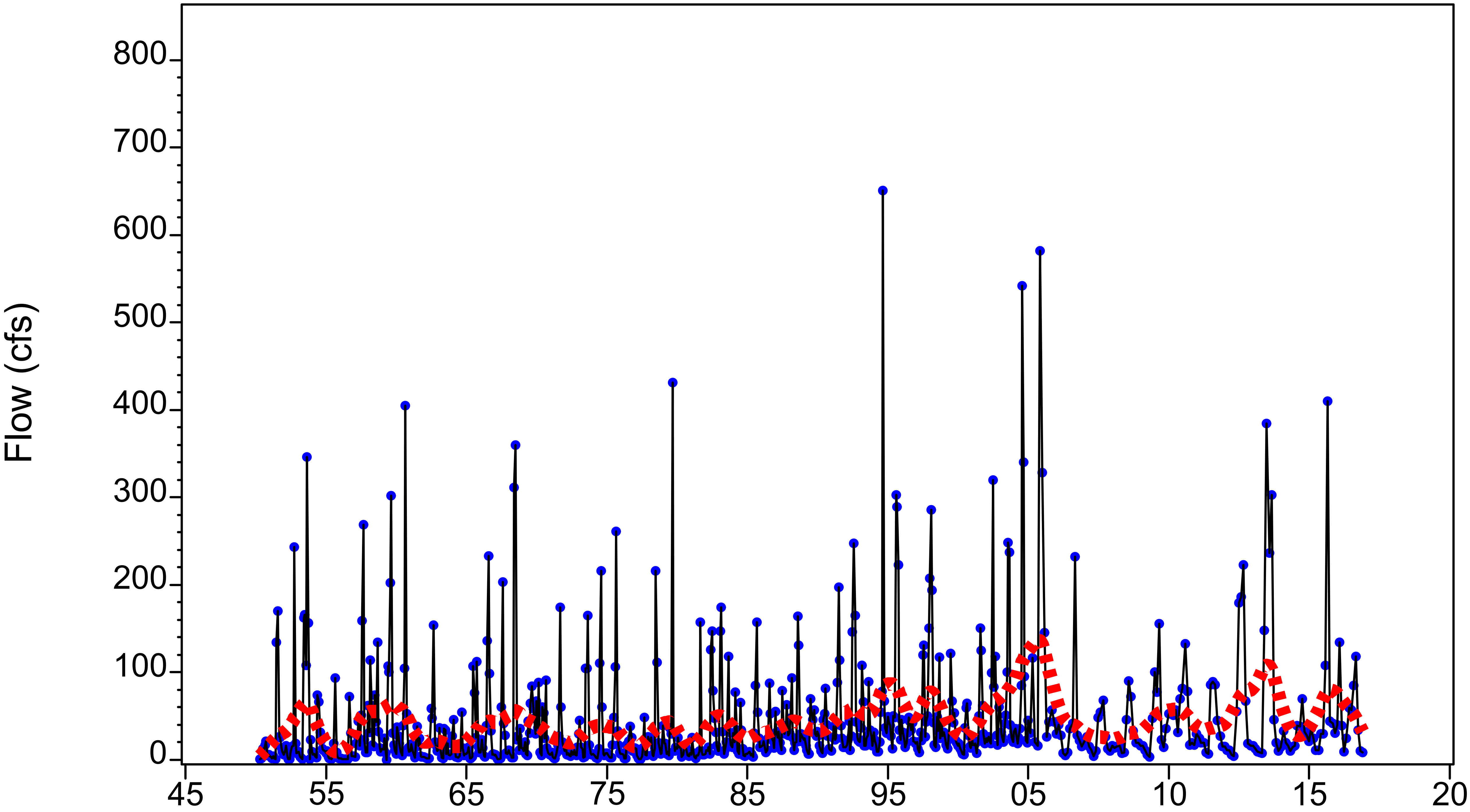


Figure 3.90 Monthly P25 flow at long-term Joshua Creek at Nocatee (2297100) gage (1950-2016)

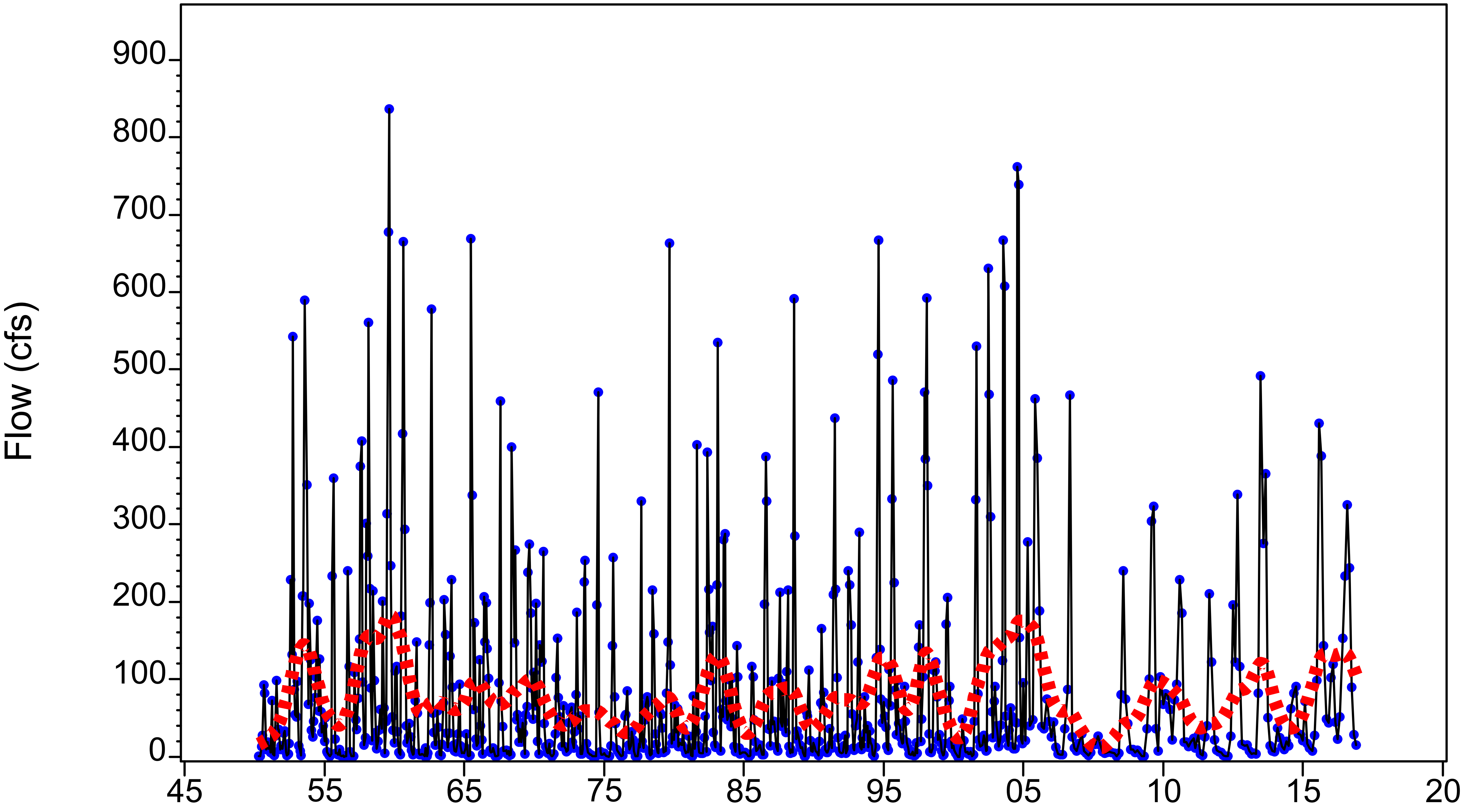


Figure 3.91 Monthly P25 flow at long-term Horse Creek near Arcadia(2297310) gage (1950-2016)

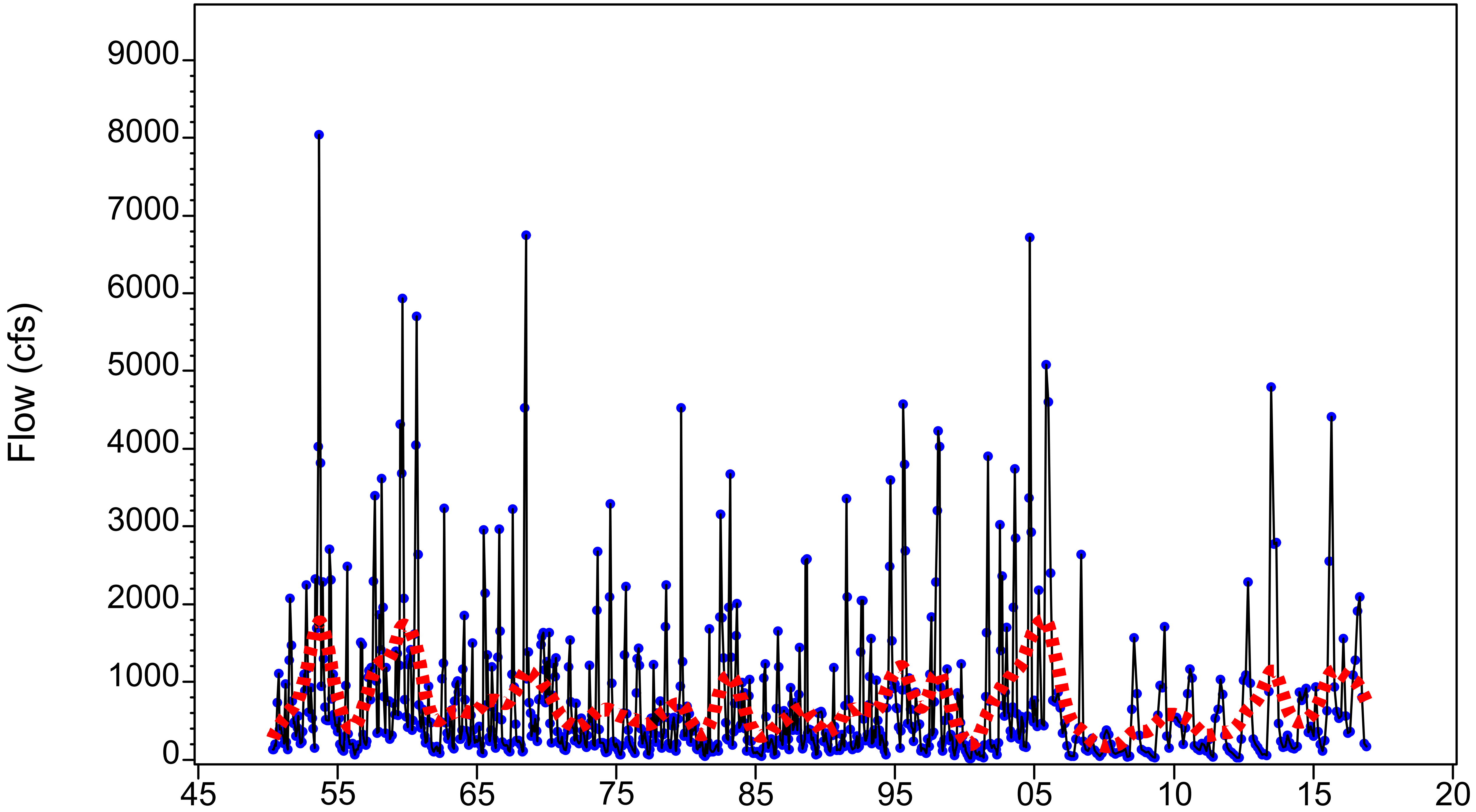


Figure 3.92 Monthly P25 flow at long-term for total gaged flow upstream of the Facility (1950-2016)

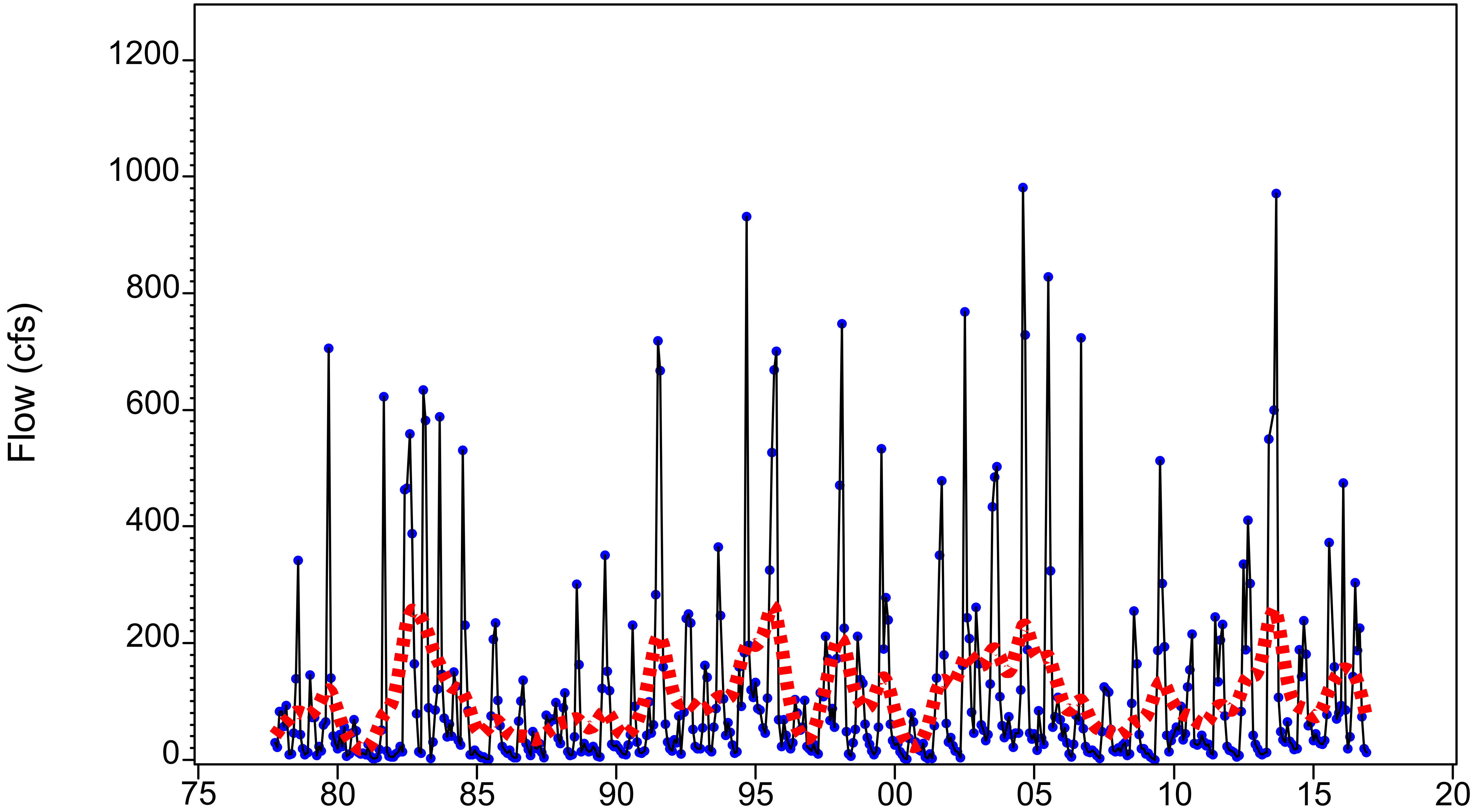


Figure 3.93 Monthly P25 flow at long-term Prairie Creek (2298123) gage (1977-2016)

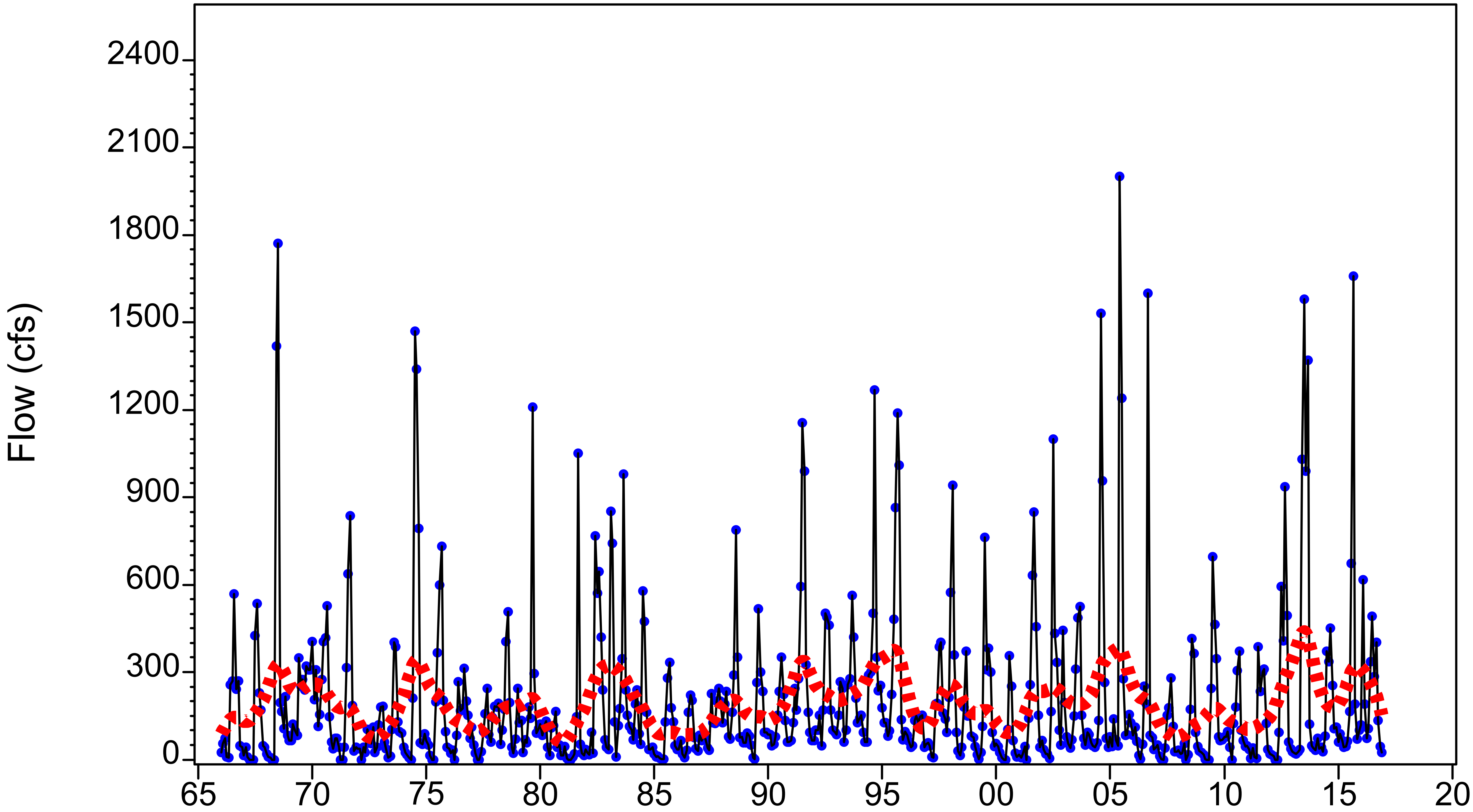


Figure 3.94 Monthly P25 flow at long-term Shell Creek gage (1965-2016)

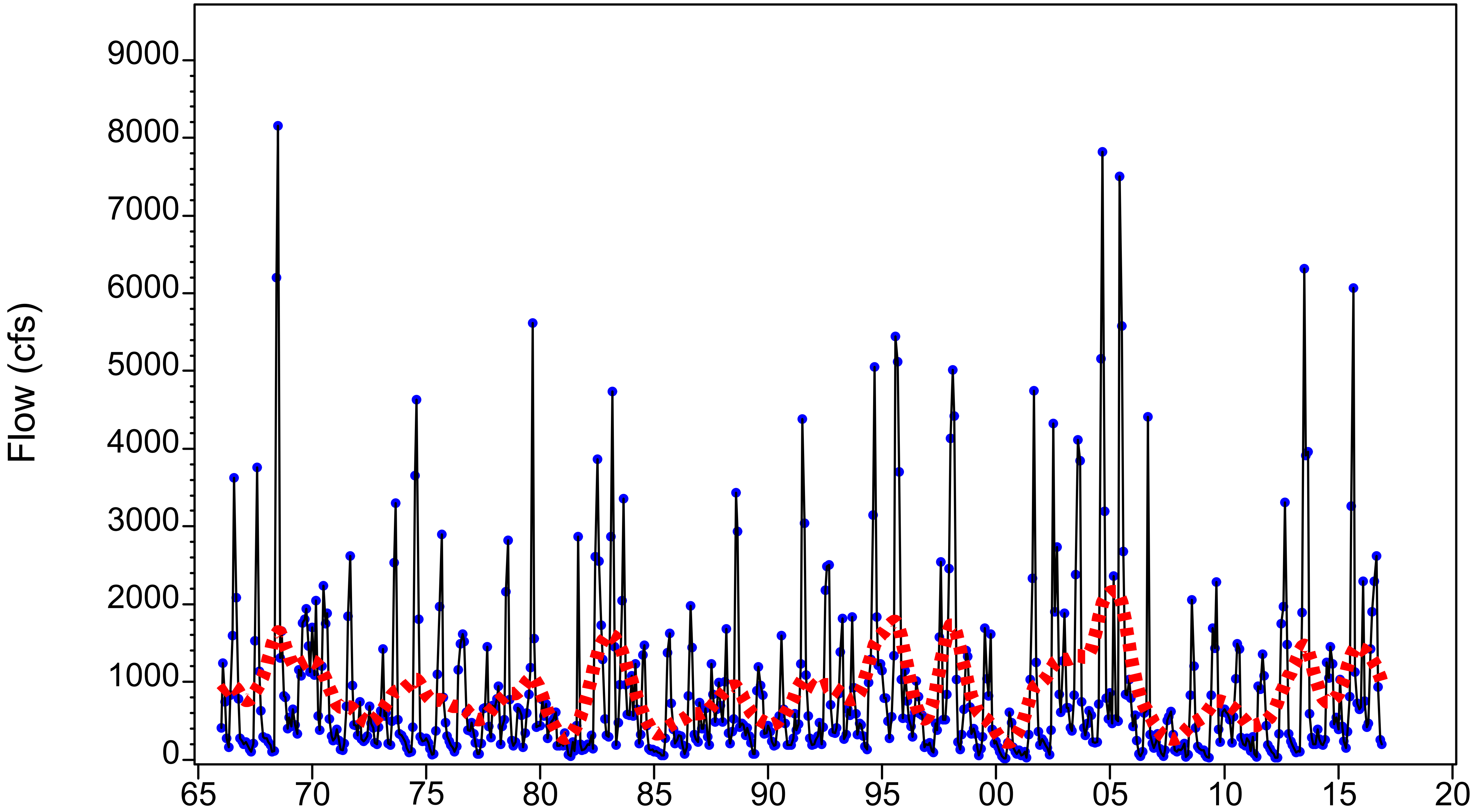


Figure 3.95 Monthly P25 flow of total gaged Peace River flow to the Upper Harbor (1965-2016)

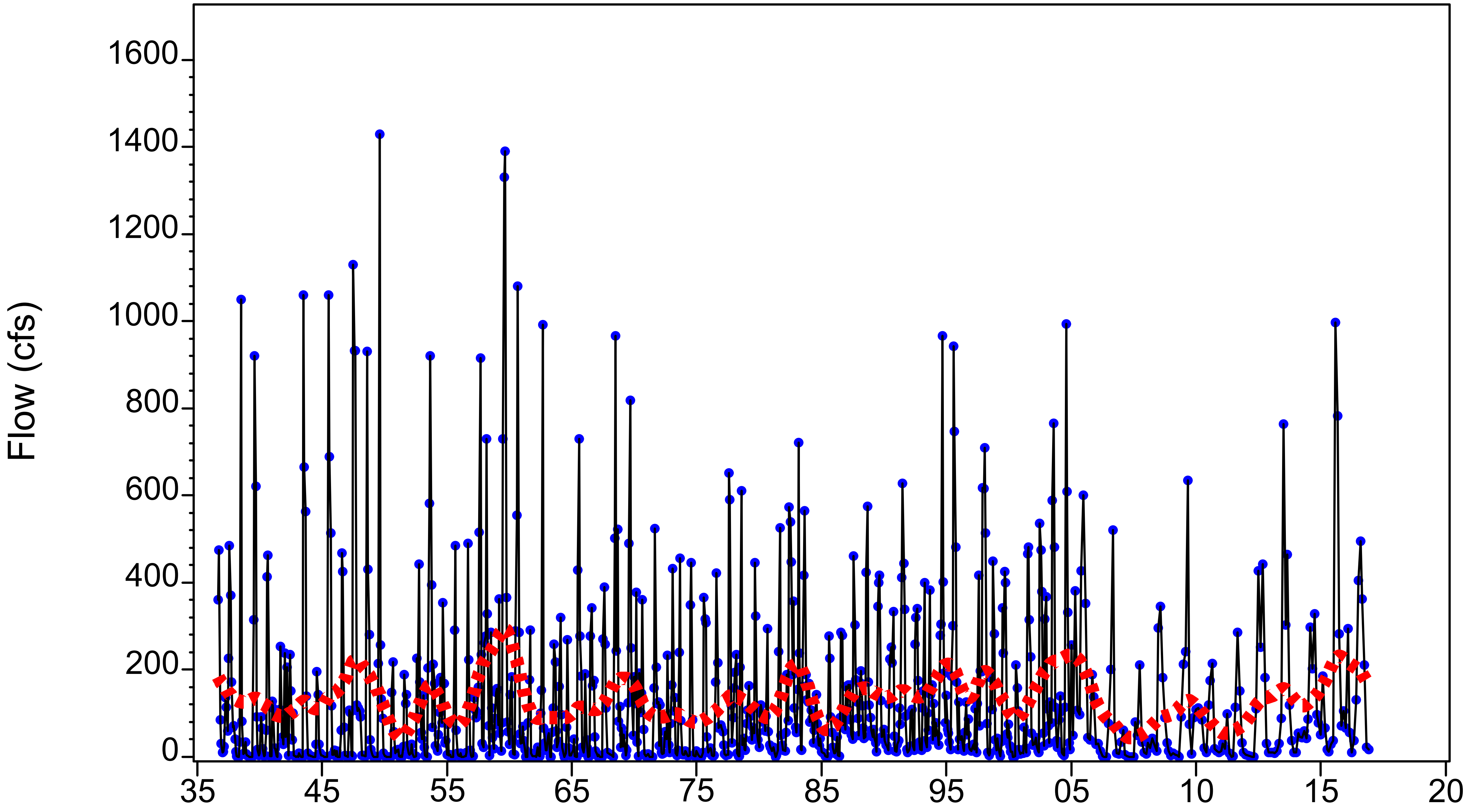


Figure 3.96 Monthly P25 flow at long-term Myakka River near Sarasota (2298830) gage (1936-2016)

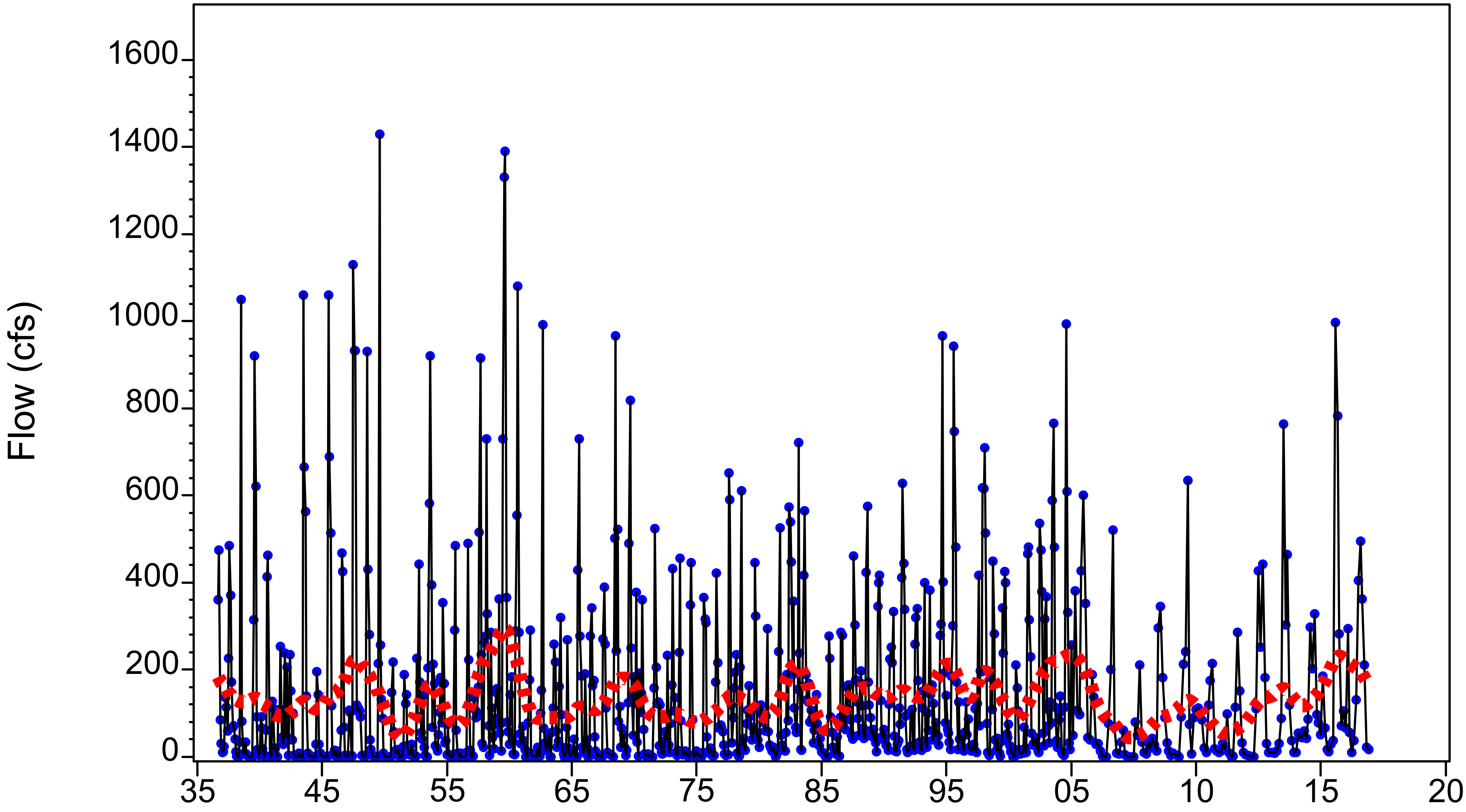


Figure 3.96 Monthly P25 flow at long-term Myakka River near Sarasota (2298830) gage (1936-2016)

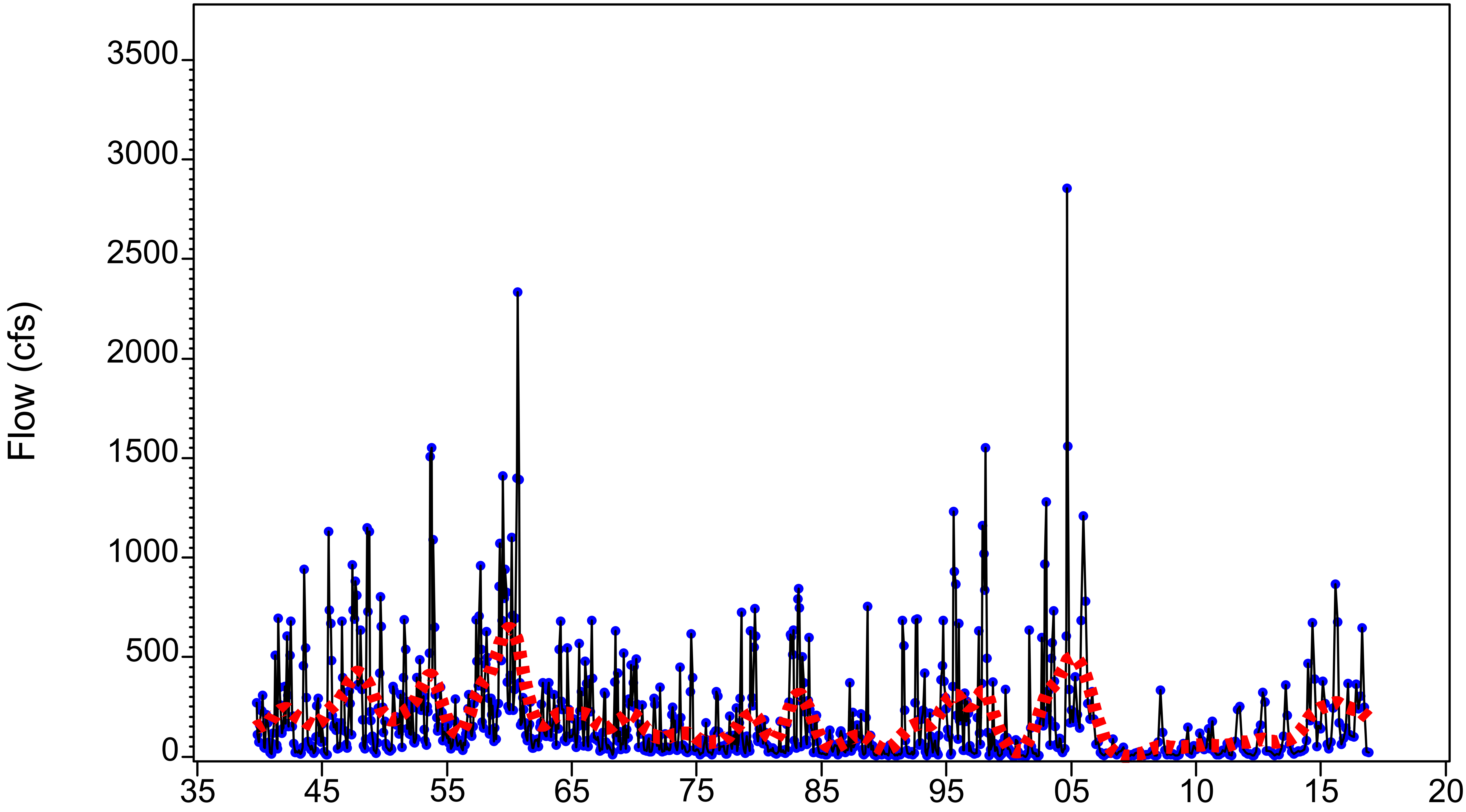


Figure 3.97 Monthly P50 (median) flow at long-term Peace River at Bartow (2294650) gage (1939-2016)

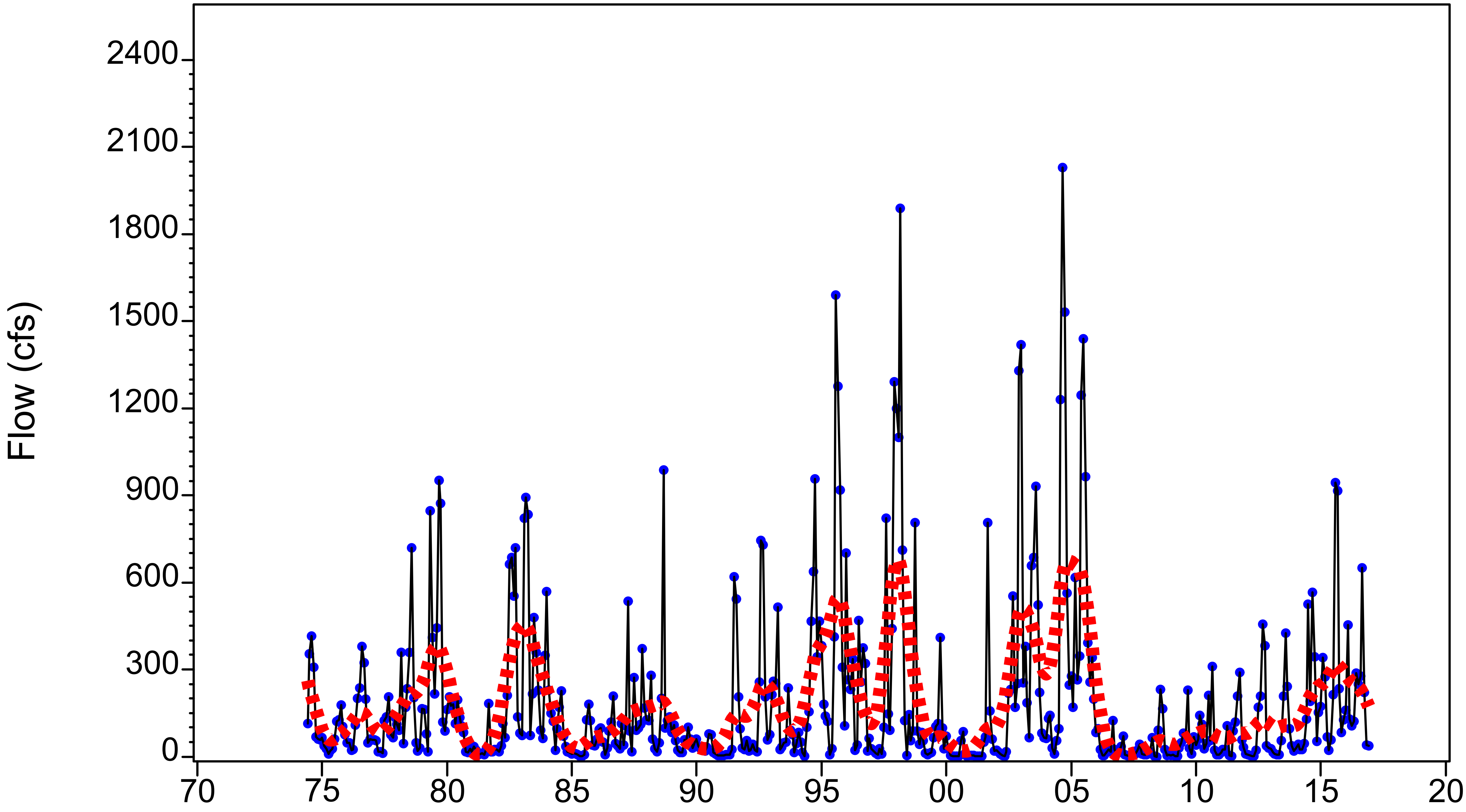


Figure 3.98 Monthly P50 (median) flow at long-term Peace River at Ft. Meade (2294898) gage (1974-2016)

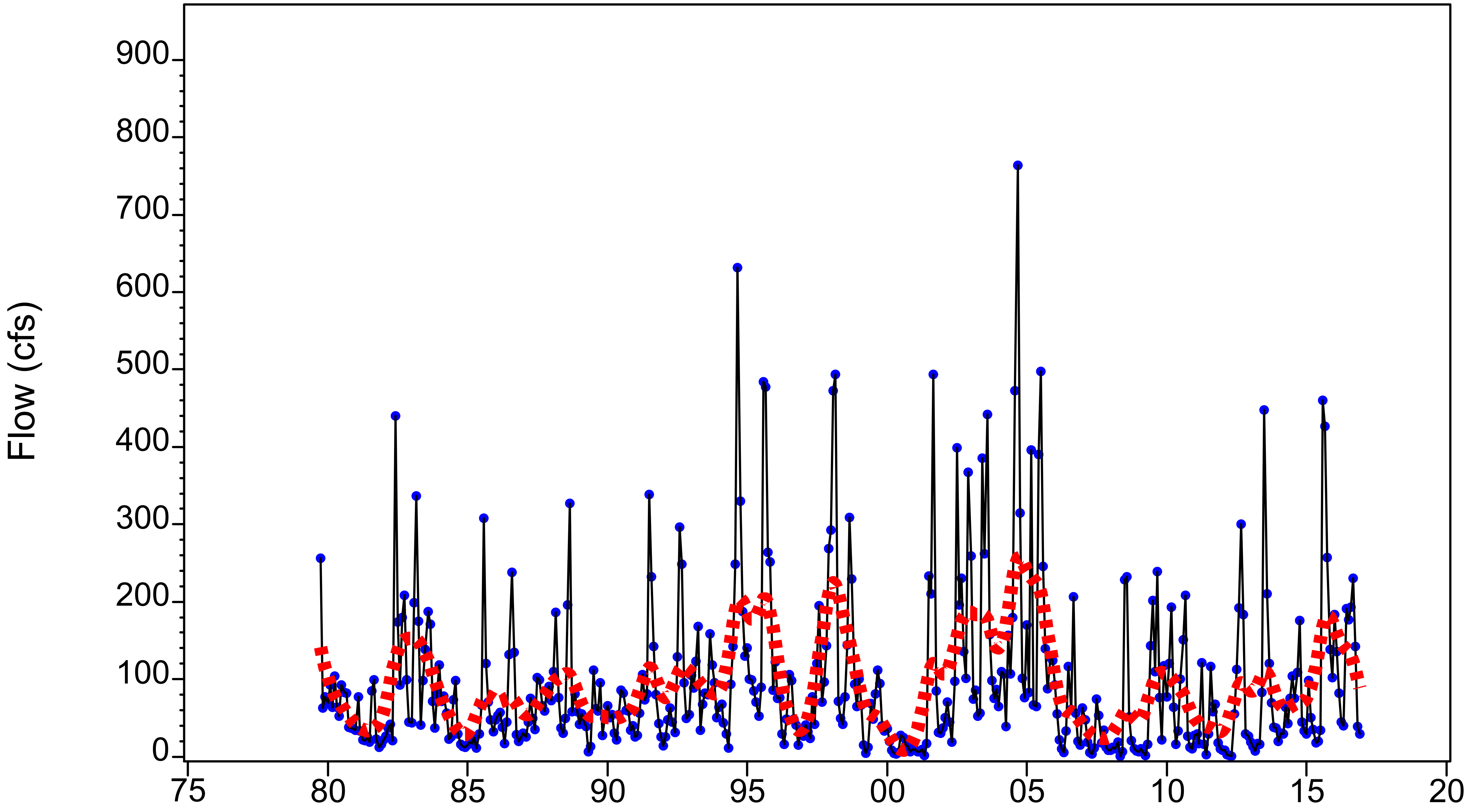


Figure 3.99 Monthly P50 (median) flow at long-term Payne Creek (2295420) gage (1979-2016)

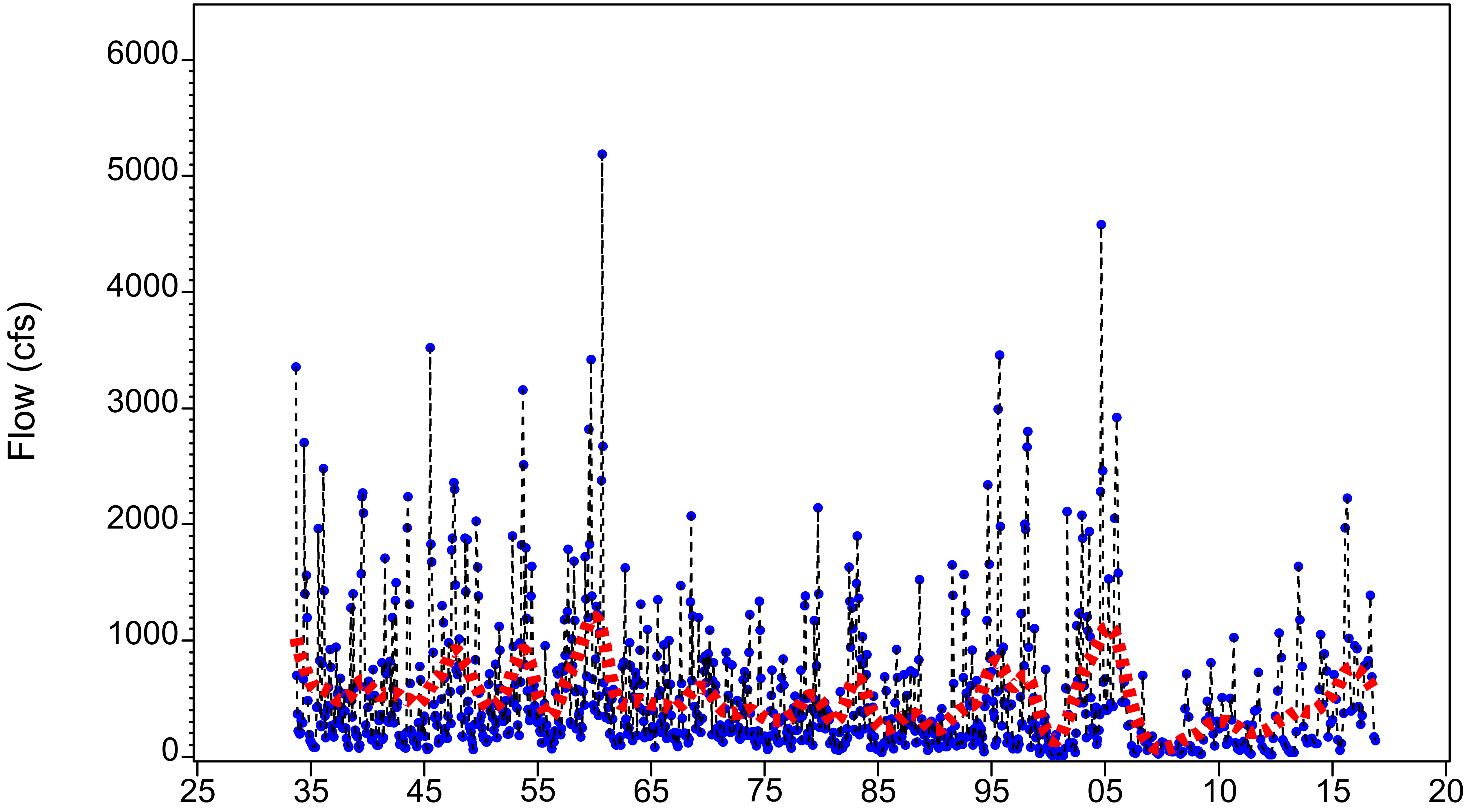


Figure 3.100 Monthly P50 (median) flow at long-term Peace River at Zolfo (2295637) gage (1933-2016)

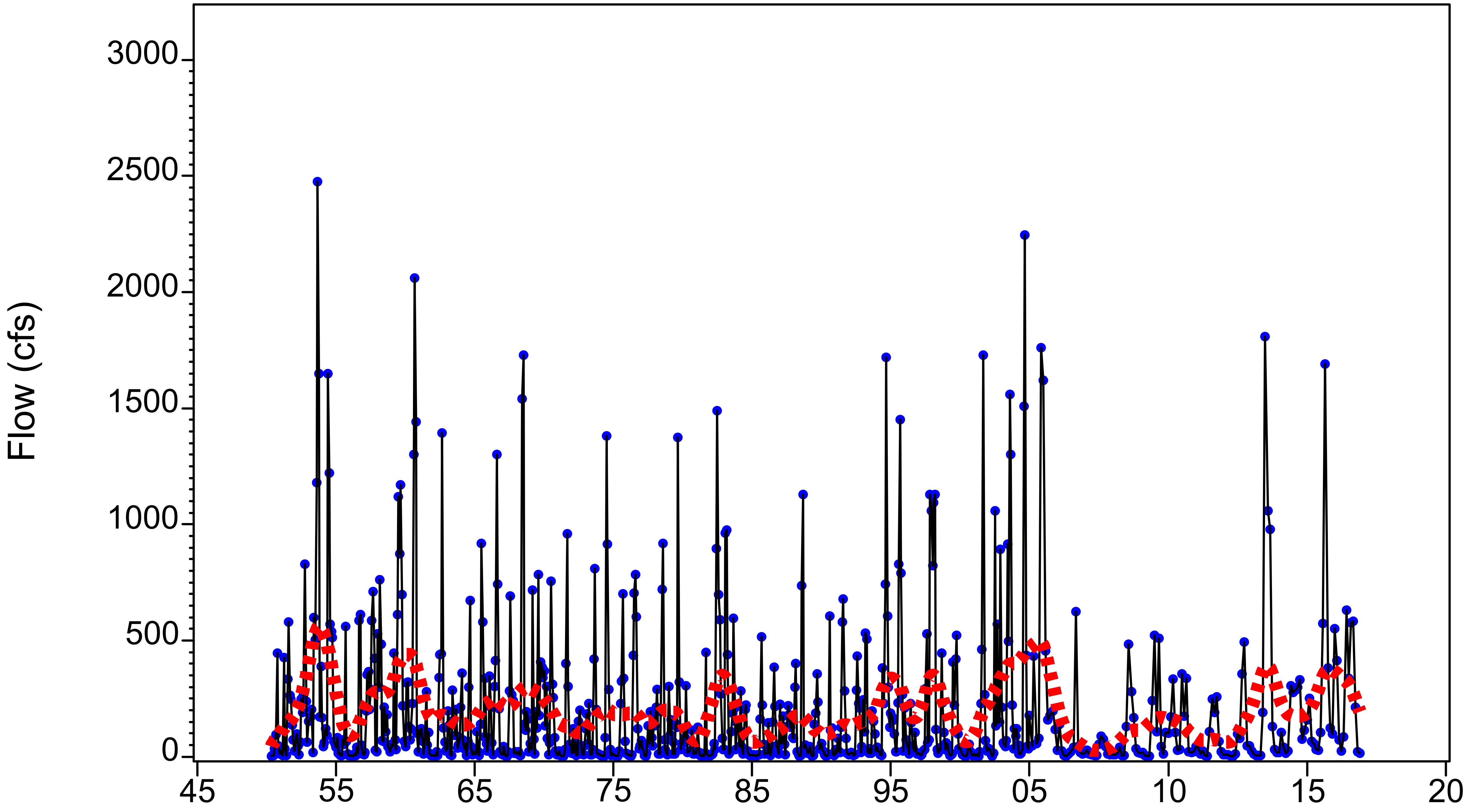


Figure 3.101 Monthly P50 (median) flow at long-term Charlie Creek (2296500) gage (1950-2016)

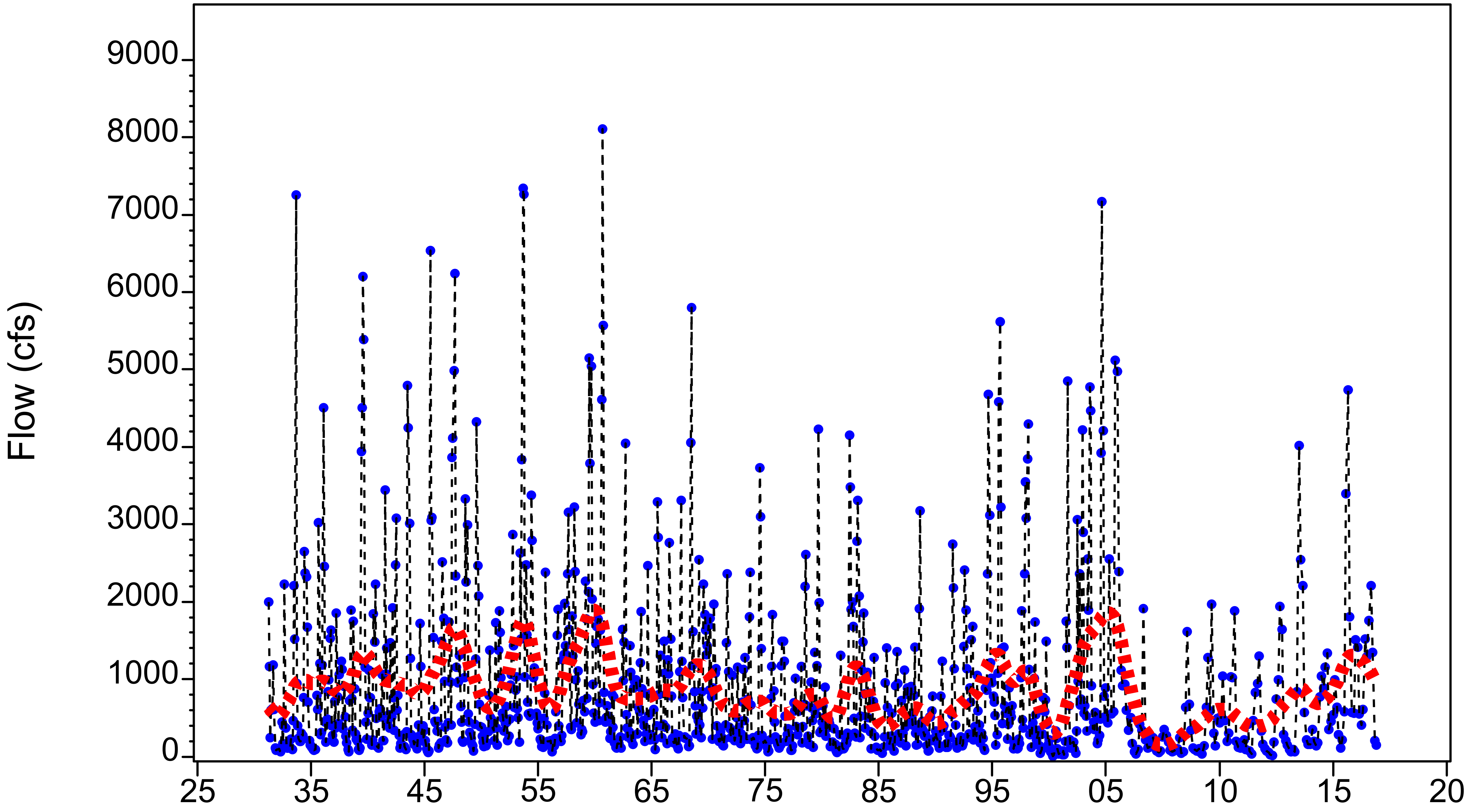


Figure 3.102 Monthly P50 (median) flow at long-term Peace River at Arcadia (2296750) gage (1931-2016)

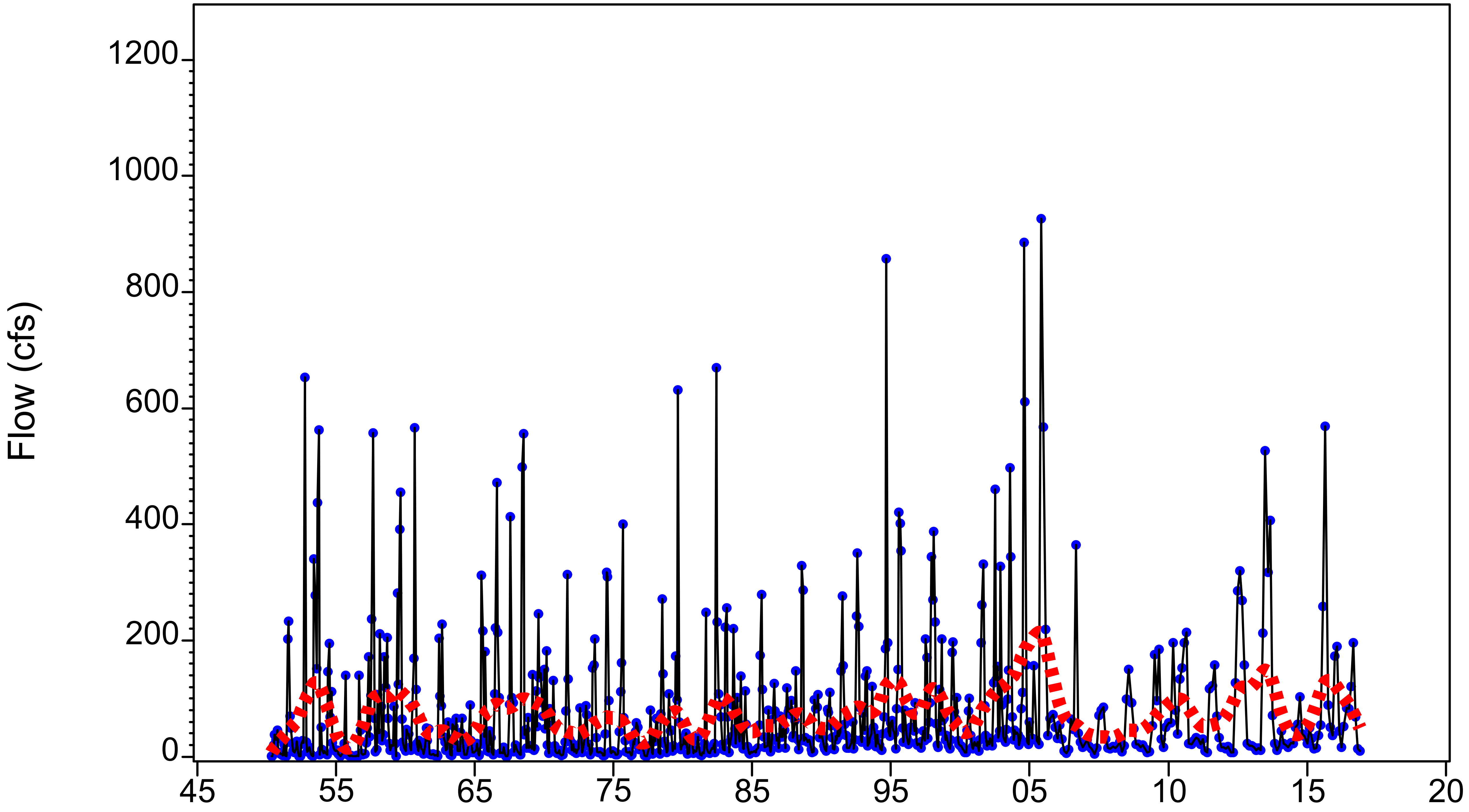


Figure 3.103 Monthly P50 (median) flow at long-term Joshua Creek at Nocatee (2297100) gage (1950-2016)

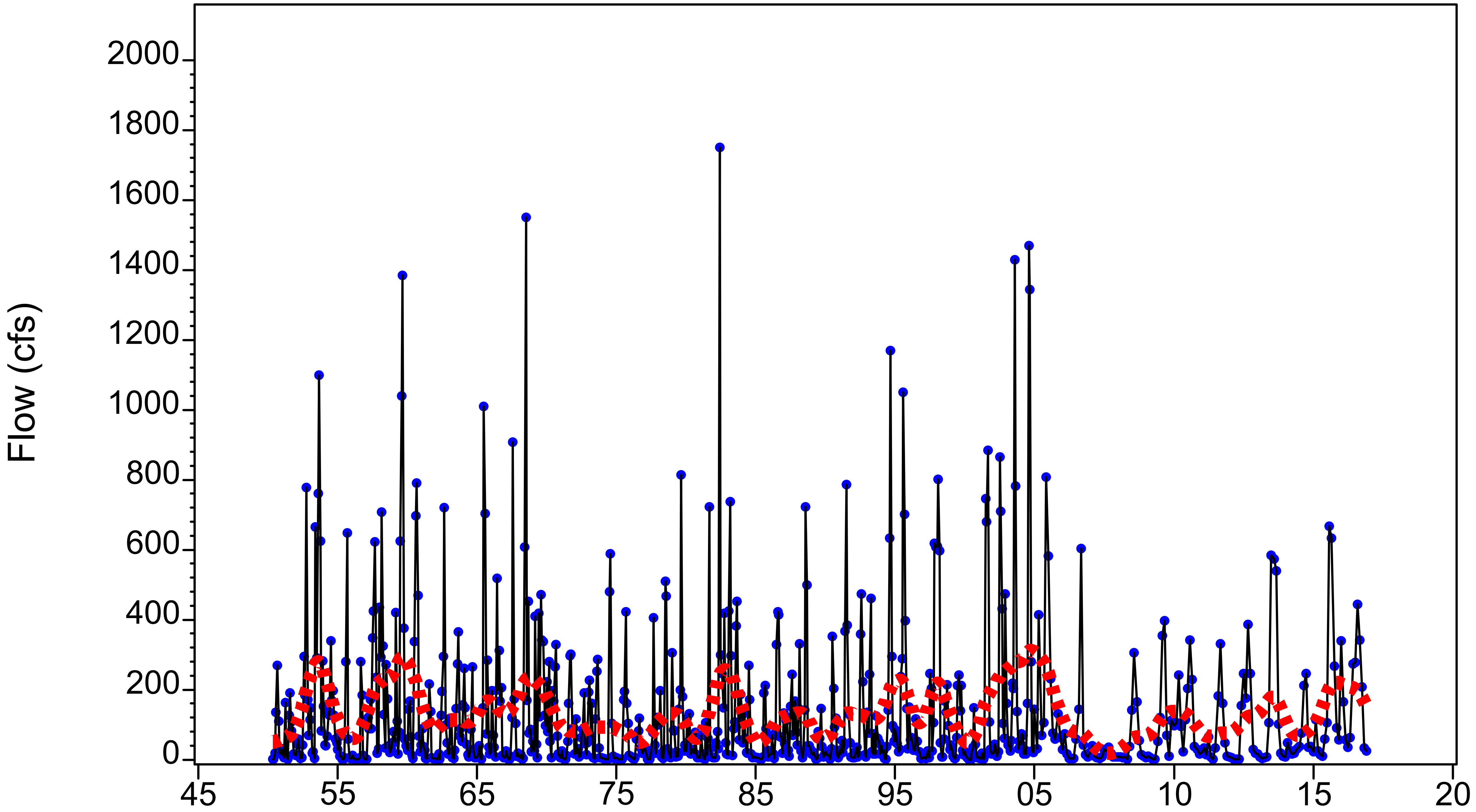


Figure 3.104 Monthly P50 (median) flow at long-term Horse Creek near Arcadia (2297310) gage (1950-2016)

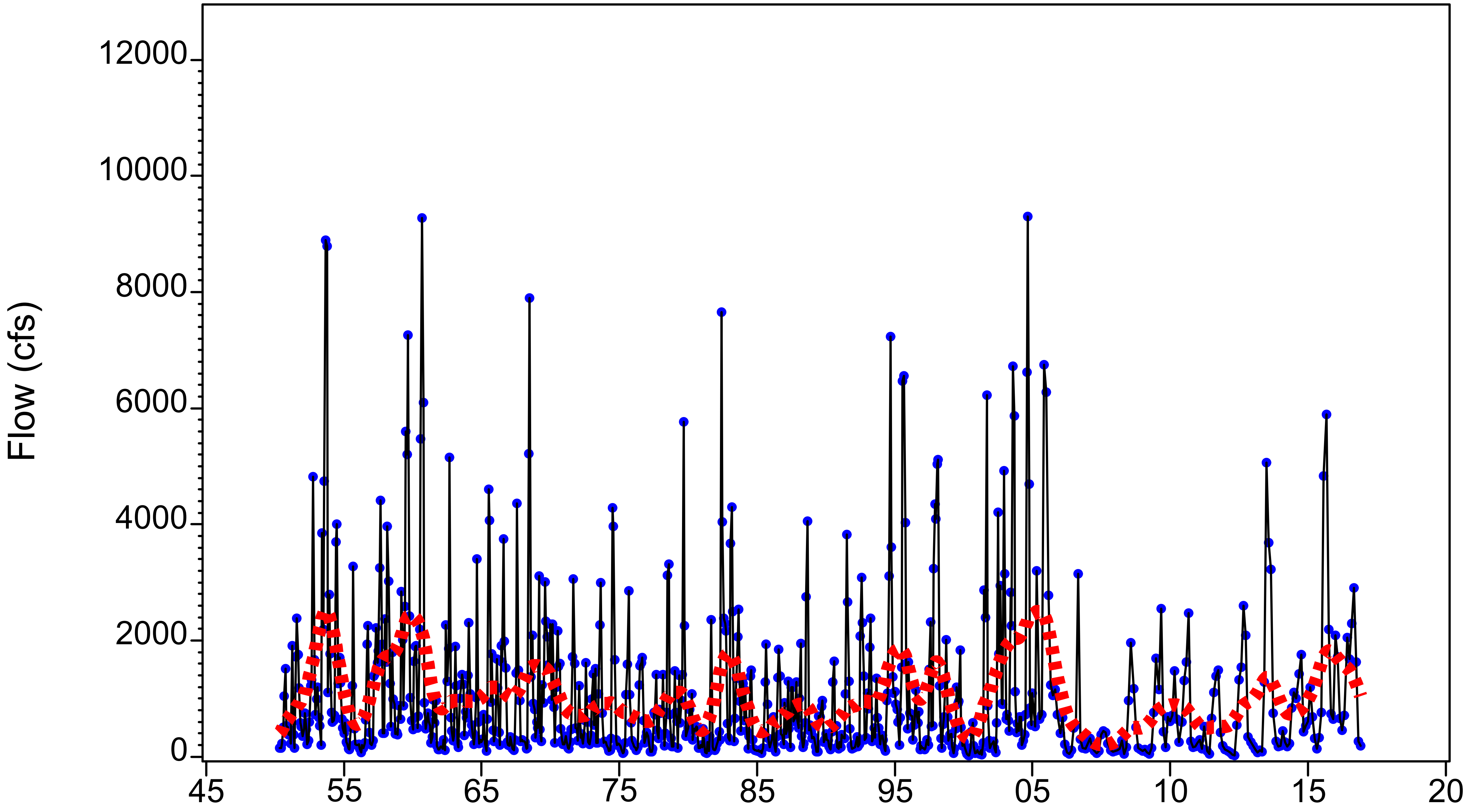


Figure 3.105 Monthly P50 (median) flow at long-term for total gaged flow upstream of the Facility (1950-2016)

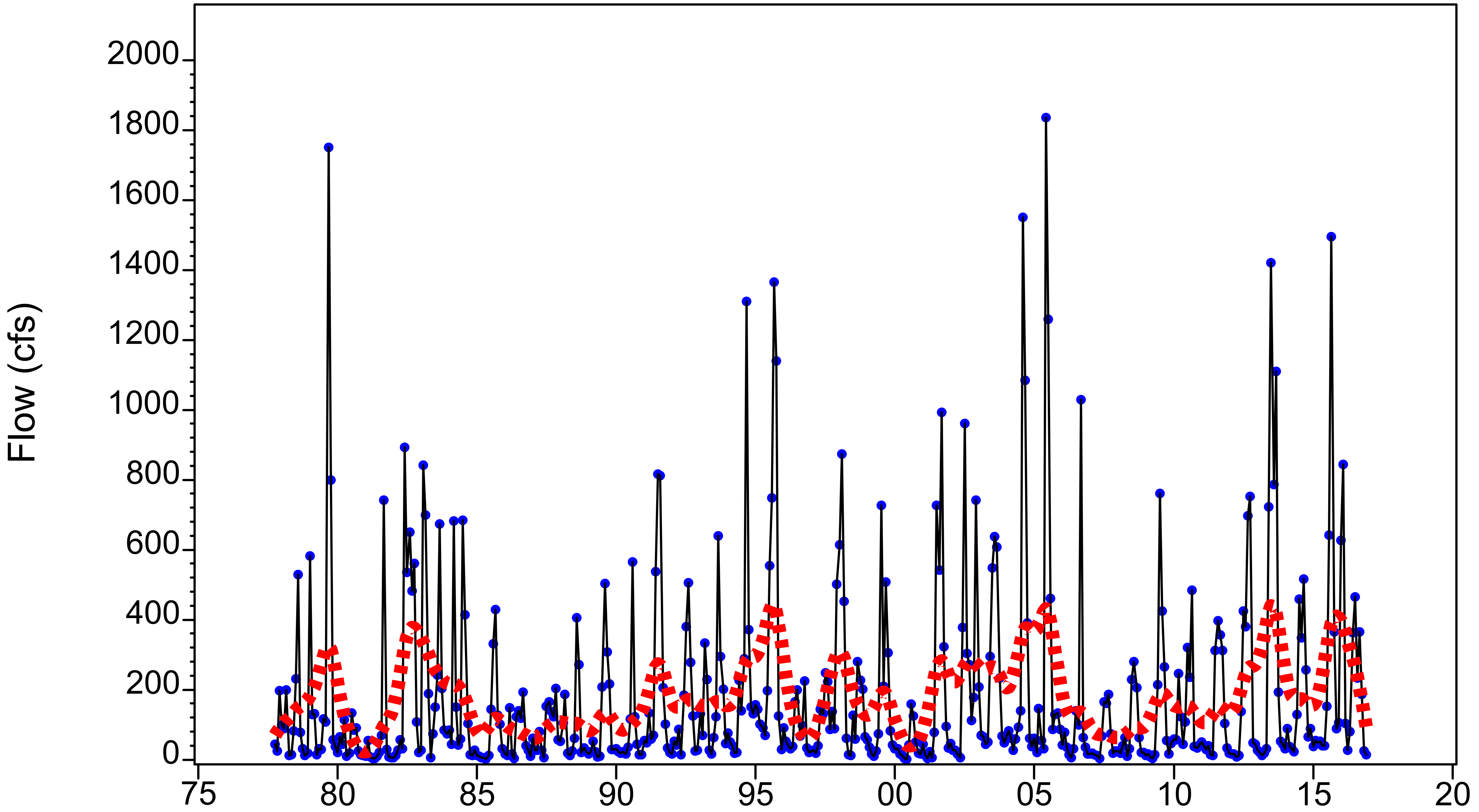


Figure 3.106 Monthly P50 (median) flow at long-term Prairie Creek (2298123) gage (1977-2016)

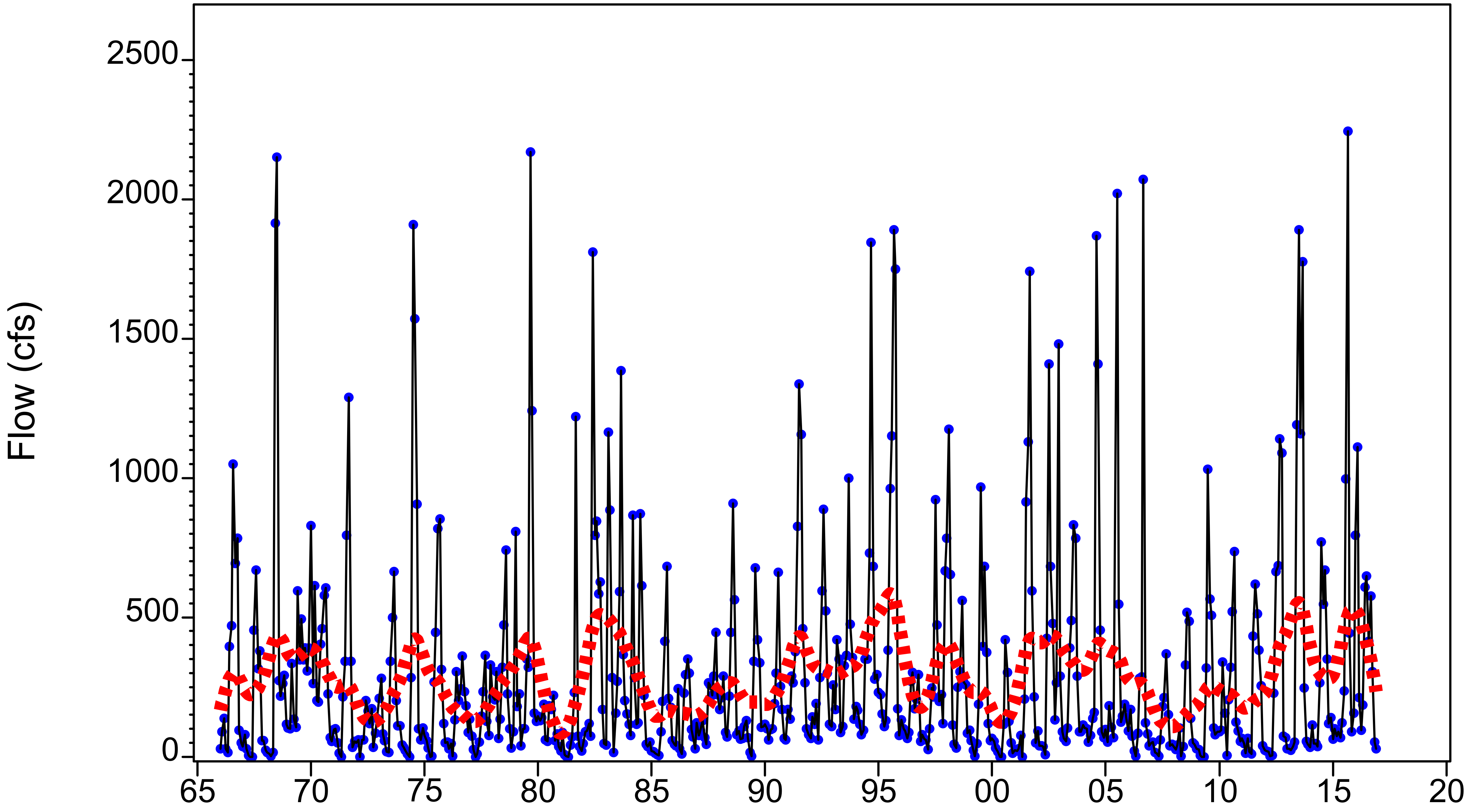


Figure 3.107 Monthly P50 (median) flow at long-term Shell Creek gage (1965-2016)

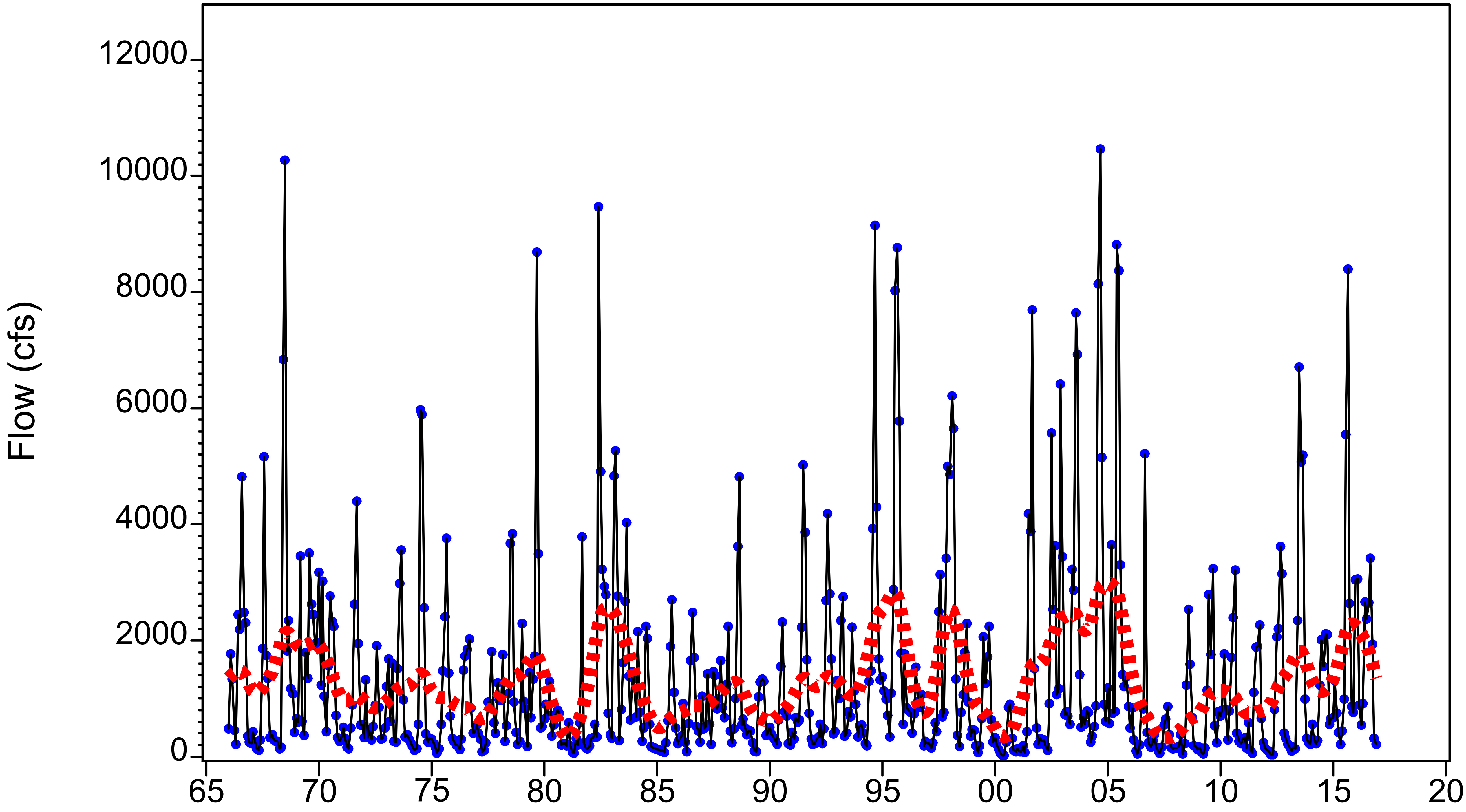


Figure 3.108 Monthly P50 (median) flow of total gaged Peace River flow to the Upper Harbor (1965-2016)

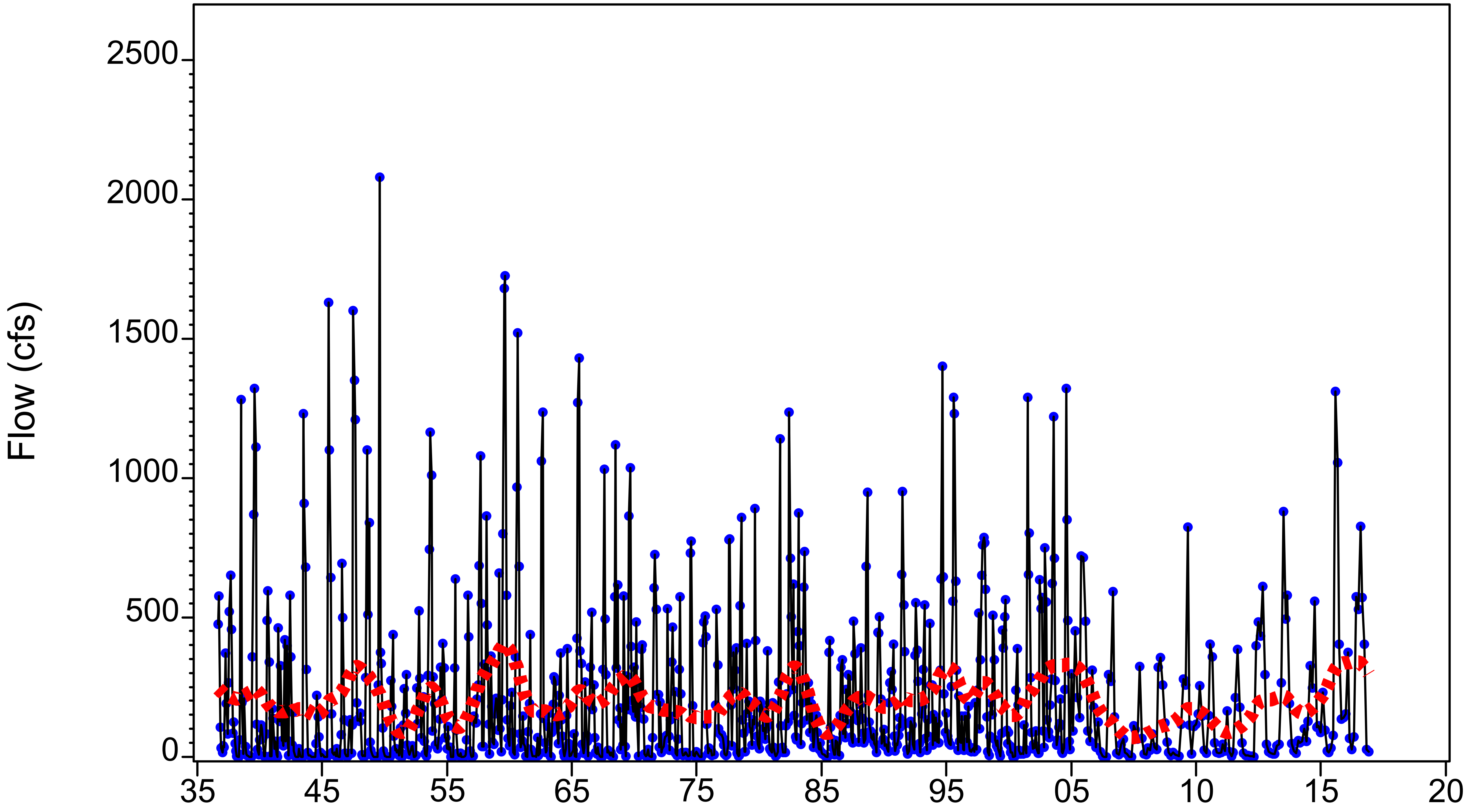


Figure 3.109 Monthly P50 (median) flow at long-term Myakka River near Sarasota (2298830) gage (1936-2016)

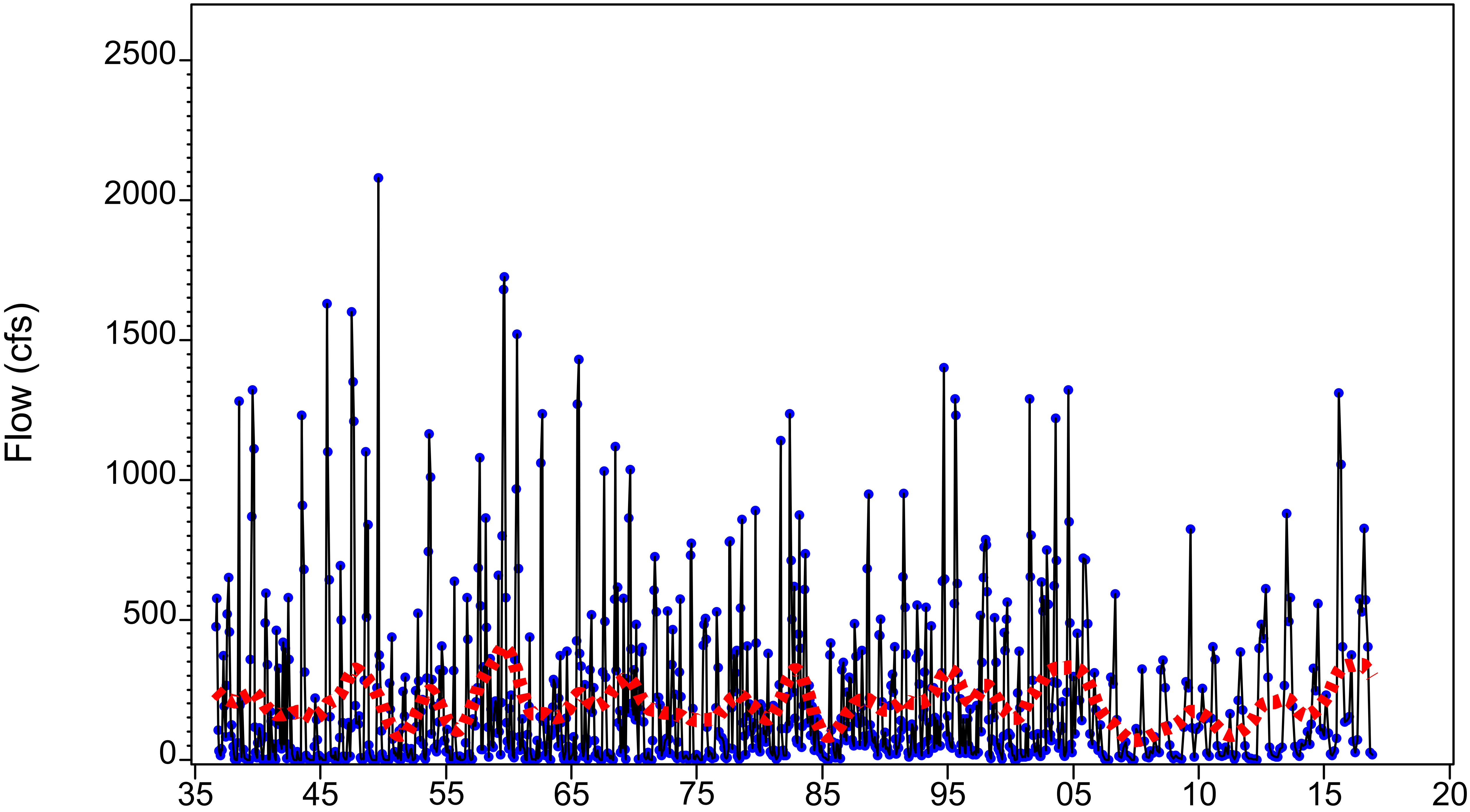


Figure 3.109 Monthly P50 (median) flow at long-term Myakka River near Sarasota (2298830) gage (1936-2016)

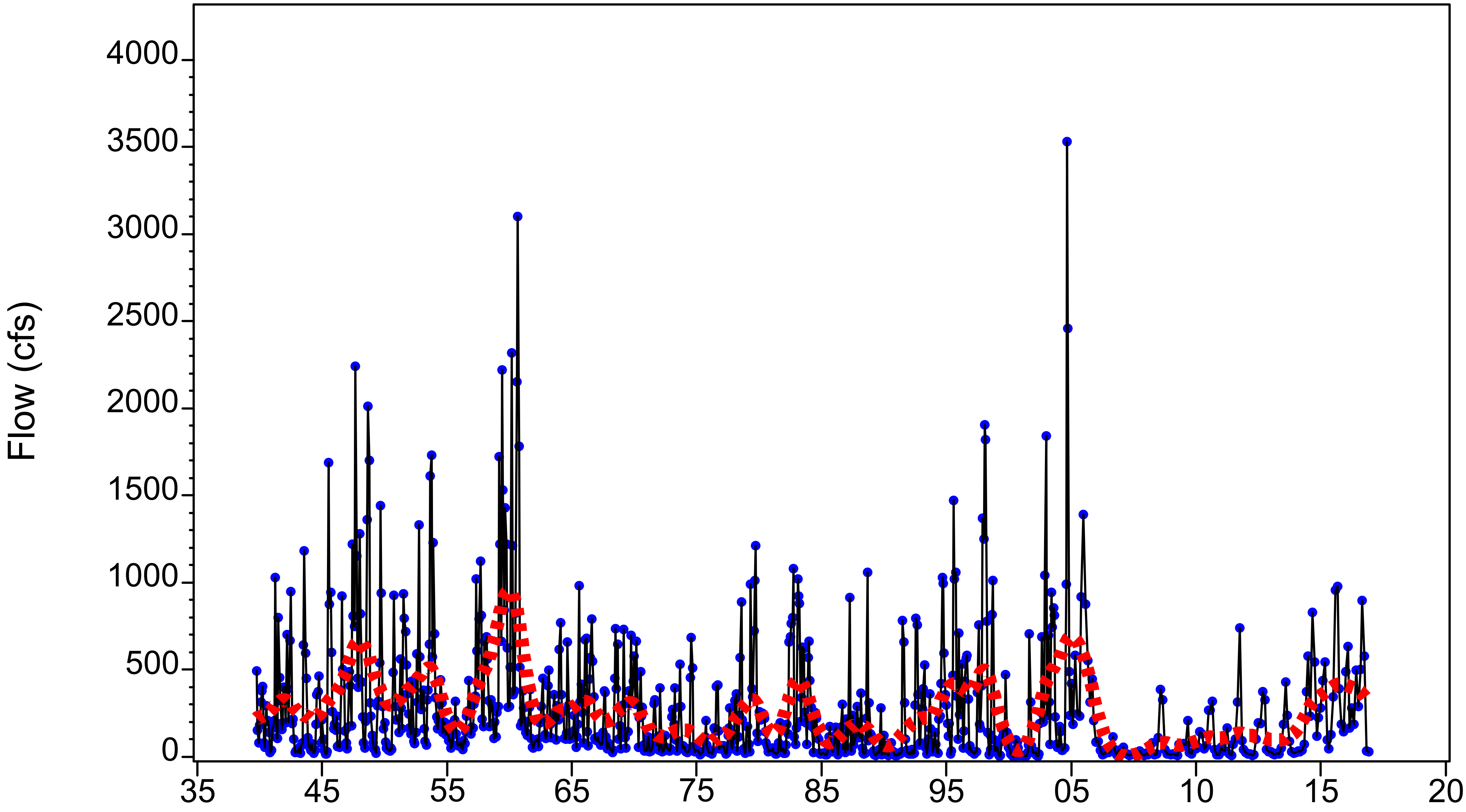


Figure 3.110 Monthly P75 flow at long-term Peace River at Bartow (2294650) gage (1939-2016)

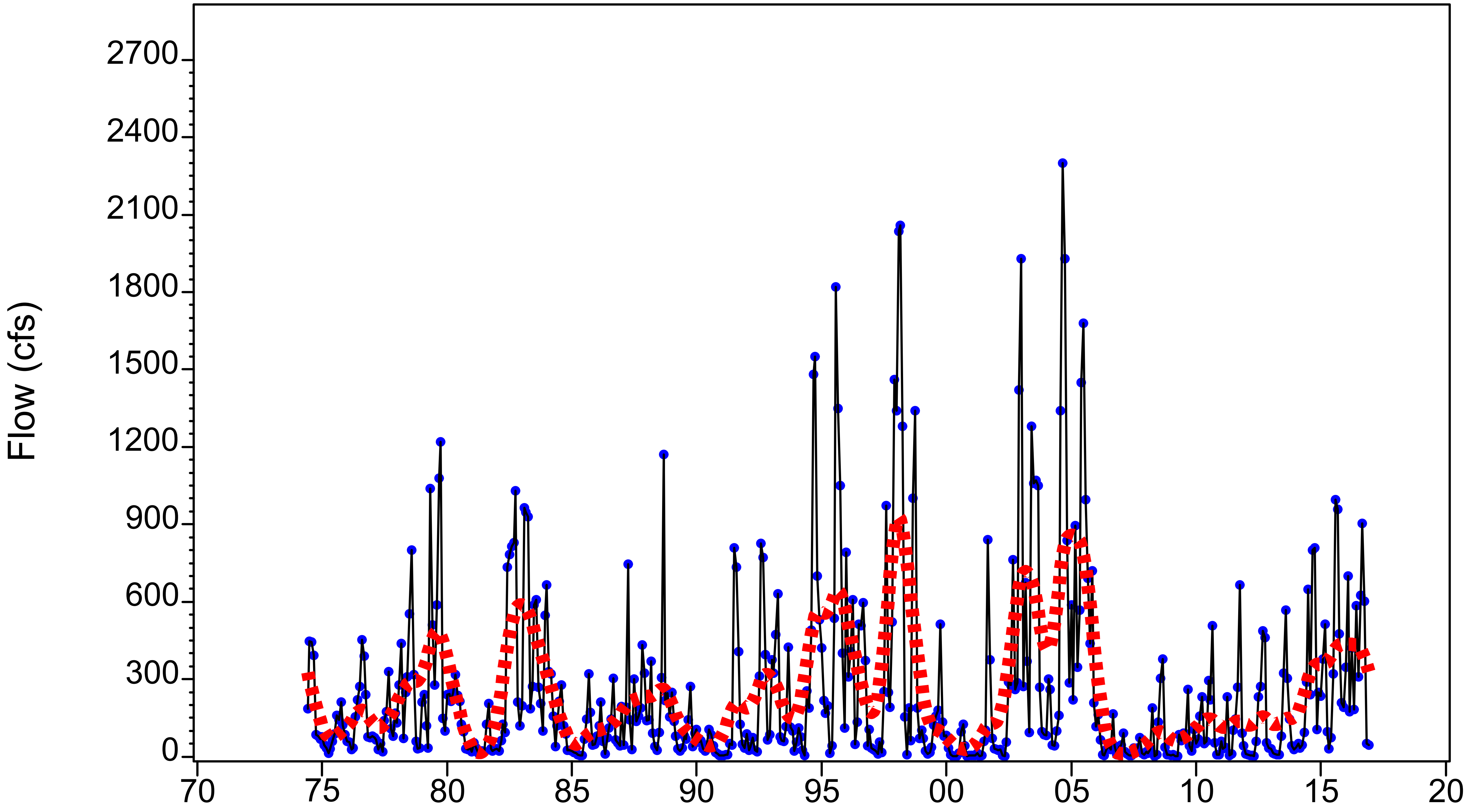


Figure 3.111 Monthly P75 flow at long-term Peace River at Ft. Meade (2294898) gage (1974-2016)

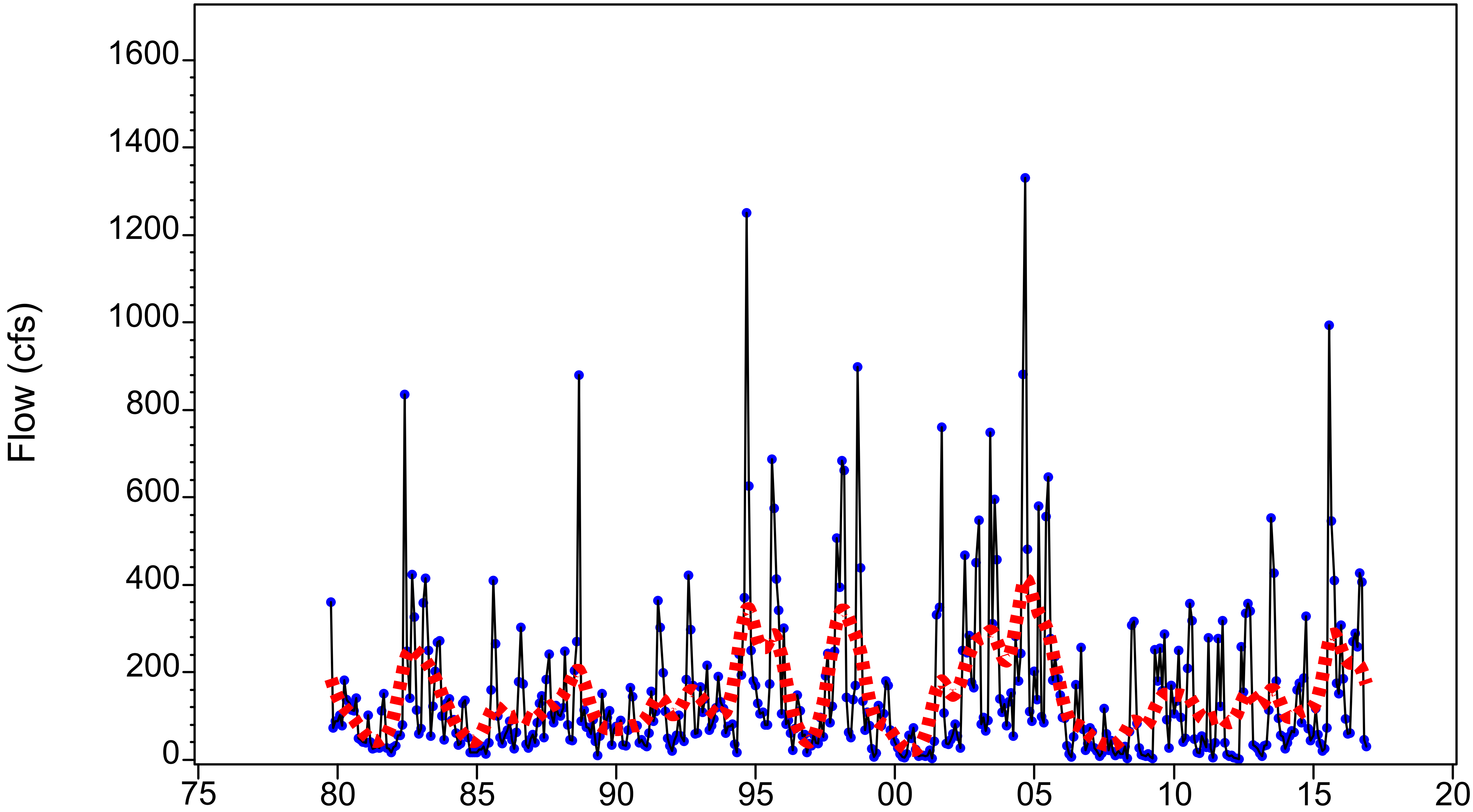


Figure 3.112 Monthly P75 flow at long-term Payne Creek (2295420) gage (1979-2016)

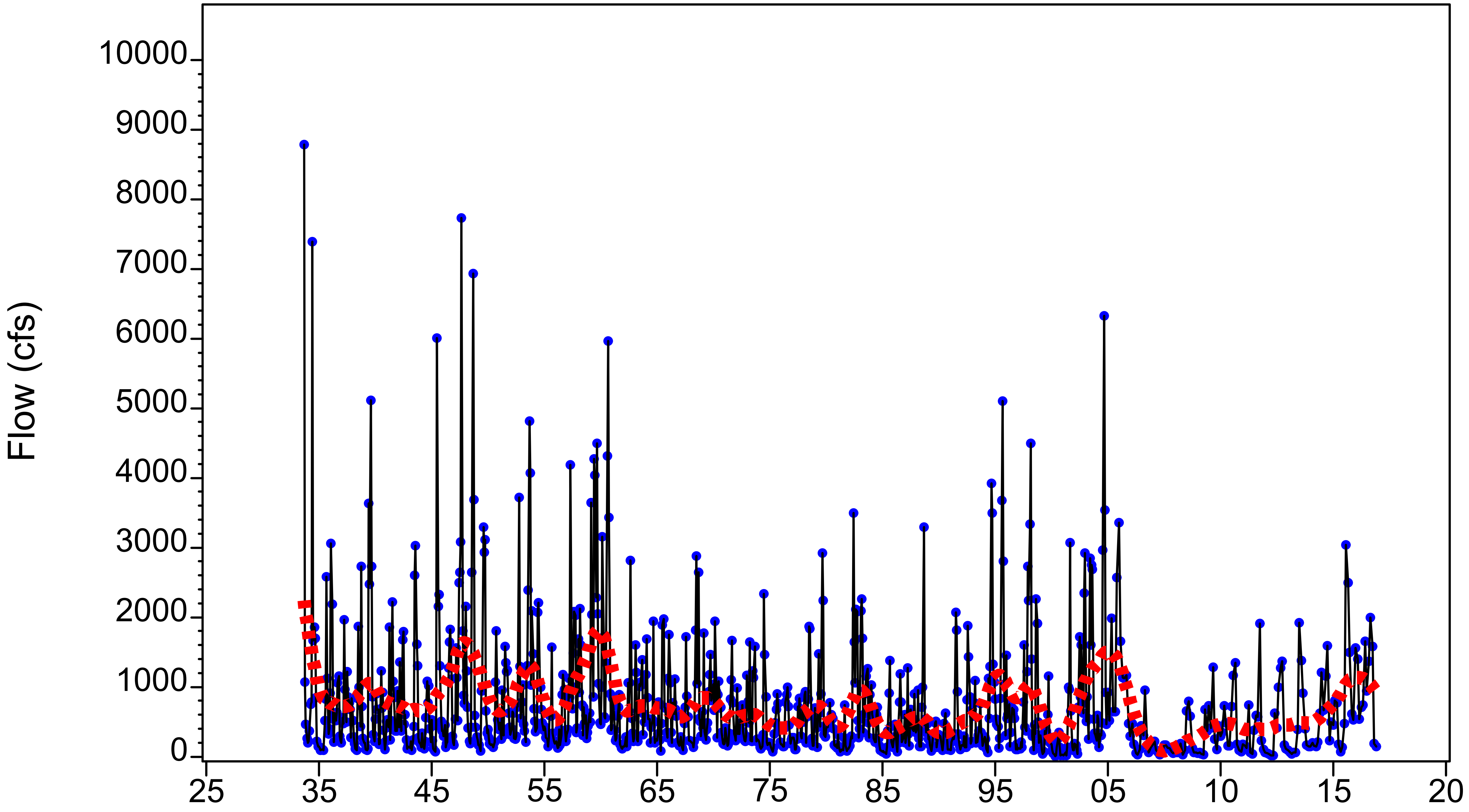


Figure 3.113 Monthly P75 flow at long-term Peace River at Zolfo (2295637) gage (1933-2016)

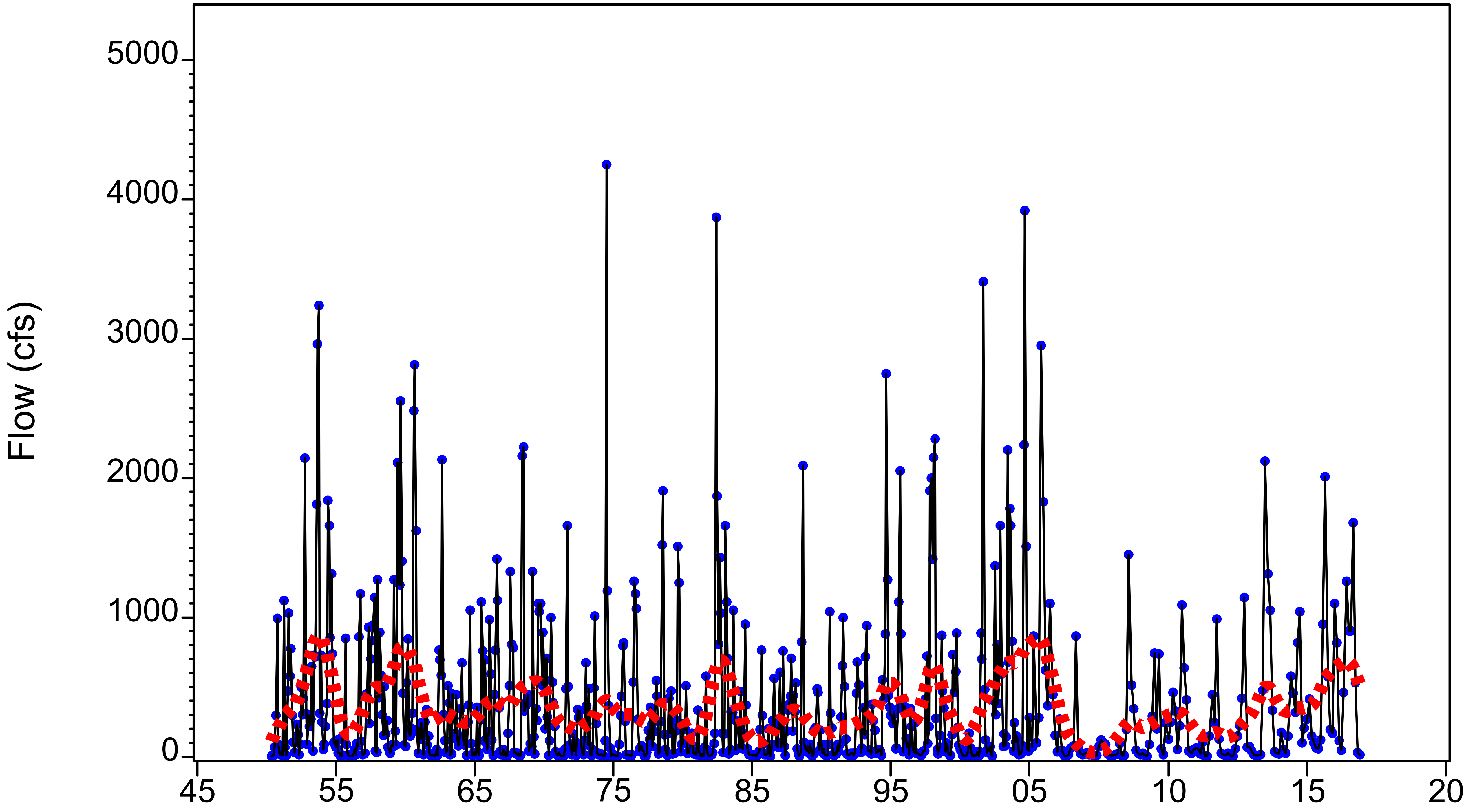


Figure 3.114 Monthly P75 flow at long-term Charlie Creek (2296500) gage (1950-2016)

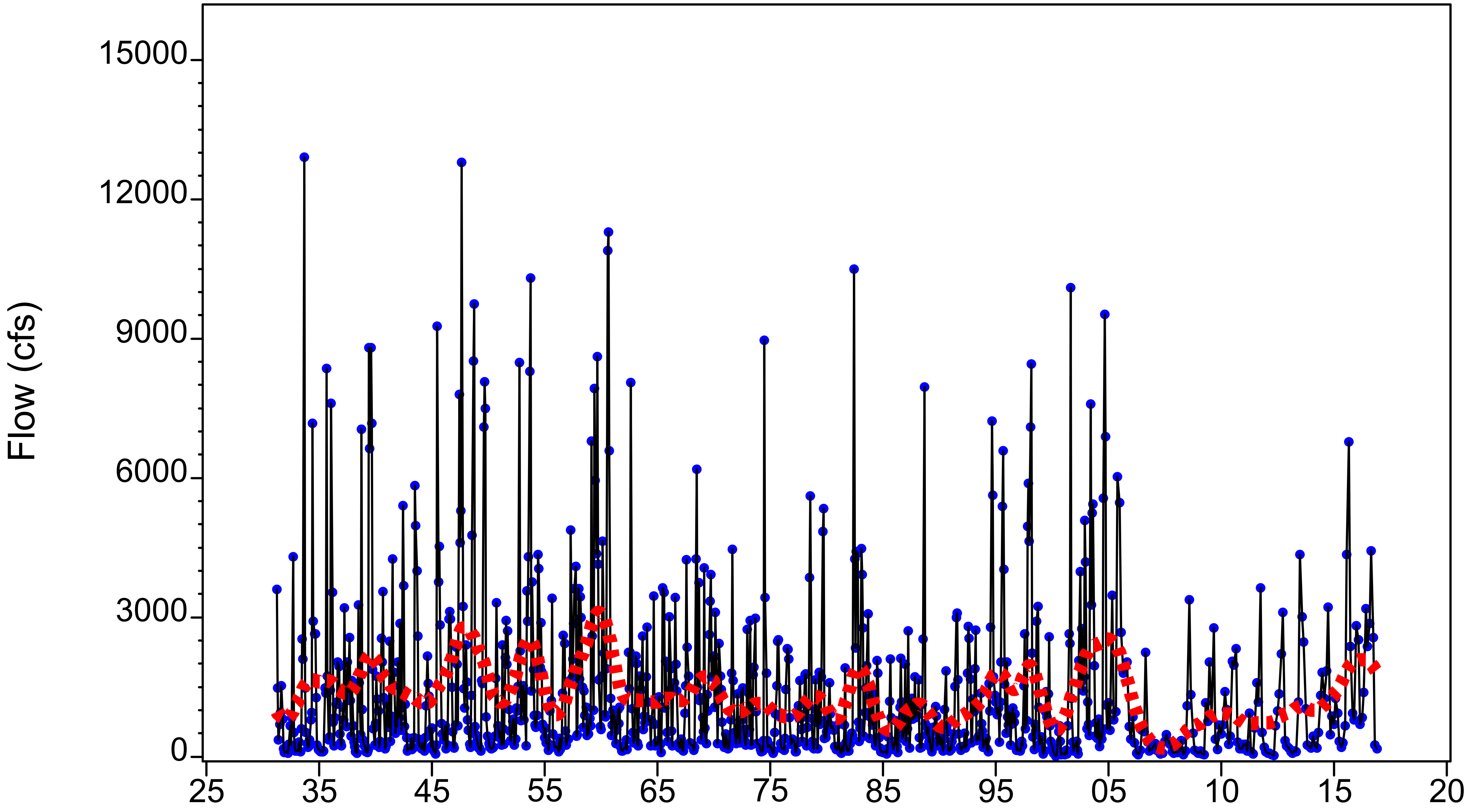


Figure 3.115 Monthly P75 flow at long-term Peace River at Arcadia (2296750) gage (1931-2016)

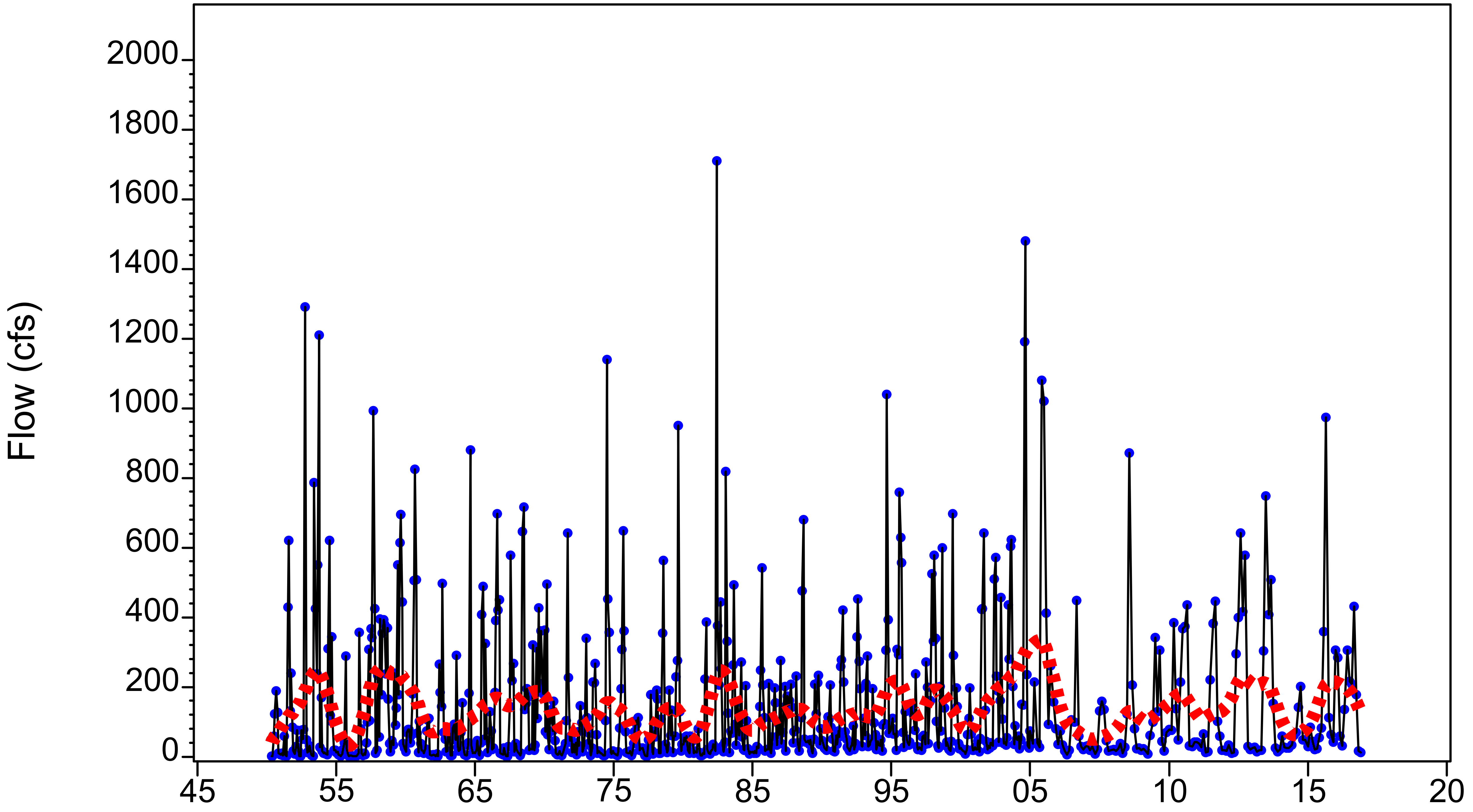


Figure 3.116 Monthly P75 flow at long-term Joshua Creek at Nocatee (2297100) gage (1950-2016)

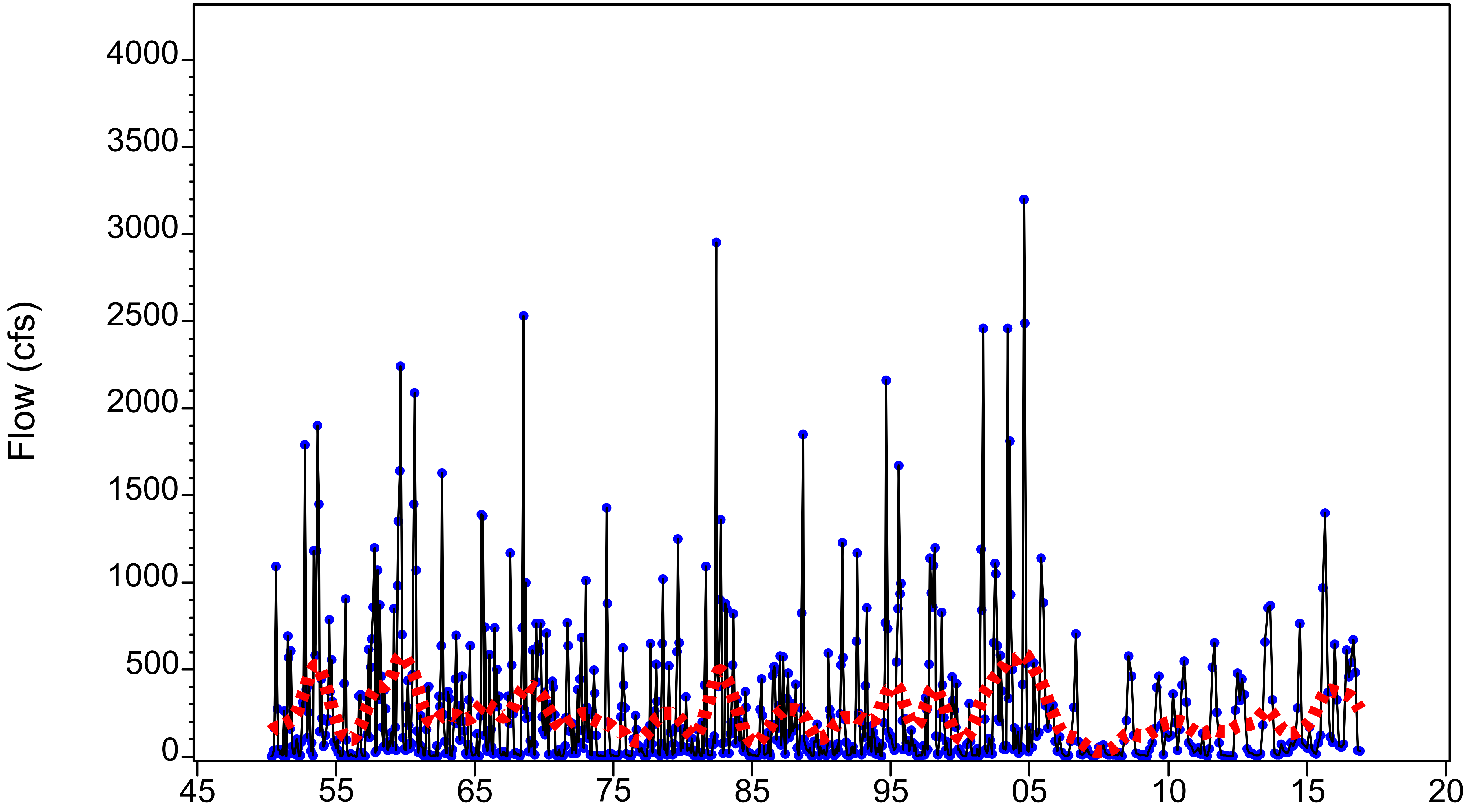


Figure 3.117 Monthly P75 flow at long-term Horse Creek near Arcadia (2297310) gage (1950-2016)

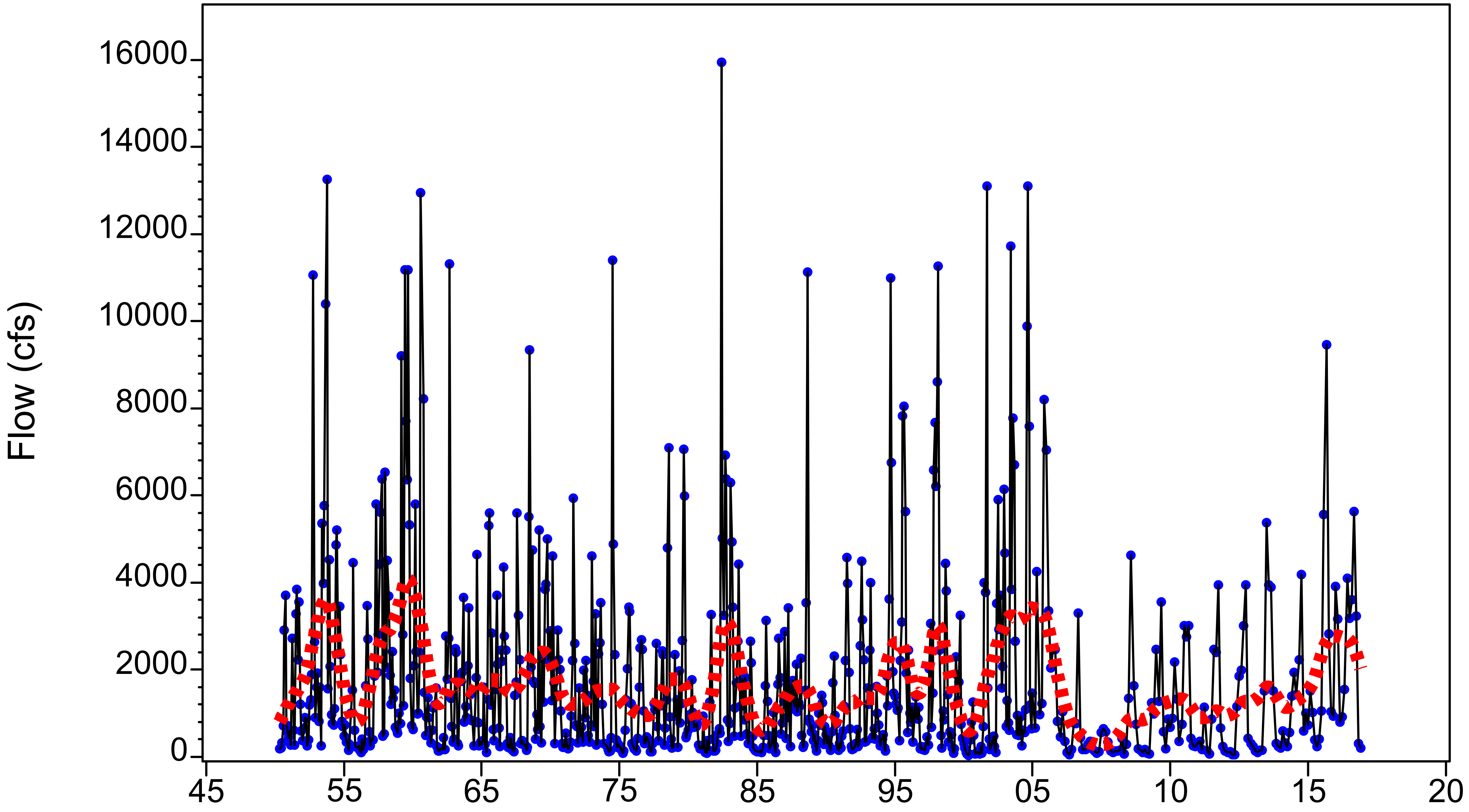


Figure 3.118 Monthly P75 flow at long-term for total gaged flow upstream of the Facility (1950-2016)

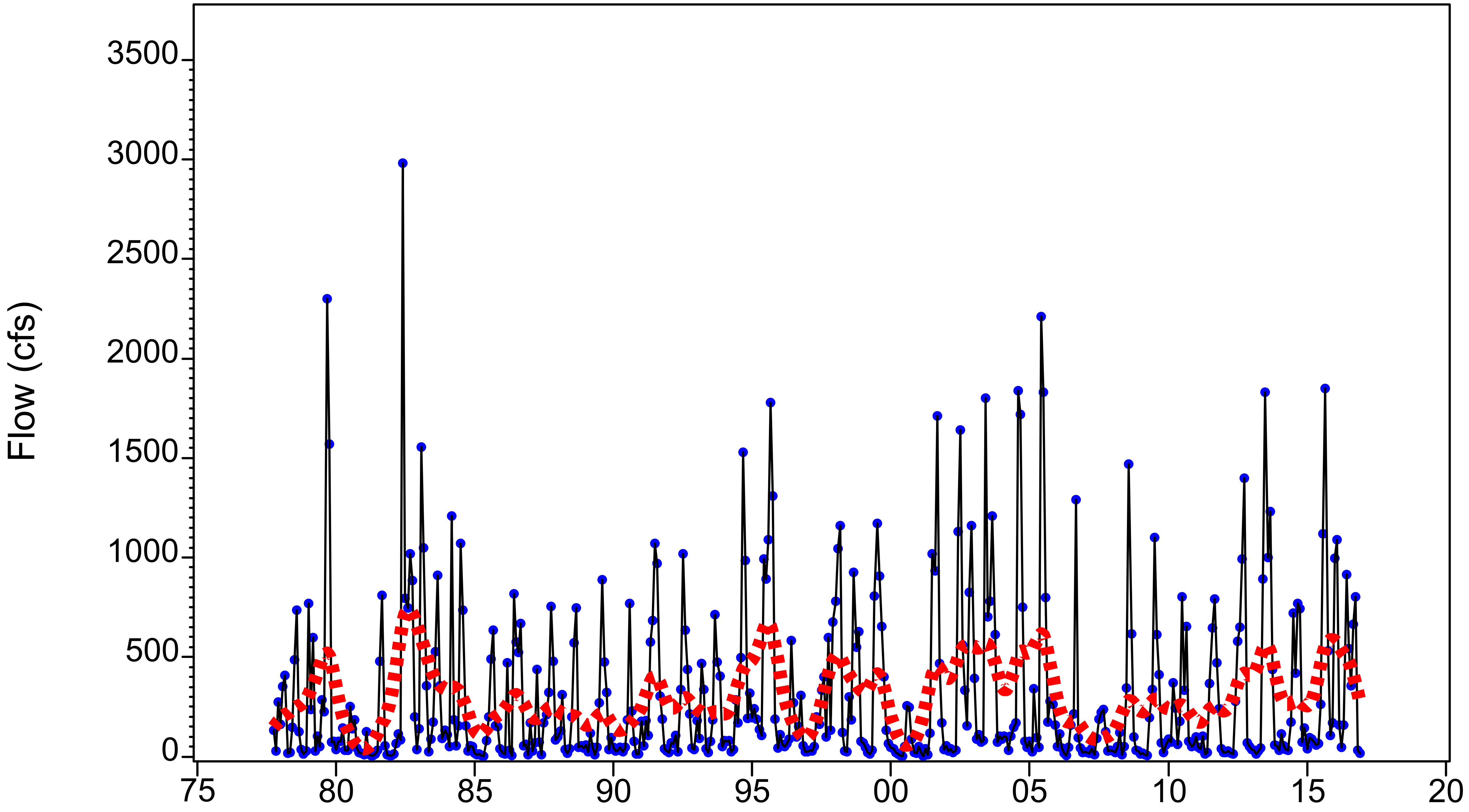


Figure 3.119 Monthly P75 flow at long-term Prairie Creek (2298123) gage (1977-2016)

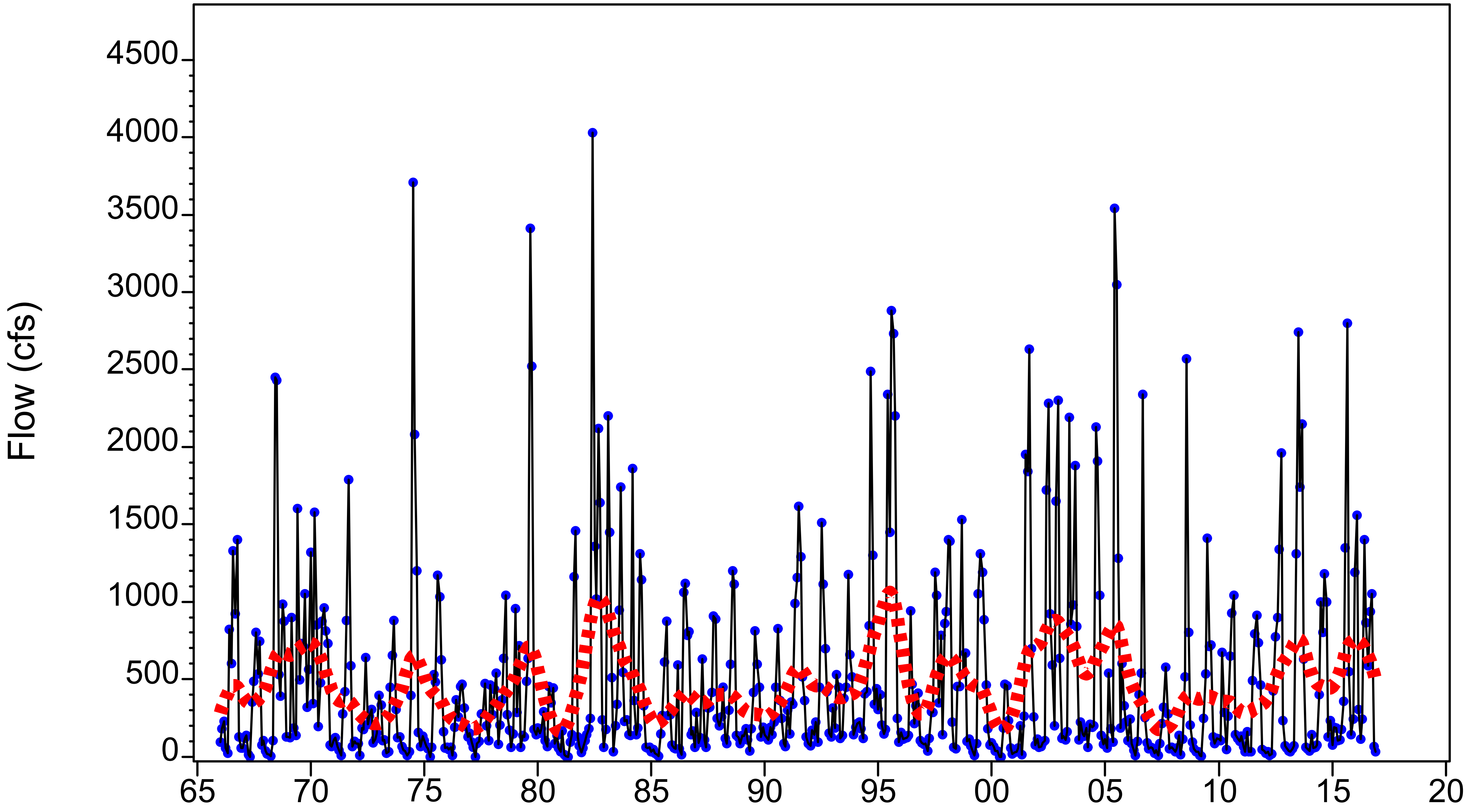


Figure 3.120 Monthly P75 flow at long-term Shell Creek gage (1965-2016)

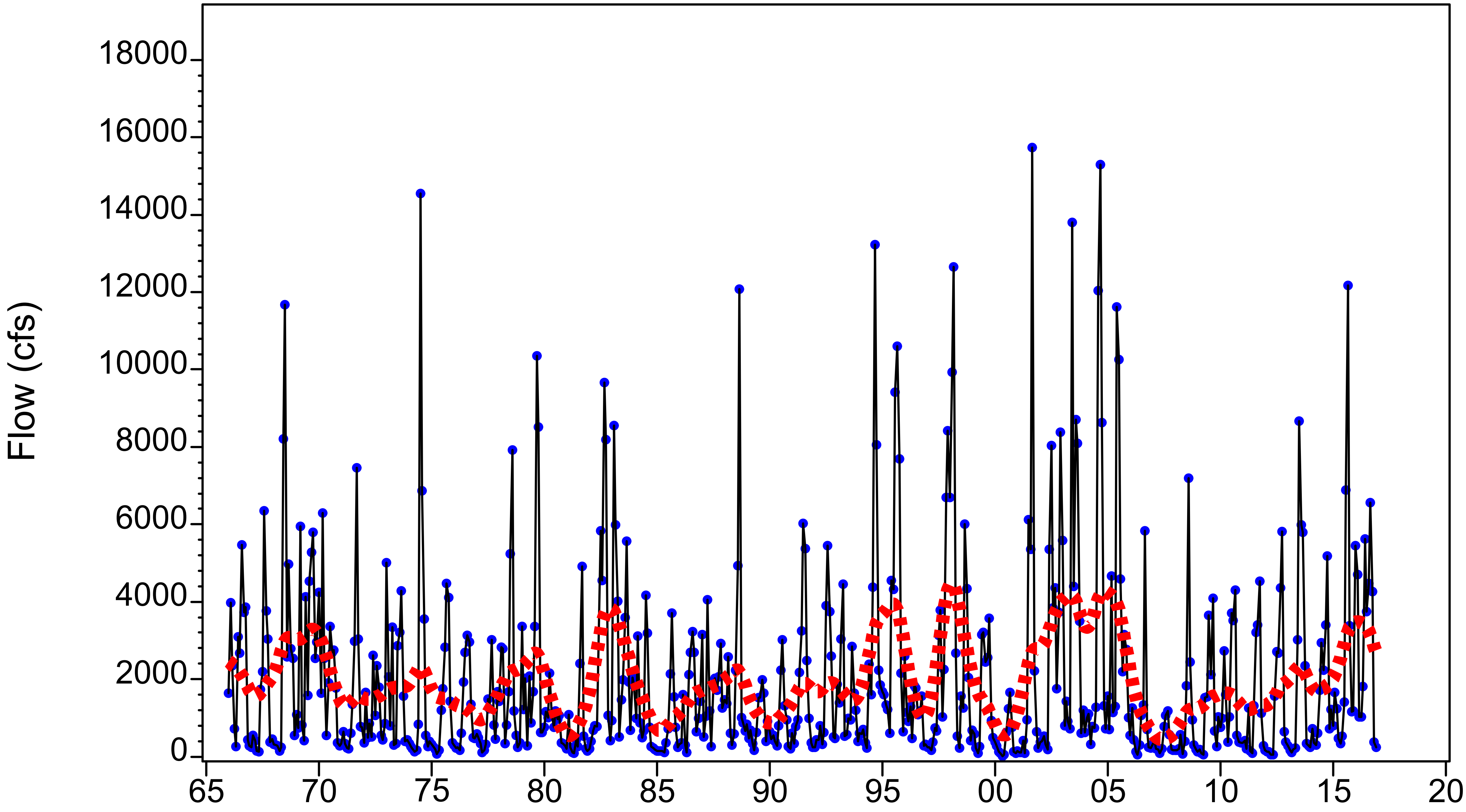


Figure 3.121 Monthly P75 flow of total gaged Peace River flow to the Upper Harbor (1965-2016)

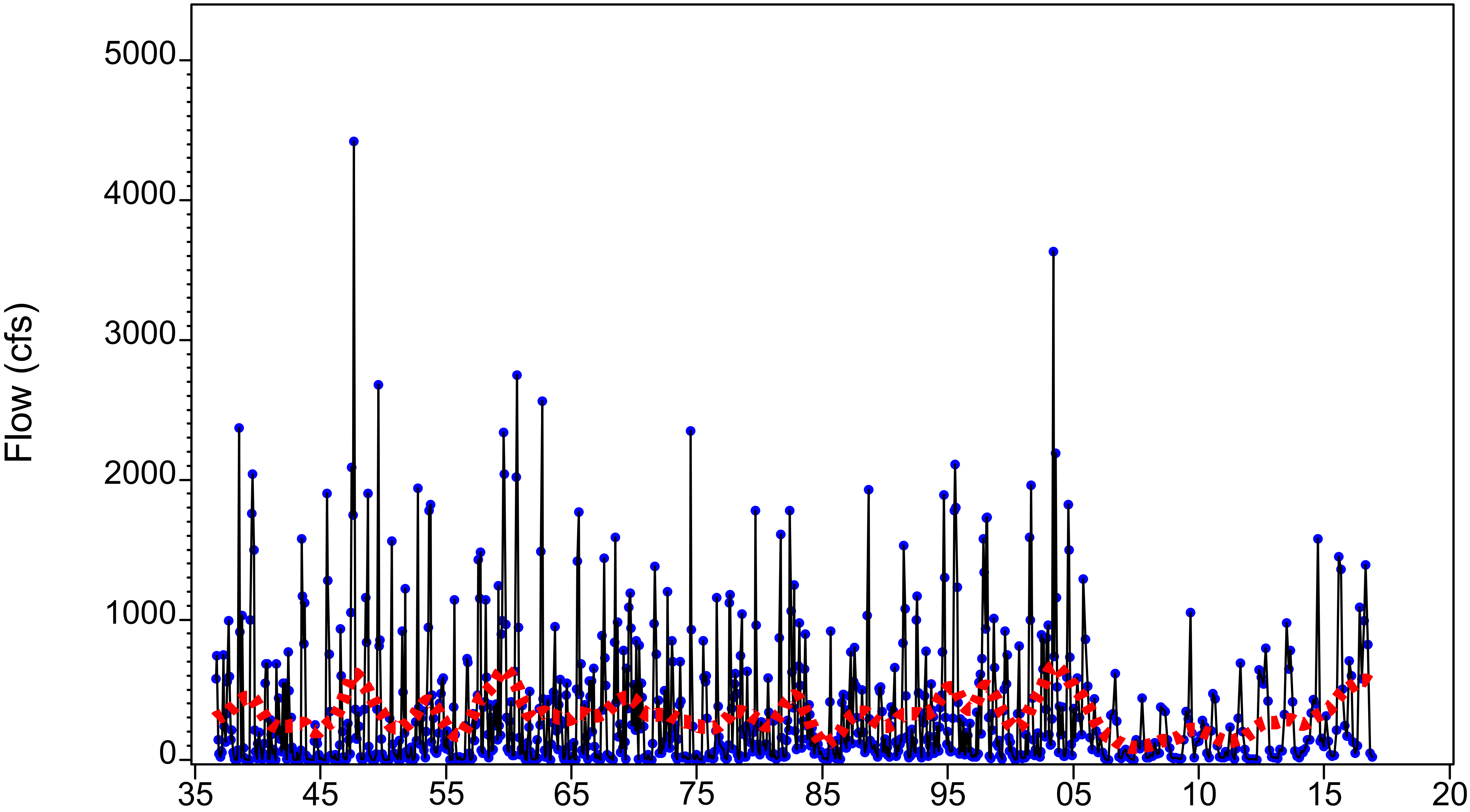


Figure 3.122 Monthly P75 flow at long-term Myakka River near Sarasota (2298830) gage (1936-2016)

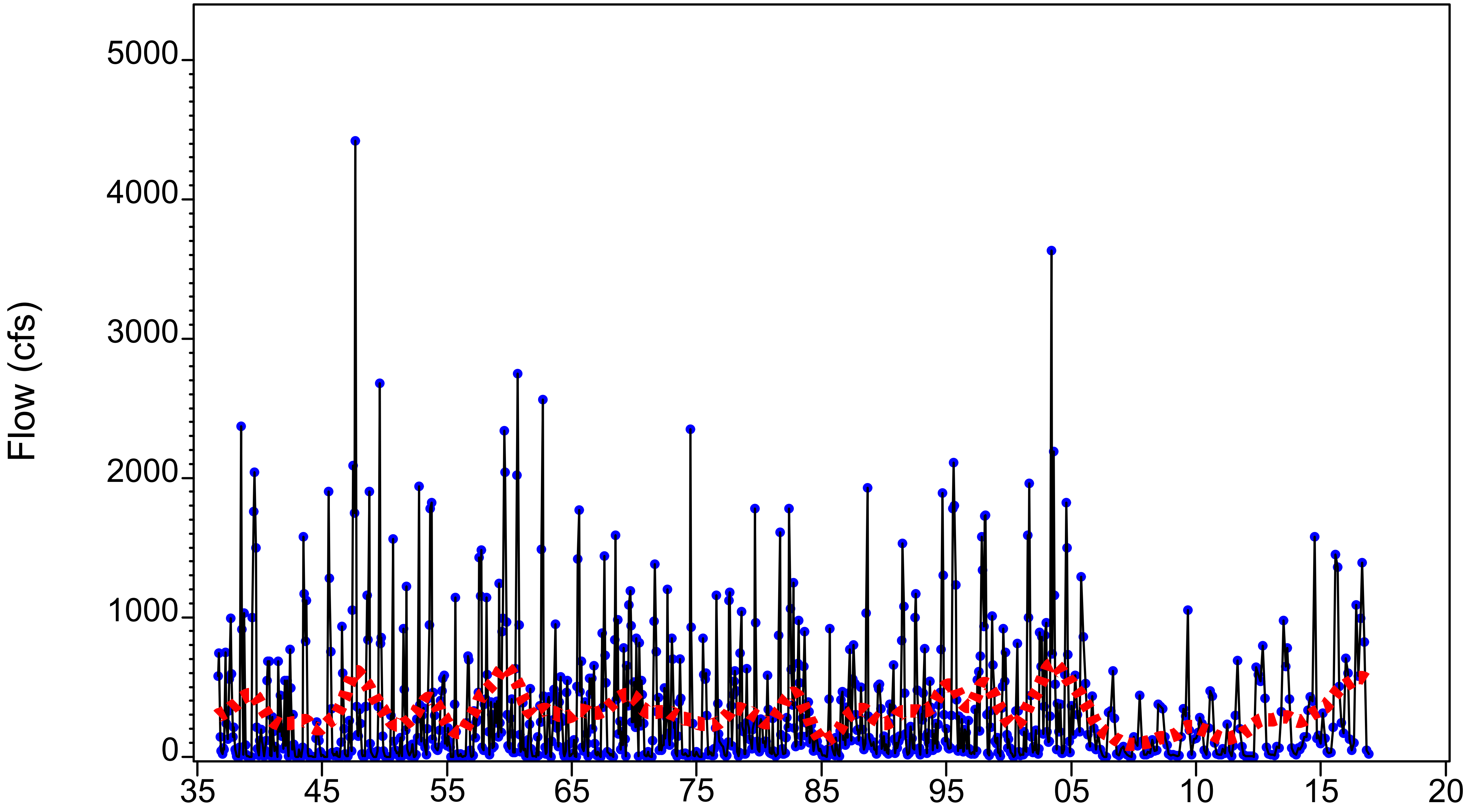


Figure 3.122 Monthly P75 flow at long-term Myakka River near Sarasota (2298830) gage (1936-2016)

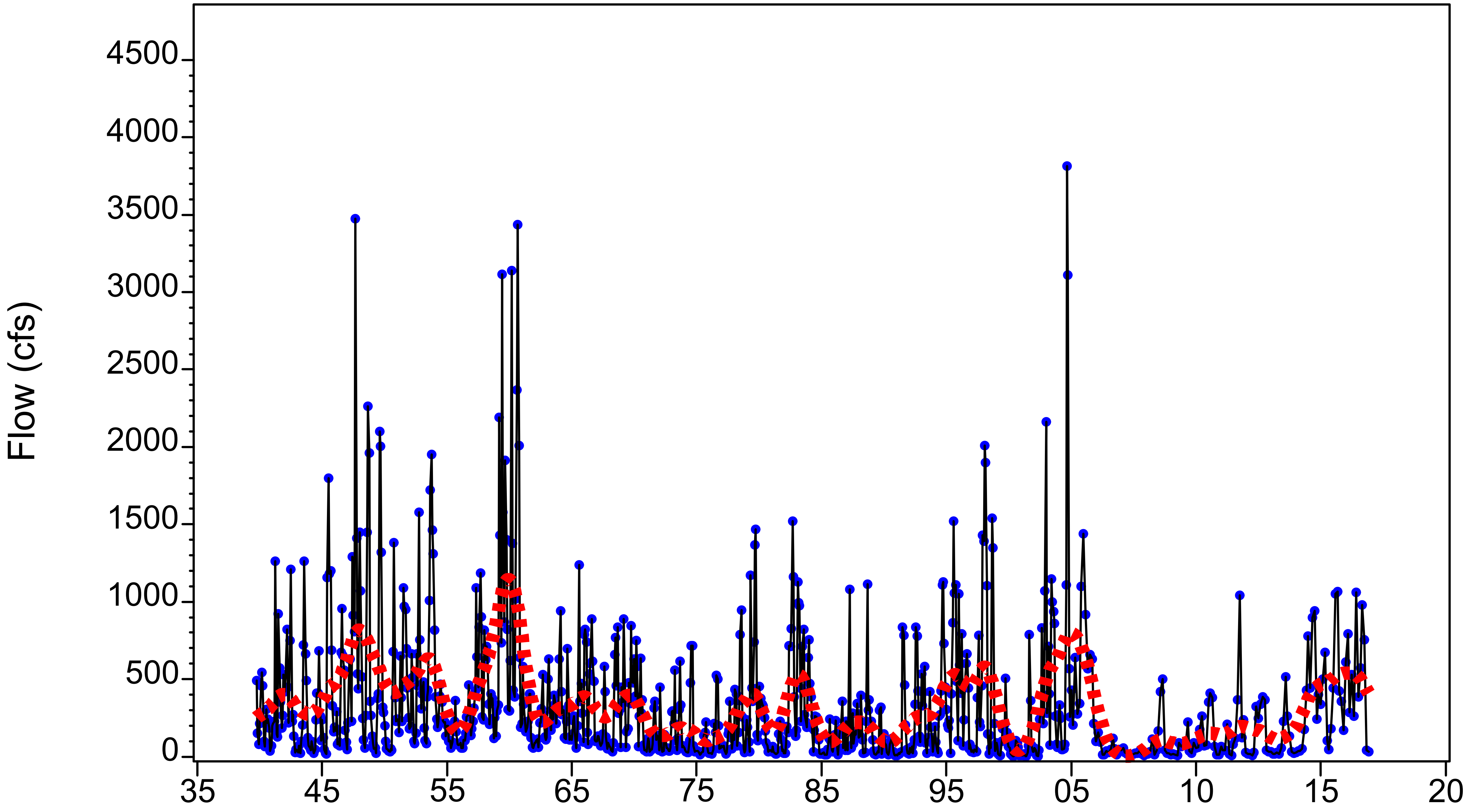


Figure 3.123 Monthly P90 flow at long-term Peace River at Bartow (2294650) gage (1939-2016)

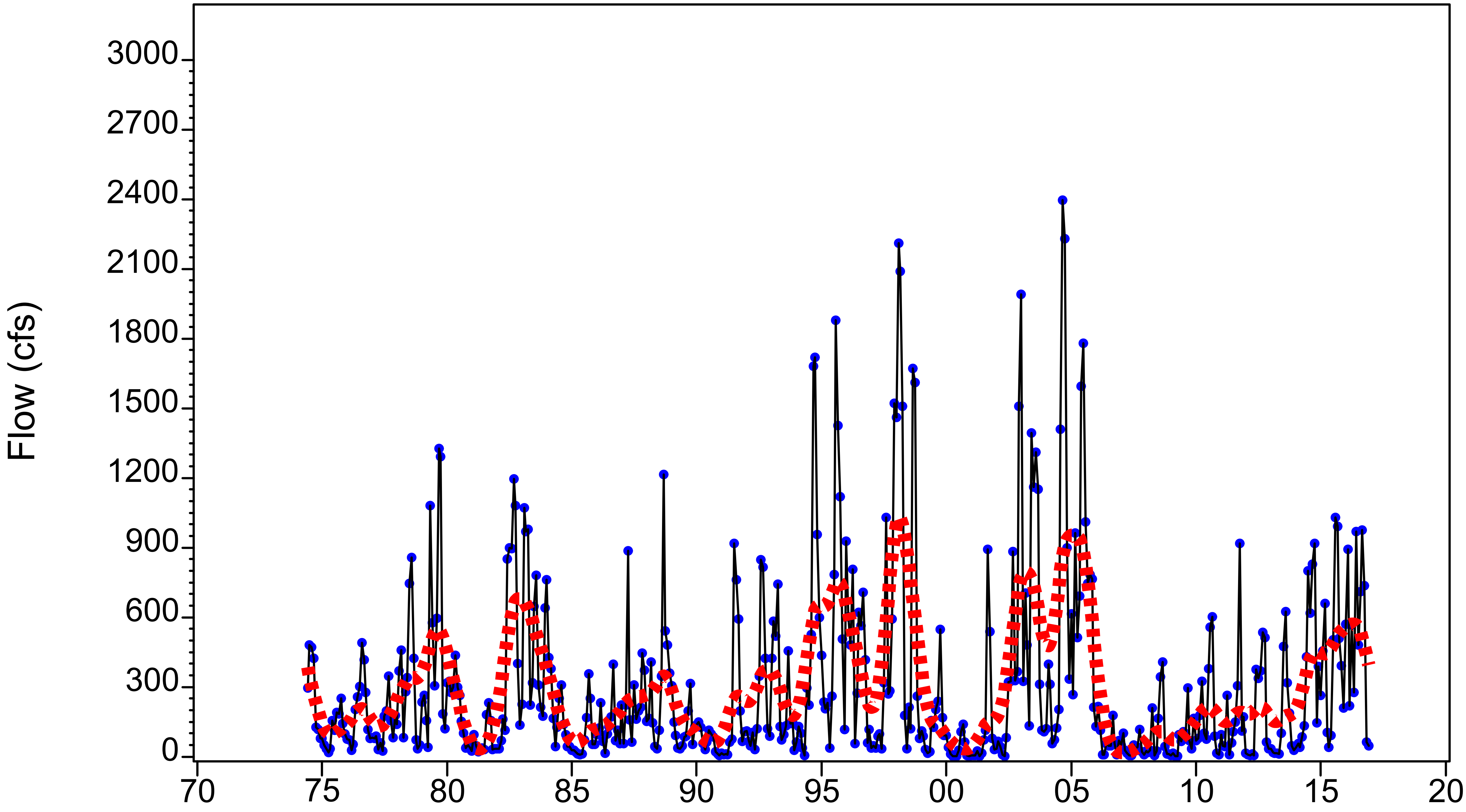


Figure 3.124 Monthly P90 flow at long-term Peace River at Ft. Meade (2294898) gage (1974-2016)

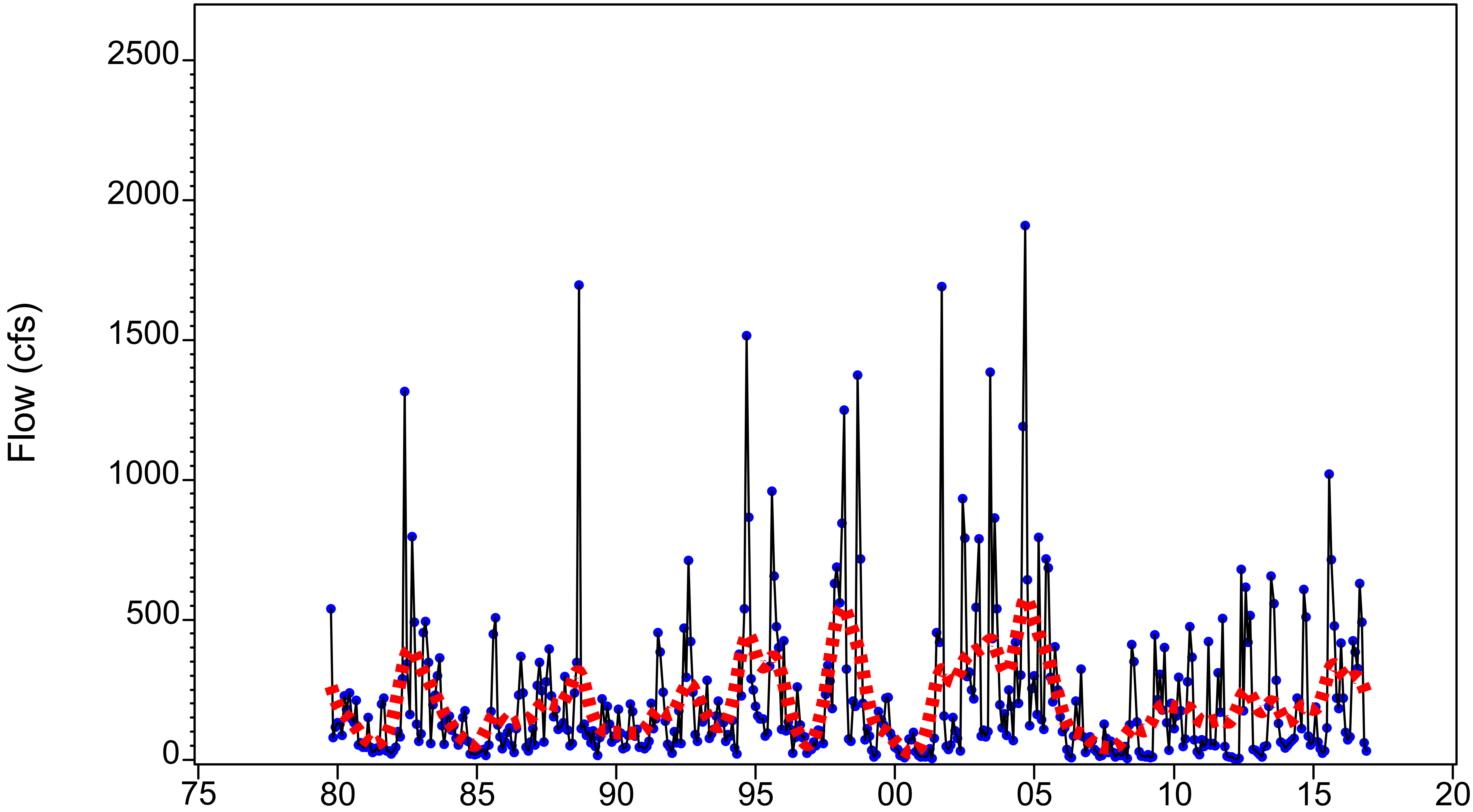


Figure 3.125 Monthly P90 flow at long-term Payne Creek (2295420) gage (1979-2016)

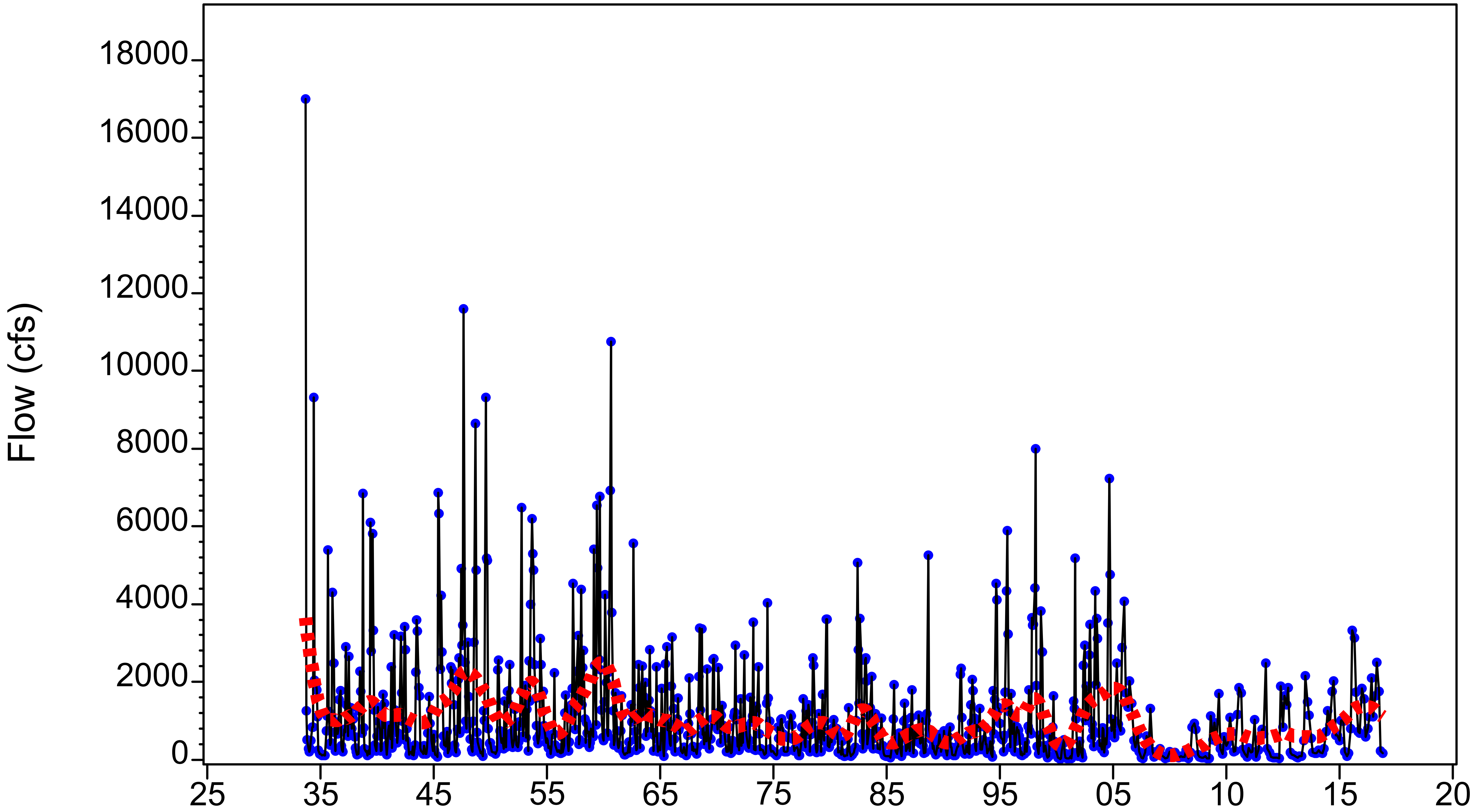


Figure 3.126 Monthly P90 flow at long-term Peace River at Zolfo (2295637) gage (1933-2016)

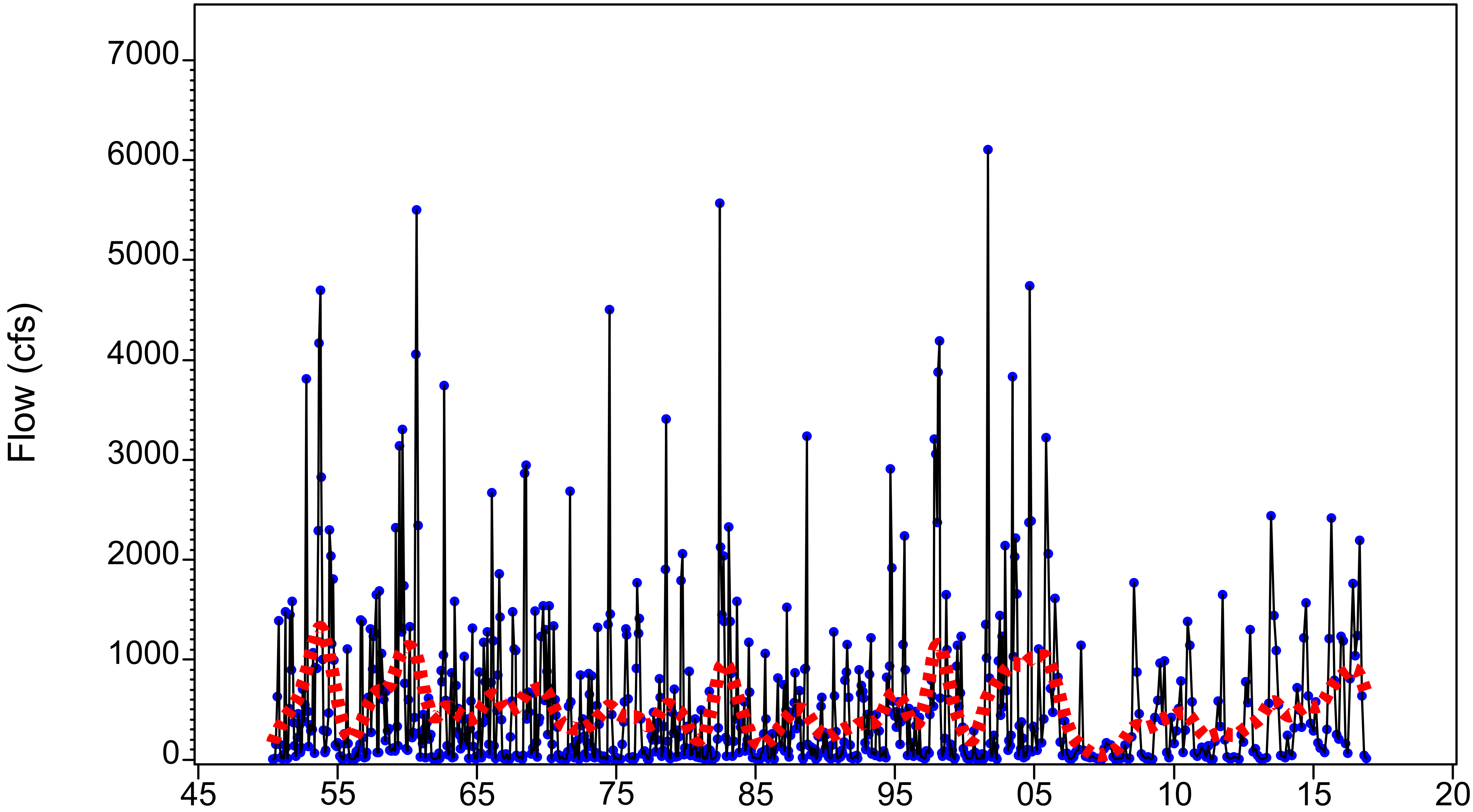


Figure 3.127 Monthly P90 flow at long-term Charlie Creek (2296500) gage (1950-2016)

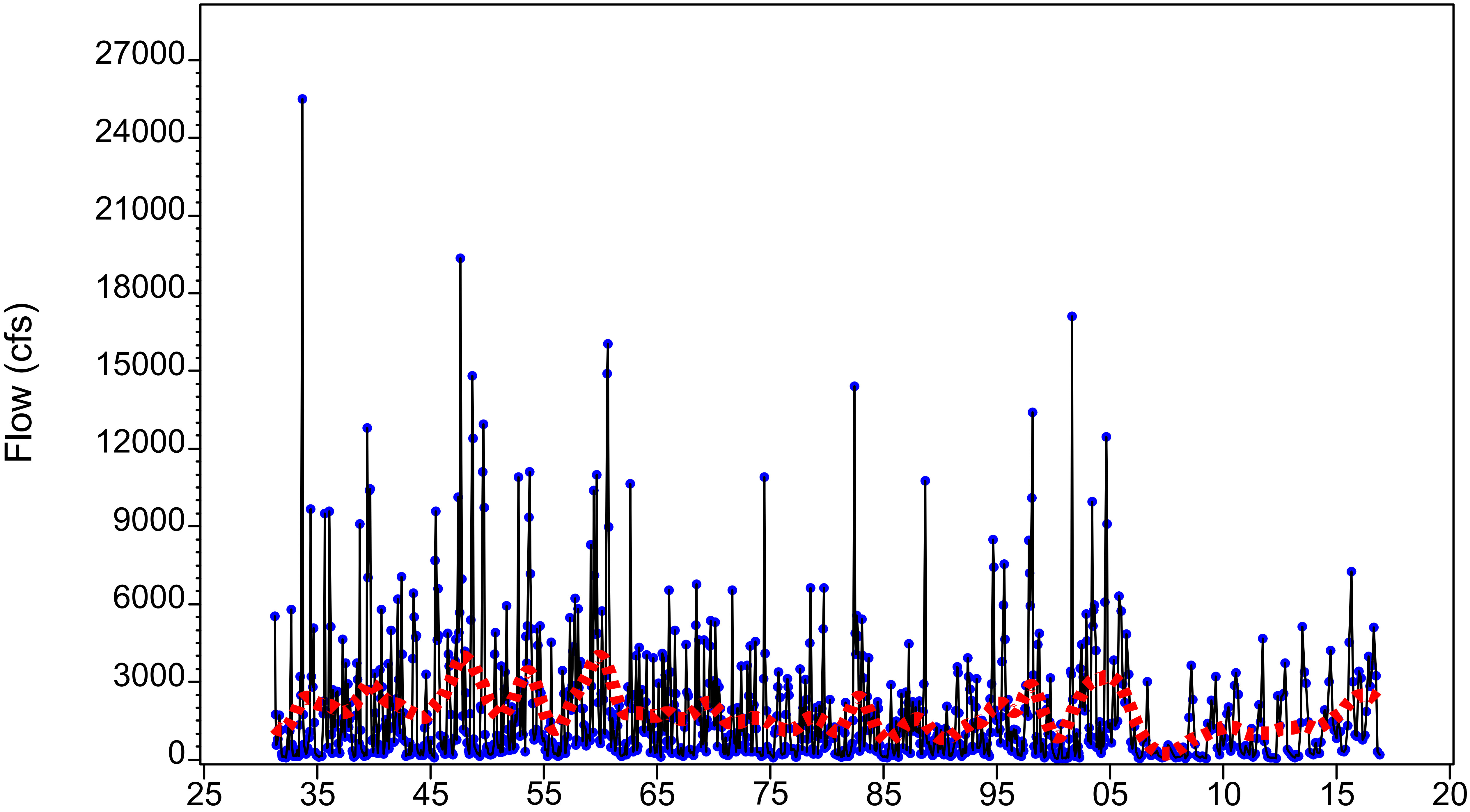


Figure 3.128 Monthly P90 flow at long-term Peace River at Arcadia (2296750) gage (1931-2016)

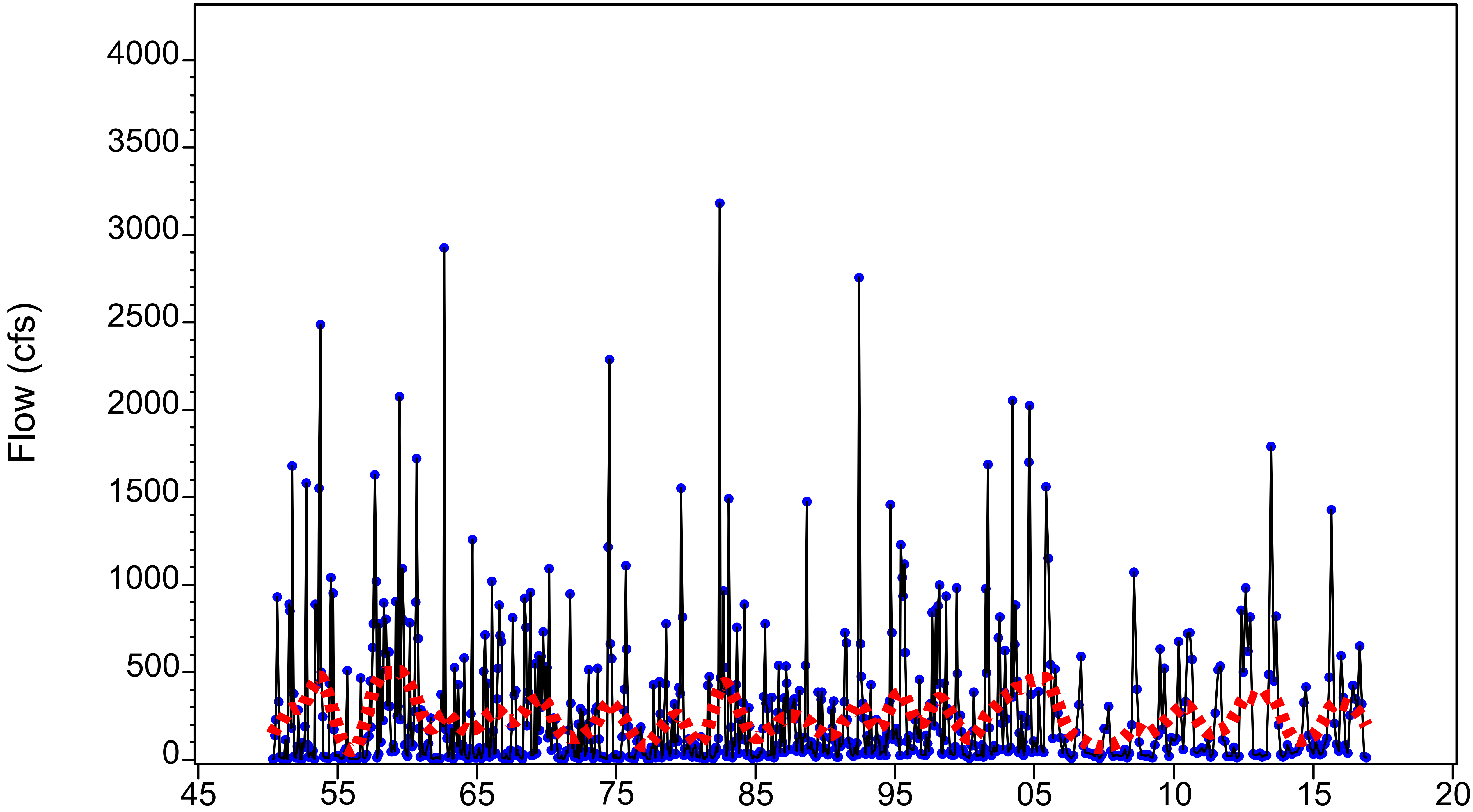


Figure 3.129 Monthly P90 flow at long-term Joshua Creek at Nocatee (2297100) gage (1950-2016)

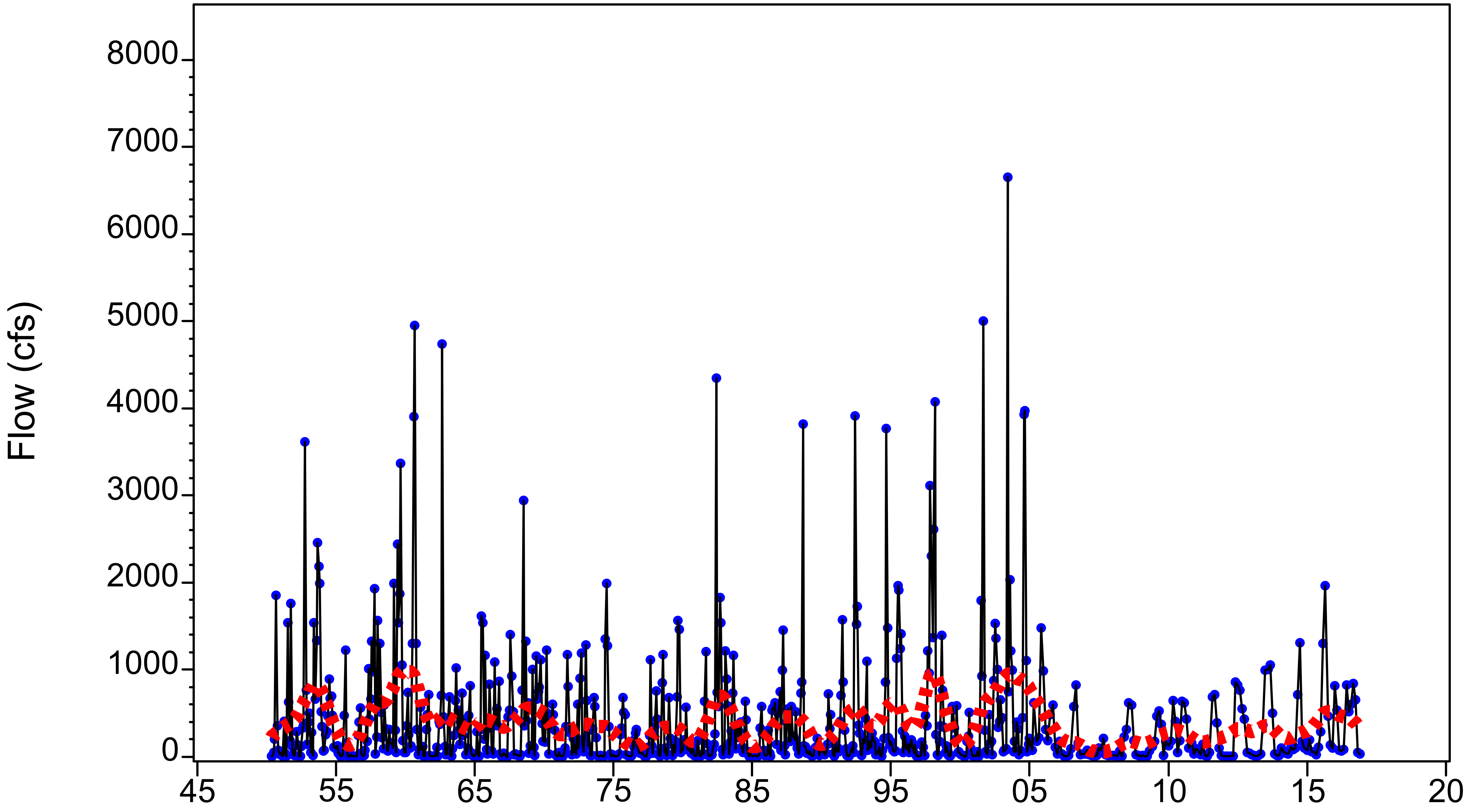


Figure 3.130 Monthly P90 flow at long-term Horse Creek near Arcadia (2297310) gage (1950-2016)

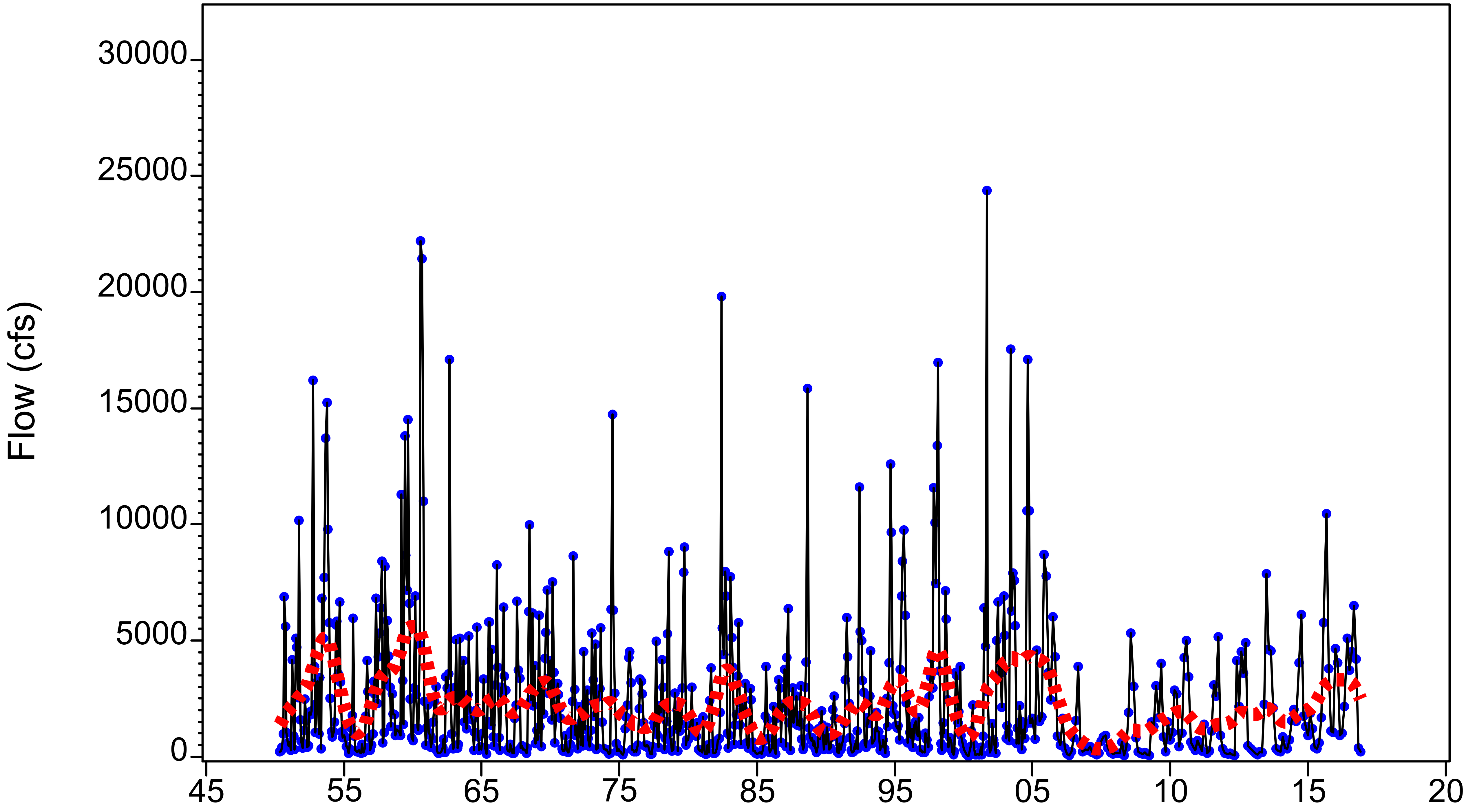


Figure 3.131 Monthly P90 flow at long-term for total gaged flow upstream of the Facility (1950-2016)

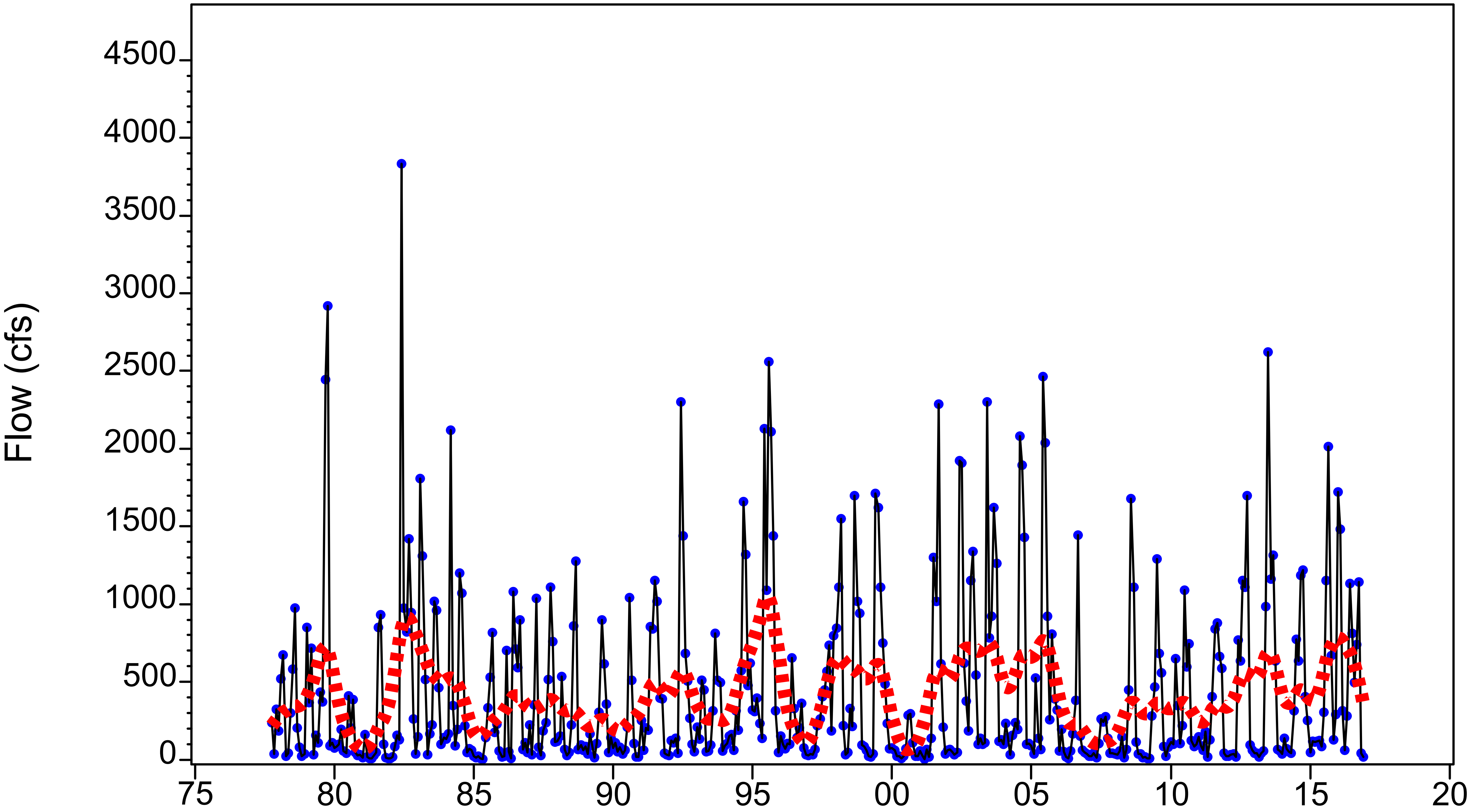


Figure 3.132 Monthly P90 flow at long-term Prairie Creek (2298123) gage (1977-2016)

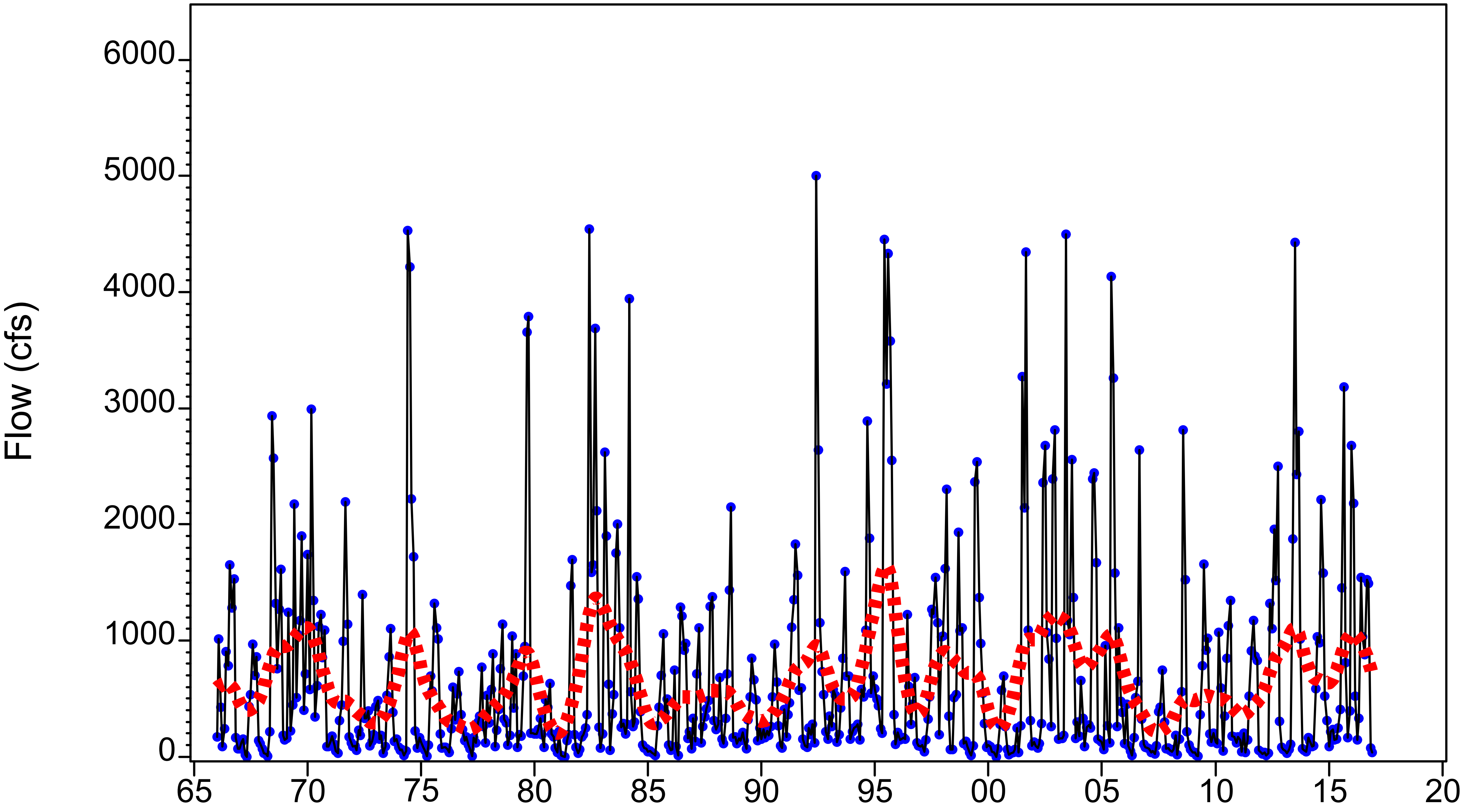


Figure 3.133 Monthly P90 flow at long-term Shell Creek gage (1965-2016)

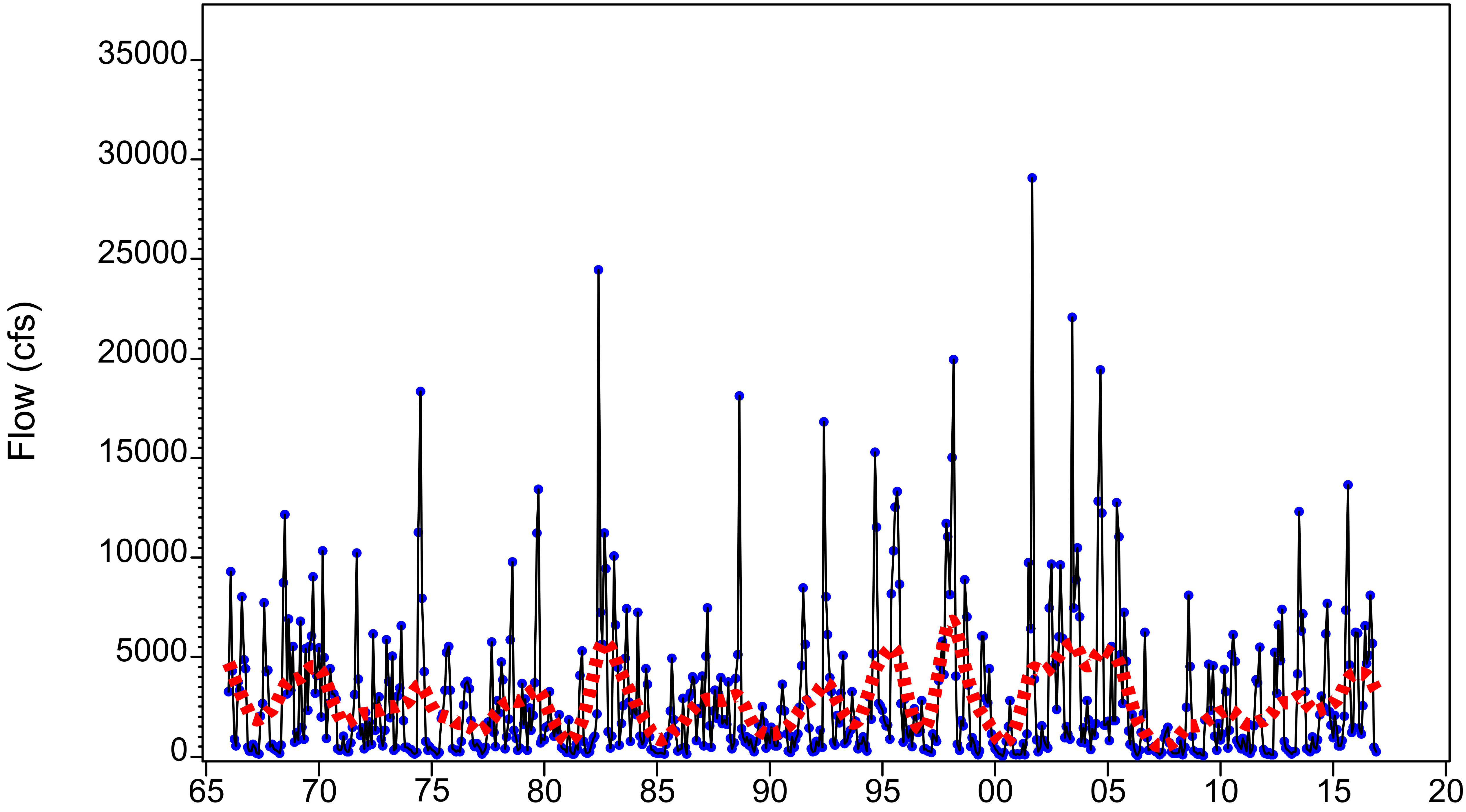


Figure 3.134 Monthly P90 flow of total gaged Peace River flow to the Upper Harbor (1965-2016)

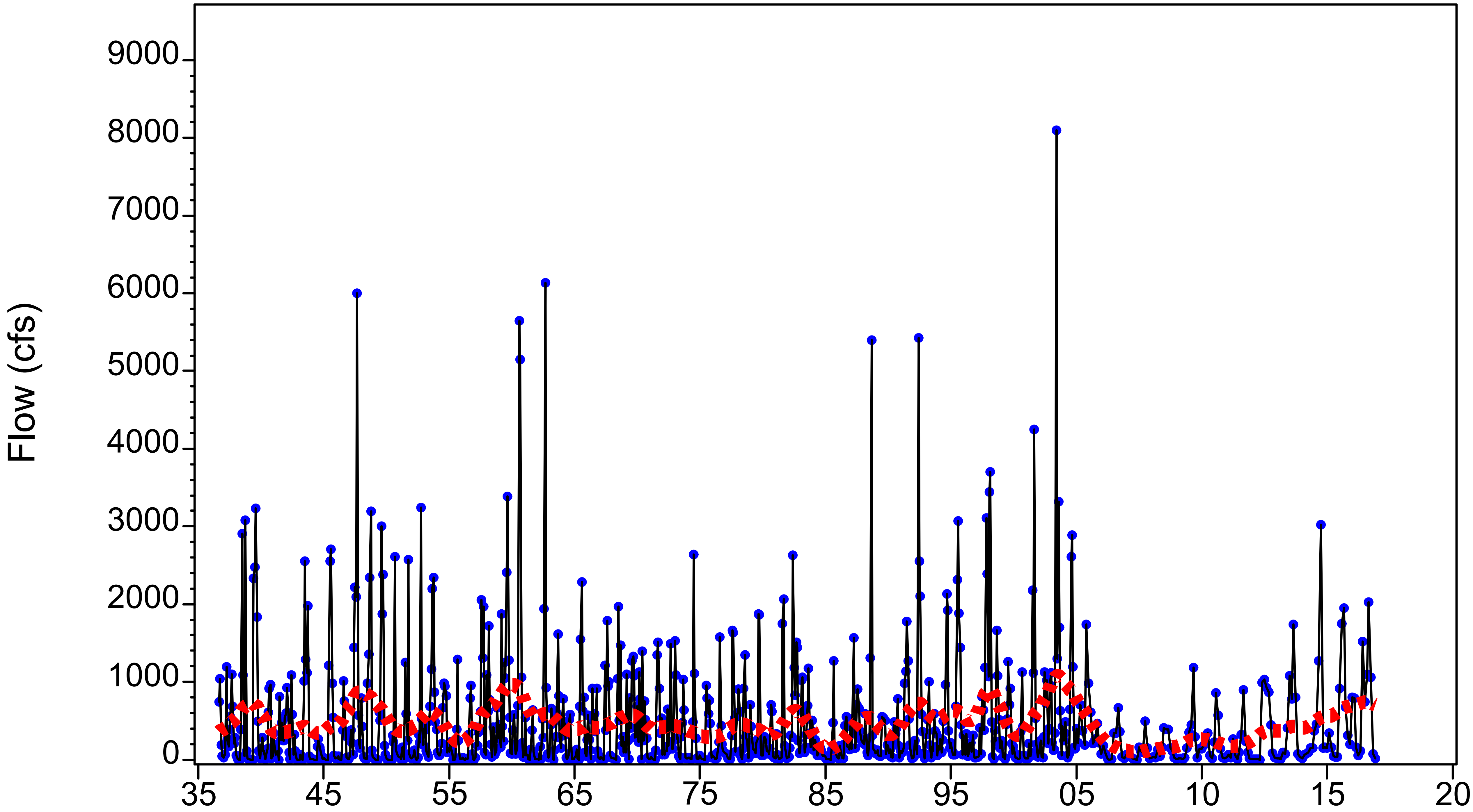


Figure 3.135 Monthly P90 flow at long-term Myakka River near Sarasota (2298830) gage (1936-2016)

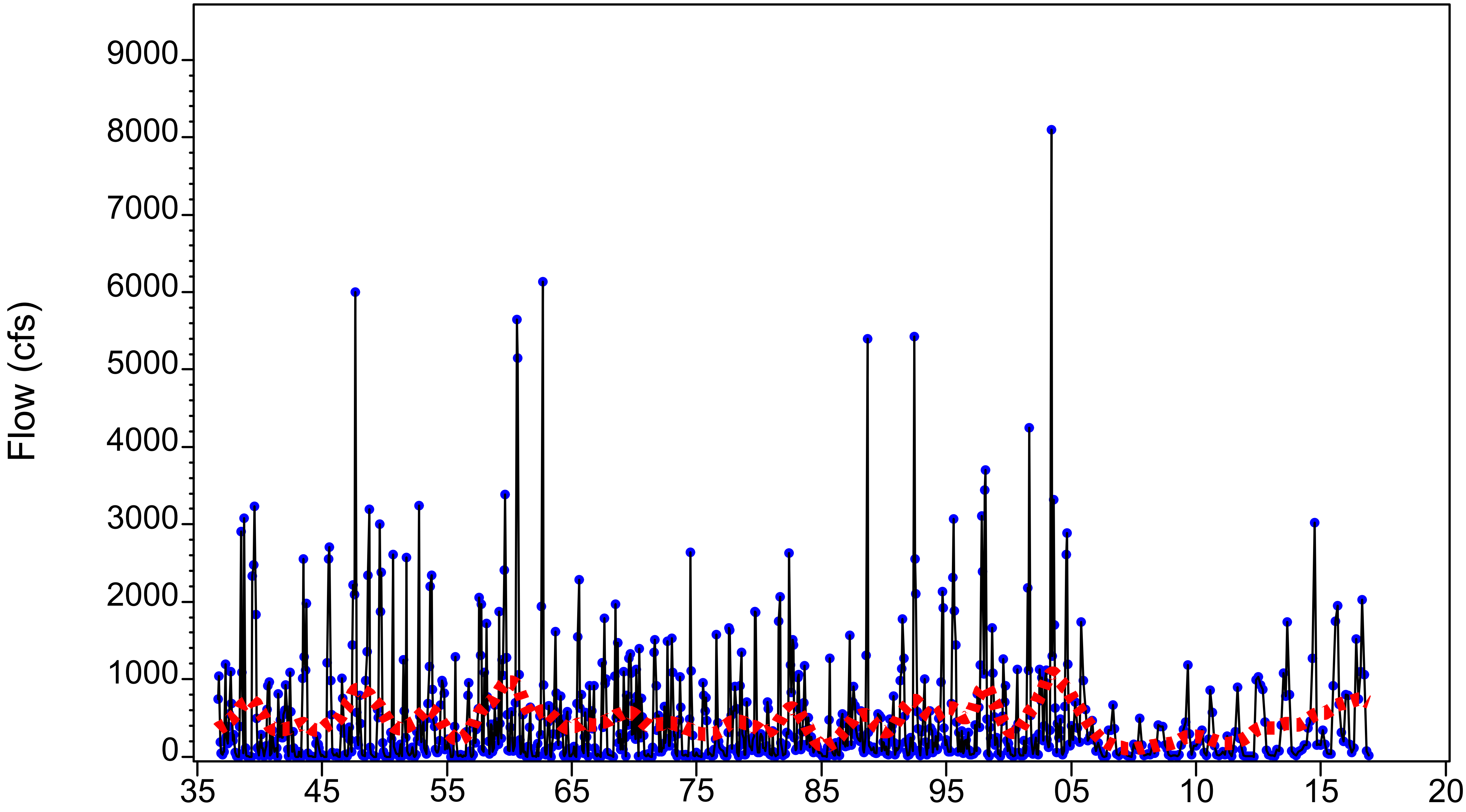


Figure 3.135 Monthly P90 flow at long-term Myakka River near Sarasota (2298830) gage (1936-2016)

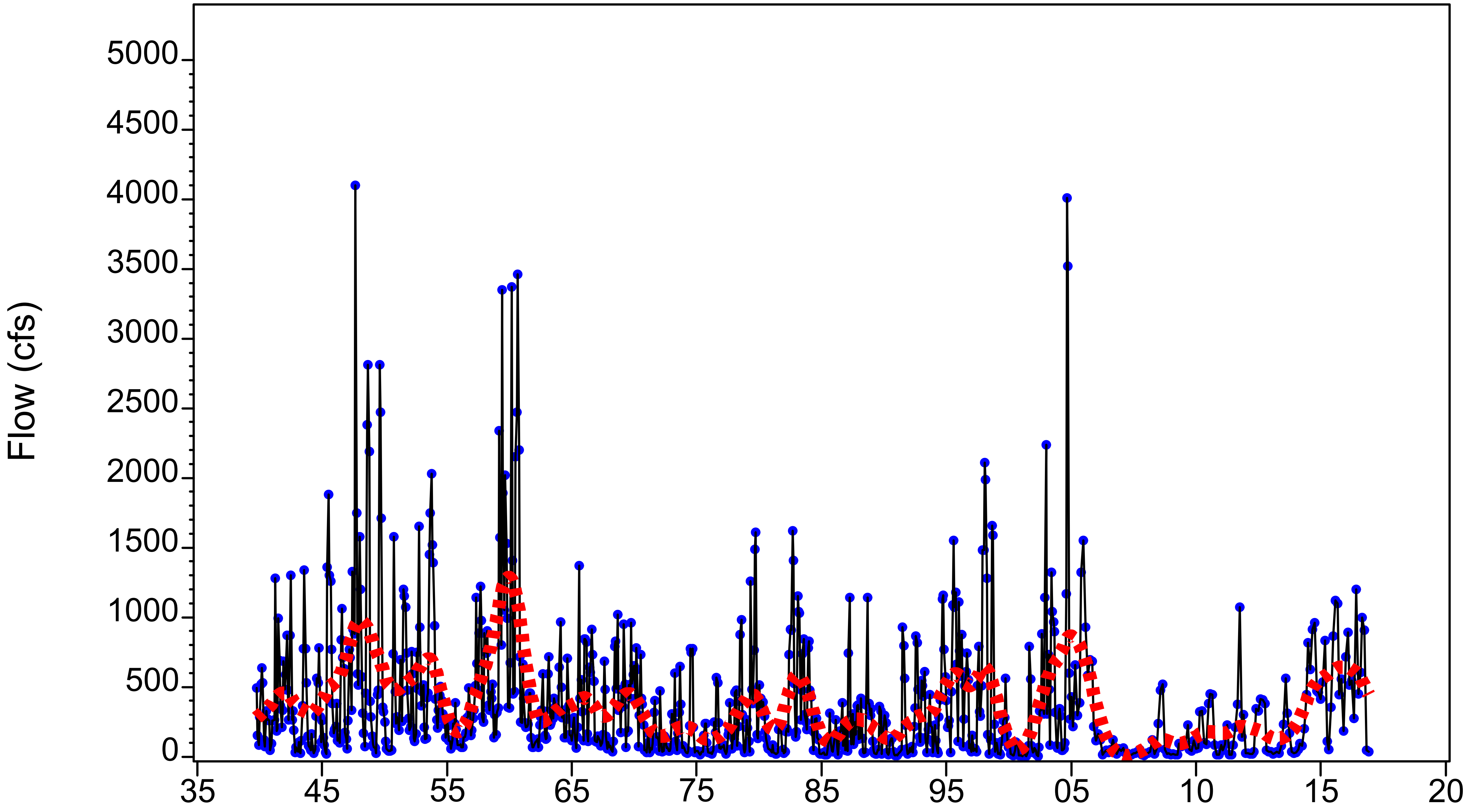


Figure 3.136 Monthly P100 (maximum) flow at long-term Peace River at Bartow (2294650) gage (1939-2016)

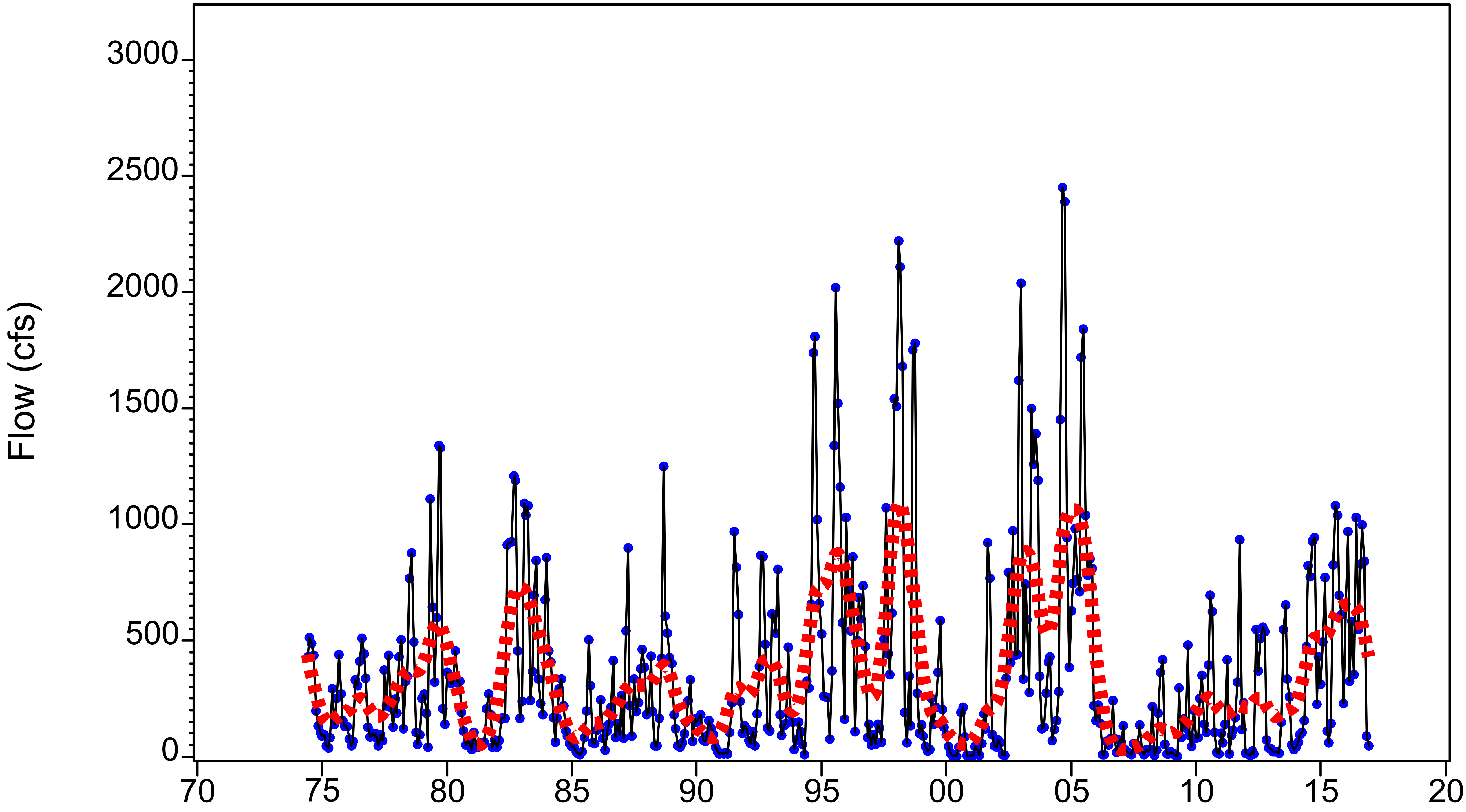


Figure 3.137 Monthly P100 (maximum) flow at long-term Peace River at Ft. Meade (2294898) gage (1974-2016)

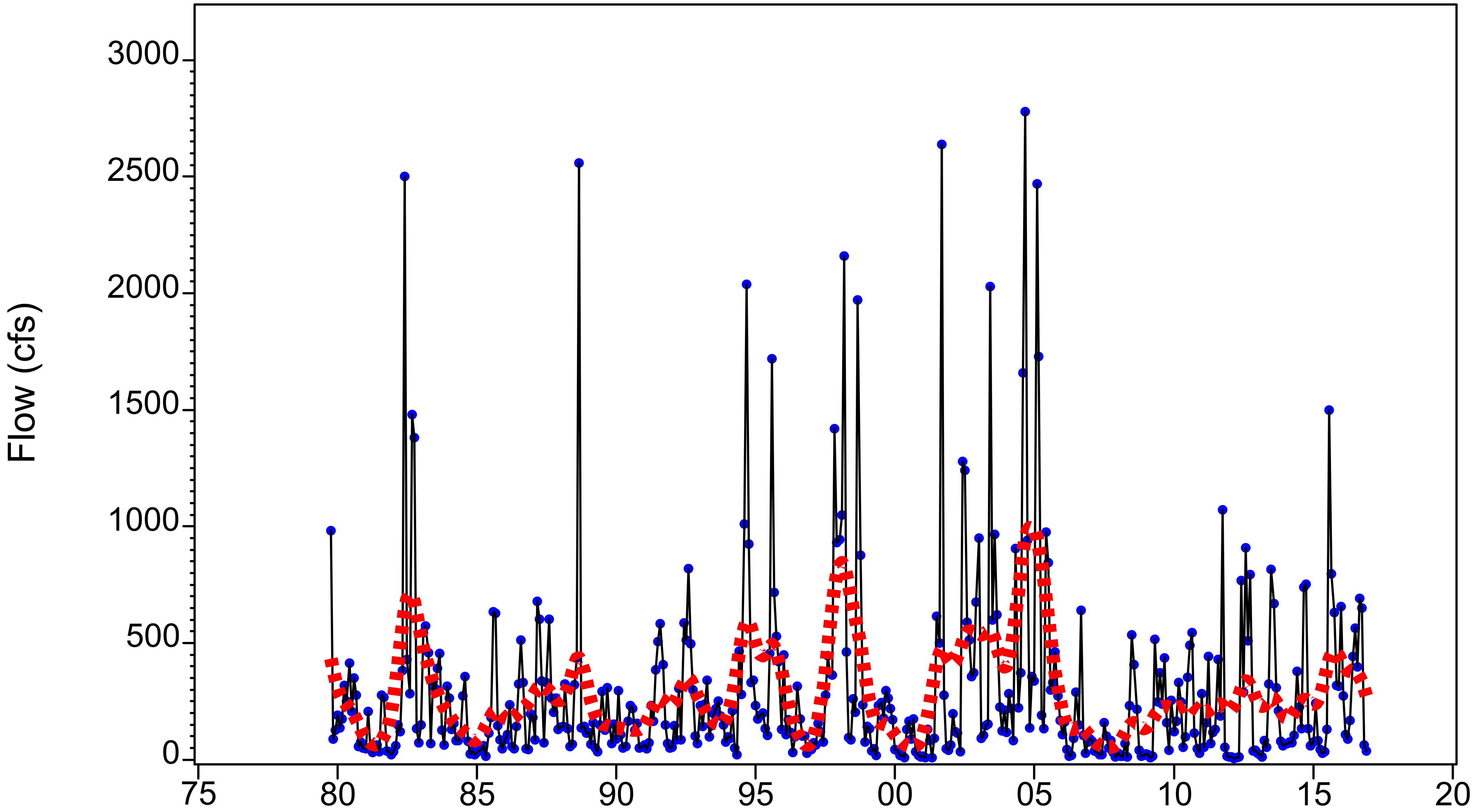


Figure 3.138 Monthly P100 (maximum) flow at long-term Payne Creek (2295420) gage (1979-2016)

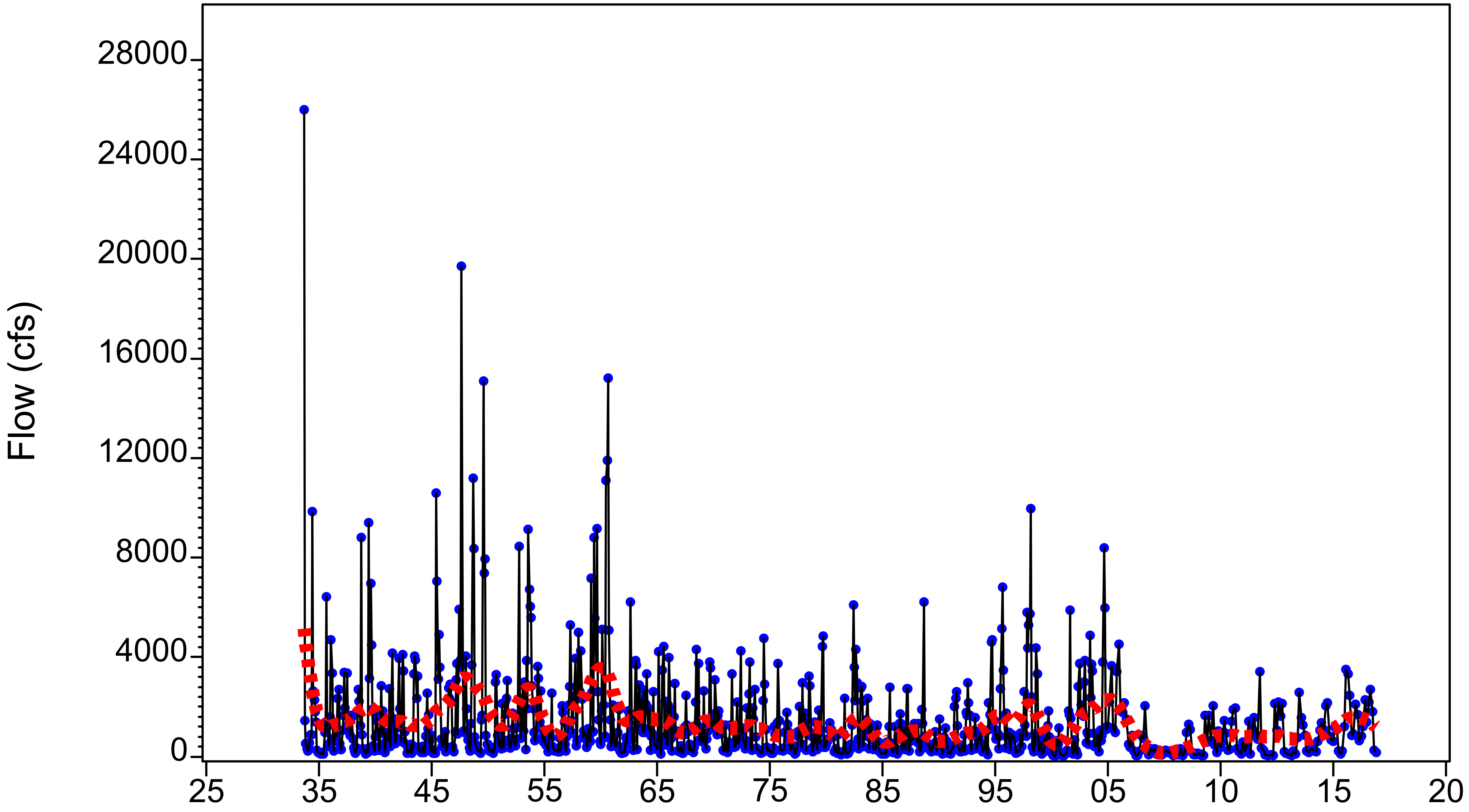


Figure 3.139 Monthly P100 (maximum) flow at long-term Peace River at Zolfo (2295637) gage (1933-2016)

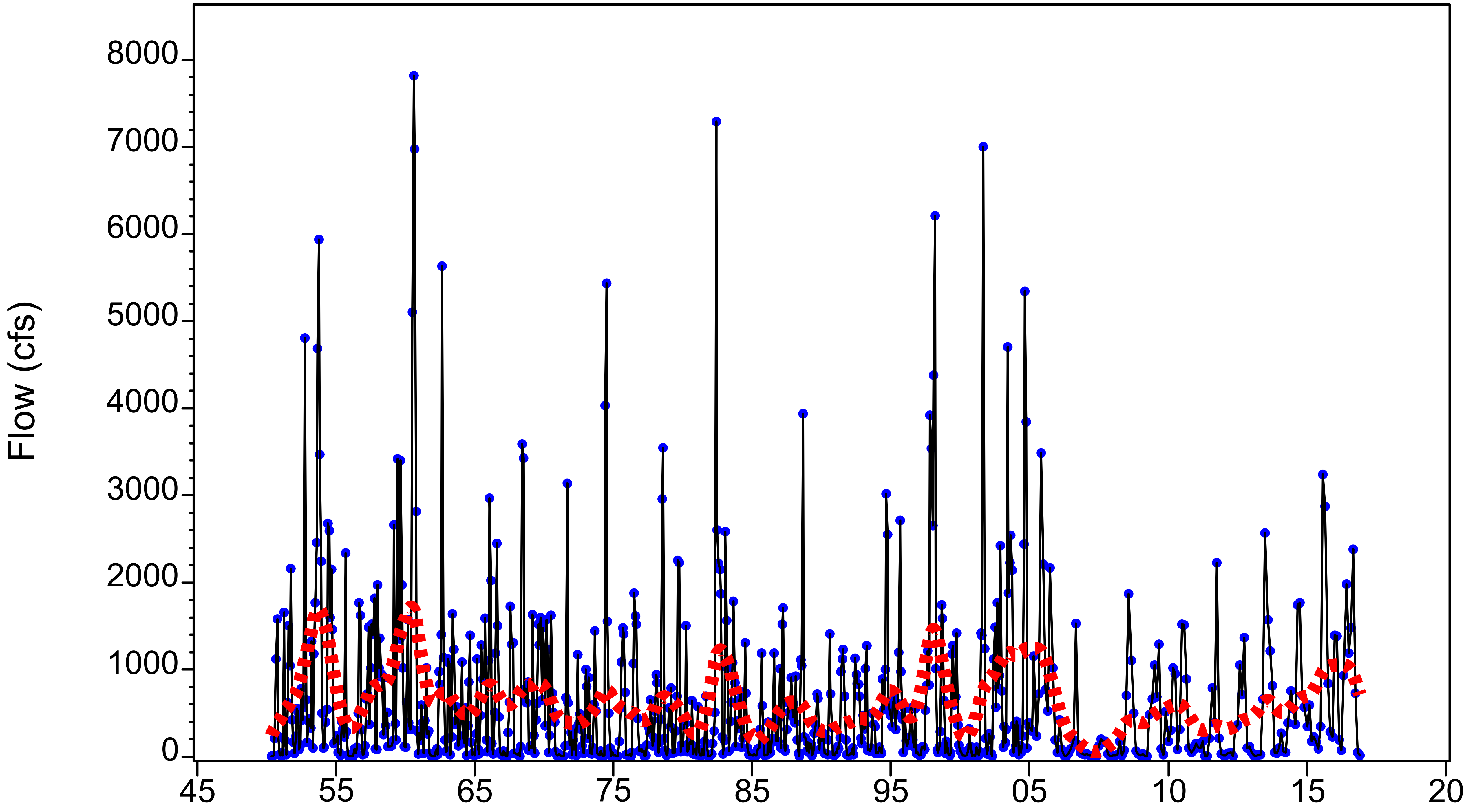


Figure 3.140 Monthly P100 (maximum) flow at long-term Charlie Creek (2296500) gage (1950-2016)

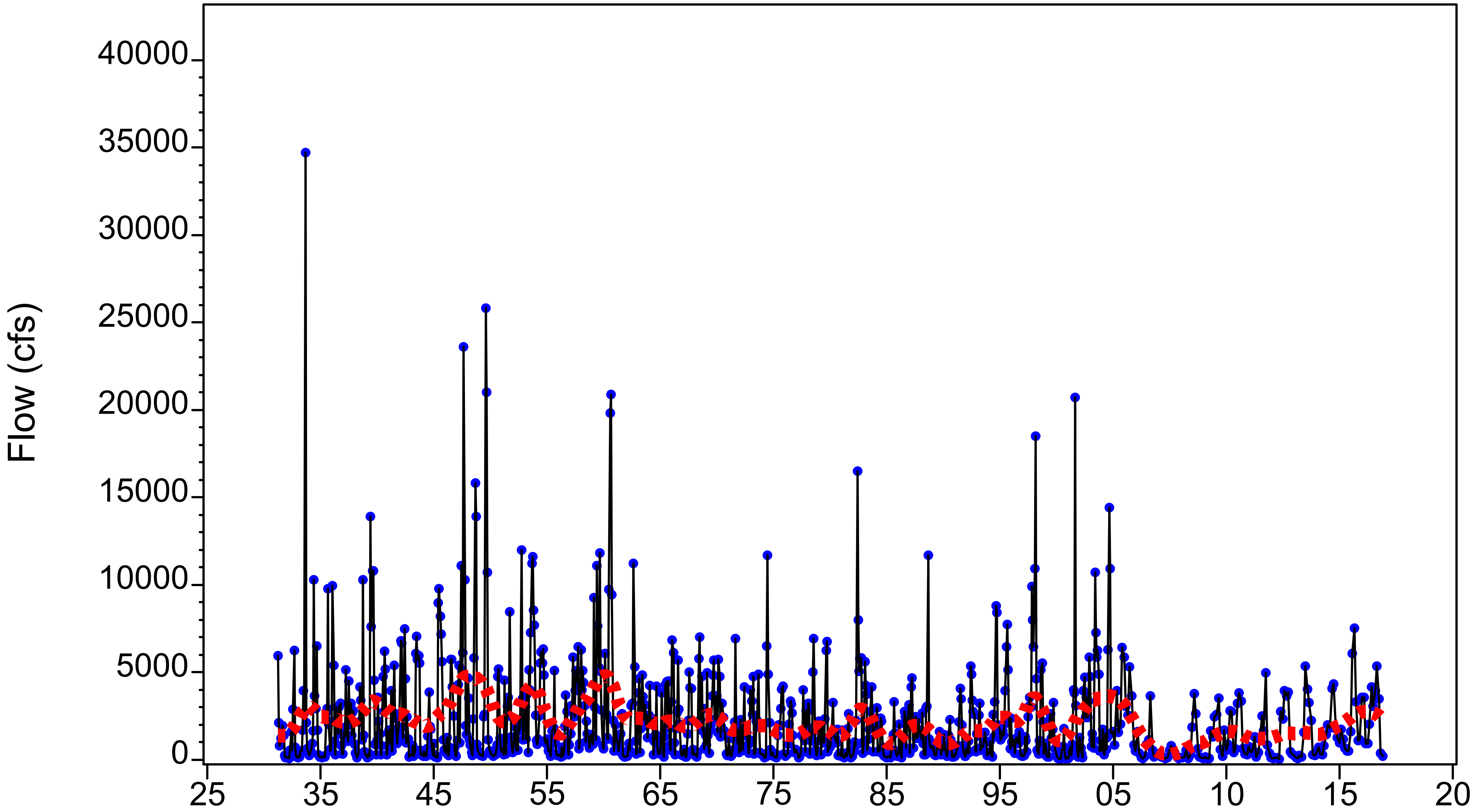


Figure 3.141 Monthly P100 (maximum) flow at long-term Peace River at Arcadia (2296750) gage (1931-2016)

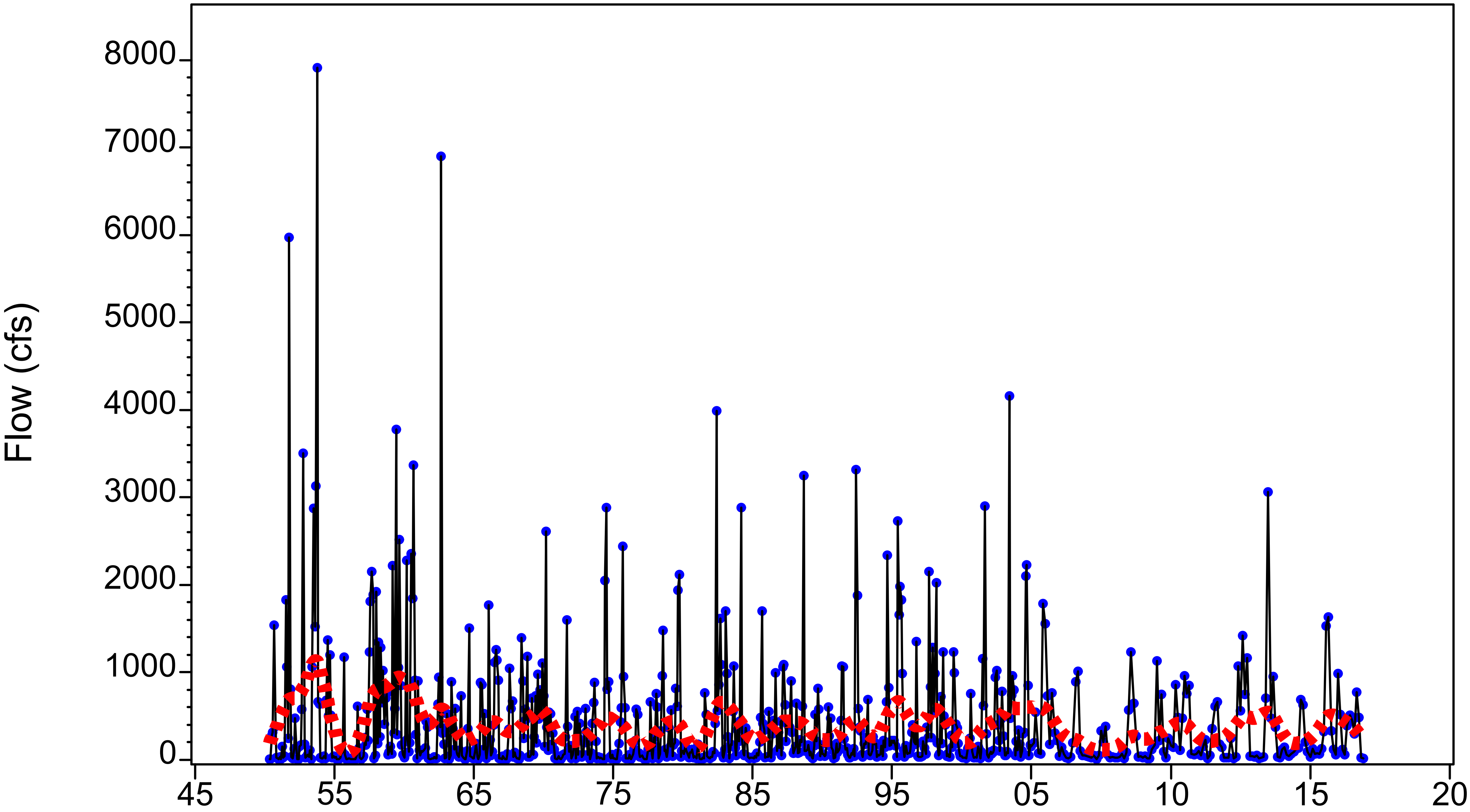


Figure 3.142 Monthly P100 (maximum) flow at long-term Joshua Creek at Nocatee (2297100) gage (1950-2016)

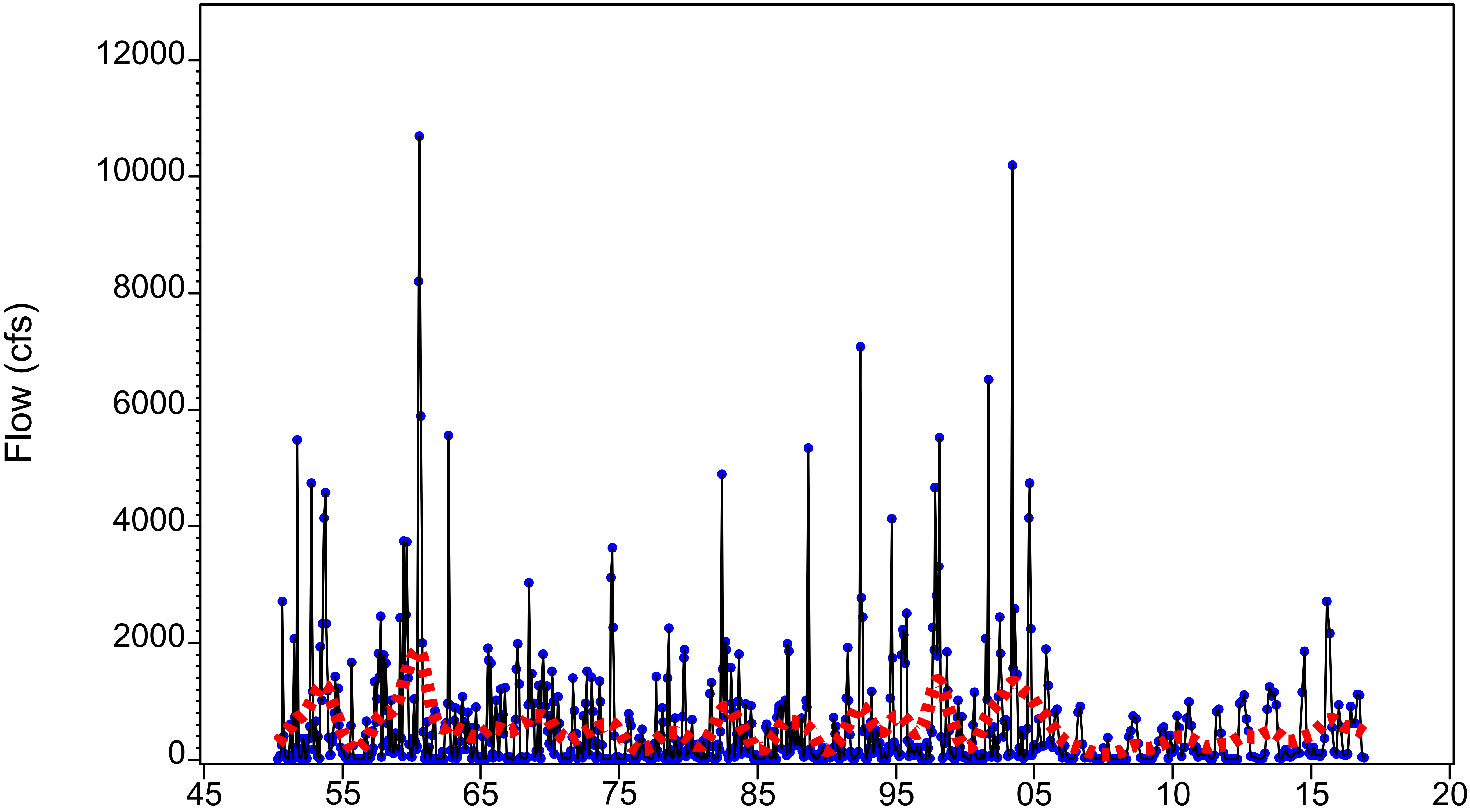


Figure 3.143 Monthly P100 (maximum) flow at long-term Horse Creek near Arcadia (2297310) gage (1950-2016)

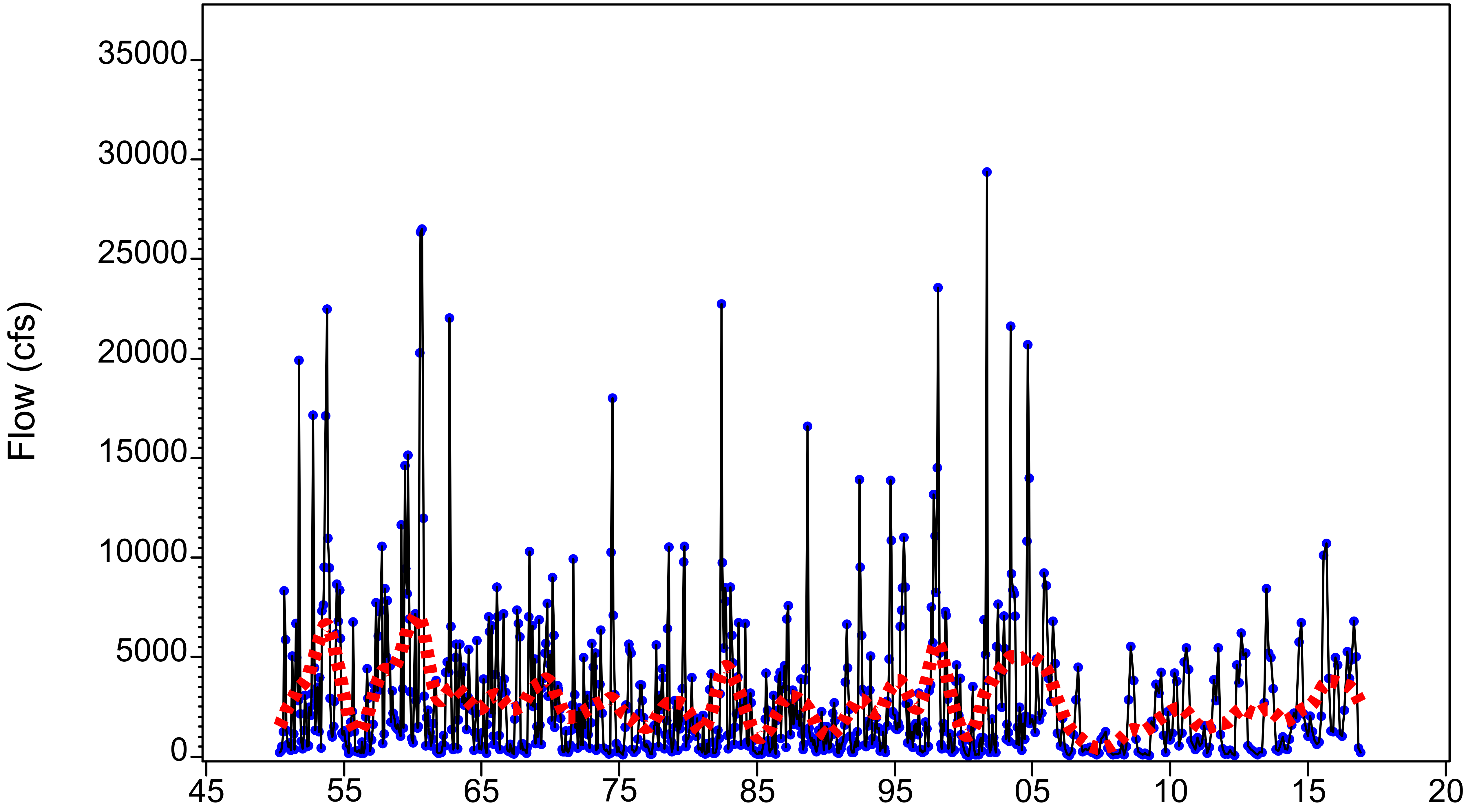


Figure 3.144 Monthly P100 (maximum) flow at long-term for total gaged flow upstream of the Facility (1950-2016)

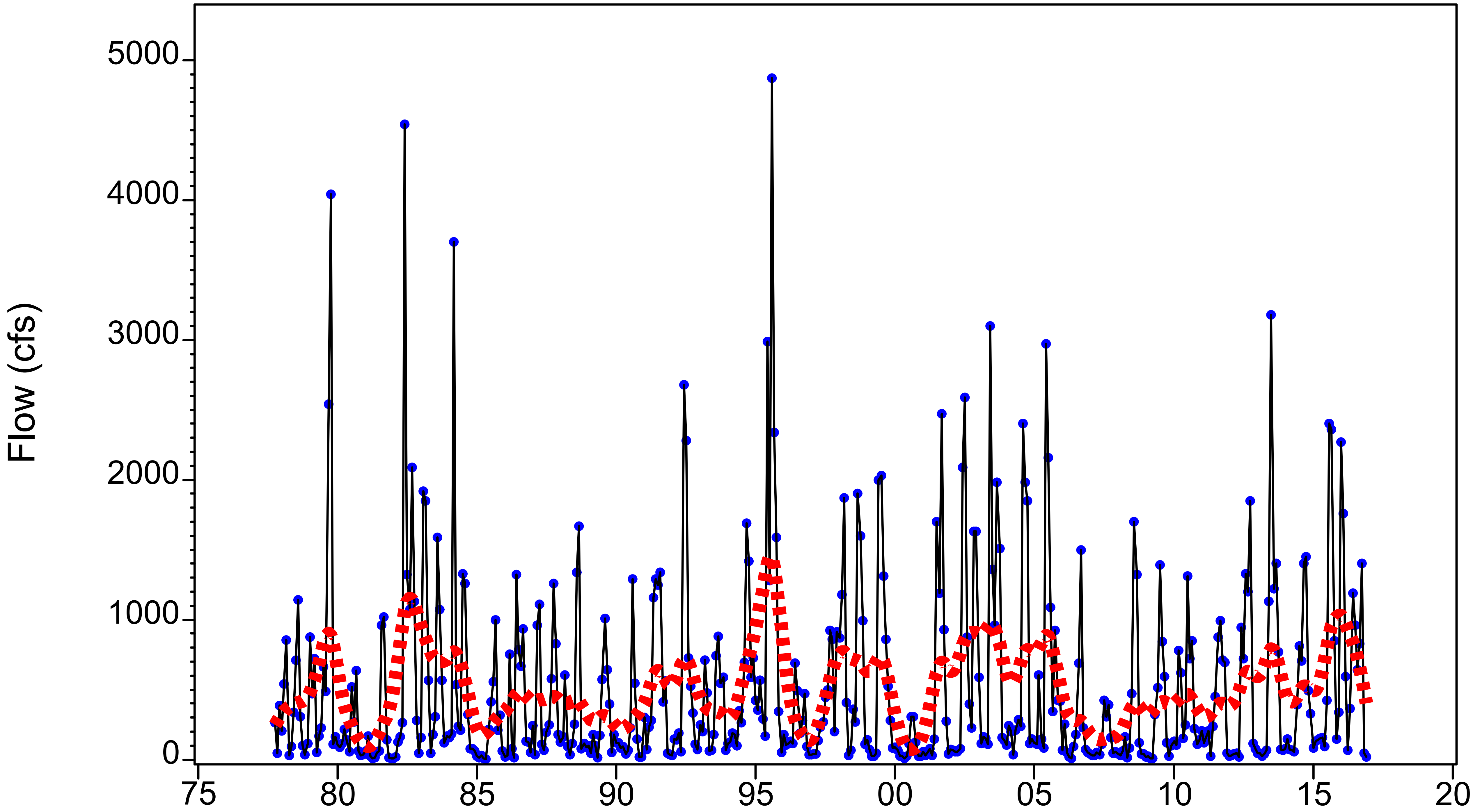


Figure 3.145 Monthly P100 (maximum) flow at long-term Prairie Creek (2298123) gage (1977-2016)

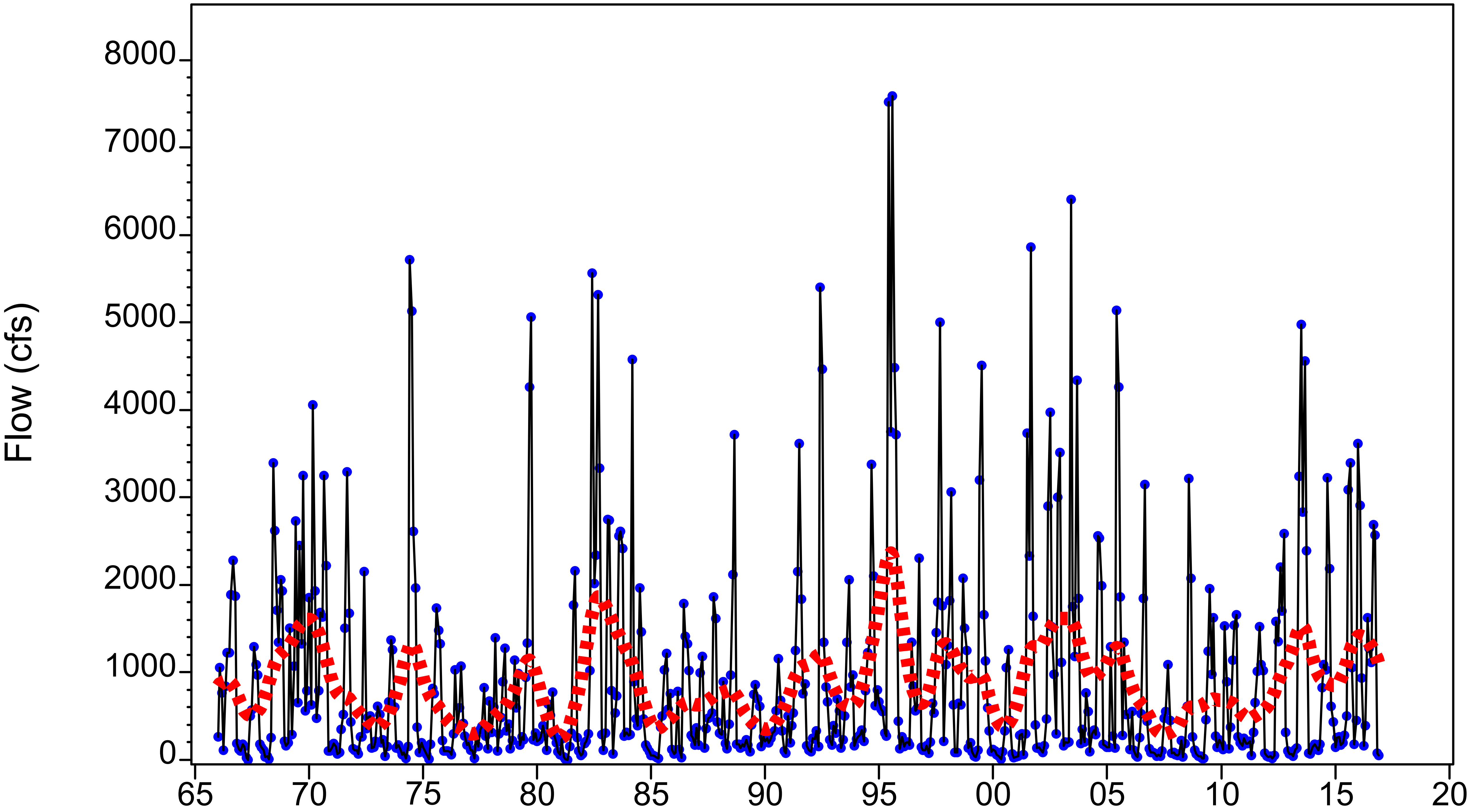


Figure 3.146 Monthly P100 (maximum) flow at long-term Shell Creek gage (1965-2016)

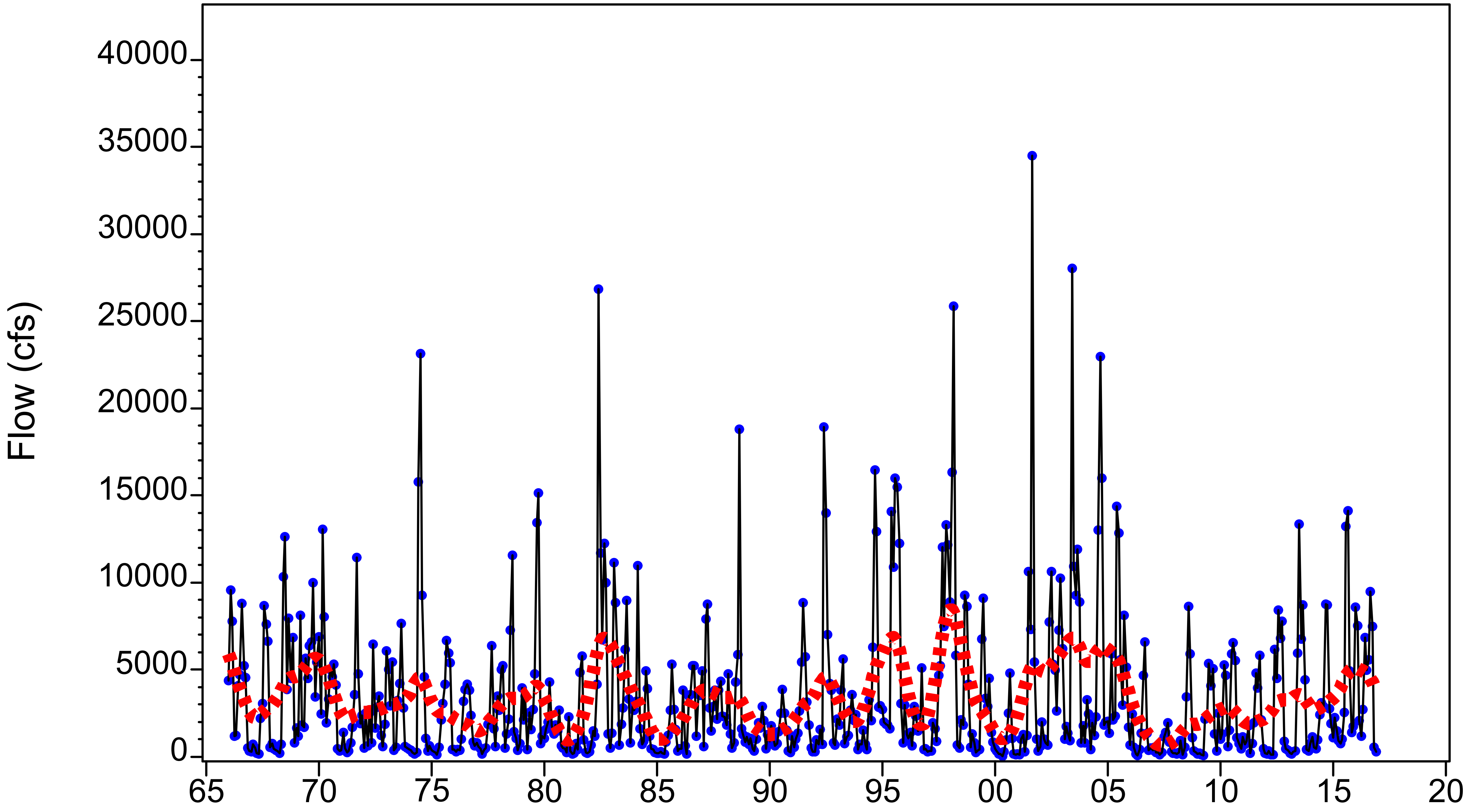


Figure 3.147 Monthly P100 (maximum) flow of total gaged Peace River flow to the Upper Harbor (1965-2016)

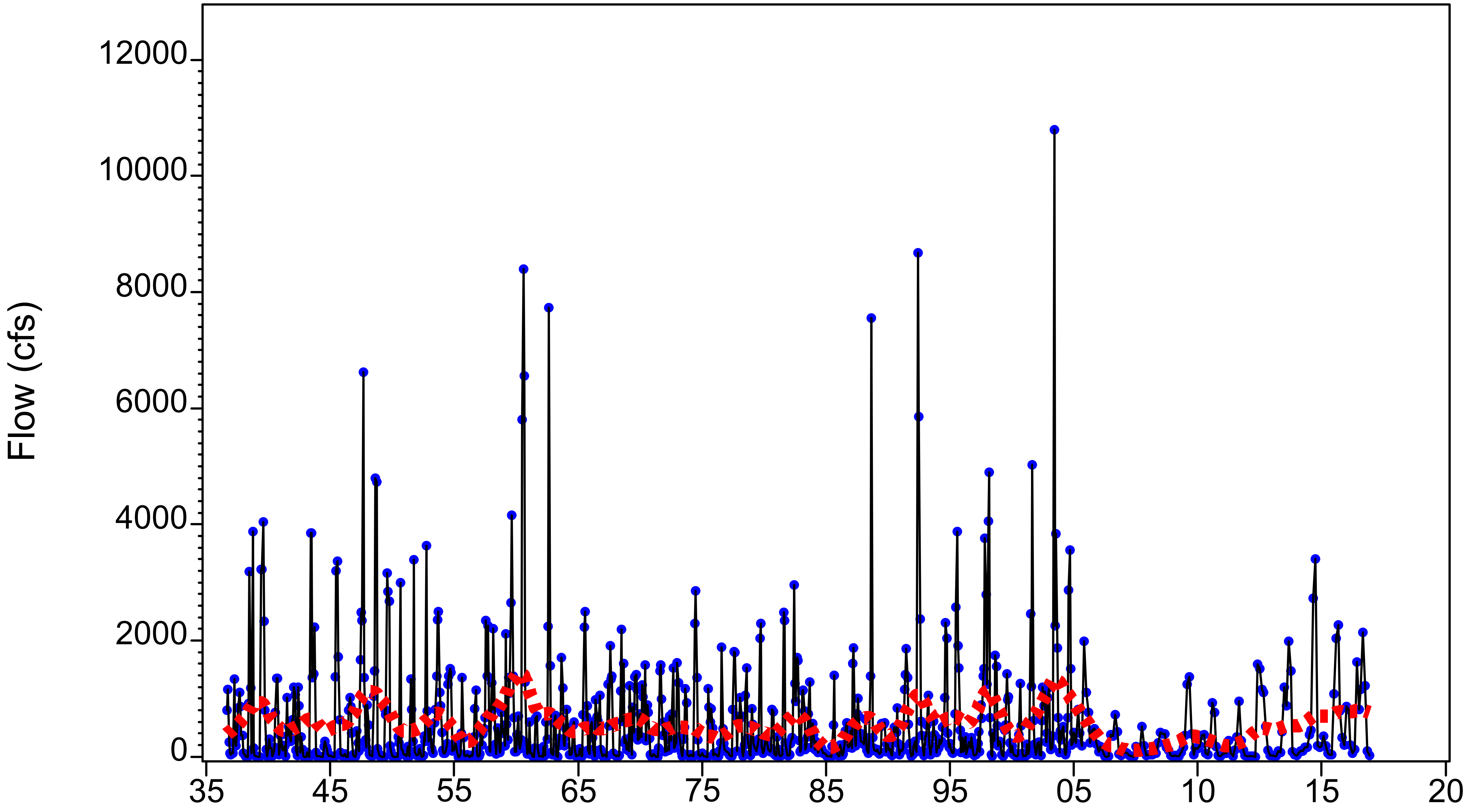


Figure 3.148 Monthly P100 (maximum) flow at long-term Myakka River near Sarasota (2298830) gage (1936-2016)

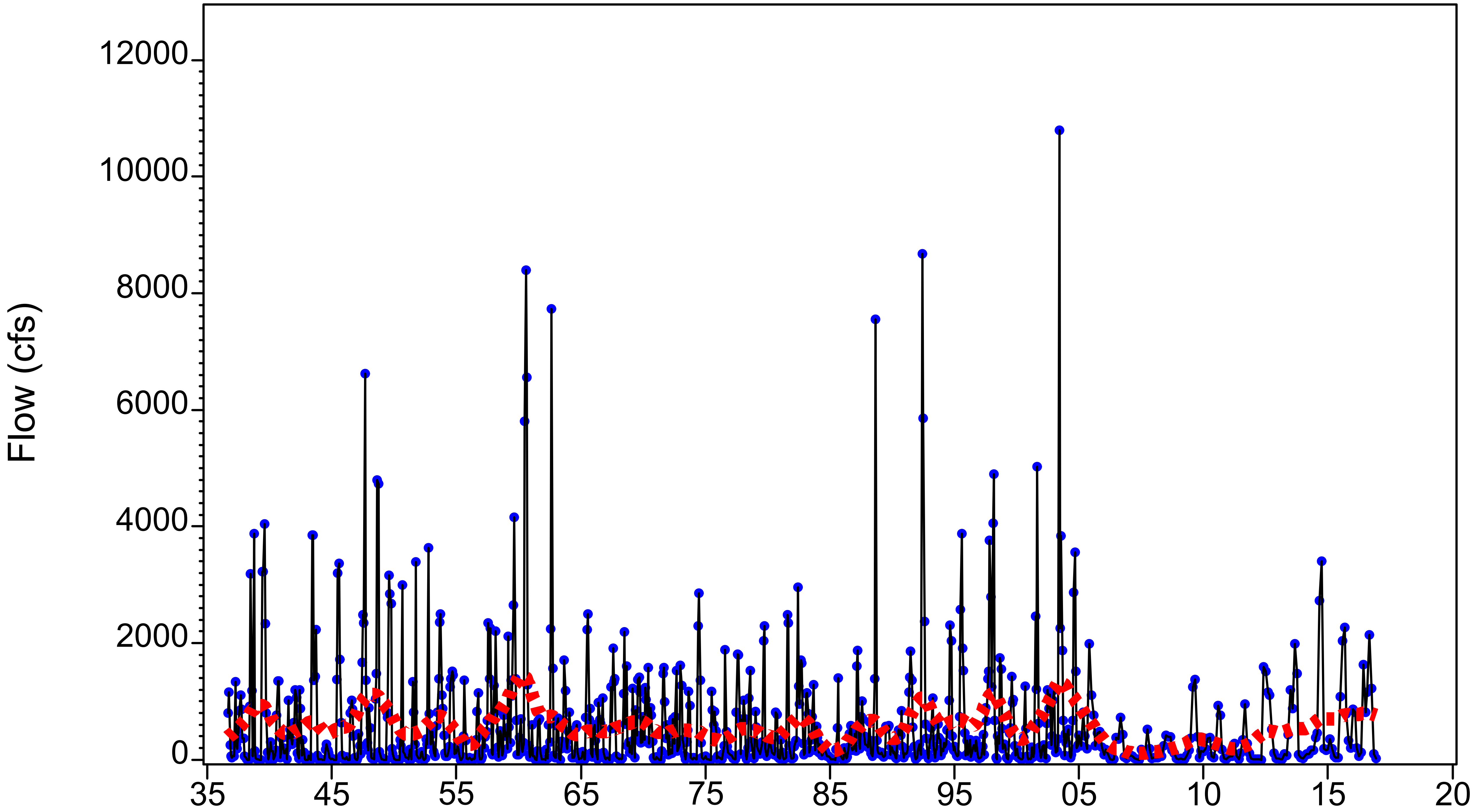


Figure 3.148 Monthly P100 (maximum) flow at long-term Myakka River near Sarasota (2298830) gage (1936-2016)

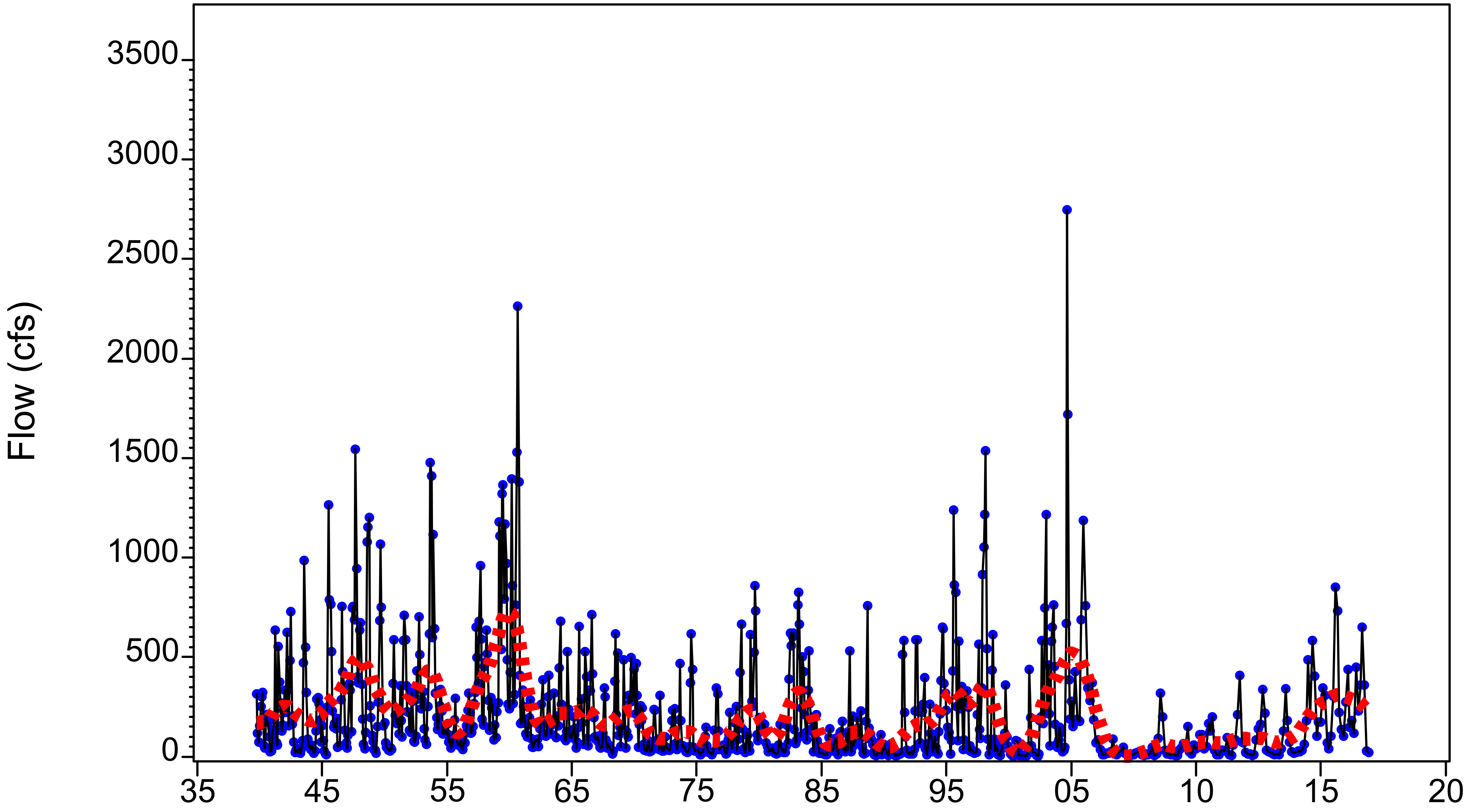


Figure 3.149 Monthly mean flow at long-term Peace River at Bartow (2294650) gage (1939-2016)

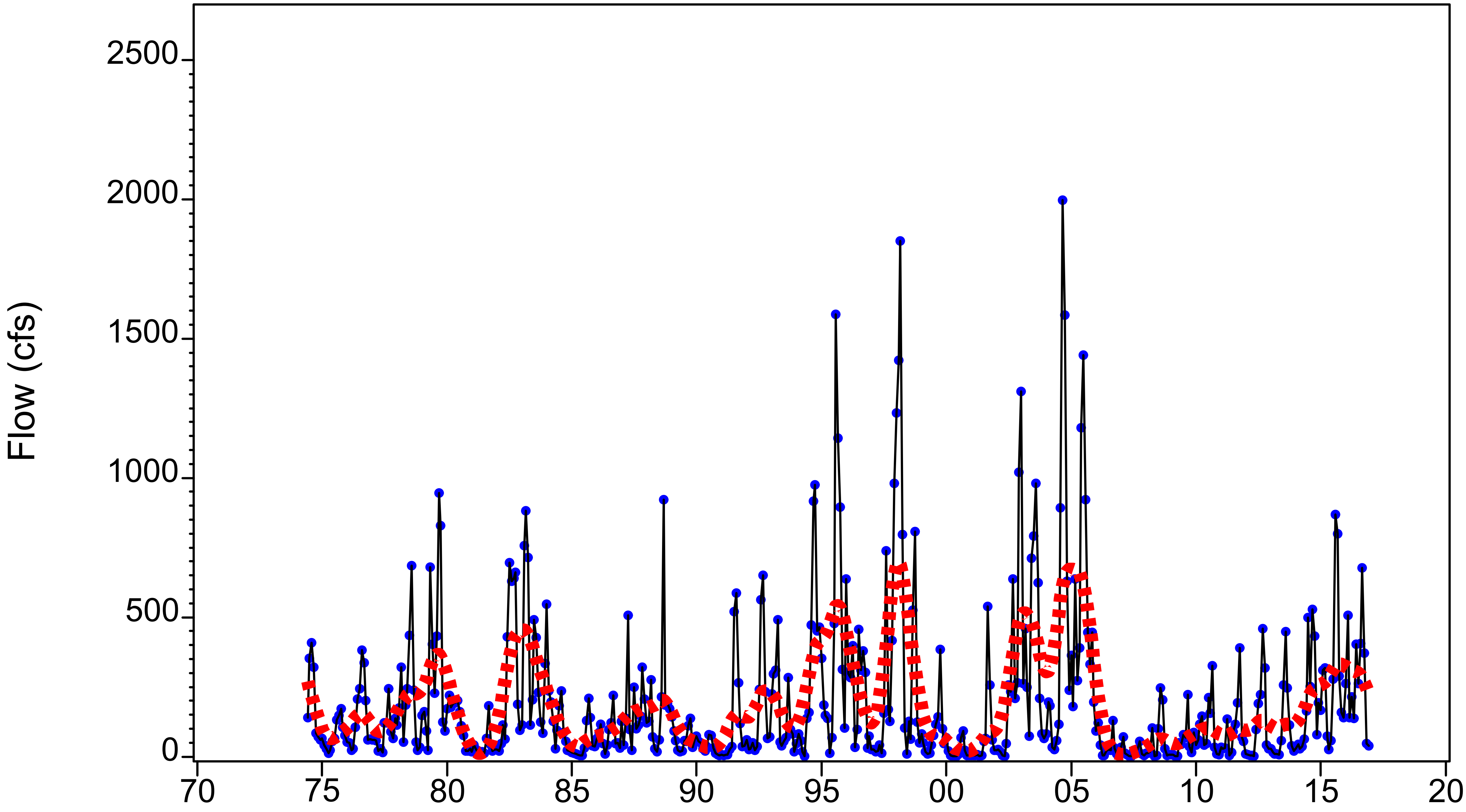


Figure 3.150 Monthly mean flow at long-term Peace River at Ft. Meade (2294898) gage (1974-2016)

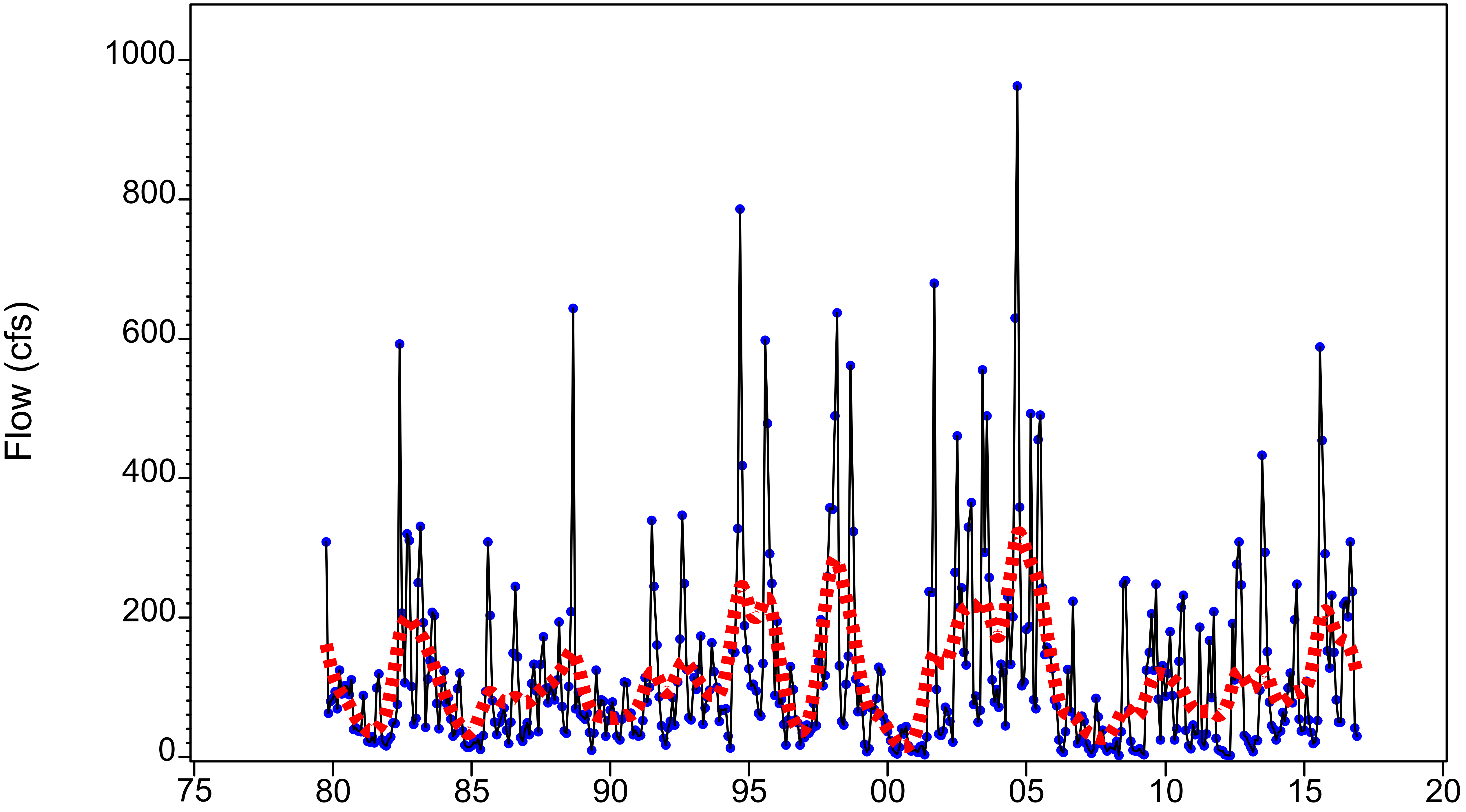


Figure 3.151 Monthly mean flow at long-term Payne Creek (2295420) gage (1979-2016)

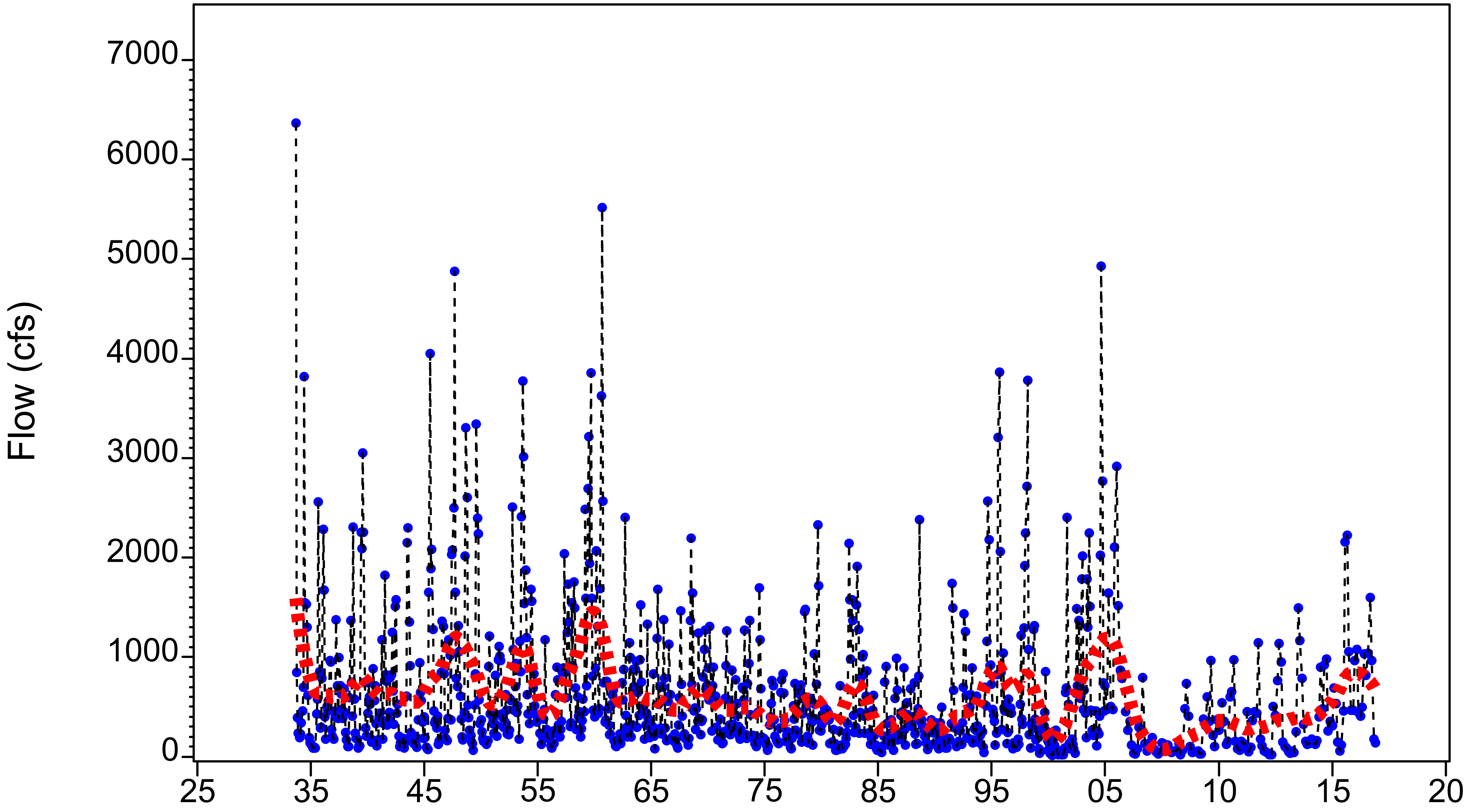


Figure 3.152 Monthly mean flow at long-term Peace River at Zolfo (2295637) gage (1933-2016)

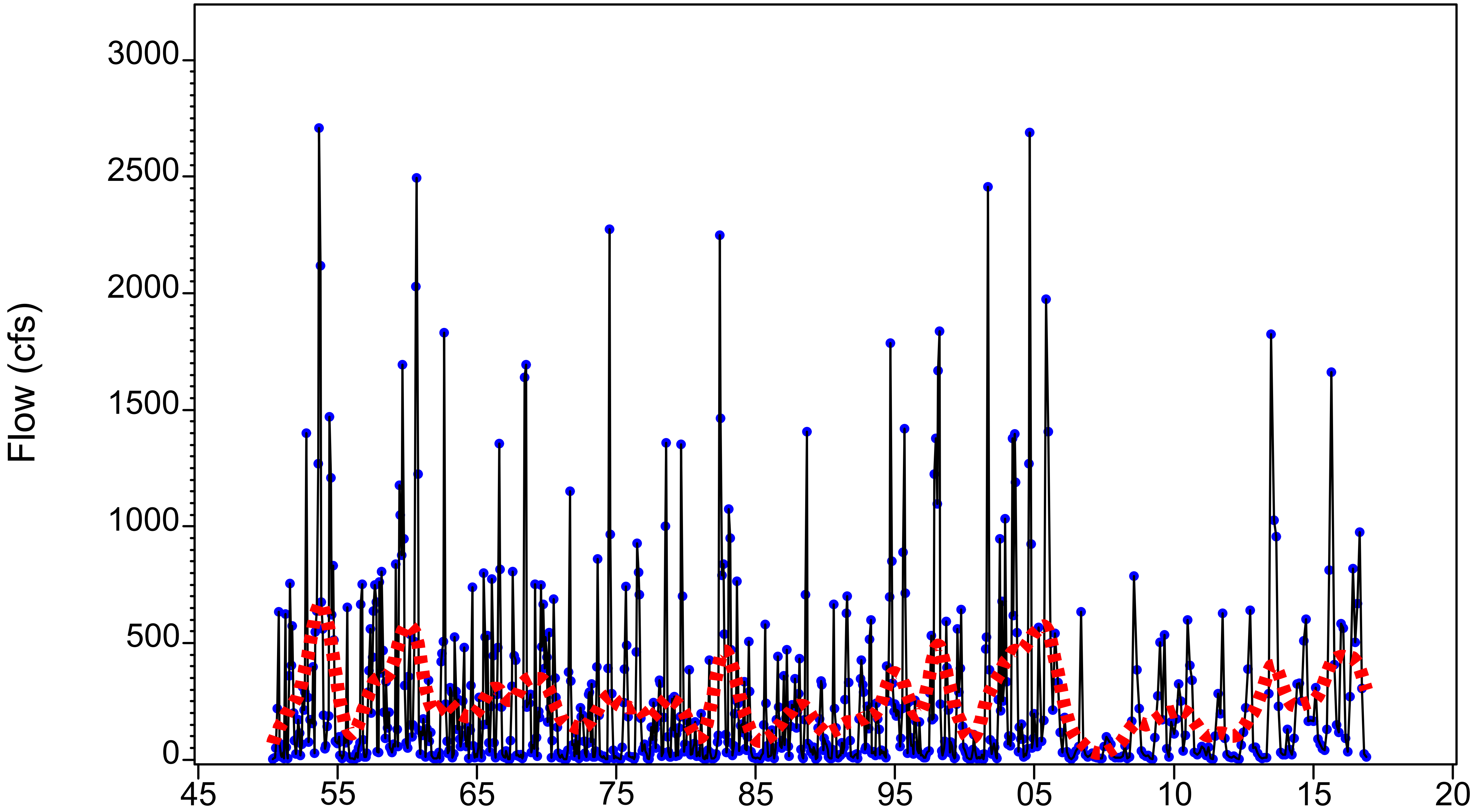


Figure 3.153 Monthly mean flow at long-term Charlie Creek (2296500) gage (1950-2016)

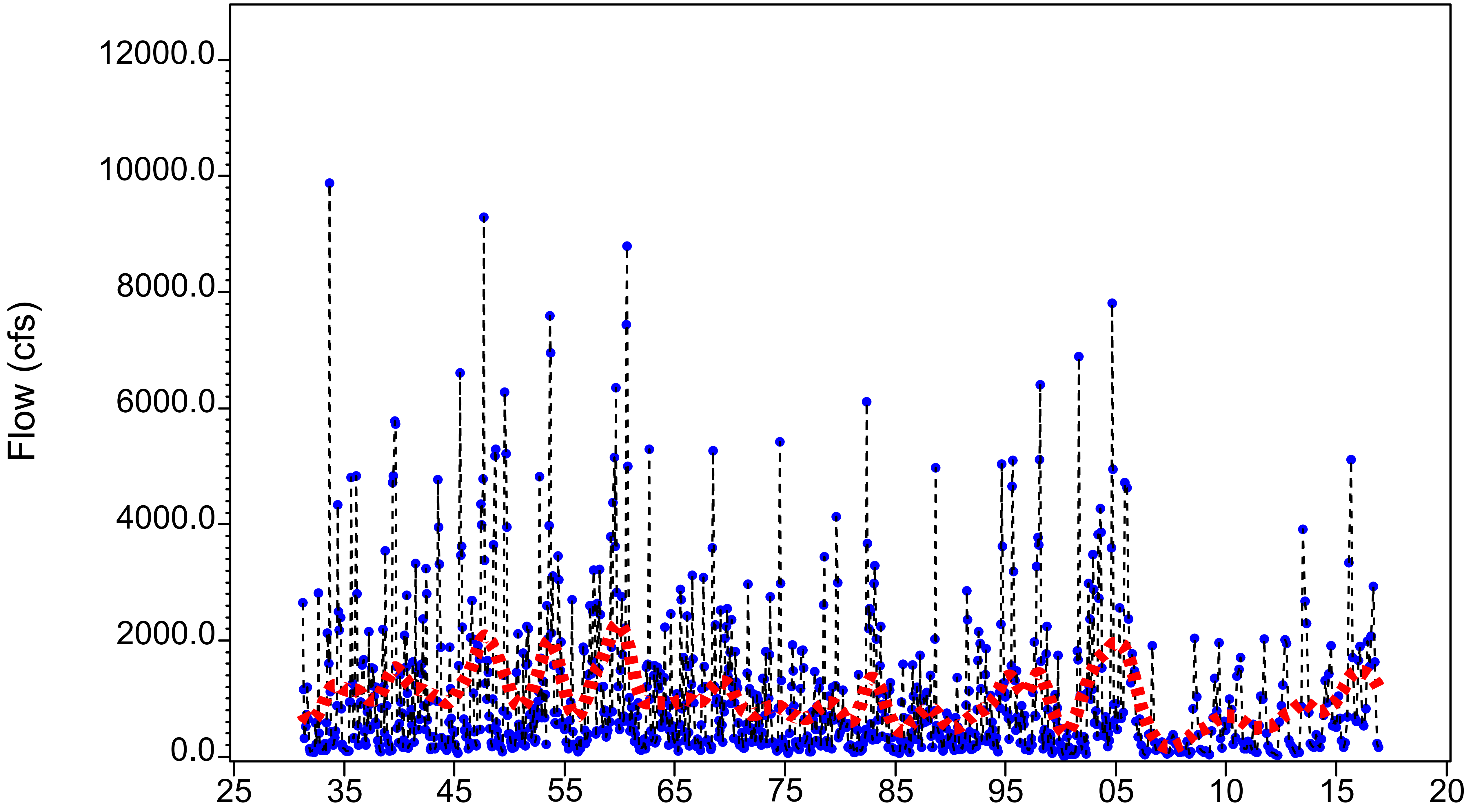


Figure 3.154 Monthly mean flow at long-term Peace River at Arcadia (2296750) gage (1931-2016)

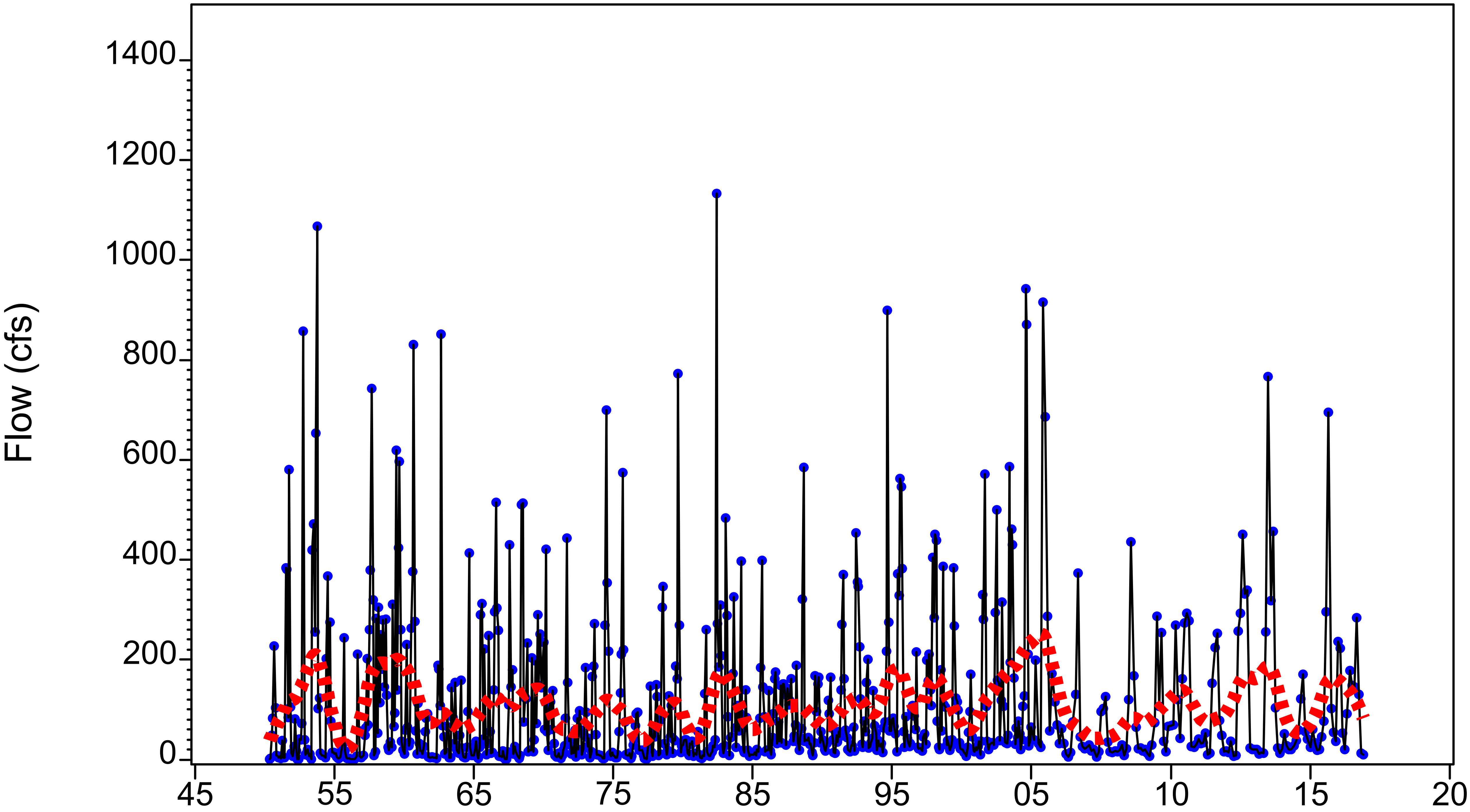


Figure 3.155 Monthly mean flow at long-term Joshua Creek at Nocatee (2297100) gage (1950-2016)

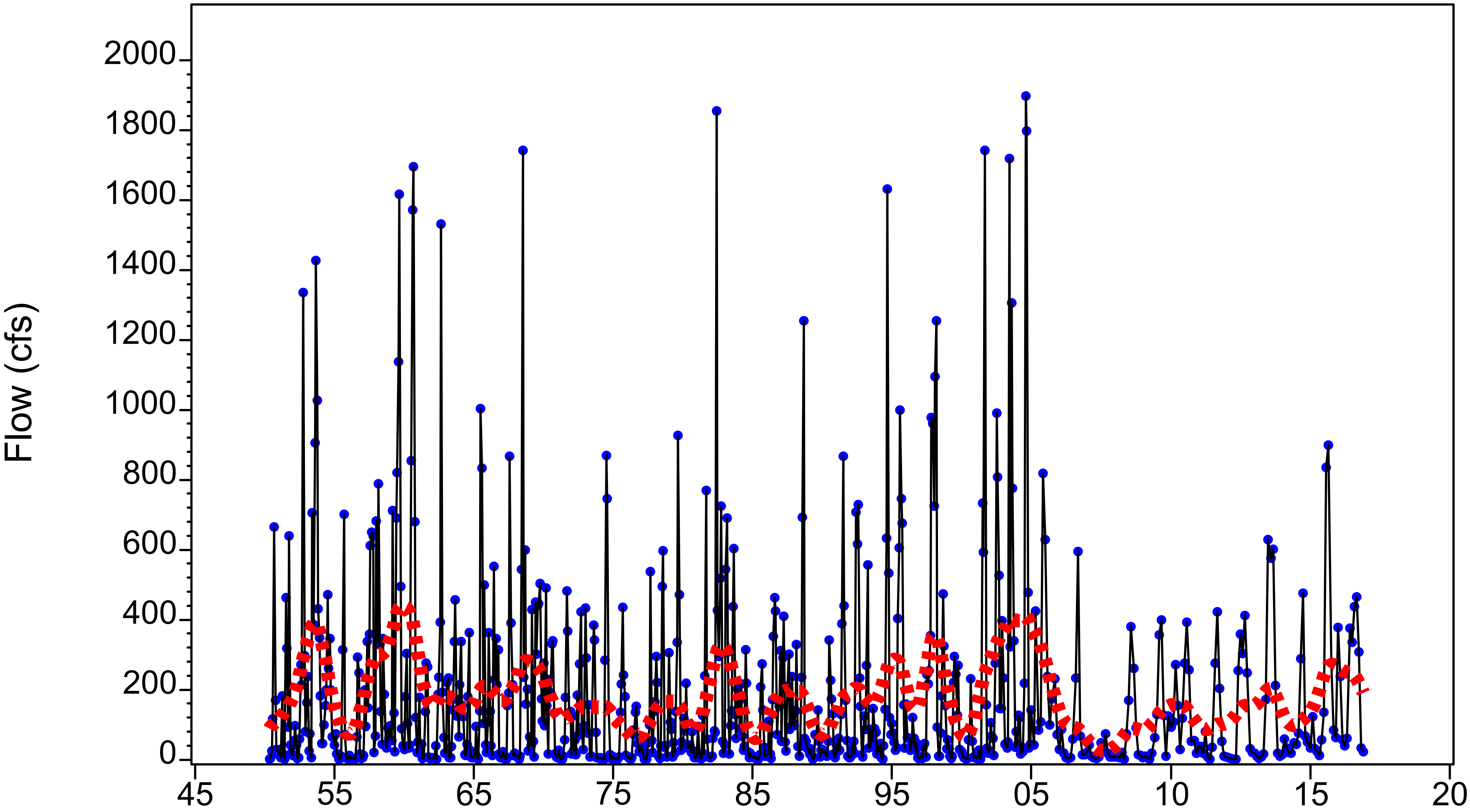


Figure 3.156 Monthly mean flow at long-term Horse Creek near Arcadia (2297310) gage (1950-2016)

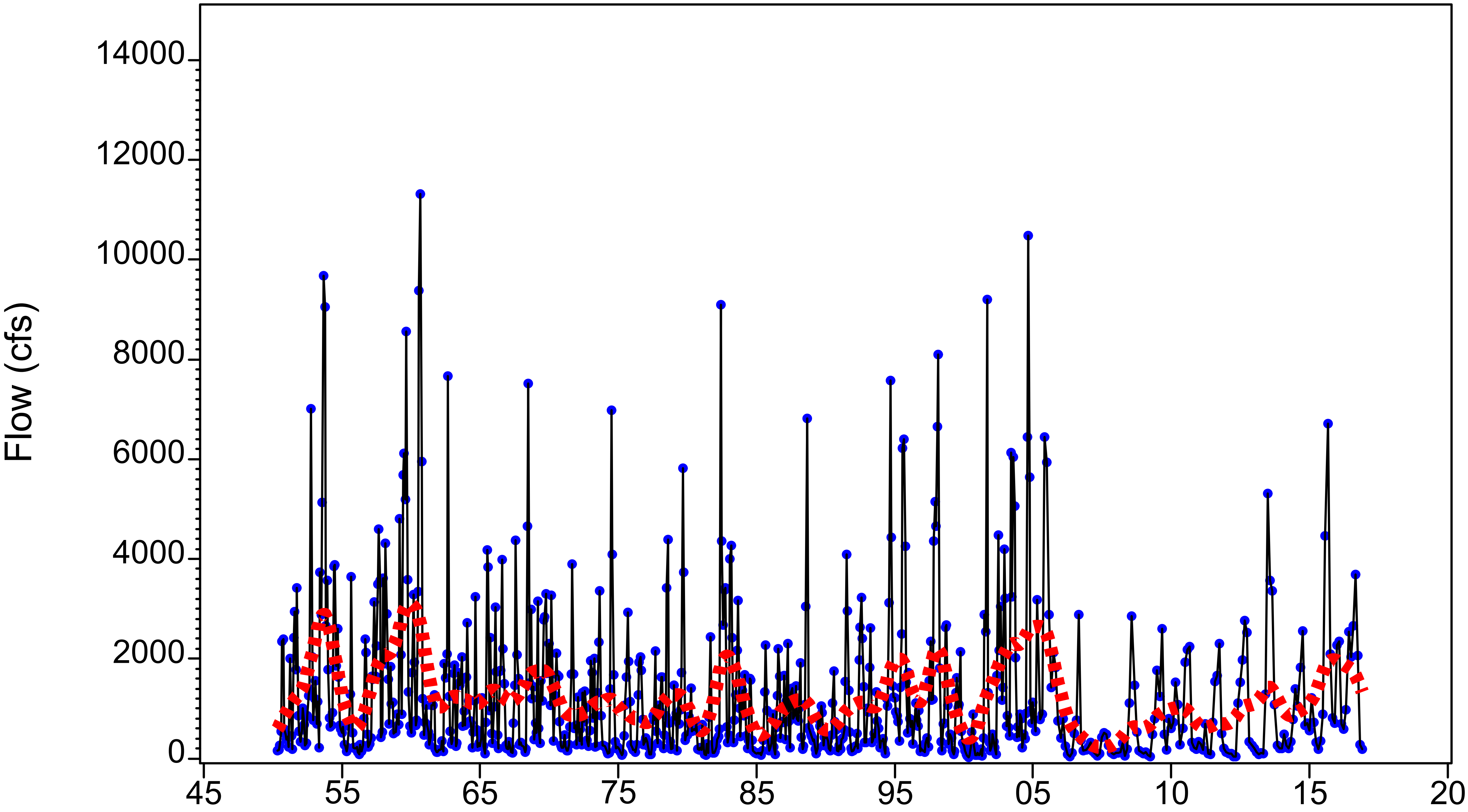


Figure 3.157 Monthly mean flow at long-term for total gaged flow upstream of the Facility (1950-2016)

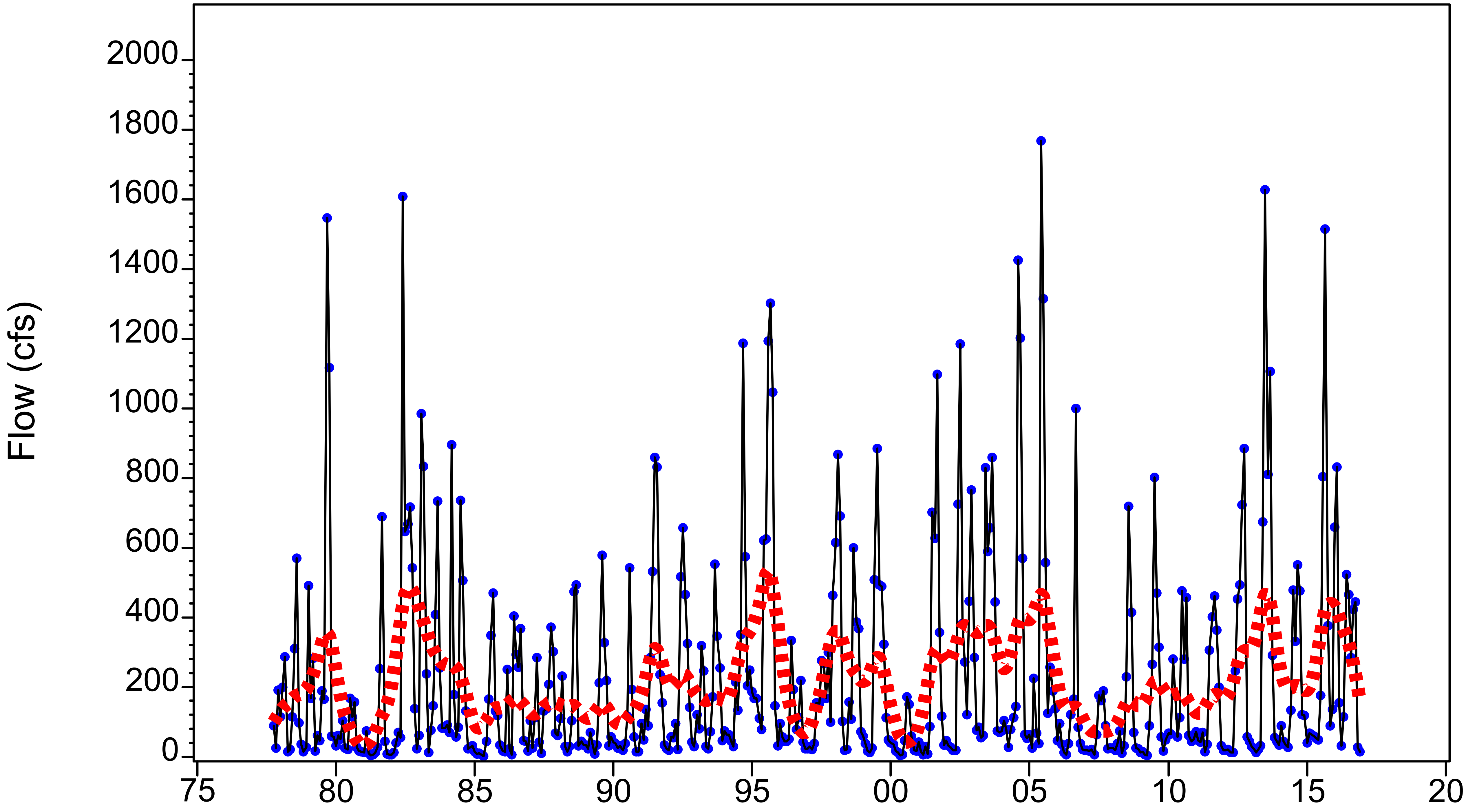


Figure 3.158 Monthly mean flow at long-term Prairie Creek (2298123) gage (1977-2016)

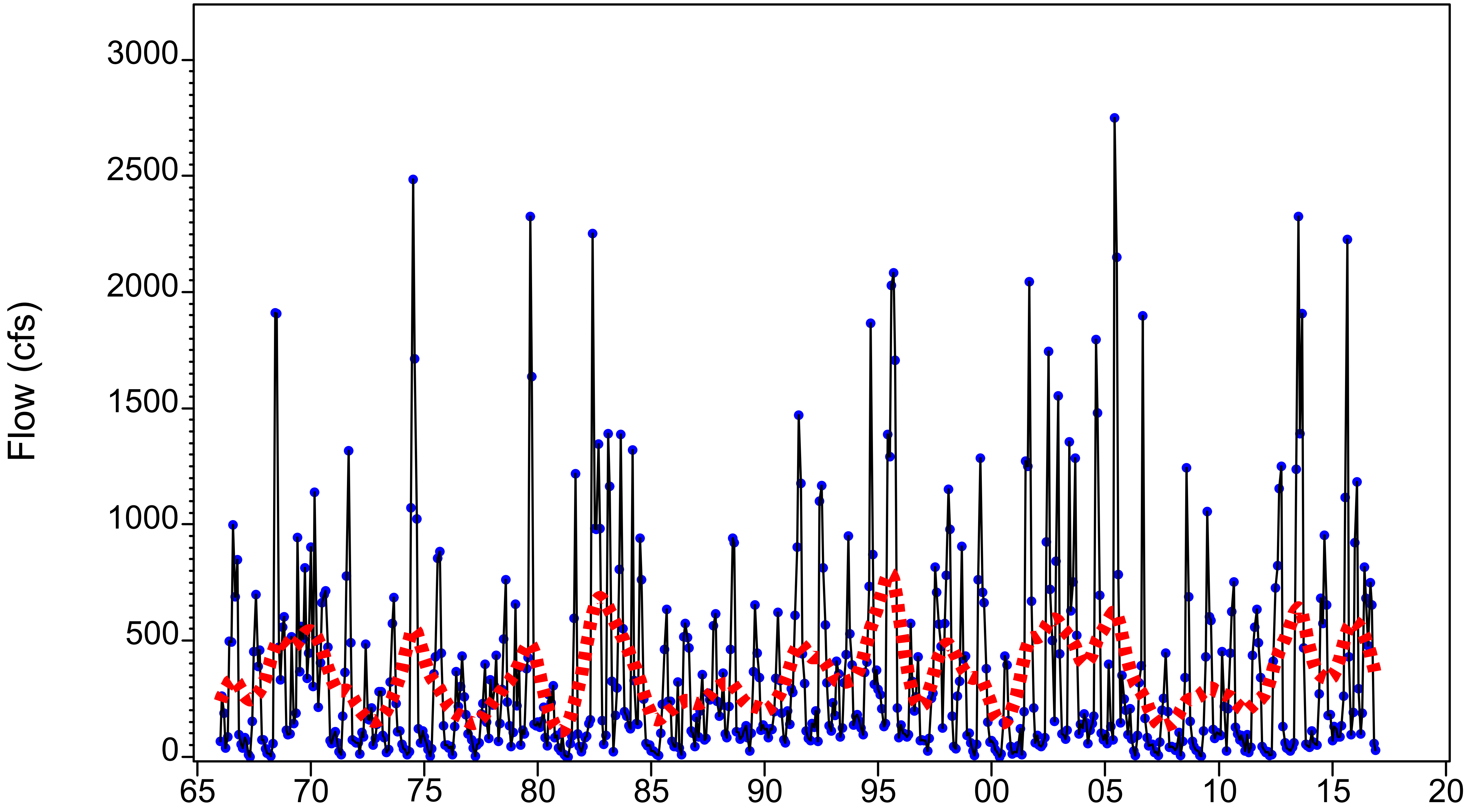


Figure 3.159 Monthly mean flow at long-term Shell Creek gage (1965-2016)

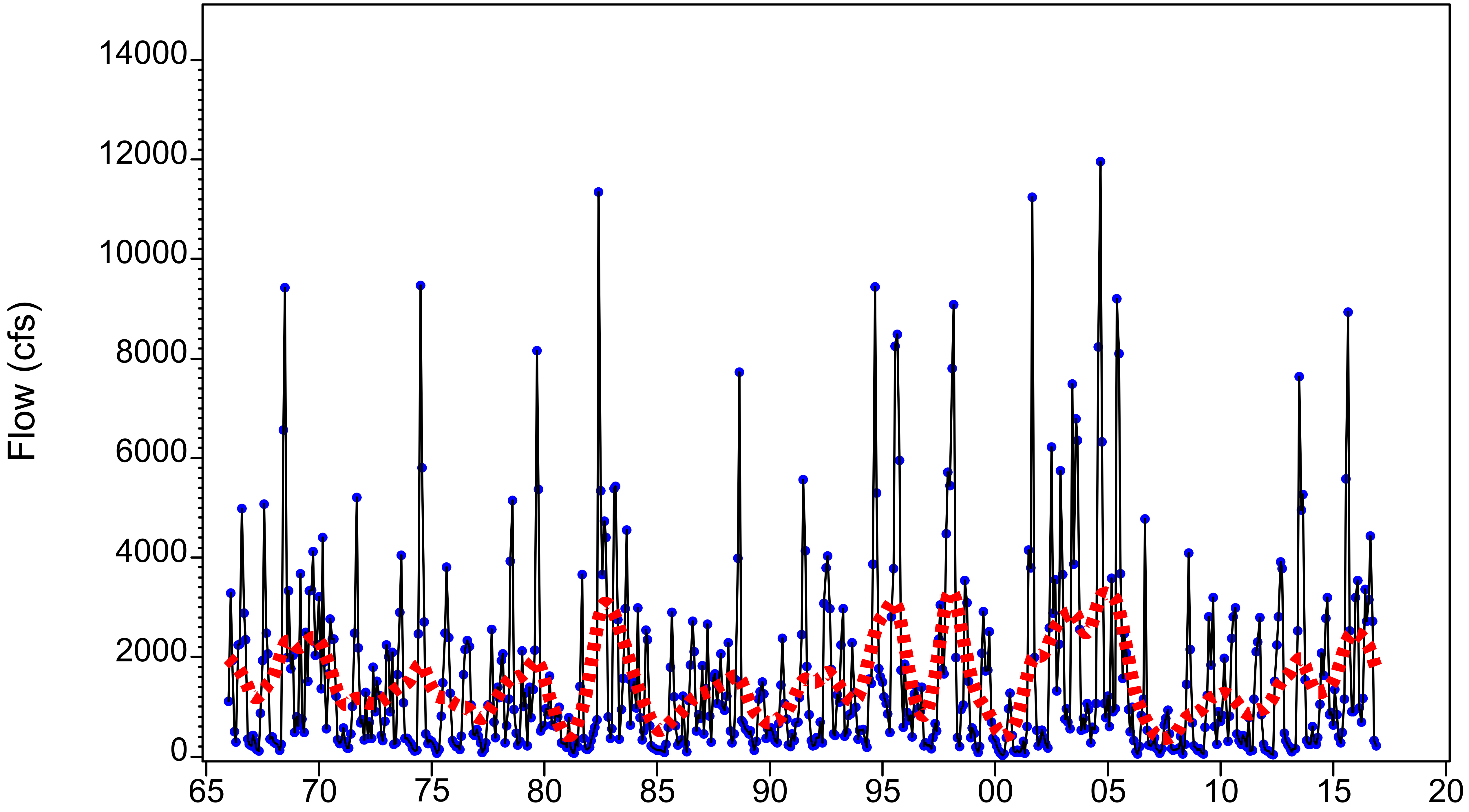


Figure 3.160 Monthly mean flow of total gaged Peace River flow to the Upper Harbor (1965-2016)

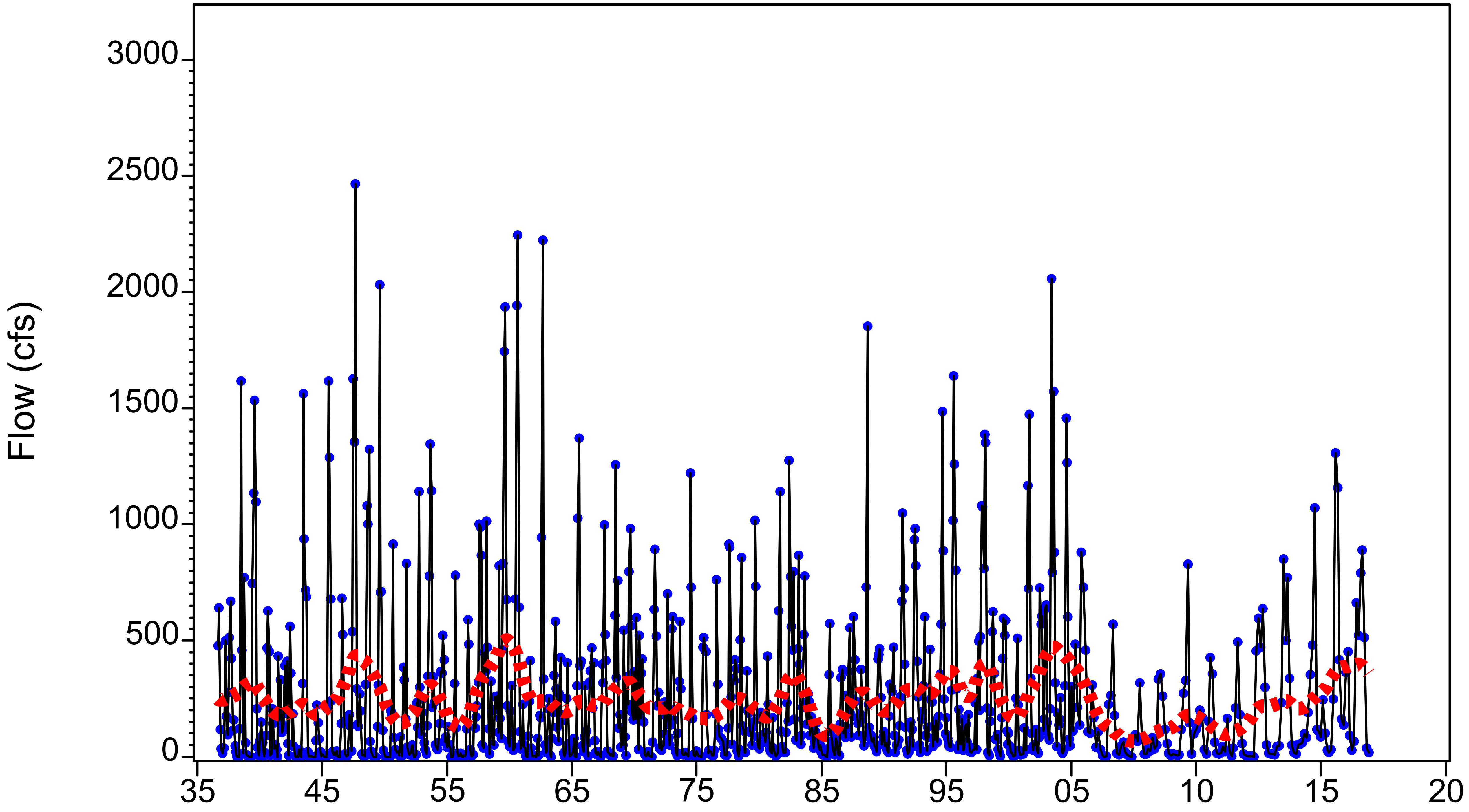


Figure 3.161 Monthly mean flow at long-term Myakka River near Sarasota (2298830) gage (1936-2016)

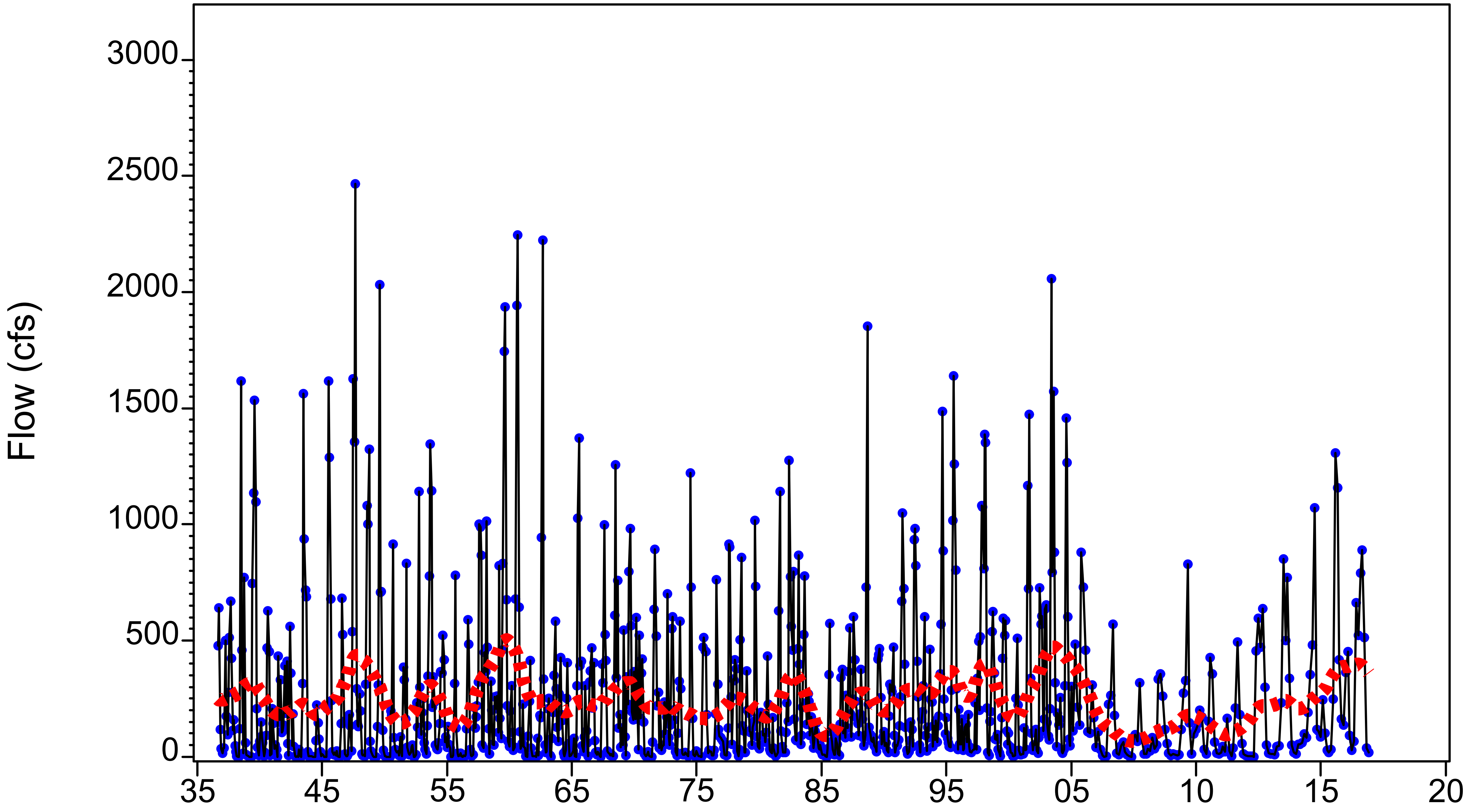


Figure 3.161 Monthly mean flow at long-term Myakka River near Sarasota (2298830) gage (1936-2016)

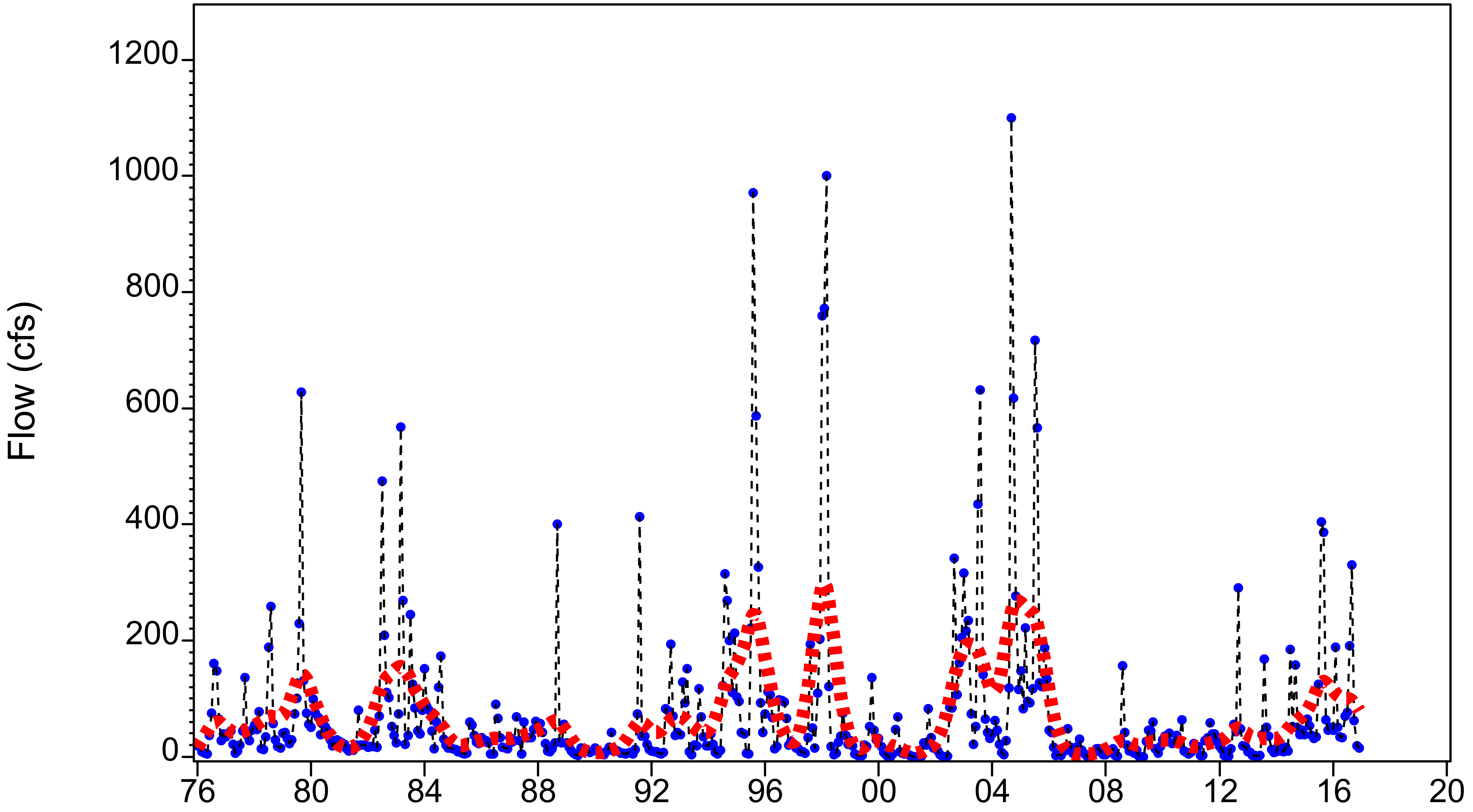


Figure 3.162 Monthly minimum flow at long-term Peace River at Bartow (2294650) gage (1976-2016)

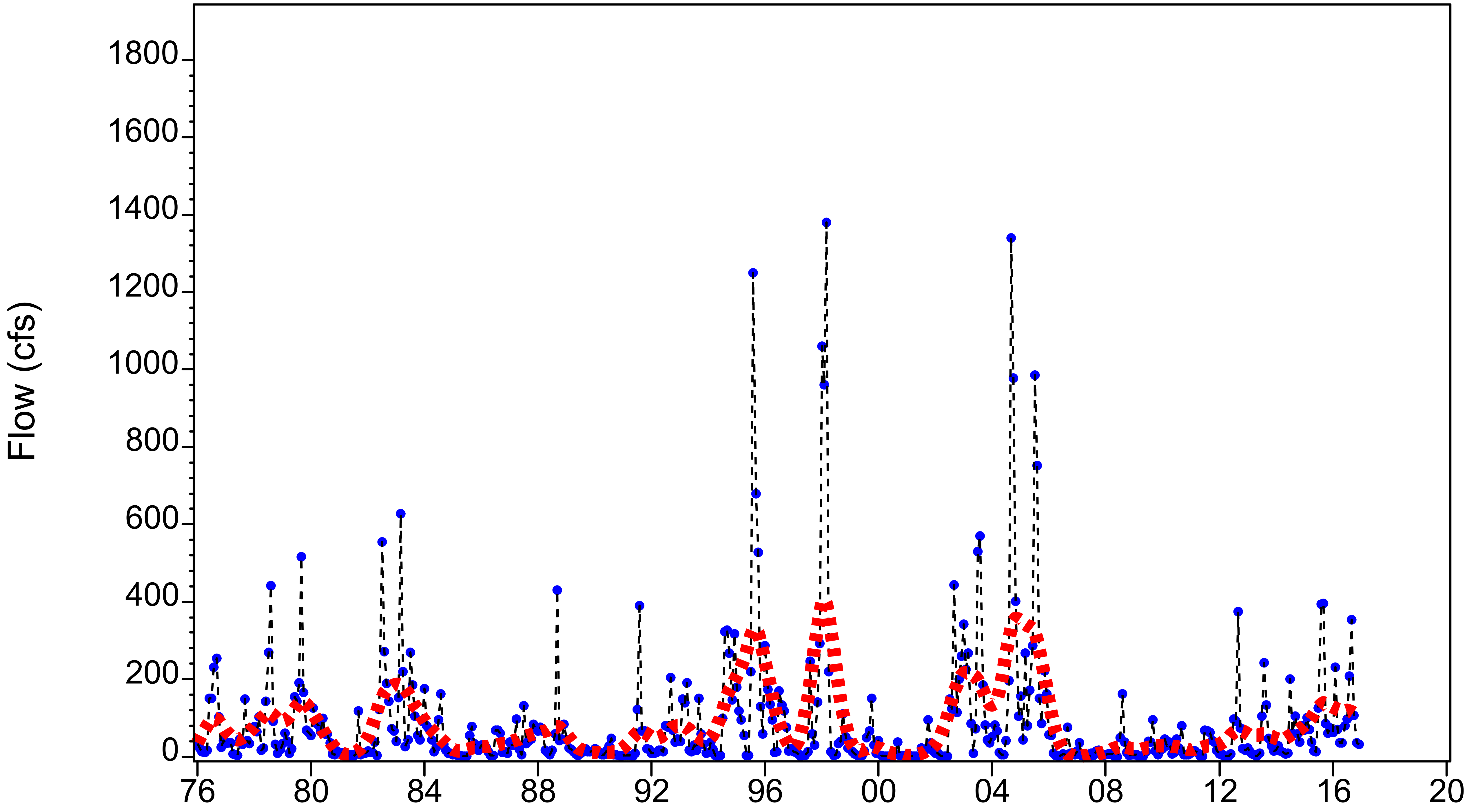


Figure 3.163 Monthly minimum flow at long-term Peace River at Ft. Meade (2294898) gage (1976-2016)

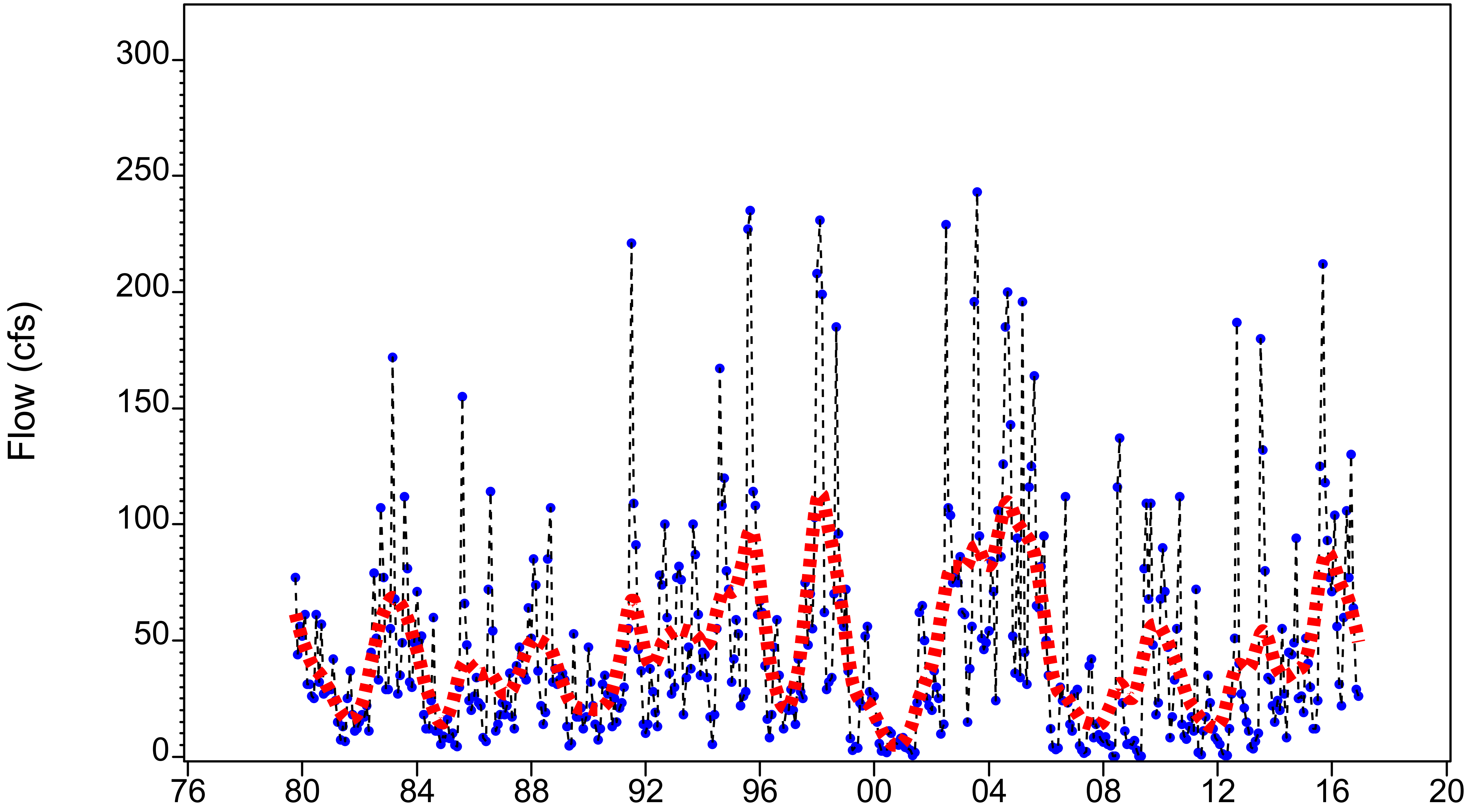


Figure 3.164 Monthly minimum flow at long-term Payne Creek (2295420) gage (1976-2016)

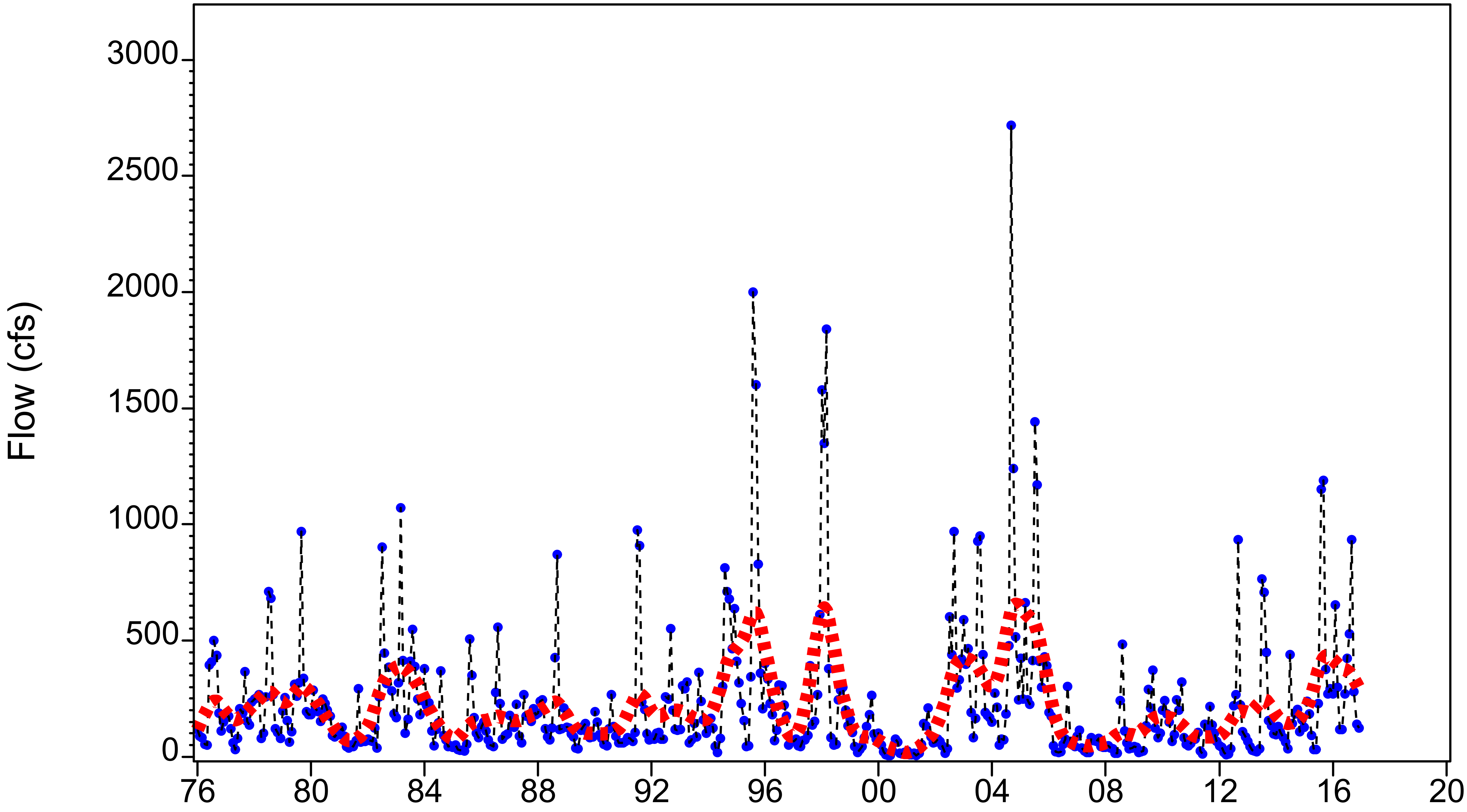


Figure 3.165 Monthly minimum flow at long-term Peace River at Zolfo (2295637) gage (1976-2016)

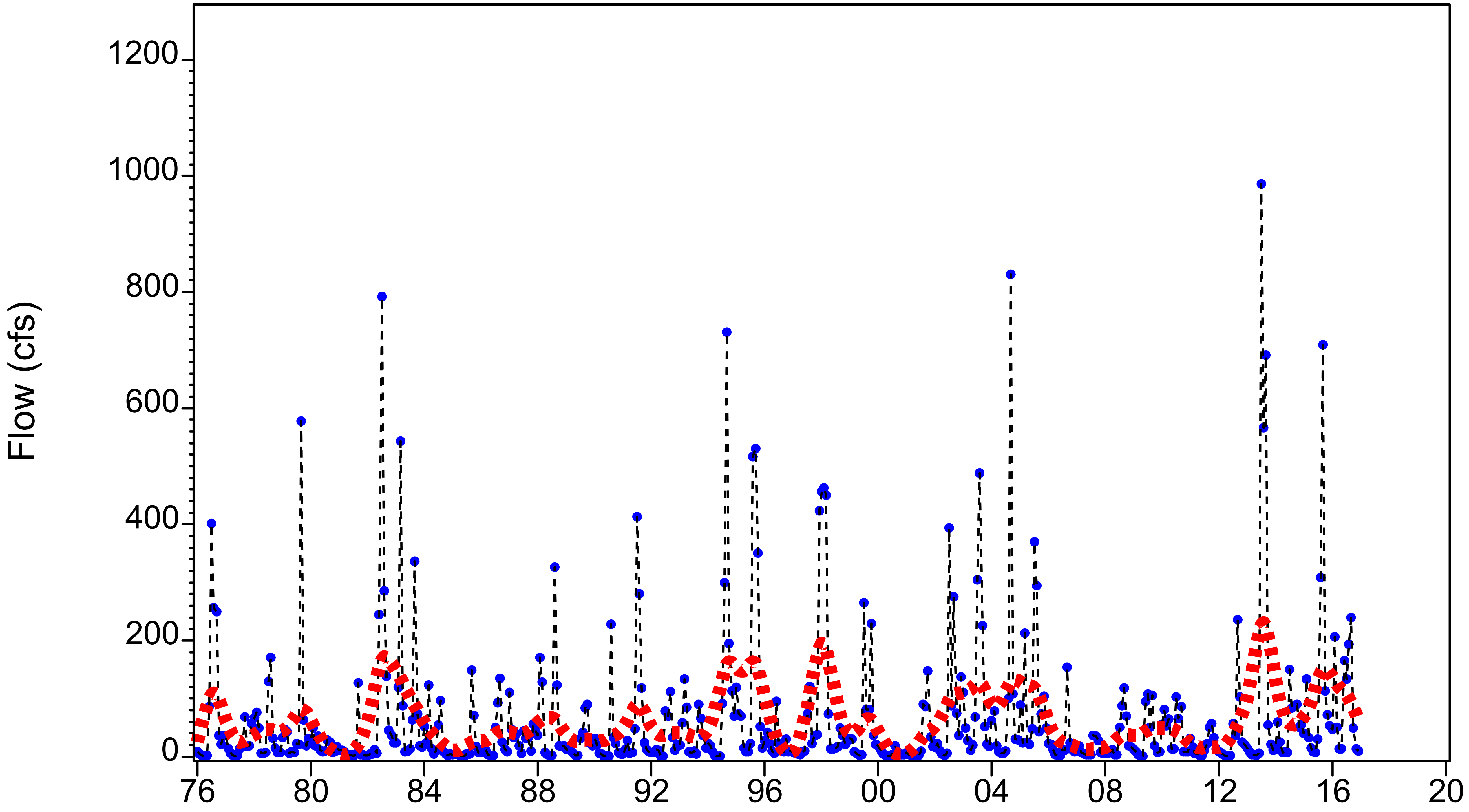


Figure 3.166 Monthly minimum flow at long-term Charlie Creek (2296500) gage (1976-2016)

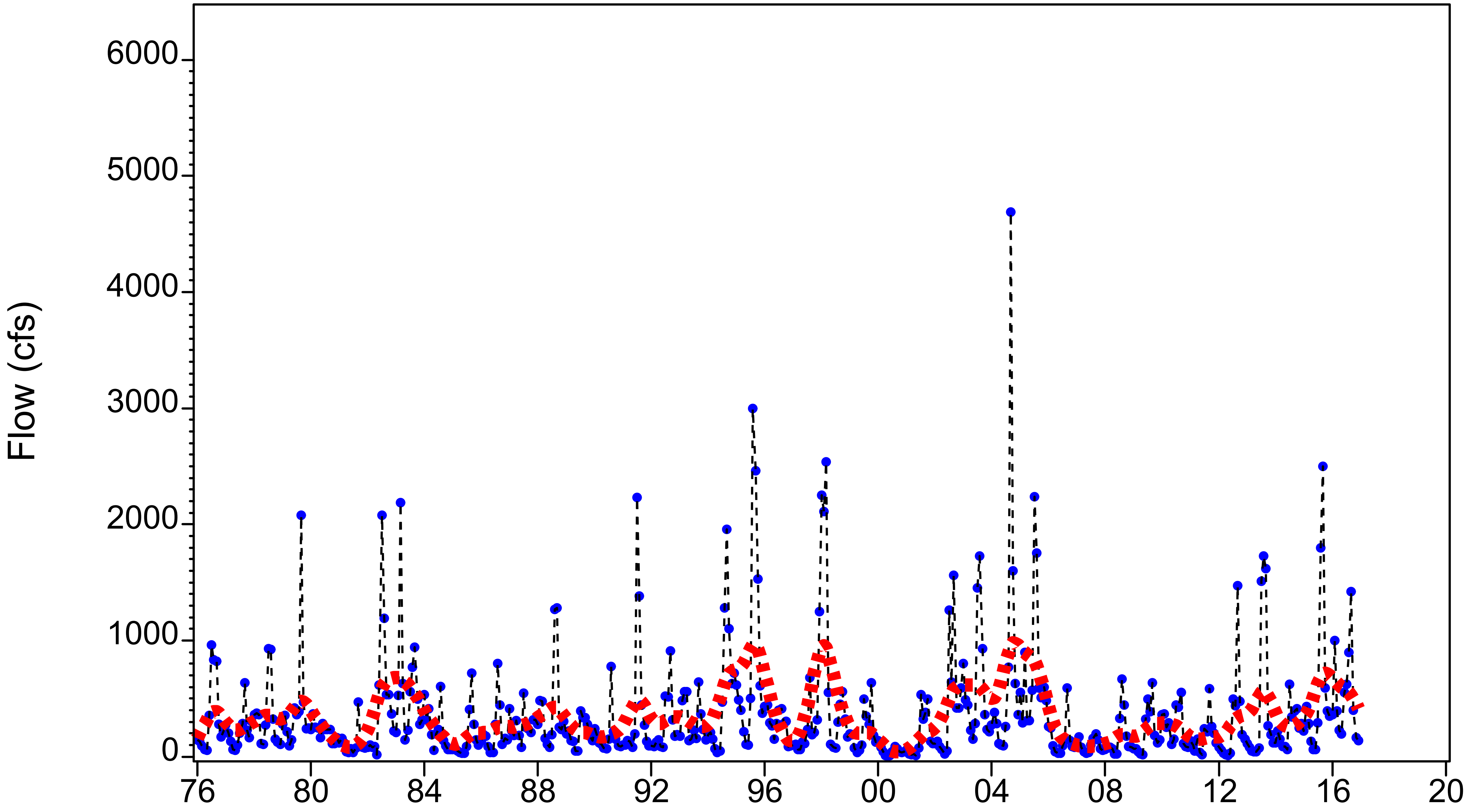


Figure 3.167 Monthly minimum flow at long-term Peace River at Arcadia (2296750) gage (1976-2016)

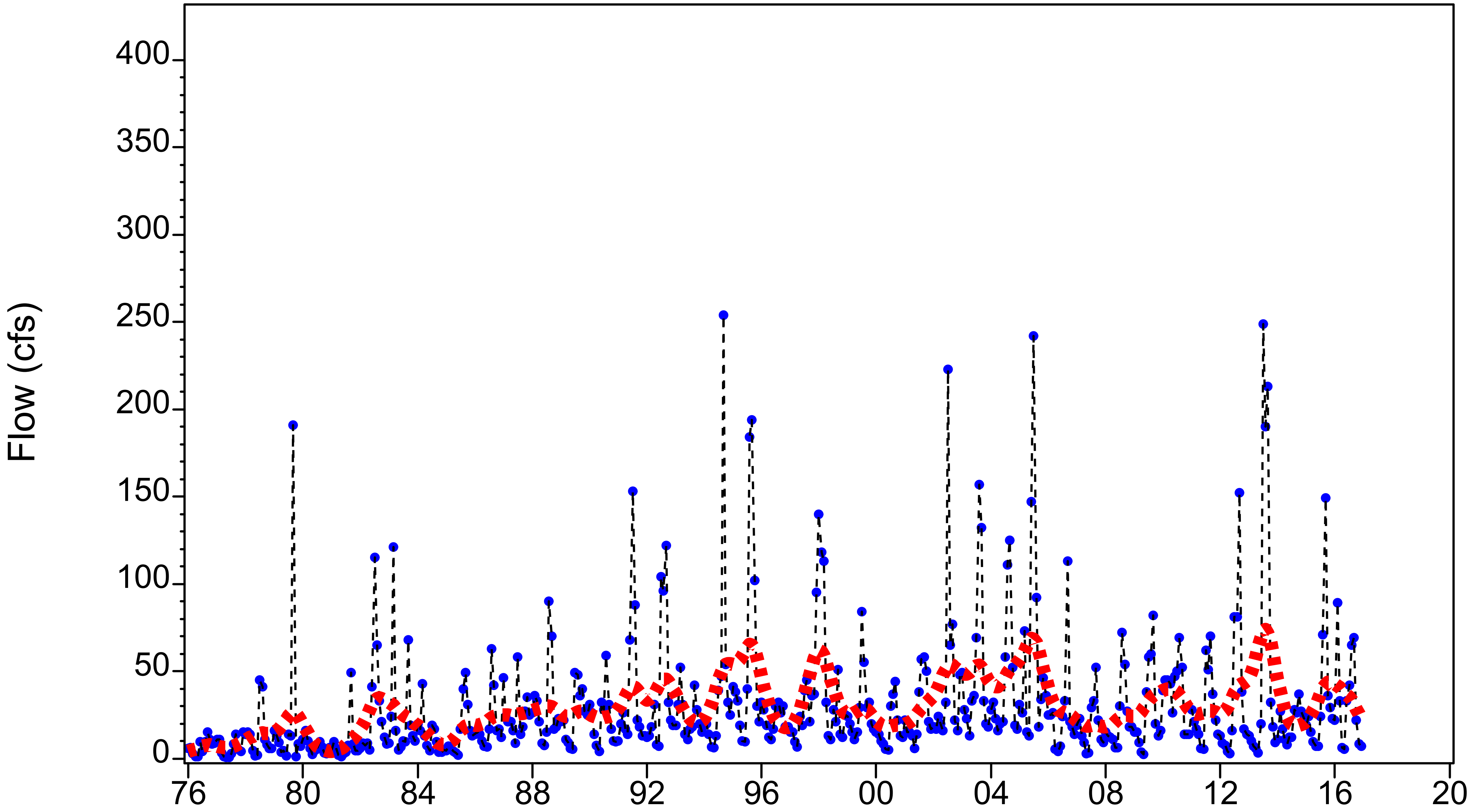


Figure 3.168 Monthly minimum flow at long-term Joshua Creek at Nocatee (2297100) gage (1976-2016)

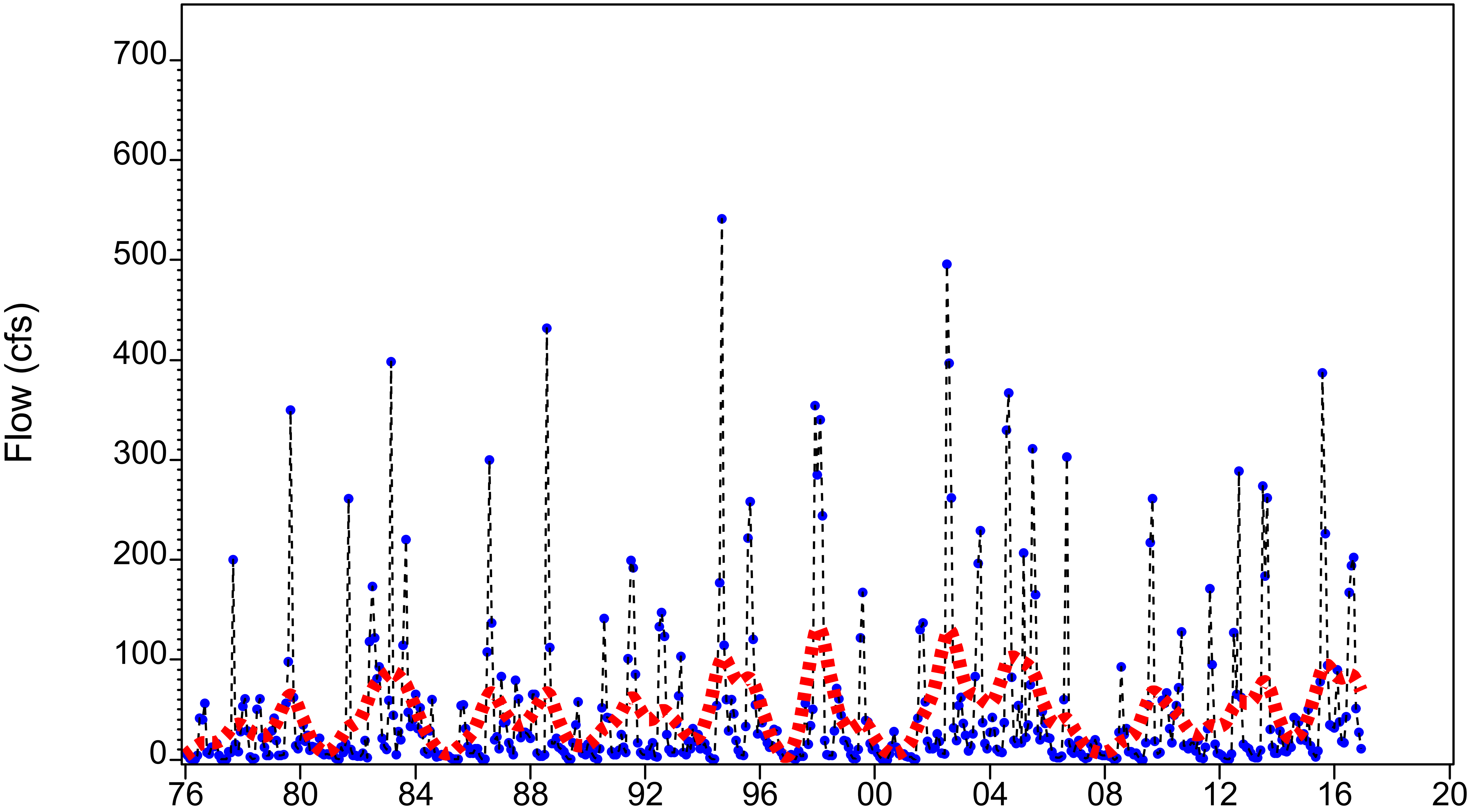


Figure 3.169 Monthly minimum flow at long-term Horse Creek near Arcadia (2297310) gage (1760-2016)

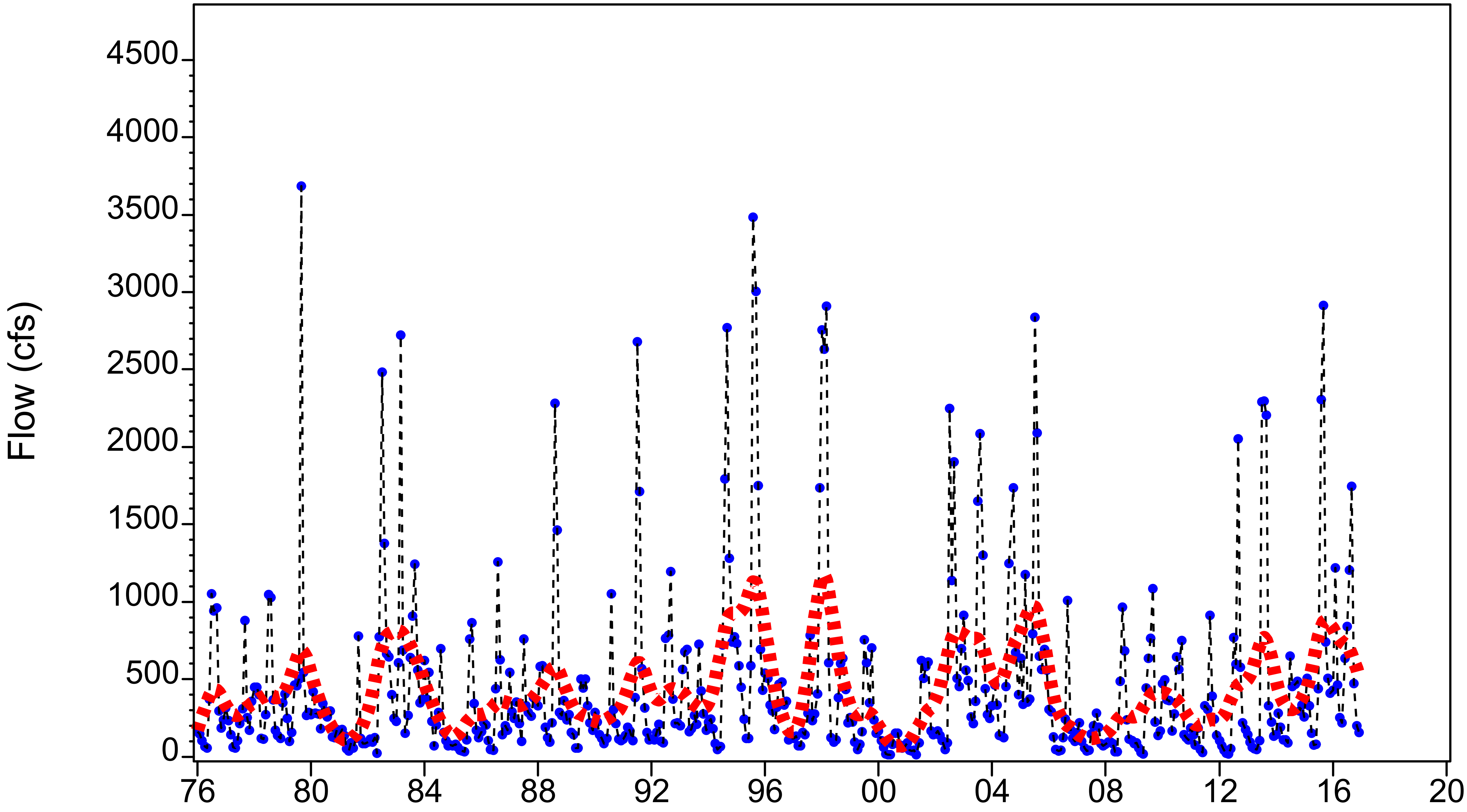


Figure 3.170 Monthly minimum flow at long-term for total gaged flow upstream of the Facility (1976-2016)

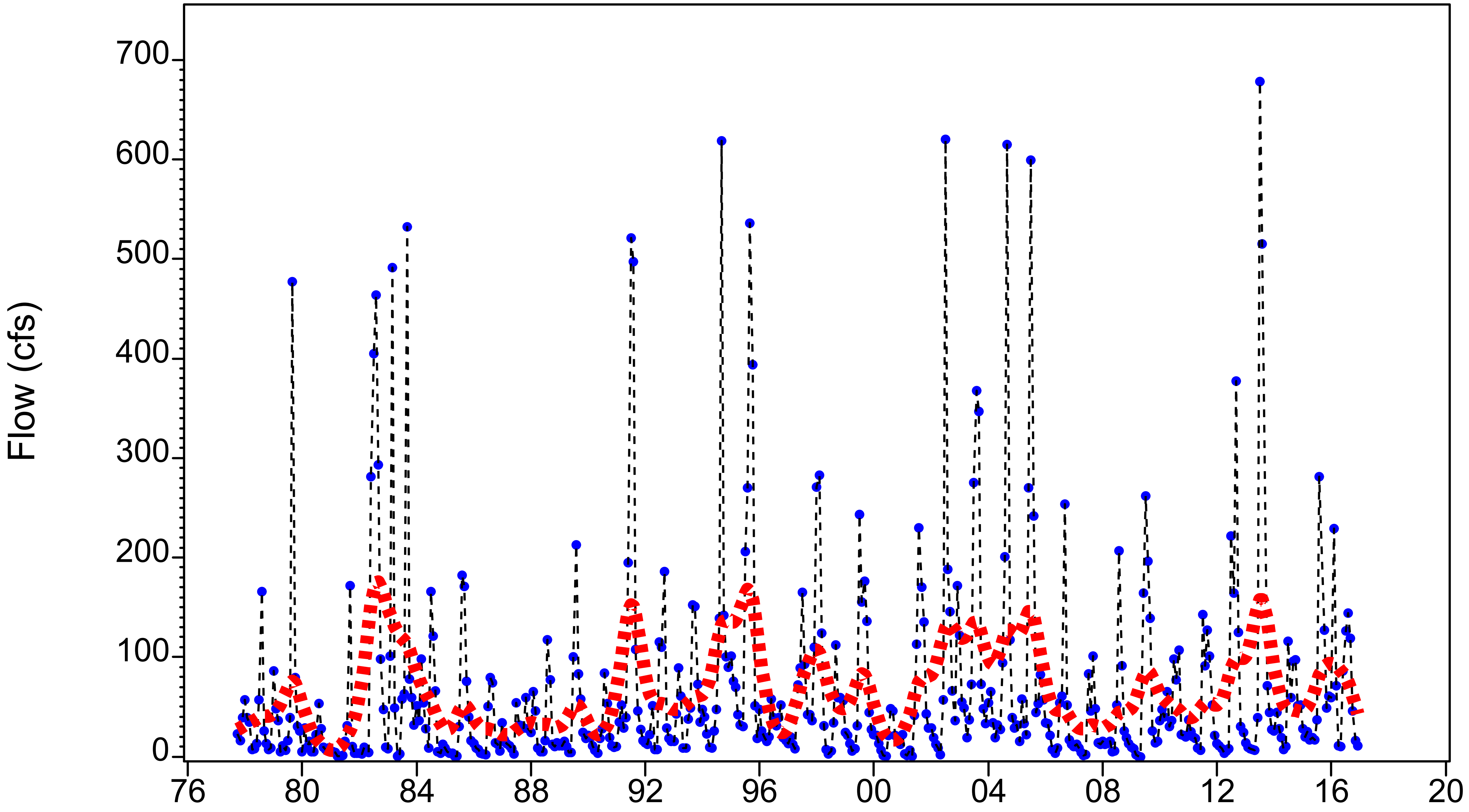


Figure 3.171 Monthly minimum flow at long-term Prairie Creek (2298123) gage (1976-2016)

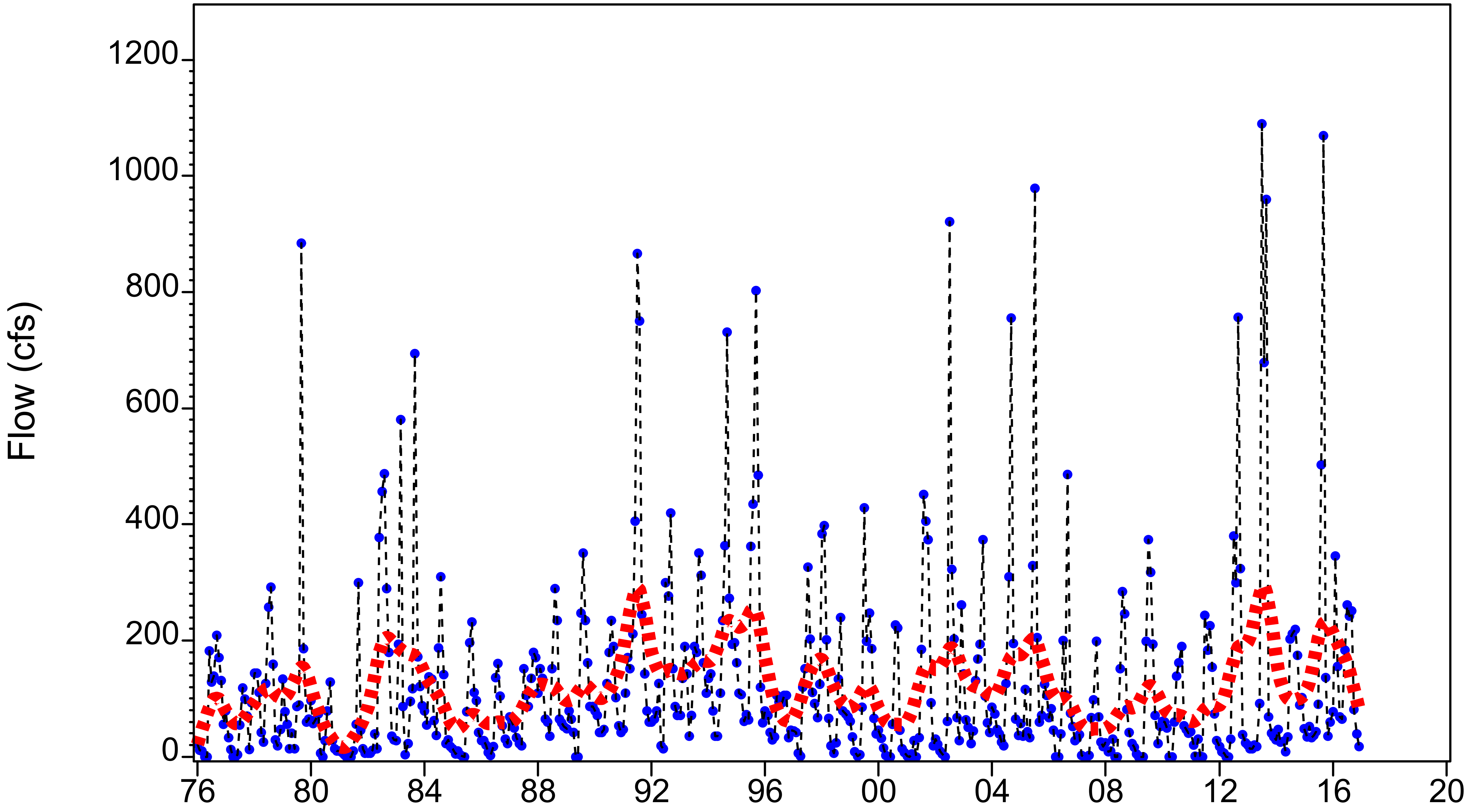


Figure 3.172 Monthly minimum flow at long-term Shell Creek gage (1976-2016)

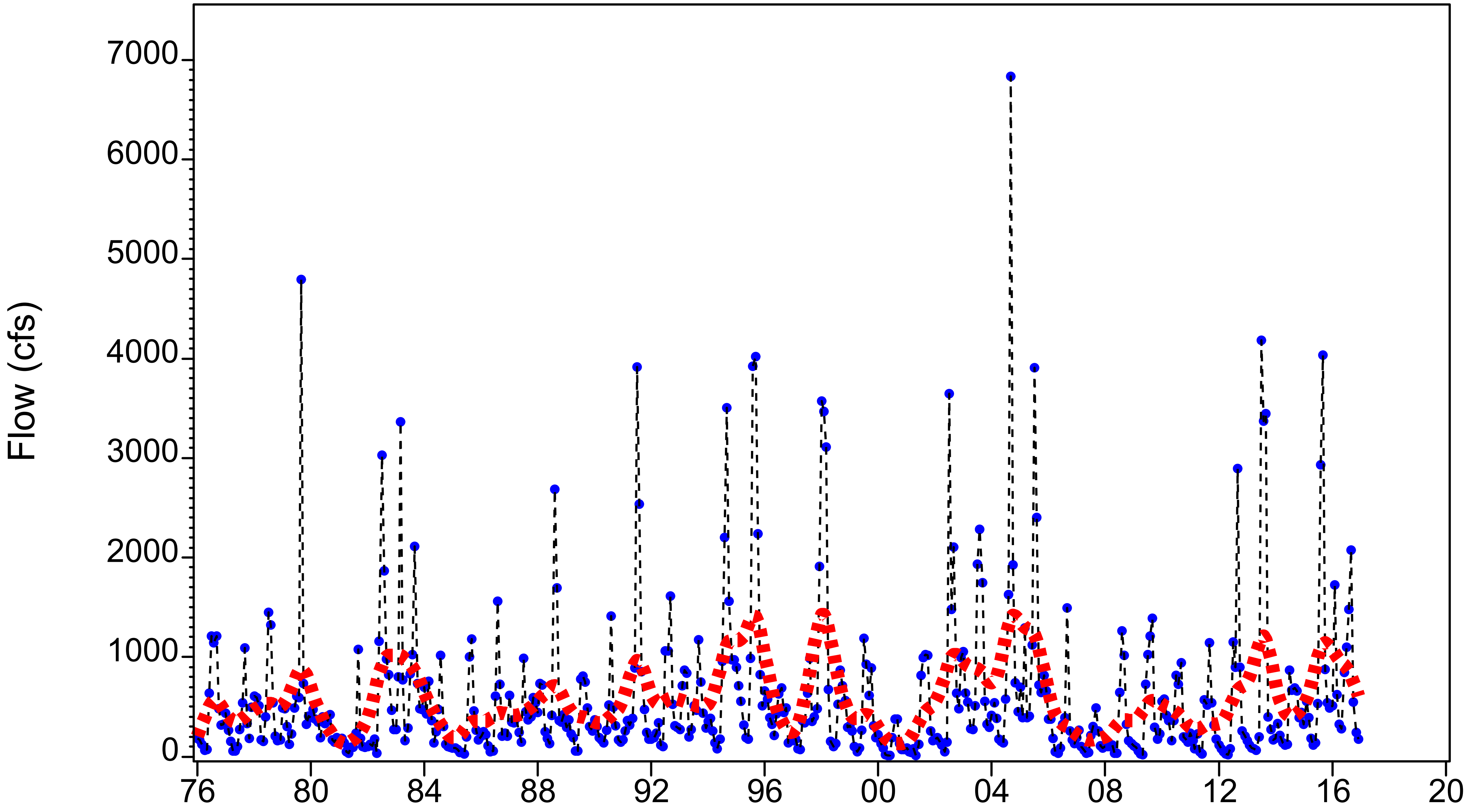


Figure 3.173 Monthly minimum flow of total gaged Peace River flow to the Upper Harbor (1976-2016)

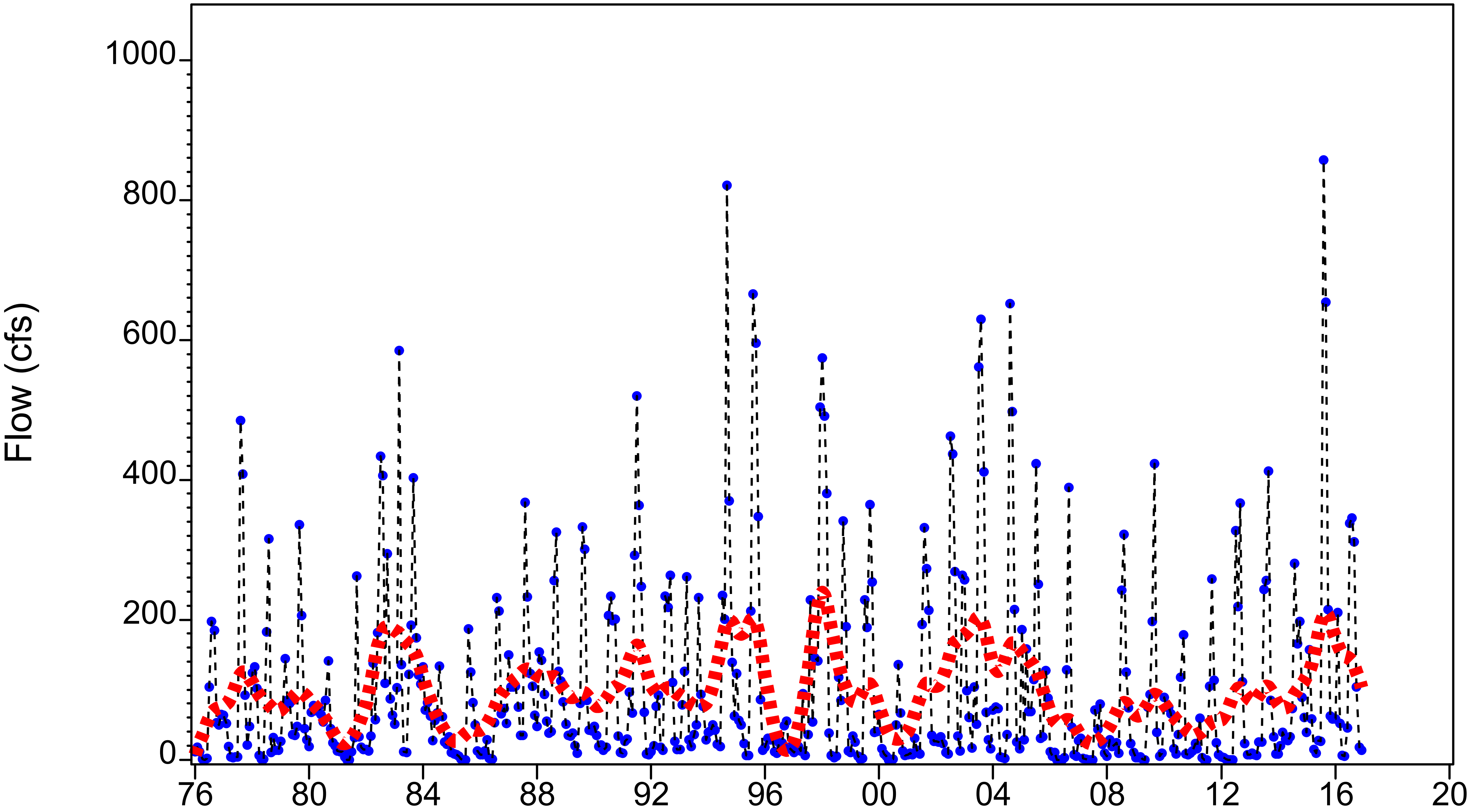


Figure 3.174 Monthly minimum flow at long-term Myakka River near Sarasota (2298830) gage (1976-2016)

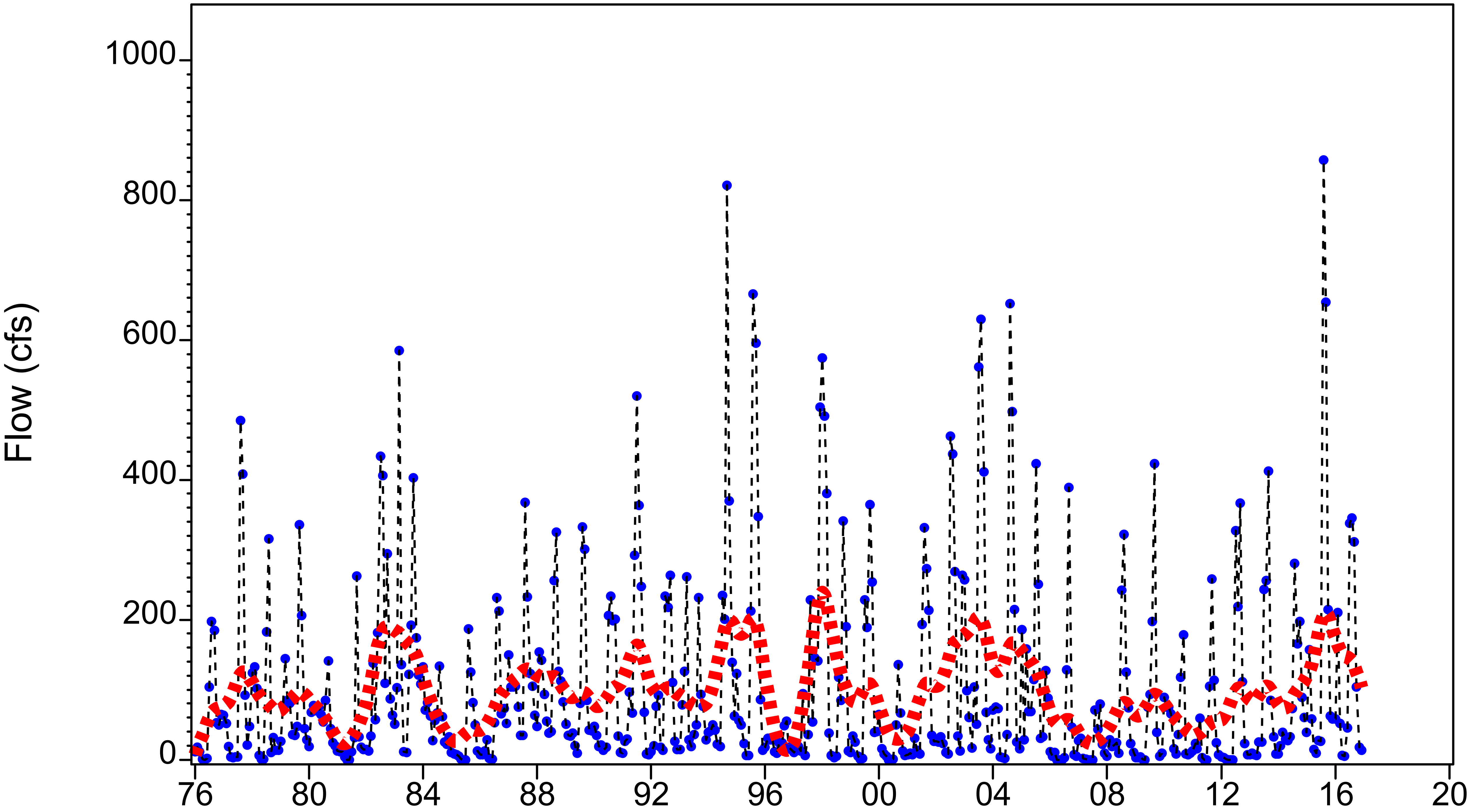


Figure 3.174 Monthly minimum flow at long-term Myakka River near Sarasota (2298830) gage (1976-2016)

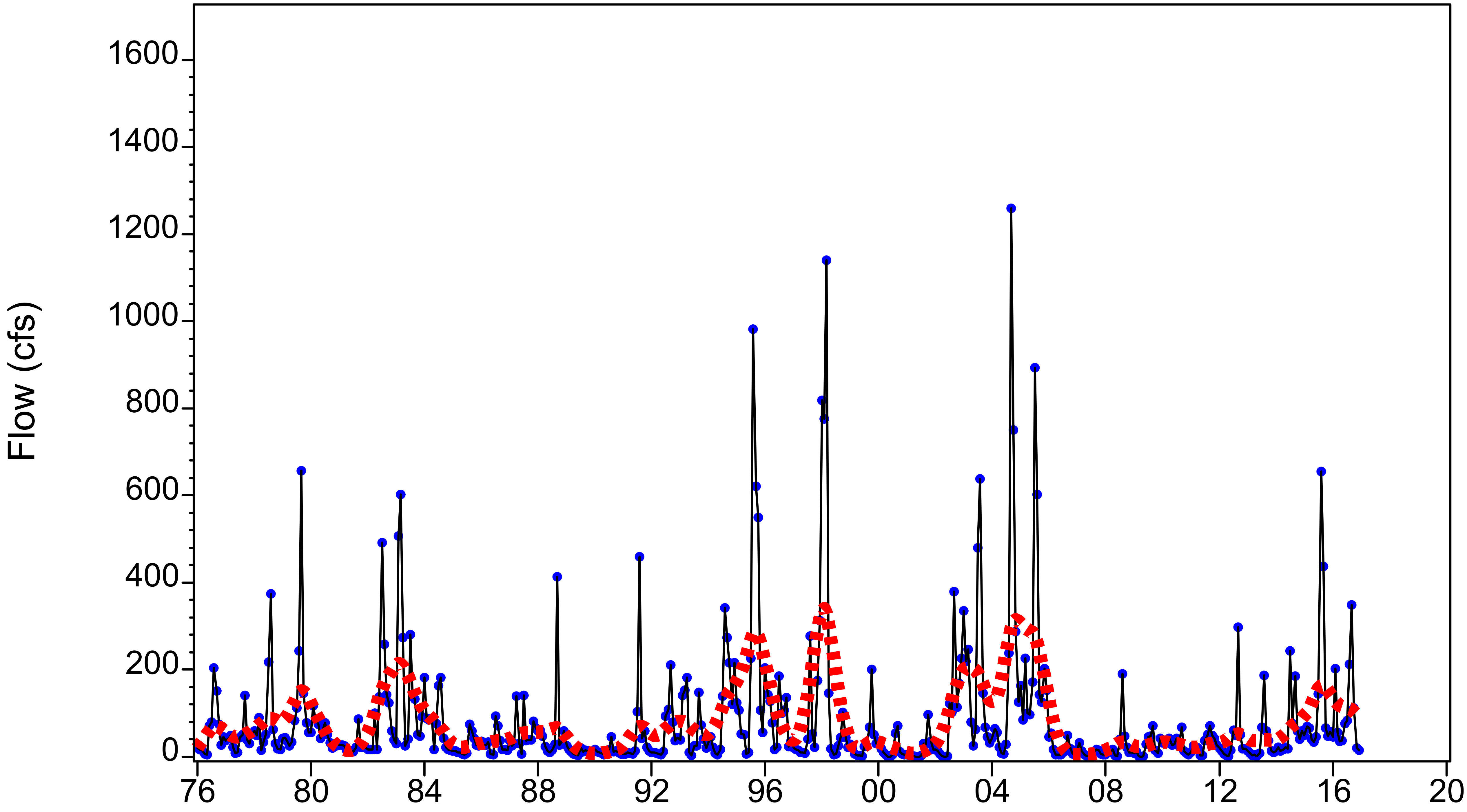


Figure 3.175 Monthly P10 flow at long-term Peace River at Bartow (2294650) gage (1976-2016)

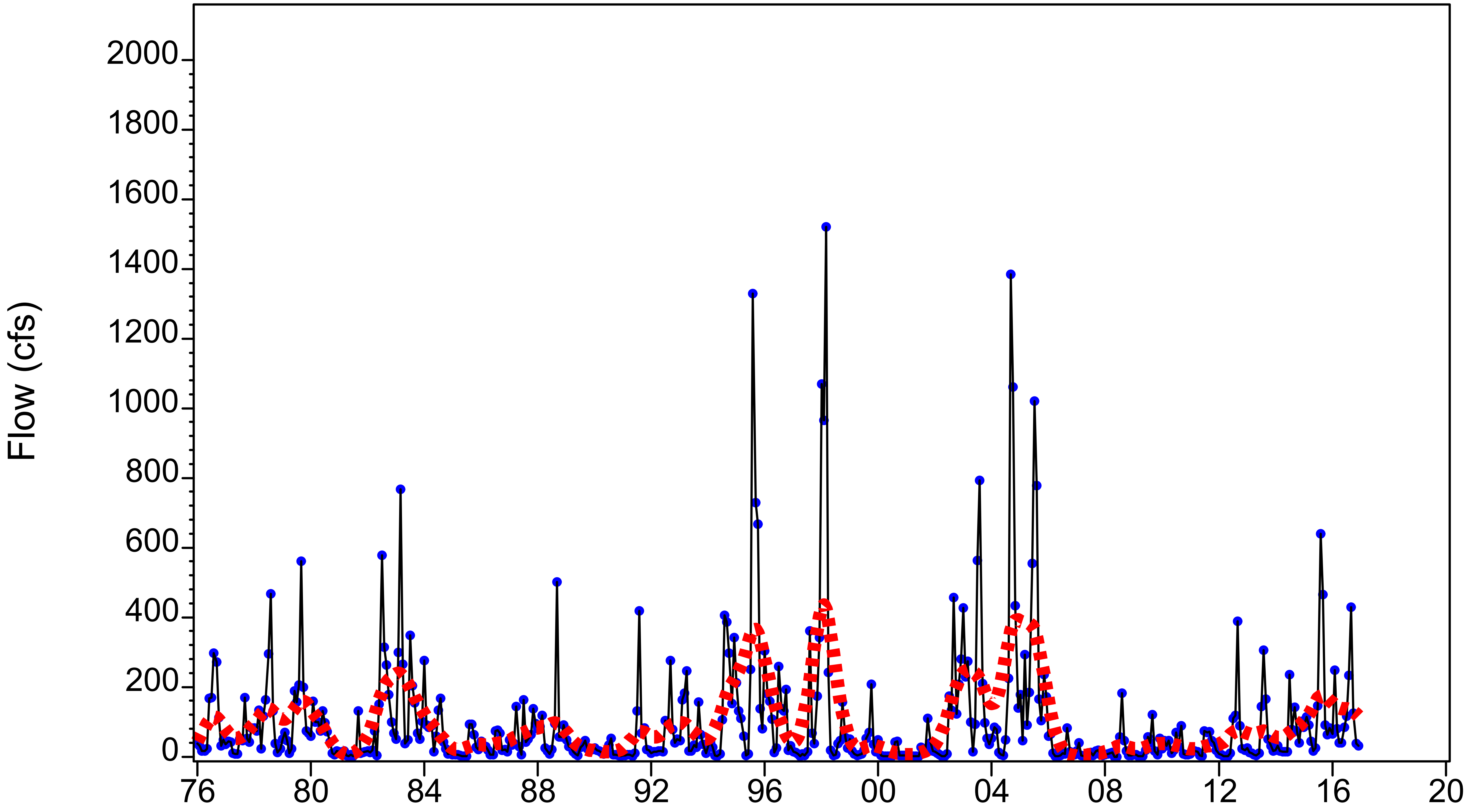


Figure 3.176 Monthly P10 flow at long-term Peace River at Ft. Meade (2294898) gage (1976-2016)

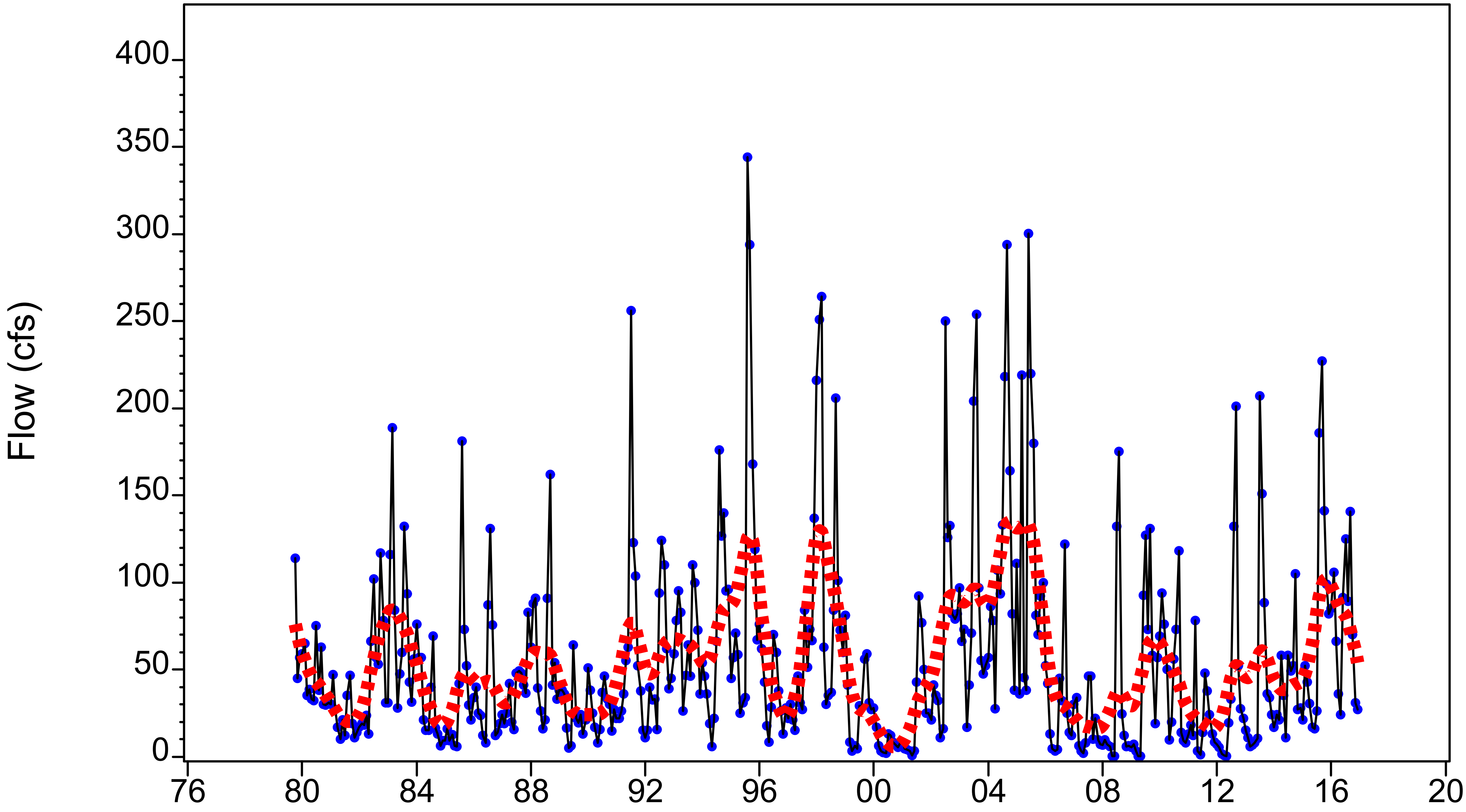


Figure 3.177 Monthly P10 flow at long-term Payne Creek (2295420) gage (1976-2016)

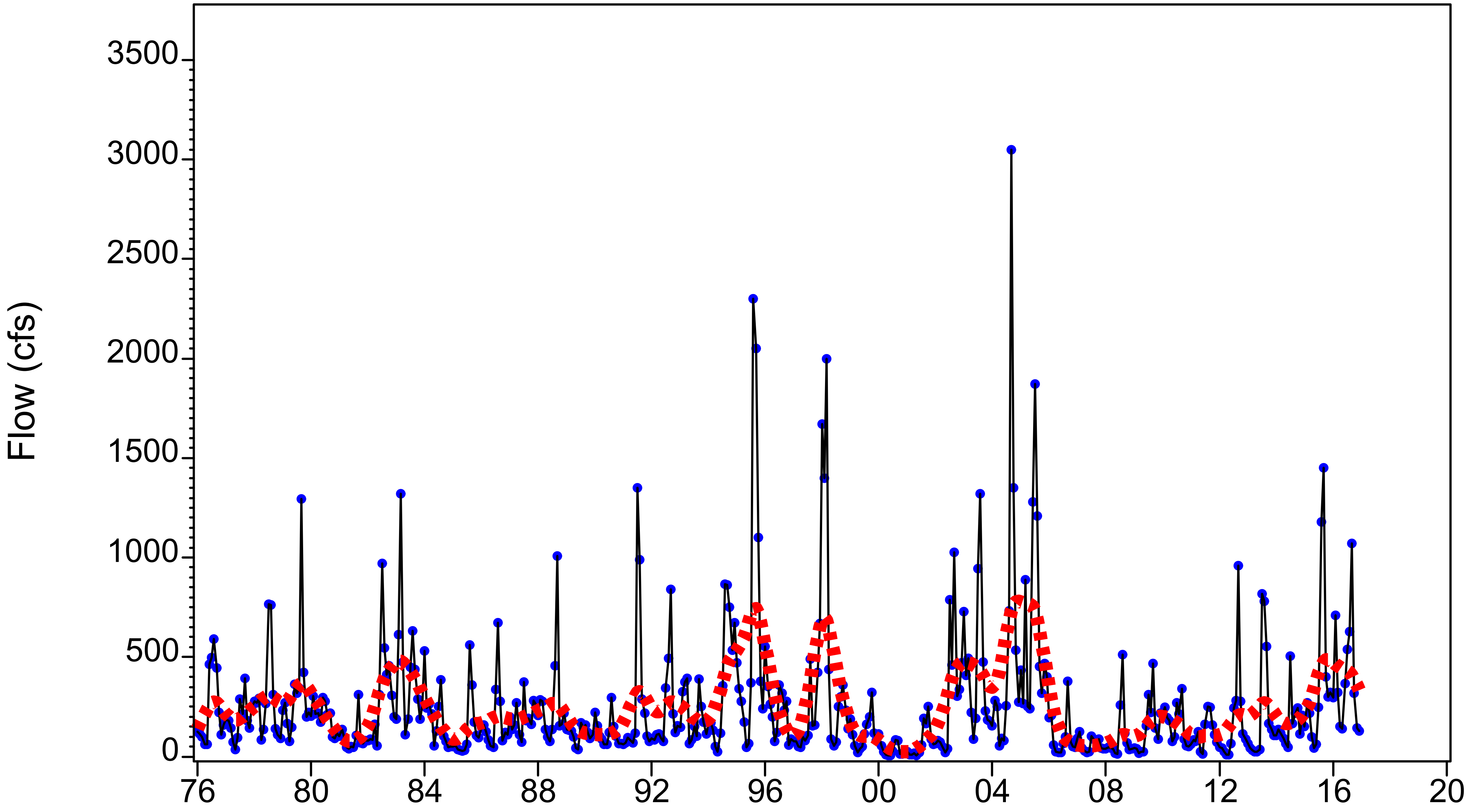


Figure 3.178 Monthly P10 flow at long-term Peace River at Zolfo (2295637) gage (1976-2016)

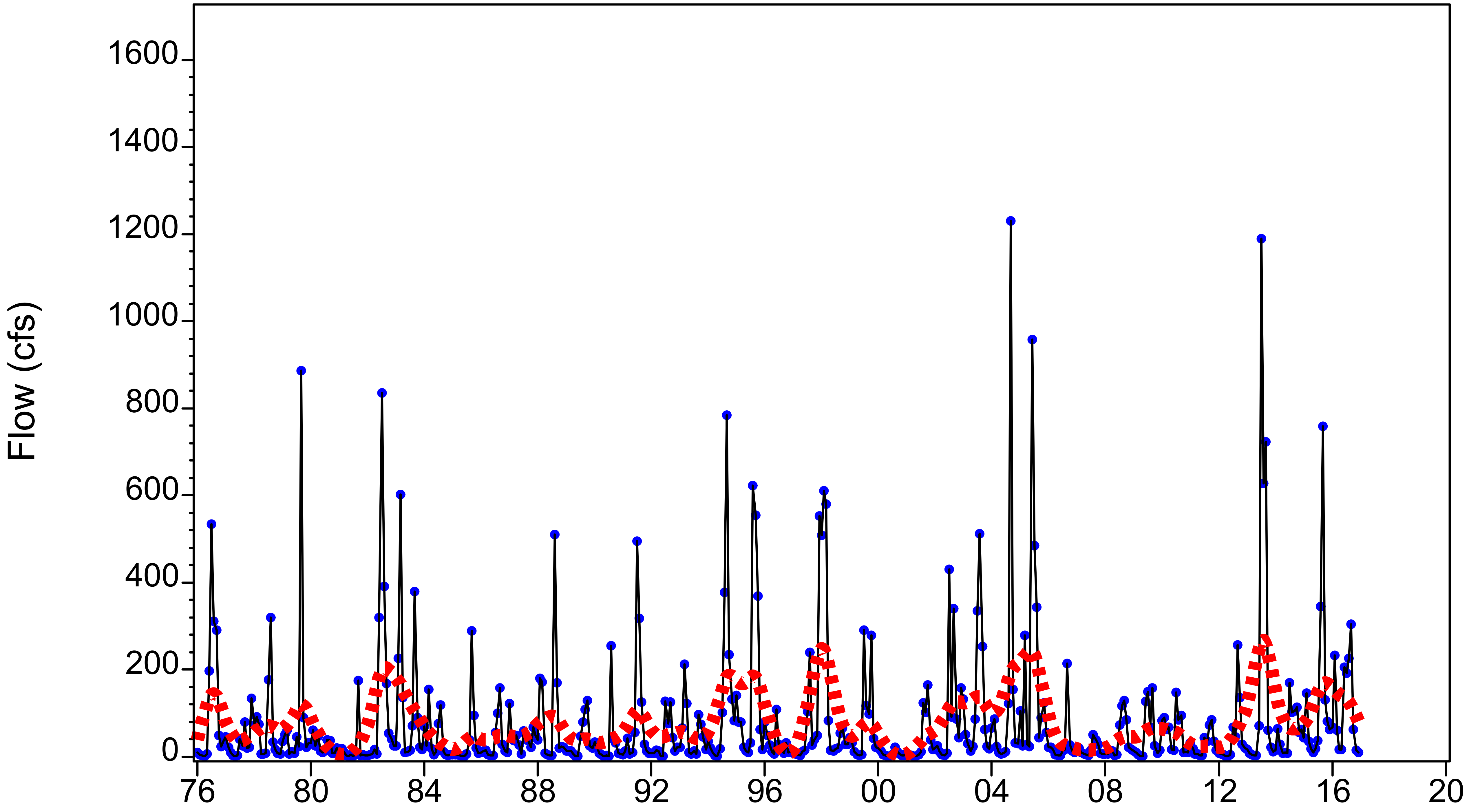


Figure 3.179 Monthly P10 flow at long-term Charlie Creek (2296500) gage (1976-2016)

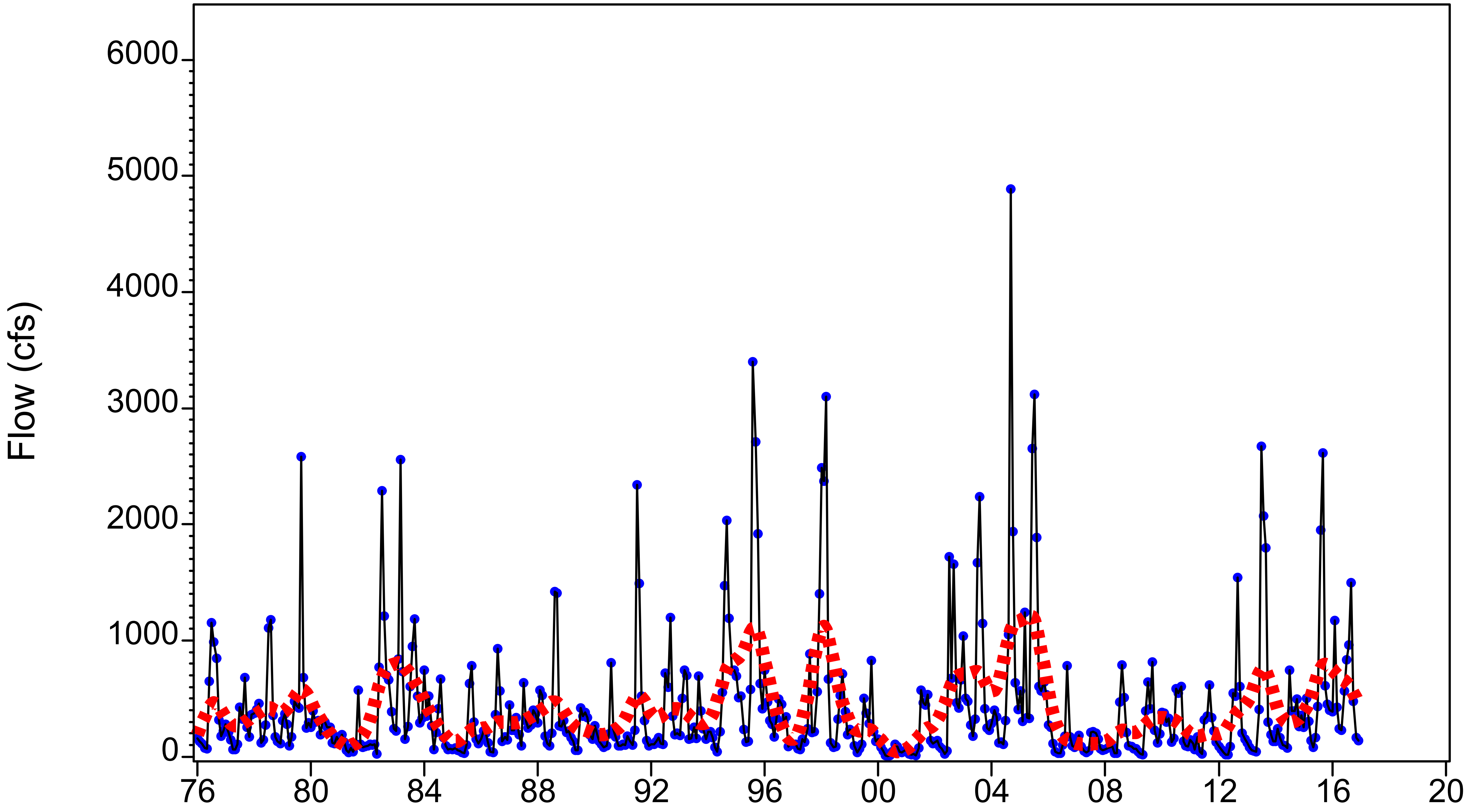


Figure 3.180 Monthly P10 flow at long-term Peace River at Arcadia (2296750) gage (1976-2016)

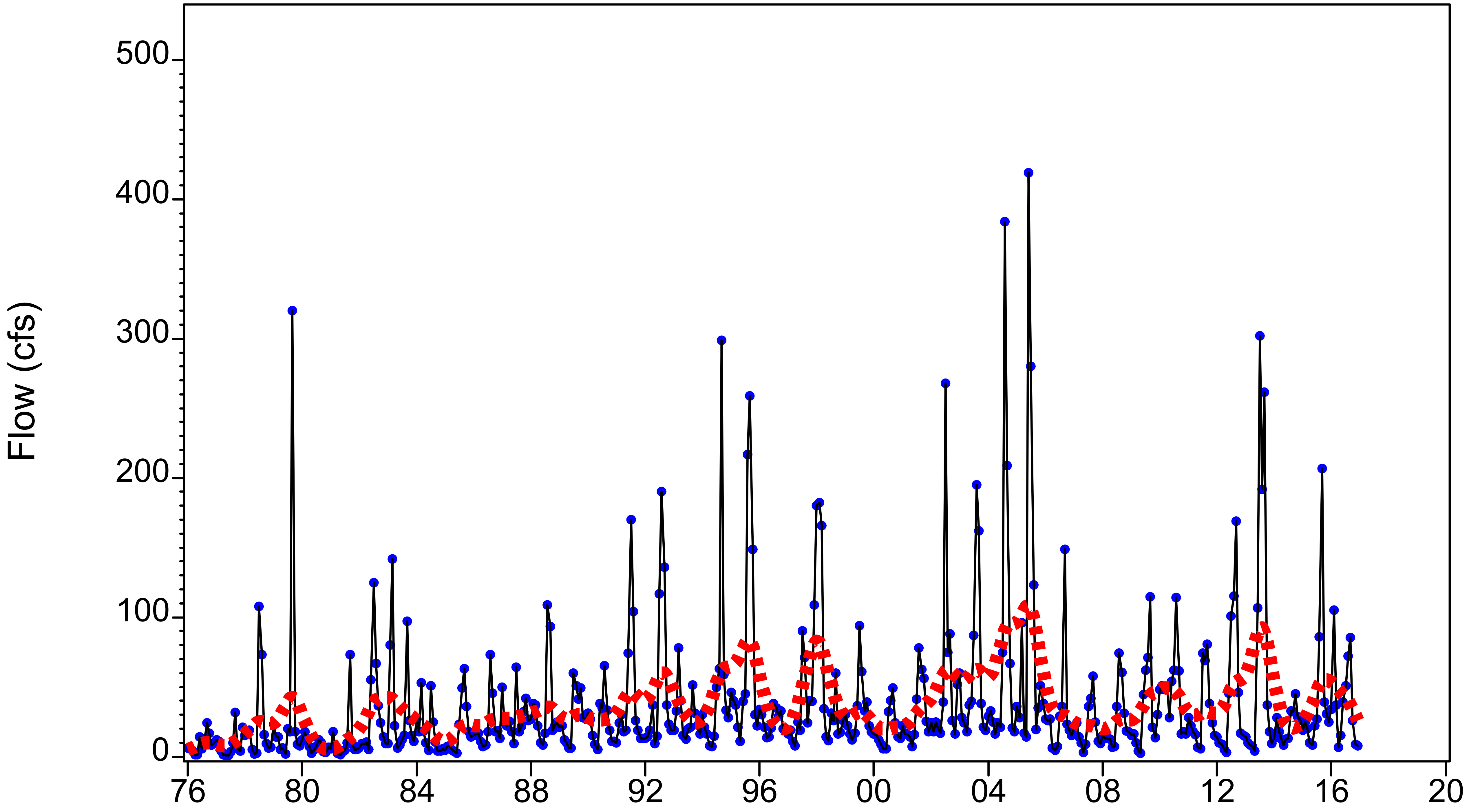


Figure 3.181 Monthly P10 flow at long-term Joshua Creek at Nocatee (2297100) gage (1976-2016)

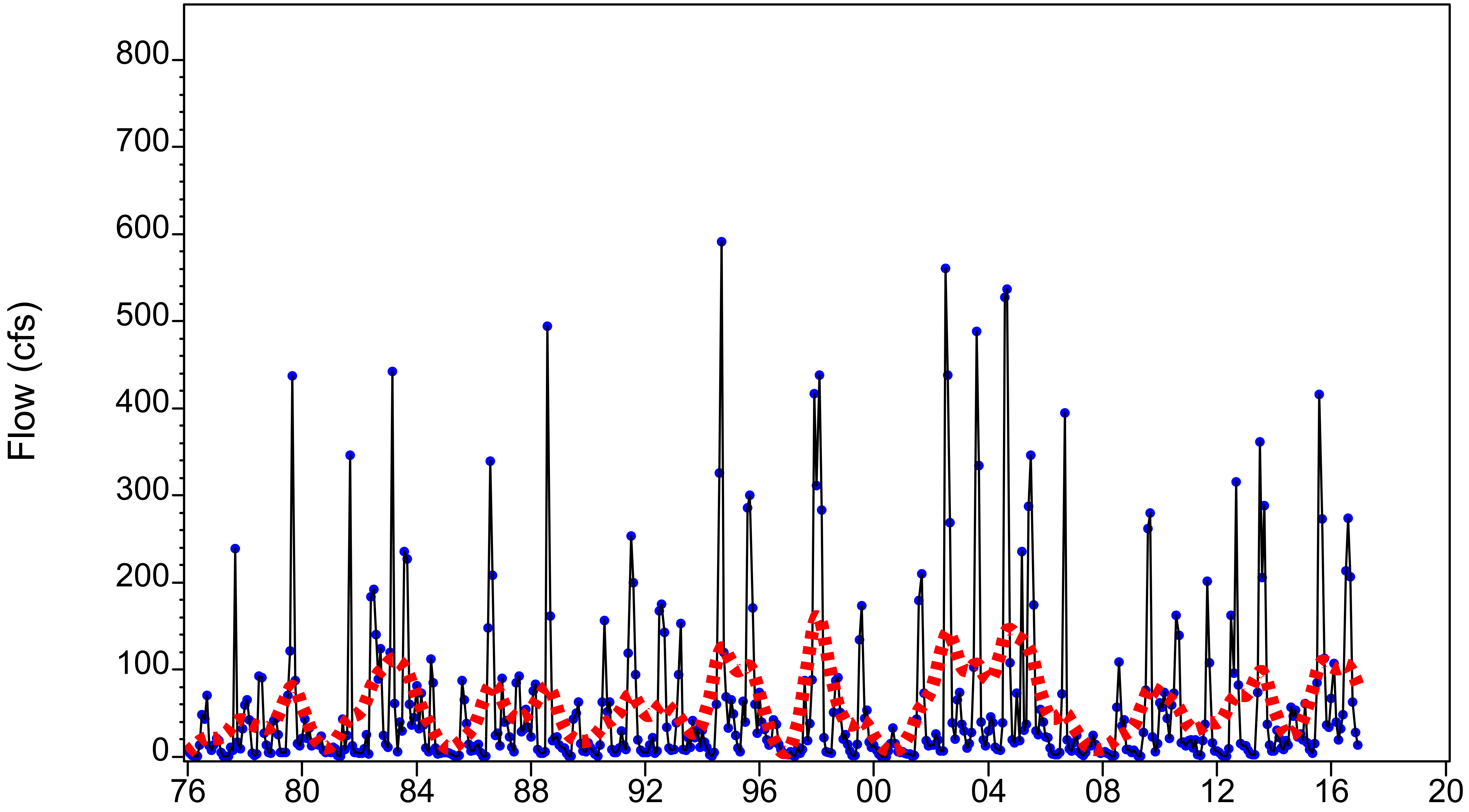


Figure 3.182 Monthly P10 flow at long-term Horse Creek near Arcadia (2297310) gage (1976-2016)

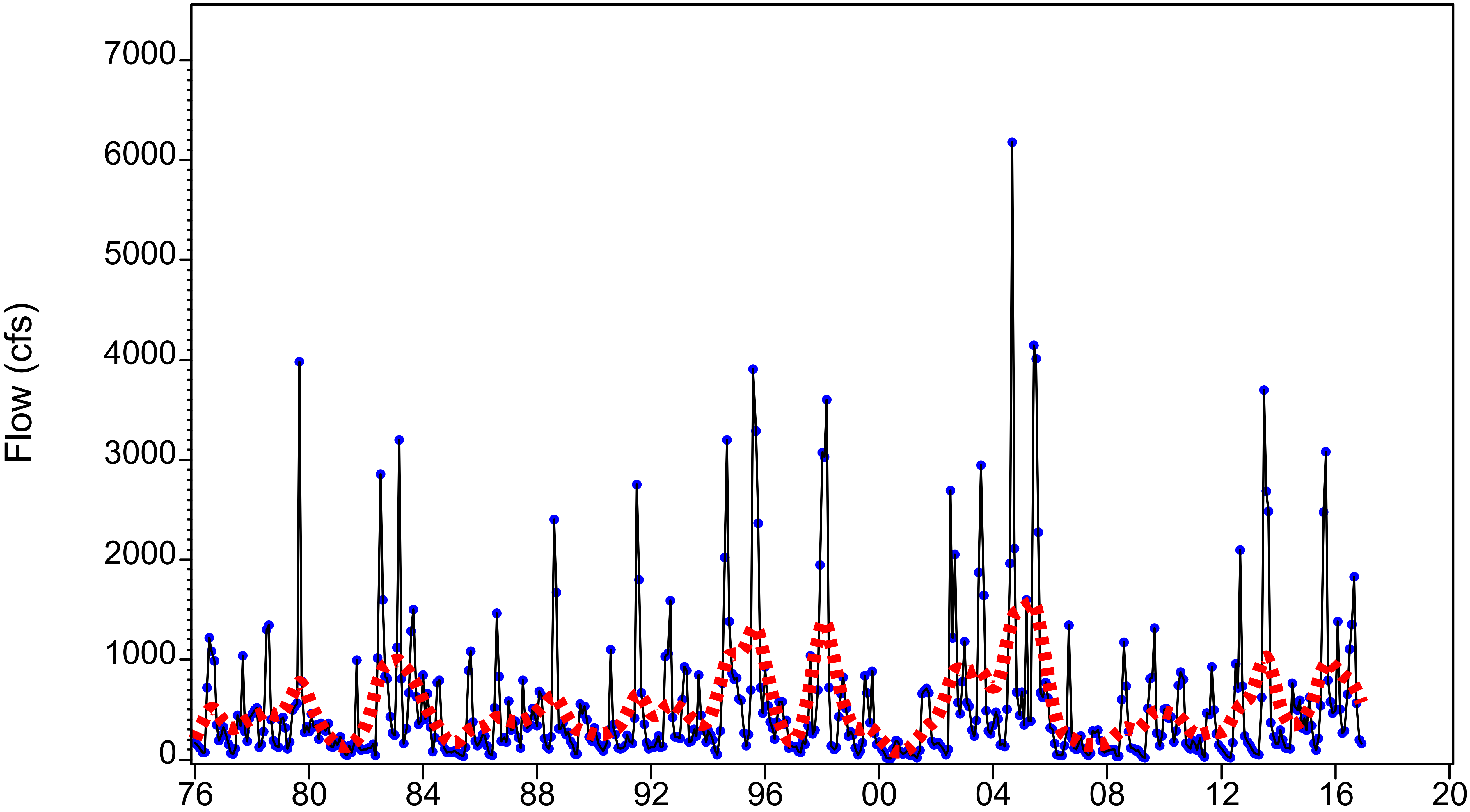


Figure 3.183 Monthly P10 flow at long-term for total gaged flow upstream of the Facility (1976-2016)

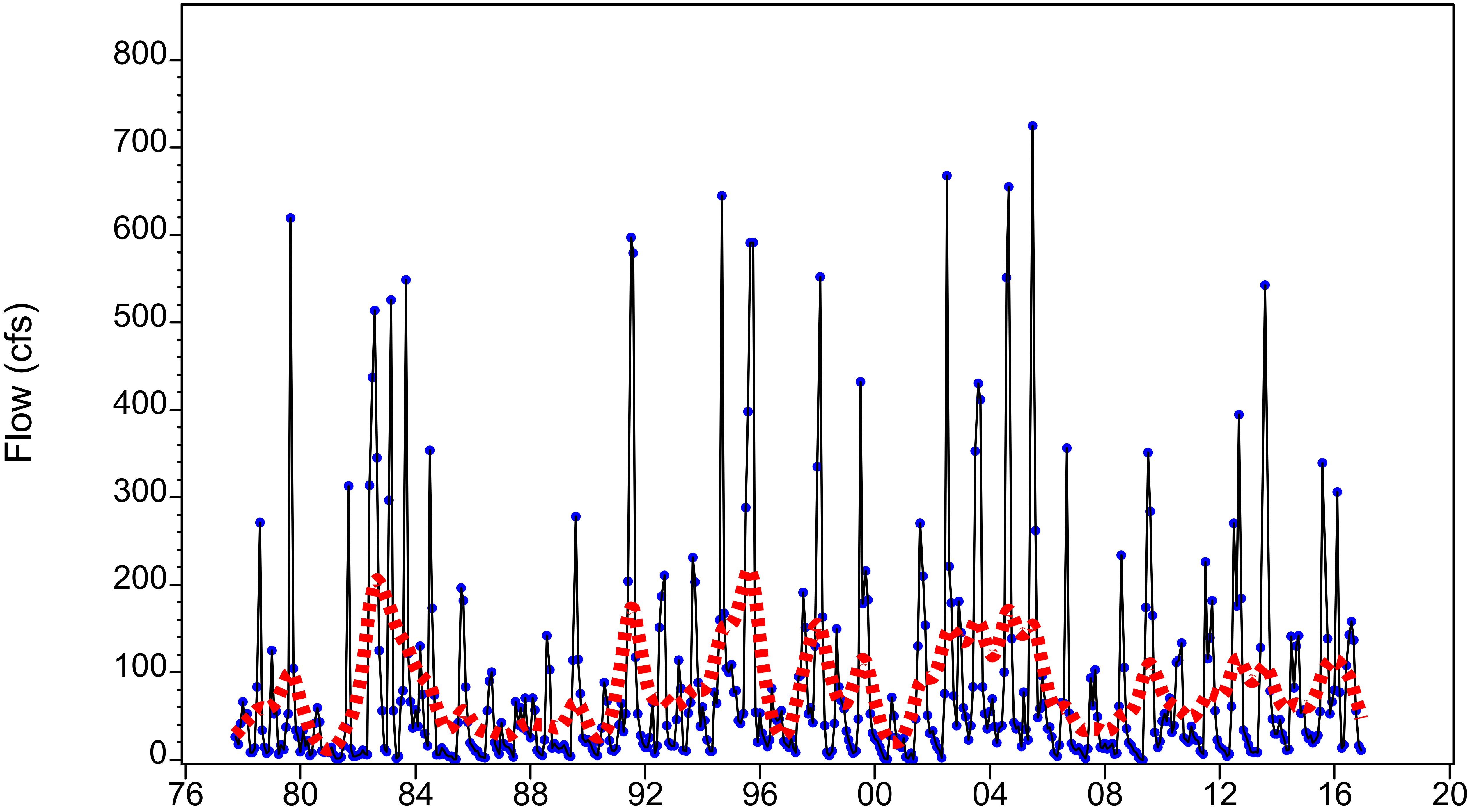


Figure 3.184 Monthly P10 flow at long-term Prairie Creek (2298123) gage (1976-2016)

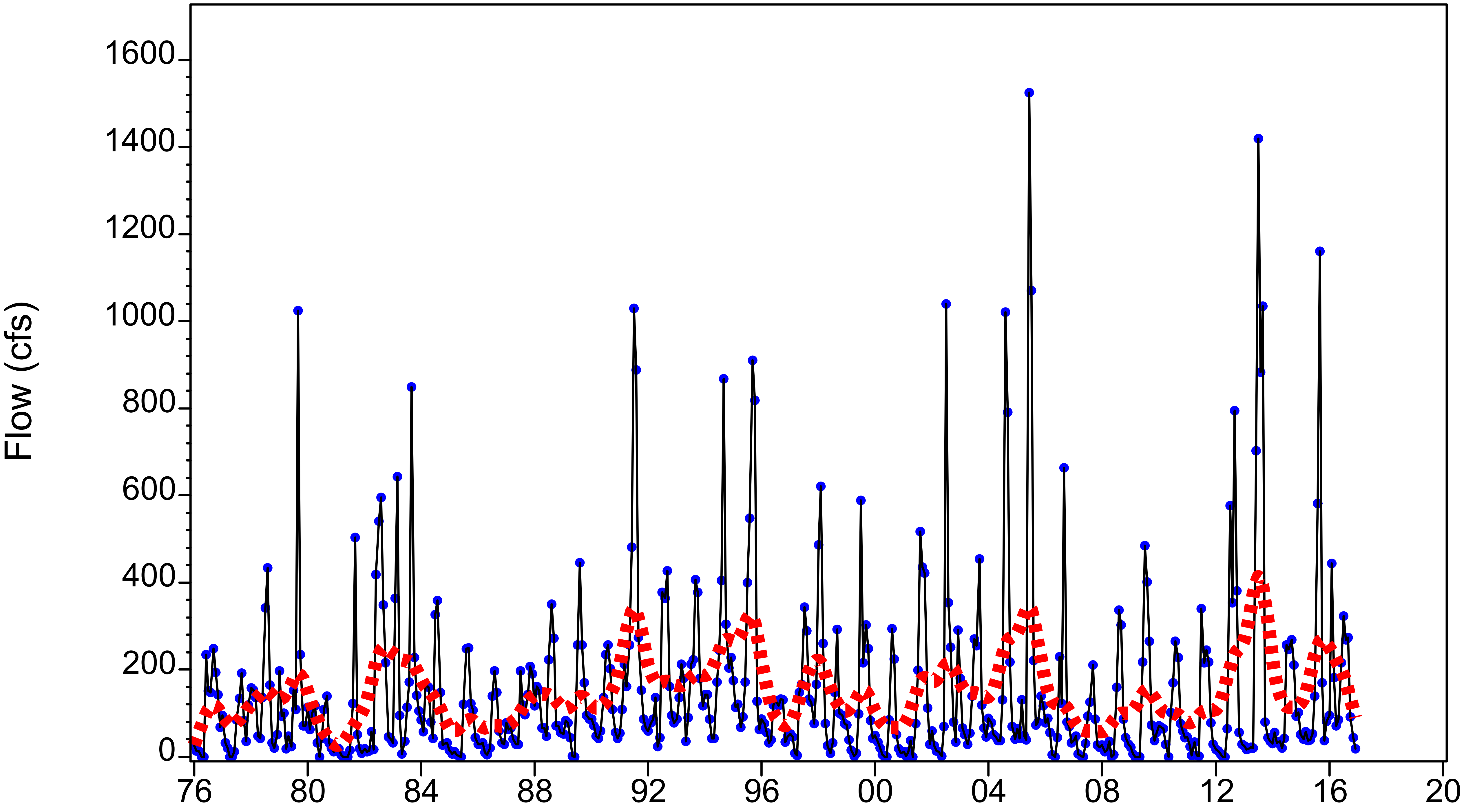


Figure 3.185 Monthly P10 flow at long-term Shell Creek gage (1976-2016)

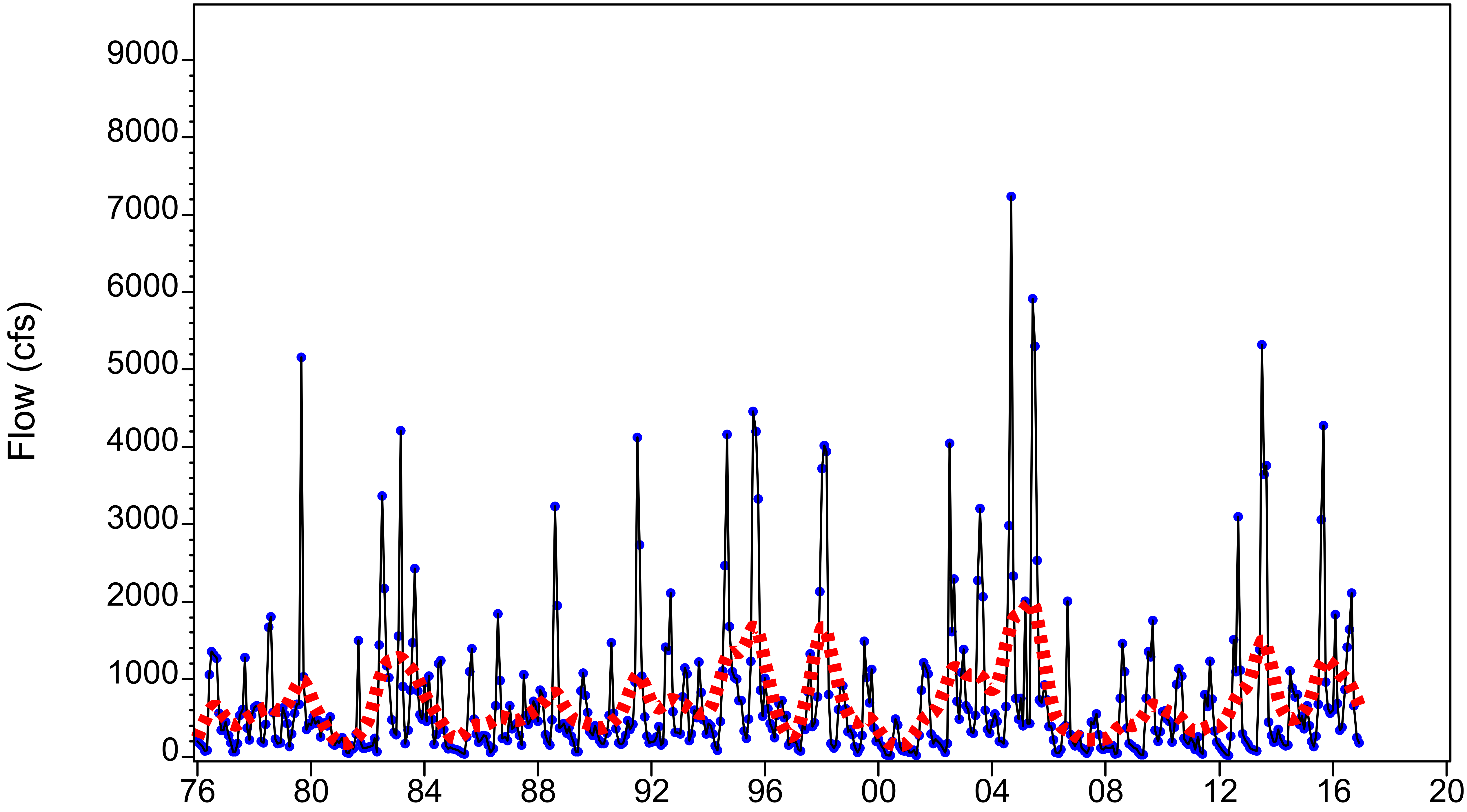


Figure 3.186 Monthly P10 flow of total gaged Peace River flow to the Upper Harbor (1976-2016)

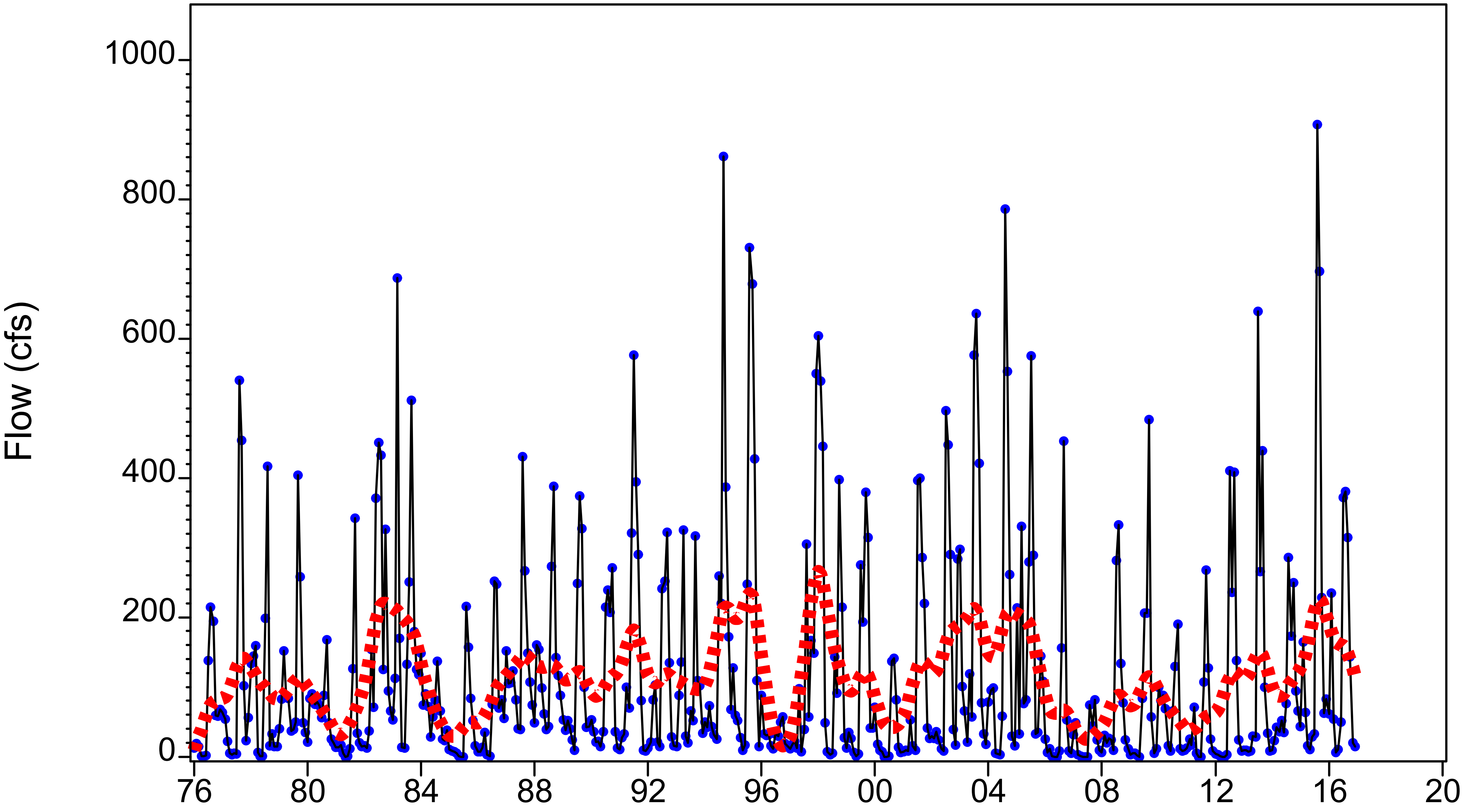


Figure 3.187 Monthly P10 flow at long-term Myakka River near Sarasota (2298830) gage (1976-2016)

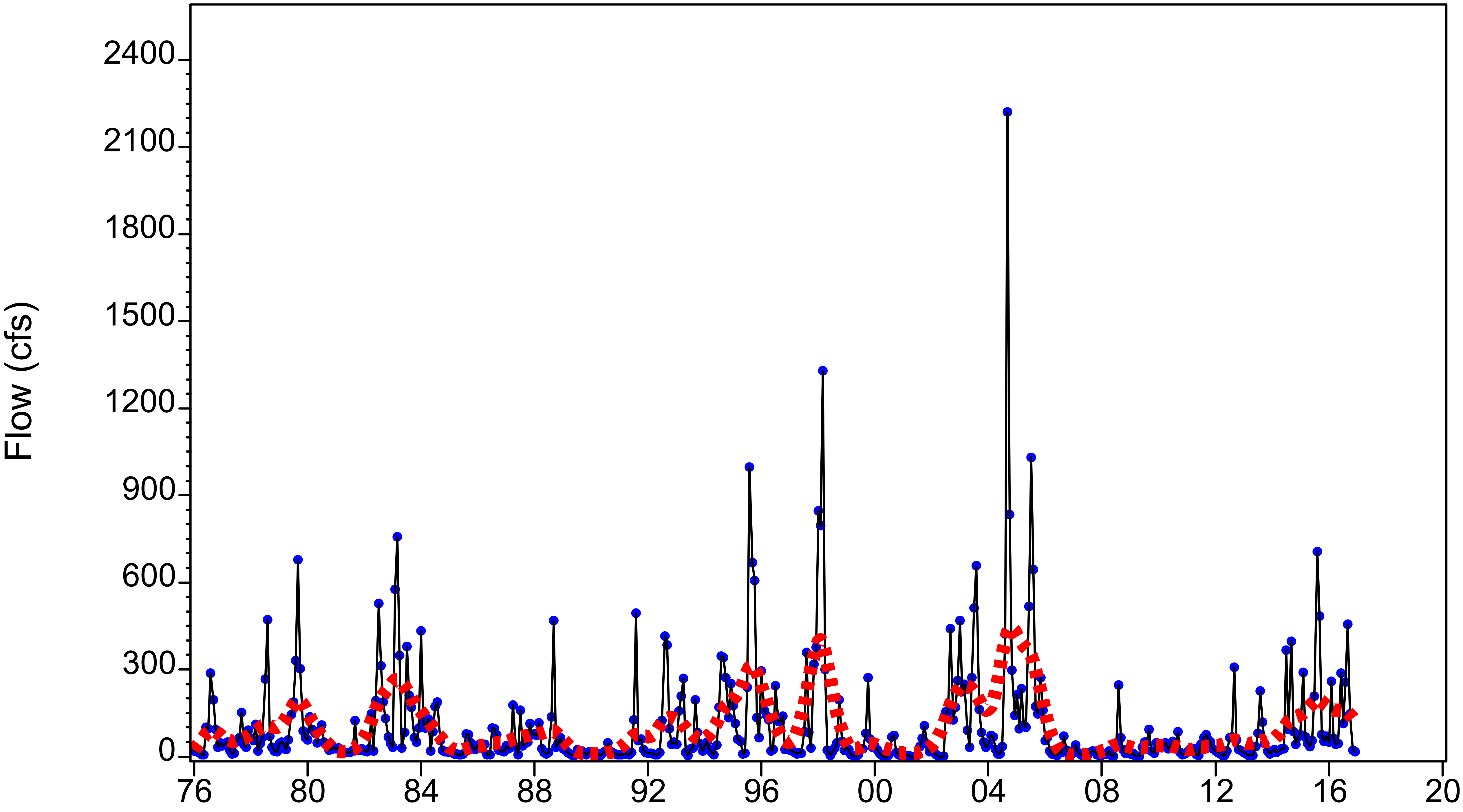


Figure 3.188 Monthly P25 flow at long-term Peace River at Bartow (2294650) gage (1976-2016)

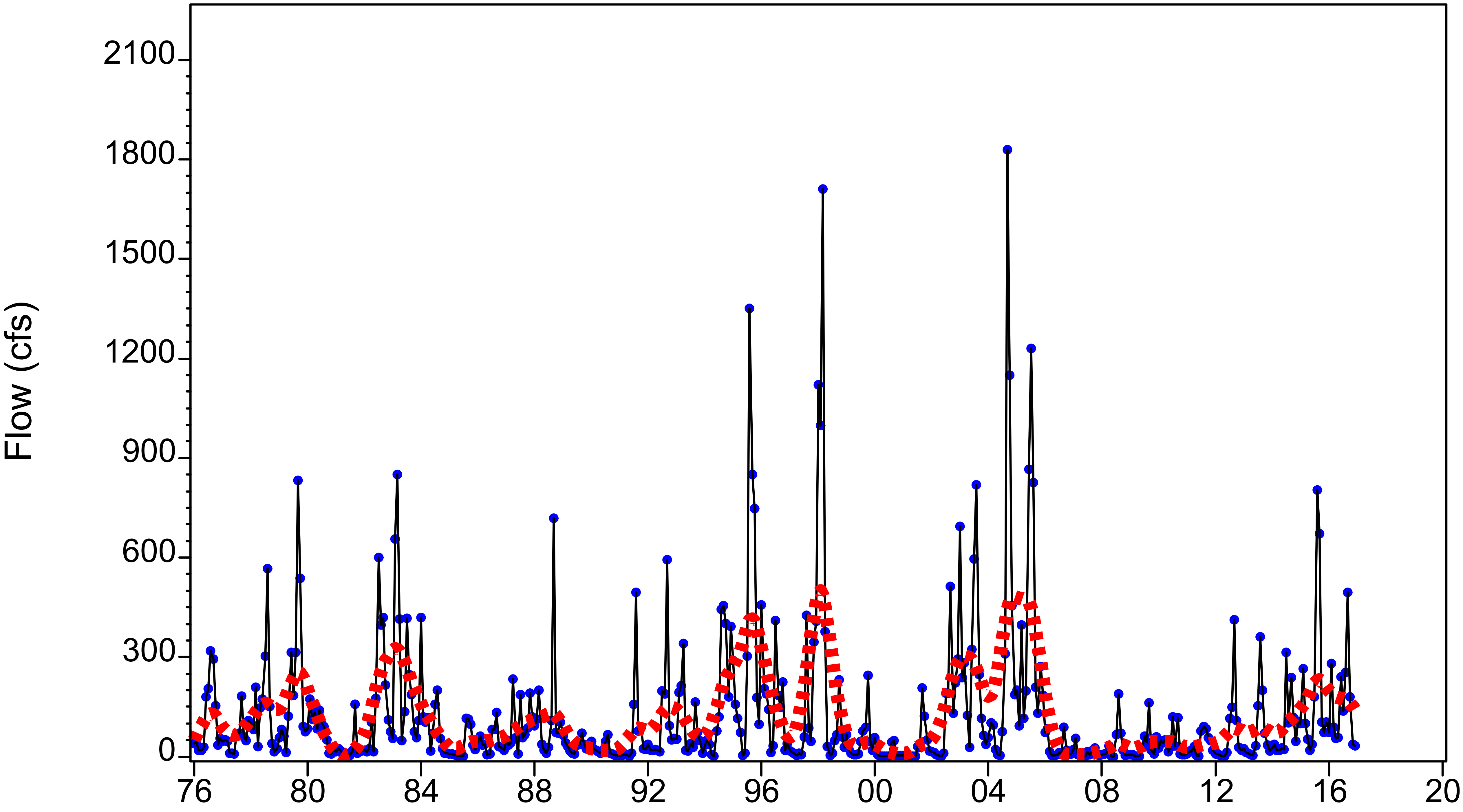


Figure 3.189 Monthly P25 flow at long-term Peace River at Ft. Meade (2294898) gage (1976-2016)

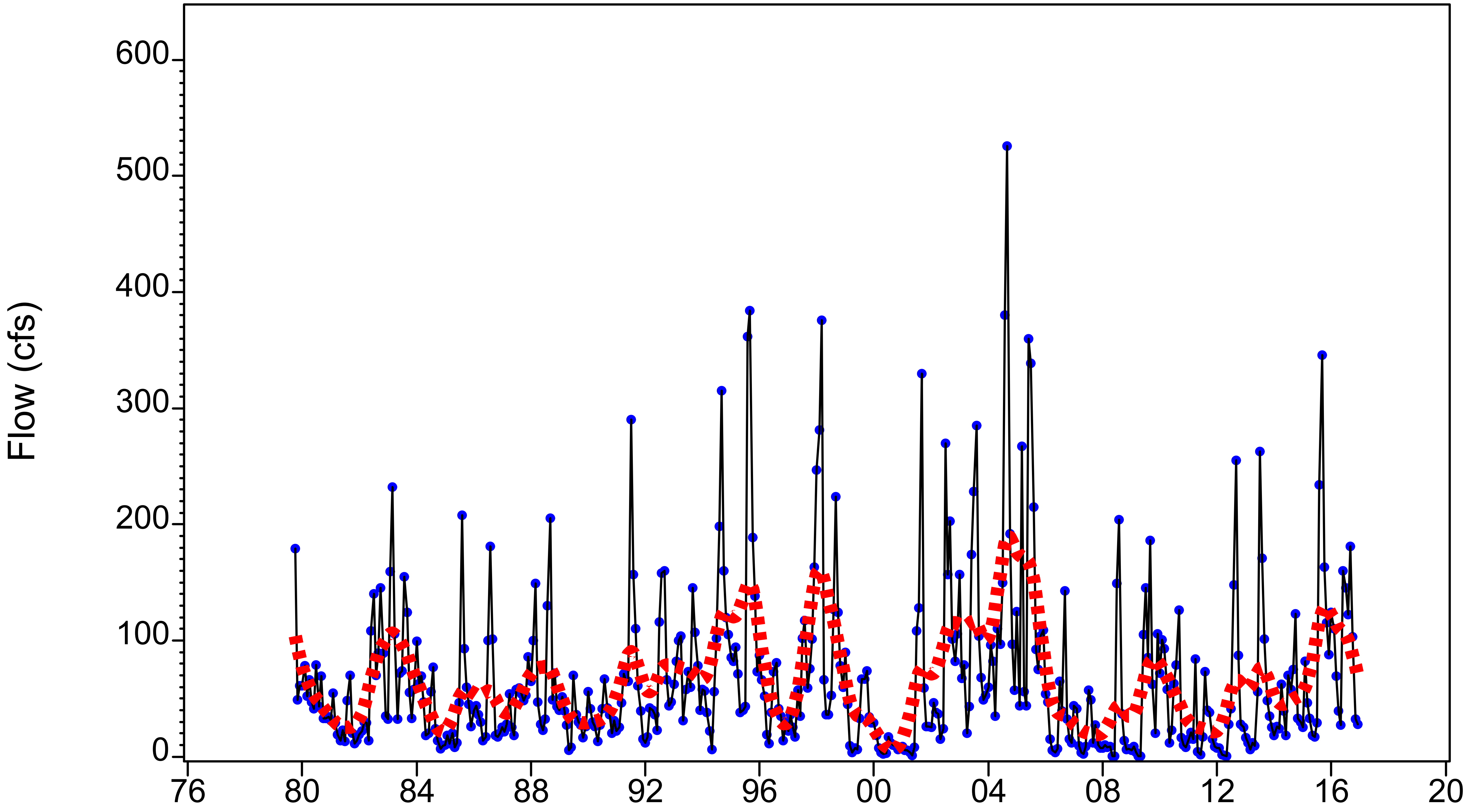


Figure 3.190 Monthly P25 flow at long-term Payne Creek (2295420) gage (1976-2016)

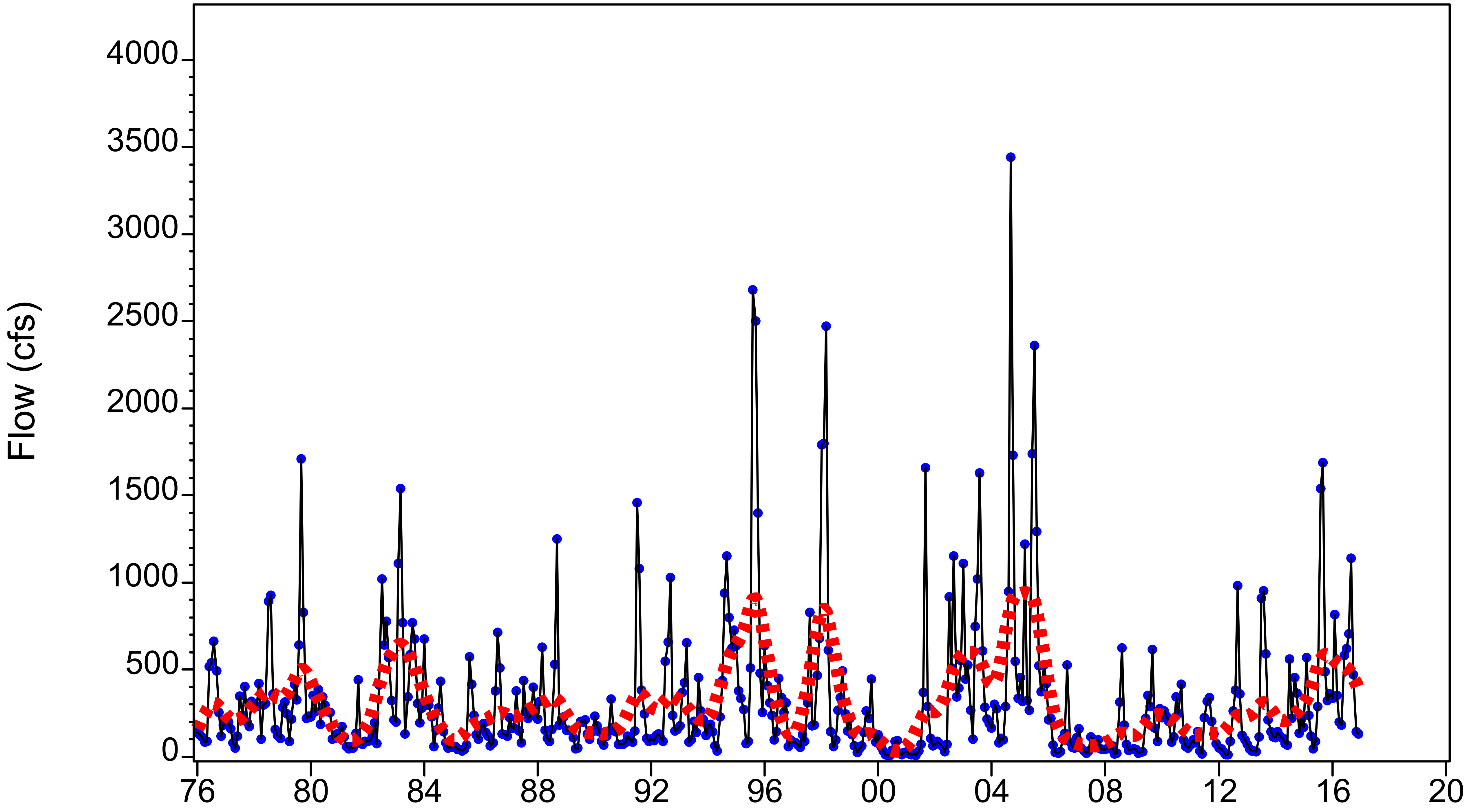


Figure 3.191 Monthly P25 flow at long-term Peace River at Zolfo (2295637) gage (1976-2016)

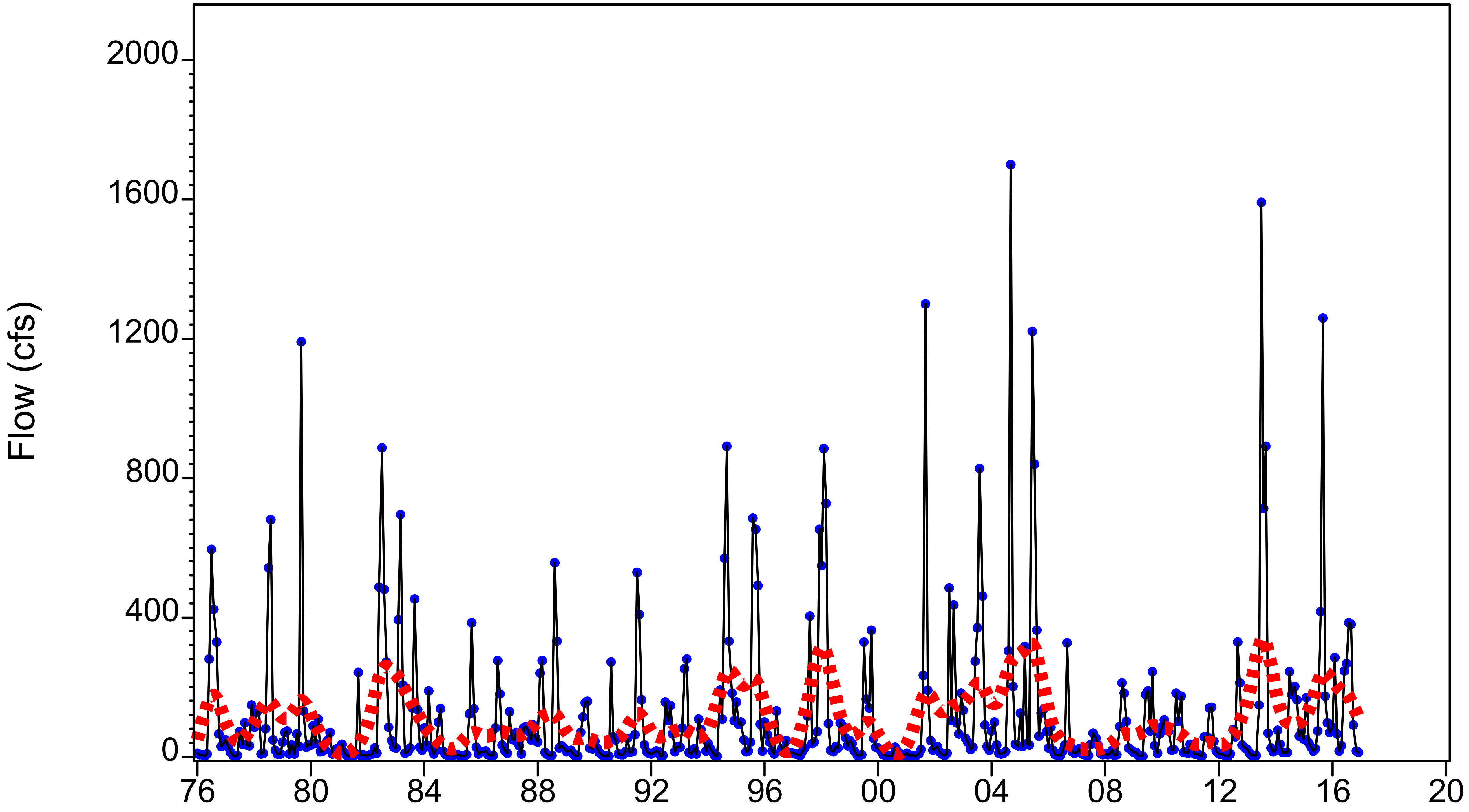


Figure 3.192 Monthly P25 flow at long-term Charlie Creek (2296500) gage (1976-2016)

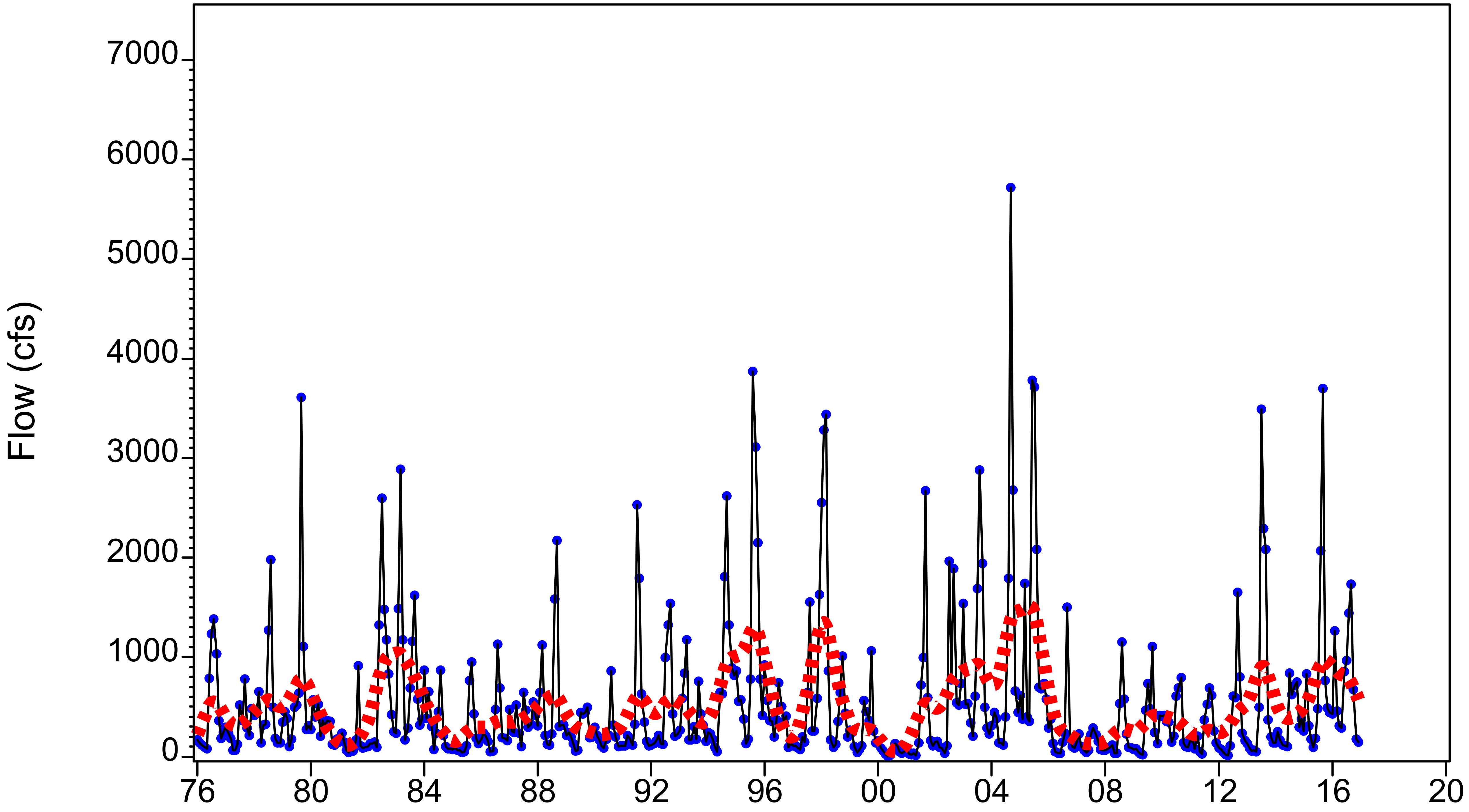


Figure 3.193 Monthly P25 flow at long-term Peace River at Arcadia (2296750) gage (1976-2016)

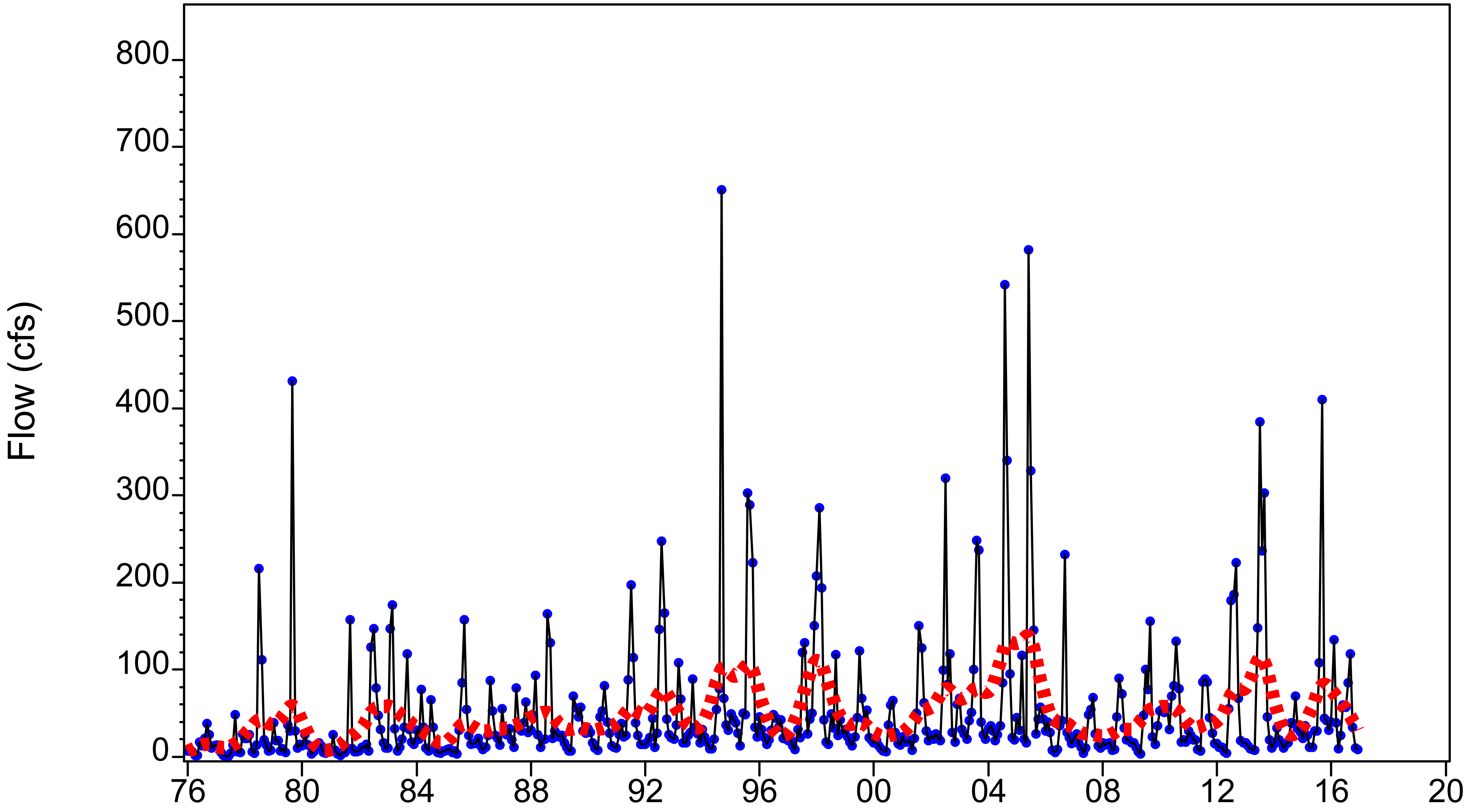


Figure 3.194 Monthly P25 flow at long-term Joshua Creek at Nocatee (2297100) gage (1976-2016)

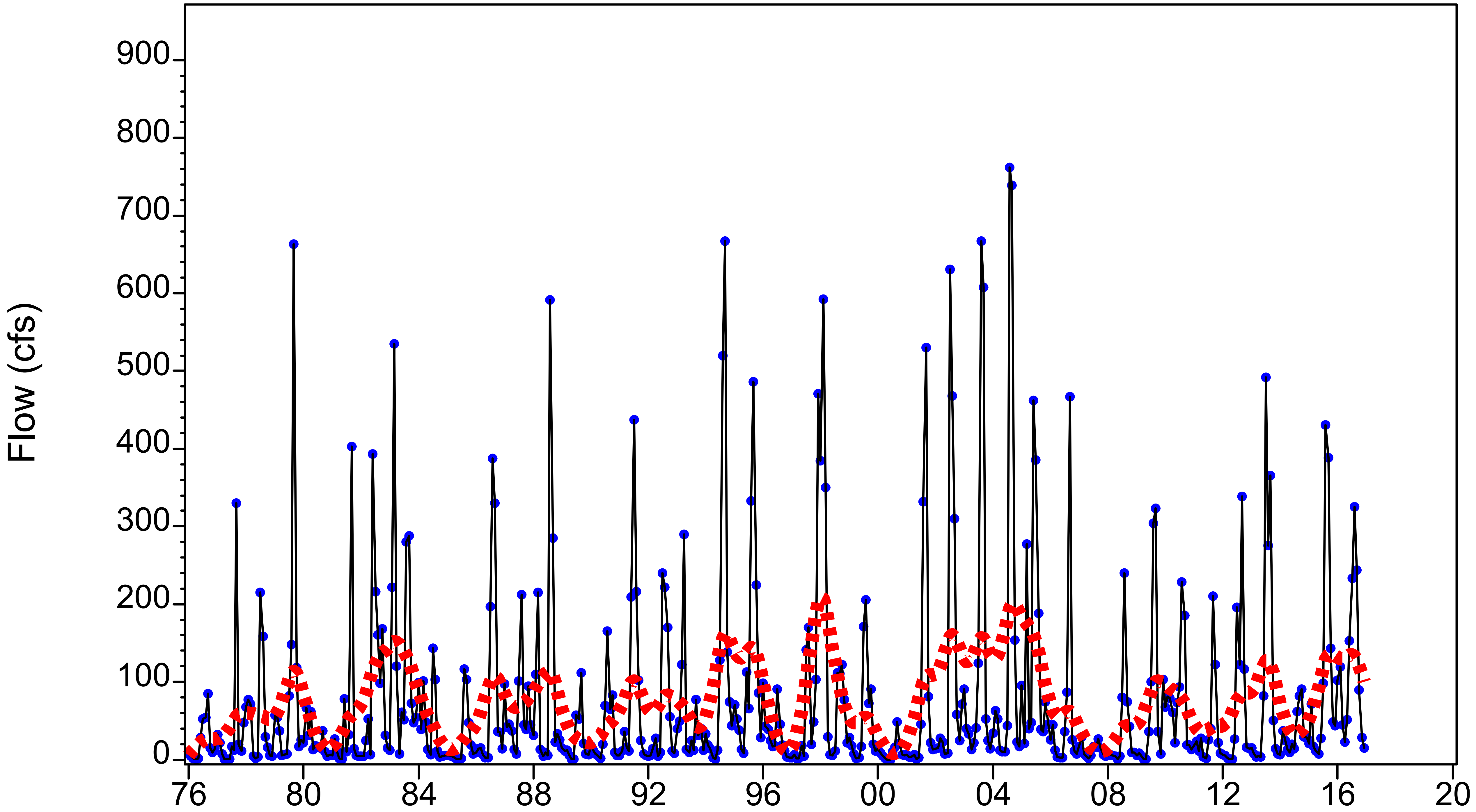


Figure 3.195 Monthly P25 flow at long-term Horse Creek near Arcadia (2297310) gage (1976-2016)

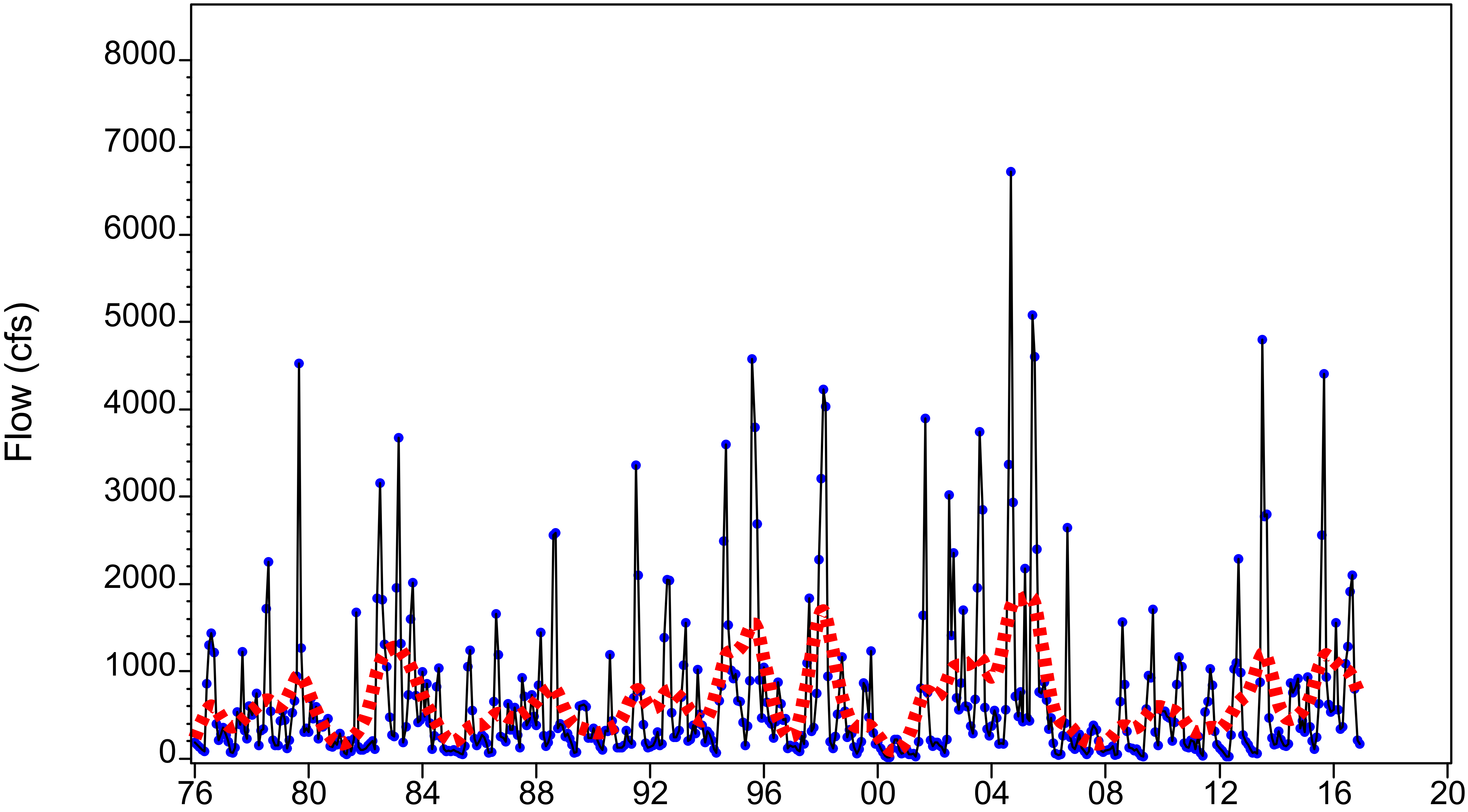


Figure 3.196 Monthly P25 flow at long-term for total gaged flow upstream of the Facility (1976-2016)

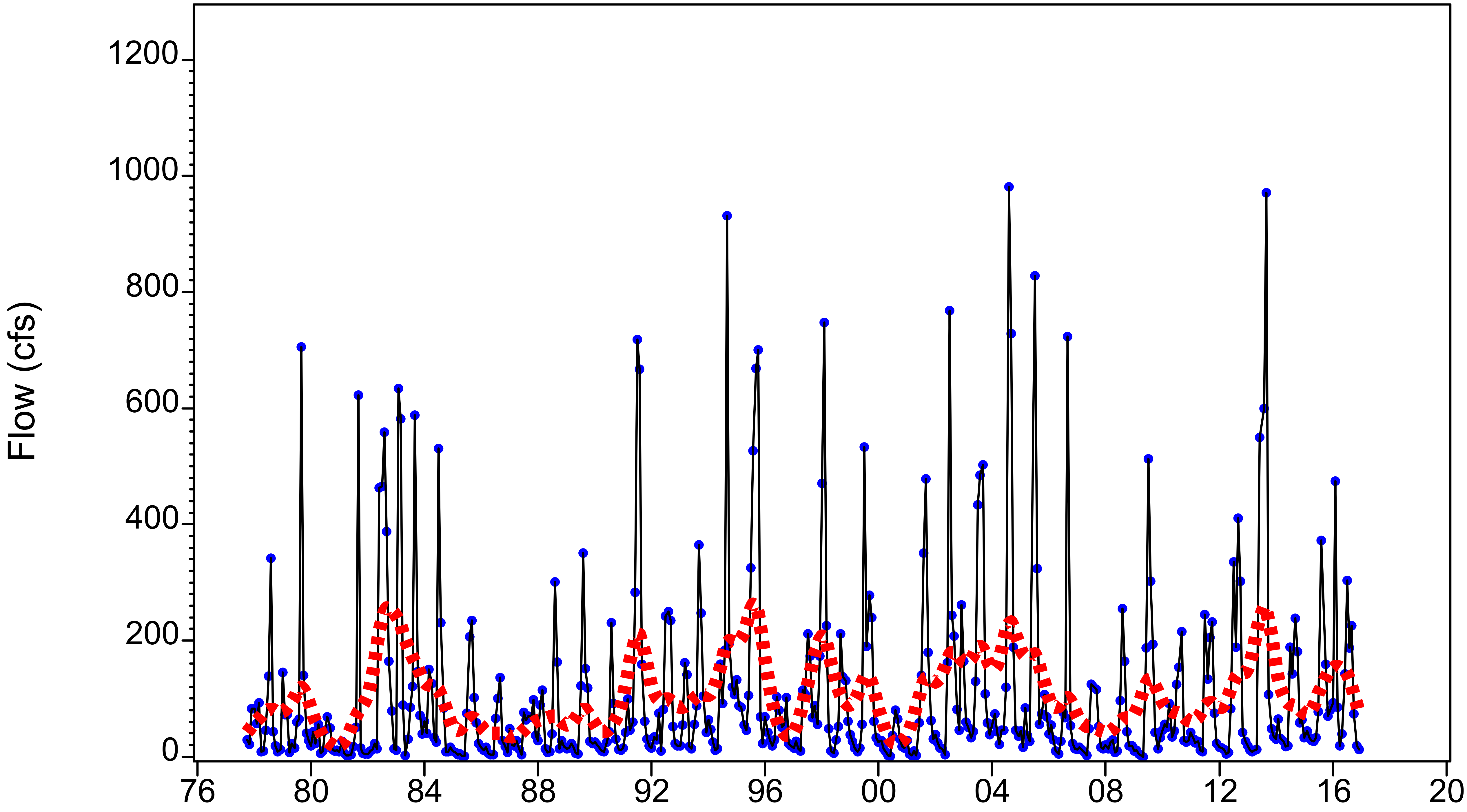


Figure 3.197 Monthly P25 flow at long-term Prairie Creek (2298123) gage (1976-2016)

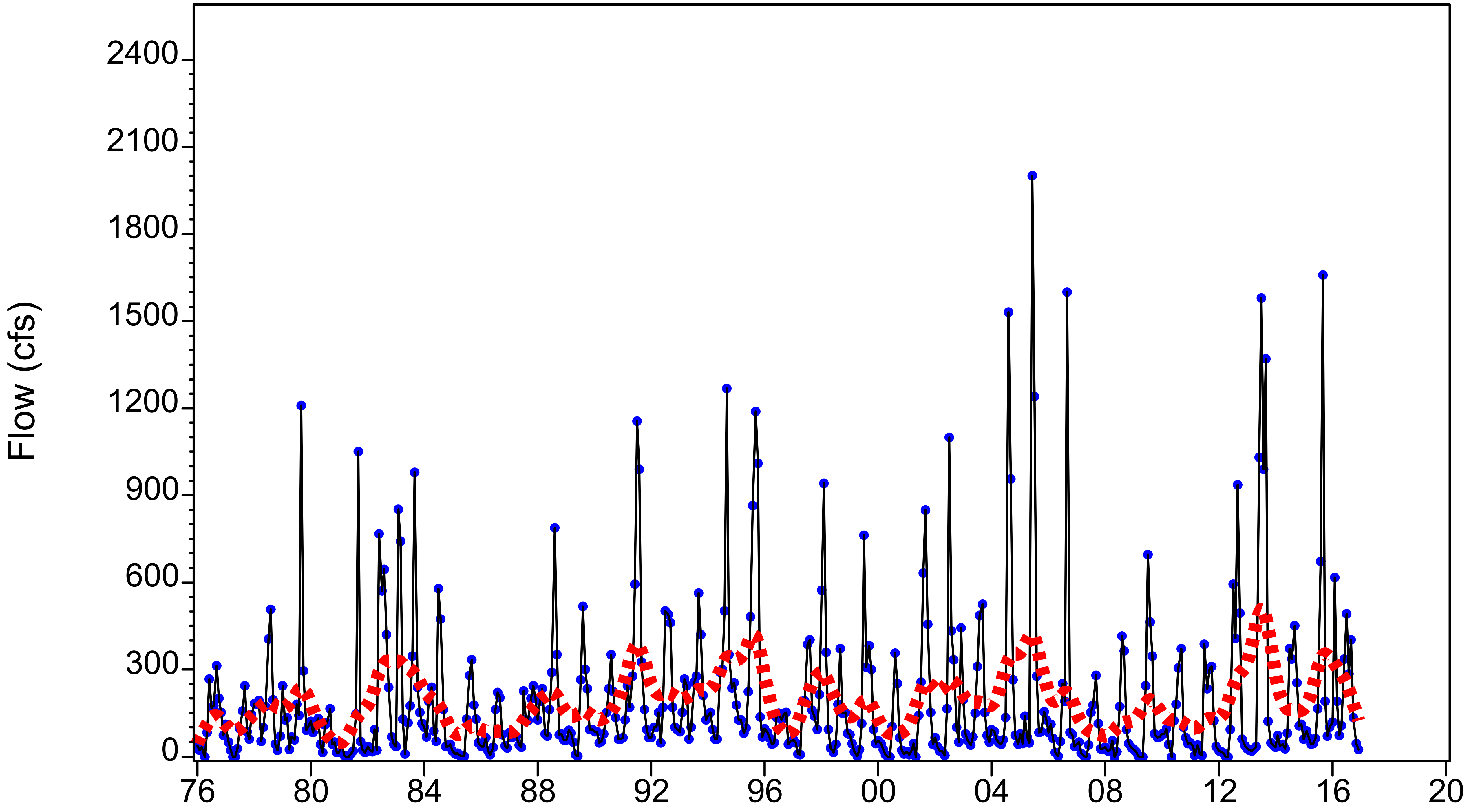


Figure 3.198 Monthly P25 flow at long-term Shell Creek gage (1976-2016)

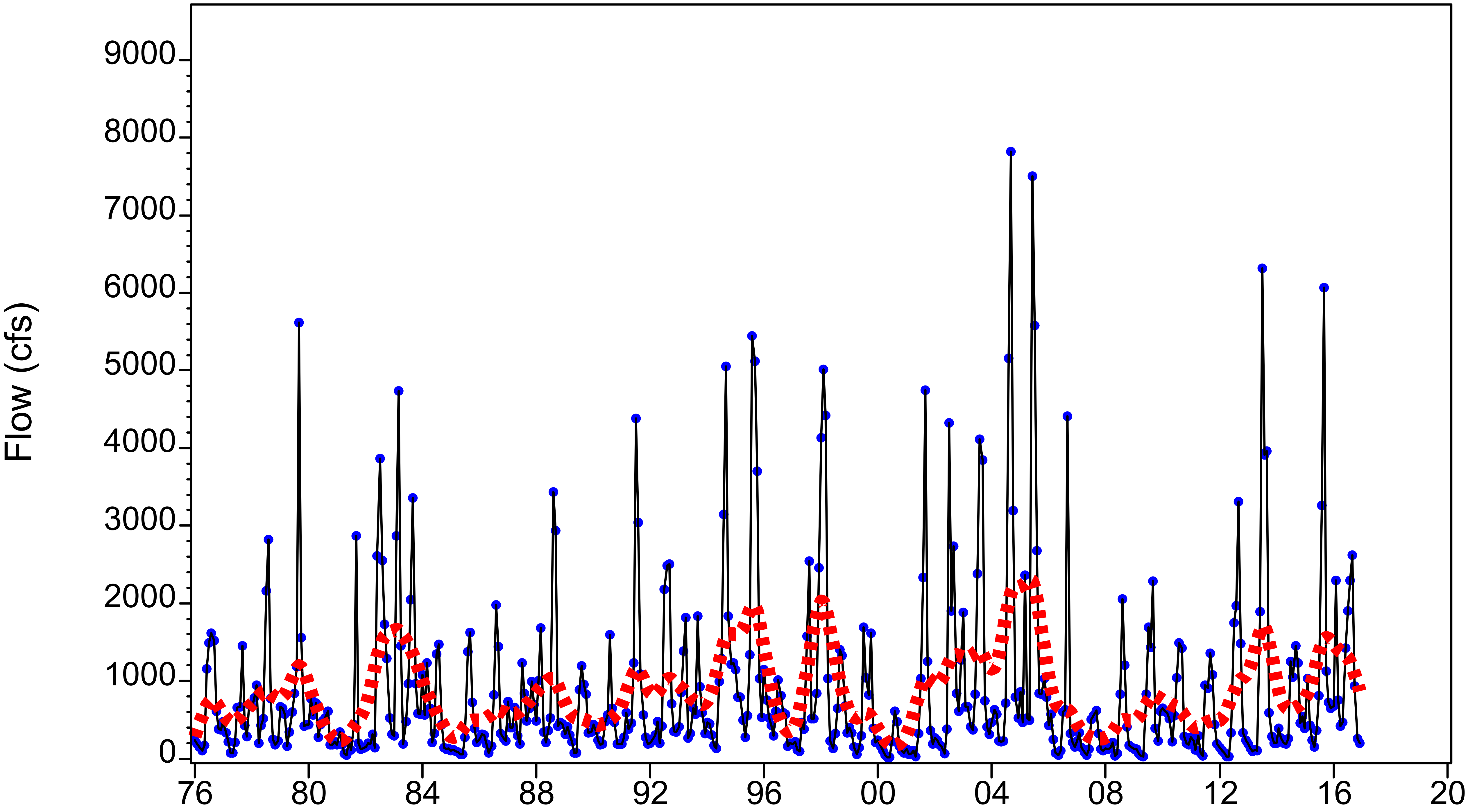


Figure 3.199 Monthly P25 flow of total gaged Peace River flow to the Upper Harbor (1976-2016)

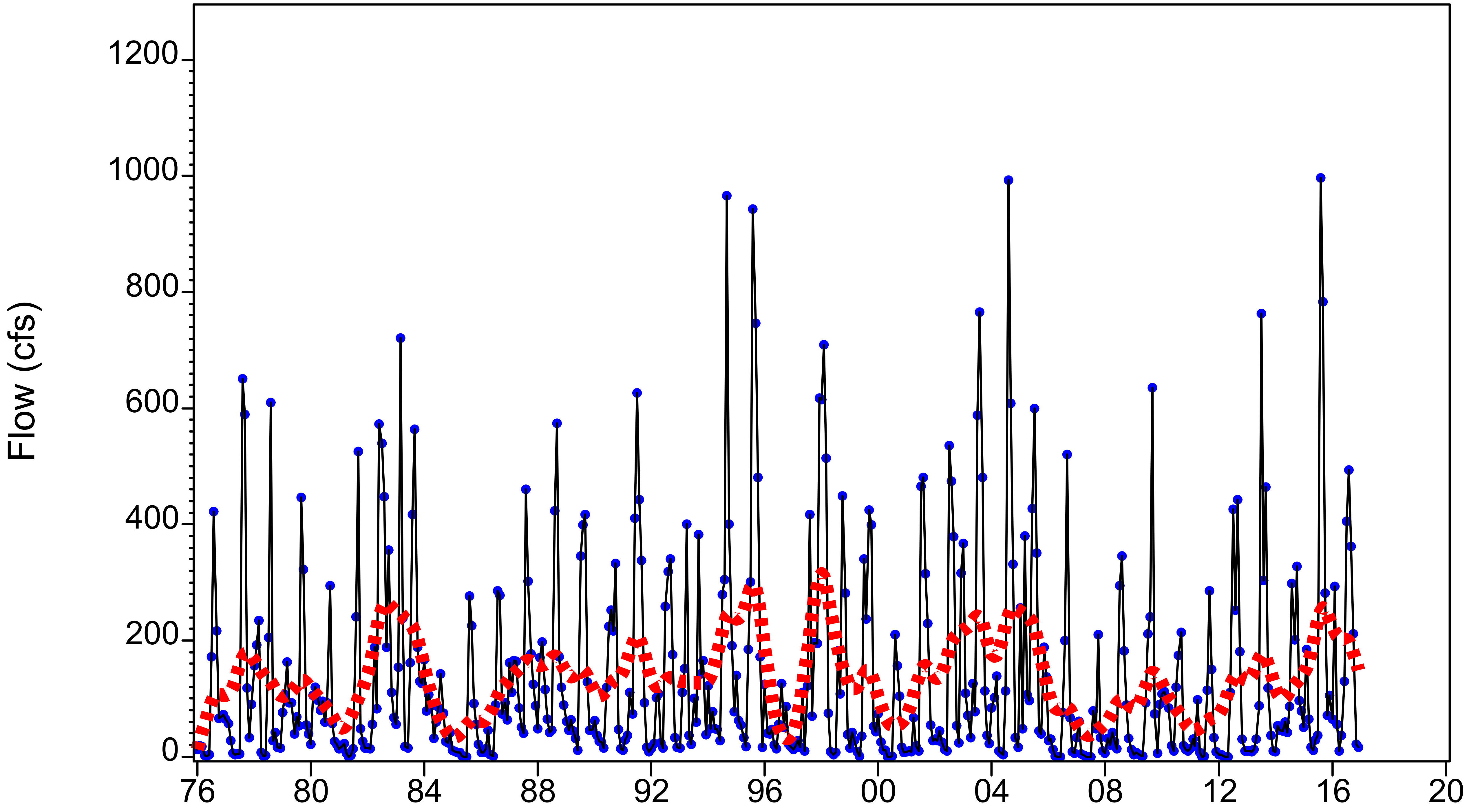


Figure 3.200 Monthly P25 flow at long-term Myakka River near Sarasota (2298830) gage (1976-2016)

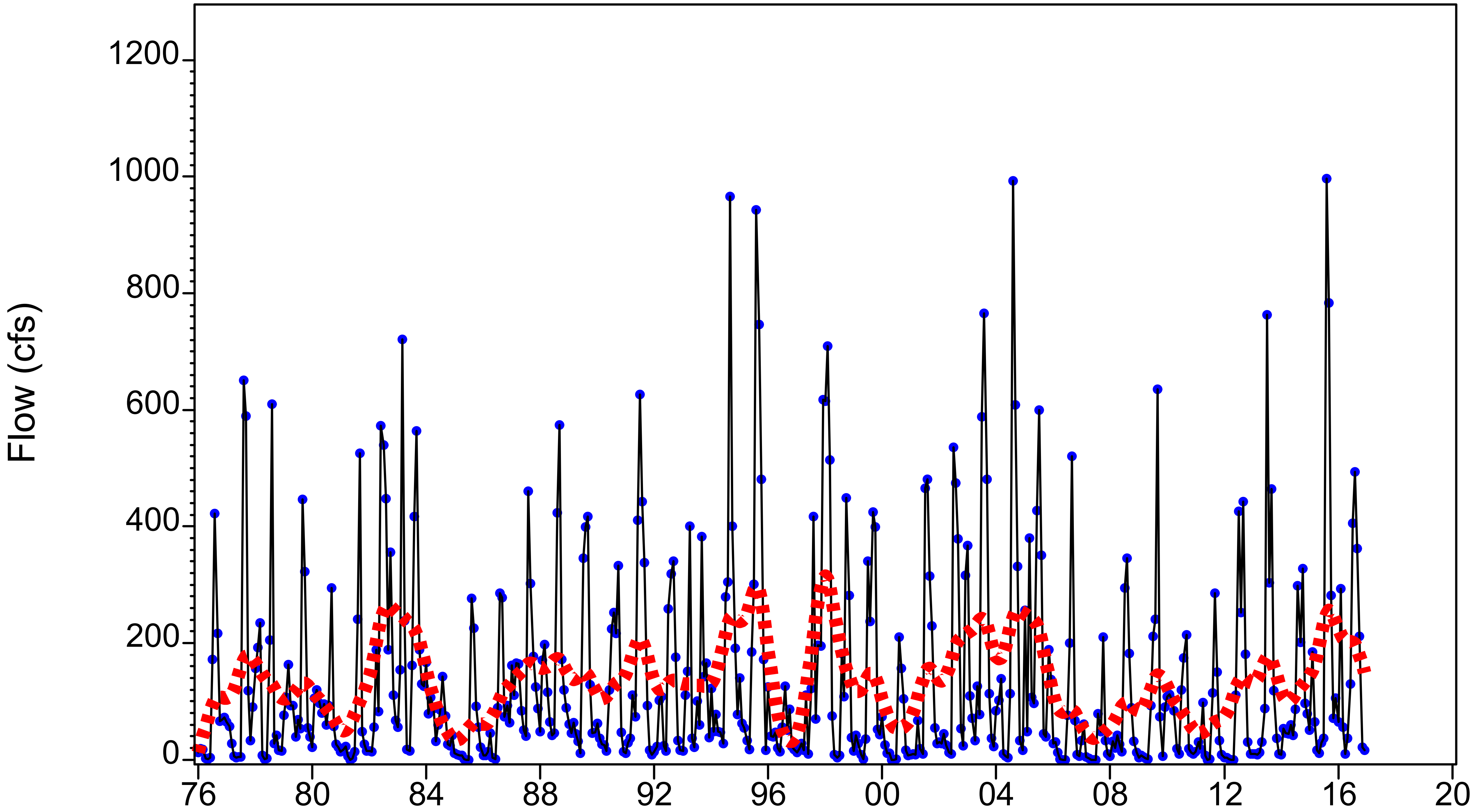


Figure 3.200 Monthly P25 flow at long-term Myakka River near Sarasota (2298830) gage (1976-2016)

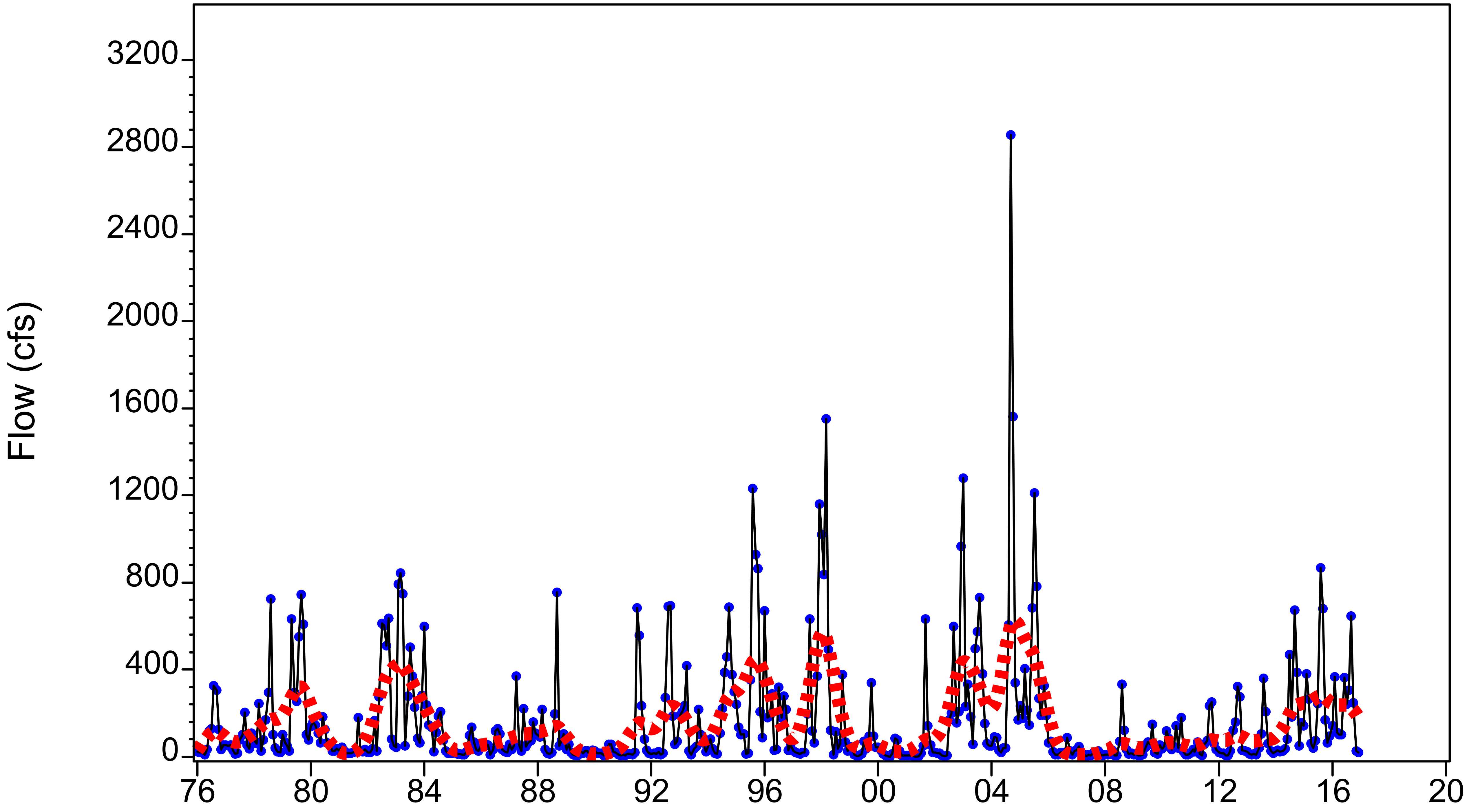


Figure 3.201 Monthly P50 (median) flow at long-term Peace River at Bartow (2294650) gage (1976-2016)

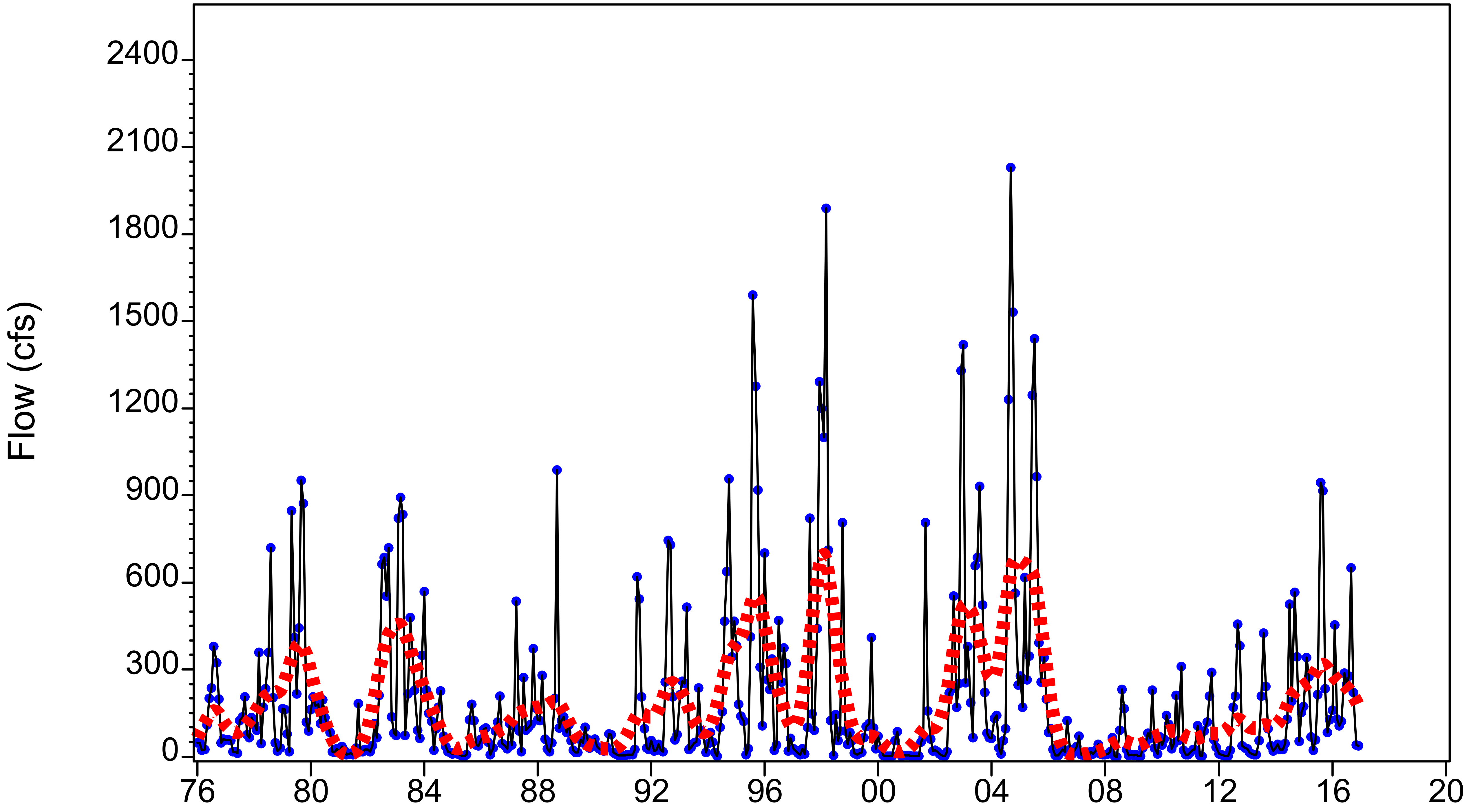


Figure 3.202 Monthly P50 (median) flow at long-term Peace River at Ft. Meade (2294898) gage (1976-2016)

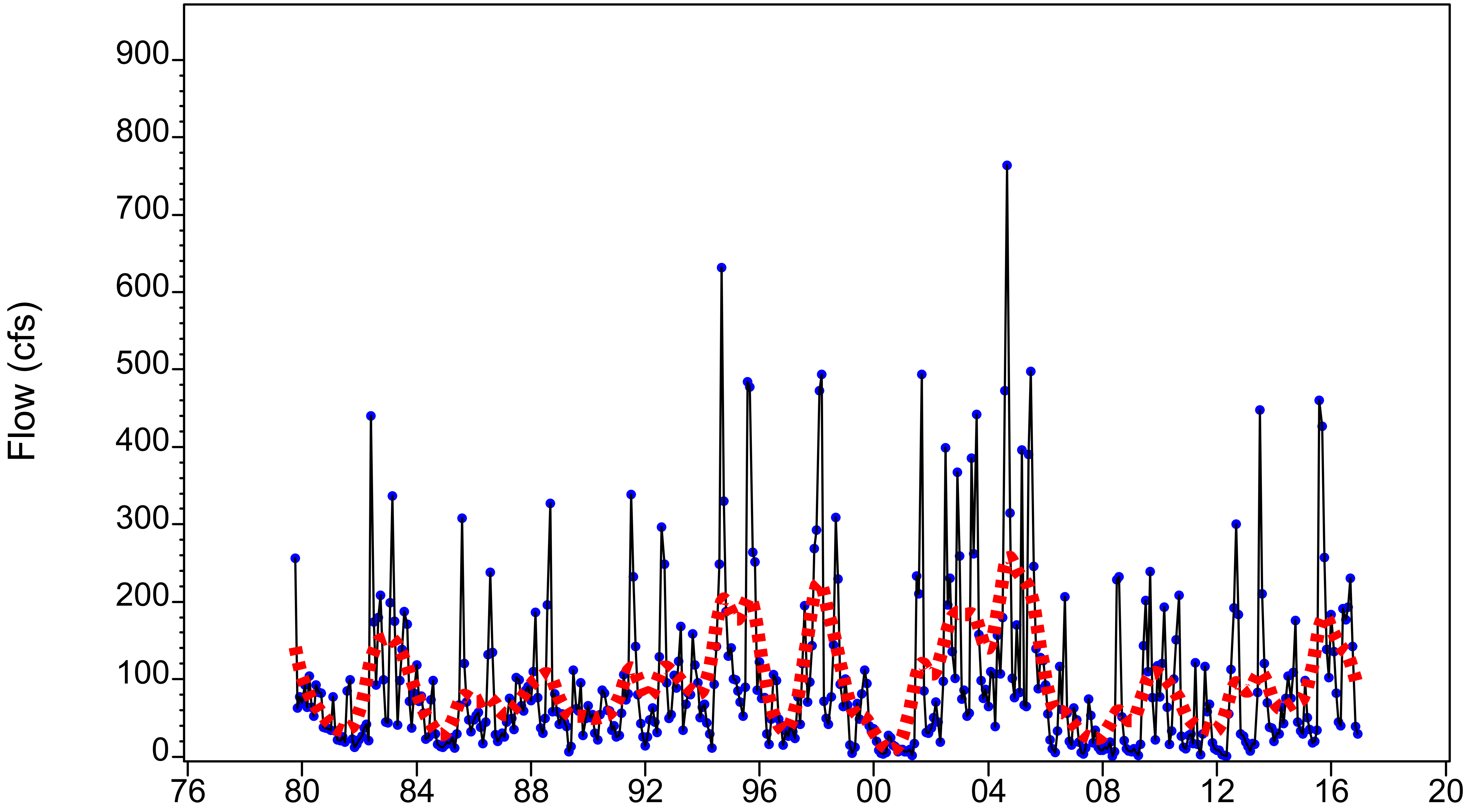


Figure 3.203 Monthly P50 (median) flow at long-term Payne Creek (2295420) gage (1976-2016)

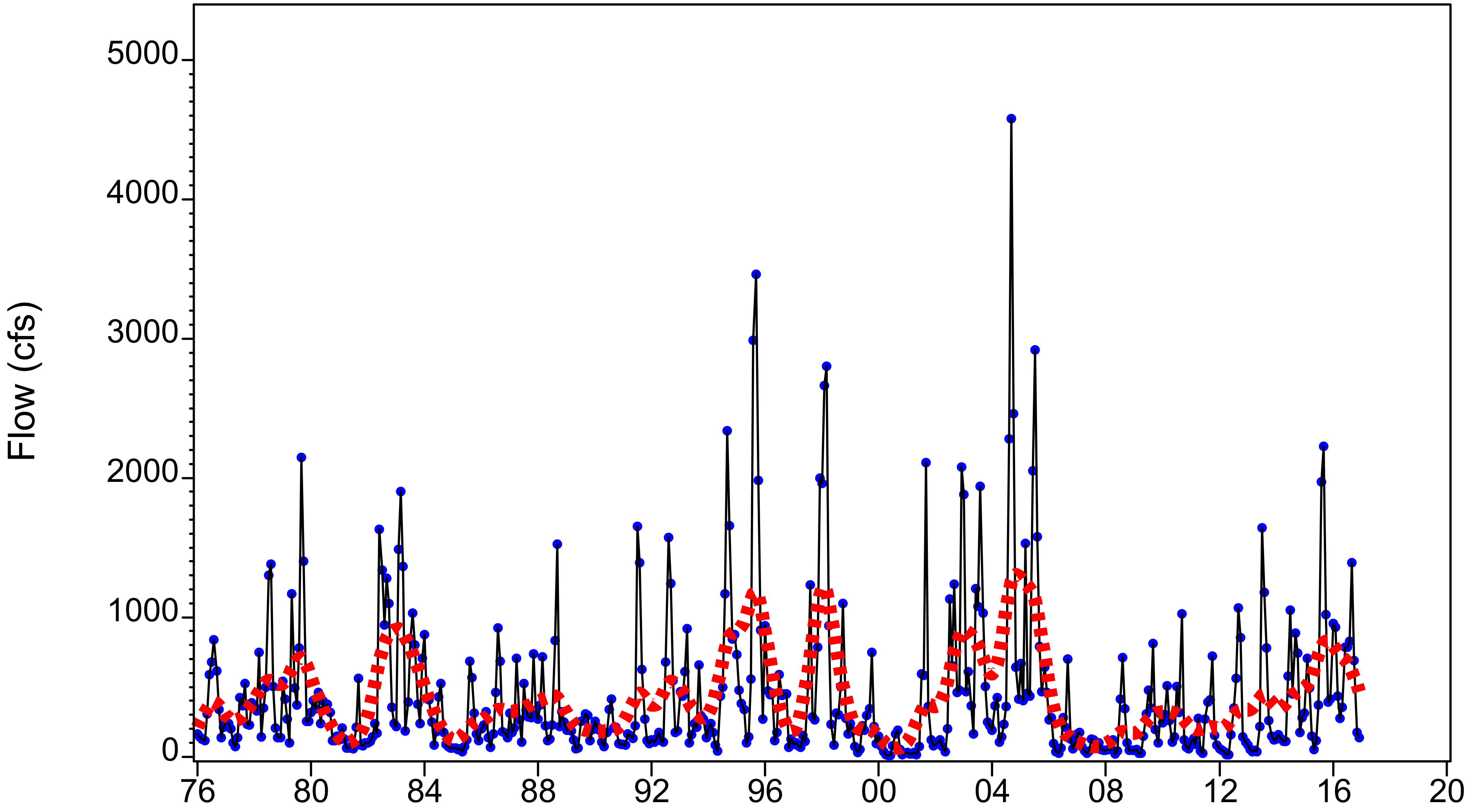


Figure 3.204 Monthly P50 (median) flow at long-term Peace River at Zolfo (2295637) gage (1976-2016)

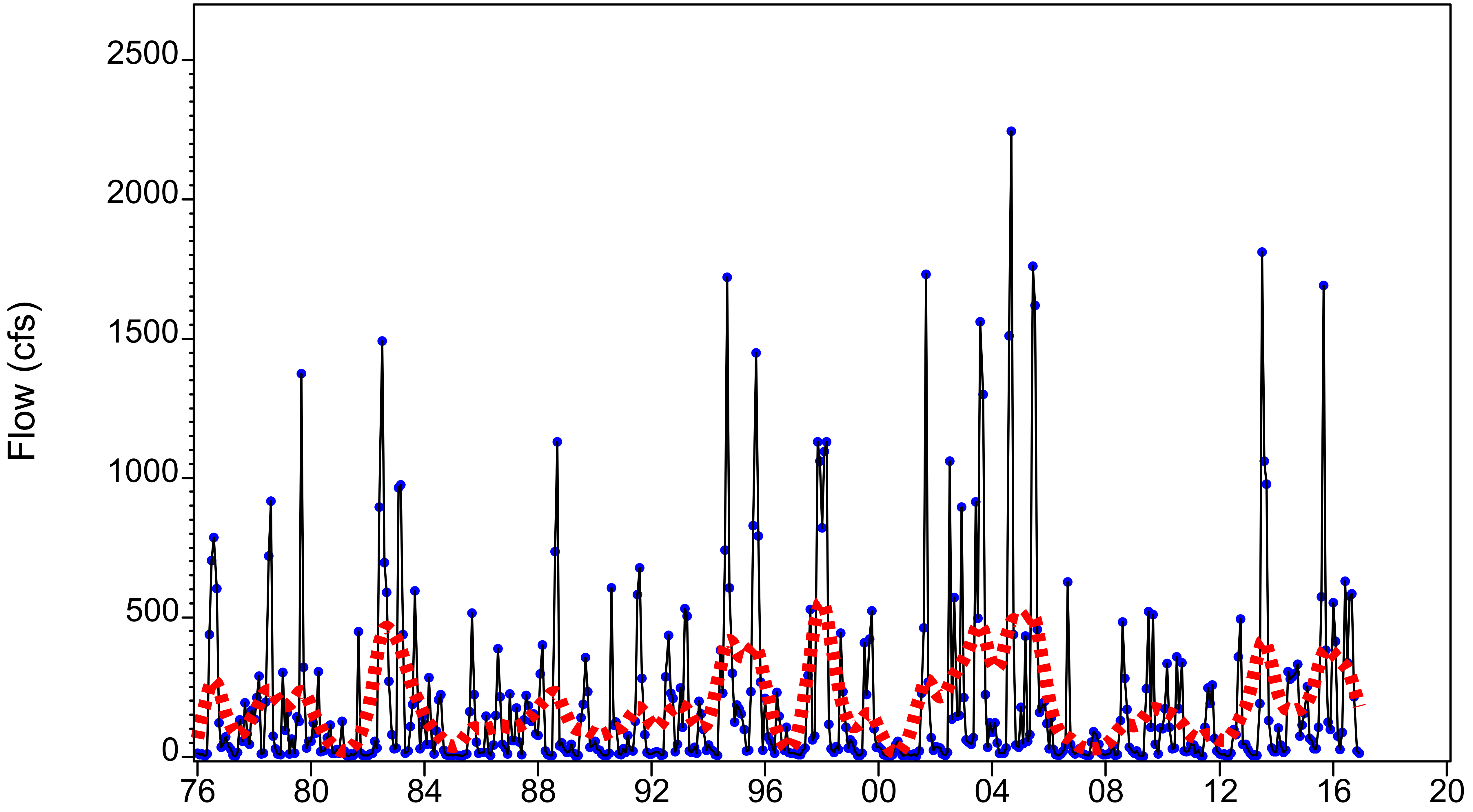


Figure 3.205 Monthly P50 (median) flow at long-term Charlie Creek (2296500) gage (1976-2016)

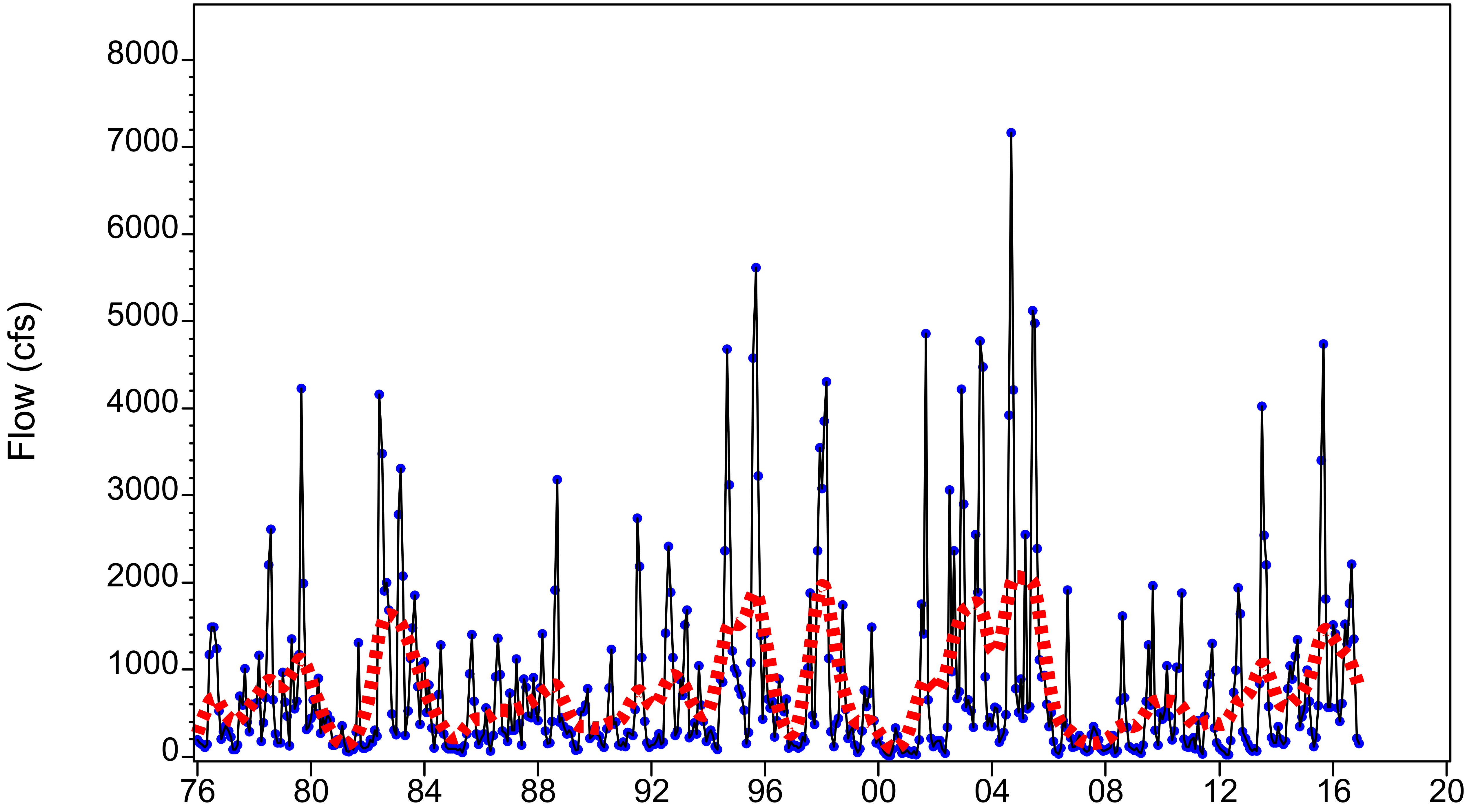


Figure 3.206 Monthly P50 (median) flow at long-term Peace River at Arcadia (2296750) gage (1976-2016)

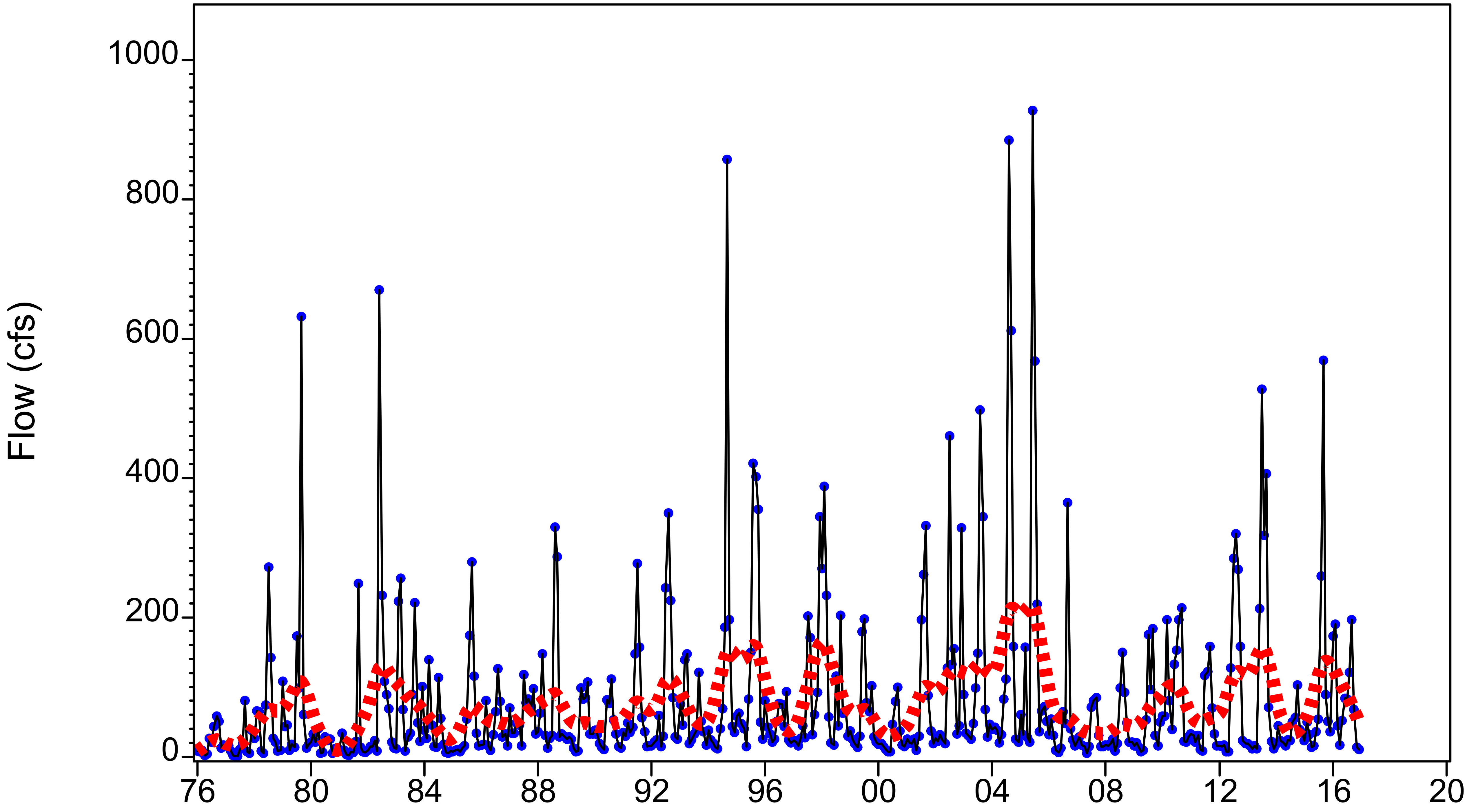


Figure 3.207 Monthly P50 (median) flow at long-term Joshua Creek at Nocatee (2297100) gage (1976-2016)

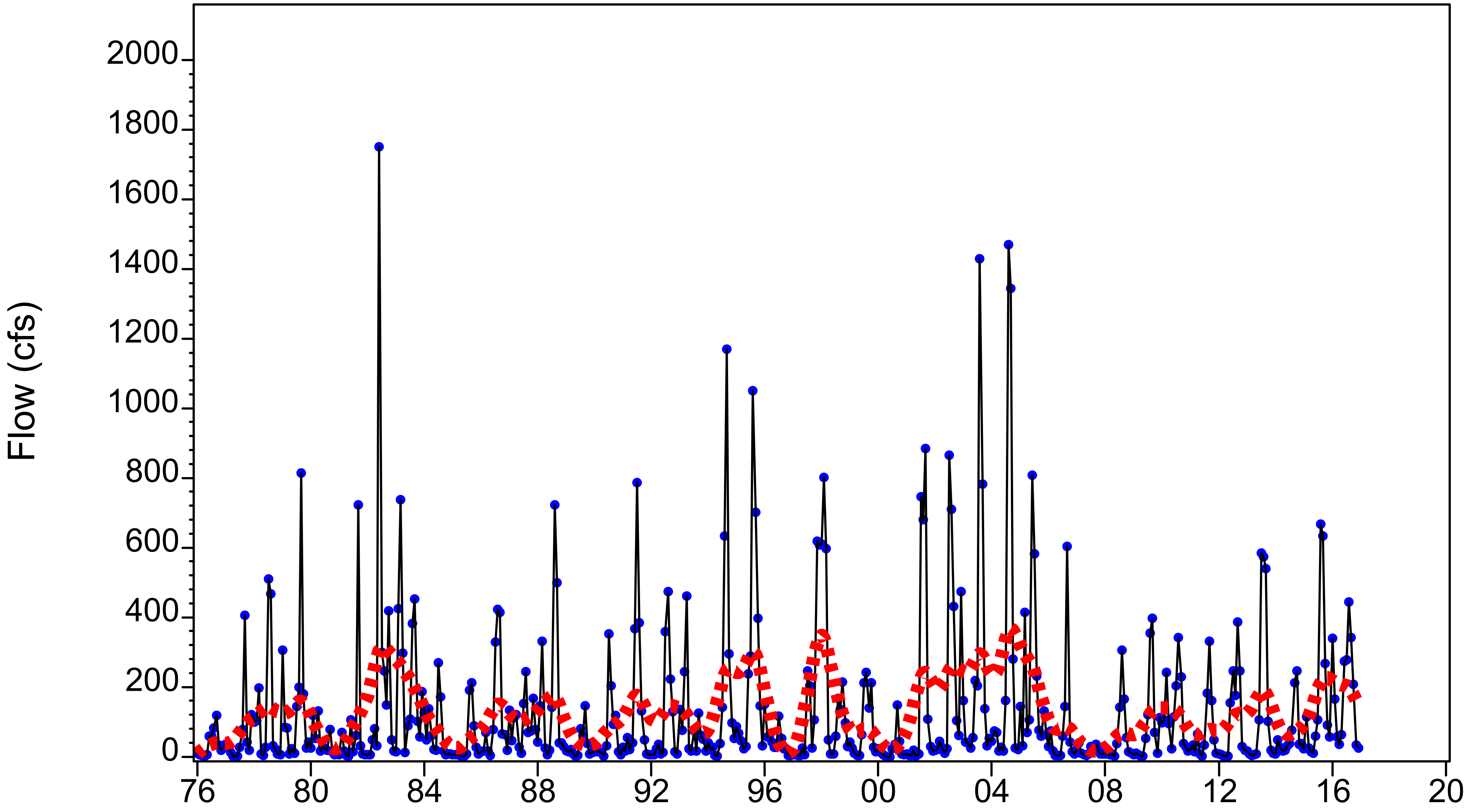


Figure 3.208 Monthly P50 (median) flow at long-term Horse Creek near Arcadia (2297310) gage (1976-2016)

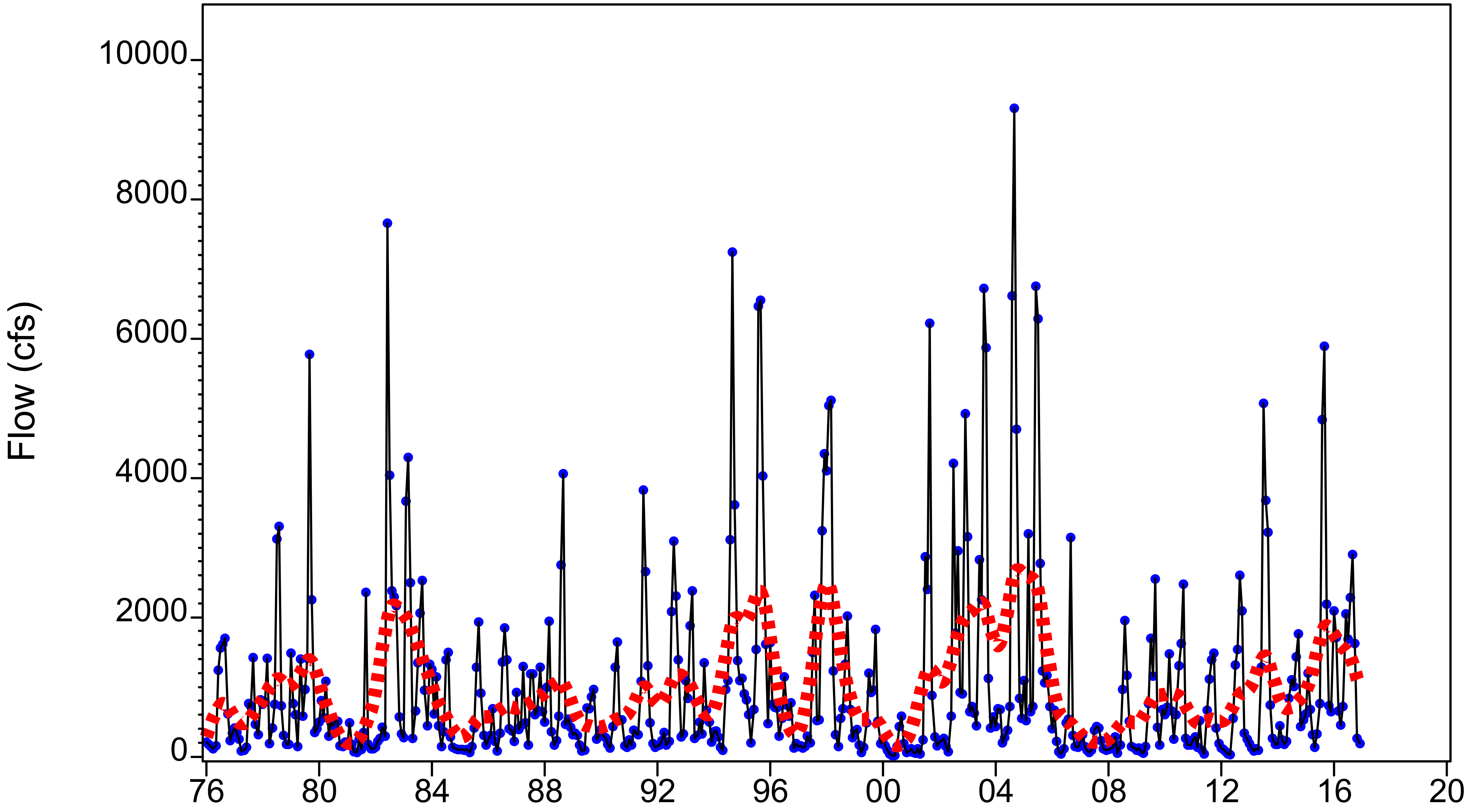


Figure 3.209 Monthly P50 (median) flow at long-term for total gaged flow upstream of the Facility (1950-2016)

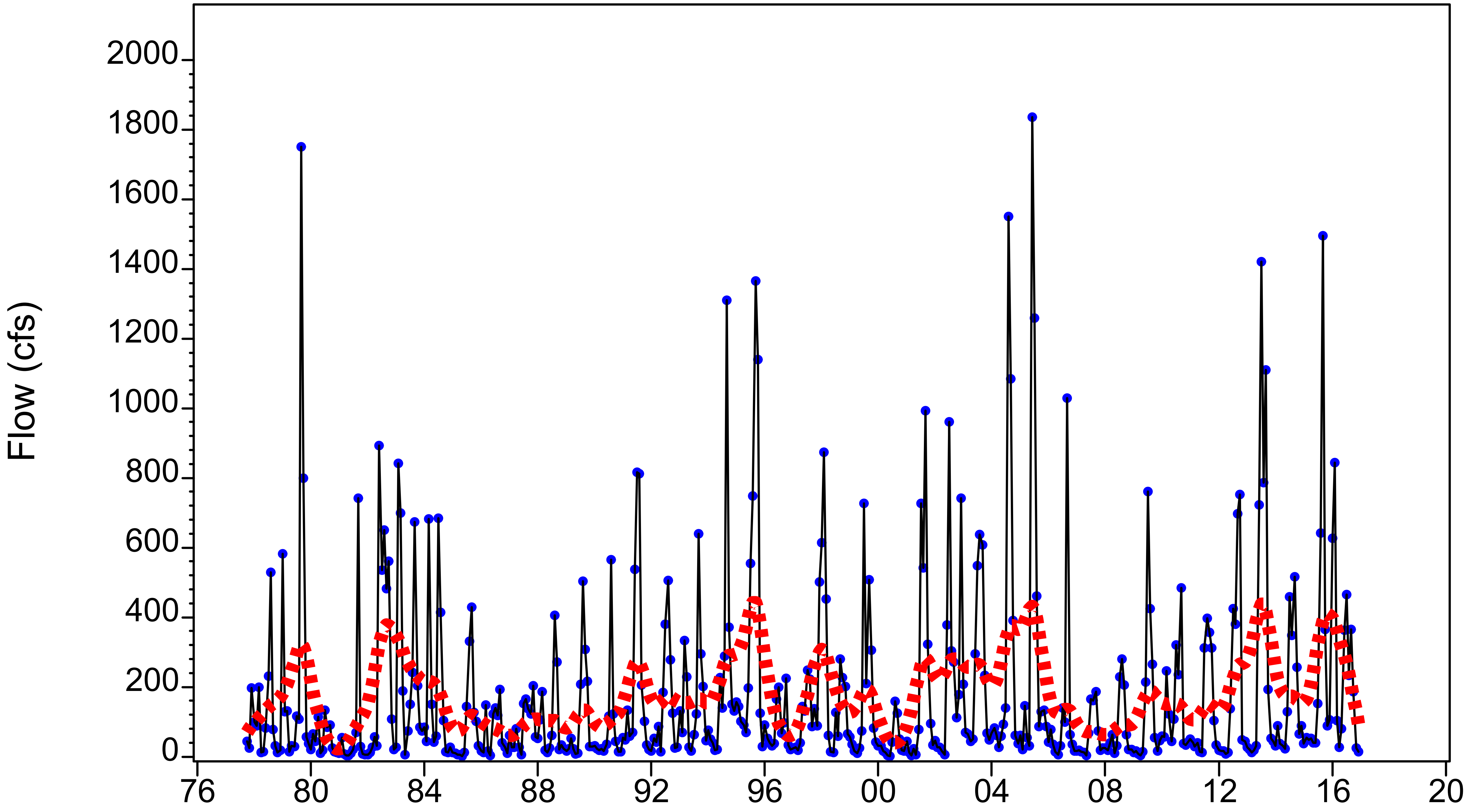


Figure 3.210 Monthly P50 (median) flow at long-term Prairie Creek (2298123) gage (1976-2016)

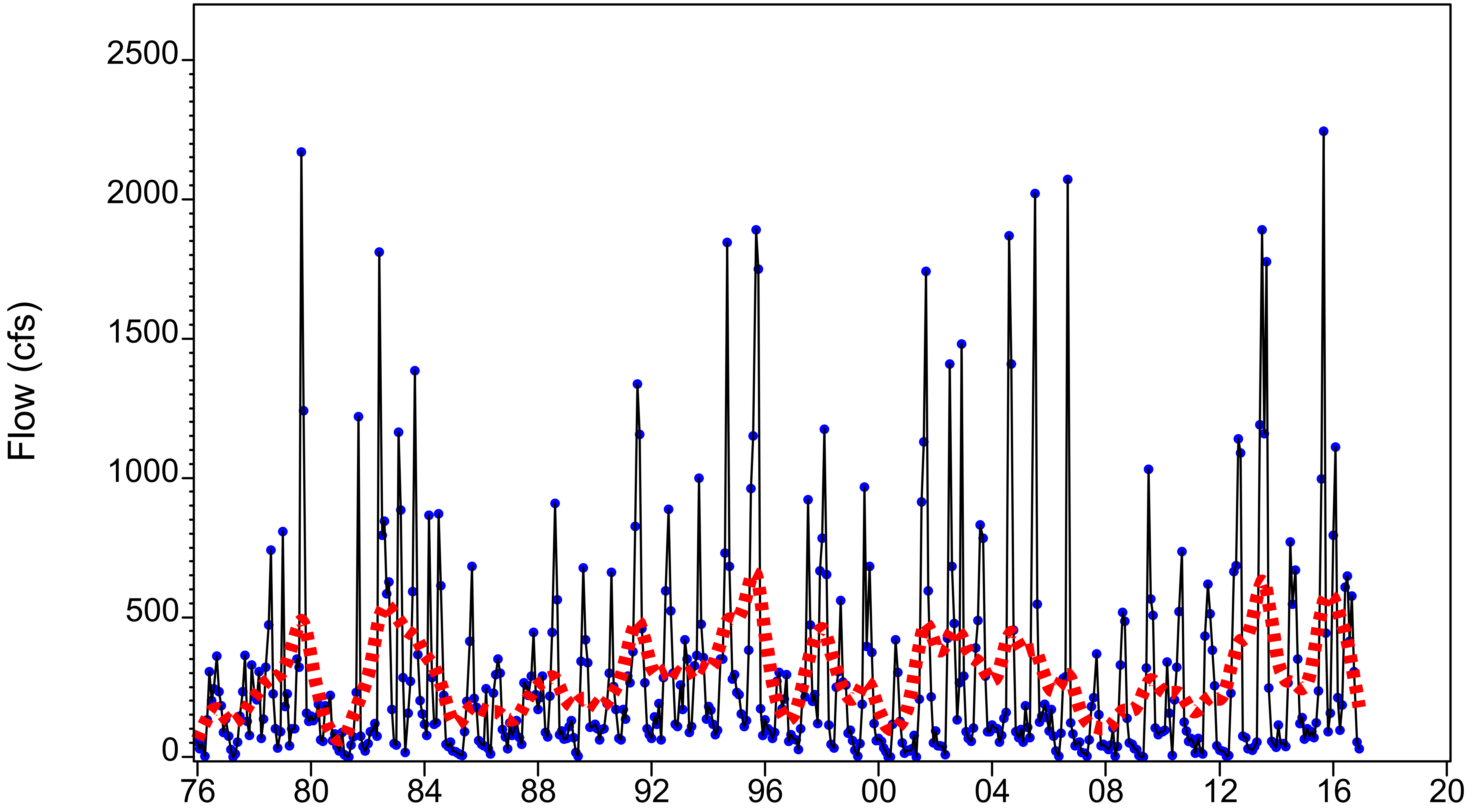


Figure 3.211 Monthly P50 (median) flow at long-term Shell Creek gage (1976-2016)

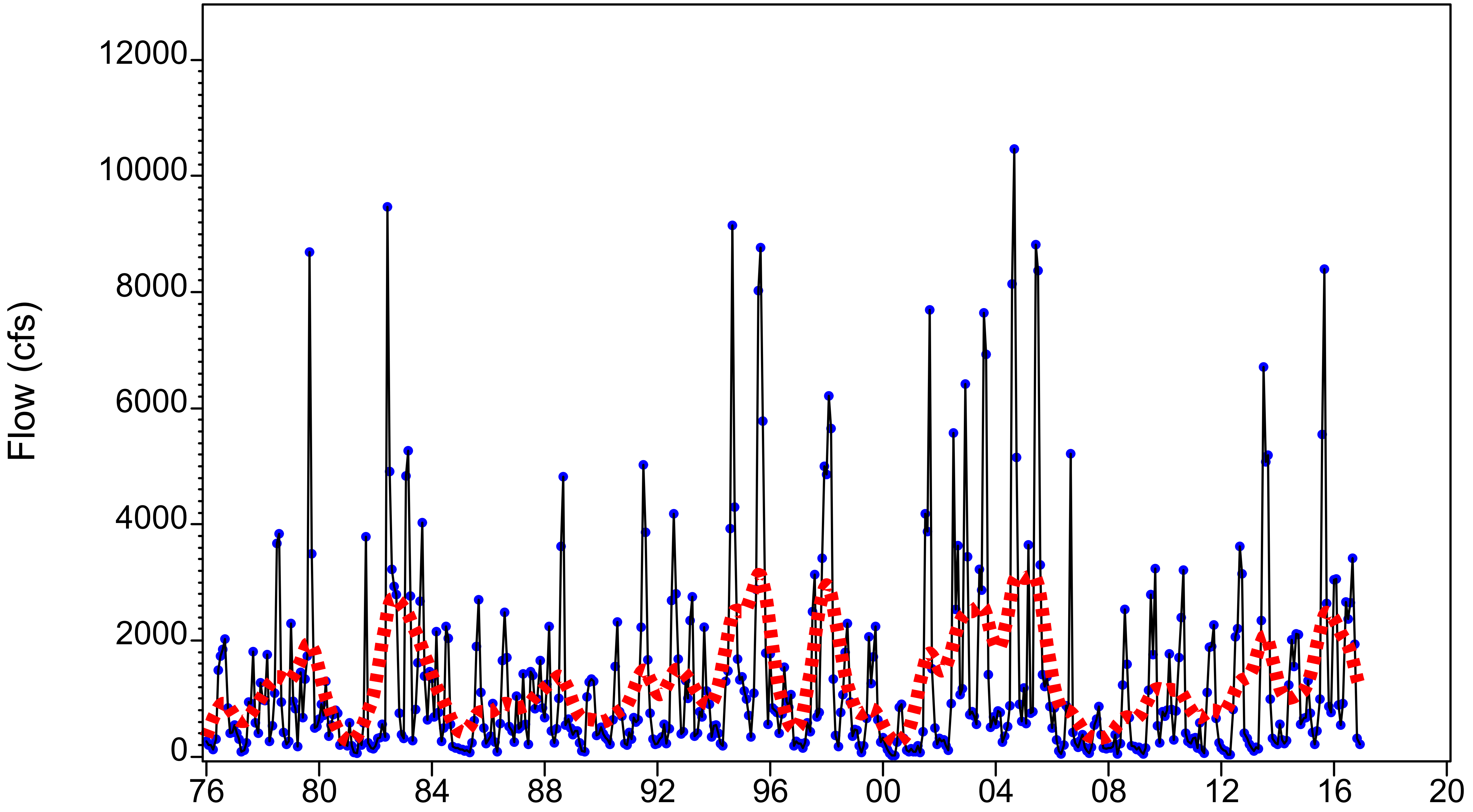


Figure 3.212 Monthly P50 (median) flow of total gaged Peace River flow to the Upper Harbor (1976-2016)

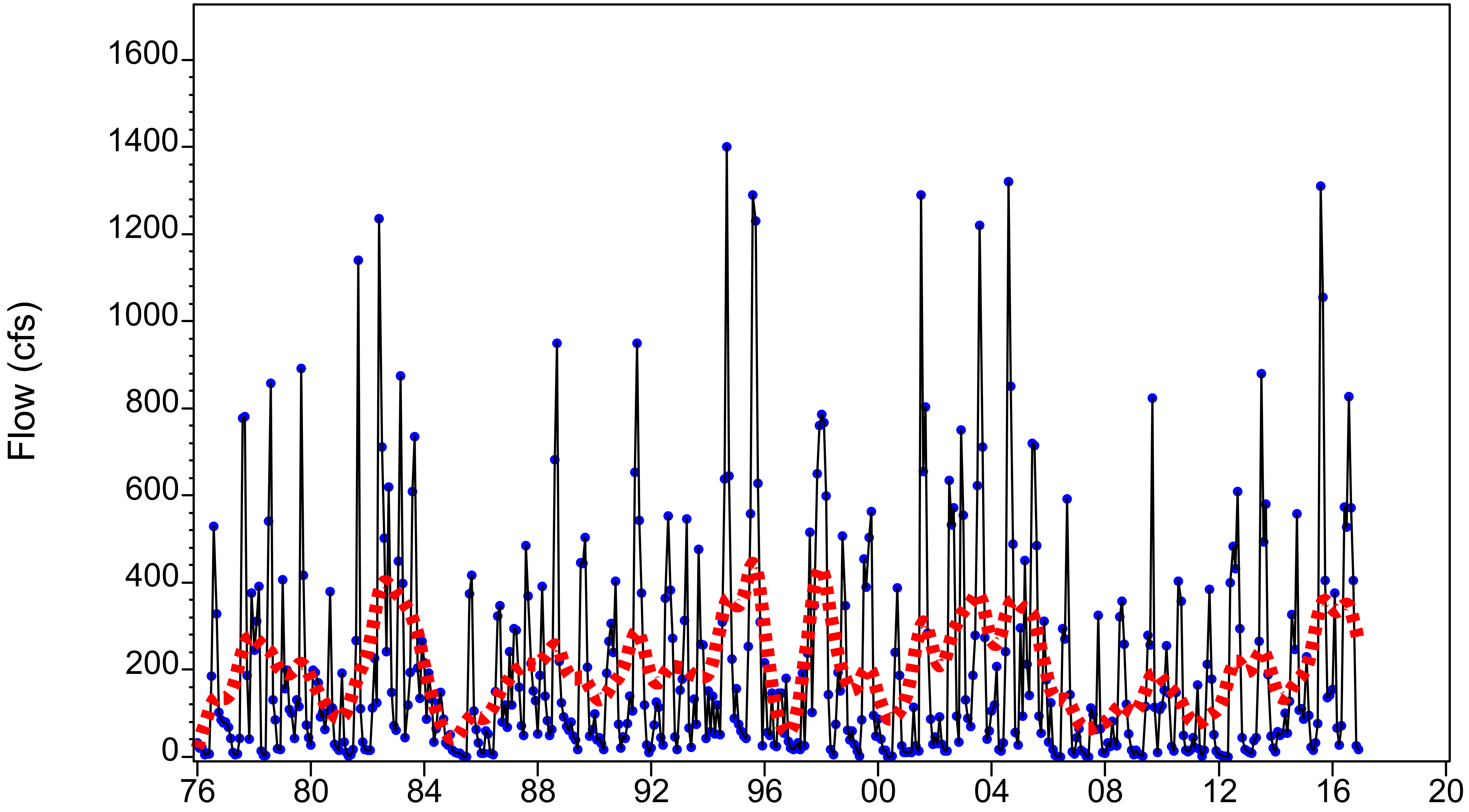


Figure 3.213 Monthly P50 (median) flow at long-term Myakka River near Sarasota (2298830) gage (1976-2016)

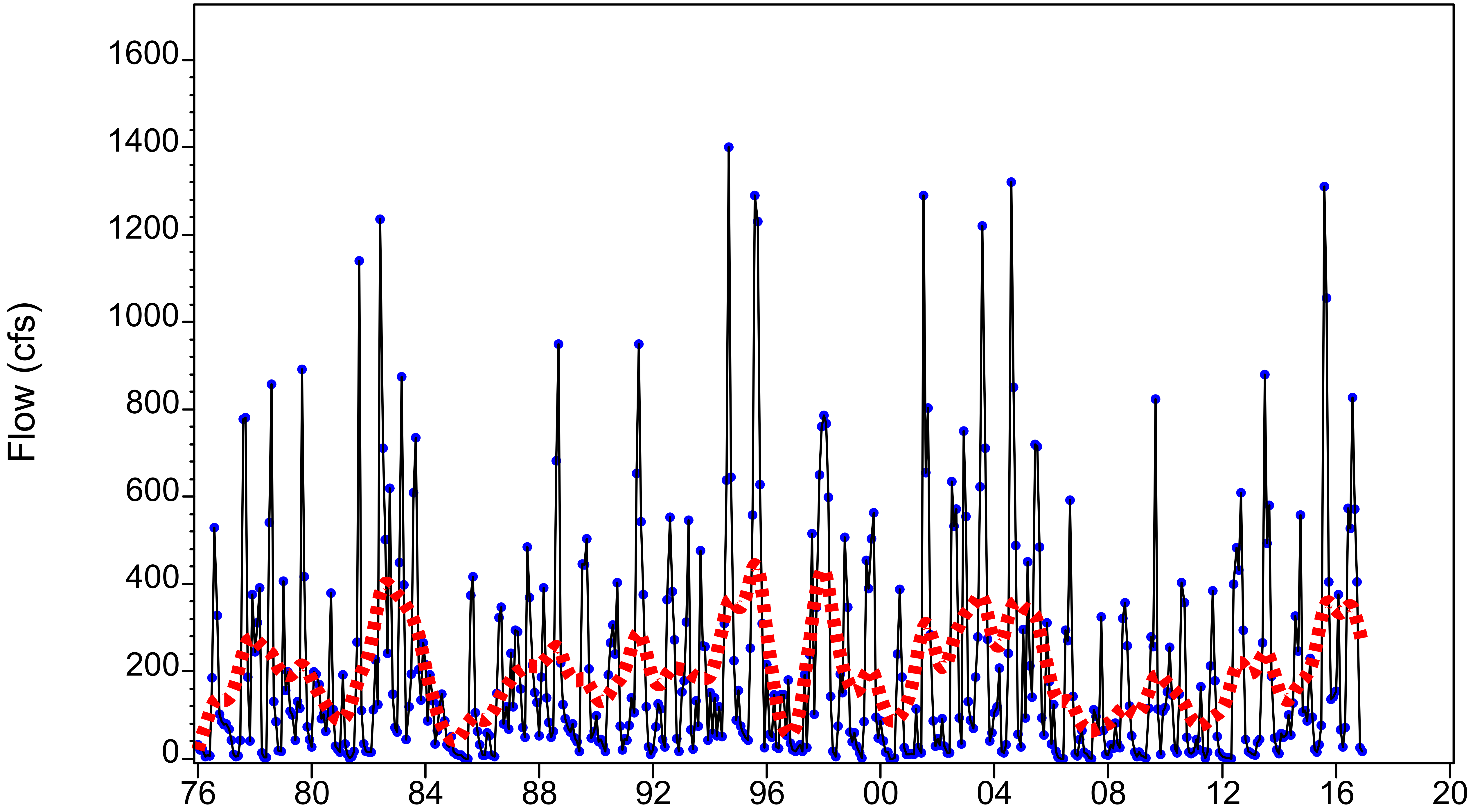


Figure 3.213 Monthly P50 (median) flow at long-term Myakka River near Sarasota (2298830) gage (1976-2016)

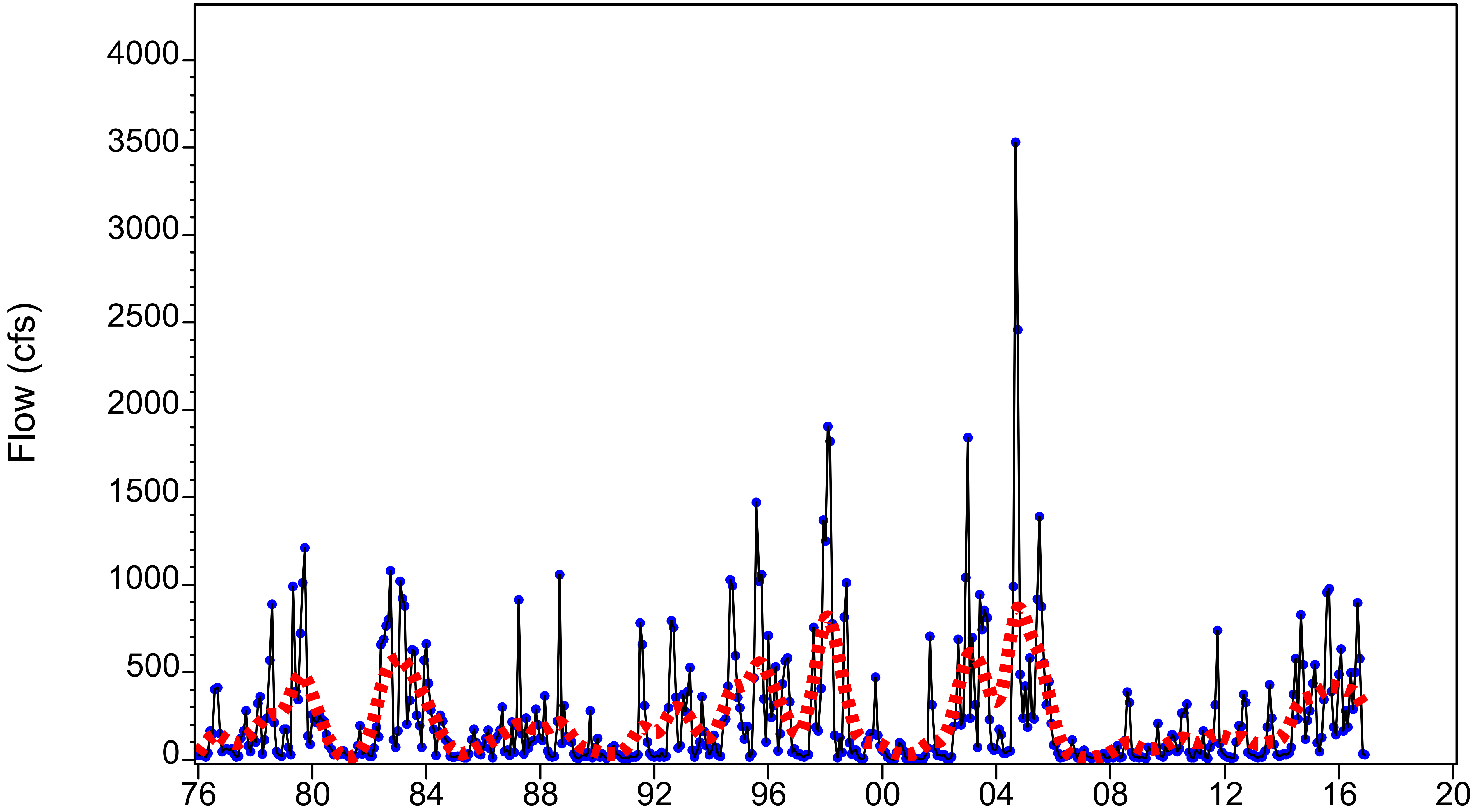


Figure 3.214 Monthly P75 flow at long-term Peace River at Bartow (2294650) gage (1976-2016)

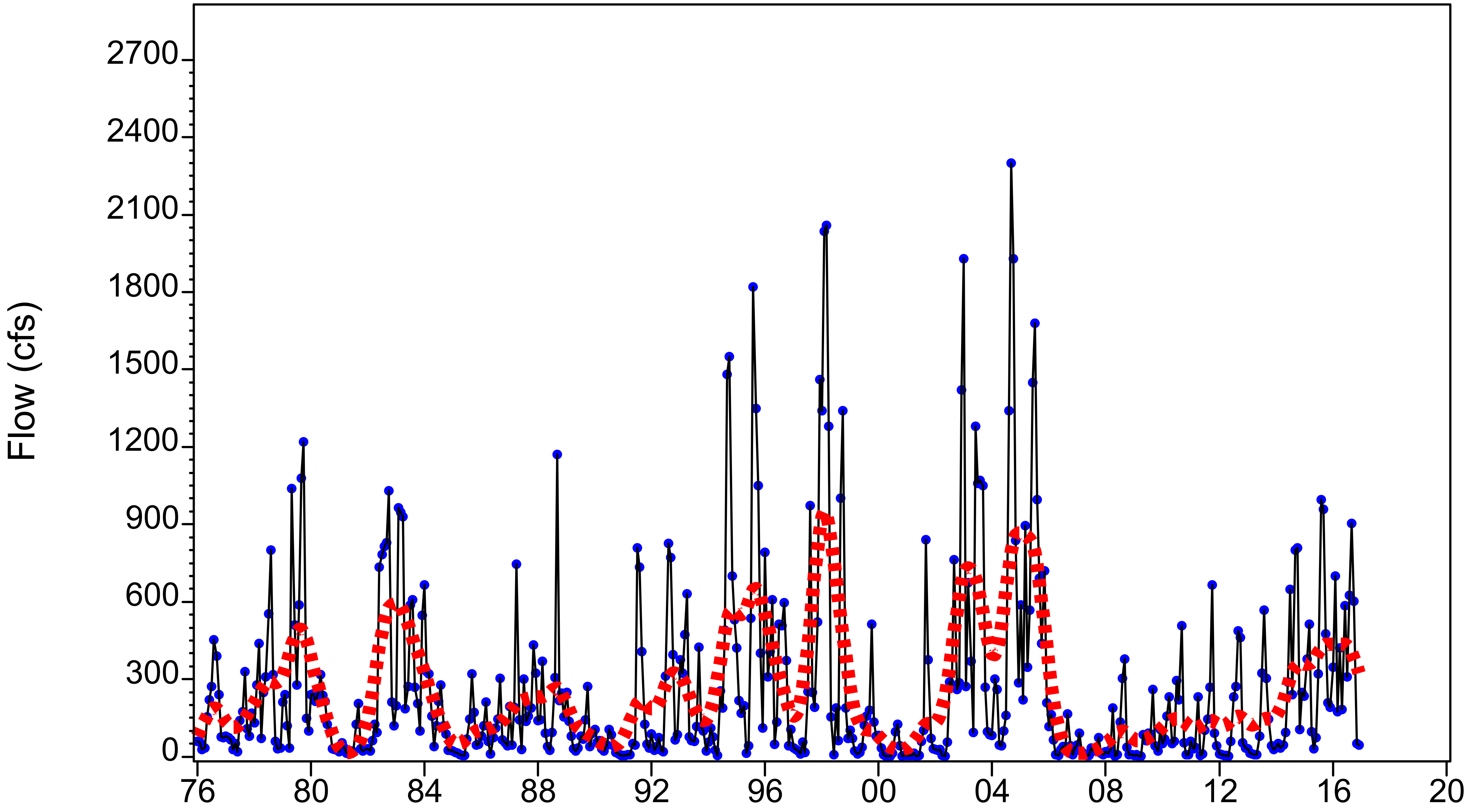


Figure 3.215 Monthly P75 flow at long-term Peace River at Ft. Meade (2294898) gage (1976-2016)

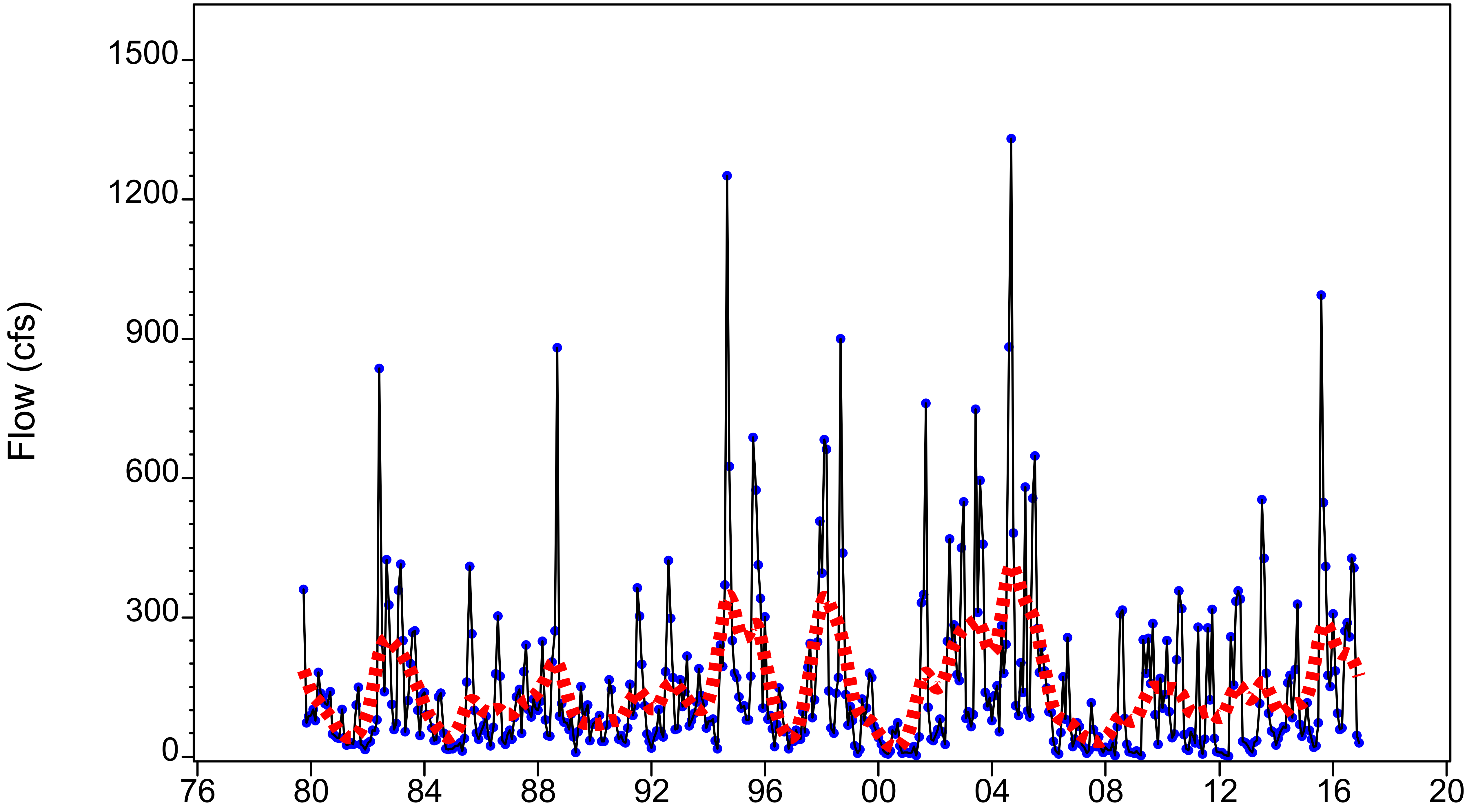


Figure 3.216 Monthly P75 flow at long-term Payne Creek (2295420) gage (1976-2016)

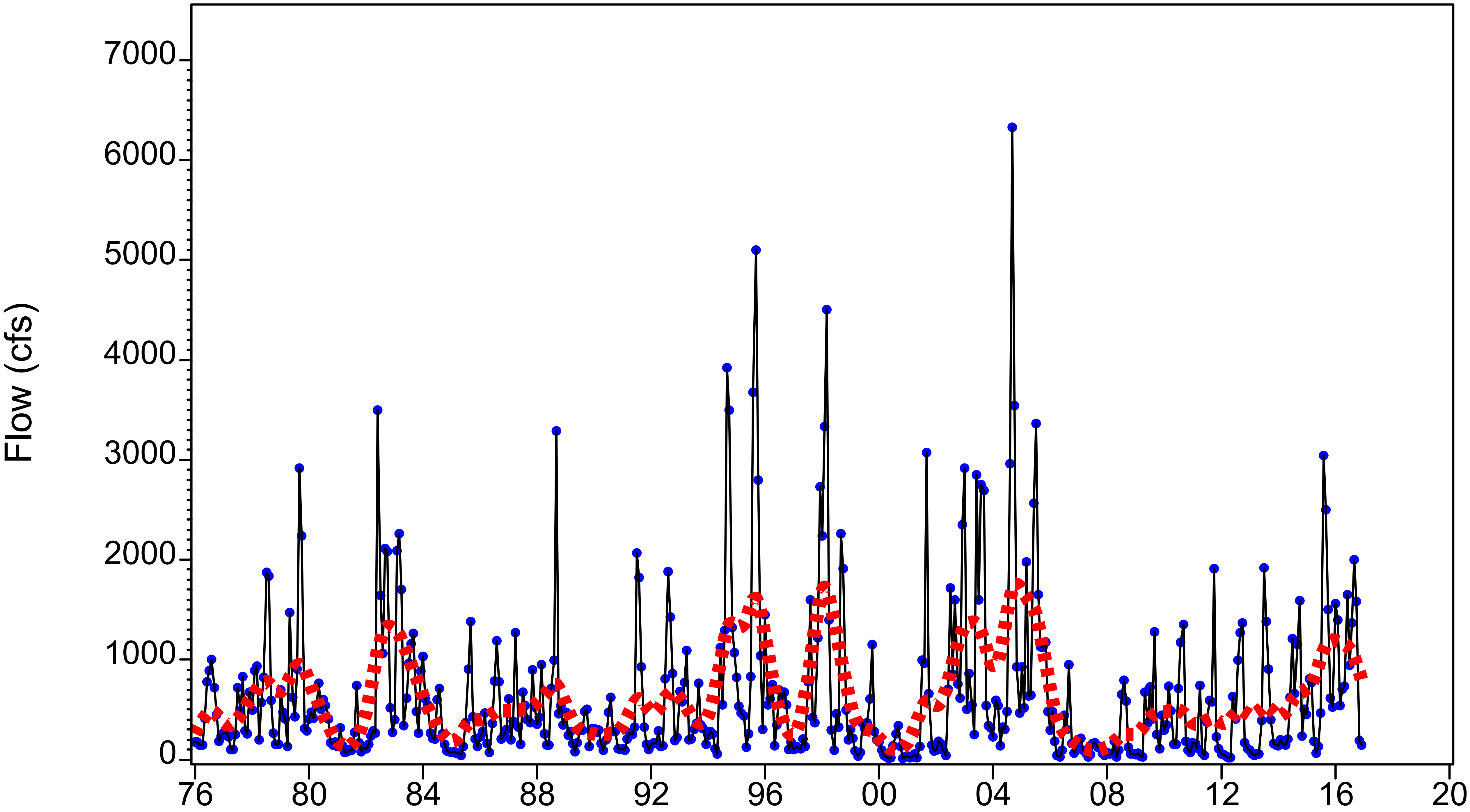


Figure 3.217 Monthly P75 flow at long-term Peace River at Zolfo (2295637) gage (1976-2016)

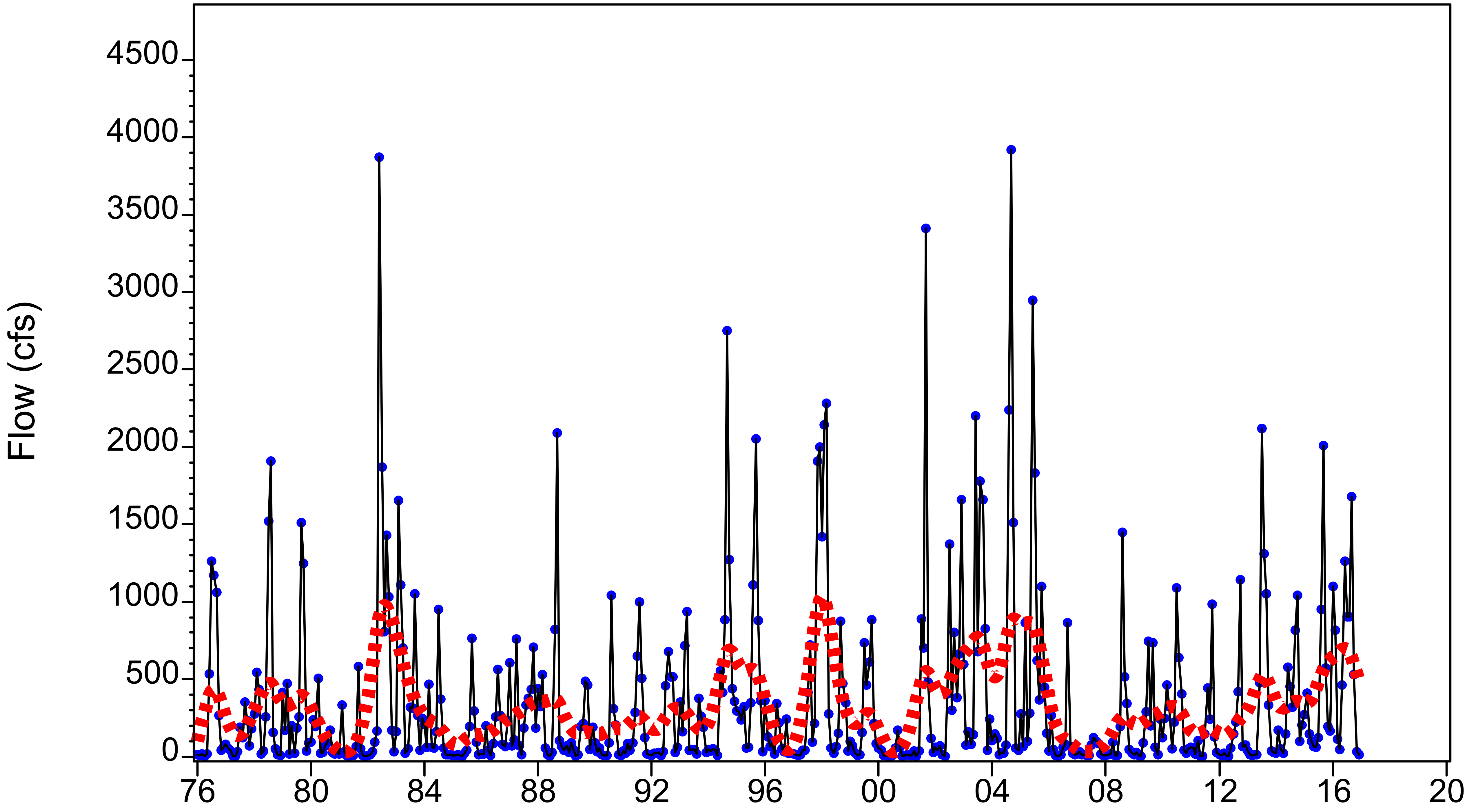


Figure 3.218 Monthly P75 flow at long-term Charlie Creek (2296500) gage (1976-2016)

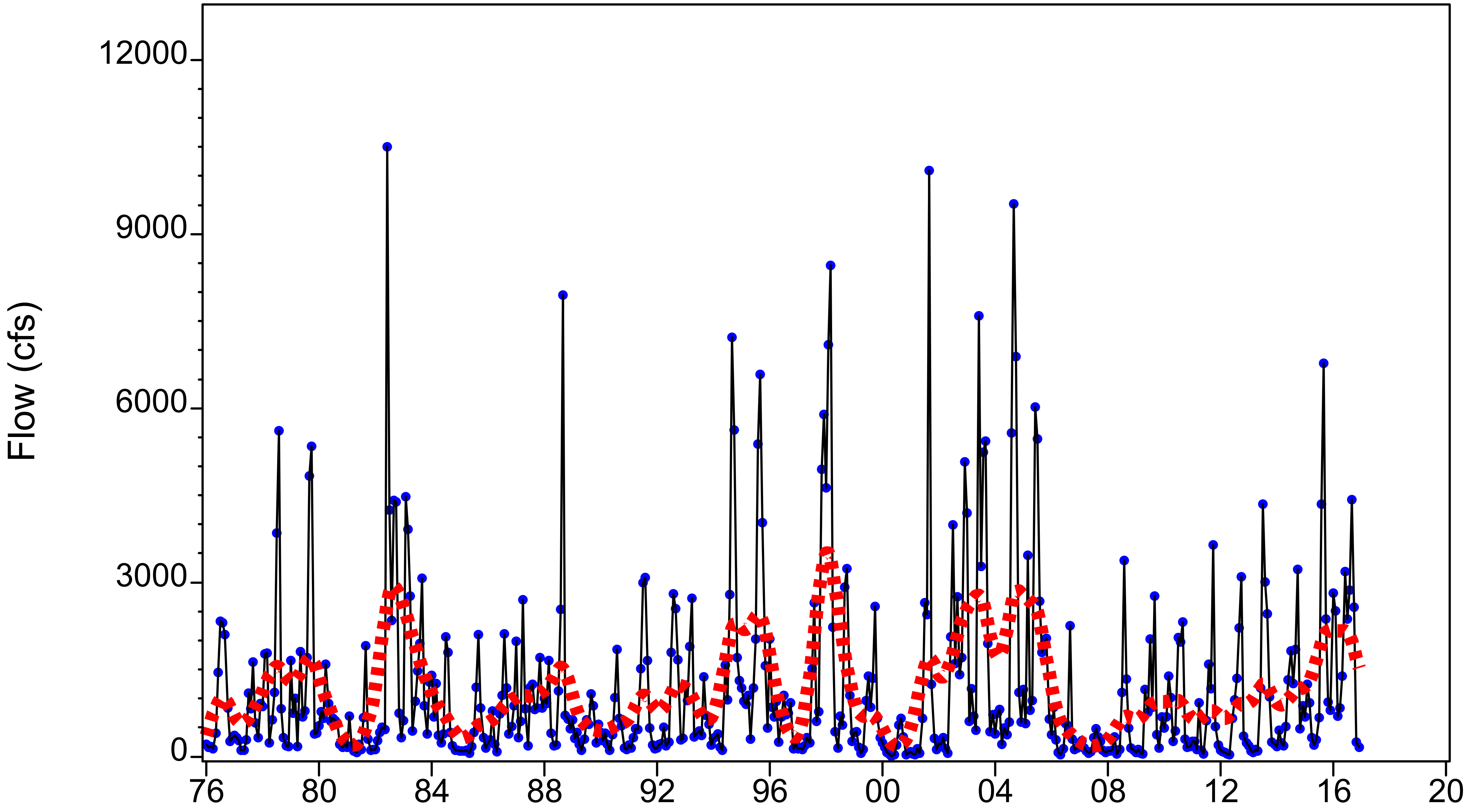


Figure 3.219 Monthly P75 flow at long-term Peace River at Arcadia (2296750) gage (1976-2016)

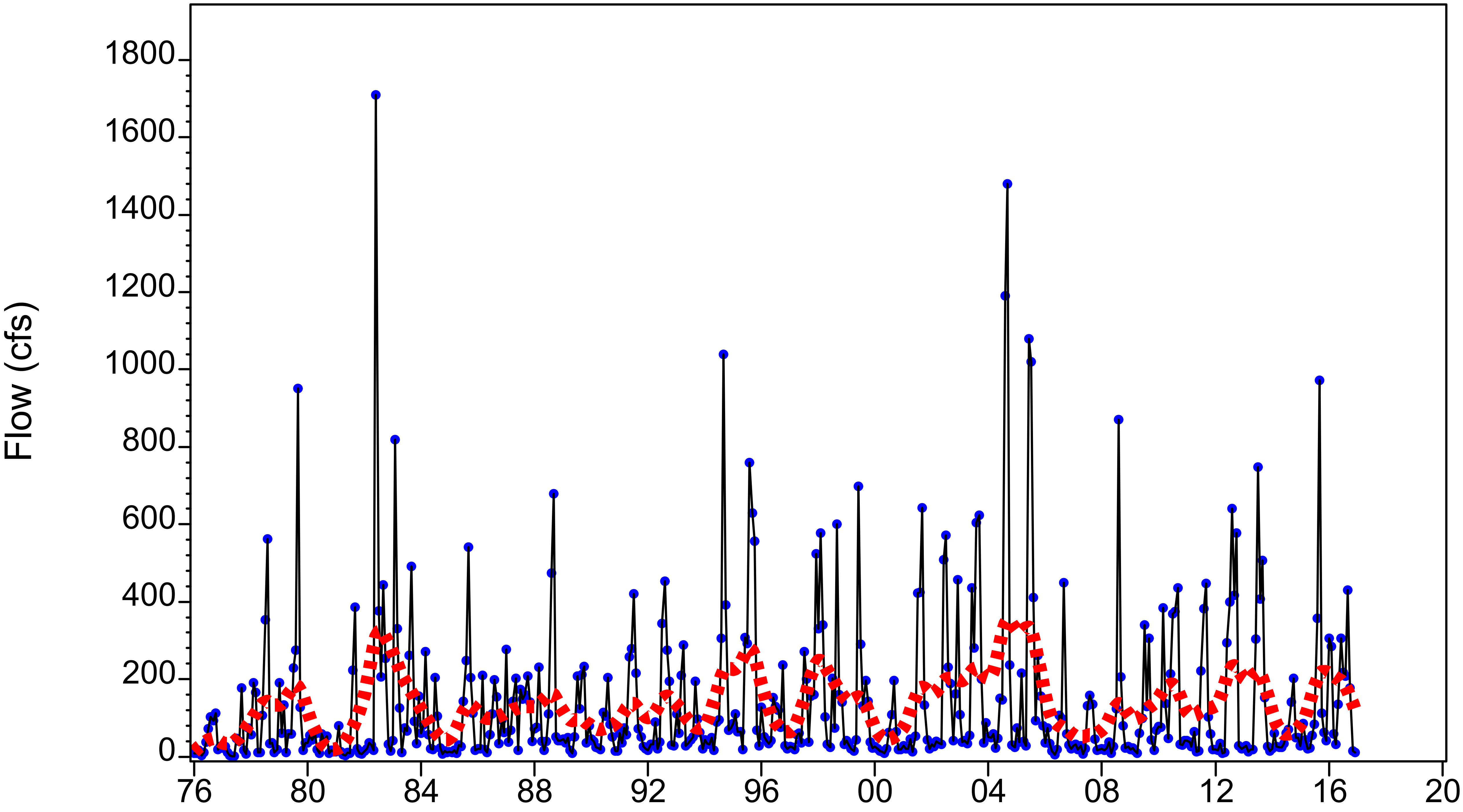


Figure 3.220 Monthly P75 flow at long-term Joshua Creek at Nocatee (2297100) gage (1976-2016)

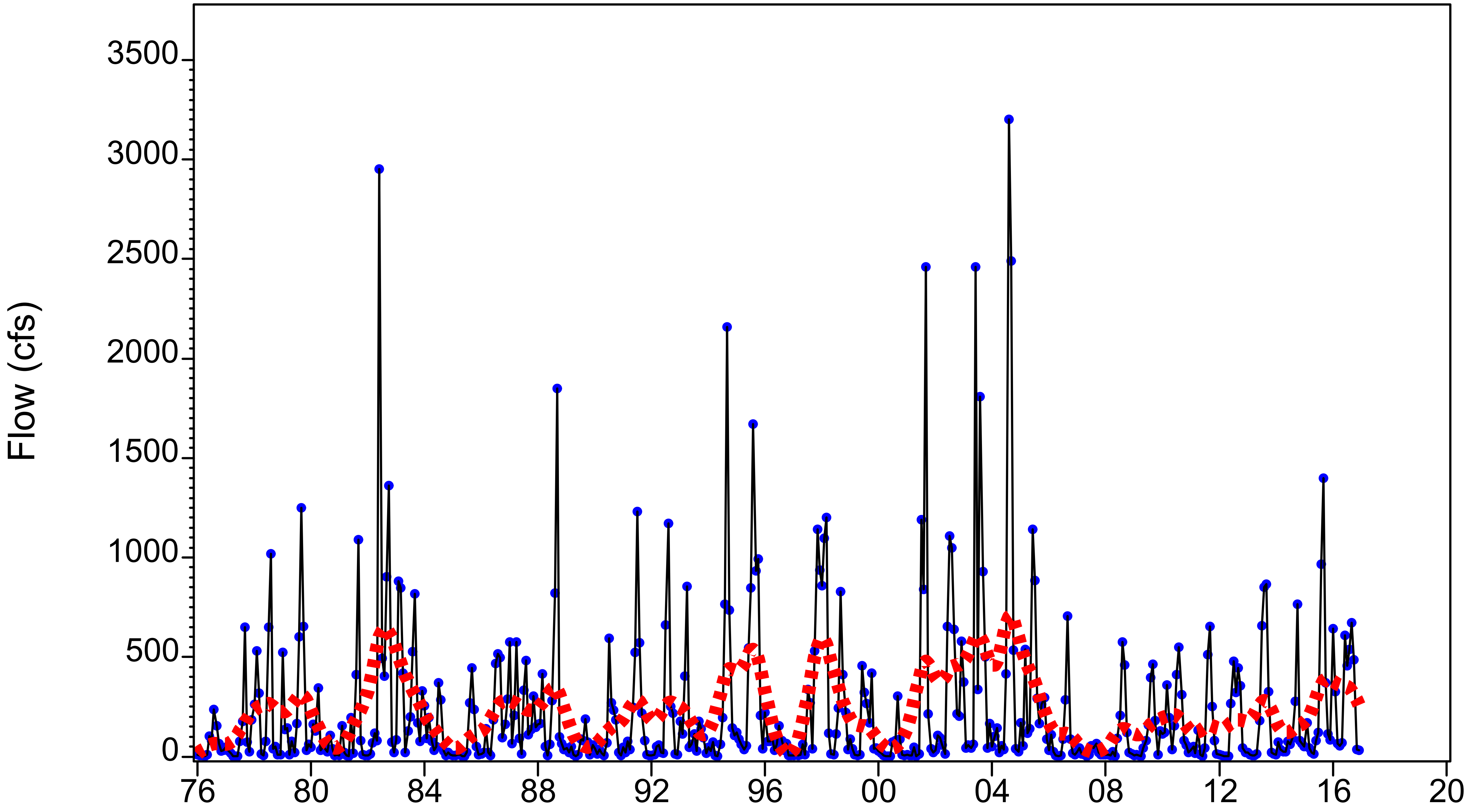


Figure 3.221 Monthly P75 flow at long-term Horse Creek near Arcadia (2297310) gage (1976-2016)

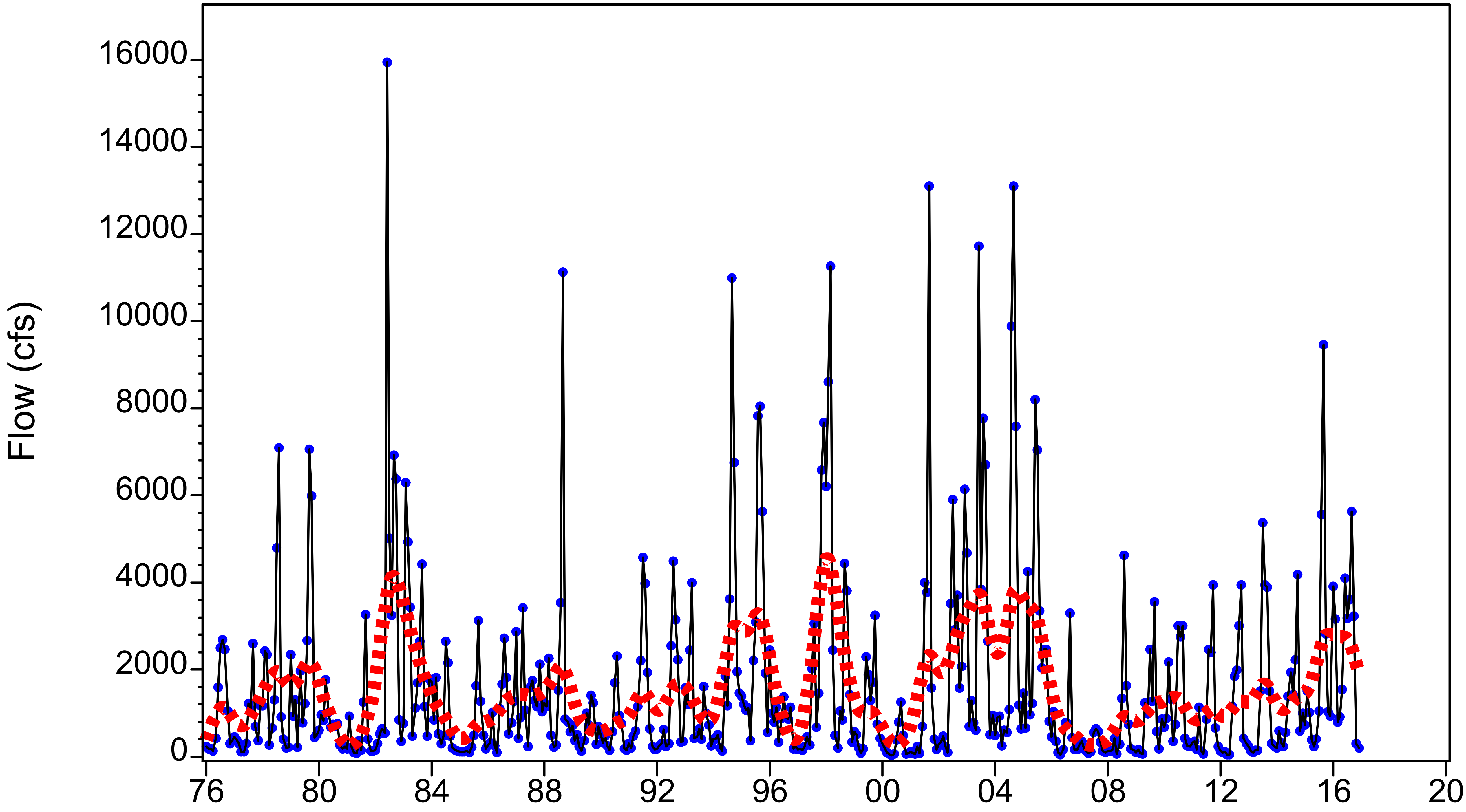


Figure 3.222 Monthly P75 flow at long-term for total gaged flow upstream of the Facility (1976-2016)

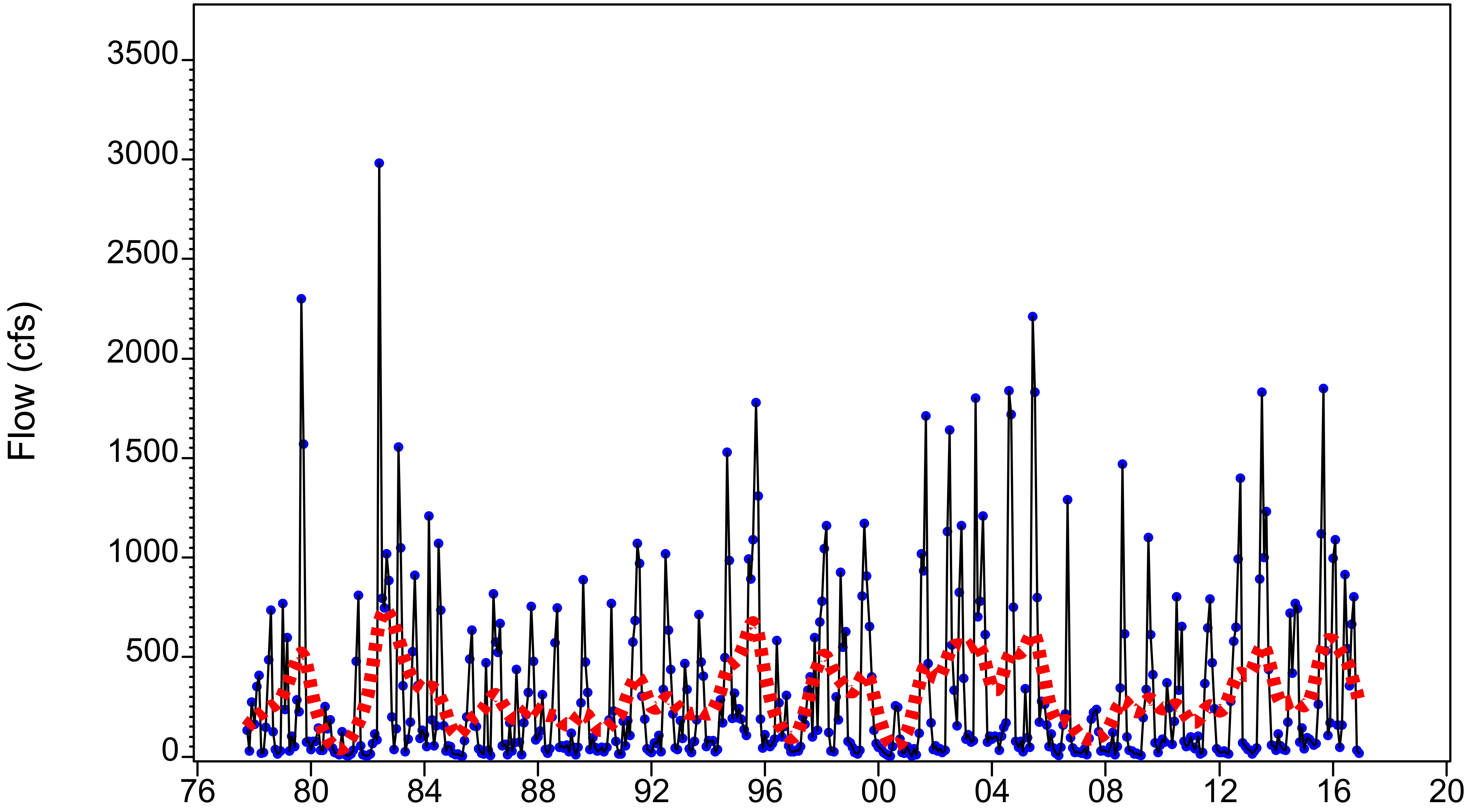


Figure 3.223 Monthly P75 flow at long-term Prairie Creek (2298123) gage (1976-2016)

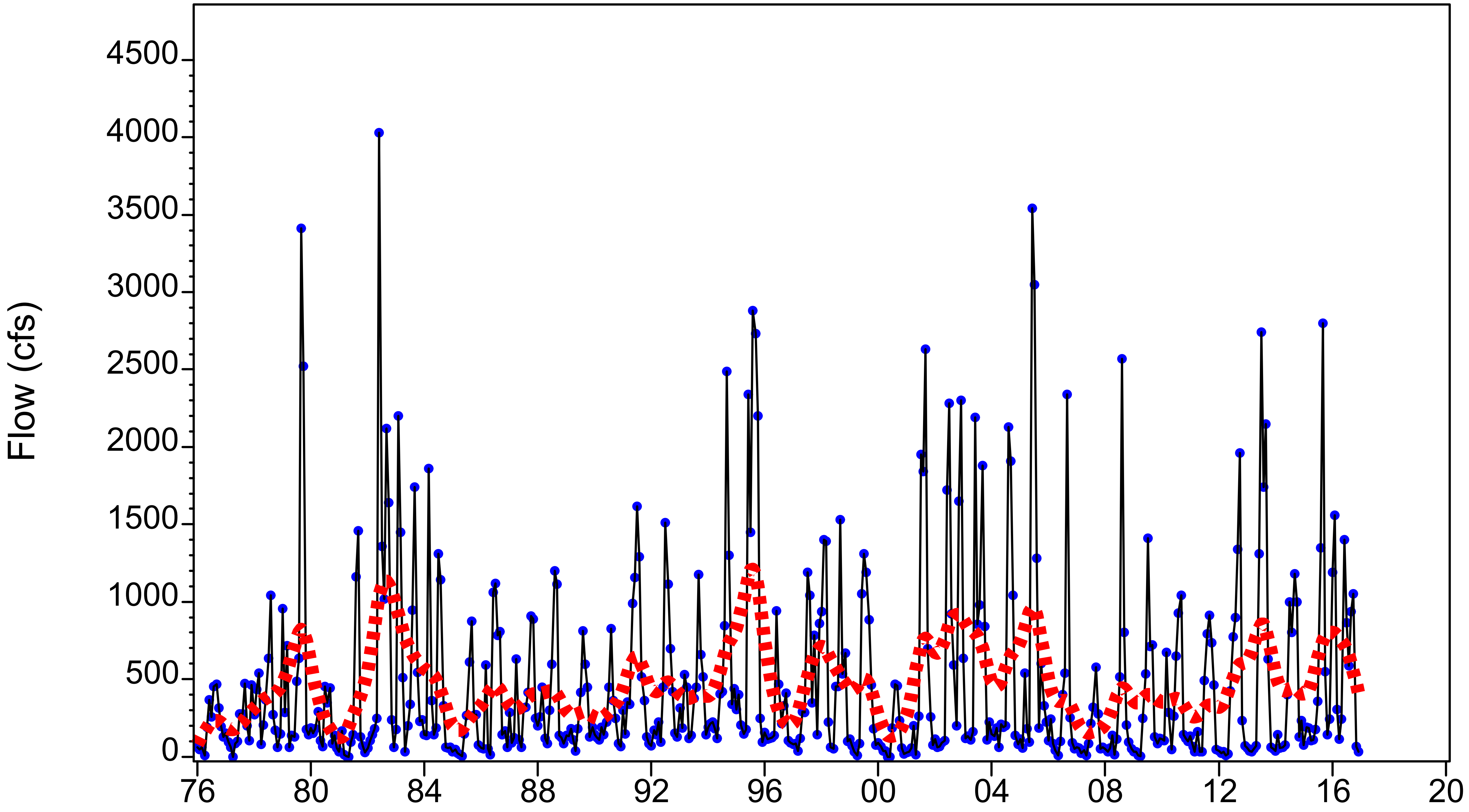


Figure 3.224 Monthly P75 flow at long-term Shell Creek gage (1976-2016)

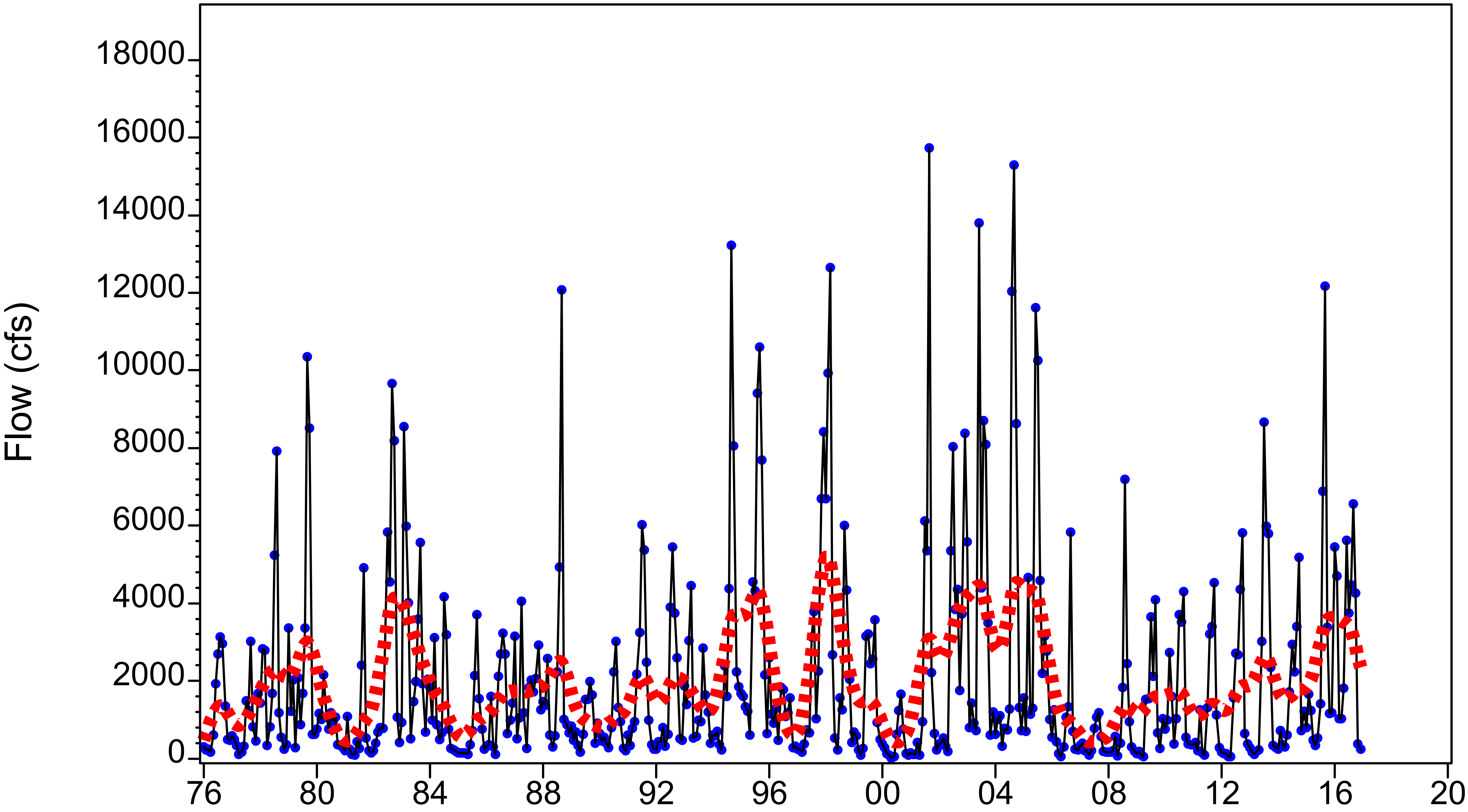


Figure 3.225 Monthly P75 flow of total gaged Peace River flow to the Upper Harbor (1976-2016)

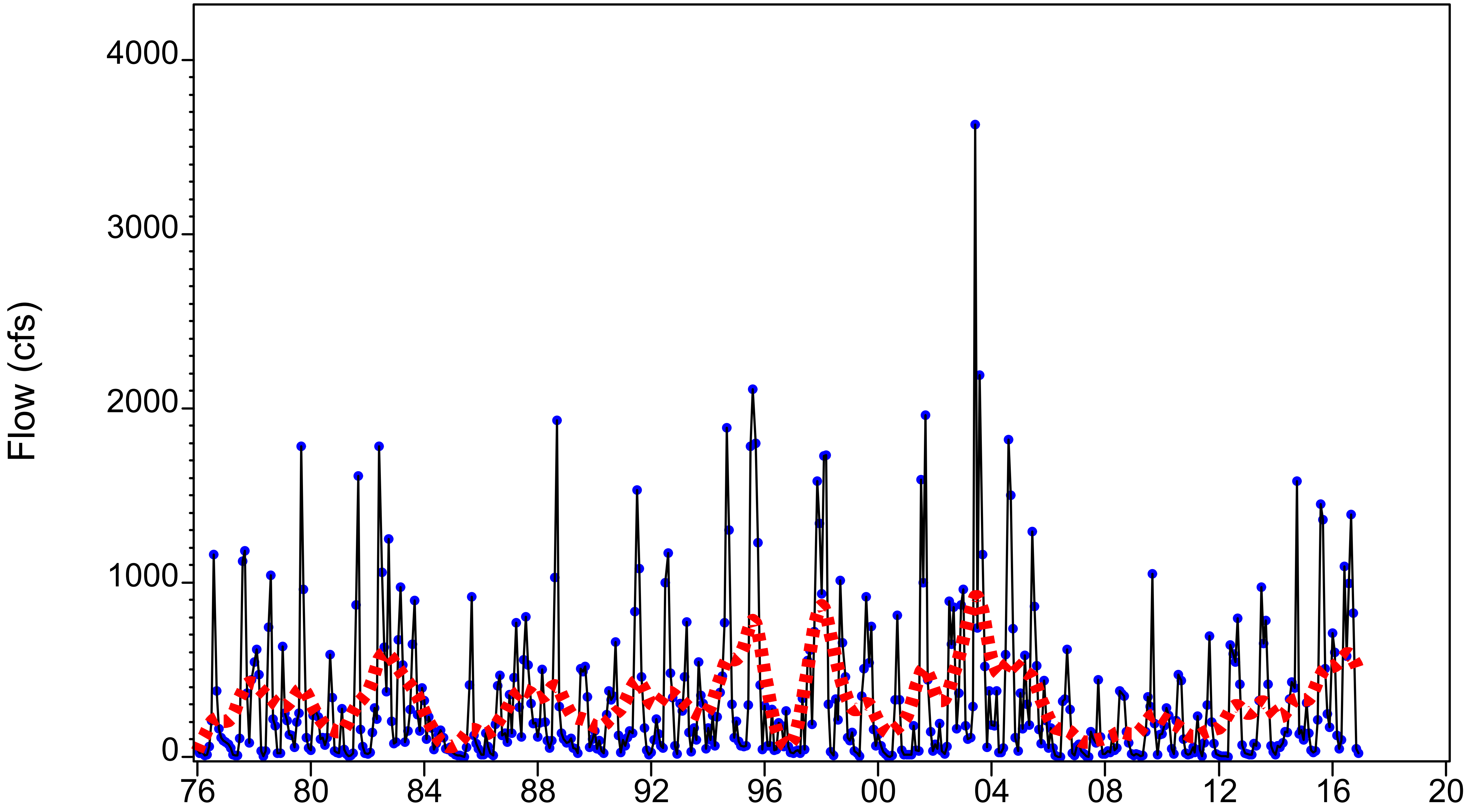


Figure 3.226 Monthly P75 flow at long-term Myakka River near Sarasota (2298830) gage (1976-2016)

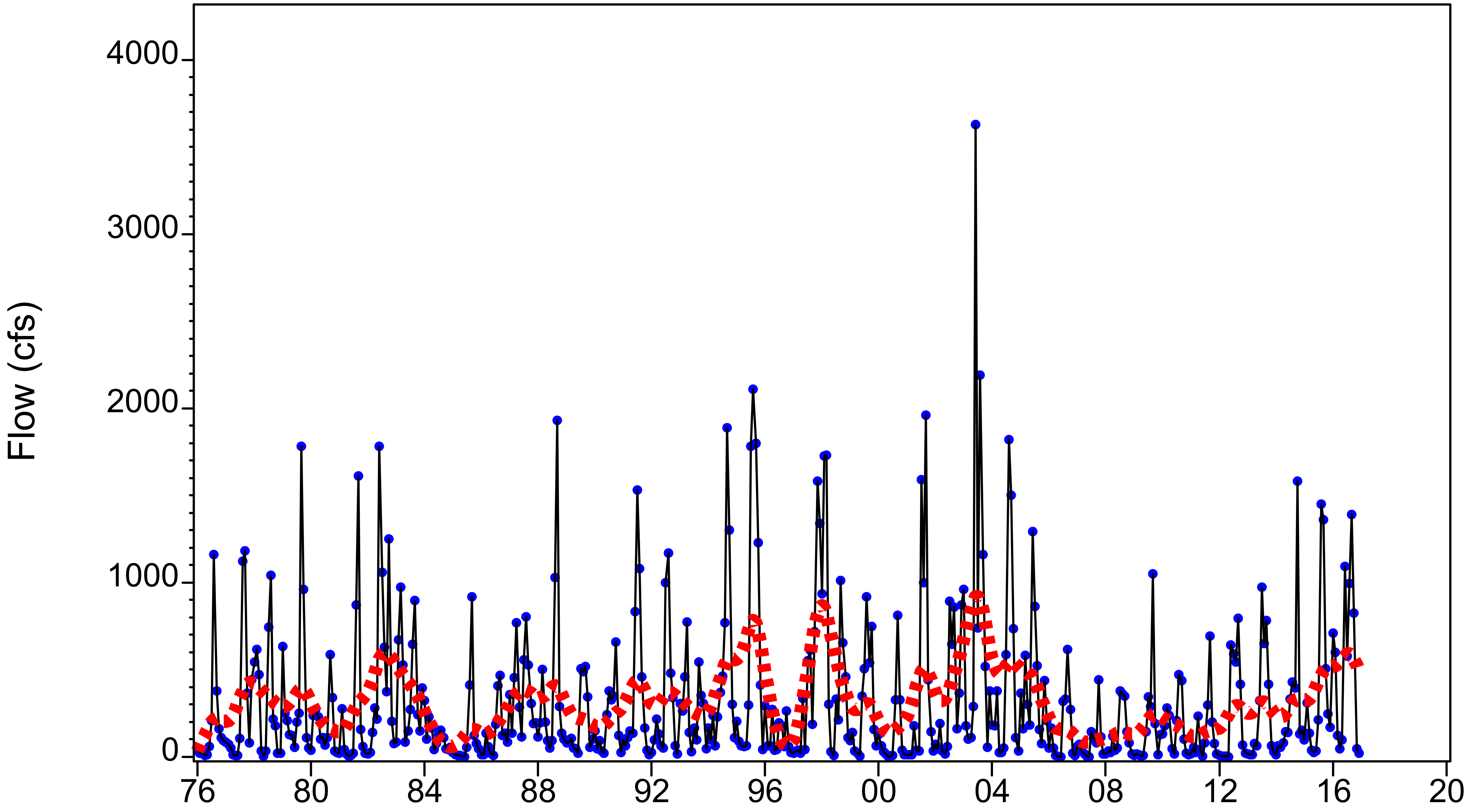


Figure 3.226 Monthly P75 flow at long-term Myakka River near Sarasota (2298830) gage (1976-2016)

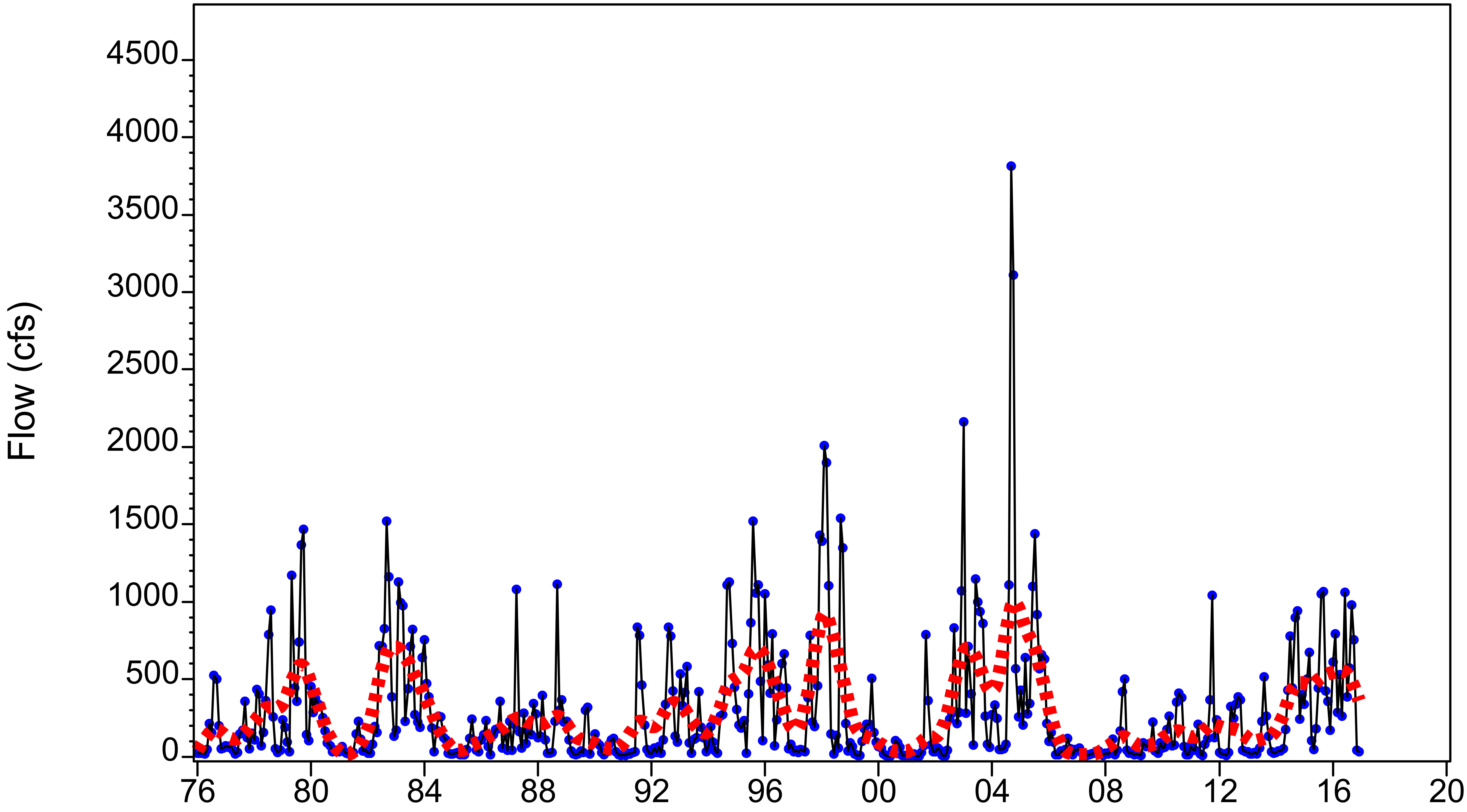


Figure 3.227 Monthly P90 flow at long-term Peace River at Bartow (2294650) gage (1976-2016)

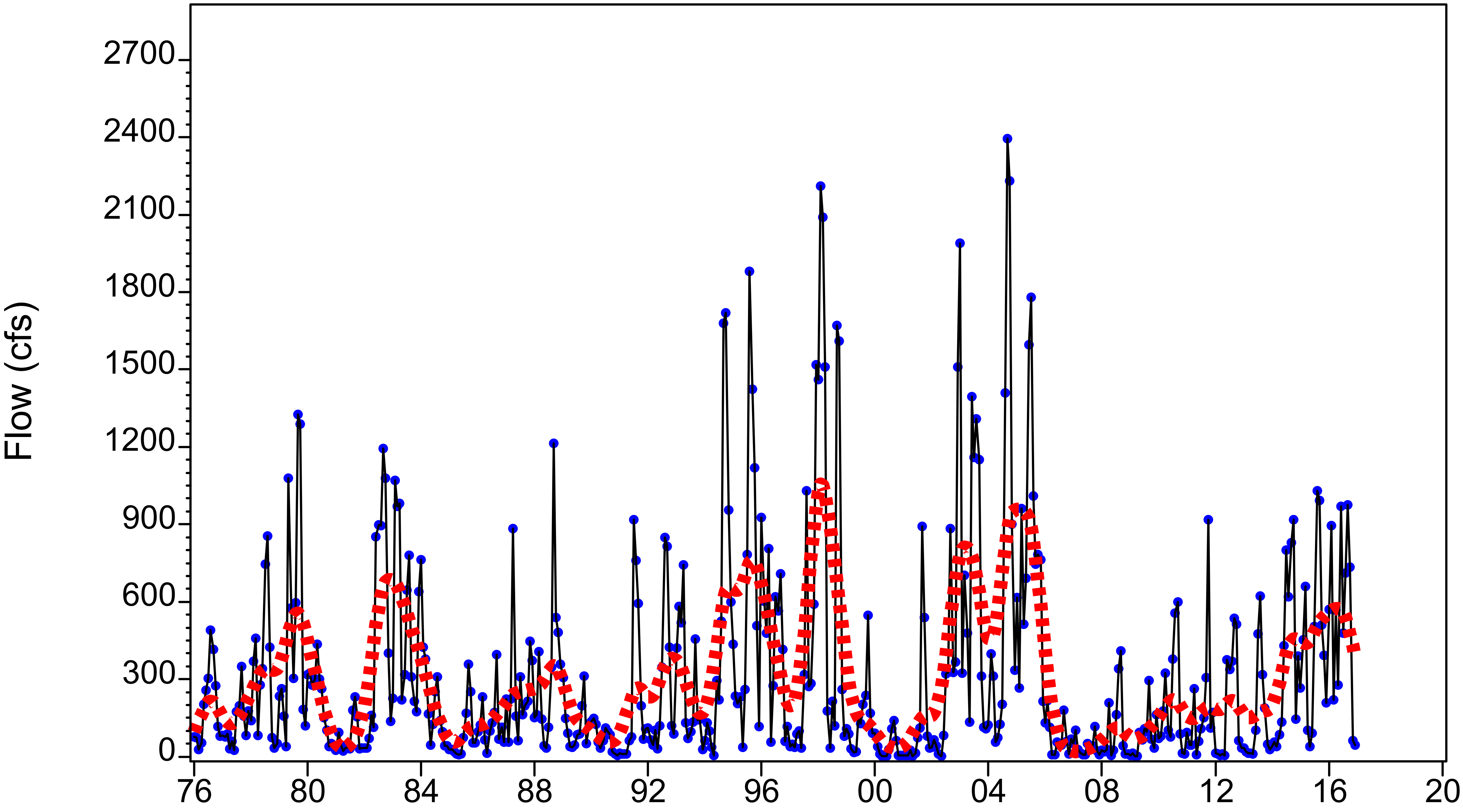


Figure 3.228 Monthly P90 flow at long-term Peace River at Ft. Meade (2294898) gage (1976-2016)

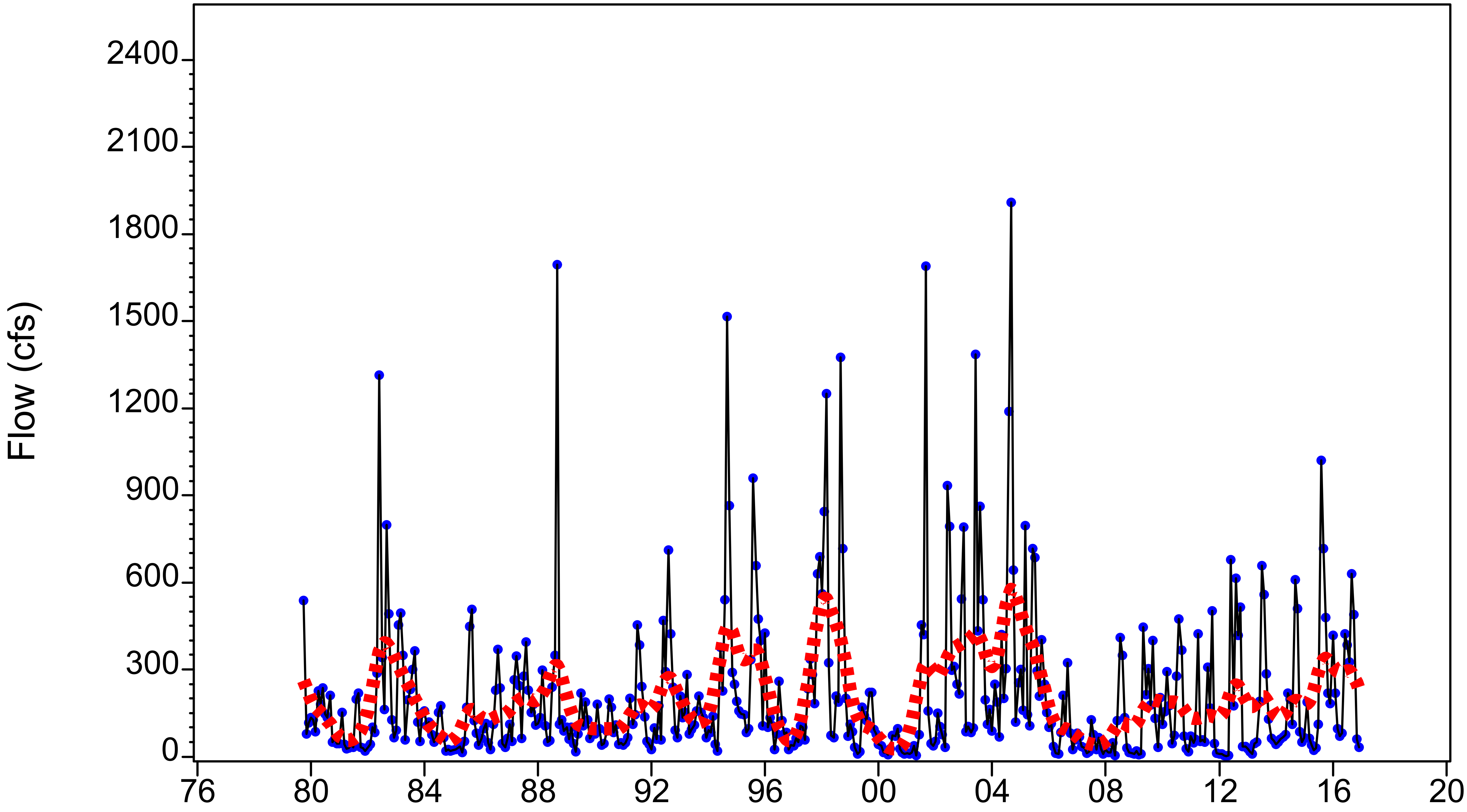


Figure 3.229 Monthly P90 flow at long-term Payne Creek (2295420) gage (1976-2016)

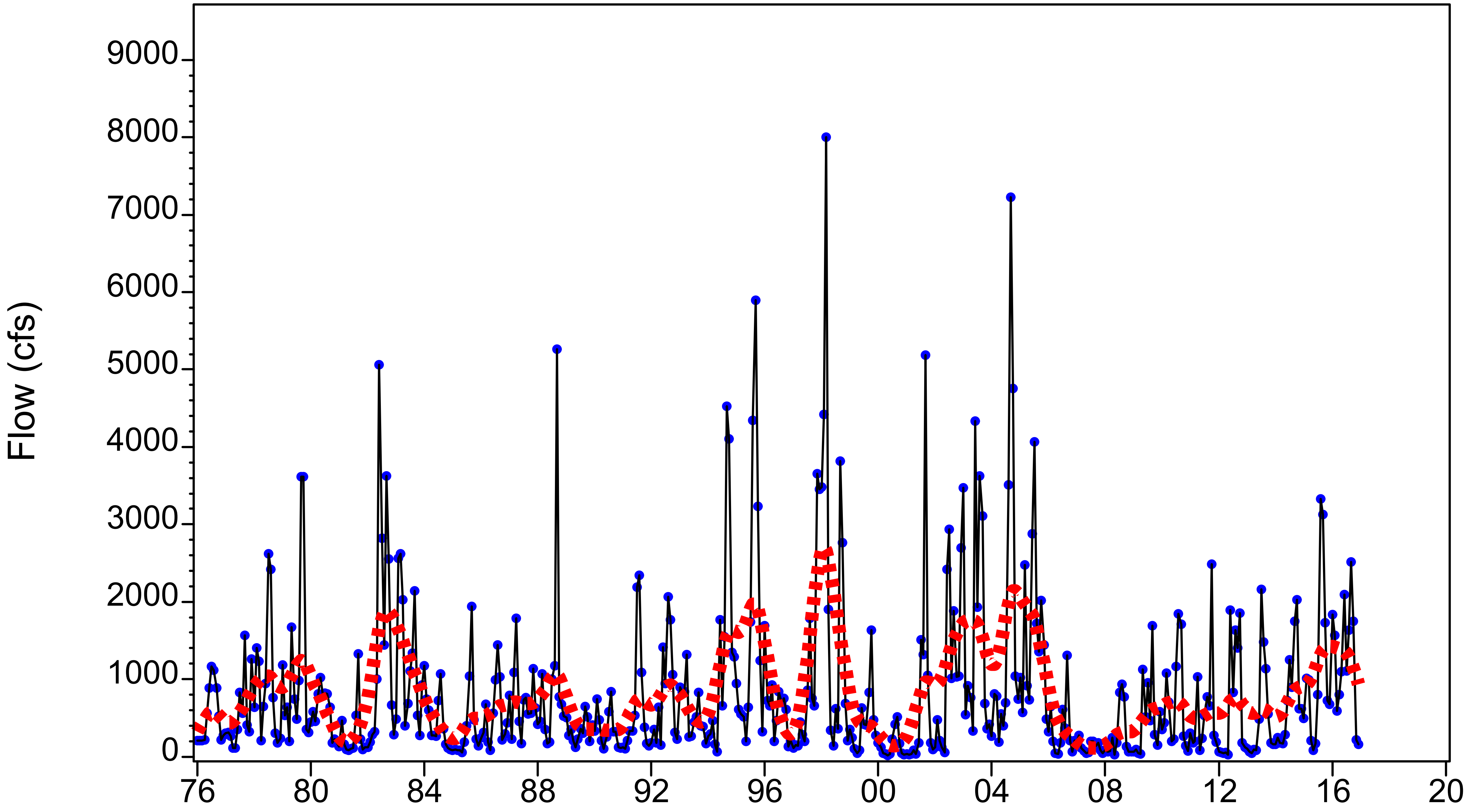


Figure 3.230 Monthly P90 flow at long-term Peace River at Zolfo (2295637) gage (1976-2016)

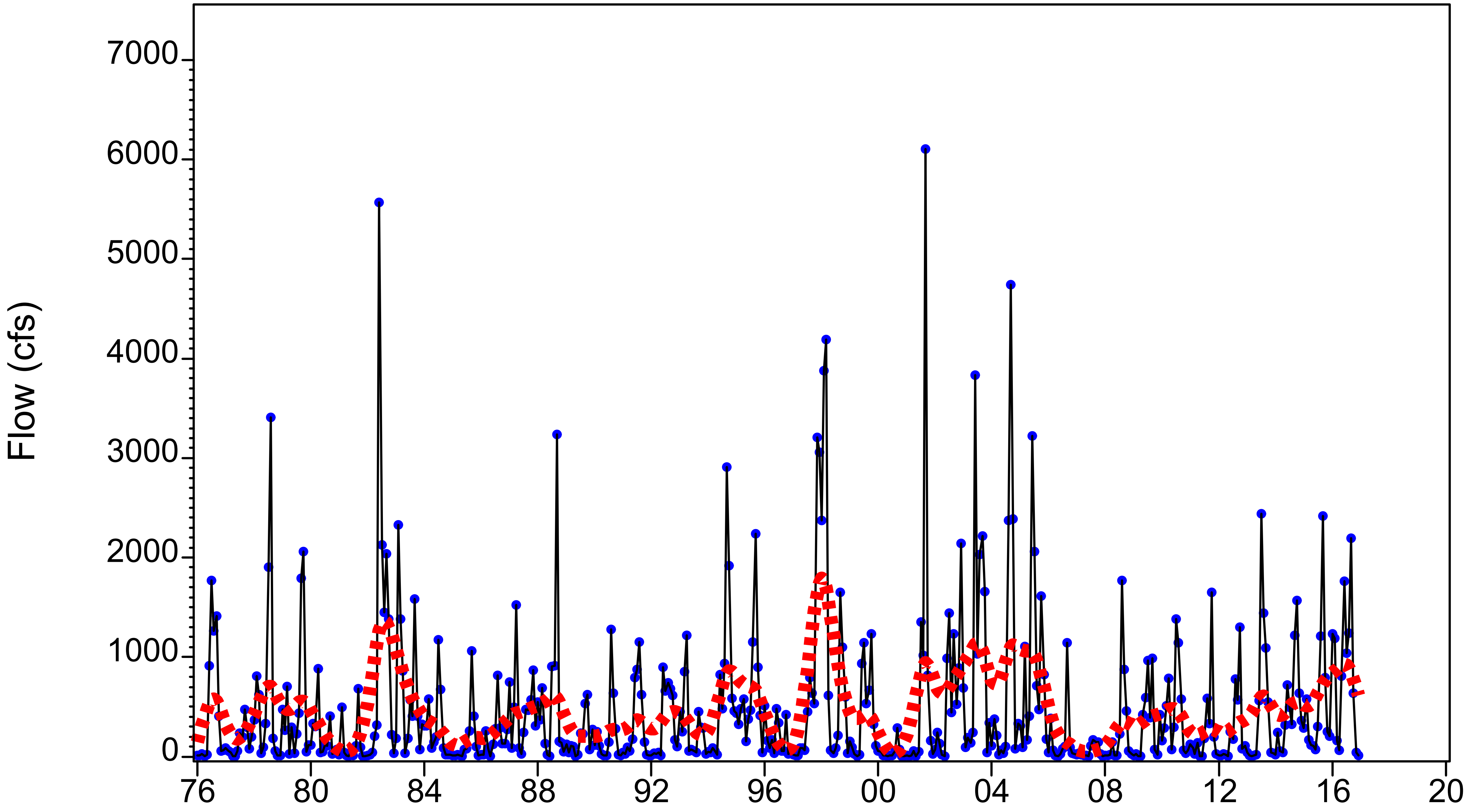


Figure 3.231 Monthly P90 flow at long-term Charlie Creek (2296500) gage (1976-2016)

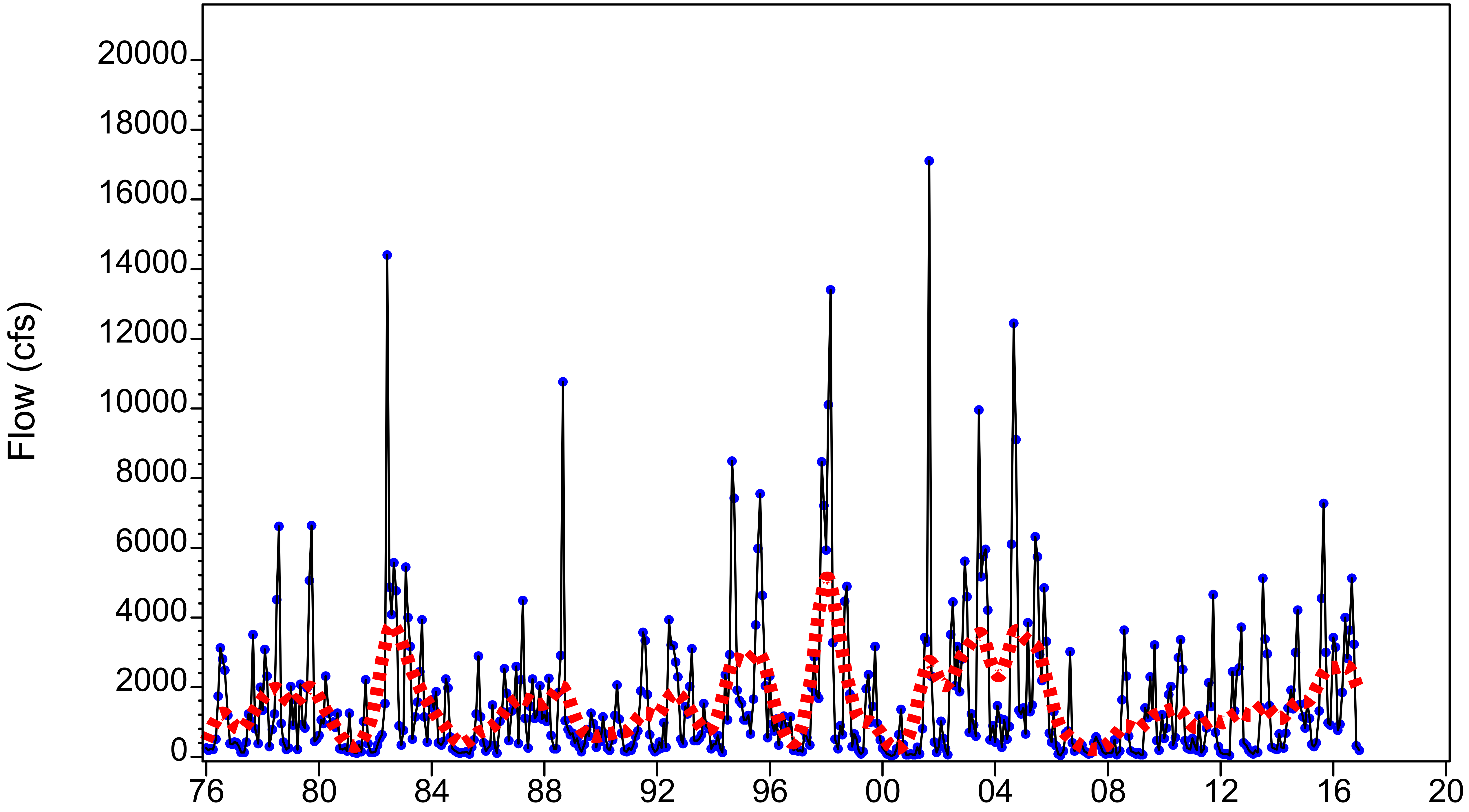


Figure 3.232 Monthly P90 flow at long-term Peace River at Arcadia (2296750) gage (1976-2016)

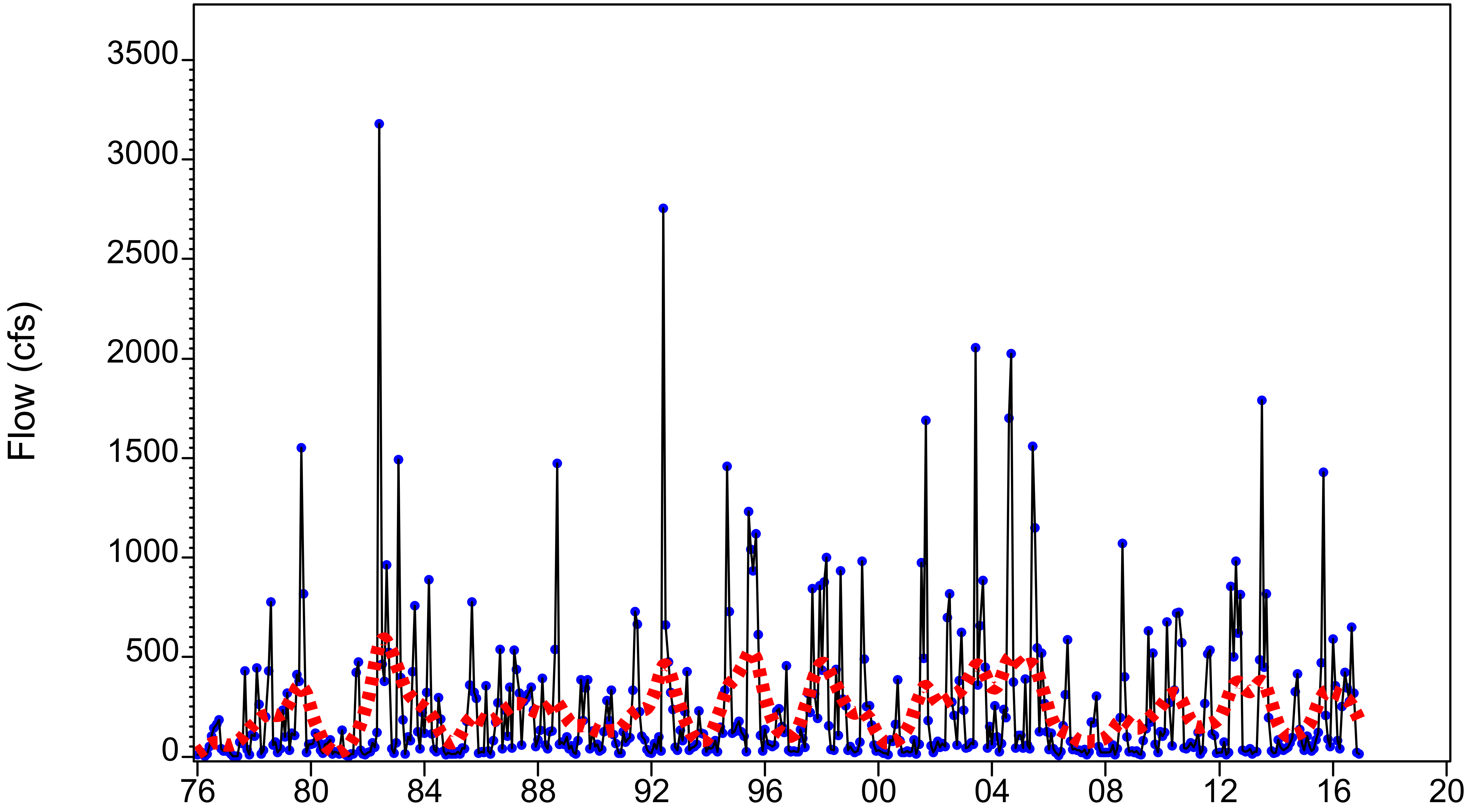


Figure 3.233 Monthly P90 flow at long-term Joshua Creek at Nocatee (2297100) gage (1976-2016)

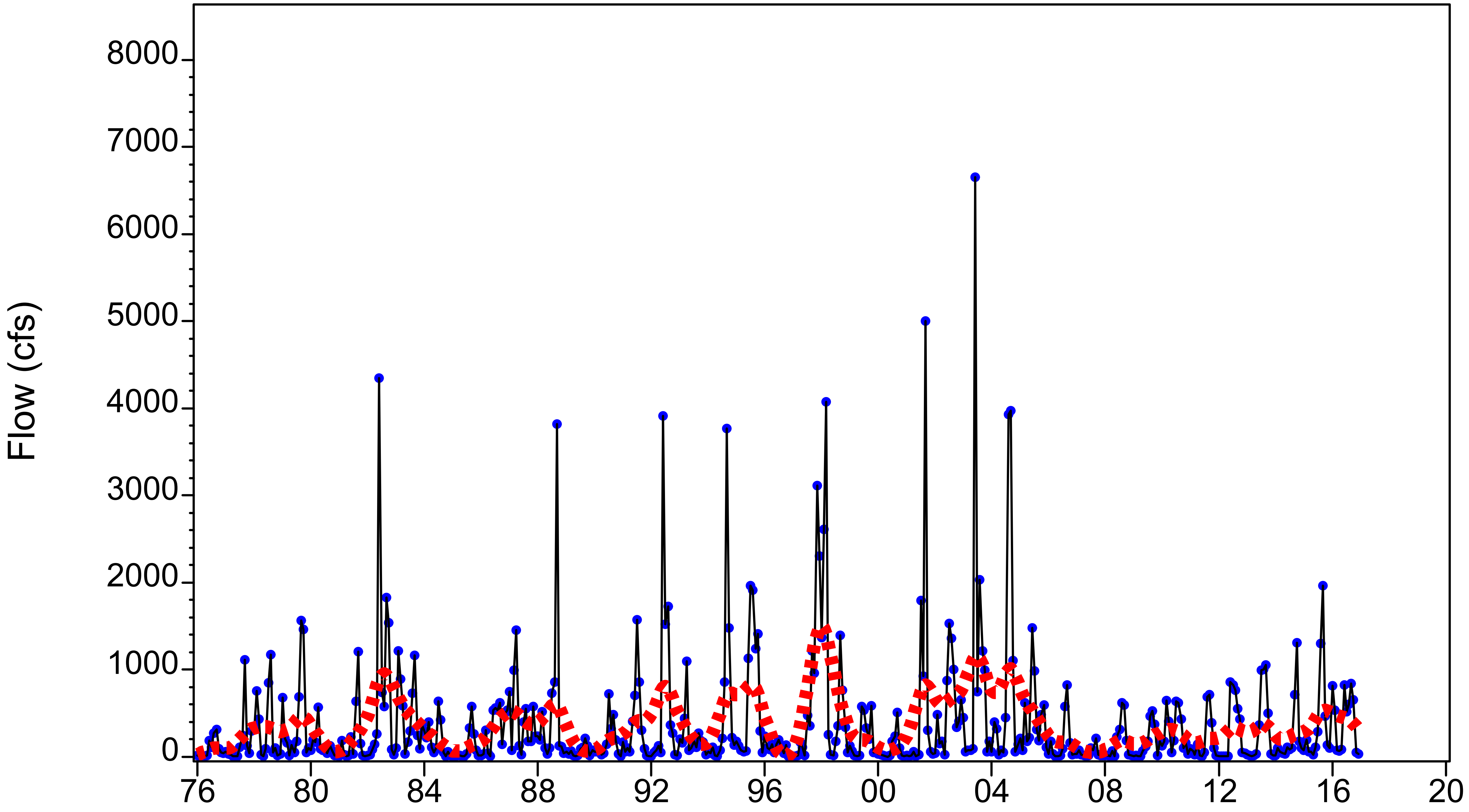


Figure 3.234 Monthly P90 flow at long-term Horse Creek near Arcadia (2297310) gage (1976-2016)

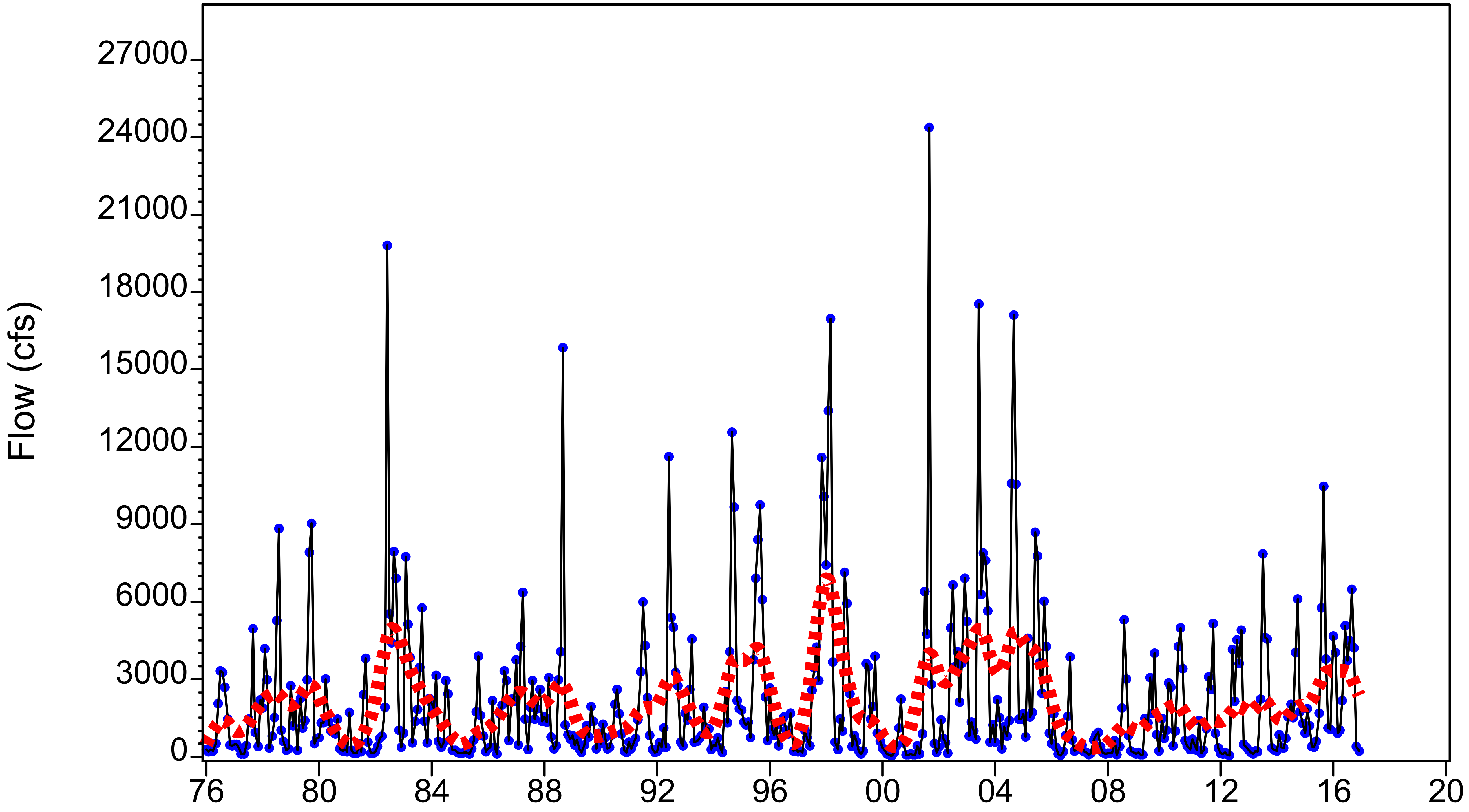


Figure 3.235 Monthly P90 flow at long-term for total gaged flow upstream of the Facility (1976-2016)

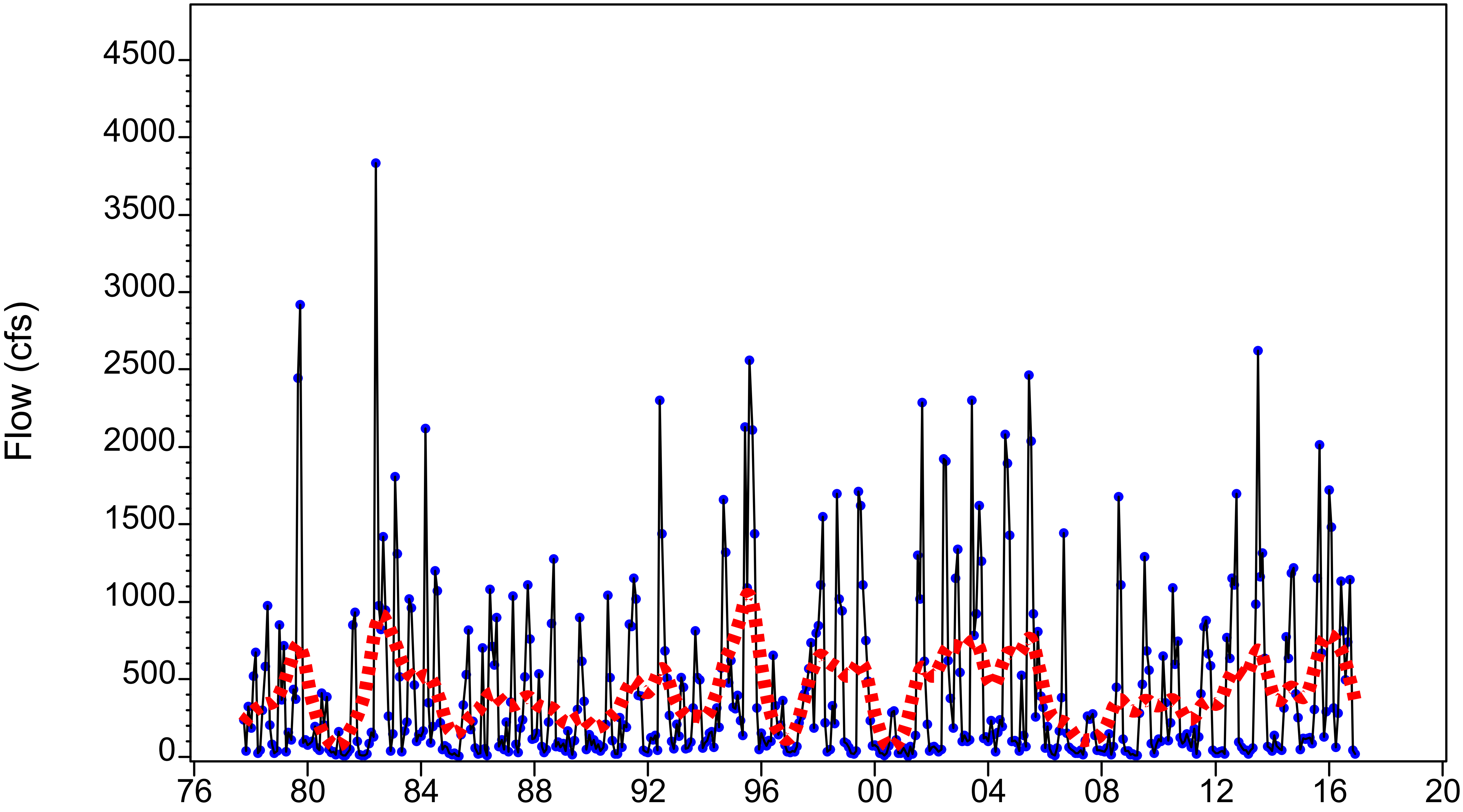


Figure 3.236 Monthly P90 flow at long-term Prairie Creek (2298123) gage (1976-2016)

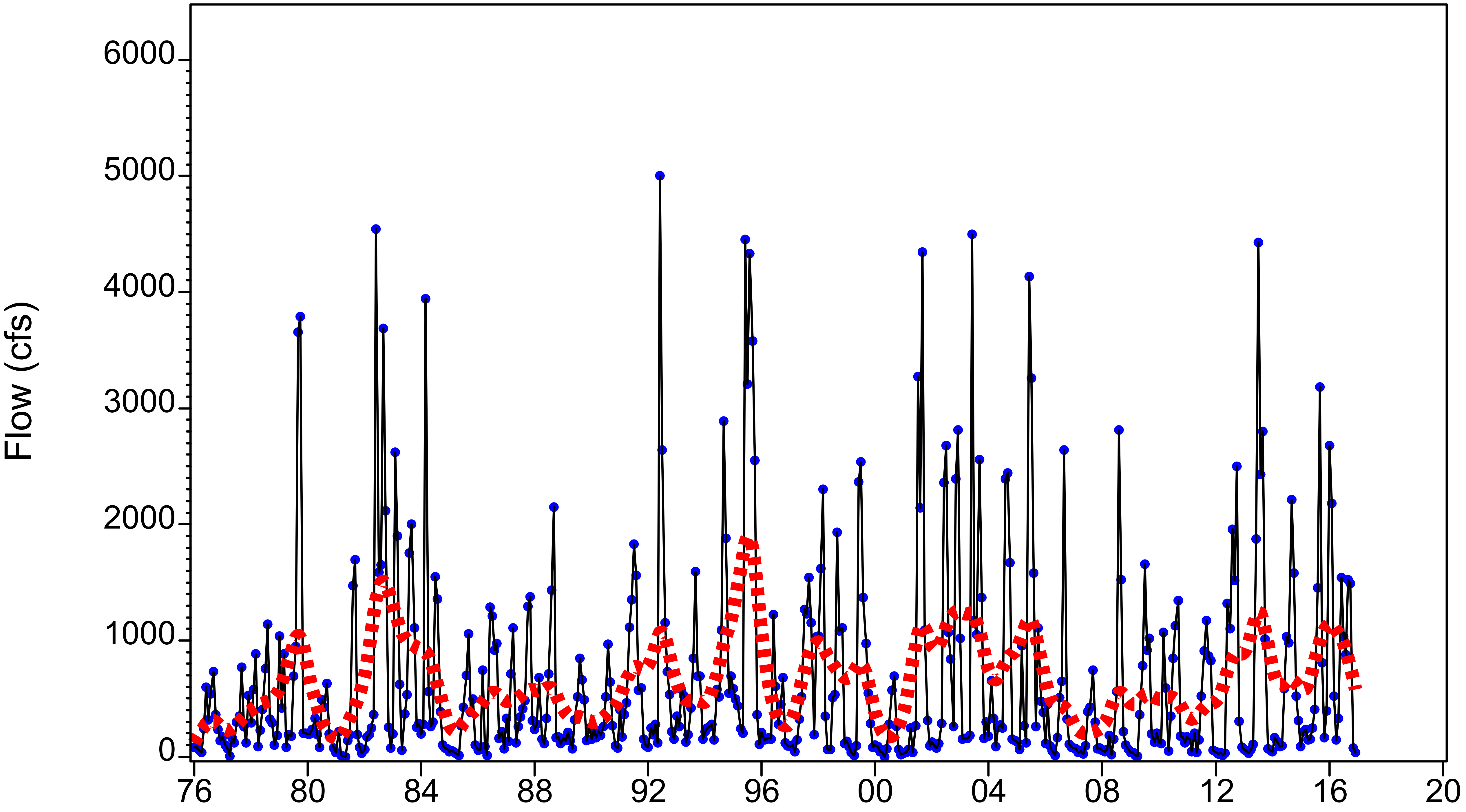


Figure 3.237 Monthly P90 flow at long-term Shell Creek gage (1976-2016)

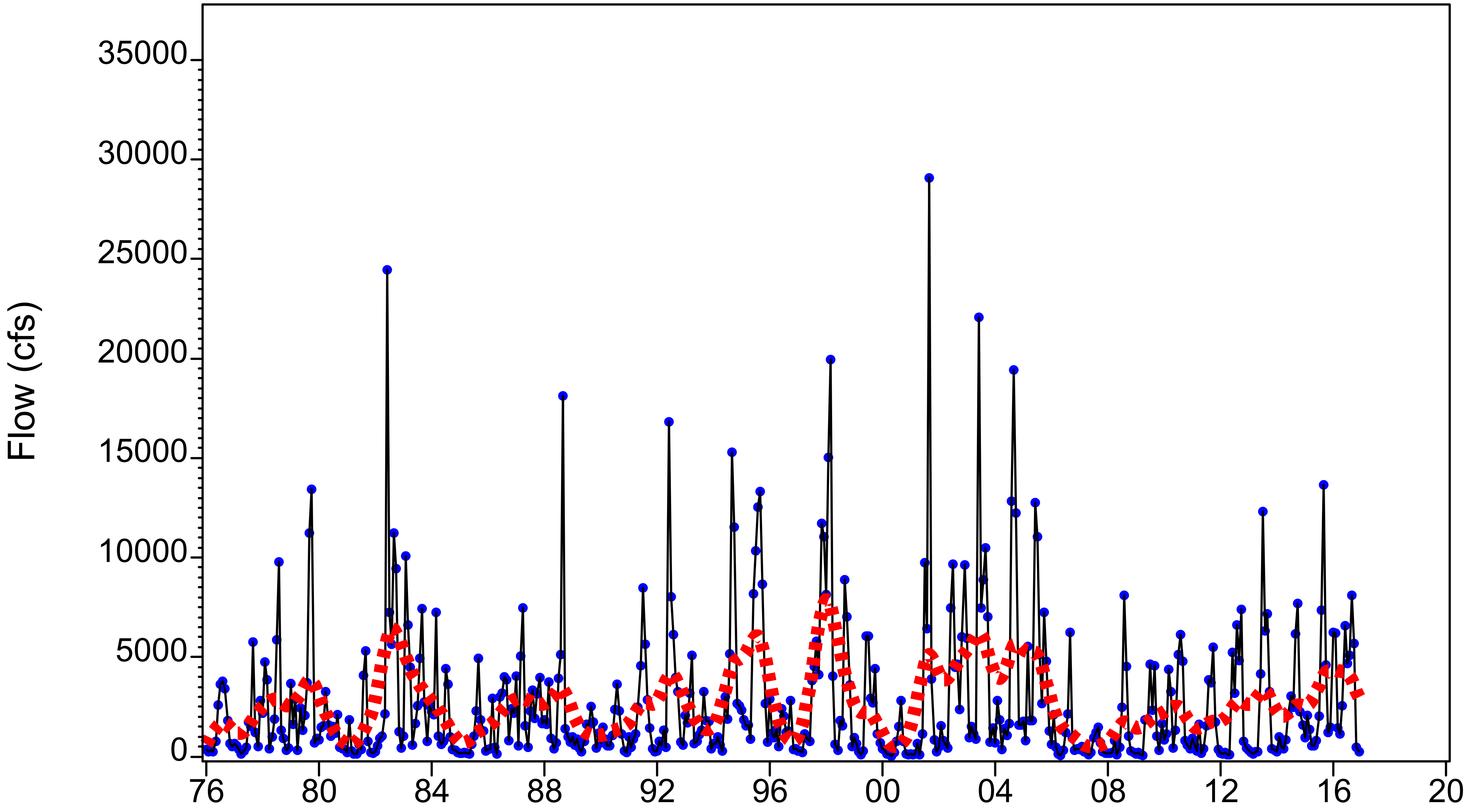


Figure 3.238 Monthly P90 flow of total gaged Peace River flow to the Upper Harbor (1976-2016)

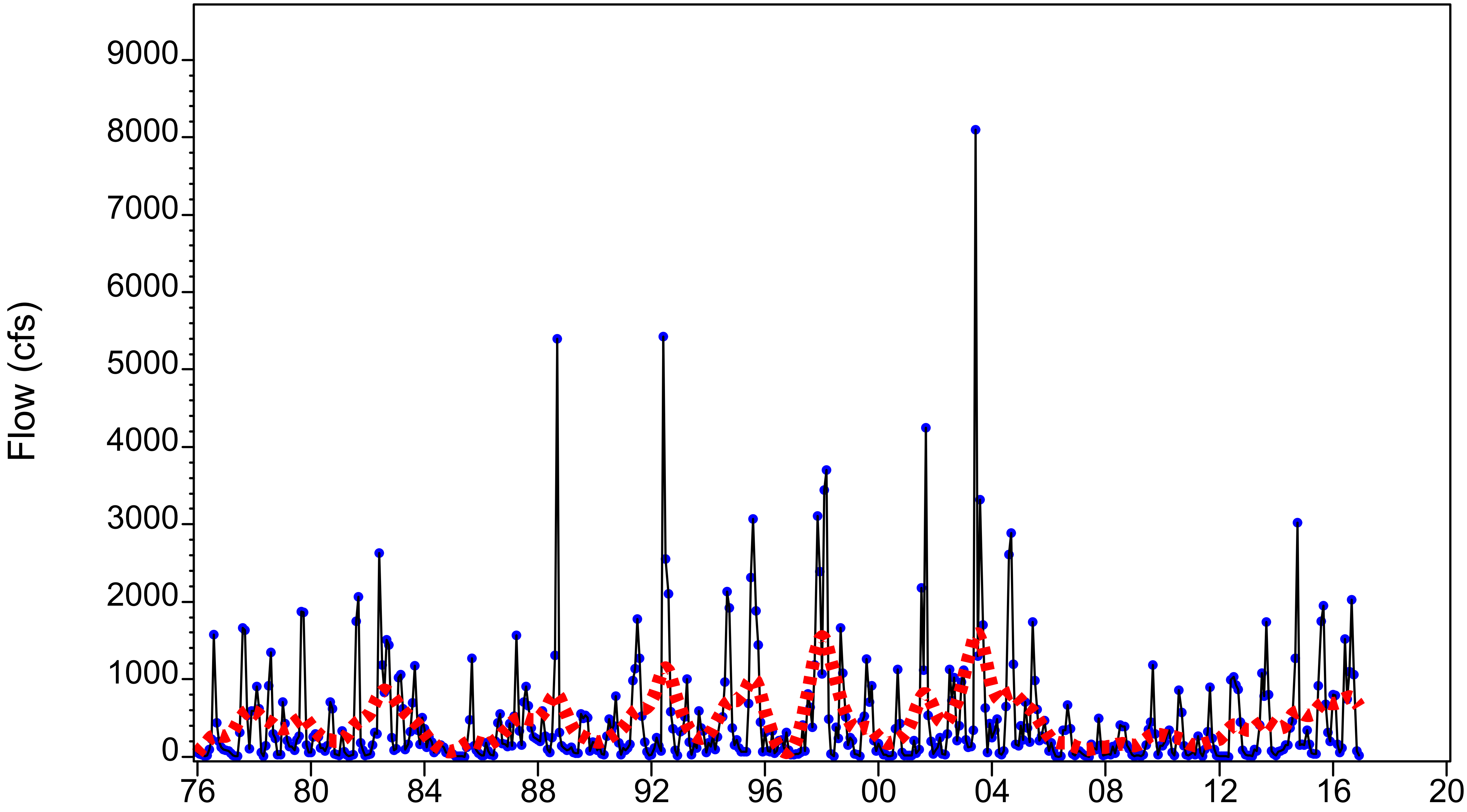


Figure 3.239 Monthly P90 flow at long-term Myakka River near Sarasota (2298830) gage (1976-2016)

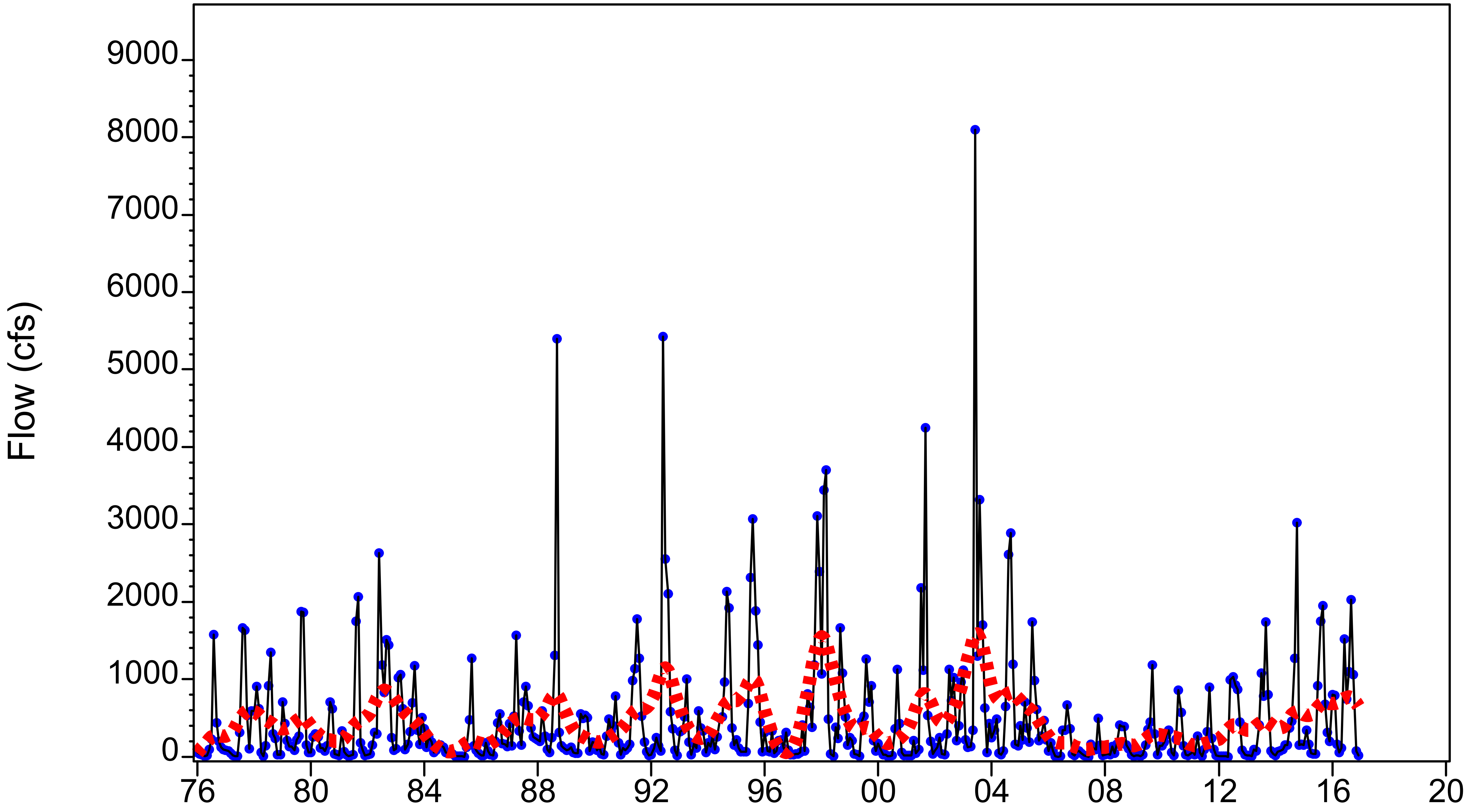


Figure 3.239 Monthly P90 flow at long-term Myakka River near Sarasota (2298830) gage (1976-2016)

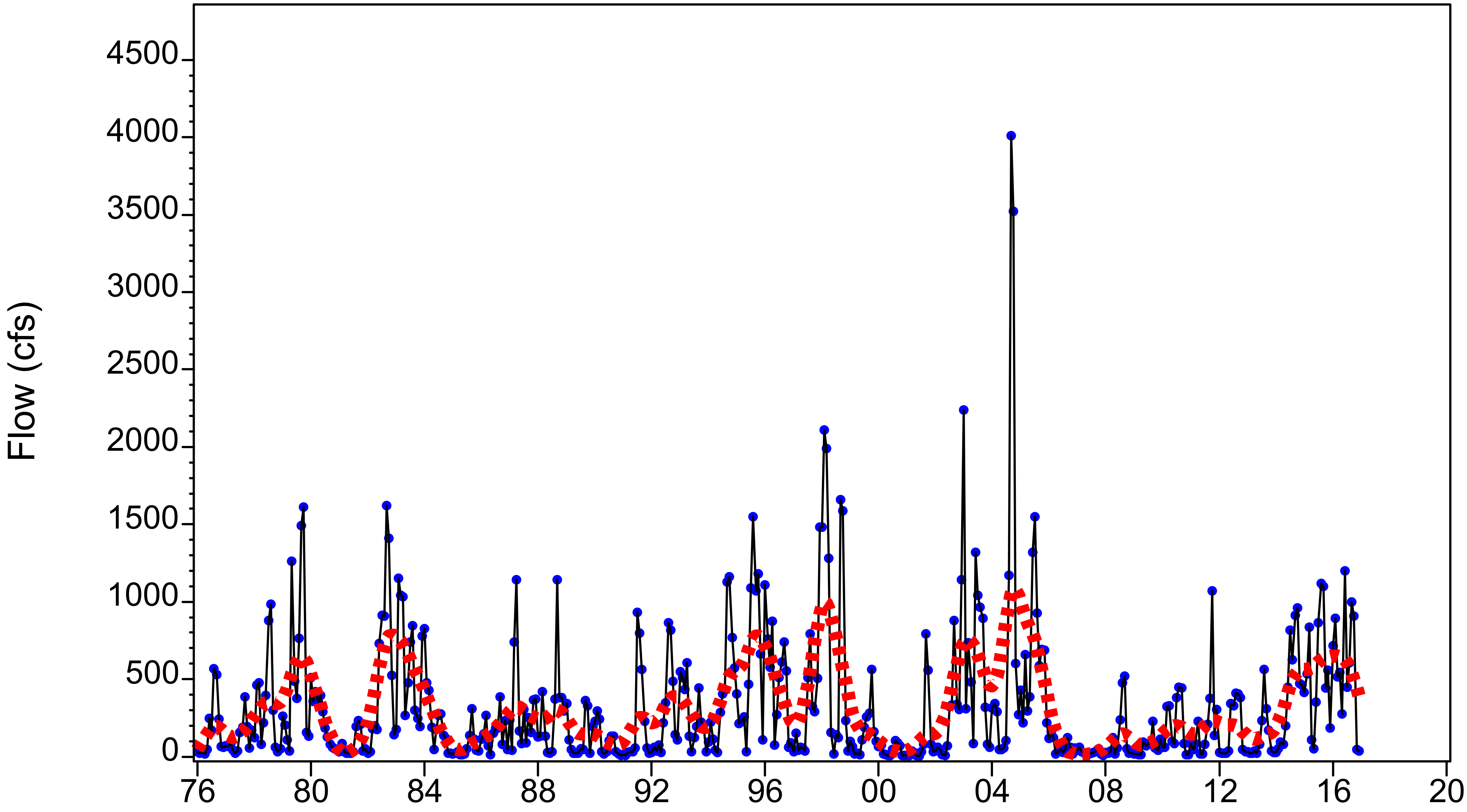


Figure 3.240 Monthly P100 (maximum) flow at long-term Peace River at Bartow (2294650) gage (1976-2016)

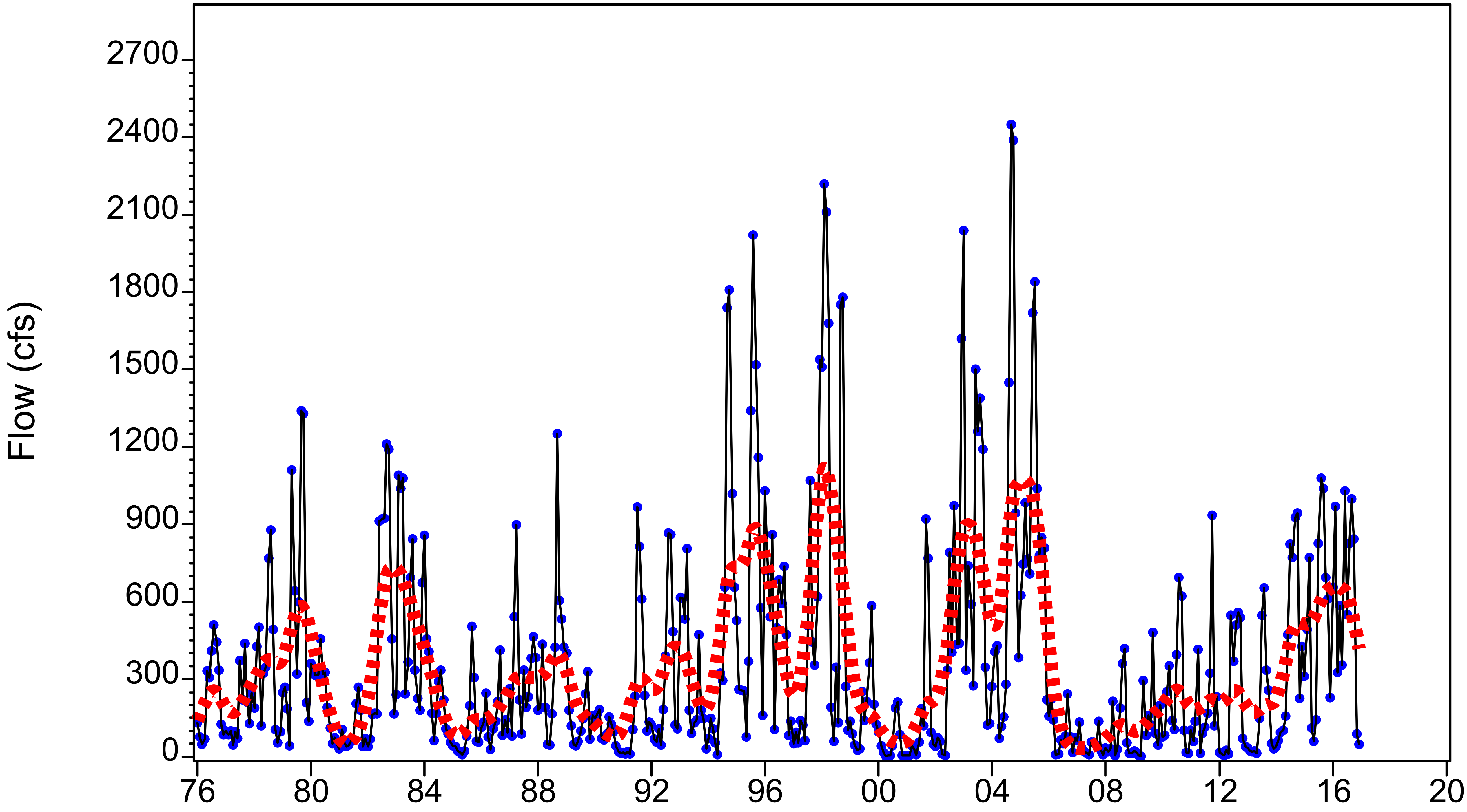


Figure 3.241 Monthly P100 (maximum) flow at long-term Peace River at Ft. Meade (2294898) gage (1976-2016)

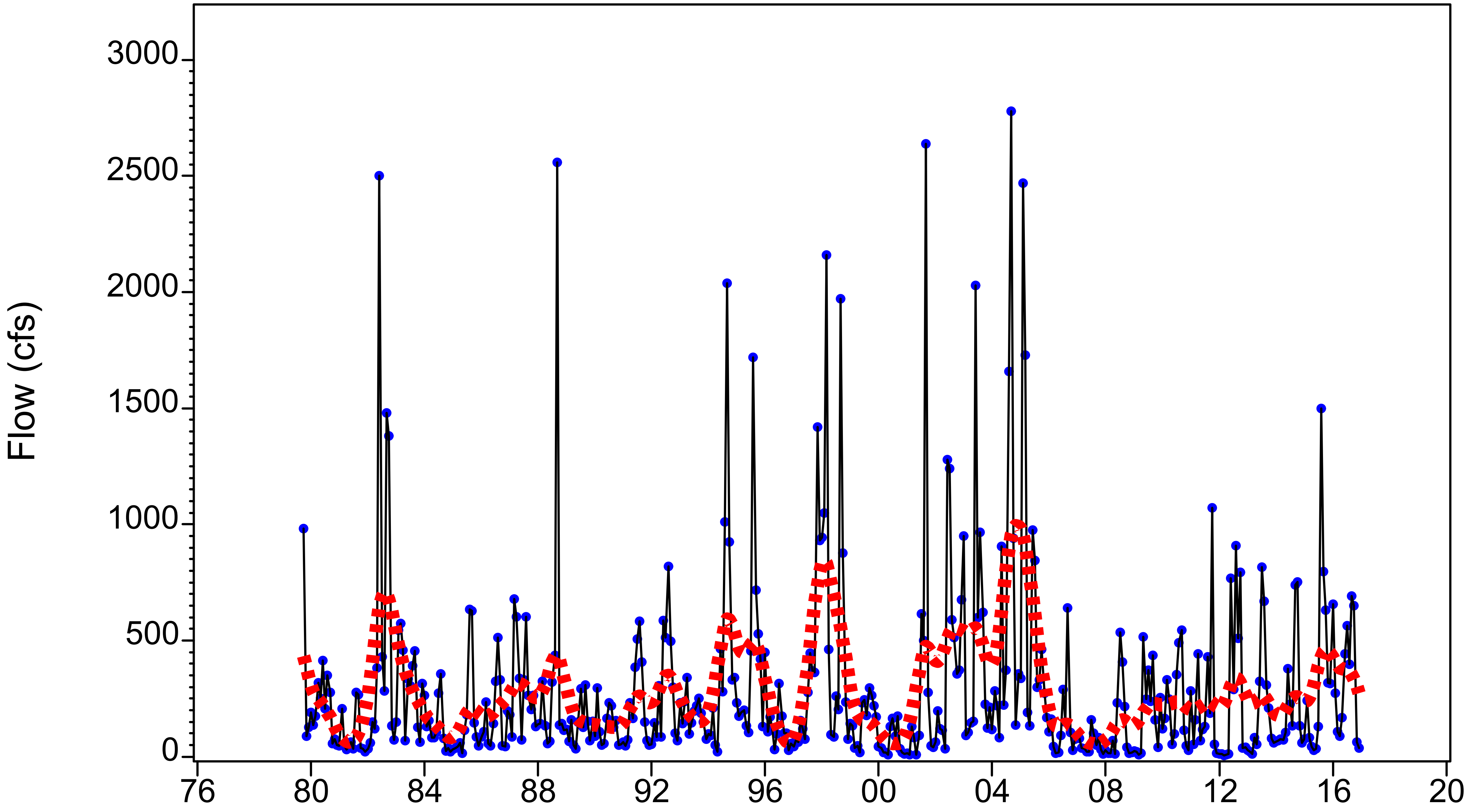


Figure 3.242 Monthly P100 (maximum) flow at long-term Payne Creek (2295420) gage (1976-2016)

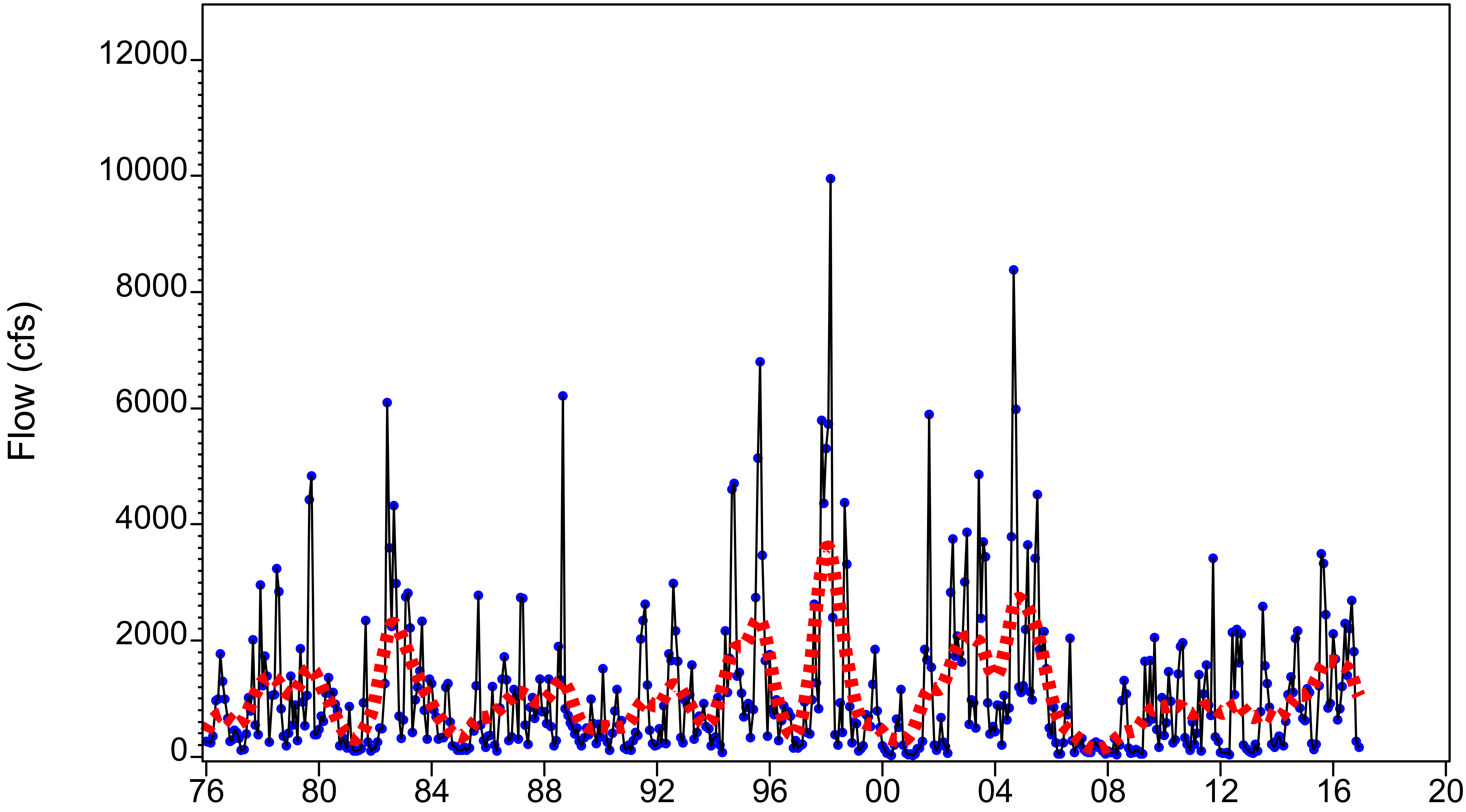


Figure 3.243 Monthly P100 (maximum) flow at long-term Peace River at Zolfo (2295637) gage (1976-2016)

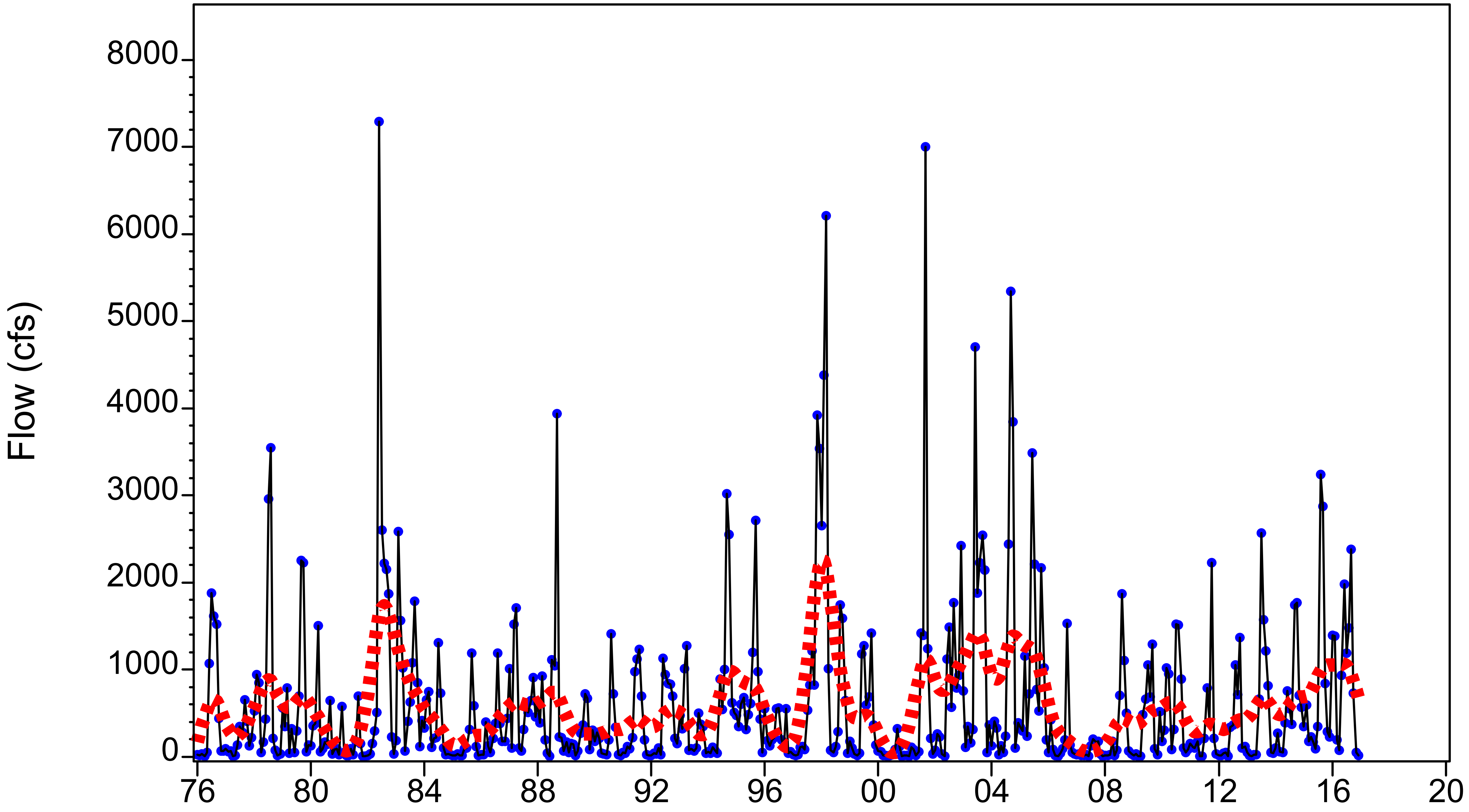


Figure 3.244 Monthly P100 (maximum) flow at long-term Charlie Creek (2296500) gage (1976-2016)

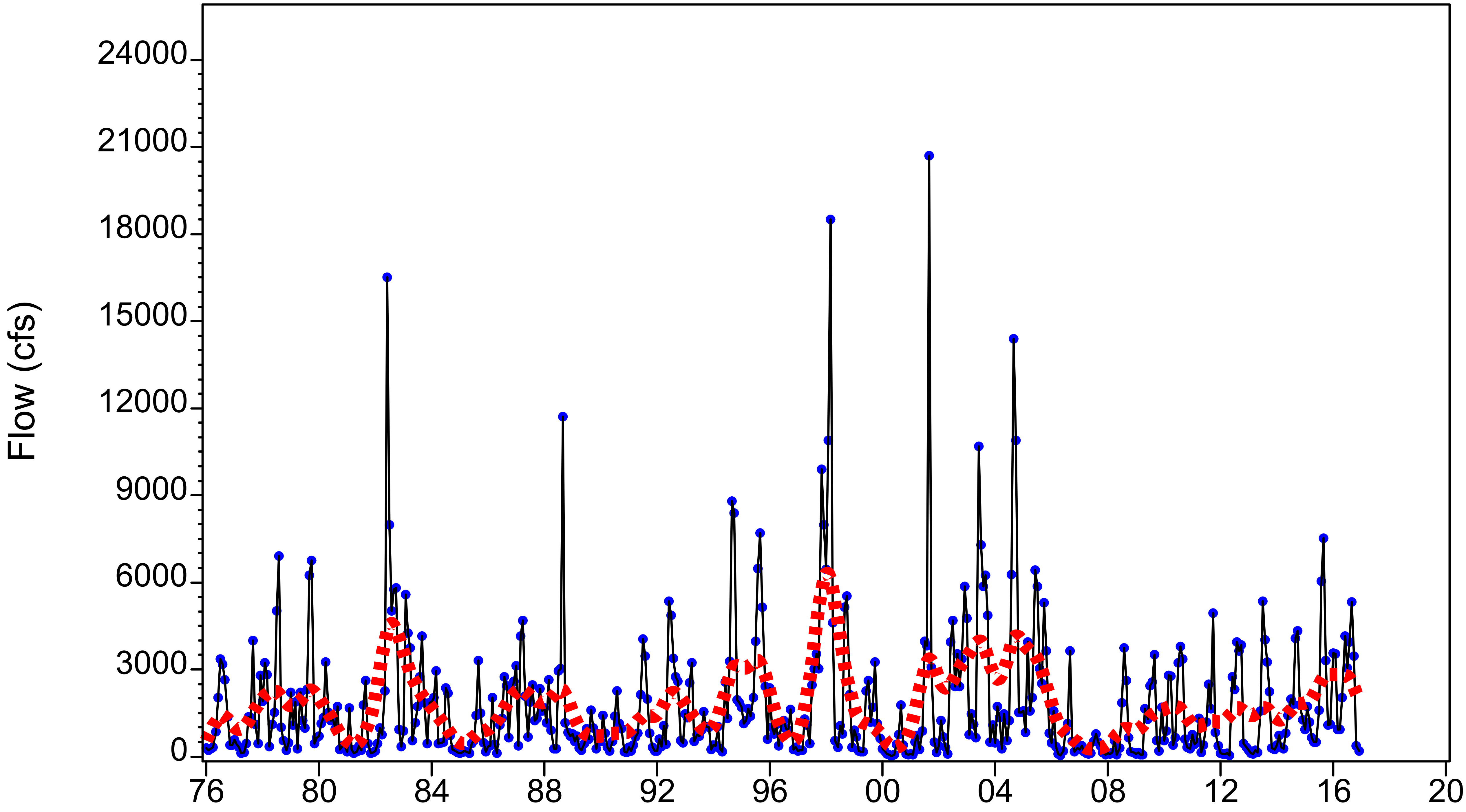


Figure 3.245 Monthly P100 (maximum) flow at long-term Peace River at Arcadia (2296750) gage (1976-2016)

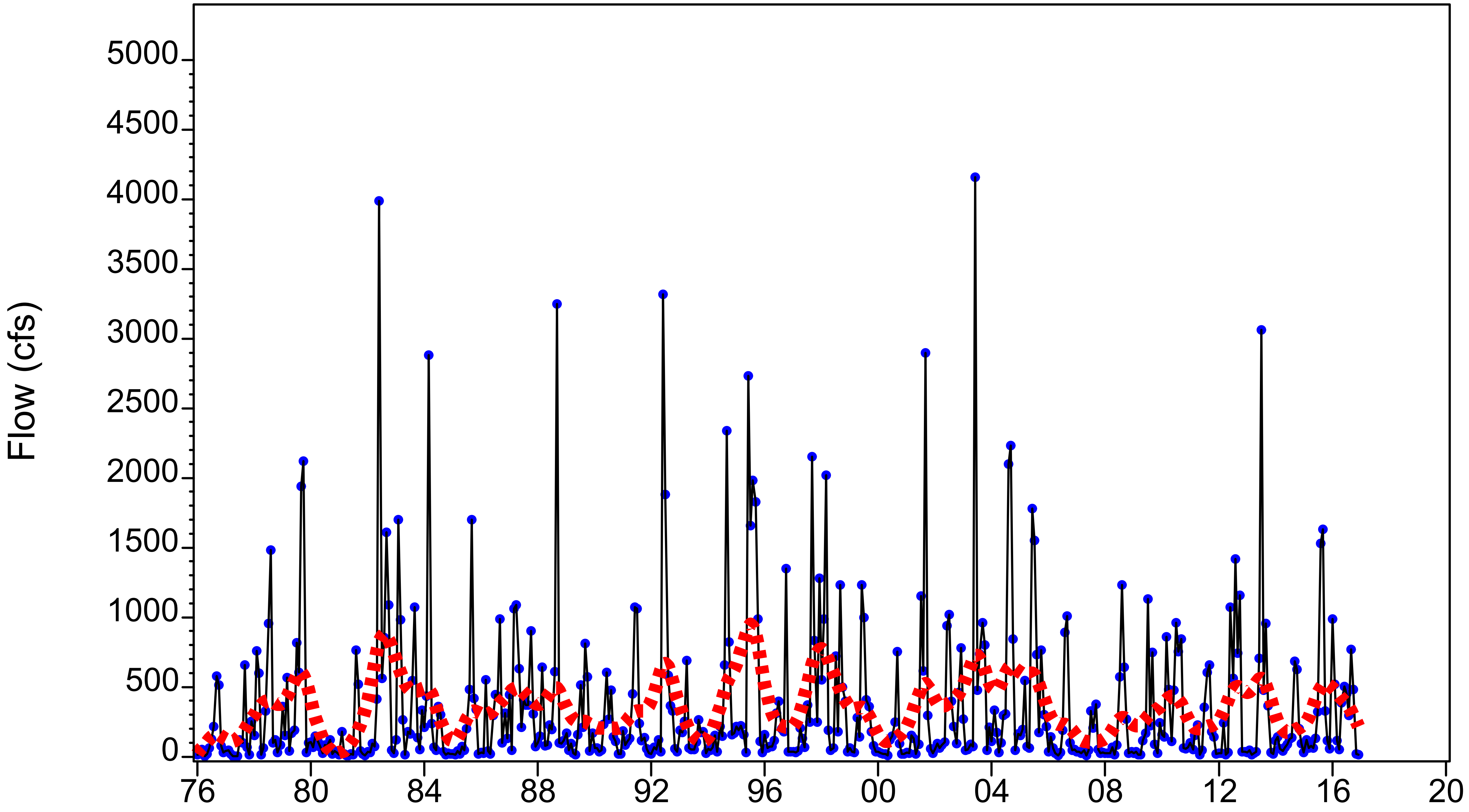


Figure 3.246 Monthly P100 (maximum) flow at long-term Joshua Creek at Nocatee (2297100) gage (1976-2016)

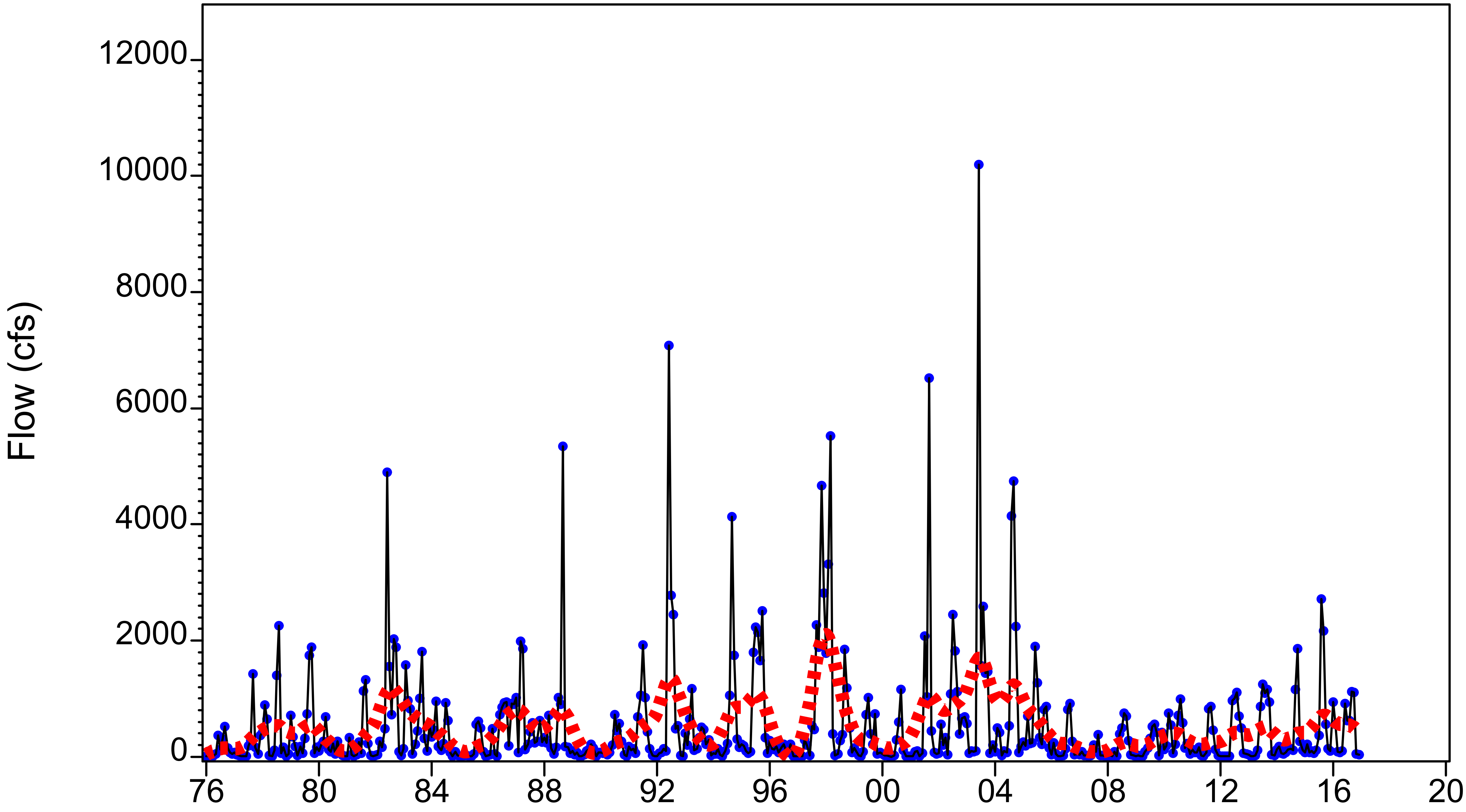


Figure 3.247 Monthly P100 (maximum) flow at long-term Horse Creek near Arcadia (2297310) gage (1976-2016)

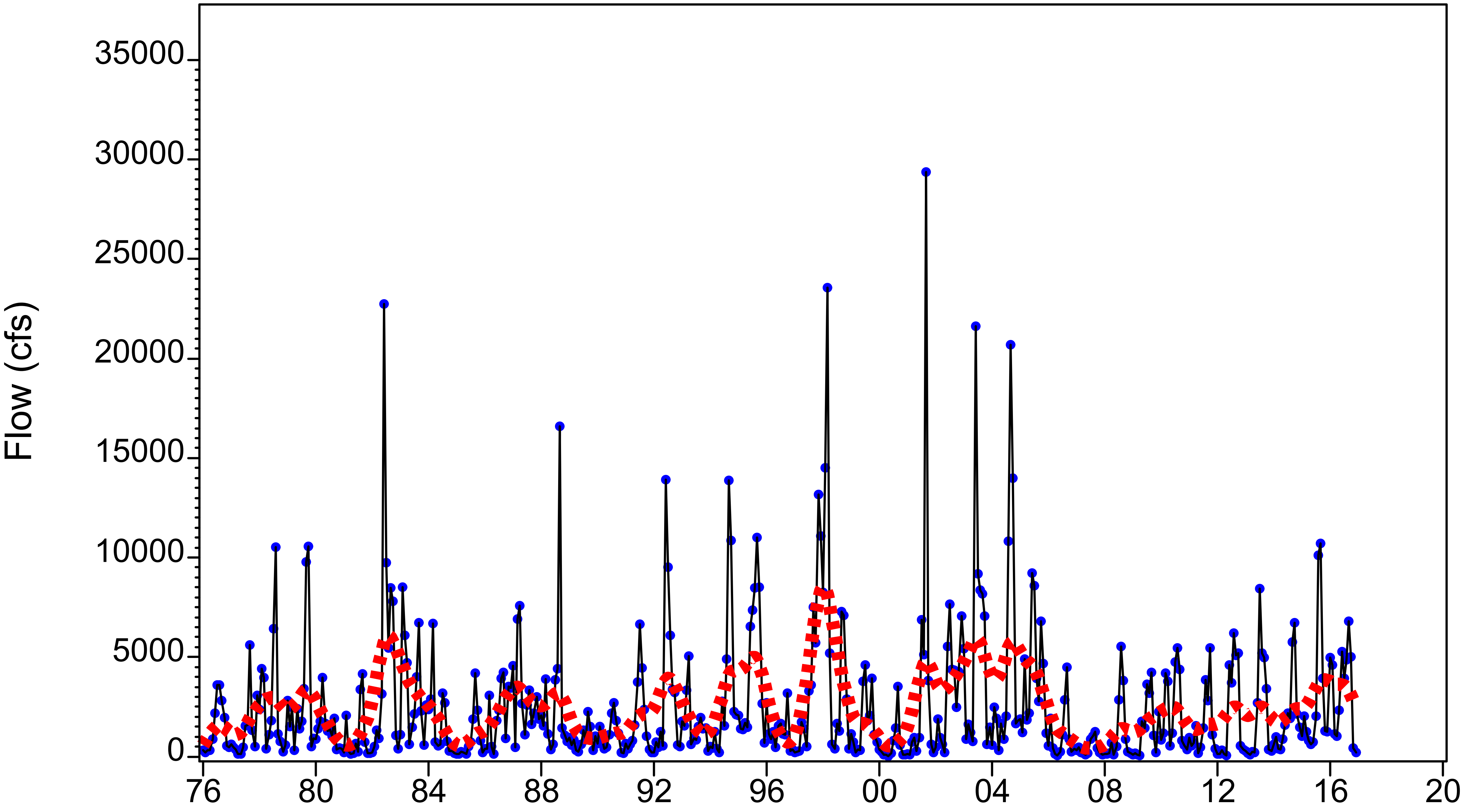


Figure 3.248 Monthly P100 (maximum) flow at long-term for total gaged flow upstream of the Facility (1976-2016)

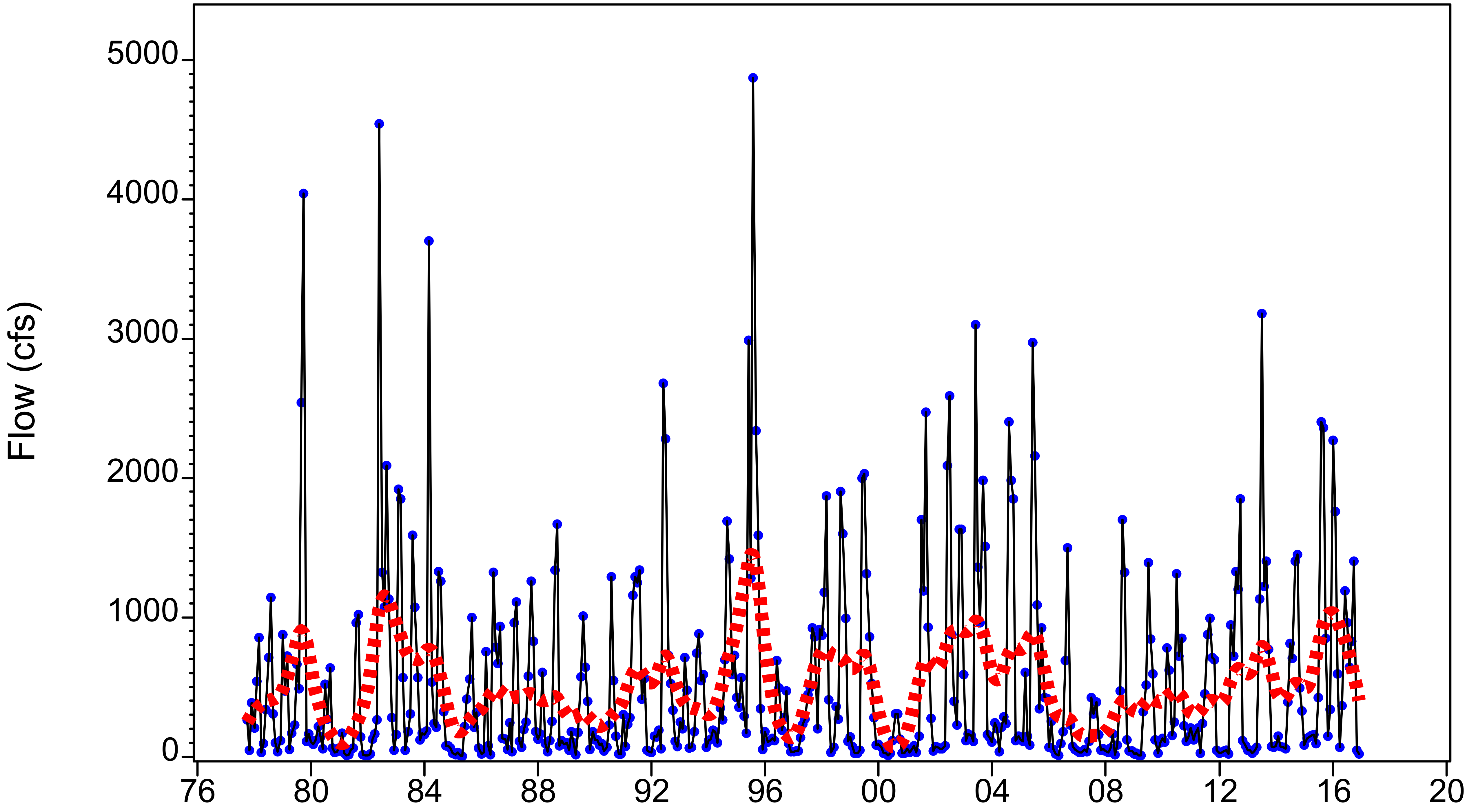


Figure 3.249 Monthly P100 (maximum) flow at long-term Prairie Creek (2298123) gage (1976-2016)

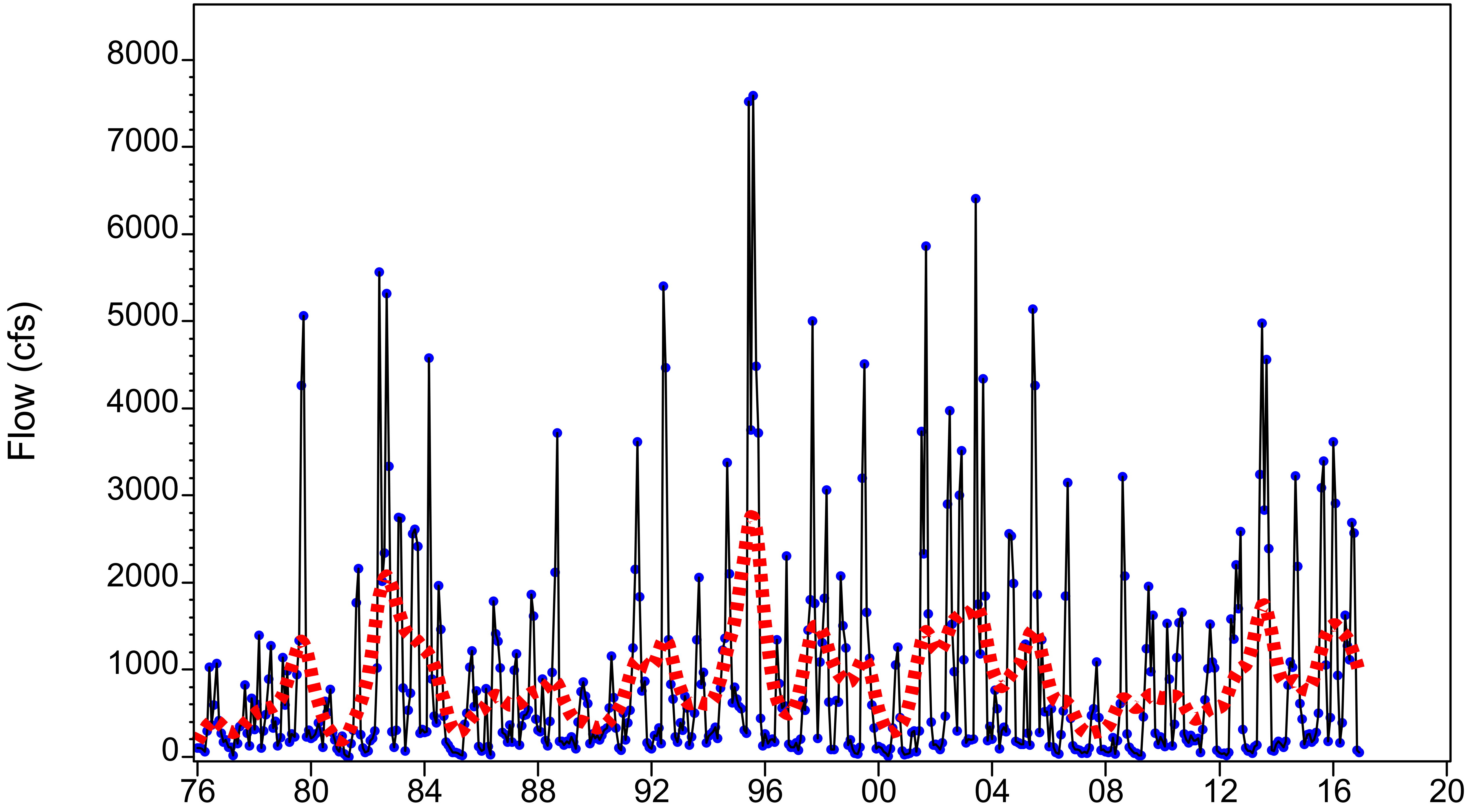


Figure 3.250 Monthly P100 (maximum) flow at long-term Shell Creek gage (1976-2016)

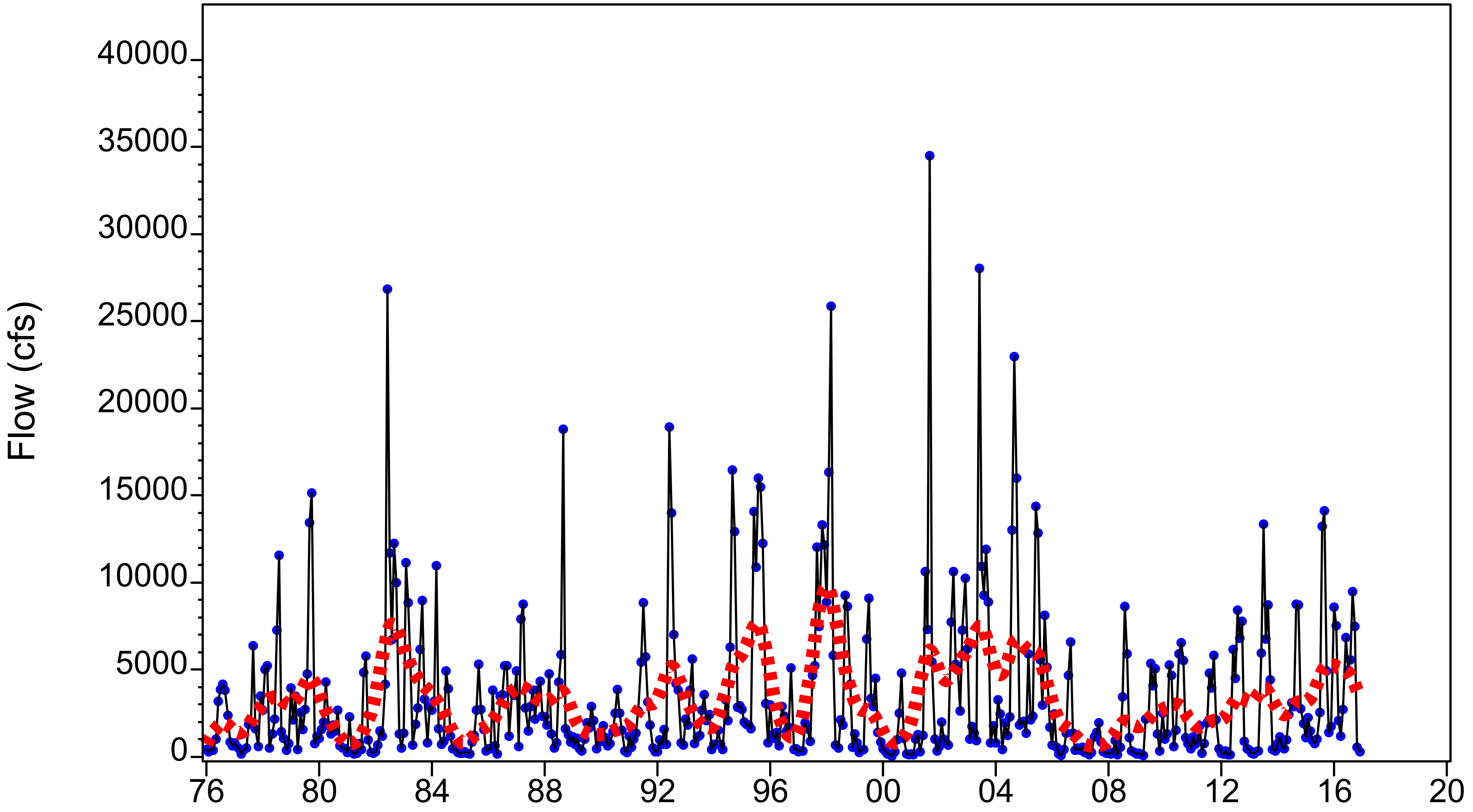


Figure 3.251 Monthly P100 (maximum) flow of total gaged Peace River flow to the Upper Harbor (1976-2016)

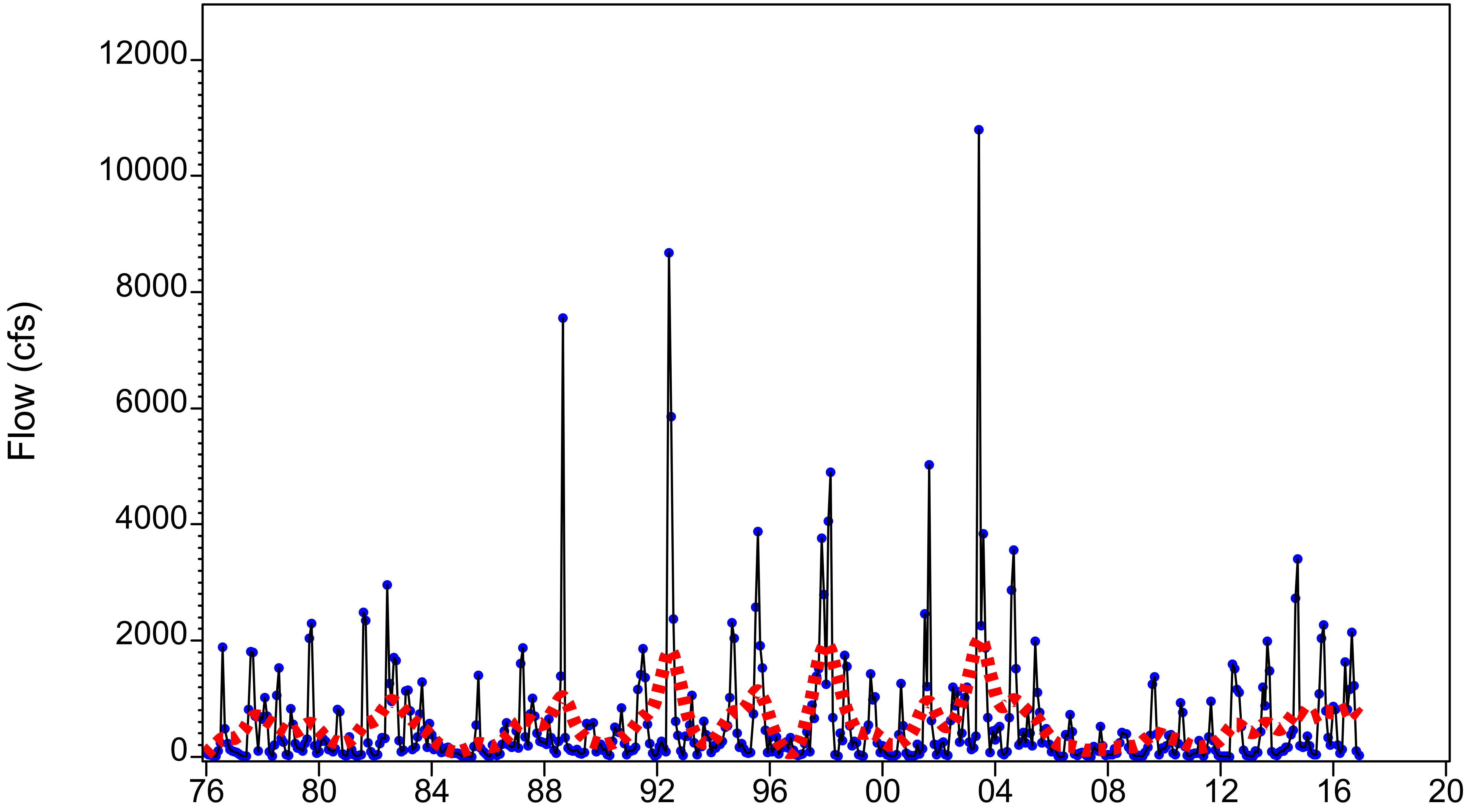


Figure 3.252 Monthly P100 (maximum) flow at long-term Myakka River near Sarasota (2298830) gage (1976-2016)

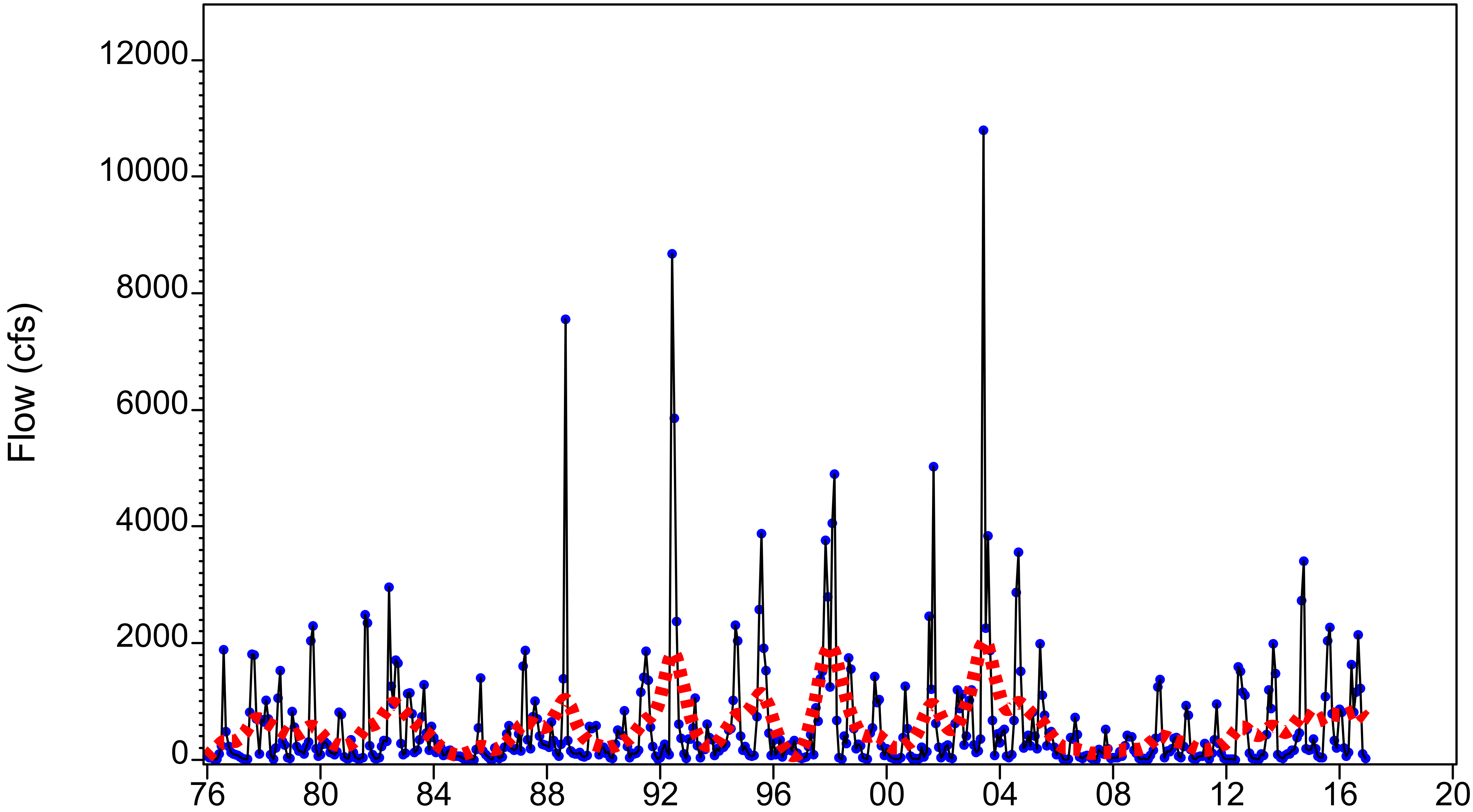


Figure 3.252 Monthly P100 (maximum) flow at long-term Myakka River near Sarasota (2298830) gage (1976-2016)

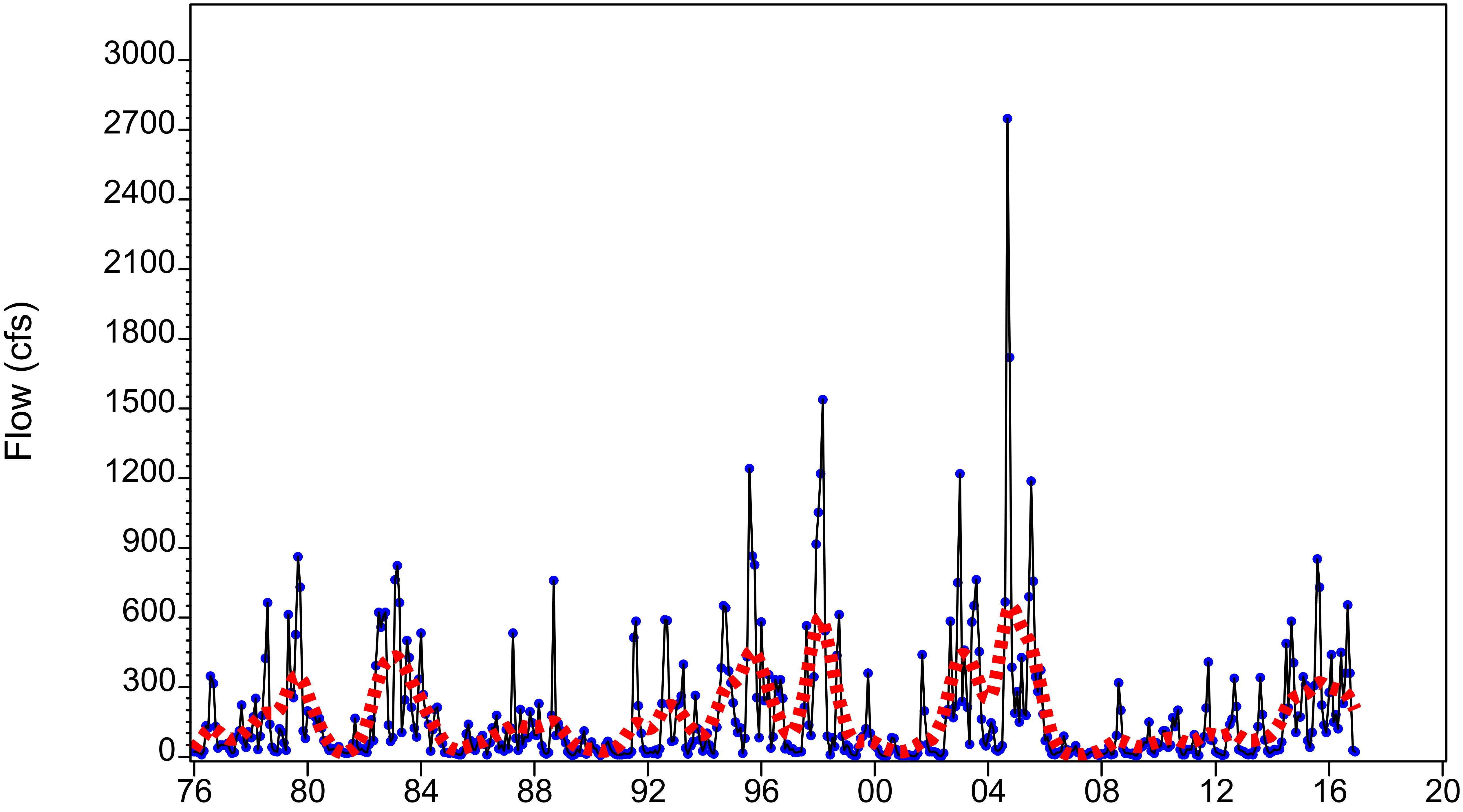


Figure 3.253 Monthly mean flow at long-term Peace River at Bartow (2294650) gage (1976-2016)

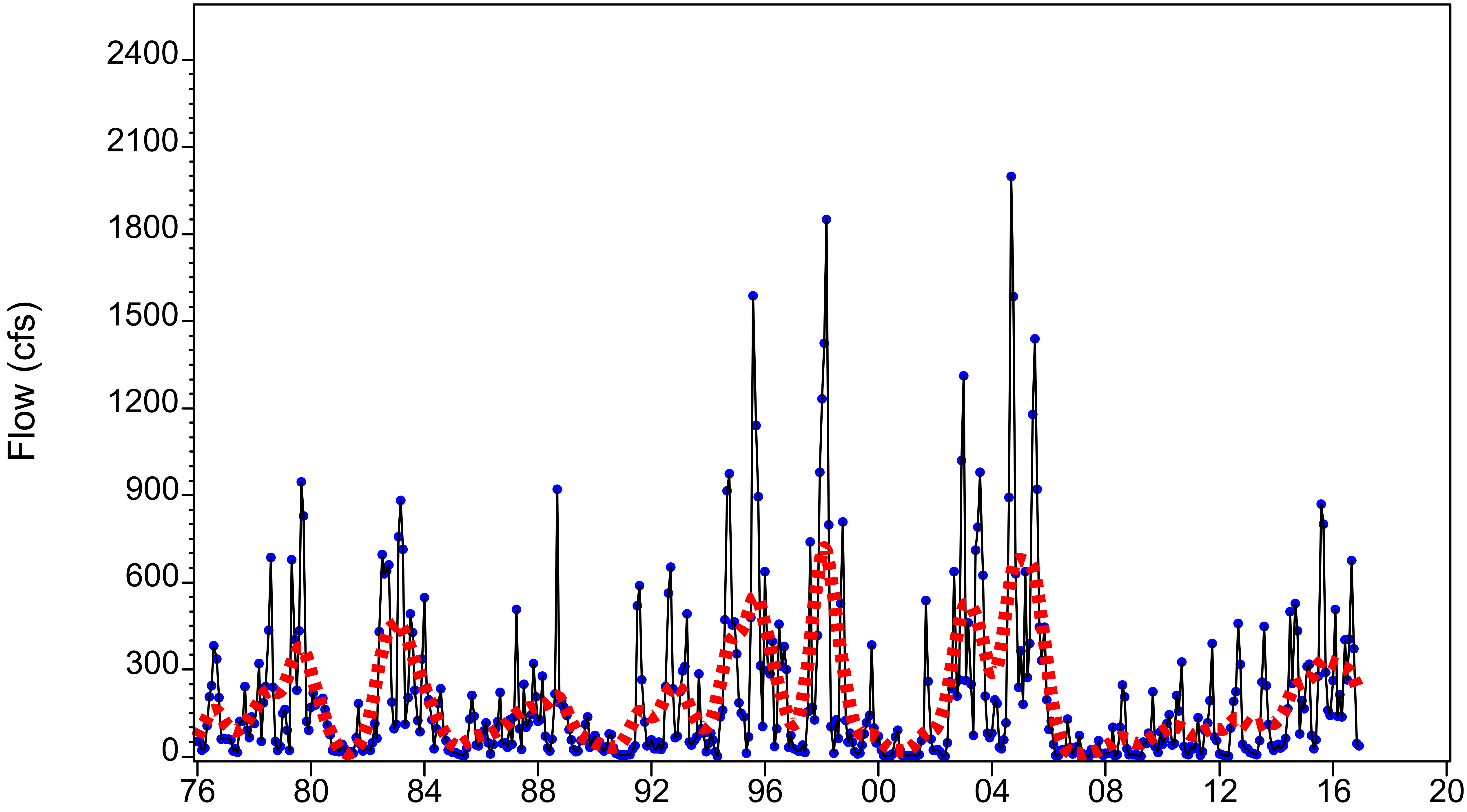


Figure 3.254 Monthly mean flow at long-term Peace River at Ft. Meade (2294898) gage (1976-2016)

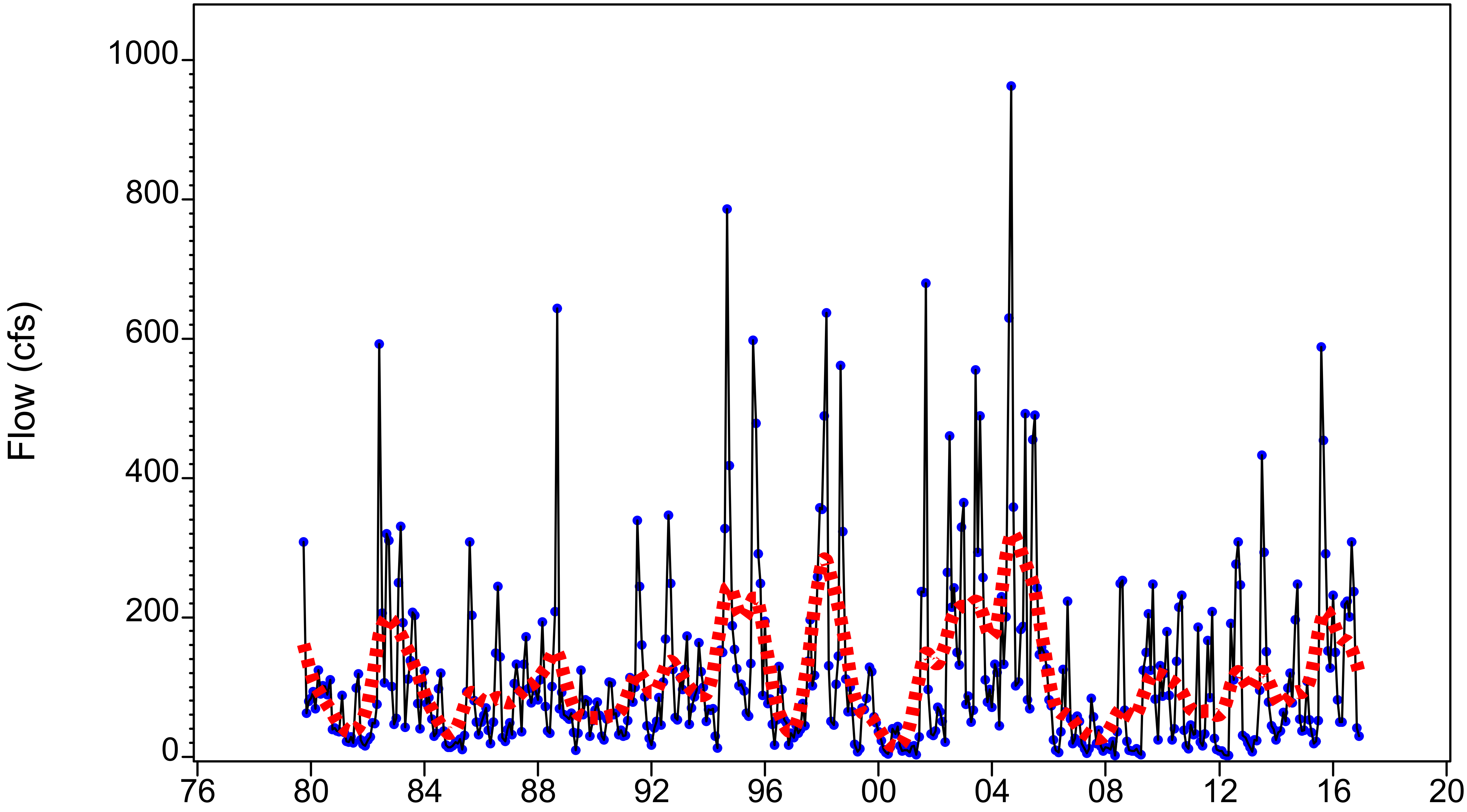


Figure 3.255 Monthly mean flow at long-term Payne Creek (2295420) gage (1976-2016)

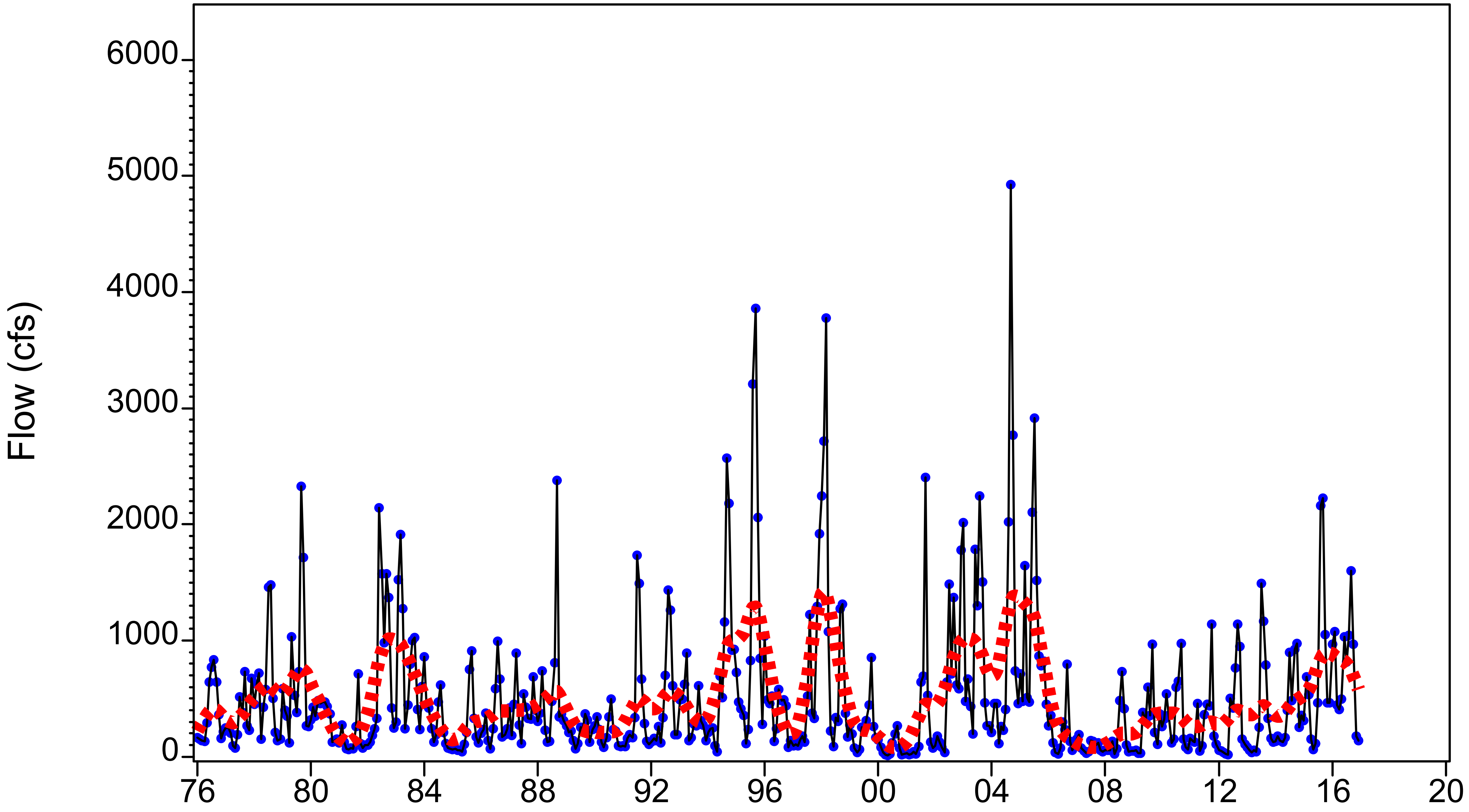


Figure 3.256 Monthly mean flow at long-term Peace River at Zolfo (2295637) gage (1976-2016)

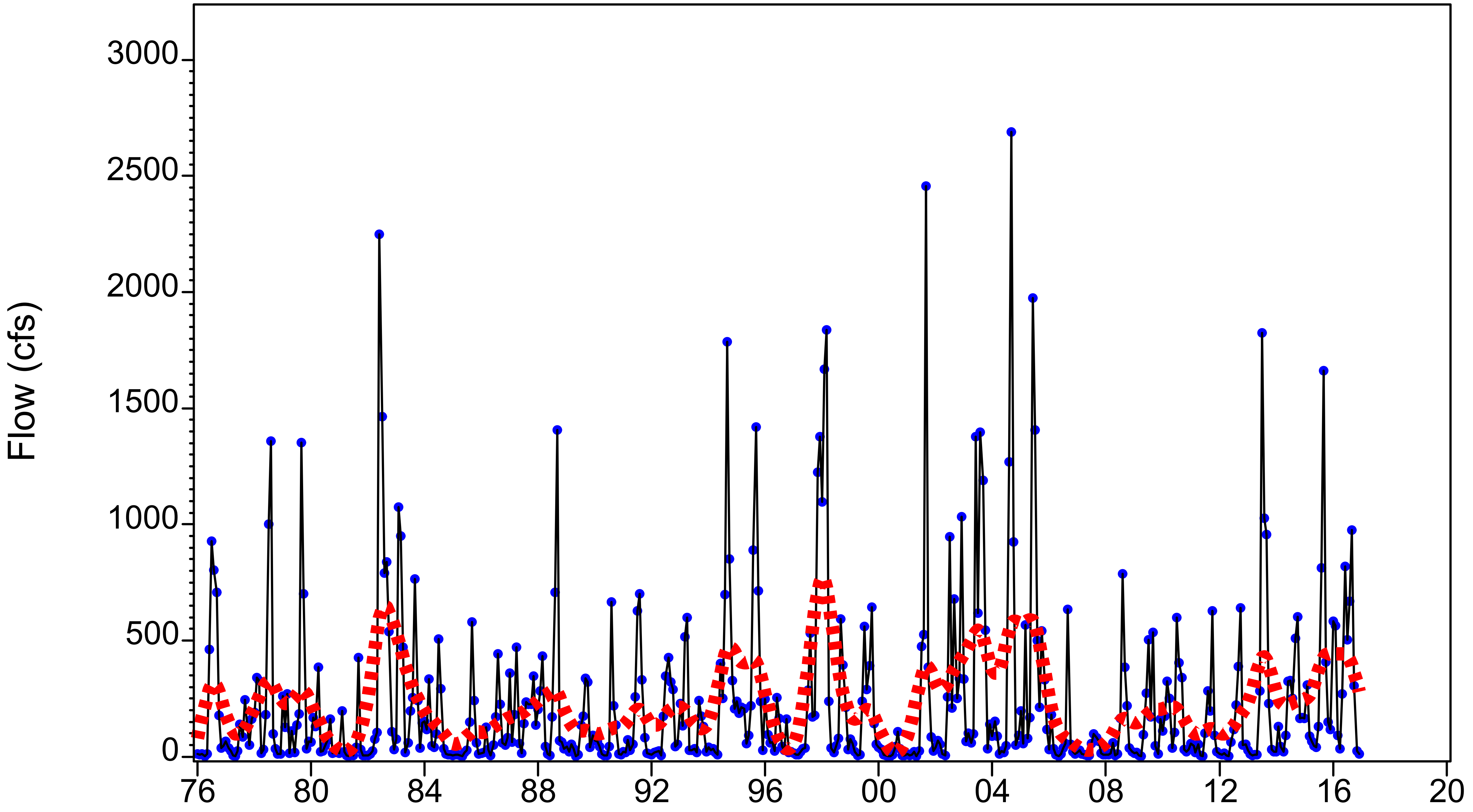


Figure 3.257 Monthly mean flow at long-term Charlie Creek (2296500) gage (1976-2016)

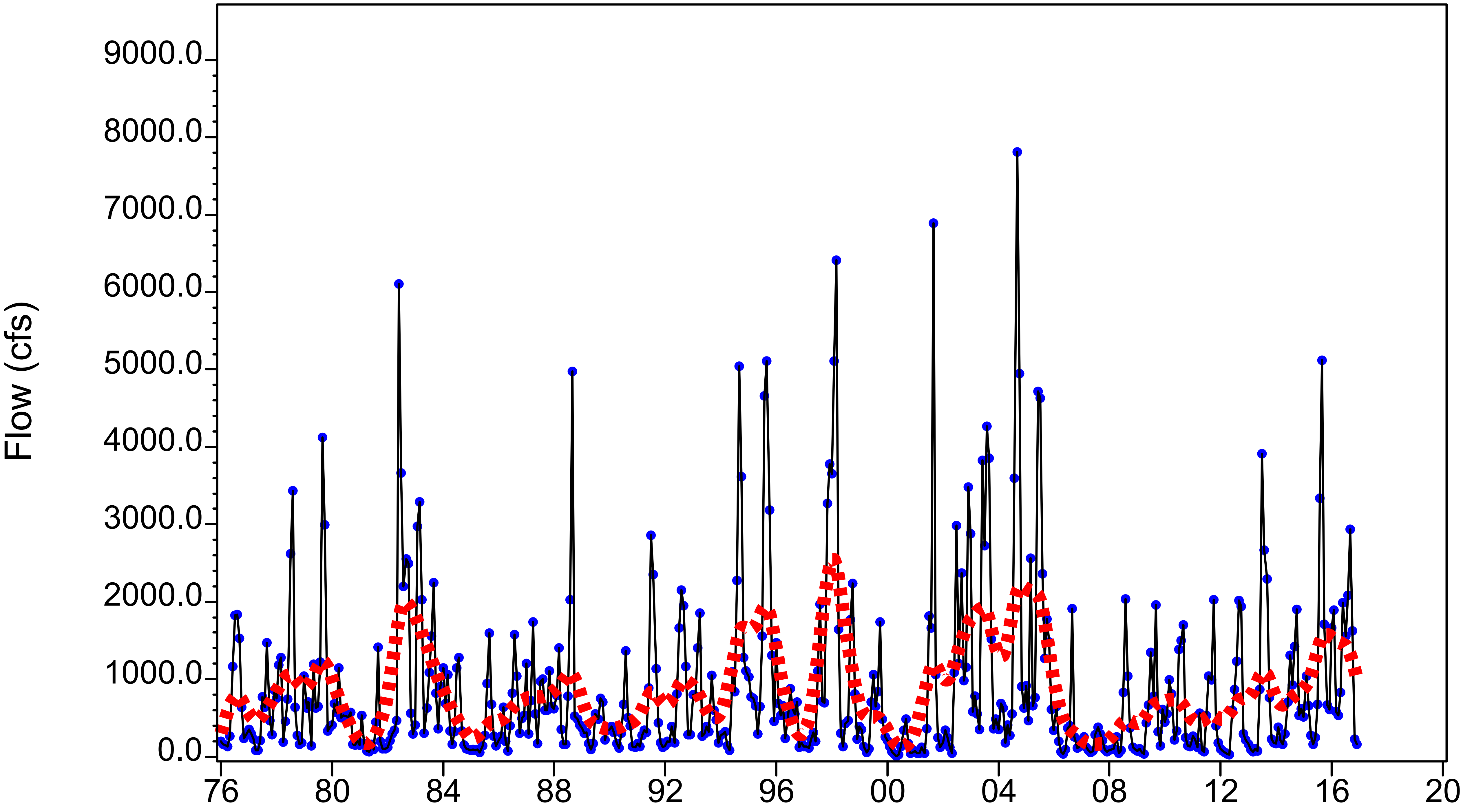


Figure 3.258 Monthly mean flow at long-term Peace River at Arcadia (2296750) gage (1976-2016)

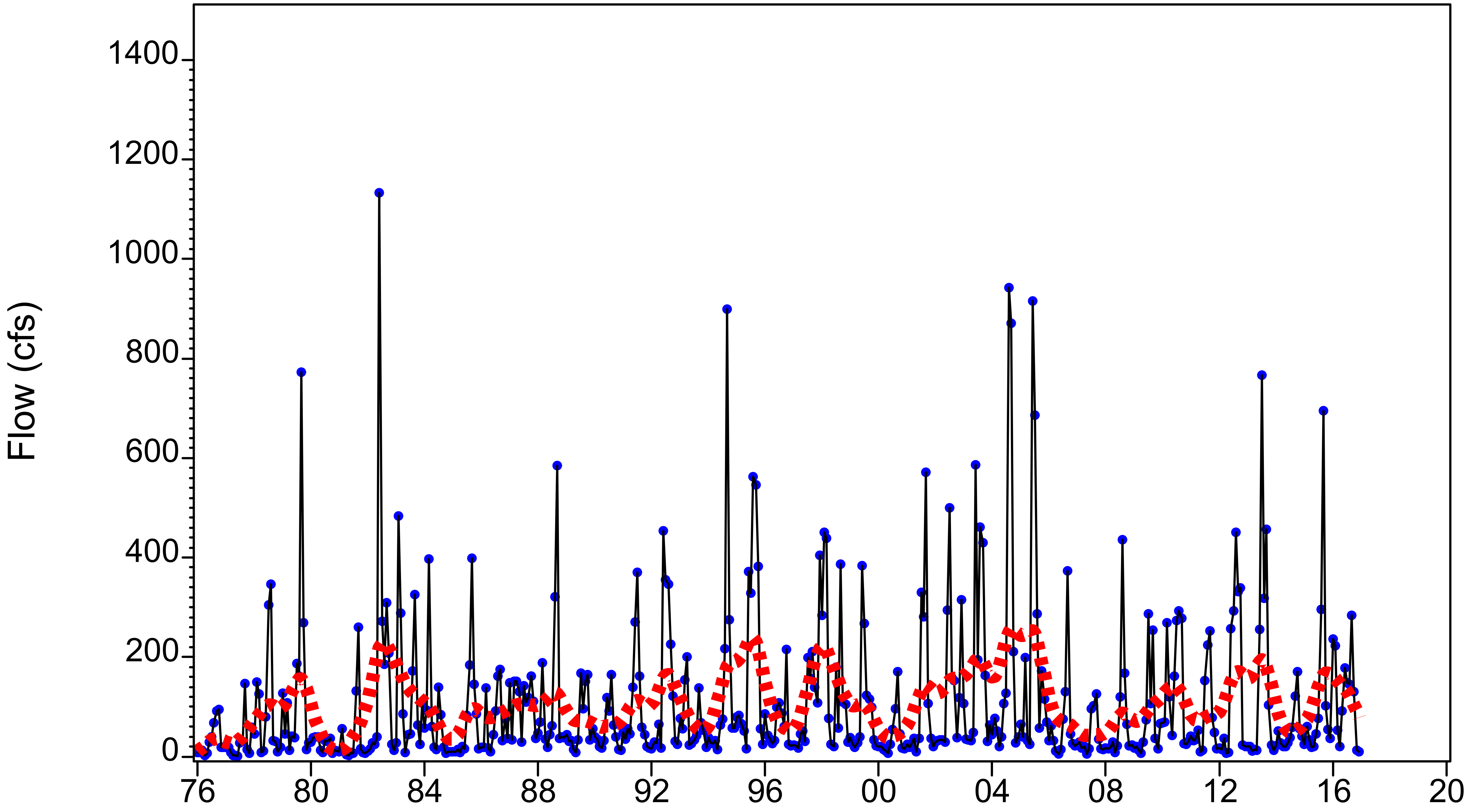


Figure 3.259 Monthly mean flow at long-term Joshua Creek at Nocatee (2297100) gage (1976-2016)

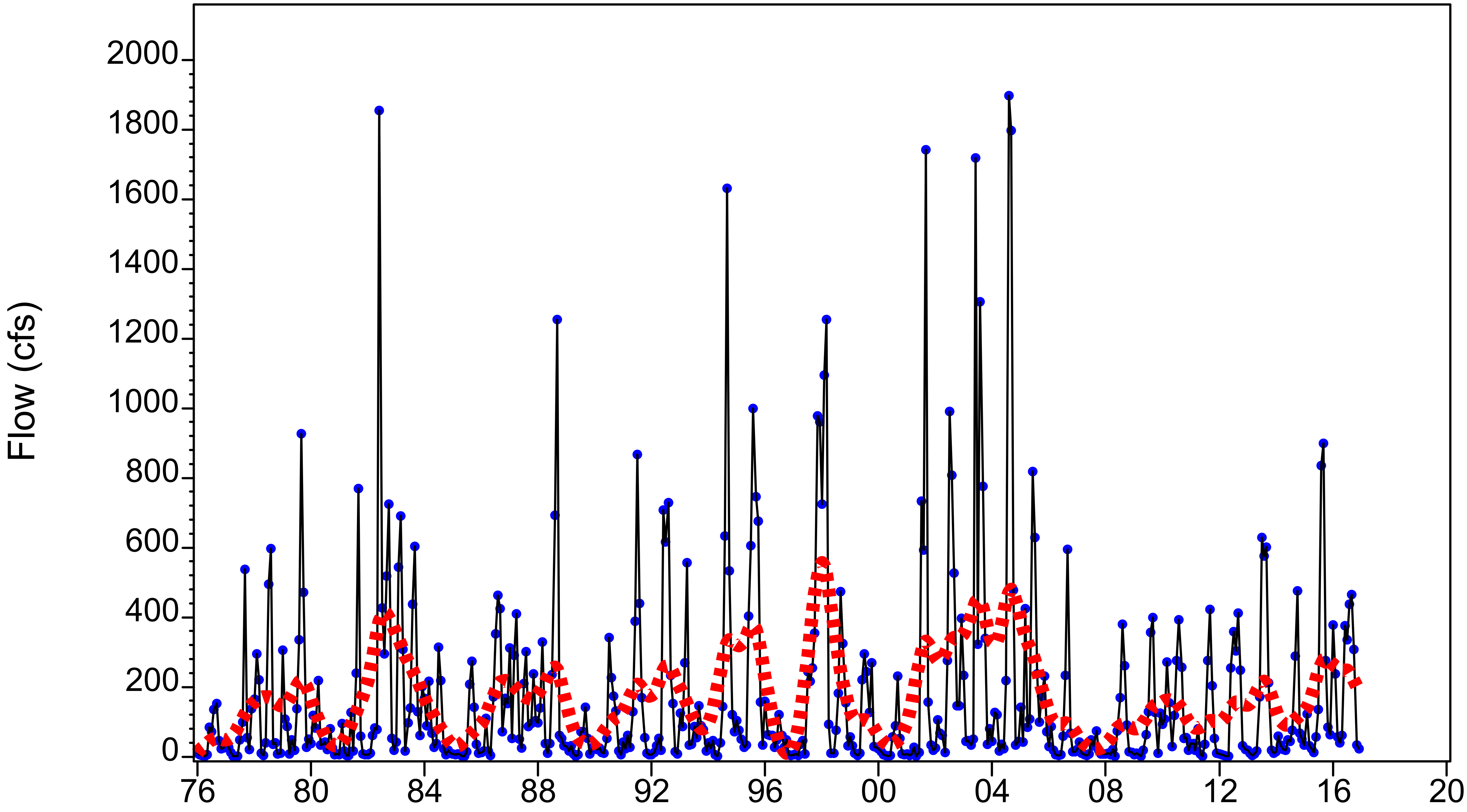


Figure 3.260 Monthly mean flow at long-term Horse Creek near Arcadia (2297310) gage (1976-2016)

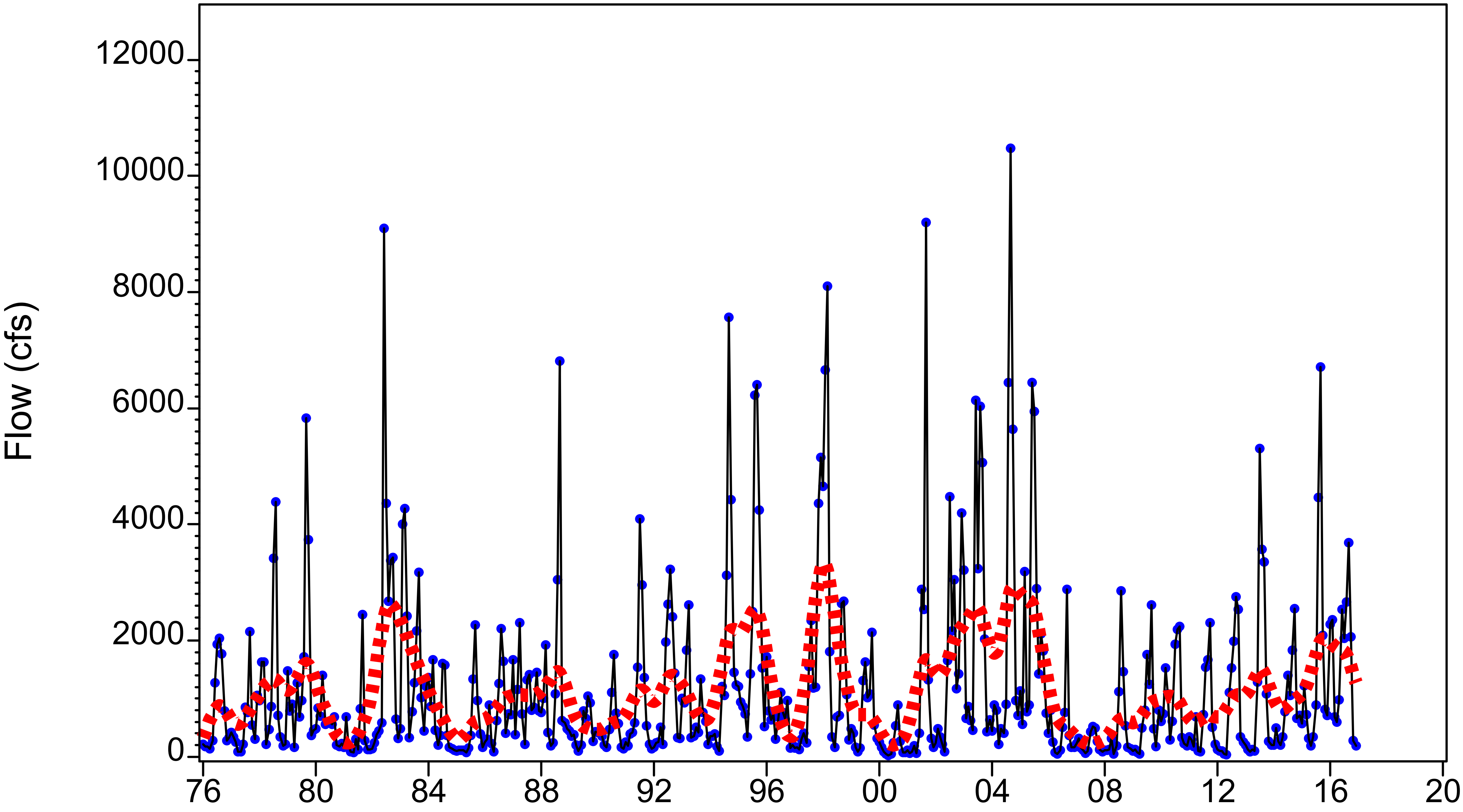


Figure 3.261 Monthly mean flow at long-term for total gaged flow upstream of the Facility (1976-2016)

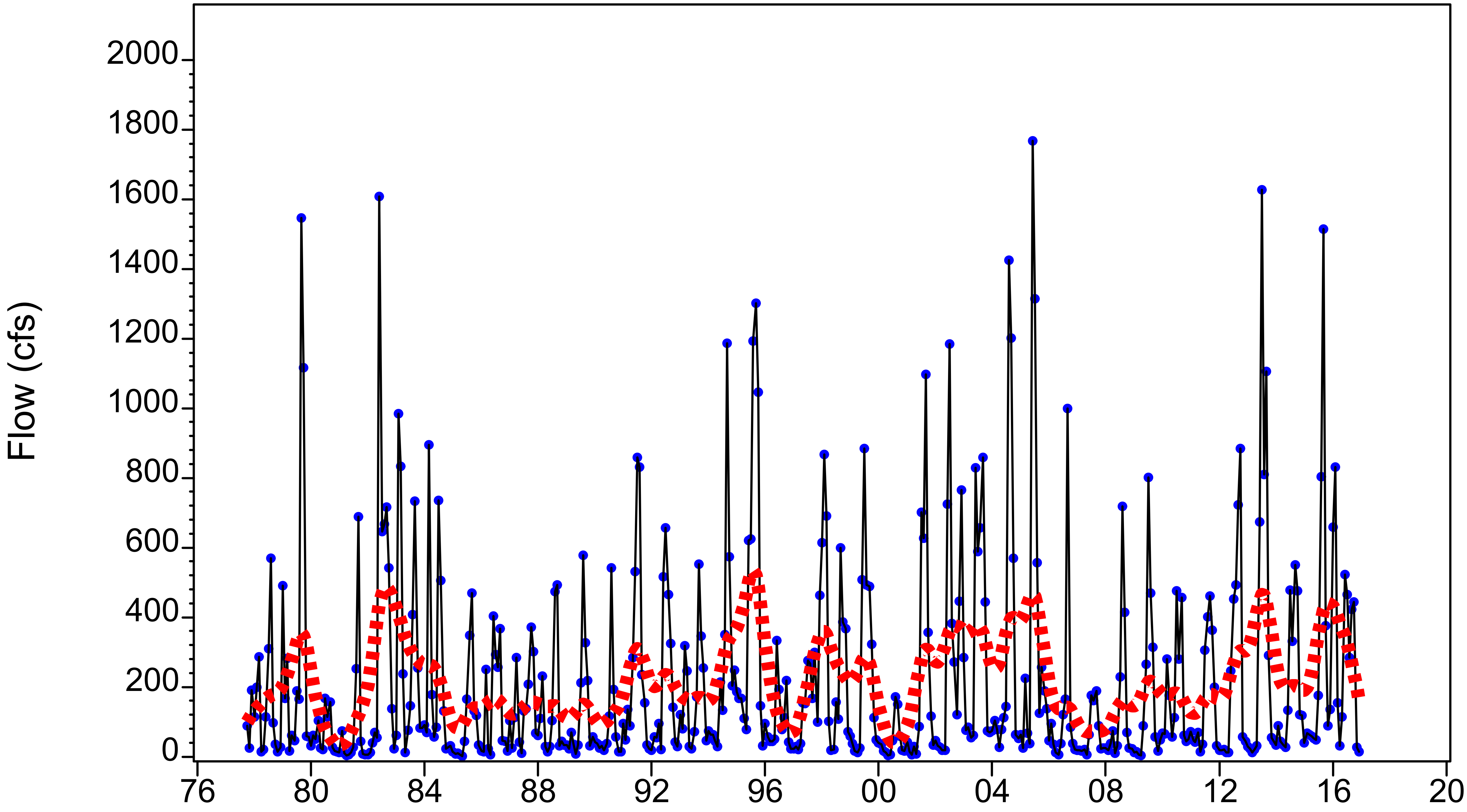


Figure 3.262 Monthly mean flow at long-term Prairie Creek (2298123) gage (1976-2016)

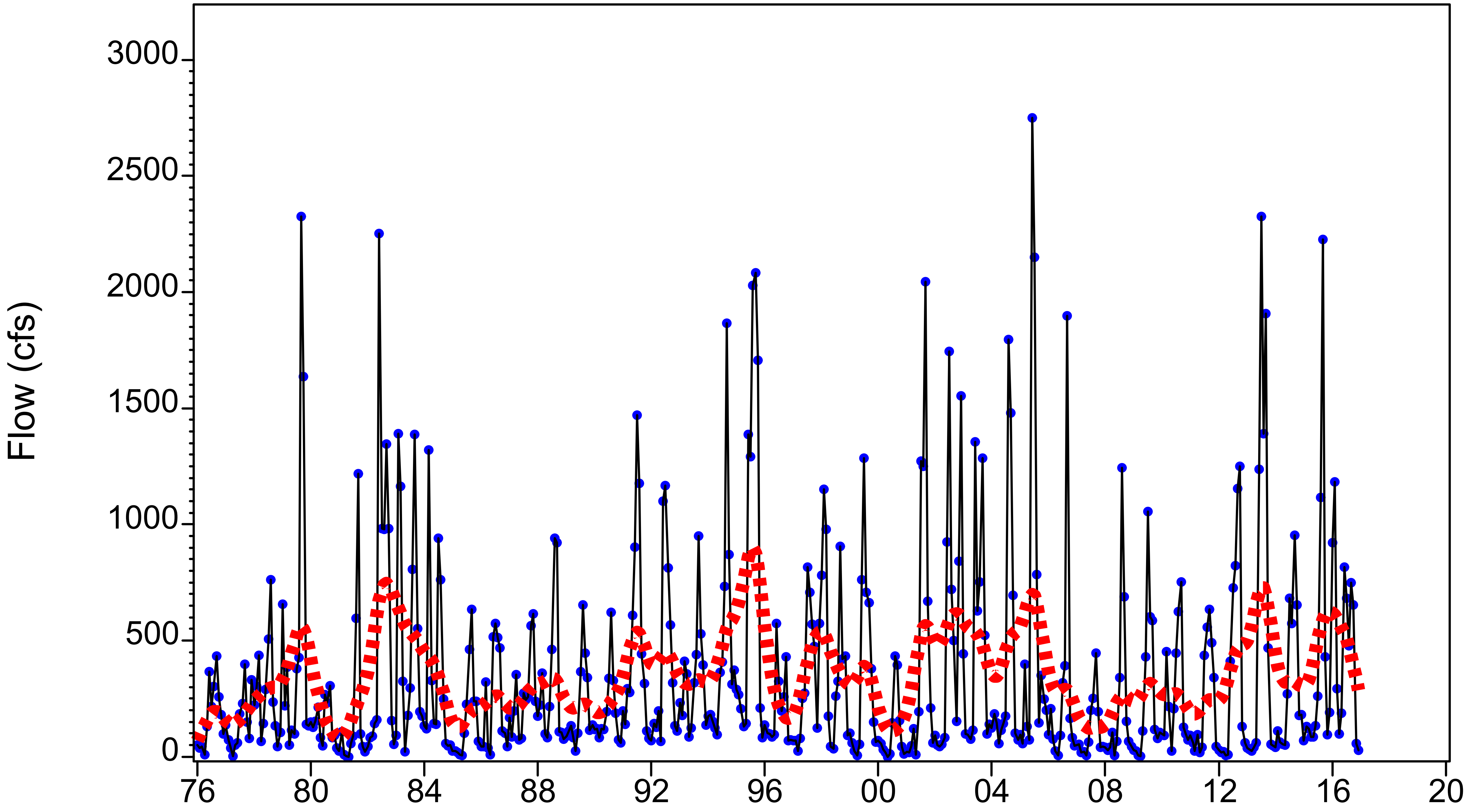


Figure 3.263 Monthly mean flow at long-term Shell Creek gage (1976-2016)

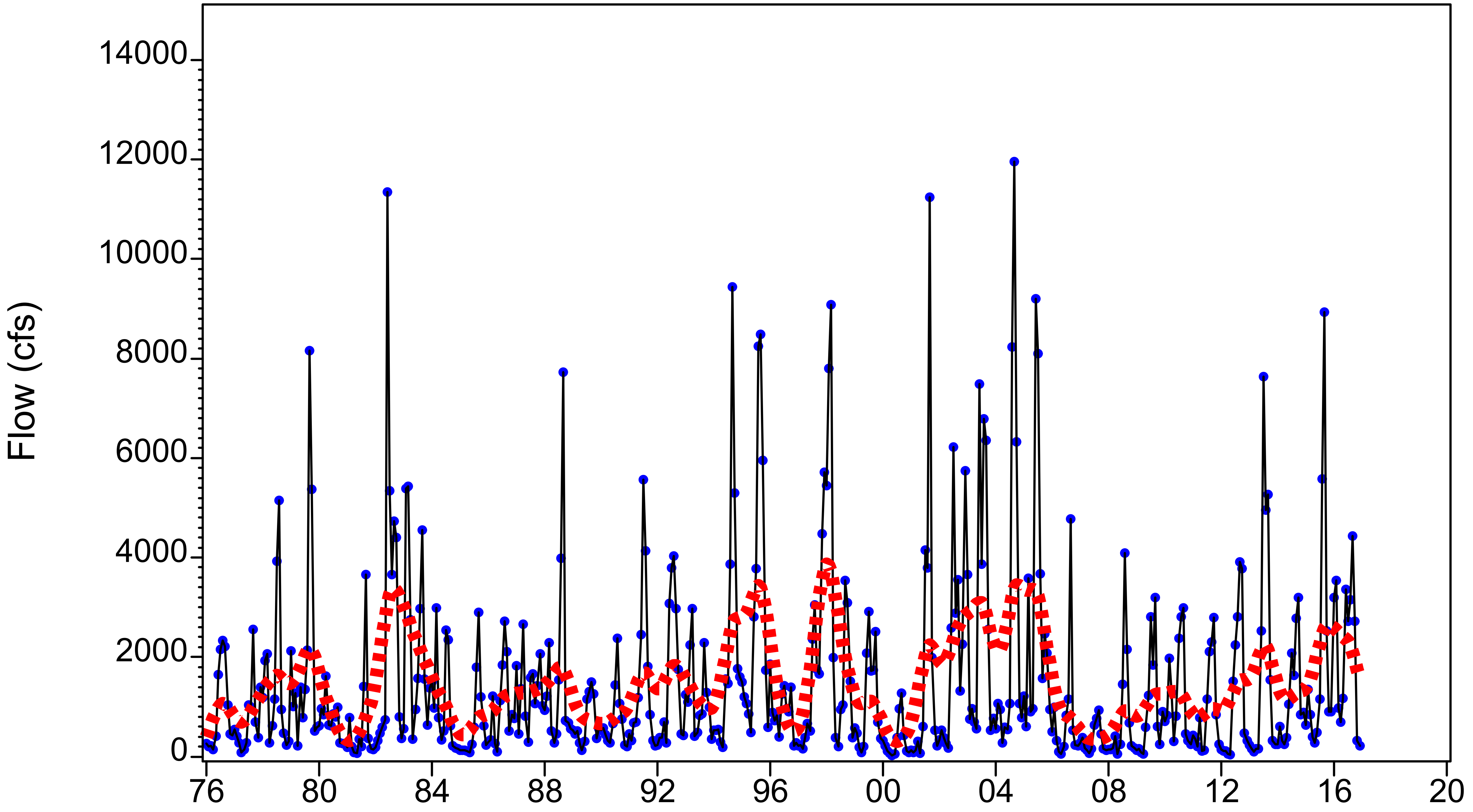


Figure 3.264 Monthly mean flow of total gaged Peace River flow to the Upper Harbor (1976-2016)

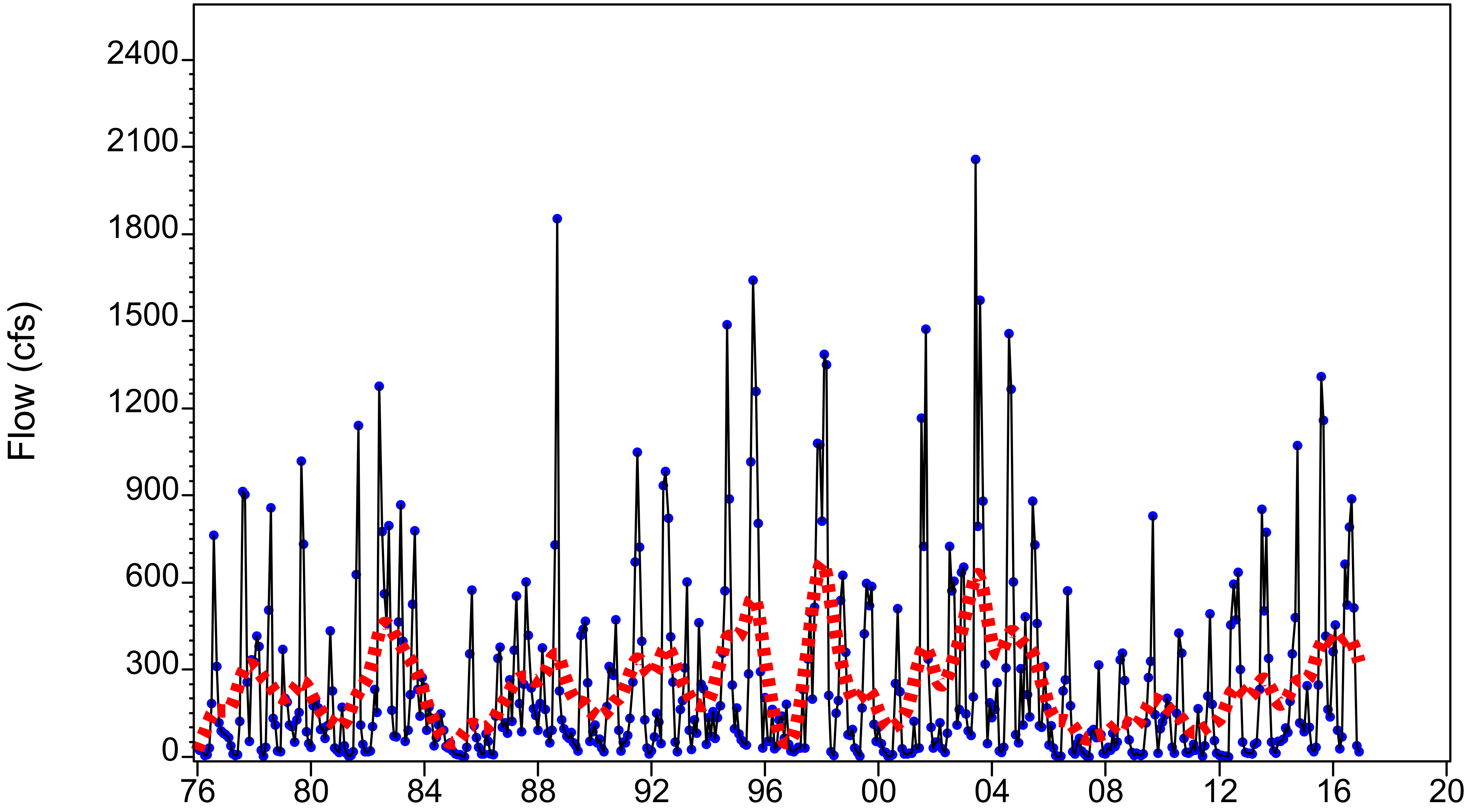


Figure 3.265 Monthly mean flow at long-term Myakka River near Sarasota (2298830) gage (1976-2016)

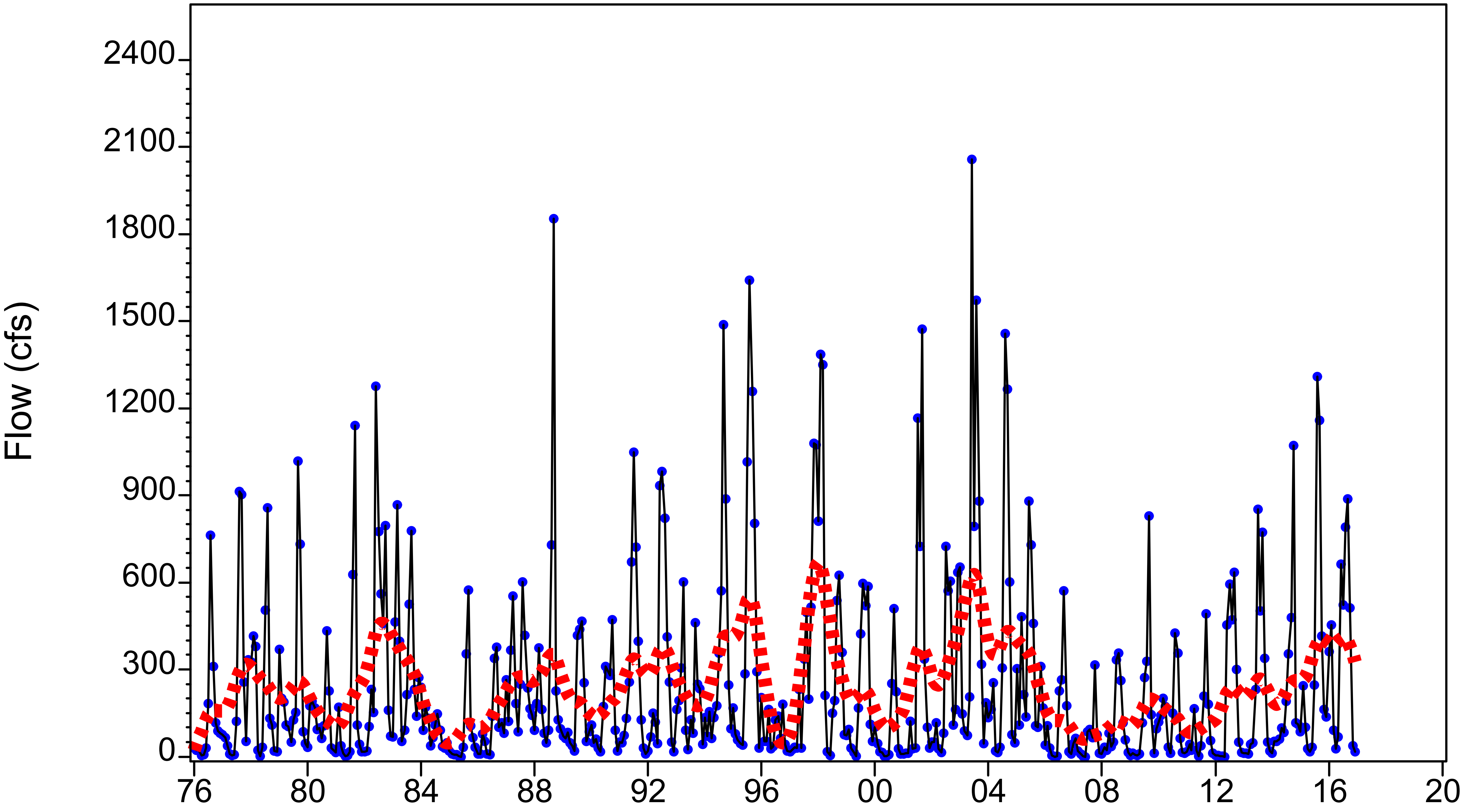


Figure 3.265 Monthly mean flow at long-term Myakka River near Sarasota (2298830) gage (1976-2016)

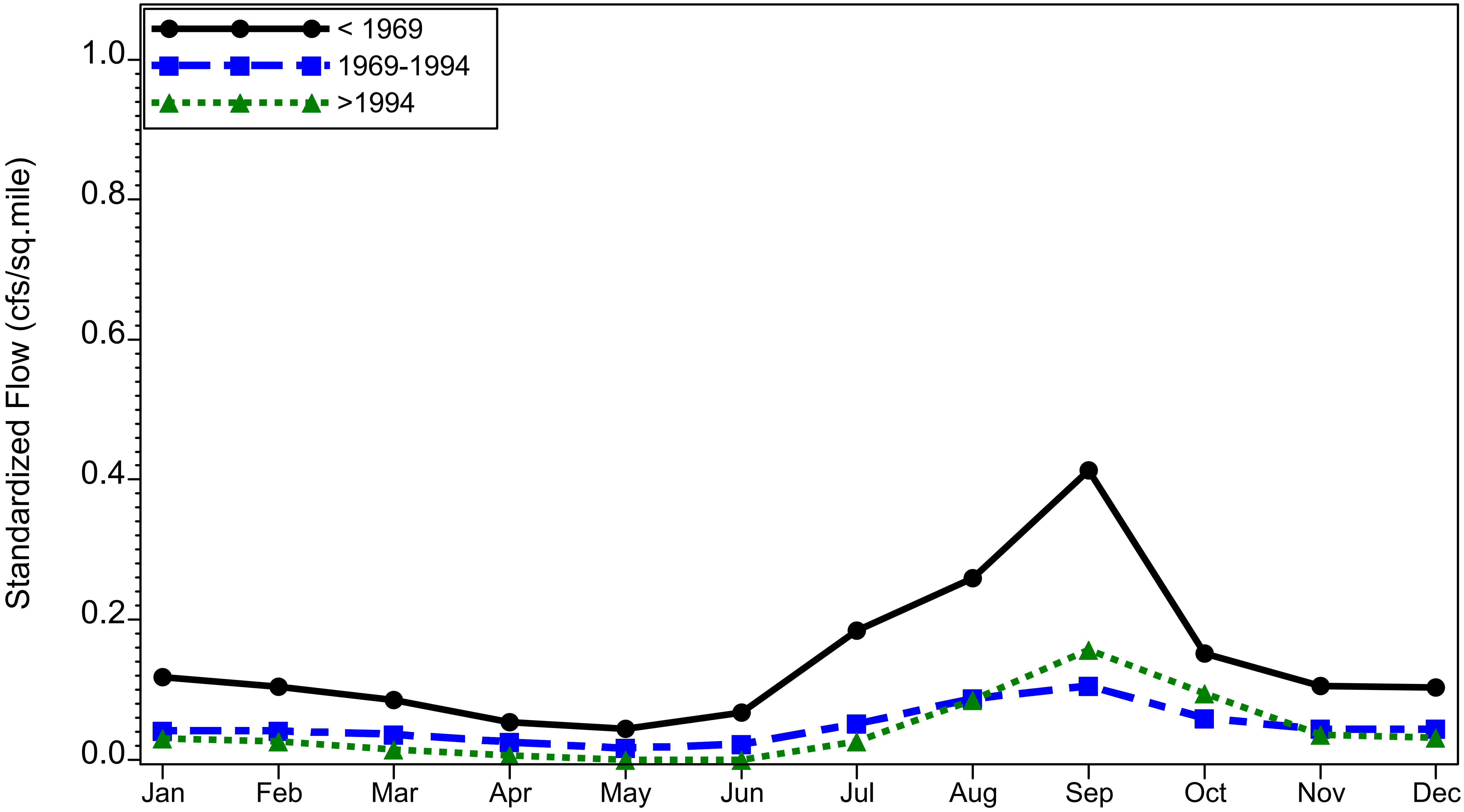


Figure 3.266 Seasonal differences among AMO periods of monthly P10 flow at long-term Peace River at Bartow (2294650) gage

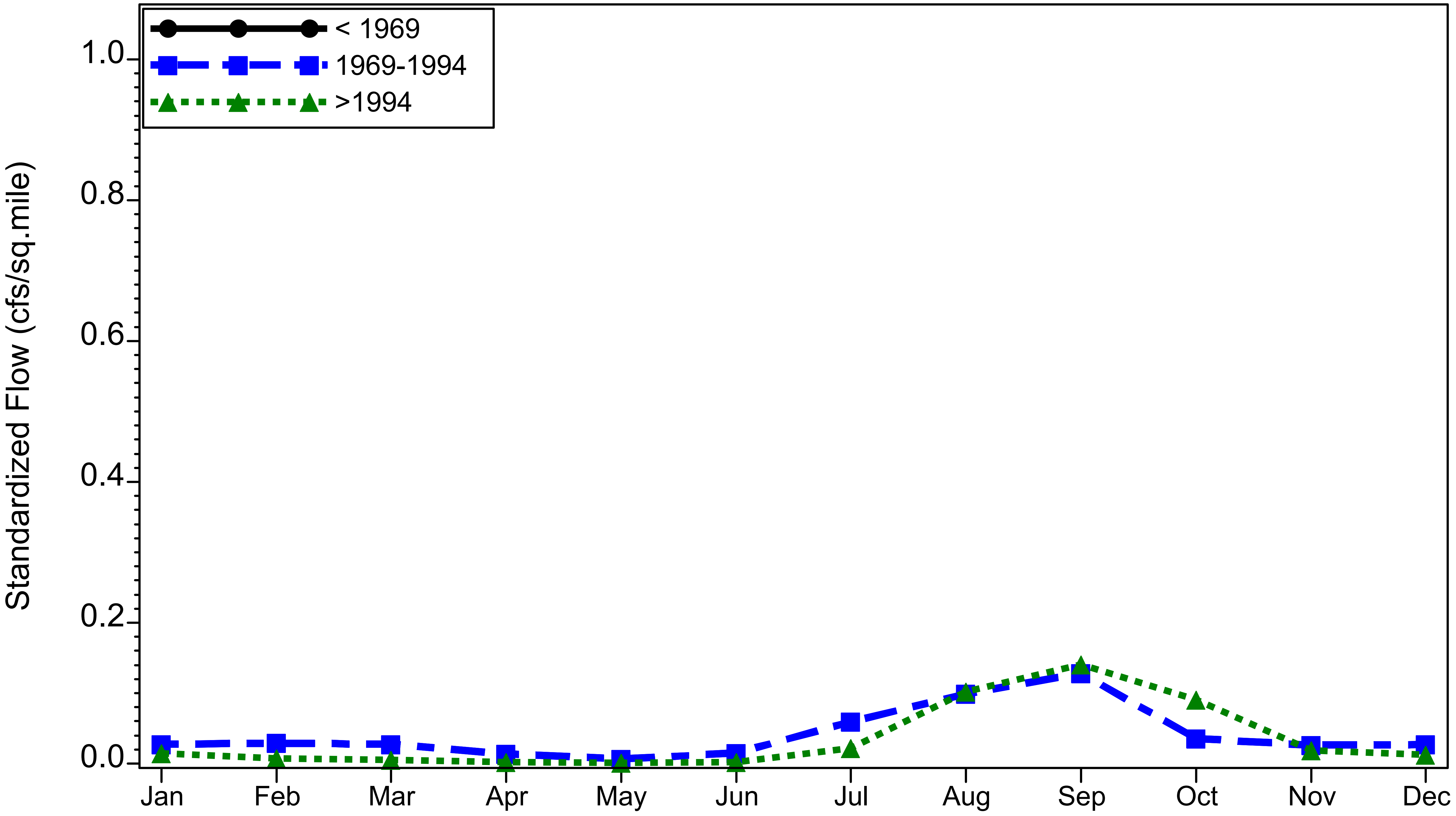


Figure 3.267 Seasonal differences among AMO periods of monthly P10 flow at long-term Peace River at Ft. Meade (2294898) gage

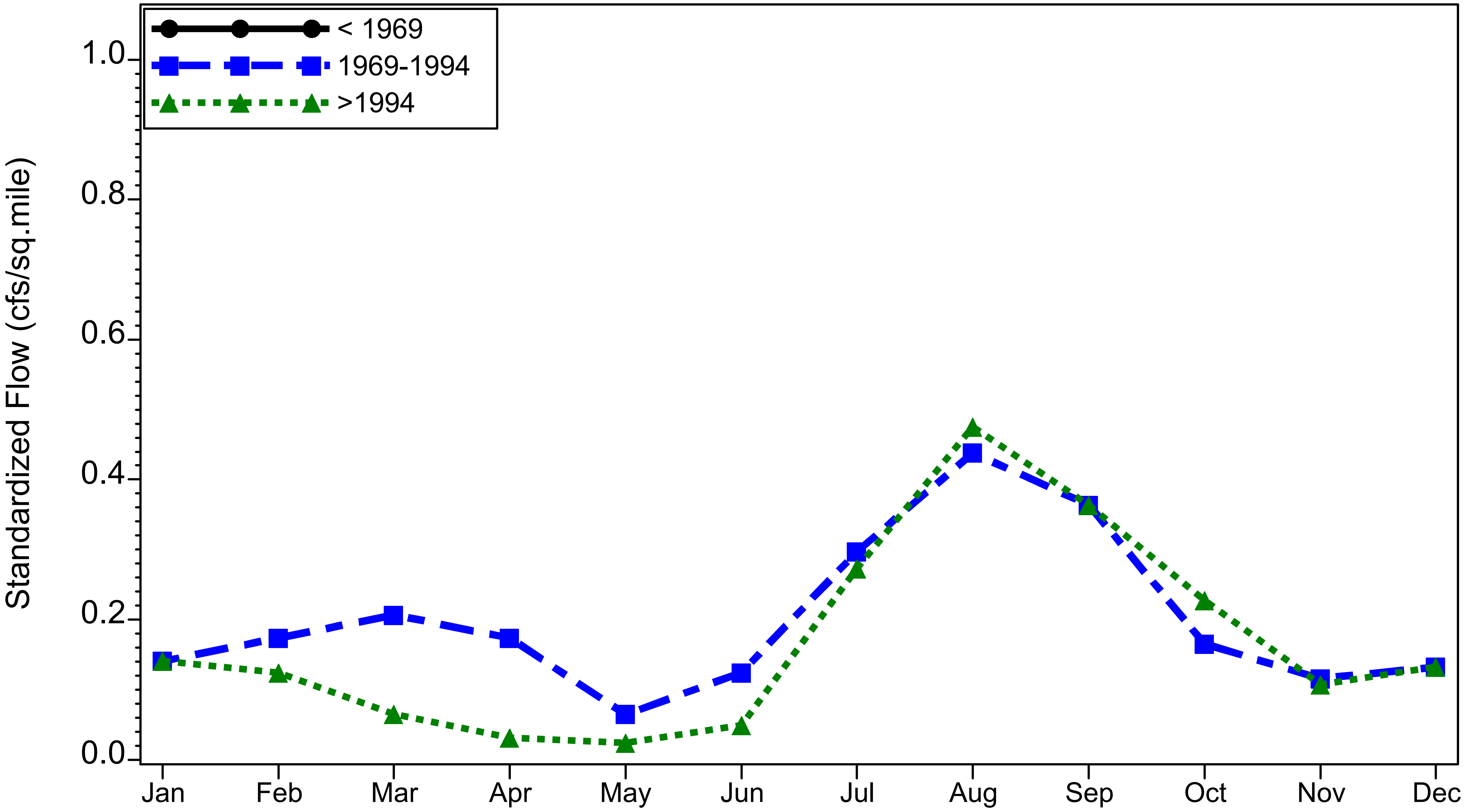


Figure 3.268 Seasonal differences among AMO periods of monthly P10 flow at long-term Payne Creek (2295420) gage

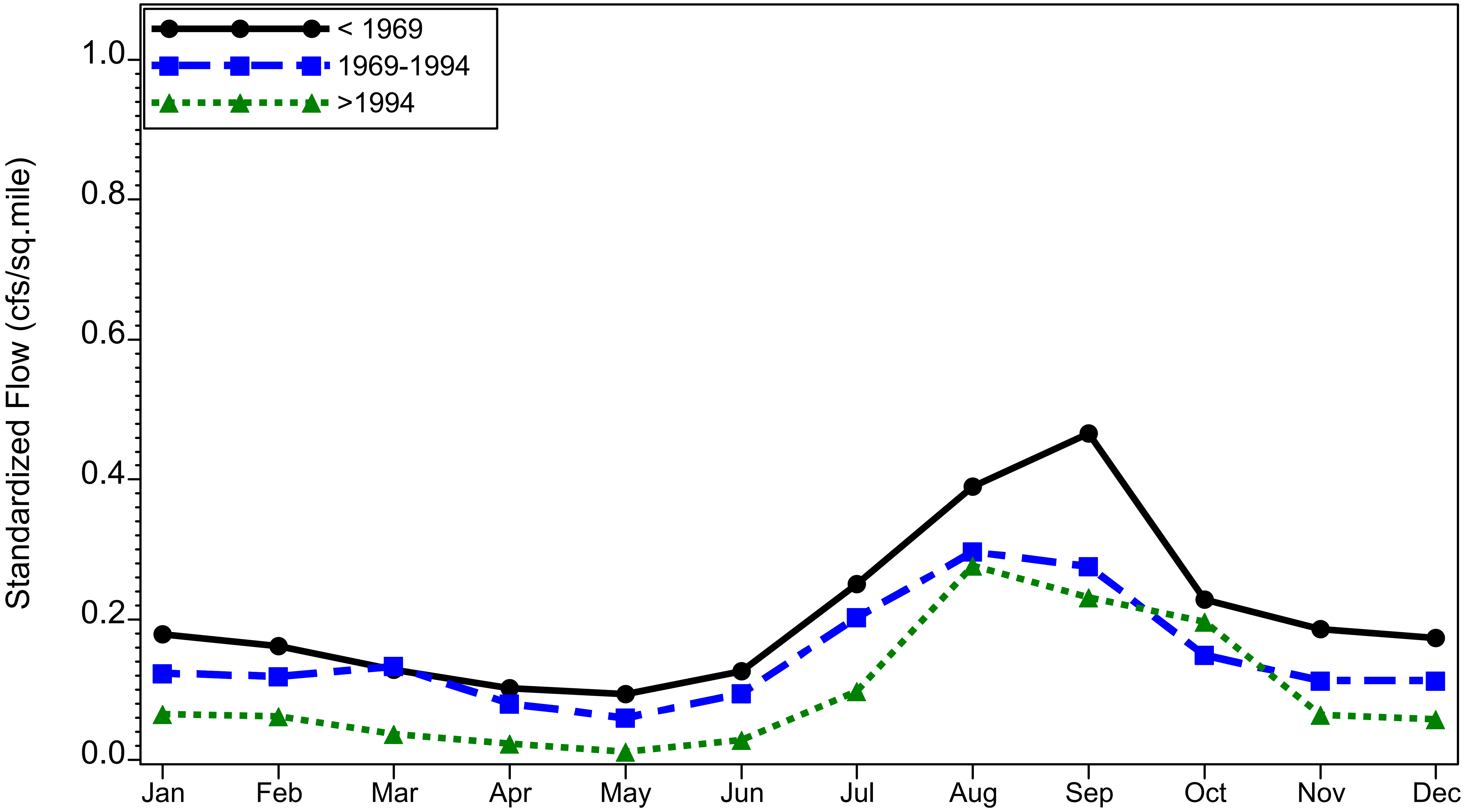


Figure 3.269 Seasonal differences among AMO periods of monthly P10 flow at long-term Peace River at Zolfo (2295637) gage

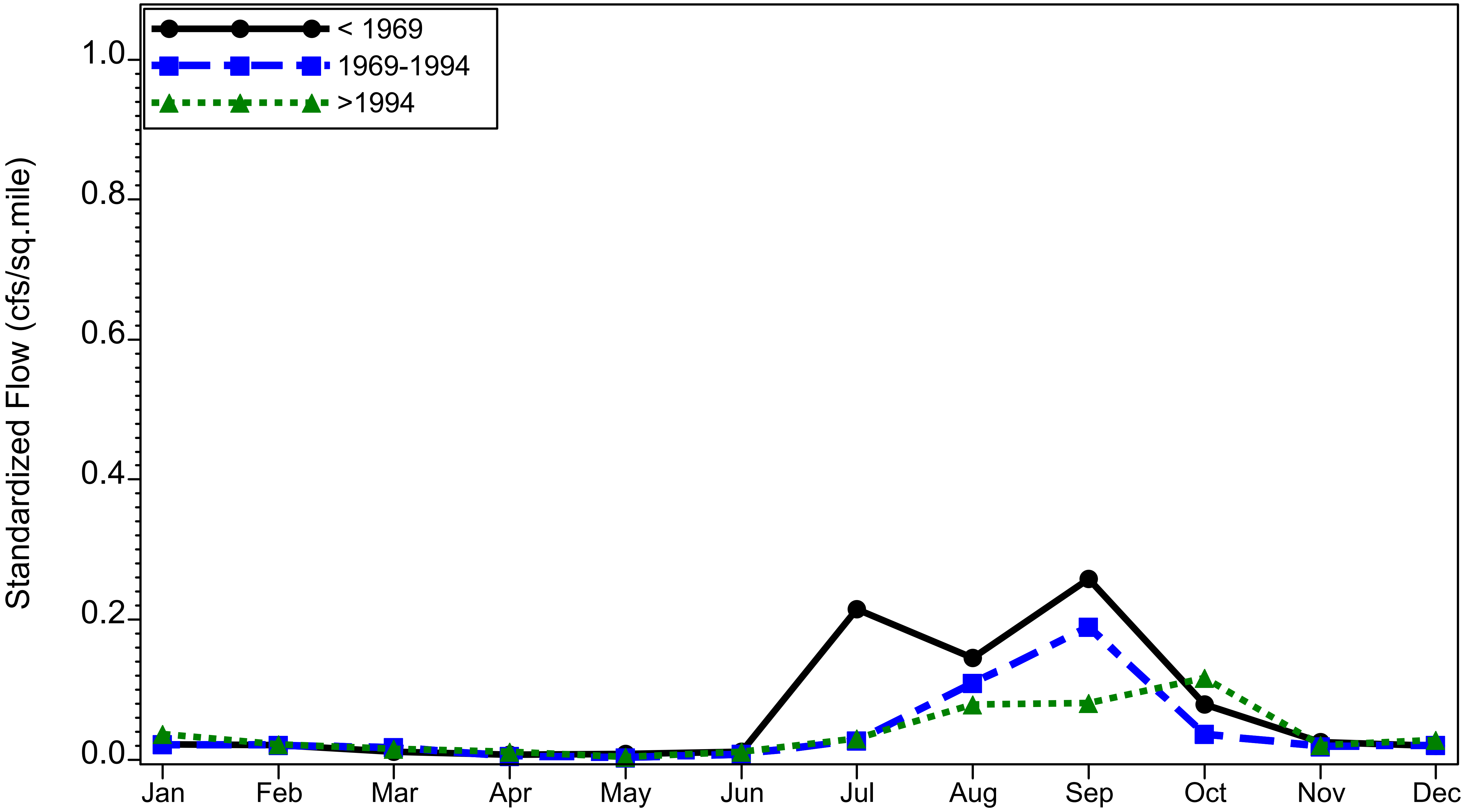


Figure 3.270 Seasonal differences among AMO periods of monthly P10 flow at long-term Charlie Creek (2296500) gage

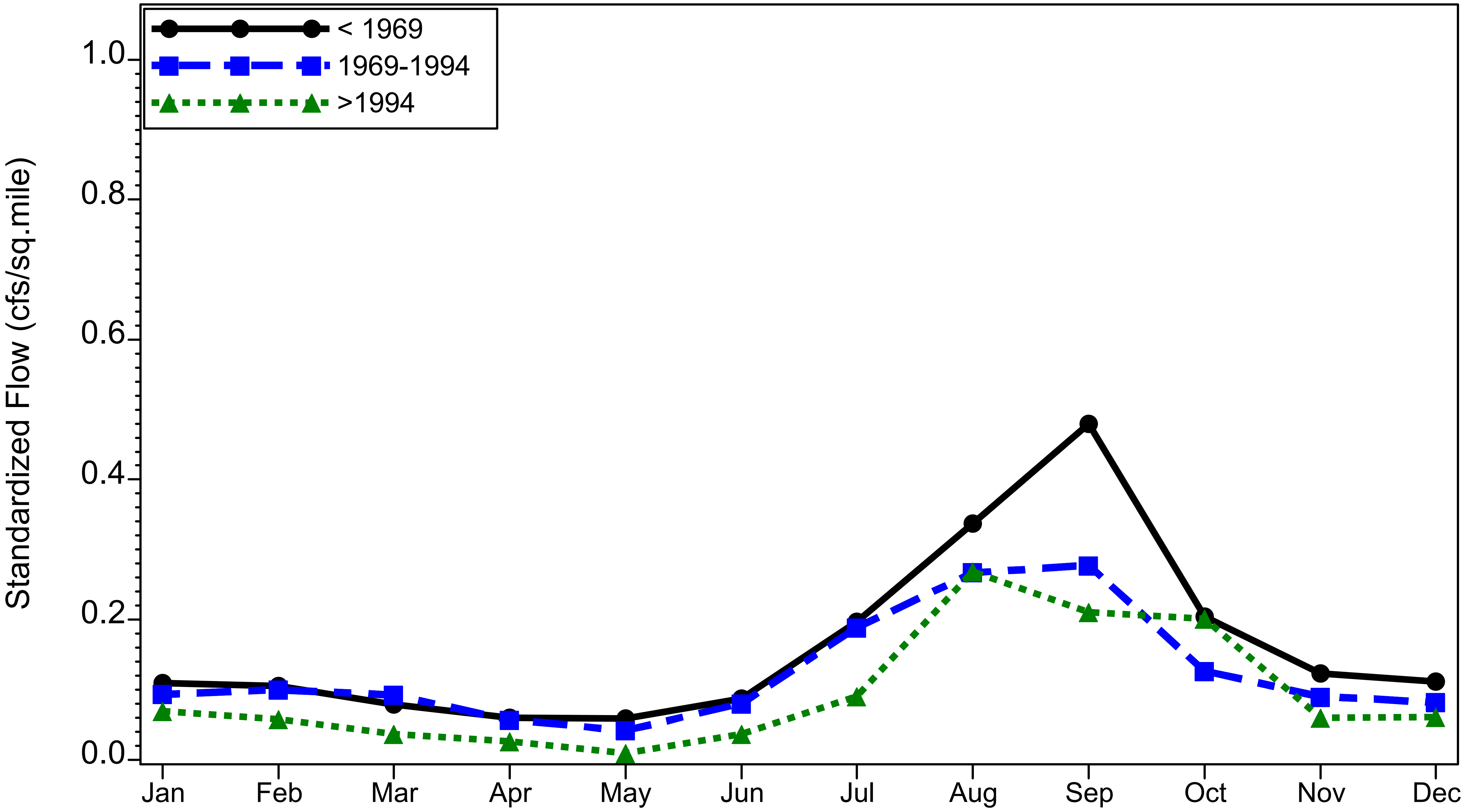


Figure 3.271 Seasonal differences among AMO periods of monthly P10 flow at long-term Peace River at Arcadia (2296750) gage

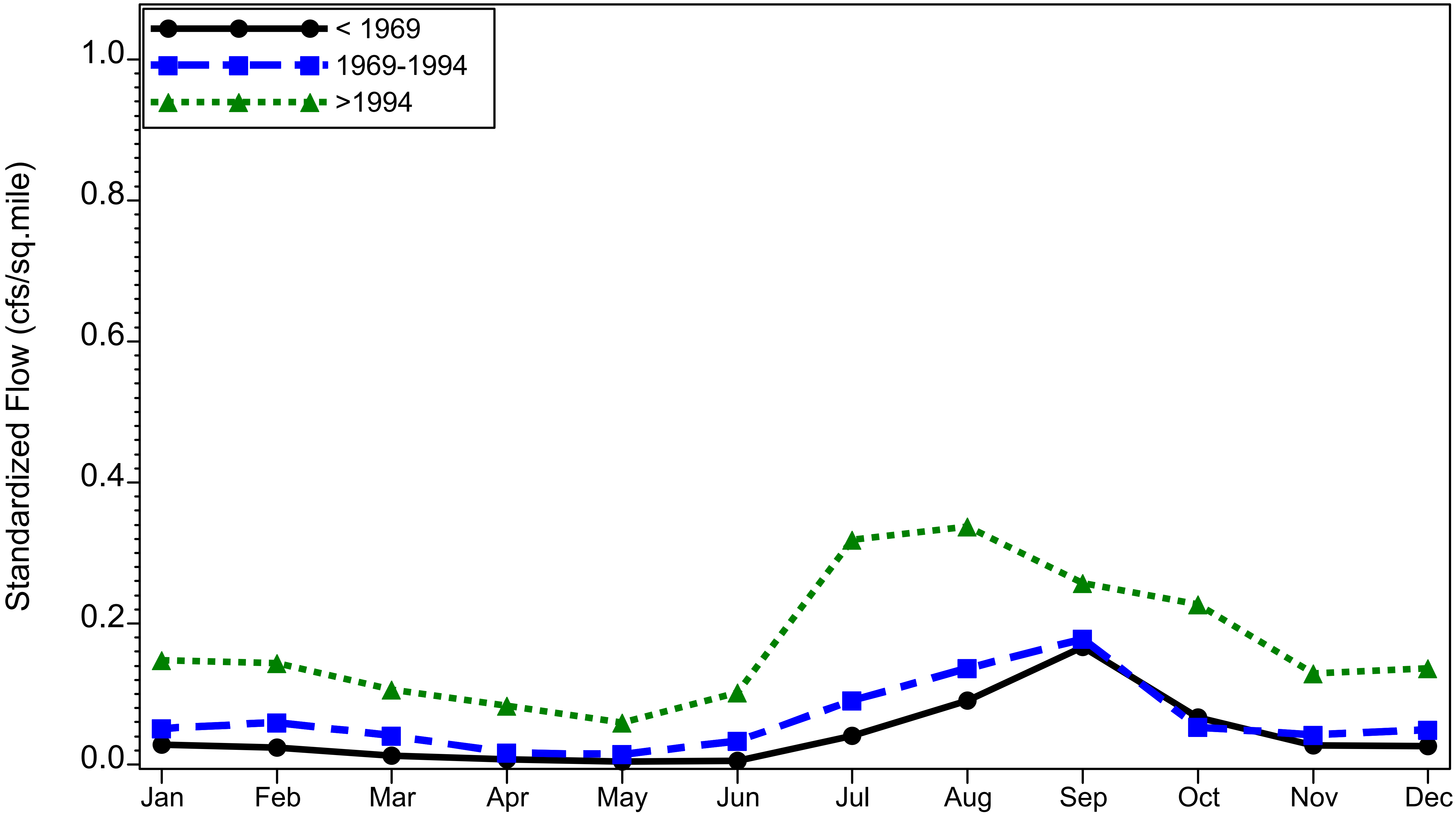


Figure 3.272 Seasonal differences among AMO periods of monthly P10 flow at long-term Joshua Creek at Nocatee (2297100) gage

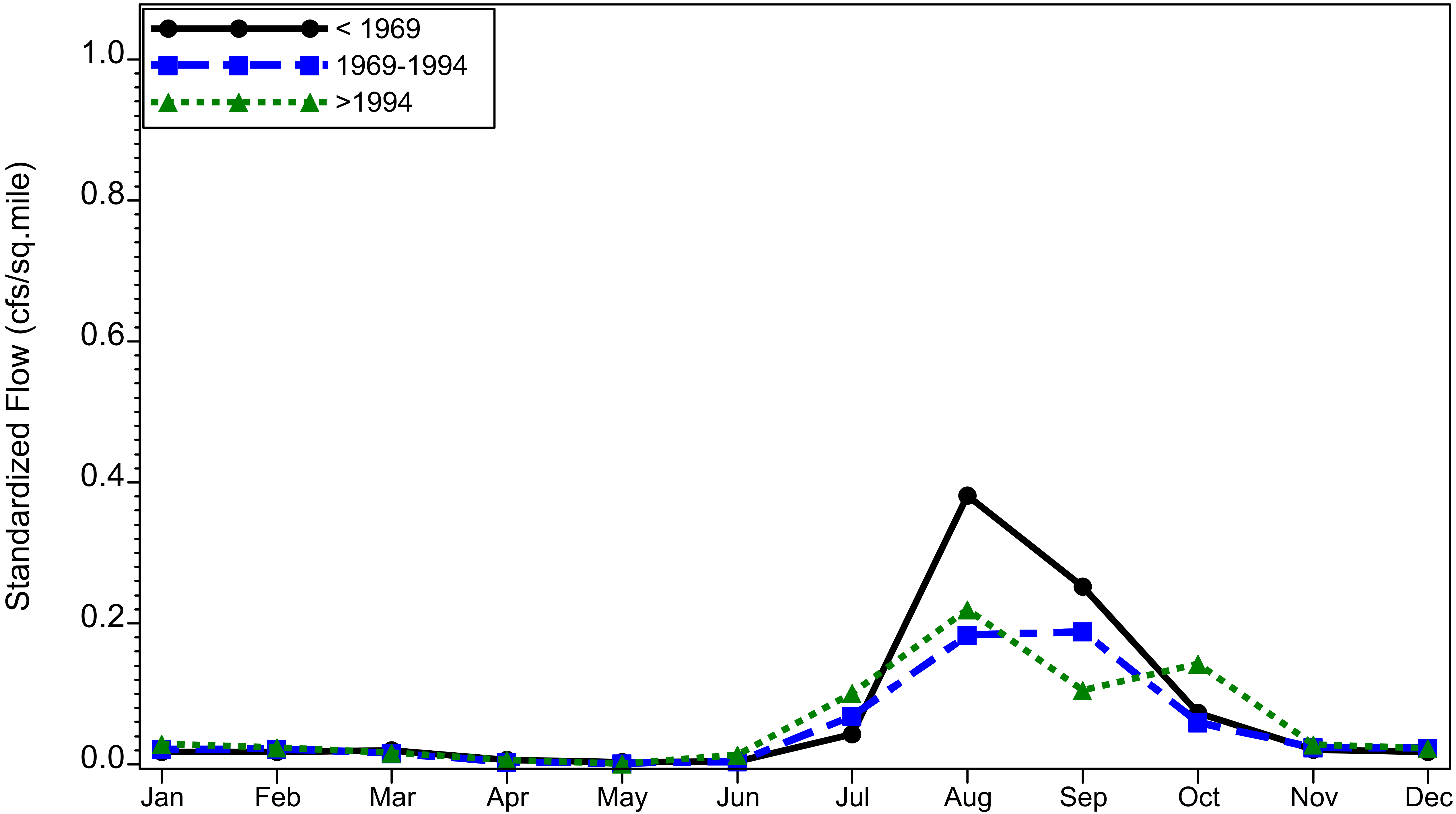


Figure 3.273 Seasonal differences among AMO periods of monthly P10 flow at long-term Horse Creek near Arcadia(2297310) gage

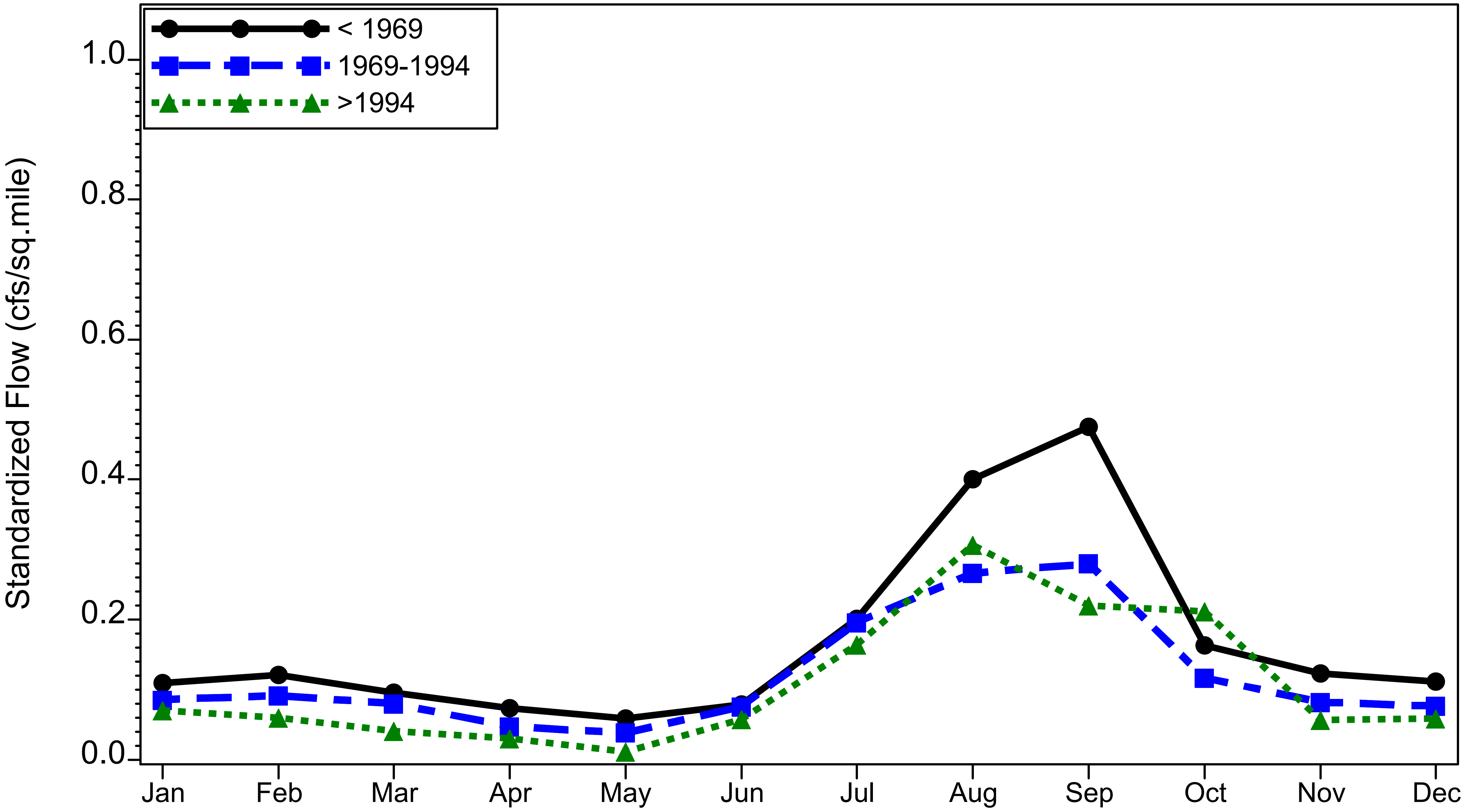


Figure 3.274 Seasonal differences among AMO periods of monthly P10 total gaged flow upstream of the Facility

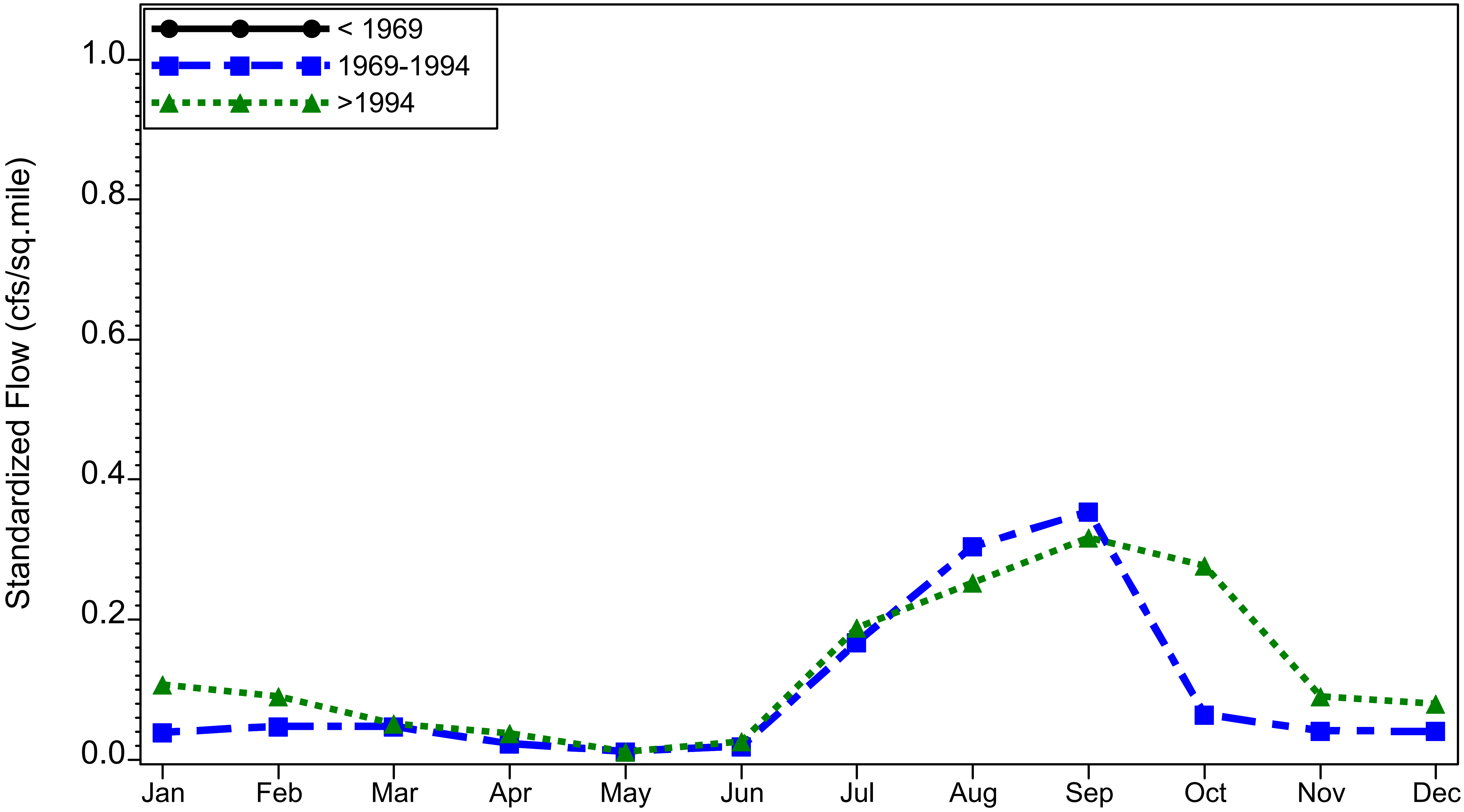


Figure 3.275 Seasonal differences among AMO periods of monthly P10 flow at long-term Prairie Creek (2298123) gage

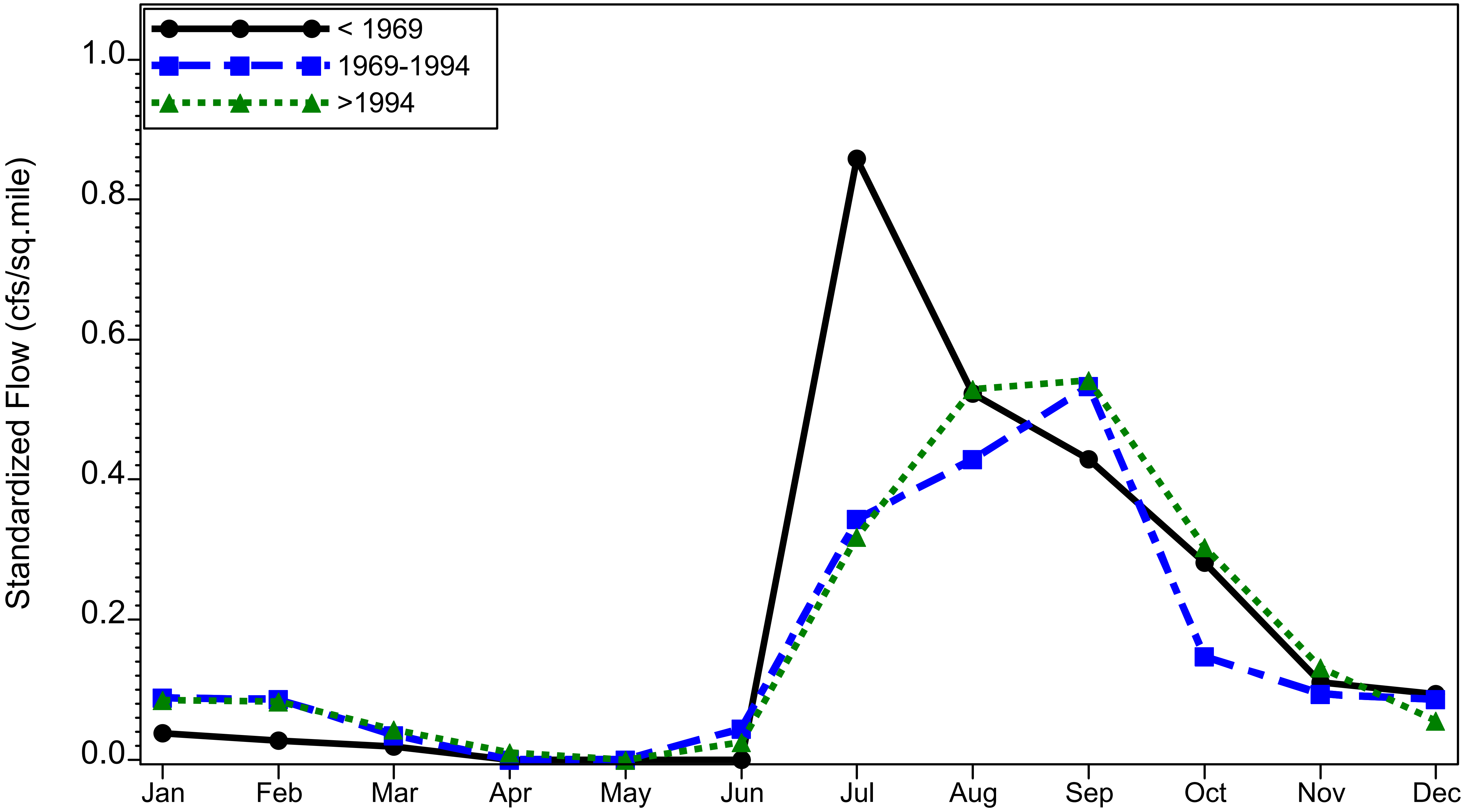


Figure 3.276 Seasonal differences among AMO periods of monthly P10 flow at long-term Shell Creek gage

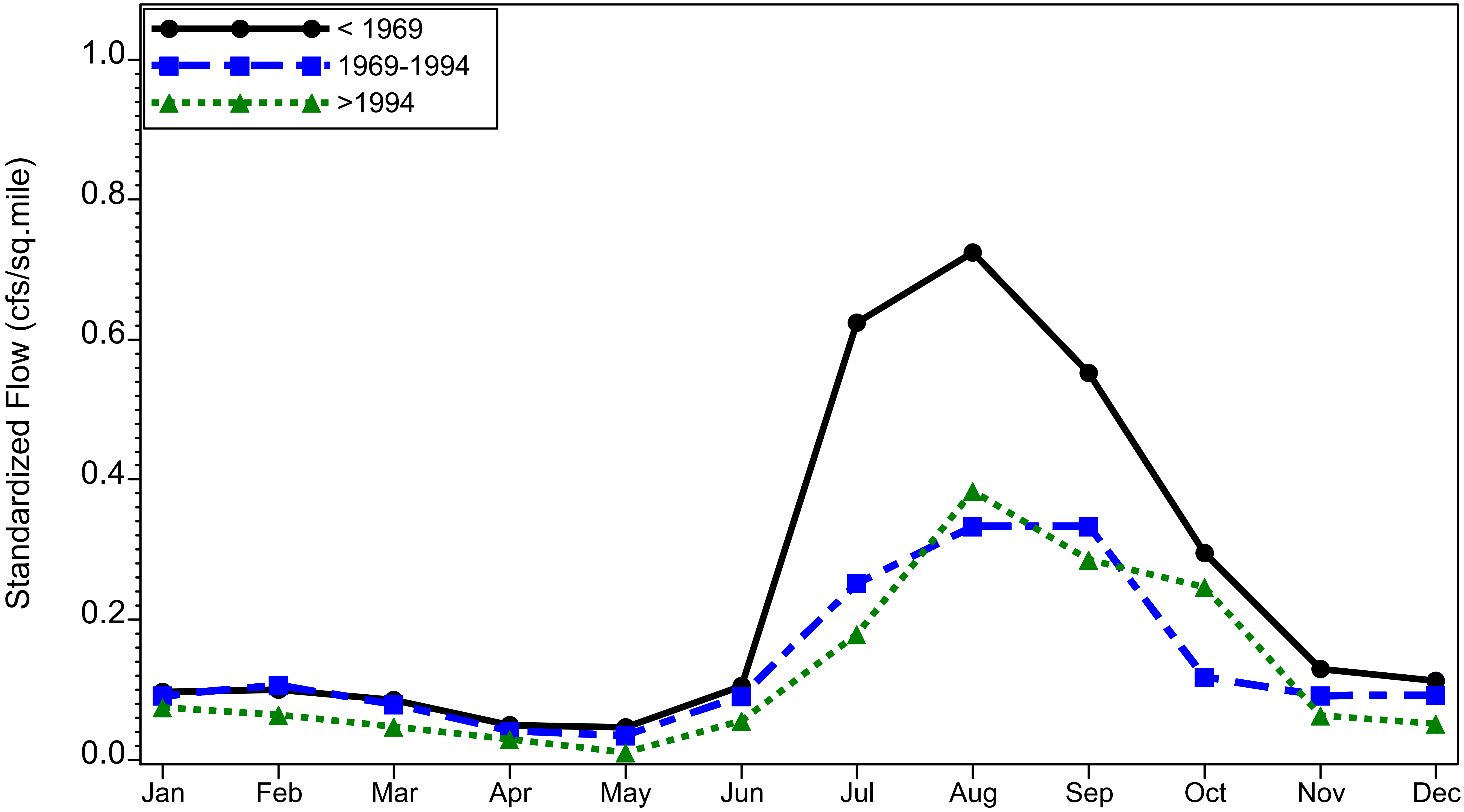


Figure 3.277 Seasonal differences among AMO periods of monthly P10 total gaged flow to the Upper Harbor

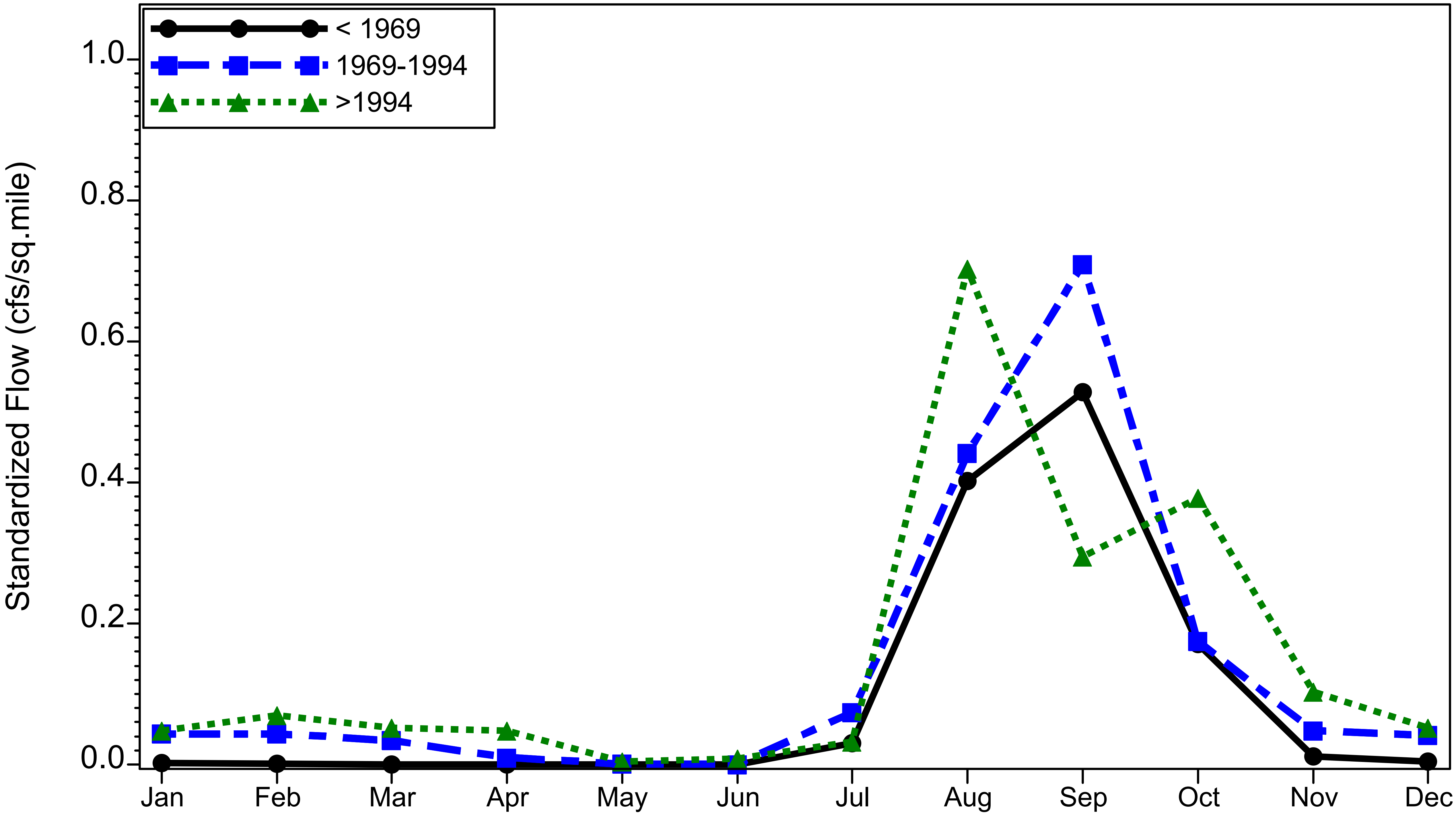


Figure 3.278 Seasonal differences among AMO periods of monthly P10 flow at long-term Myakka River near Sarasota (2298830) gage

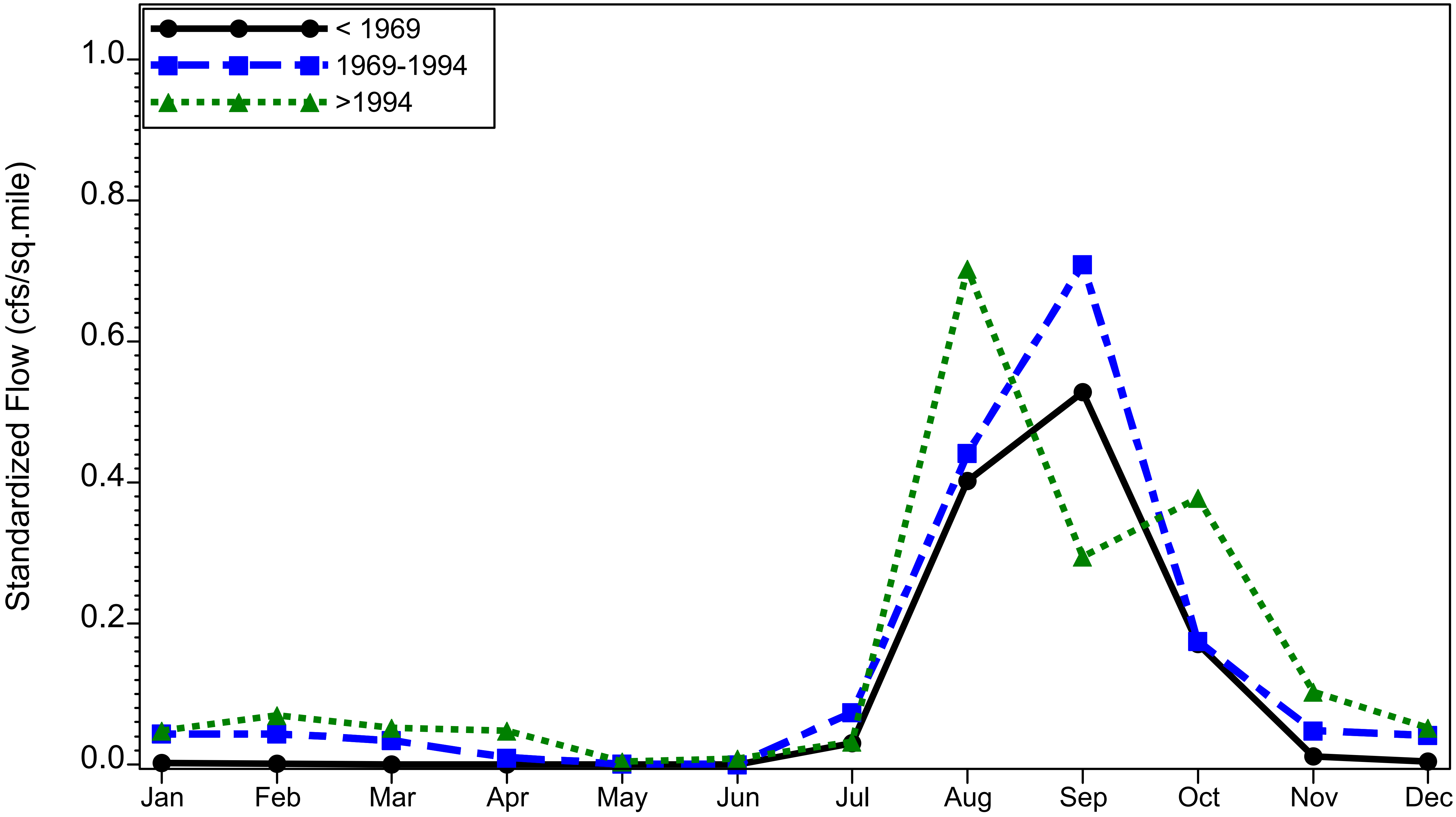


Figure 3.278 Seasonal differences among AMO periods of monthly P10 flow at long-term Myakka River near Sarasota (2298830) gage

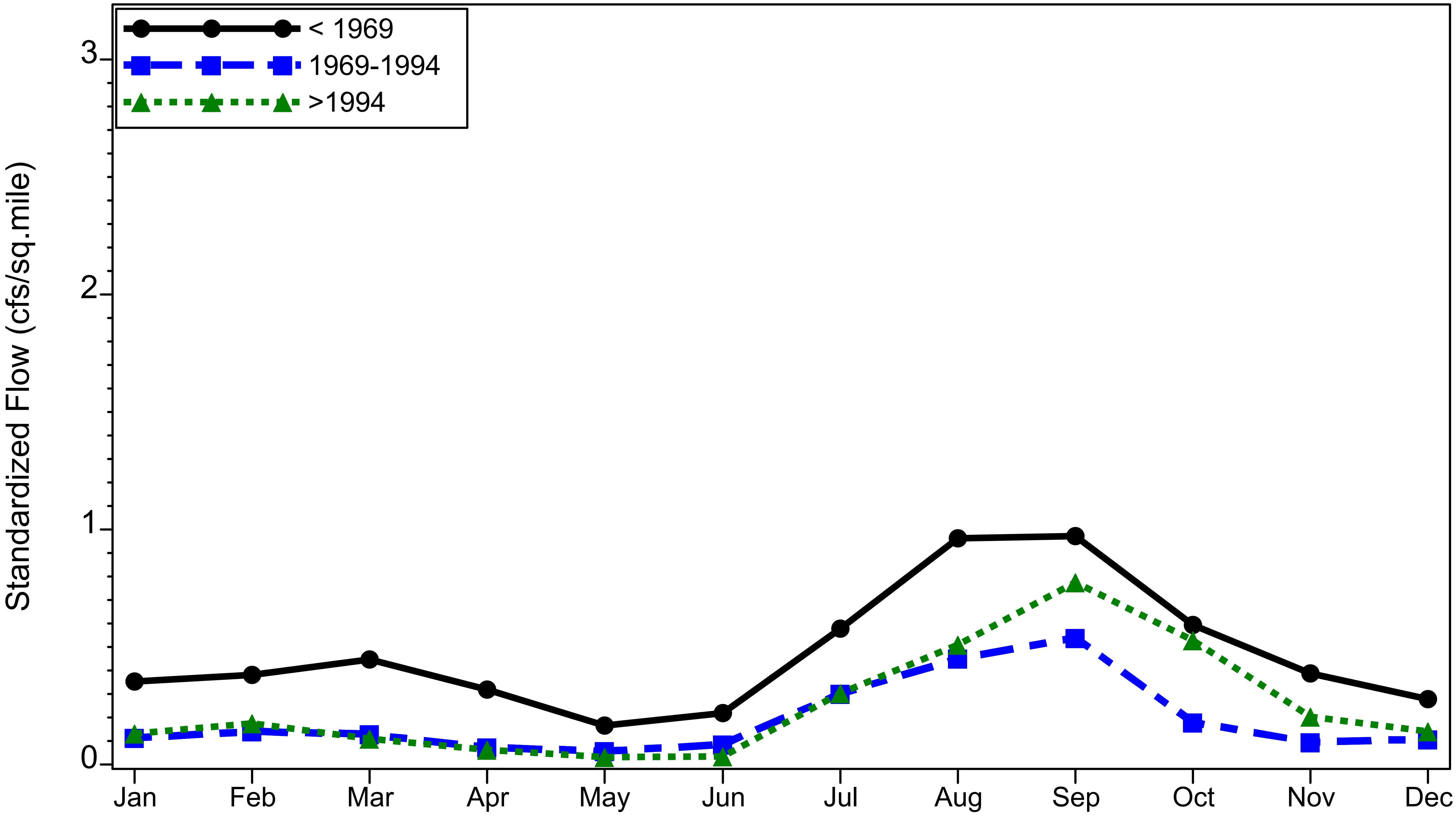


Figure 3.279 Seasonal differences among AMO periods of monthly median flow at long-term Peace River at Bartow (2294650) gage

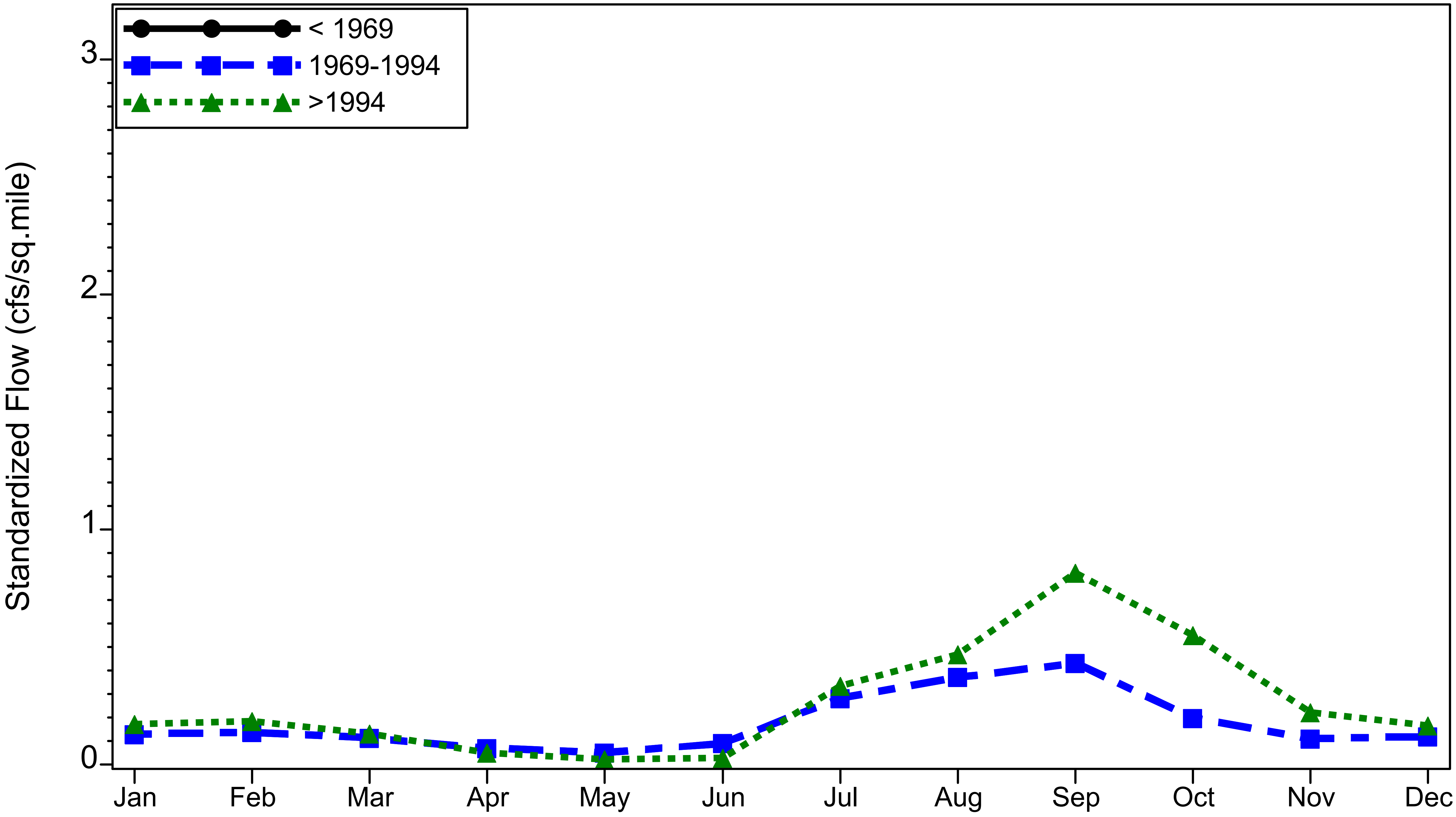


Figure 3.280 Seasonal differences among AMO periods of monthly median flow at long-term Peace River at Ft. Meade (2294898) gage

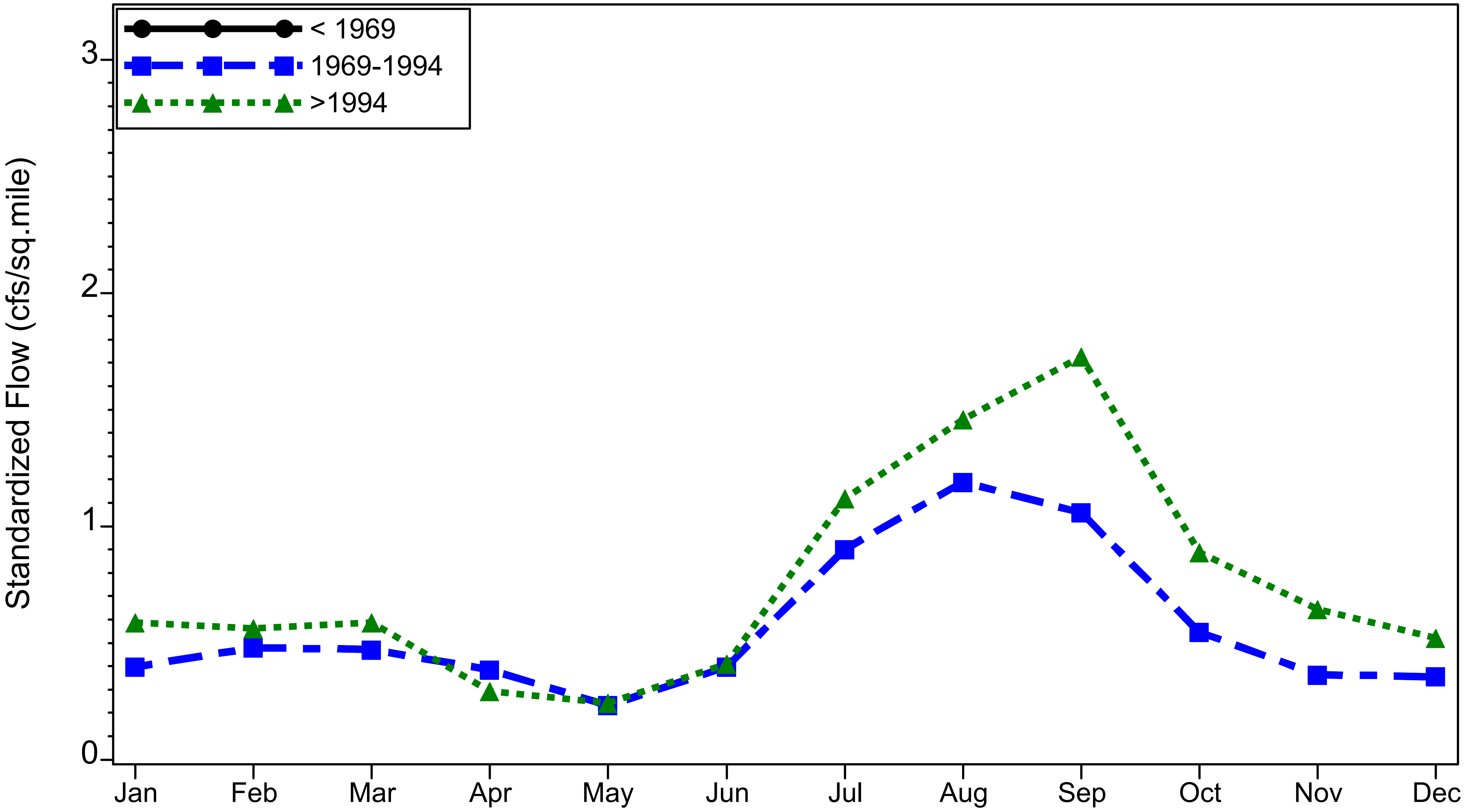


Figure 3.281 Seasonal differences among AMO periods of monthly median flow at long-term Payne Creek (2295420) gage

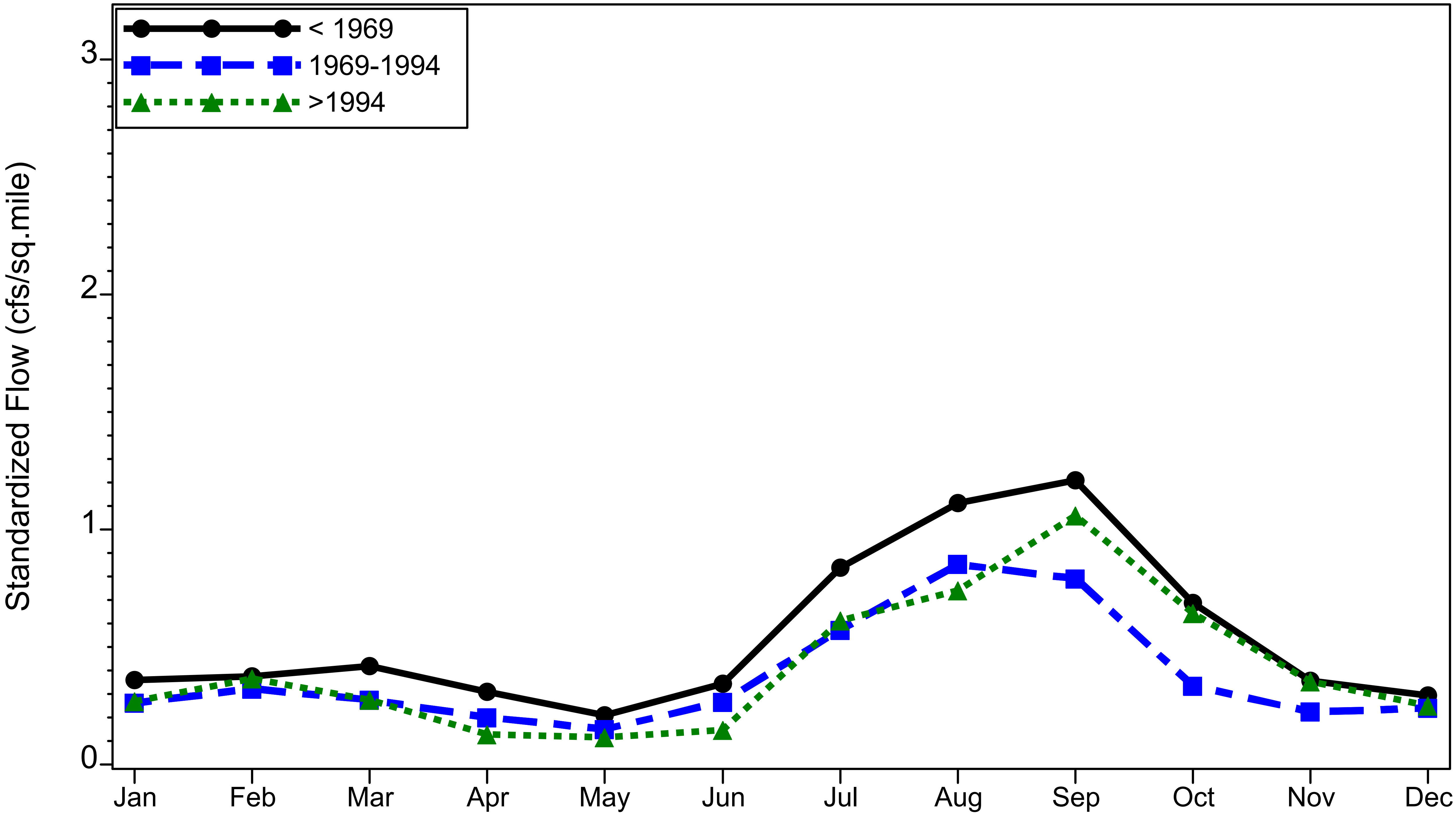


Figure 3.282 Seasonal differences among AMO periods of monthly median flow at long-term Peace River at Zolfo (2295637) gage

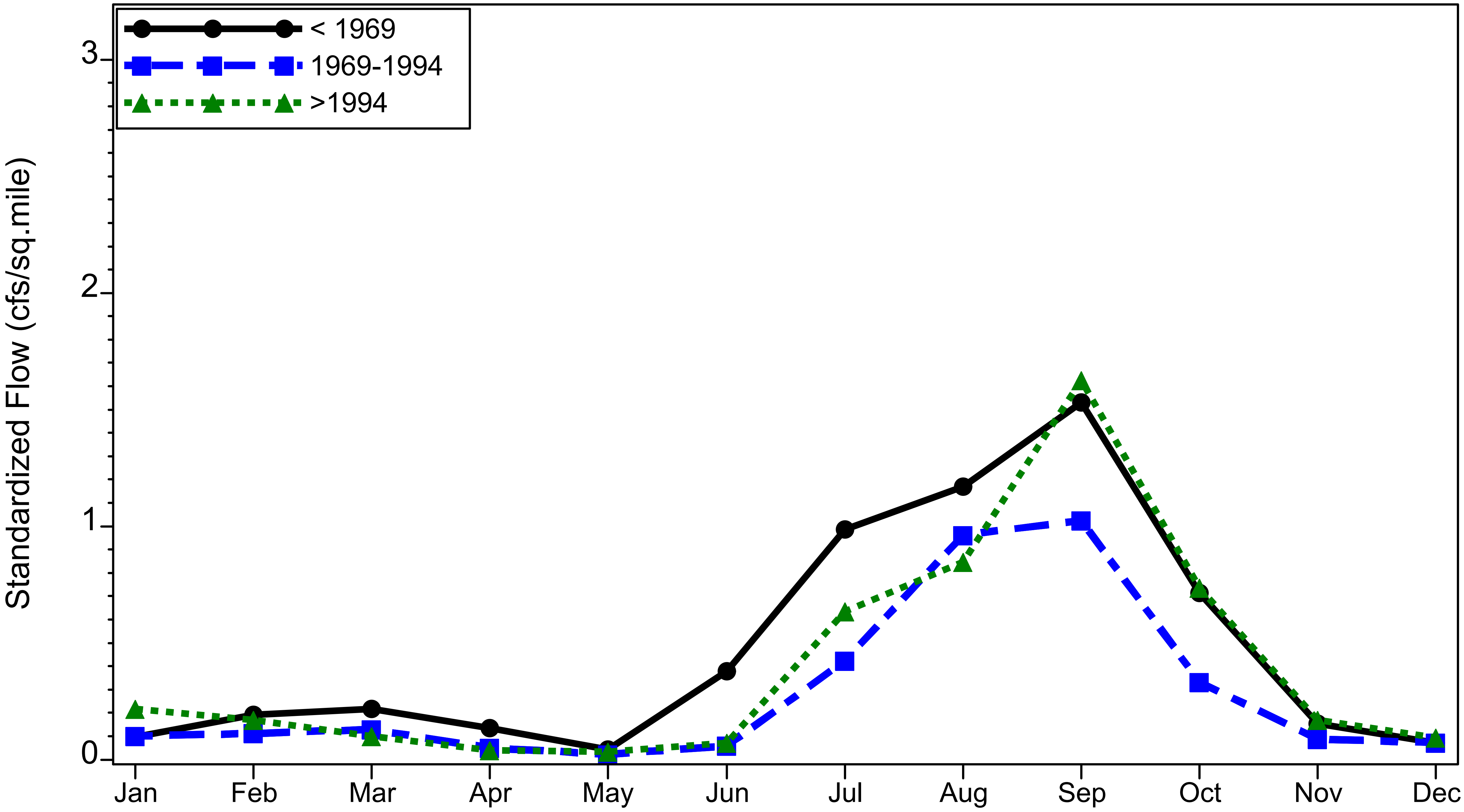


Figure 3.283 Seasonal differences among AMO periods of monthly median flow at long-term Charlie Creek (2296500) gage

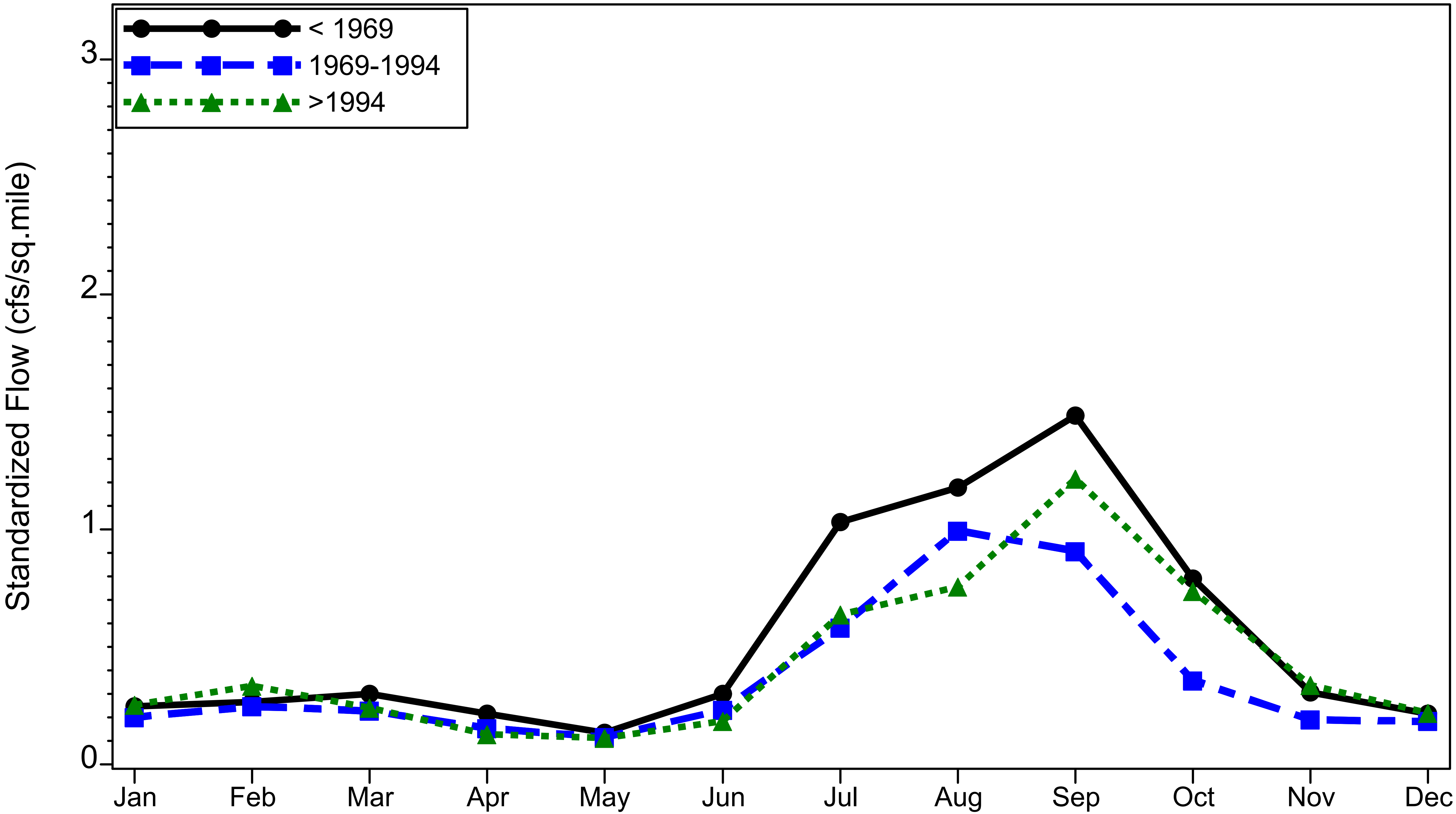


Figure 3.284 Seasonal differences among AMO periods of monthly median flow at long-term Peace River at Arcadia (2296750) gage

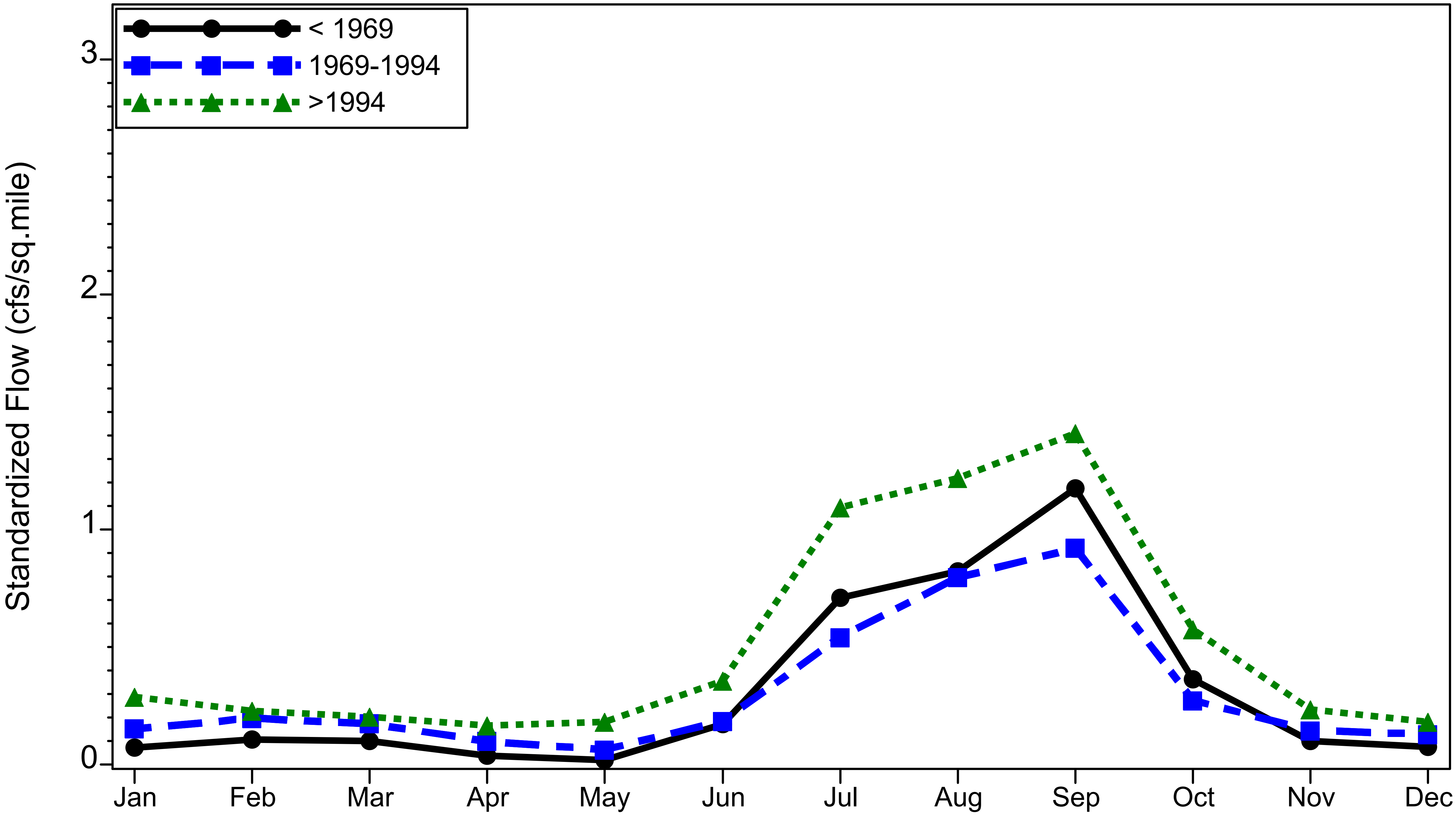


Figure 3.285 Seasonal differences among AMO periods of monthly median flow at long-term Joshua Creek at Nocatee (2297100) gage

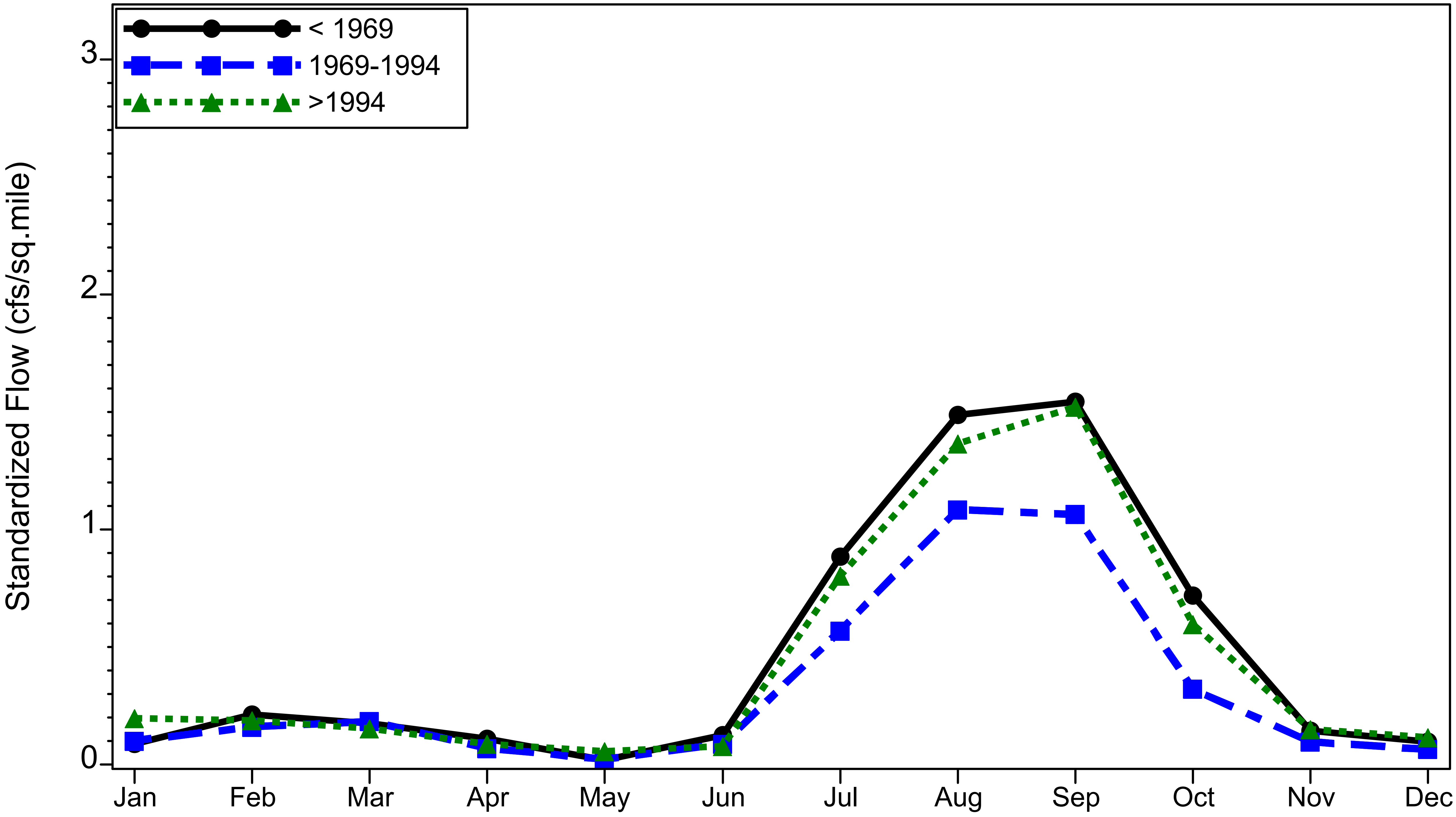


Figure 3.286 Seasonal differences among AMO periods of monthly median flow at long-term Horse Creek near Arcadia (2297310) gage

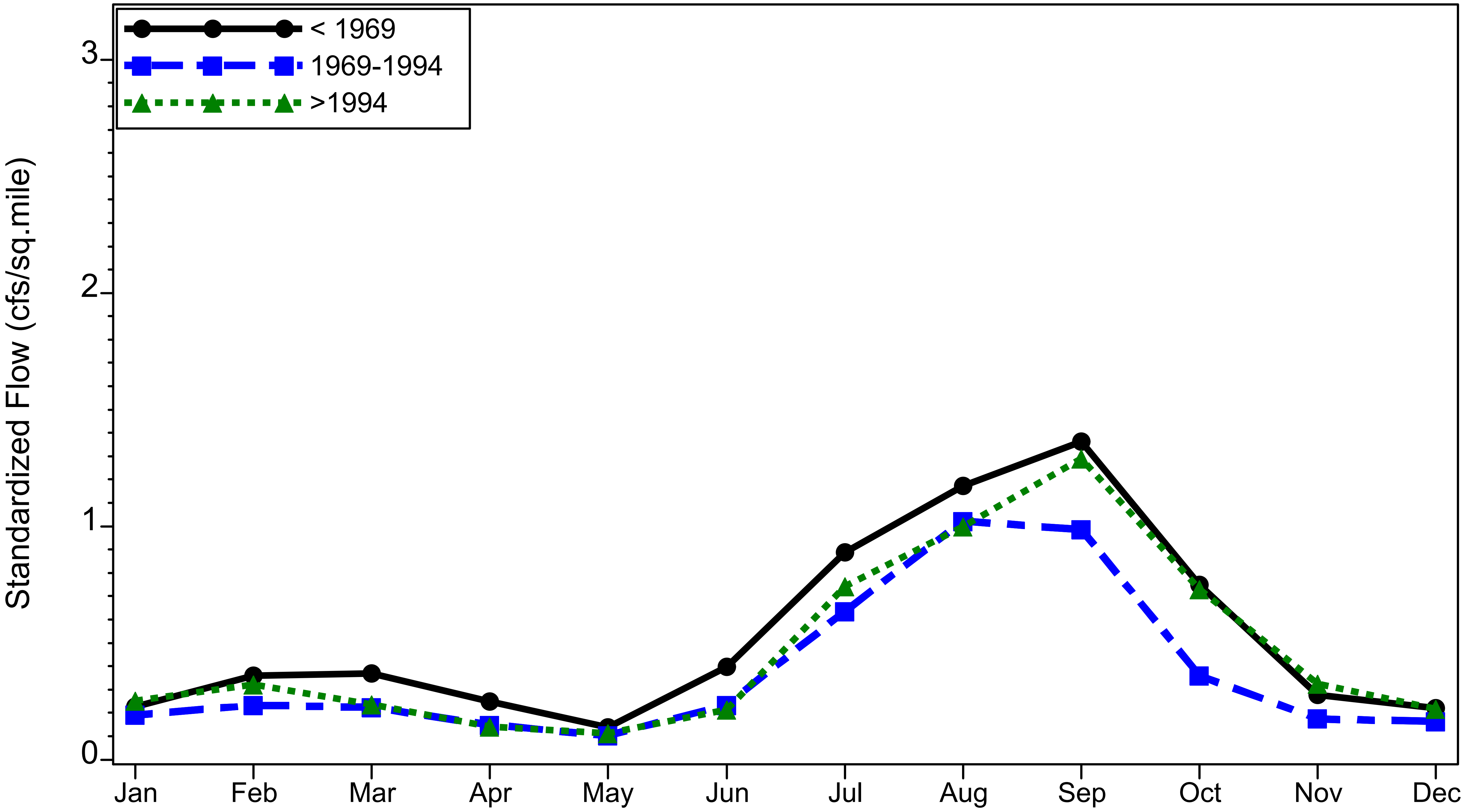


Figure 3.287 Seasonal differences among AMO periods of monthly median total gaged flow upstream of the Facility

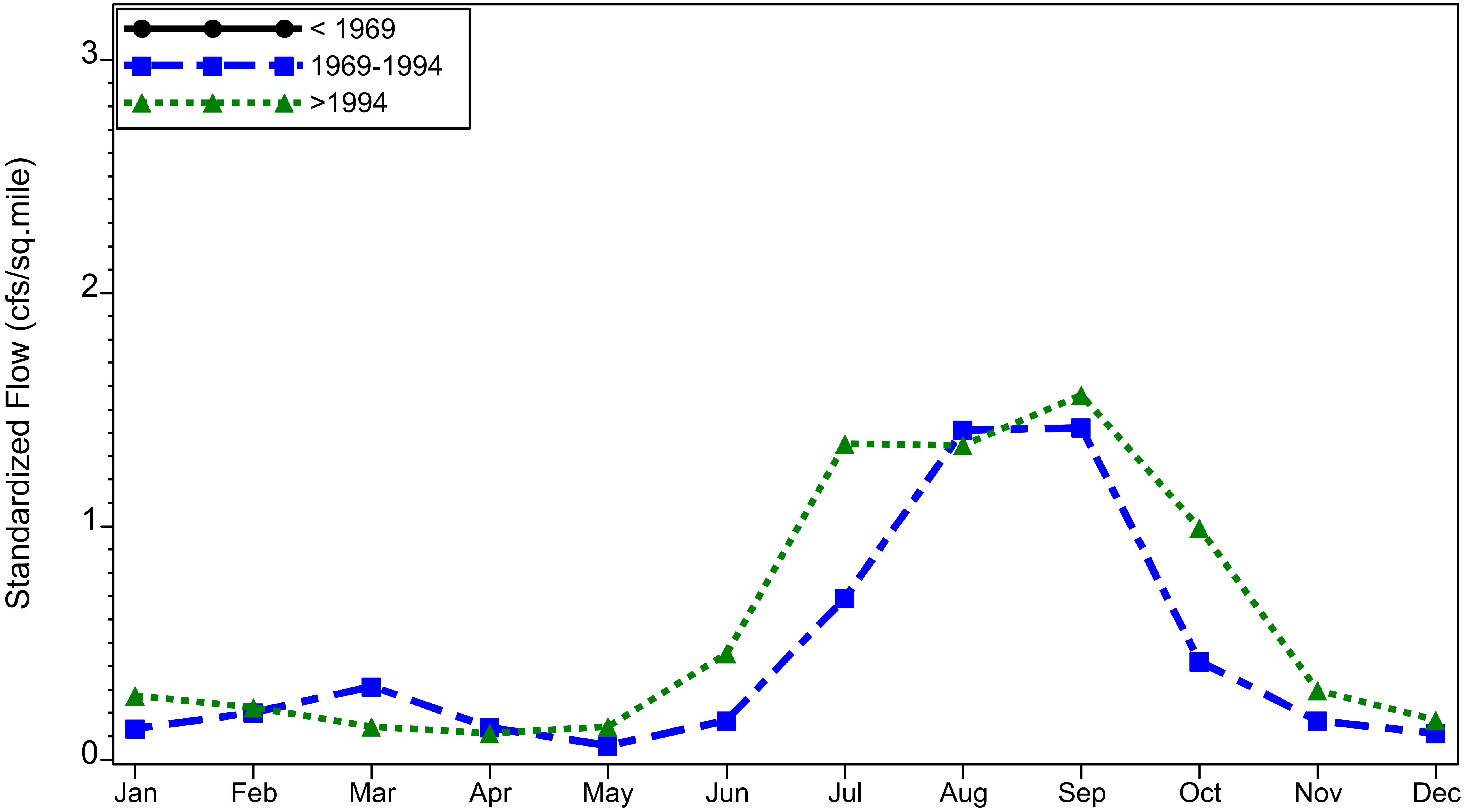


Figure 3.288 Seasonal differences among AMO periods of monthly median flow at long-term Prairie Creek (2298123) gage

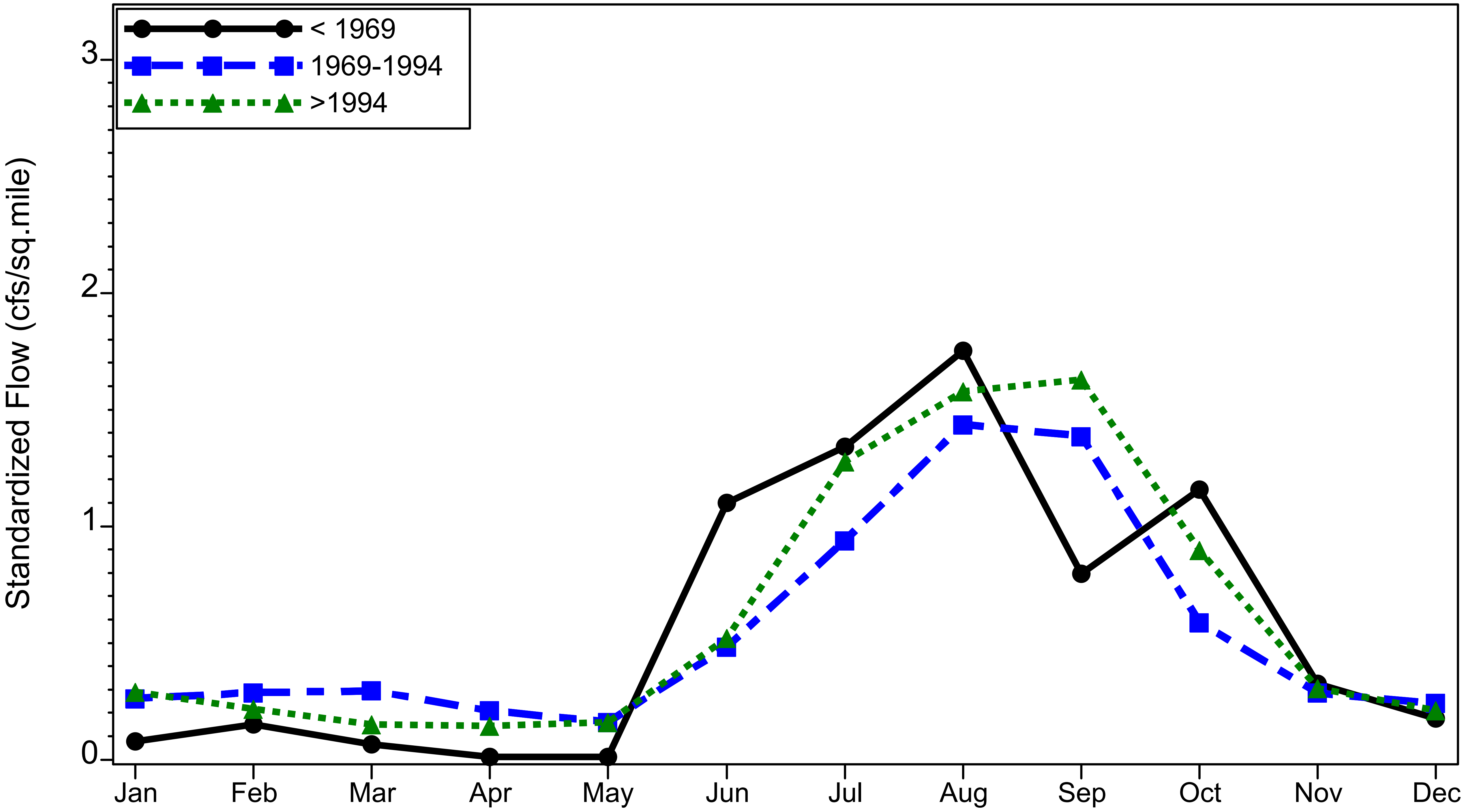


Figure 3.289 Seasonal differences among AMO periods of monthly median flow at long-term Shell Creek gage

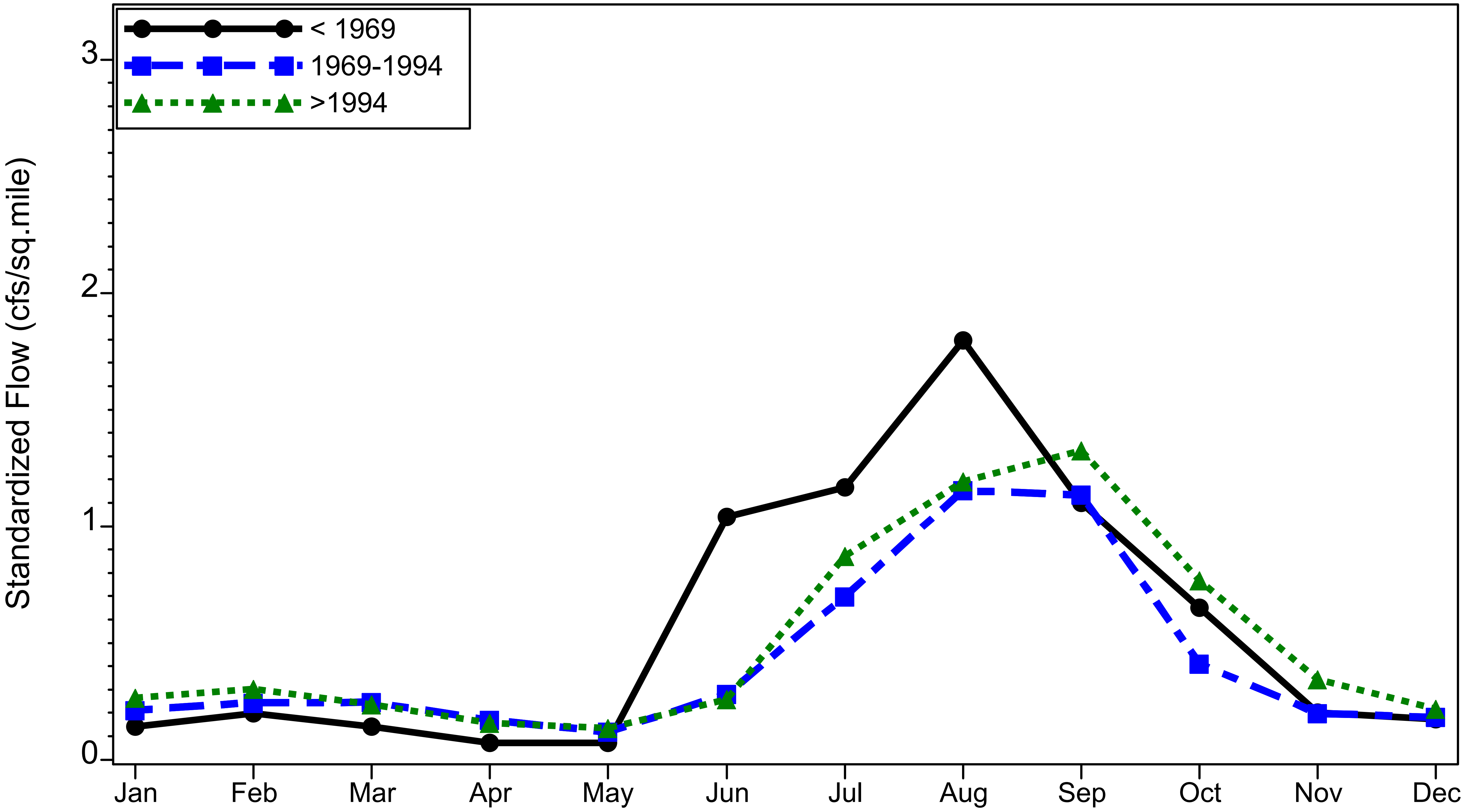


Figure 3.290 Seasonal differences among AMO periods of monthly median total gaged flow to the Upper Harbor

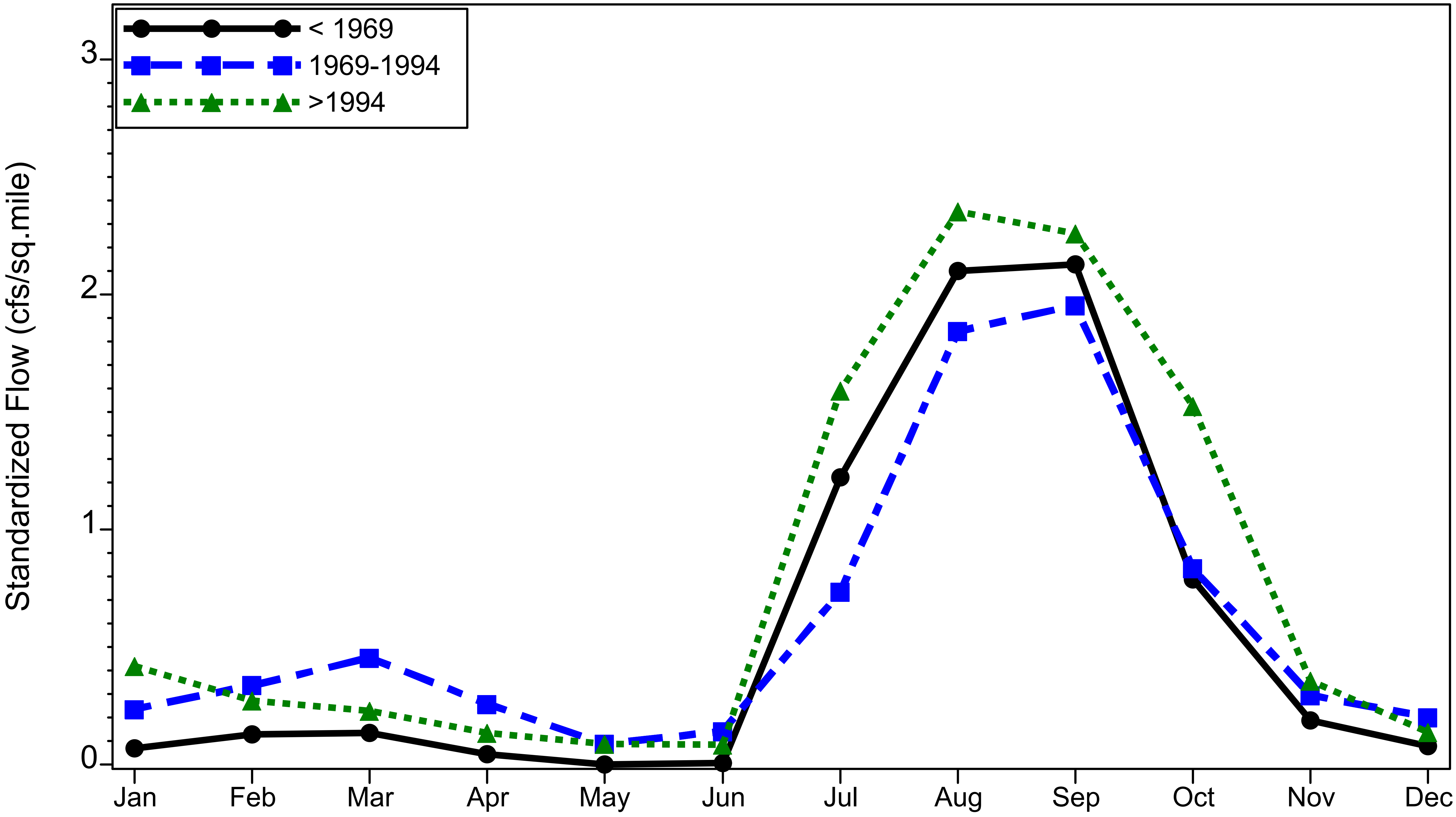


Figure 3.291 Seasonal differences among AMO periods of monthly median flow at long-term Myakka River near Sarasota (2298830) gage

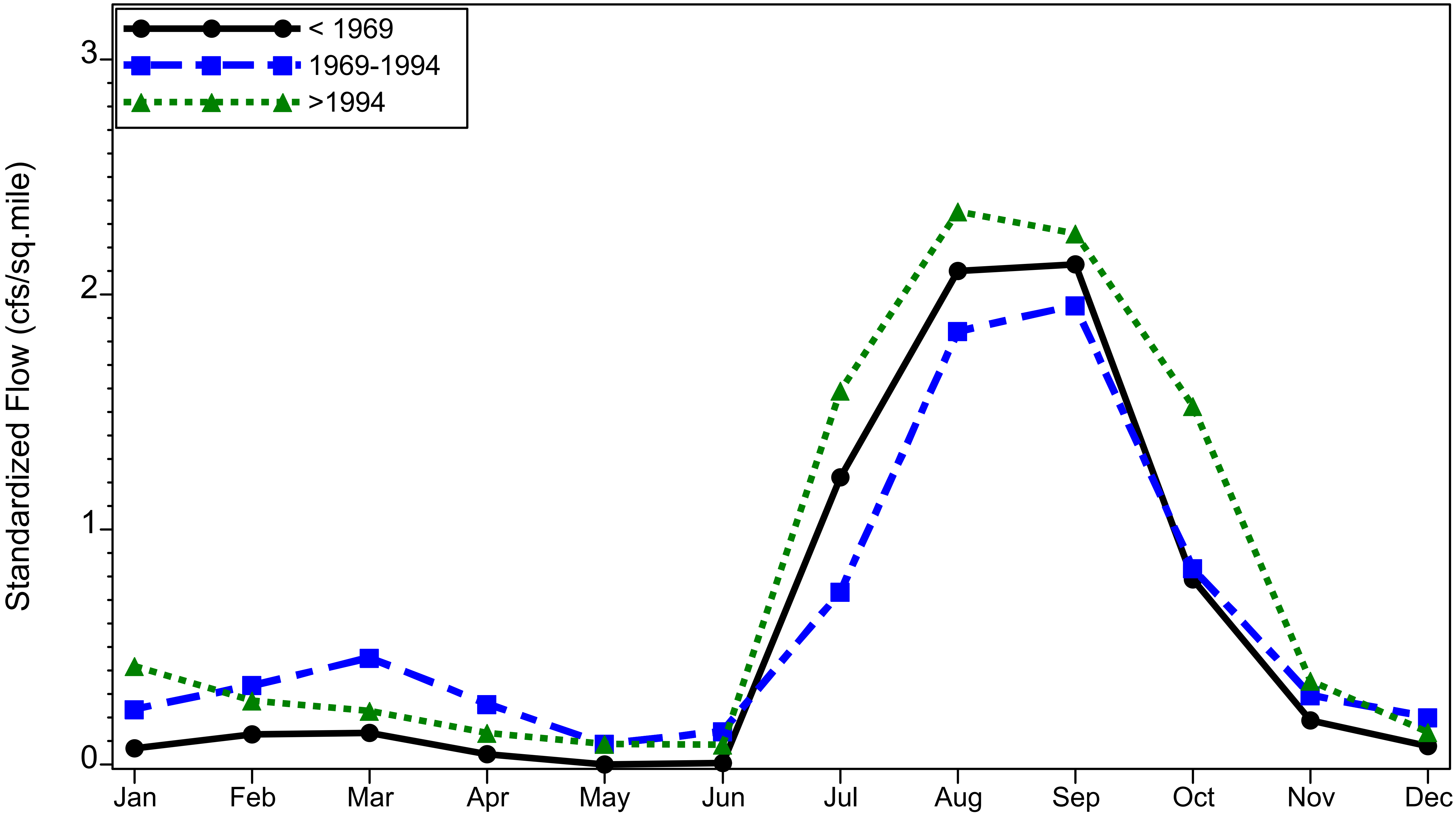


Figure 3.291 Seasonal differences among AMO periods of monthly median flow at long-term Myakka River near Sarasota (2298830) gage

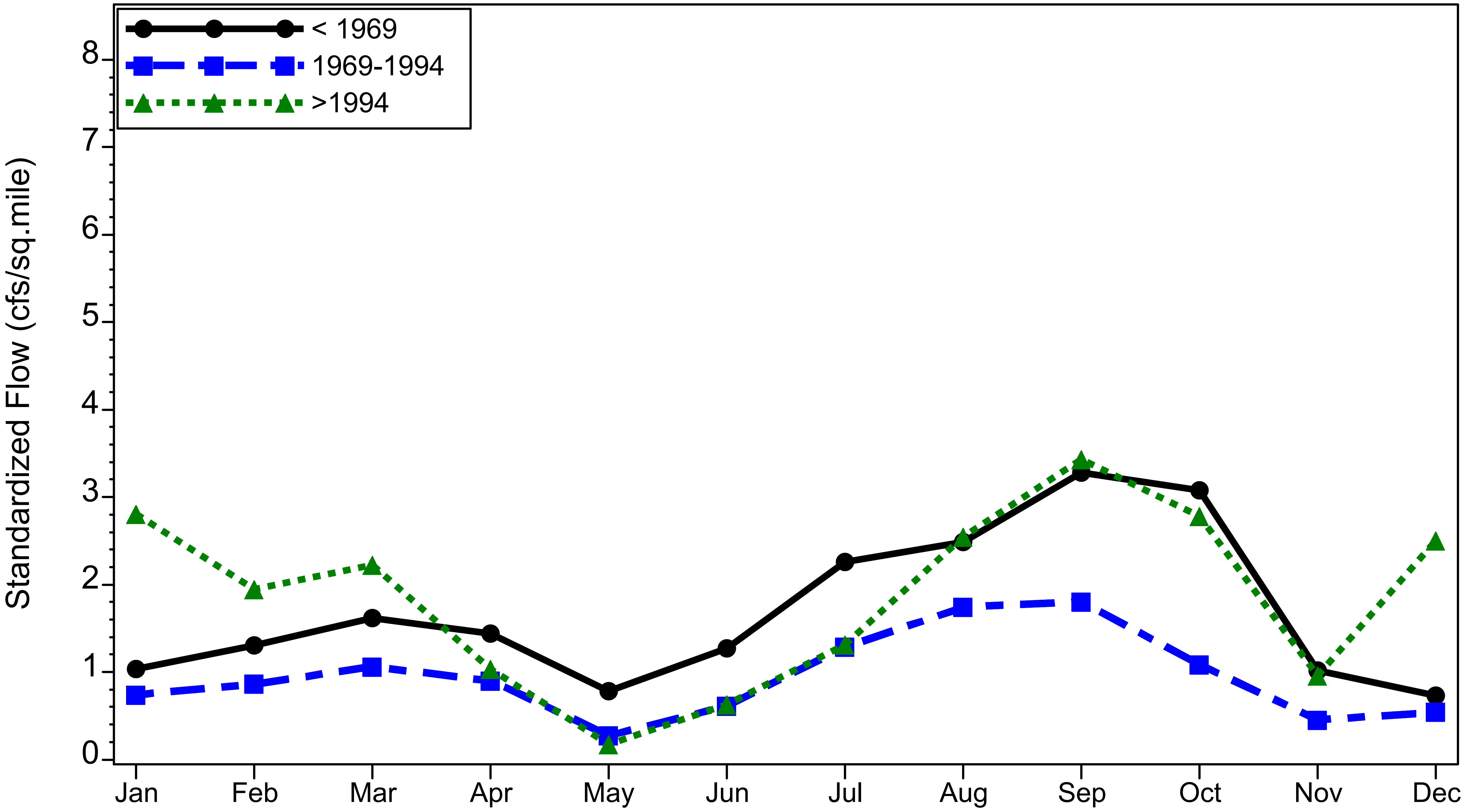


Figure 3.292 Seasonal differences among AMO periods of monthly P90 flow at long-term Peace River at Bartow (2294650) gage

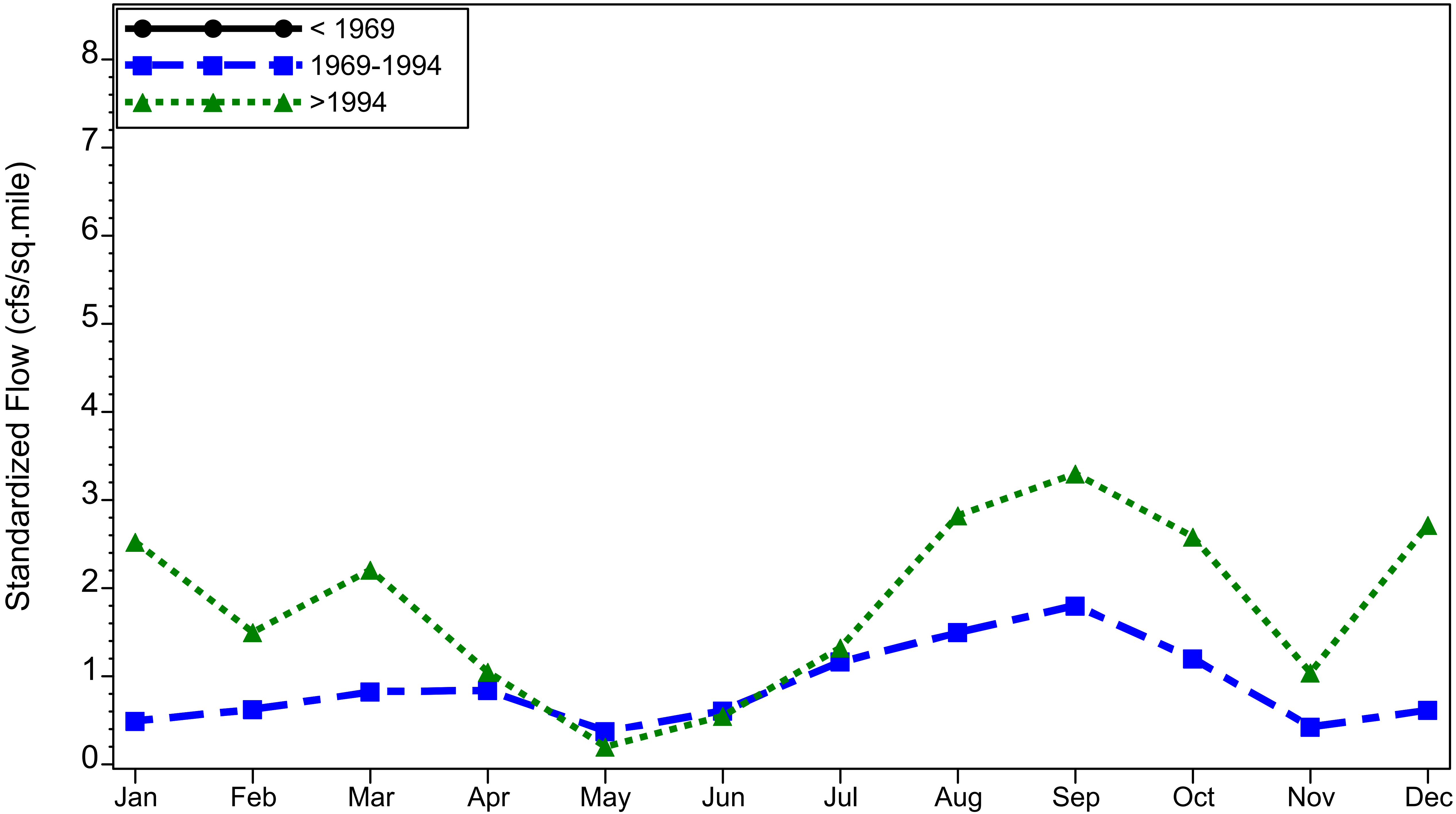


Figure 3.293 Seasonal differences among AMO periods of monthly P90 flow at long-term Peace River at Ft. Meade (2294898) gage

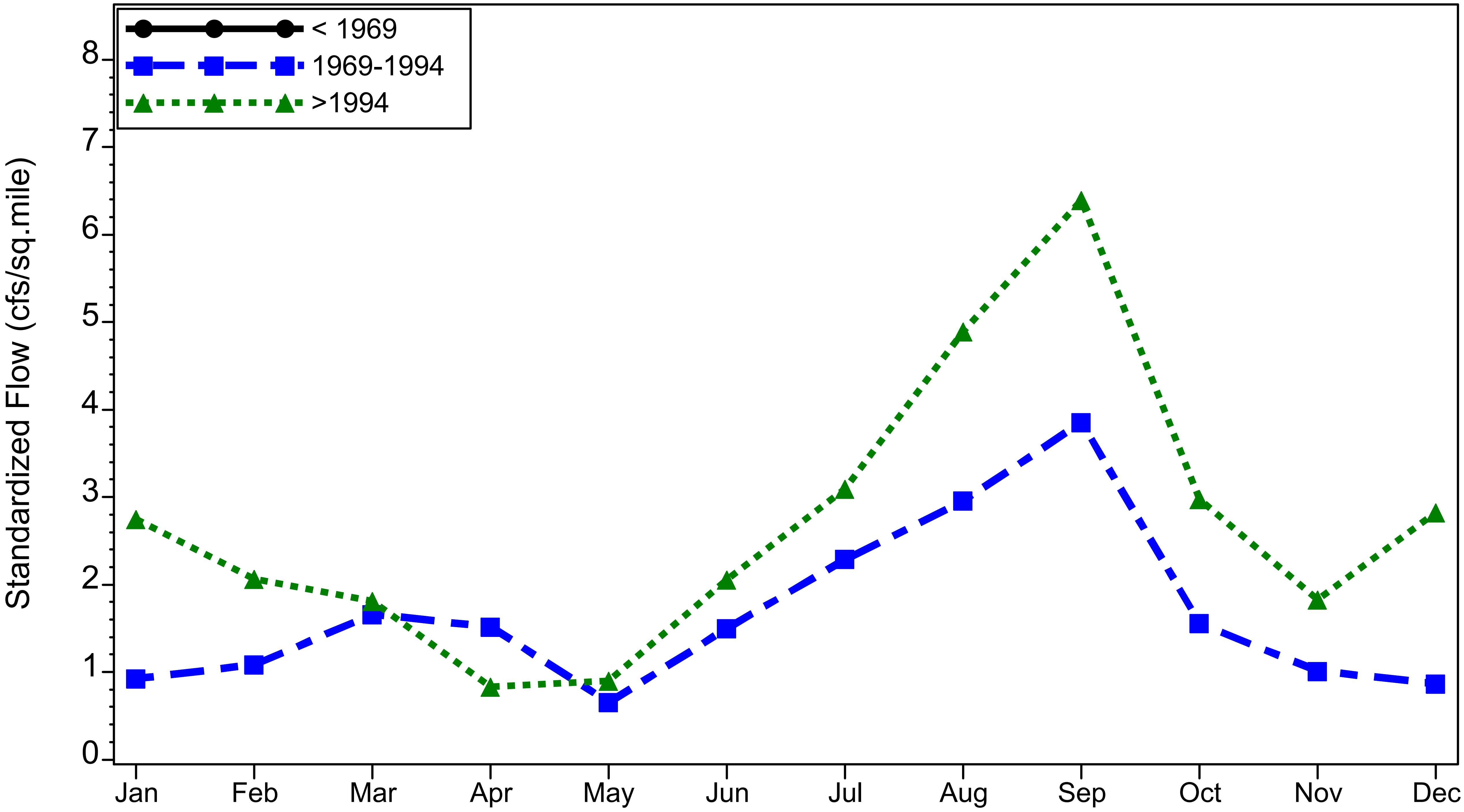


Figure 3.294 Seasonal differences among AMO periods of monthly P90 flow at long-term Payne Creek (2295420) gage

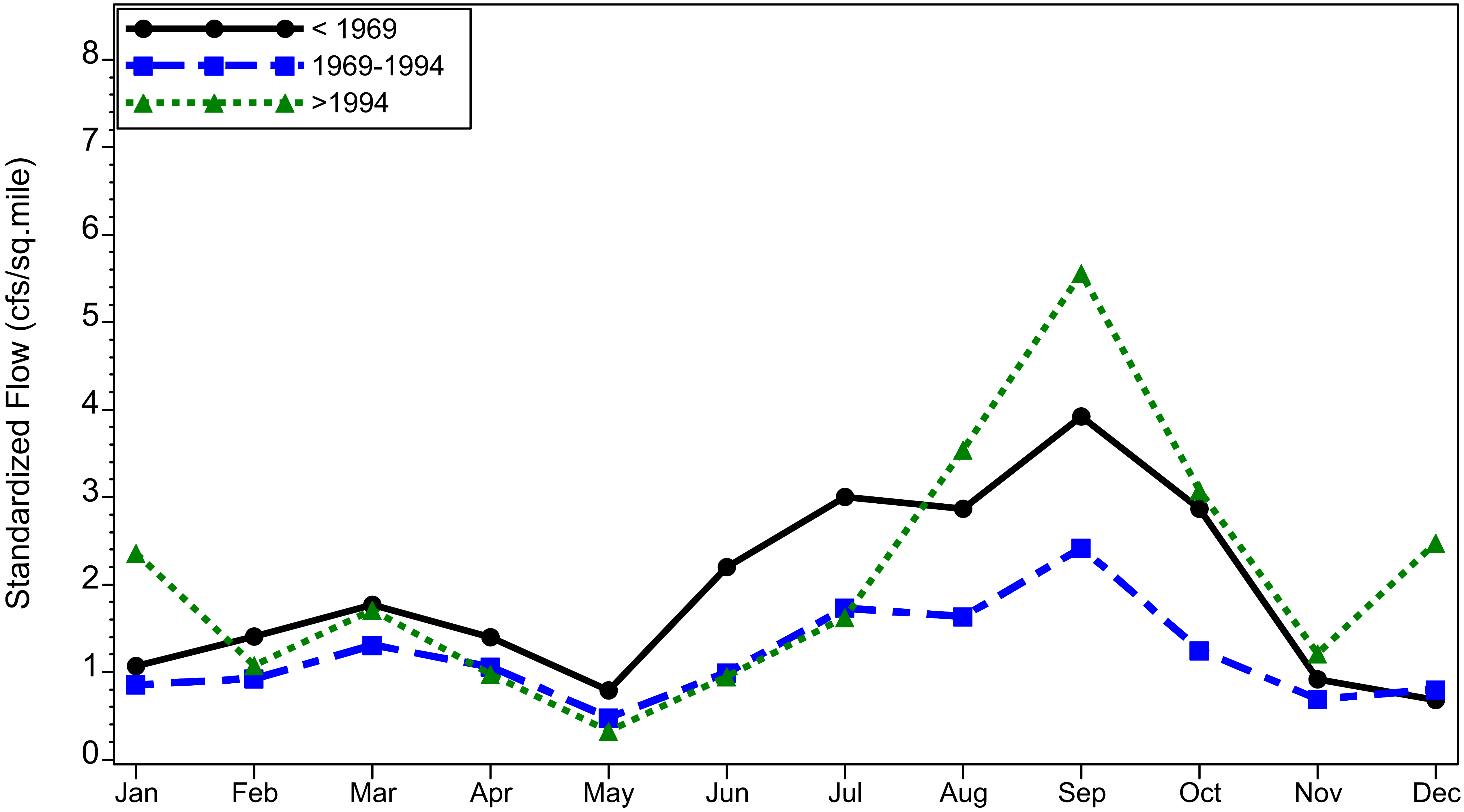


Figure 3.295 Seasonal differences among AMO periods of monthly P90 flow at long-term Peace River at Zolfo (2295637) gage

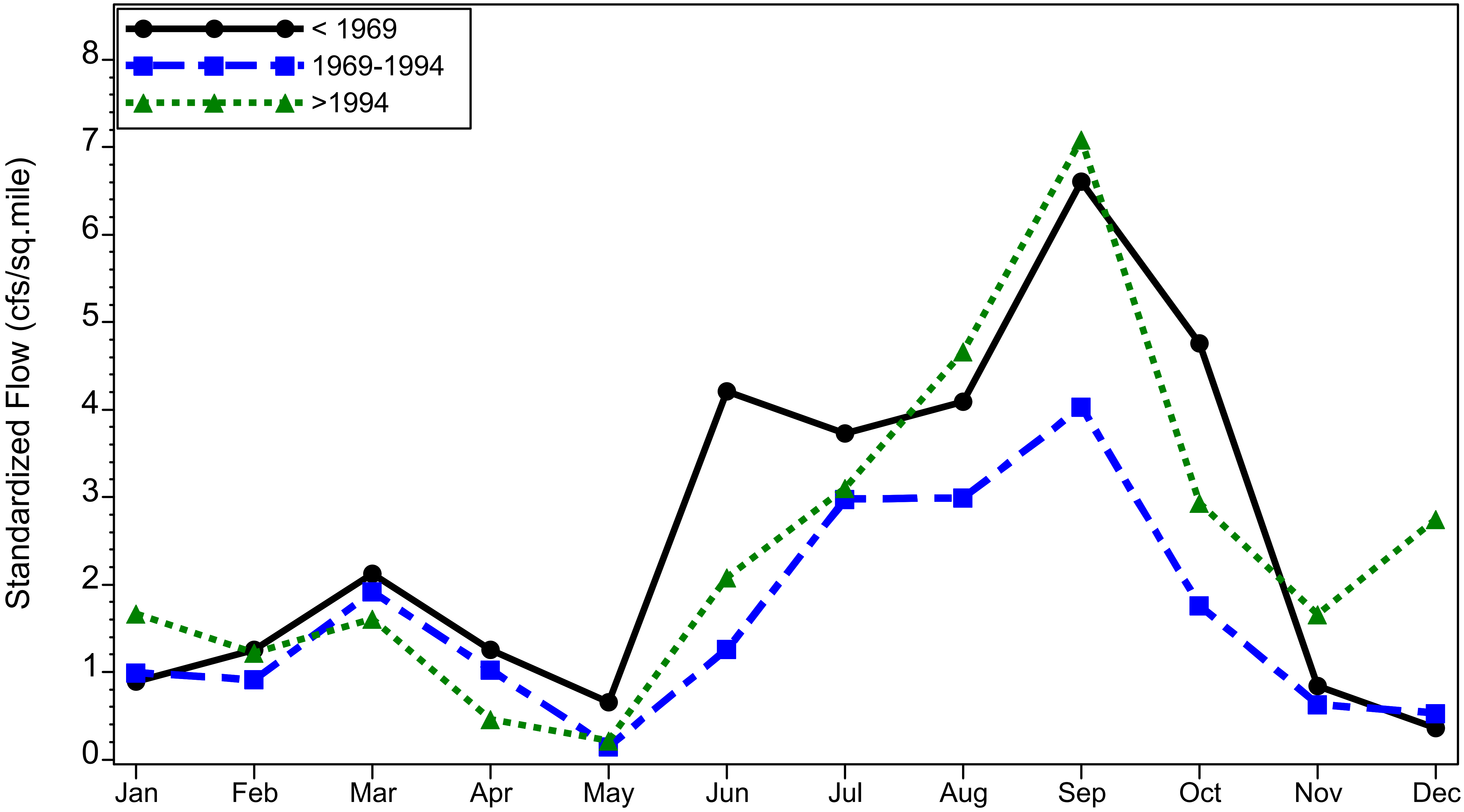


Figure 3.296 Seasonal differences among AMO periods of monthly P90 flow at long-term Charlie Creek (2296500) gage

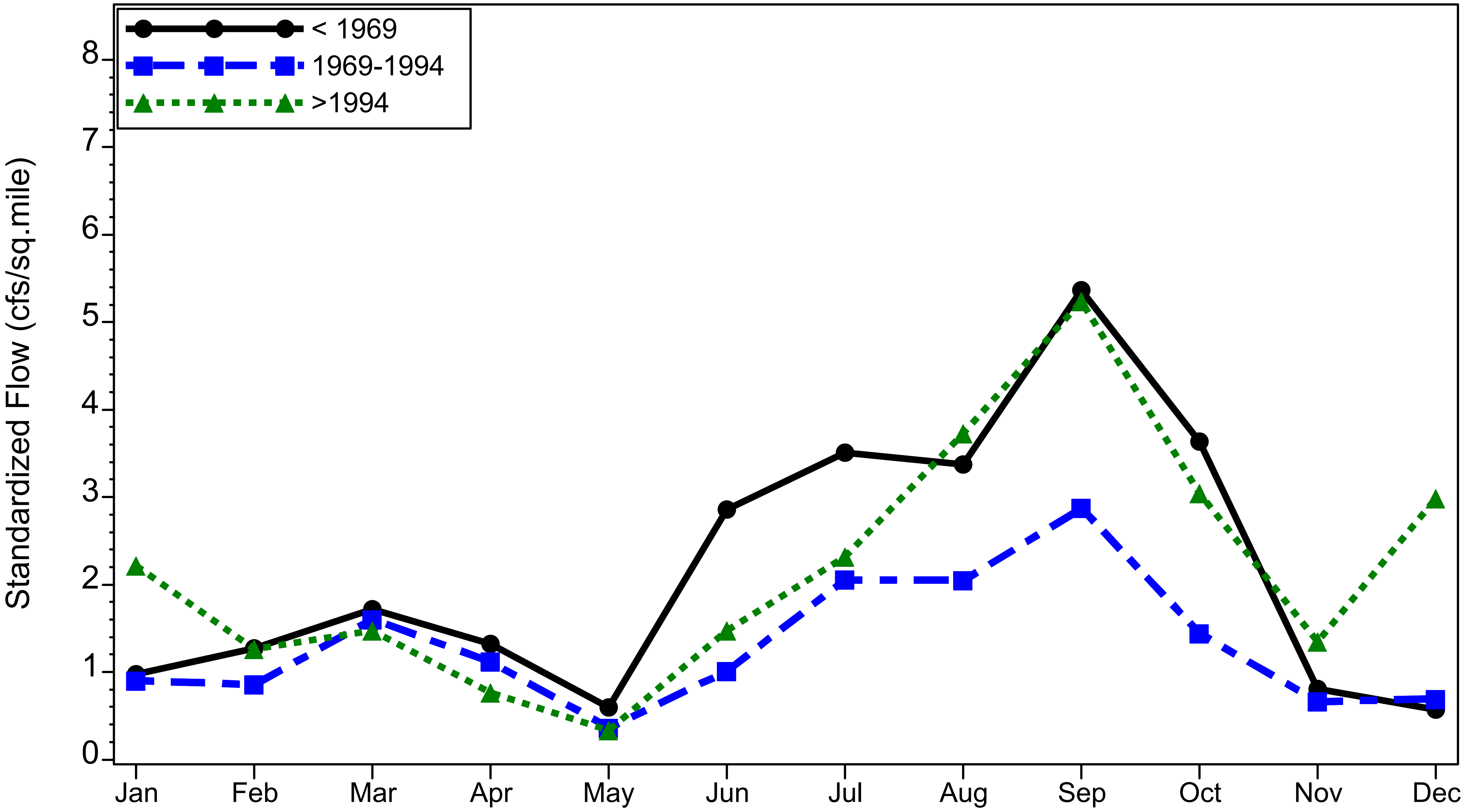


Figure 3.297 Seasonal differences among AMO periods of monthly P90 flow at long-term Peace River at Arcadia (2296750) gage

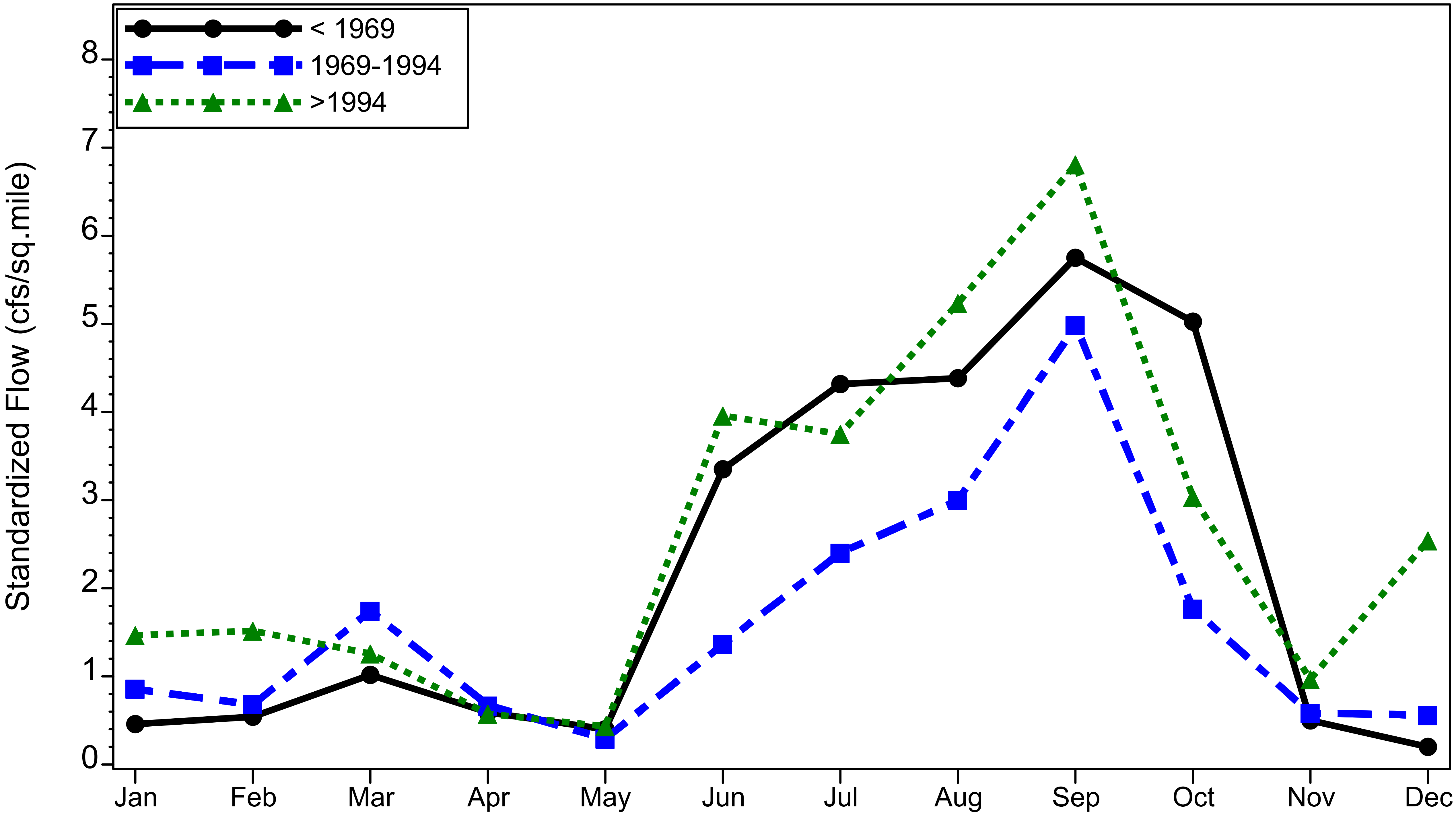


Figure 3.298 Seasonal differences among AMO periods of monthly P90 flow at long-term Joshua Creek at Nocatee (2297100) gage

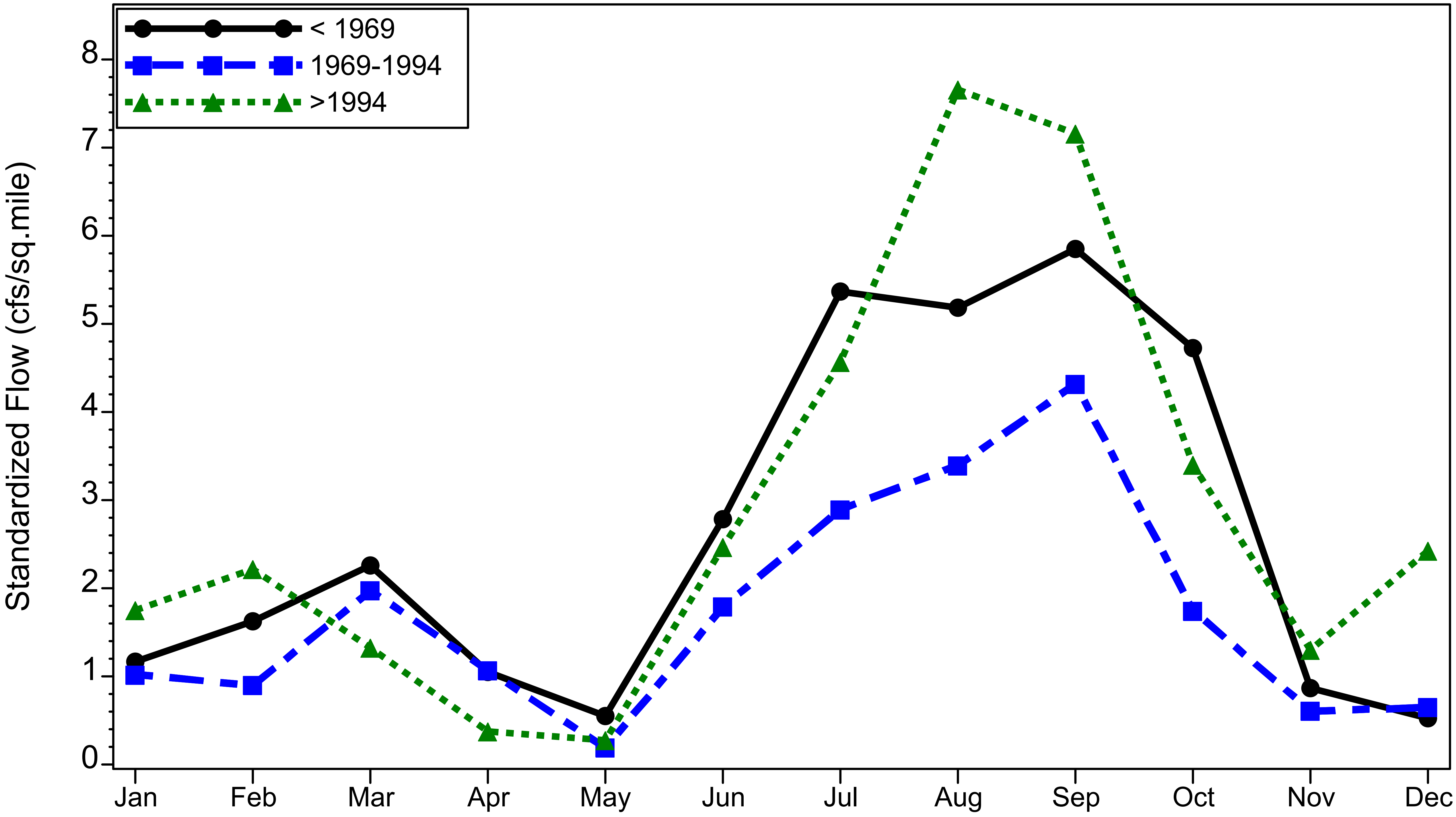


Figure 3.299 Seasonal differences among AMO periods of monthly P90 flow at long-term Horse Creek near Arcadia (2297310) gage

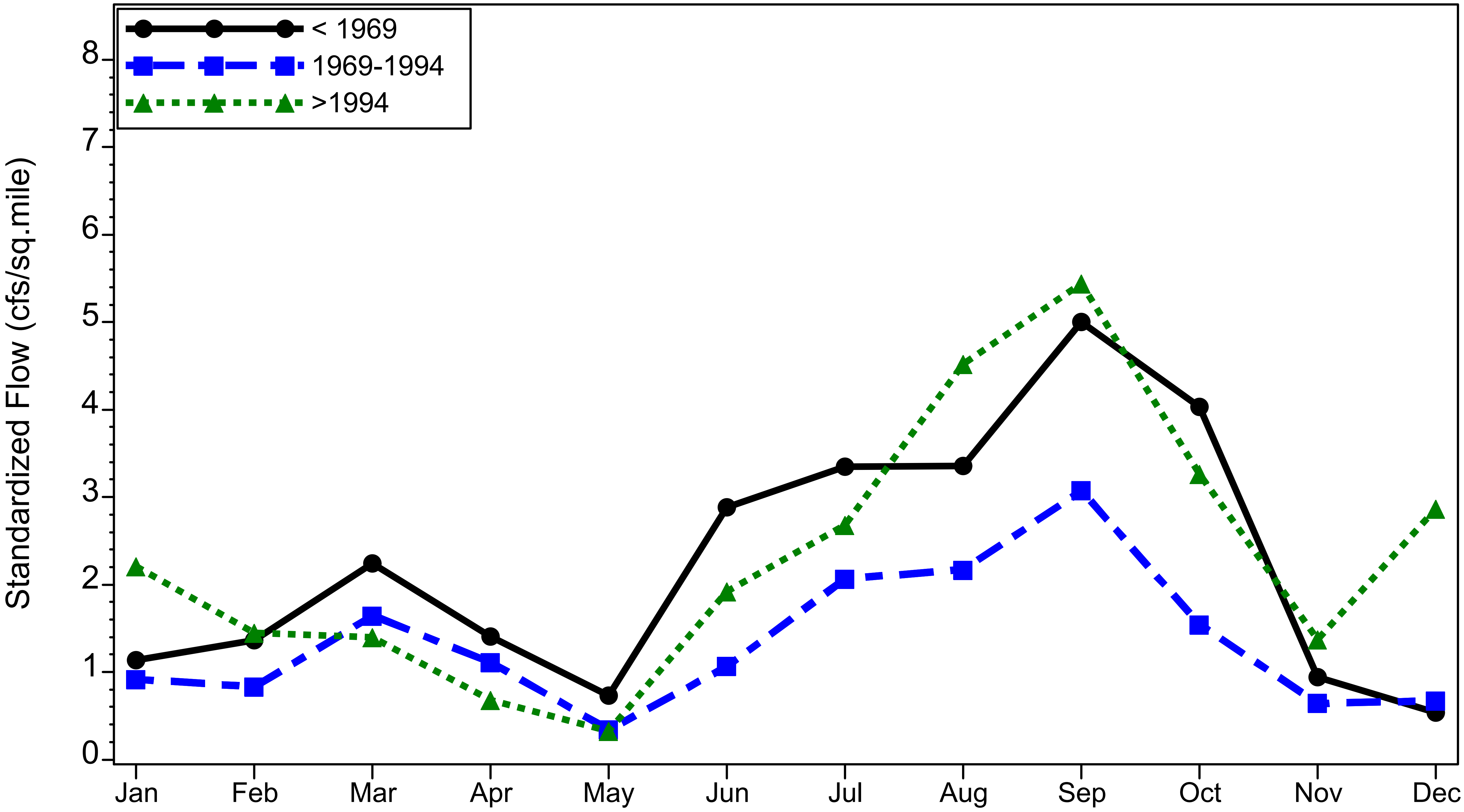


Figure 3.300 Seasonal differences among AMO periods of monthly P90 total gaged flow upstream of the Facility

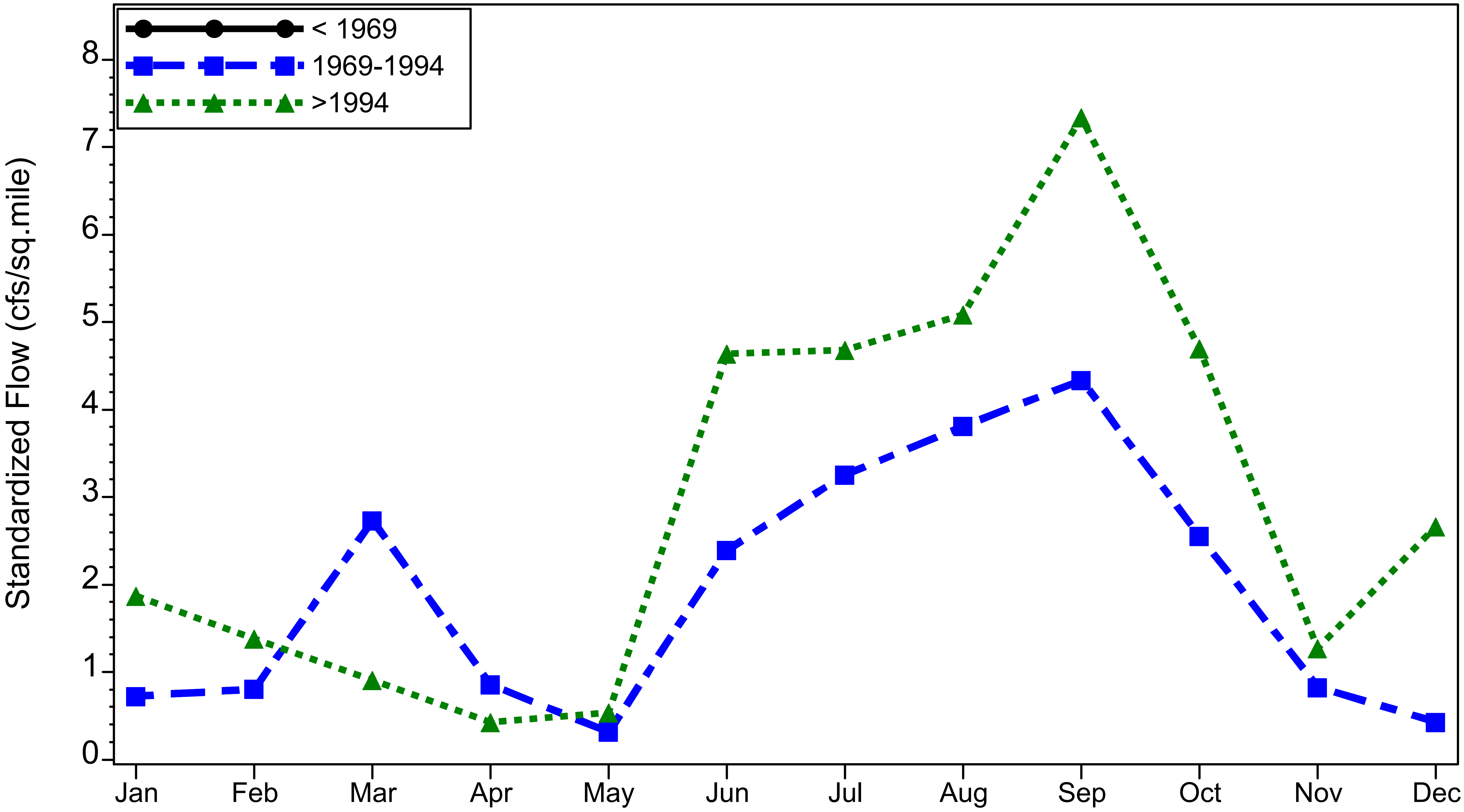


Figure 3.301 Seasonal differences among AMO periods of monthly P90 flow at long-term Prairie Creek (2298123) gage

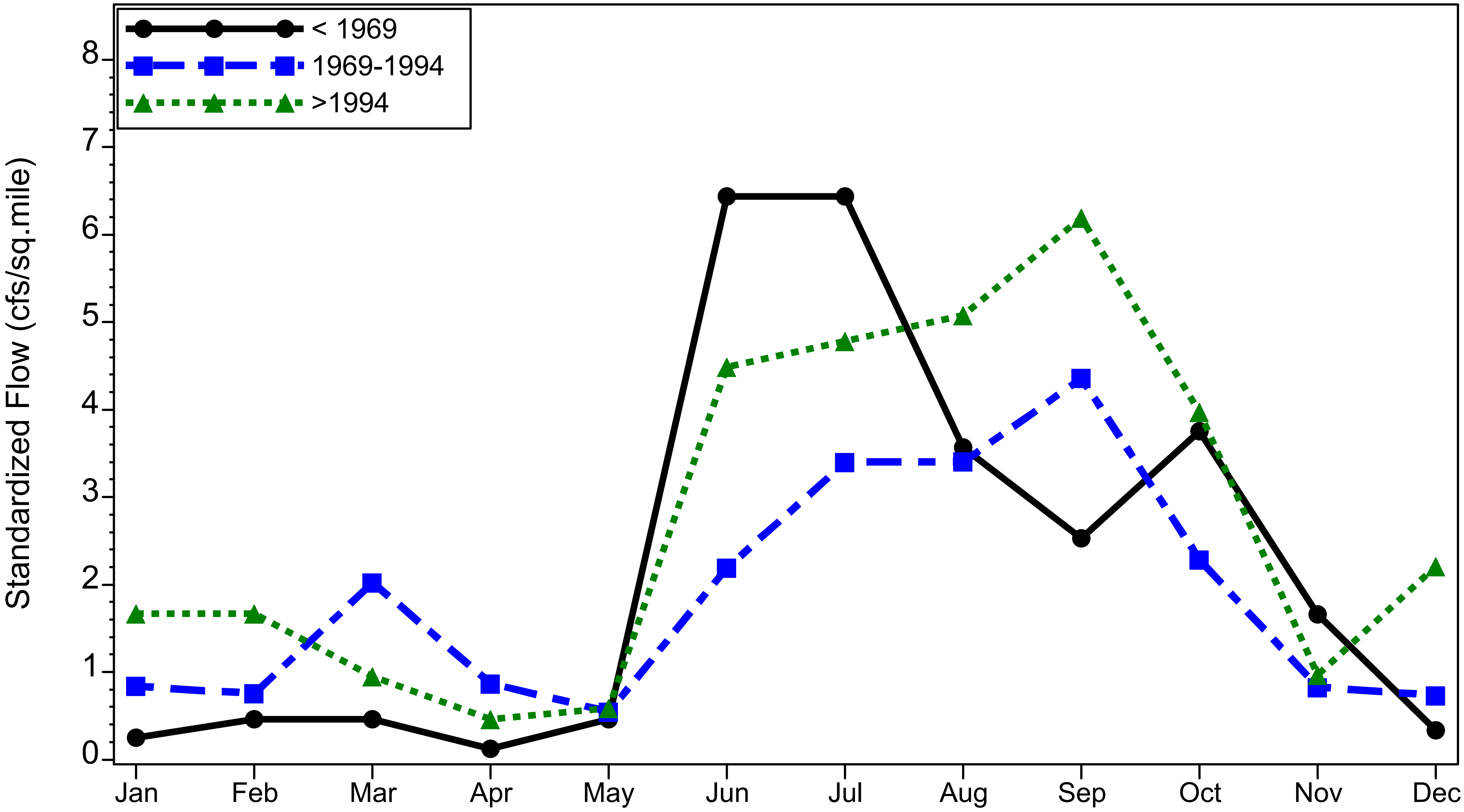


Figure 3.302 Seasonal differences among AMO periods of monthly P90 flow at long-term Shell Creek gage

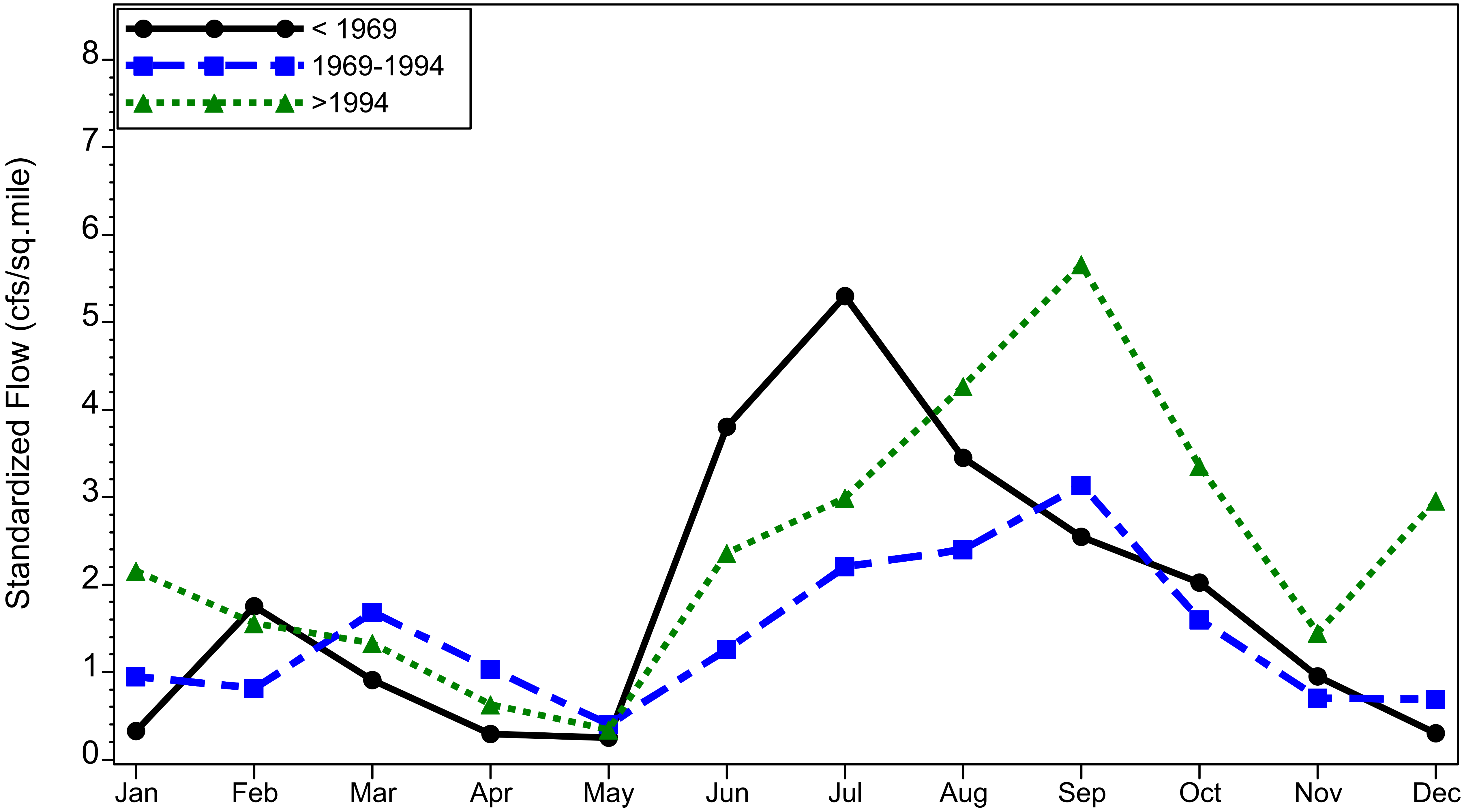


Figure 3.303 Seasonal differences among AMO periods of monthly P90 total gaged flow to the Upper Harbor

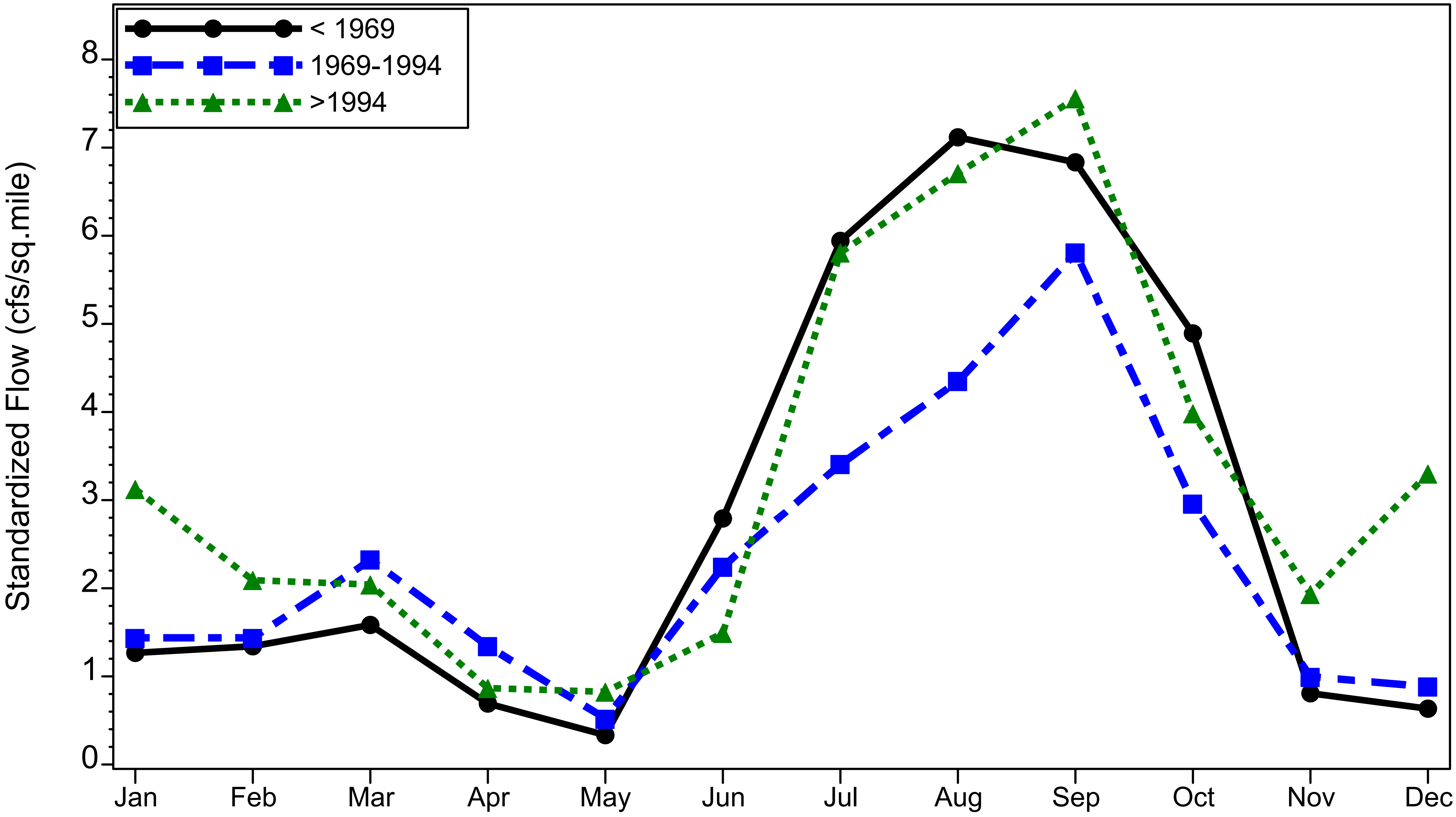


Figure 3.304 Seasonal differences among AMO periods of monthly P90 flow at long-term Myakka River near Sarasota (2298830) gage

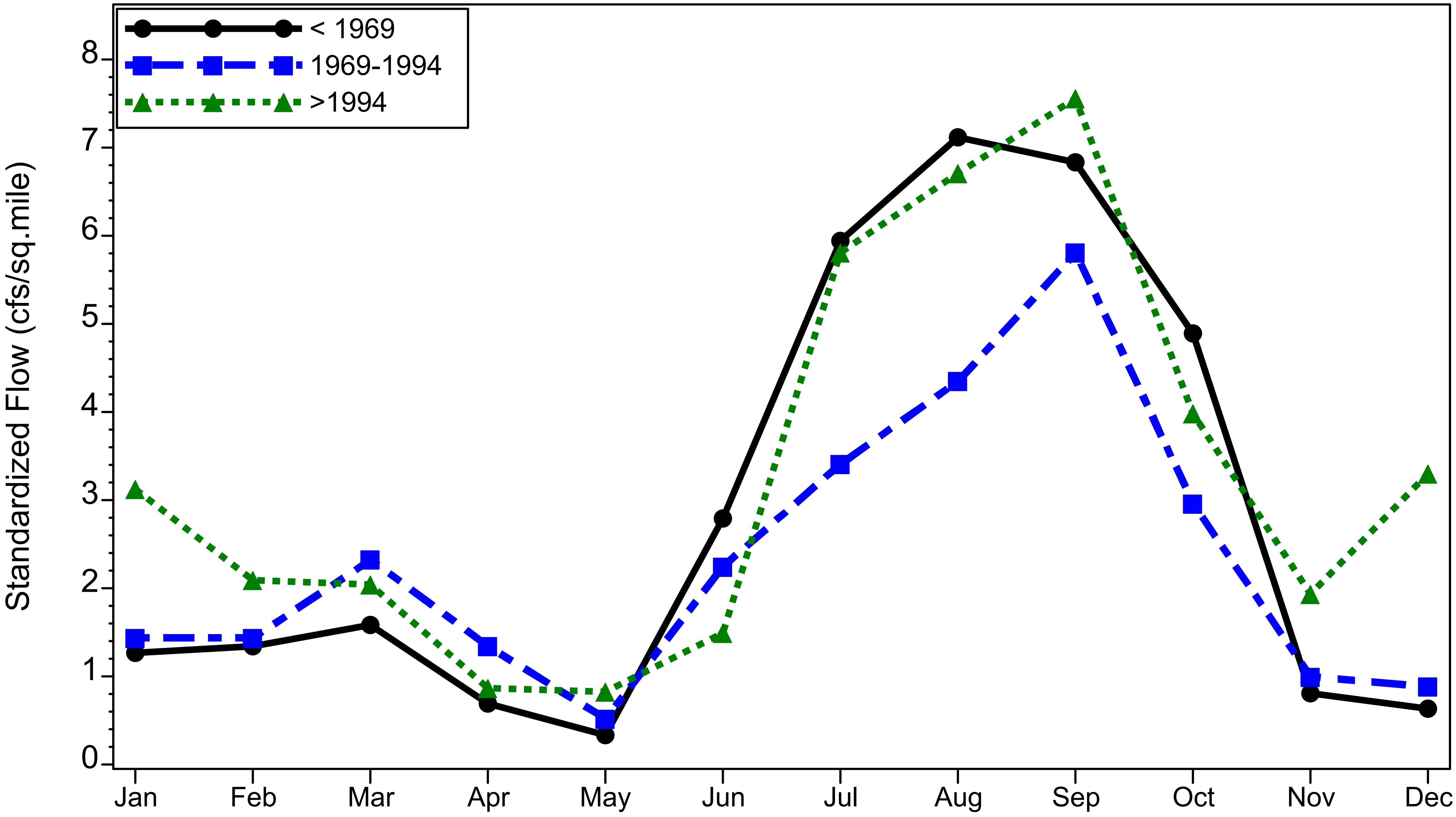


Figure 3.304 Seasonal differences among AMO periods of monthly P90 flow at long-term Myakka River near Sarasota (2298830) gage

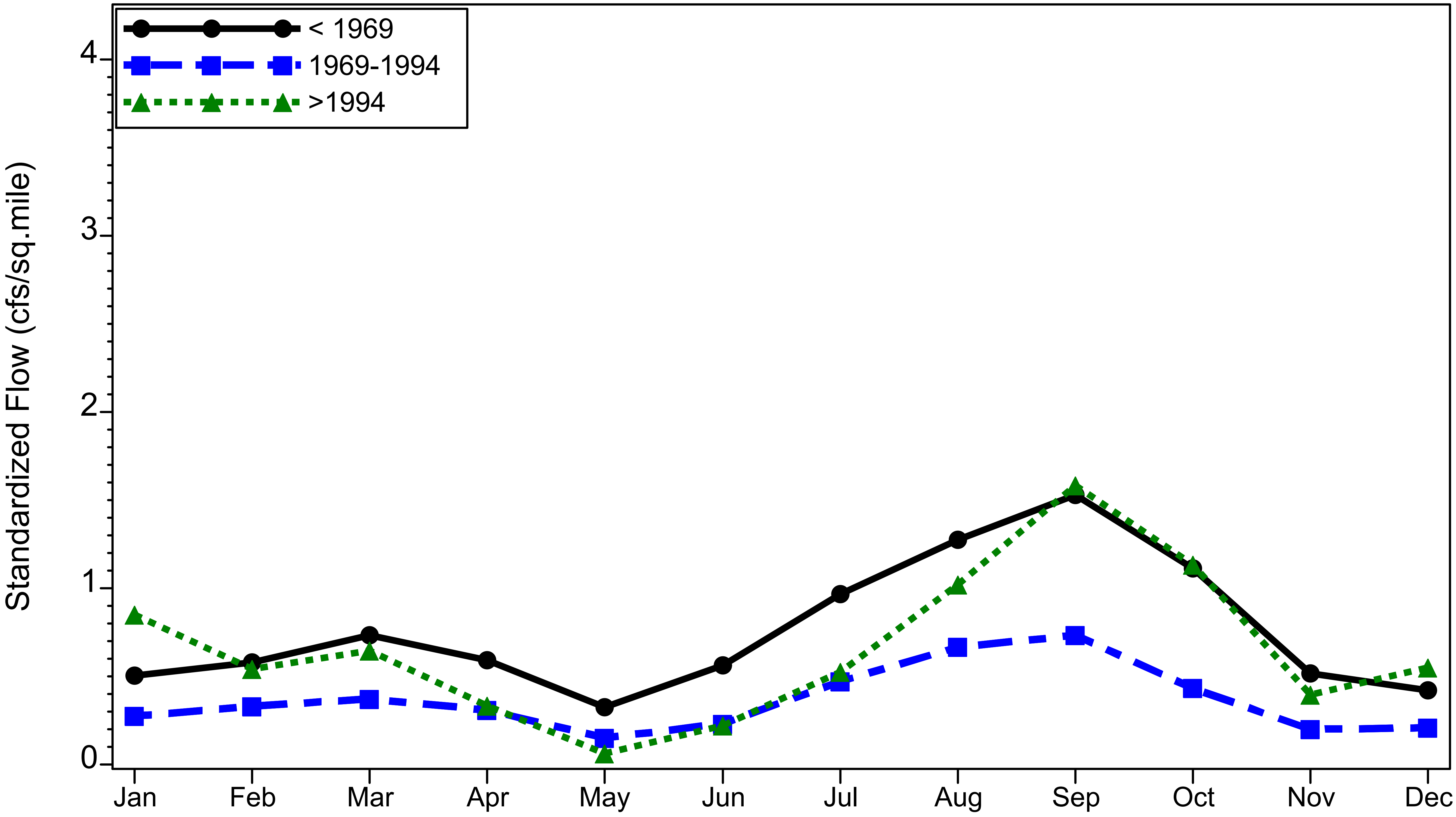


Figure 3.305 Seasonal differences among AMO periods of monthly mean flow at long-term Peace River at Bartow (2294650) gage

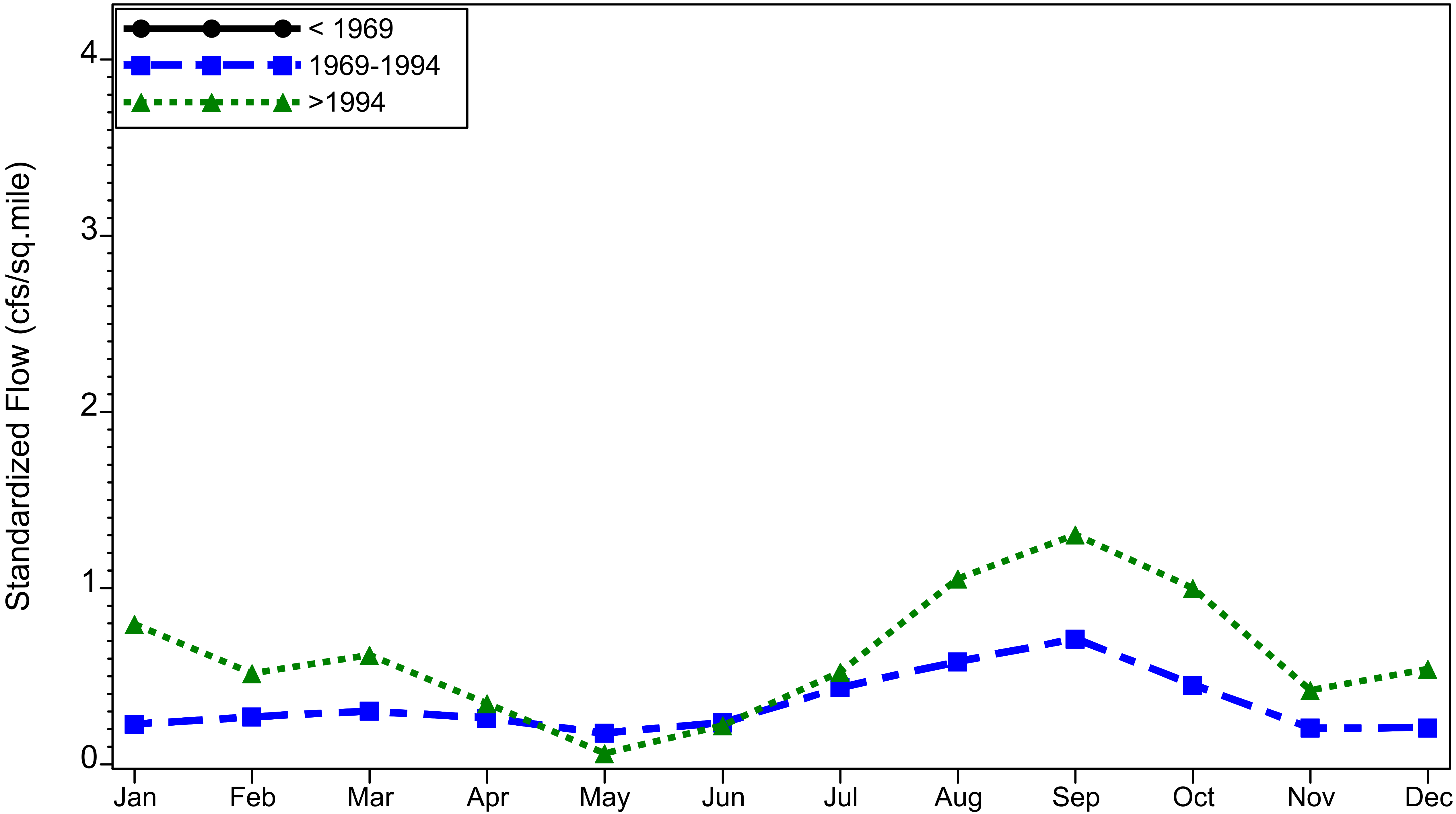


Figure 3.306 Seasonal differences among AMO periods of monthly mean flow at long-term Peace River at Ft. Meade (2294898) gage

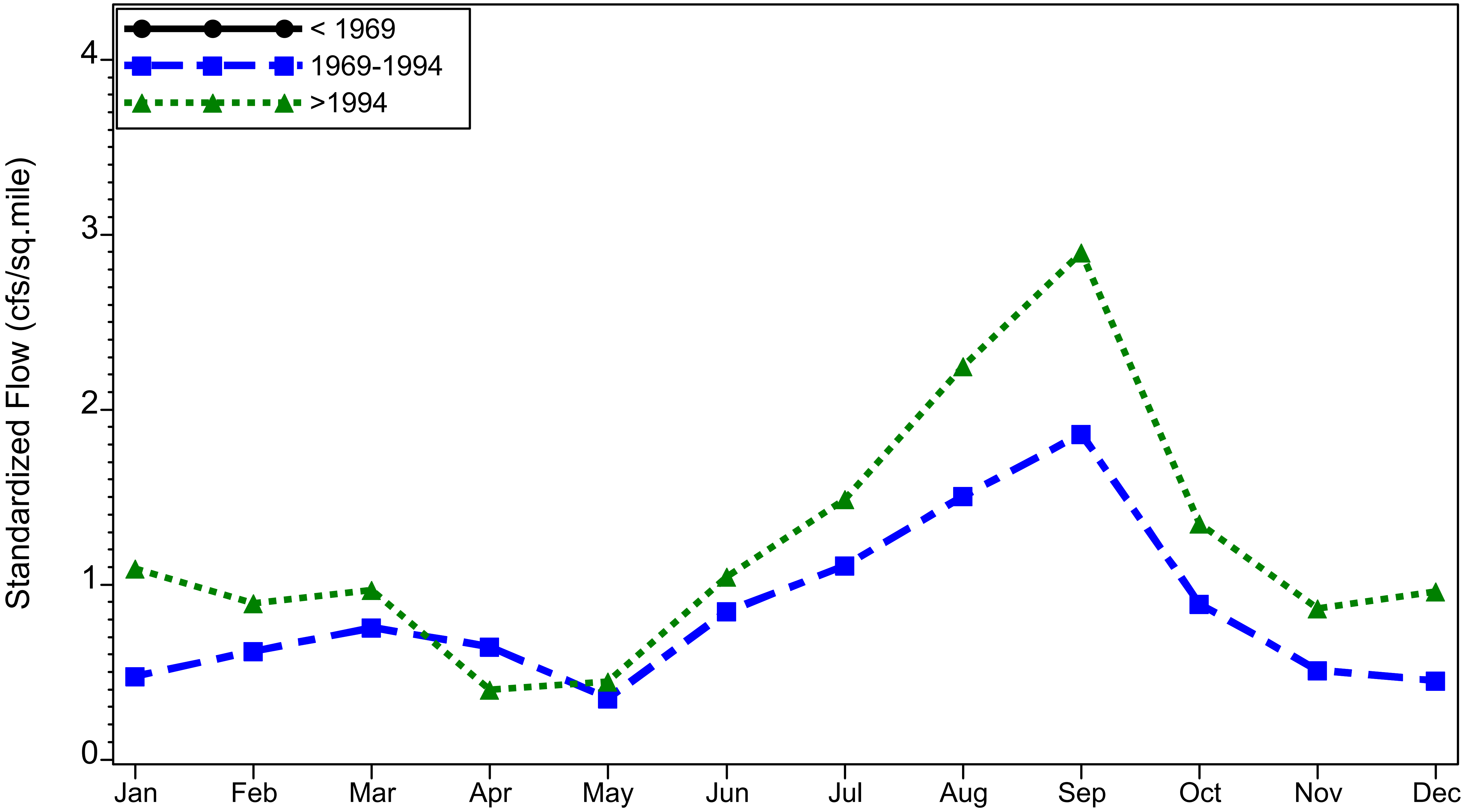


Figure 3.307 Seasonal differences among AMO periods of monthly mean flow at long-term Payne Creek (2295420) gage

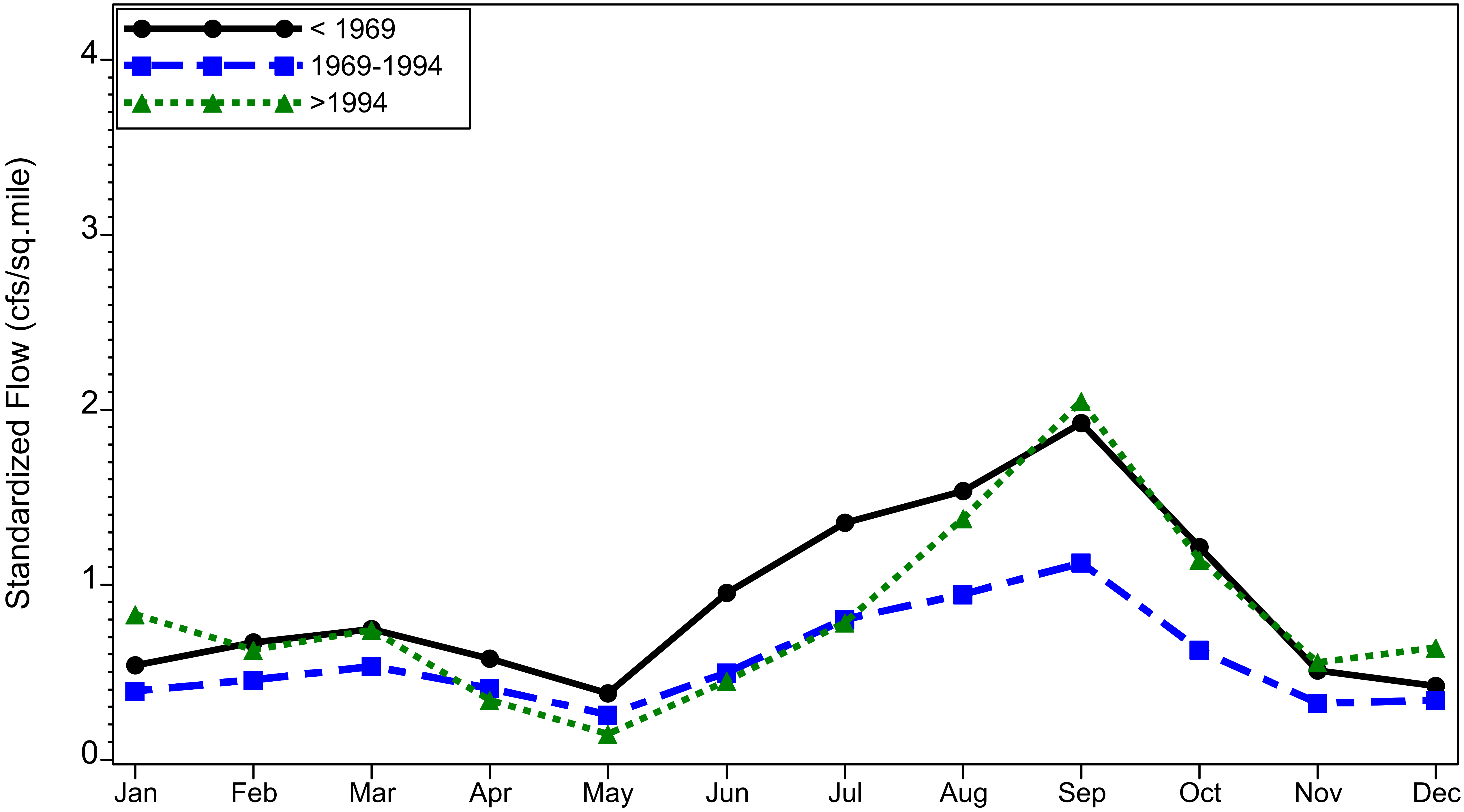


Figure 3.308 Seasonal differences among AMO periods of monthly mean flow at long-term Peace River at Zolfo (2295637) gage

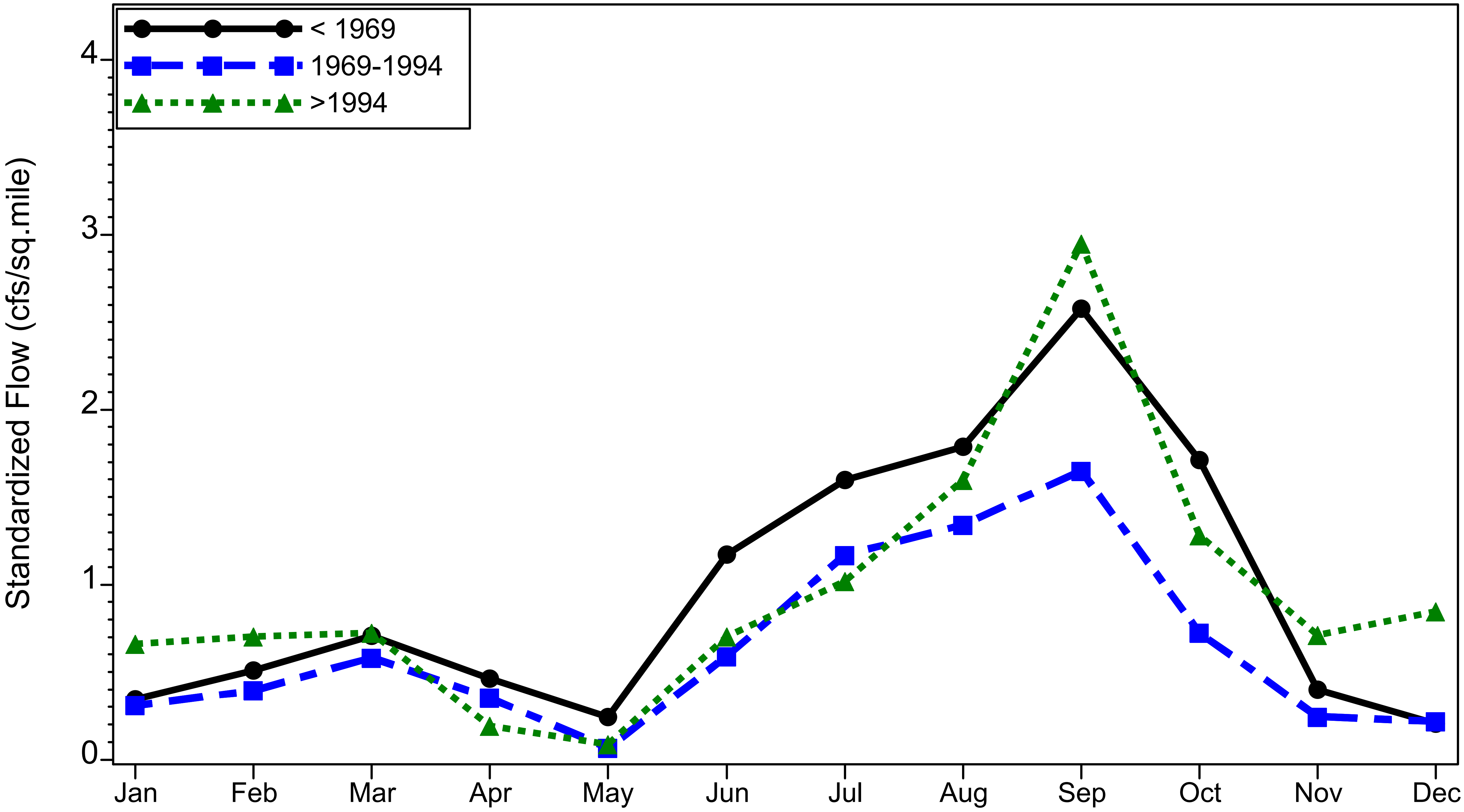


Figure 3.309 Seasonal differences among AMO periods of monthly mean flow at long-term Charlie Creek (2296500) gage

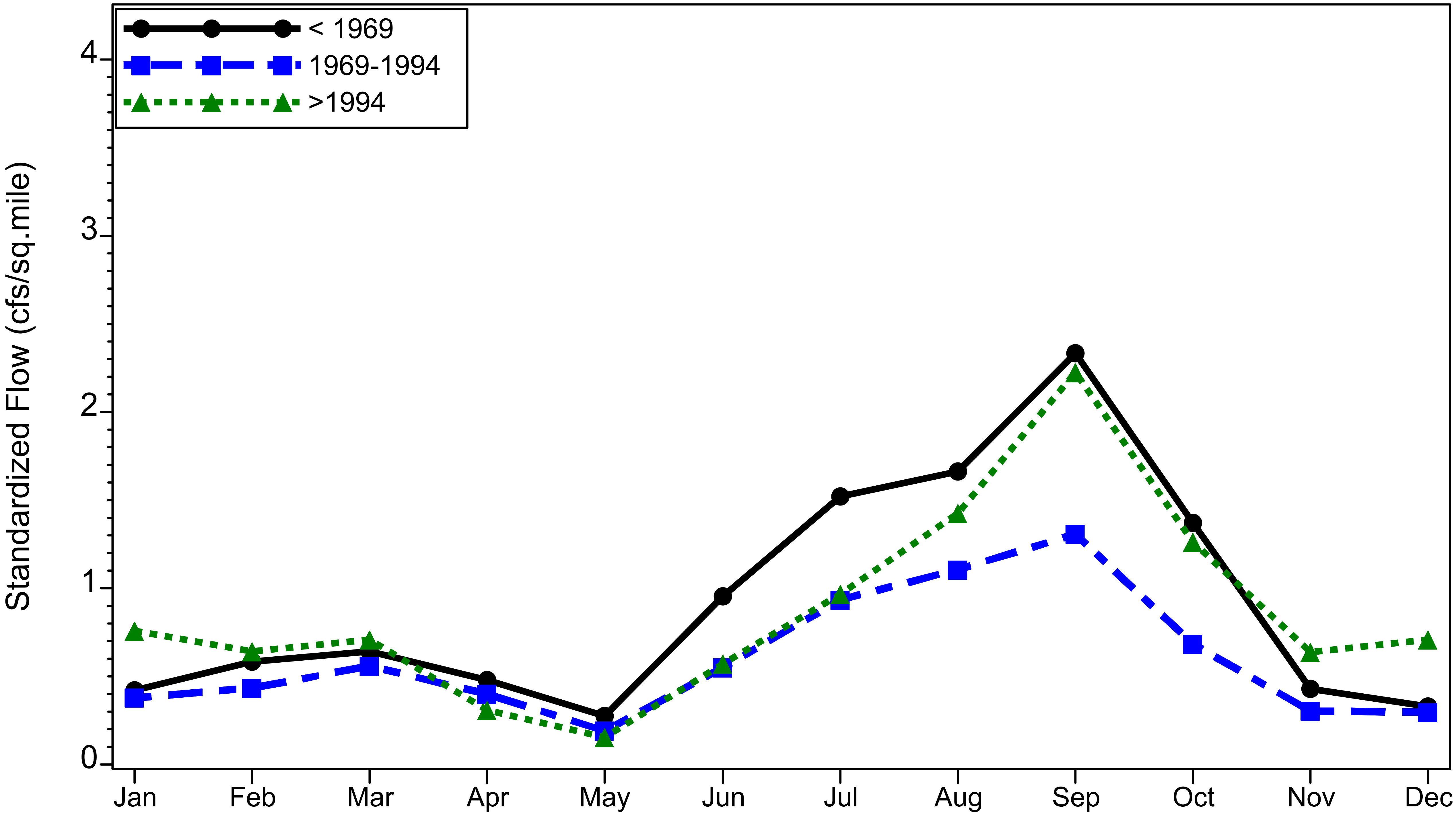


Figure 3.310 Seasonal differences among AMO periods of monthly mean flow at long-term Peace River at Arcadia (2296750) gage

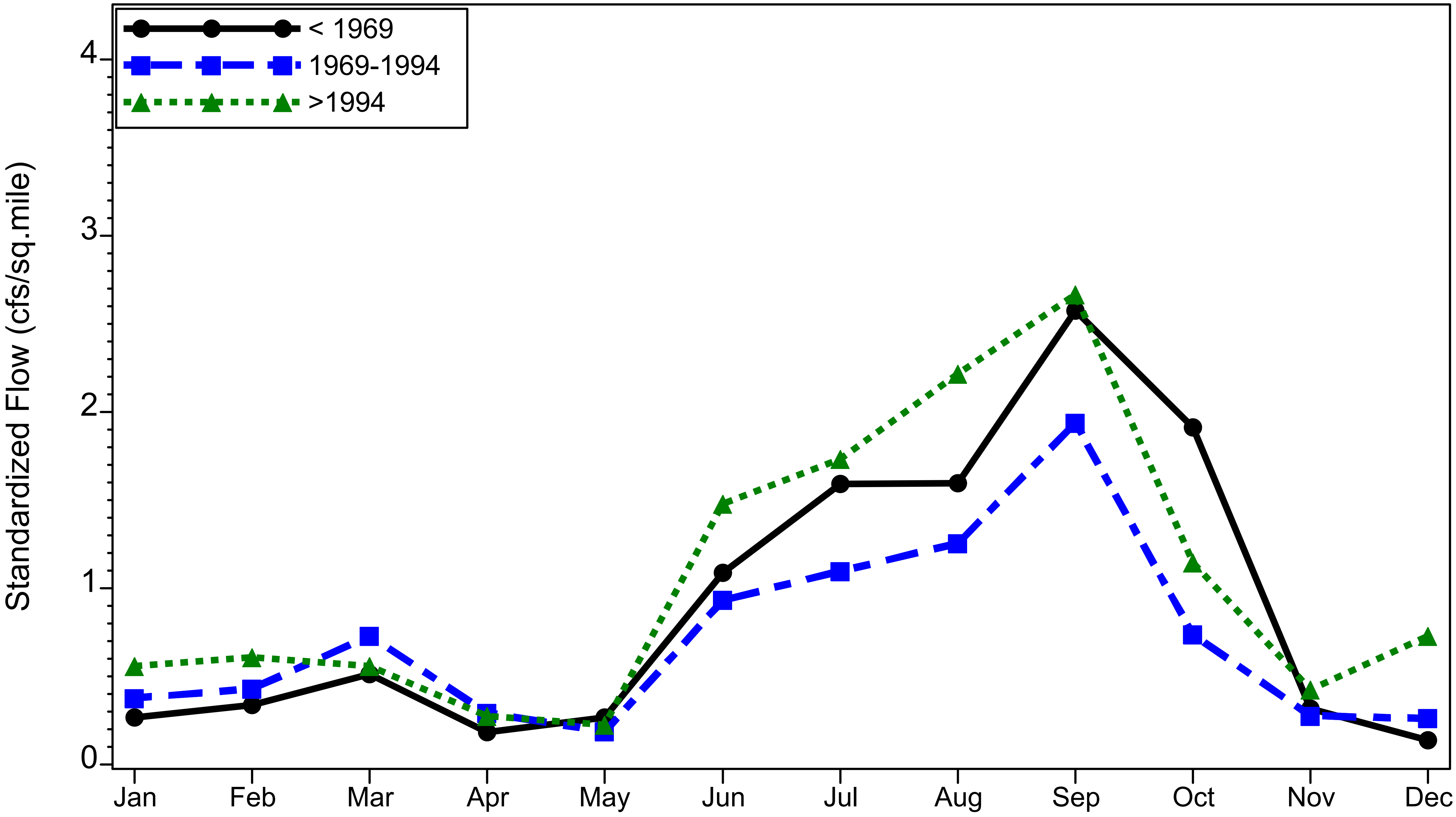


Figure 3.311 Seasonal differences among AMO periods of monthly mean flow at long-term Joshua Creek at Nocatee (2297100) gage

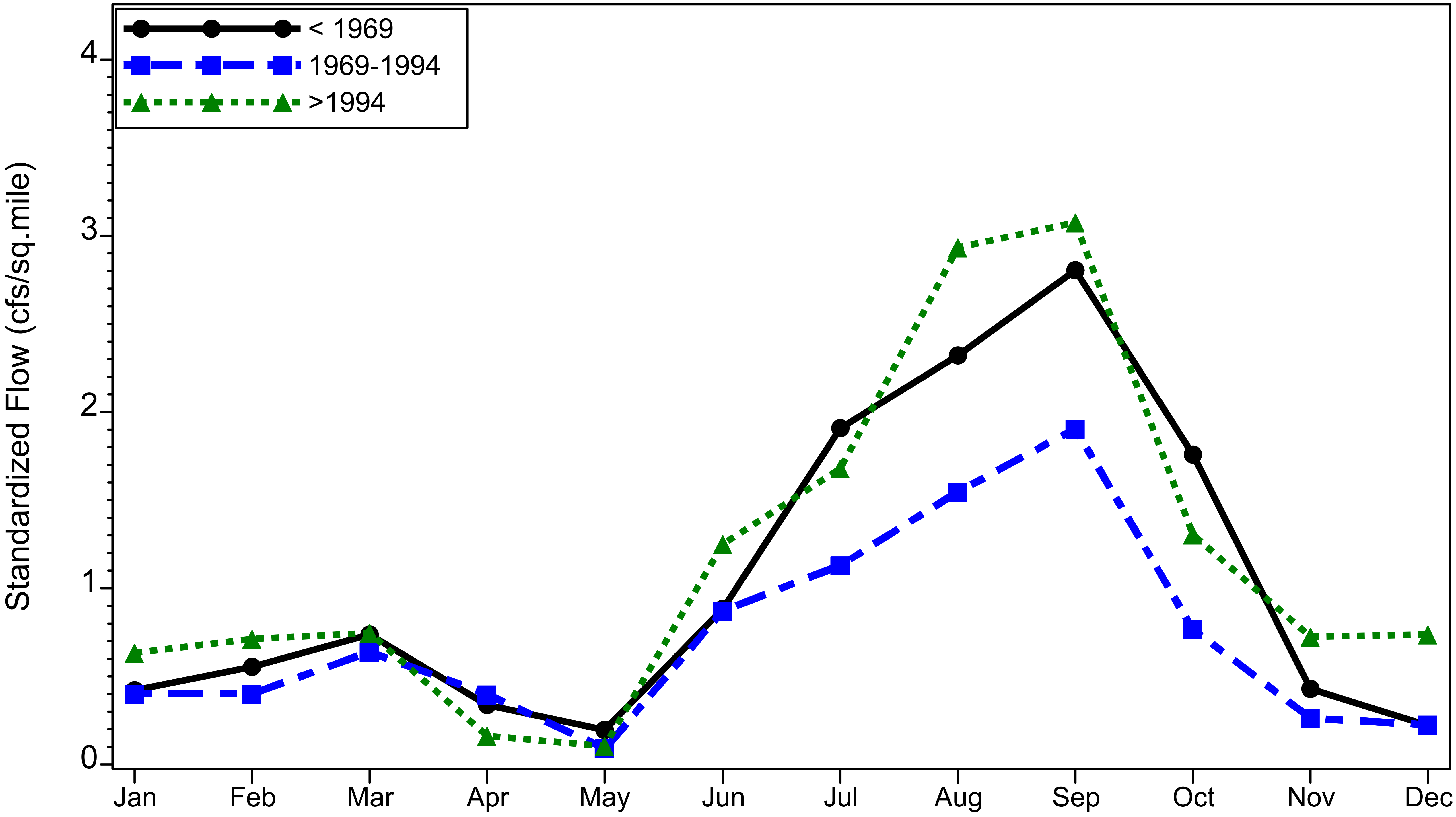


Figure 3.312 Seasonal differences among AMO periods of monthly mean flow at long-term Horse Creek near Arcadia (2297310) gage

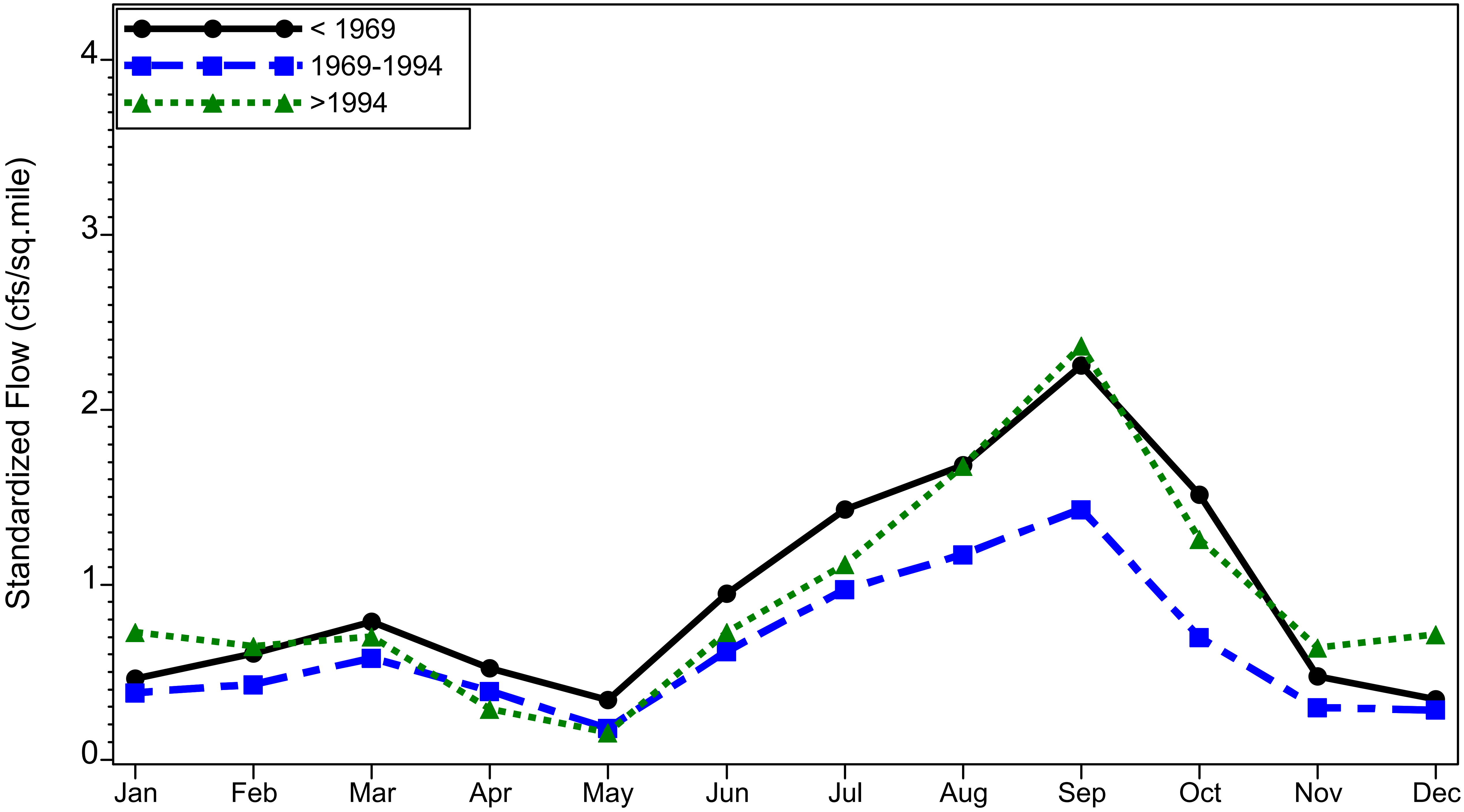


Figure 3.313 Seasonal differences among AMO periods of monthly mean total gaged flow upstream of the Facility

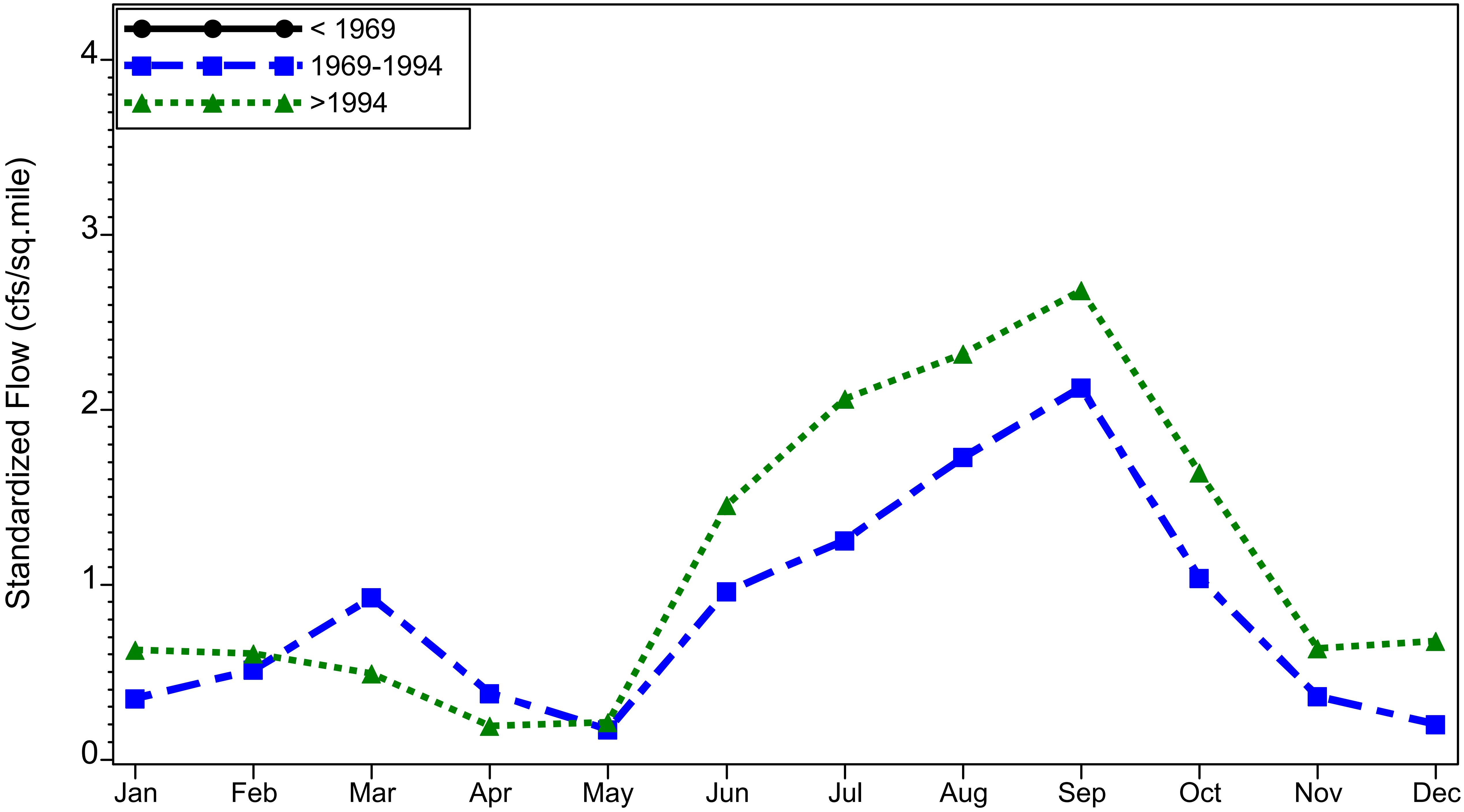


Figure 3.314 Seasonal differences among AMO periods of monthly mean flow at long-term Prairie Creek (2298123) gage

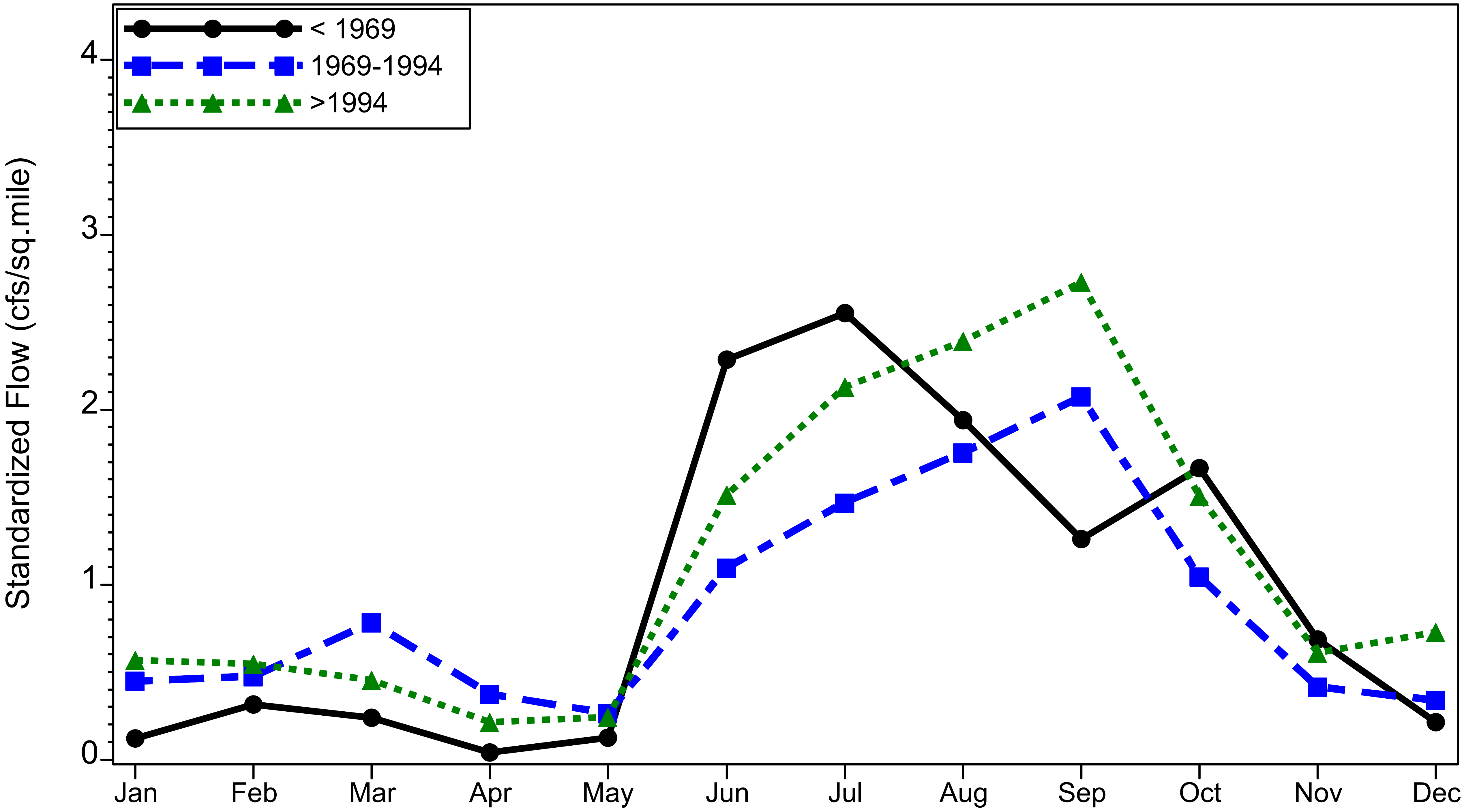


Figure 3.315 Seasonal differences among AMO periods of monthly mean flow at long-term Shell Creek gage

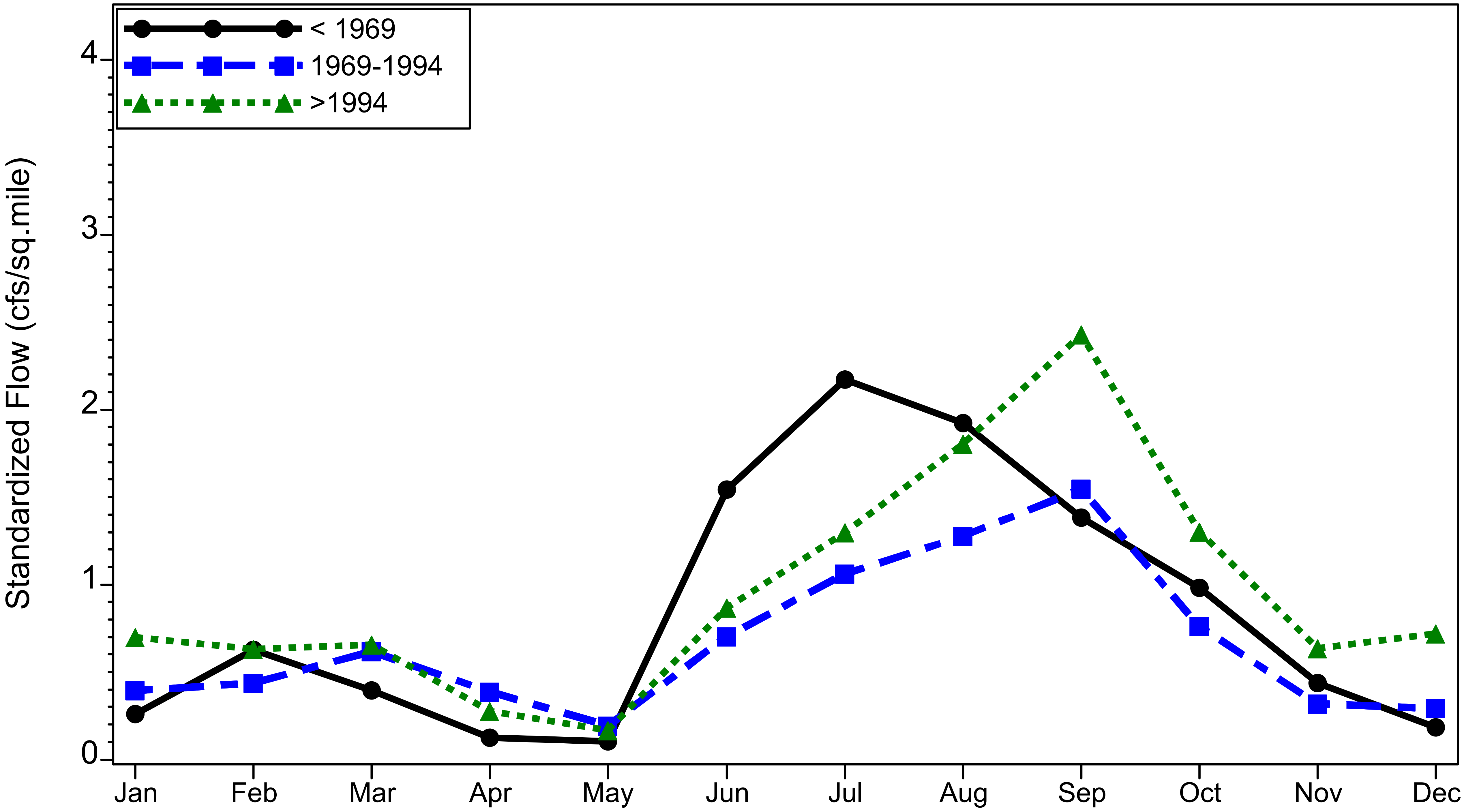


Figure 3.316 Seasonal differences among AMO periods of monthly mean total gaged flow to the Upper Harbor

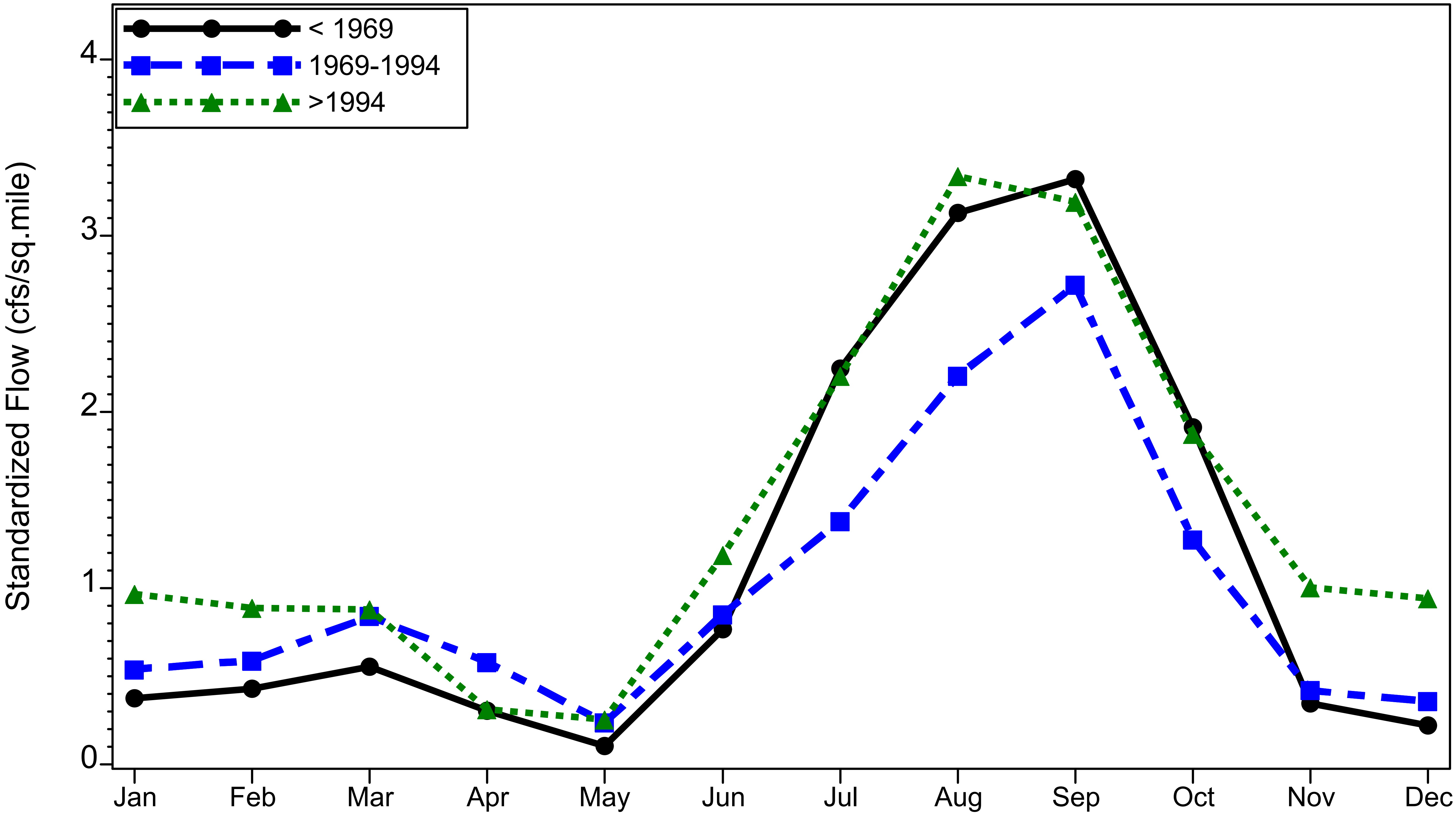


Figure 3.317 Seasonal differences among AMO periods of monthly mean flow at long-term Myakka River near Sarasota (2298830) gage

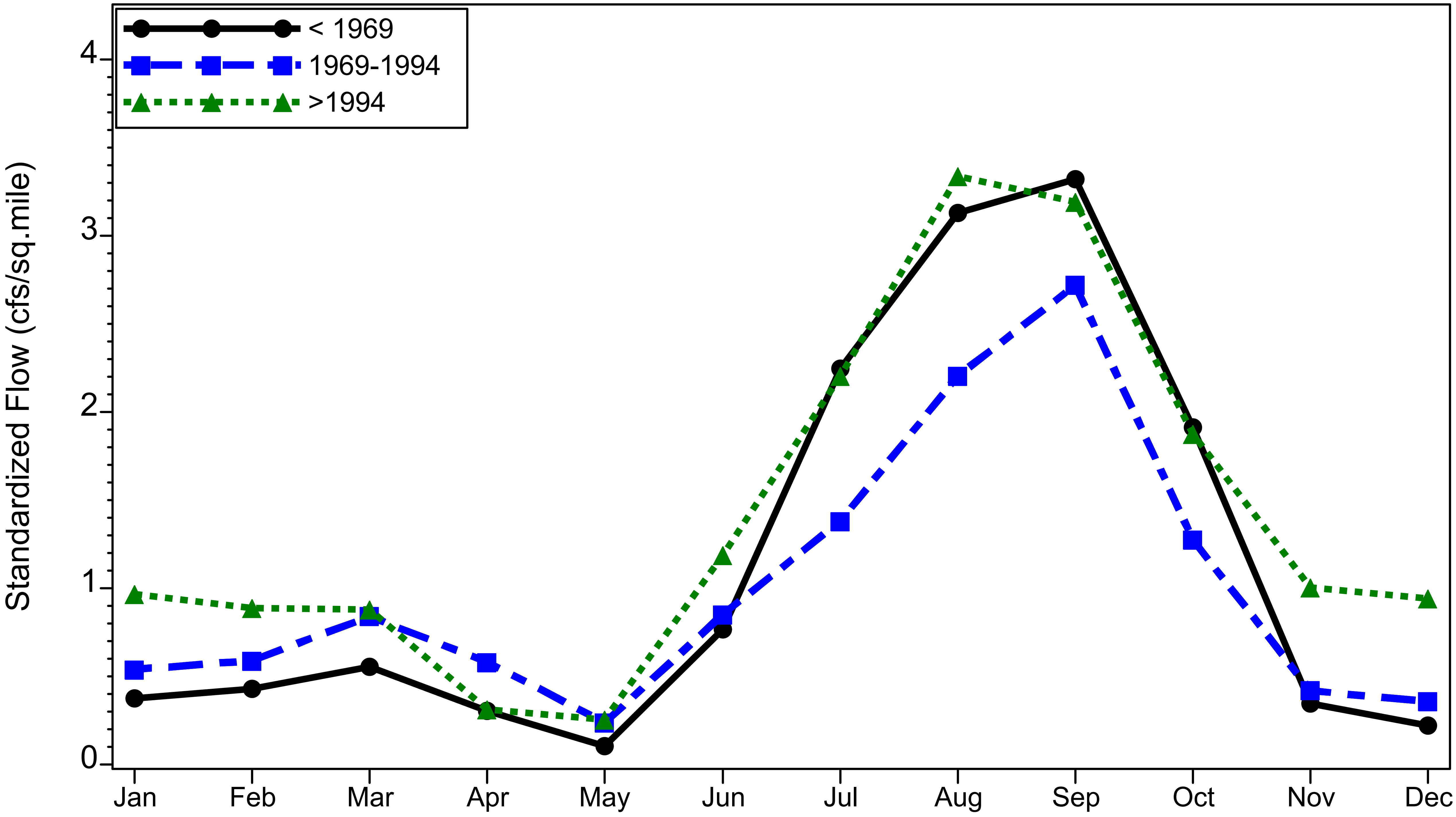


Figure 3.317 Seasonal differences among AMO periods of monthly mean flow at long-term Myakka River near Sarasota (2298830) gage

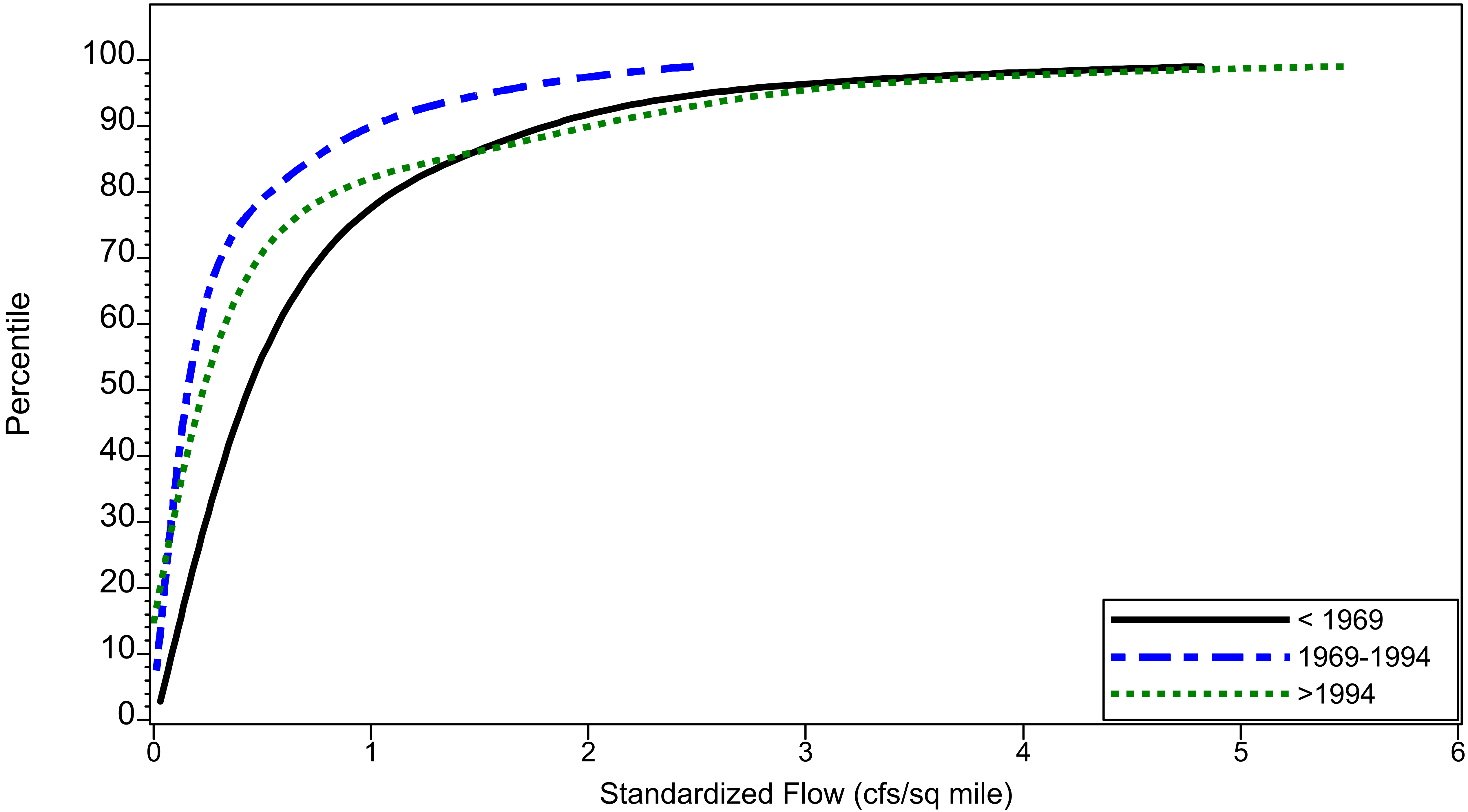


Figure 3.318 Differences in CDFs among AMO periods in flow at long-term Peace River at Bartow (2294650) gage

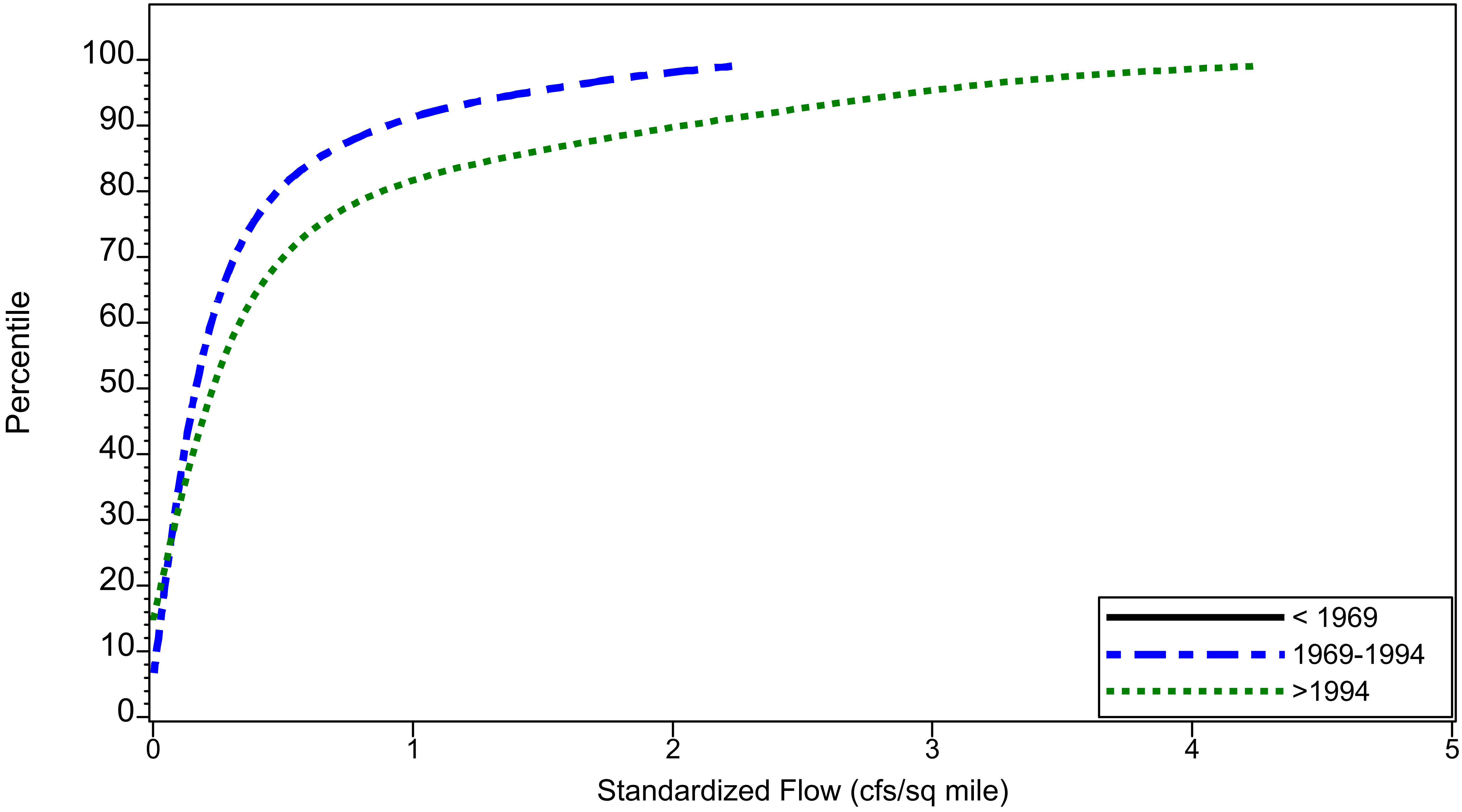


Figure 3.319 Differences in CDFs among AMO periods in flow at long-term Peace River at Ft. Meade (2294898) gage

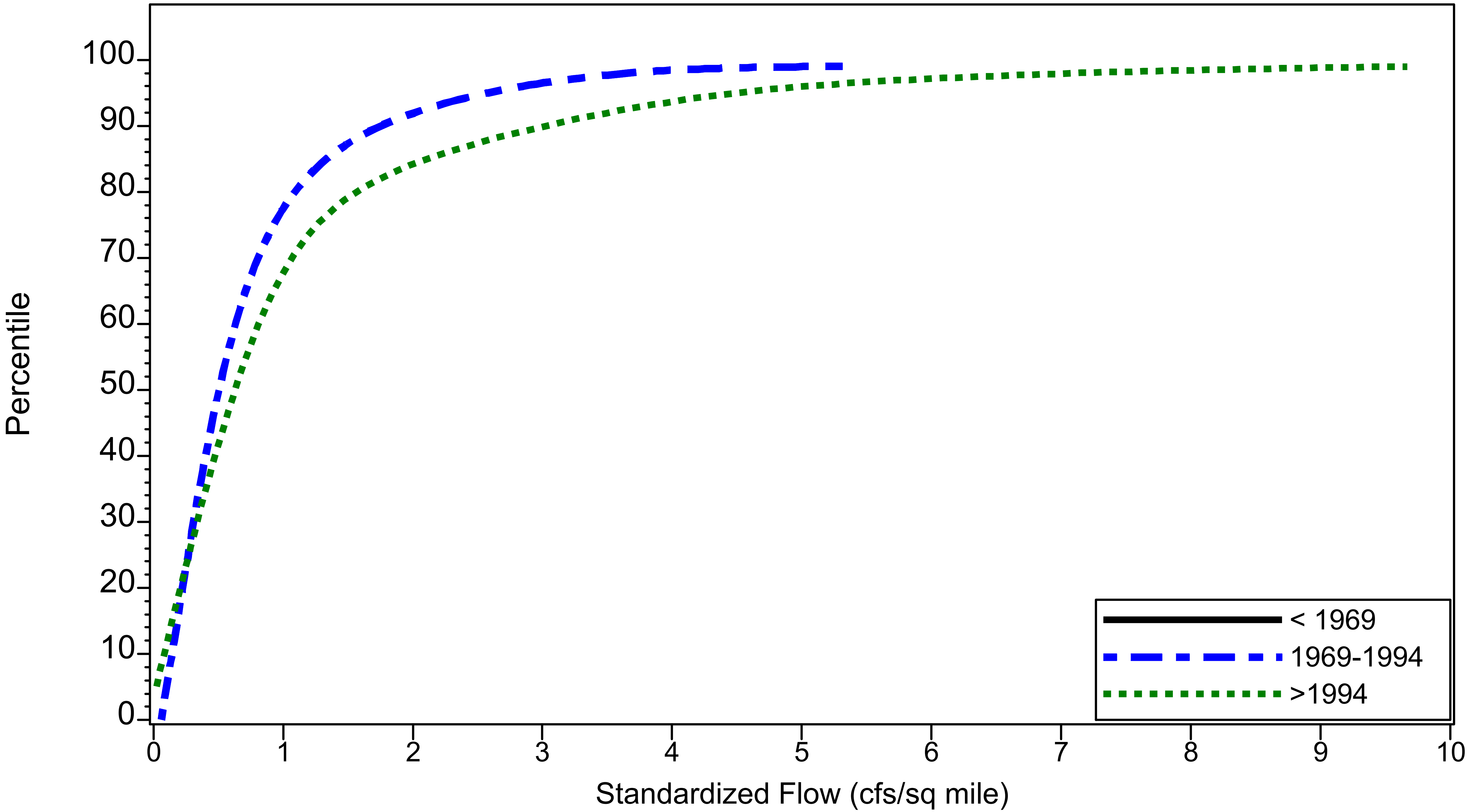


Figure 3.320 Differences in CDFs among AMO periods in flow at long-term Payne Creek (2295420) gage

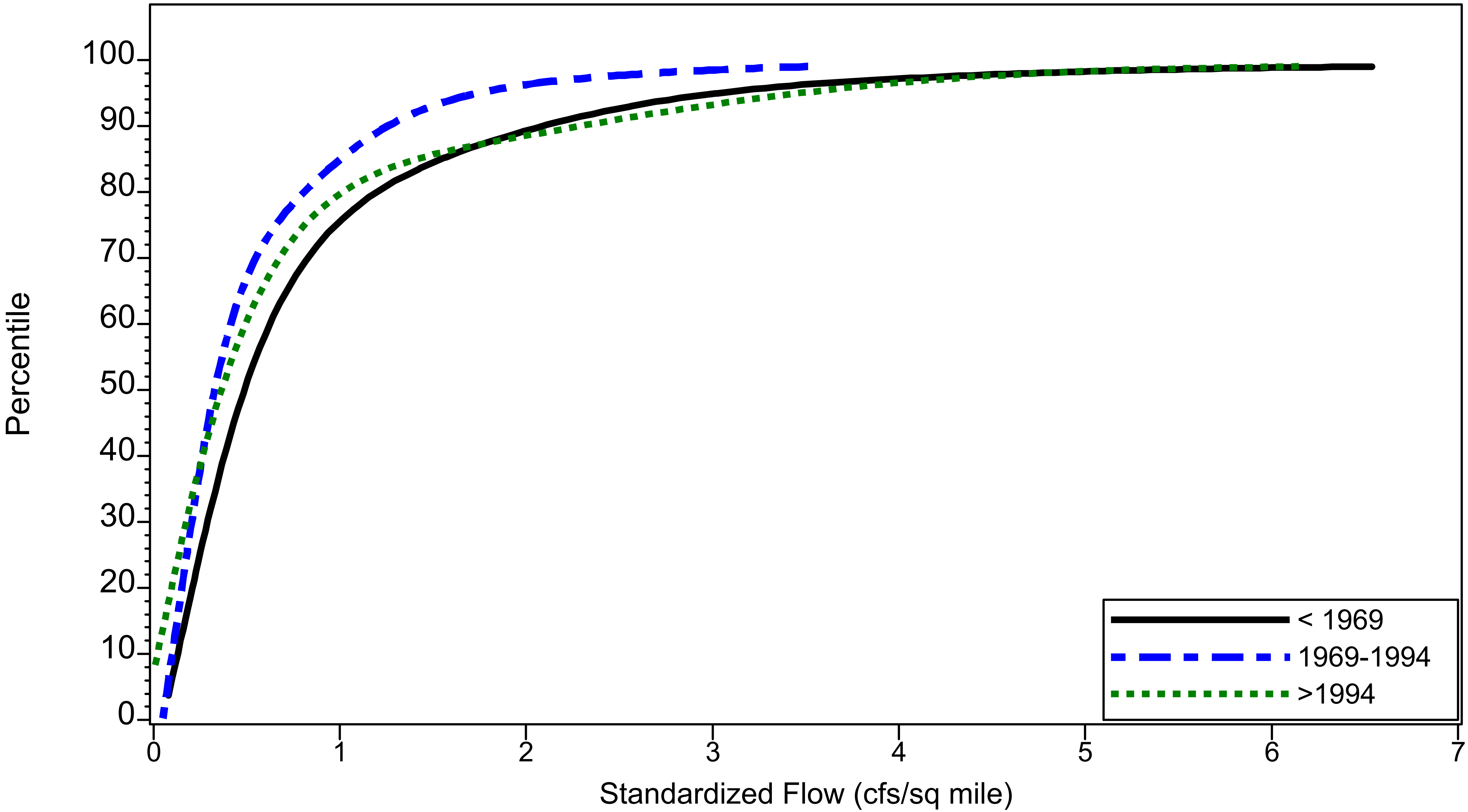


Figure 3.321 Differences in CDFs among AMO periods in flow at long-term Peace River at Zolfo (2295637) gage

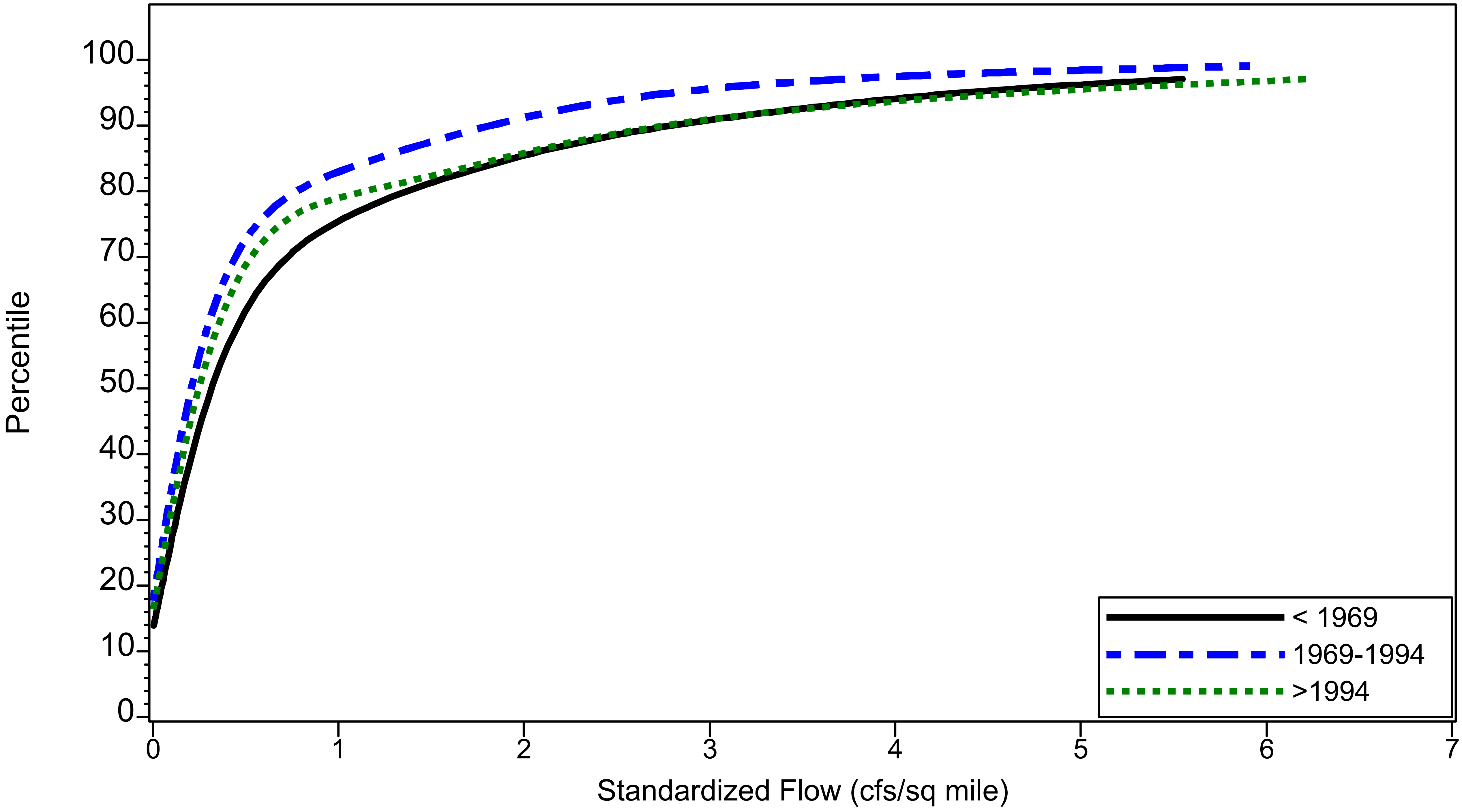


Figure 3.322 Differences in CDFs among AMO periods in flow at long-term Charlie Creek (2296500) gage

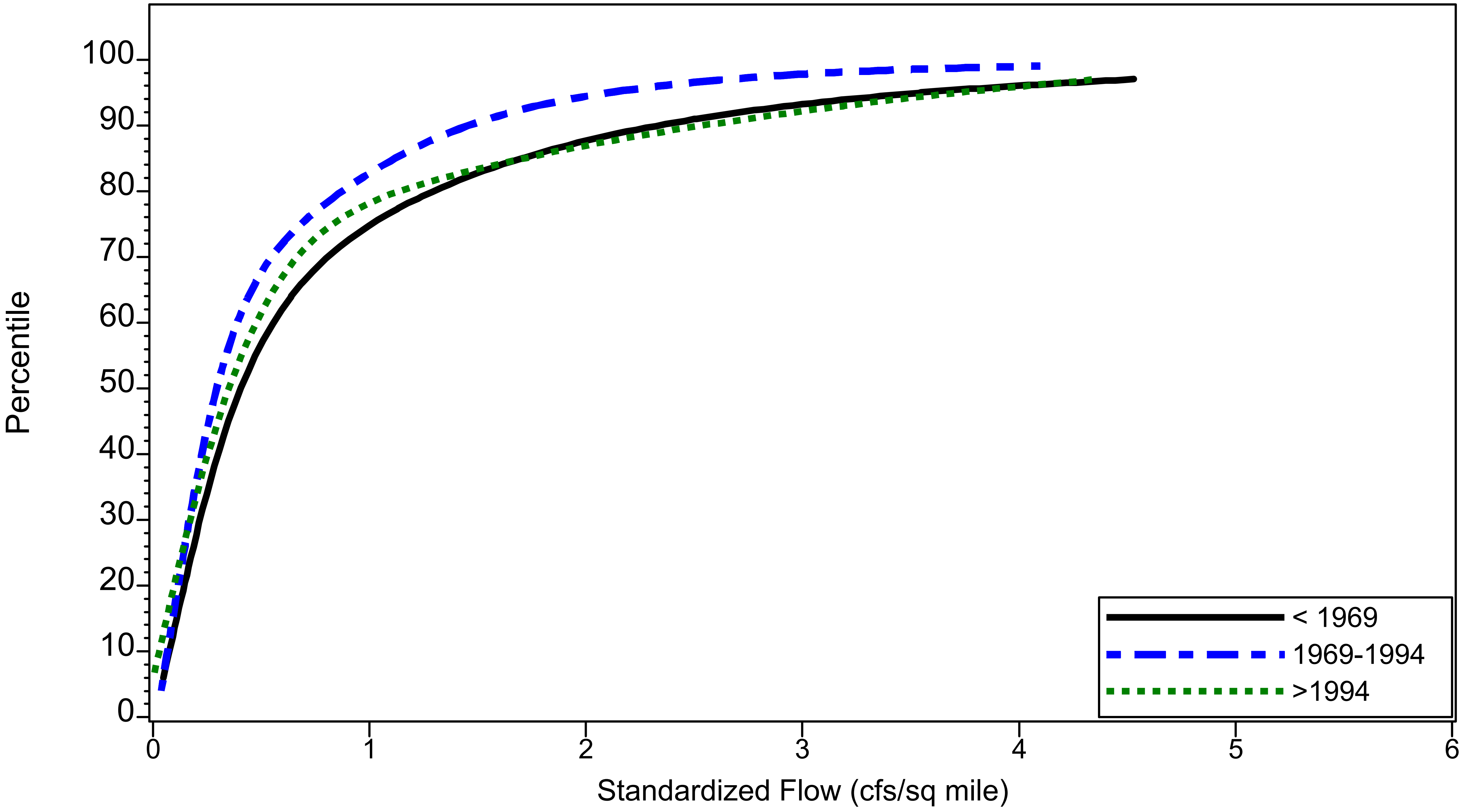


Figure 3.323 Differences in CDFs among AMO periods in flow at long-term Peace River at Arcadia (2296750) gage

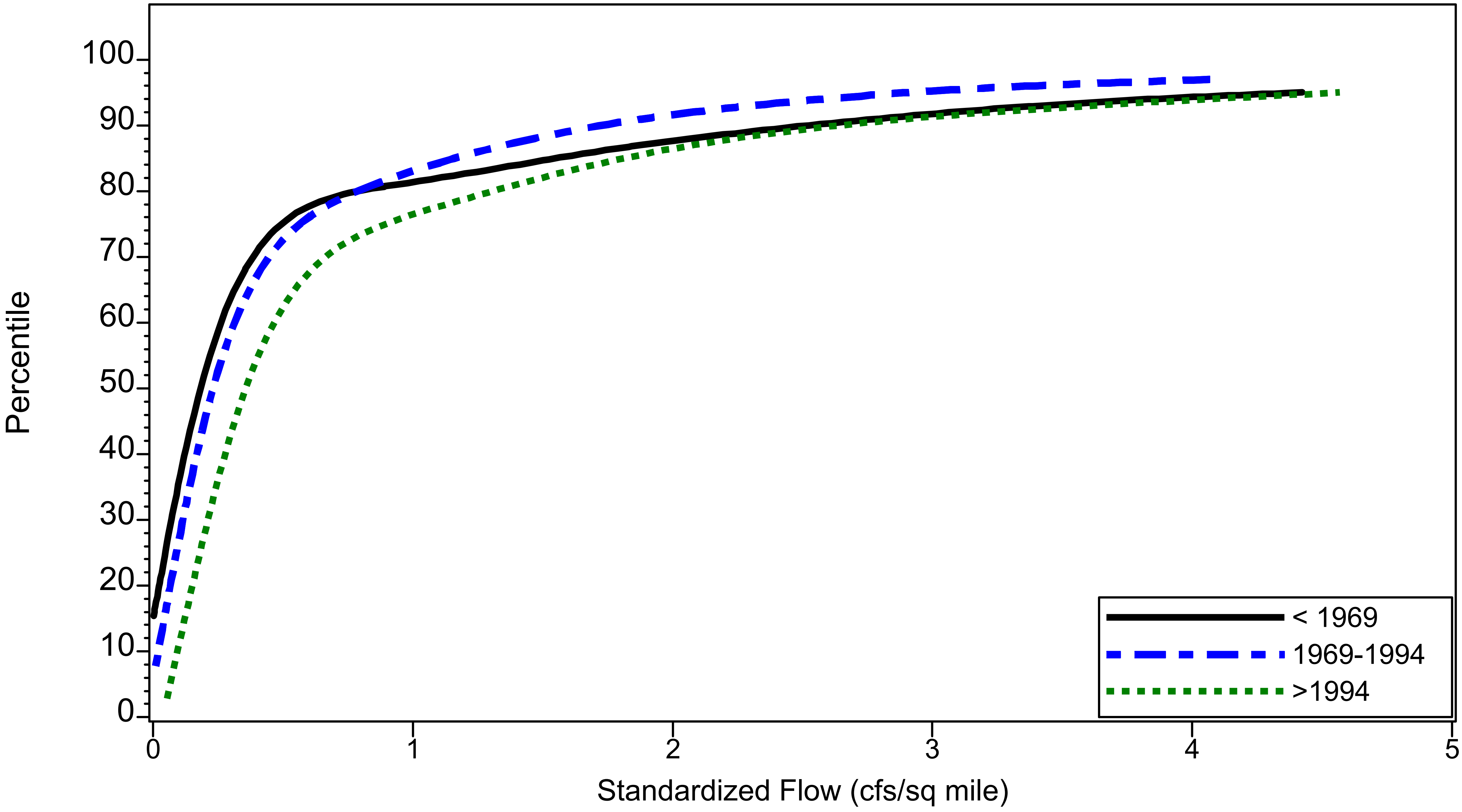


Figure 3.324 Differences in CDFs among AMO periods in flow at long-term Joshua Creek at Nocatee (2297100) gage

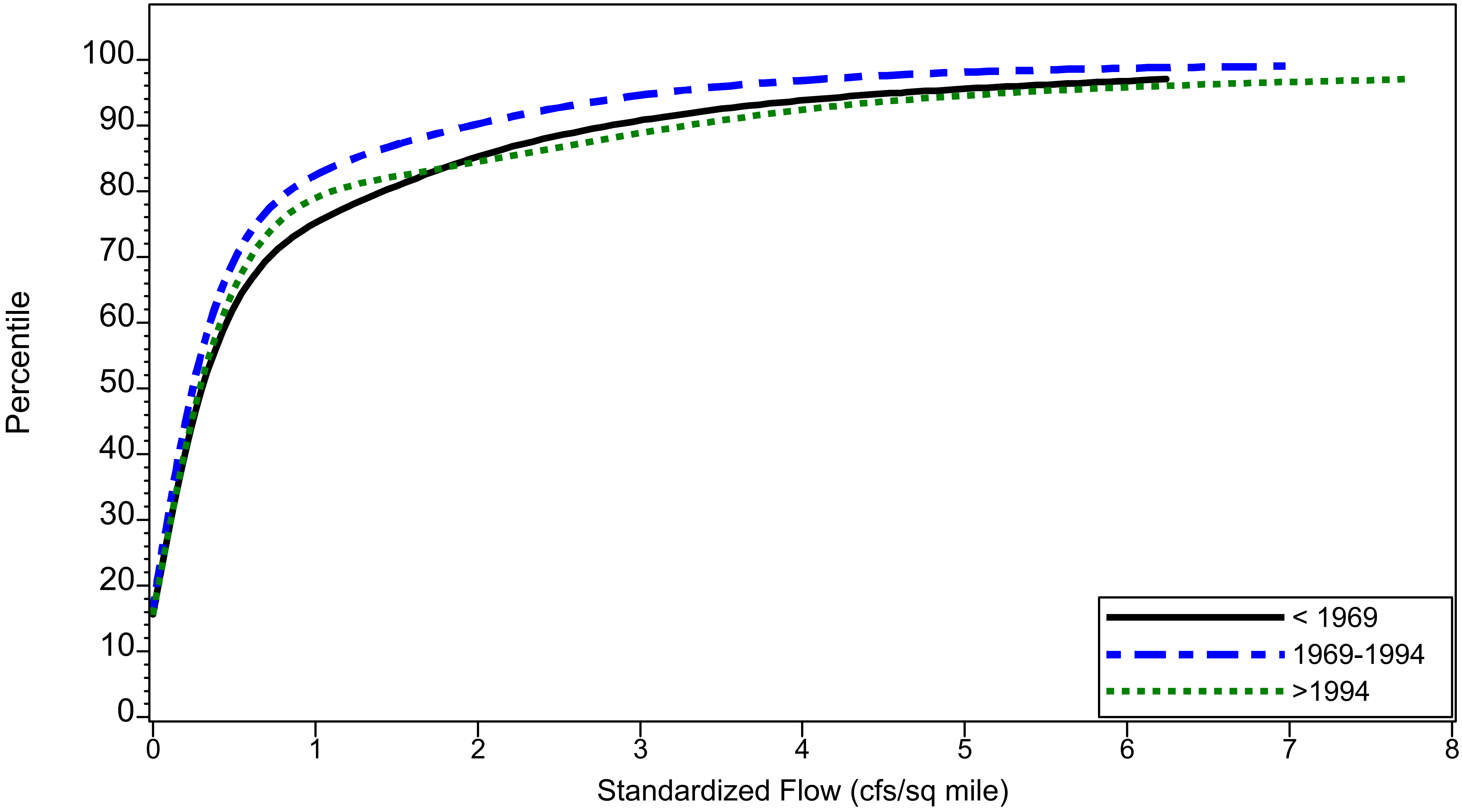


Figure 3.325 Differences in CDFs among AMO periods in flow at long-term Horse Creek near Arcadia (2297310) gage

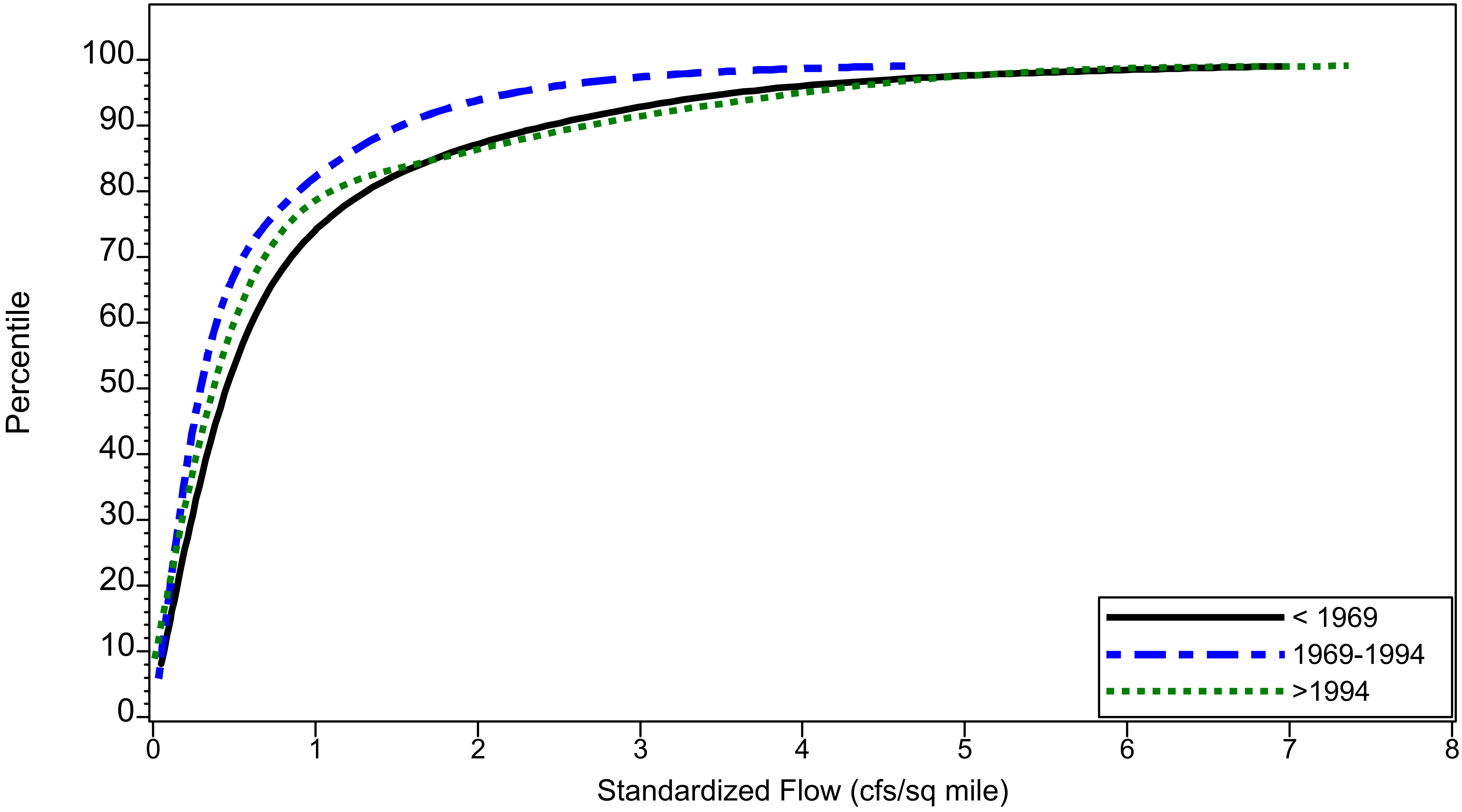


Figure 3.326 Differences in CDFs among AMO periods in total gaged flow upstream of the Facility

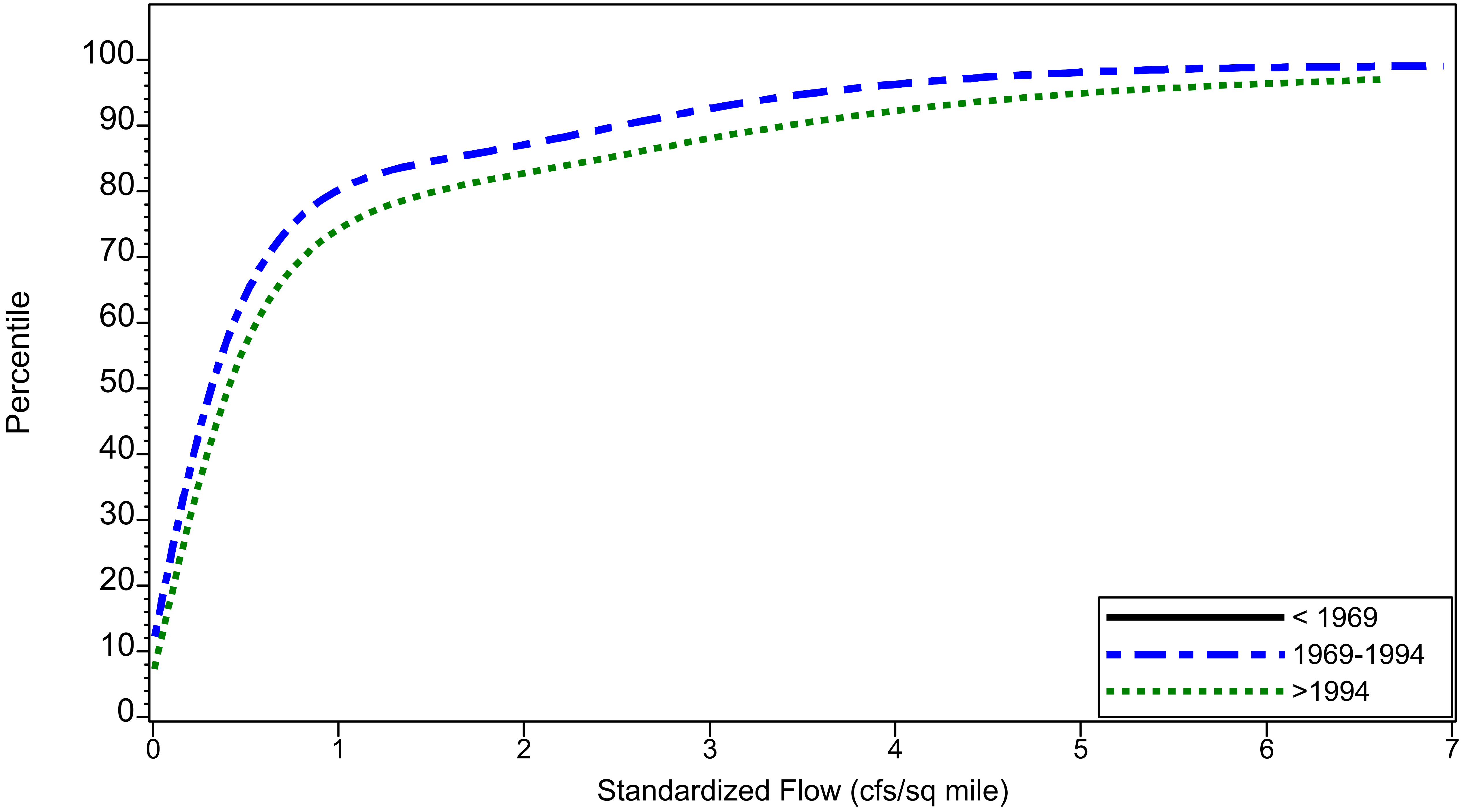


Figure 3.327 Differences in CDFs among AMO periods in flow at long-term Prairie Creek (2298123) gage

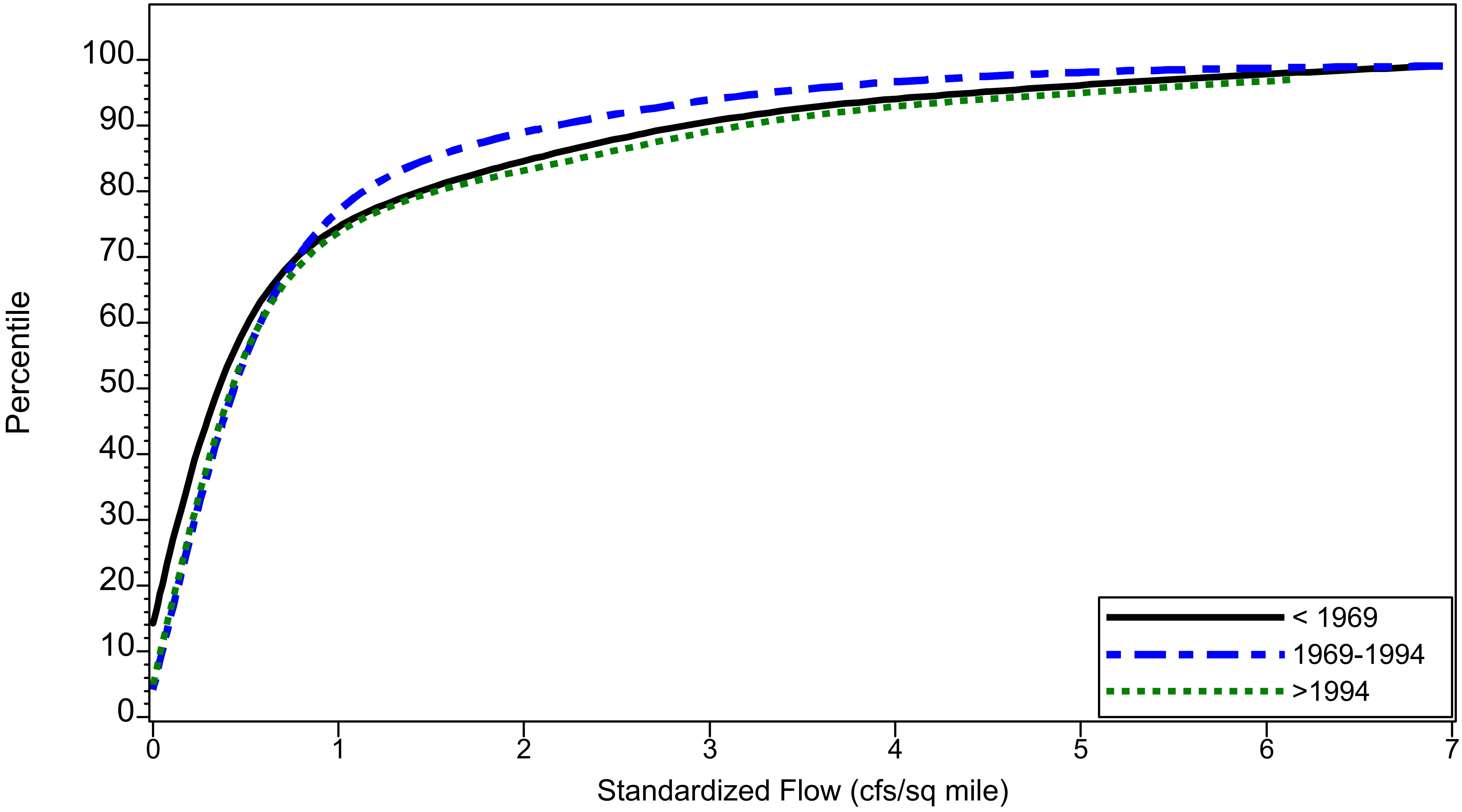


Figure 3.328 Differences in CDFs among AMO periods in flow at long-term Shell Creek gage

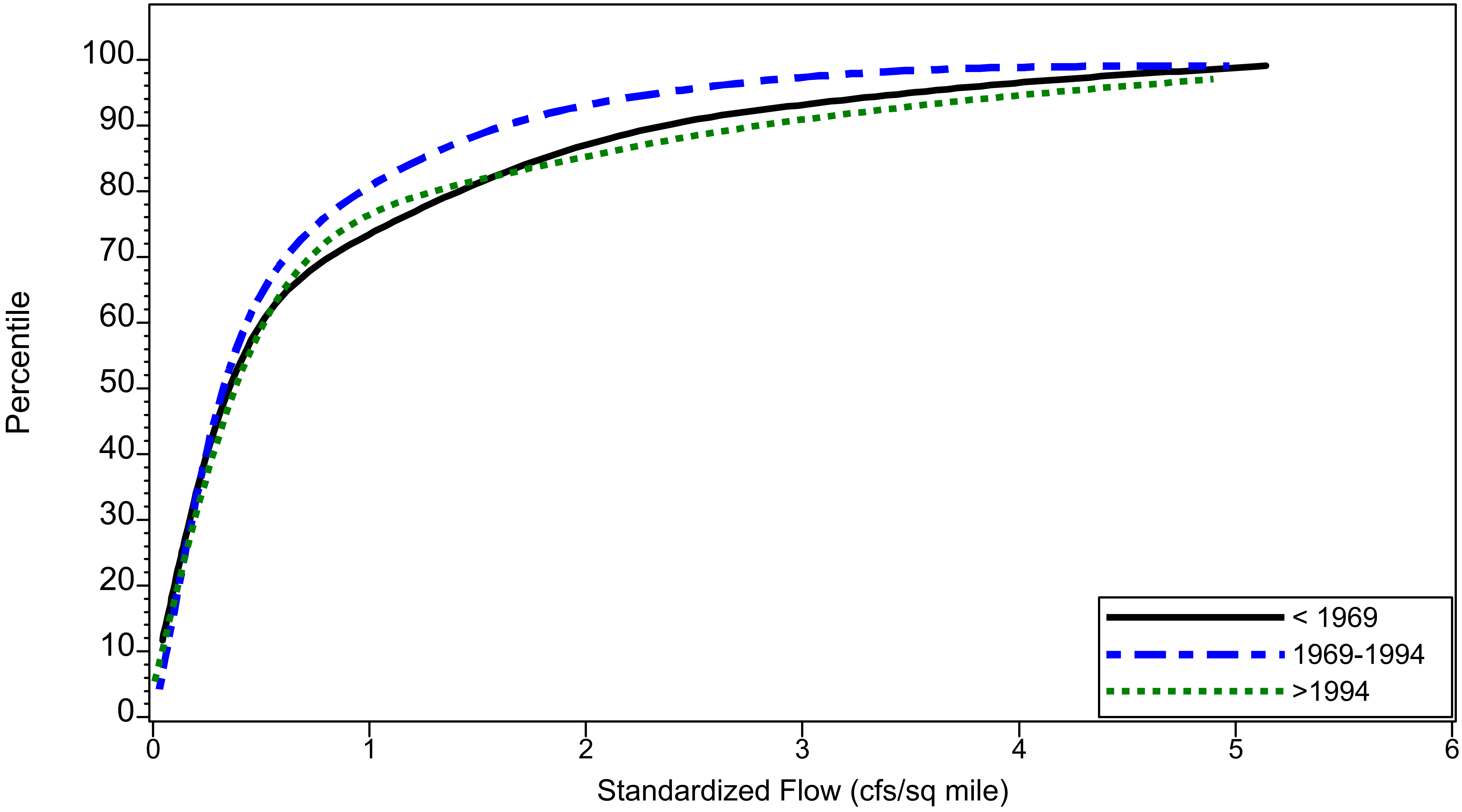


Figure 3.329 Differences in CDFs among AMO periods in total gaged Peace River flow to the Upper Harbor

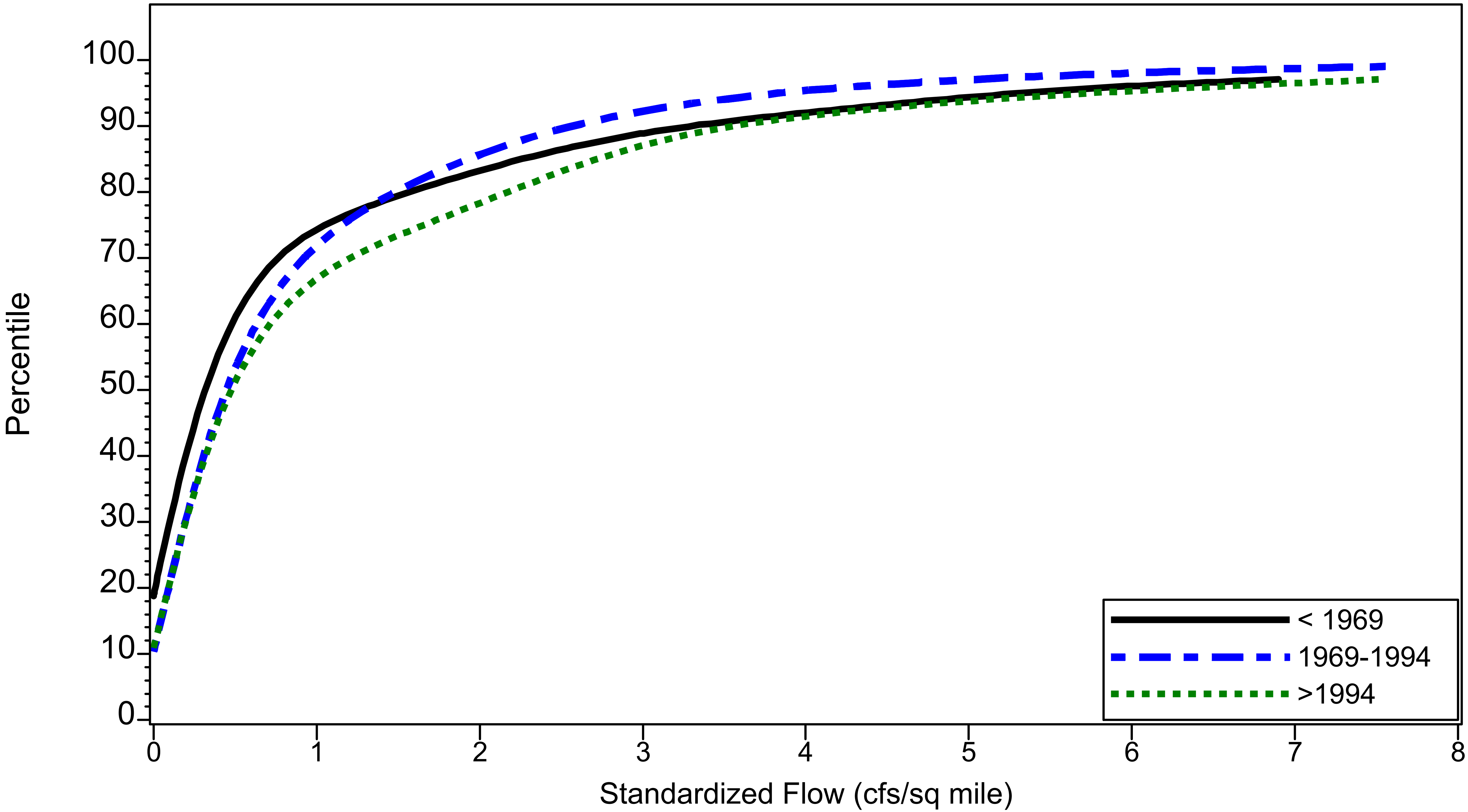


Figure 3.330 Differences in CDFs among AMO periods in flow at long-term Myakka River near Sarasota (2298830) gage

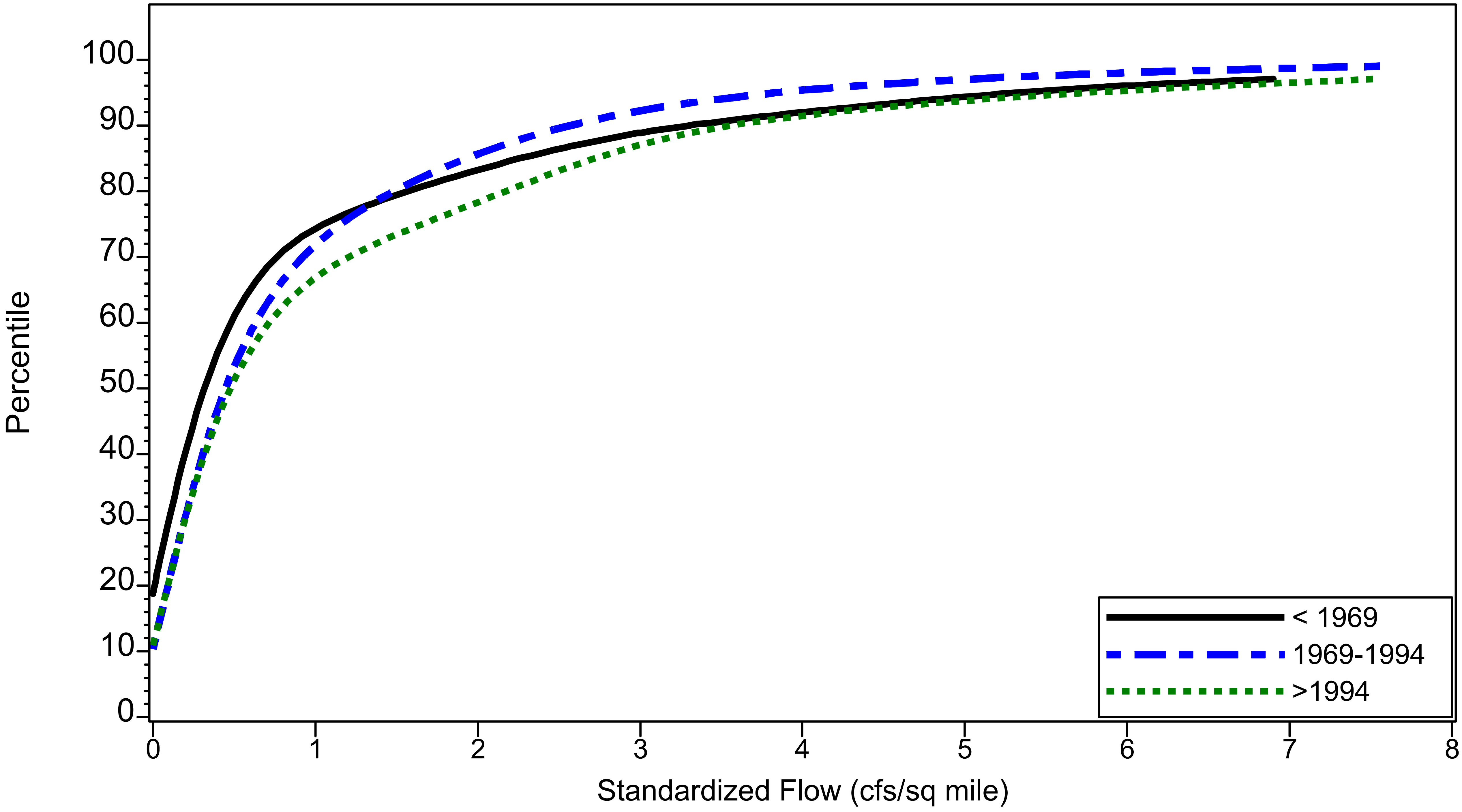


Figure 3.330 Differences in CDFs among AMO periods in flow at long-term Myakka River near Sarasota (2298830) gage

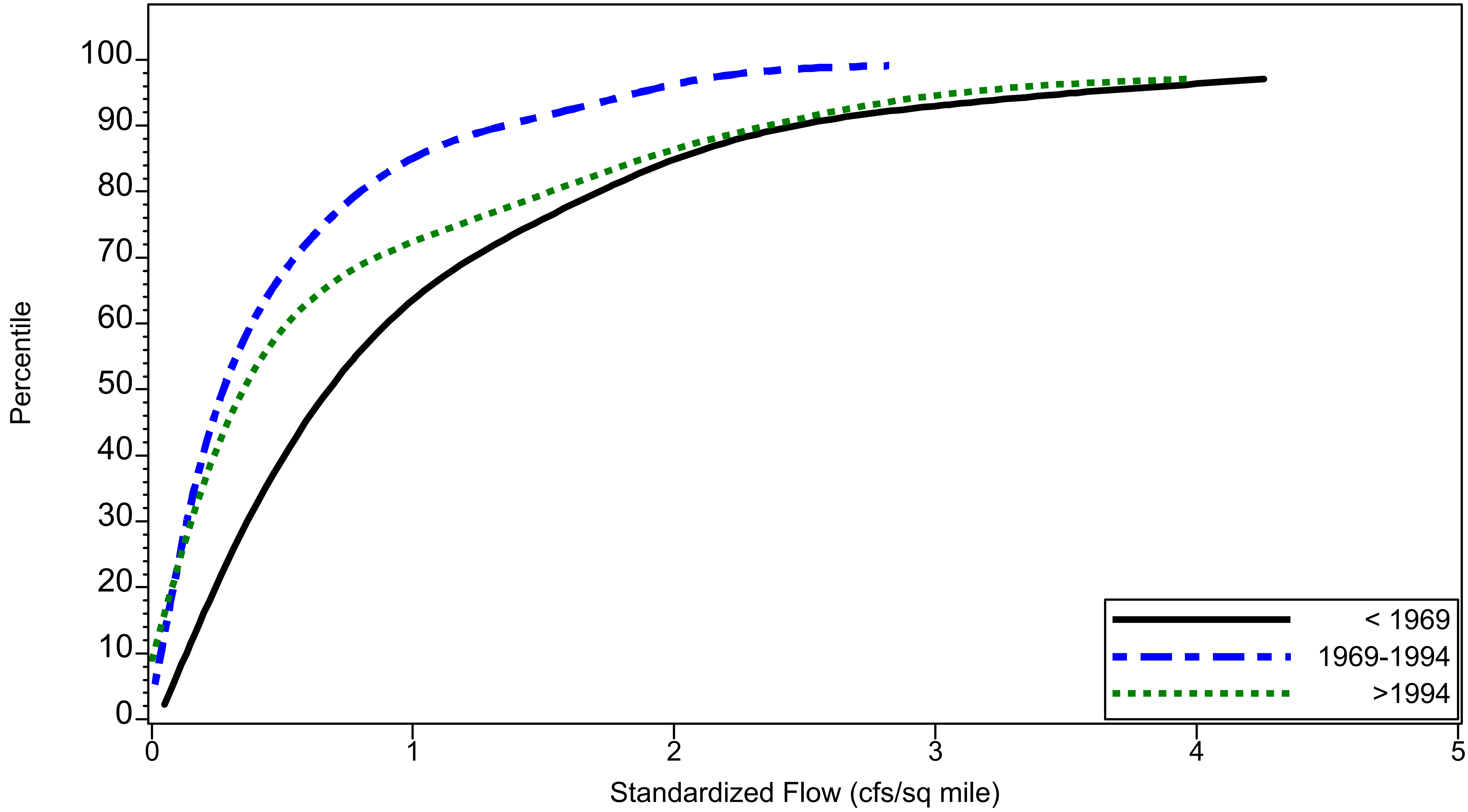


Figure 3.331 Wet season differences in CDFs among AMO periods in flow at long-term Peace River at Bartow (2294650) gage

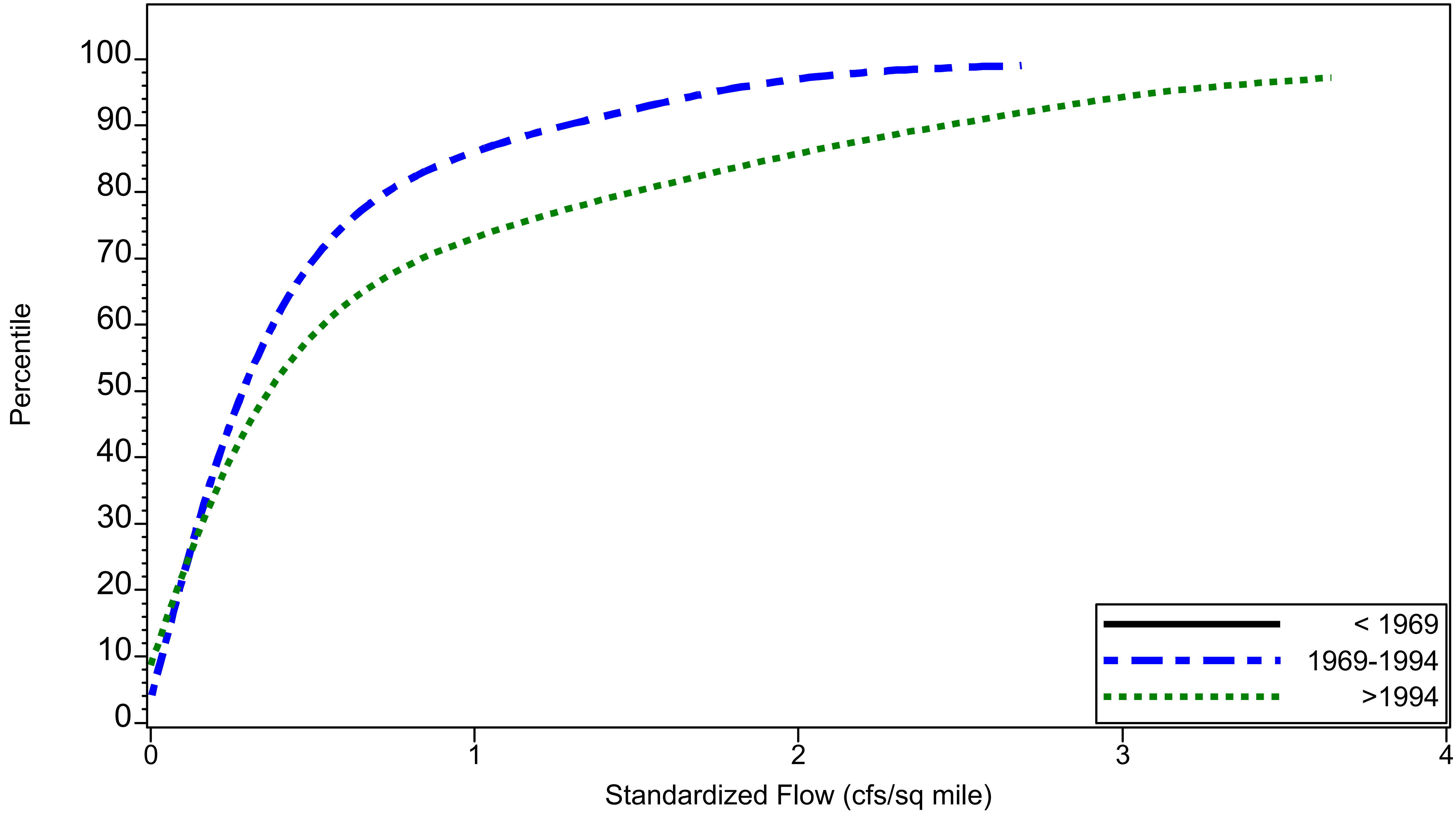


Figure 3.332 Wet season differences in CDFs among AMO periods in flow at long-term Peace River at Ft. Meade (2294898) gage

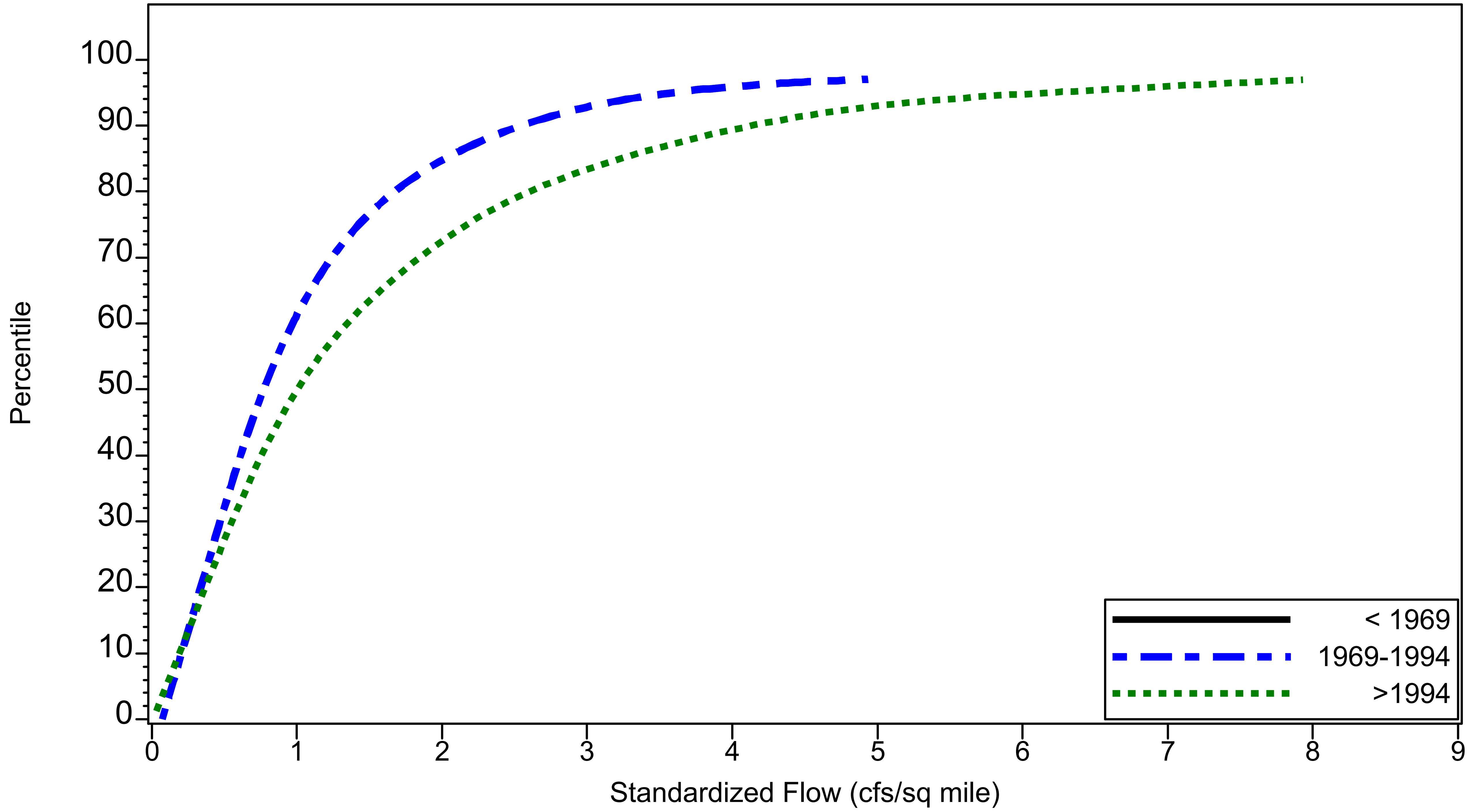


Figure 3.333 Wet season differences in CDFs among AMO periods in flow at long-term Payne Creek (2295420) gage

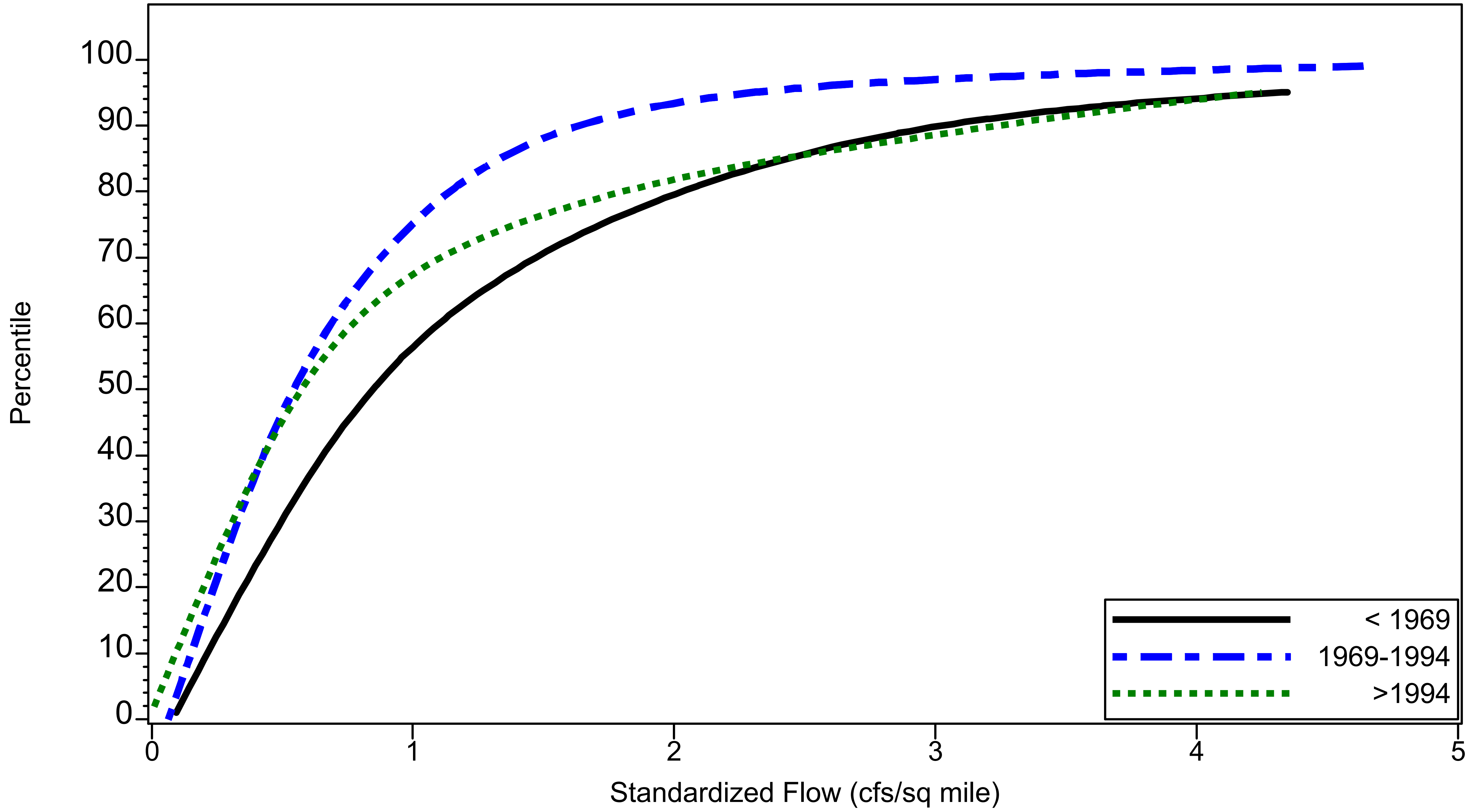


Figure 3.334 Wet season differences in CDFs among AMO periods in flow at long-term Peace River at Zolfo (2295637) gage

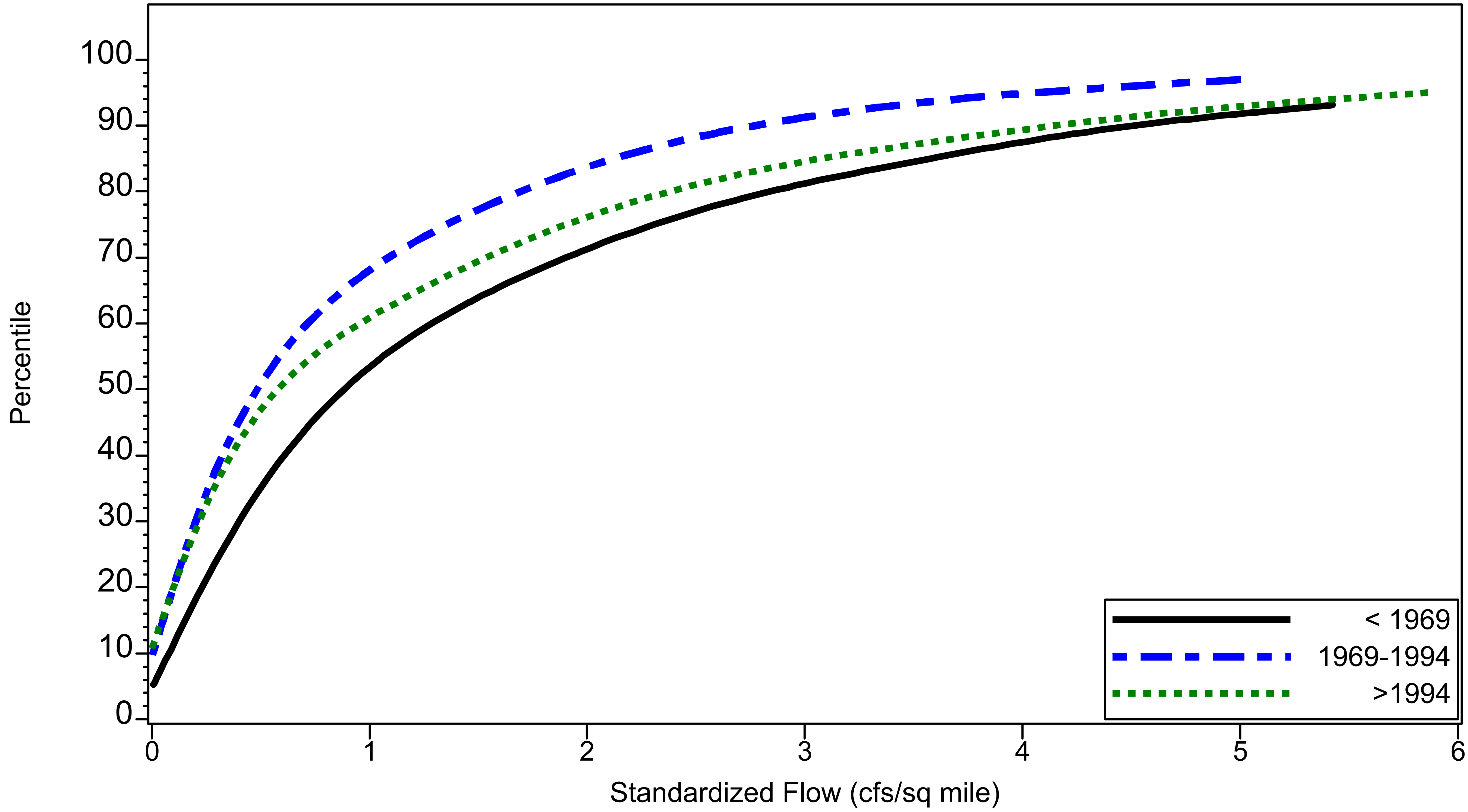


Figure 3.335 Wet season differences in CDFs among AMO periods in flow at long-term Charlie Creek (2296500) gage

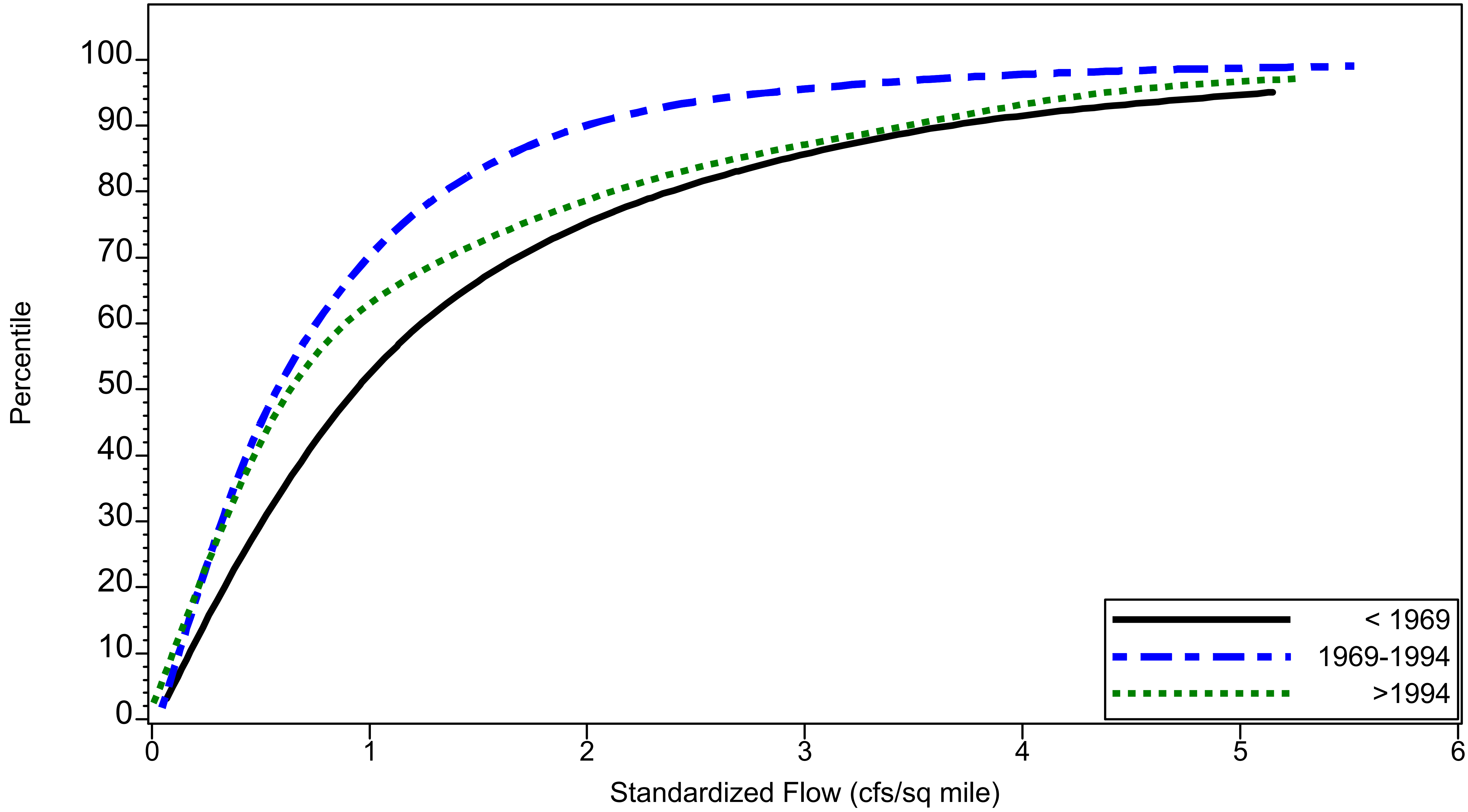


Figure 3.336 Wet season differences in CDFs among AMO periods in flow at long-term Peace River at Arcadia (2296750) gage

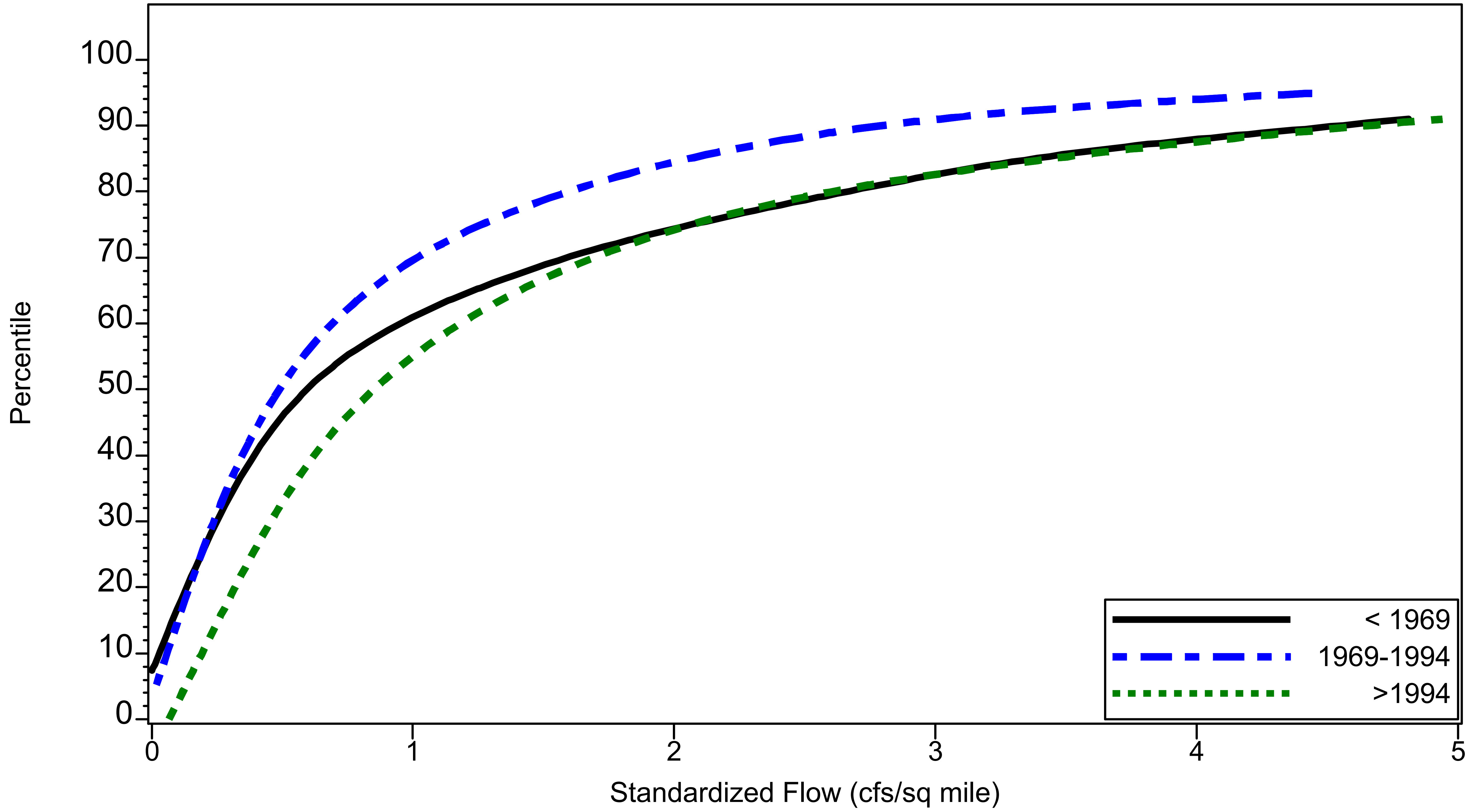


Figure 3.337 Wet season differences in CDFs among AMO periods in flow at long-term Joshua Creek at Nocatee (2297100) gage

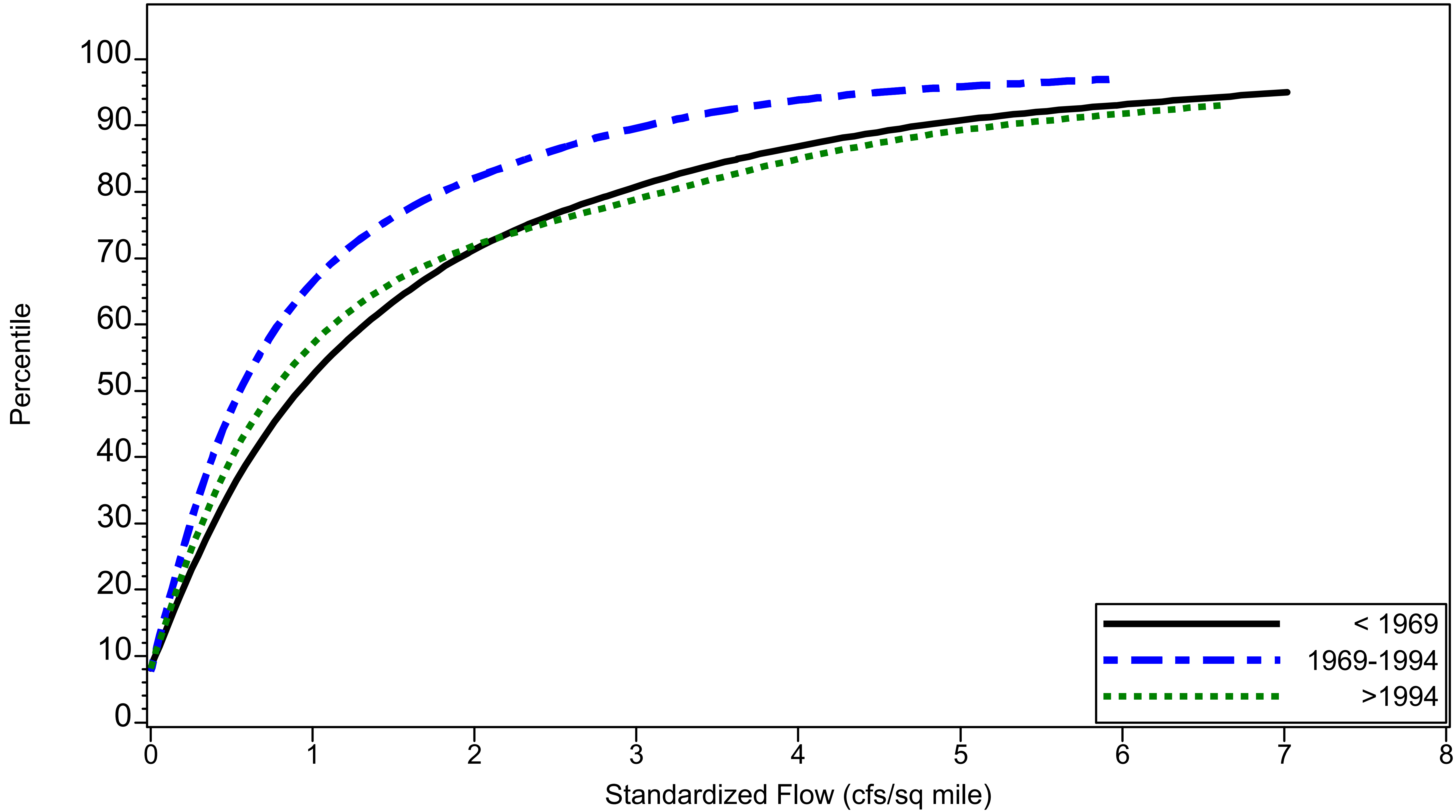


Figure 3.338 Wet season differences in CDFs among AMO periods in flow at long-term Horse Creek near Arcadia (2297310) gage

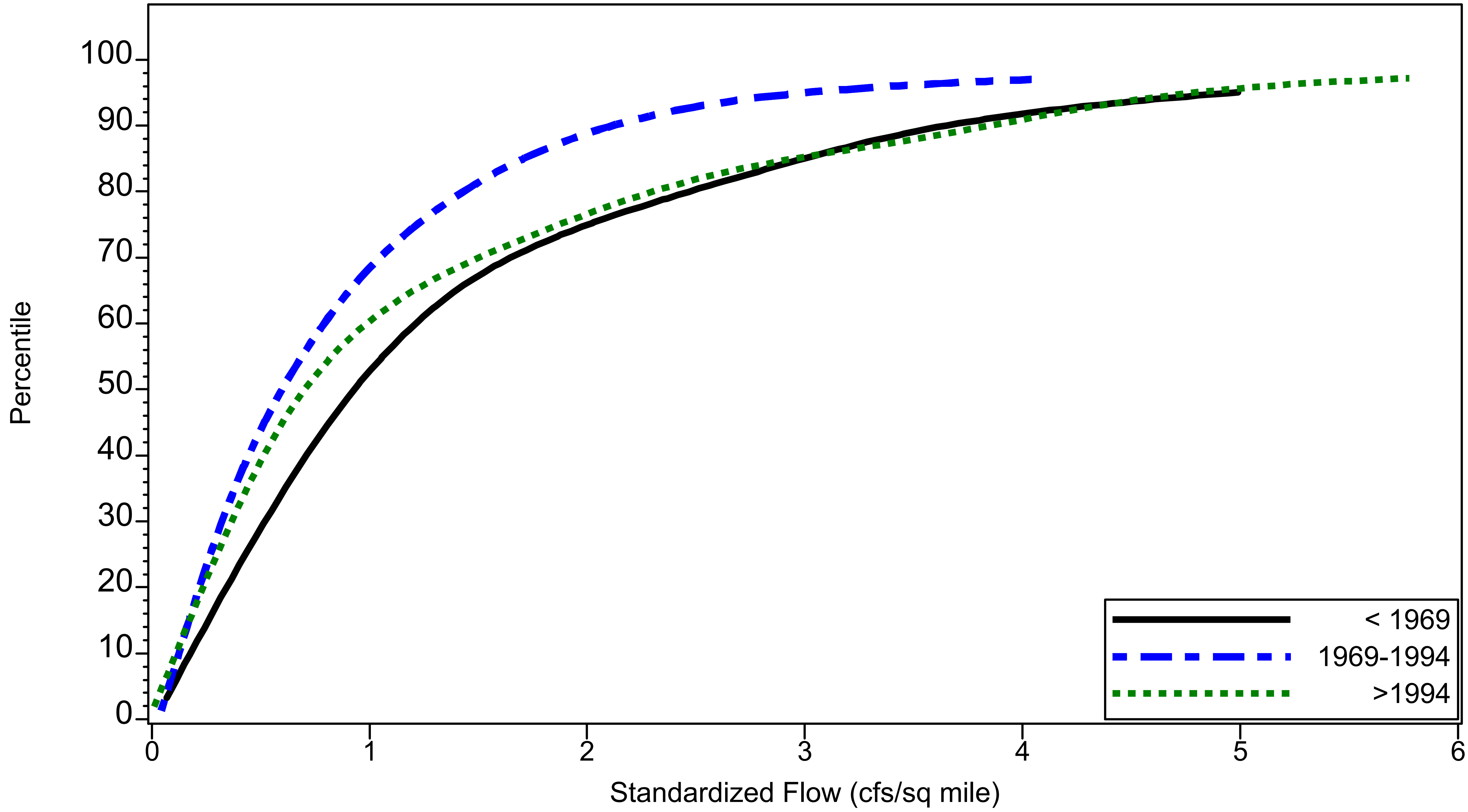


Figure 3.339 Wet season differences in CDFs among AMO periods in total gaged flow upstream of the Facility

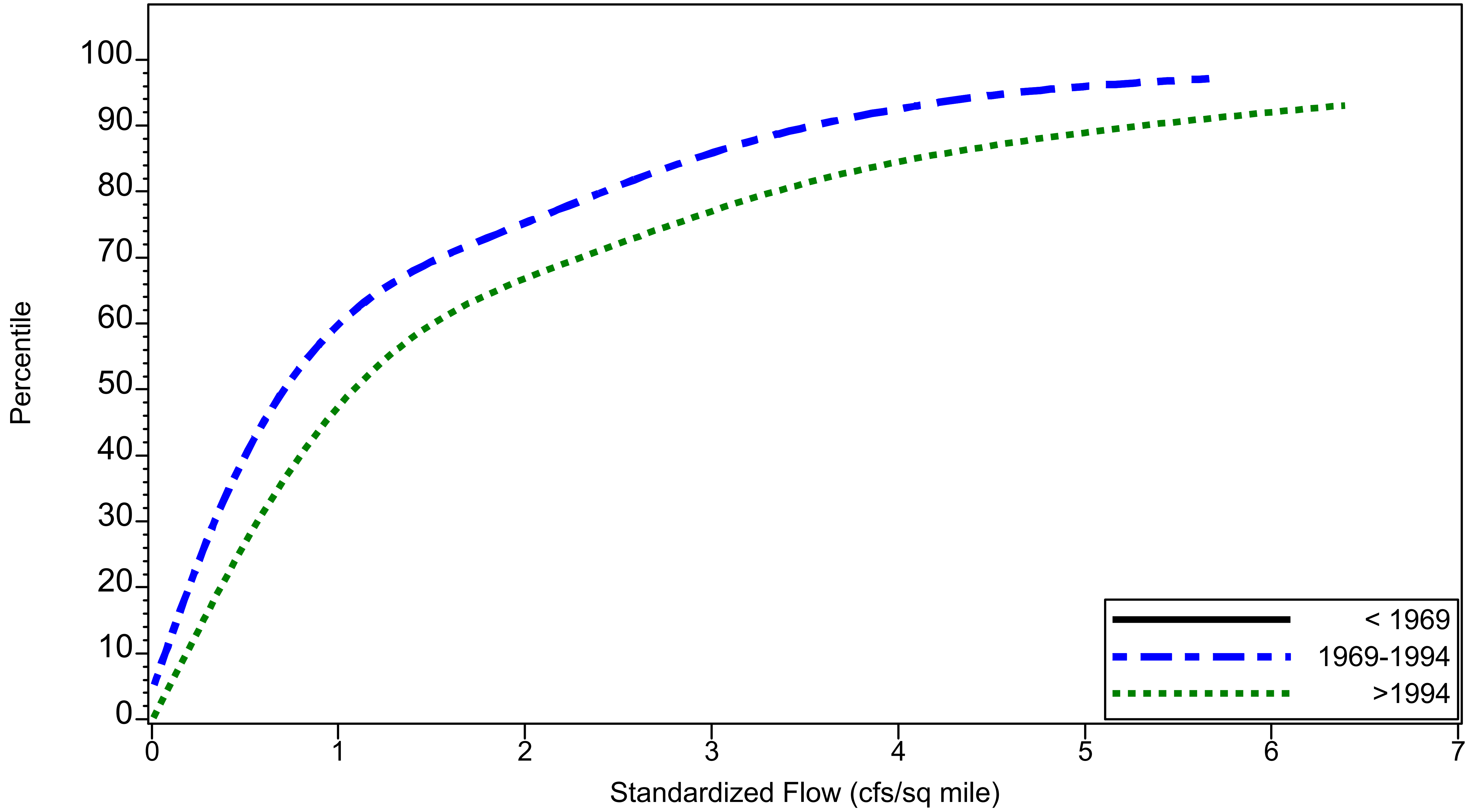


Figure 3.340 Wet season differences in CDFs among AMO periods in flow at long-term Prairie Creek (2298123) gage

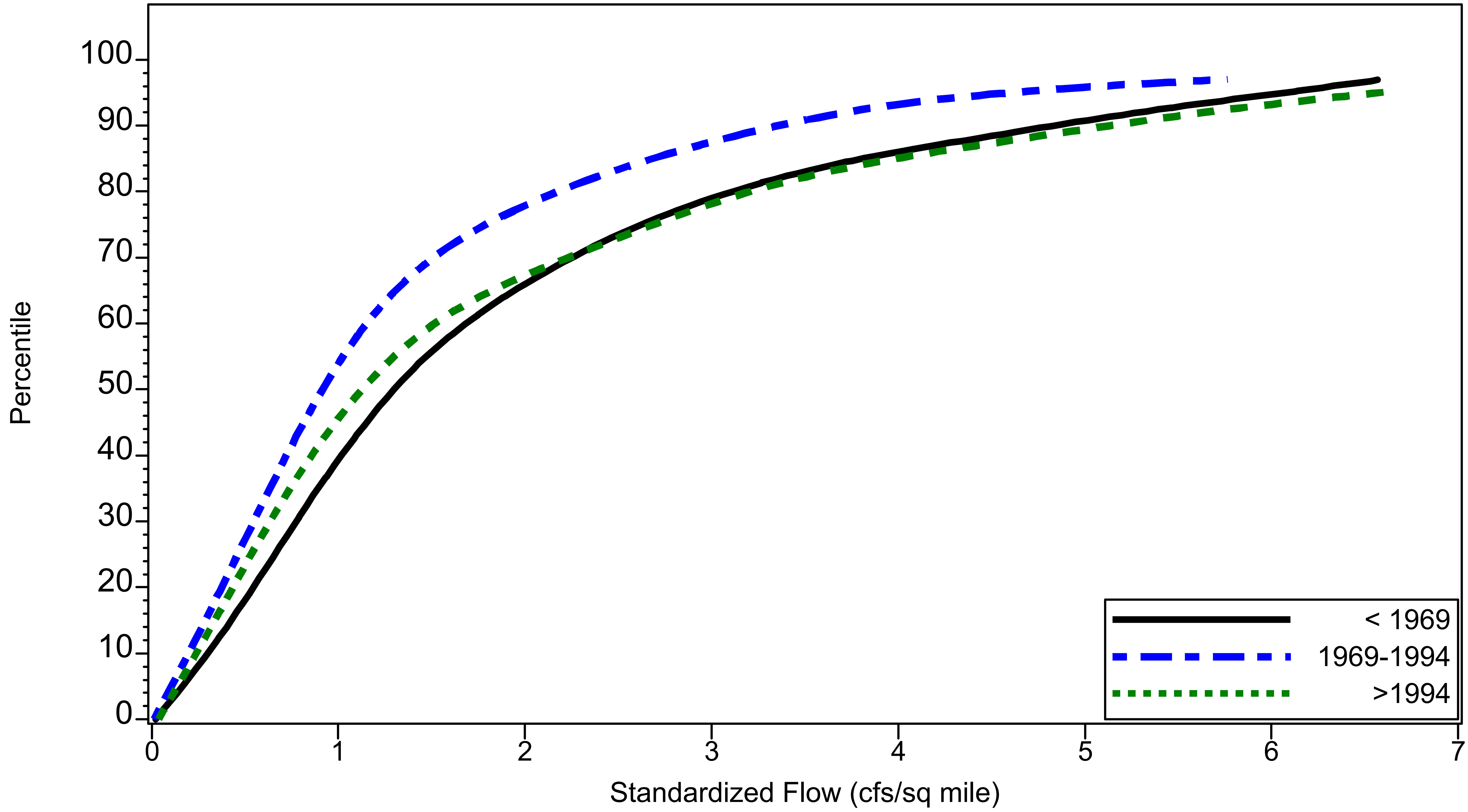


Figure 3.341 Wet season differences in CDFs among AMO periods in flow at long-term Shell Creek gage

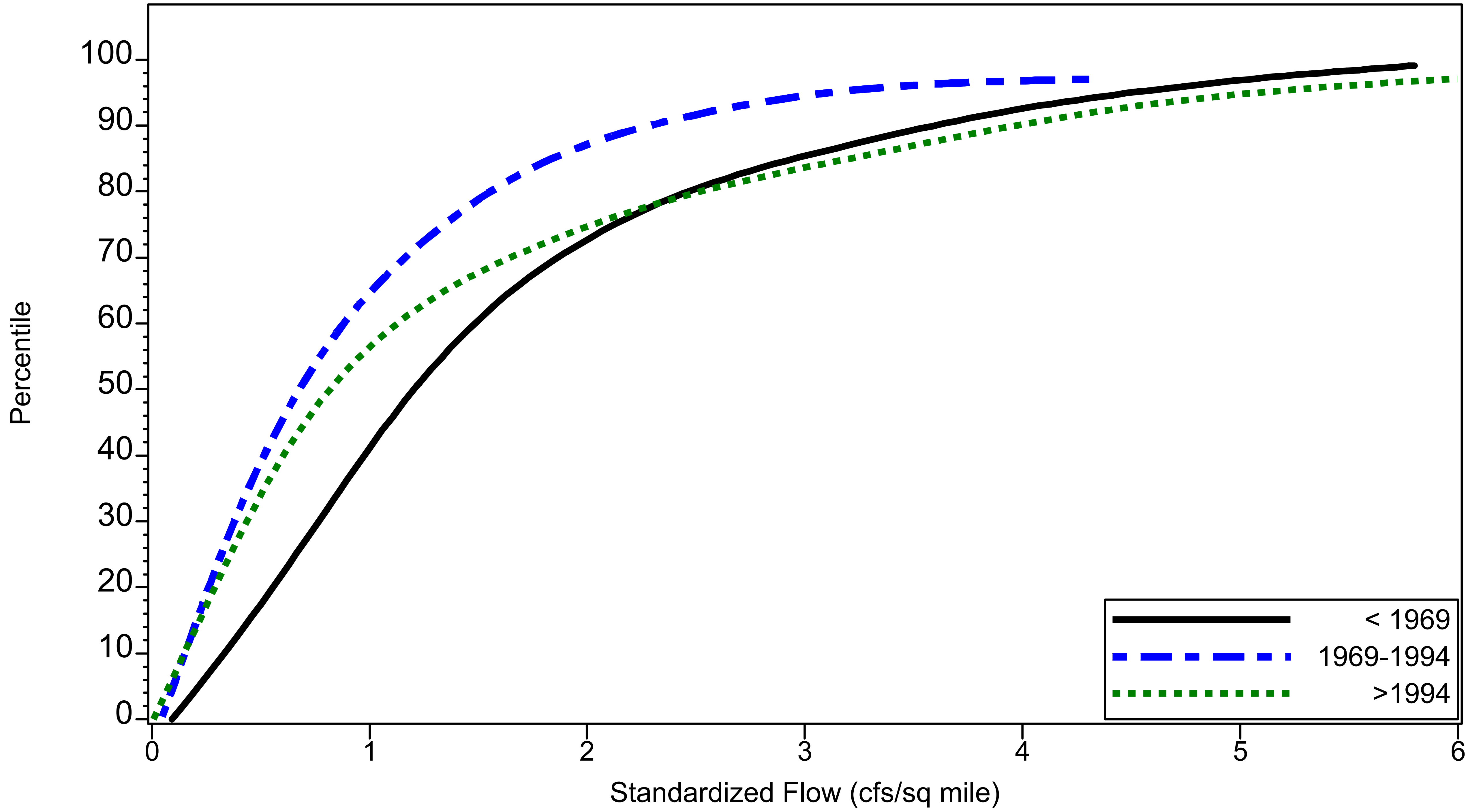


Figure 3.342 Wet season differences in CDFs among AMO periods in total gaged Peace River flow to the Upper Harbor

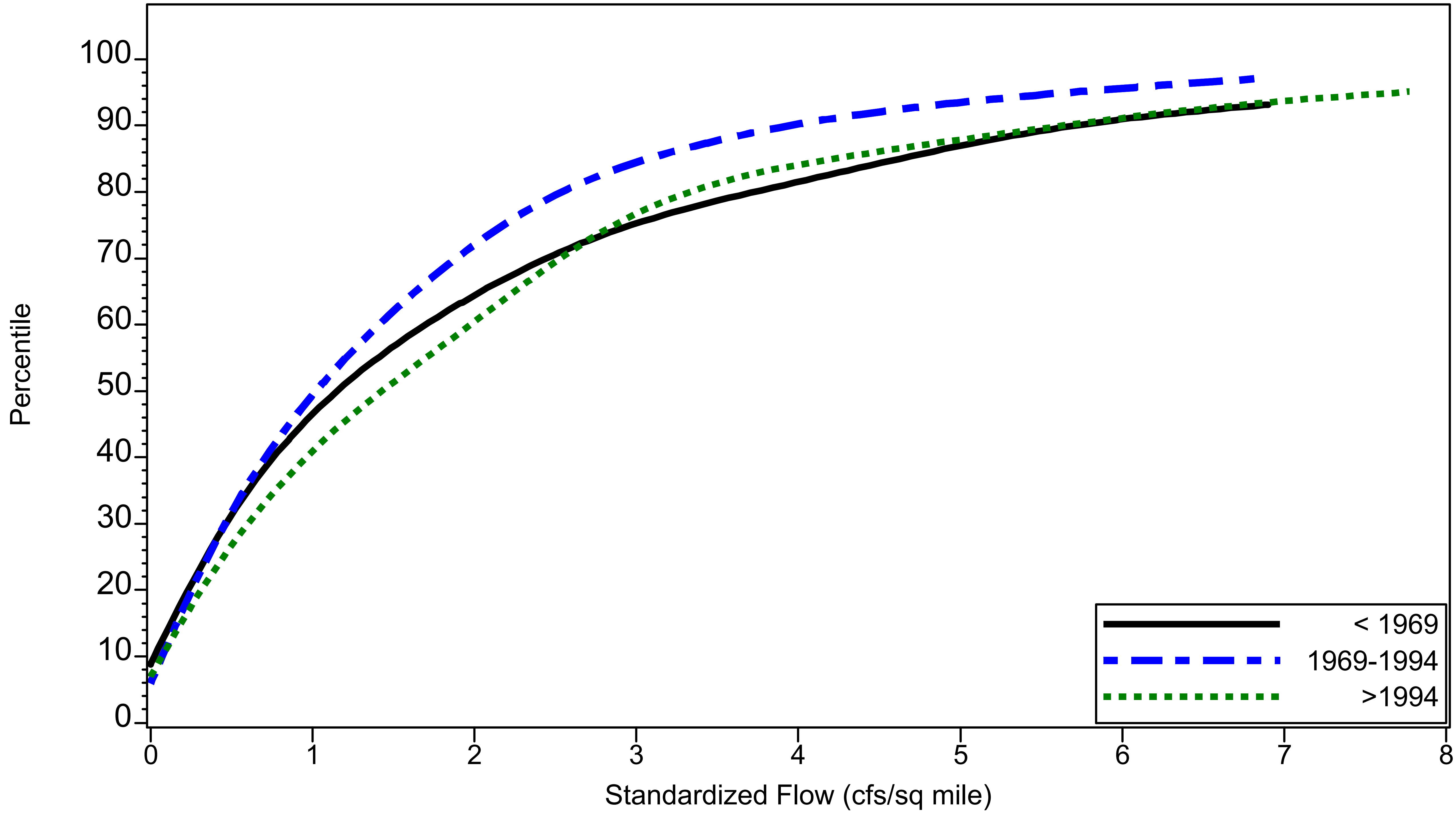


Figure 3.343 Wet season differences in CDFs among AMO periods in flow at long-term Myakka River near Sarasota (2298830) gage

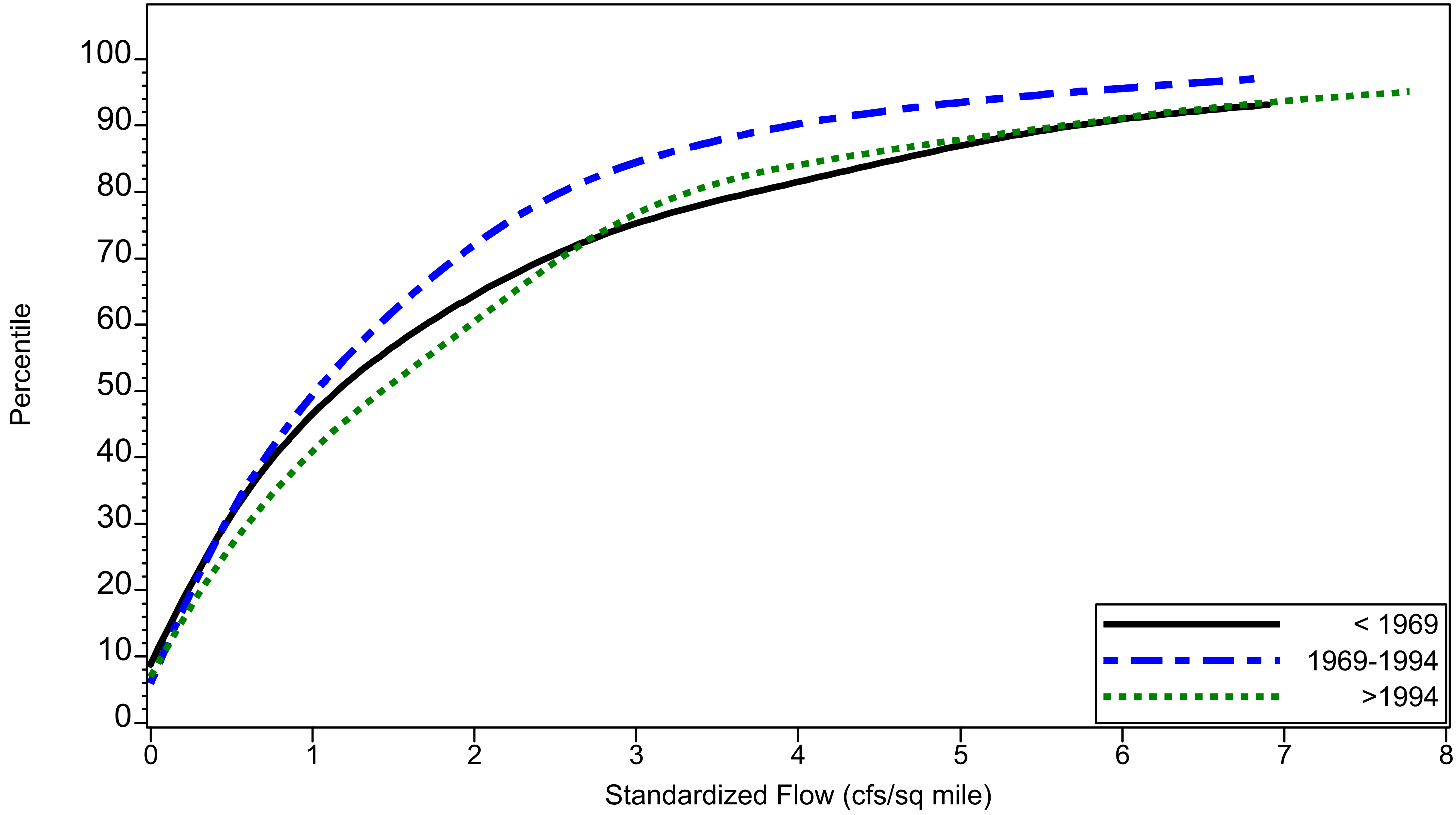


Figure 3.343 Wet season differences in CDFs among AMO periods in flow at long-term Myakka River near Sarasota (2298830) gage

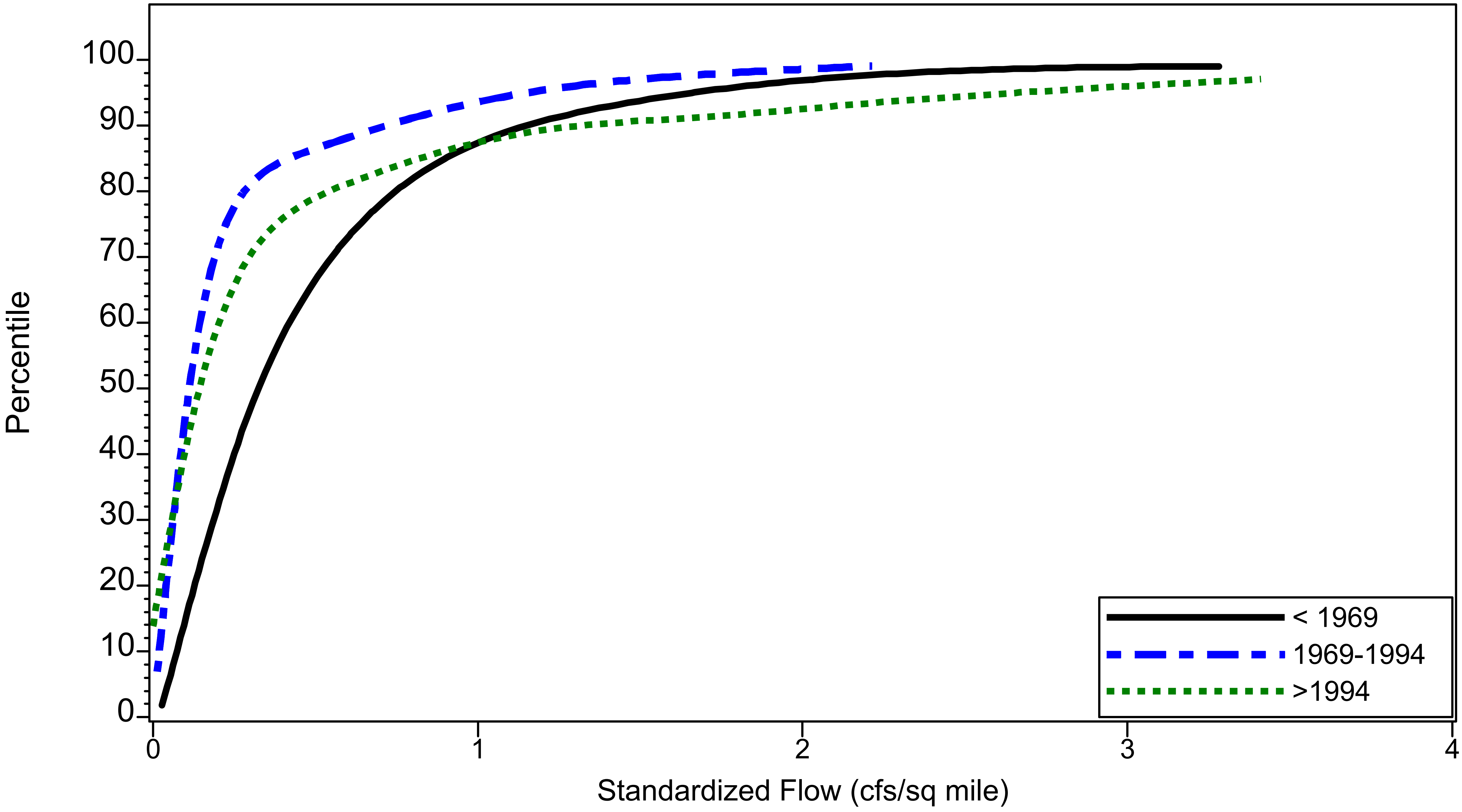


Figure 3.344 Dry season differences in CDFs among AMO periods in flow at long-term Peace River at Bartow (2294650) gage

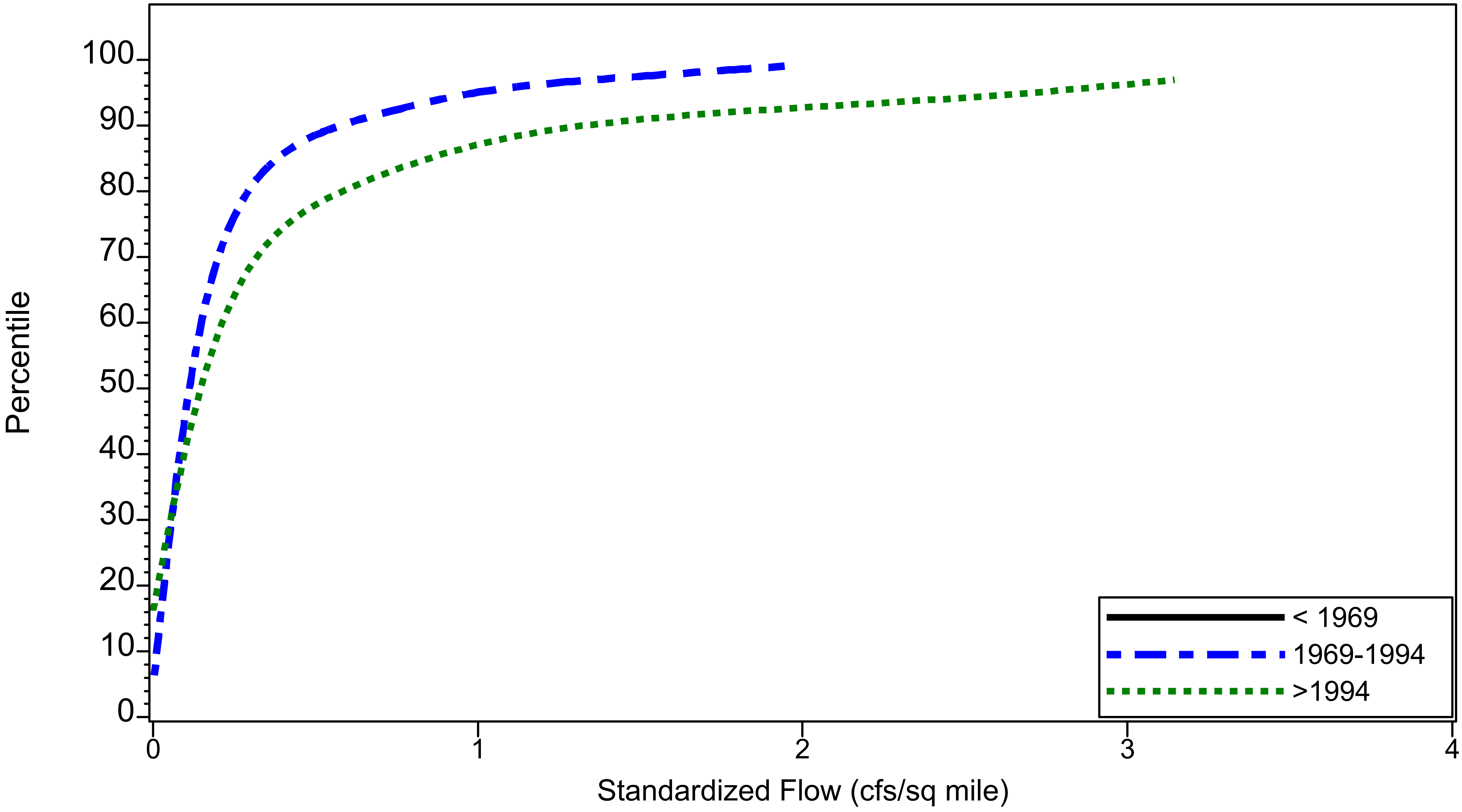


Figure 3.345 Dry season differences in CDFs among AMO periods in flow at long-term Peace River at Ft. Meade (2294898) gage

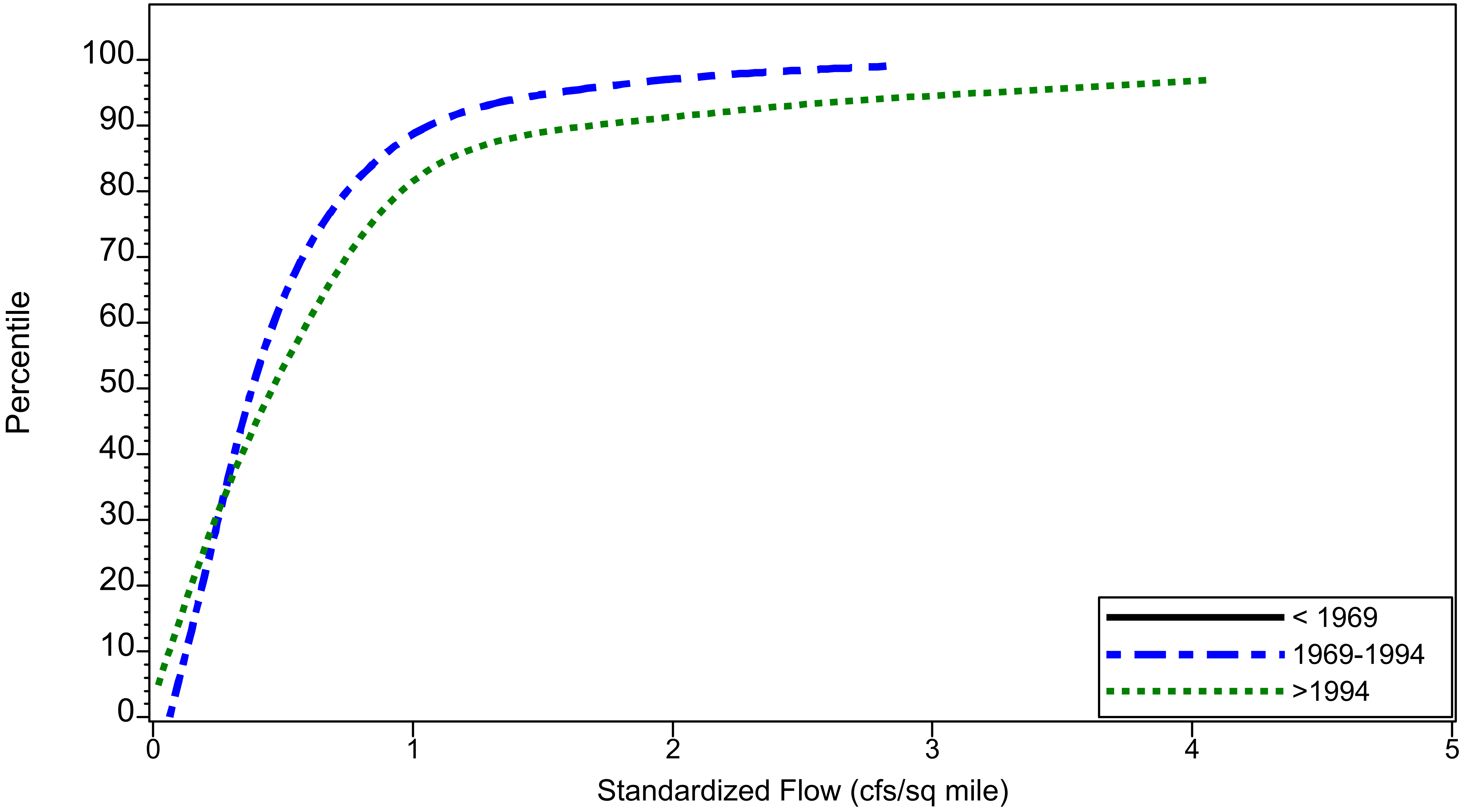


Figure 3.346 Dry season differences in CDFs among AMO periods in flow at long-term Payne Creek (2295420) gage

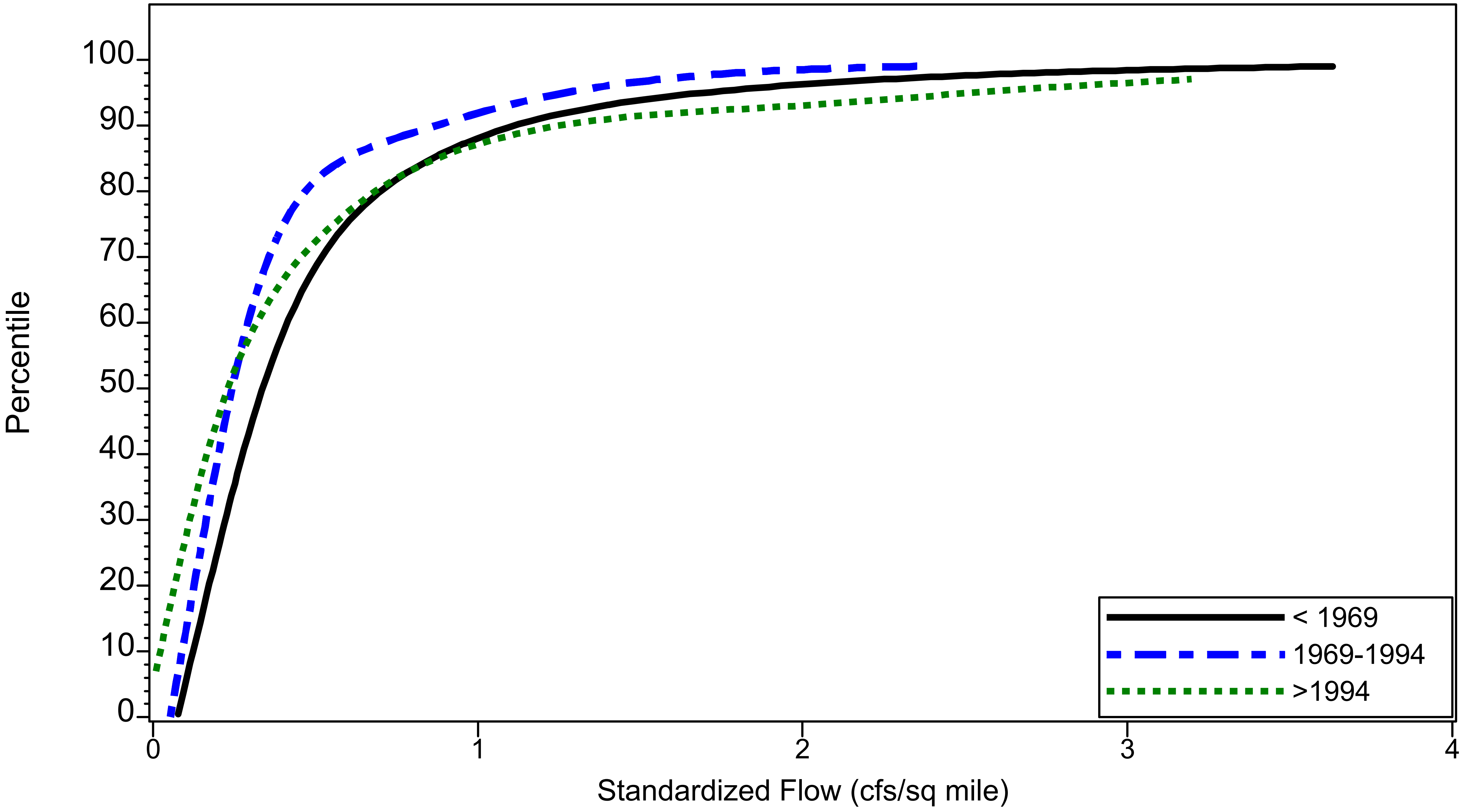


Figure 3.347 Dry season differences in CDFs among AMO periods in flow at long-term Peace River at Zolfo (2295637) gage

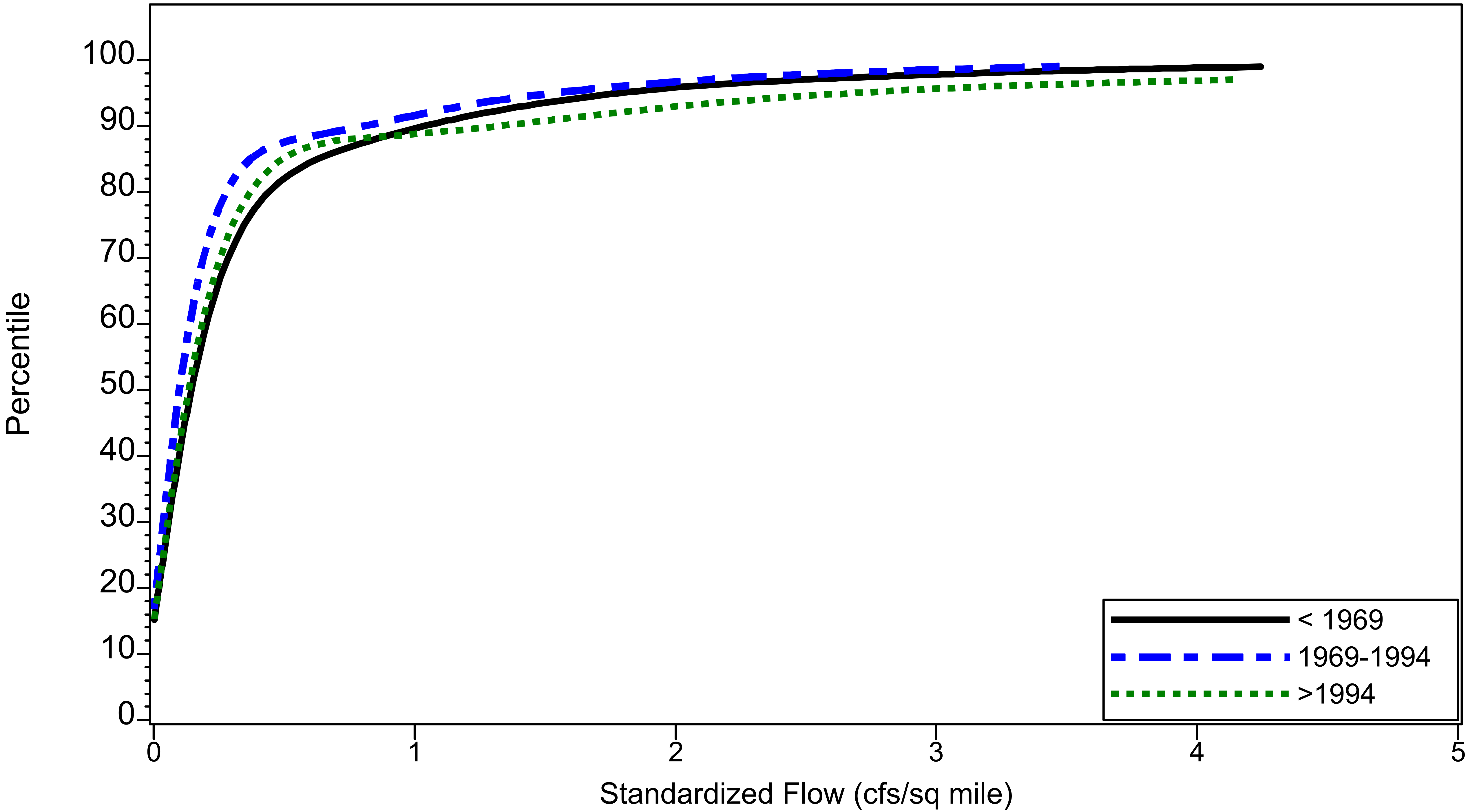


Figure 3.348 Dry season differences in CDFs among AMO periods in flow at long-term Charlie Creek (2296500) gage

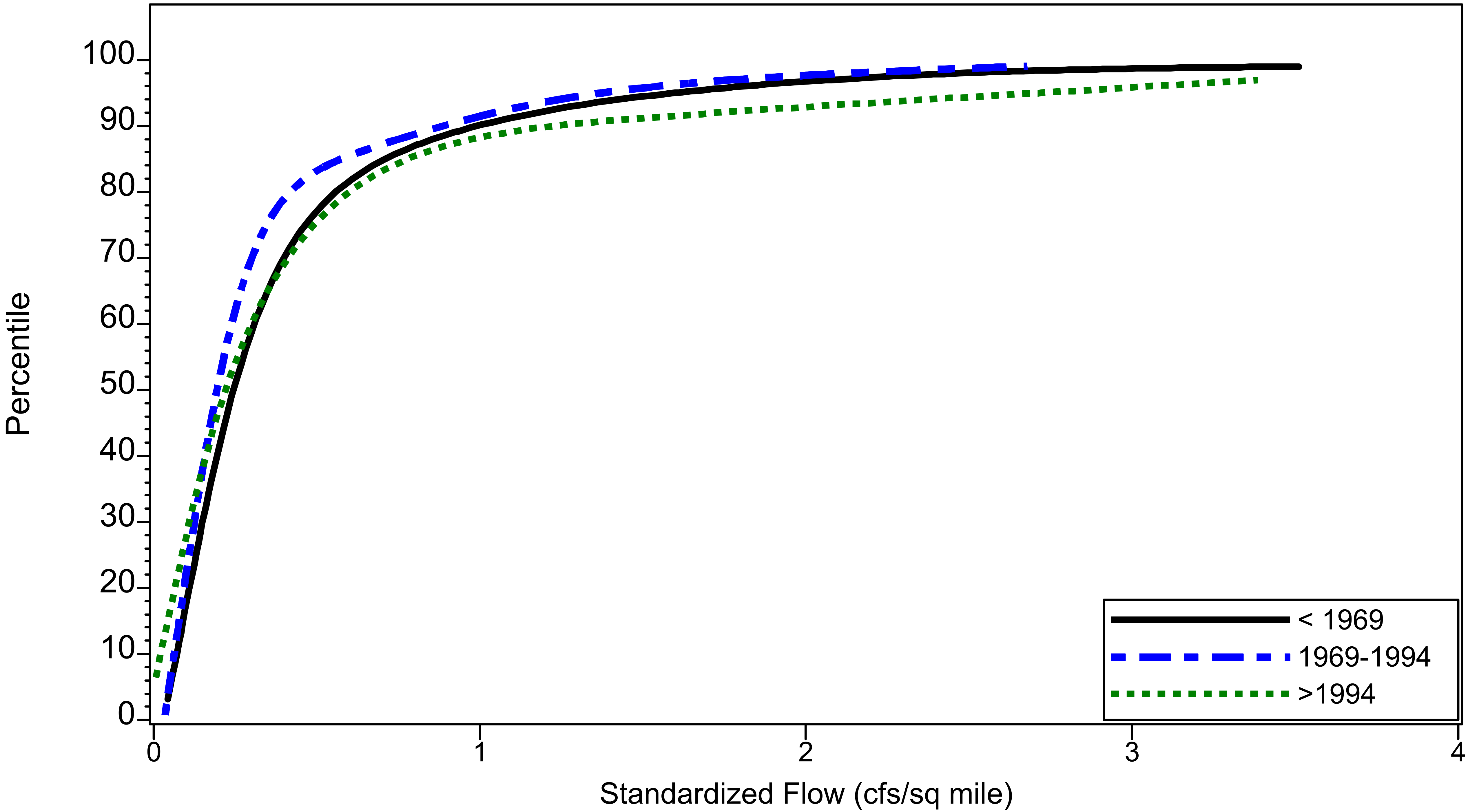


Figure 3.349 Dry season differences in CDFs among AMO periods in flow at long-term Peace River at Arcadia (2296750) gage

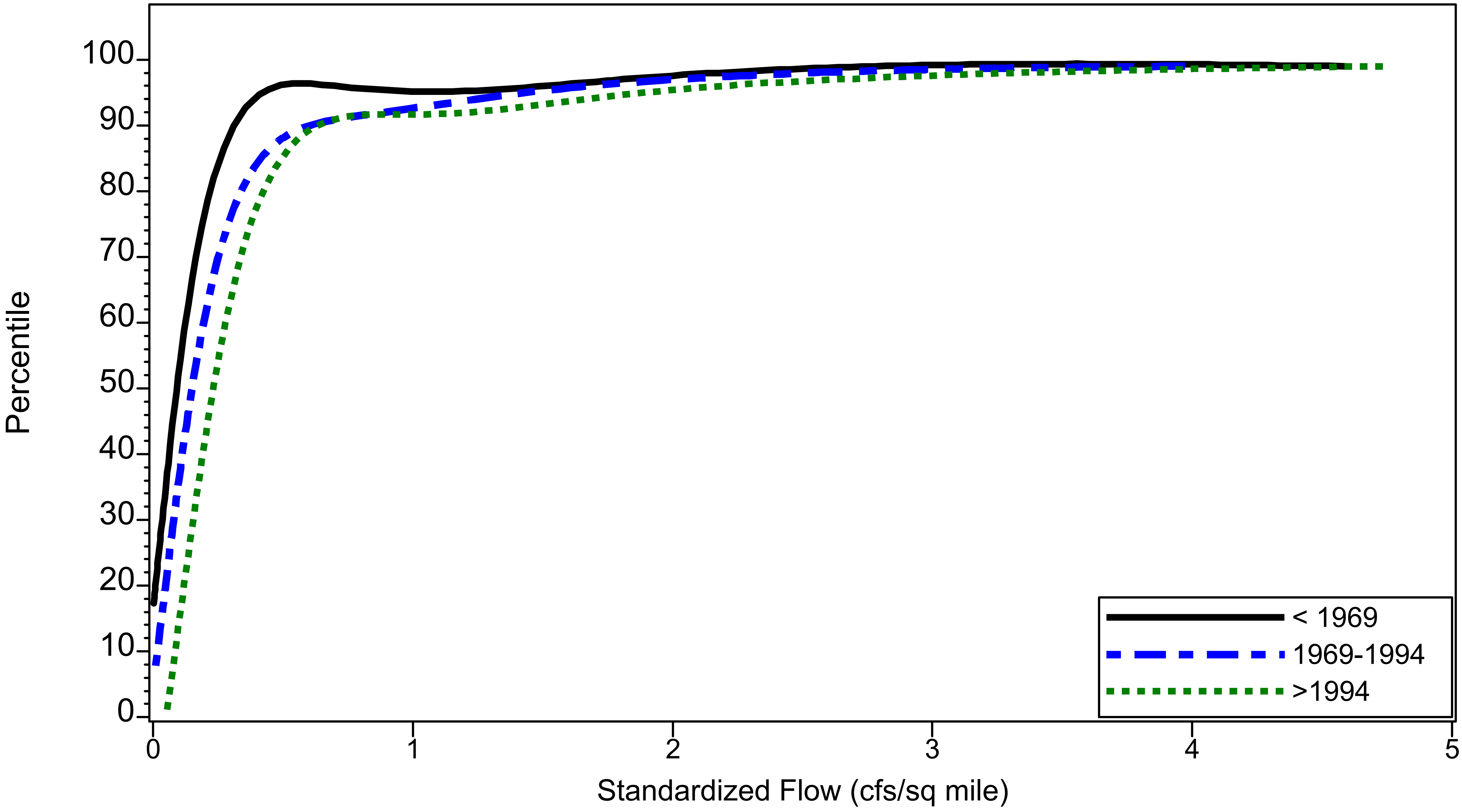


Figure 3.350 Dry season differences in CDFs among AMO periods in flow at long-term Joshua Creek at Nocatee (2297100) gage

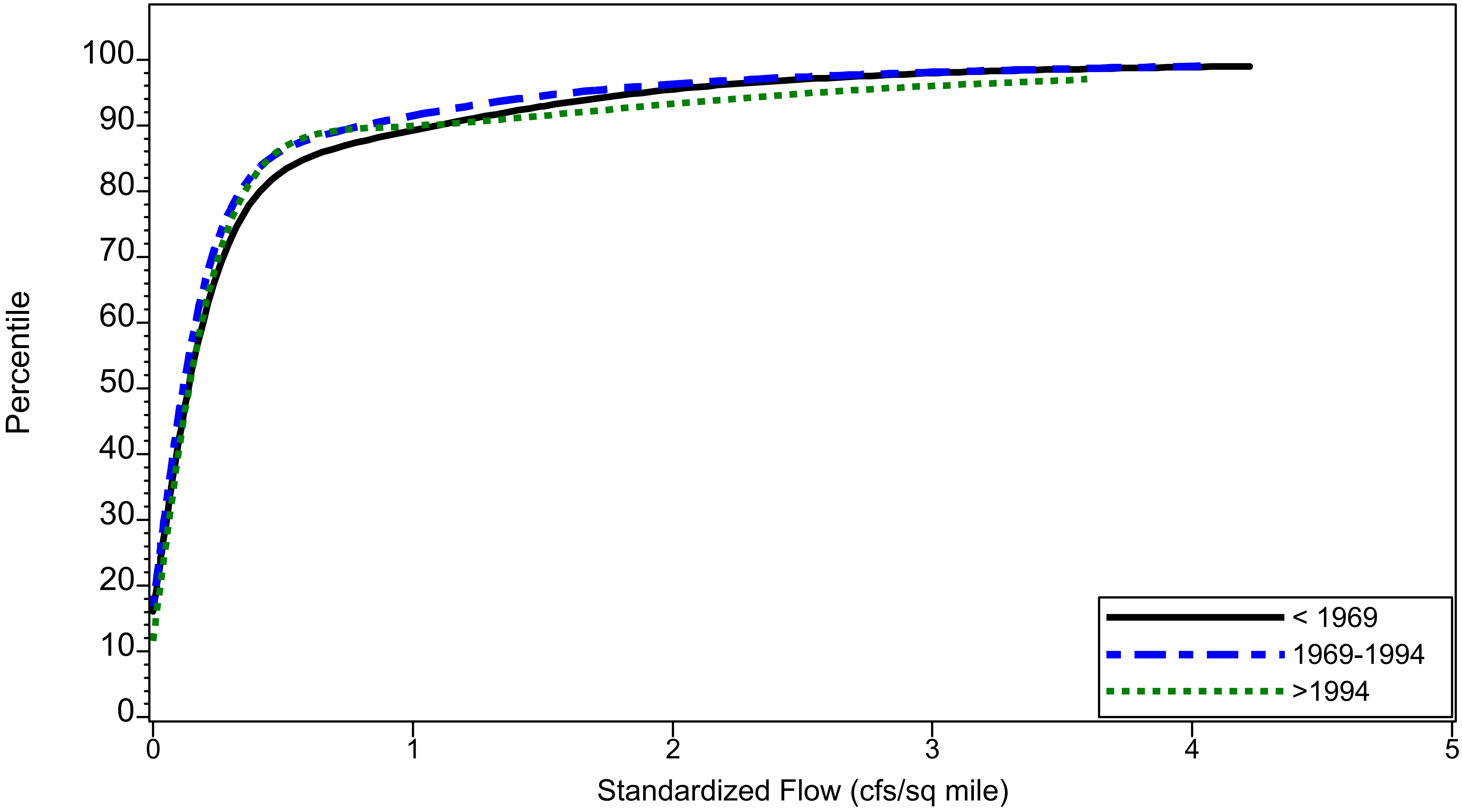


Figure 3.351 Dry season differences in CDFs among AMO periods in flow at long-term Horse Creek near Arcadia(2297310) gage

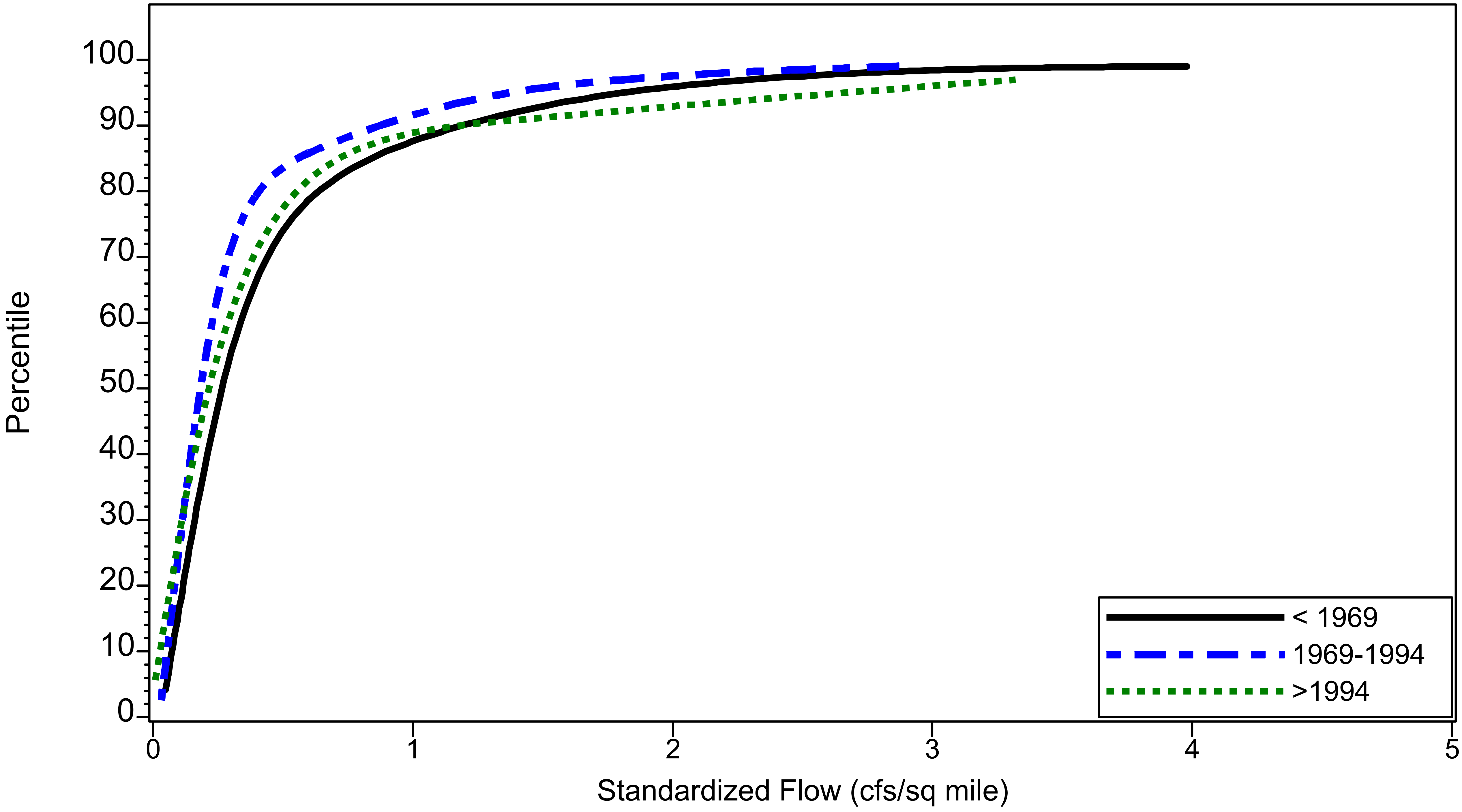


Figure 3.352 Dry season differences in CDFs among AMO periods in total gaged flow upstream of the Facility

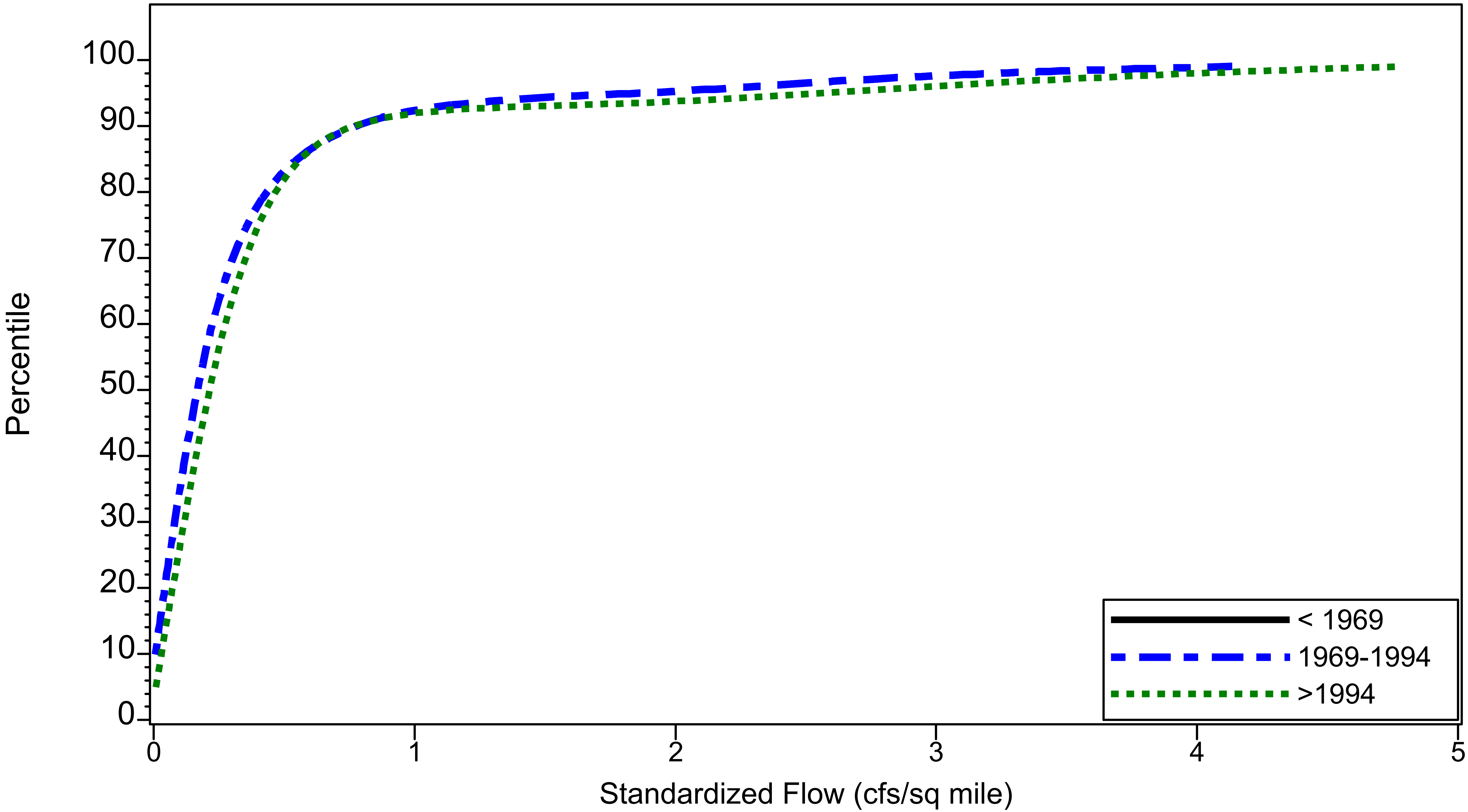


Figure 3.353 Dry season differences in CDFs among AMO periods in flow at long-term Prairie Creek (2298123) gage

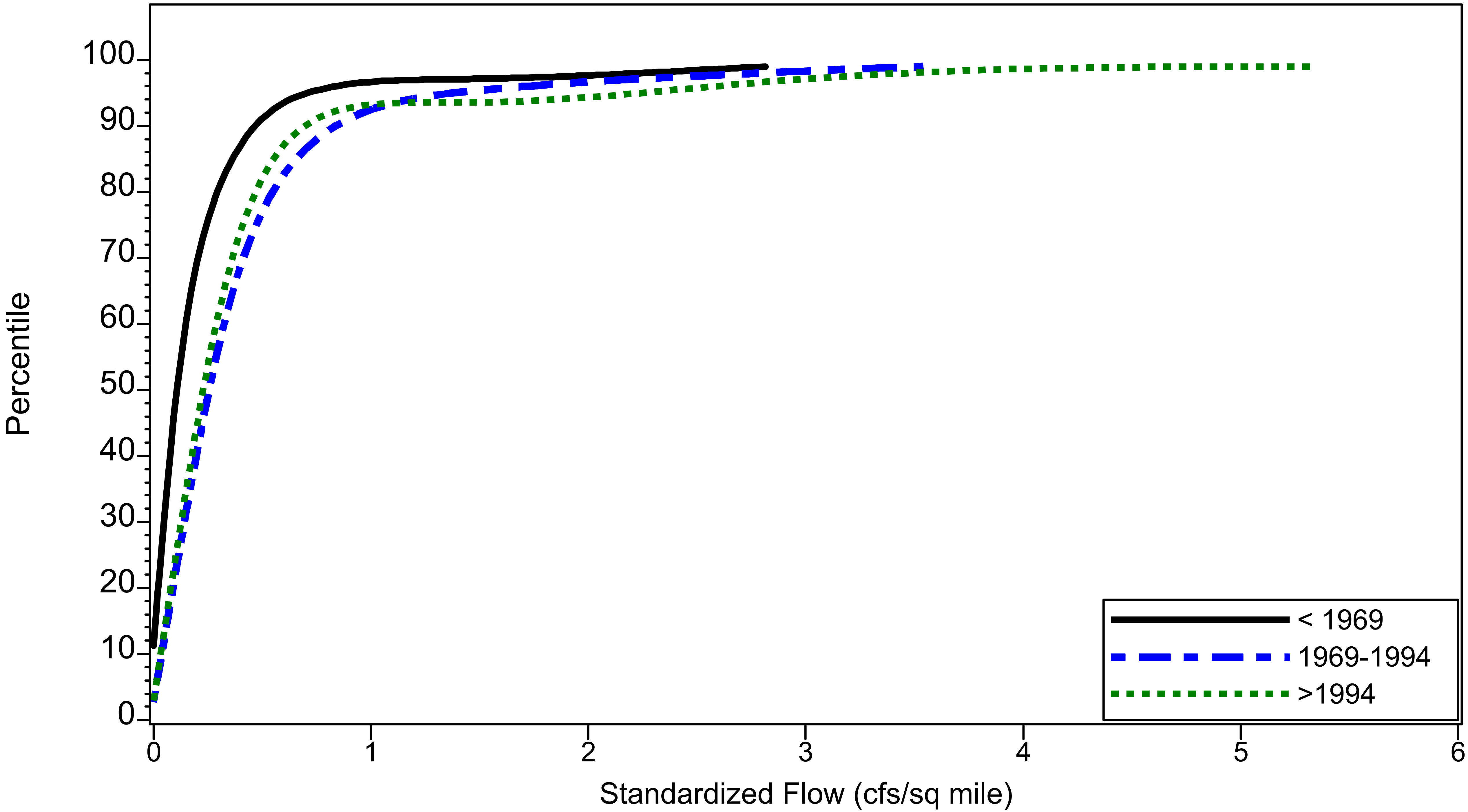


Figure 3.354 Dry season differences in CDFs among AMO periods in flow at long-term Shell Creek gage

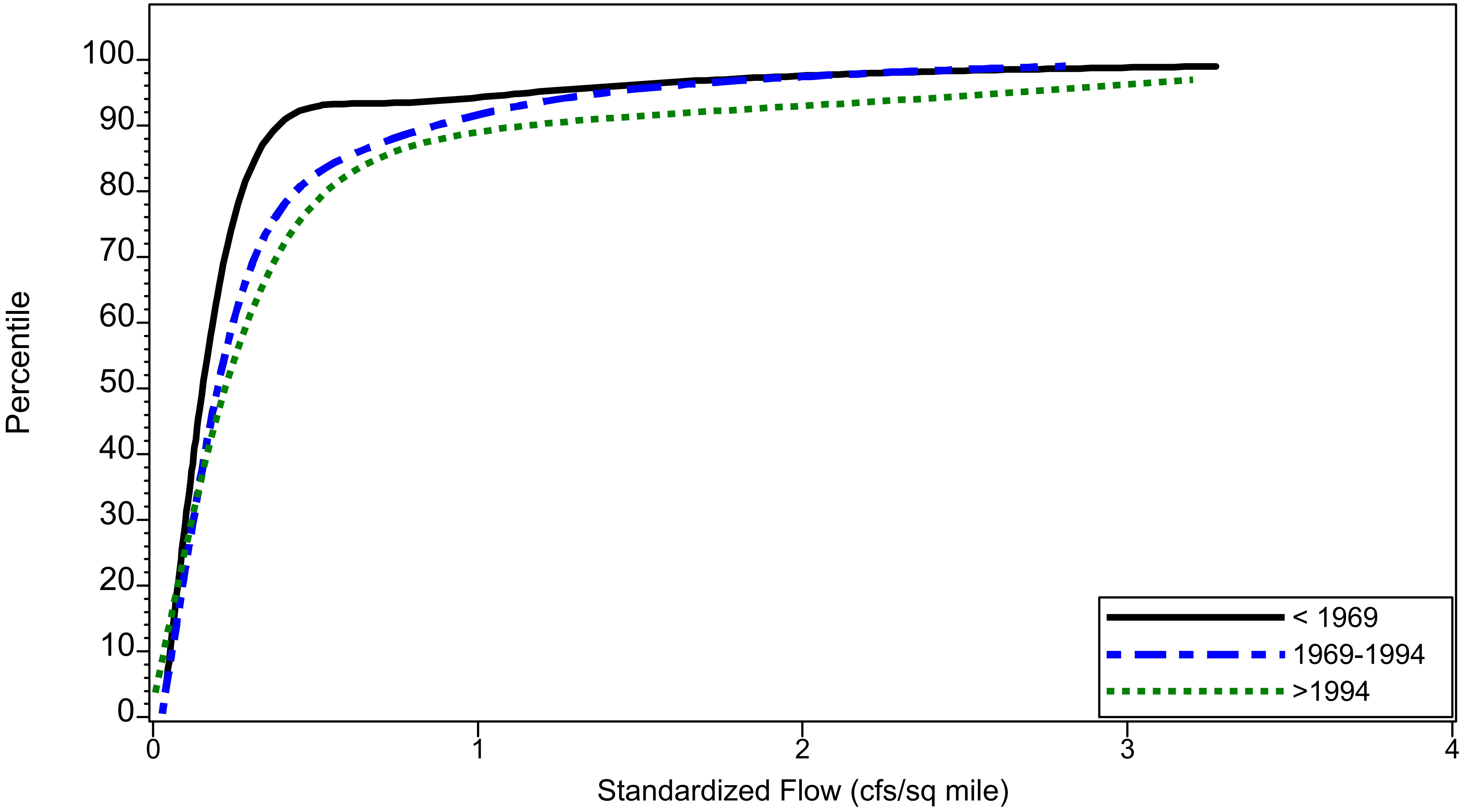


Figure 3.355 Dry season differences in CDFs among AMO periods in total gaged Peace River flow to the Upper Harbor

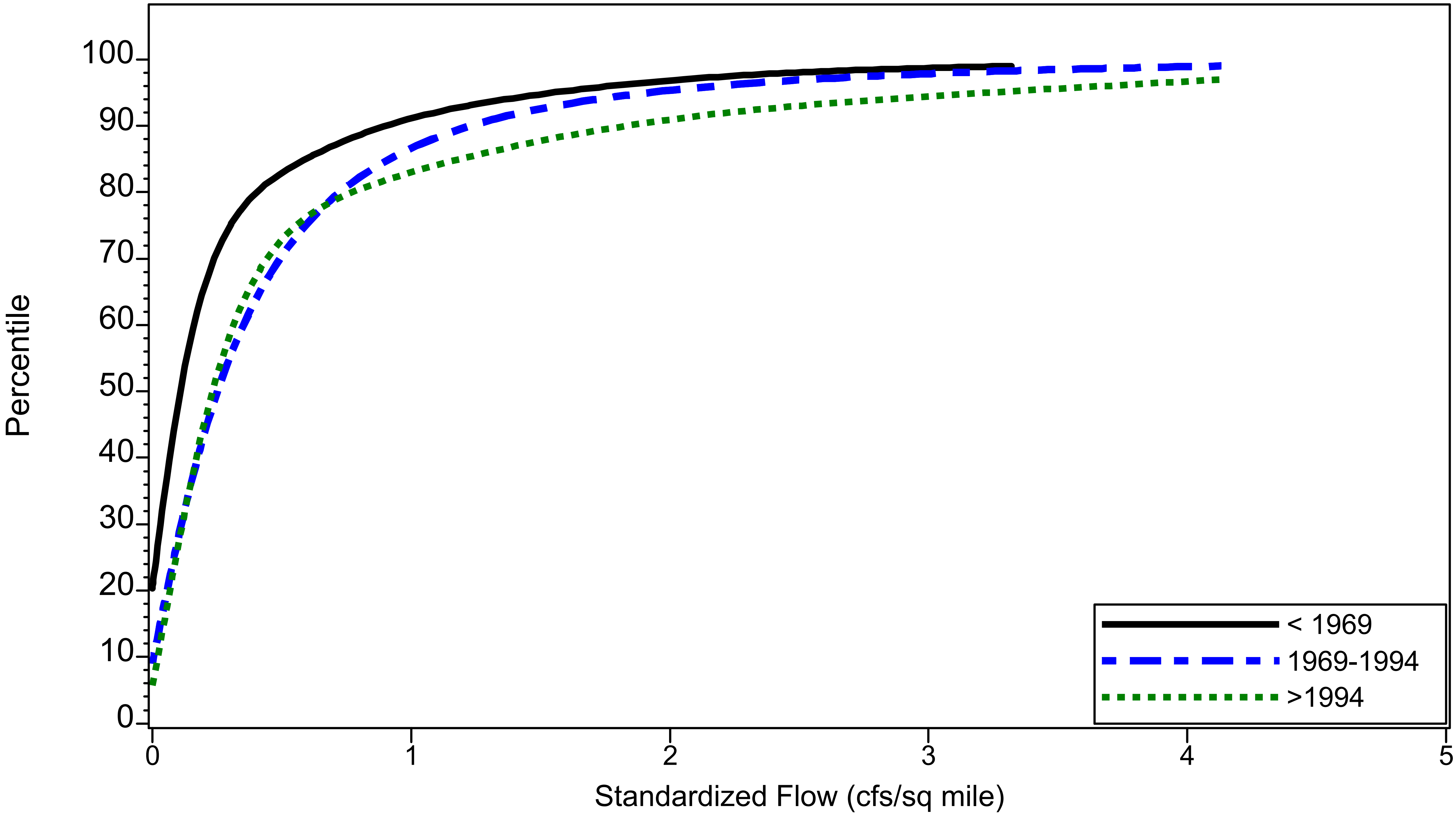


Figure 3.356 Dry season differences in CDFs among AMO periods in flow at long-term Myakka River near Sarasota (2298830) gage

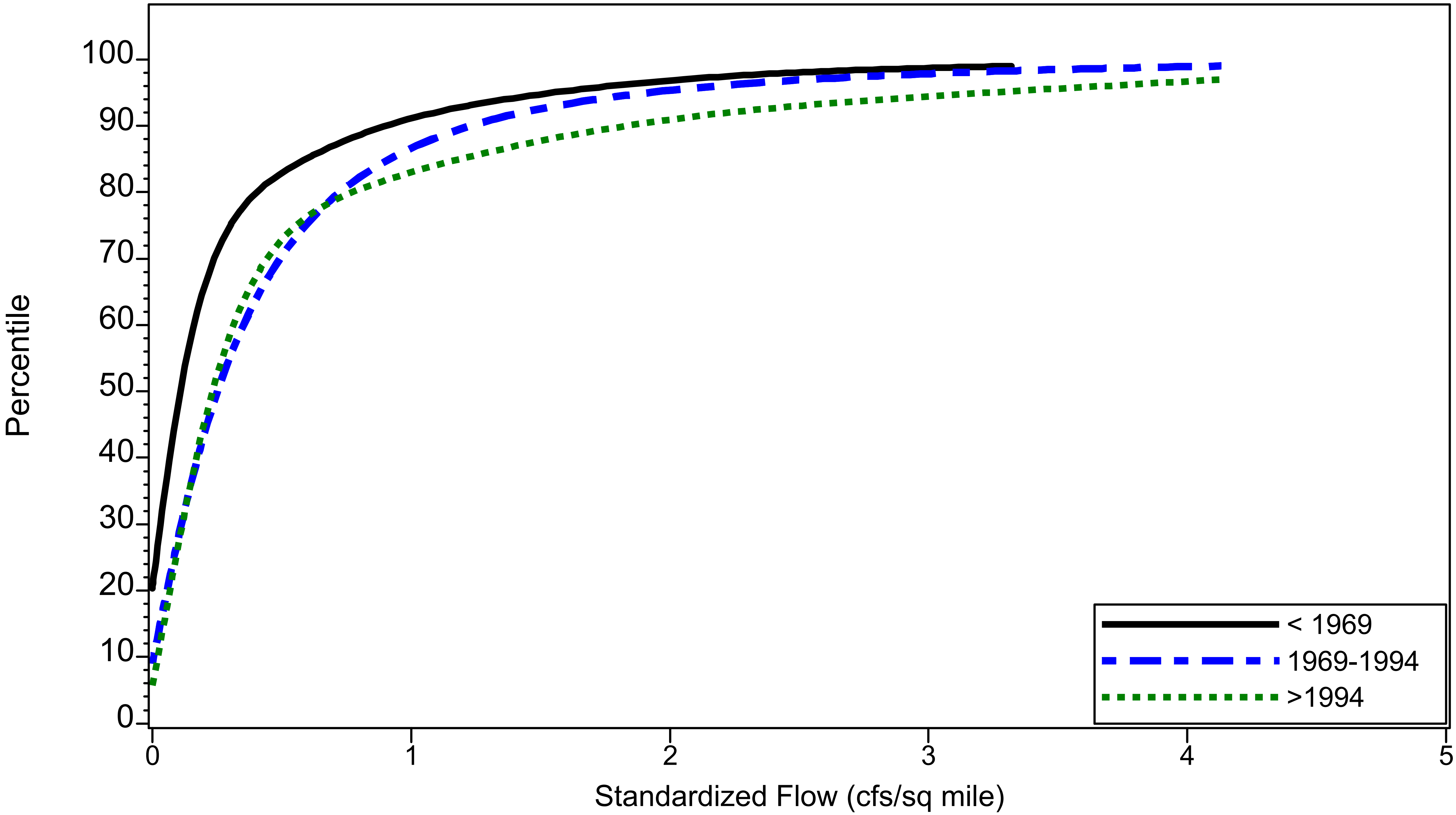


Figure 3.356 Dry season differences in CDFs among AMO periods in flow at long-term Myakka River near Sarasota (2298830) gage

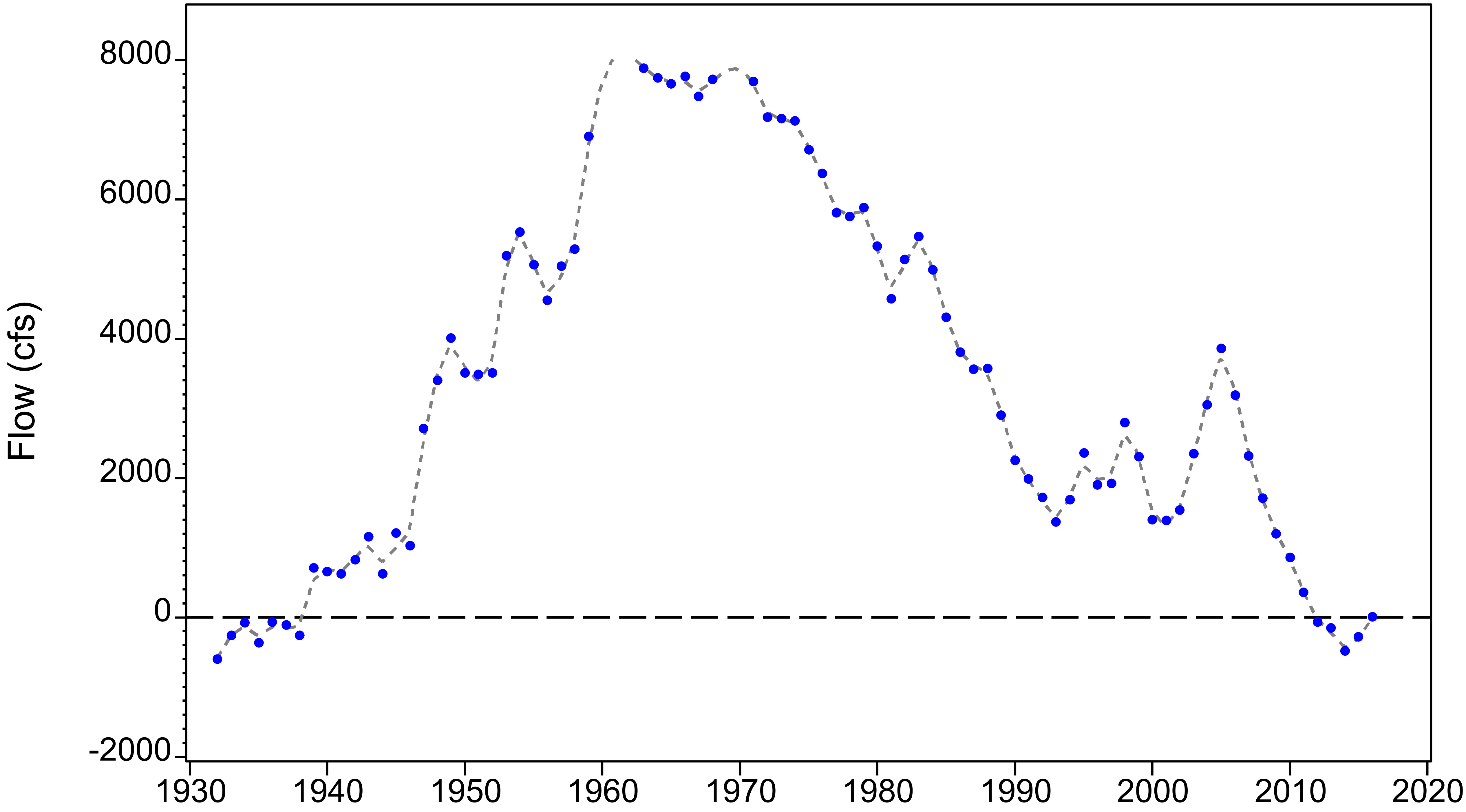


Figure 3.357 Long-term cumulative Peace River at Arcadia flow over 1046 cfs (1932-2016)

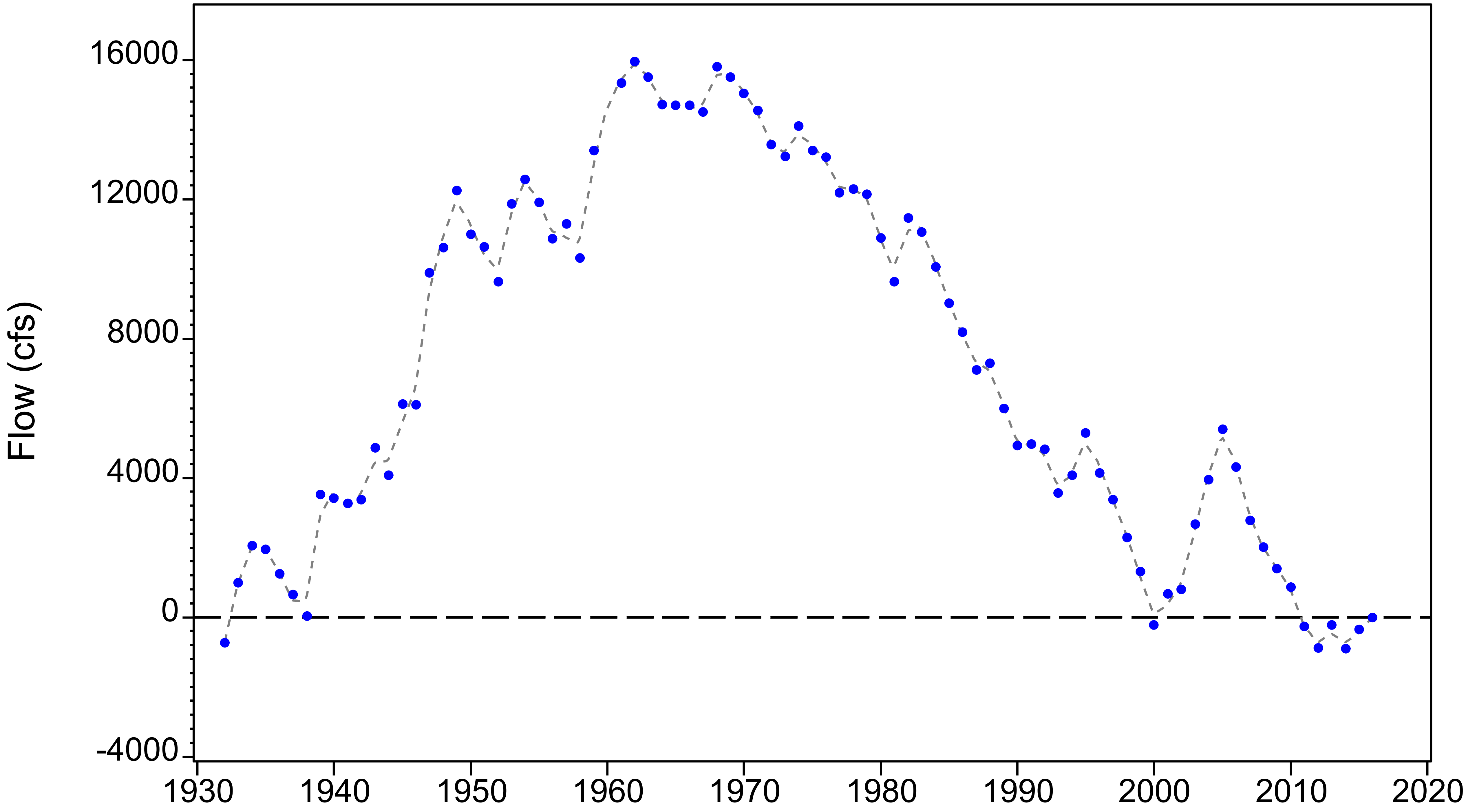


Figure 3.358 Long-term cumulative wet-season Peace River at Arcadia flow over 1783 cfs (1932-2016)

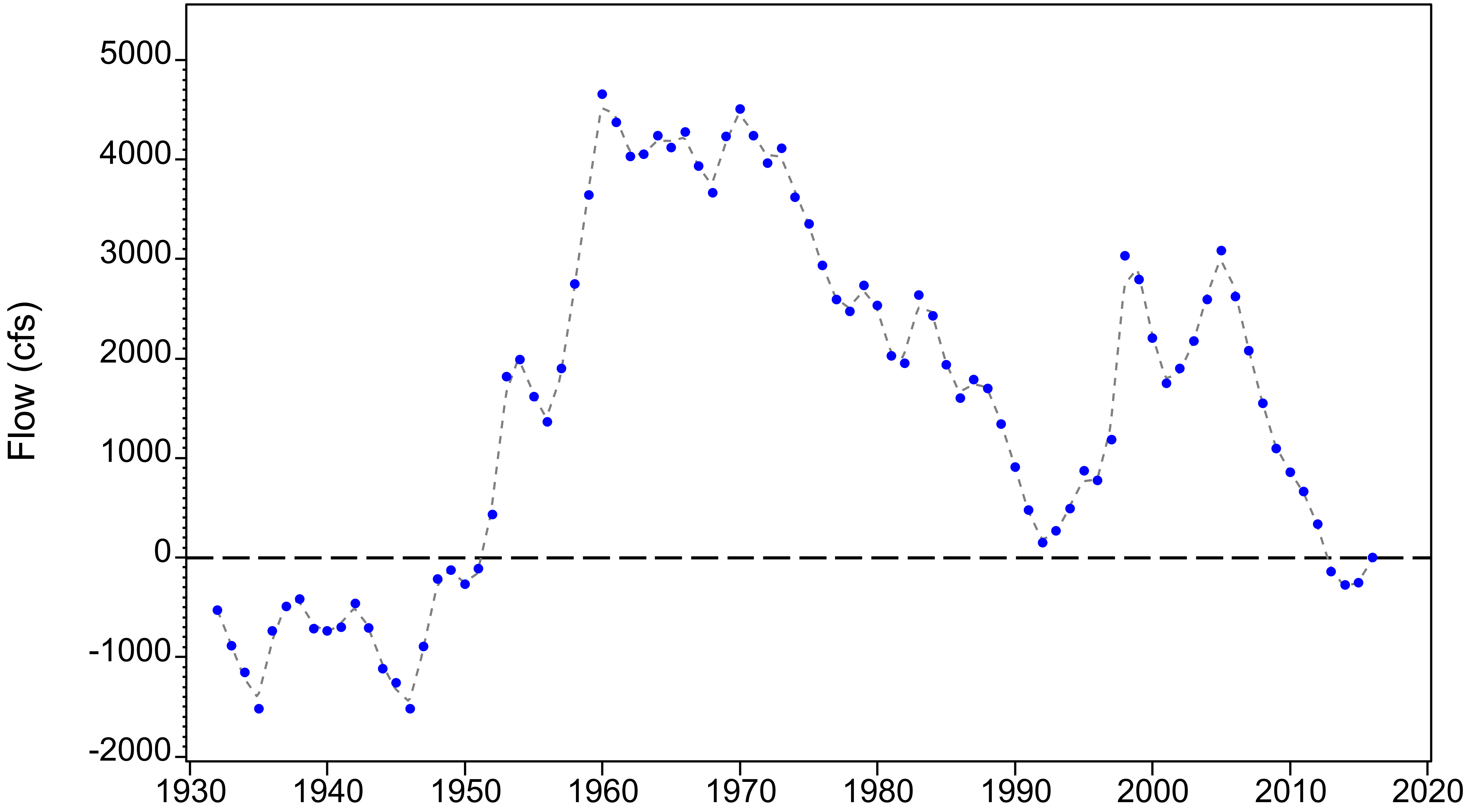


Figure 3.359 Long-term cumulative dry-season Peace River at Arcadia flow over 676 cfs (1932-2016)

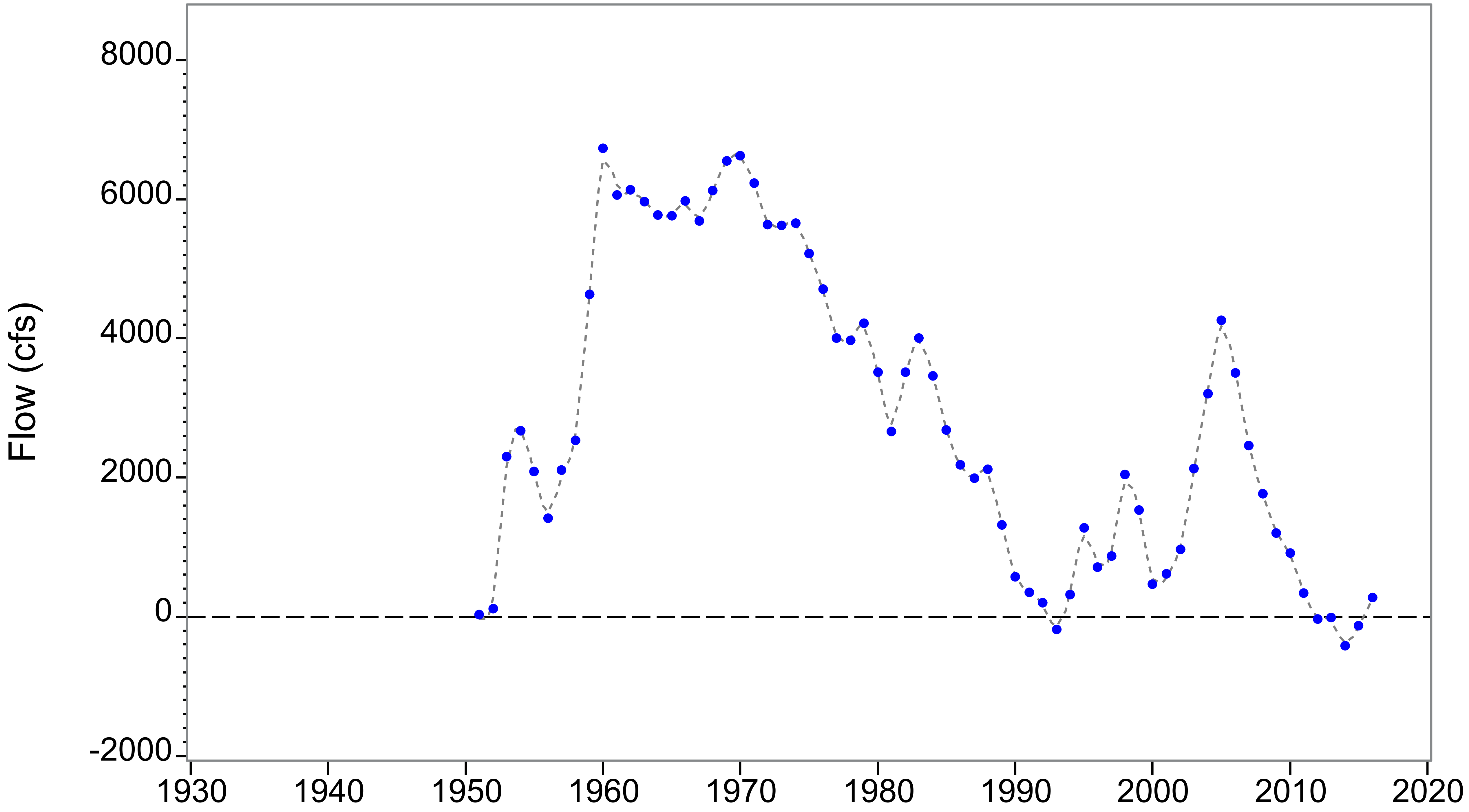


Figure 3.360 Long-term cumulative Peace River flow upstream of the Facility over 1288 cfs (1952-2016)

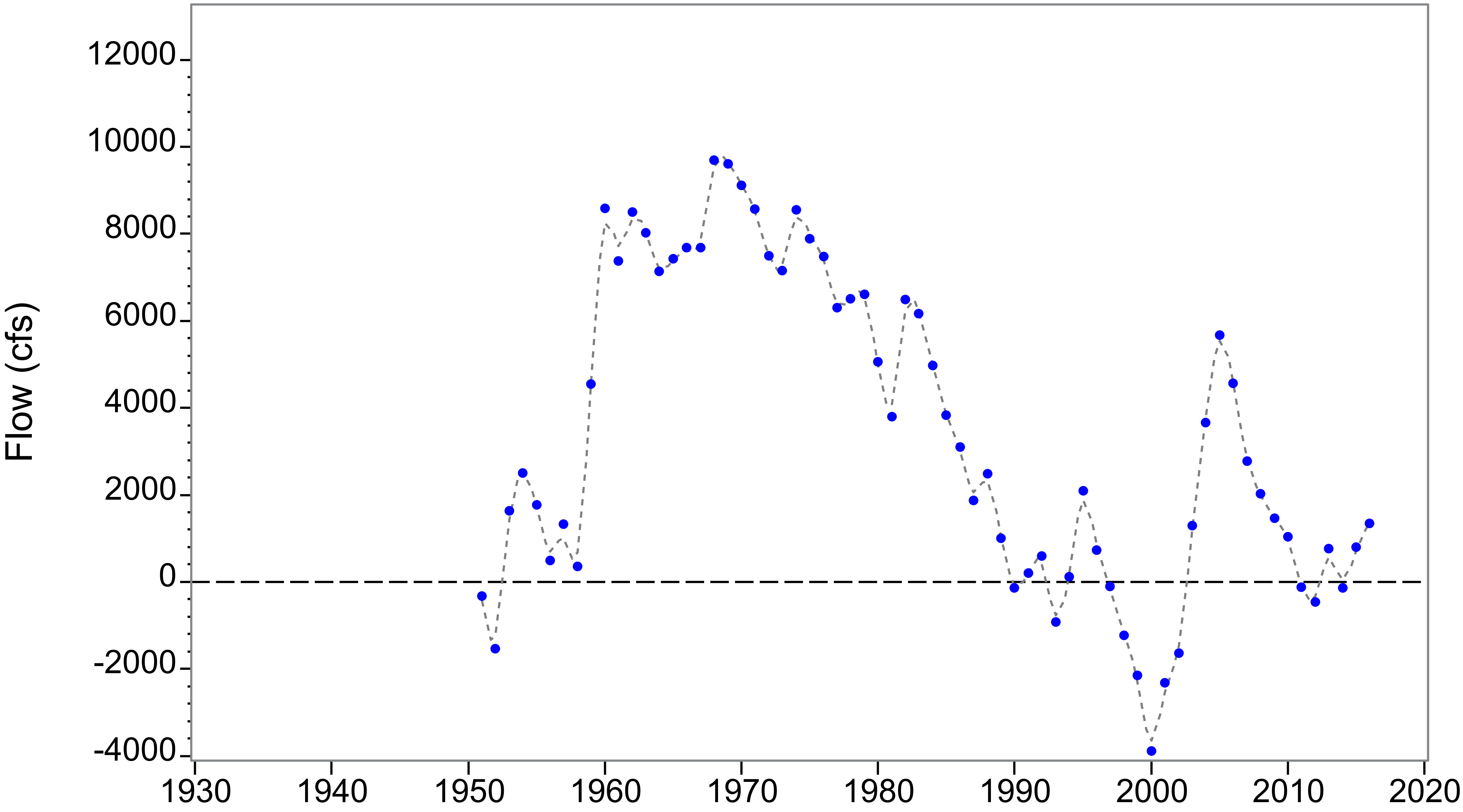


Figure 3.361 Long-term cumulative wet-season Peace River flow upstream of the Facility over 2169 cfs (1952-2016)

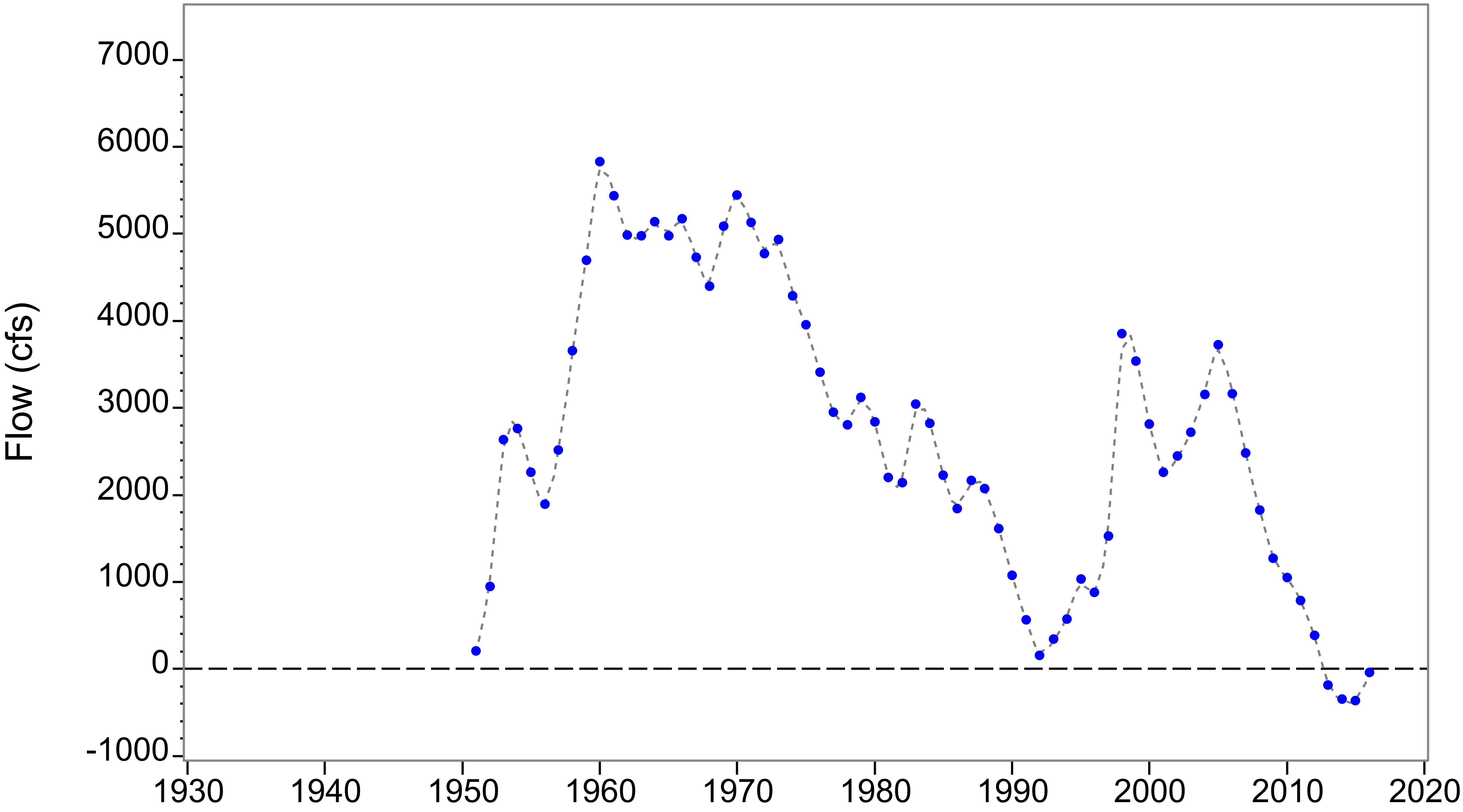


Figure 3.362 Long-term cumulative dry-season Peace River flow upstream of the Facility over 843 cfs (1952-2016)

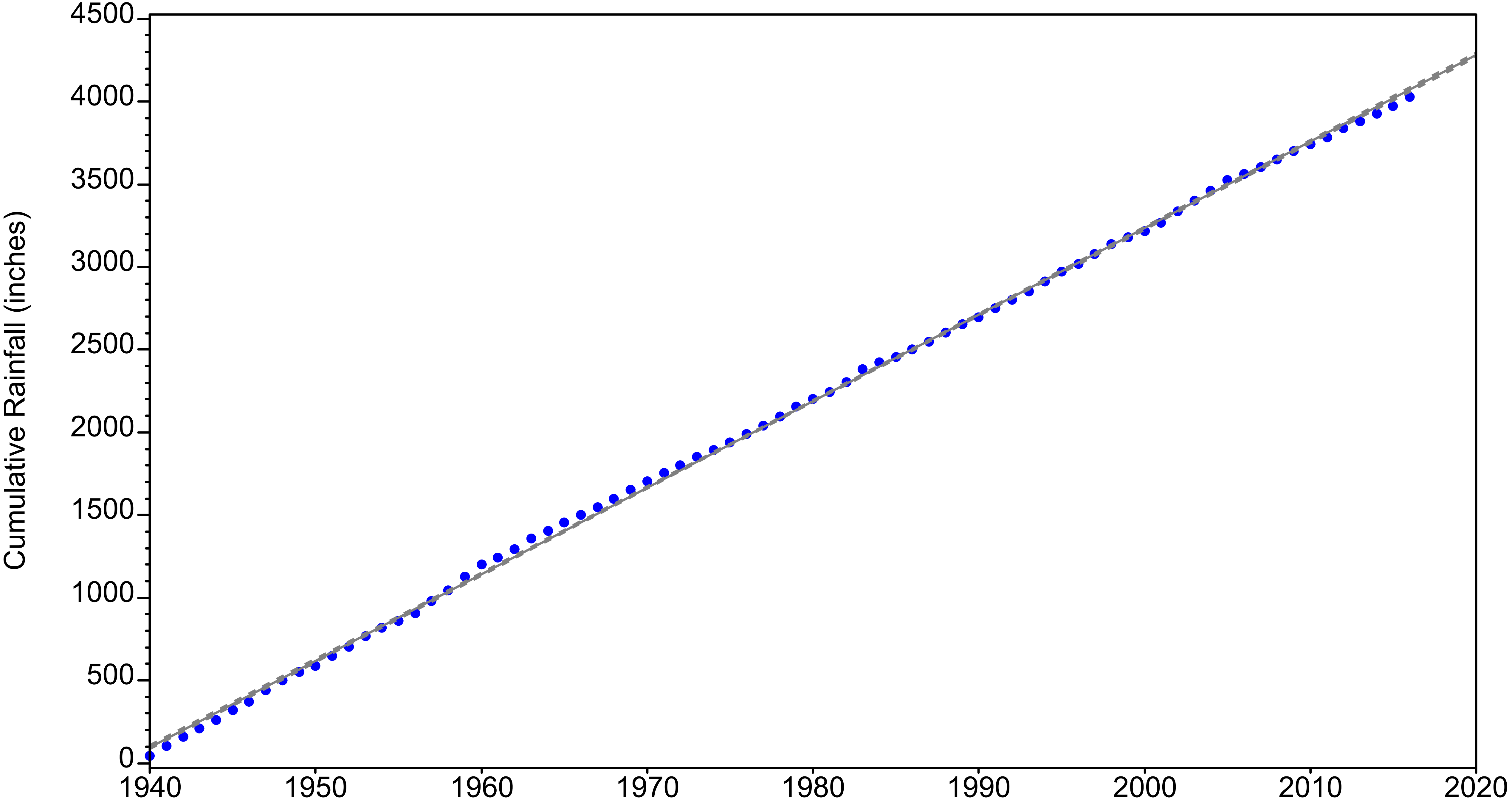


Figure 3.363 Sum of yearly rainfall at Bartow over time (1940-2016)

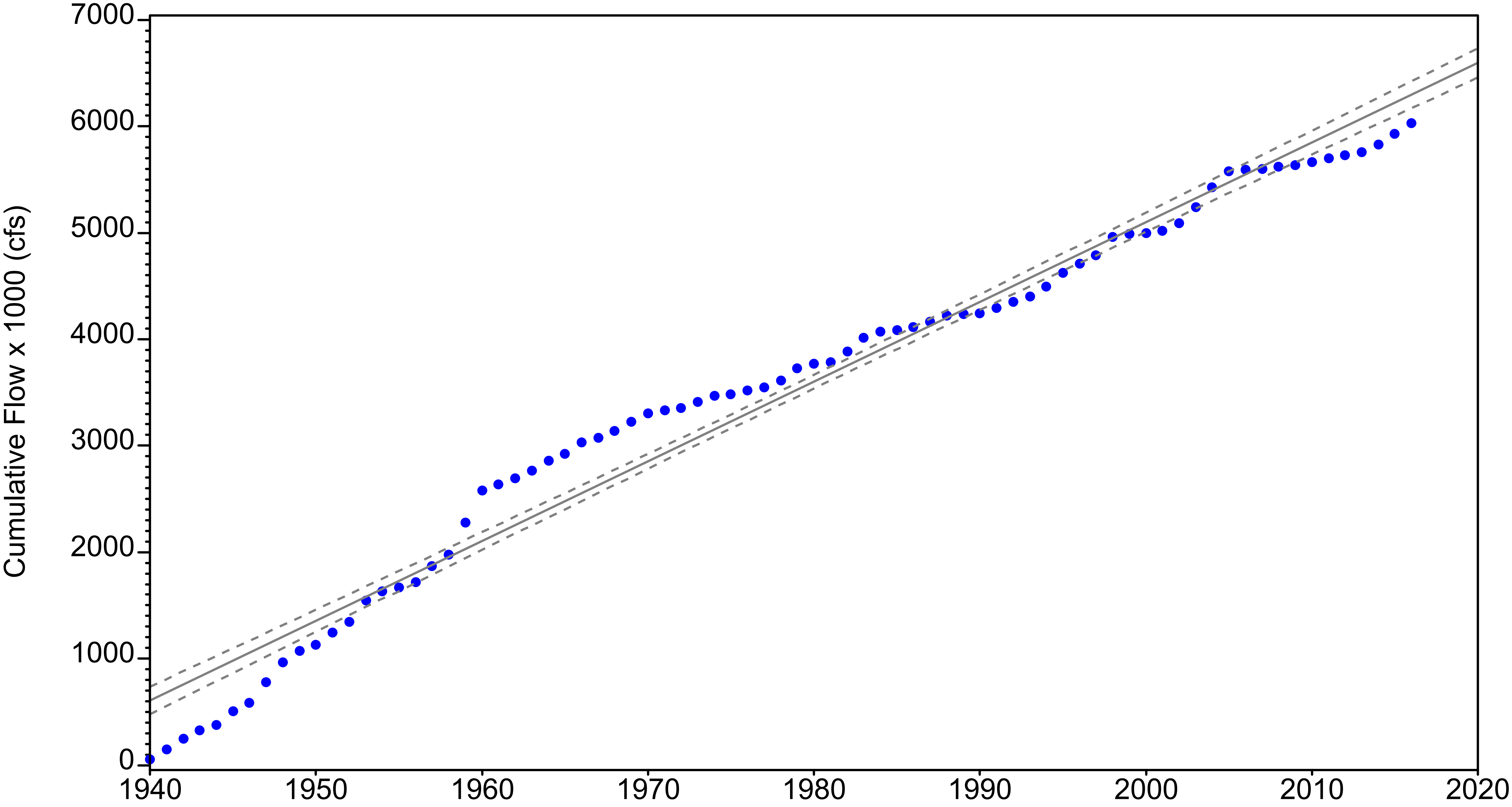


Figure 3.364 Sum of total yearly Peace River at Bartow flow over time (1940-2016)

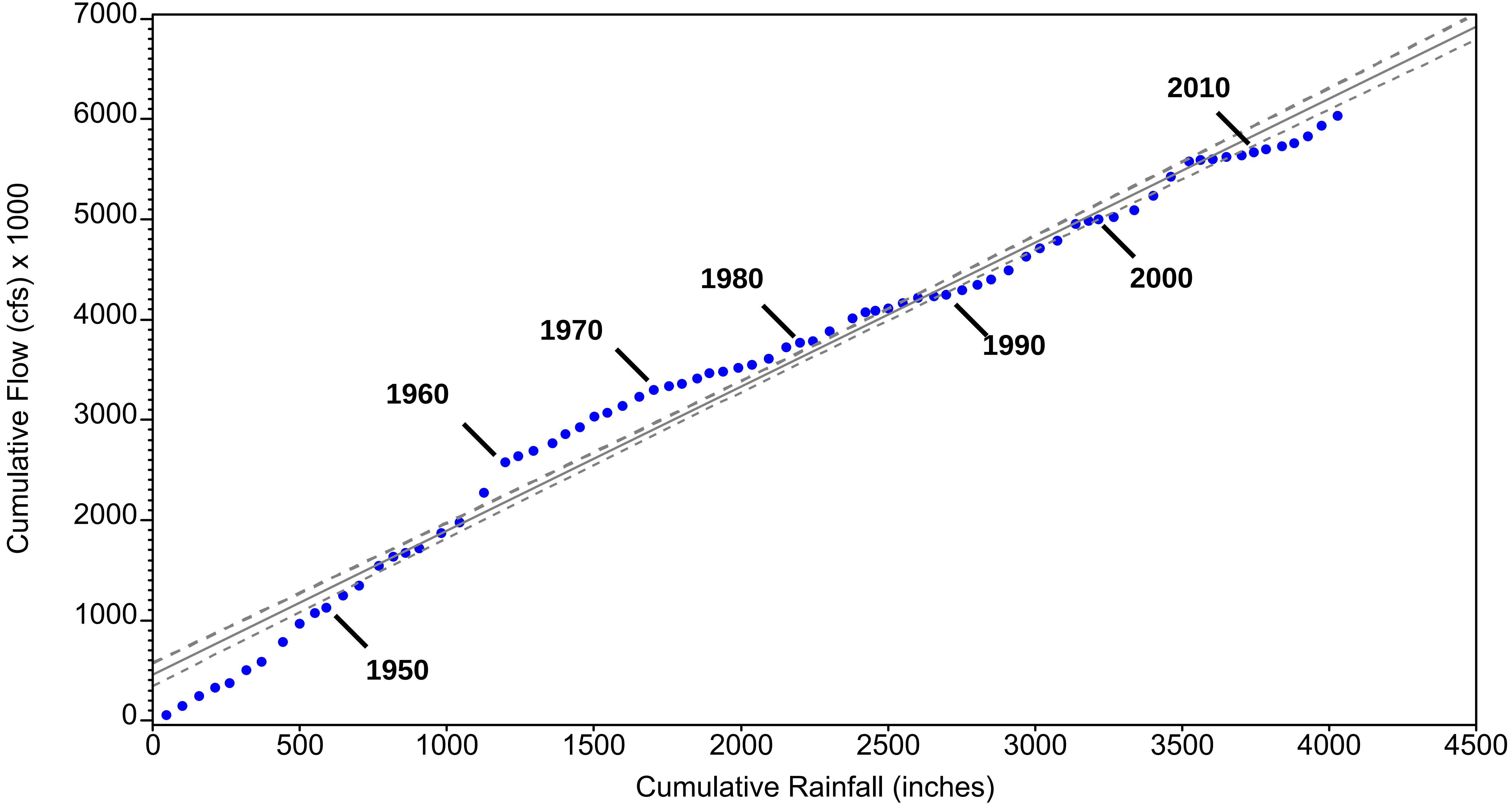


Figure 3.365 NOAA rainfall at Bartow vs. USGS gaged Peace River flow at Bartow (1940-2016)

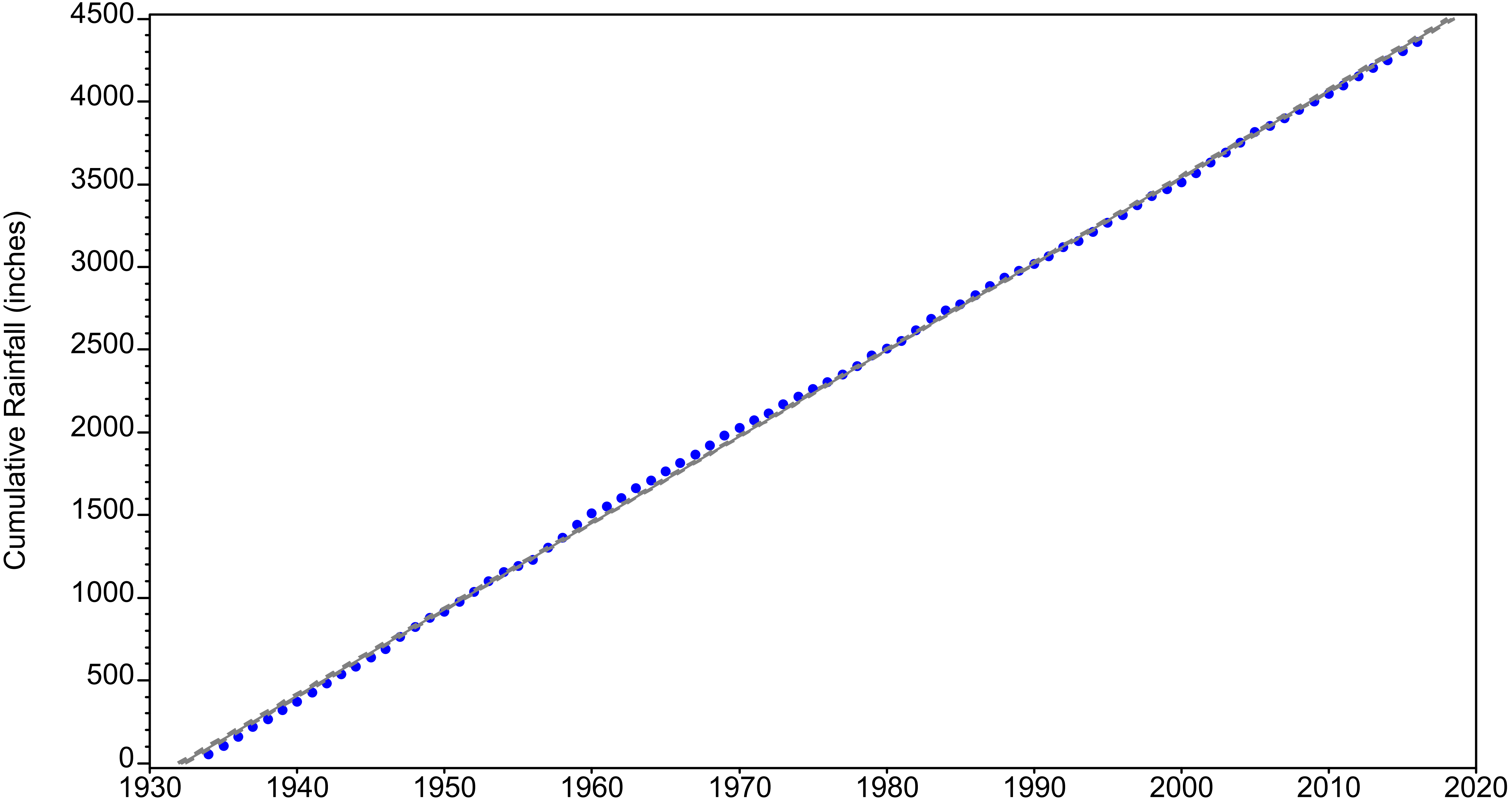


Figure 3.366 Sum of yearly average Bartow/Arcadia NOAA rainfall over time (1934-2016)

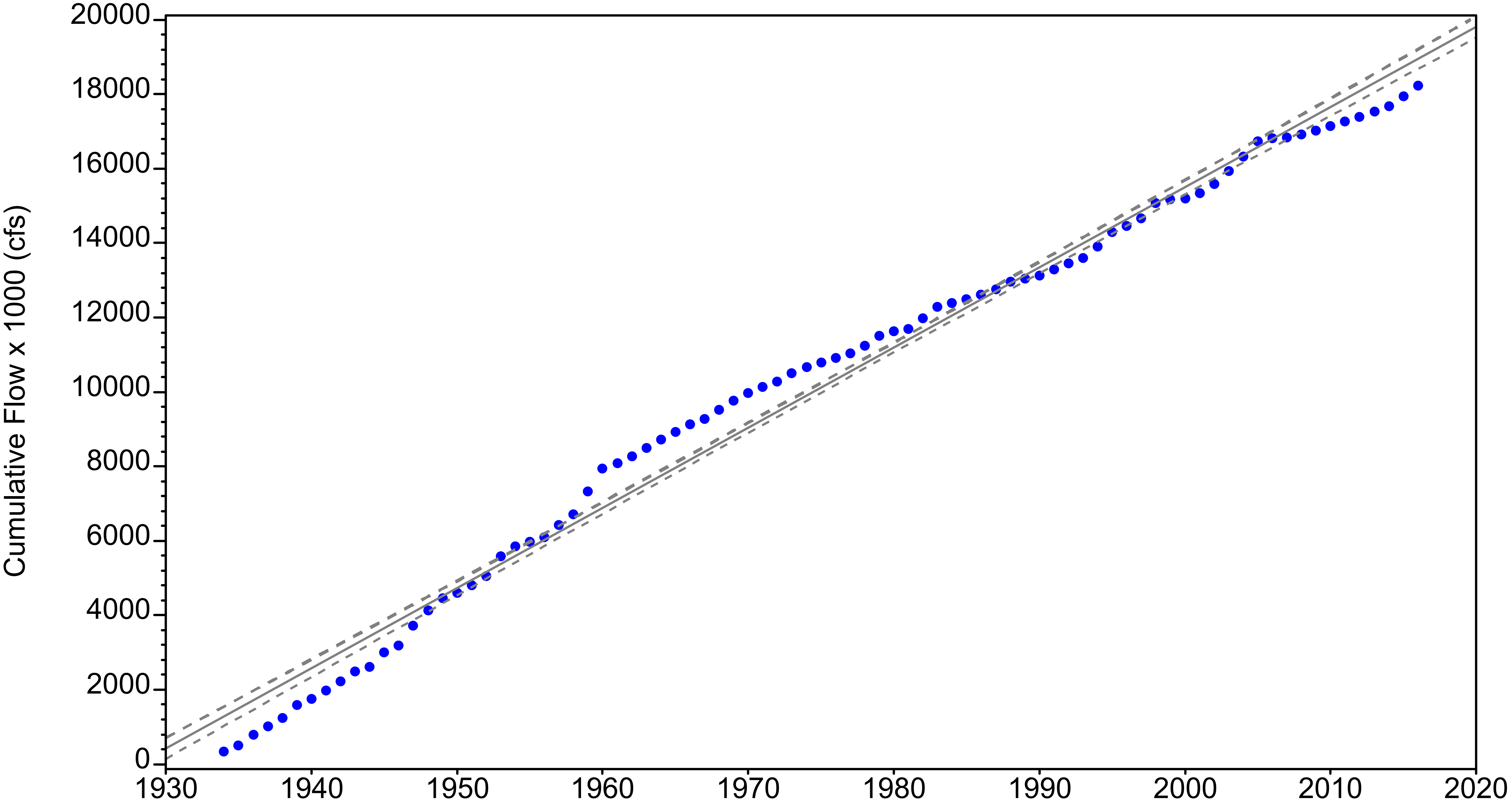


Figure 3.367 Sum of total yearly Peace River at Zolfo Springs flow over time (1934-2016)

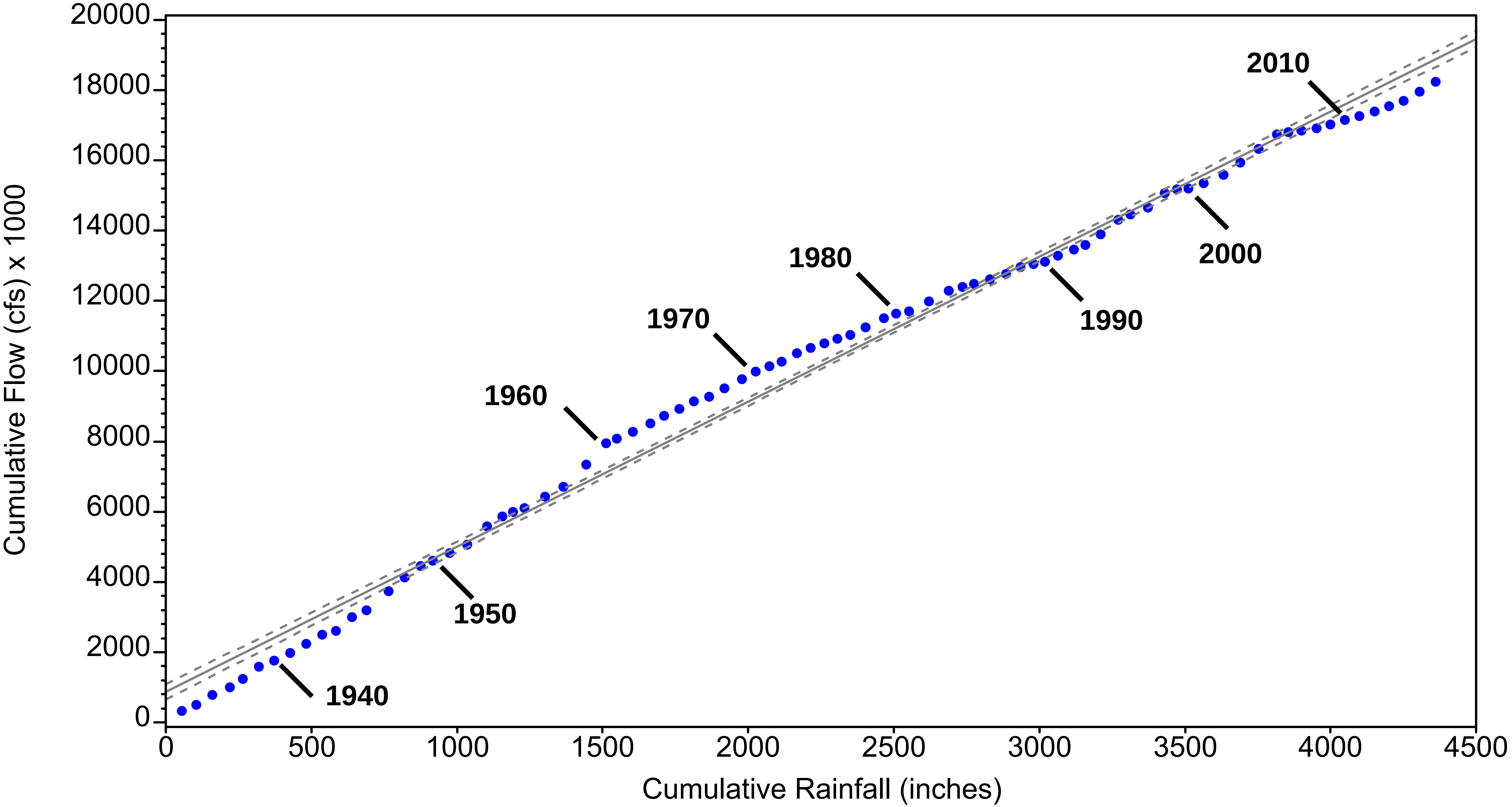


Figure 3.368 Average of Bartow/Arcadia NOAA rainfall vs. USGS gaged Peace River at Zolfo Springs flow (1934-2016)

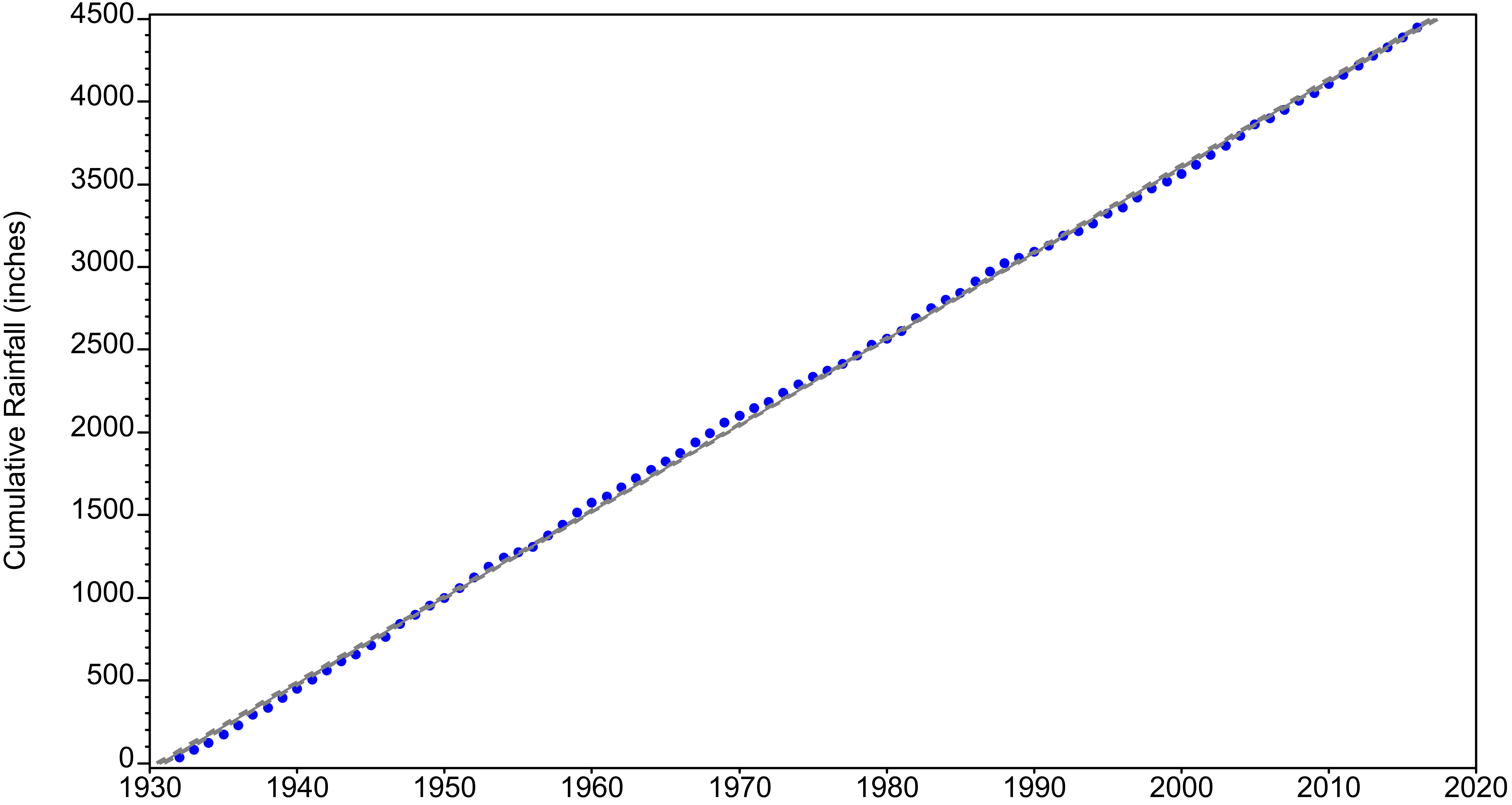


Figure 3.369 Sum of yearly rainfall at Arcadia over time (1932-2016)

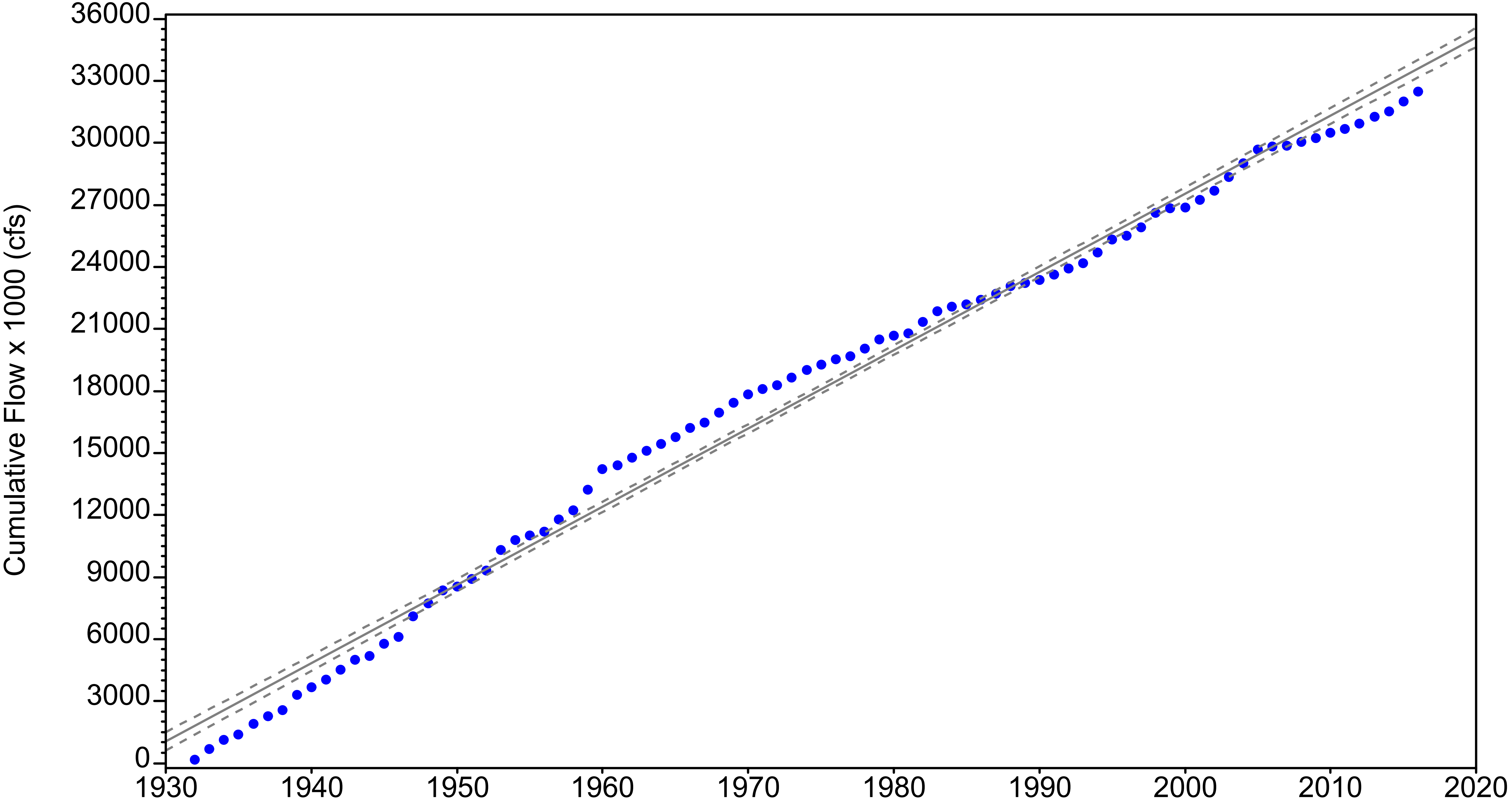


Figure 3.370 Sum of total yearly Peace River at Arcadia flow over time (1932-2016)

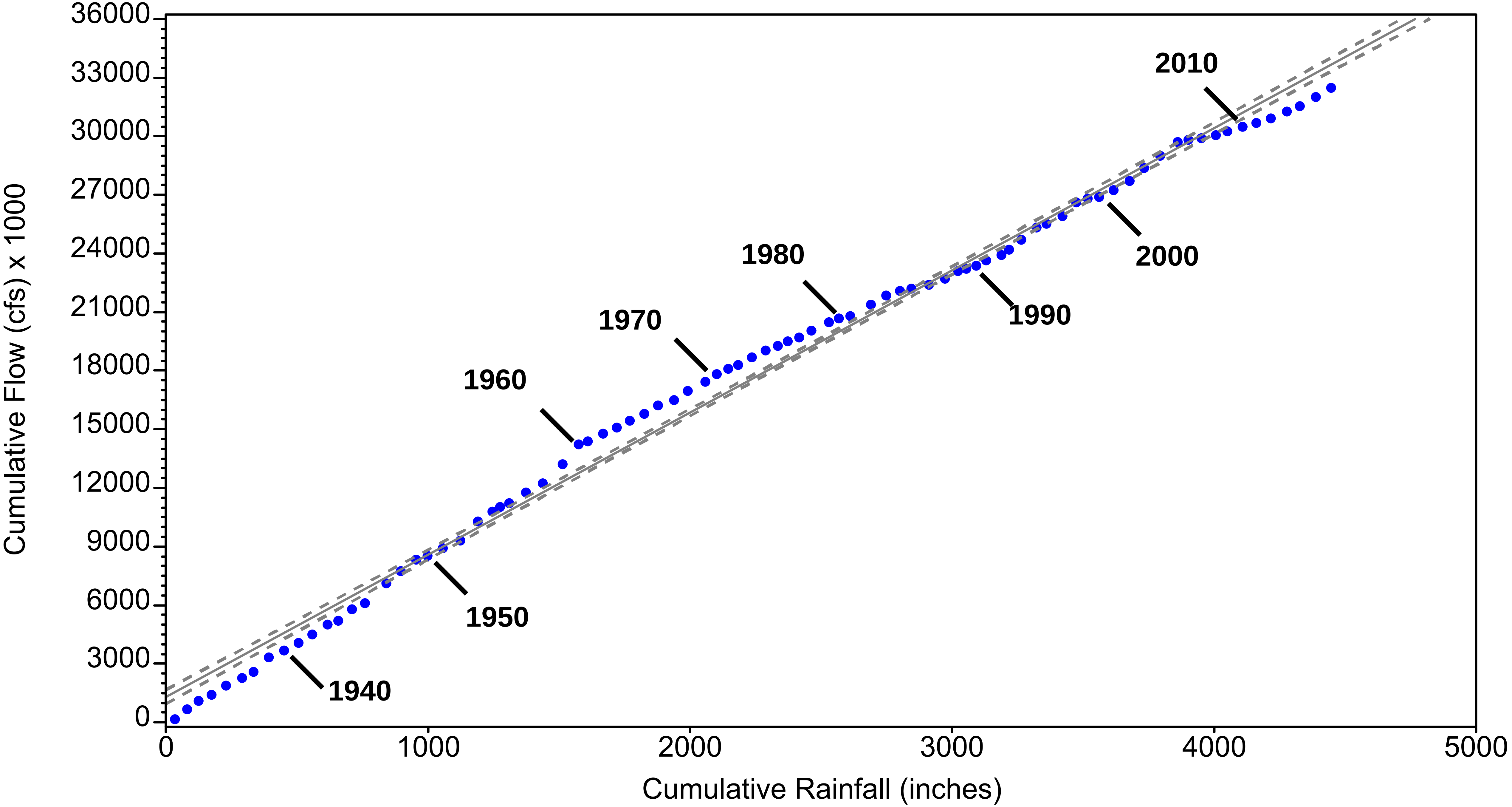


Figure 3.371 NOAA rainfall at Arcadia vs. USGS gaged Peace River at Arcadia flow (1932-2016)

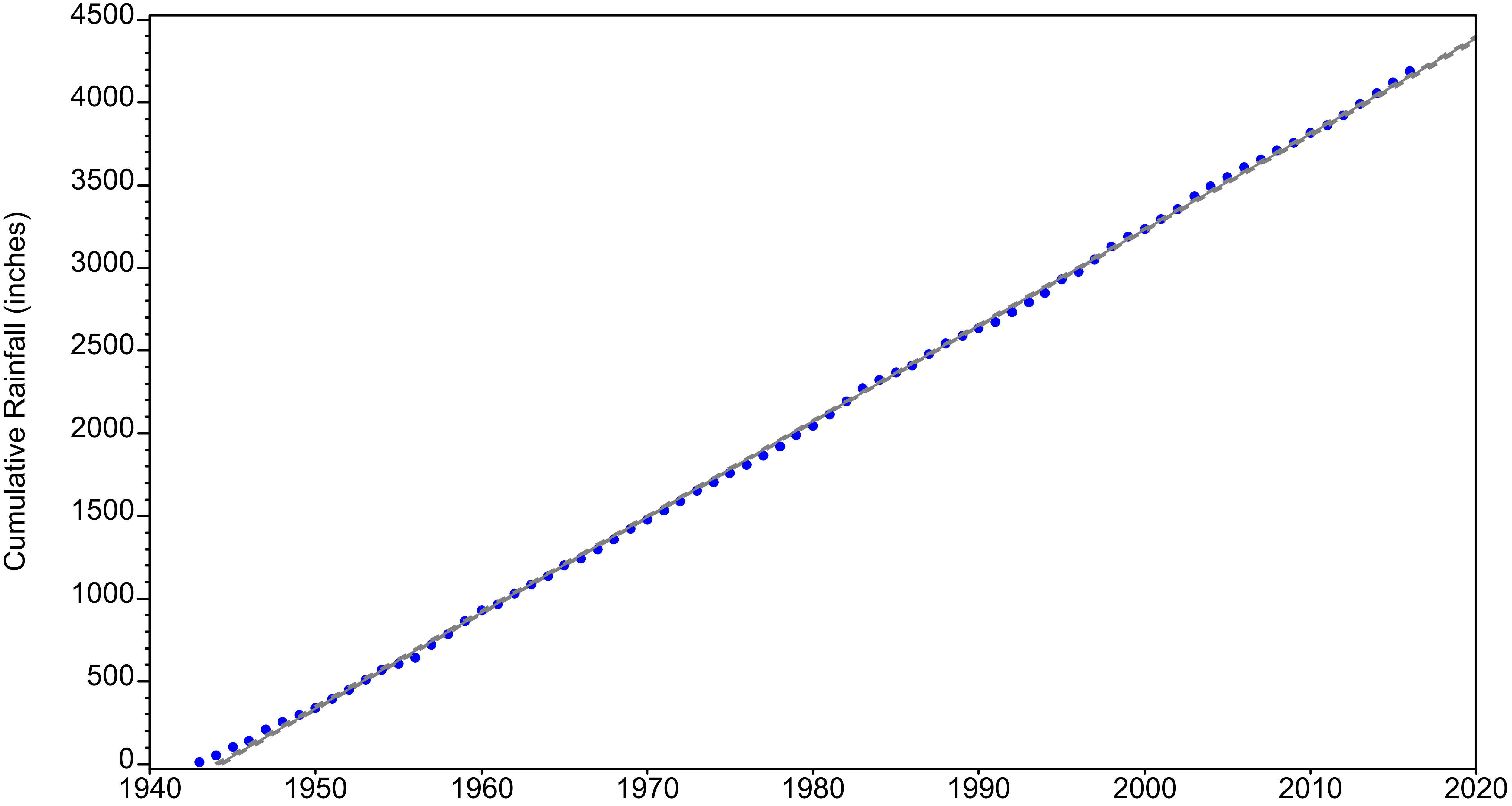


Figure 3.372 Sum of yearly rainfall at Myakka State Park over time (1943-2016)

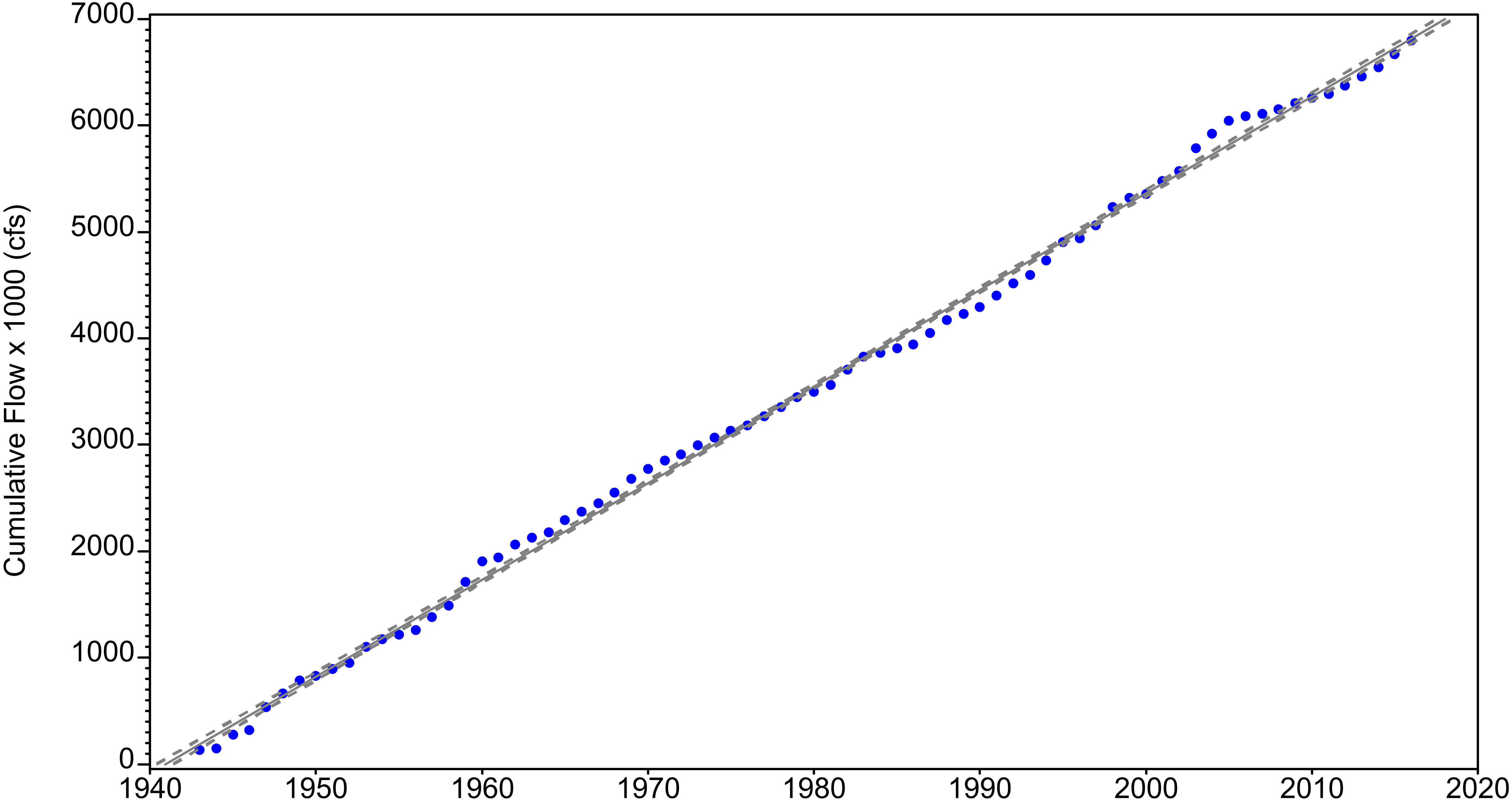


Figure 3.373 Sum of total yearly Myakka River near Sarasota flow over time (1943-2016)

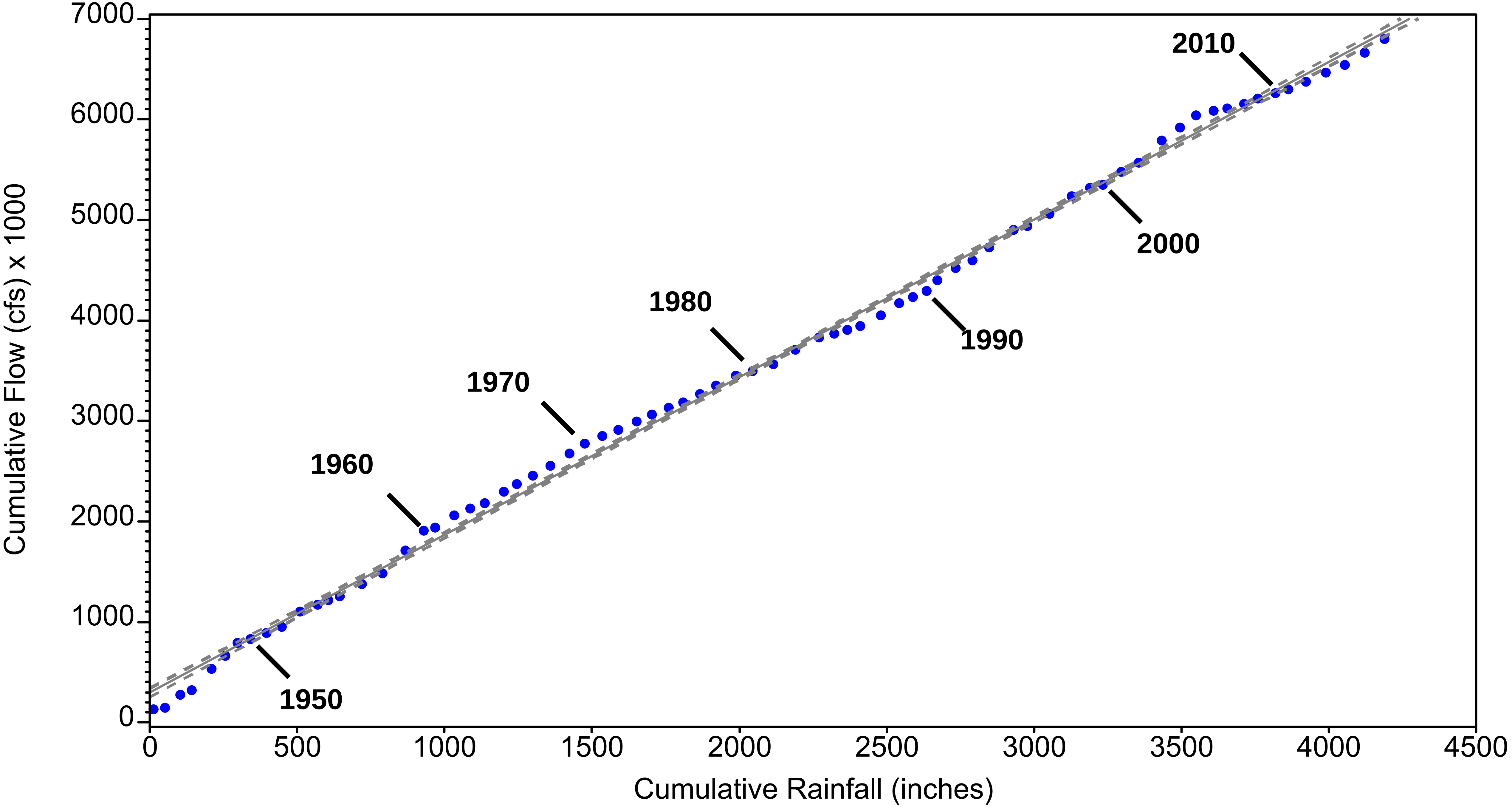


Figure 3.374 NOAA rainfall at Myakka State Park vs. USGS gaged Myakka River flow (1943-2016)

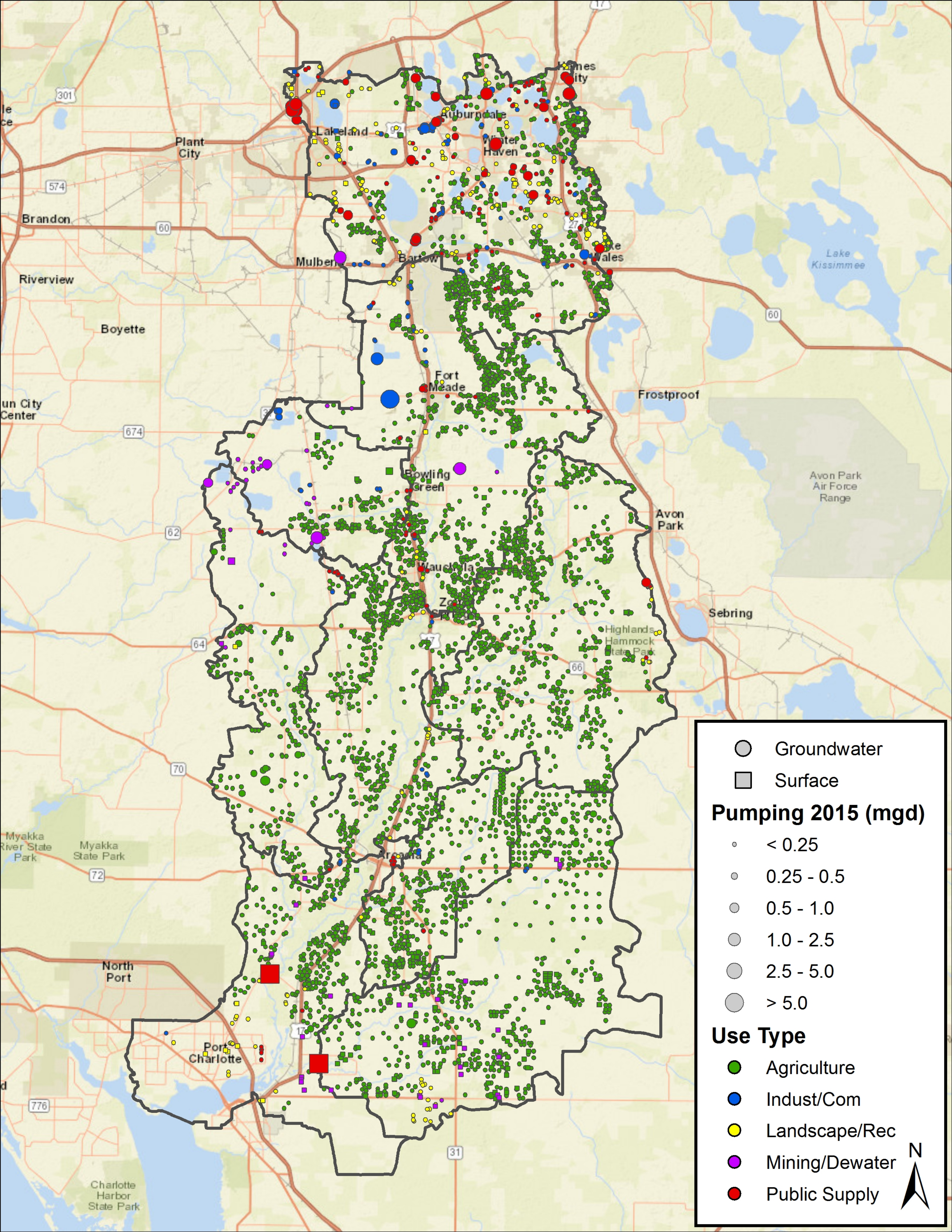

Groundwater
Surface
Pumping 2015 (mgd)
< 0.25
0.25 - 0.5
0.5 - 1.0
1.0 - 2.5
2.5 - 5.0
> 5.0
Use Type
Agriculture
Indust/Com
Landscape/Rec
Mining/Dewater
Public Supply
N
Lakeland
Auburndale
Winter Haven
Haines City
Lake Wales
Plant City
Brandon
Riverview
Boyette
Mulberry
Bartow
Fort Meade
Frostproof
Lake Kissimmee
Avon Park Air Force Range
Avon Park
Sebring
Highlands Hammock State Park
Bowling Green
Wauchula
Zolfo Springs
Arcadia
Myakka River State Park
Myakka State Park
North Port
Port Charlotte
Charlotte Harbor State Park
301
574
60
674
62
64
66
70
72
17
27
31
776

Figure 3.376
Facility Location

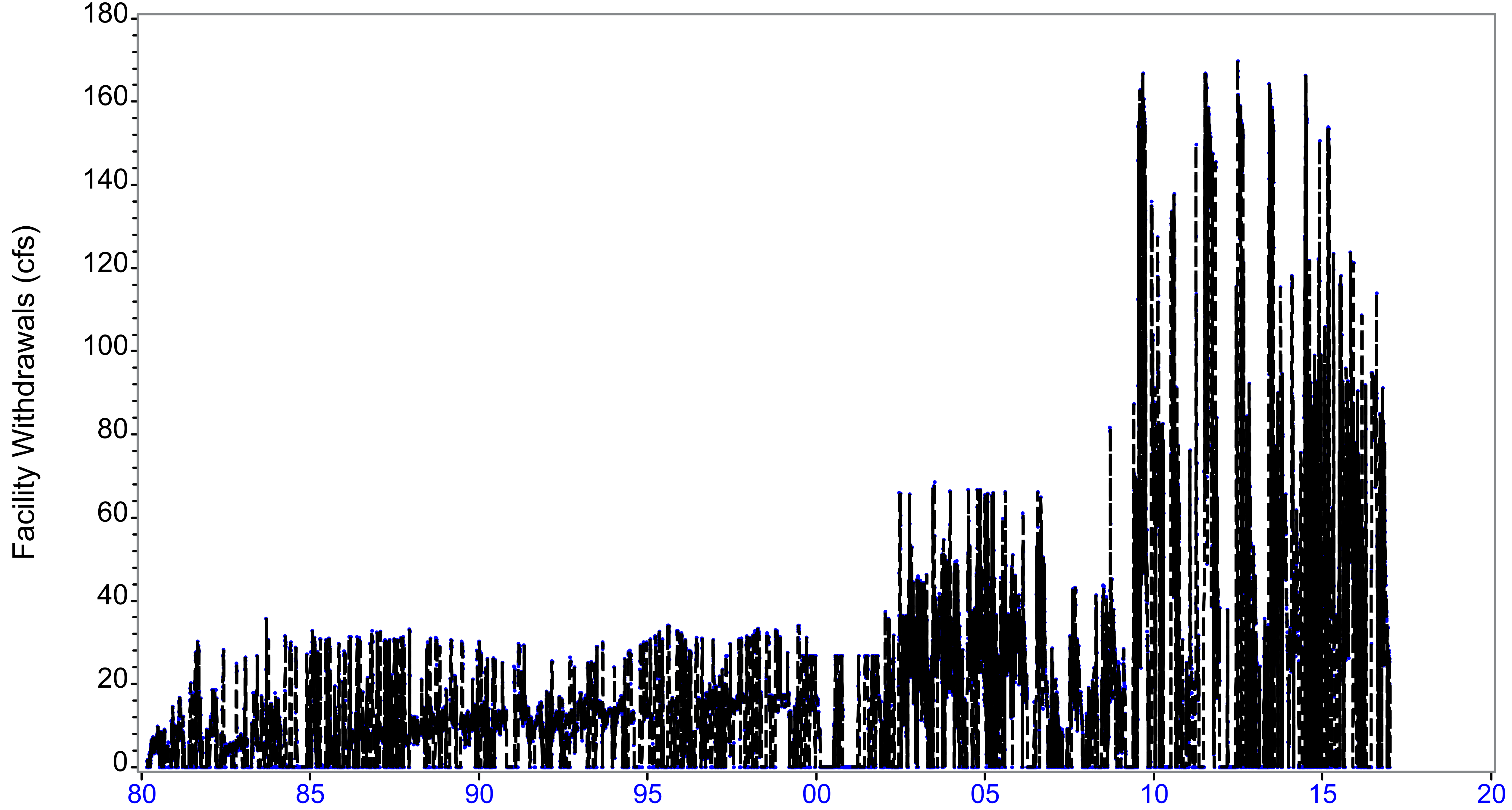


Figure 3.379 Daily water treatment facility withdrawals (1980-2016)

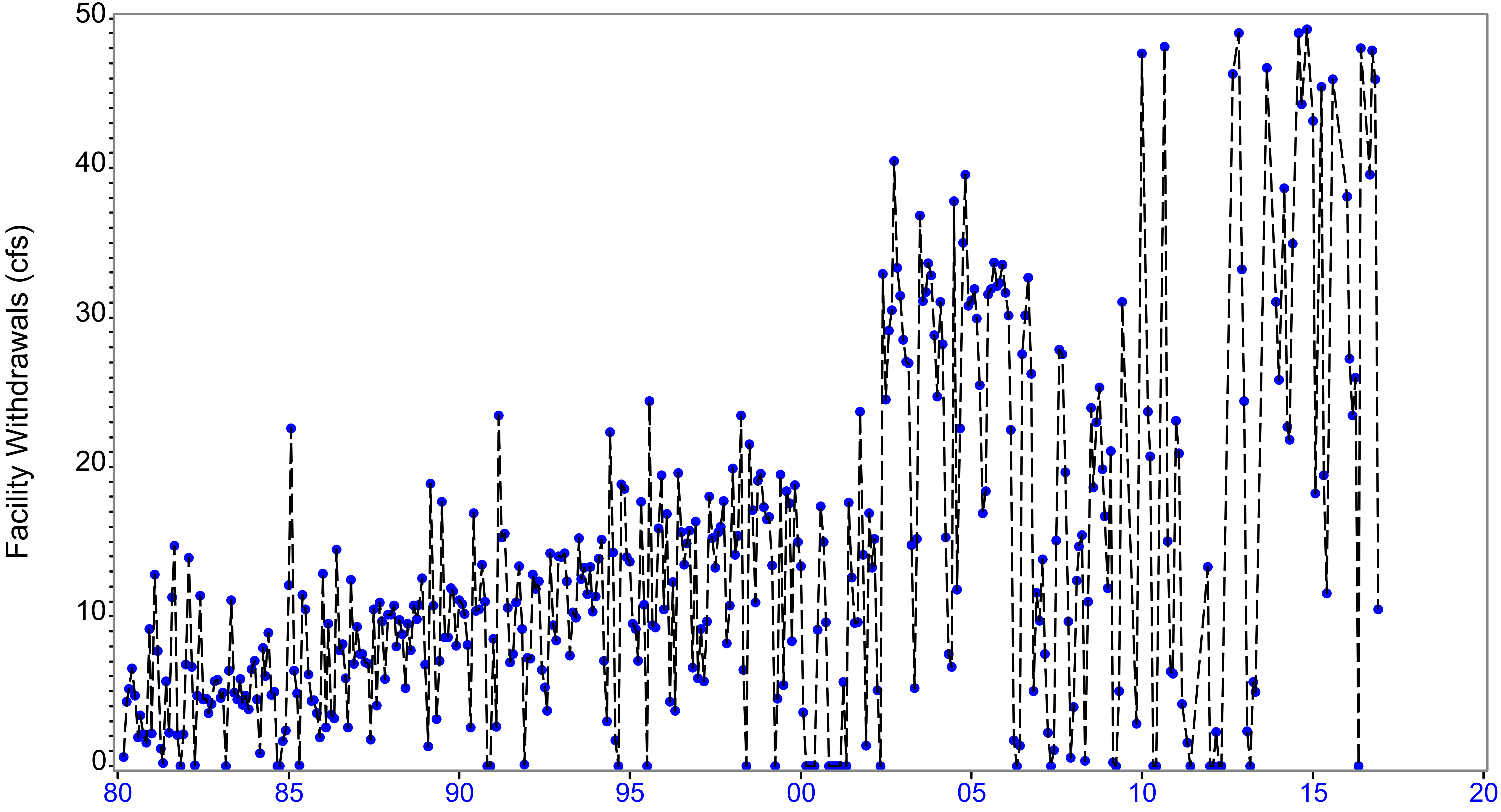


Figure 3.380 Monthly mean water treatment facility withdrawals (1980-2016)

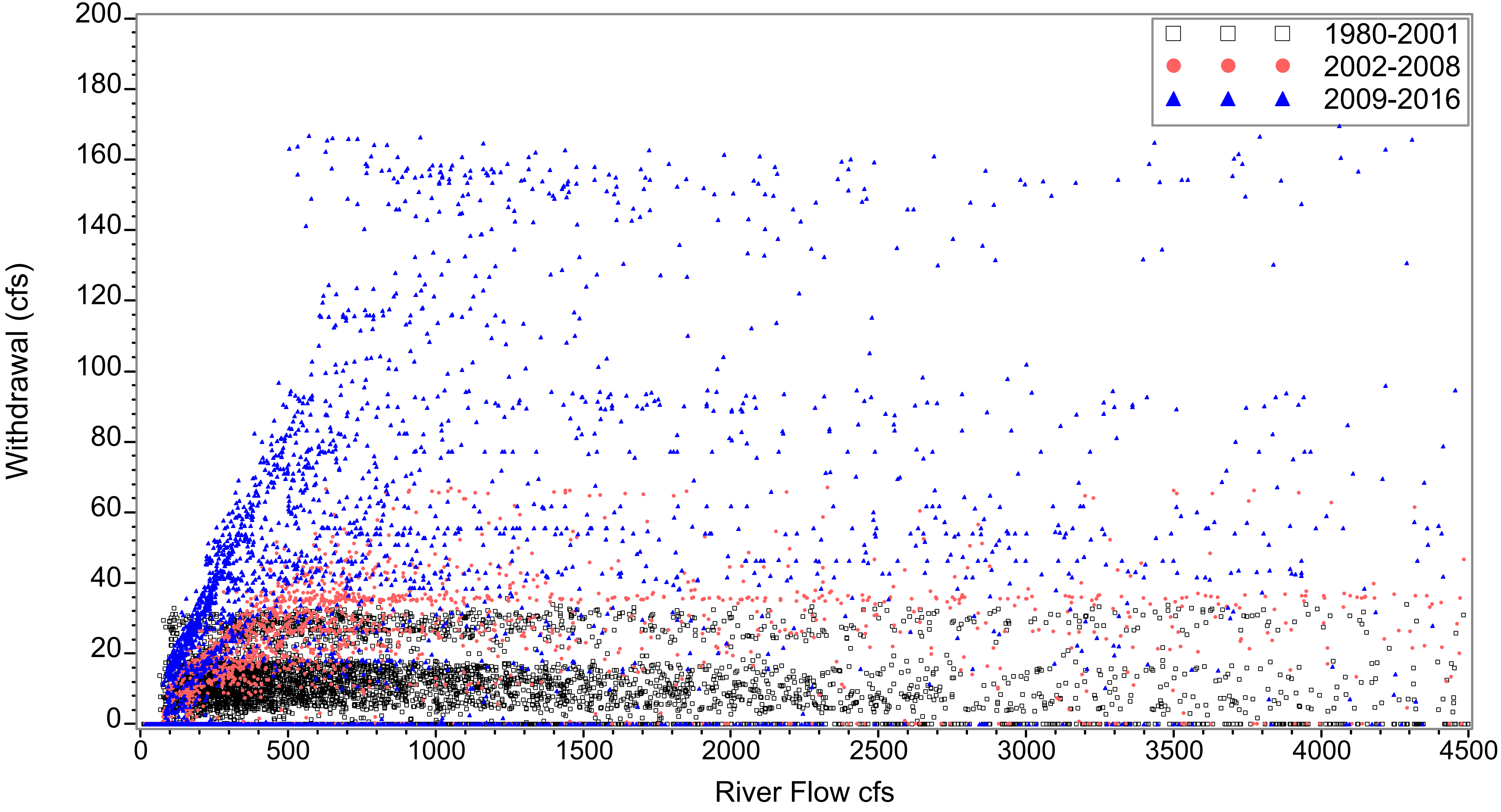


Figure 3.381 Total gaged Peace River flows upstream of the Facility vs. withdrawals

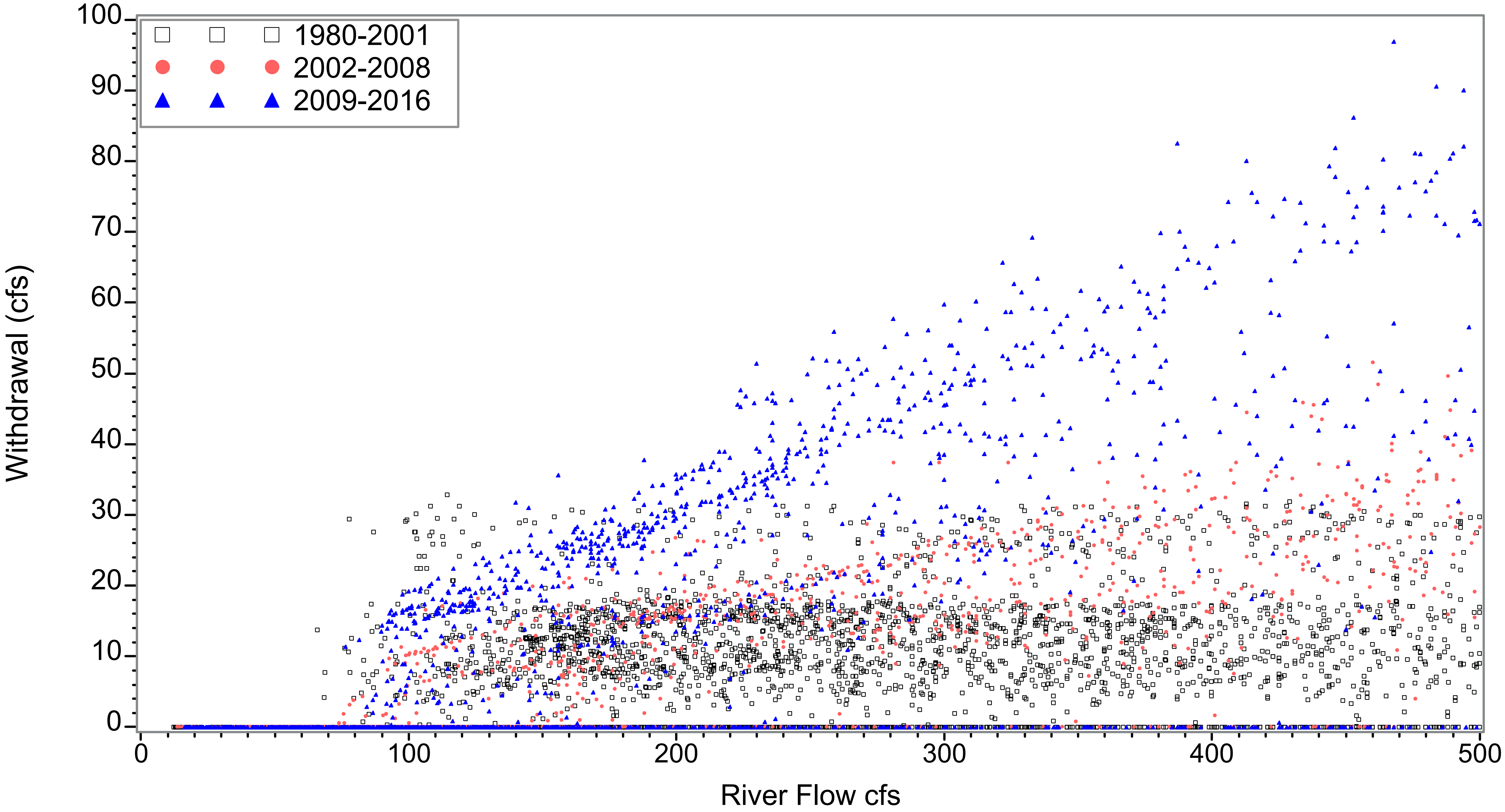


Figure 3.382 Total gaged Peace River flows upstream of the Facility vs. withdrawals

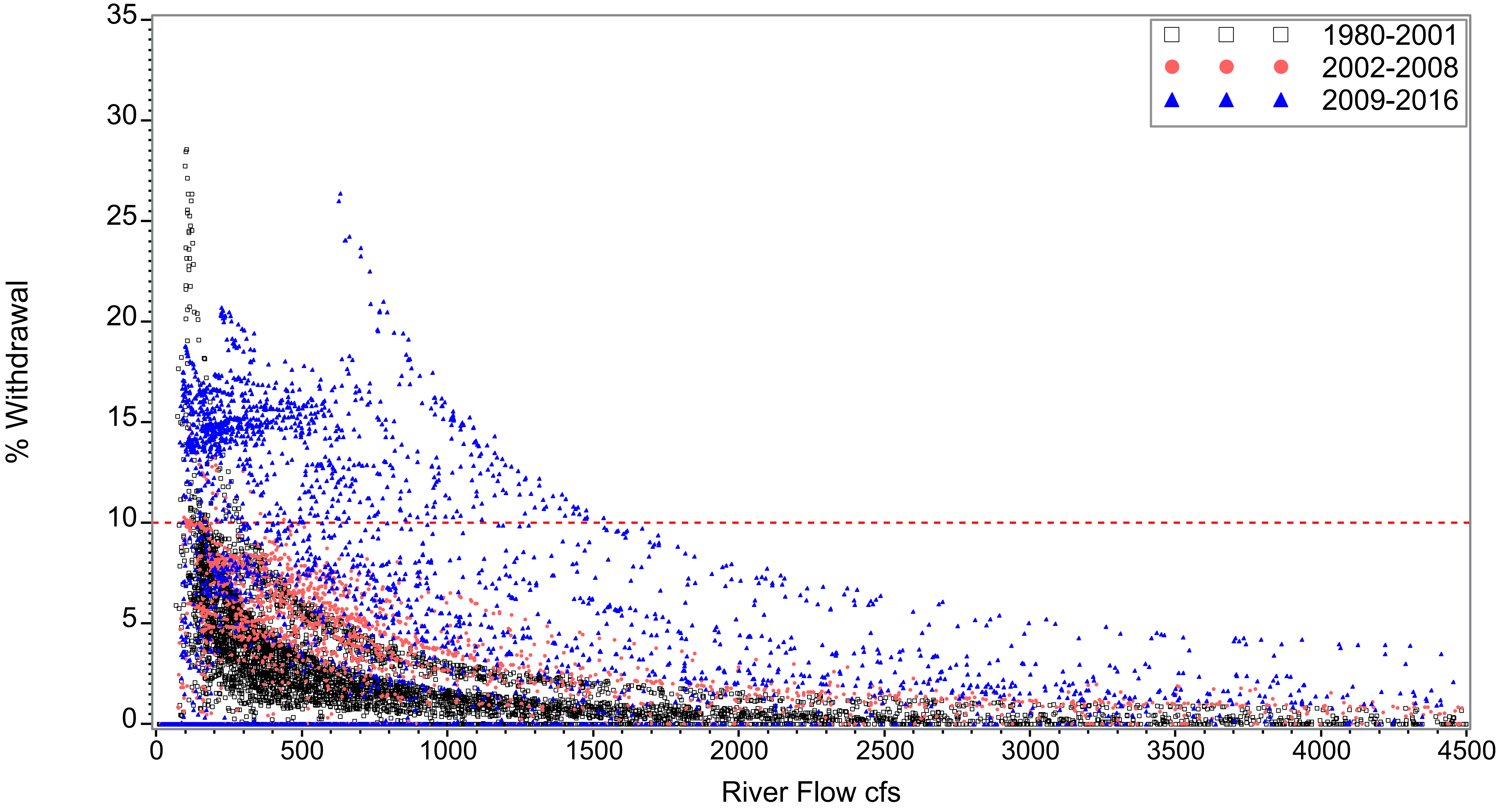


Figure 3.383 Total gaged Peace River flows upstream of the Facility vs. % withdrawals

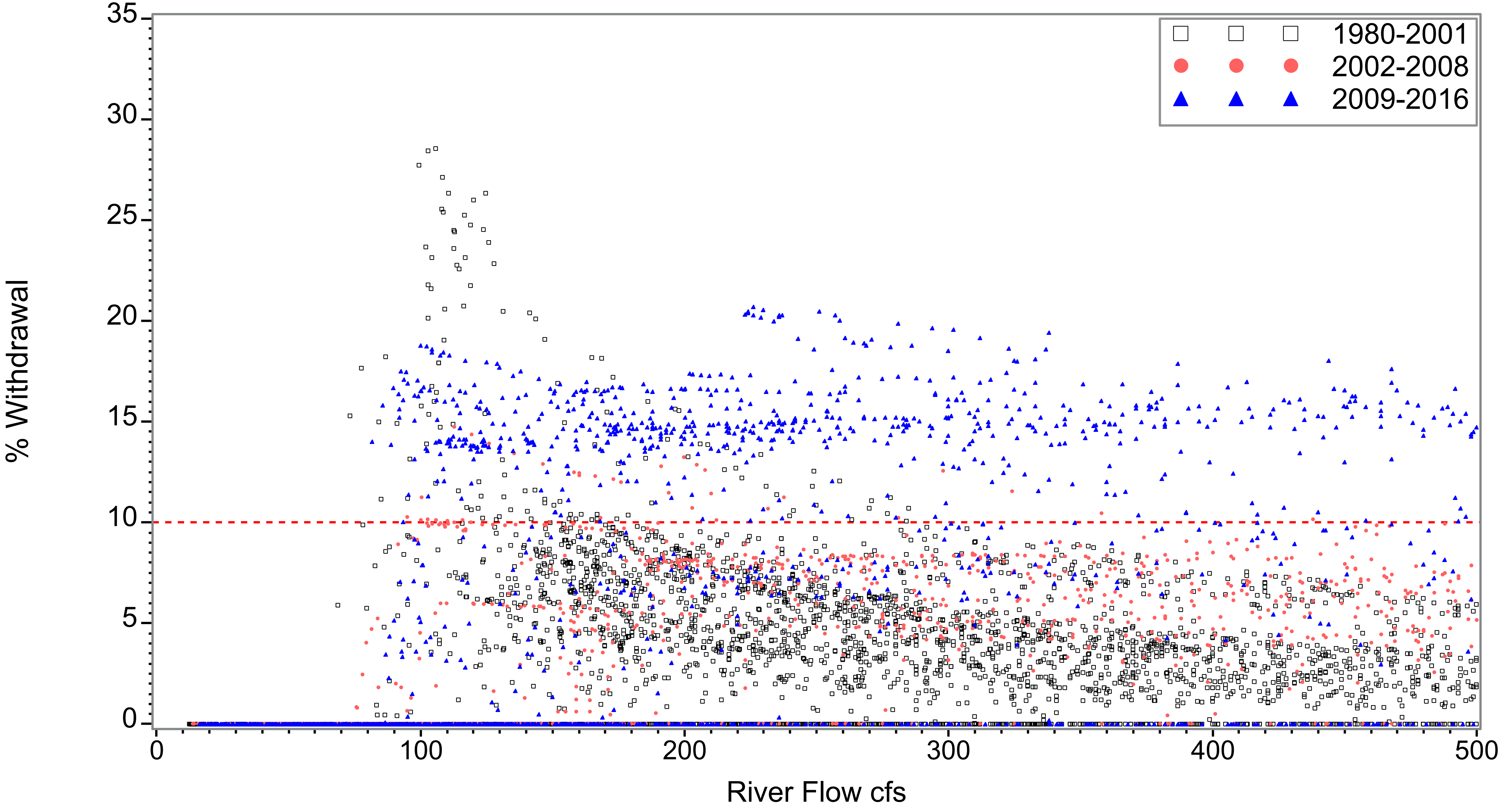


Figure 3.384 Peace River flows at Arcadia vs. % water treatment facility withdrawals

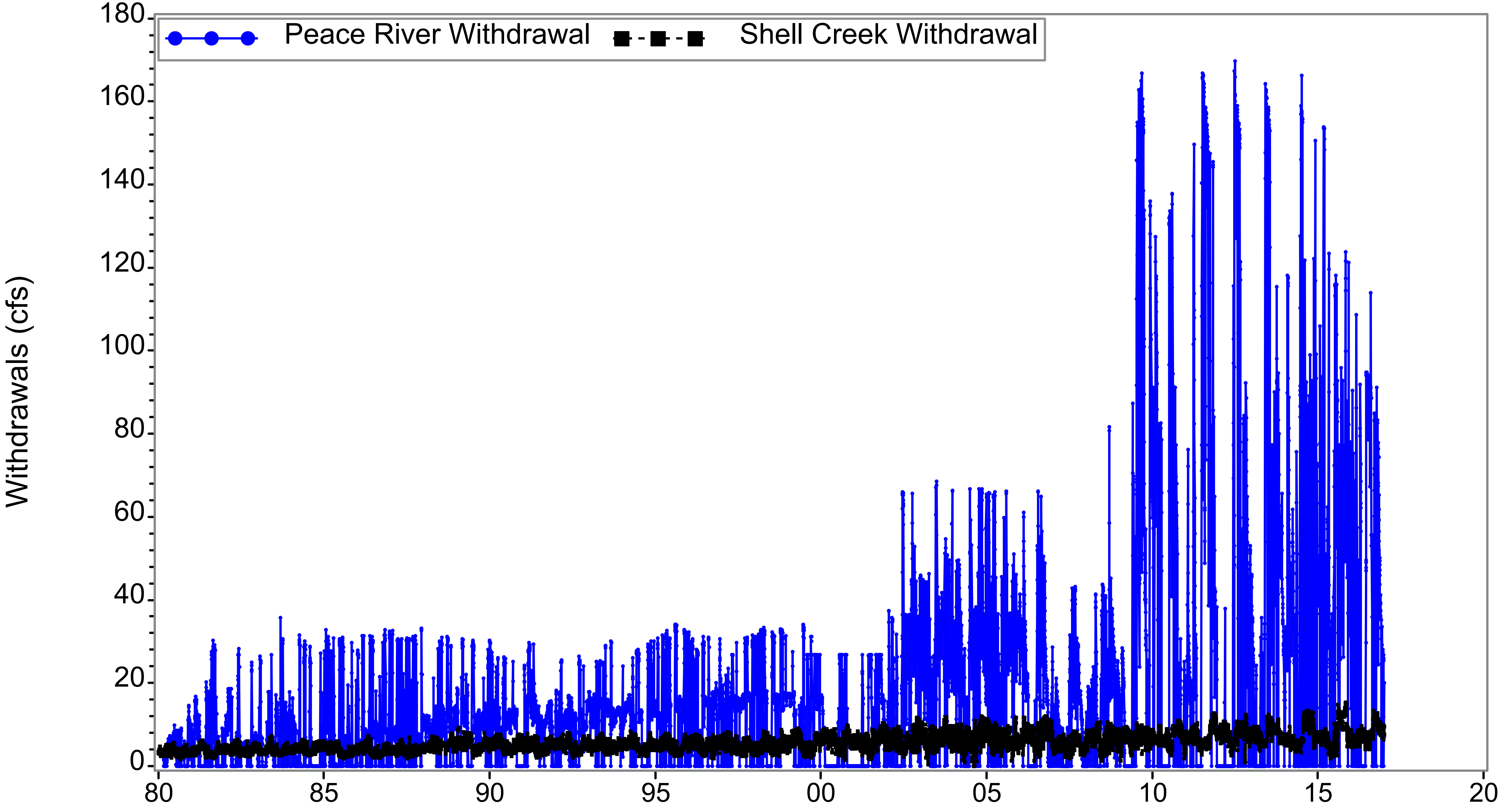


Figure 3.385 Daily Peace River and Shell Creek water treatment facility withdrawals (1980-2016)

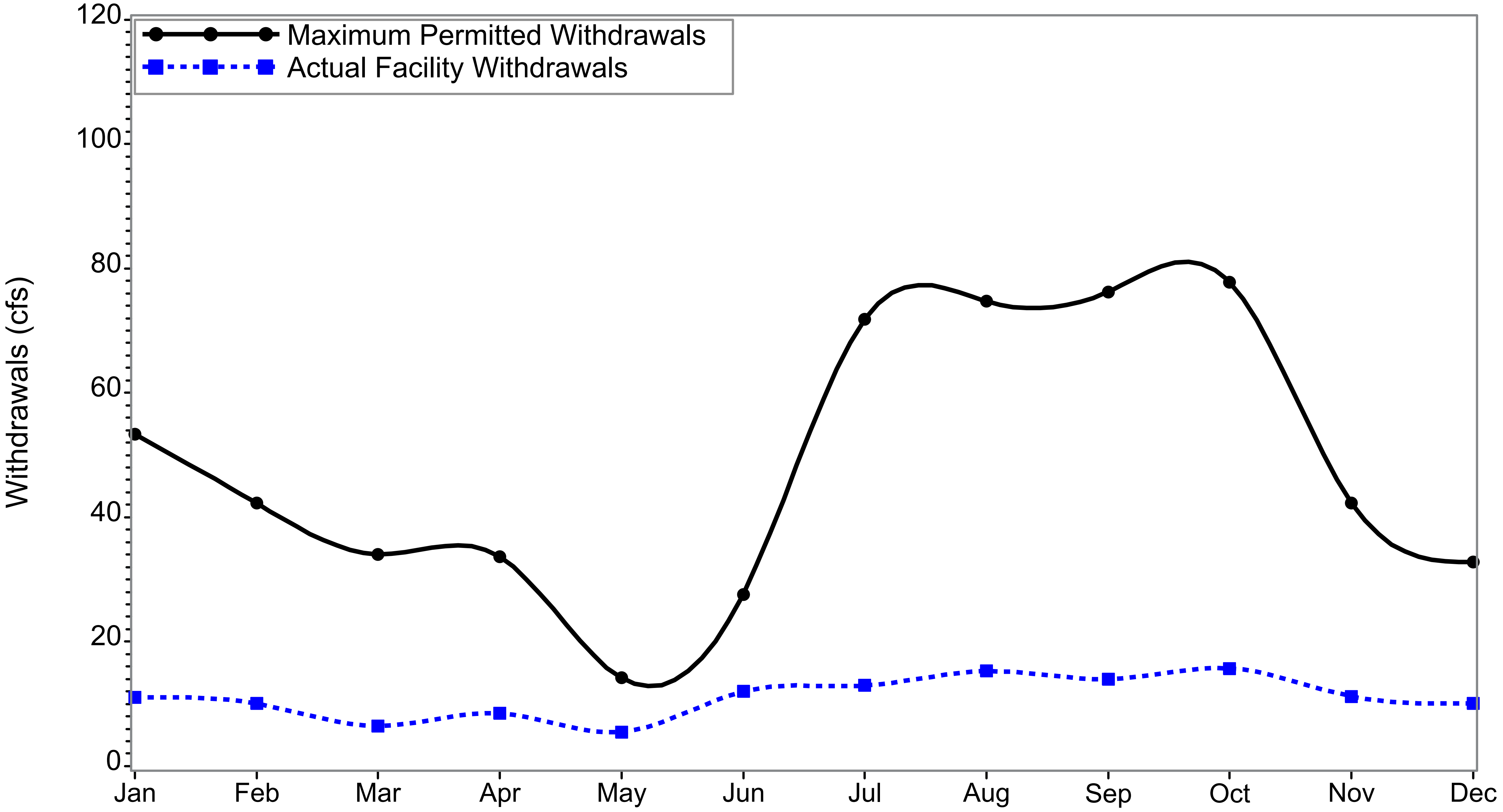


Figure 3.386 Average monthly maximum permitted and actual Facility withdrawals (1996-2001)

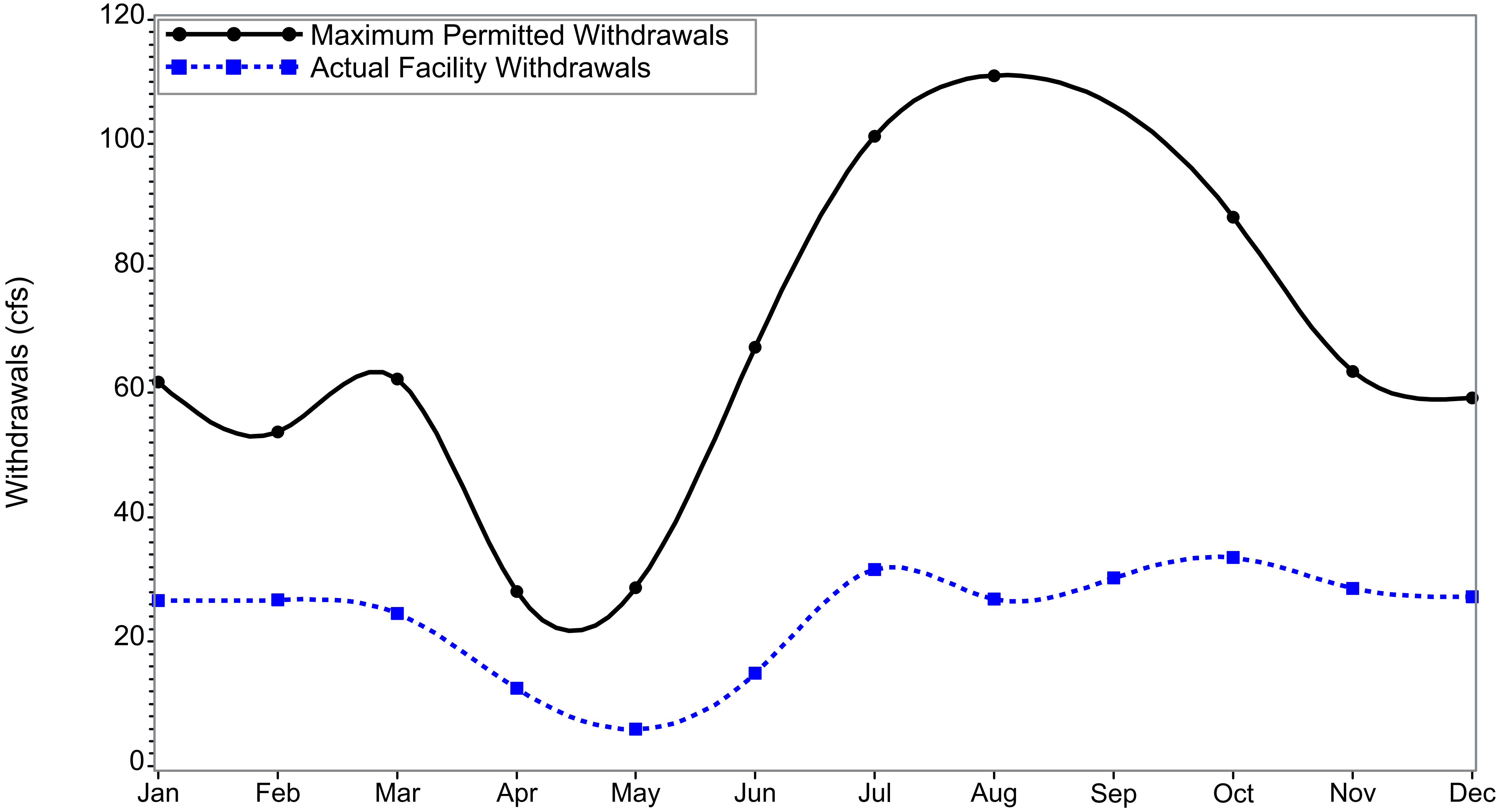


Figure 3.387 Average monthly maximum permitted and actual Facility withdrawals (2002-2006)

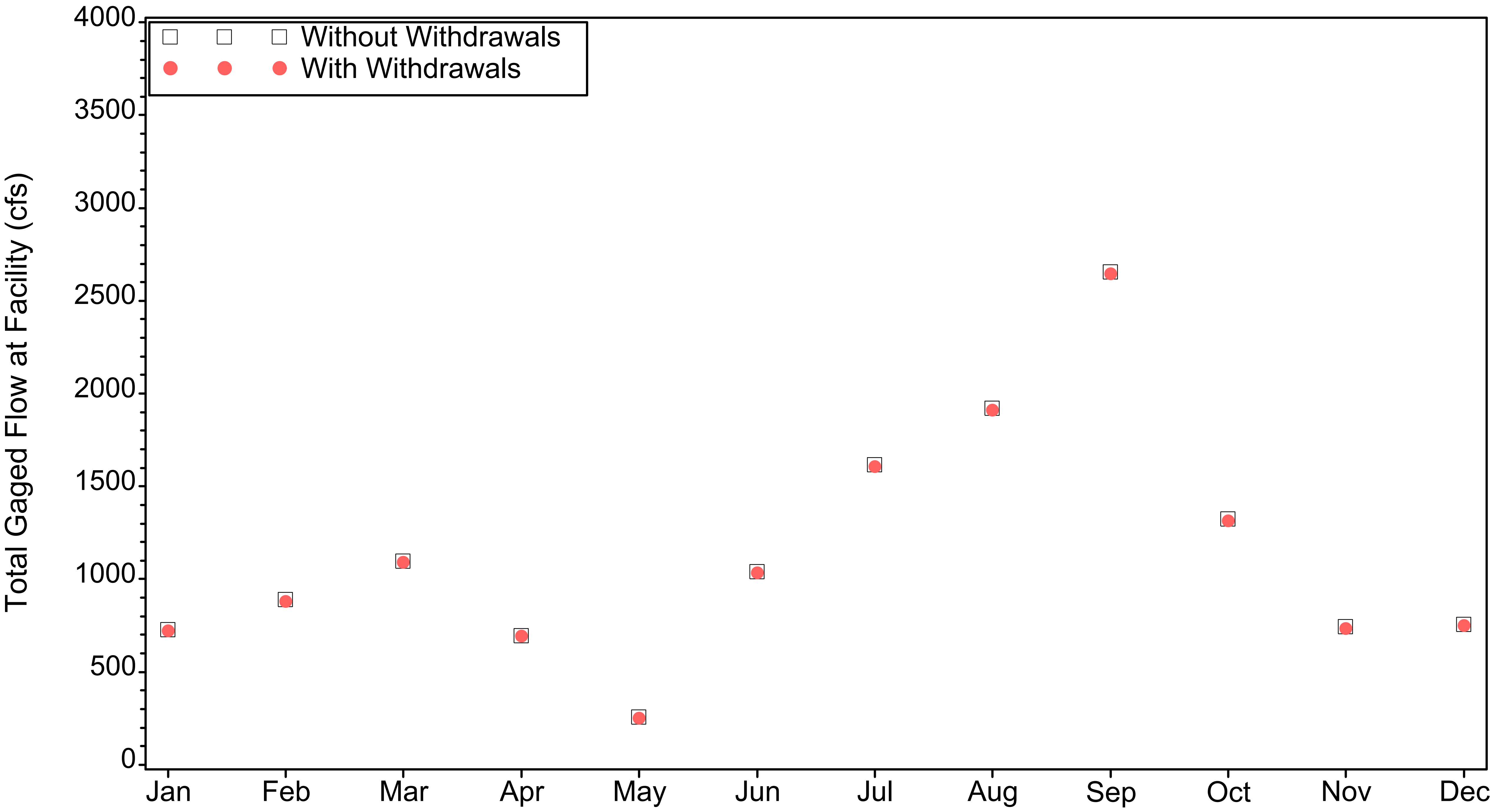


Figure 3.388 Average monthly gaged flow upsteam of the Facility with and without withdrawals (1980-2001)

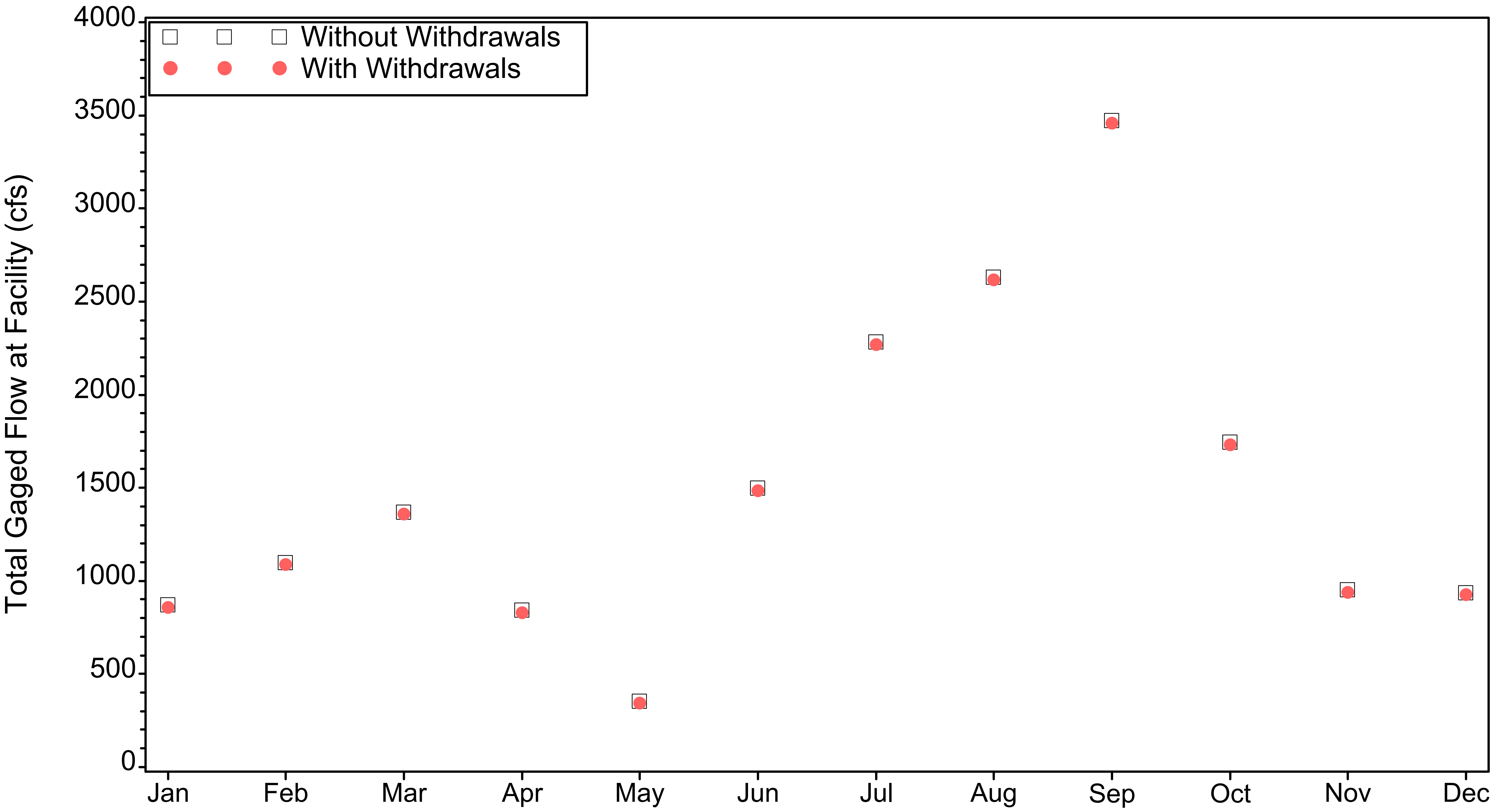


Figure 3.389 Average monthly gaged flow upstream of US41 with and without withdrawals (1980-2001)

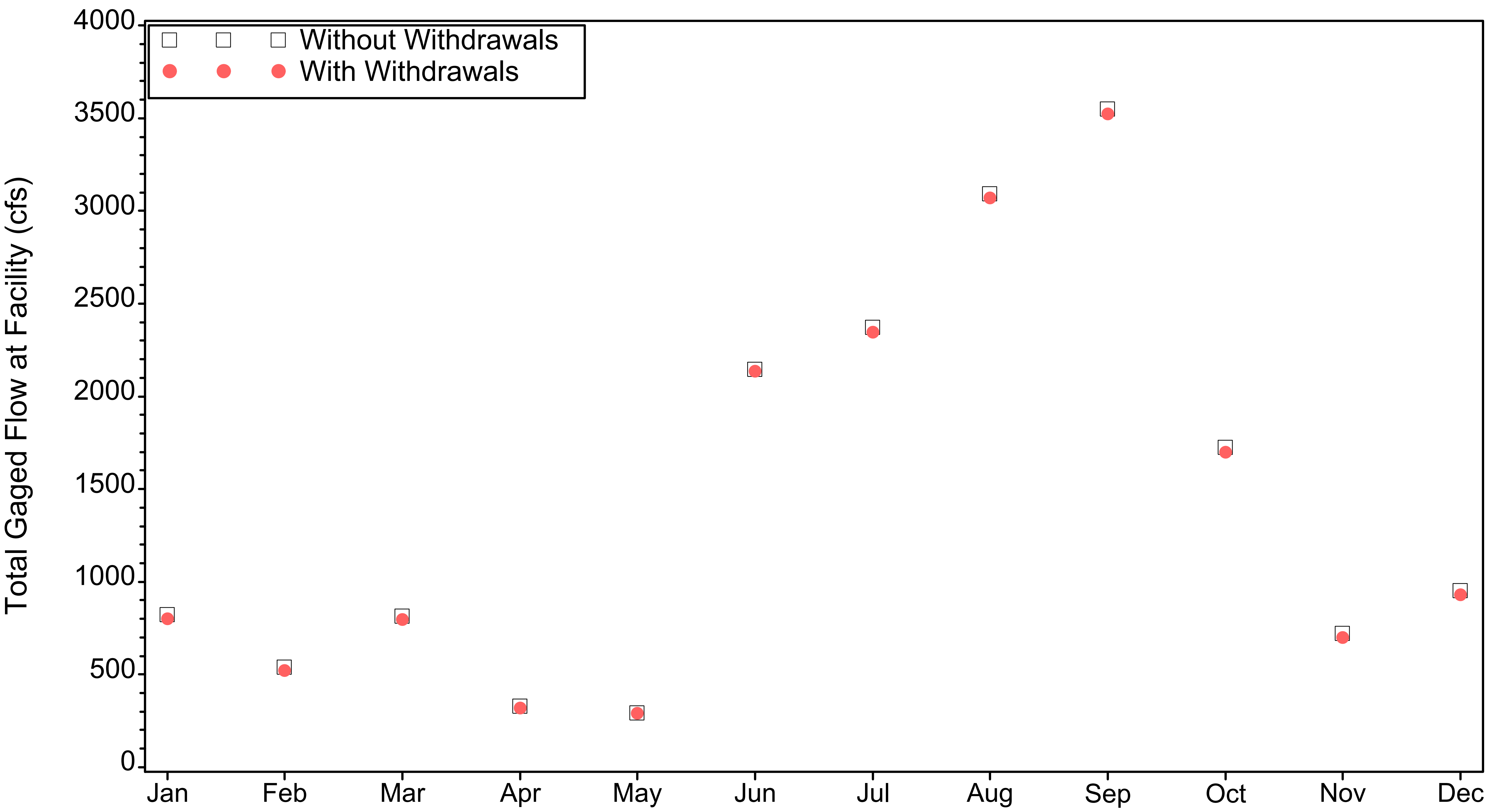


Figure 3.390 Average monthly flow upstream of the Facility with and without withdrawals (2002-2008)

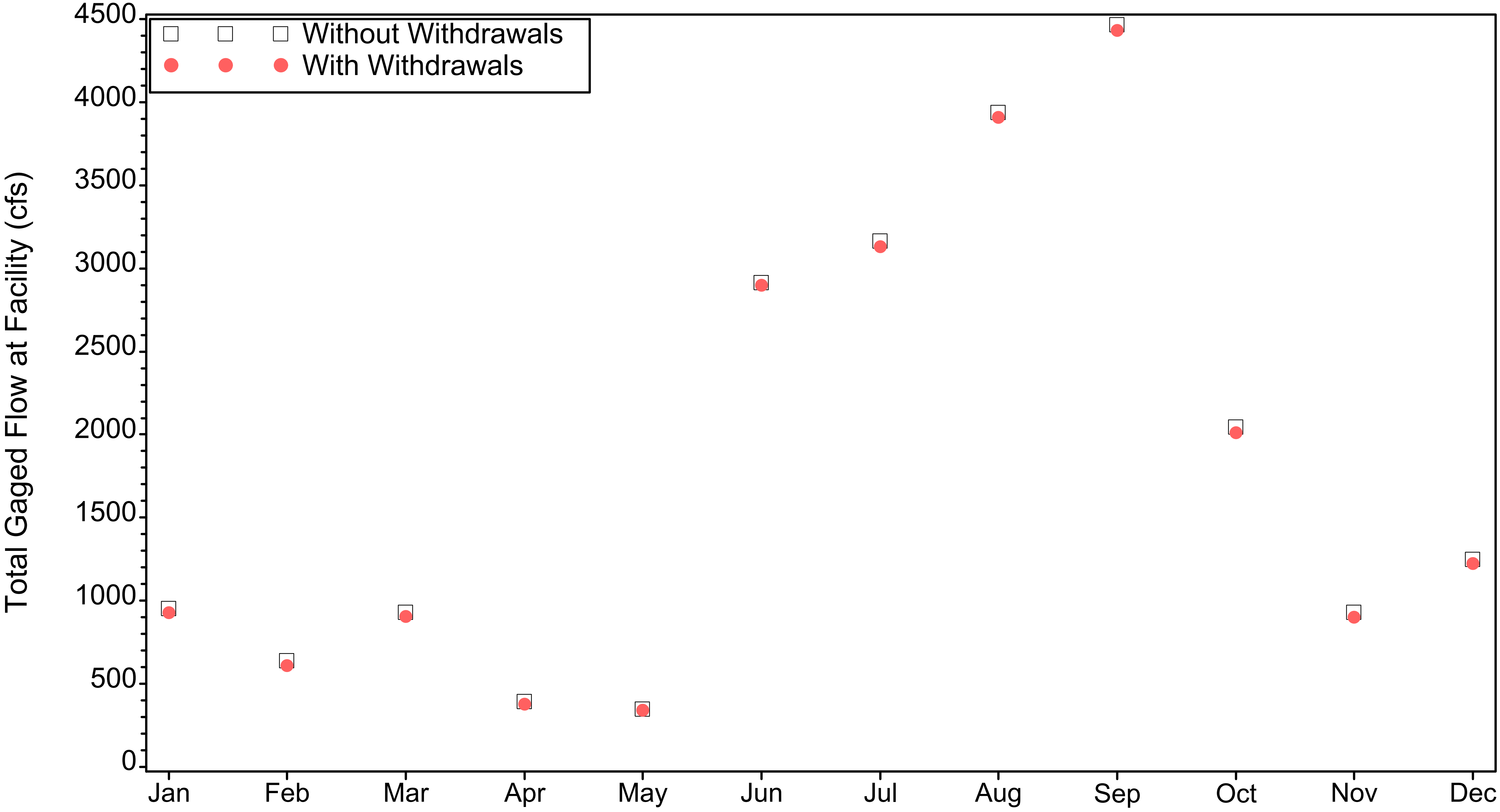


Figure 3.391 Average monthly gaged flow upstream of US41 with and without withdrawals (2002-2008)

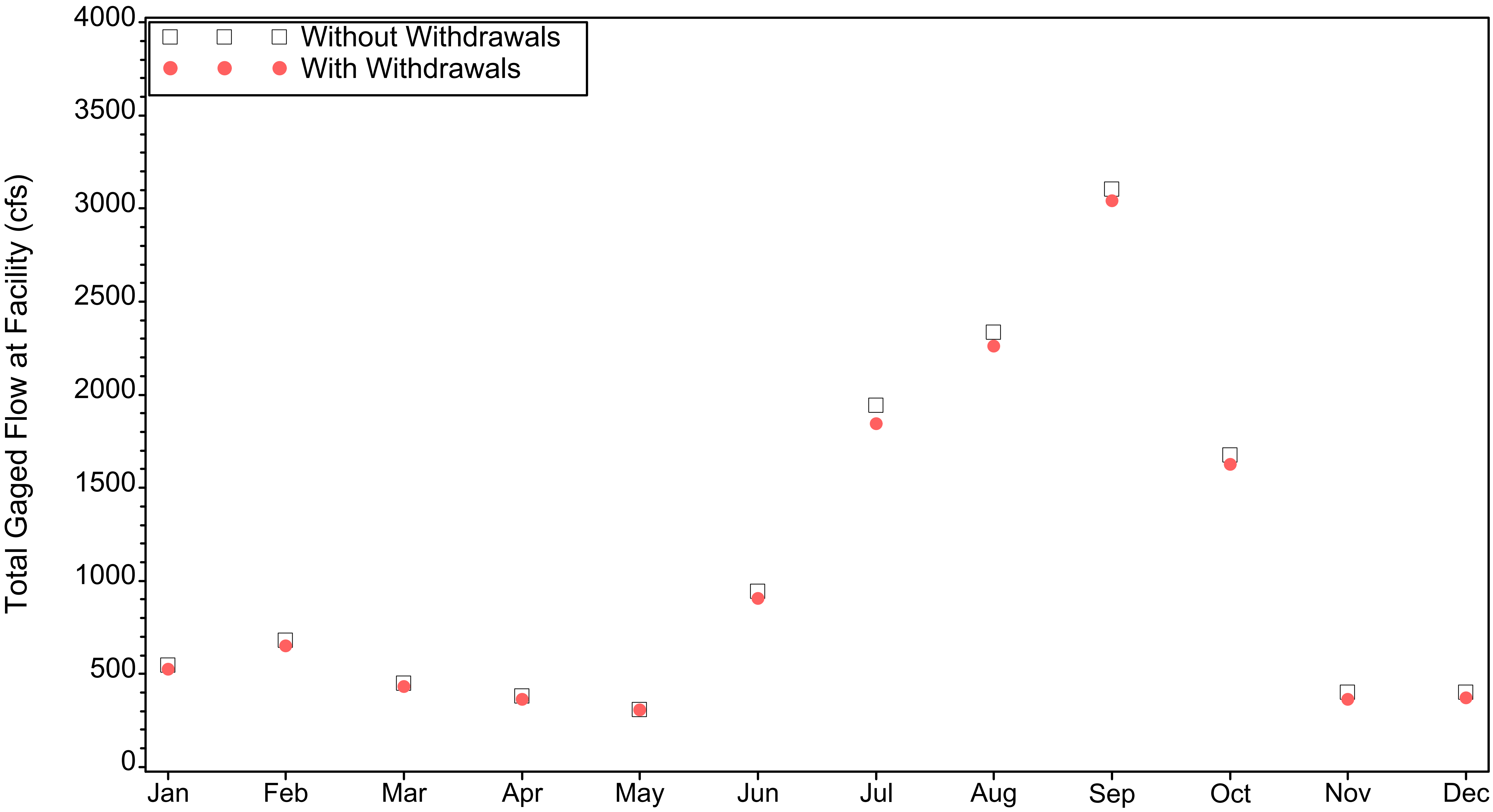


Figure 3.392 Average monthly flow upsteam of the Facility with and without withdrawals (2009-2016)

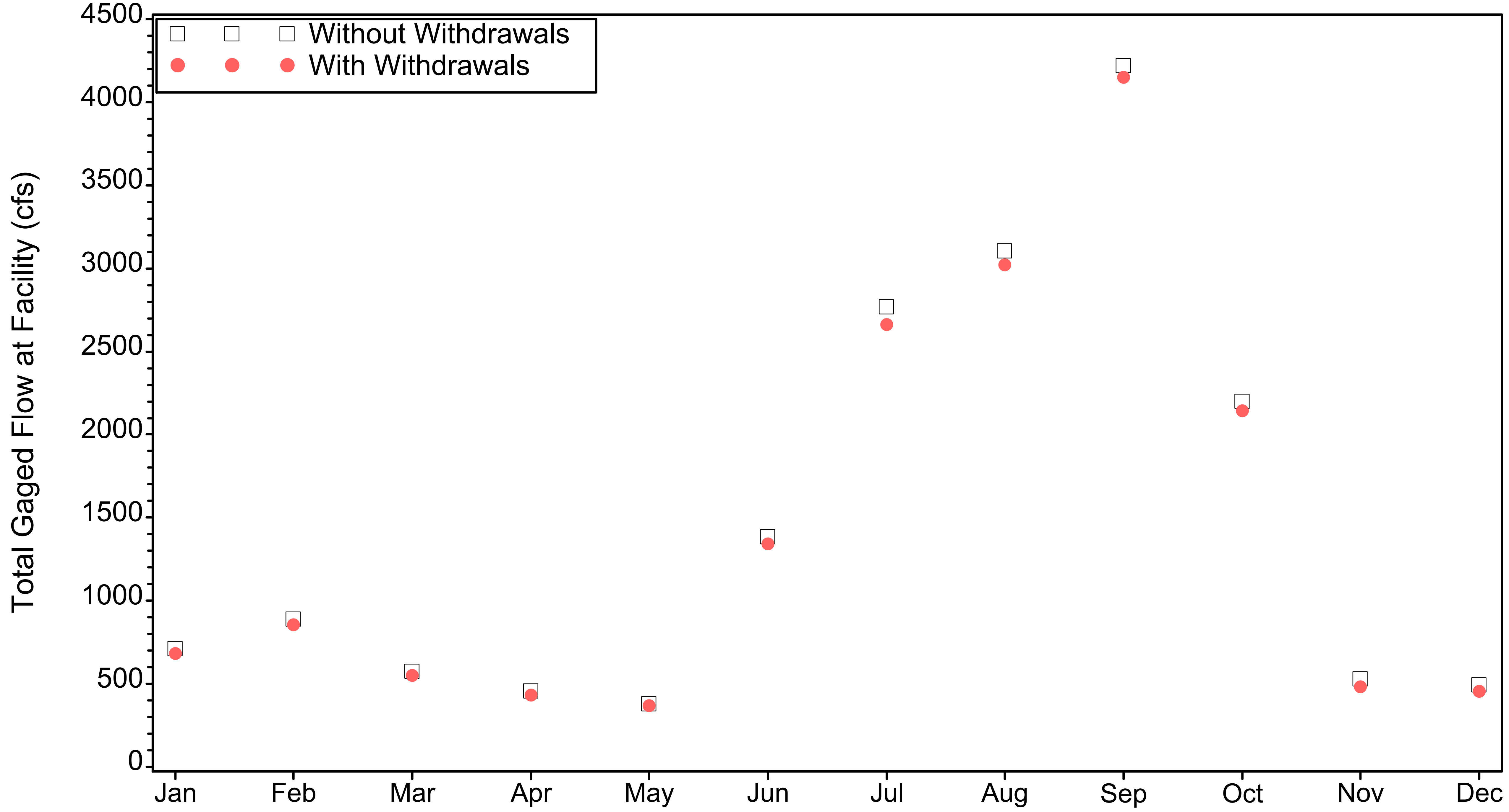


Figure 3.393 Average monthly gaged flow upstream US41 with and without withdrawals (2009-2016)

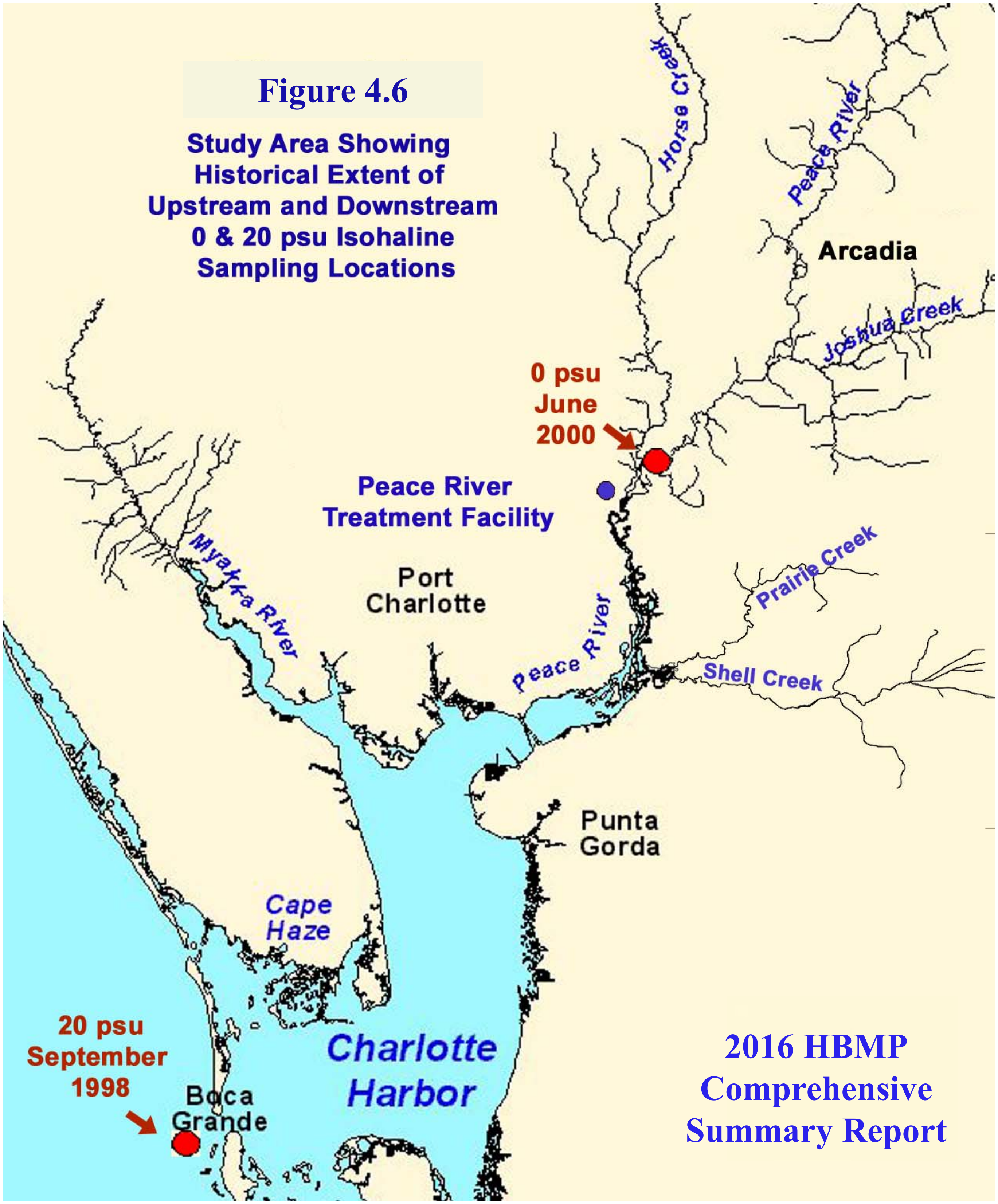


Figure 4.6

Study Area Showing Historical Extent of Upstream and Downstream 0 & 20 psu Isohaline Sampling Locations

2016 HBMP Comprehensive Summary Report

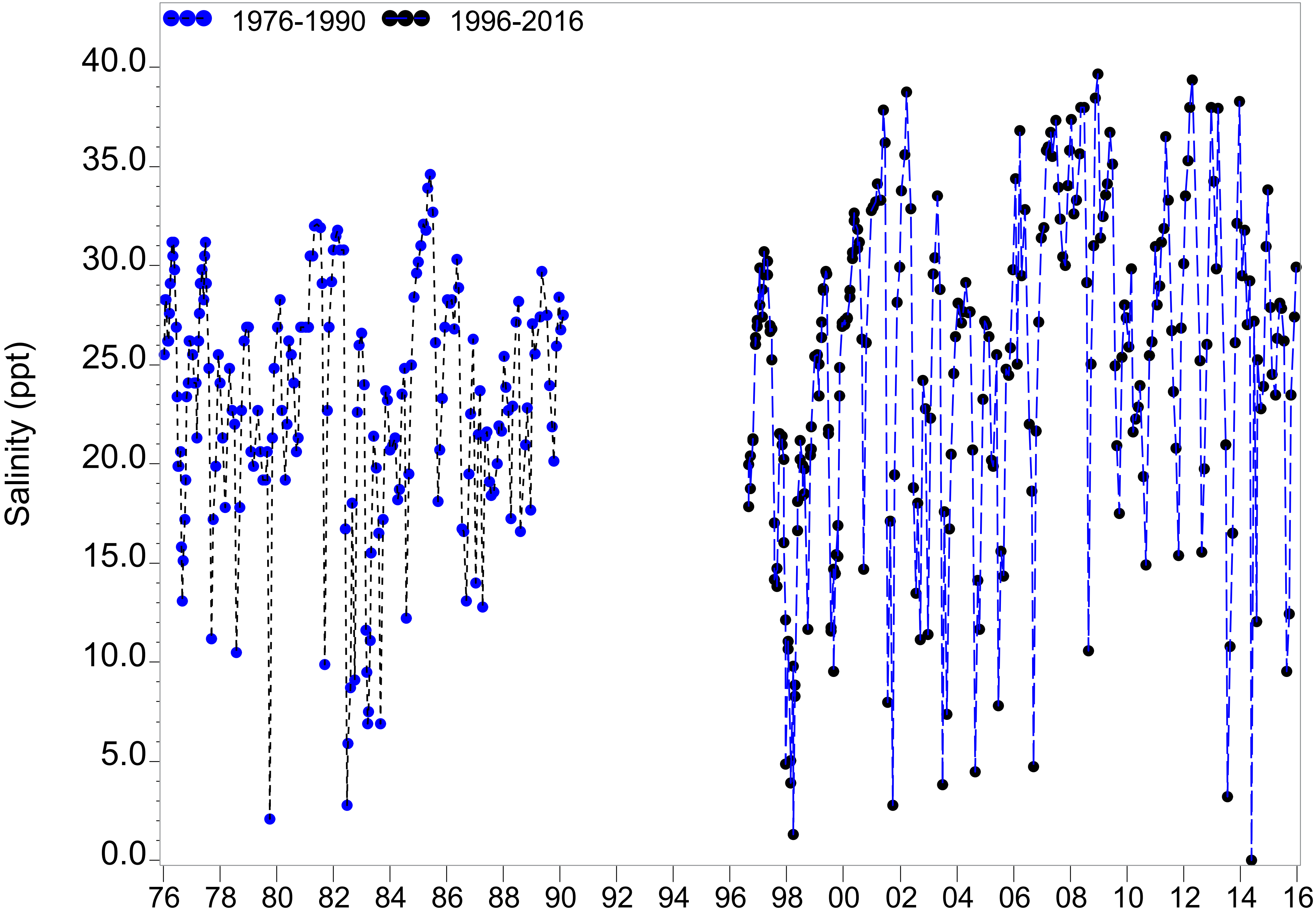


Figure 4.7. Monthly long-term Surface Salinity at river kilometer -2.4

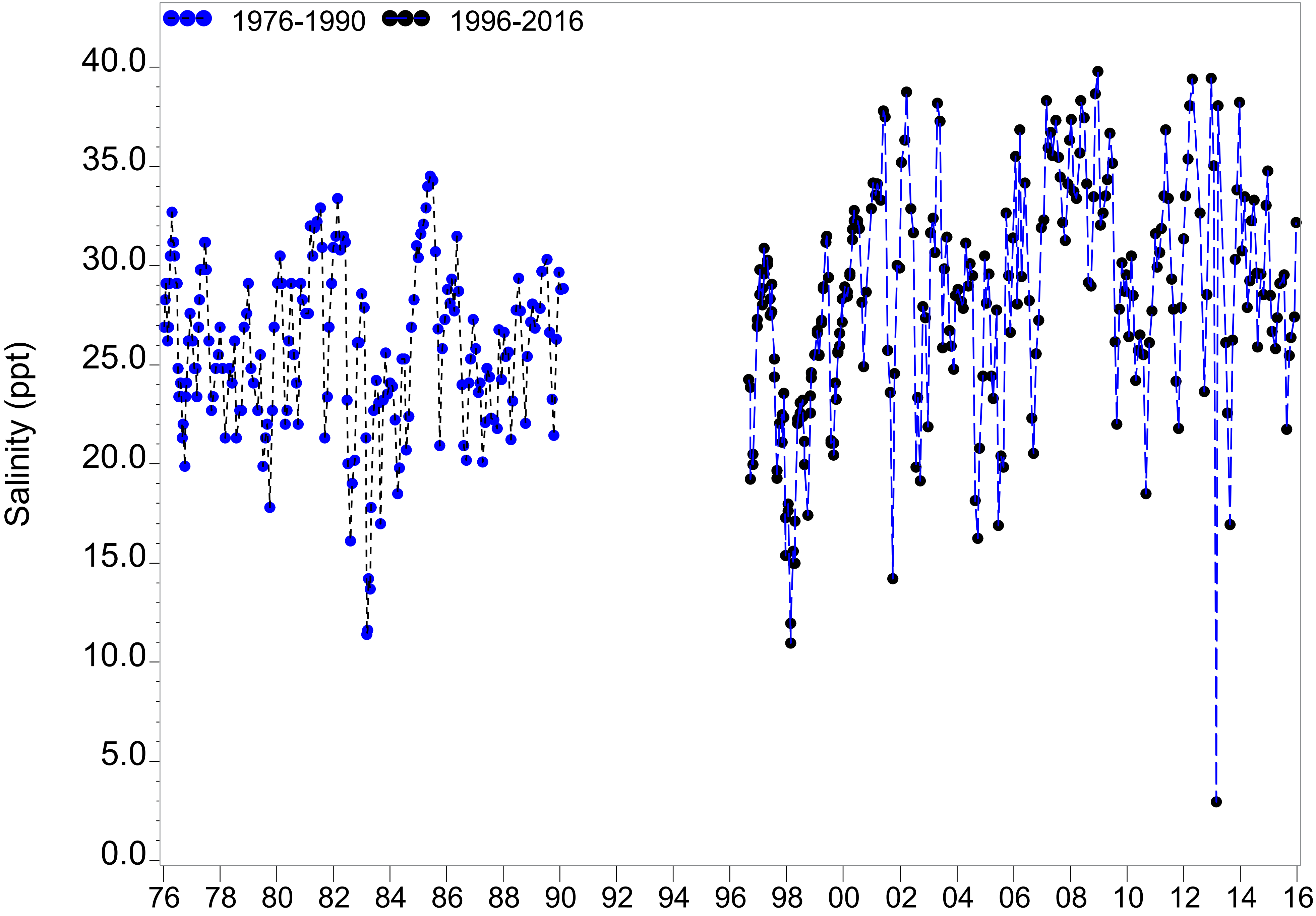


Figure 4.8. Monthly long-term Bottom Salinity at river kilometer -2.4

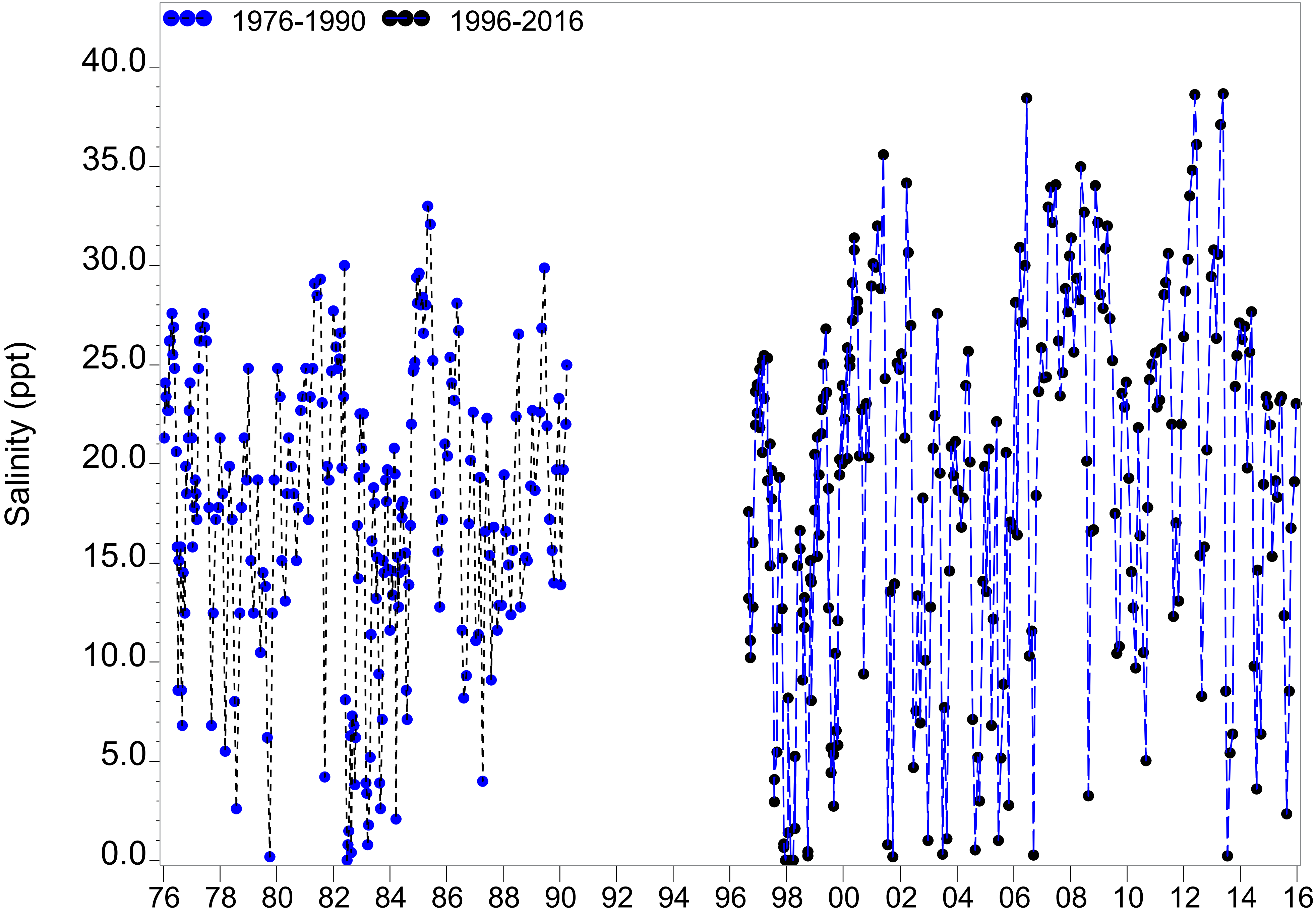


Figure 4.9. Monthly long-term Surface Salinity at river kilometer 6.6

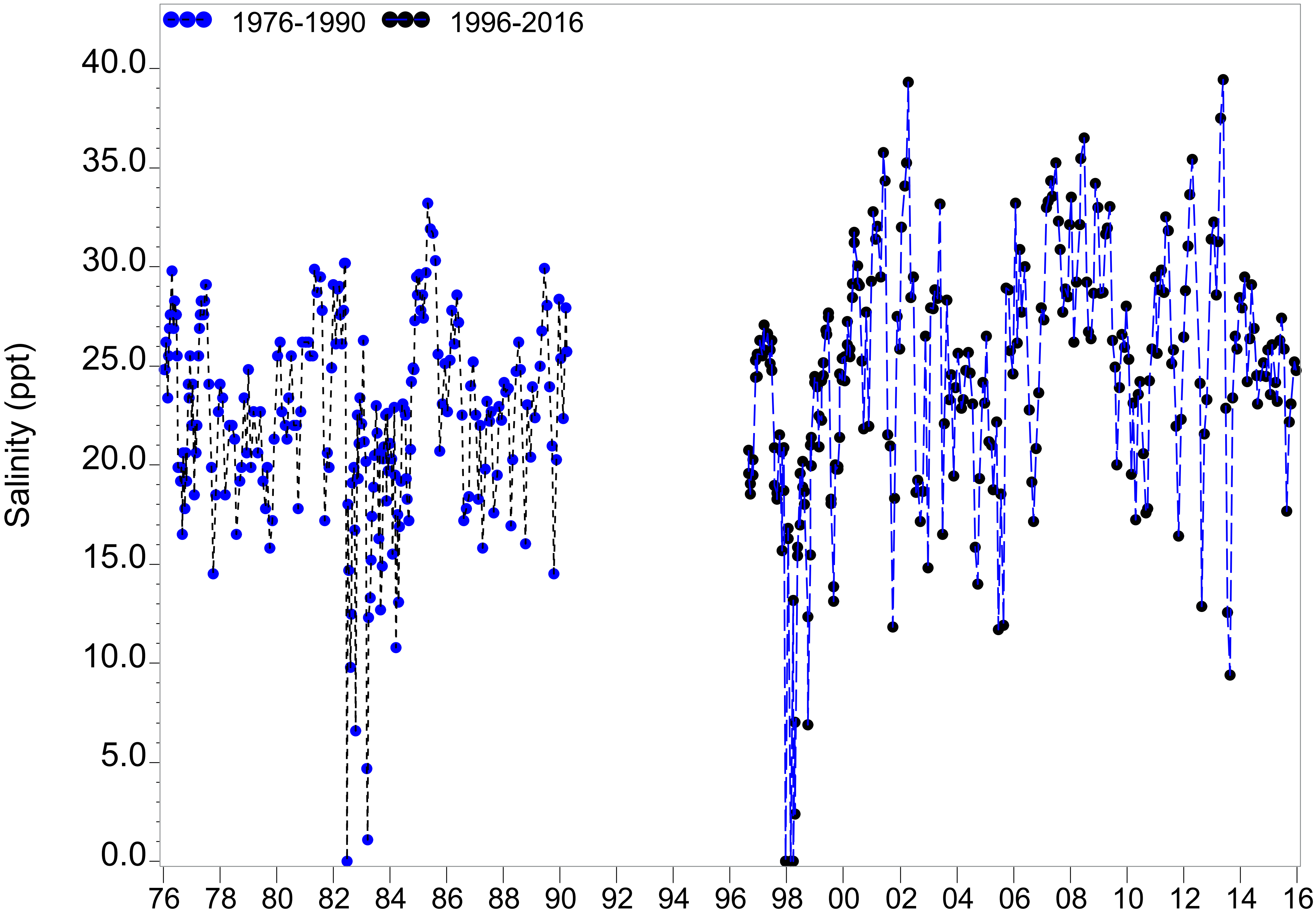


Figure 4.10. Monthly long-term Bottom Salinity at river kilometer 6.6

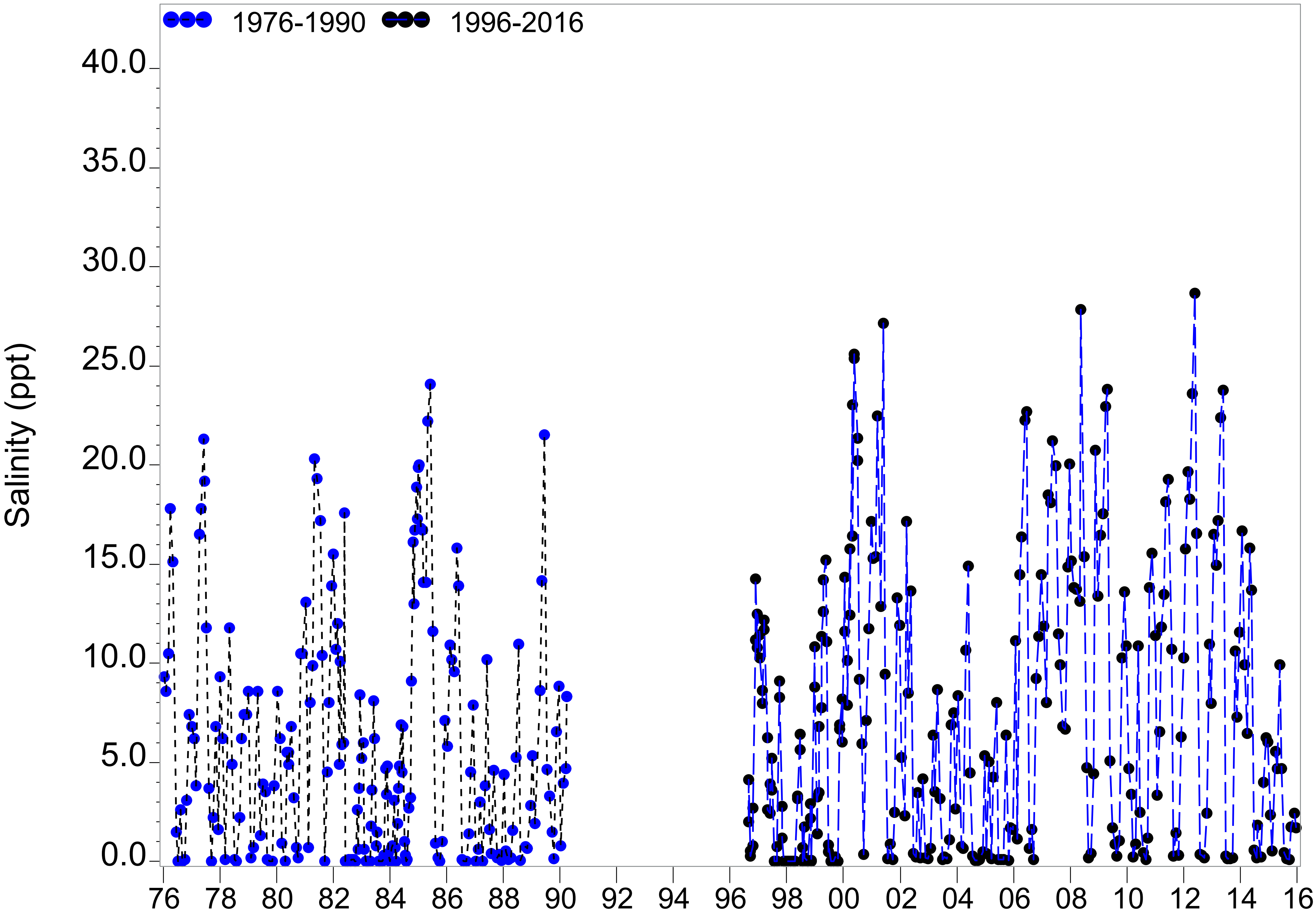


Figure 4.11. Monthly long-term Surface Salinity at river kilometer 15.5

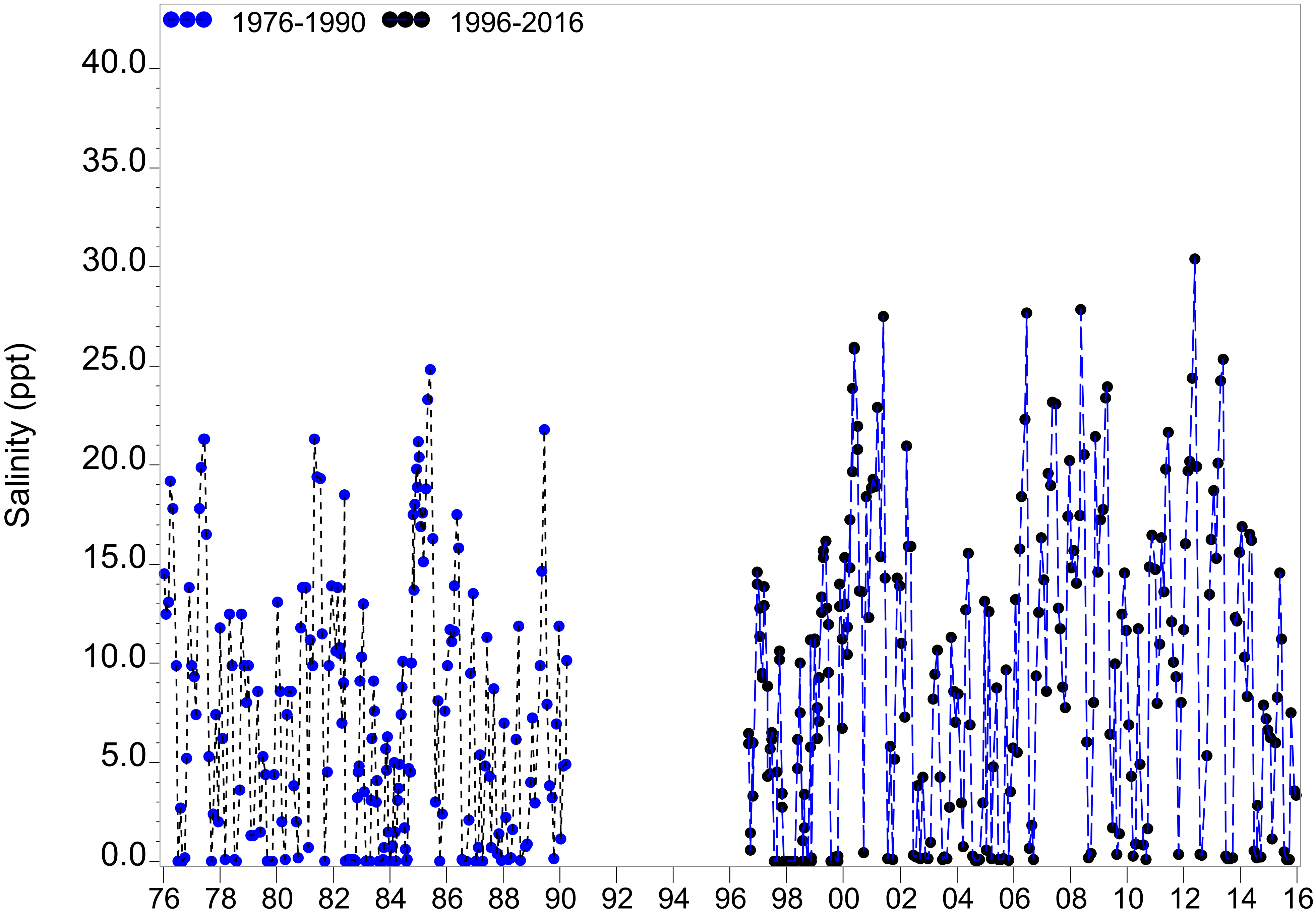


Figure 4.12. Monthly long-term Bottom Salinity at river kilometer 15.5

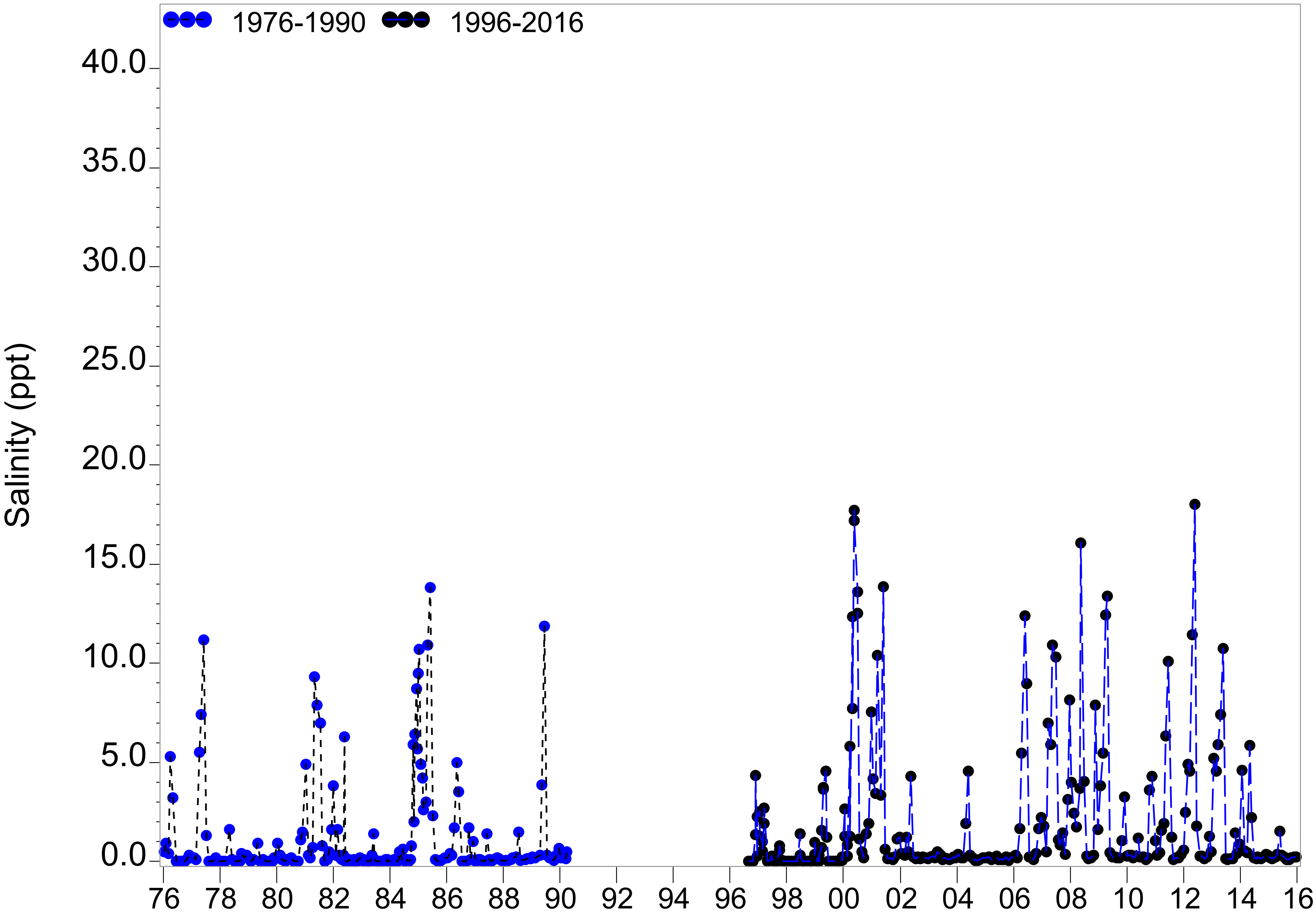


Figure 4.13. Monthly long-term Surface Salinity at river kilometer 23.6

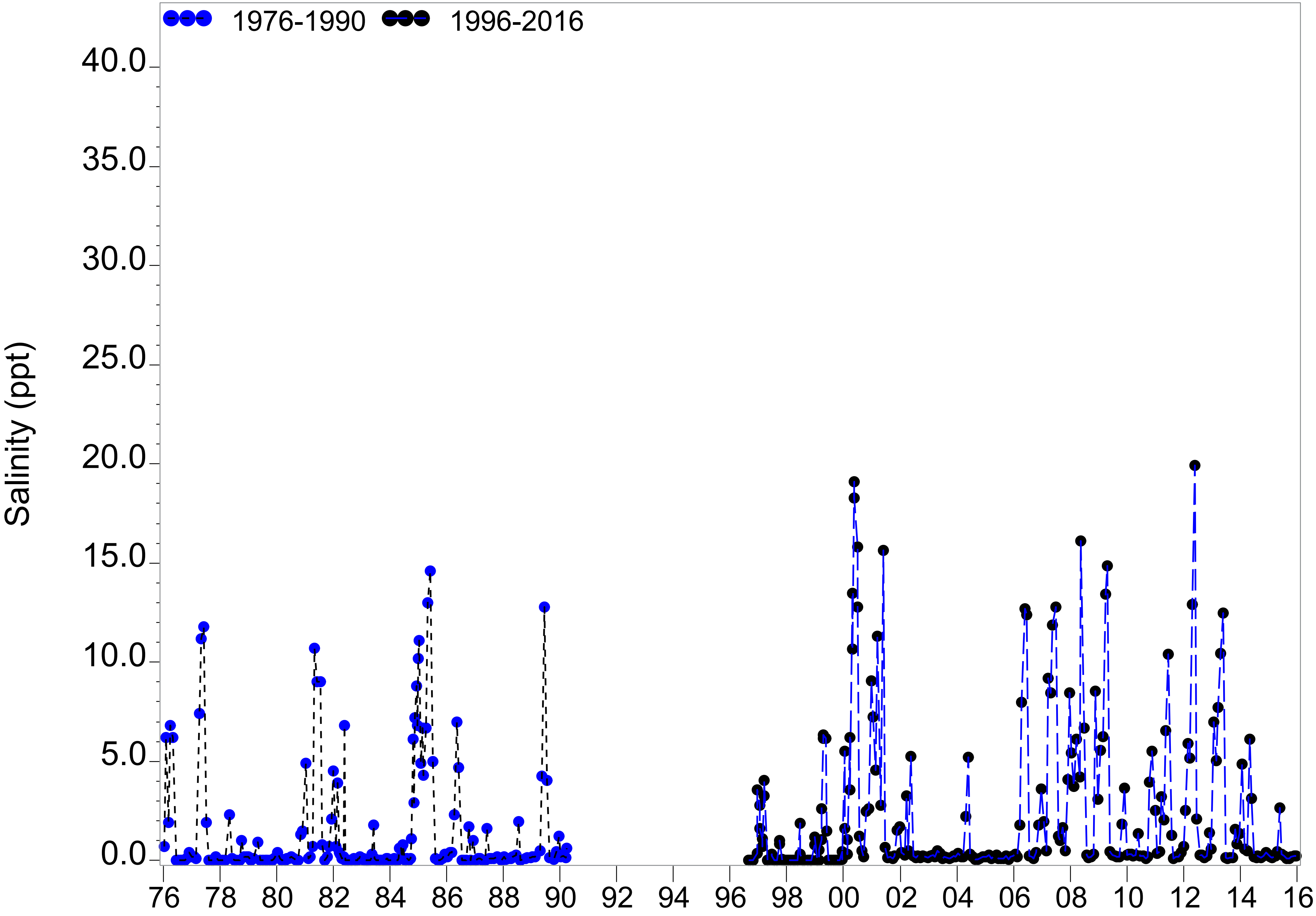


Figure 4.14. Monthly long-term Bottom Salinity at river kilometer 23.6

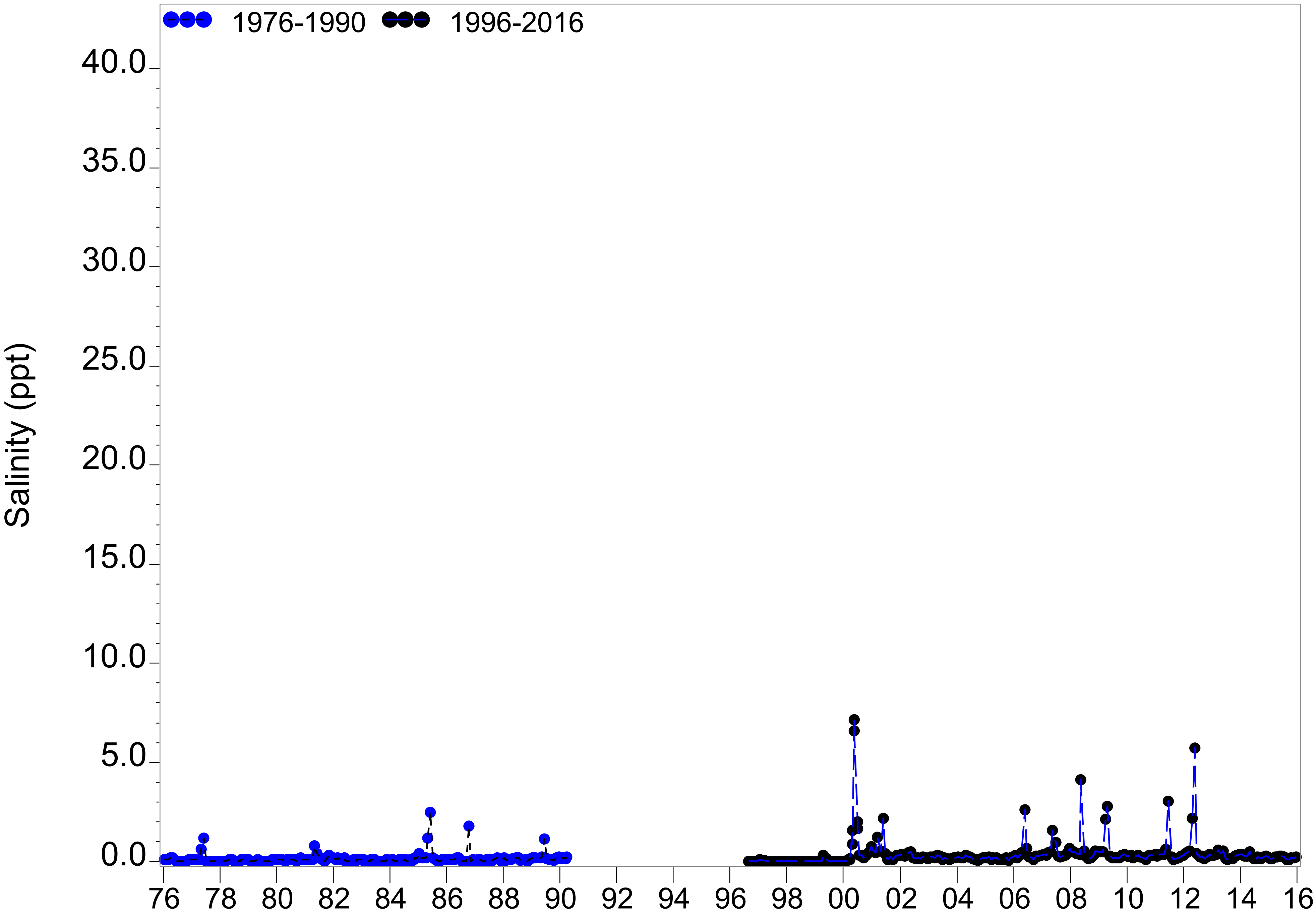


Figure 4.15. Monthly long-term Surface Salinity at river kilometer 30.7

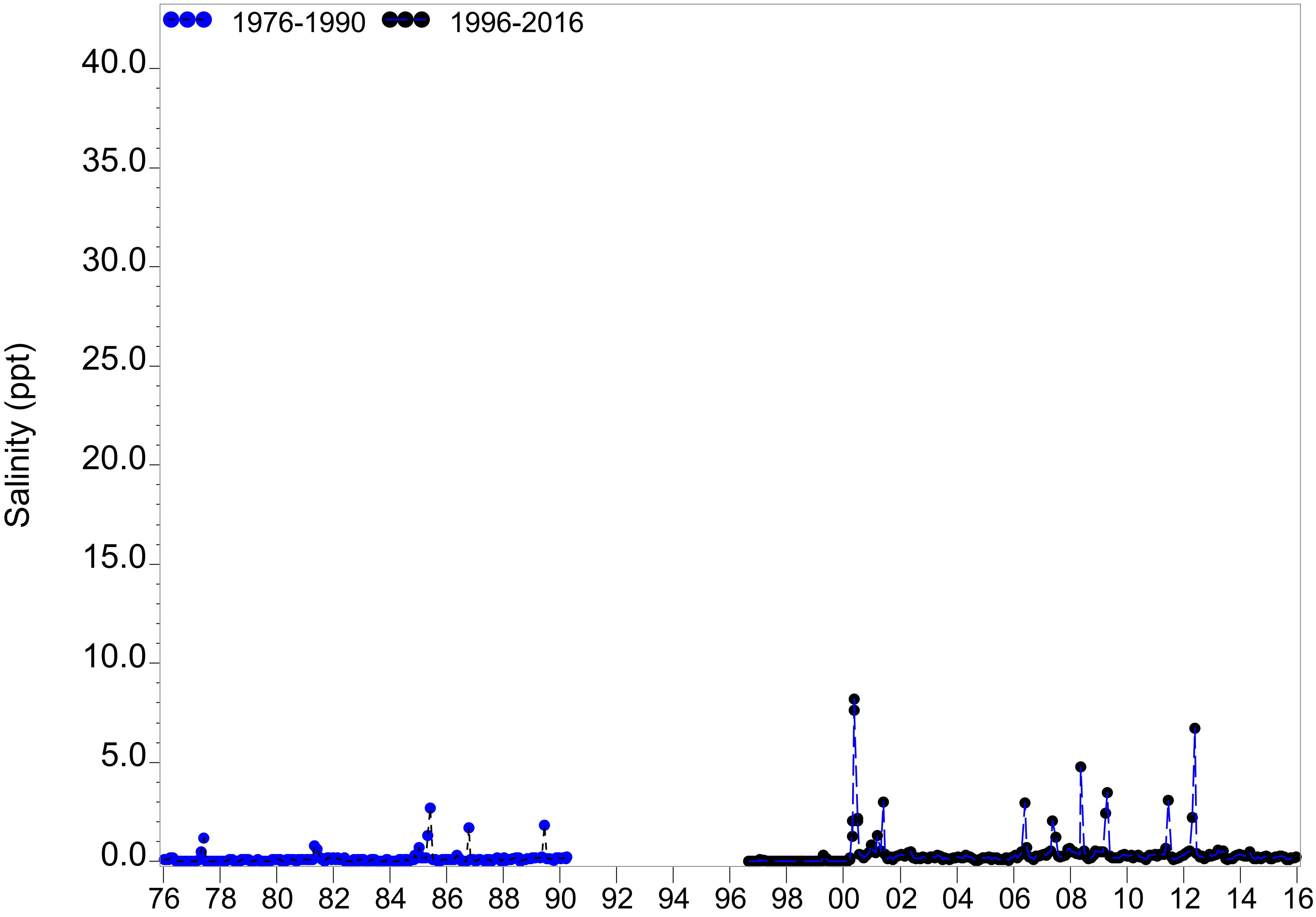


Figure 4.16. Monthly long-term Bottom Salinity at river kilometer 30.7

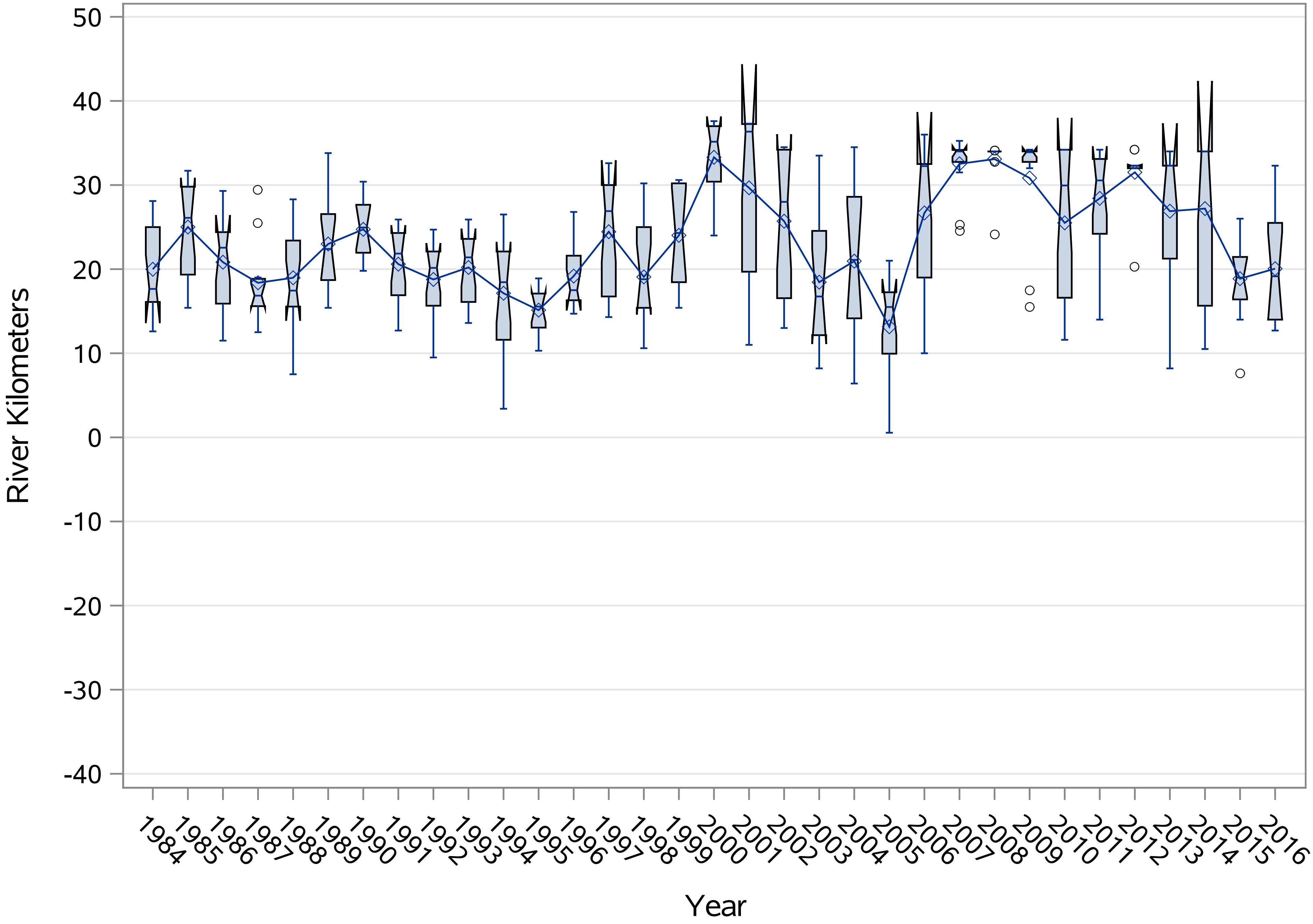


Figure 4.17. Annual mean boxplots of location of 0 psu isohaline (1984-2016)

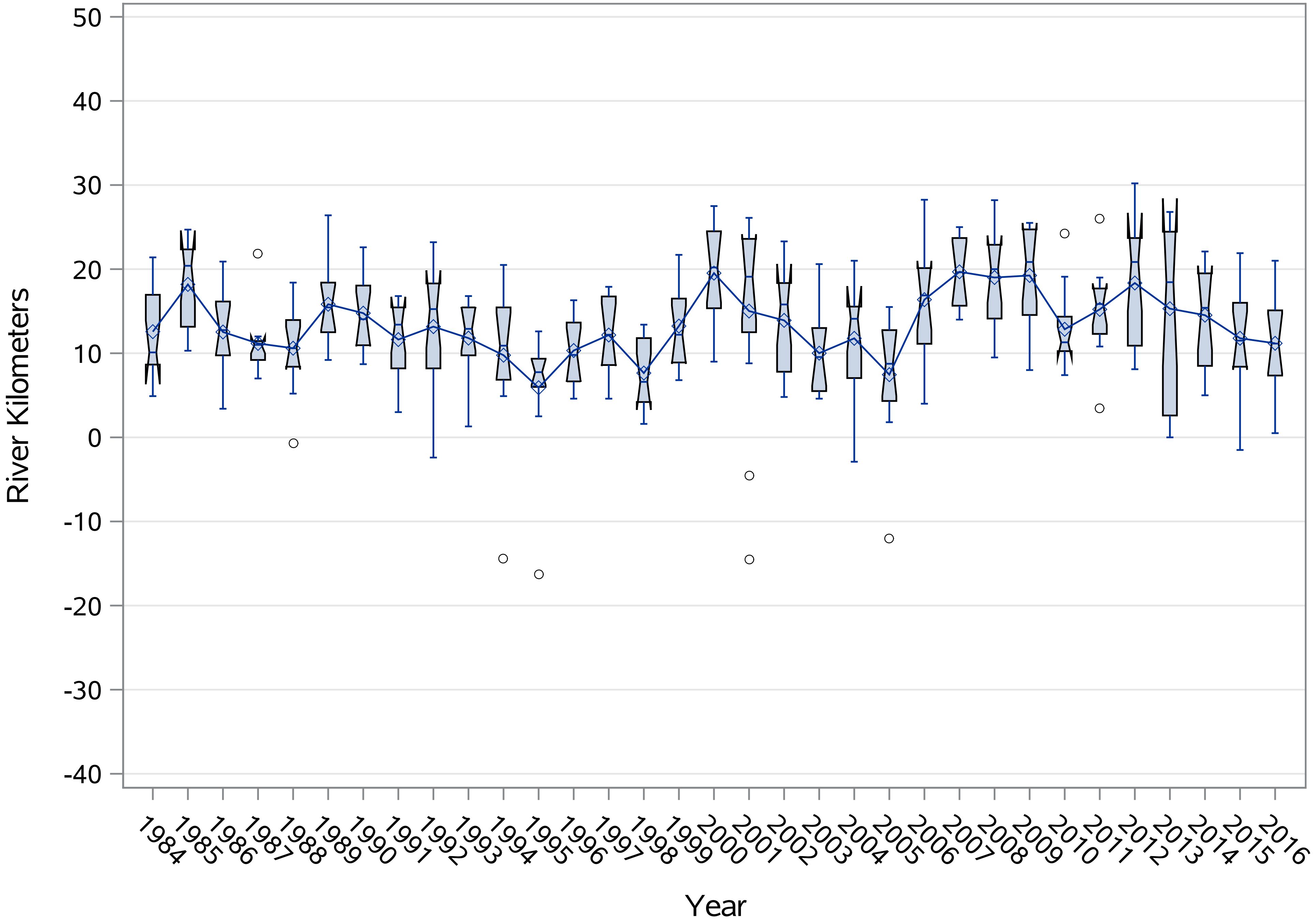


Figure 4.18. Annual mean boxplots of location of 6 psu isohaline (1984-2016)

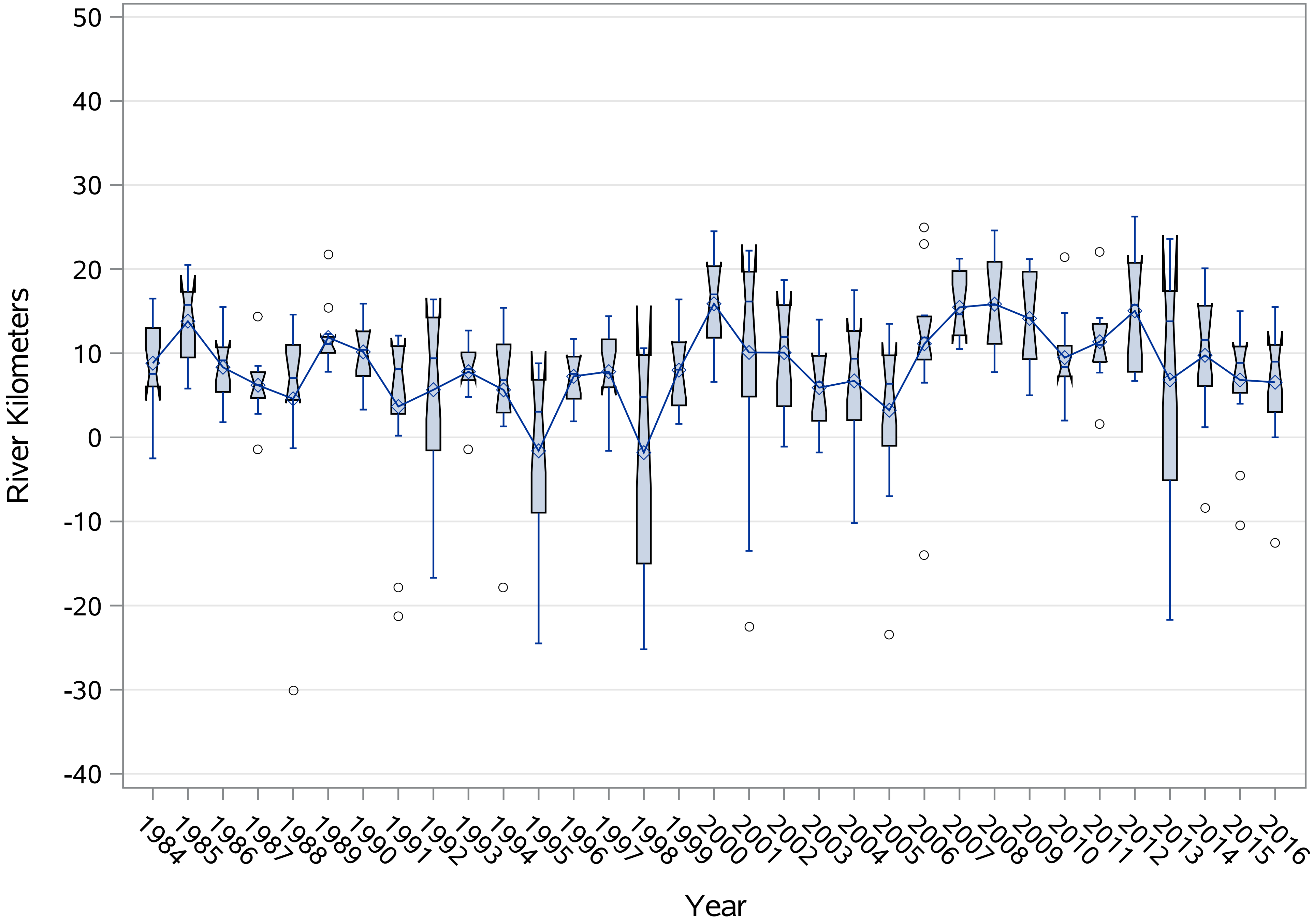


Figure 4.19. Annual mean boxplots of location of 12 psu isohaline (1984-2016)

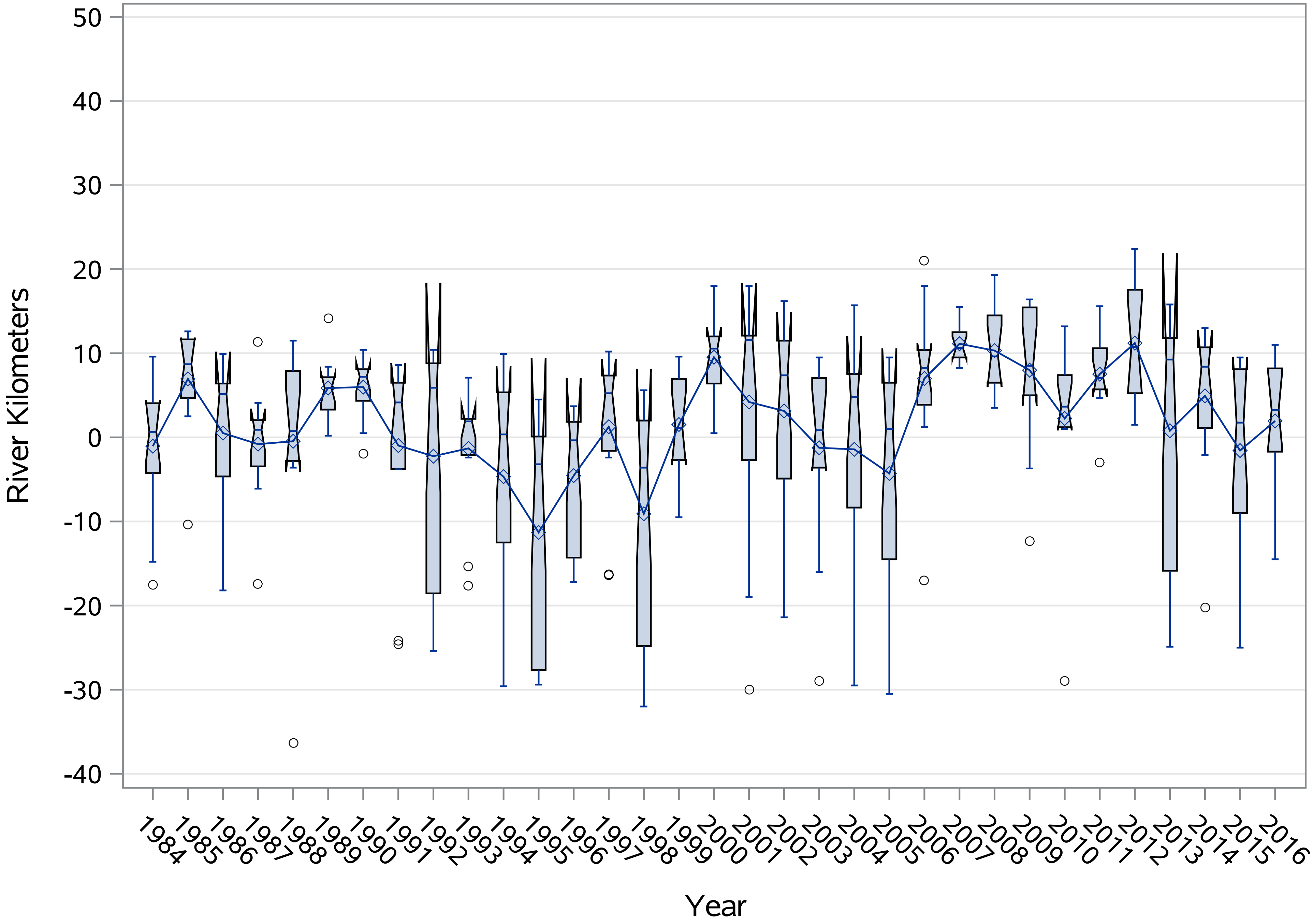


Figure 4.20. Annual mean boxplots of location of 20 psu isohaline (1984-2016)

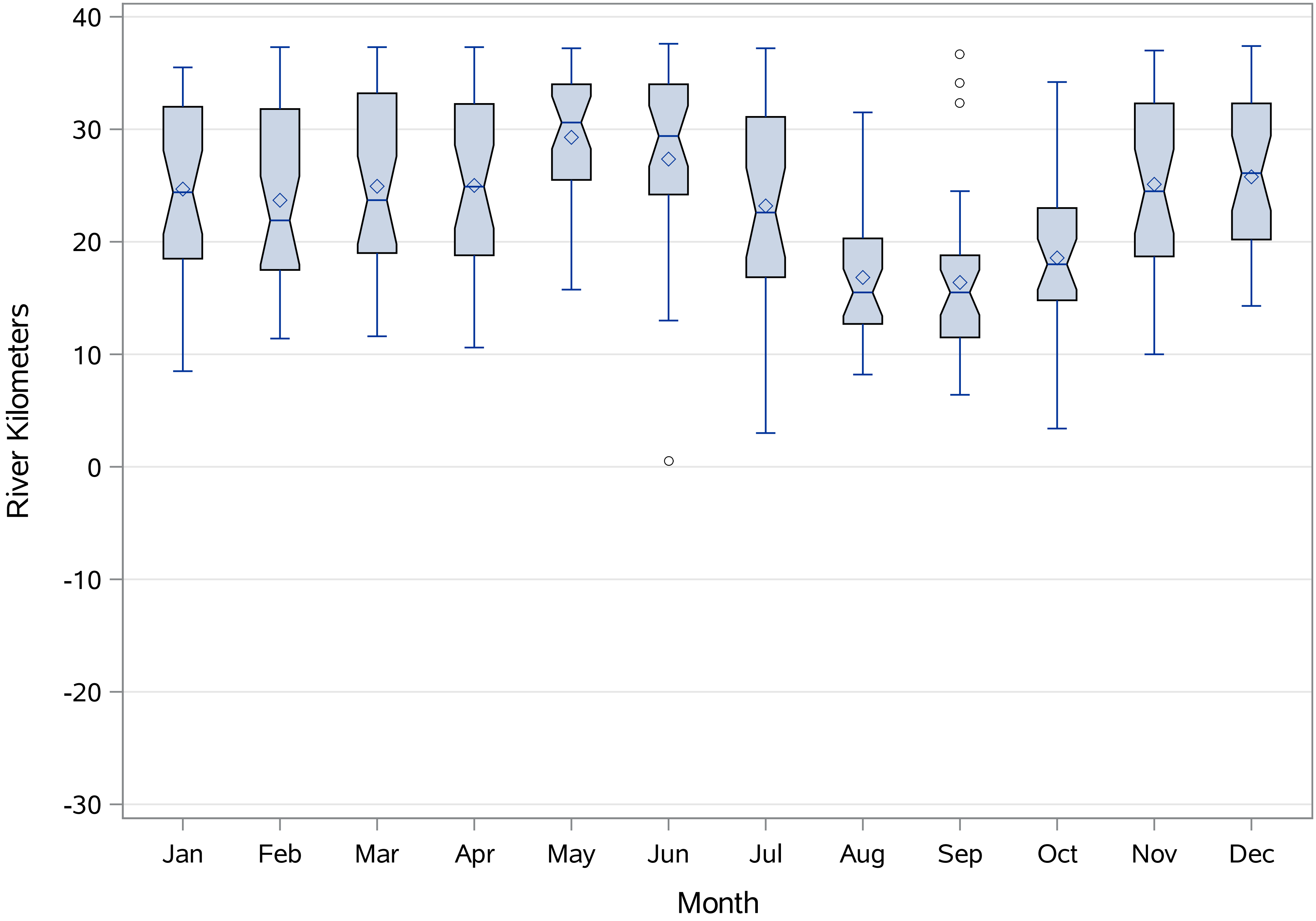


Figure 4.21. Mean monthly boxplots of location of 0 psu isohaline (1984-2016)

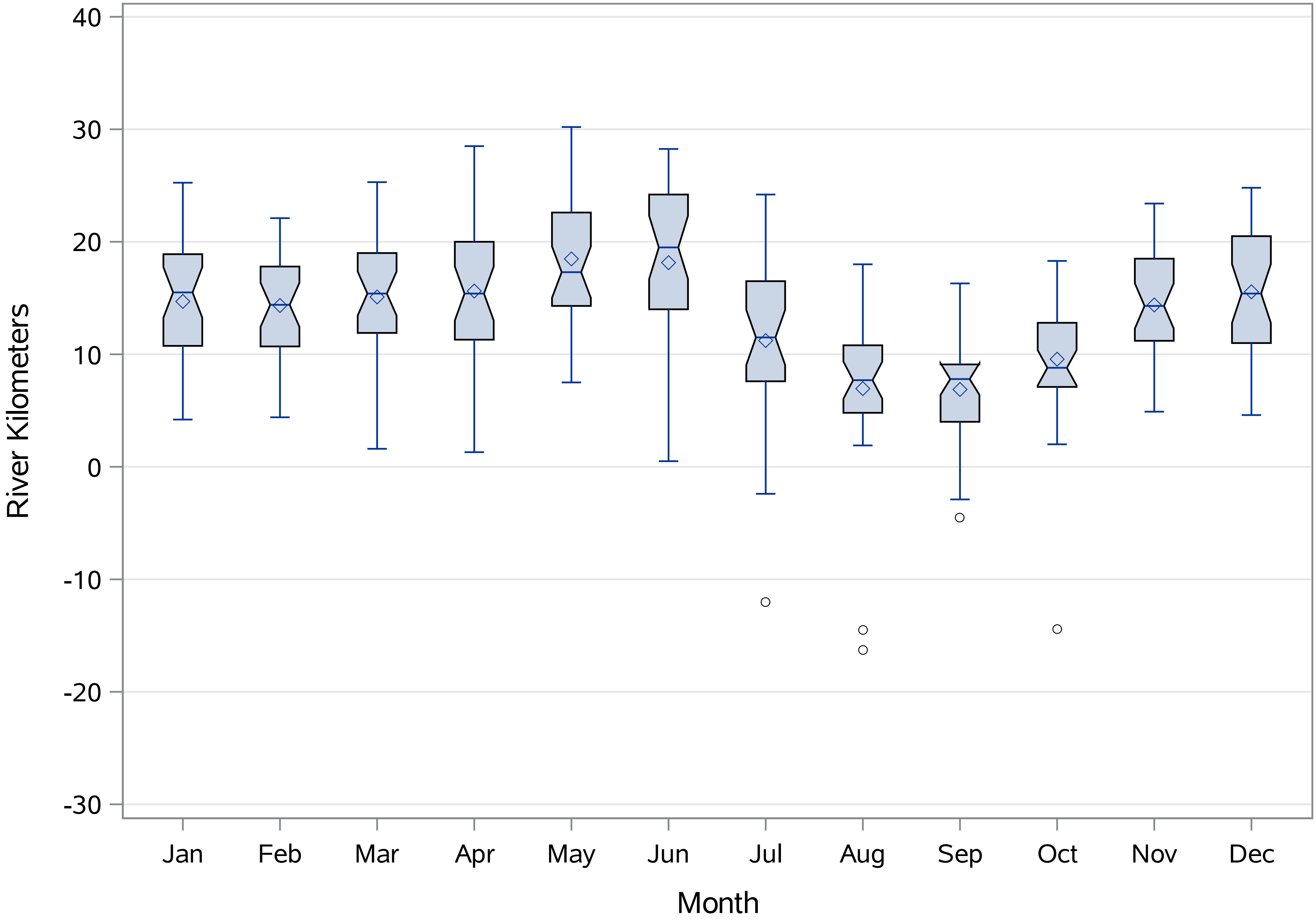


Figure 4.22. Mean monthly boxplots of location of 6 psu isohaline (1984-2016)

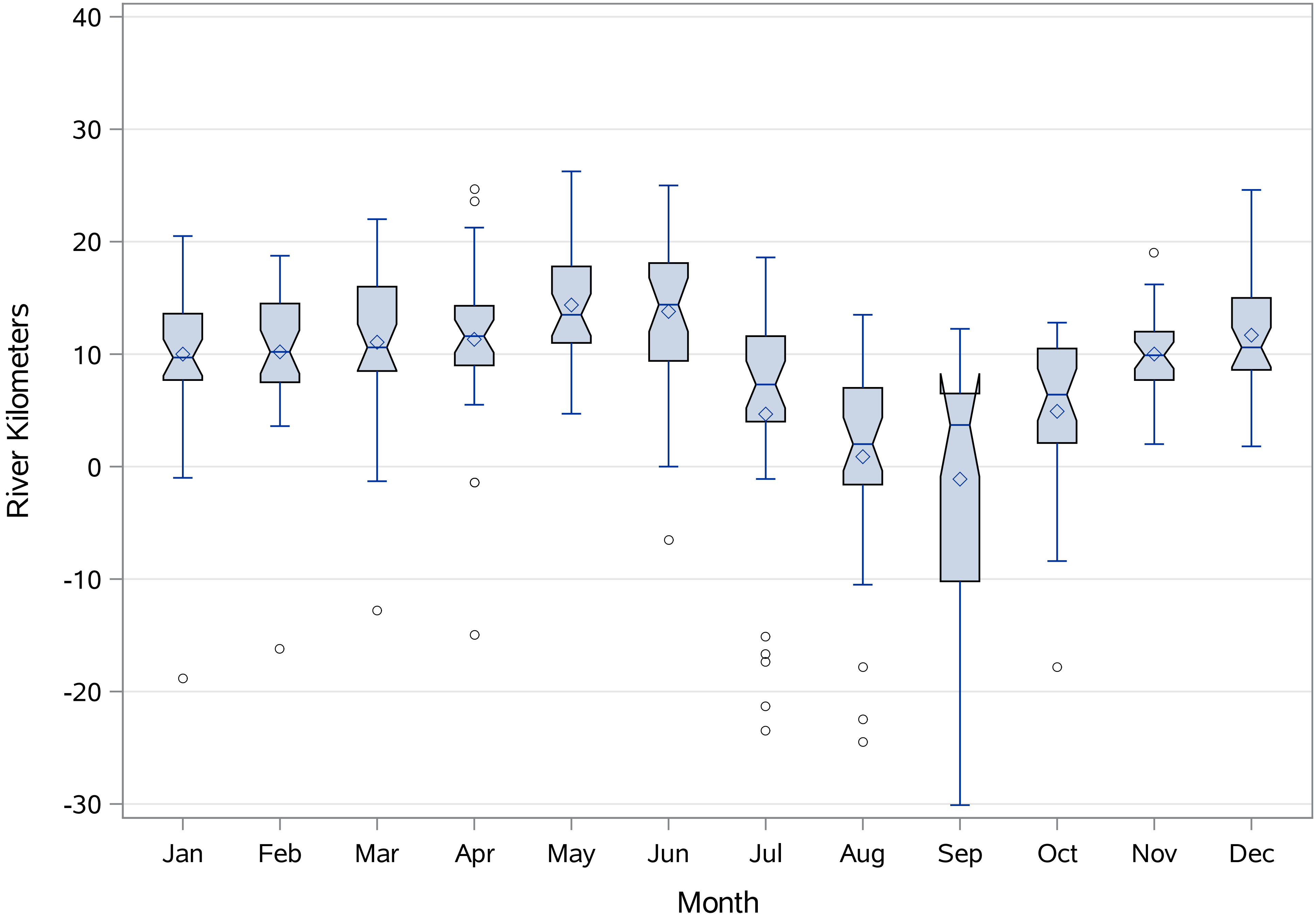


Figure 4.23. Mean monthly boxplots of location of 12 psu isohaline (1984-2016)

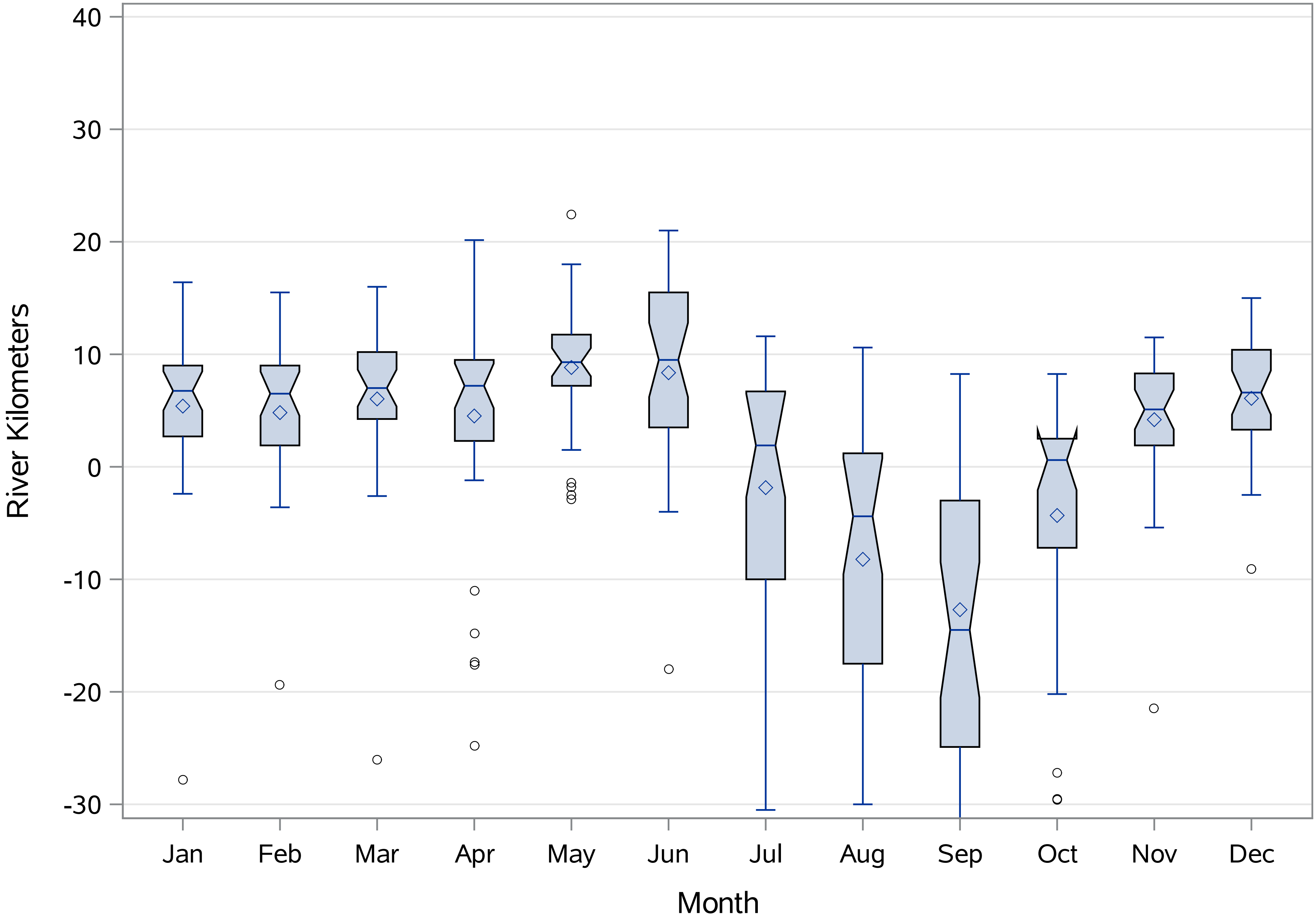


Figure 4.24. Mean monthly boxplots of location of 20 psu isohaline (1984-2016)

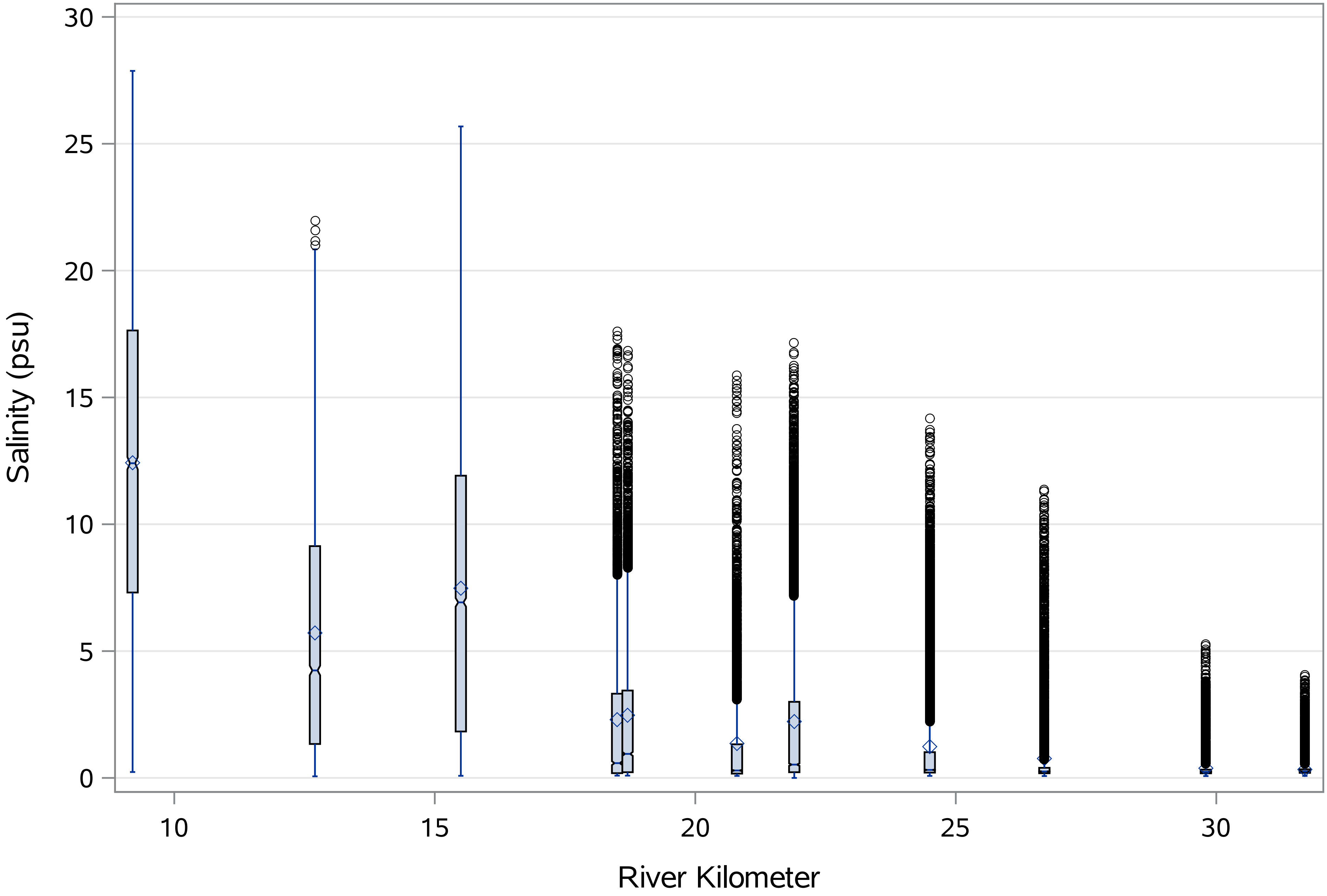


Figure 4.25. Box and whisker plots of annual variability in surface salinity during 2011 at the continuous recorders with a complete year of data

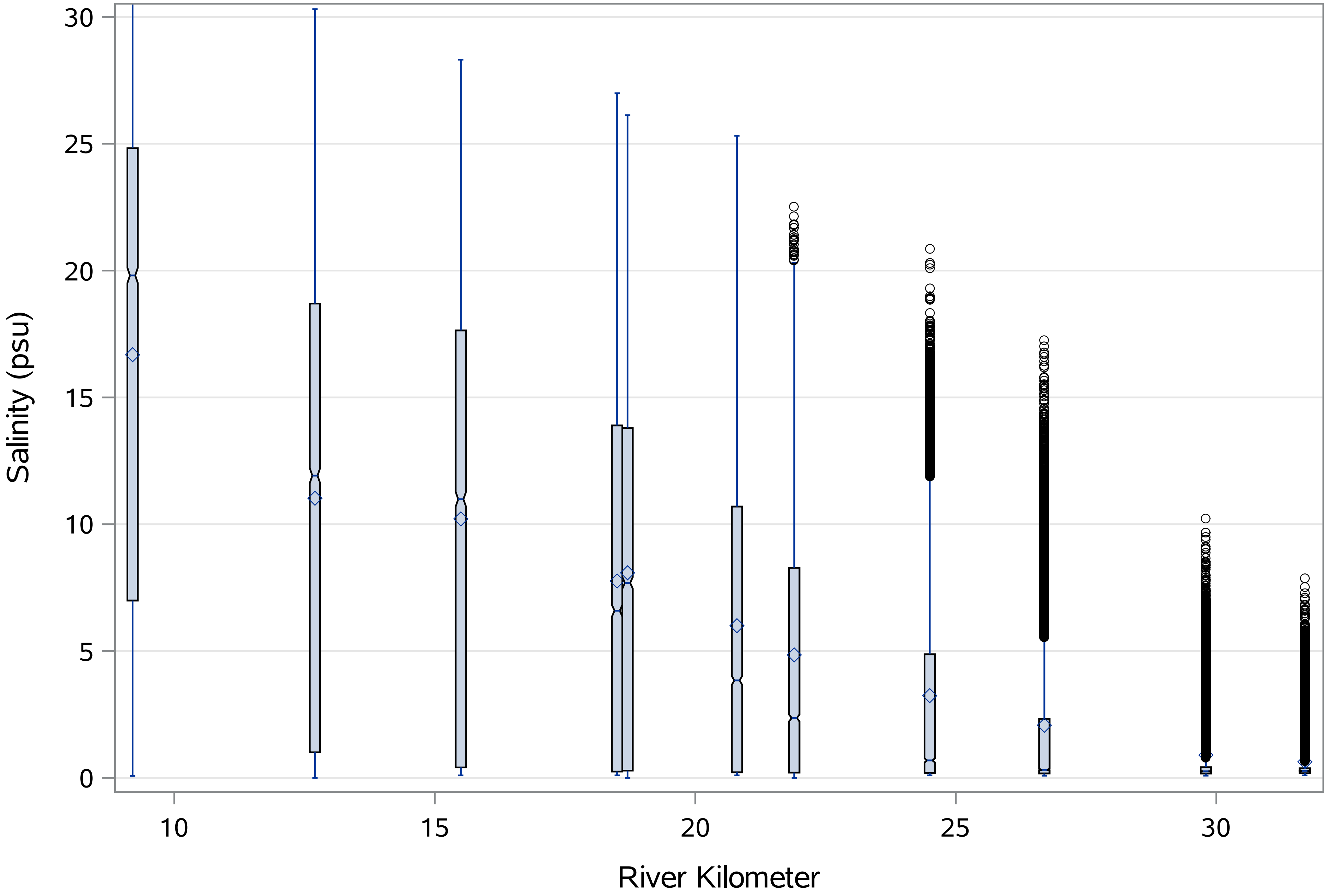


Figure 4.26. Box and whisker plots of annual variability in surface salinity during 2012 at the continuous recorders with a complete year of data

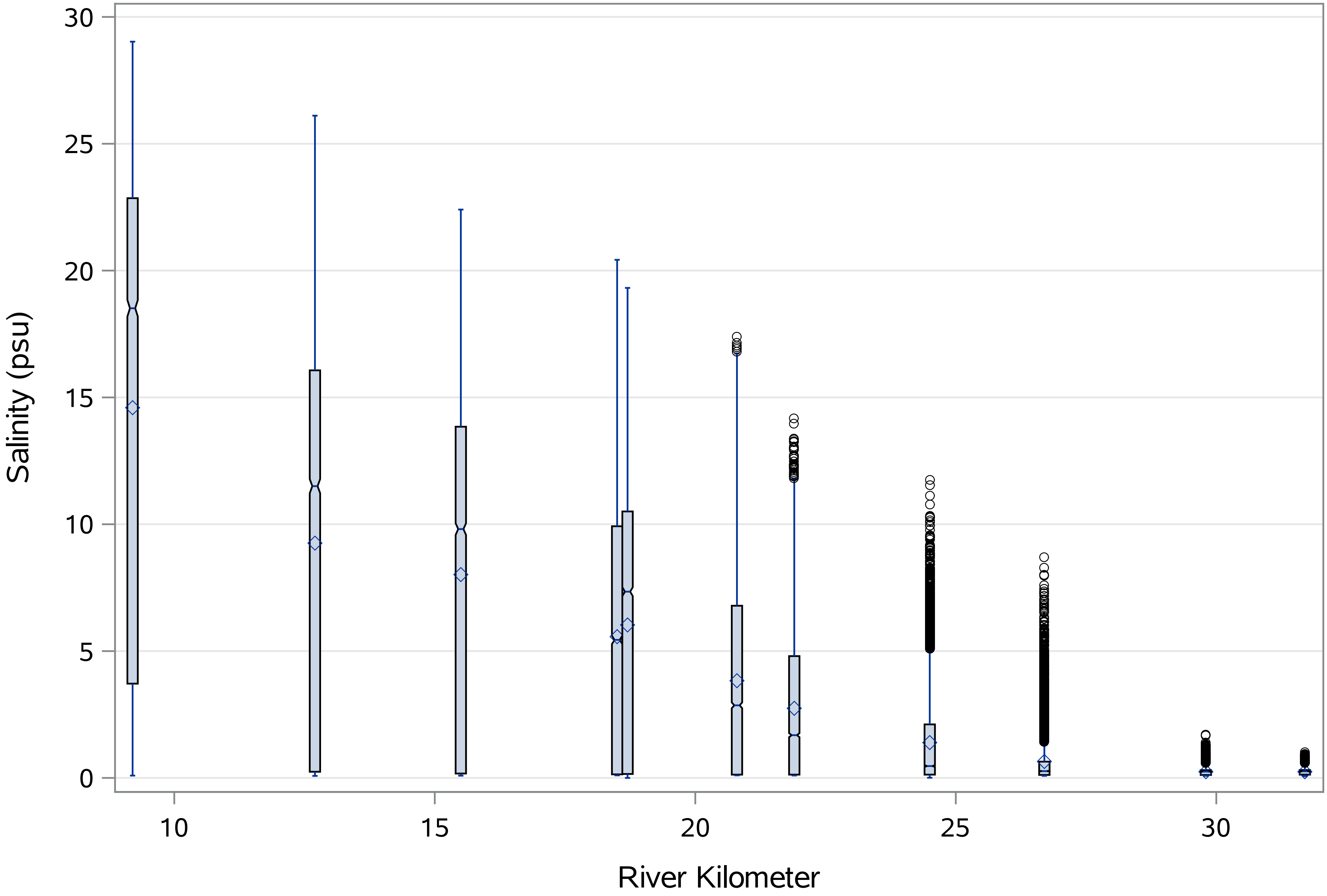


Figure 4.27. Box and whisker plots of annual variability in surface salinity during 2013 at the continuous recorders with a complete year of data

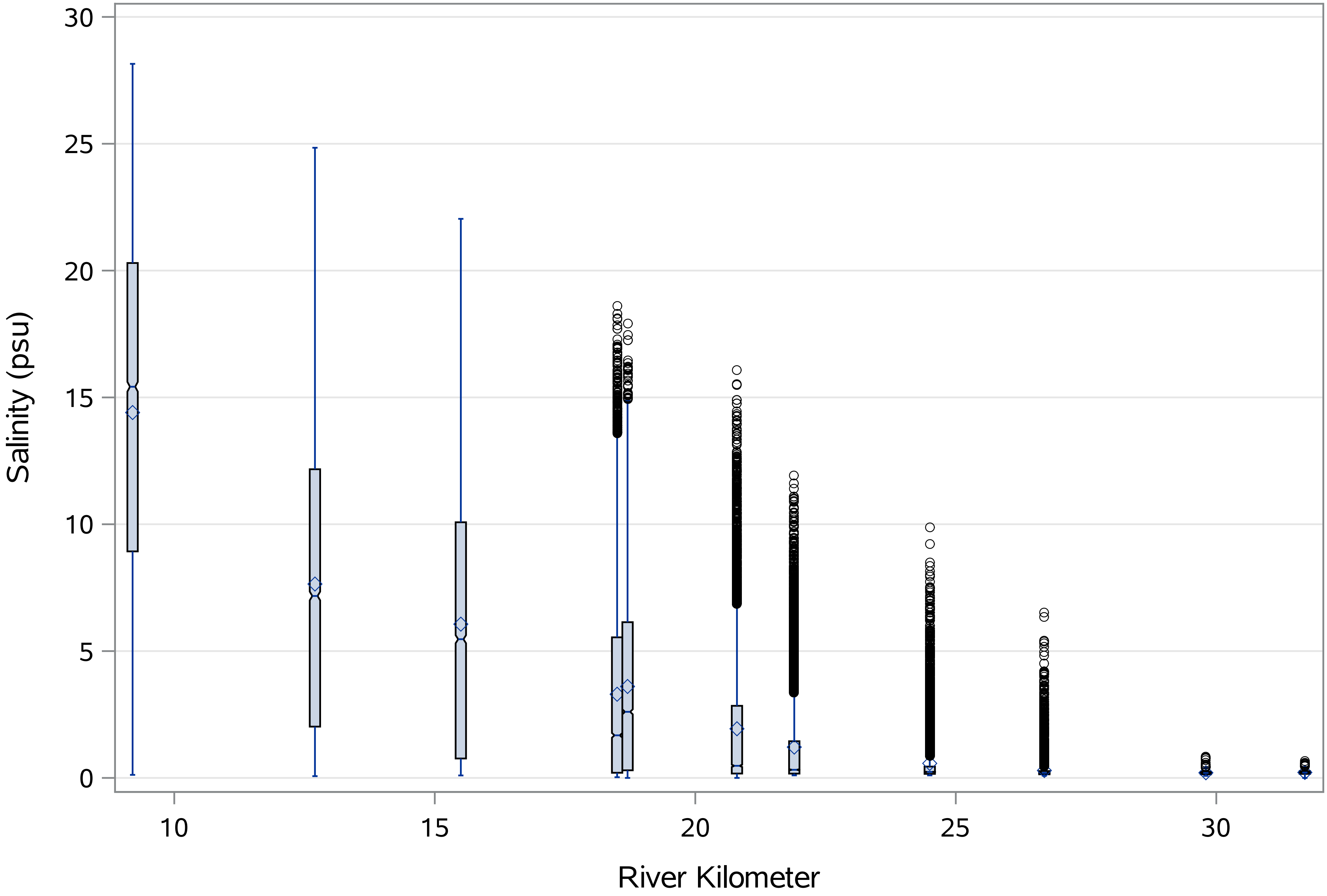


Figure 4.28. Box and whisker plots of annual variability in surface salinity during 2014 at the continuous recorders with a complete year of data

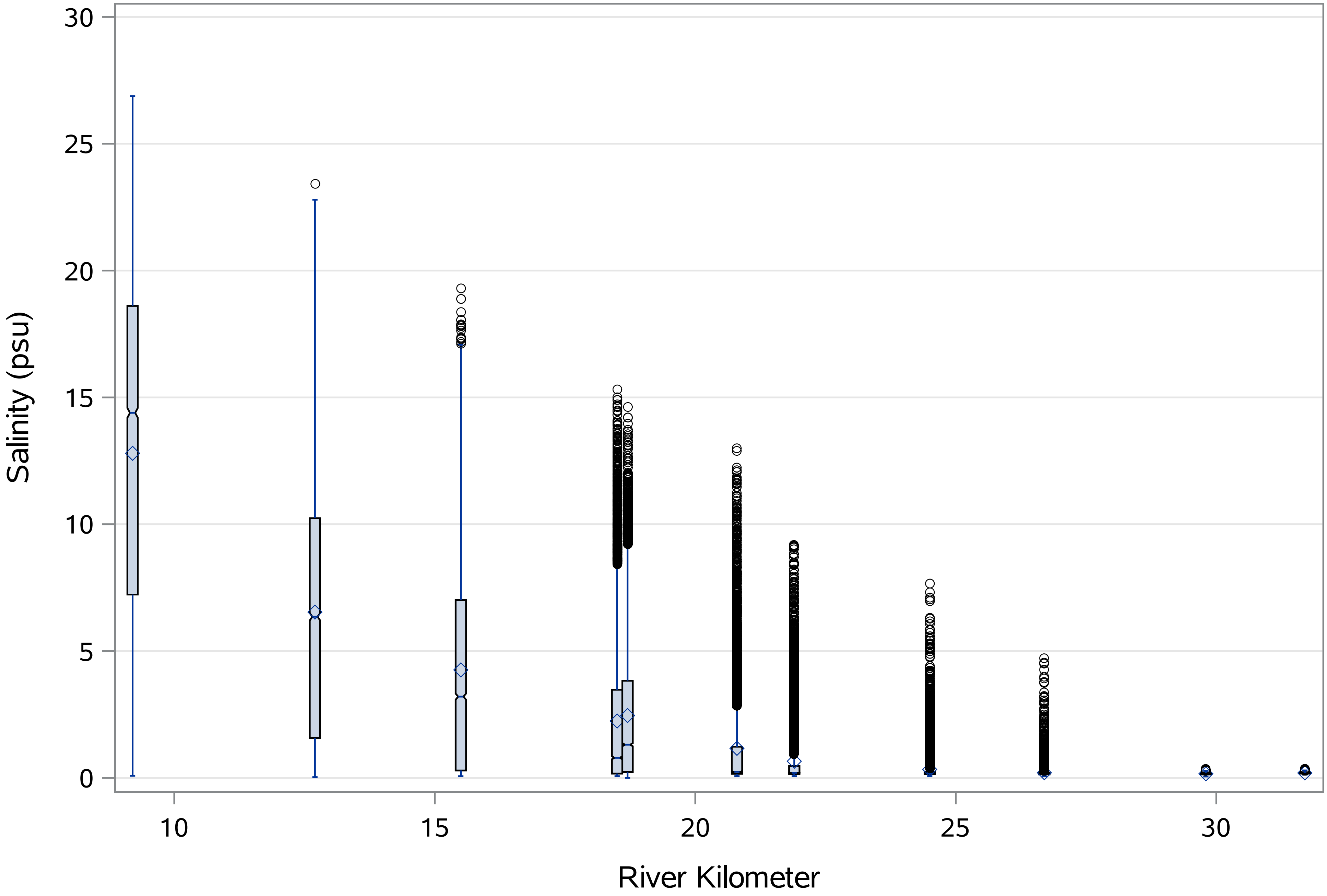


Figure 4.29. Box and whisker plots of annual variability in surface salinity during 2015 at the continuous recorders with a complete year of data

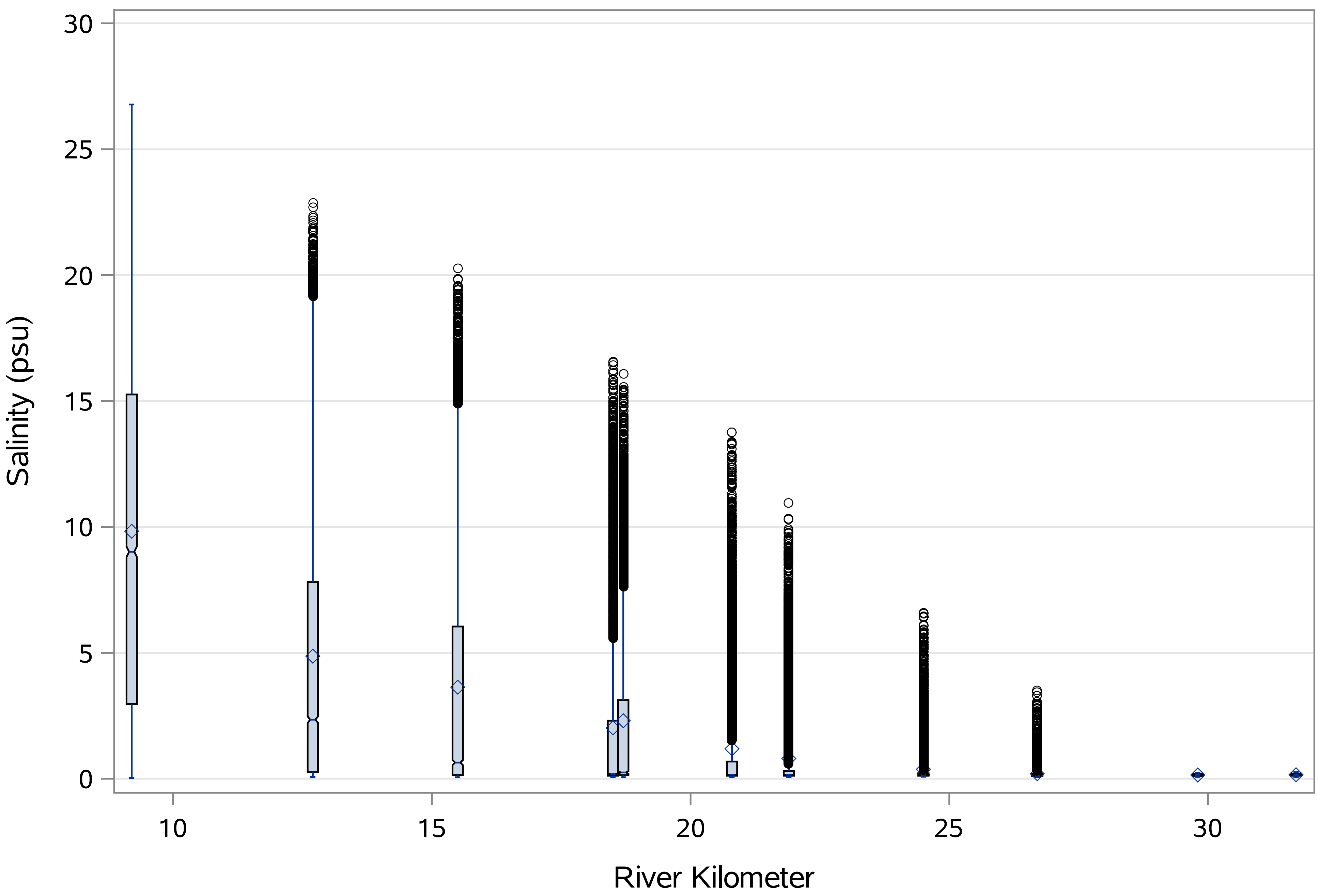


Figure 4.30. Box and whisker plots of annual variability in surface salinity during 2016 at the continuous recorders with a complete year of data

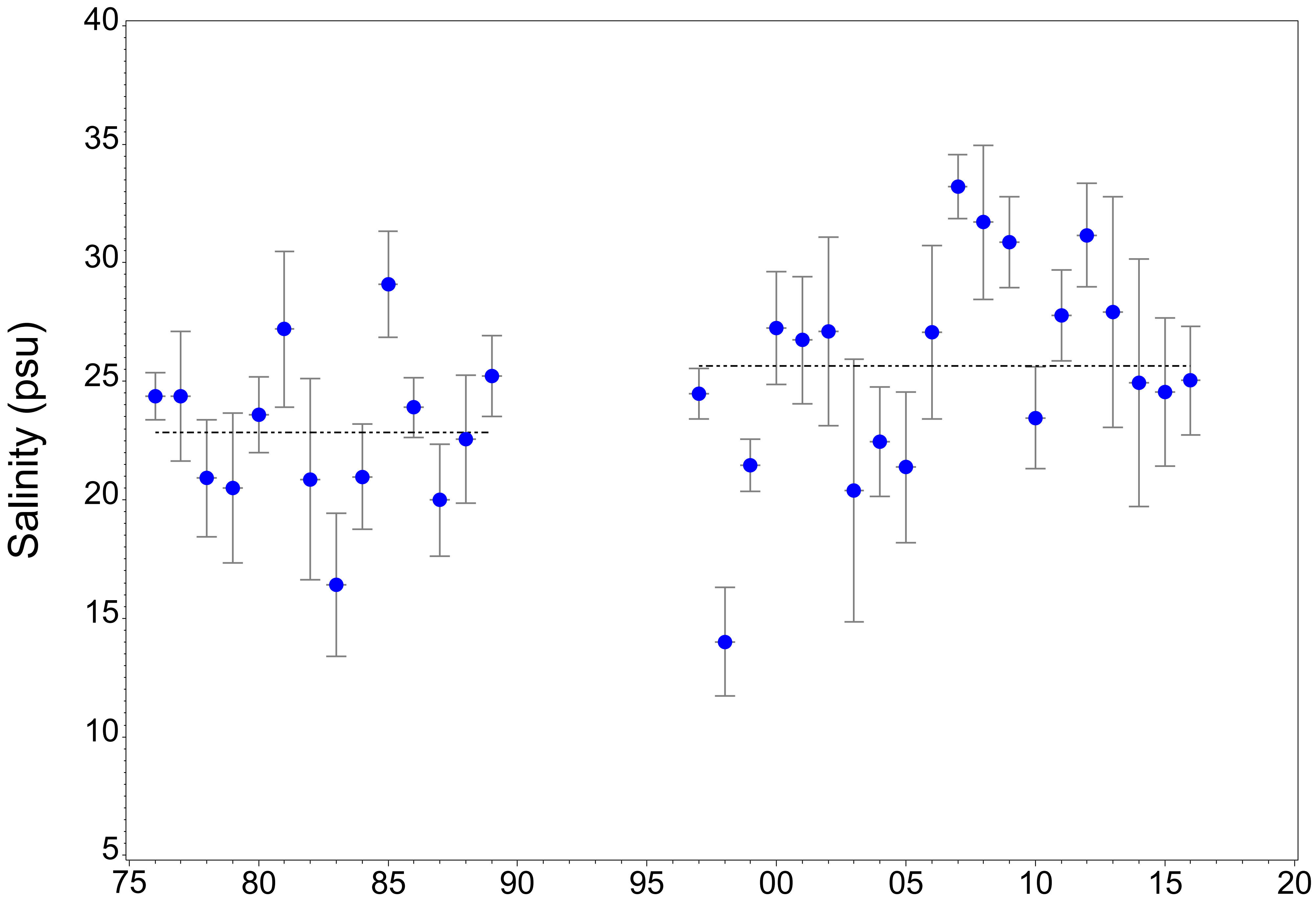


Figure 4.31. Long-term Station 9 Surface Salinity at river kilometer -2.4

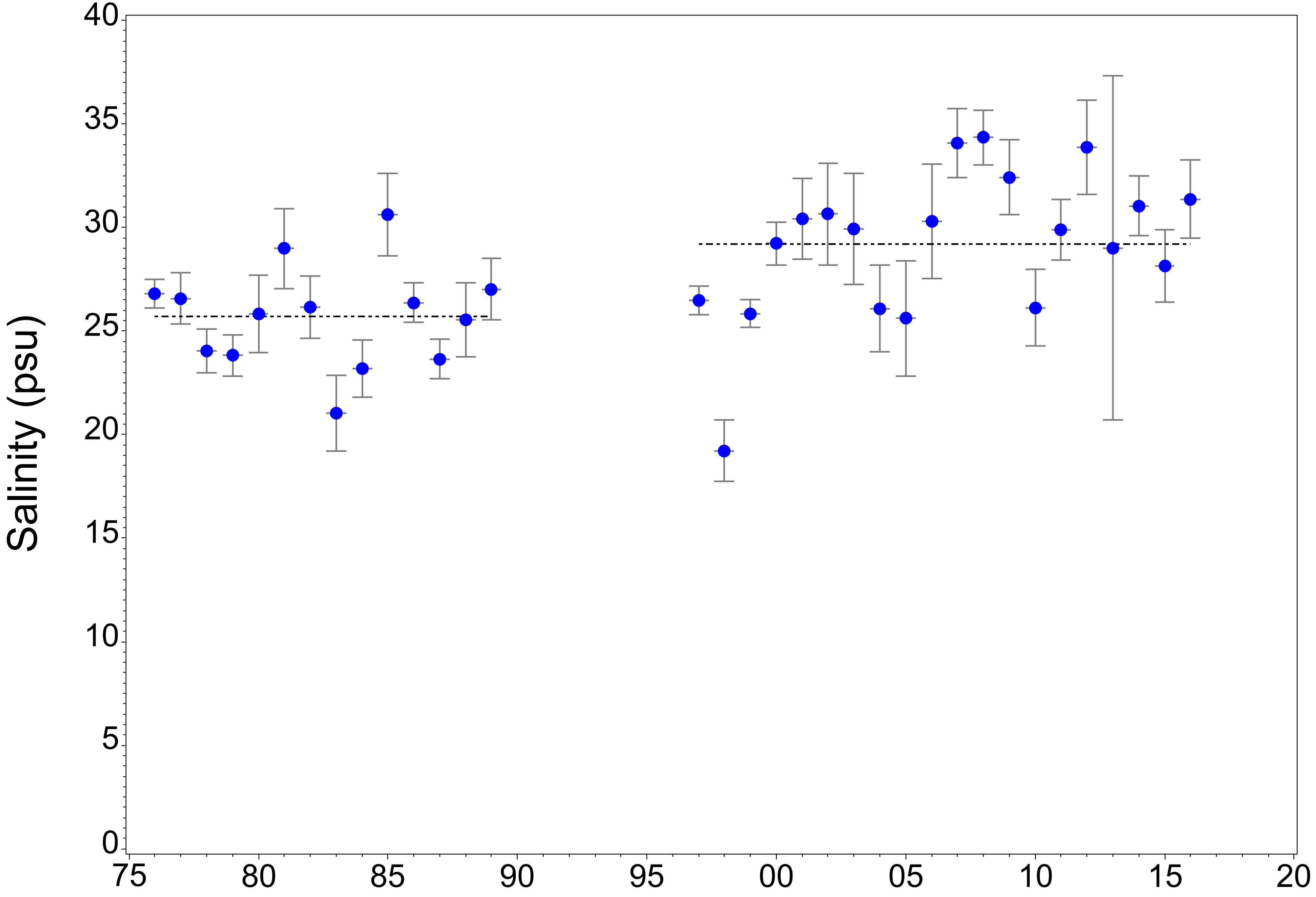


Figure 4.32. Long-term Station 9 Bottom Salinity at river kilometer -2.4

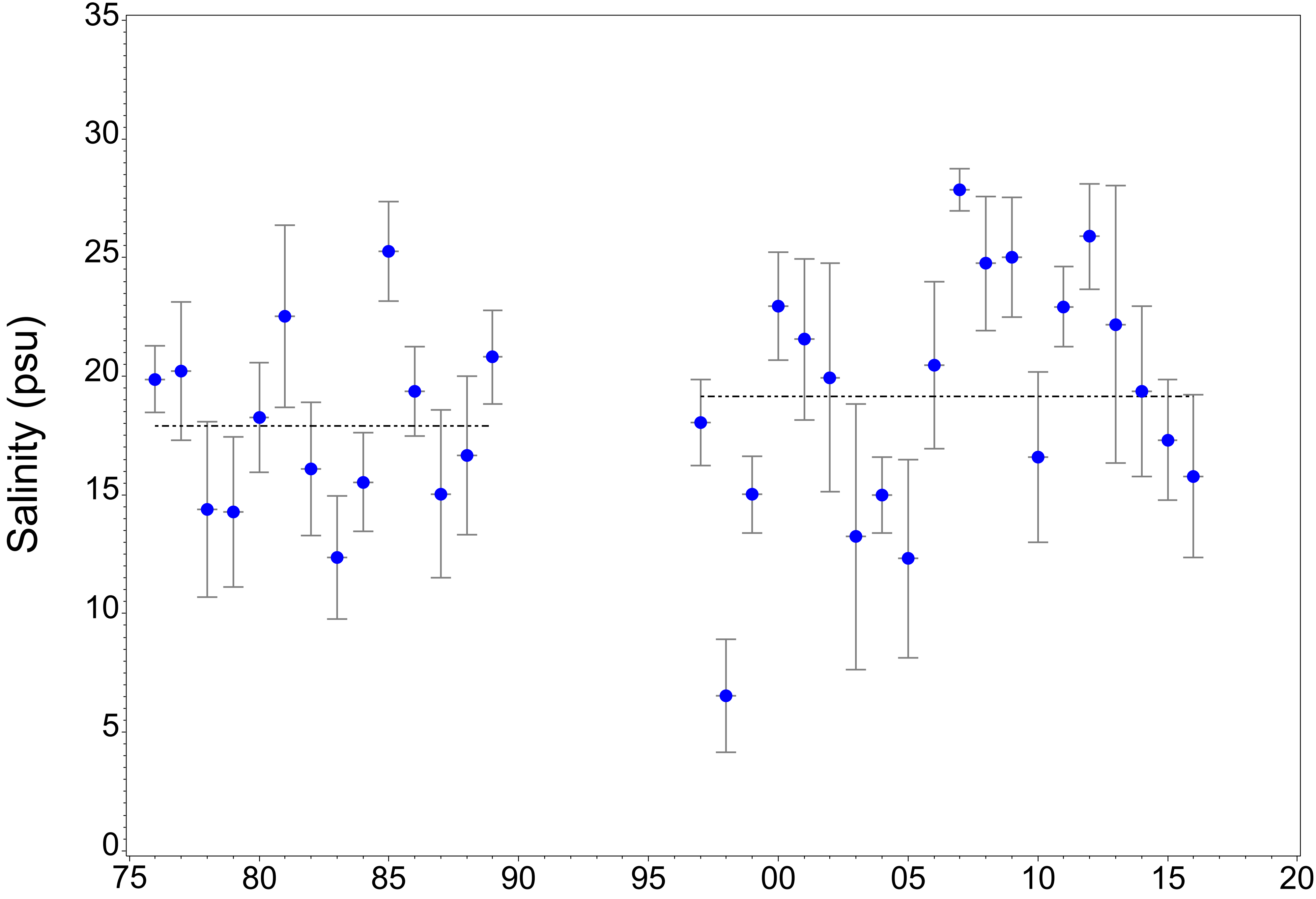


Figure 4.33. Long-term Station 10 Surface Salinity at river kilometer 6.6

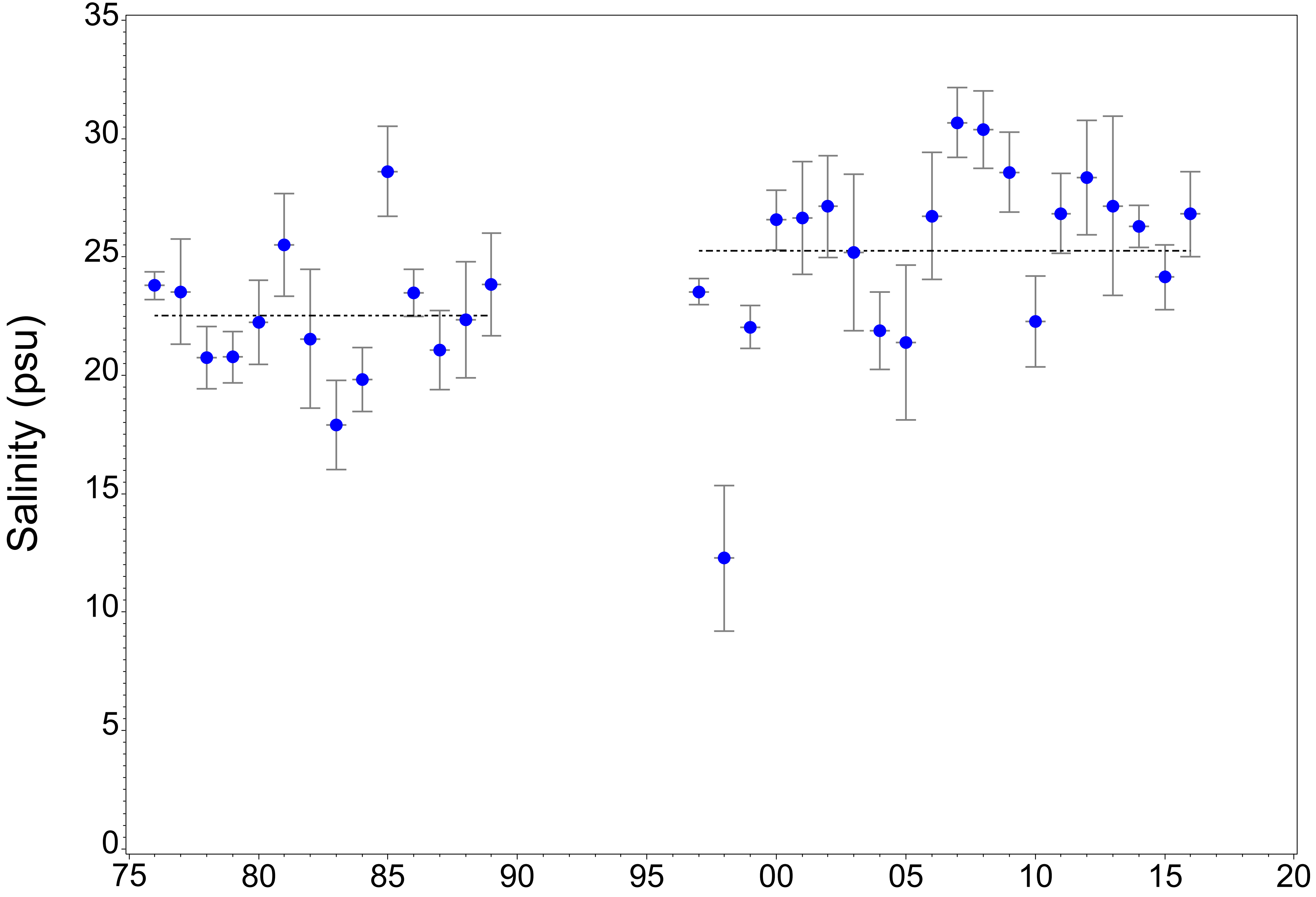


Figure 4.34. Long-term Station 10 Bottom Salinity at river kilometer 6.6

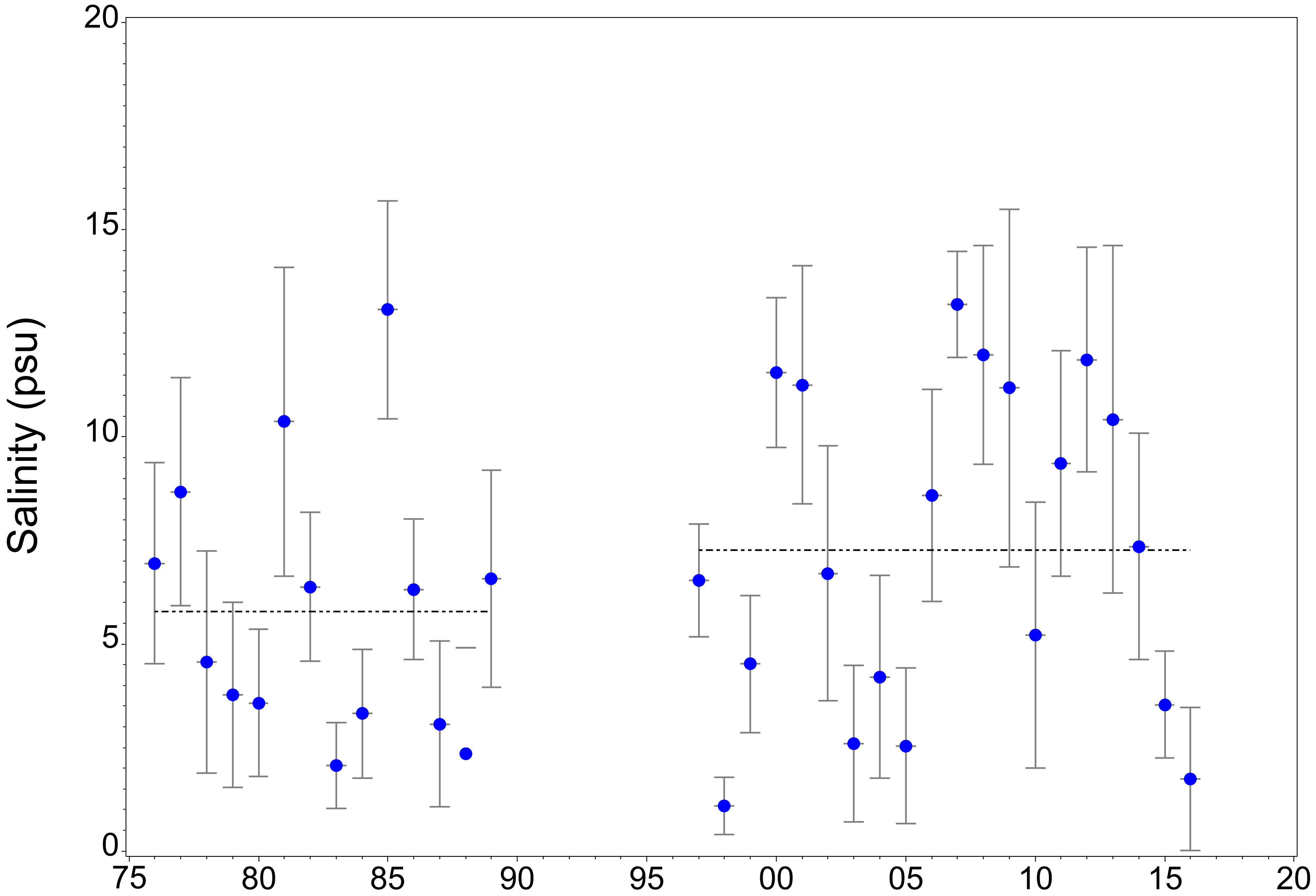


Figure 4.35. Long-term Station 12 Surface Salinity at river kilometer 15.5

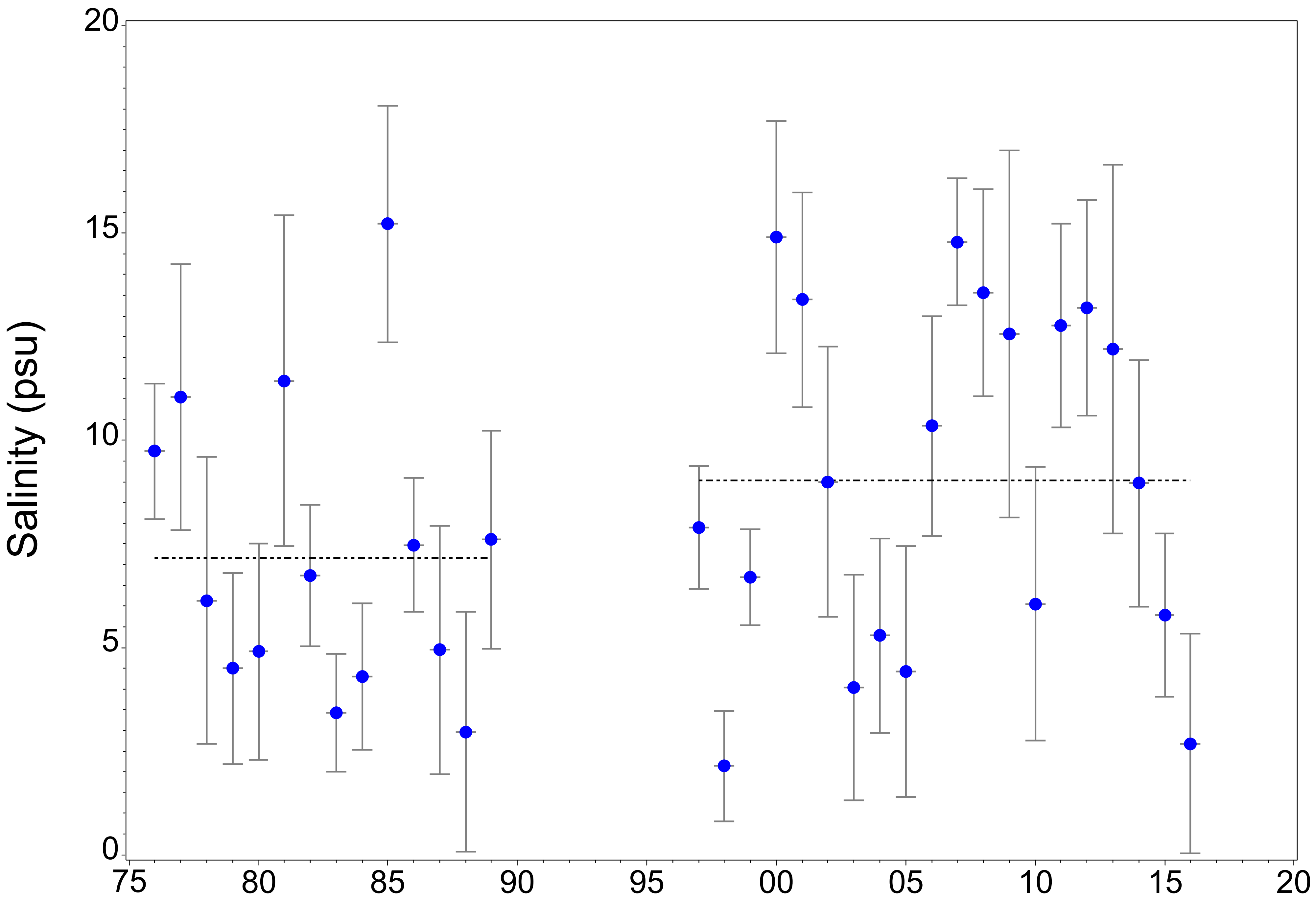


Figure 4.36. Long-term Station 12 Bottom Salinity at river kilometer 15.5

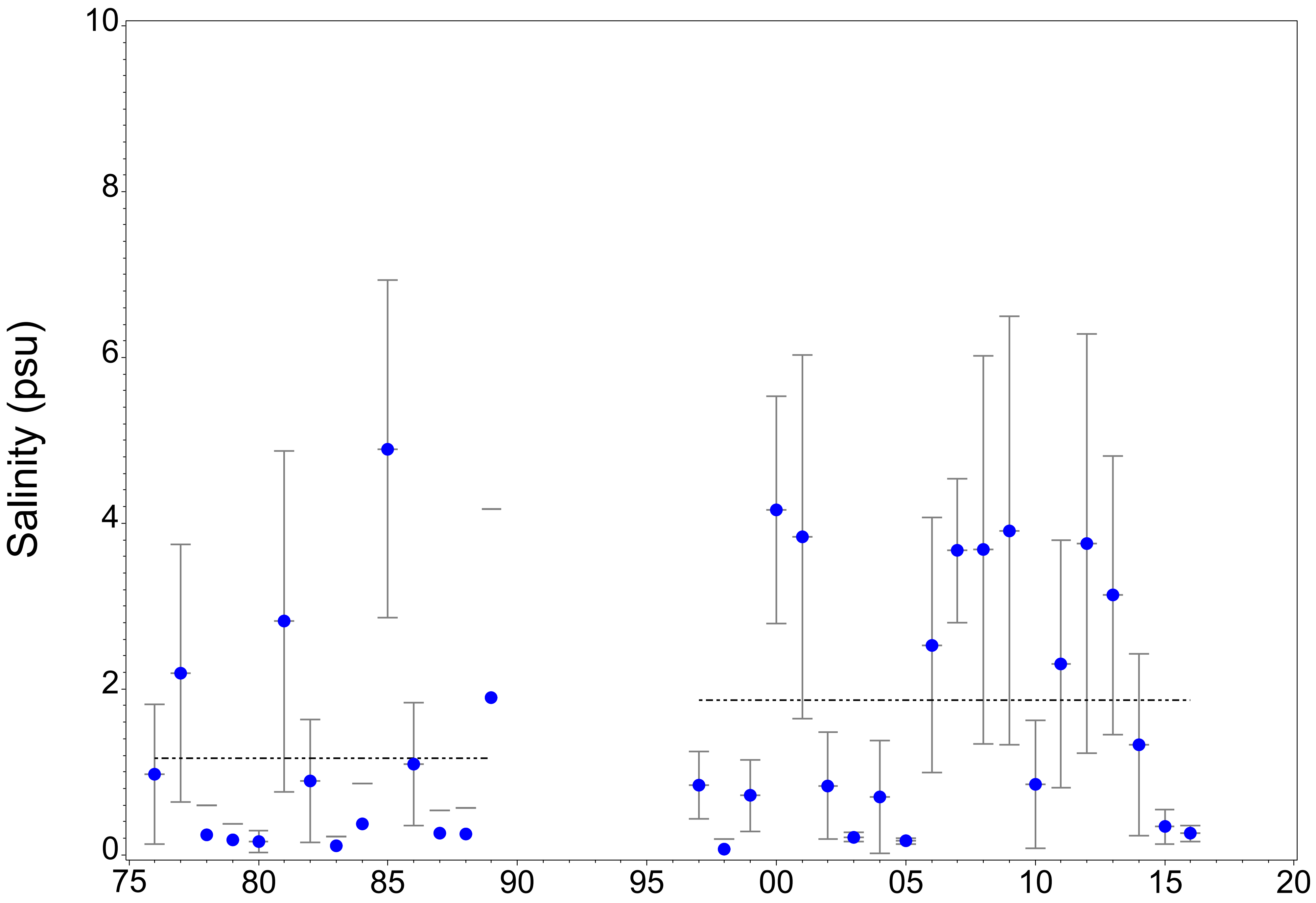


Figure 4.37. Long-term Station 14 Surface Salinity at river kilometer 23.6

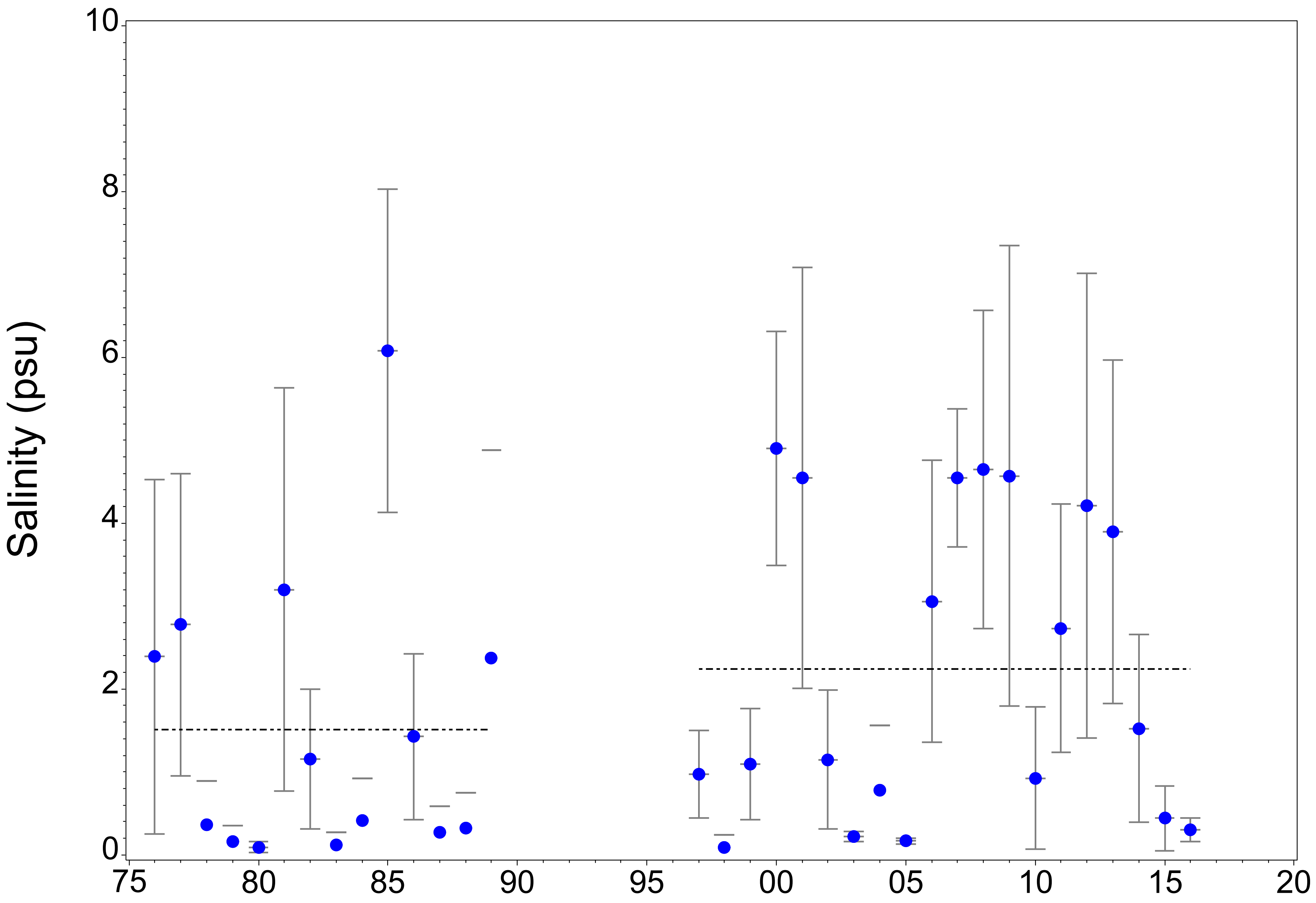


Figure 4.38. Long-term Station 14 Bottom Salinity at river kilometer 23.6

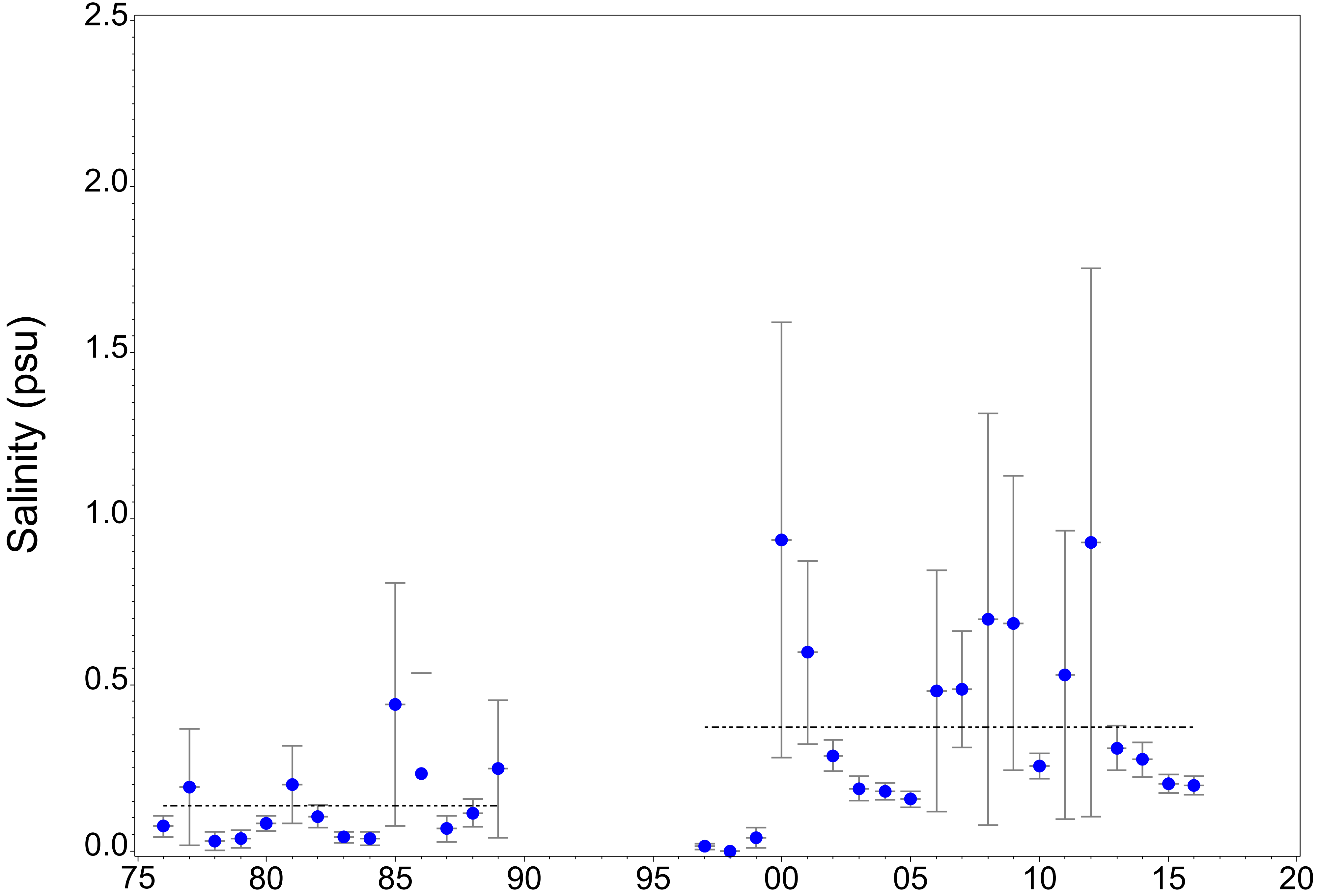


Figure 4.39. Long-term Station 18 Surface Salinity at river kilometer 30.4

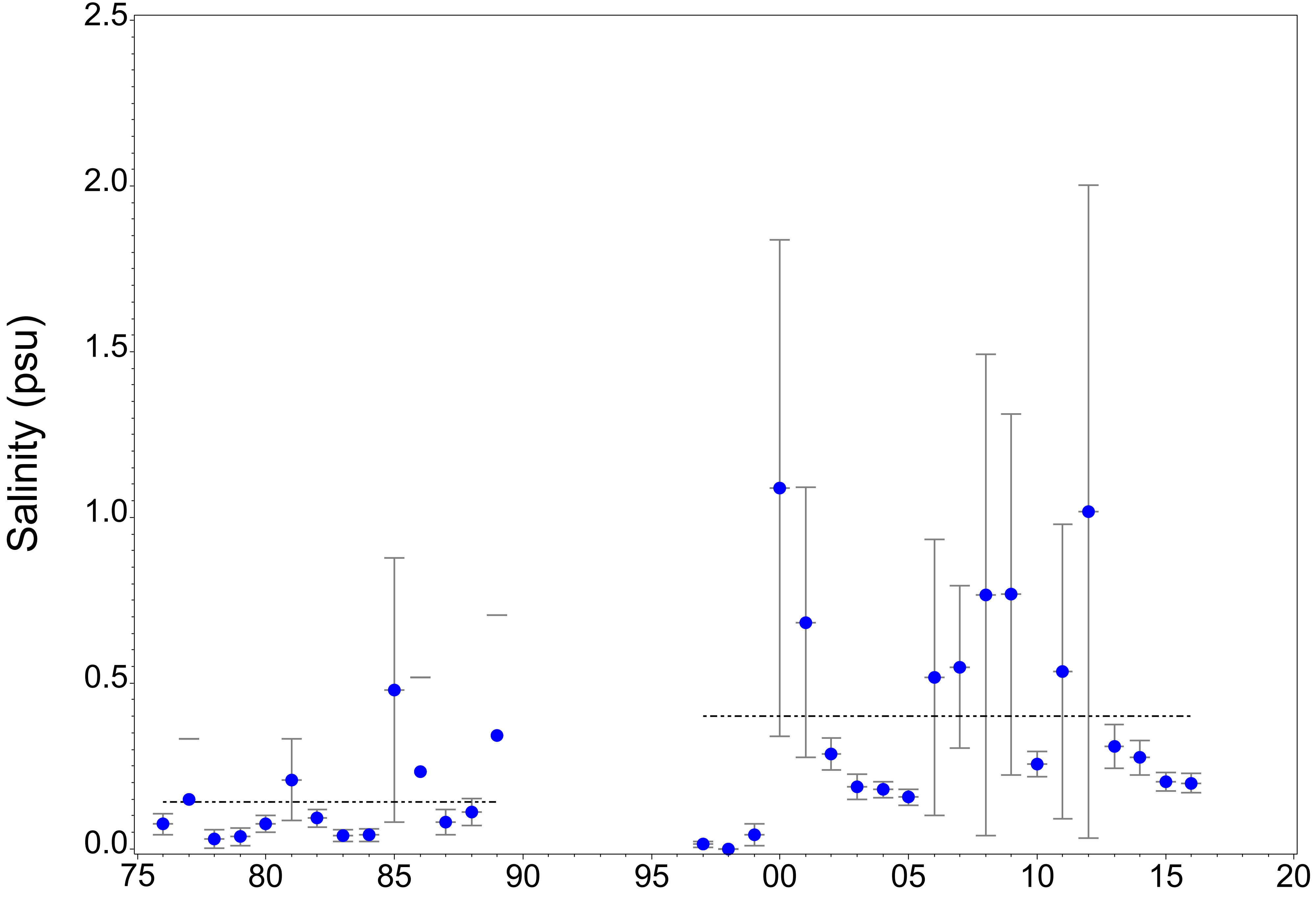


Figure 4.40. Long-term Station 18 Bottom Salinity at river kilometer 30.4

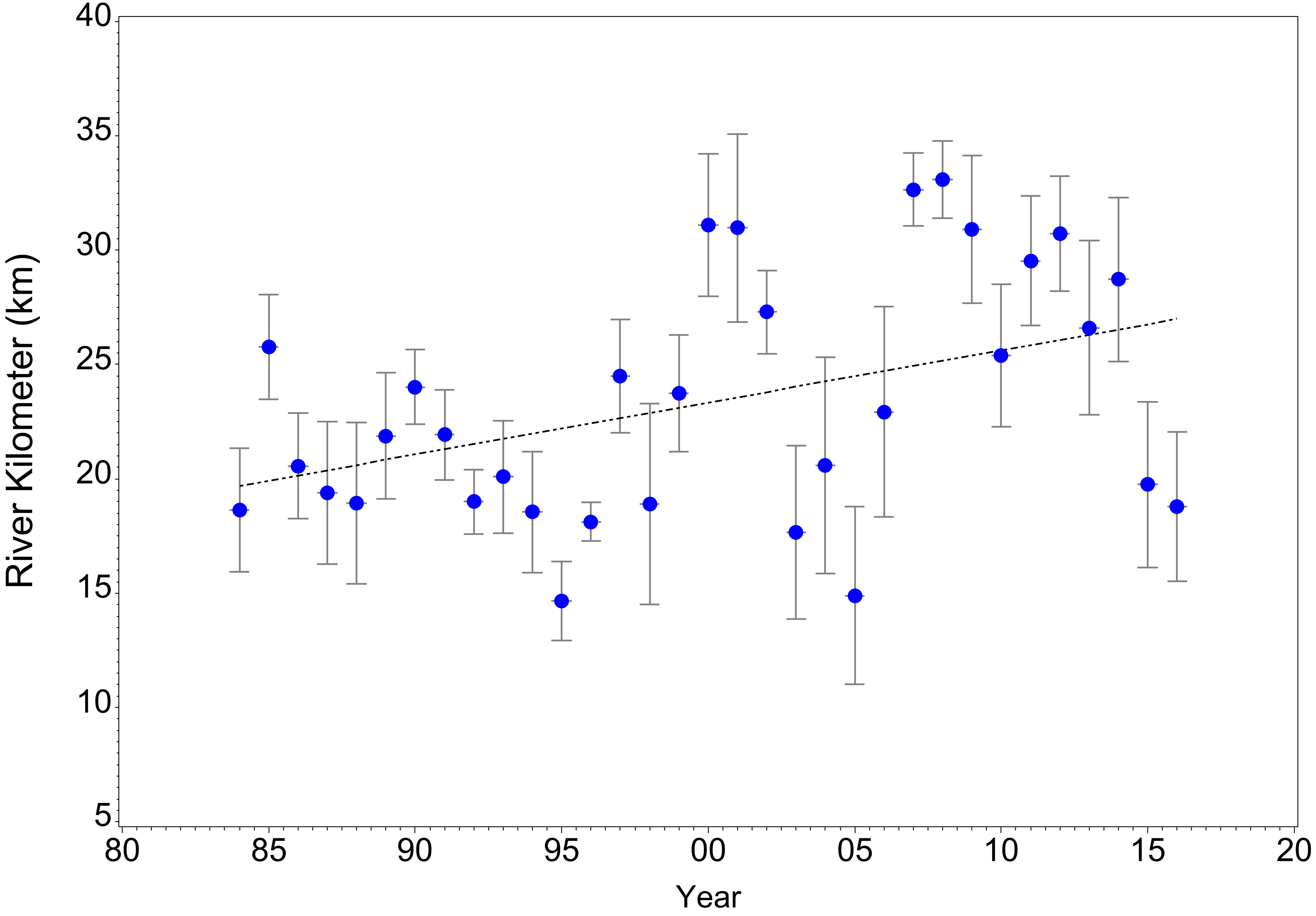


Figure 4.41. Annual monthly river kilometer location of the 0 psu isohaline (1984-2016)

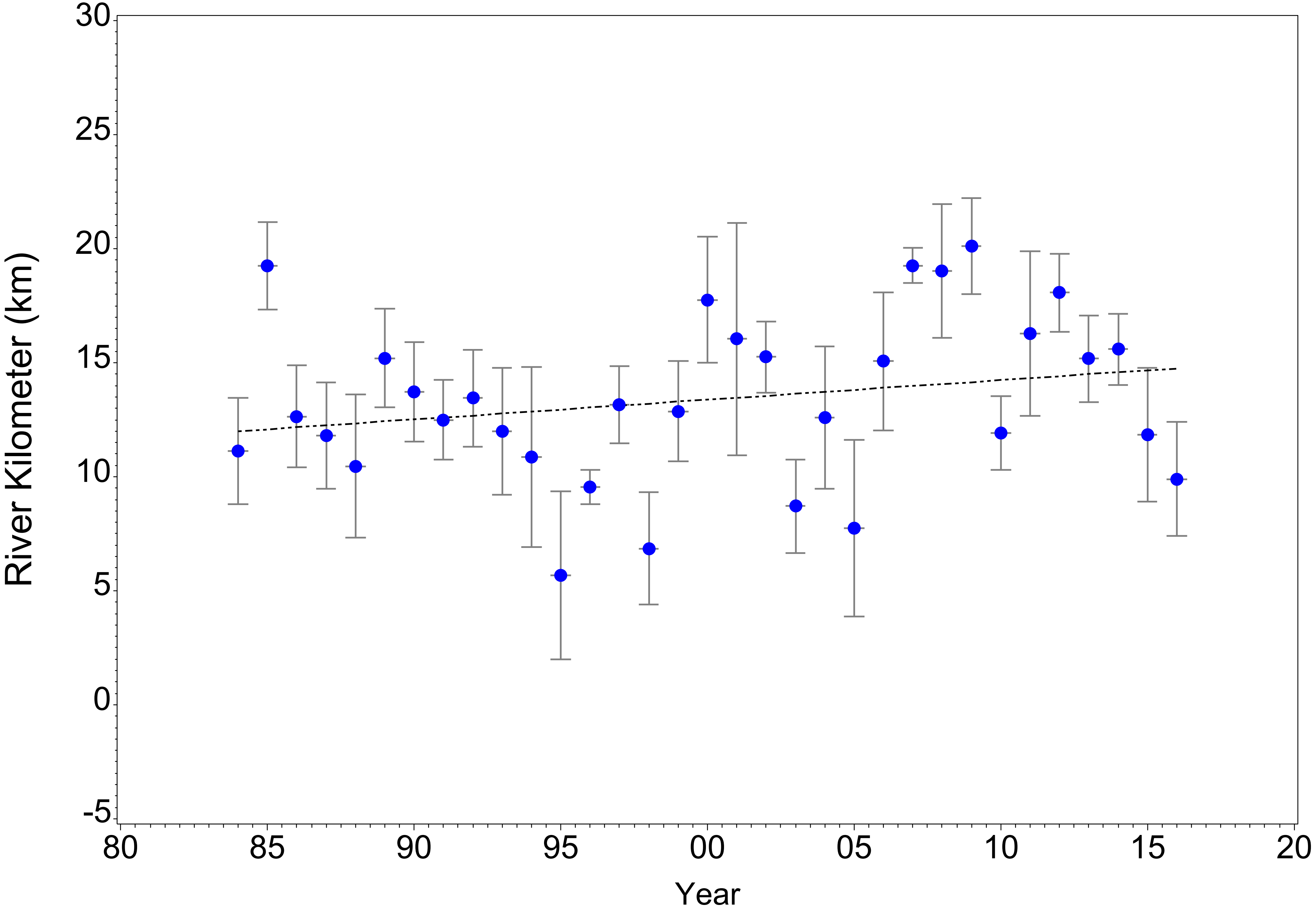


Figure 4.42. Annual monthly river kilometer location of the 6 psu isohaline (1984-2016)

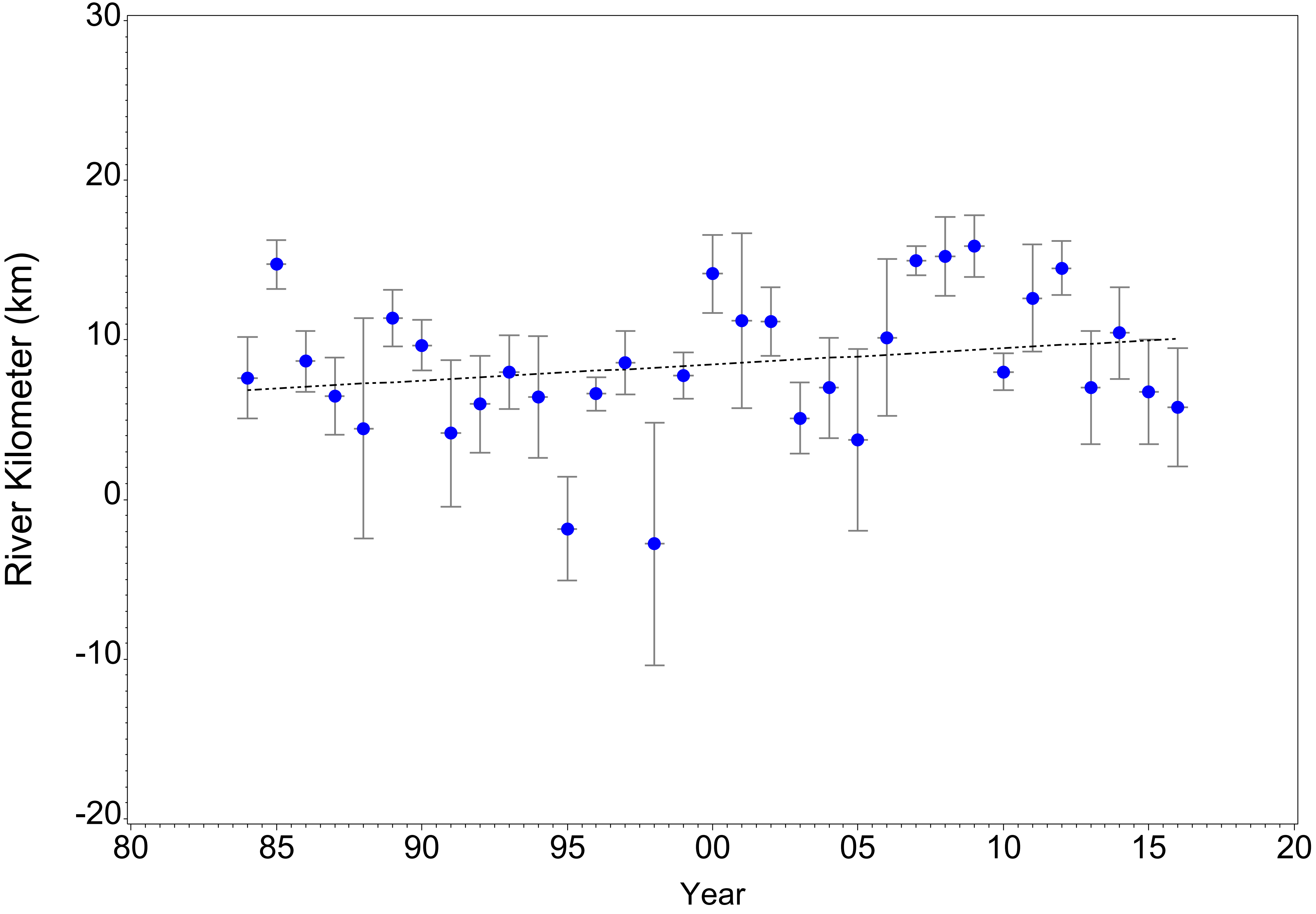


Figure 4.43. Annual monthly river kilometer location of the 12 psu isohaline (1984-2016)

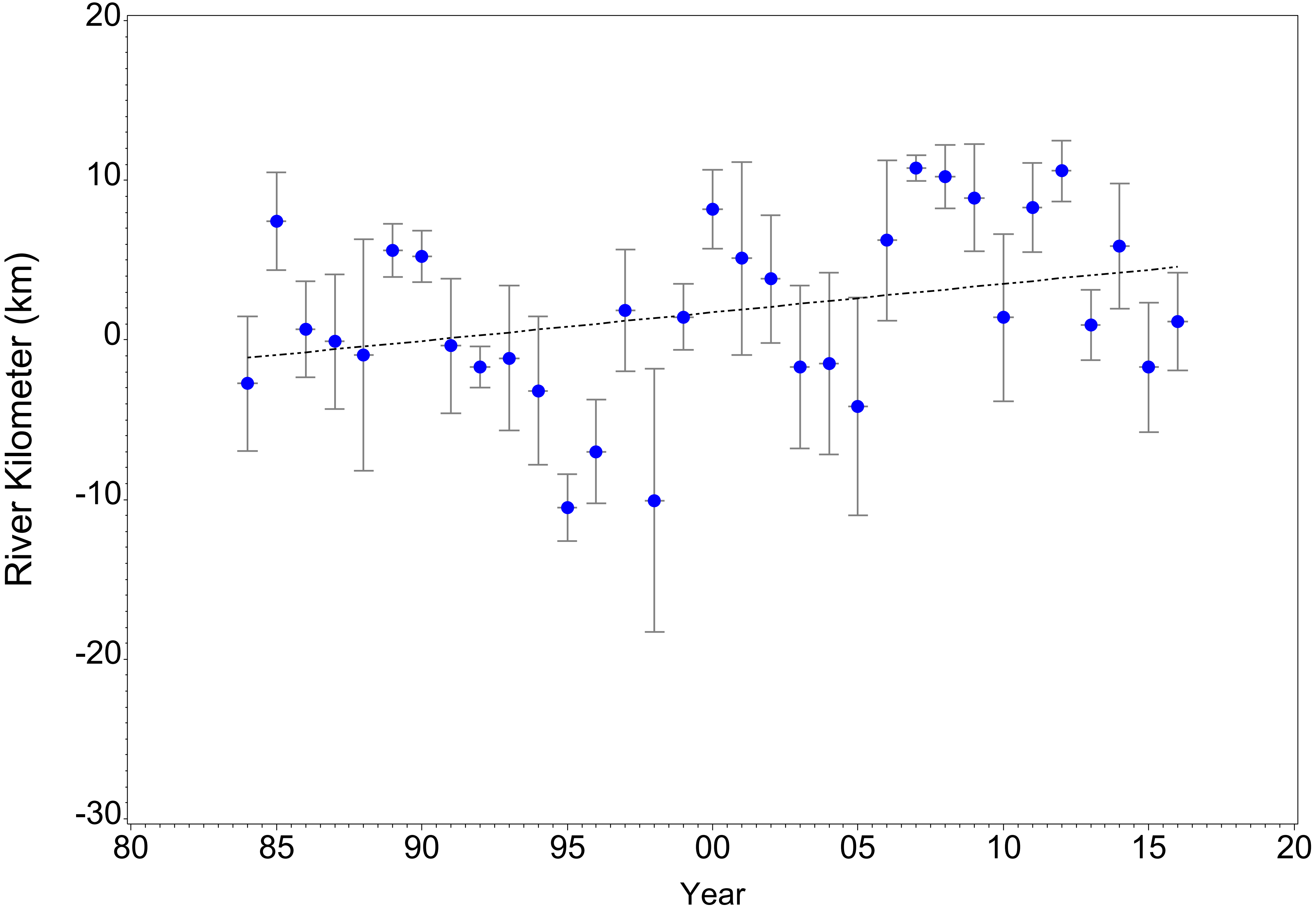


Figure 4.44. Annual monthly river kilometer location of the 20 psu isohaline (1984-2016)

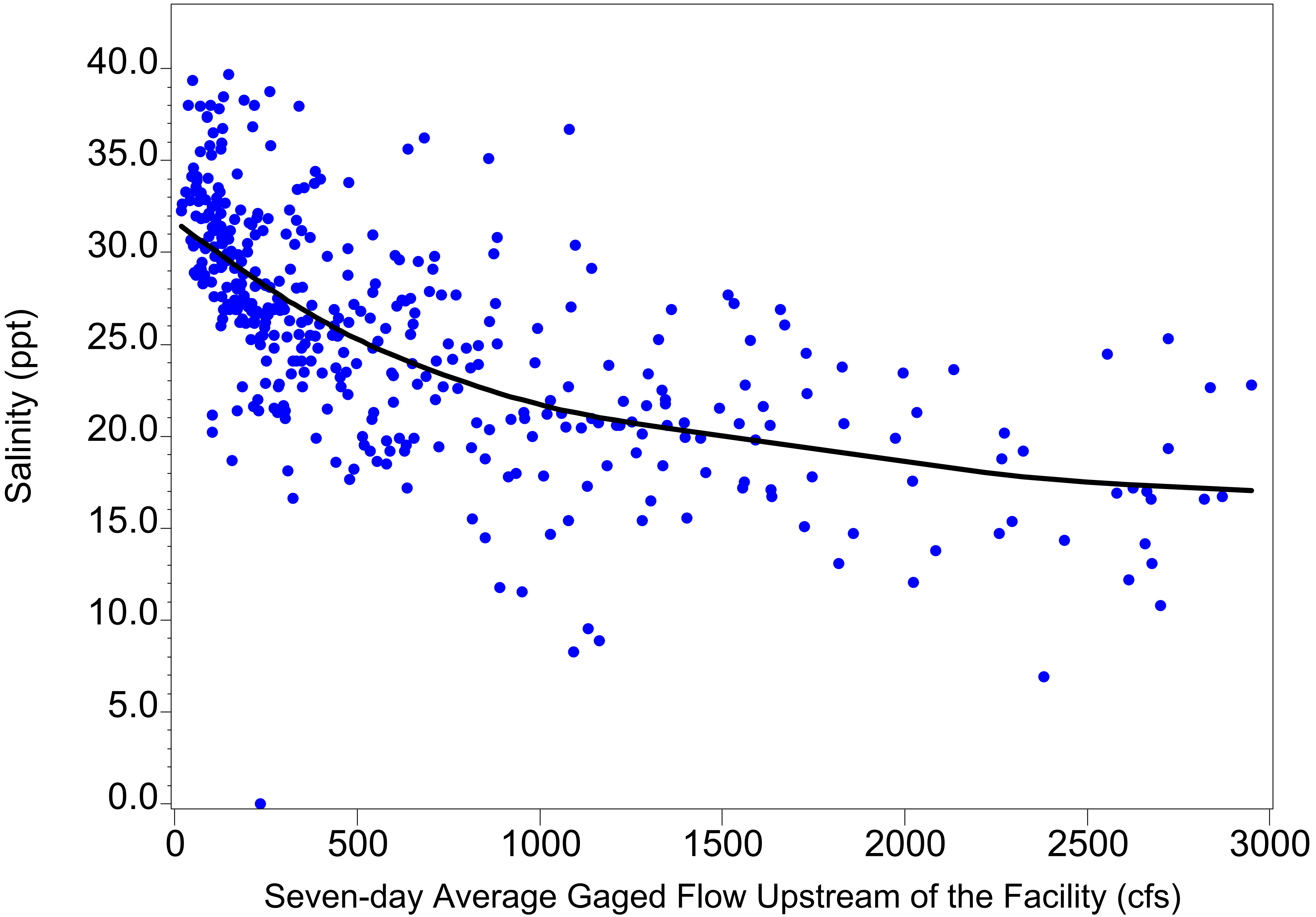


Figure 4.45. Surface Salinity at river kilometer -2.4 versus flow

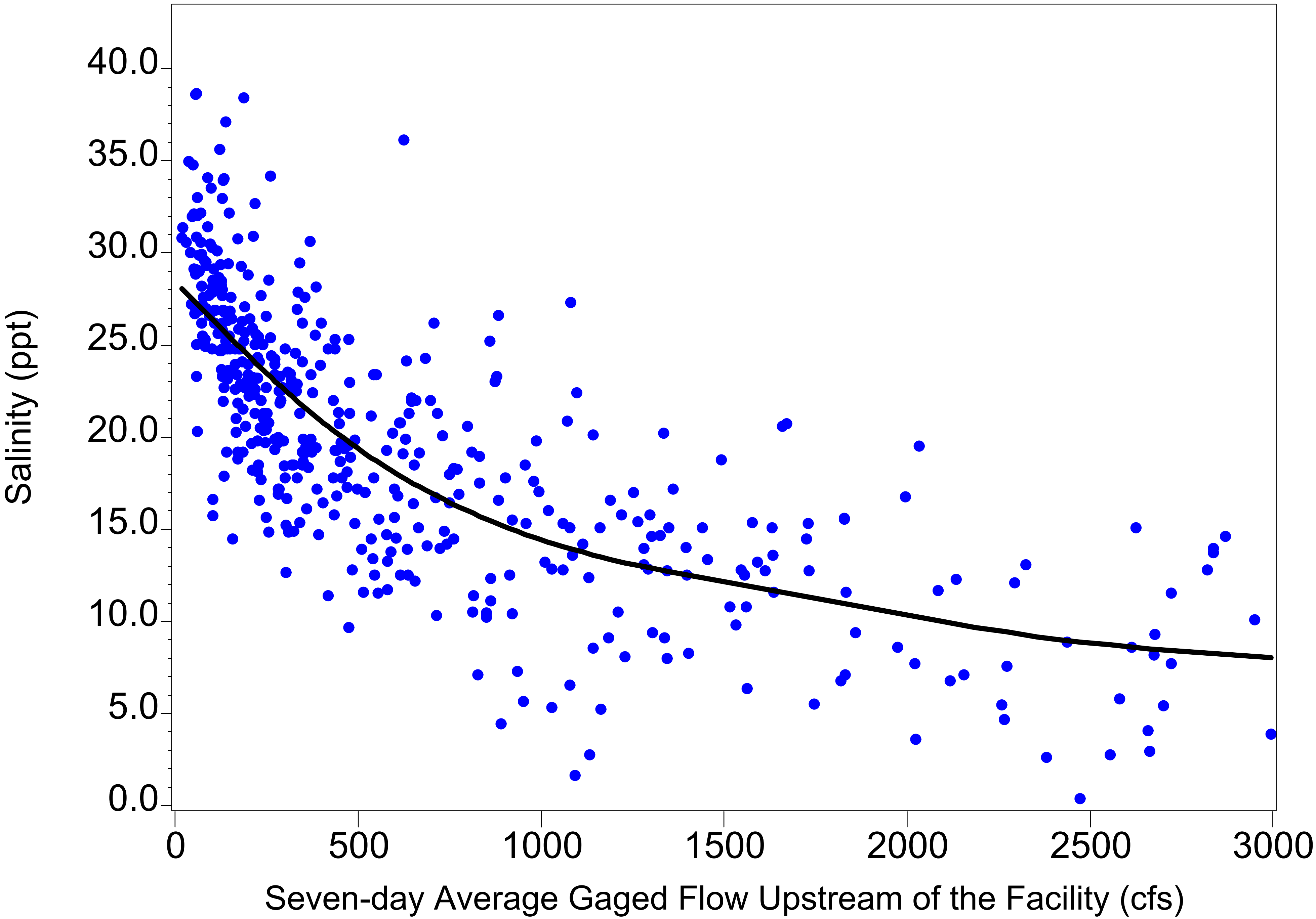


Figure 4.46. Surface Salinity at river kilometer 6.6 versus flow

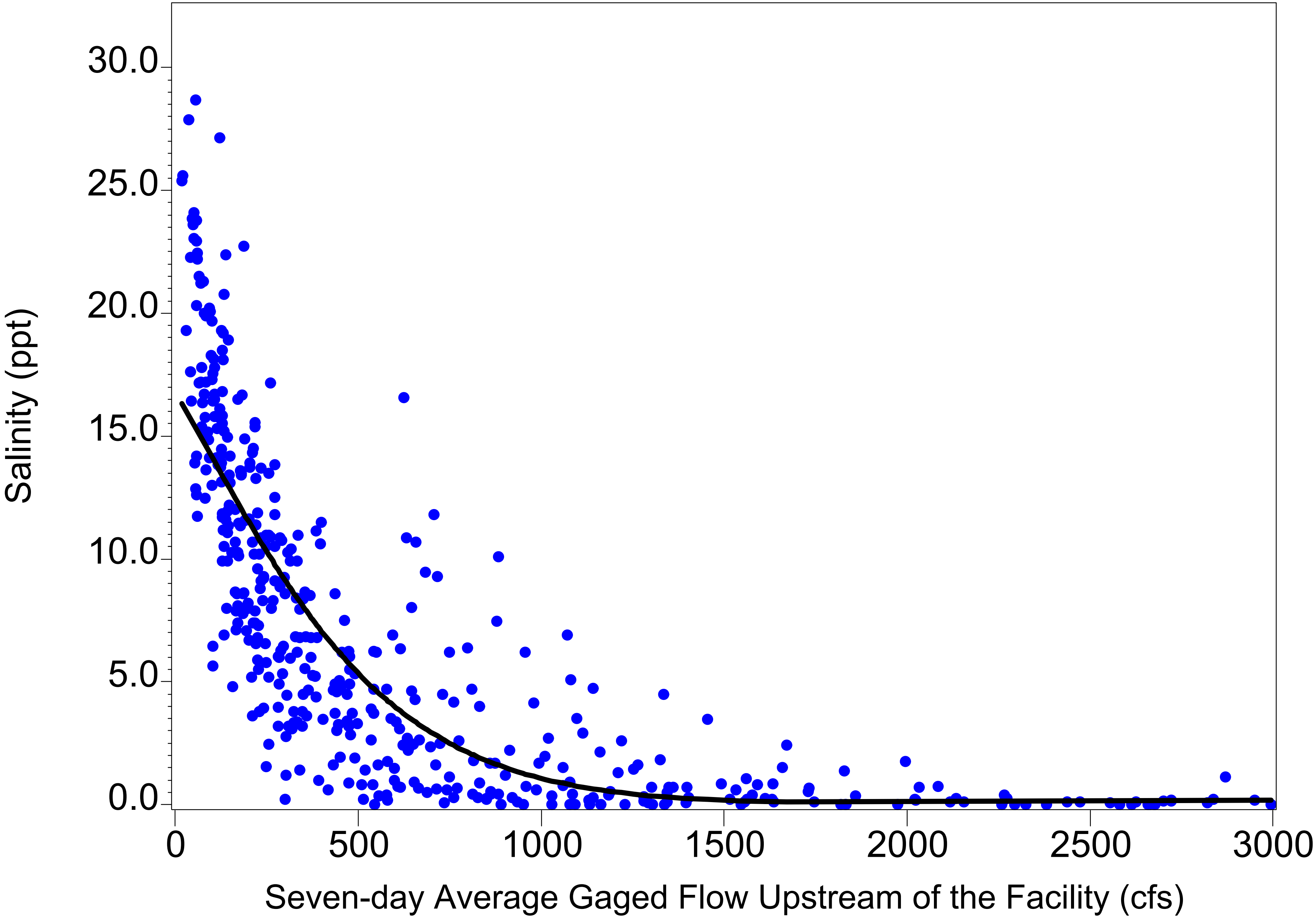


Figure 4.47. Surface Salinity at river kilometer 15.5 versus flow

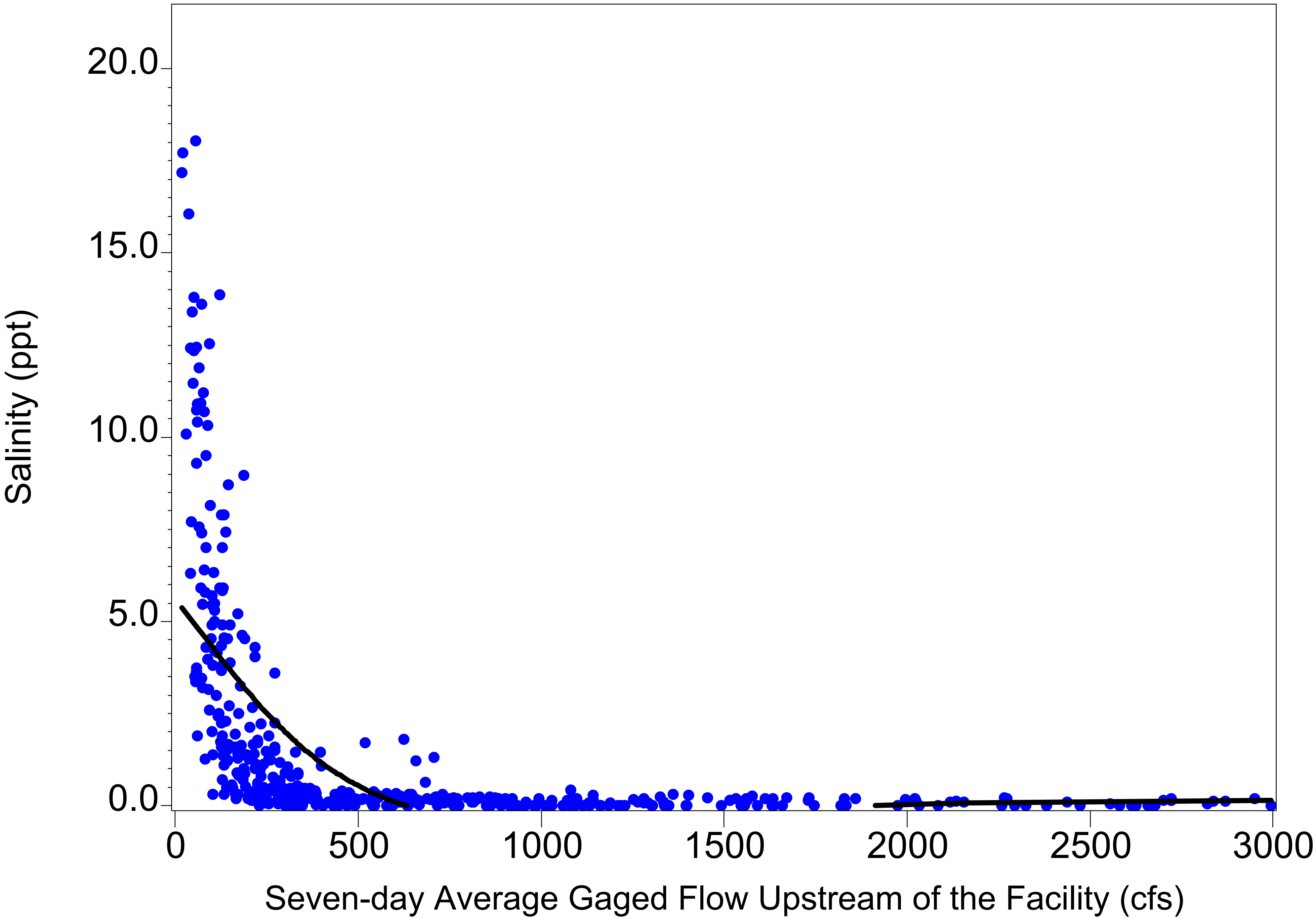


Figure 4.48. Surface Salinity at river kilometer 23.6 versus flow

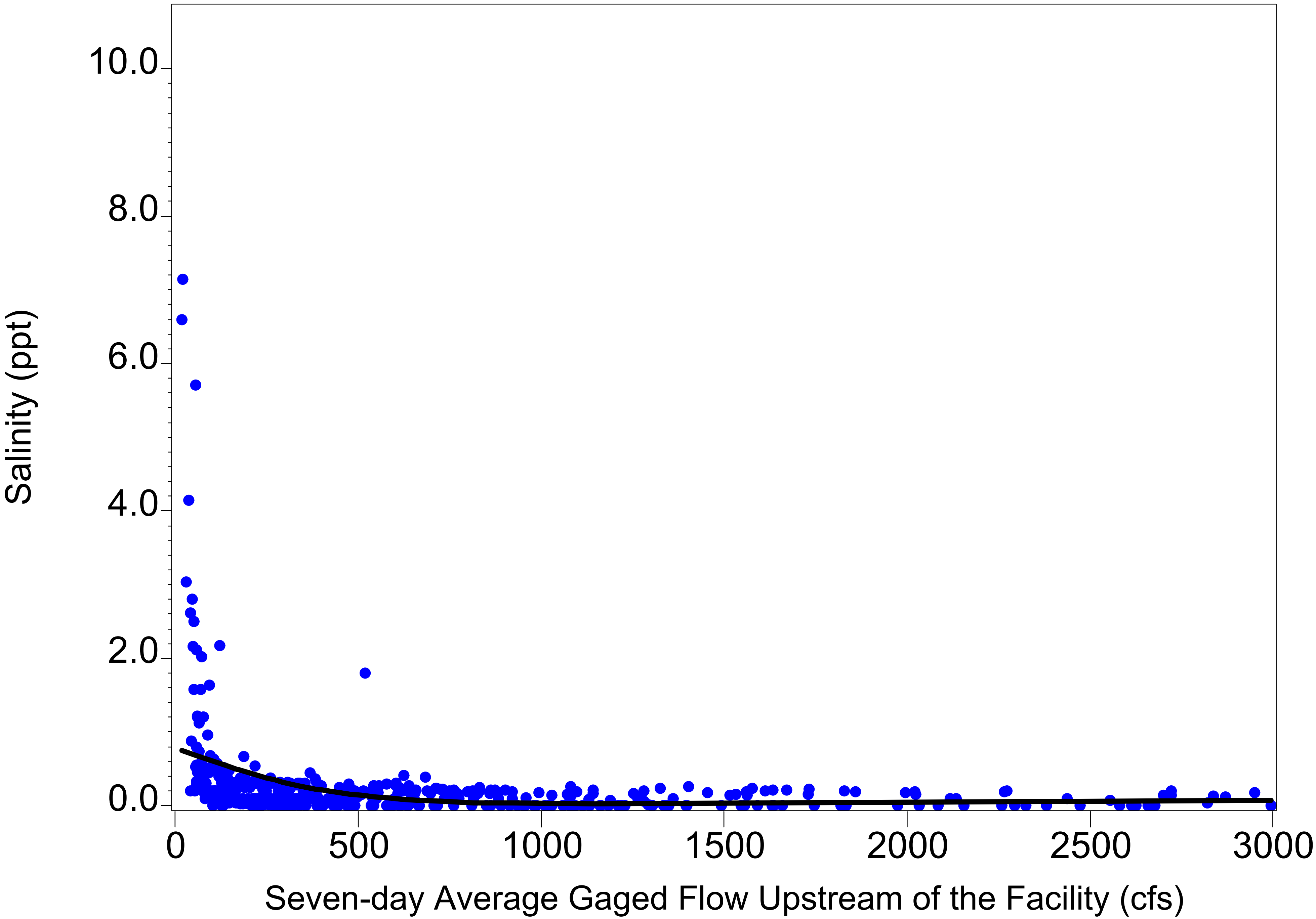


Figure 4.49. Surface Salinity at river kilometer 30.4 versus flow

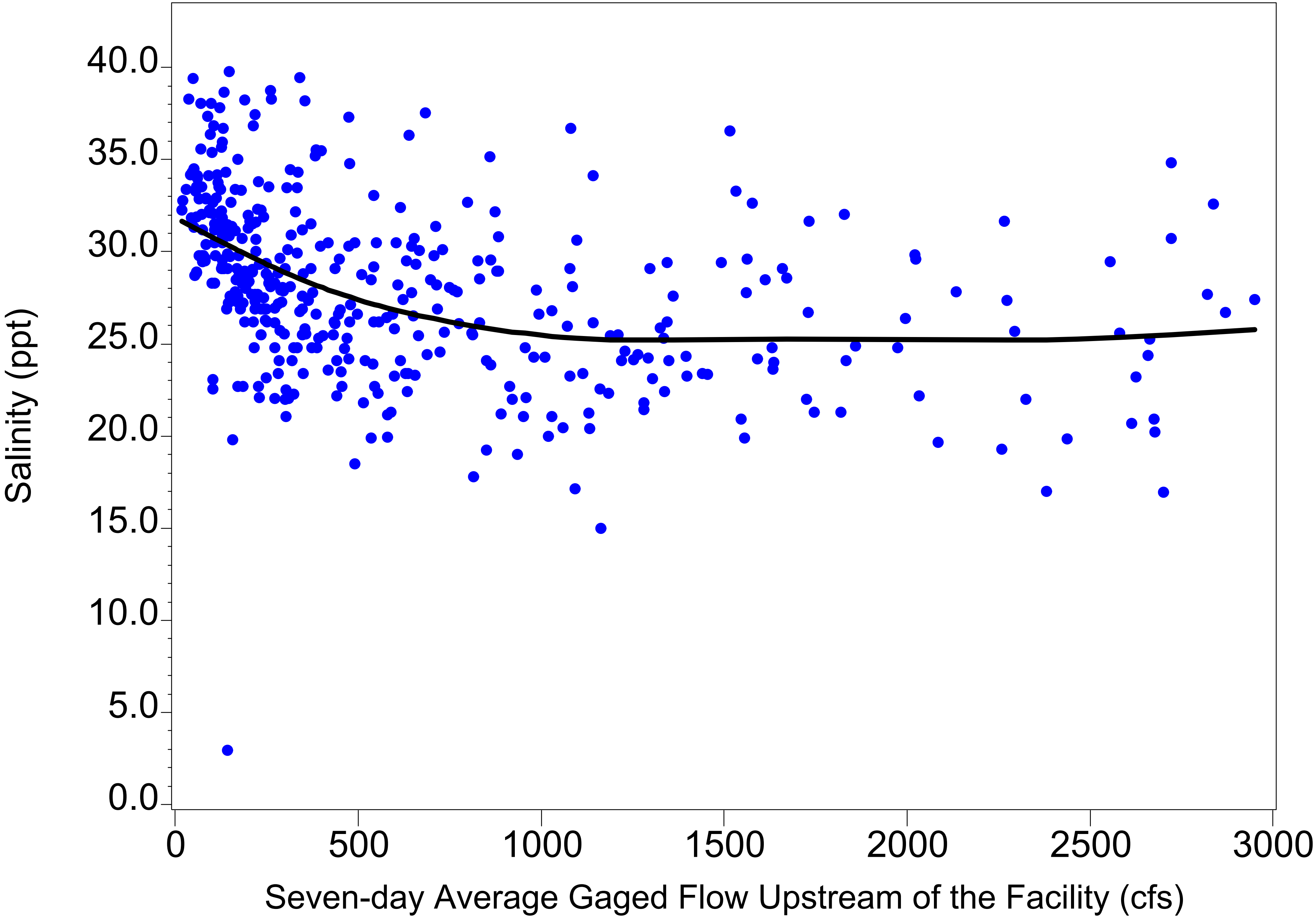


Figure 4.50. Bottom Salinity at river kilometer -2.4 versus flow

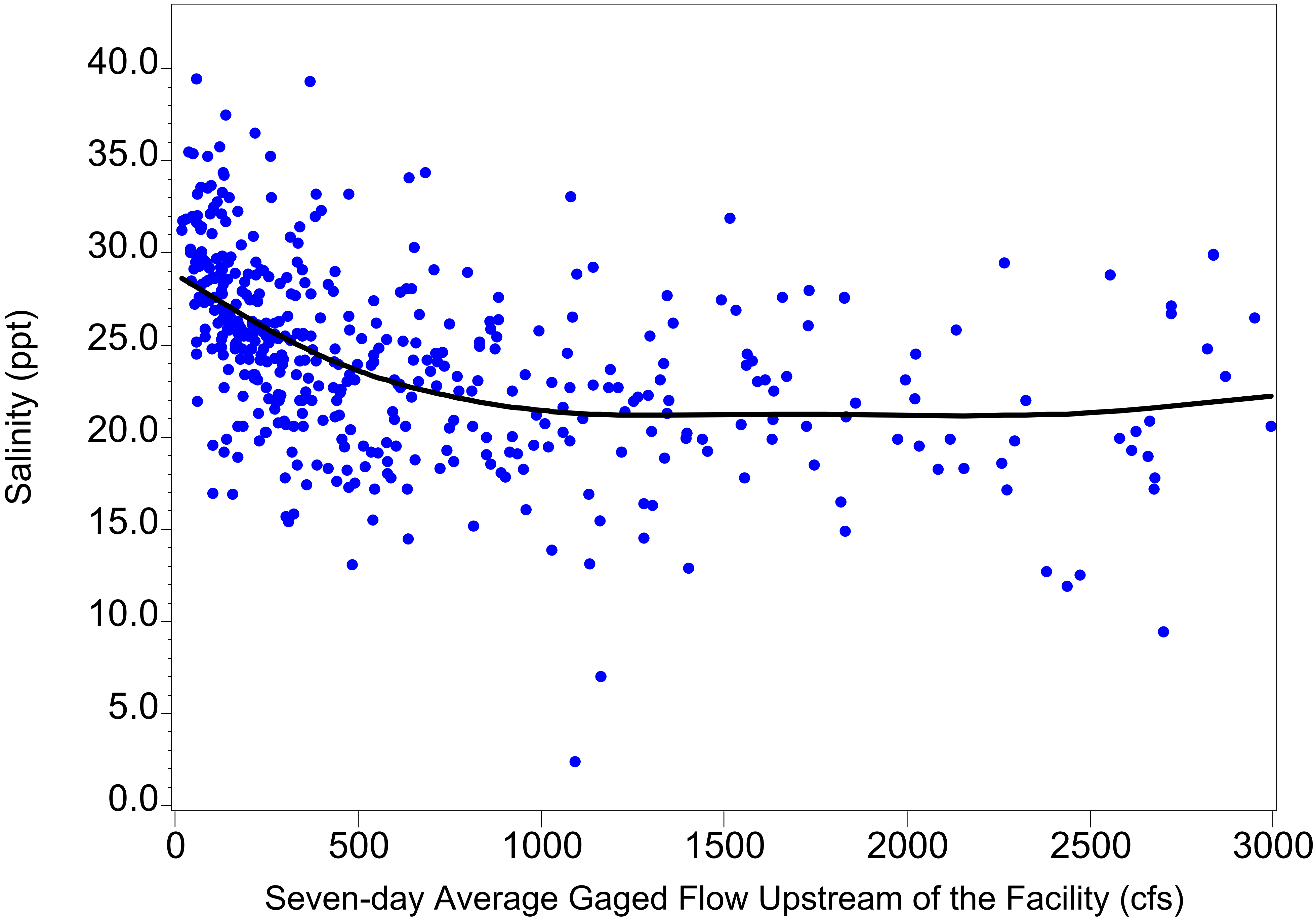


Figure 4.51. Bottom Salinity at river kilometer 6.6 versus flow

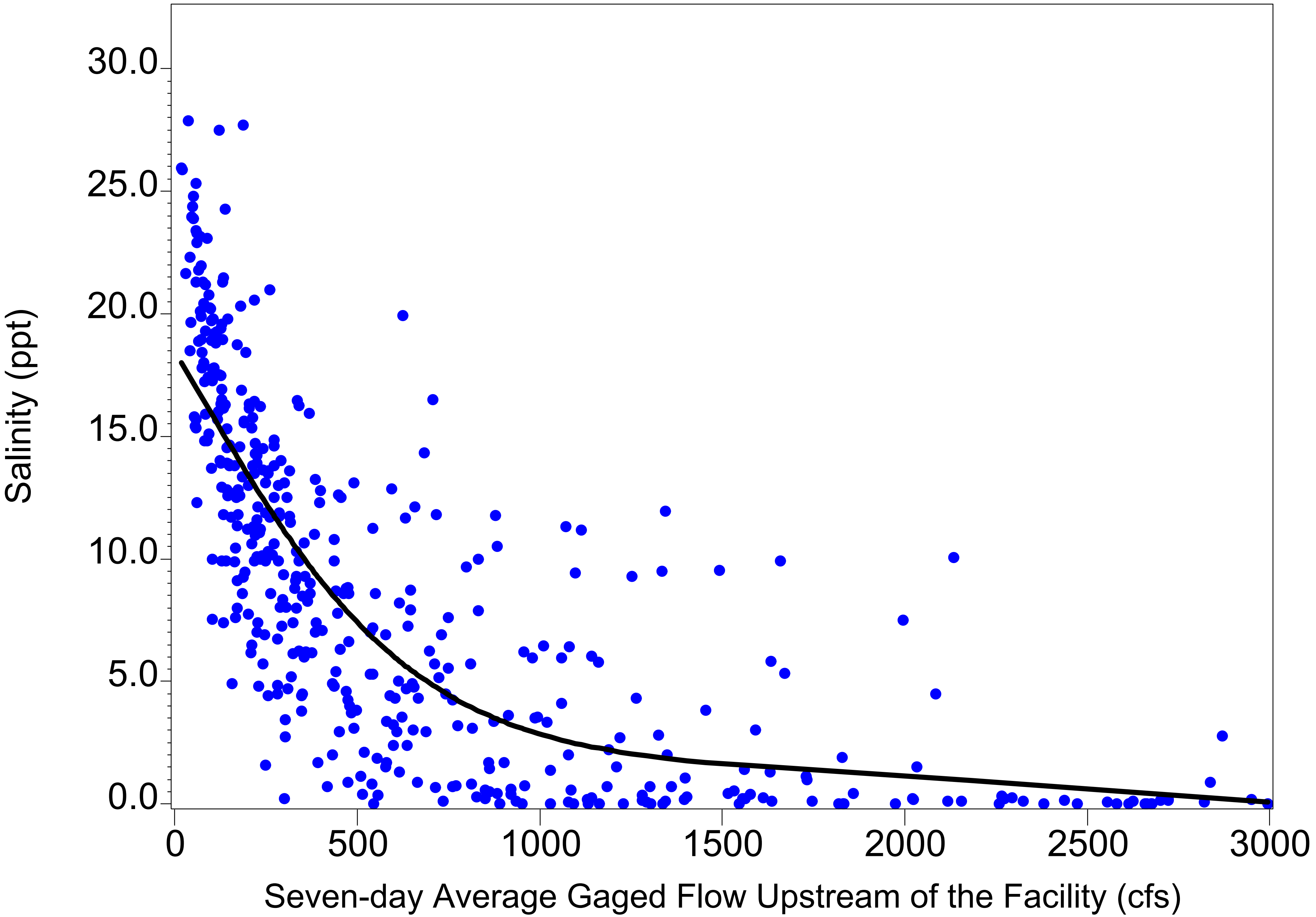


Figure 4.52. Bottom Salinity at river kilometer 15.5 versus flow

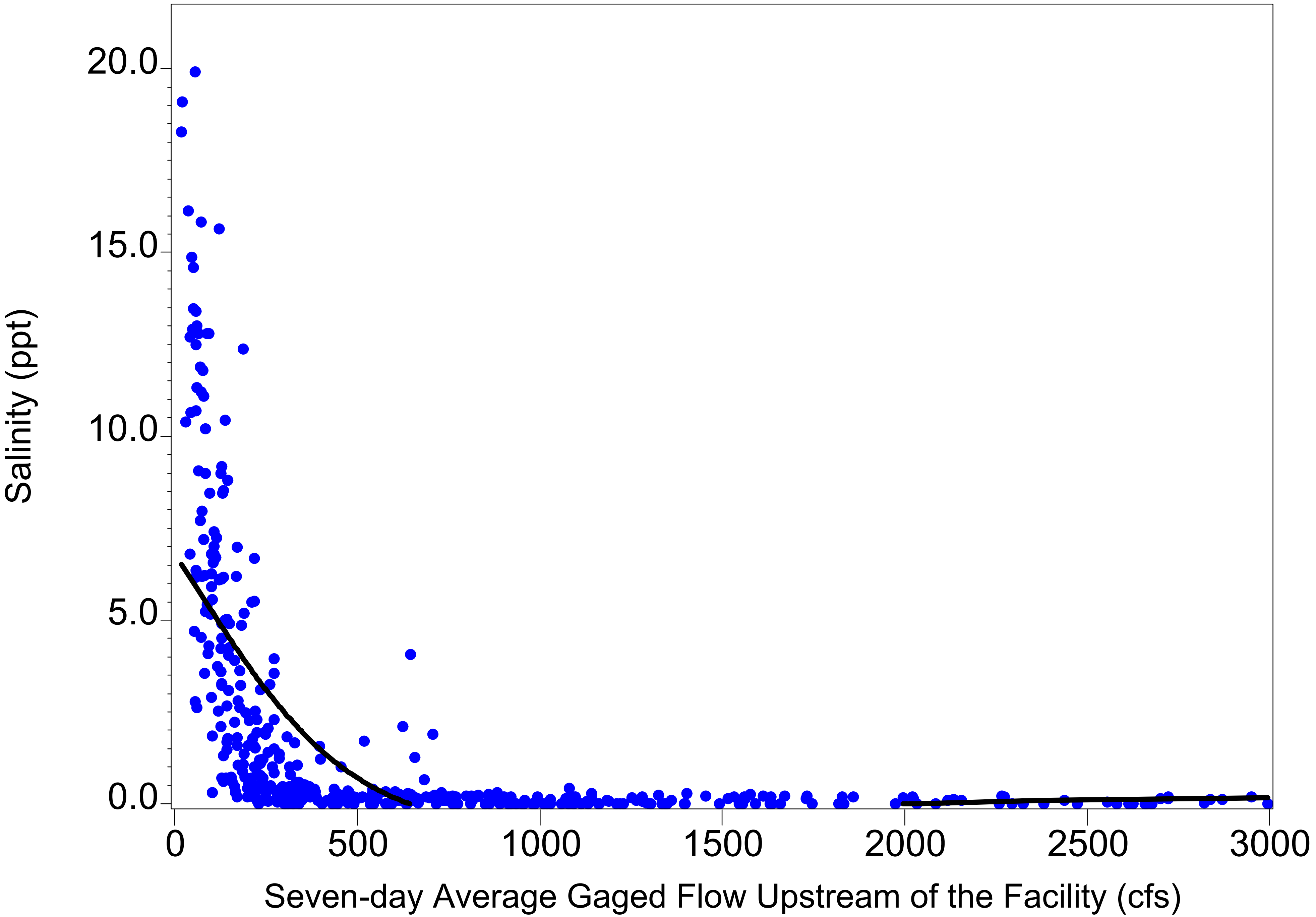


Figure 4.53. Bottom Salinity at river kilometer 23.6 versus flow

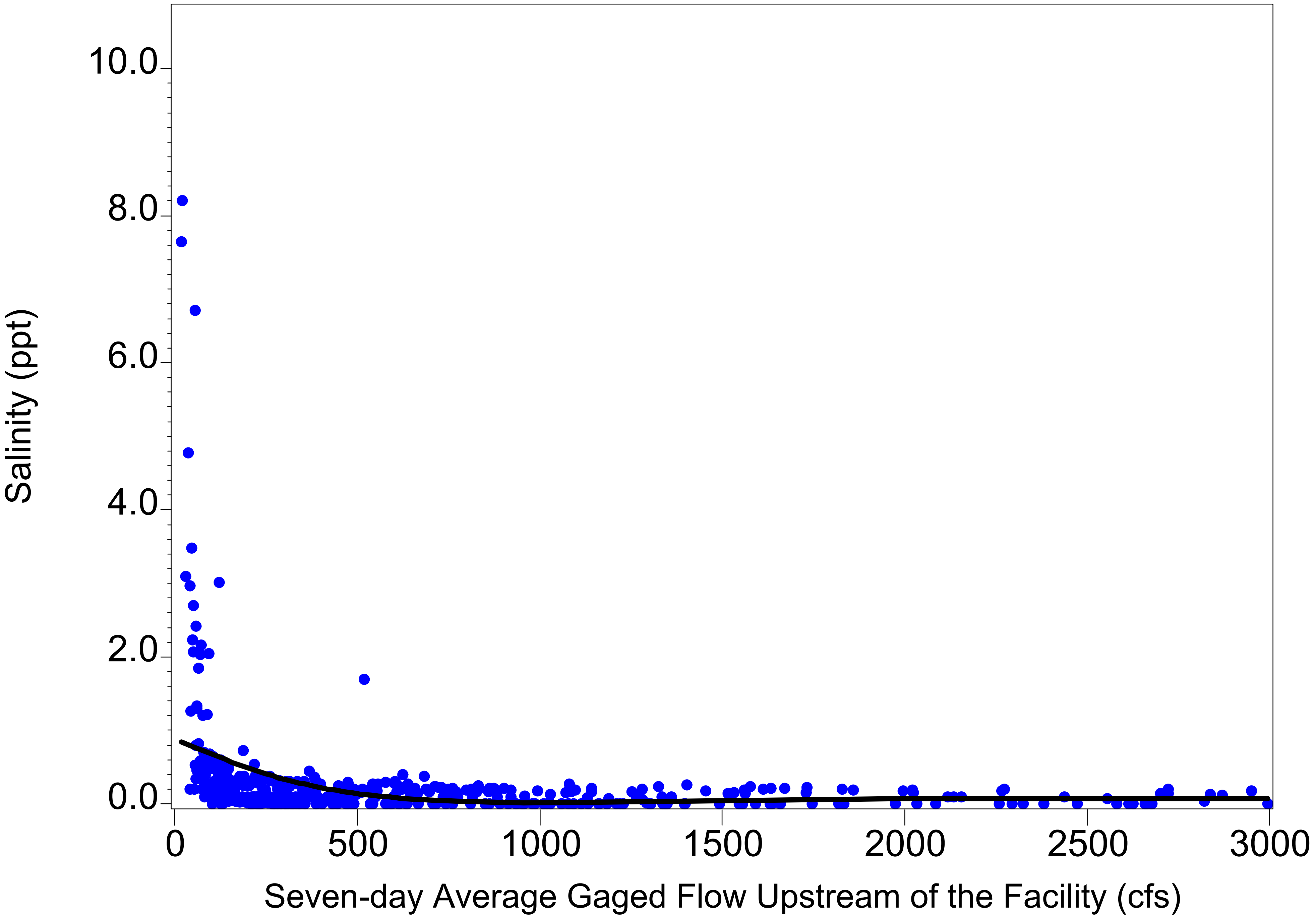


Figure 4.54. Bottom Salinity at river kilometer 30.4 versus flow

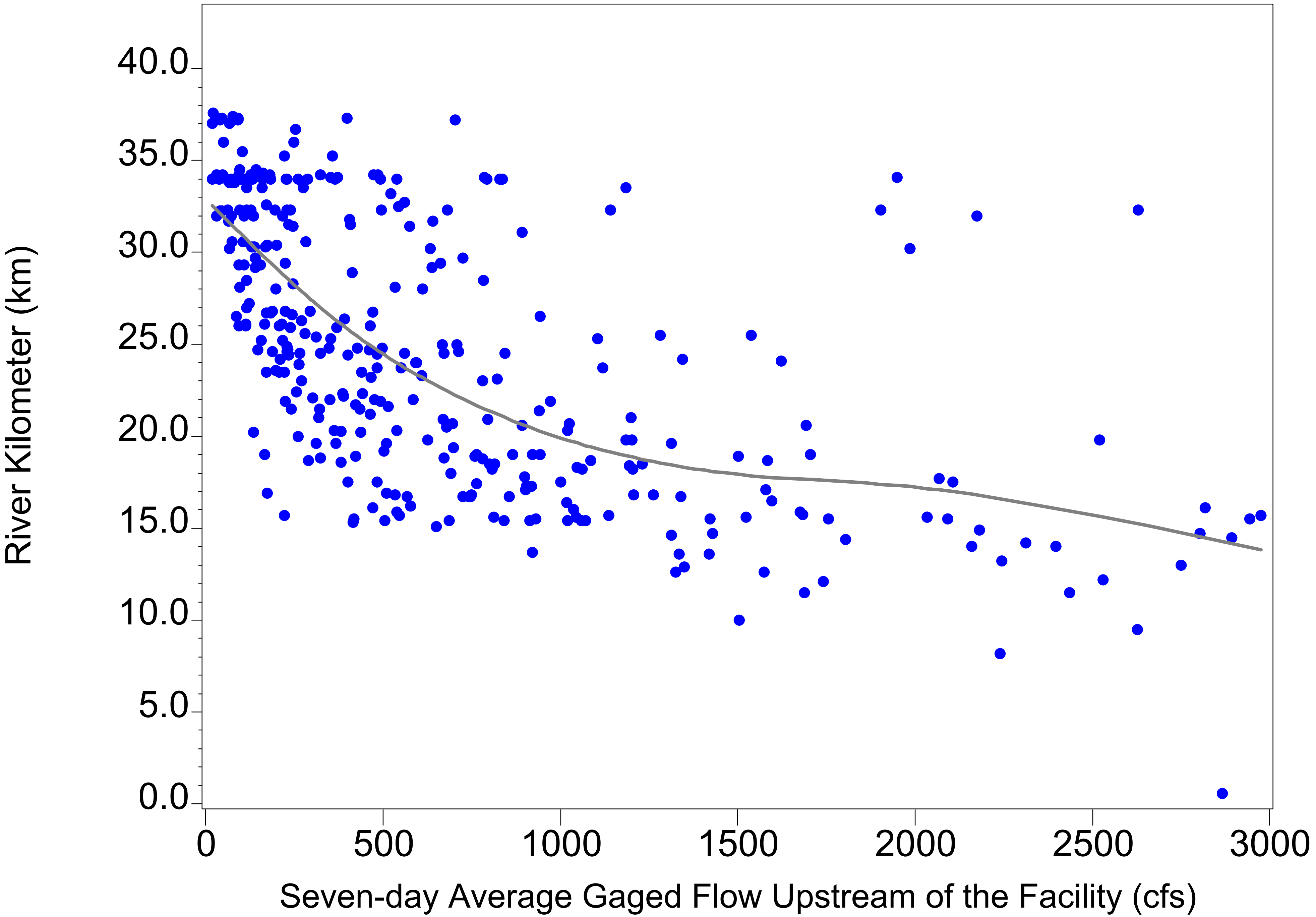


Figure 4.55. Isohaline sampling location versus flow - 0 ppt isohaline

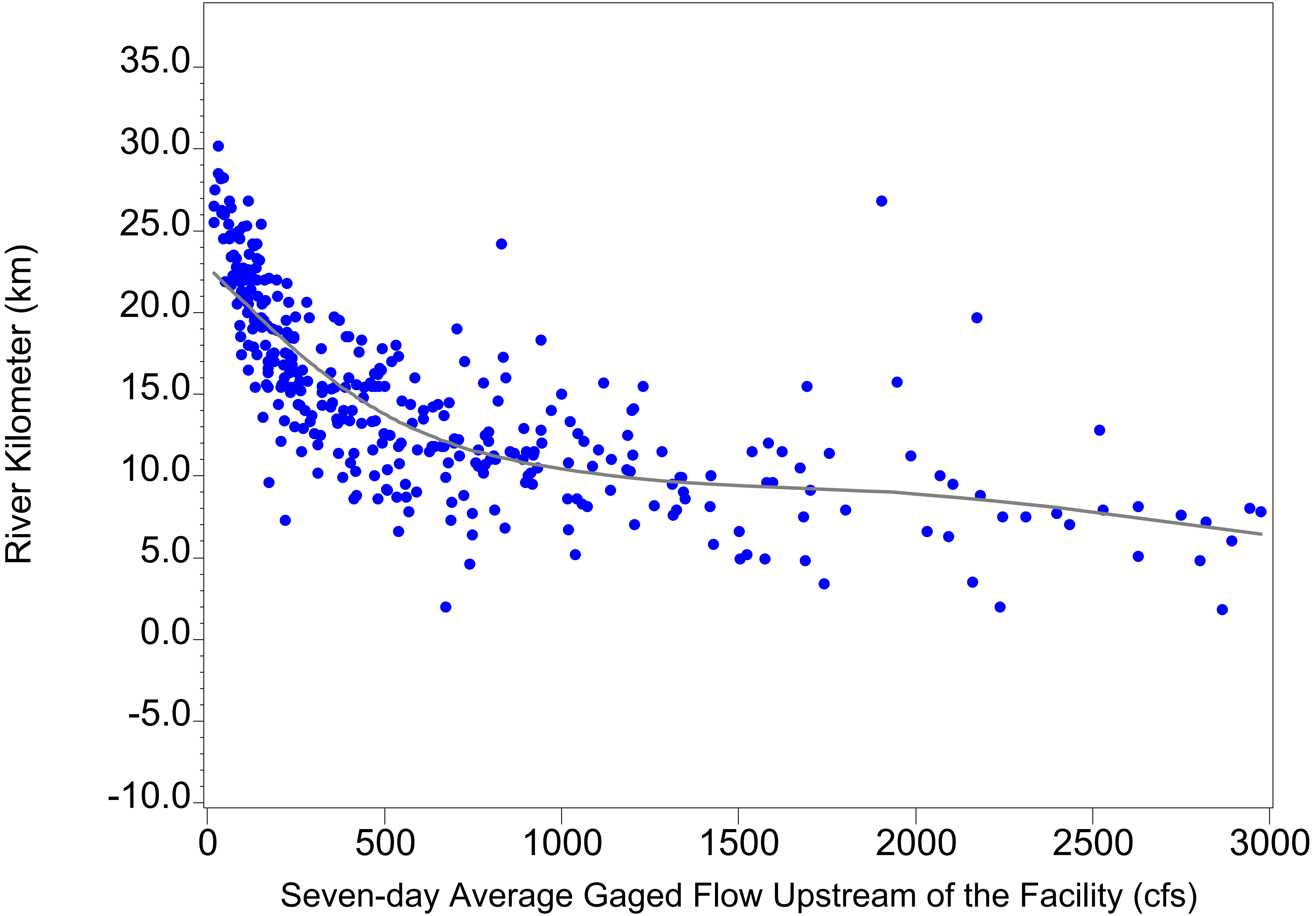


Figure 4.56. Isohaline sampling location versus flow - 6 ppt isohaline

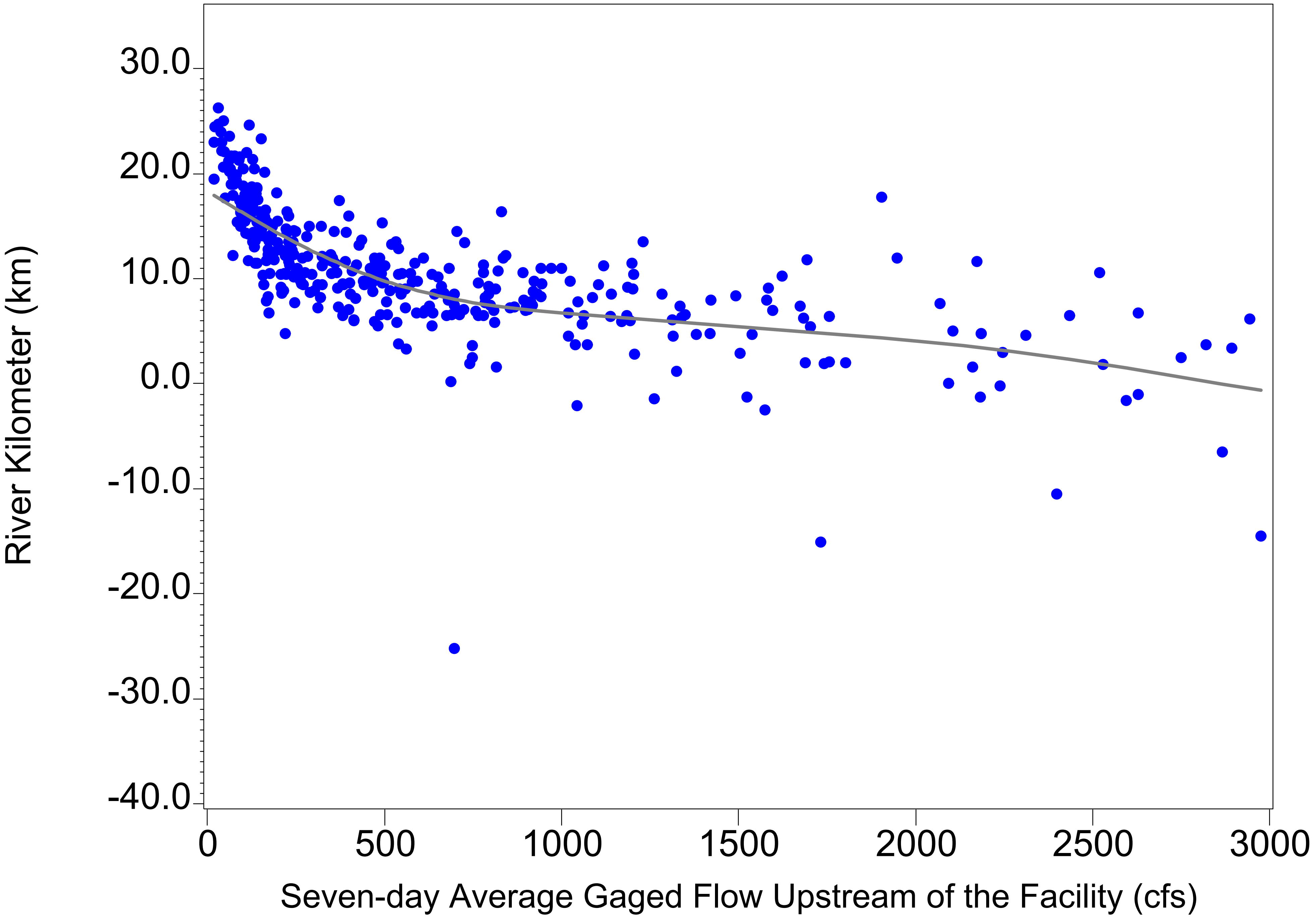


Figure 4.57. Isohaline sampling location versus flow - 12 ppt isohaline

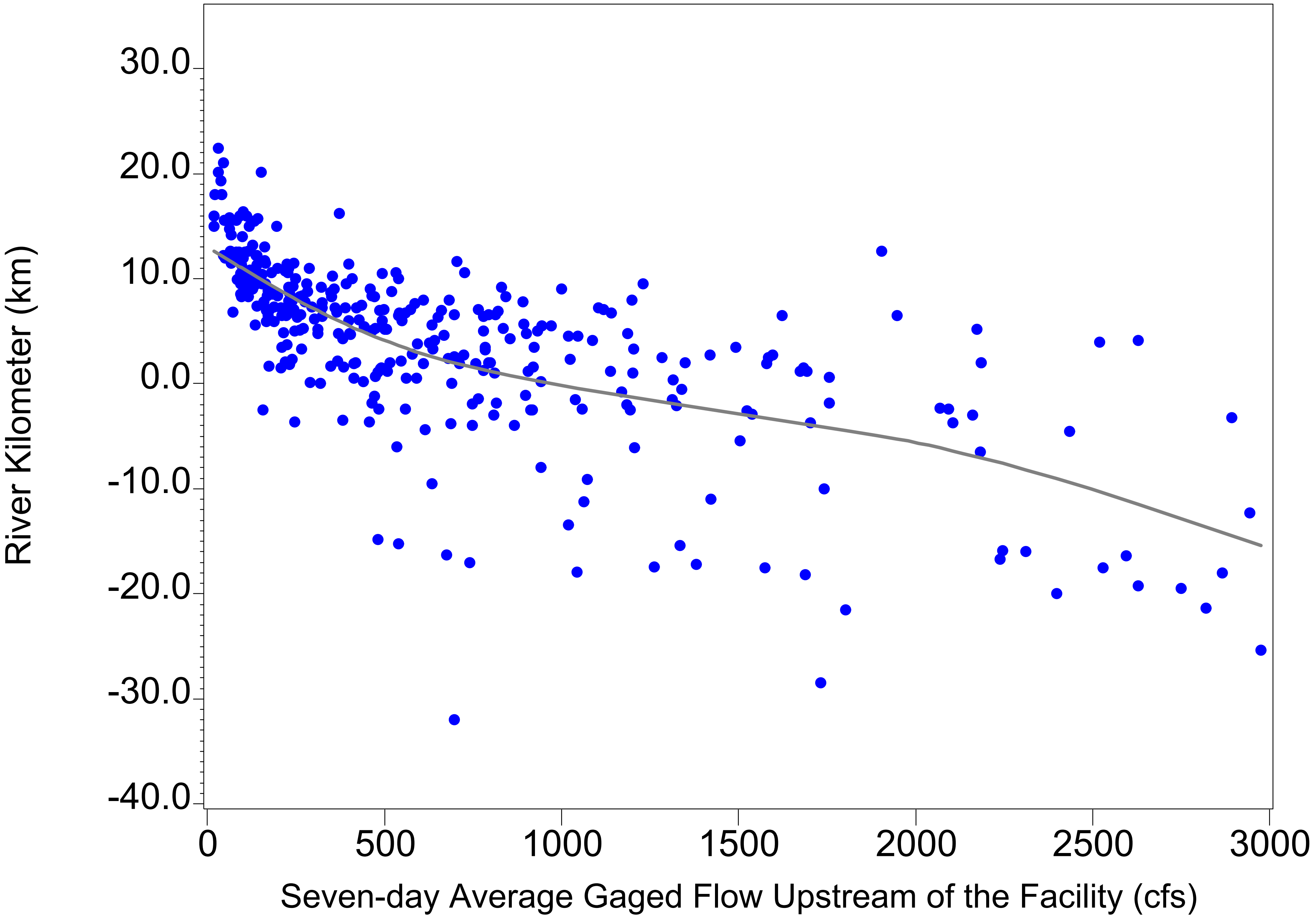


Figure 4.58. Isohaline sampling location versus flow - 20 ppt isohaline

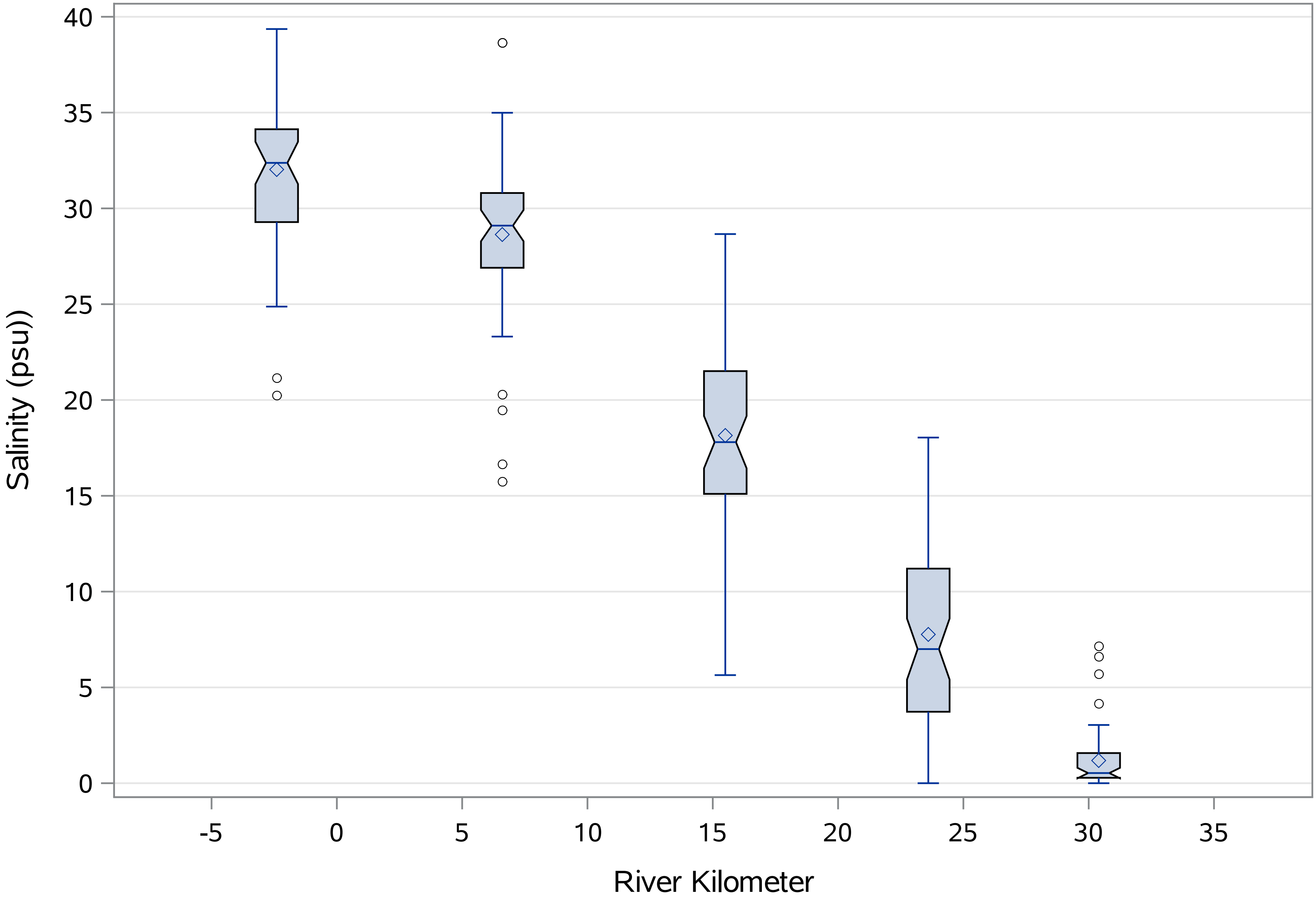


Figure 4.59. Box & whiskers of Surface Salinity by river kilomter (0 to 106 cfs)

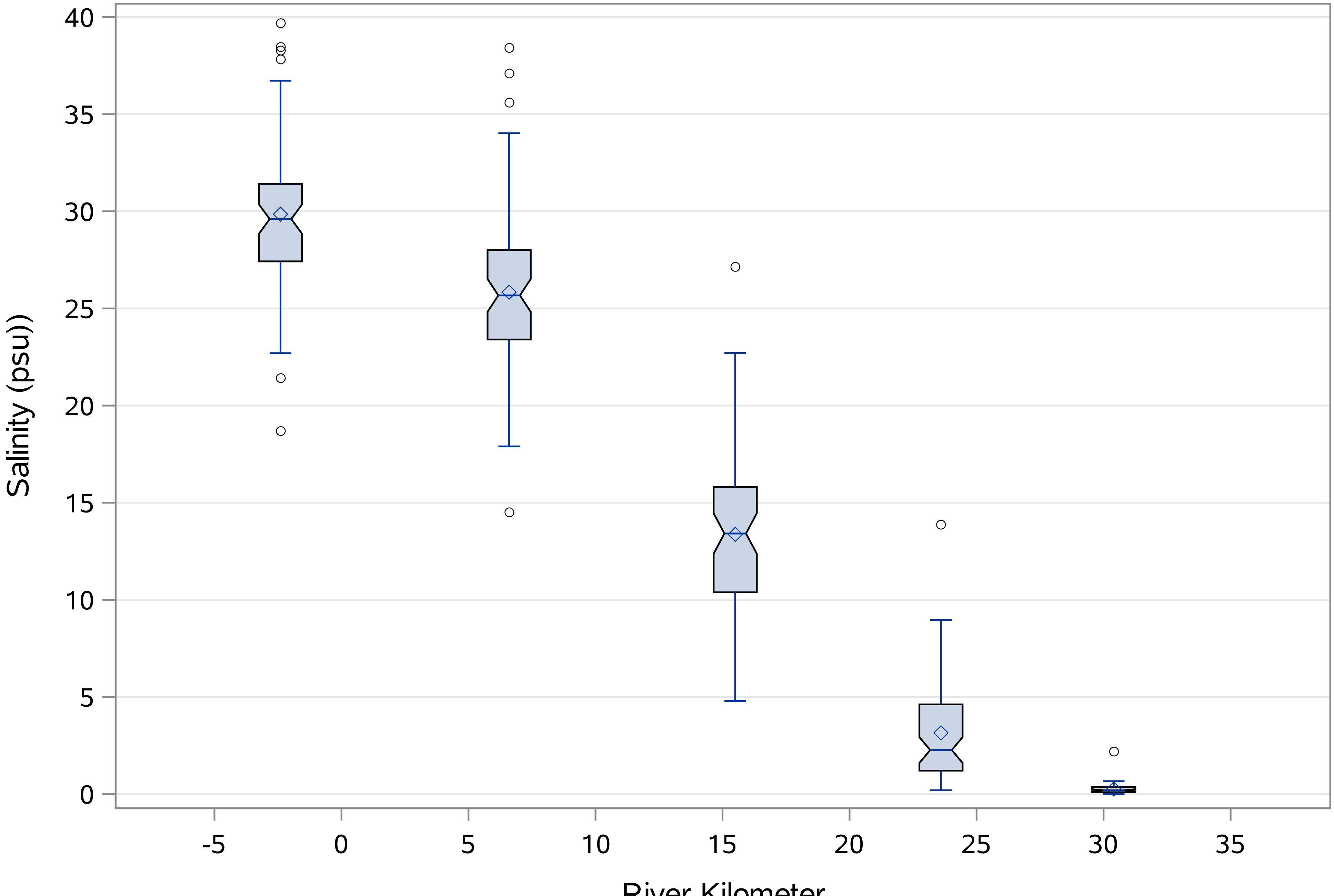


Figure 4.60. Box & whiskers of Surface Salinity by river kilomter (106 to 192 cfs)

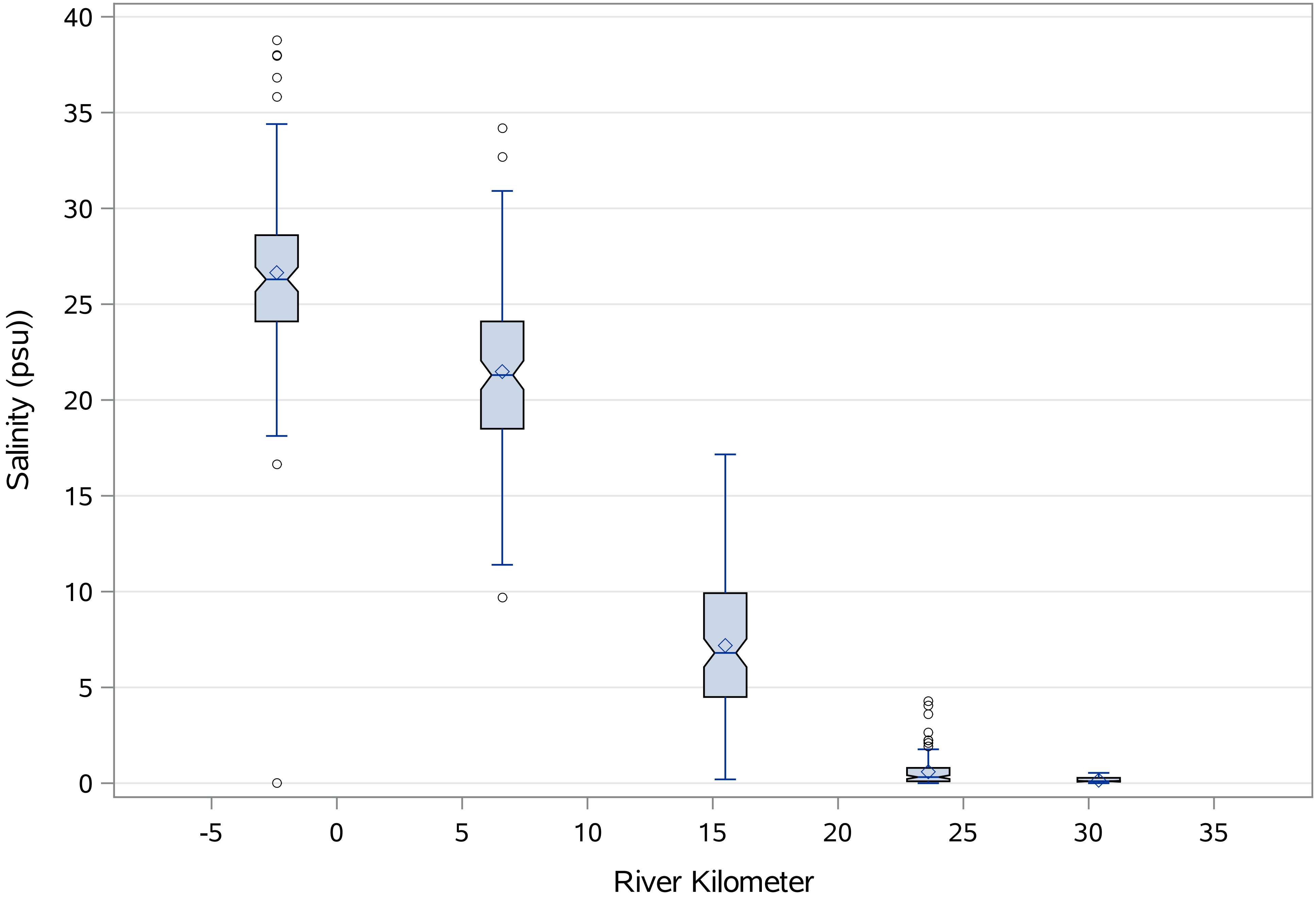


Figure 4.61. Box & whiskers of Surface Salinity by river kilomter (192 to 477 cfs)

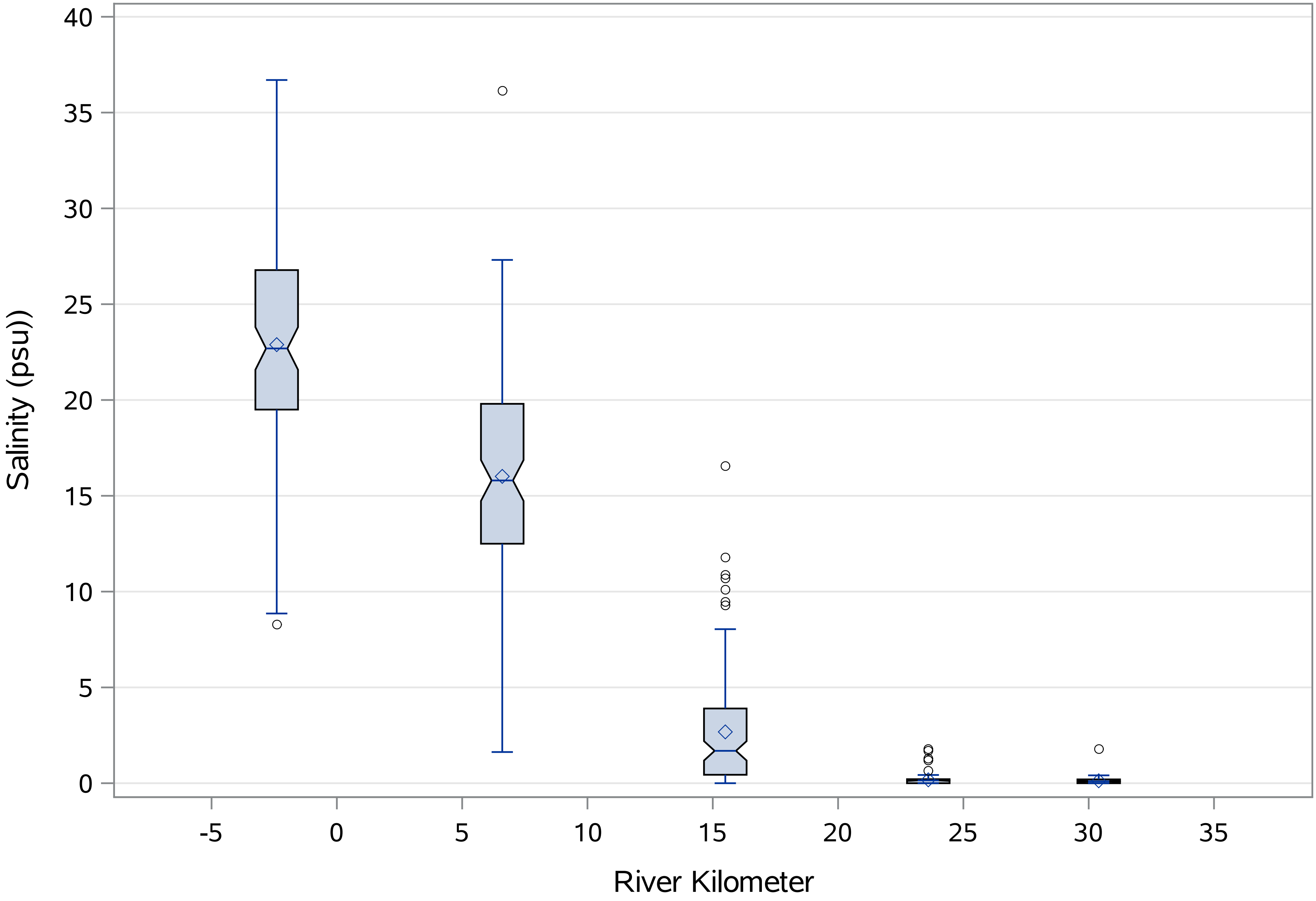


Figure 4.62. Box & whiskers of Surface Salinity by river kilomter (477 to 1259 cfs)

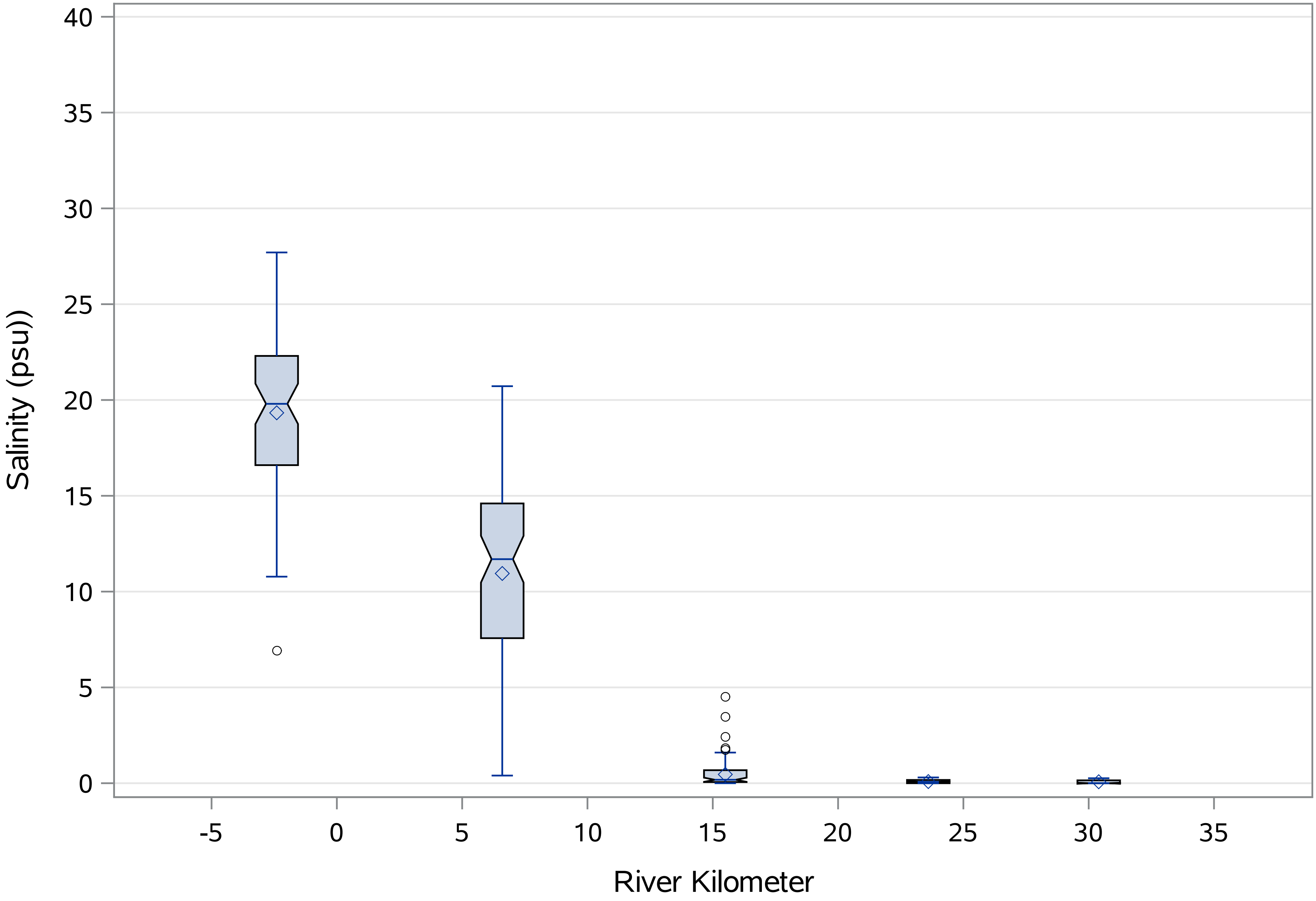


Figure 4.63. Box & whiskers of Surface Salinity by river kilomter (1259 to 3063 cfs)

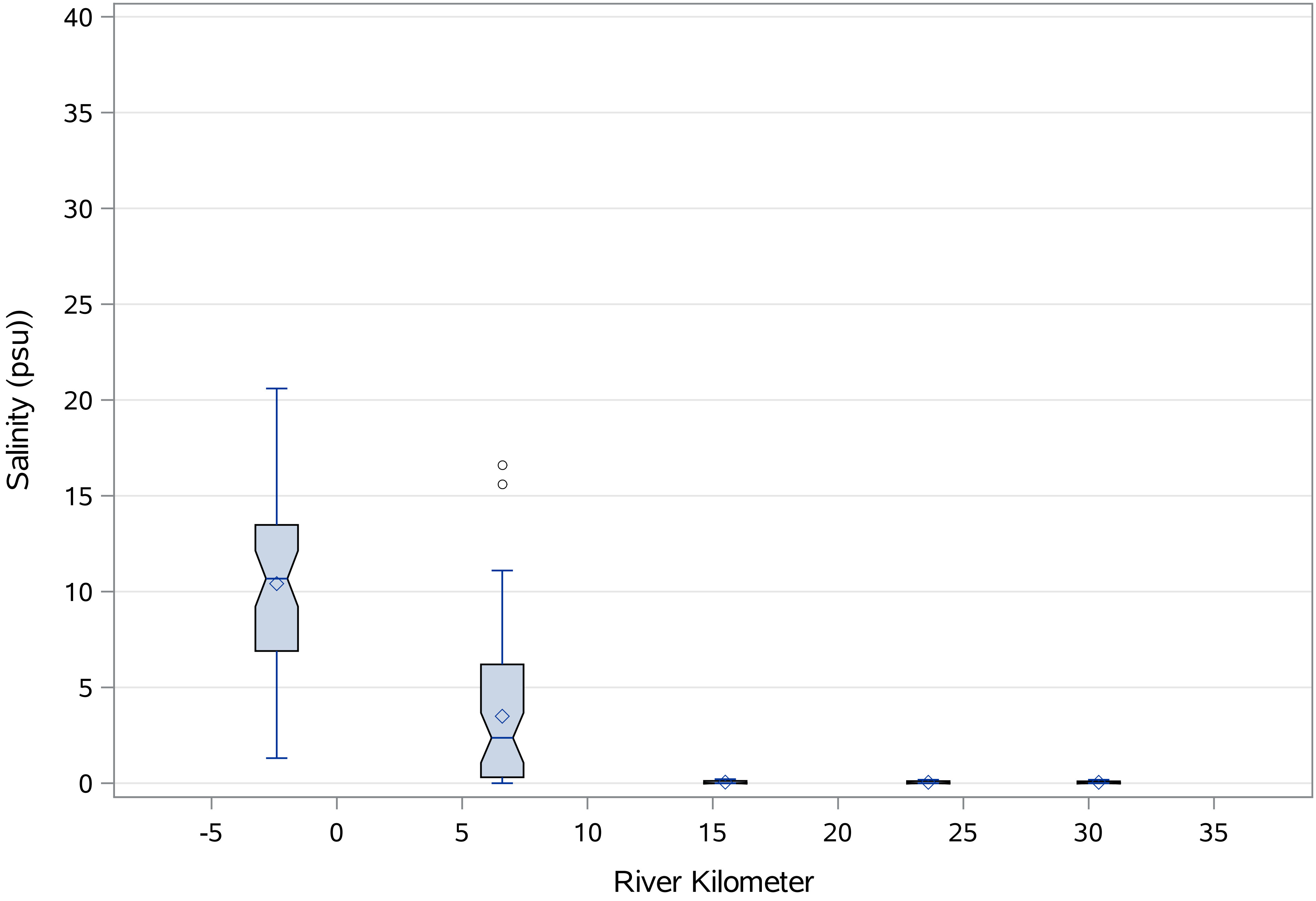


Figure 4.64. Box & whiskers of Surface Salinity by river kilomter (> 3063 cfs)

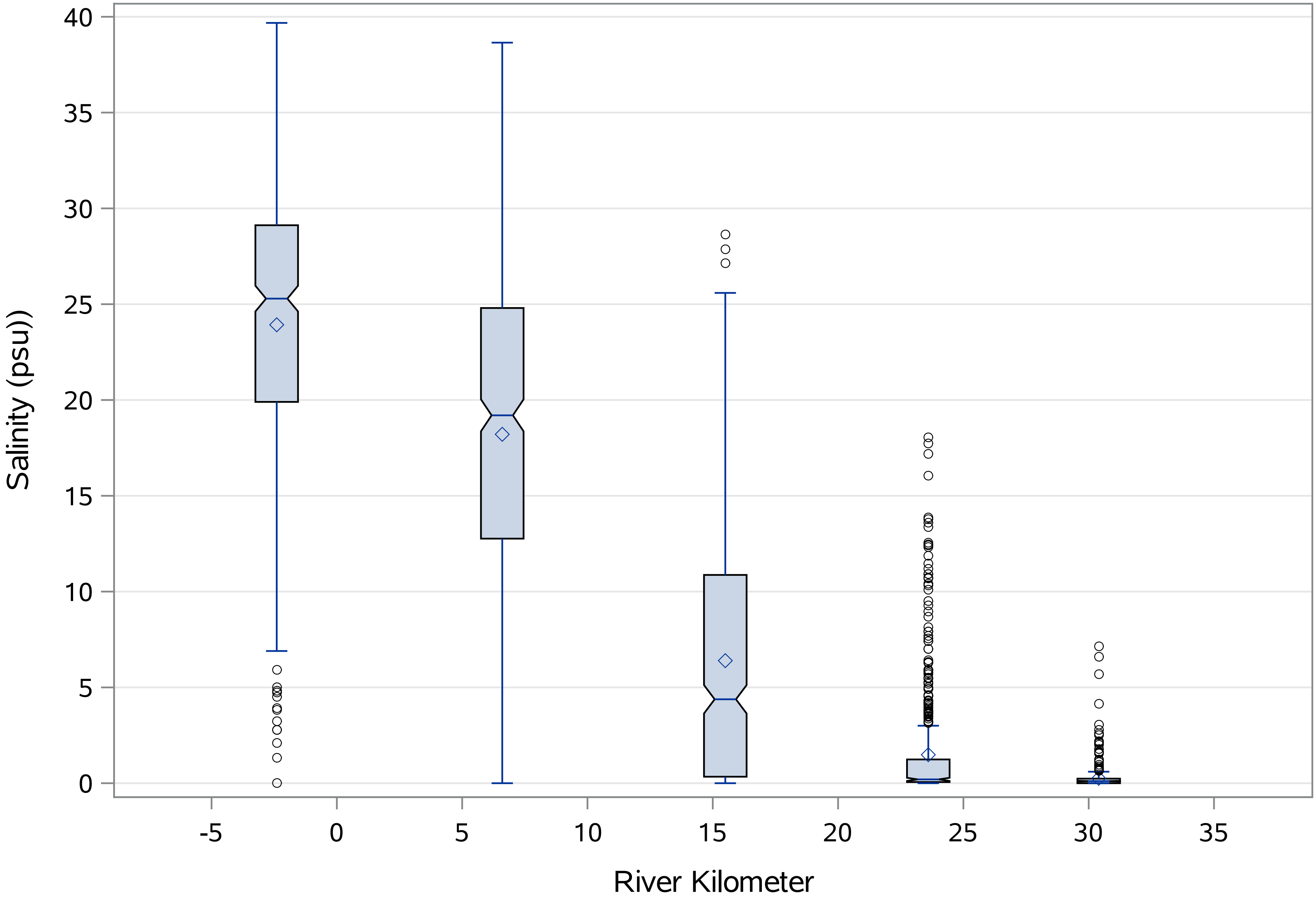


Figure 4.65. Box & whiskers of Surface Salinity by river kilomter (all flows)

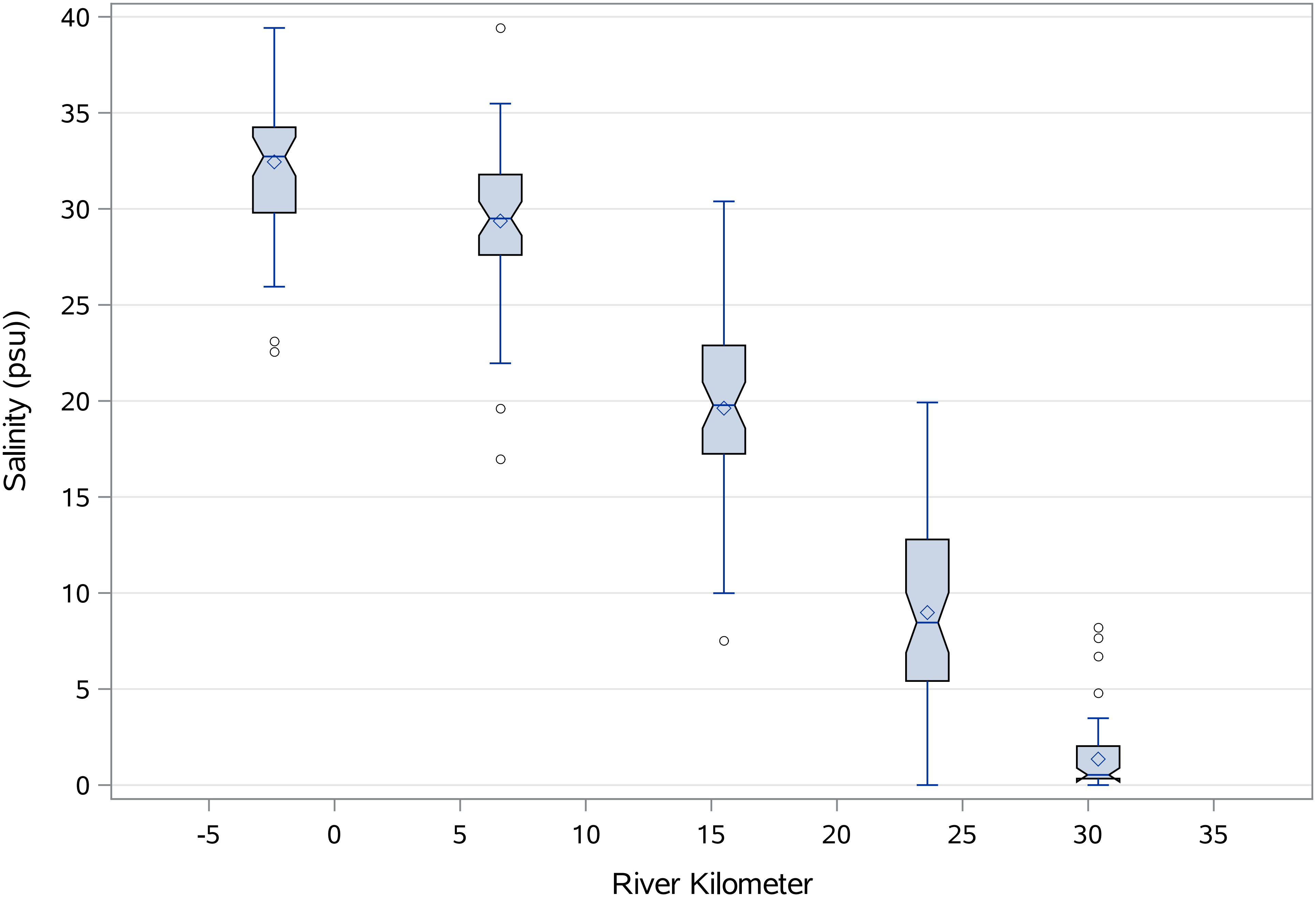


Figure 4.66. Box & whiskers of Bottom Salinity by river kilomter (0 to 106 cfs)

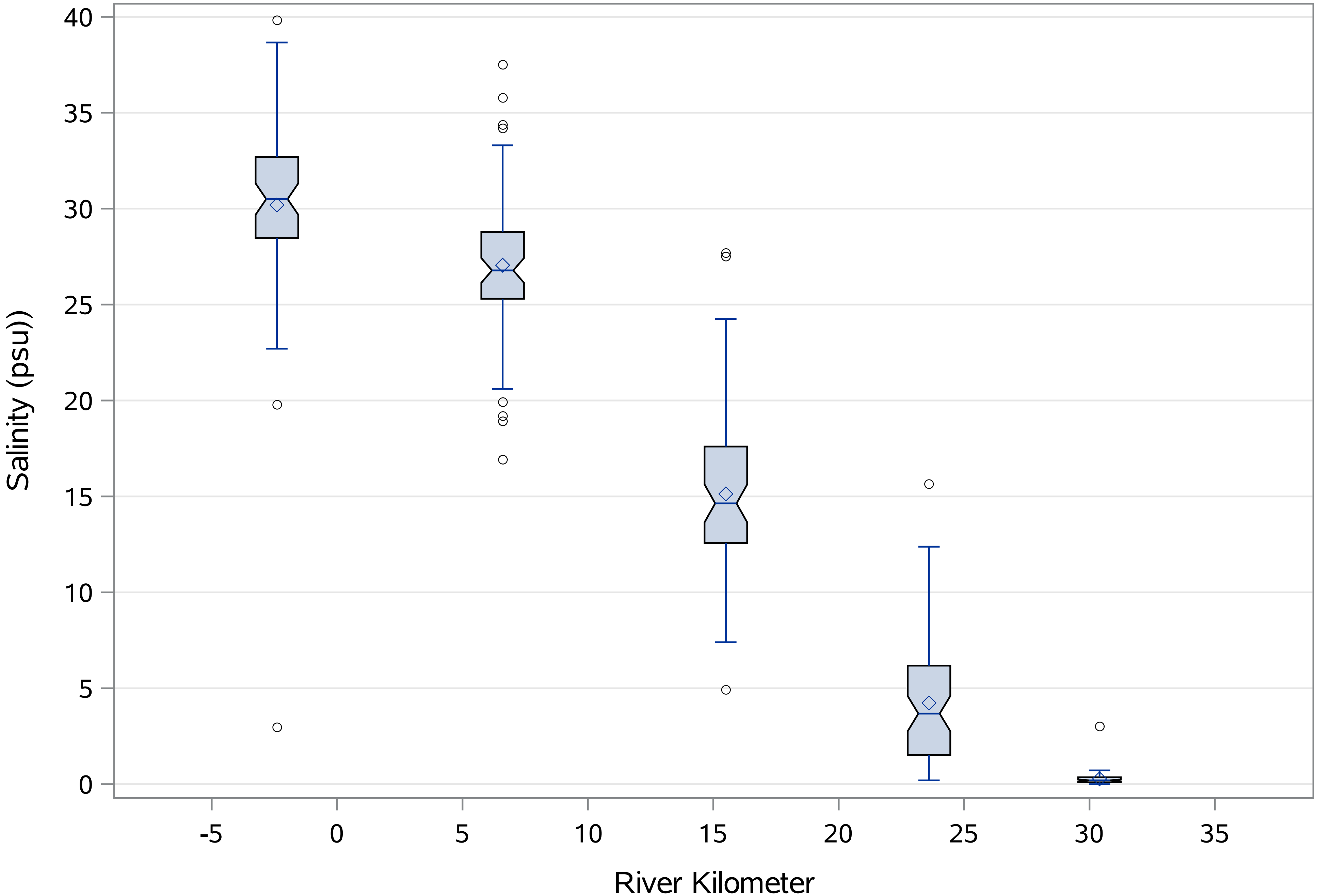


Figure 4.67. Box & whiskers of Bottom Salinity by river kilomter (106 to 192 cfs)

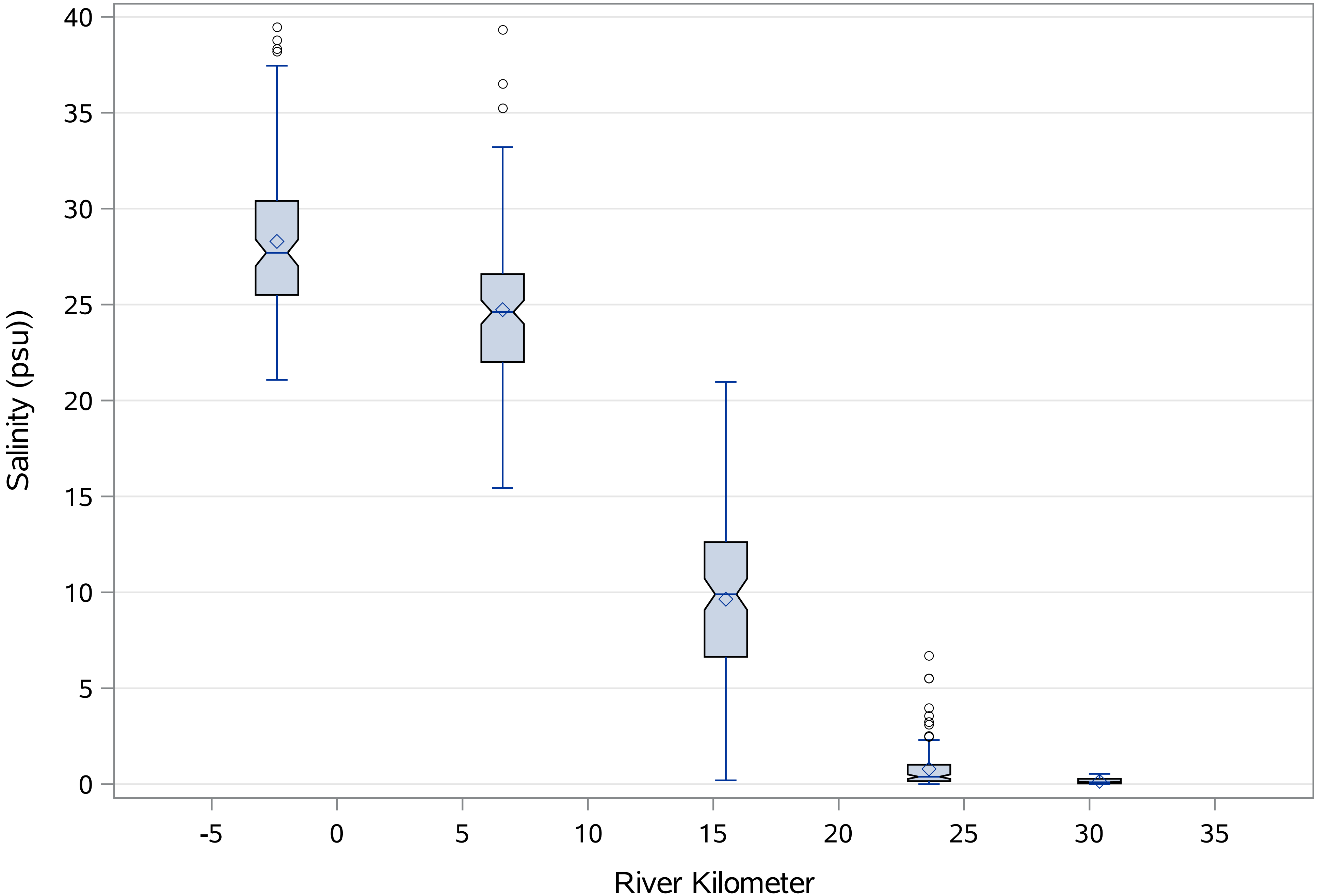


Figure 4.68. Box & whiskers of Bottom Salinity by river kilomter (192 to 477 cfs)

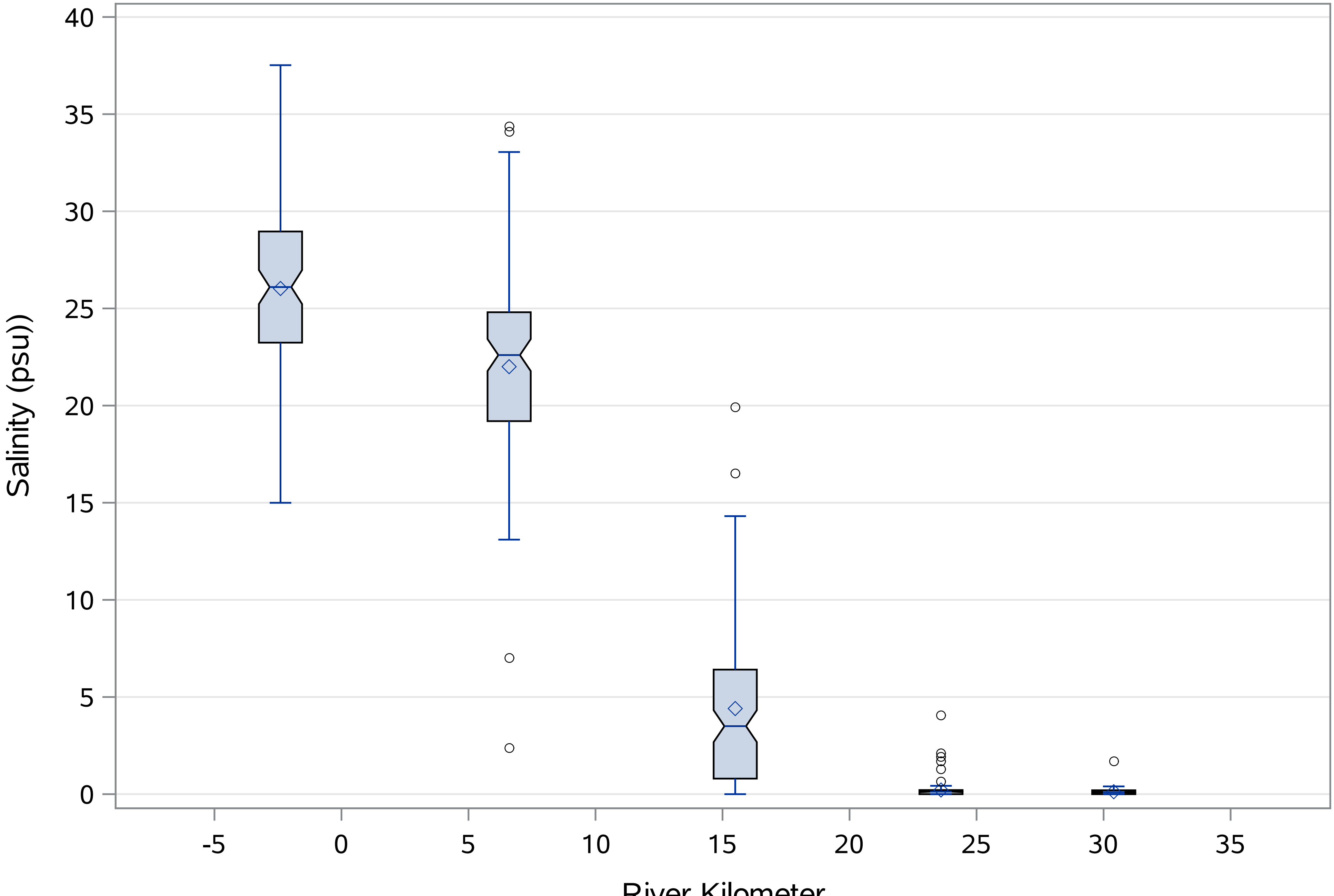


Figure 4.69. Box & whiskers of Bottom Salinity by river kilomter (477 to 1259 cfs)

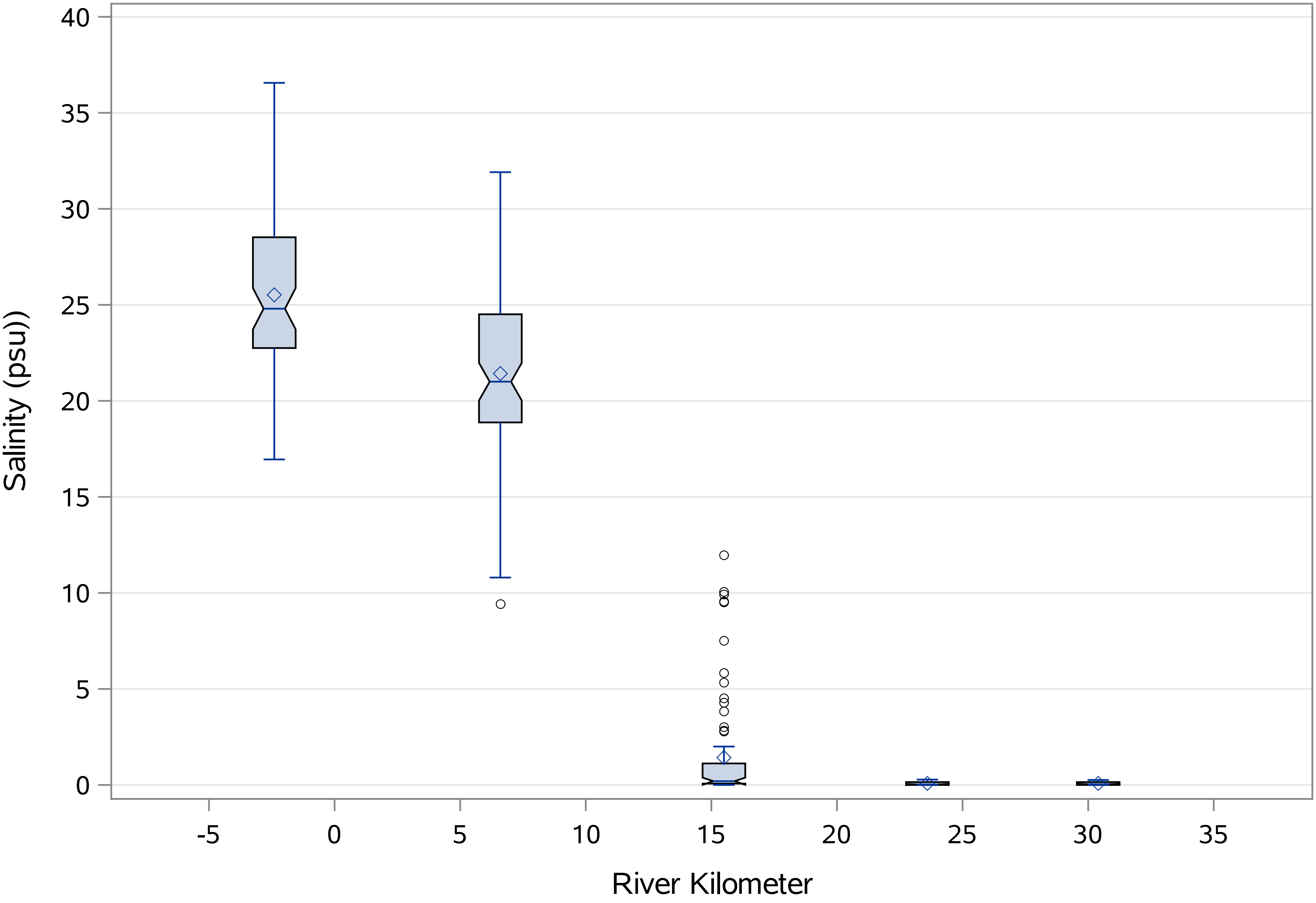


Figure 4.70. Box & whiskers of Bottom Salinity by river kilomter (1259 to 3063 cfs)

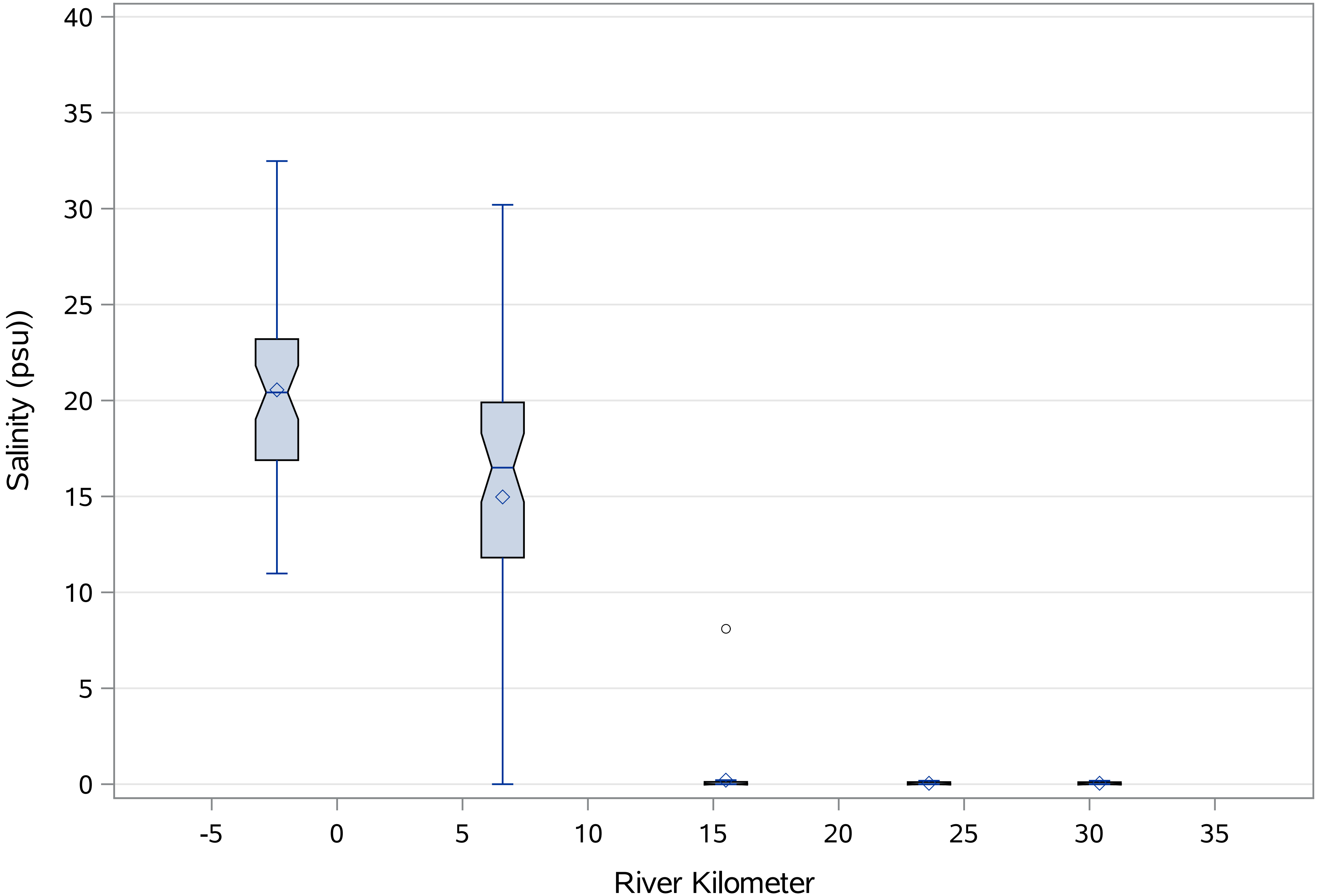


Figure 4.71. Box & whiskers of Bottom Salinity by river kilomter (> 3063 cfs)

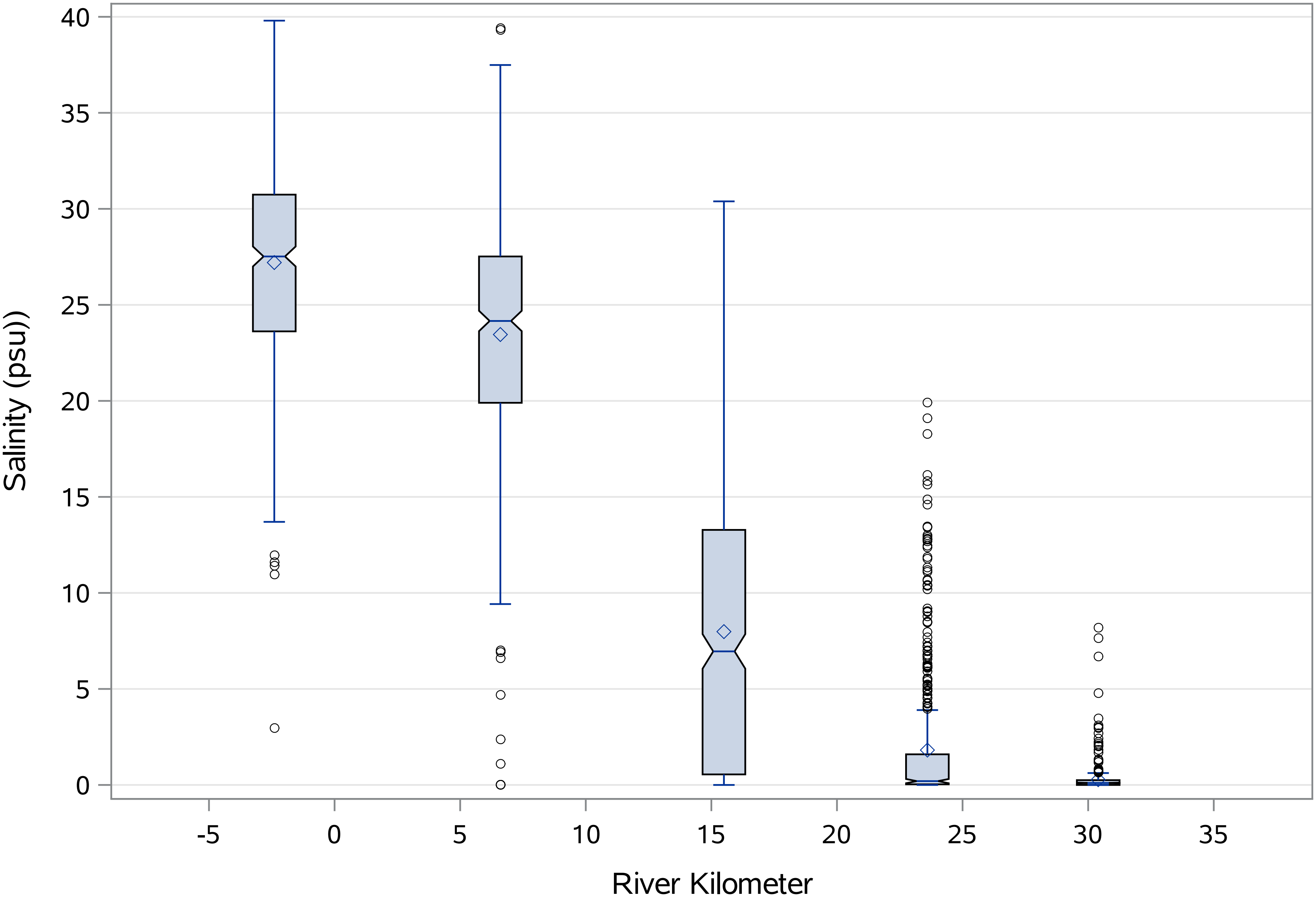


Figure 4.72. Box & whiskers of Bottom Salinity by river kilomter (all flows)

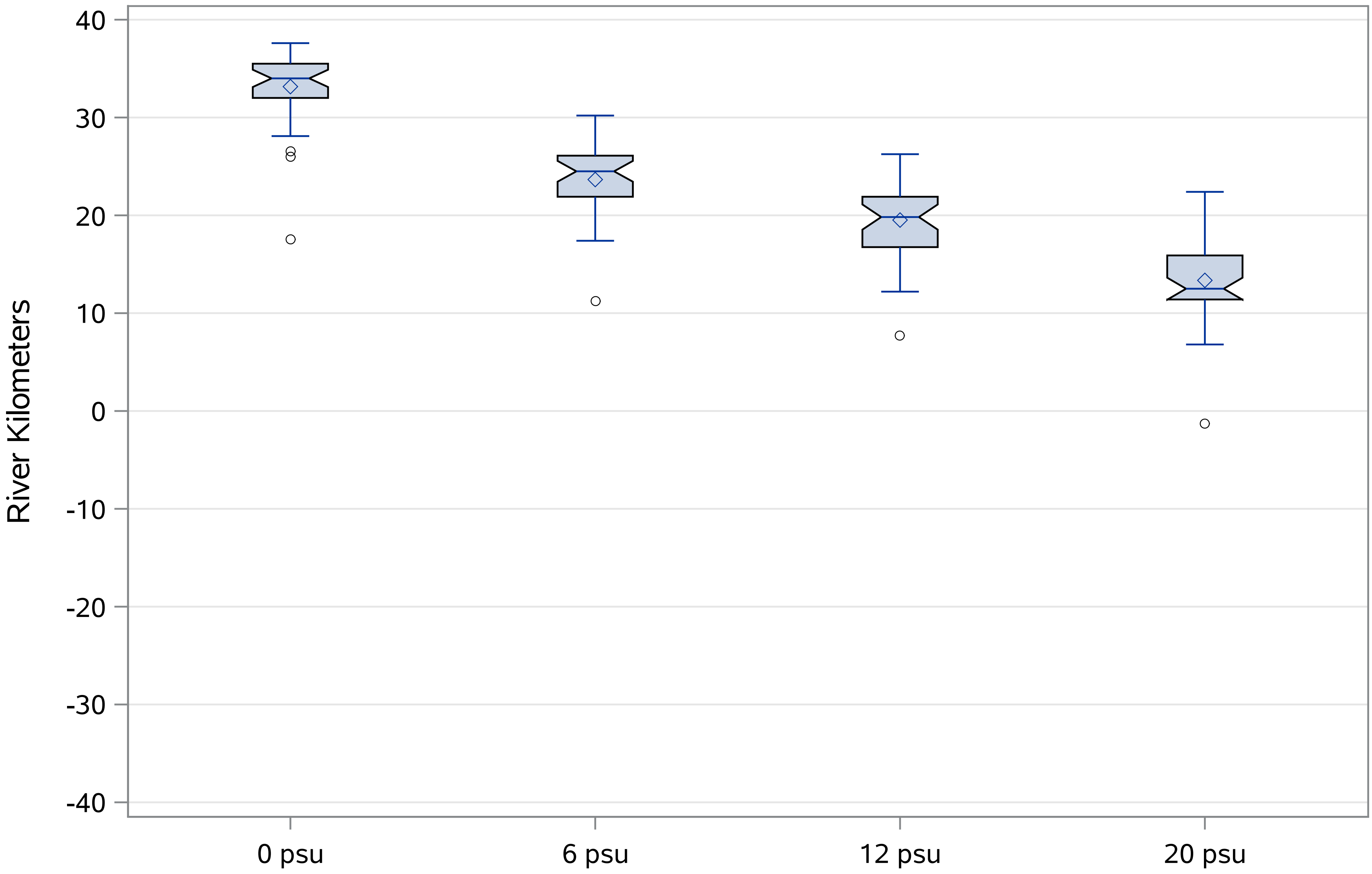


Figure 4.73 Box & whiskers of isohaline sampling location (0 to 106 cfs)

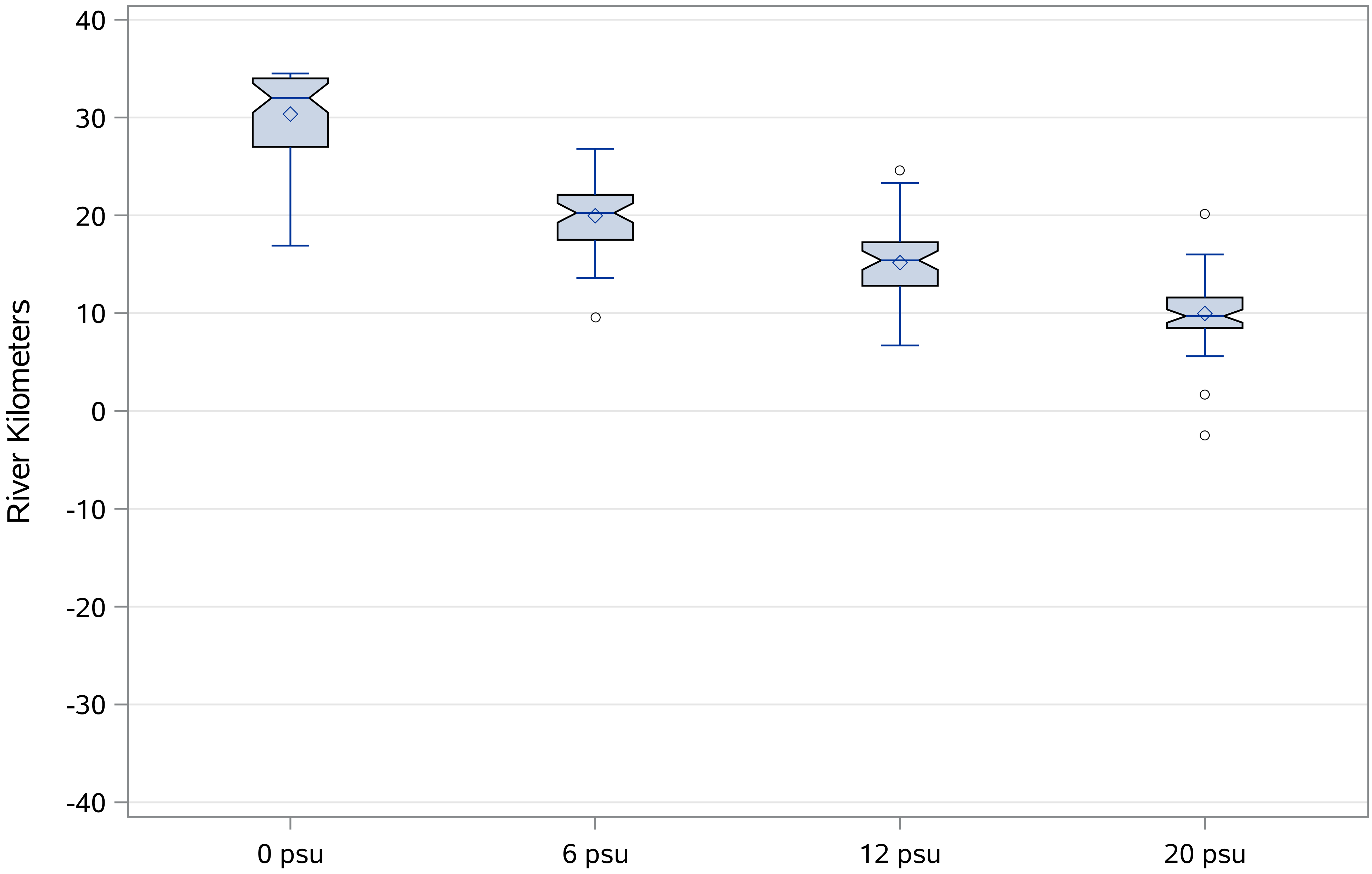


Figure 4.74 Box & whiskers of isohaline sampling location (106 to 192 cfs)

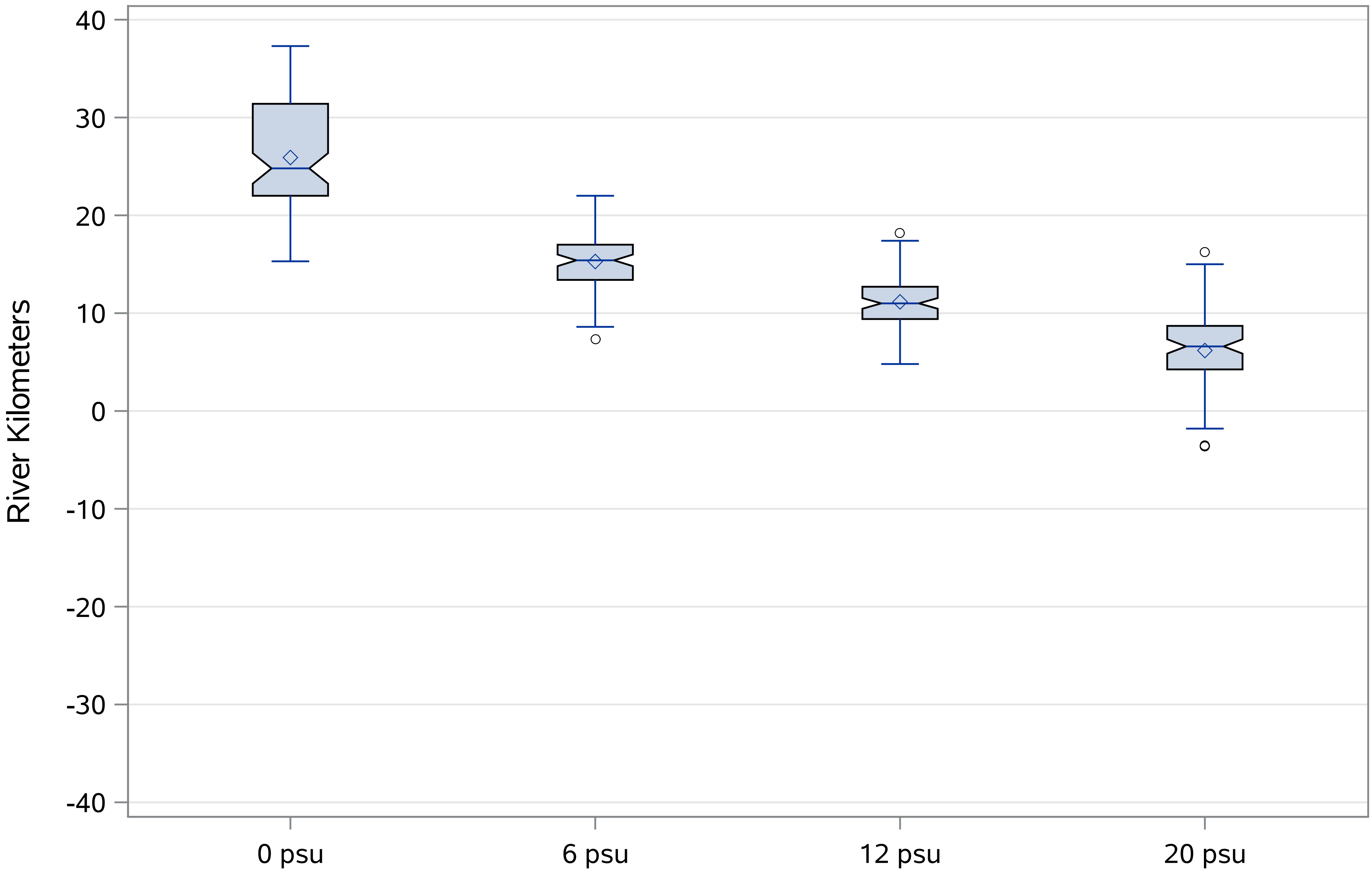


Figure 4.75 Box & whiskers of isohaline sampling location (92 to 477 cfs)

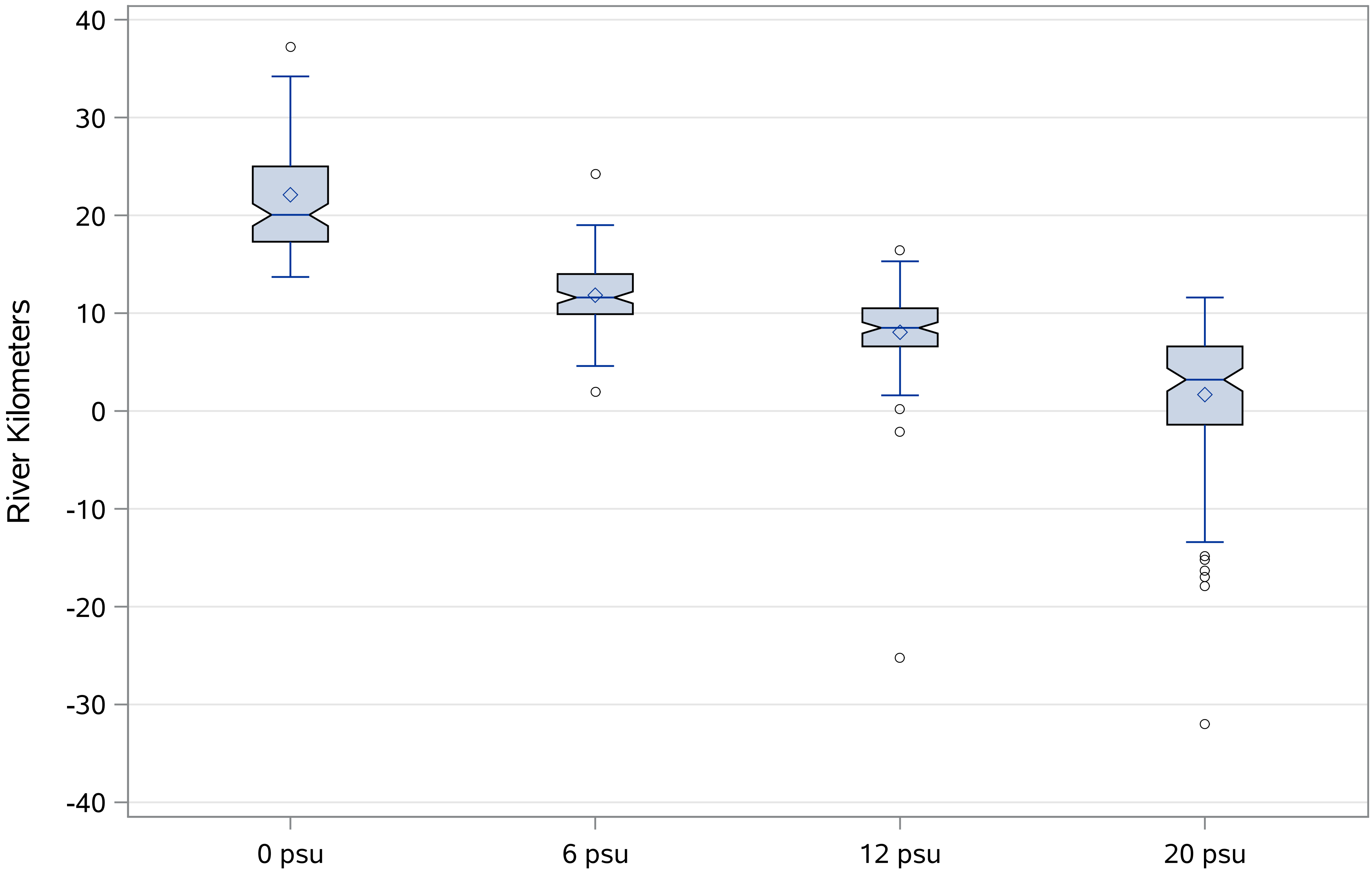


Figure 4.76 Box & whiskers of isohaline sampling location (477 to 1259 cfs)

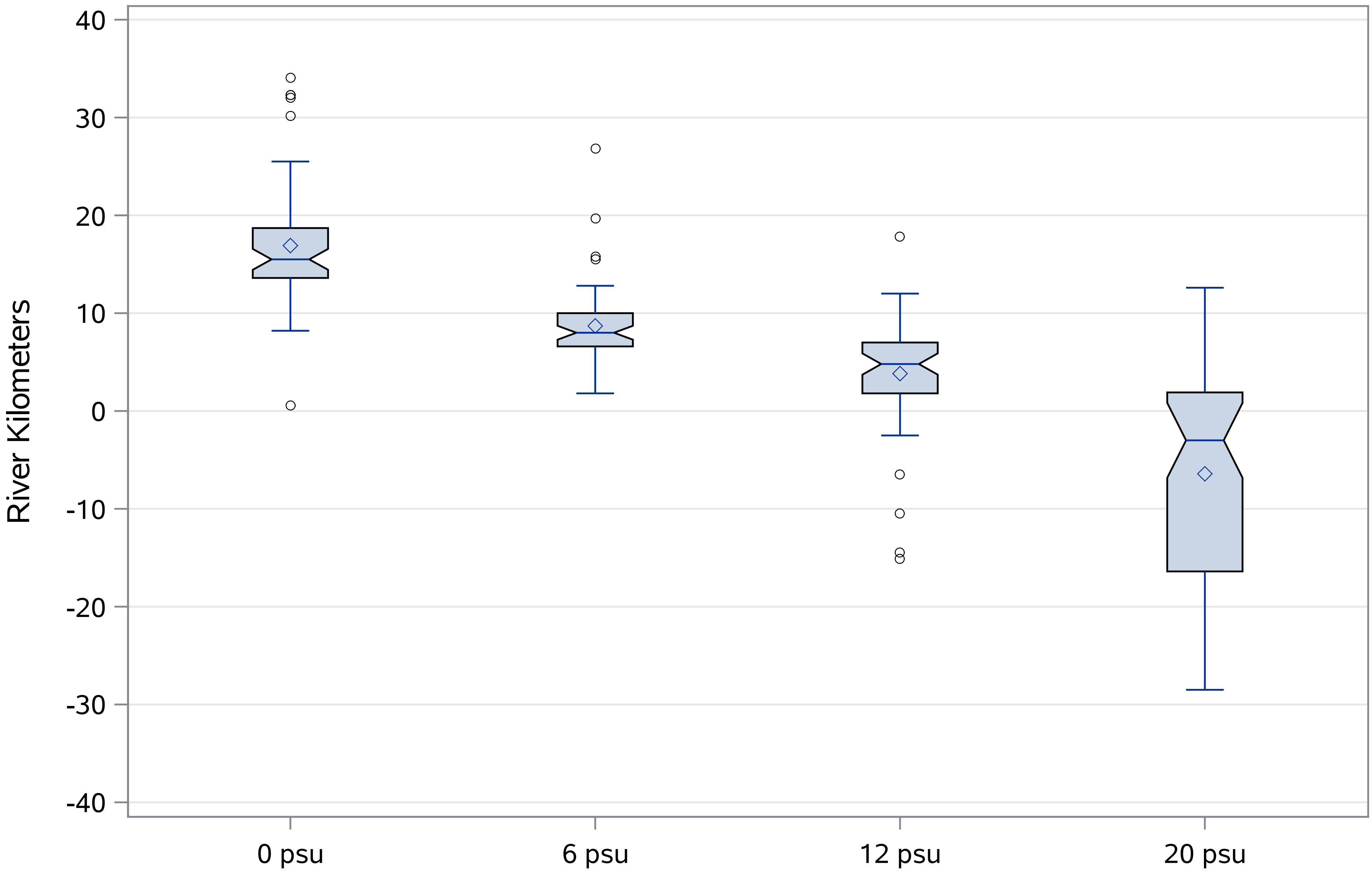


Figure 4.77 Box & whiskers of isohaline sampling location (1259 to 3063 cfs)

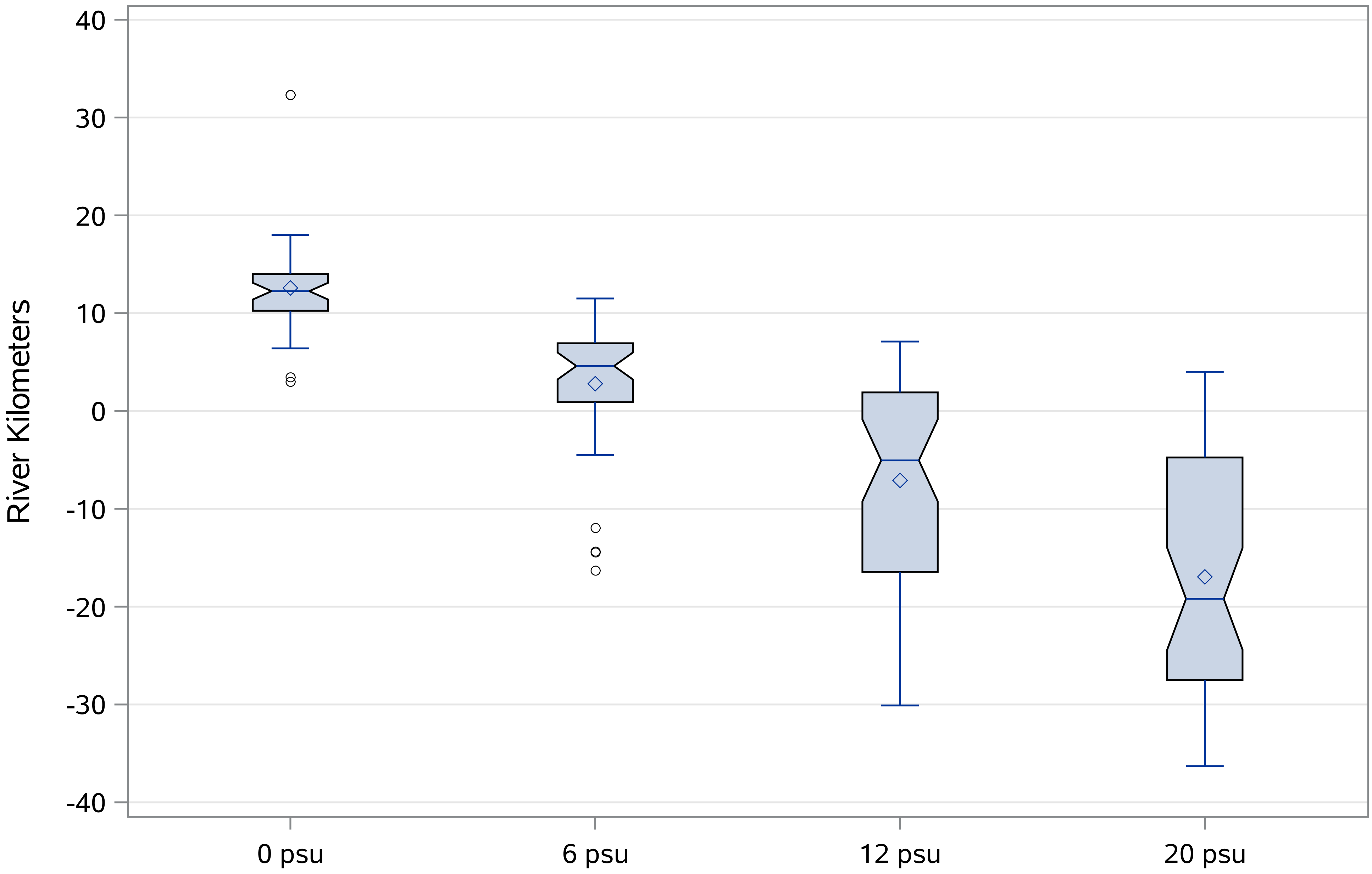


Figure 4.78 Box & whiskers of isohaline sampling location (> 3063 cfs)

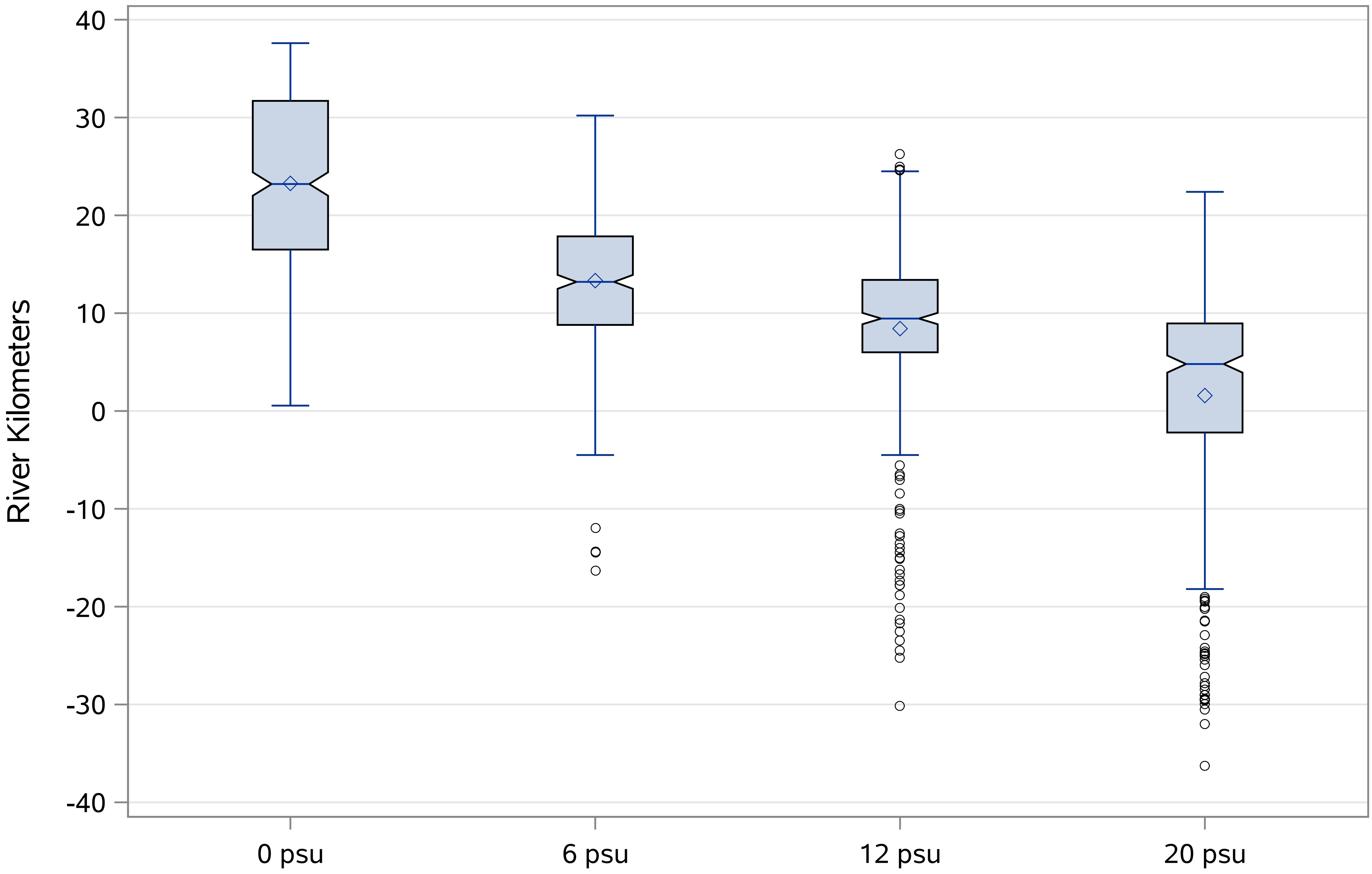


Figure 4.79 Box & whiskers of isohaline sampling location (all flows)

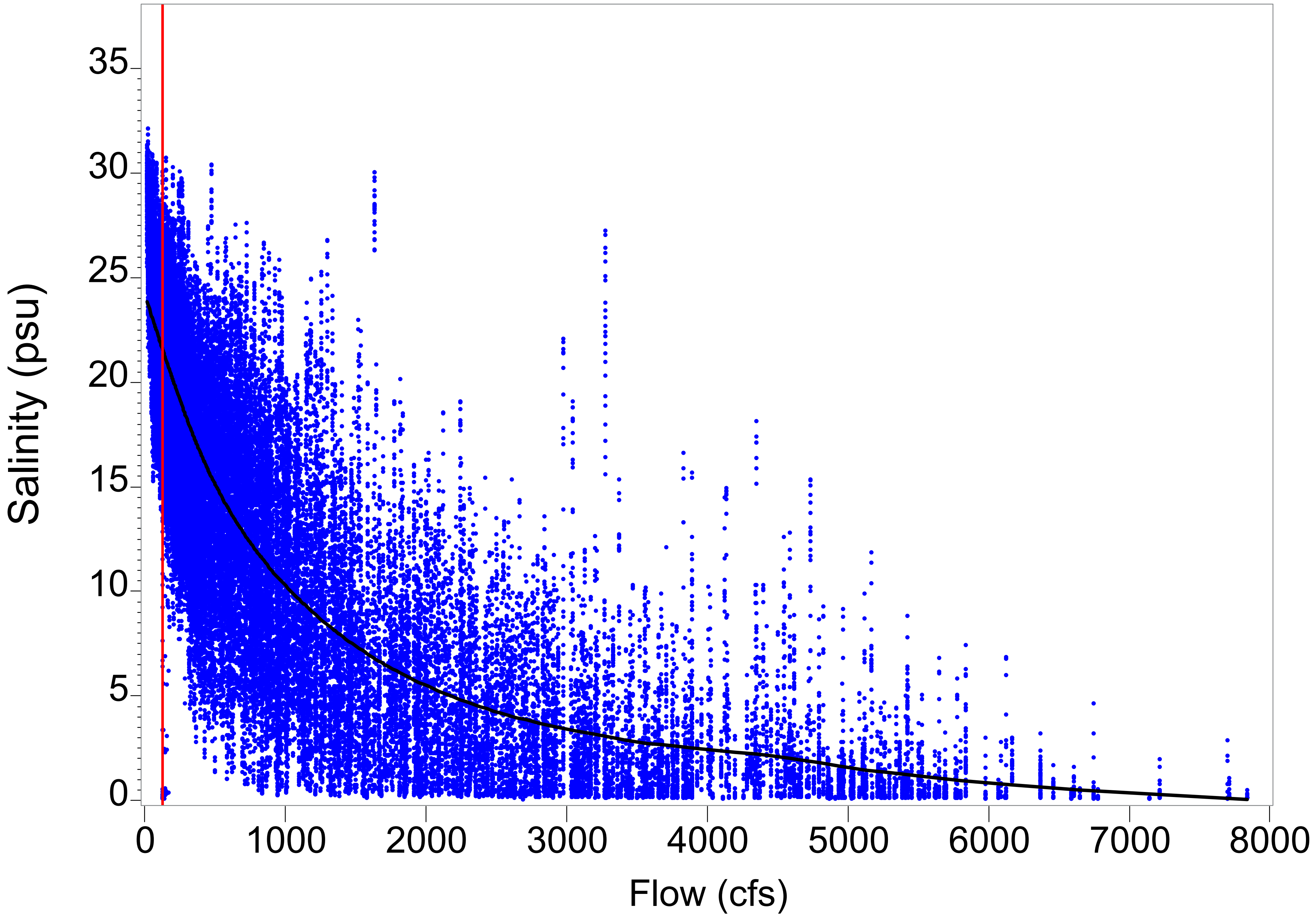


Figure 4.80. Recorder surface salinity at river kilometer 9.2 versus withdrawal corrected upstream gaged flow

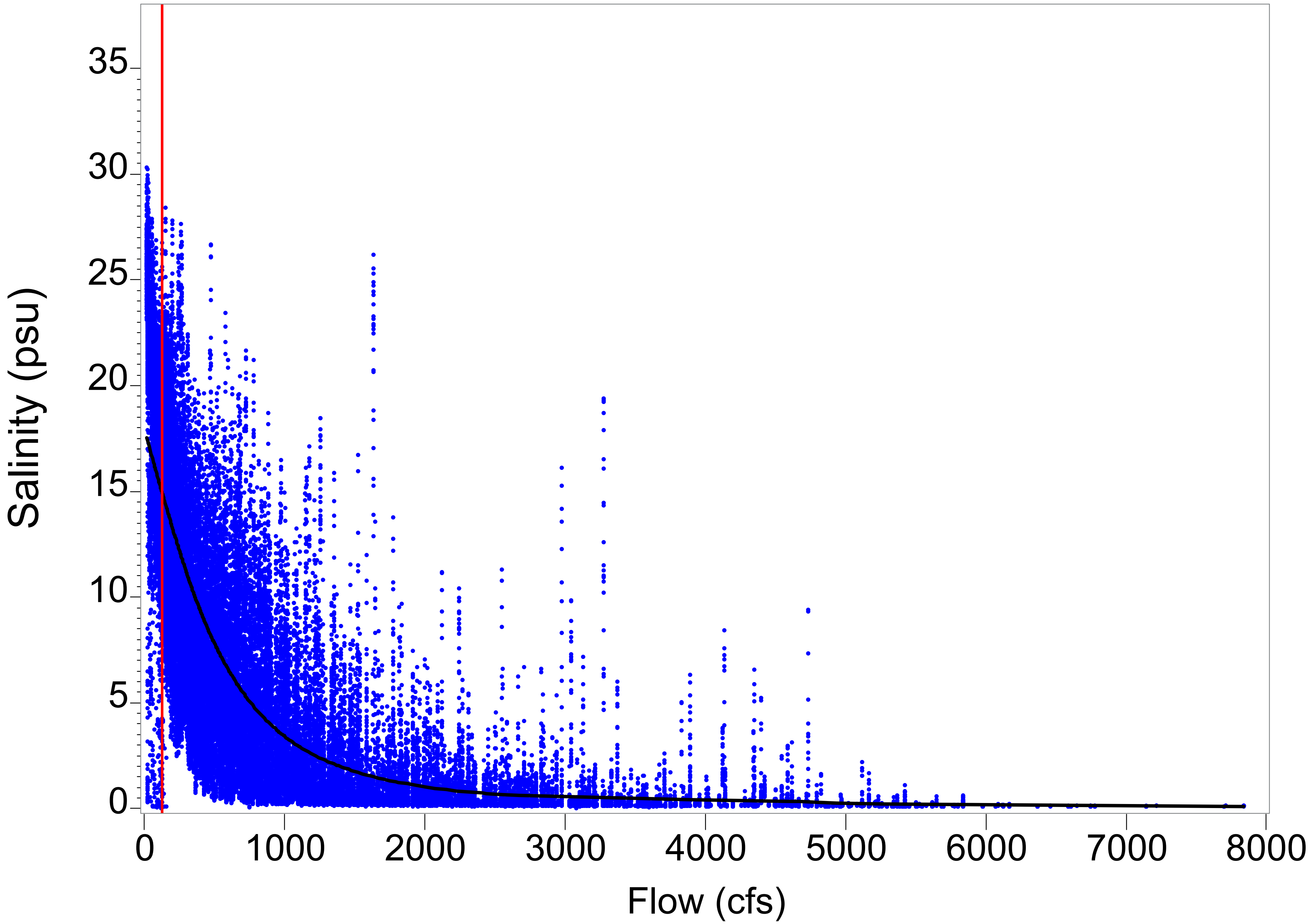


Figure 4.81. Recorder surface salinity at river kilometer 12.7 versus withdrawal corrected upstream gaged flow

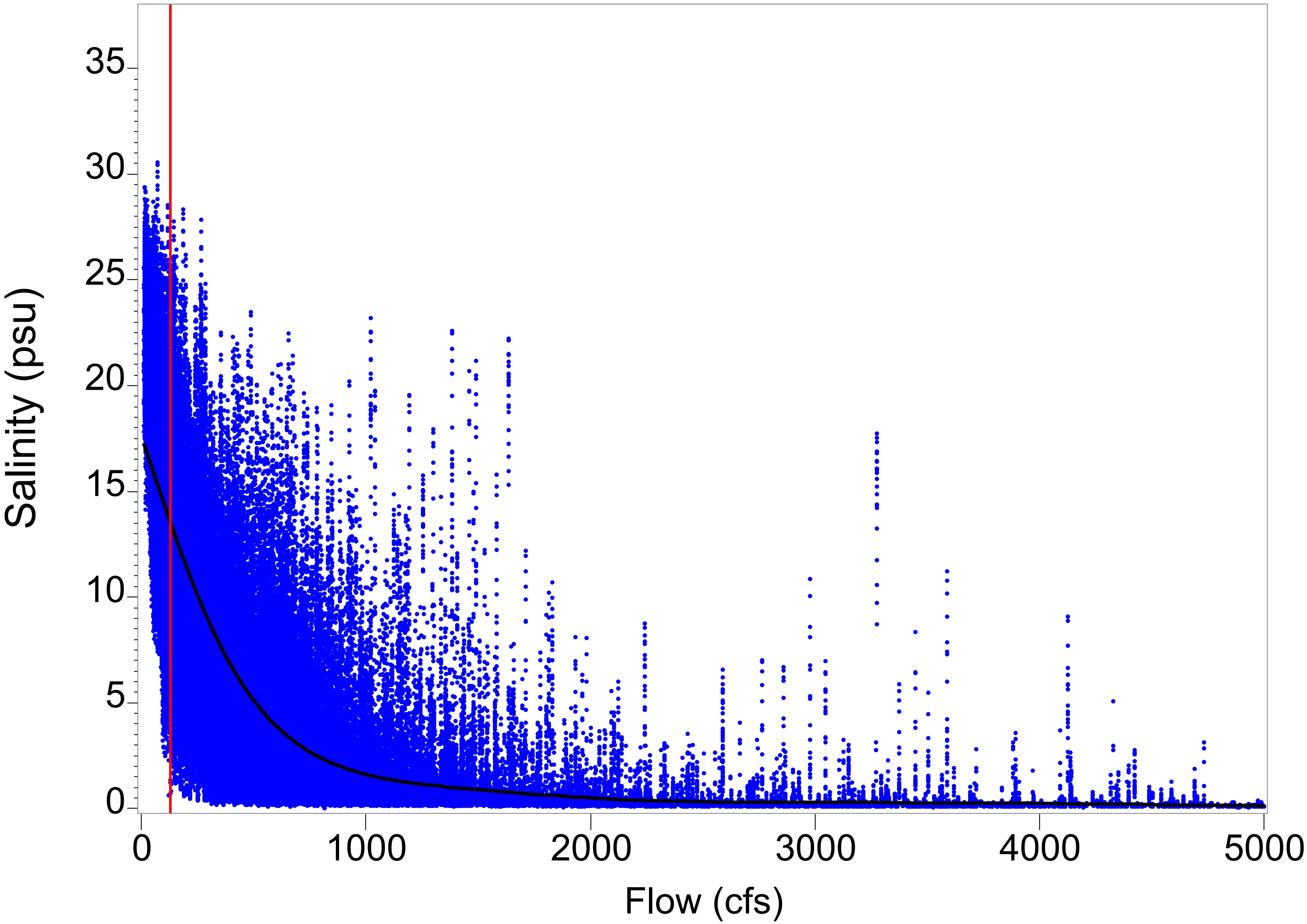


Figure 4.82. Recorder surface salinity at river kilometer 15.5 versus withdrawal corrected upstream gaged flow

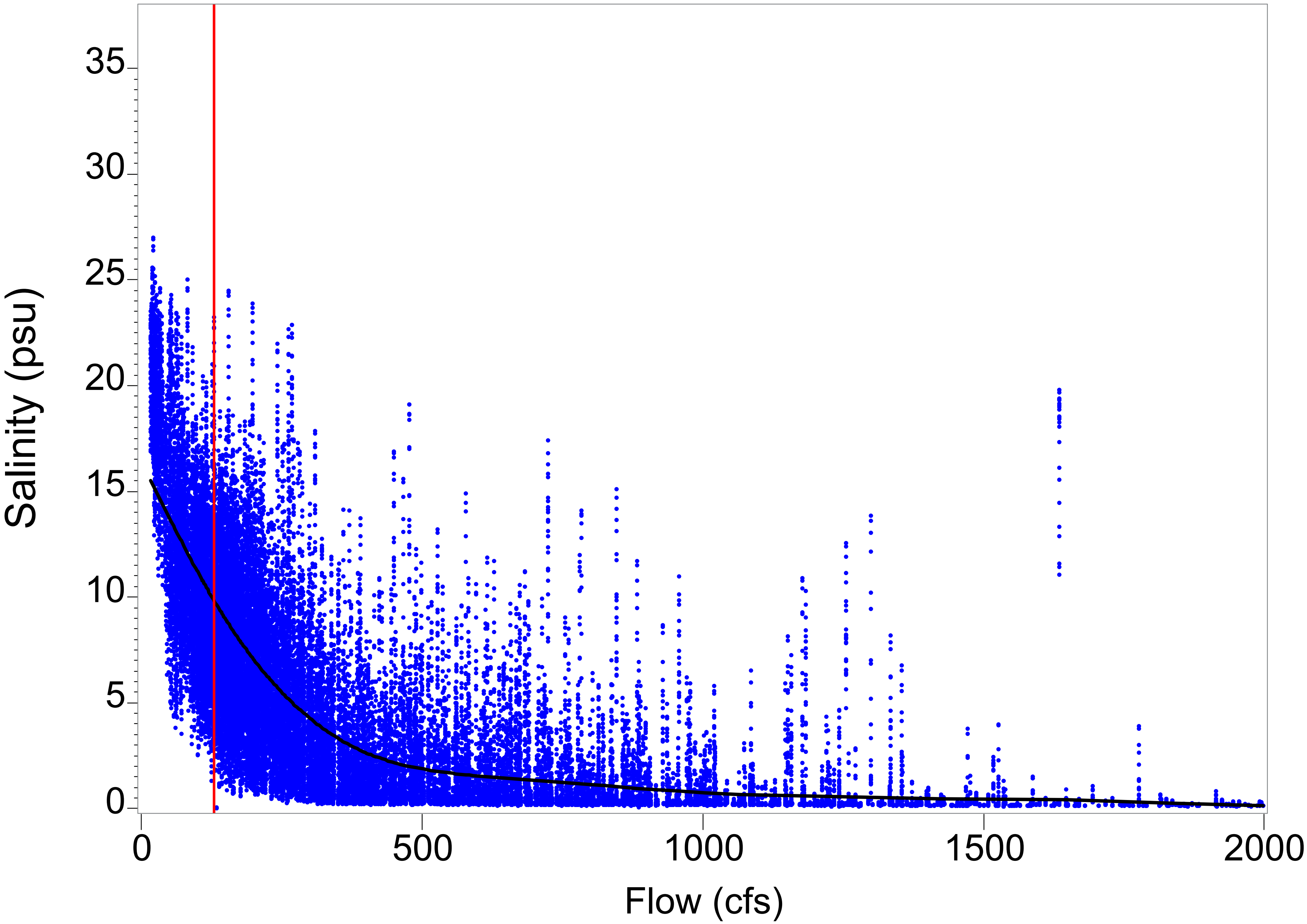


Figure 4.83. Recorder surface salinity at river kilometer 18.5 versus withdrawal corrected upstream gaged flow

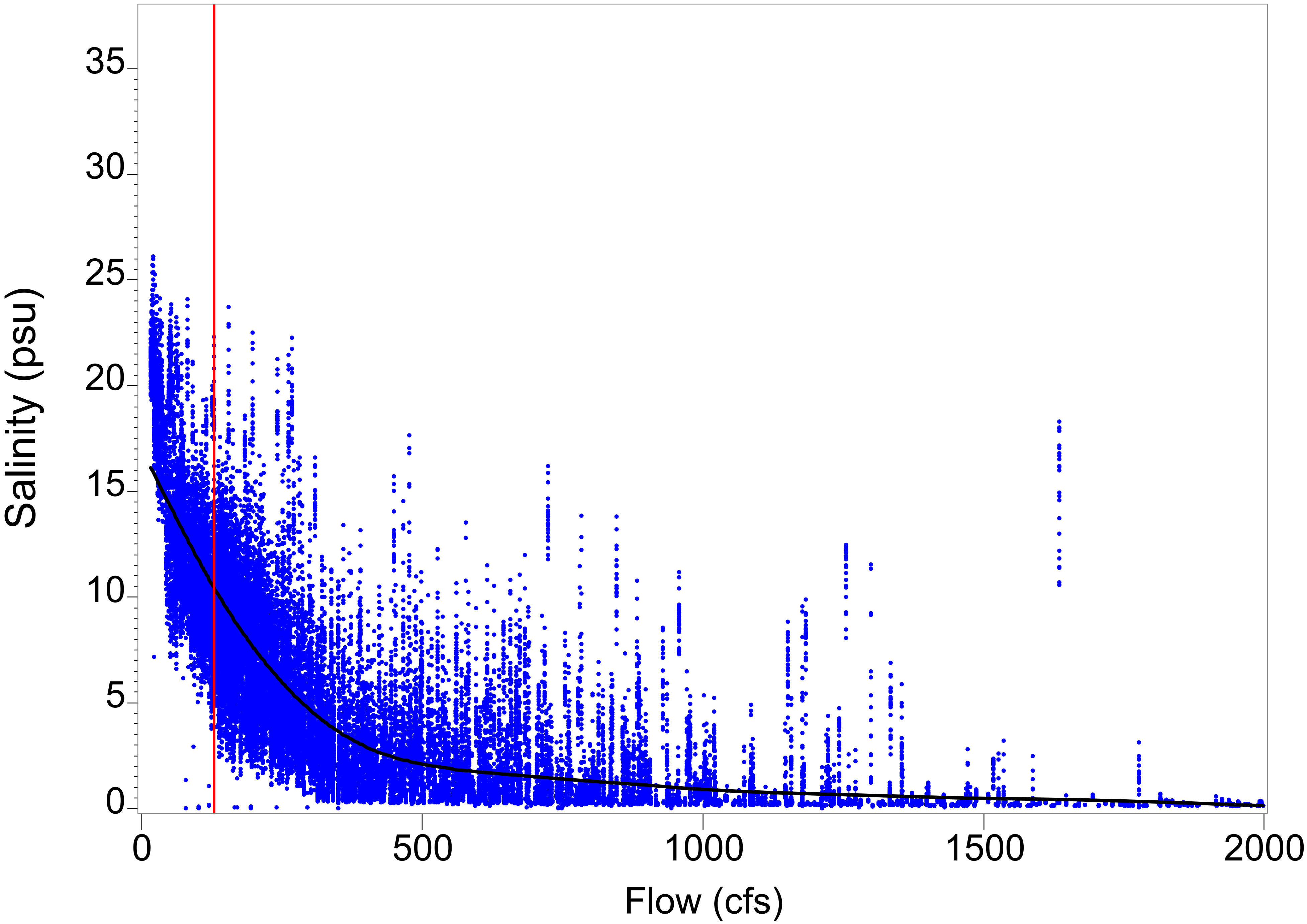


Figure 4.84. Recorder surface salinity at river kilometer 18.7 versus withdrawal corrected upstream gaged flow

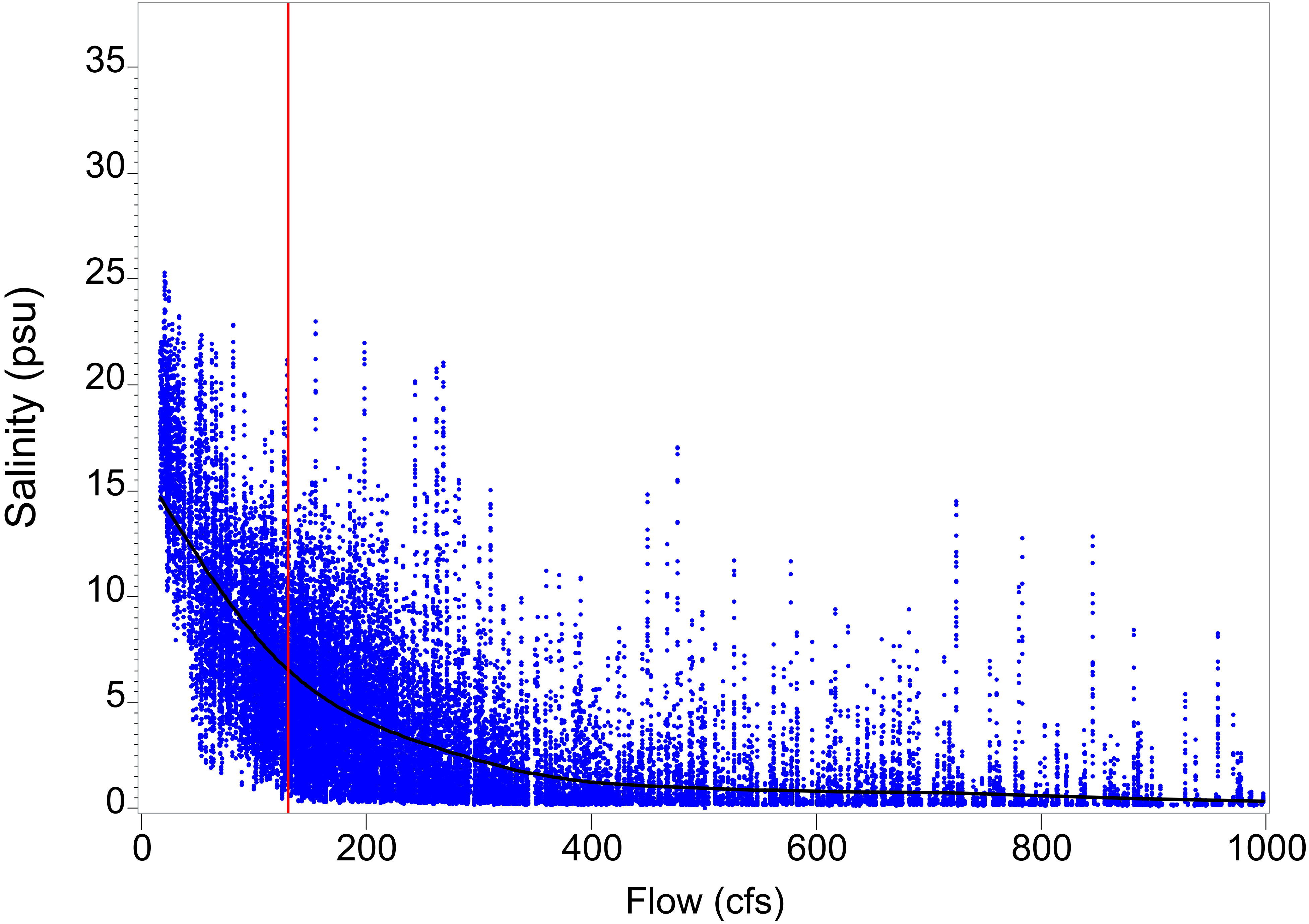


Figure 4.85. Recorder surface salinity at river kilometer 20.8 versus withdrawal corrected upstream gaged flow

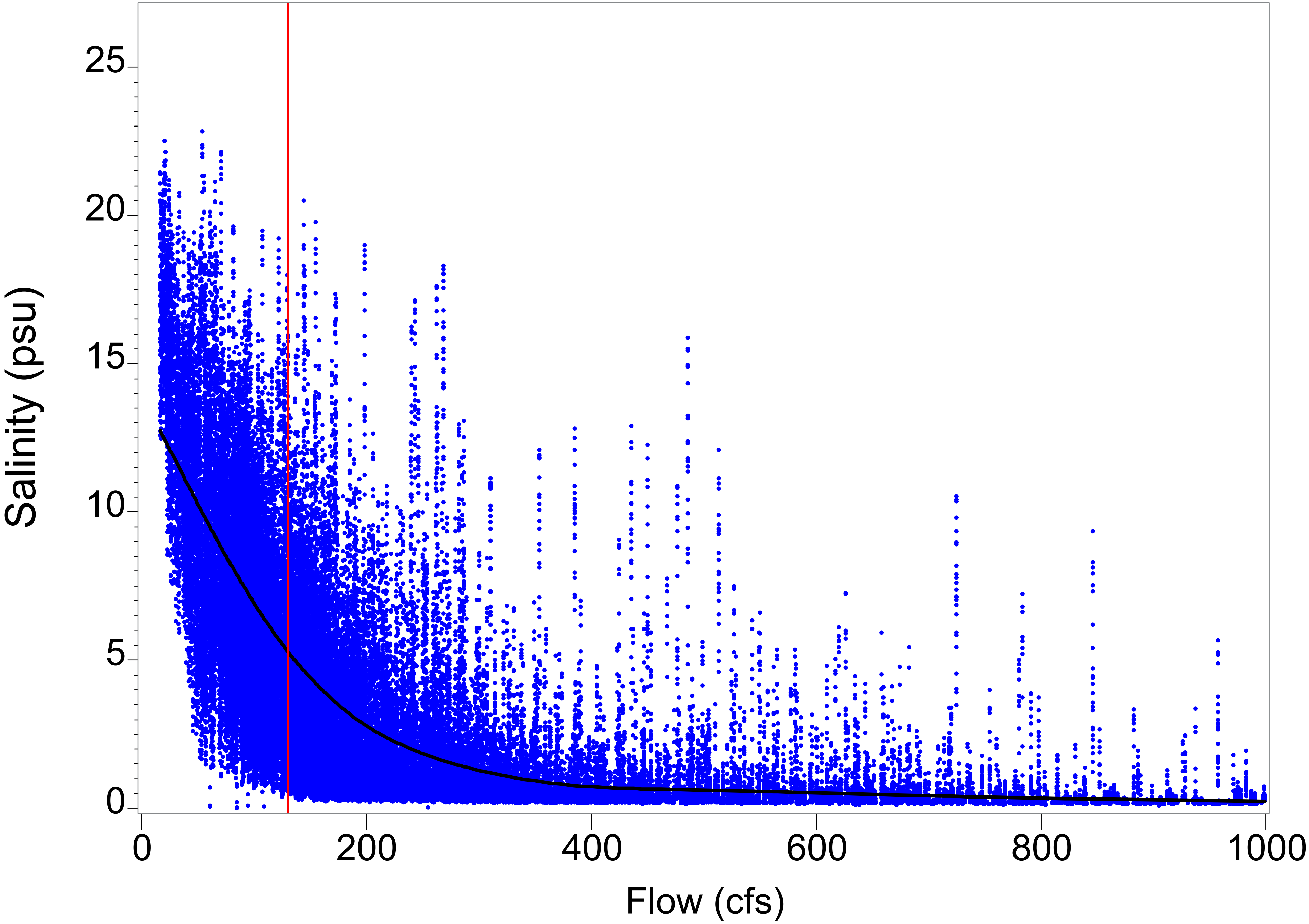


Figure 4.86. Recorder surface salinity at river kilometer 21.9 versus withdrawal corrected upstream gaged flow

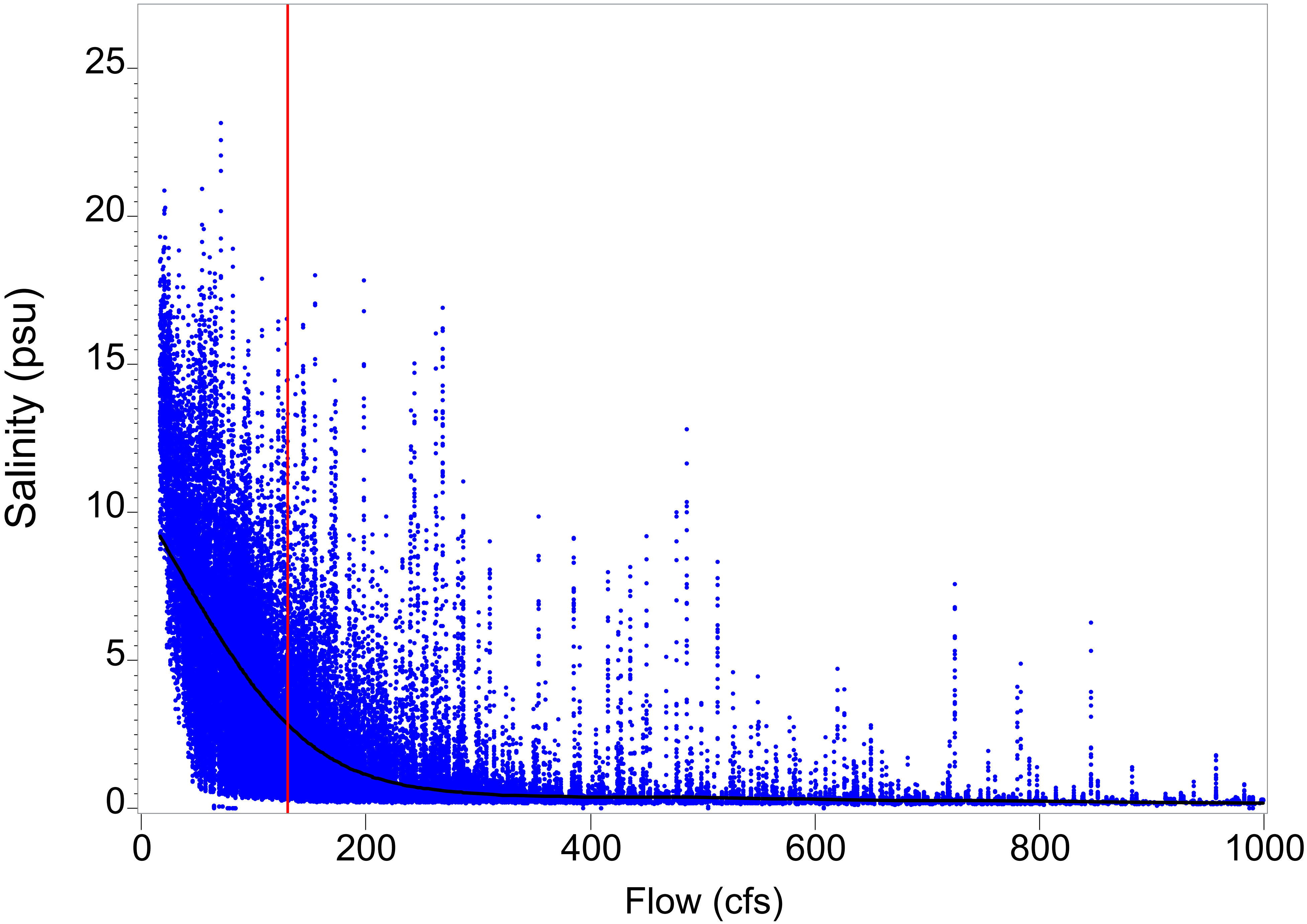


Figure 4.87. Recorder surface salinity at river kilometer 24.5 versus withdrawal corrected upstream gaged flow

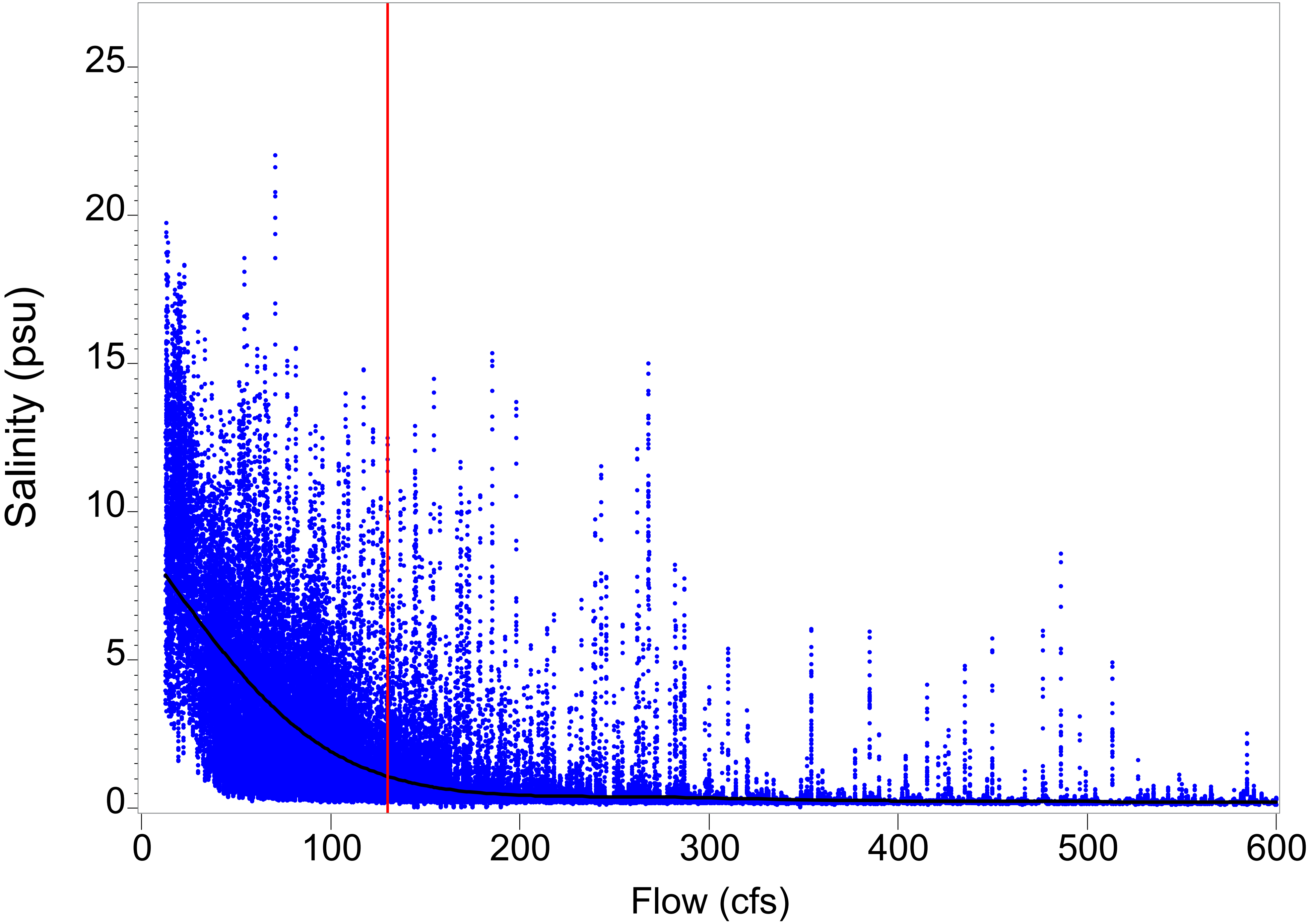


Figure 4.88. Recorder surface salinity at river kilometer 26.7 versus withdrawal corrected upstream gaged flow

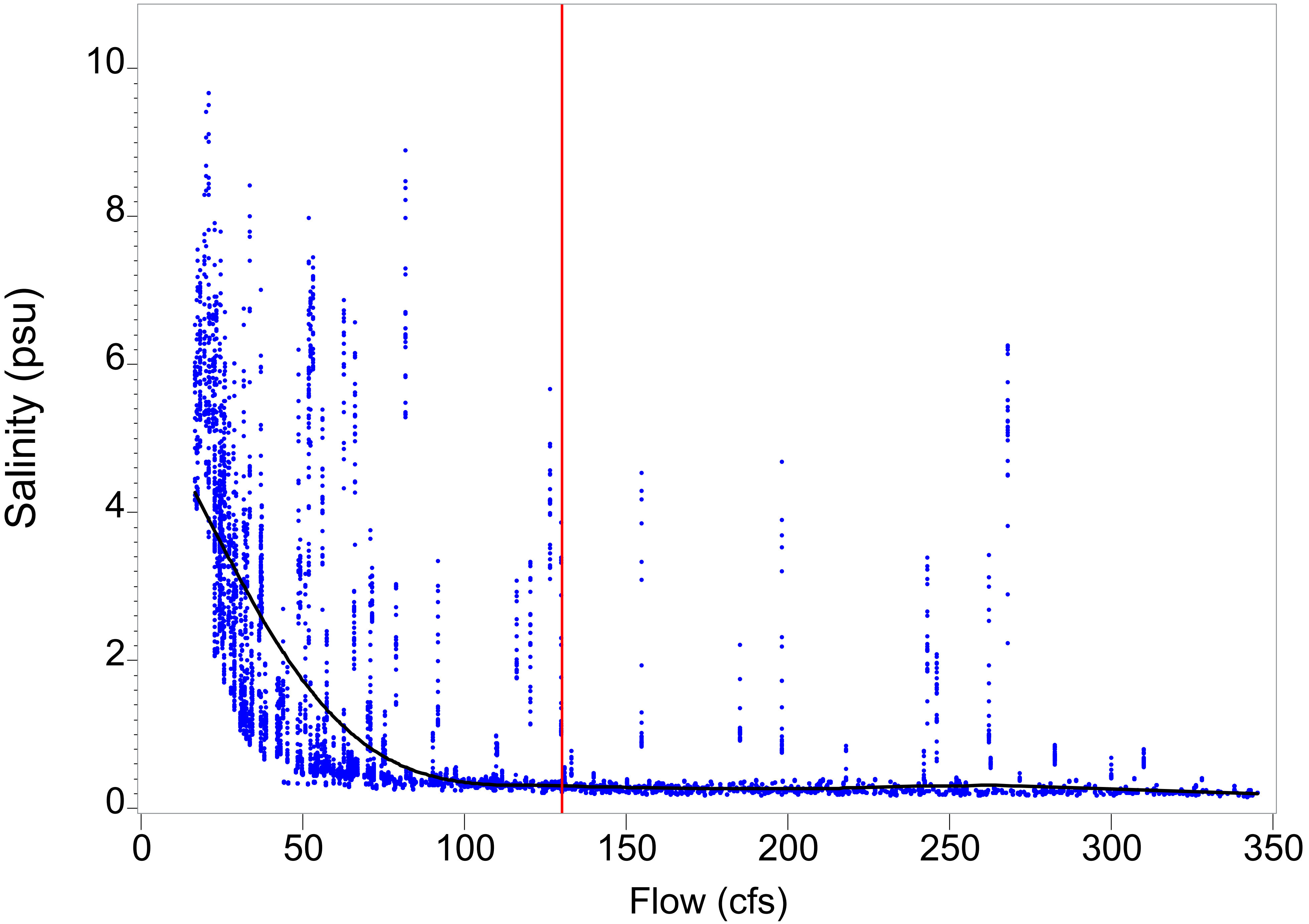


Figure 4.89. Recorder surface salinity at river kilometer 29.8 versus withdrawal corrected upstream gaged flow

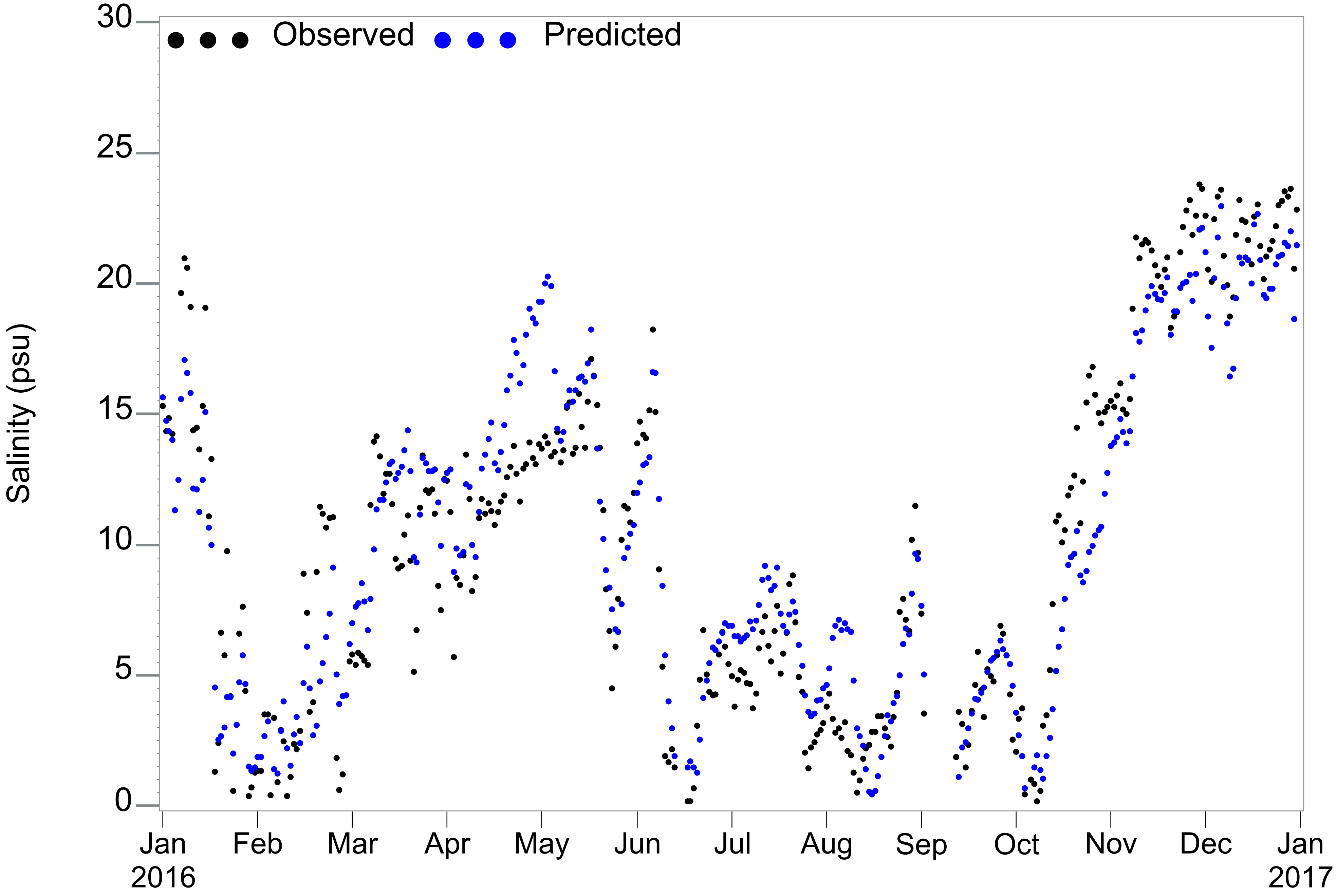


Figure 4.90. Observed versus modeled surface salinity at HBMP recorder at RK 9.2

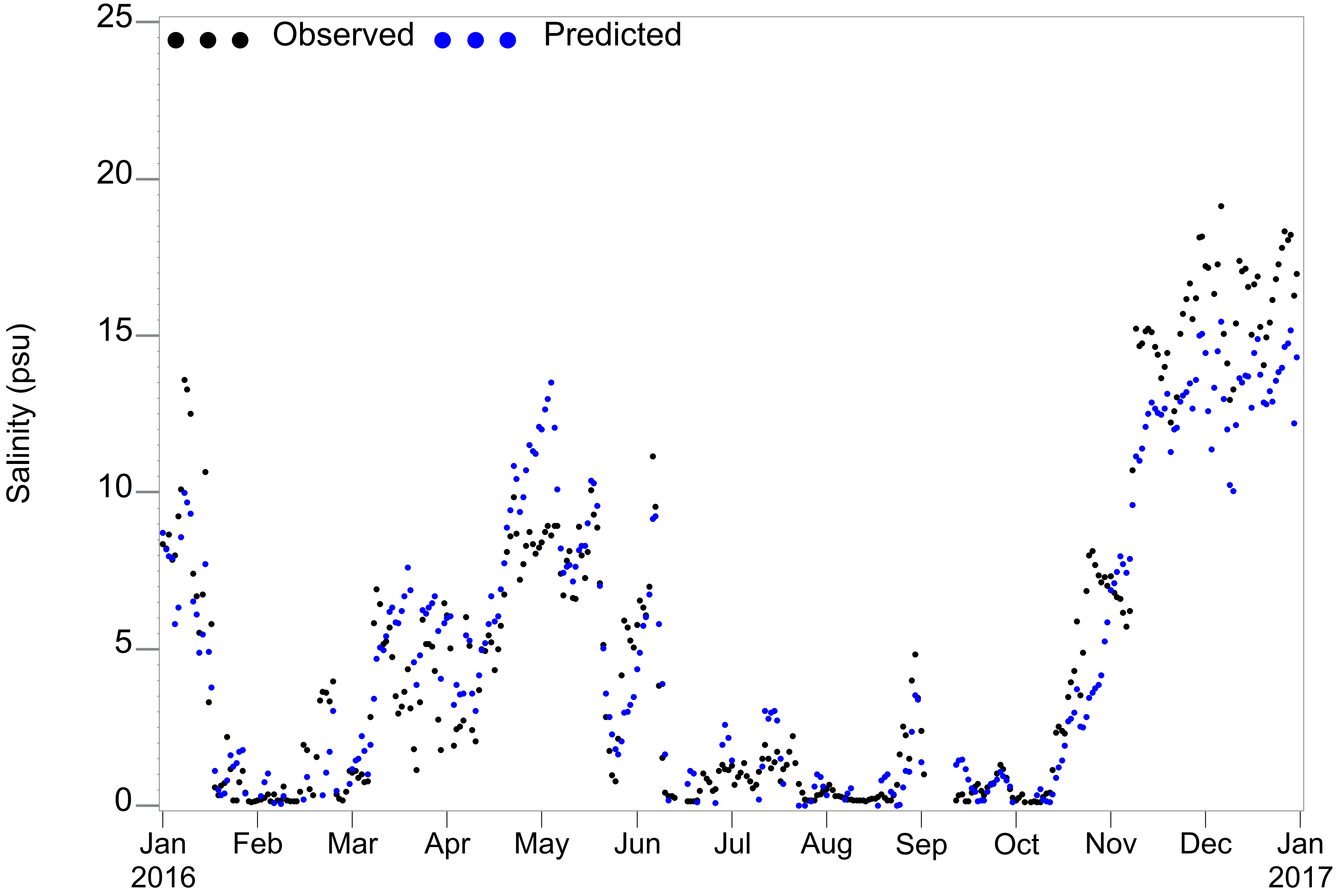


Figure 4.91. Observed versus modeled surface salinity at HBMP recorder at RK 12.7

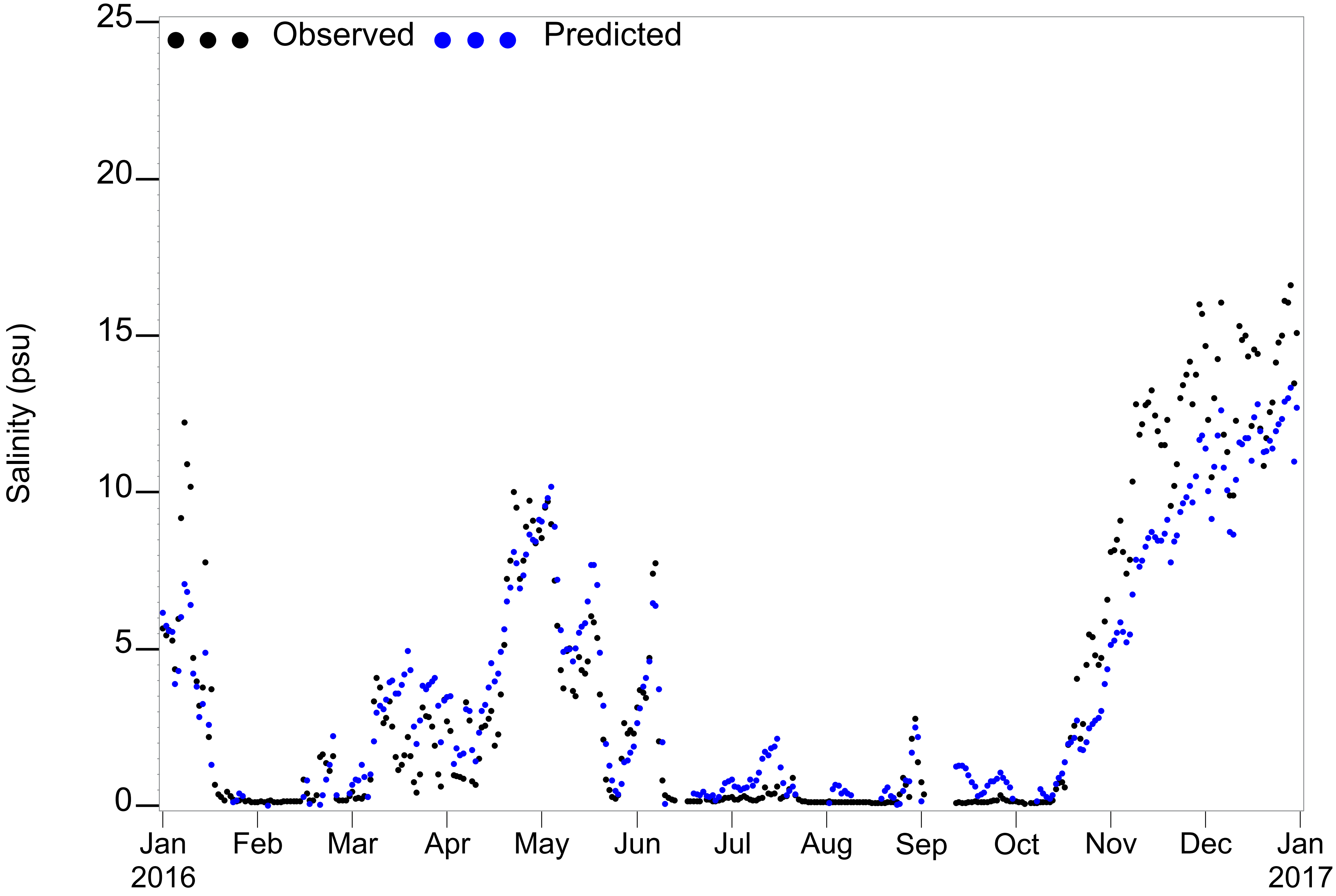


Figure 4.92. Observed versus modeled surface salinity at Harbour Heights (RK 15.5)

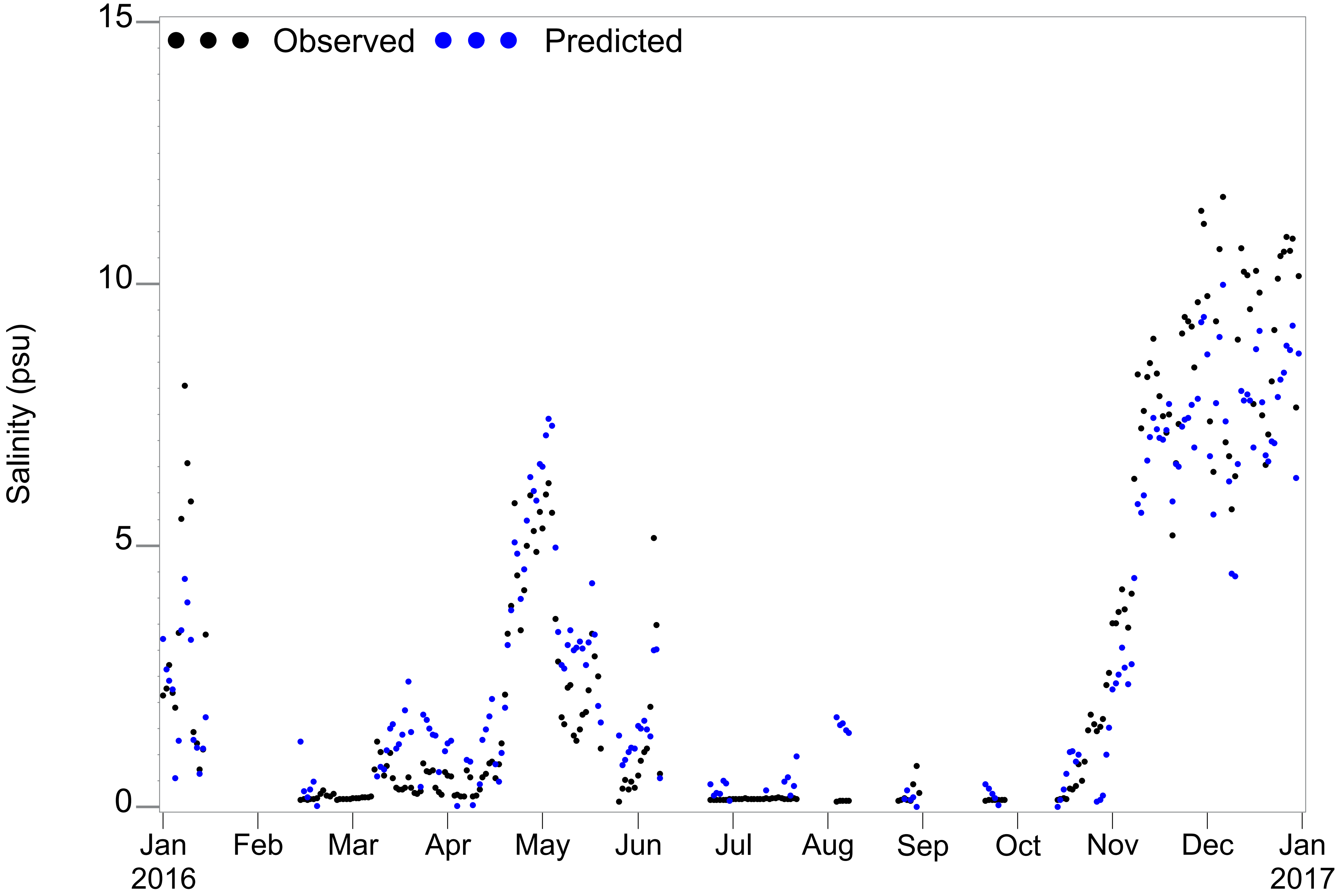


Figure 4.93. Observed versus modeled surface salinity at HBMP recorder at RK 18.5

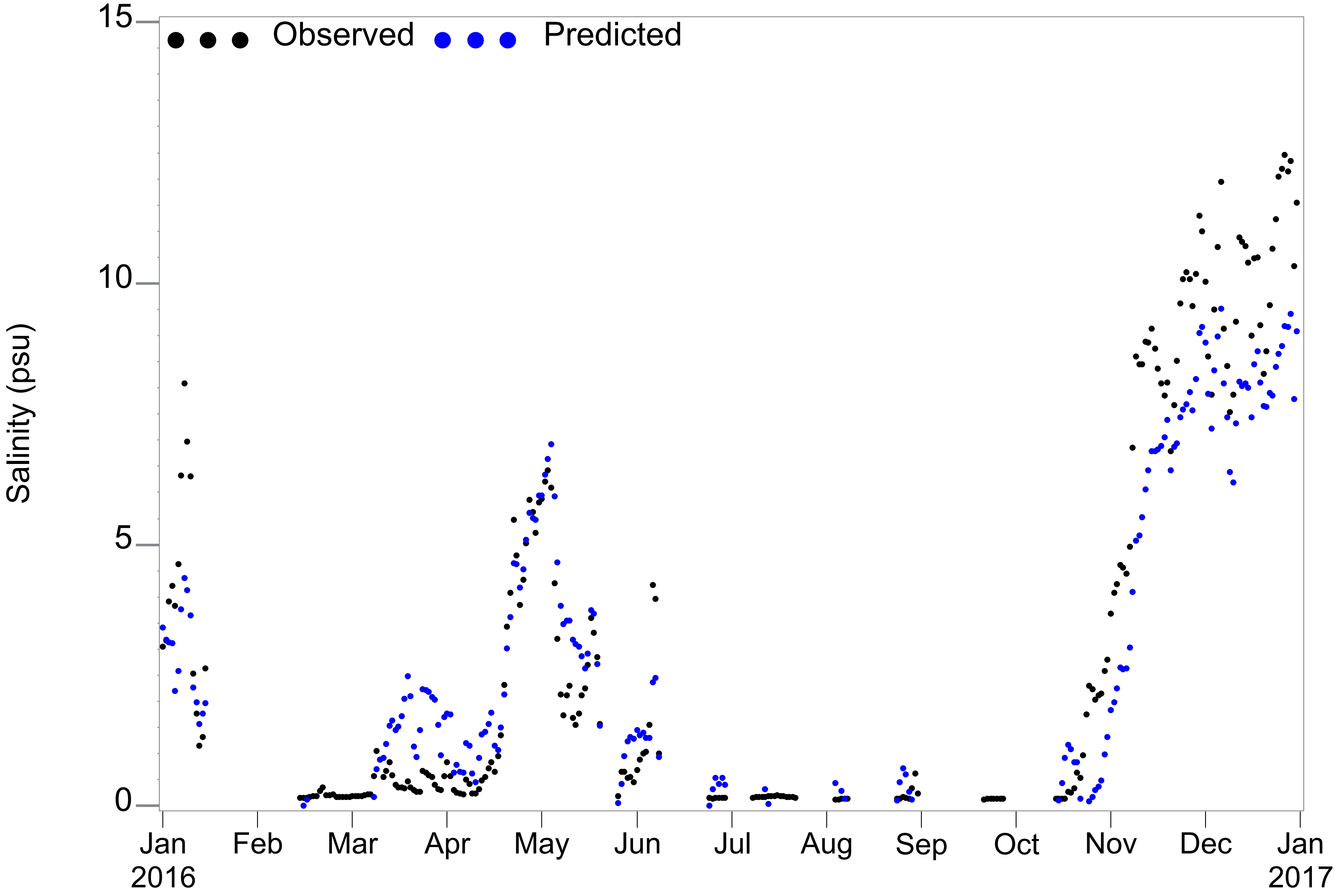


Figure 4.94. Observed versus modeled surface salinity at HBMP recorder at RK 18.7

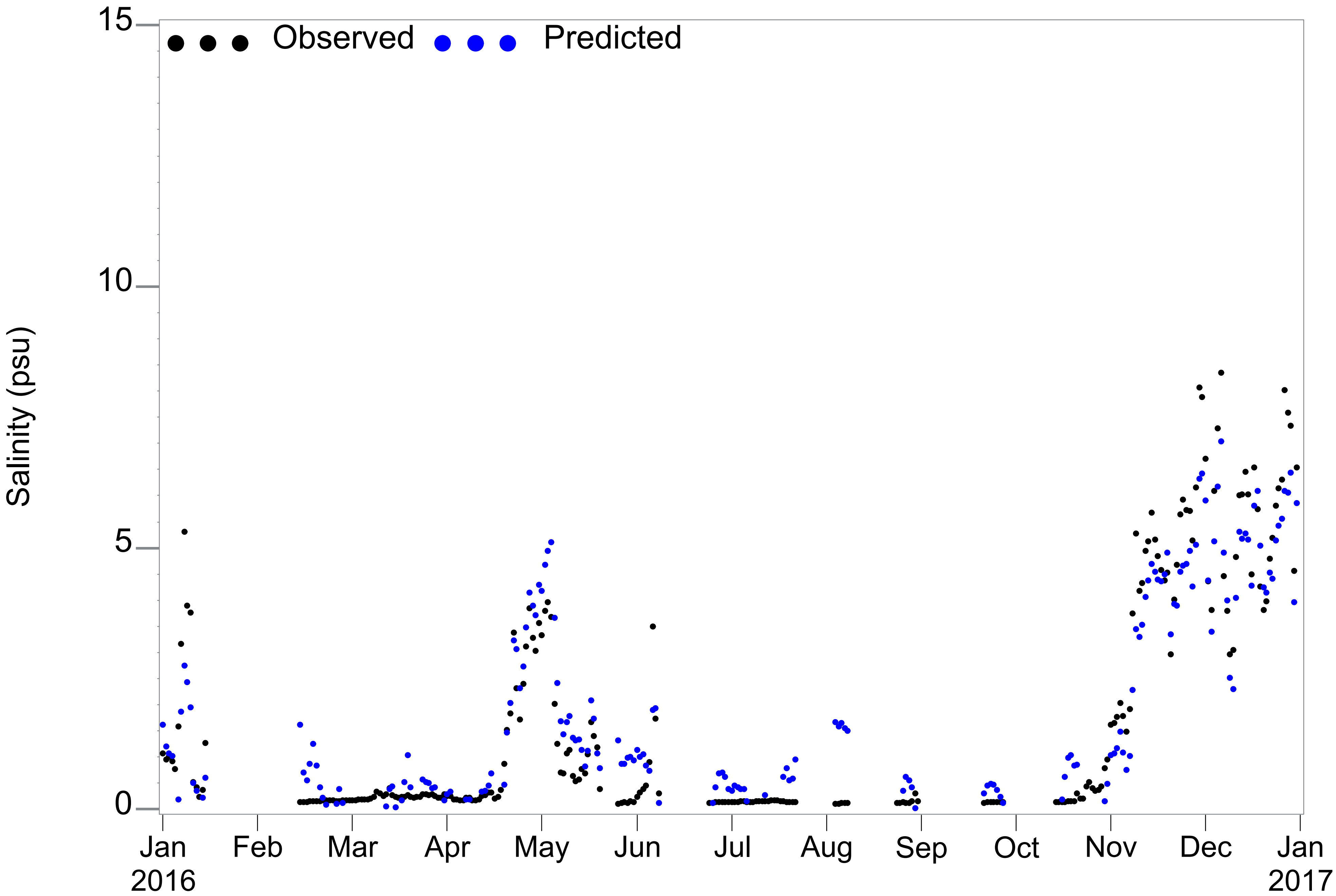


Figure 4.95. Observed versus modeled surface salinity at HBMP recorder at RK 20.8

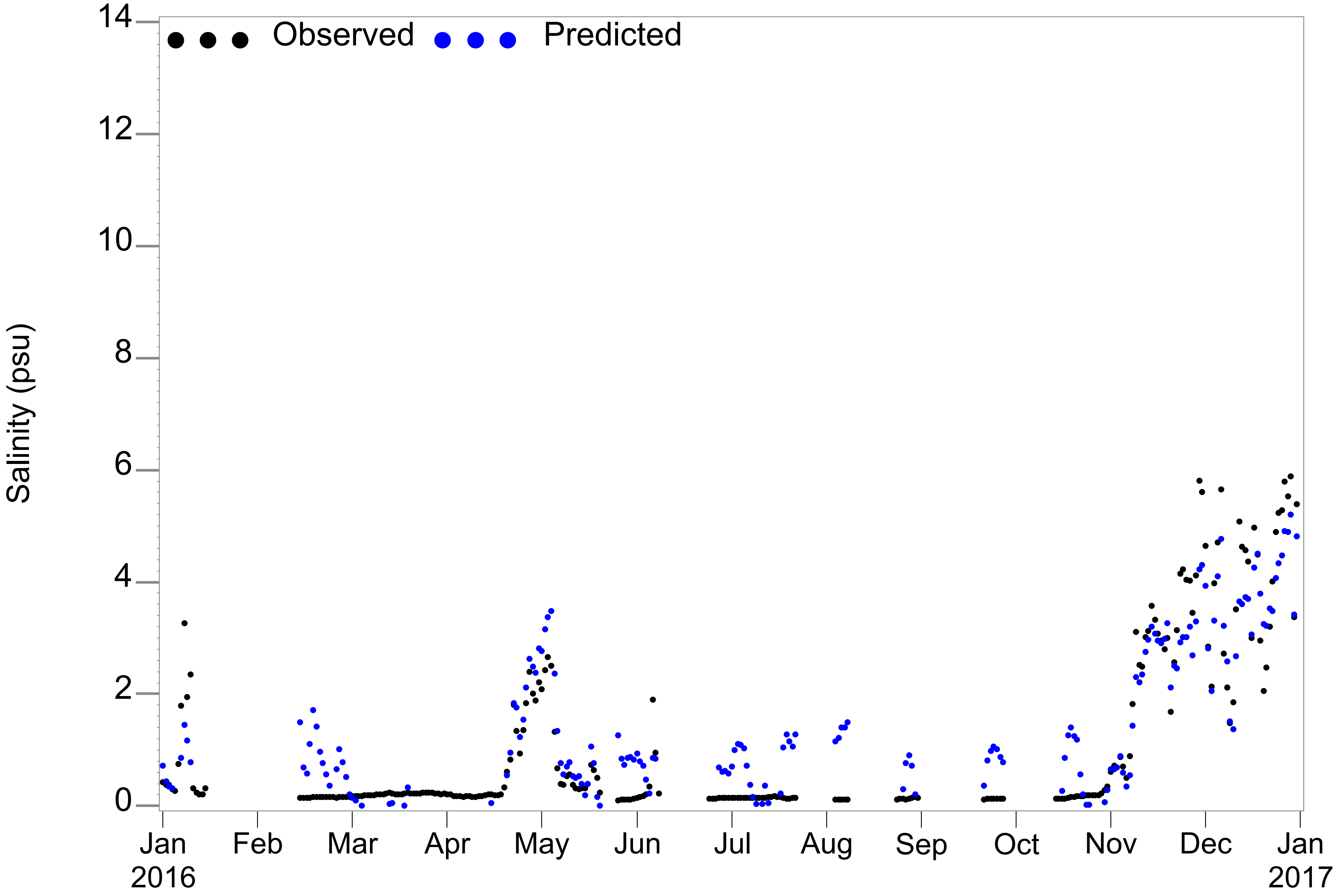


Figure 4.96. Observed versus modeled surface salinity at HBMP recorder at RK 21.9

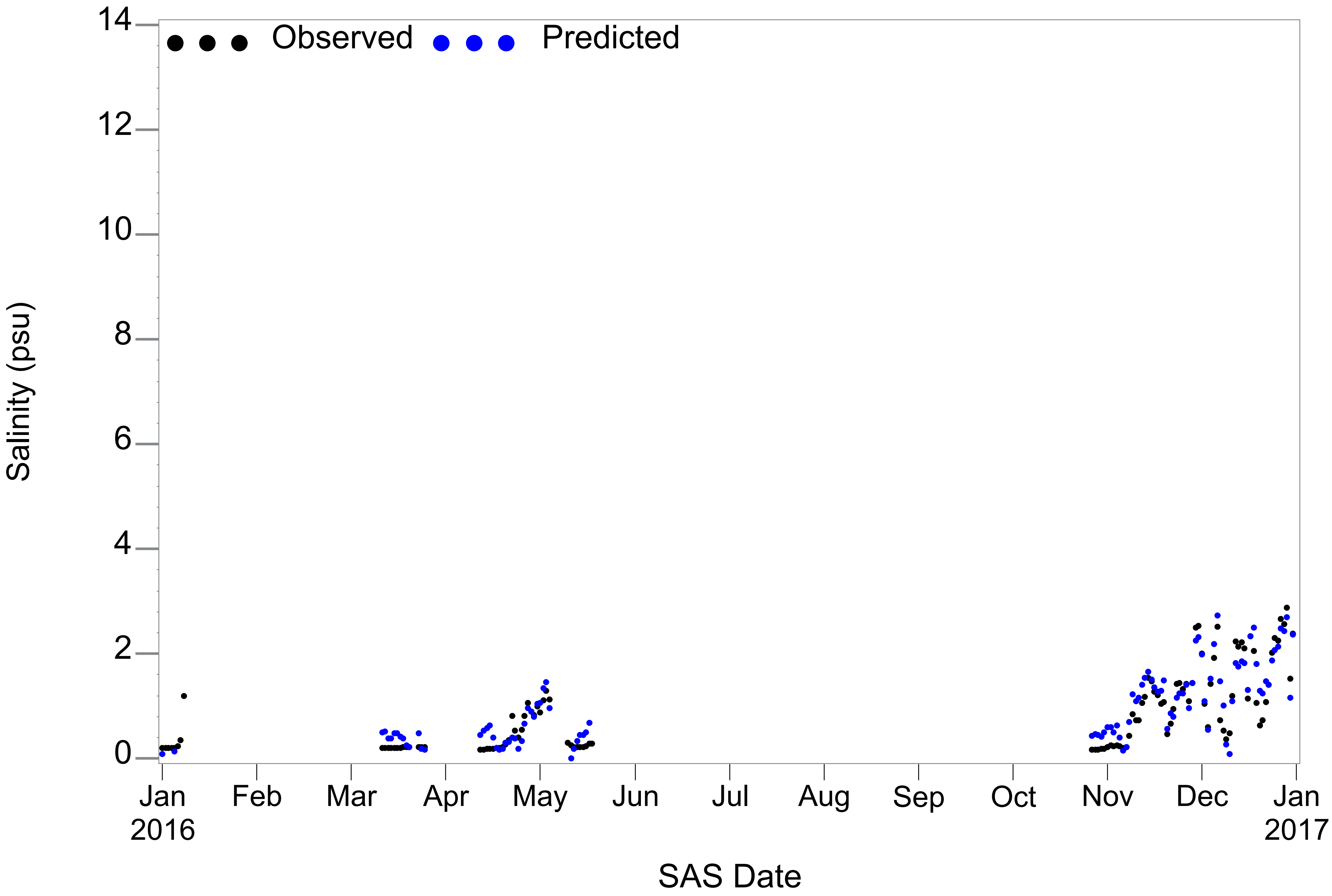


Figure 4.97. Observed versus modeled surface salinity at HBMP recorder at RK 24.5

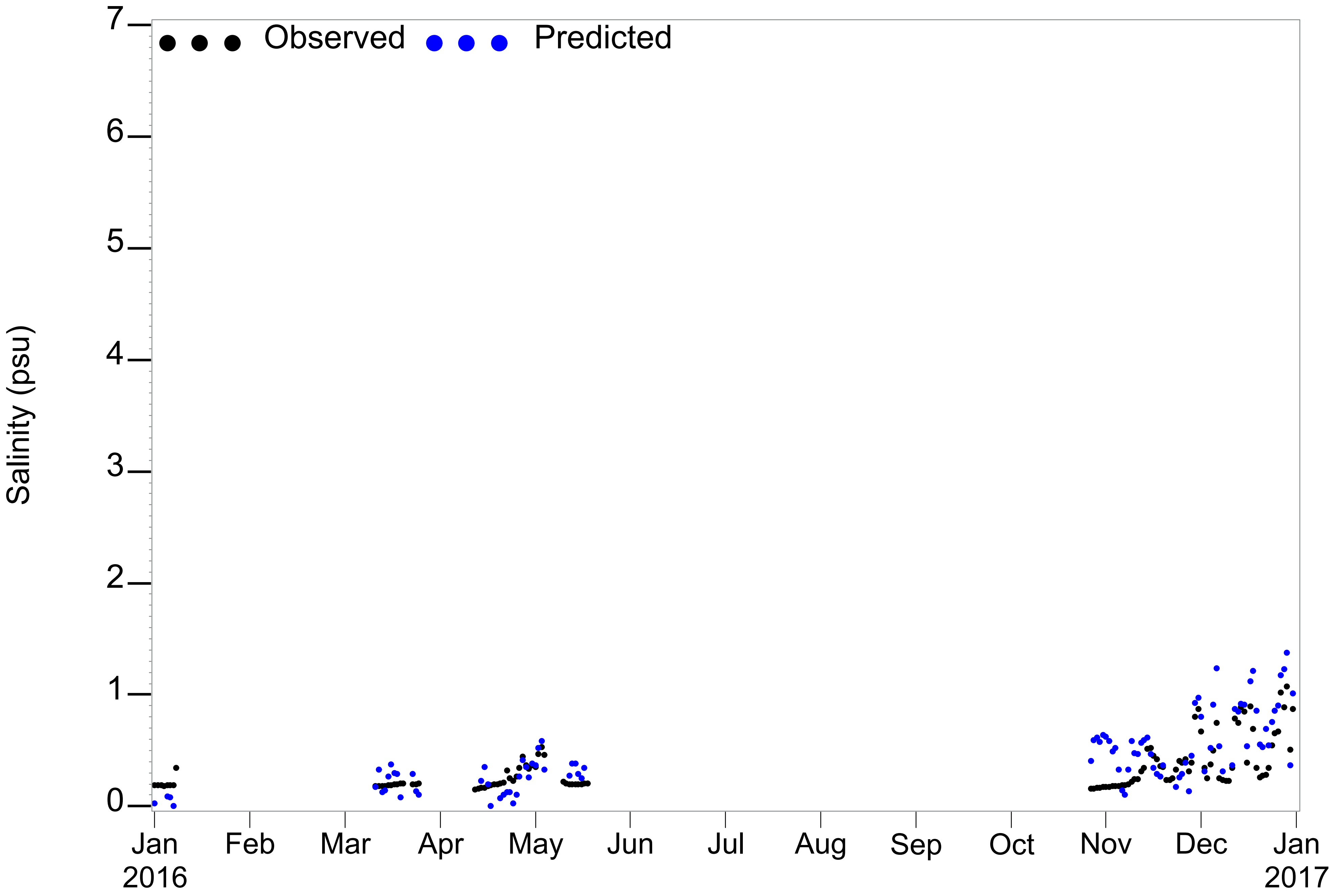


Figure 4.98. Observed versus modeled surface salinity at Peace River Heights (RK 26.7)

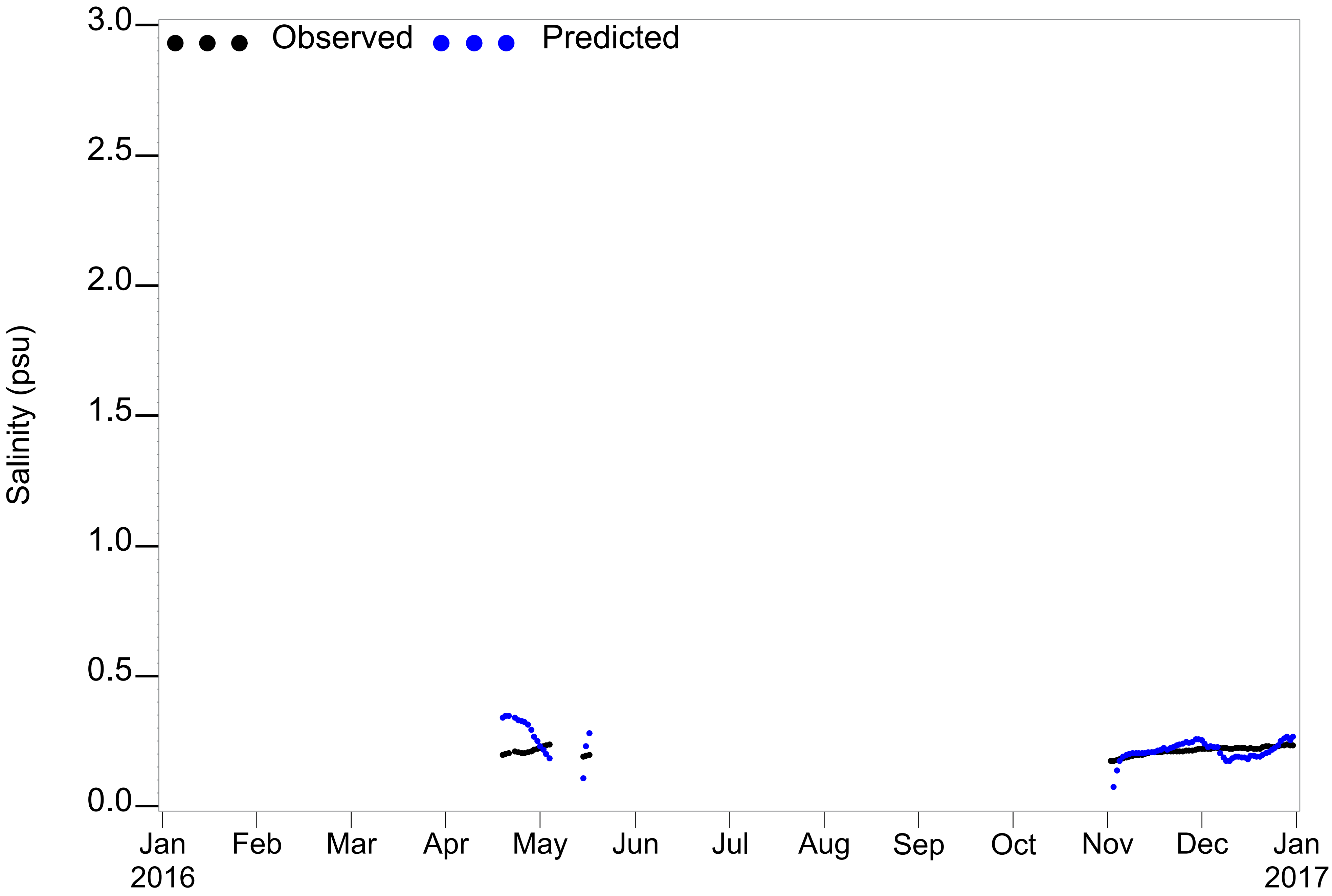


Figure 4.99. Observed versus modeled surface salinity at Platt (RK 29.8)

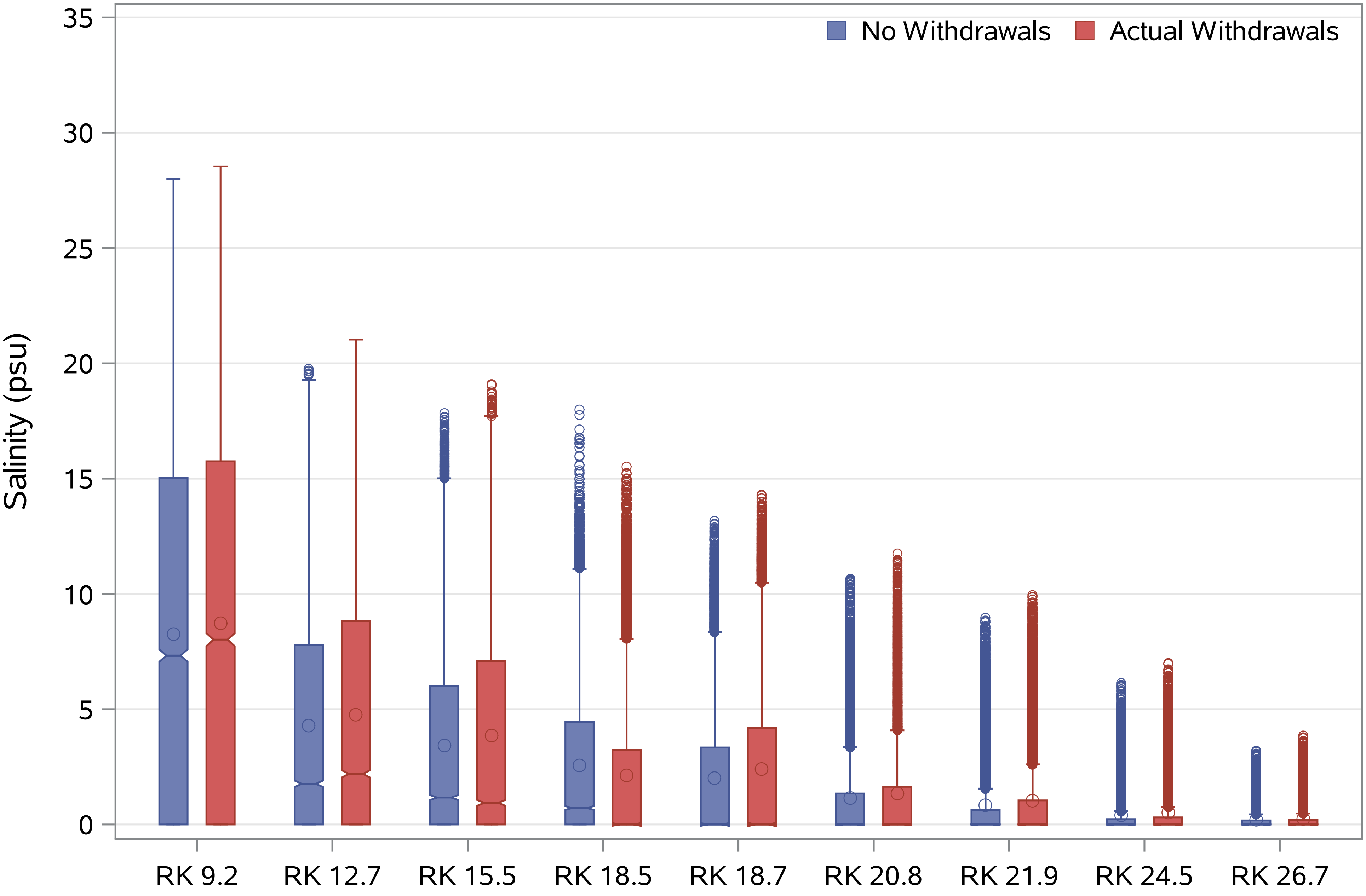


Figure 4.100. Box and whisker plots of salinity variability during 1998 at the continuous recorders

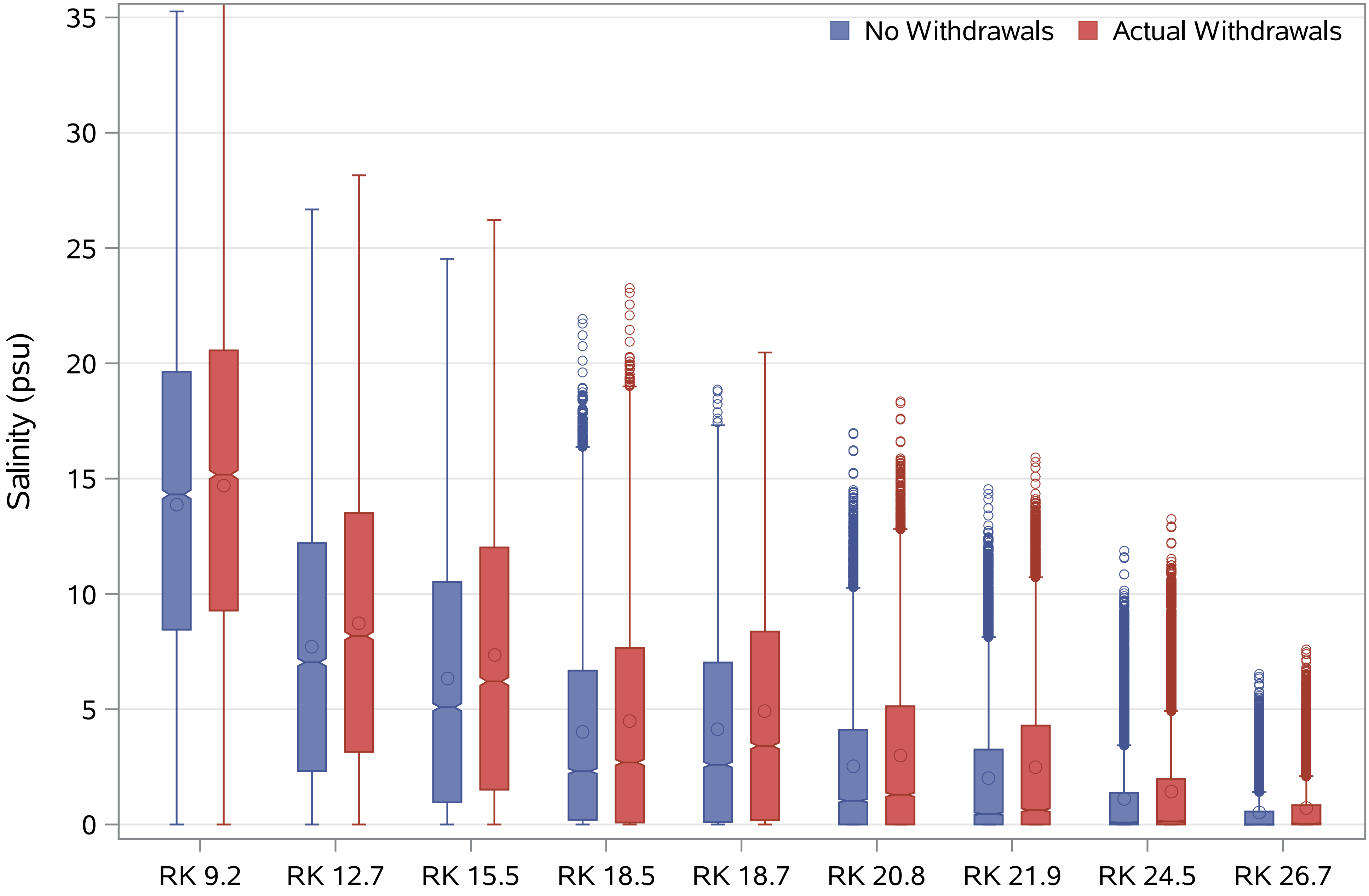


Figure 4.101. Box and whisker plots of salinity variability during 1999 at the continuous recorders

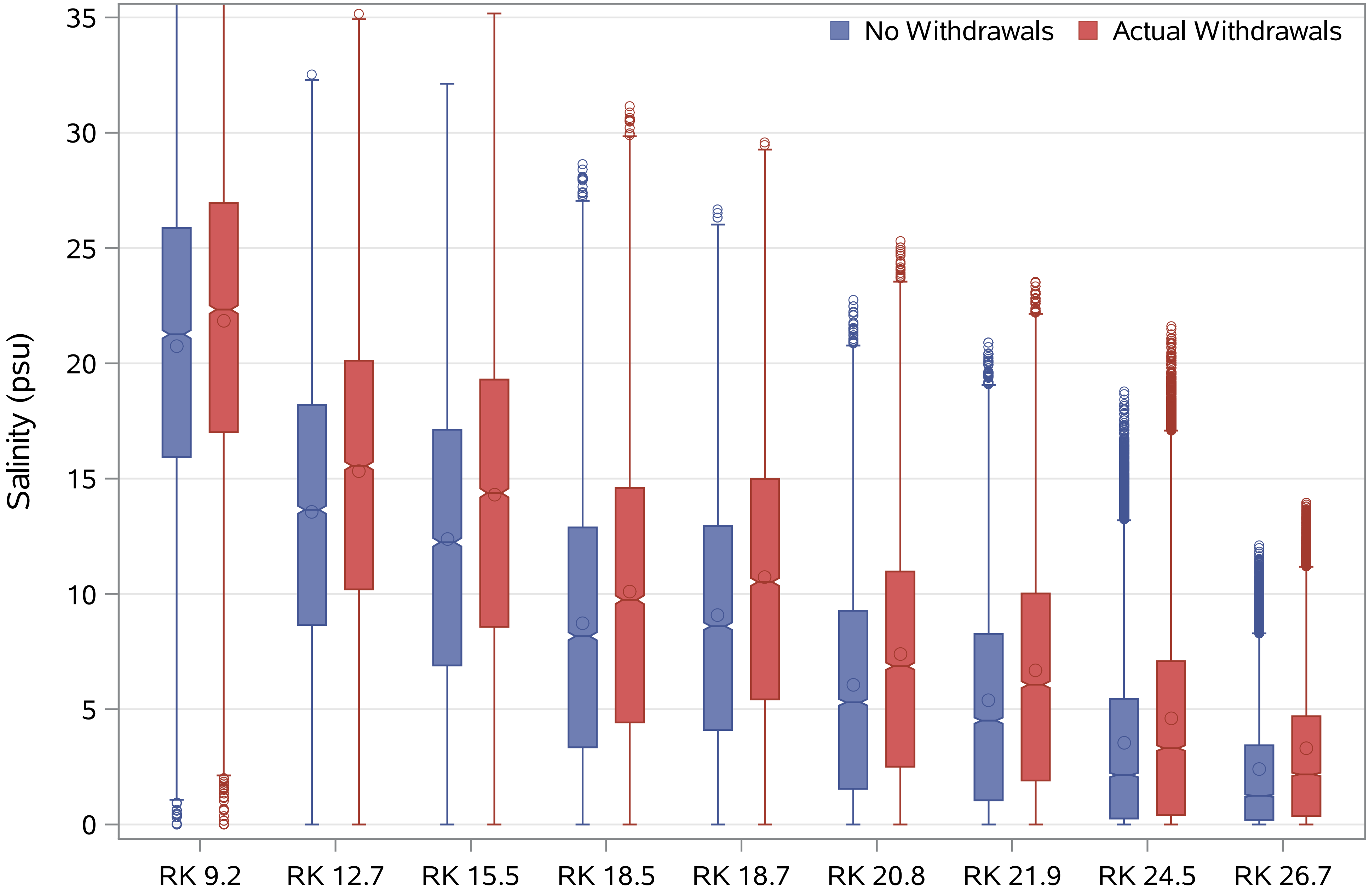


Figure 4.102. Box and whisker plots of salinity variability during 2000 at the continuous recorders

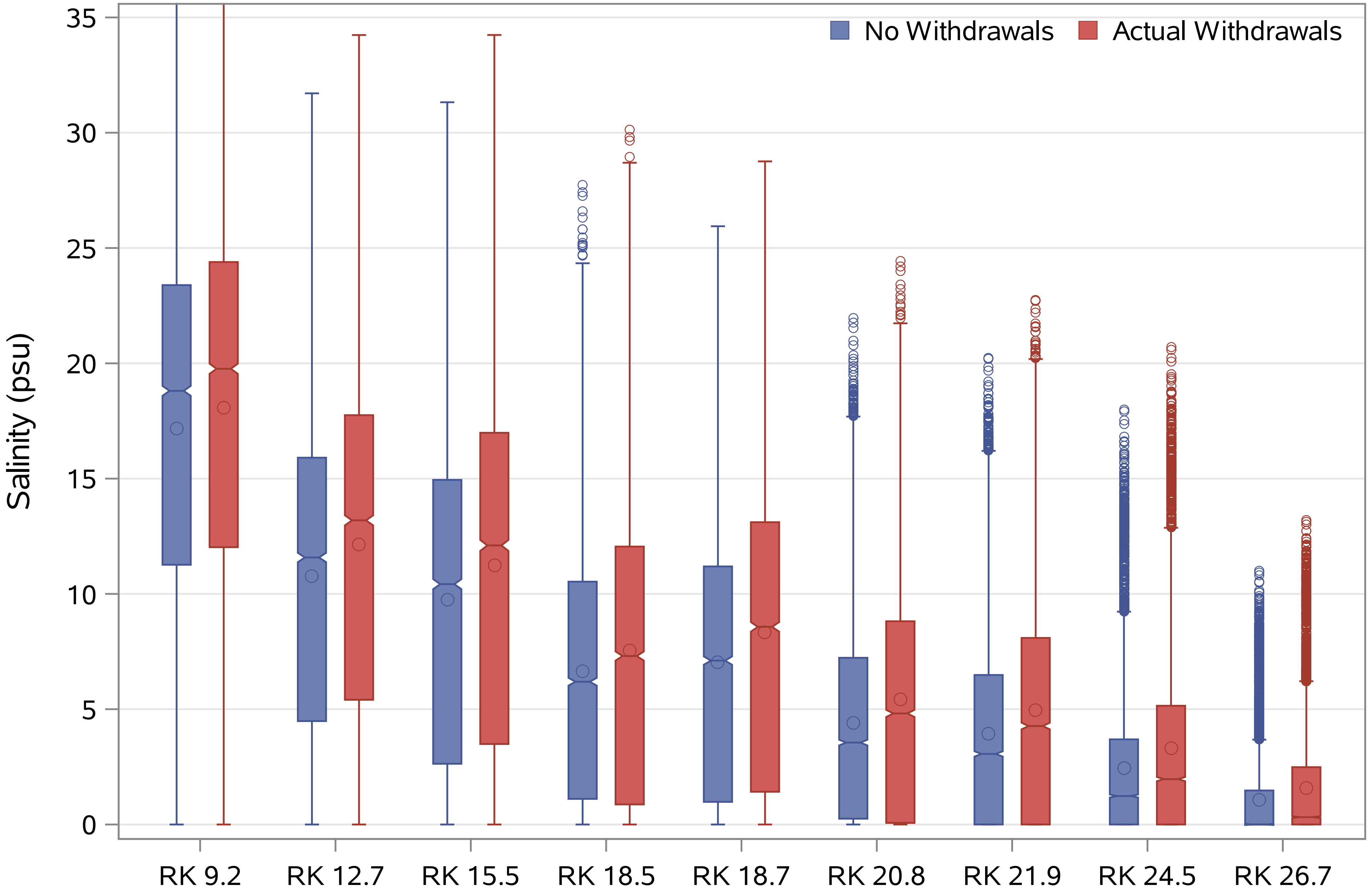


Figure 4.103. Box and whisker plots of salinity variability during 2001 at the continuous recorders

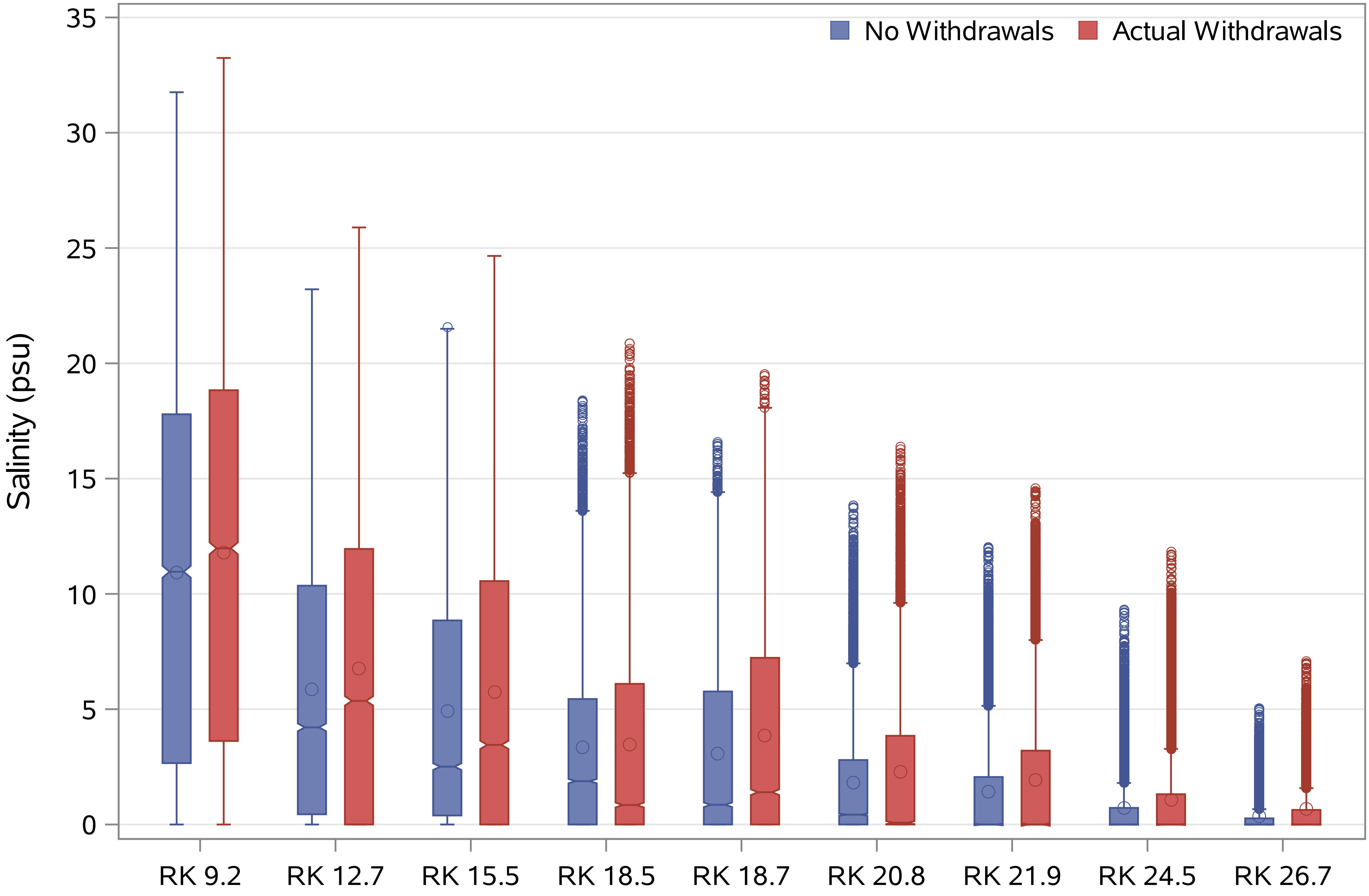


Figure 4.104. Box and whisker plots of salinity variability during 2002 at the continuous recorders

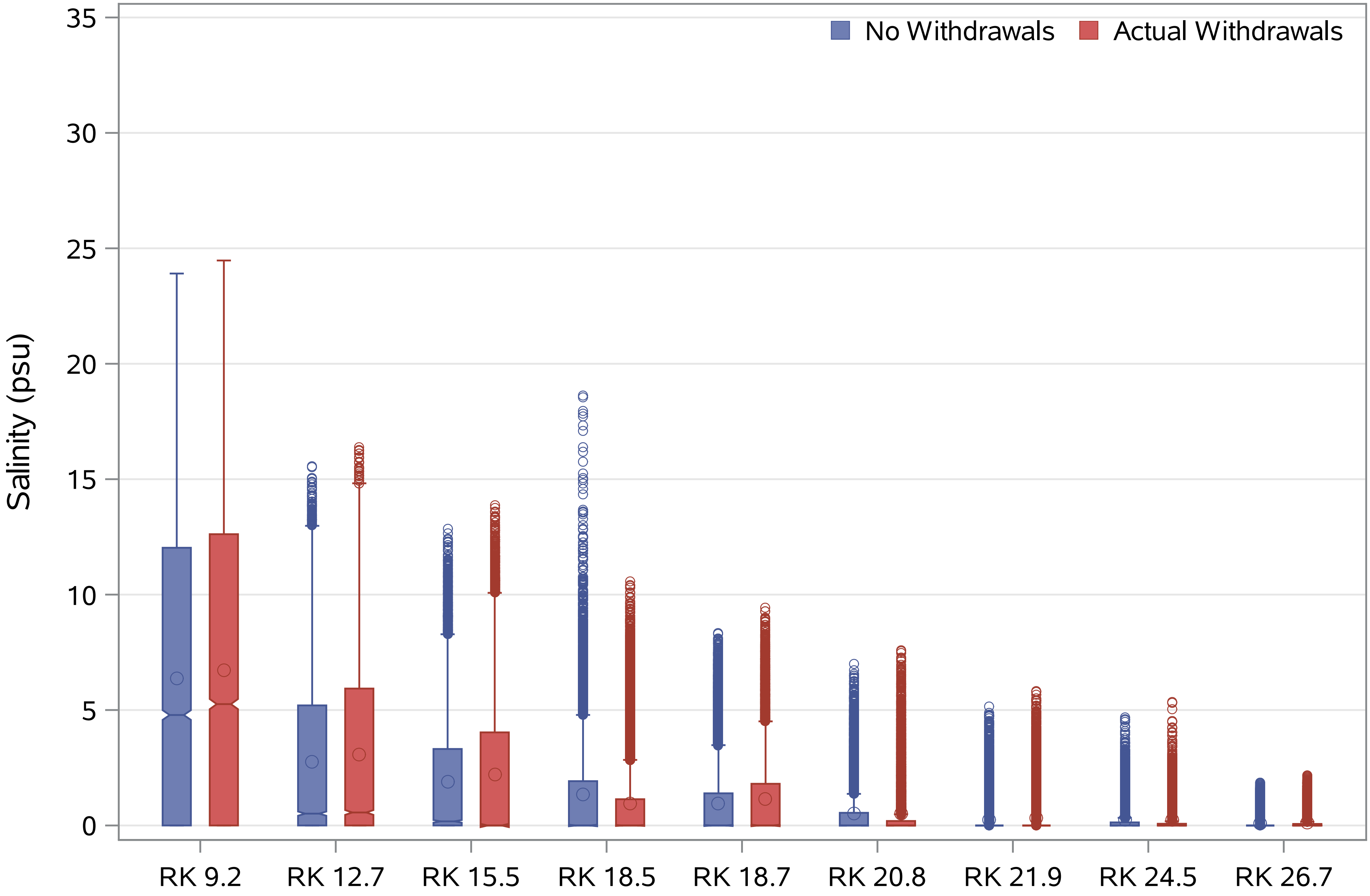


Figure 4.105. Box and whisker plots of salinity variability during 2003 at the continuous recorders

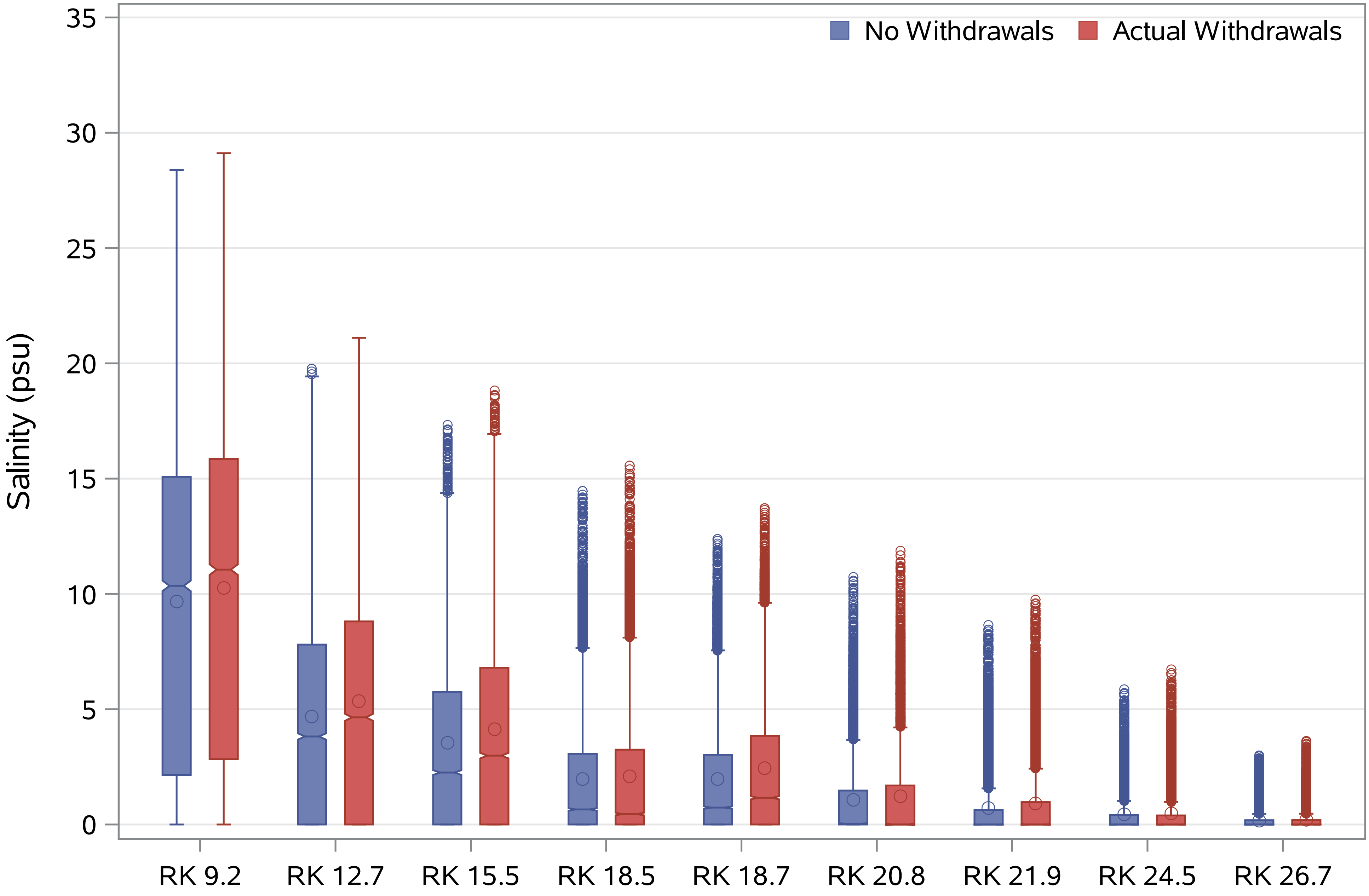


Figure 4.106. Box and whisker plots of salinity variability during 2004 at the continuous recorders

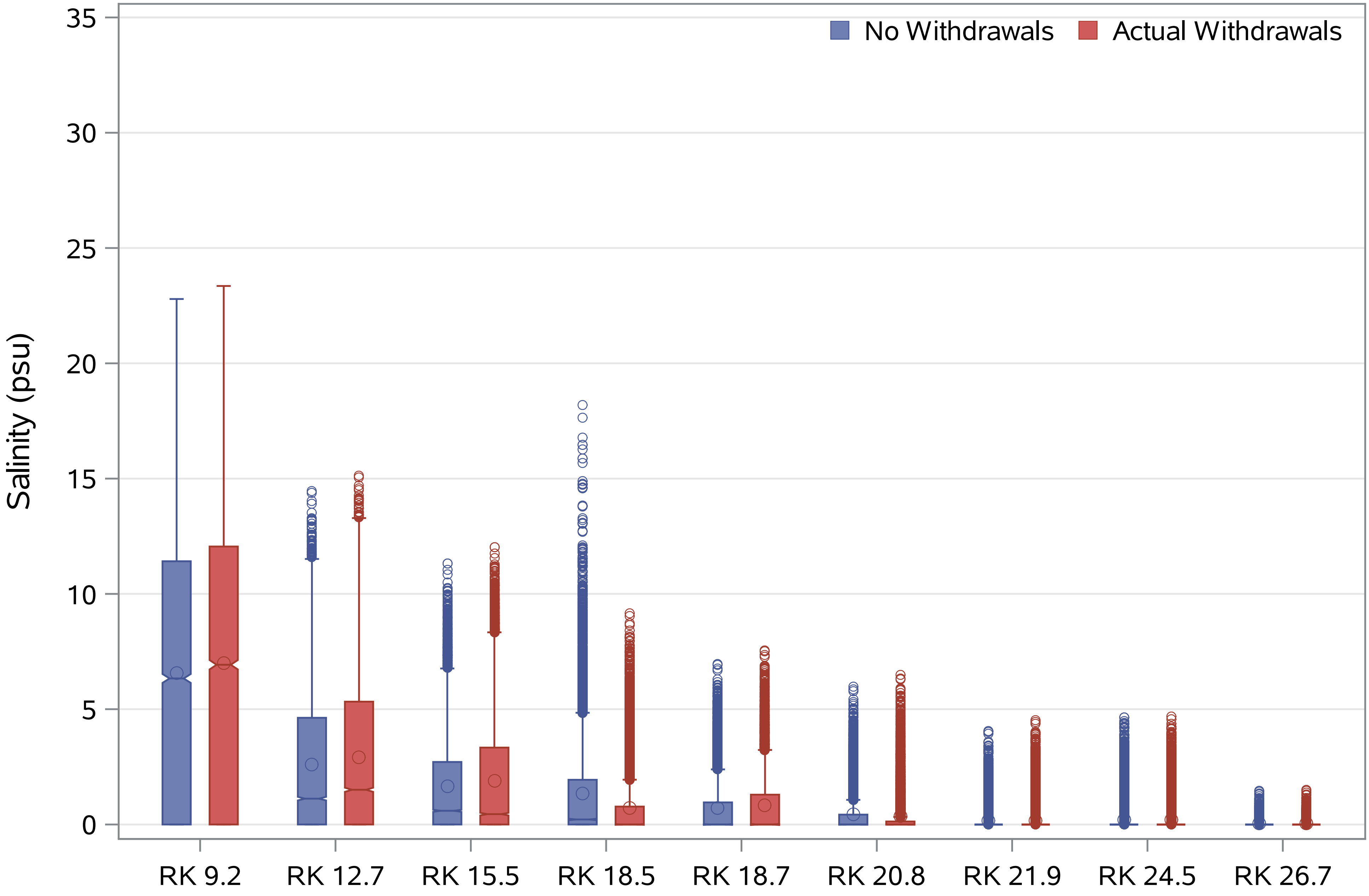


Figure 4.107. Box and whisker plots of salinity variability during 2005 at the continuous recorders

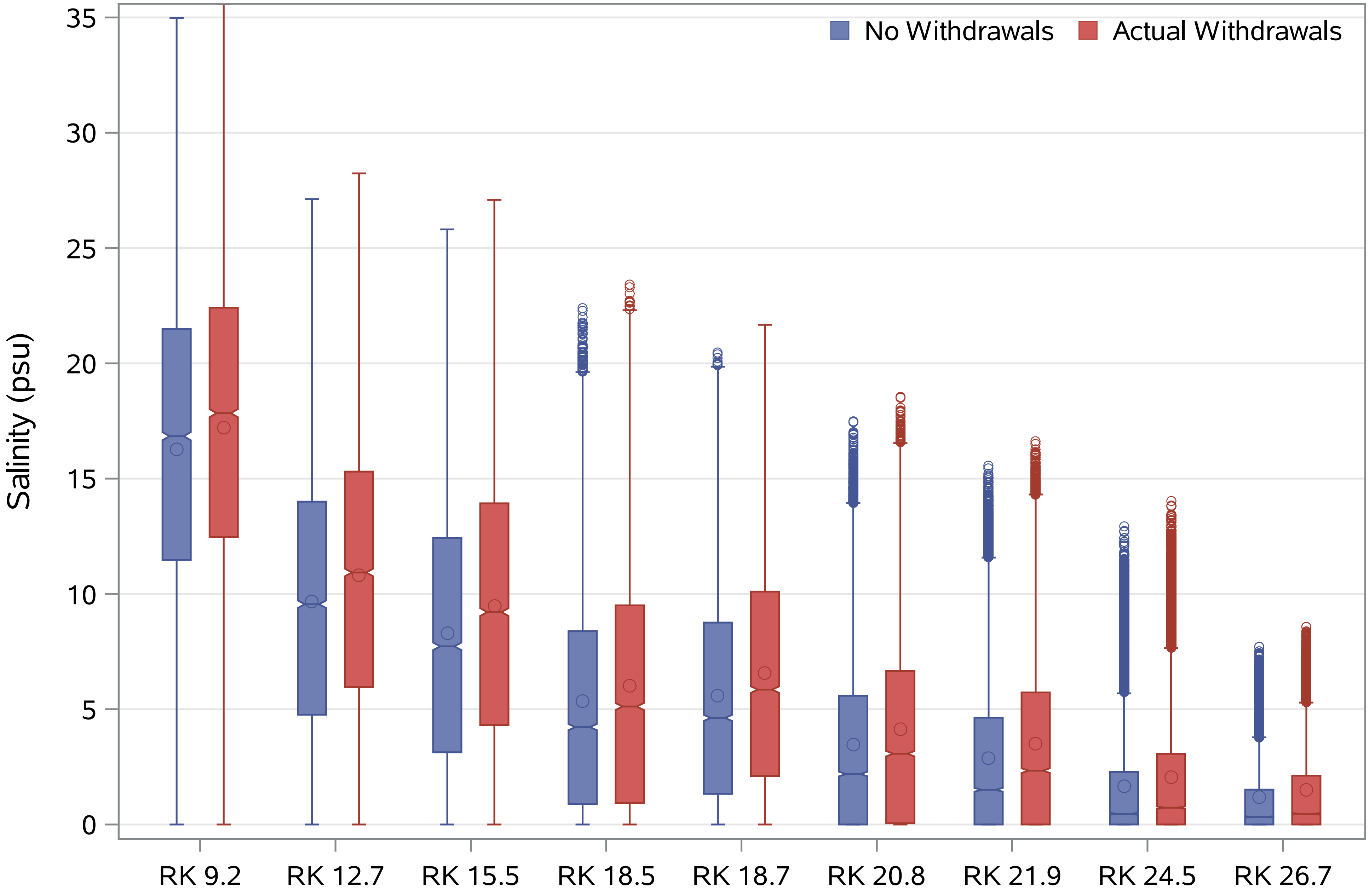


Figure 4.108. Box and whisker plots of salinity variability during 2006 at the continuous recorders

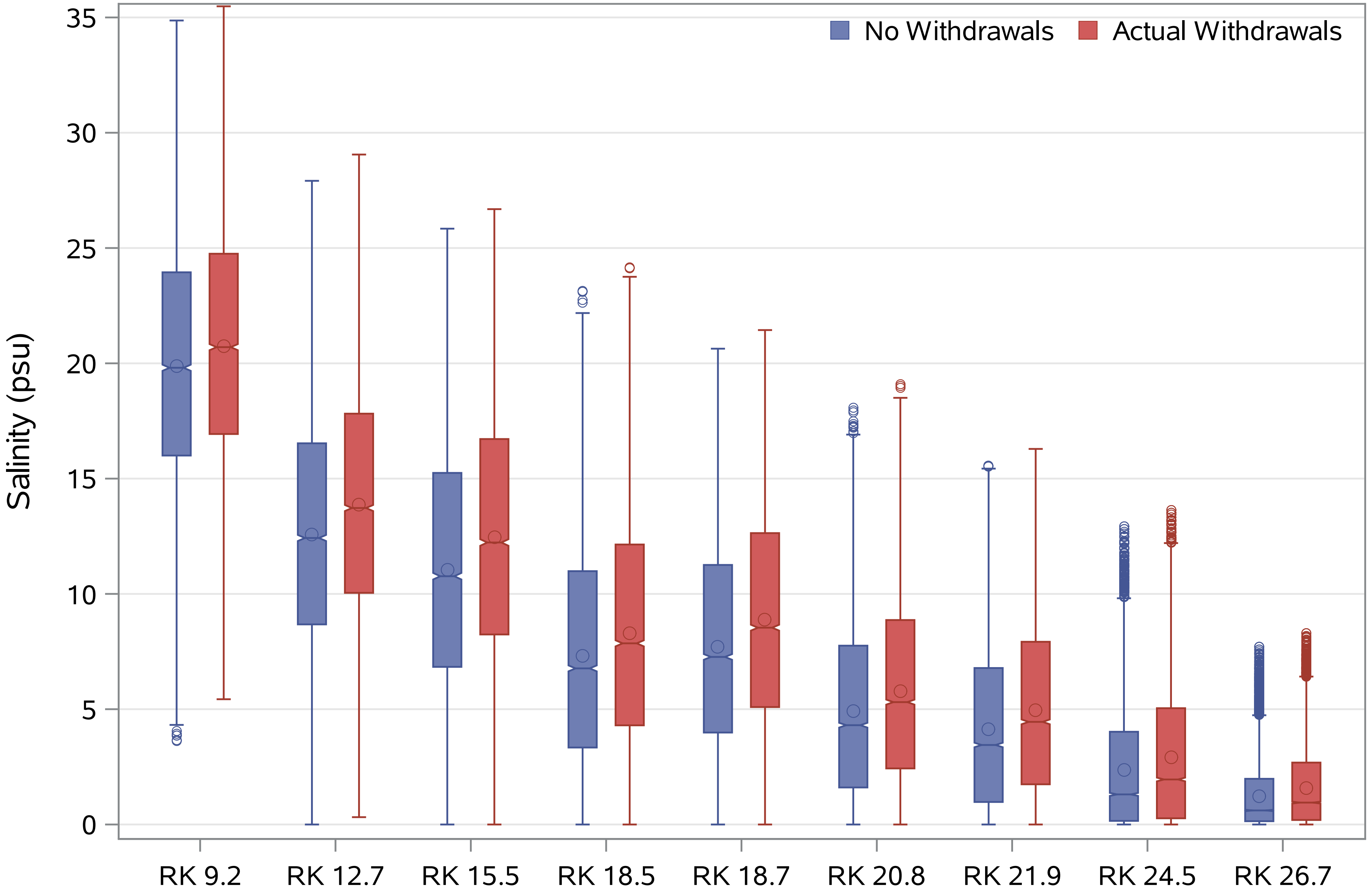


Figure 4.109. Box and whisker plots of salinity variability during 2007 at the continuous recorders

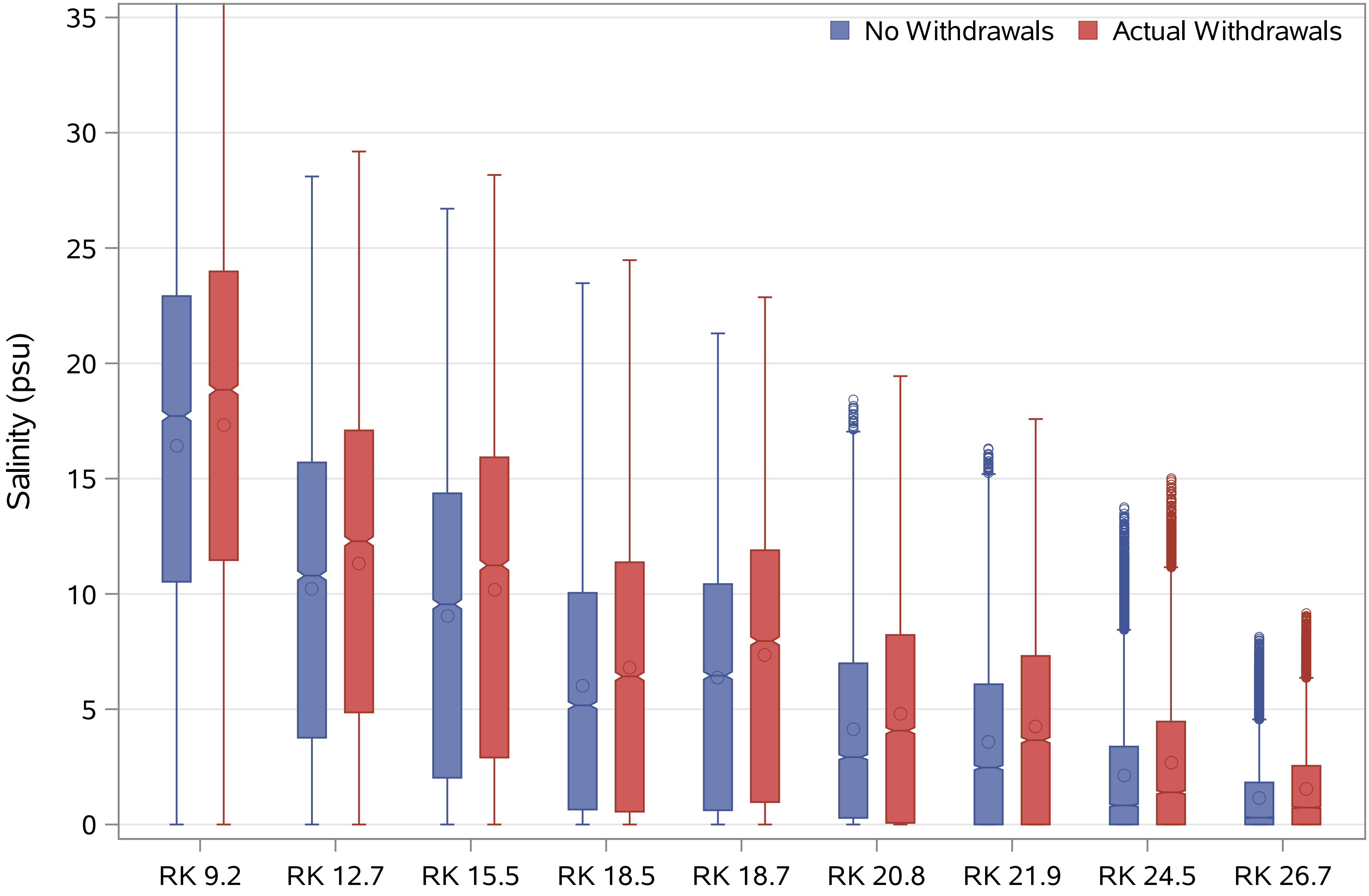


Figure 4.110. Box and whisker plots of salinity variability during 2008 at the continuous recorders

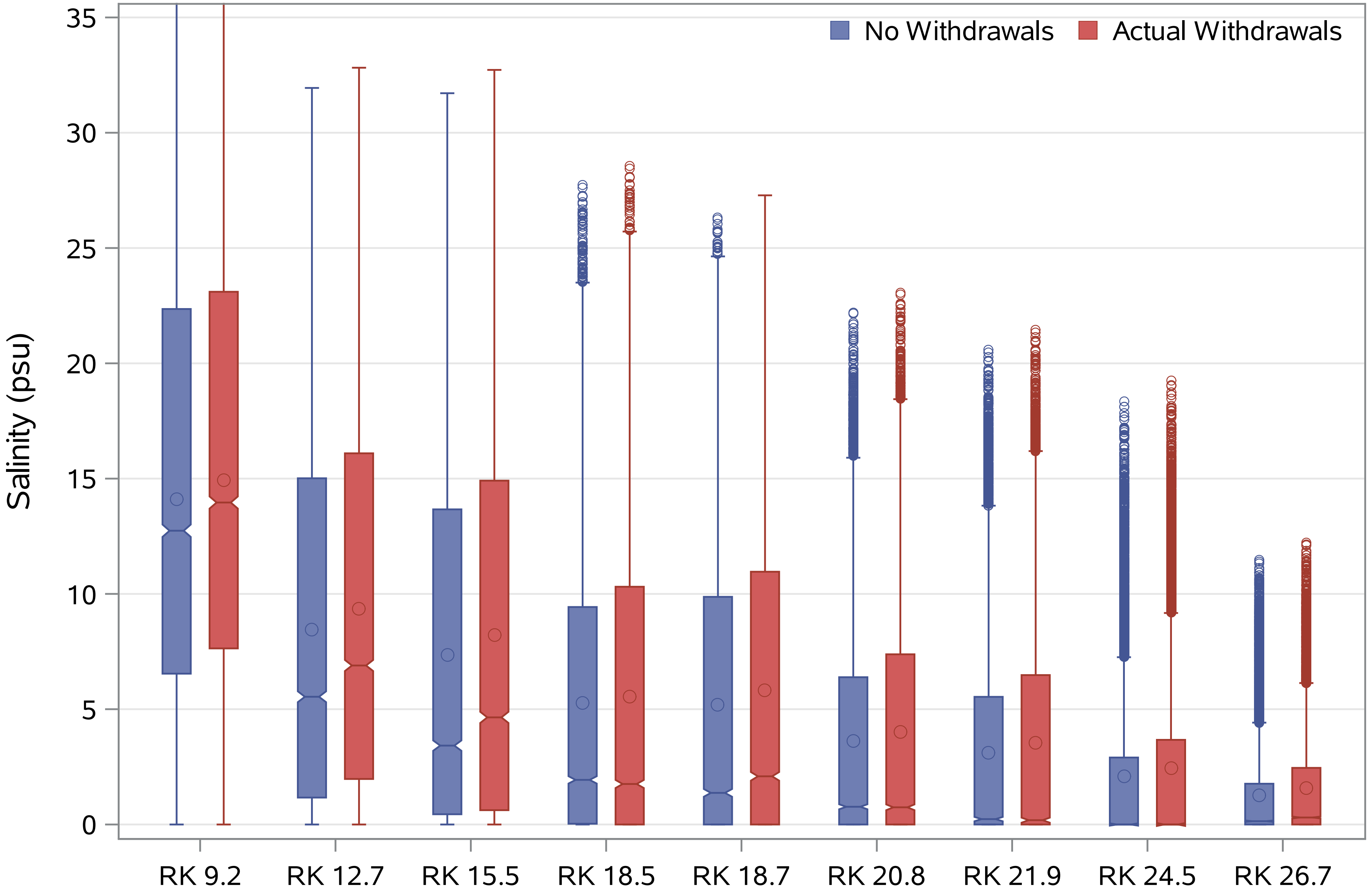


Figure 4.111. Box and whisker plots of salinity variability during 2009 at the continuous recorders

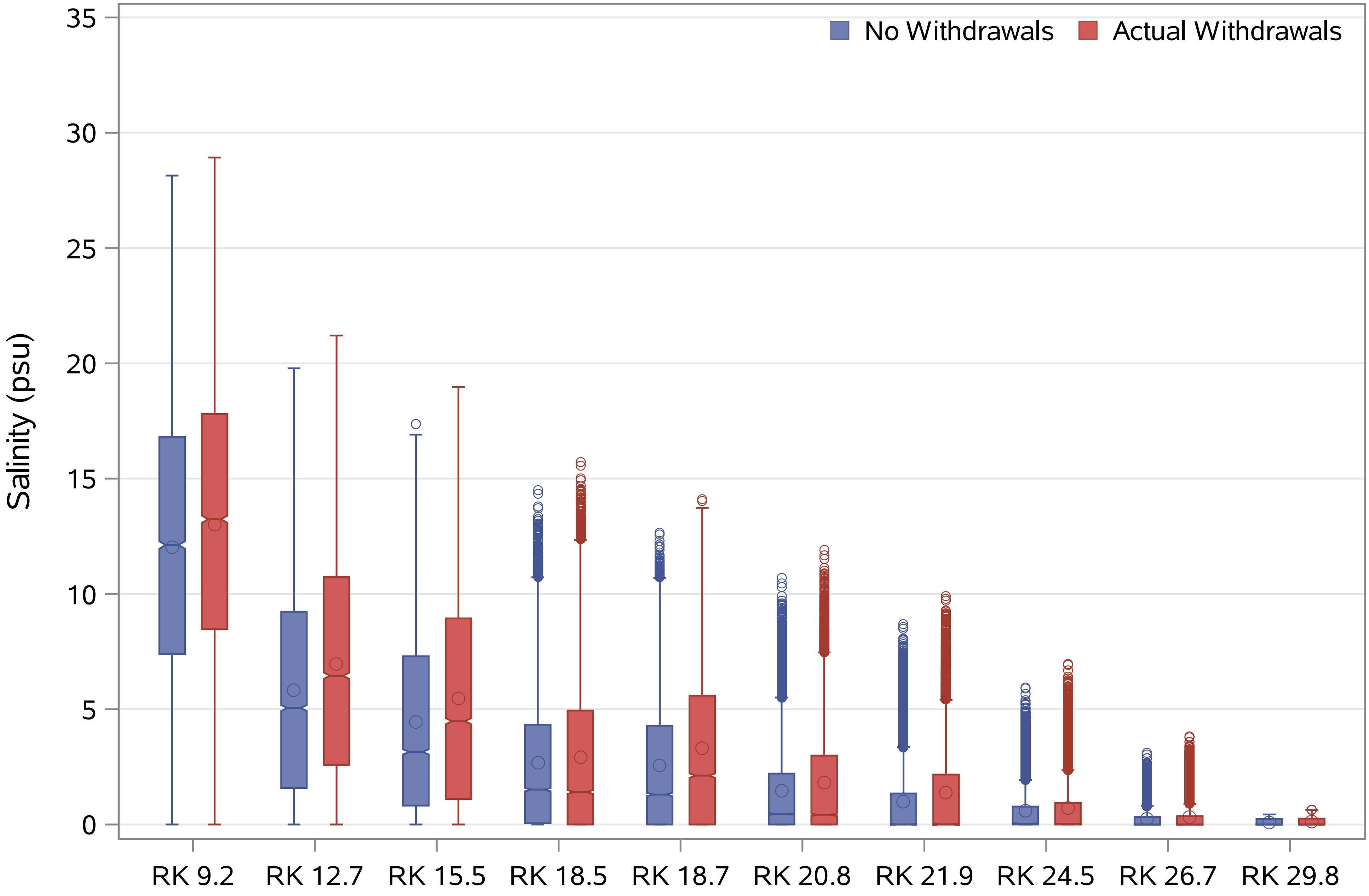


Figure 4.112. Box and whisker plots of salinity variability during 2010 at the continuous recorders

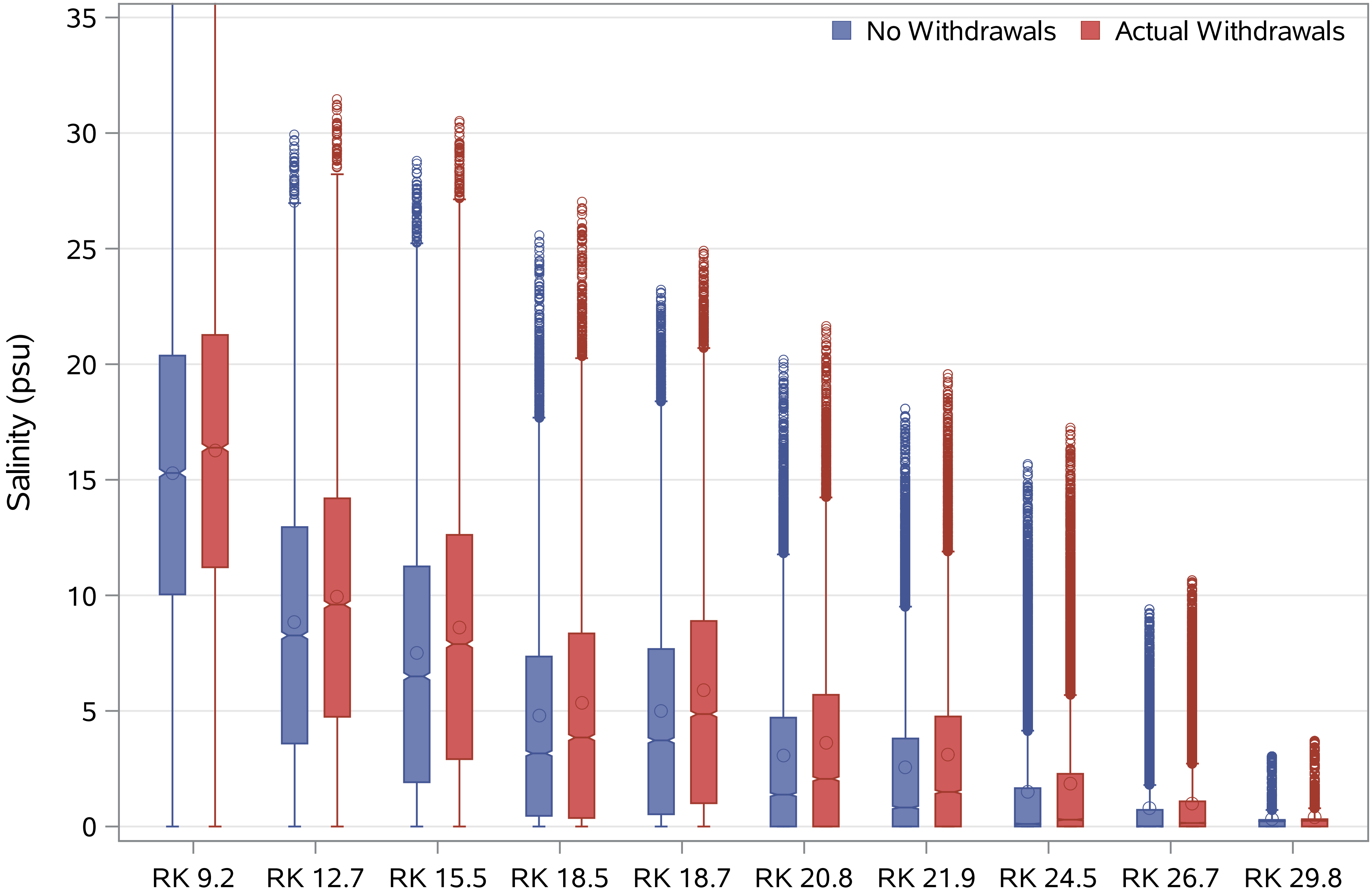


Figure 4.113. Box and whisker plots of salinity variability during 2011 at the continuous recorders

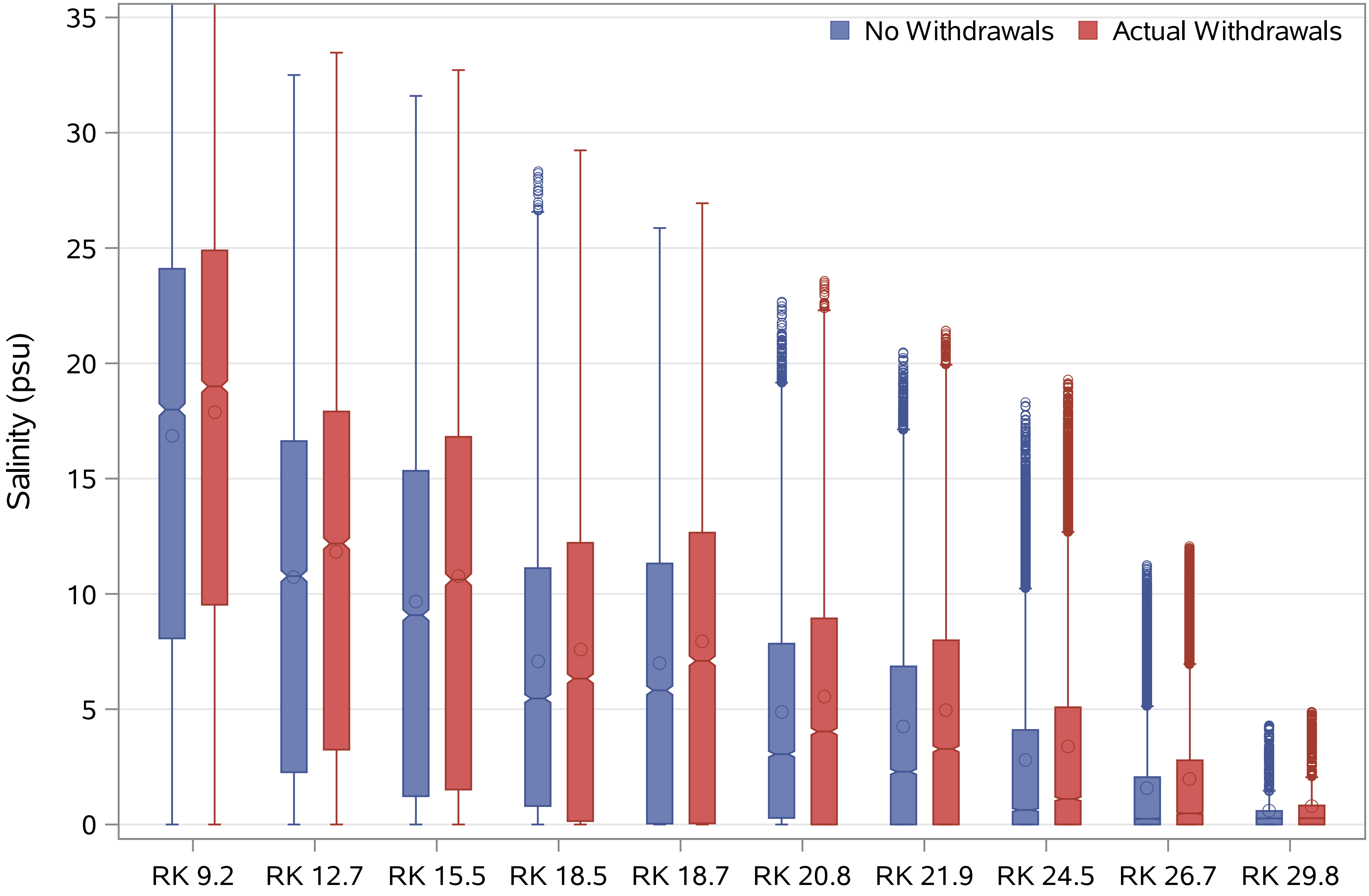


Figure 4.114. Box and whisker plots of salinity variability during 2012 at the continuous recorders

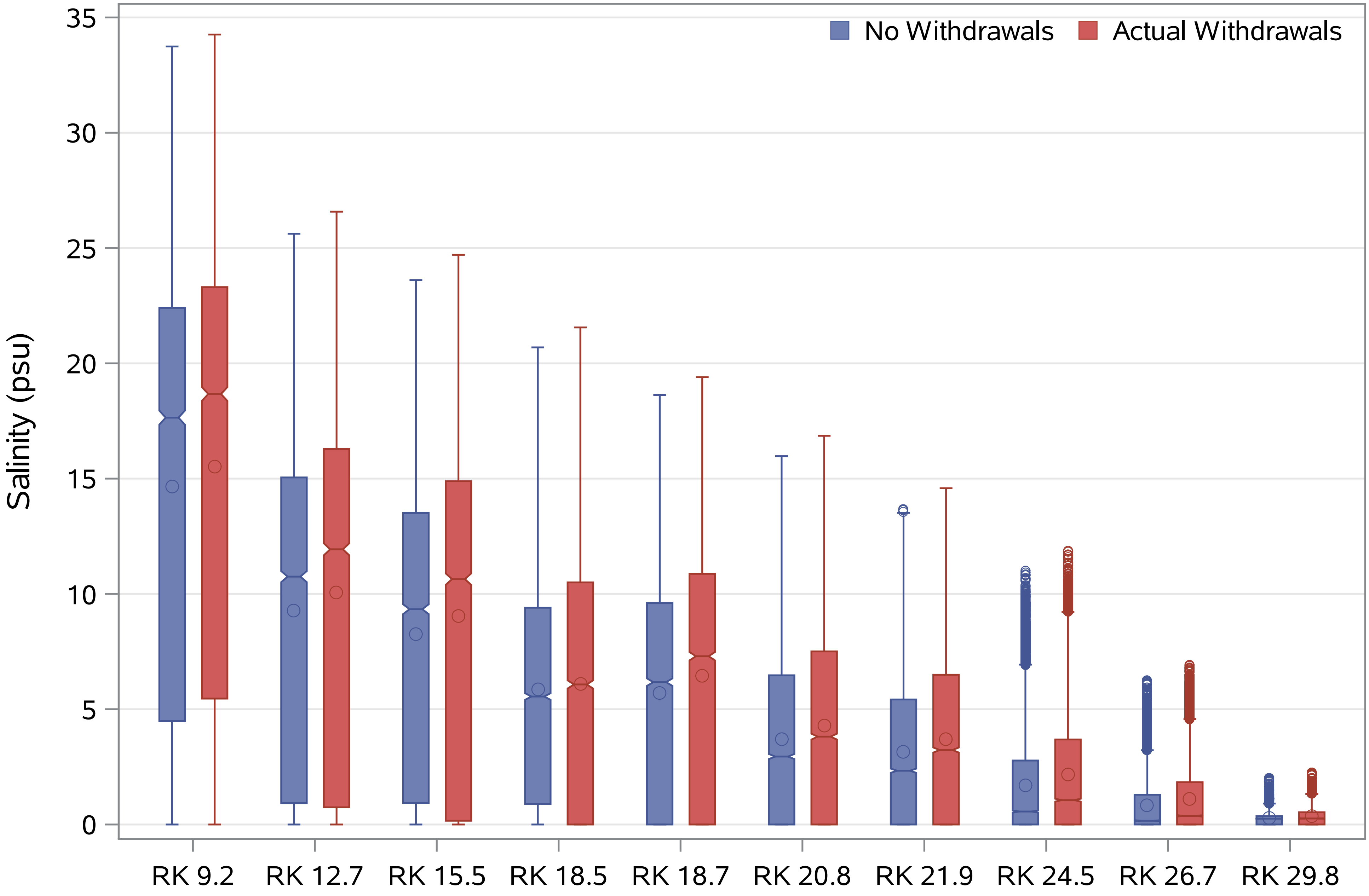


Figure 4.115. Box and whisker plots of salinity variability during 2013 at the continuous recorders

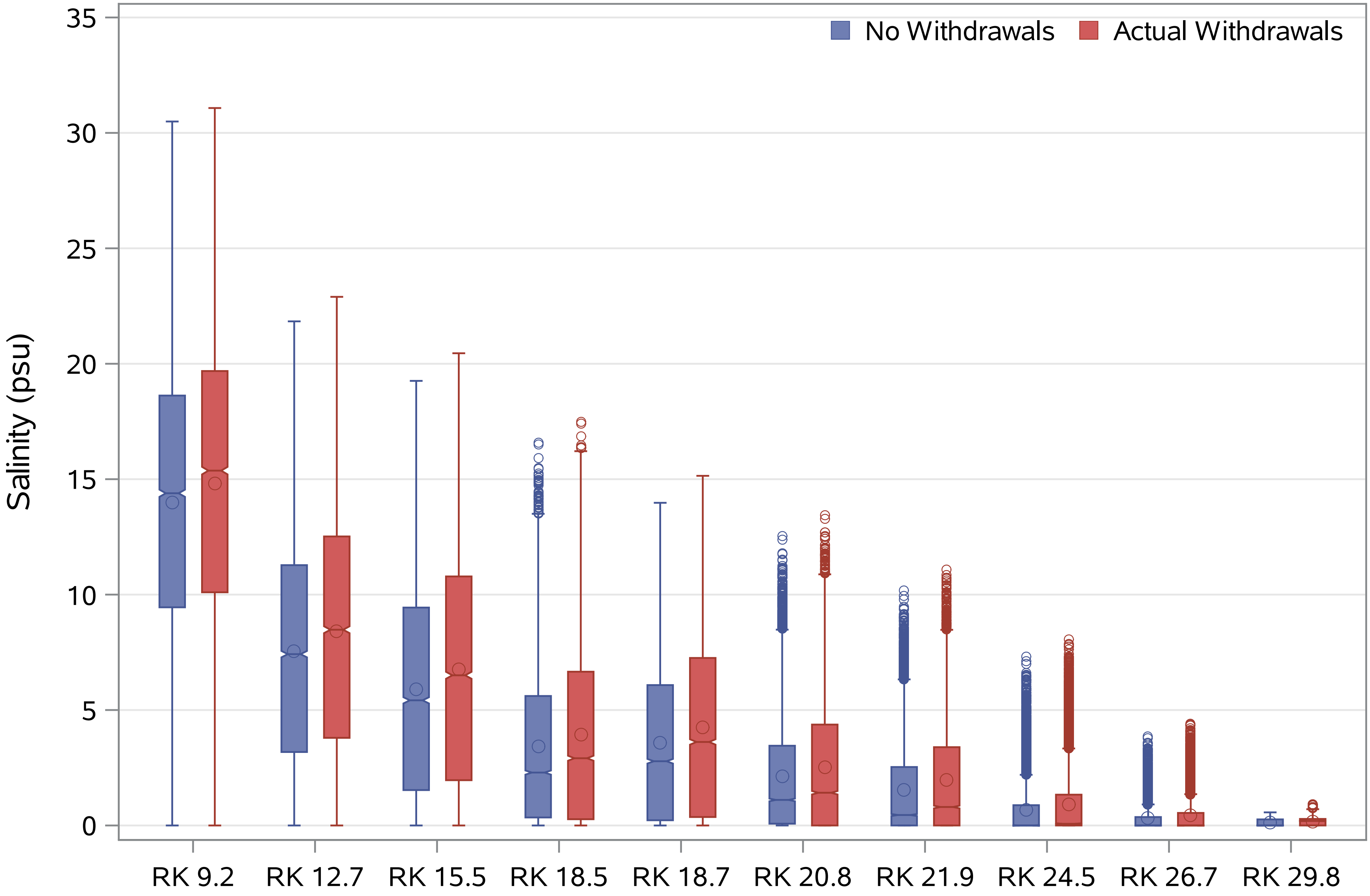


Figure 4.116. Box and whisker plots of salinity variability during 2014 at the continuous recorders

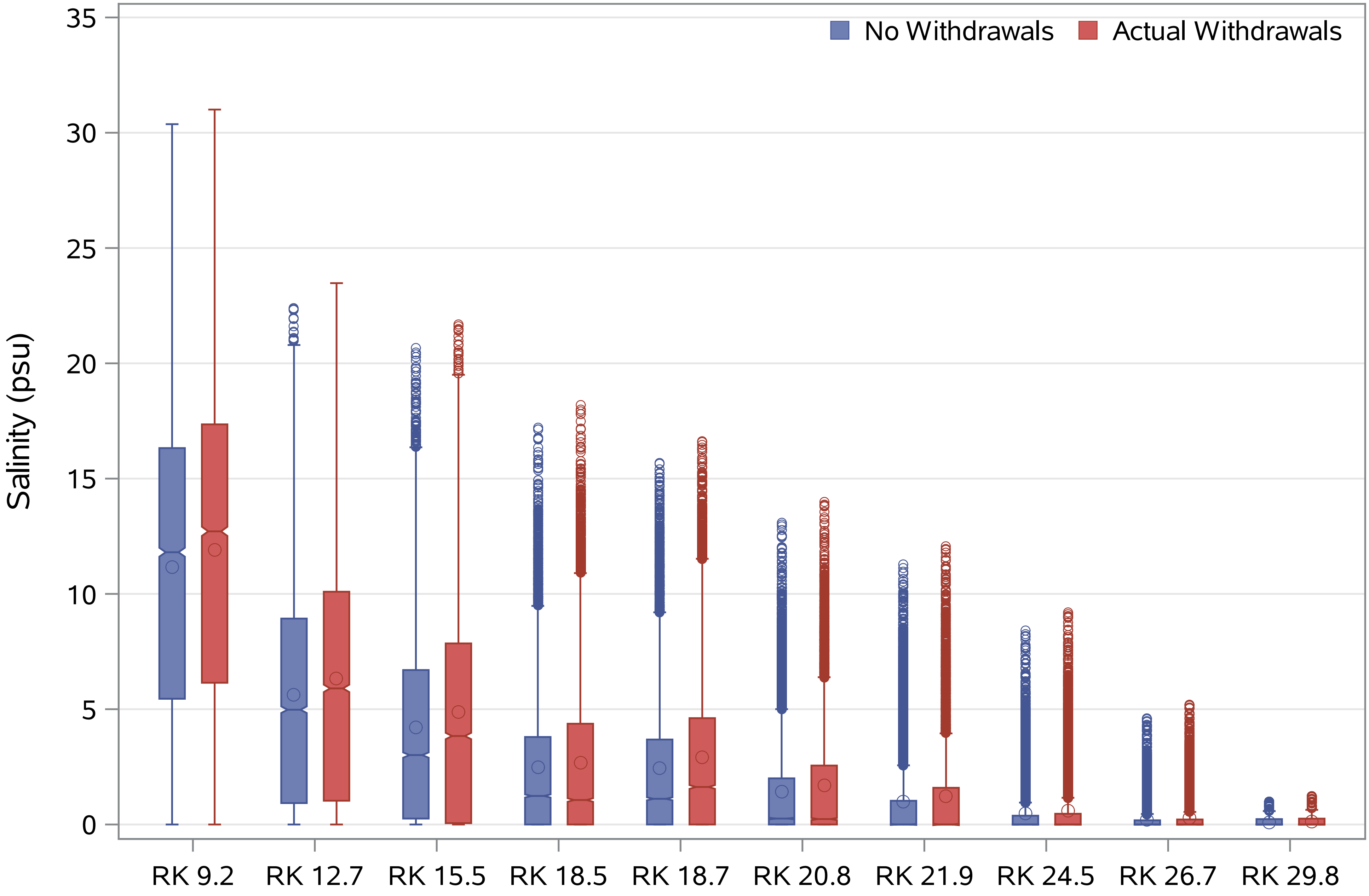


Figure 4.117. Box and whisker plots of salinity variability during 2015 at the continuous recorders

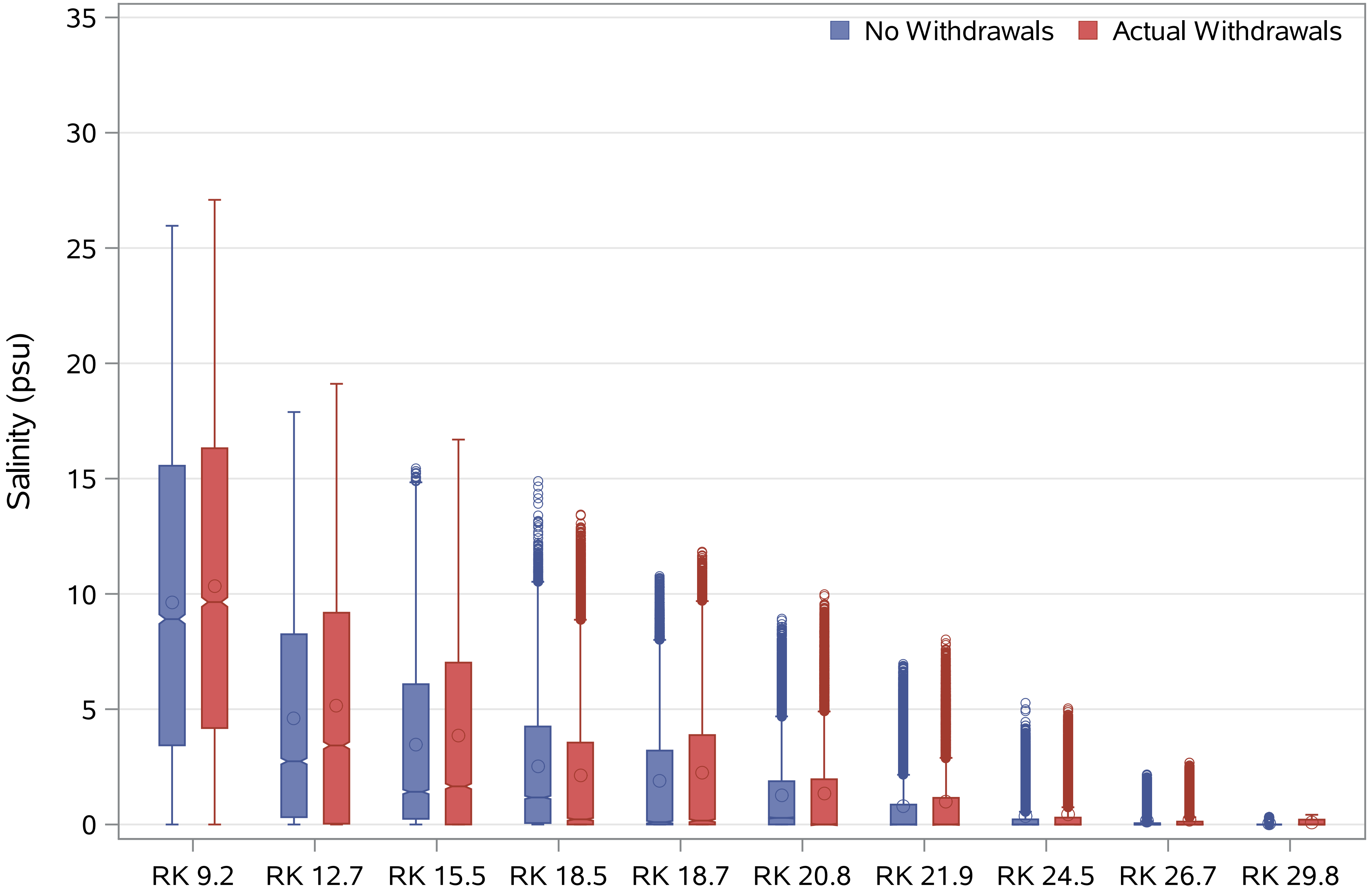


Figure 4.118. Box and whisker plots of salinity variability during 2016 at the continuous recorders

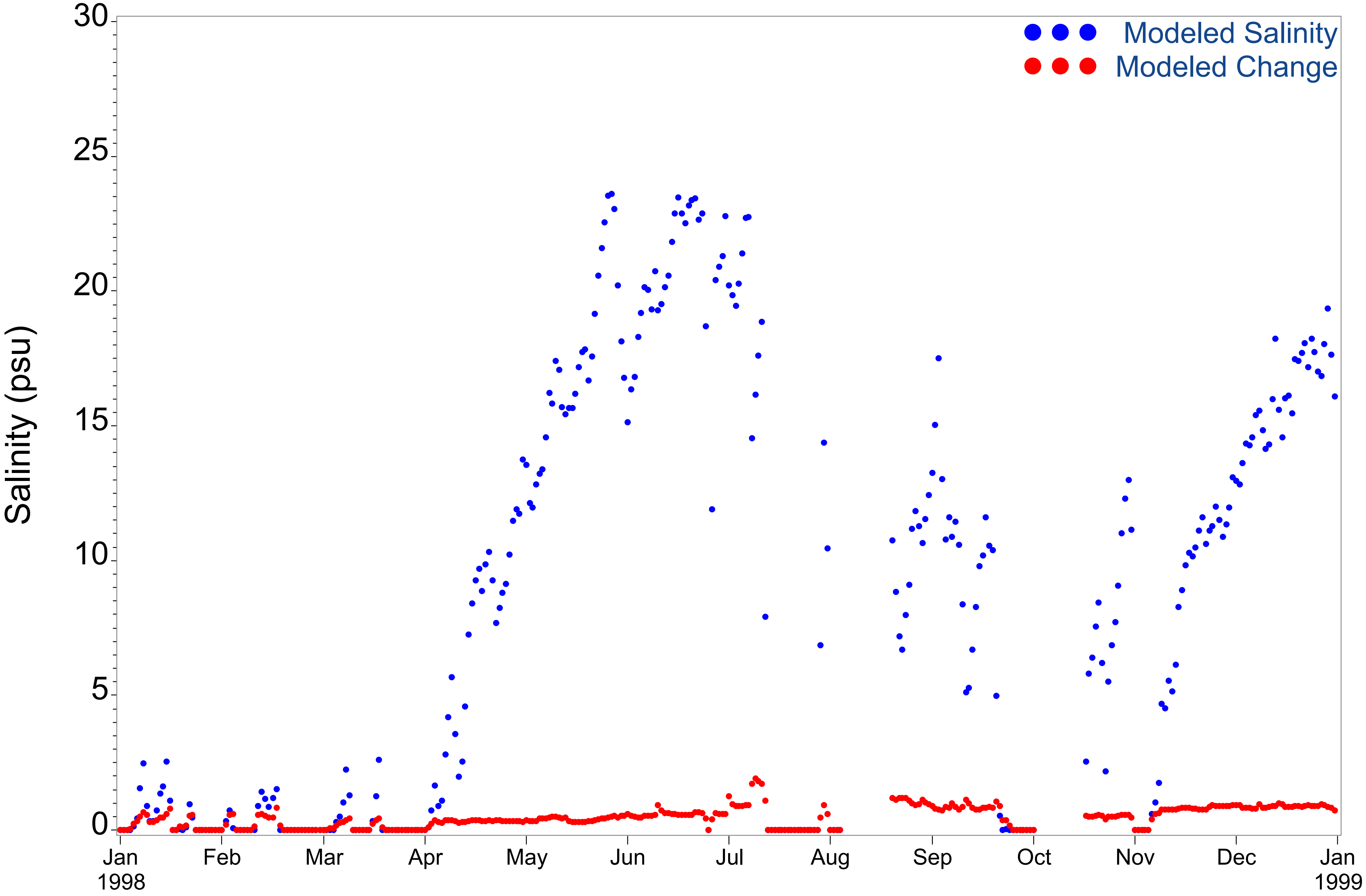


Figure 4.119 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 9.2 (1998)

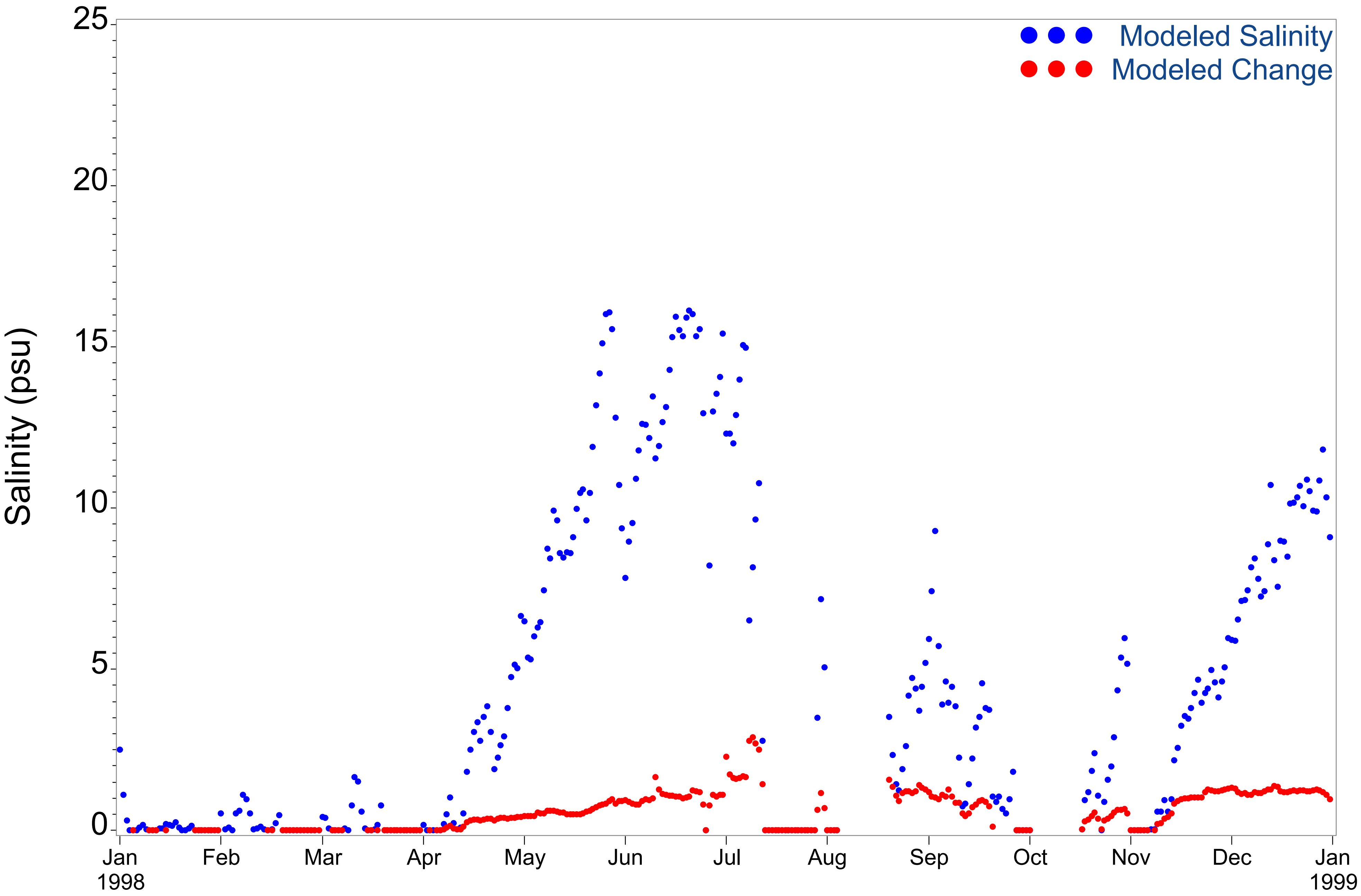


Figure 4.120 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 12.7 (1998)

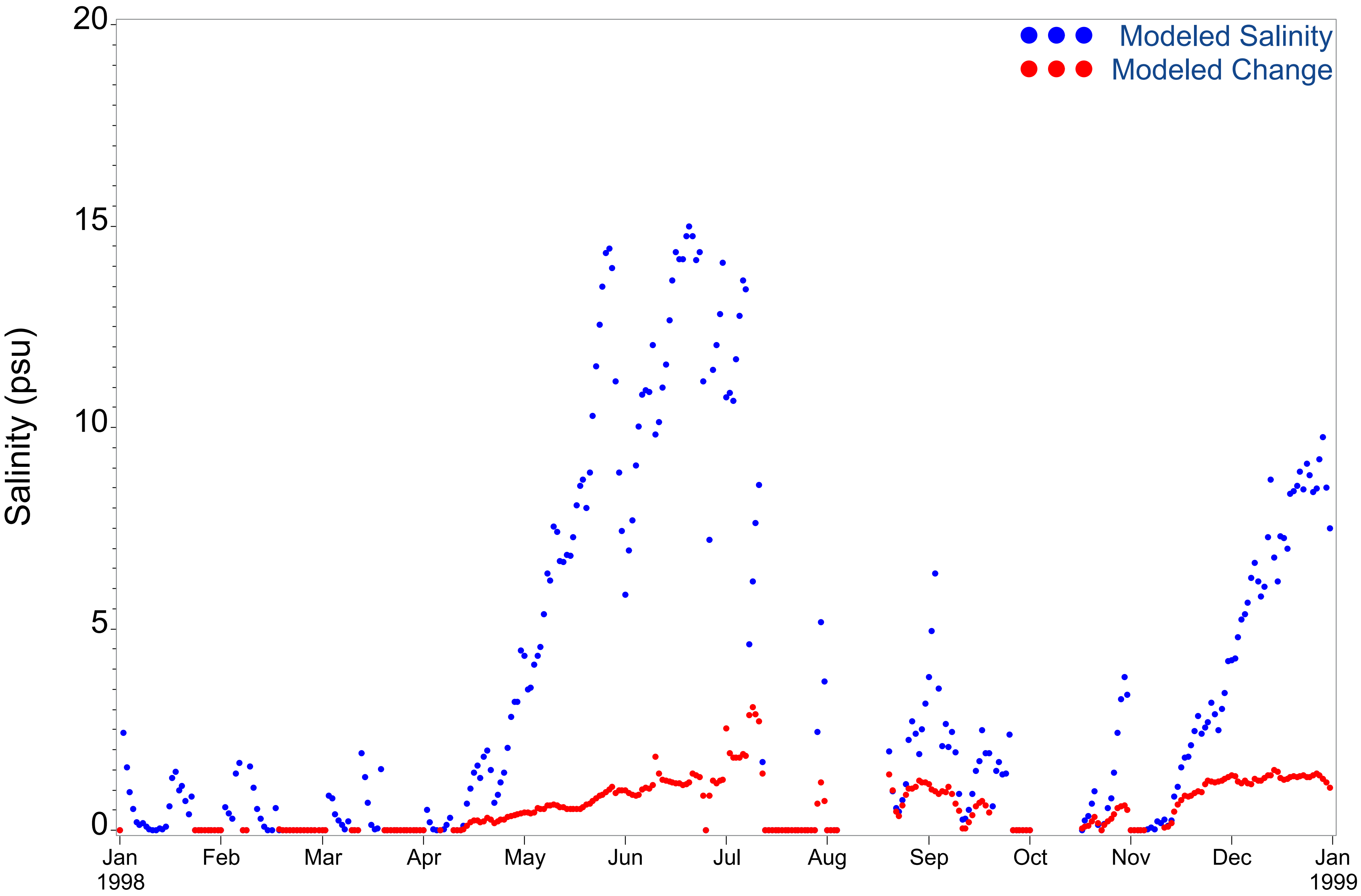


Figure 4.121 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 15.5 (1998)

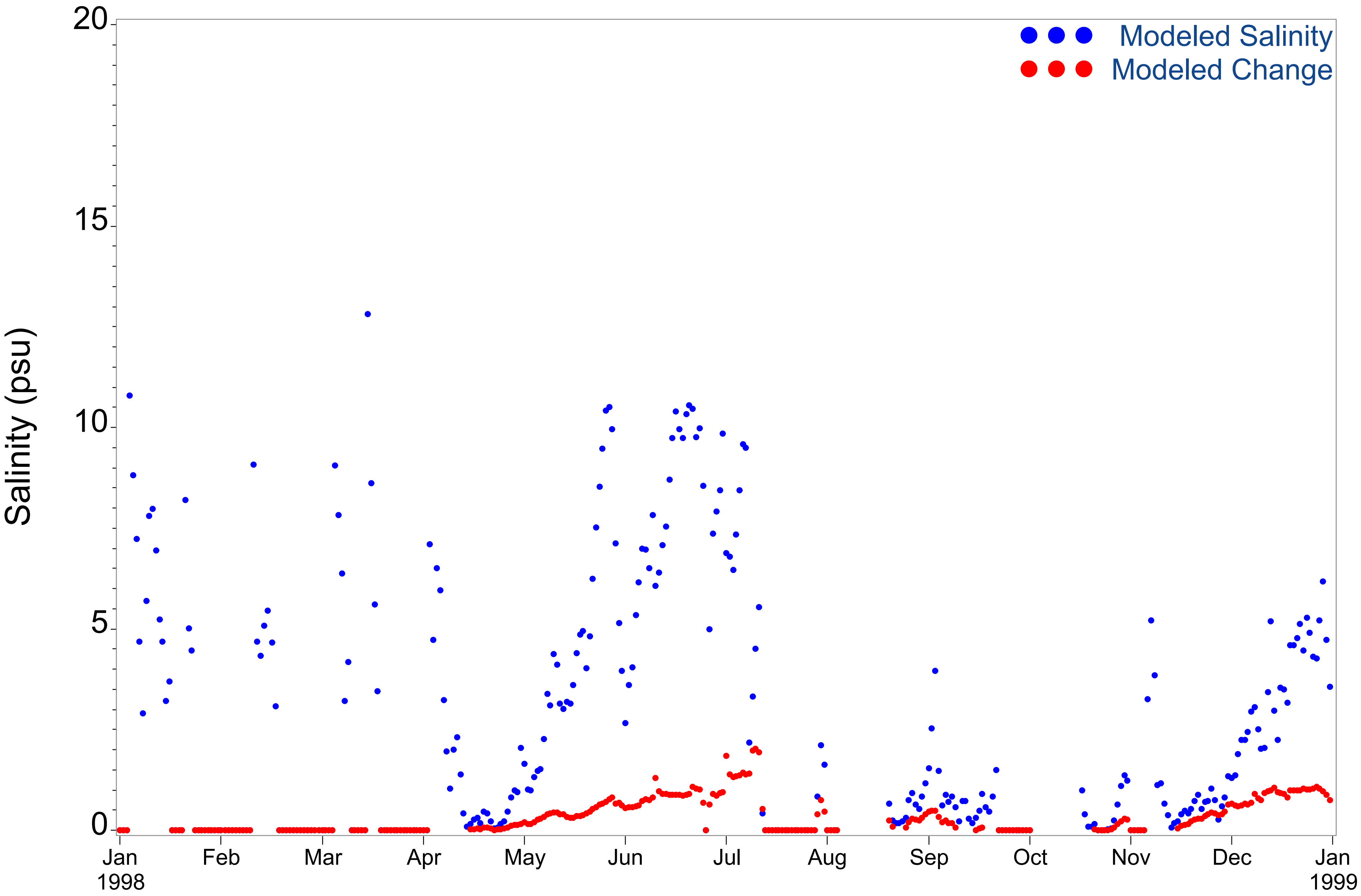


Figure 4.122 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.5 (1998)

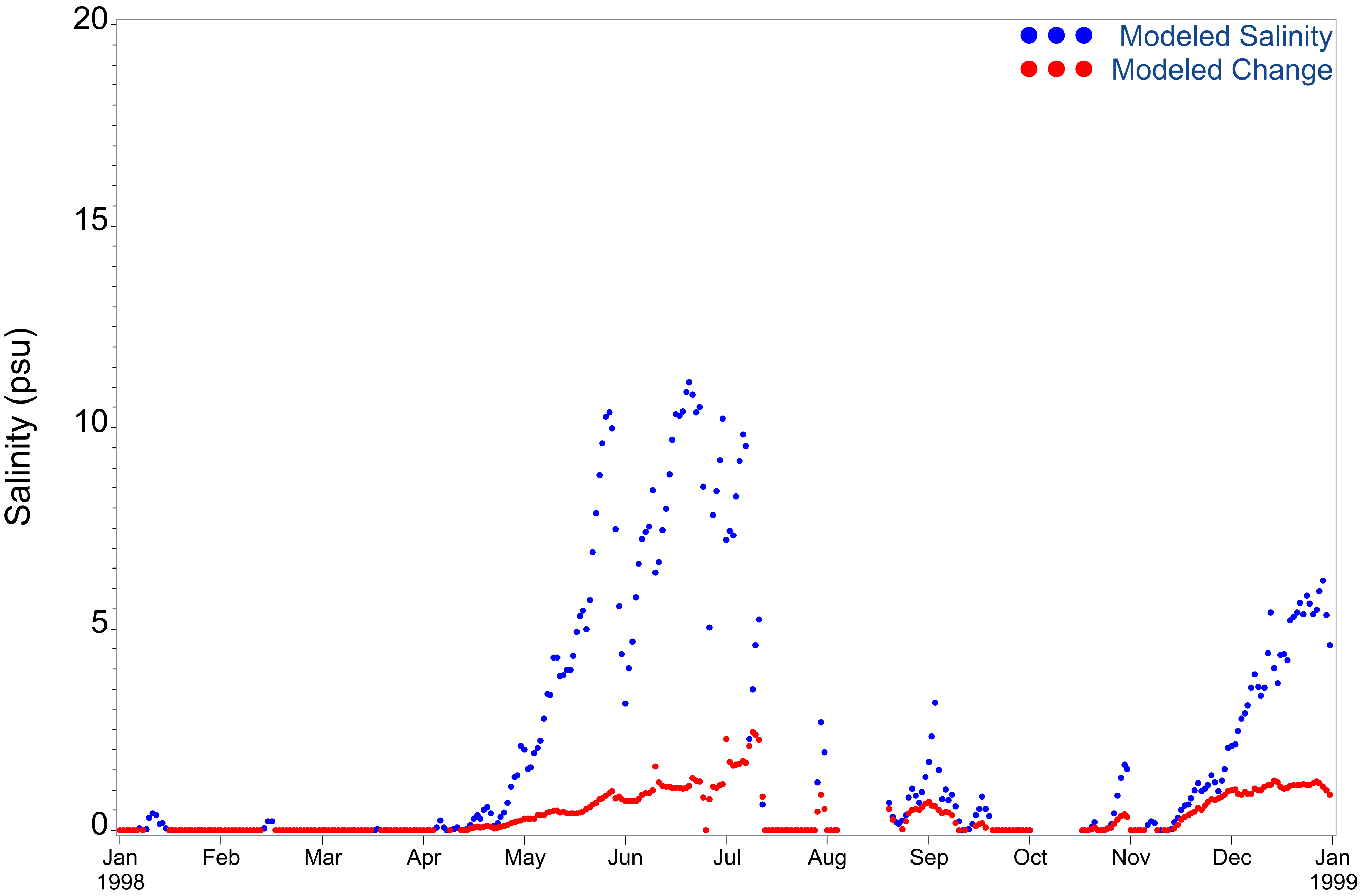


Figure 4.123 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.7 (1998)

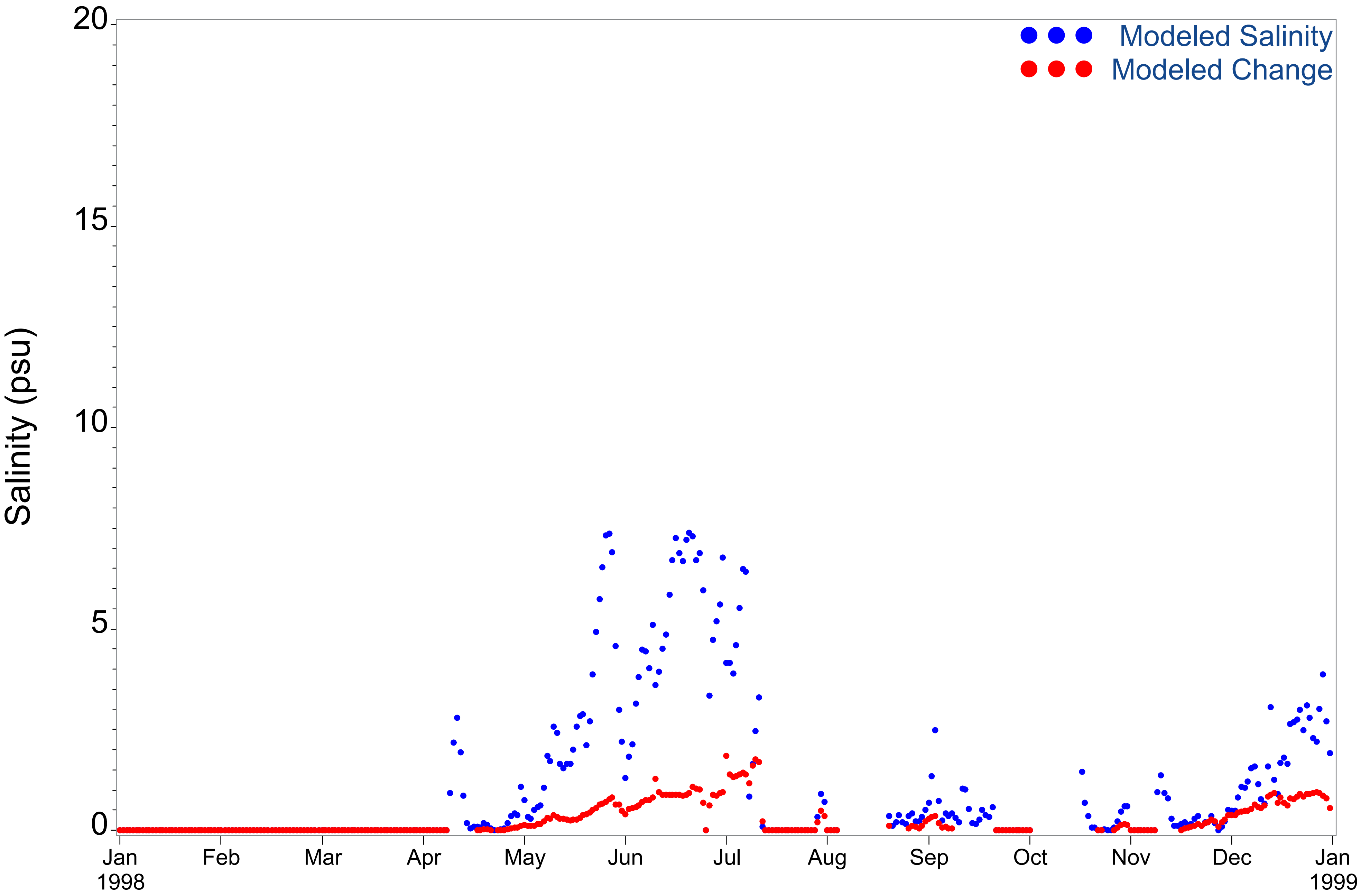


Figure 4.124 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 20.8 (1998)

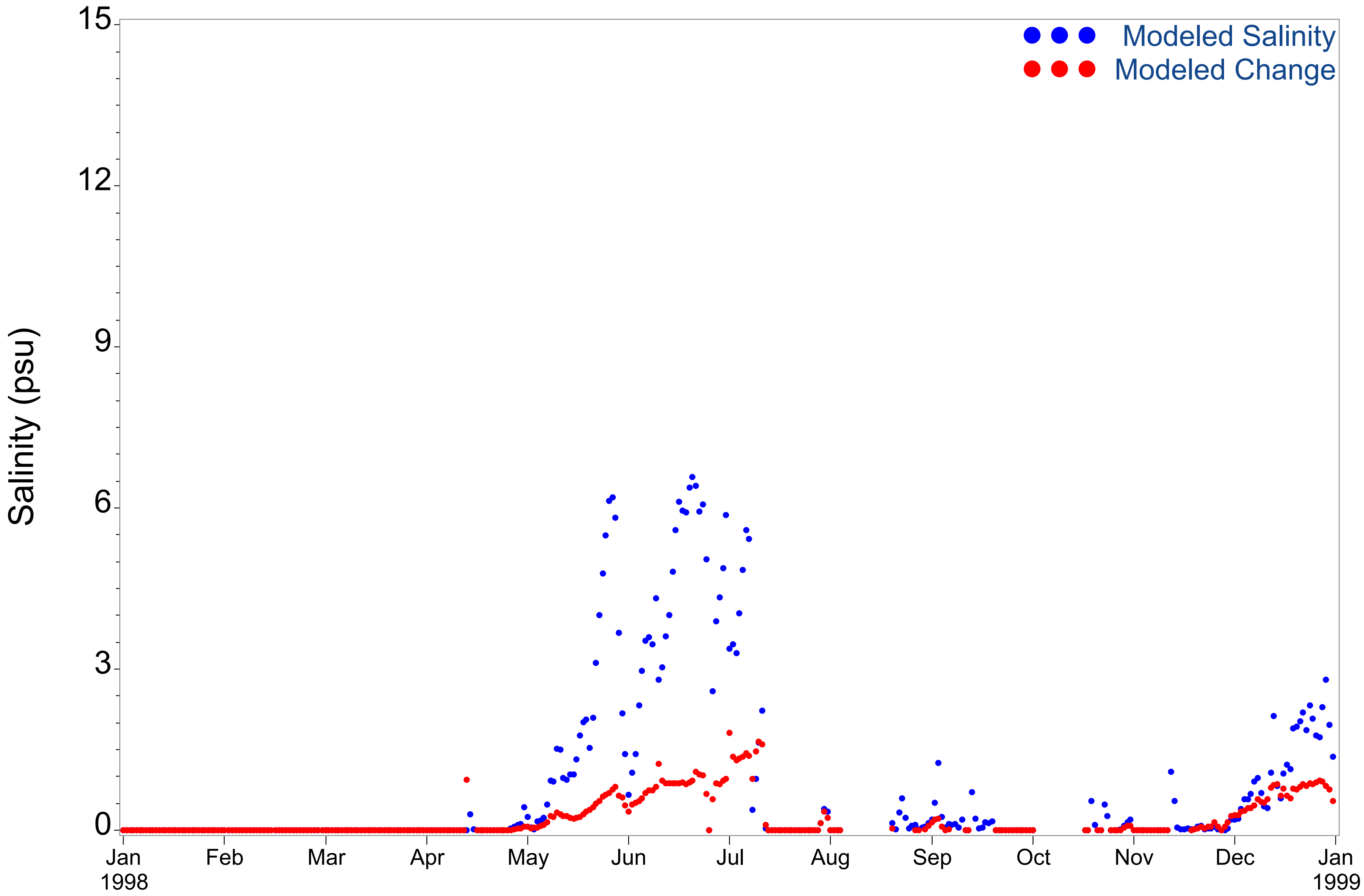


Figure 4.125 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 21.9 (1998)

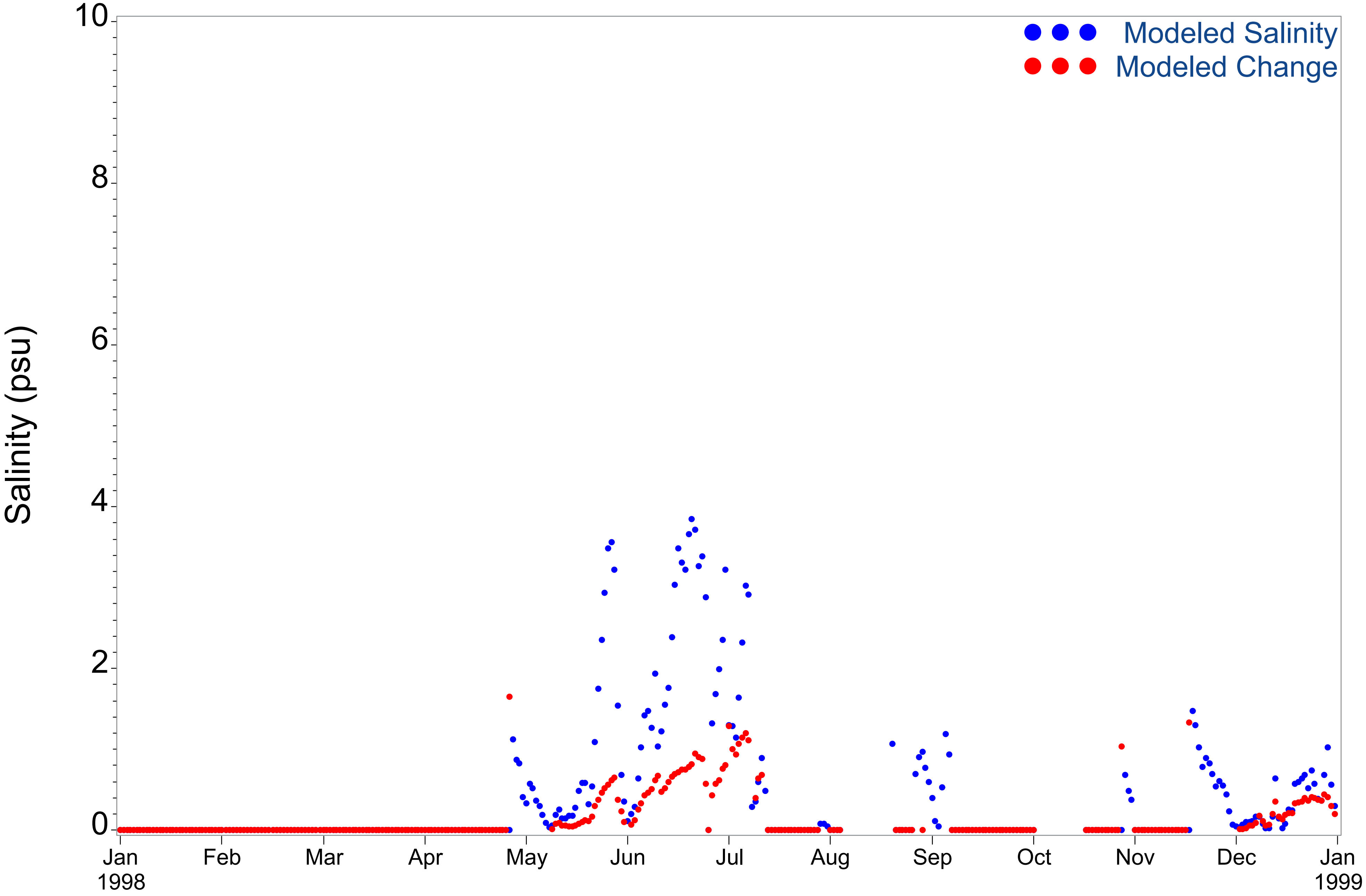


Figure 4.126 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 24.5 (1998)

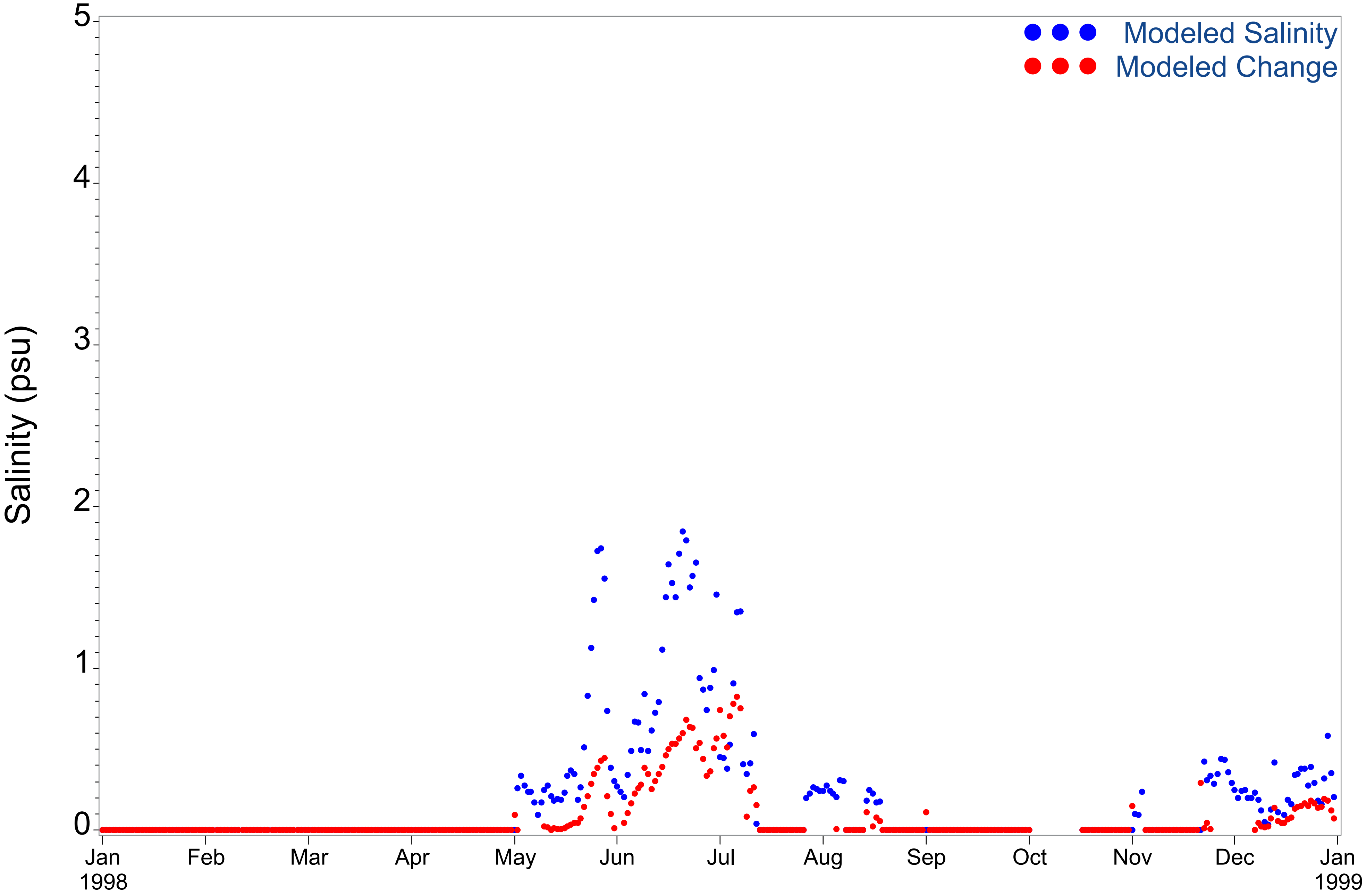


Figure 4.127 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 26.7 (1998)

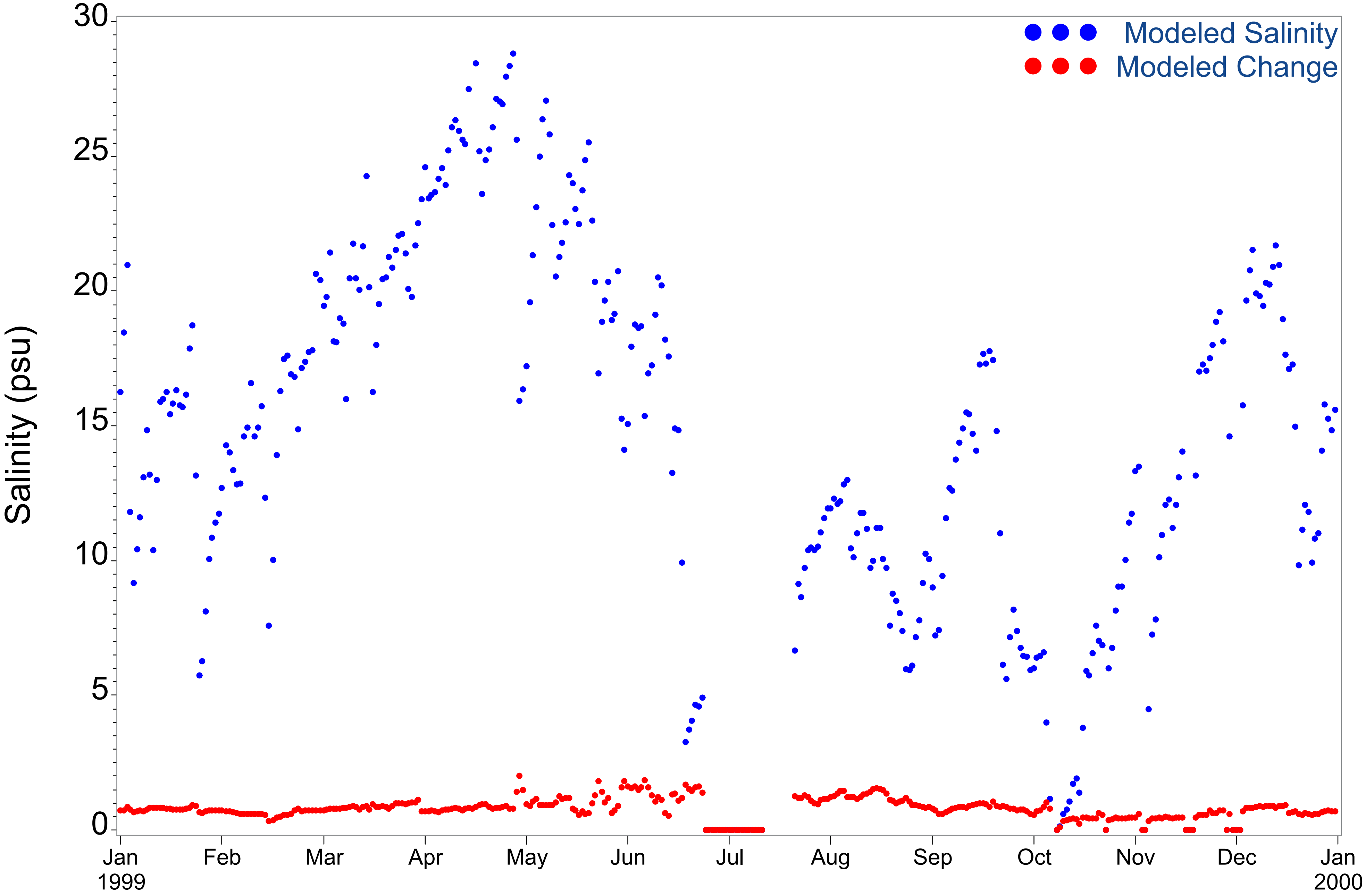


Figure 4.128 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 9.2 (1999)

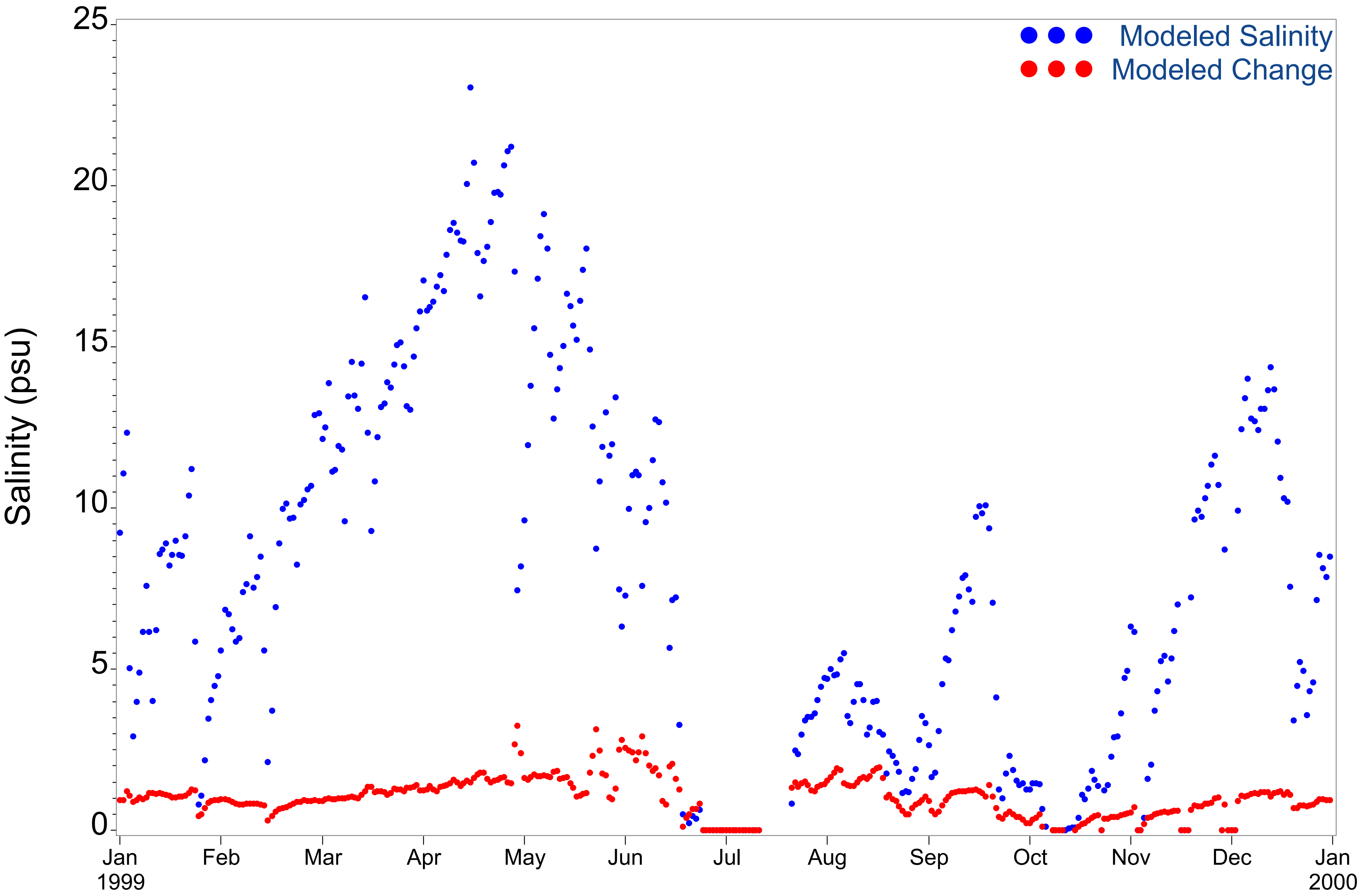


Figure 4.129 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 12.7 (1999)

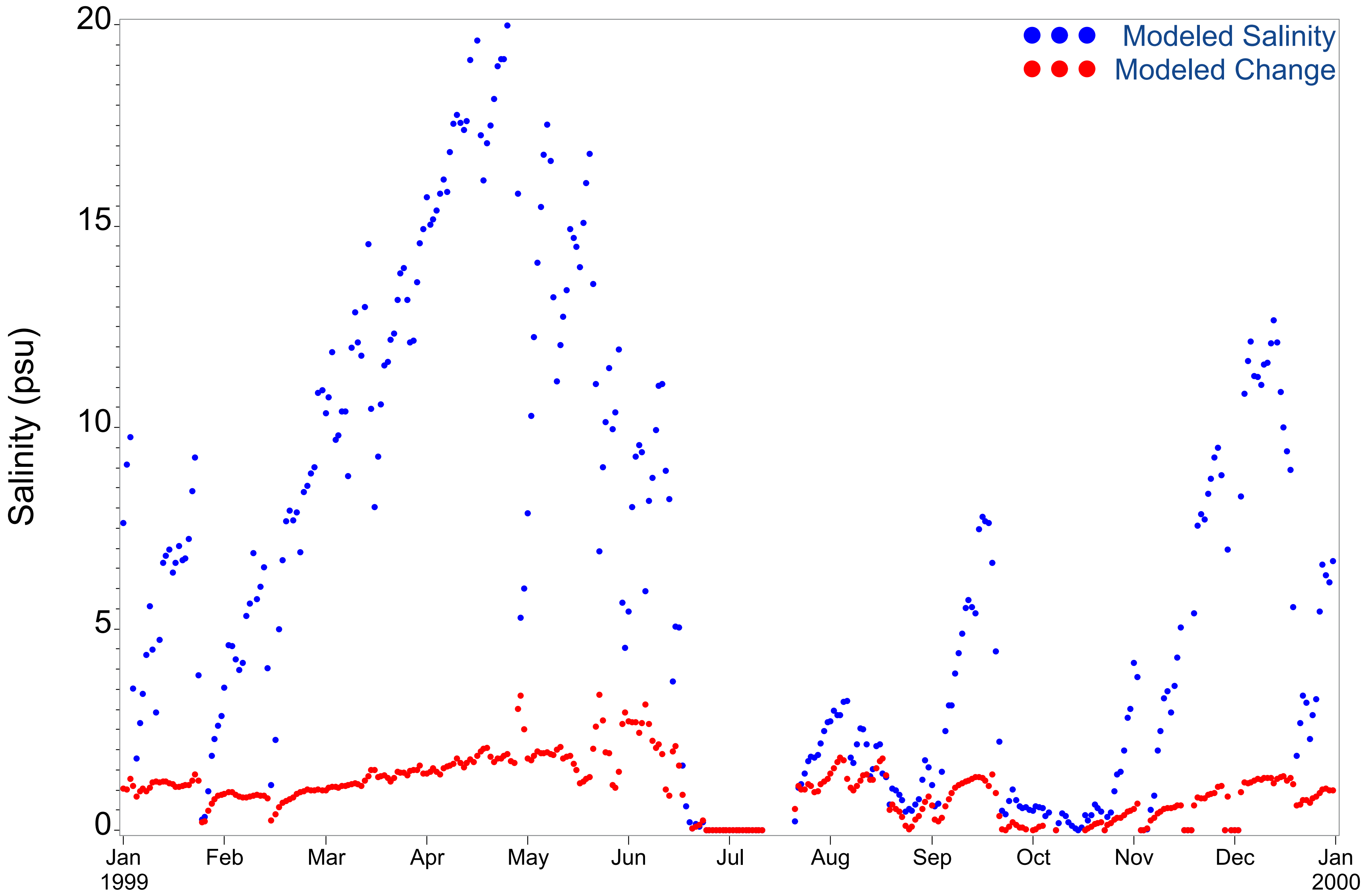


Figure 4.130 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 15.5 (1999)

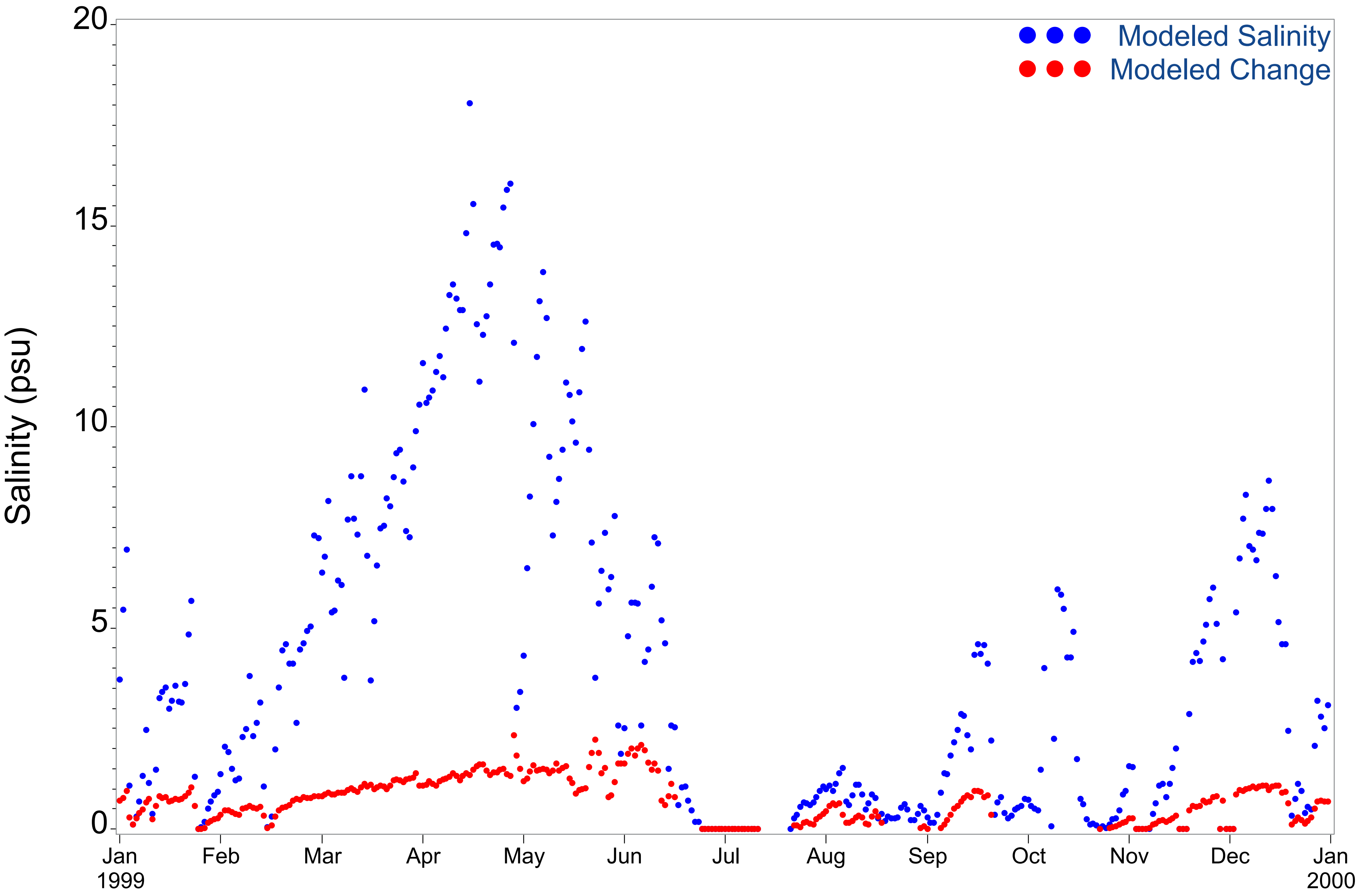


Figure 4.131 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.5 (1999)

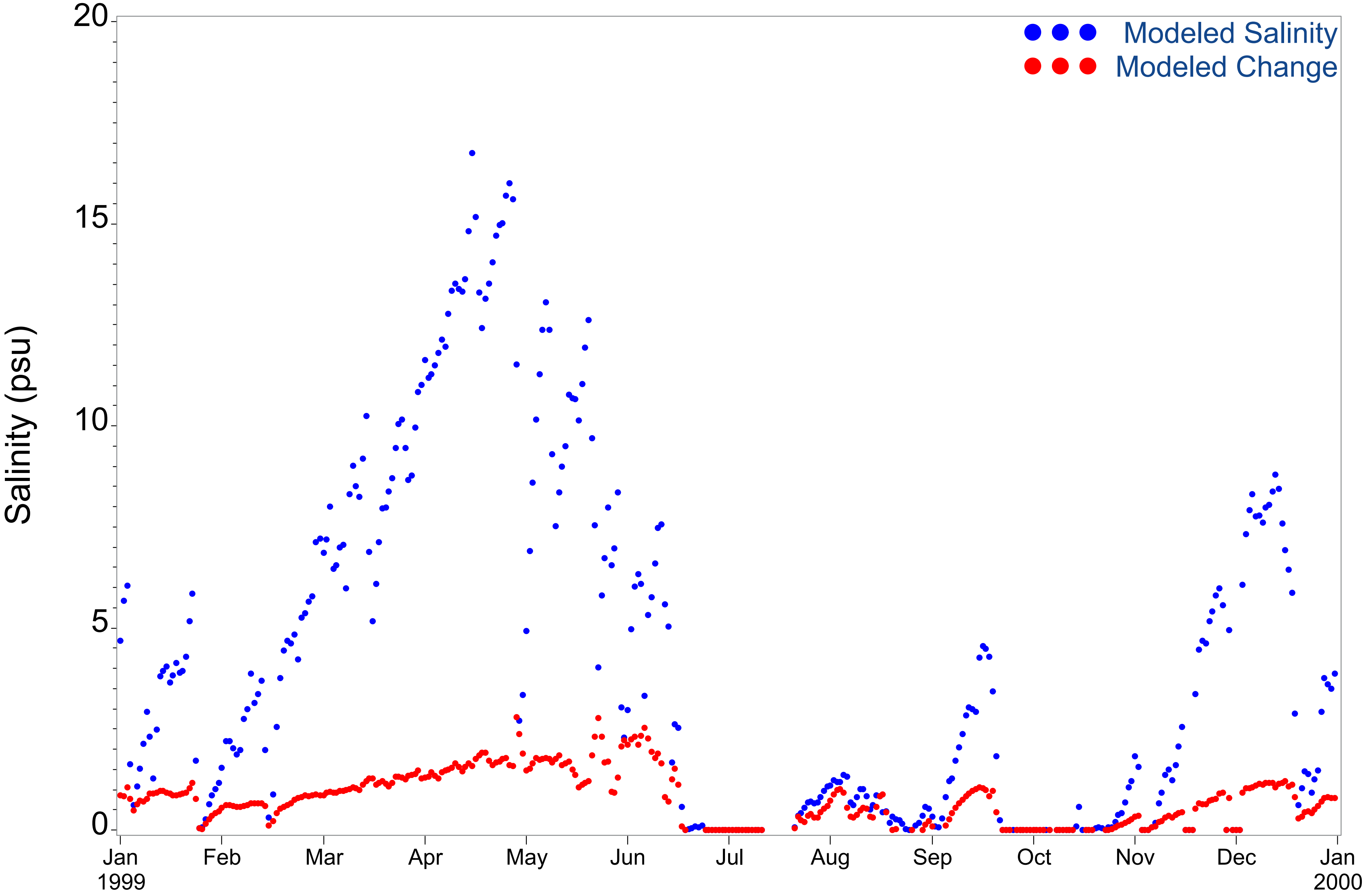


Figure 4.132 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.7 (1999)

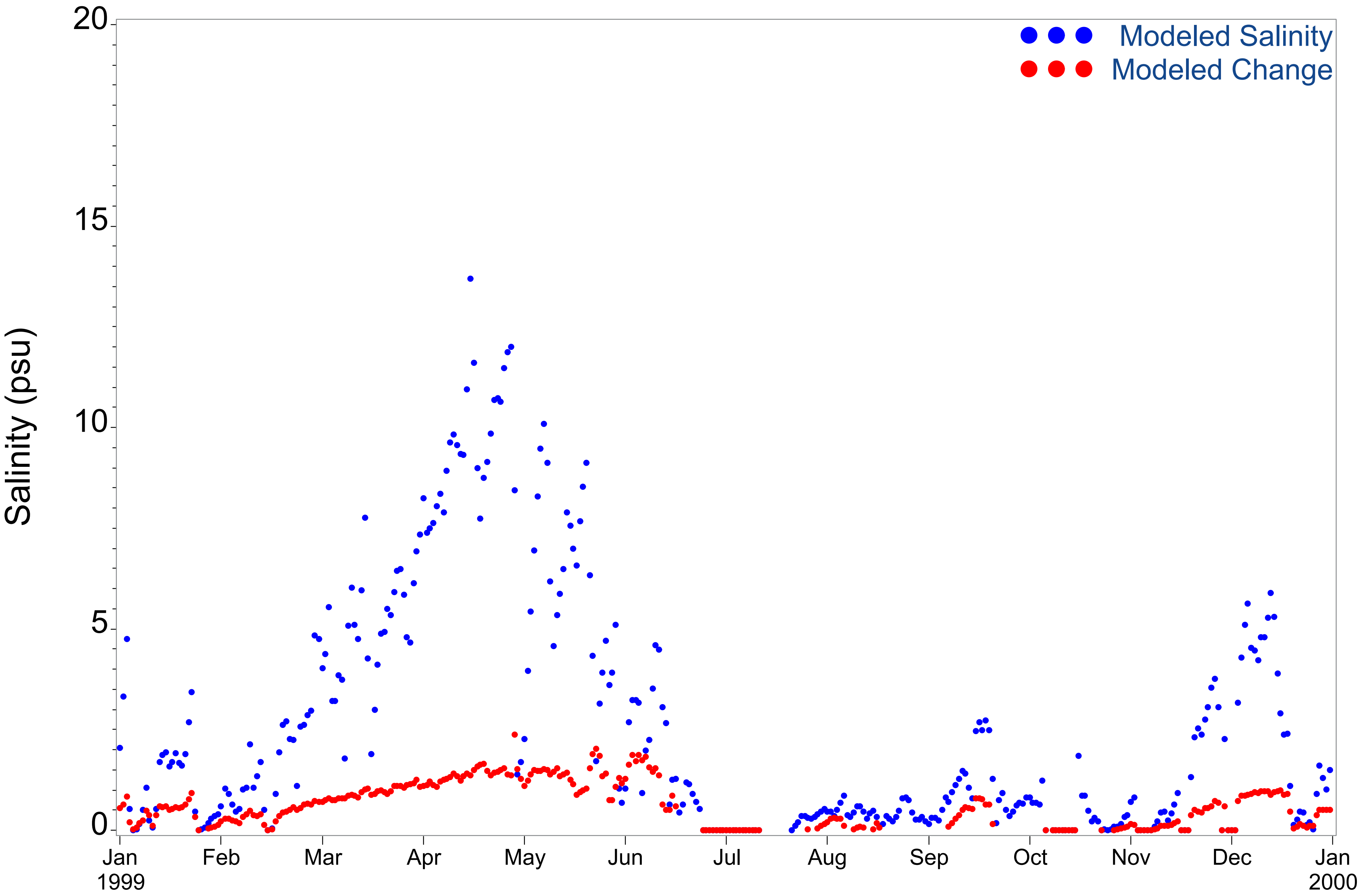


Figure 4.133 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 20.8 (1999)

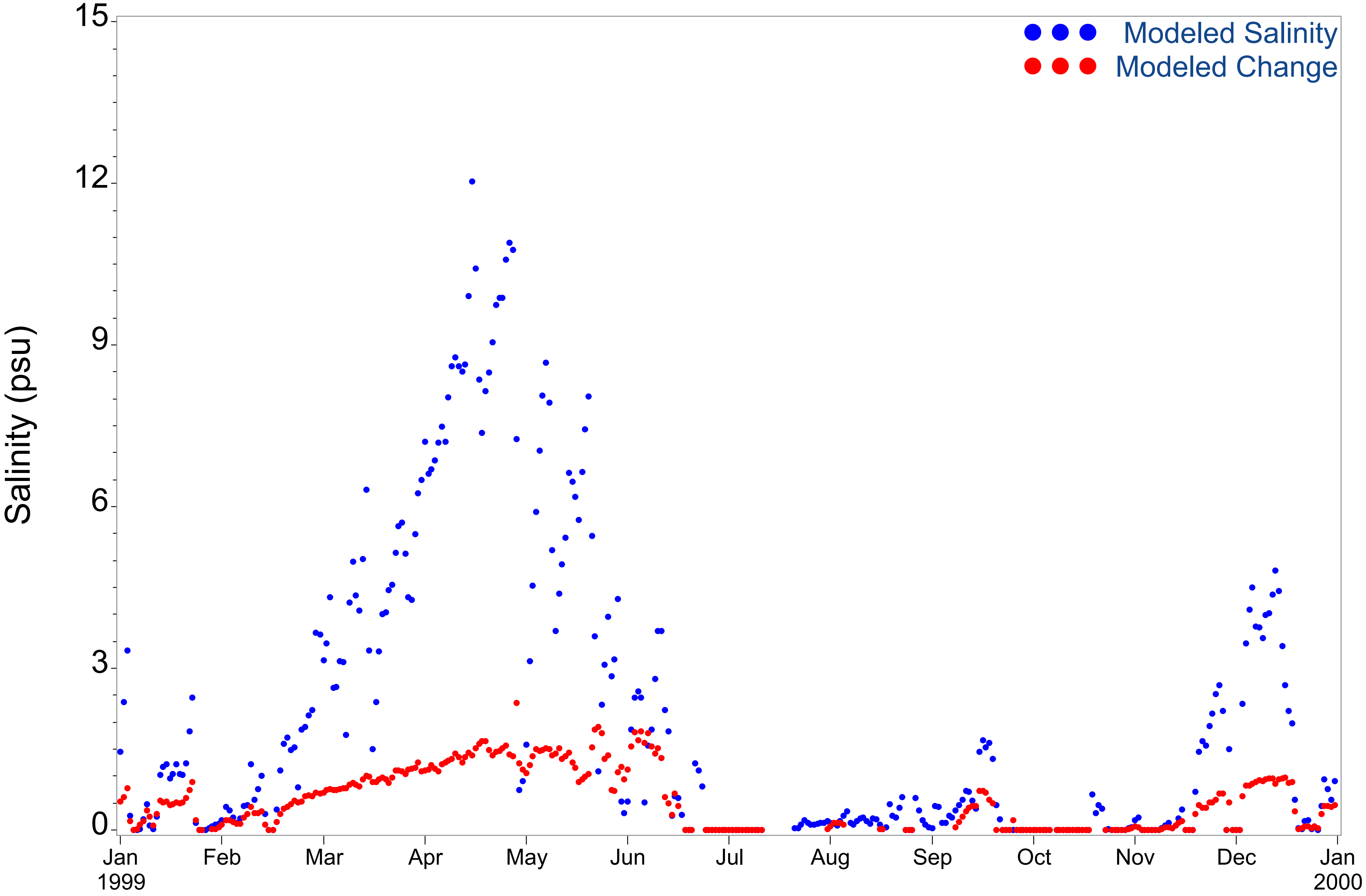


Figure 4.134 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 21.9 (1999)

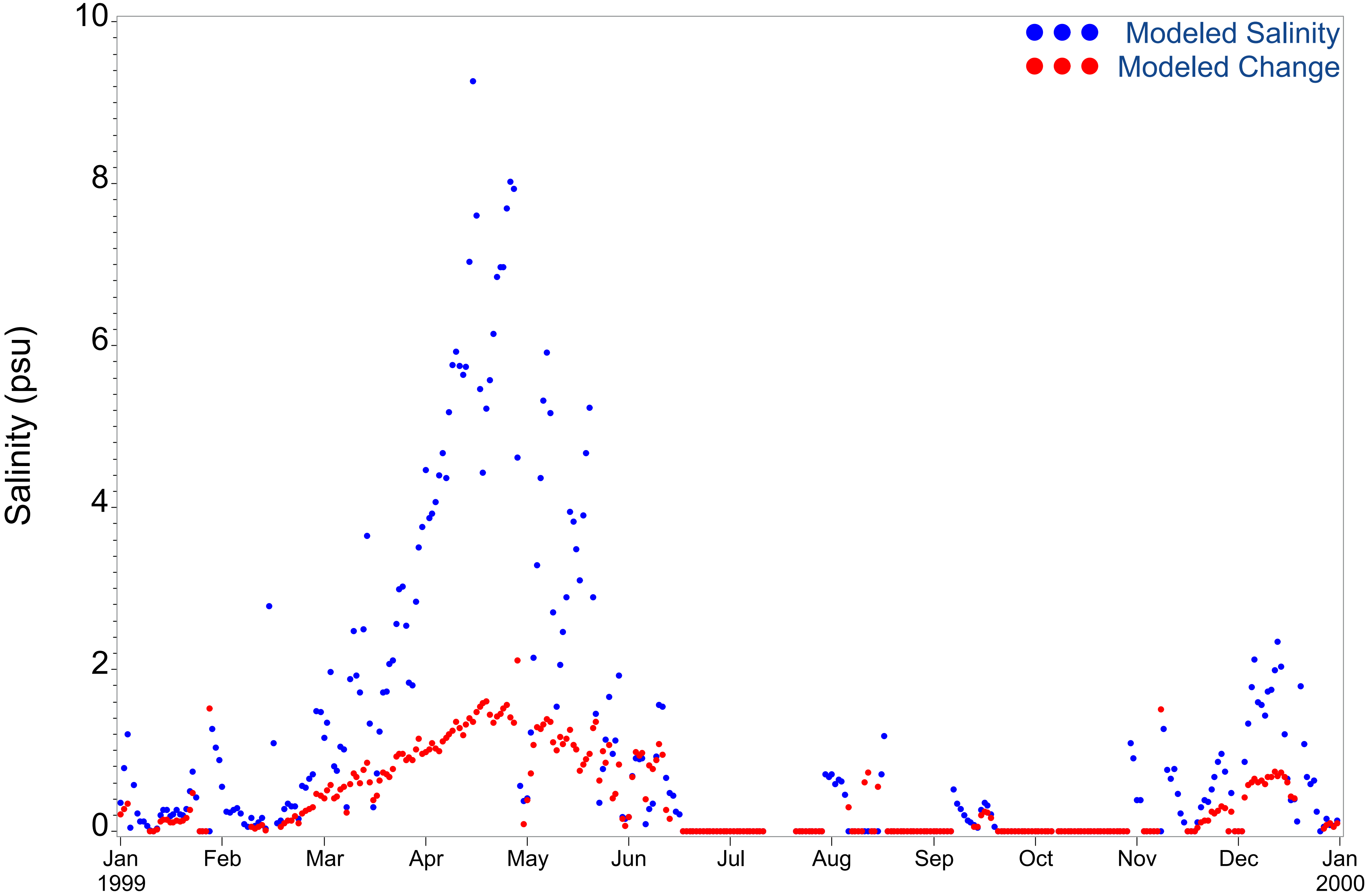


Figure 4.135 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 24.5 (1999)

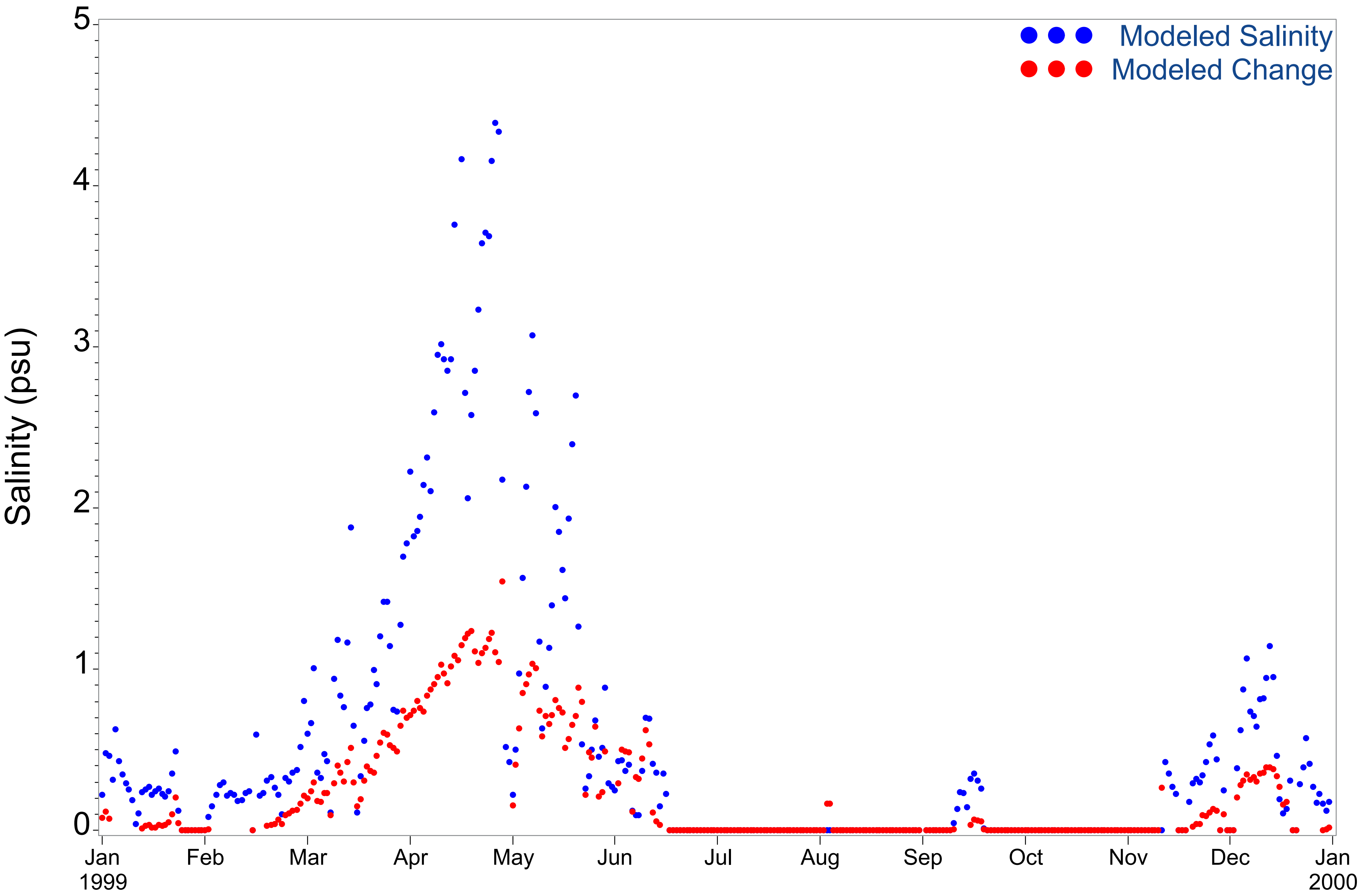


Figure 4.136 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 26.7 (1999)

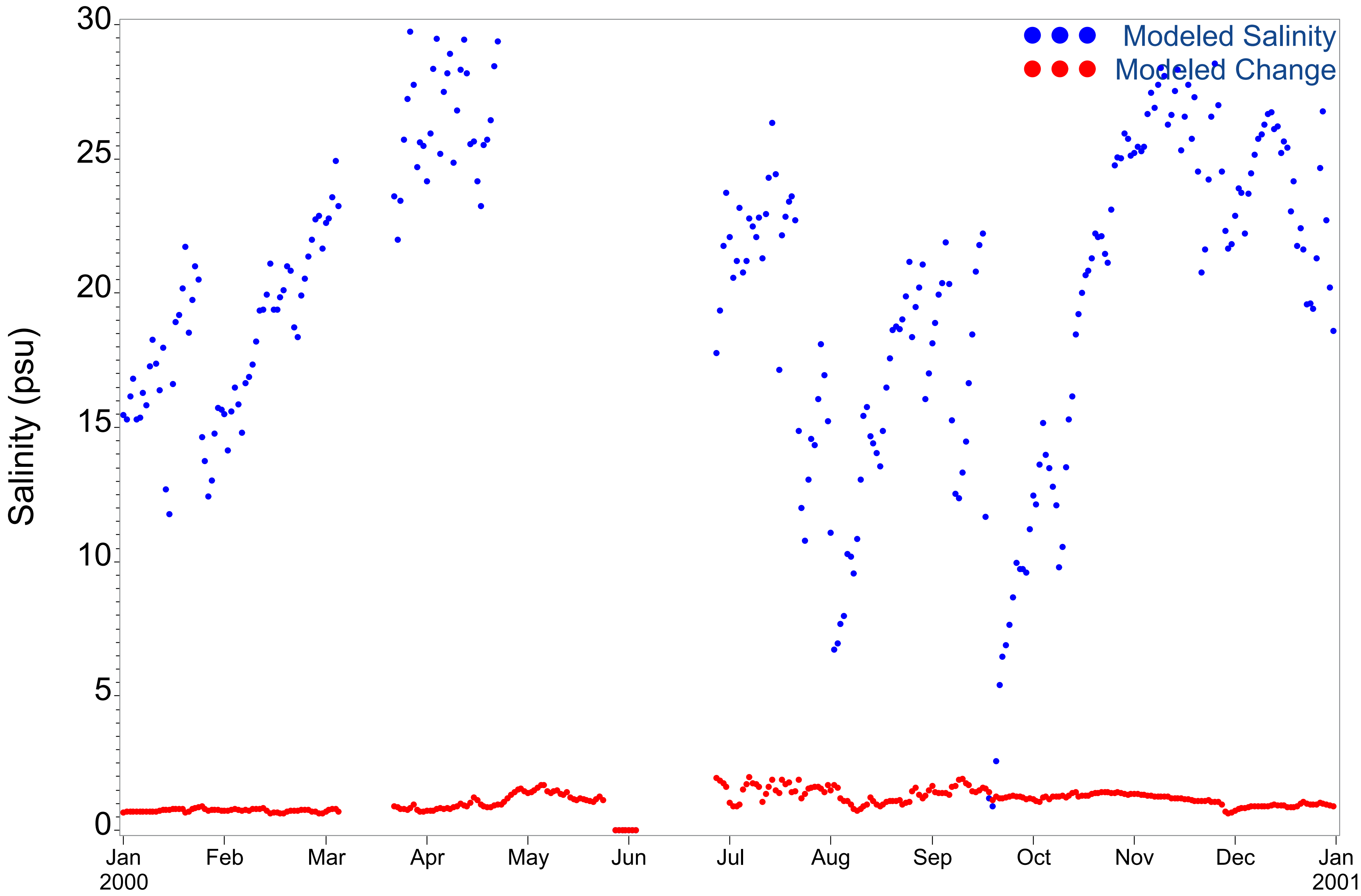


Figure 4.137 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 9.2 (2000)

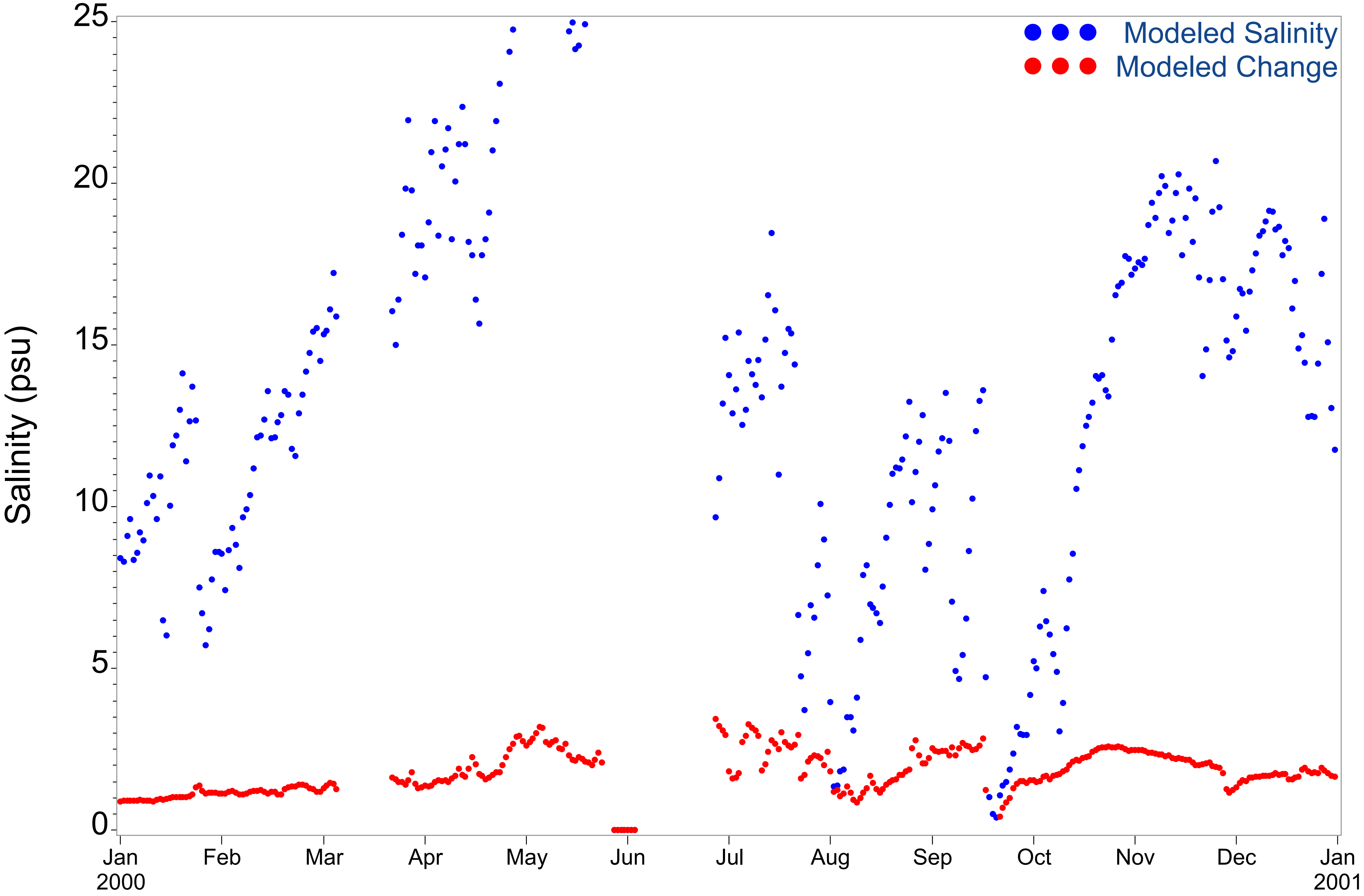


Figure 4.138 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 12.7 (2000)

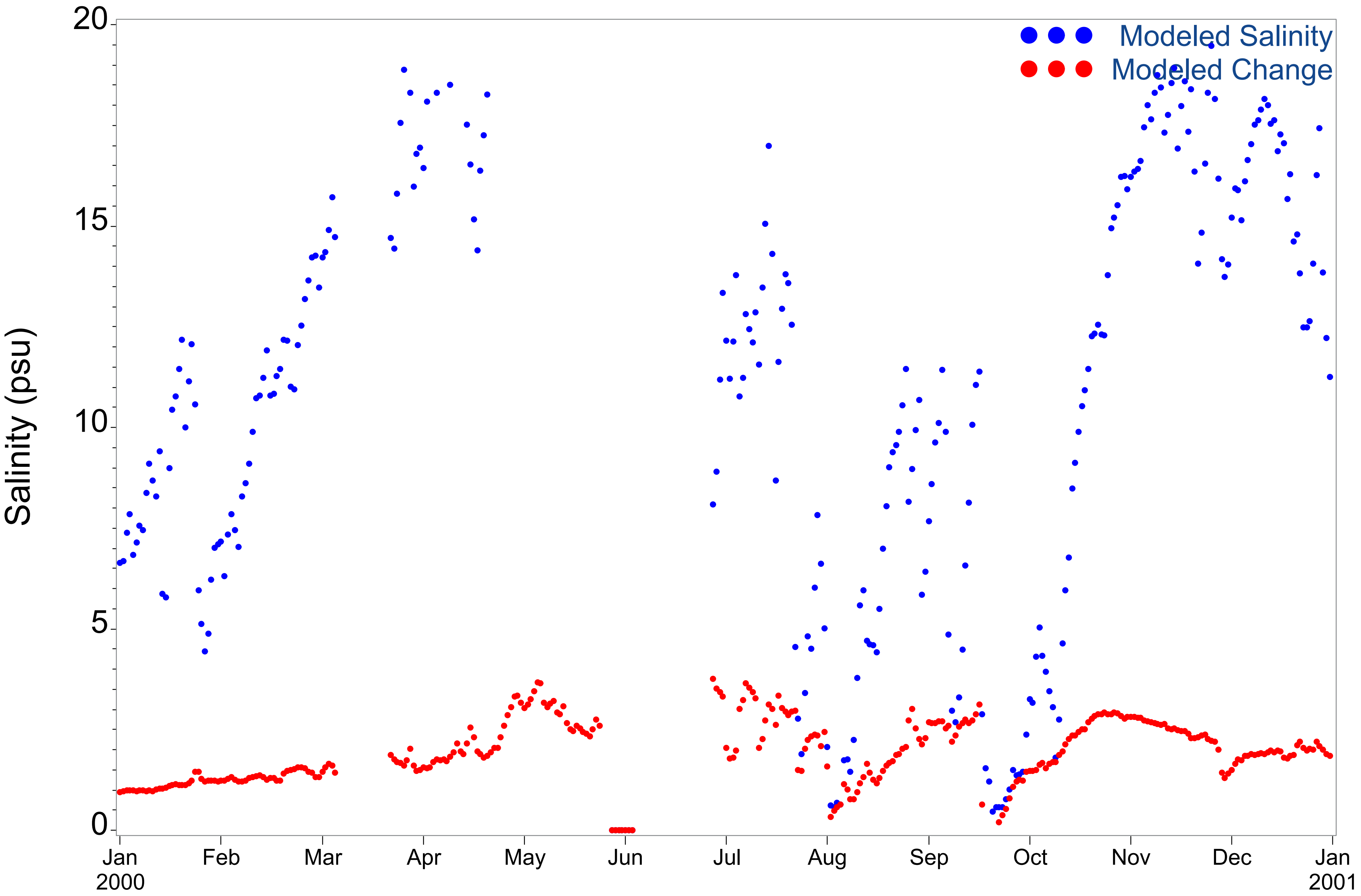


Figure 4.139 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 15.5 (2000)

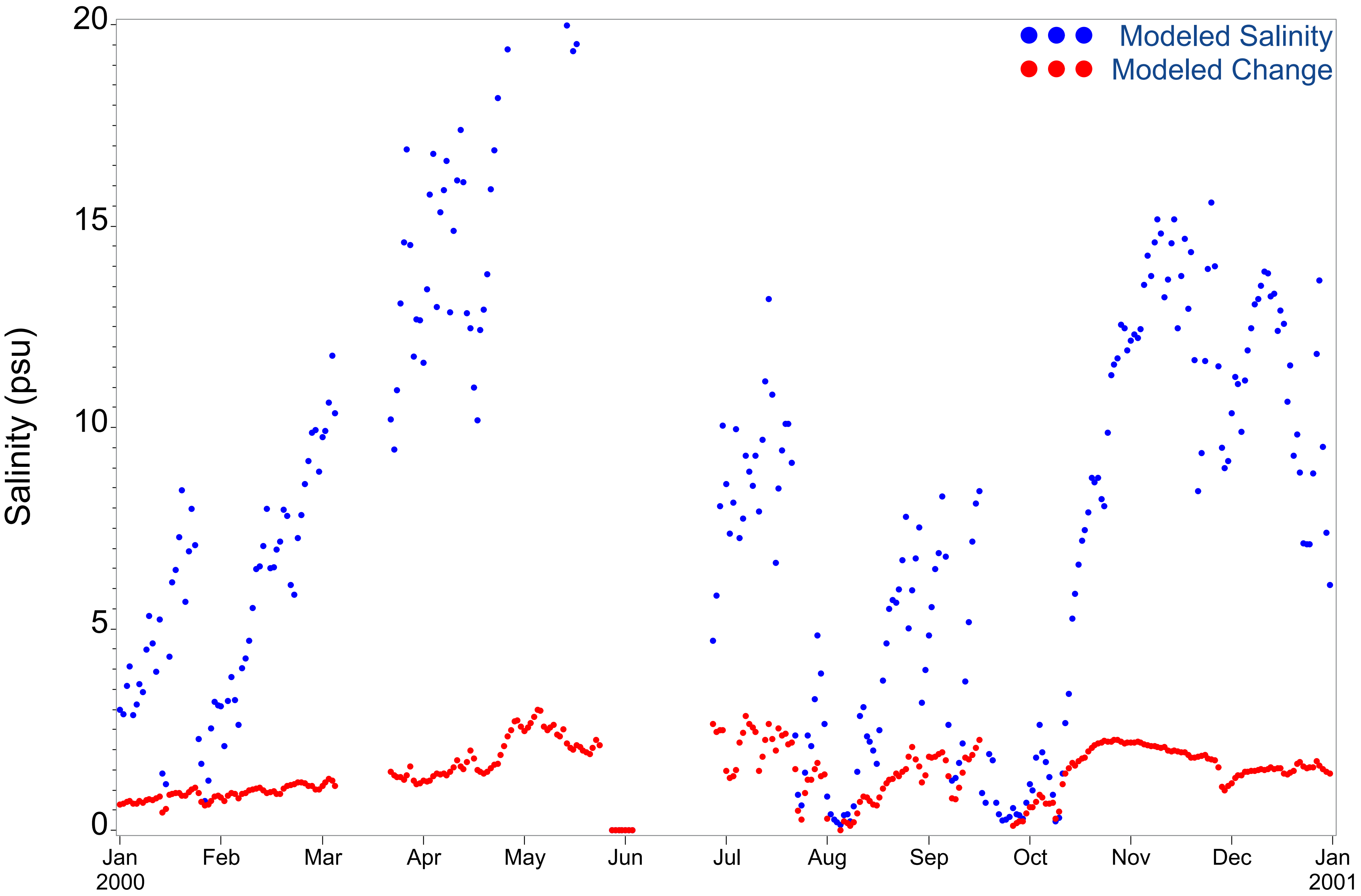


Figure 4.140 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.5 (2000)

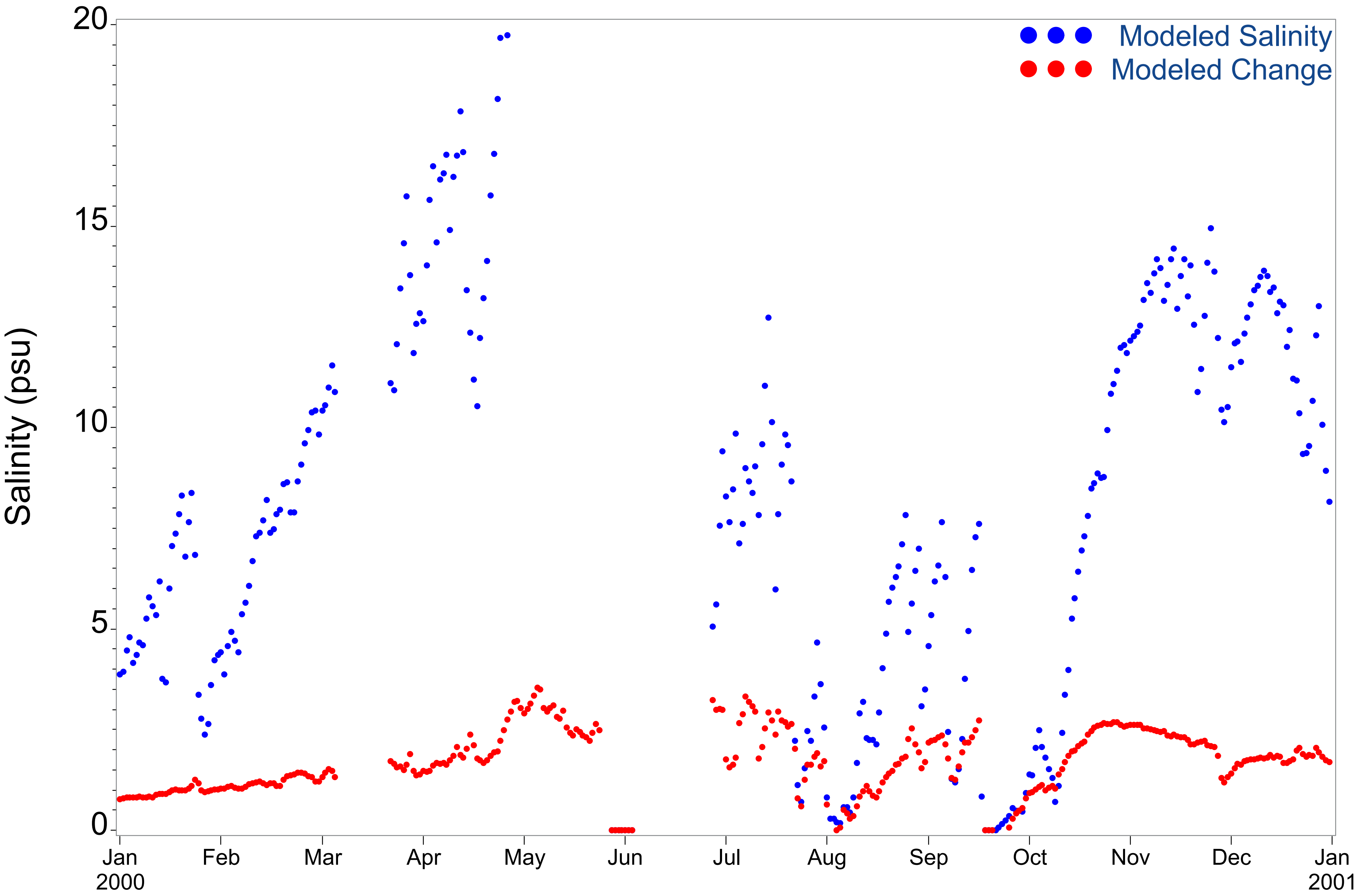


Figure 4.141 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.7 (2000)

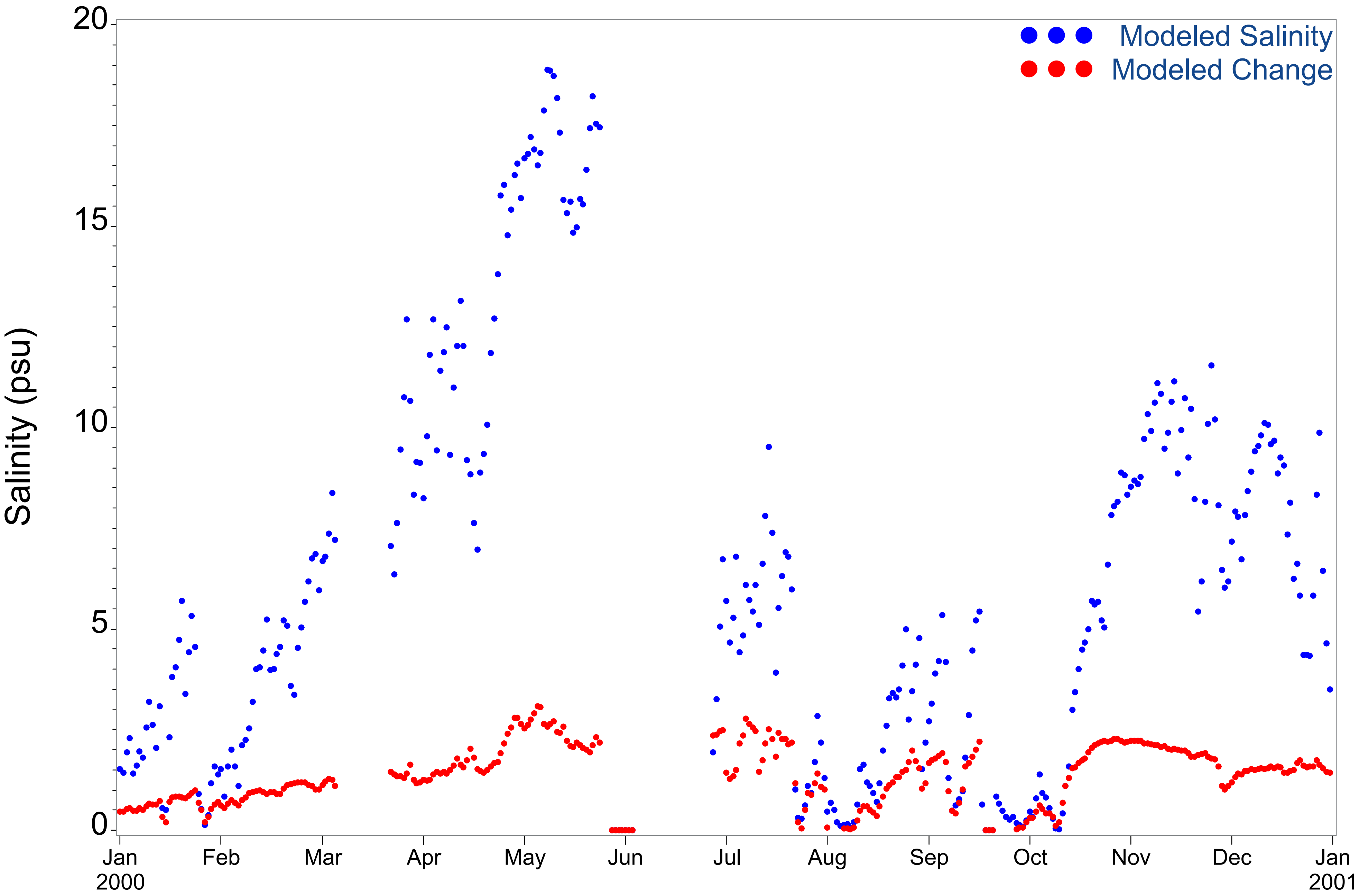


Figure 4.142 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 20.8 (2000)

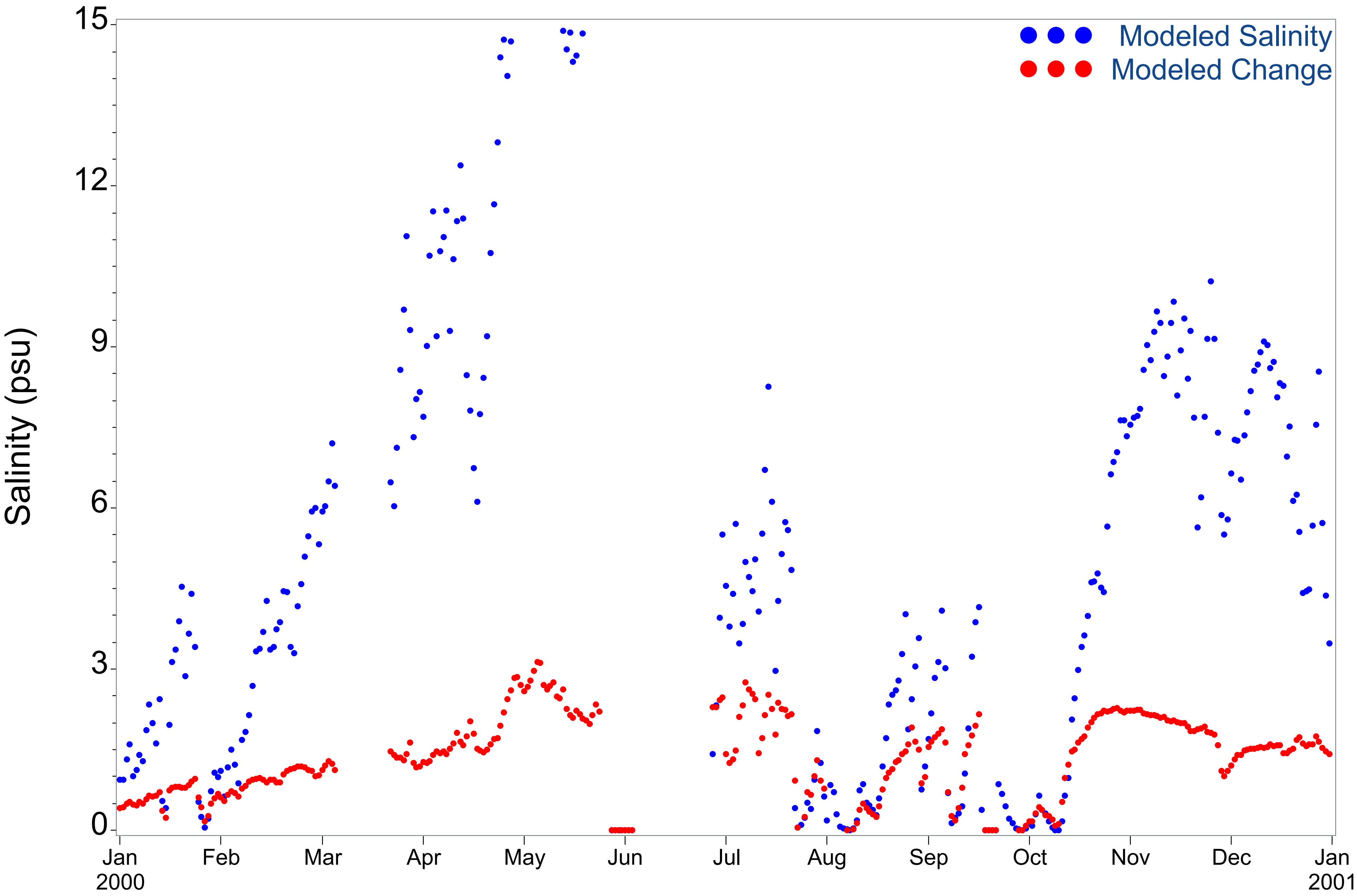


Figure 4.143 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 21.9 (2000)

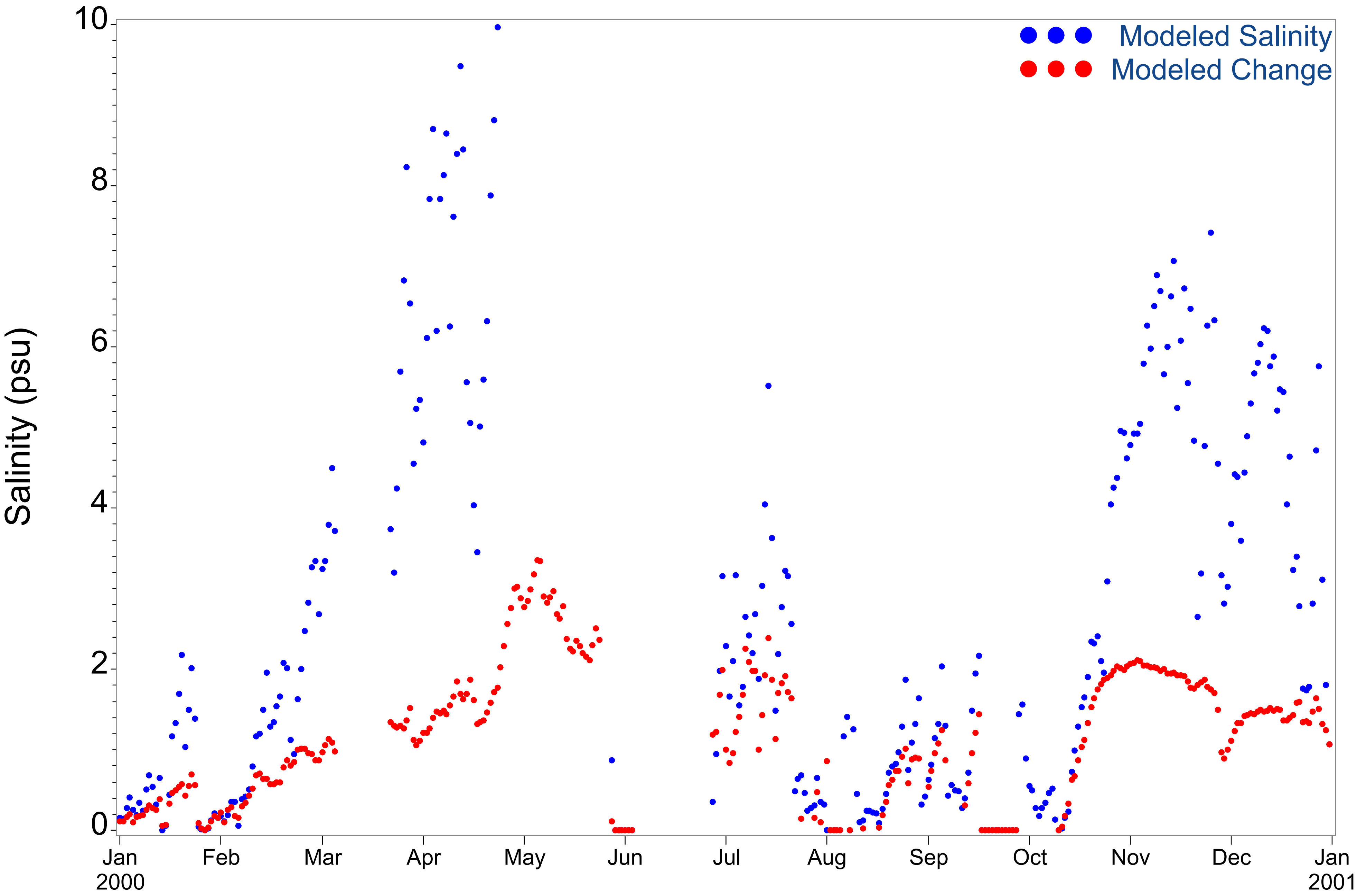


Figure 4.144 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 24.5 (2000)

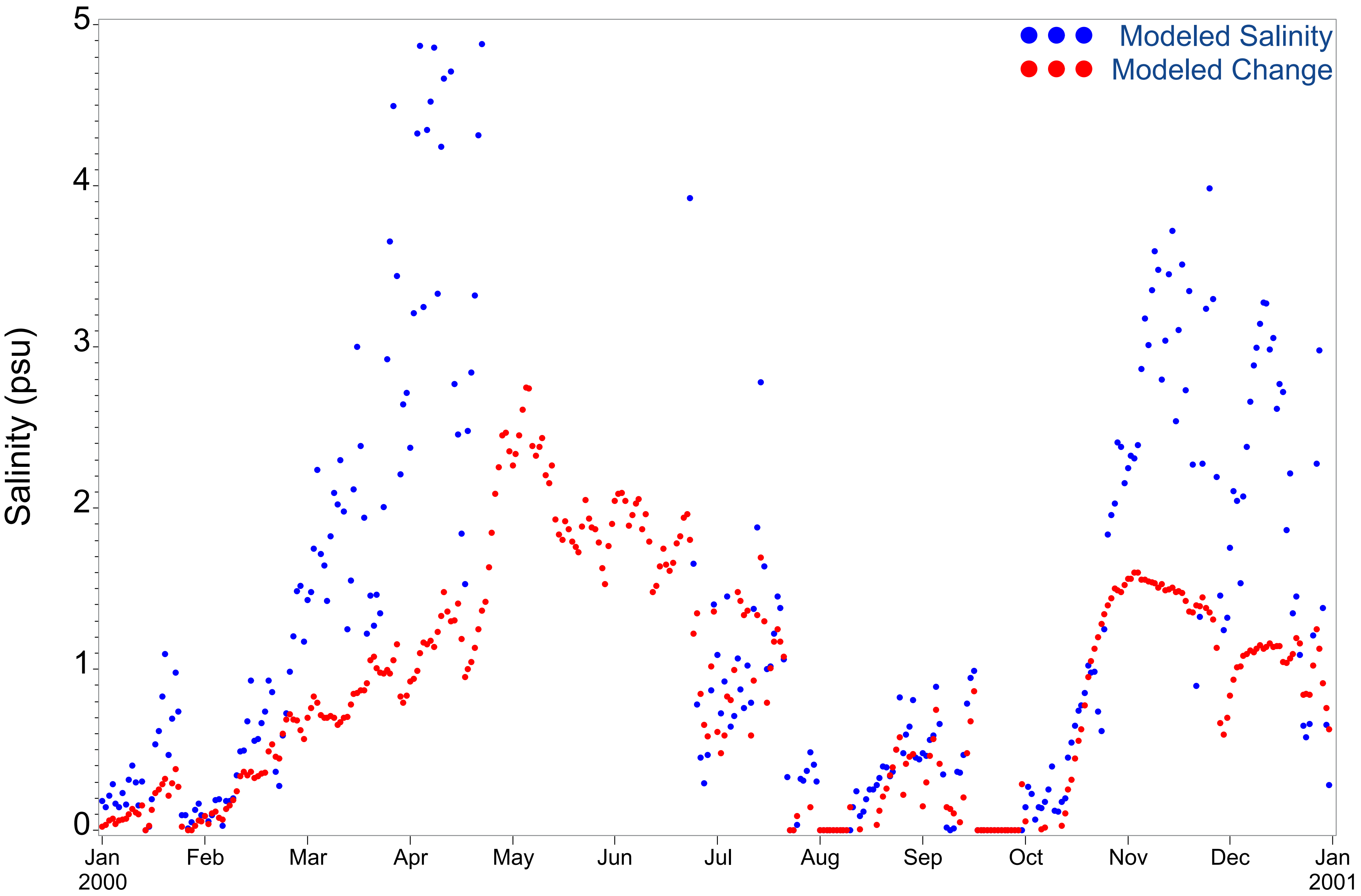


Figure 4.145 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 26.7 (2000)

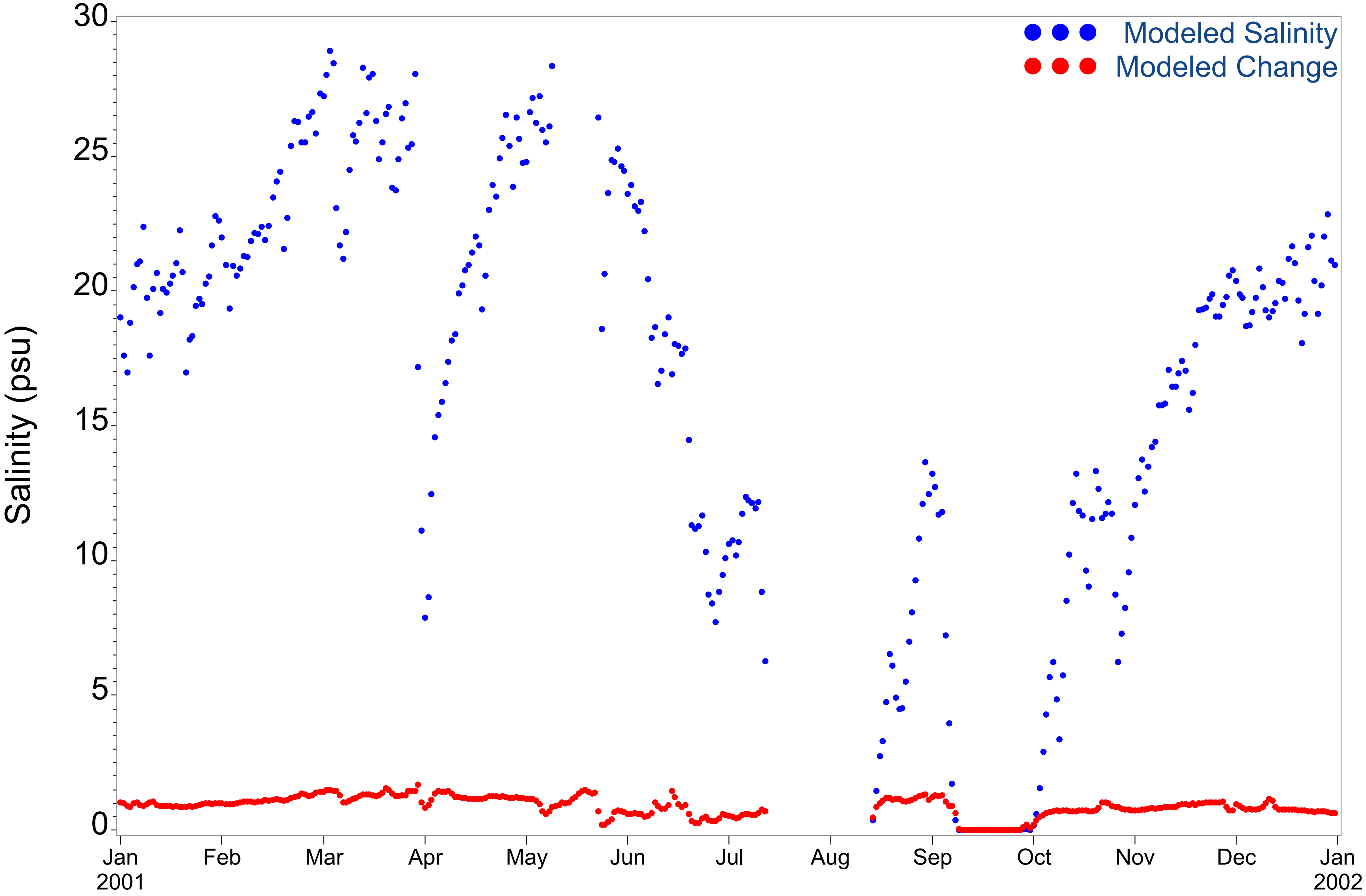


Figure 4.146 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 9.2 (2001)

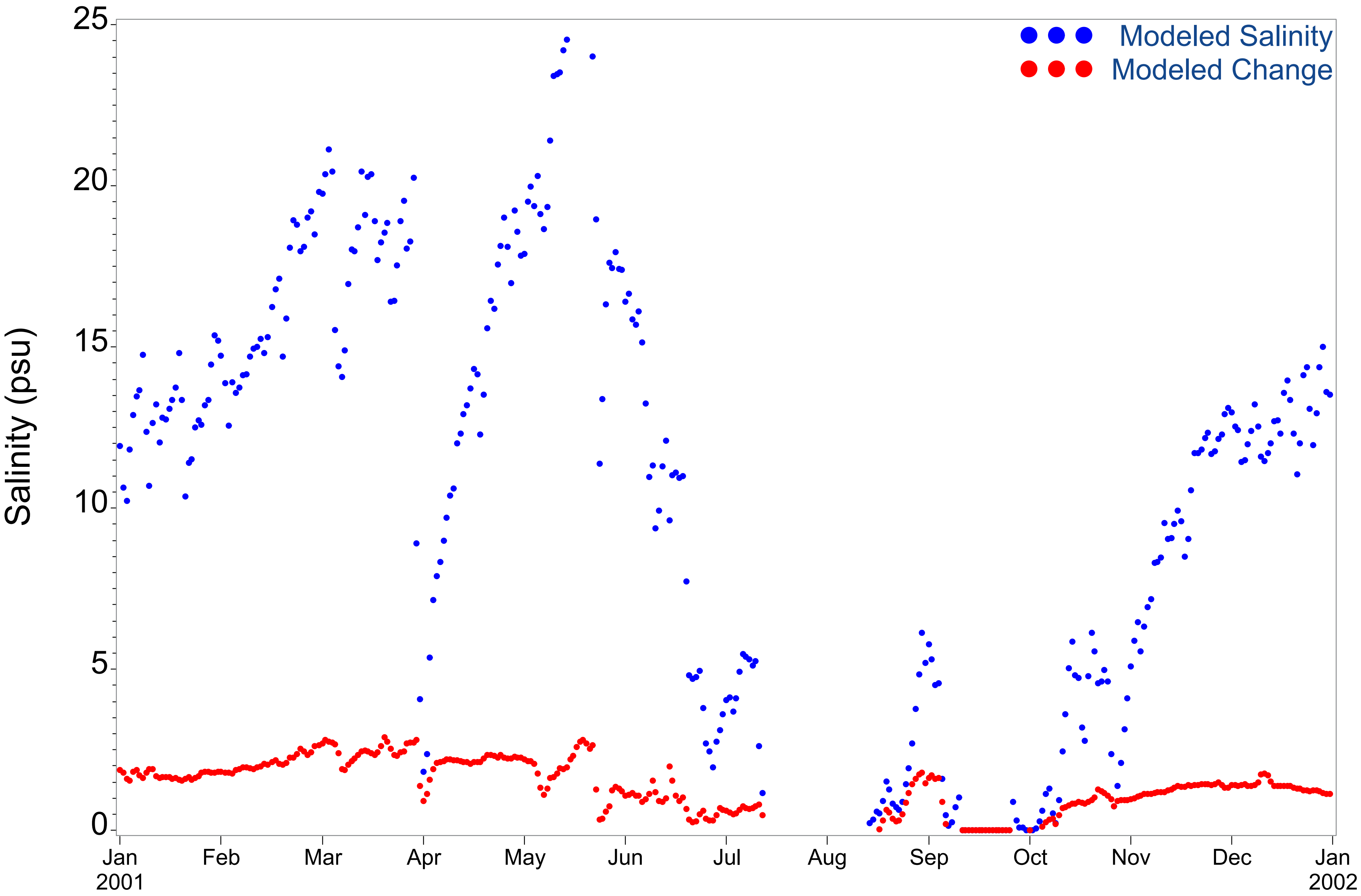


Figure 4.147 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 12.7 (2001)

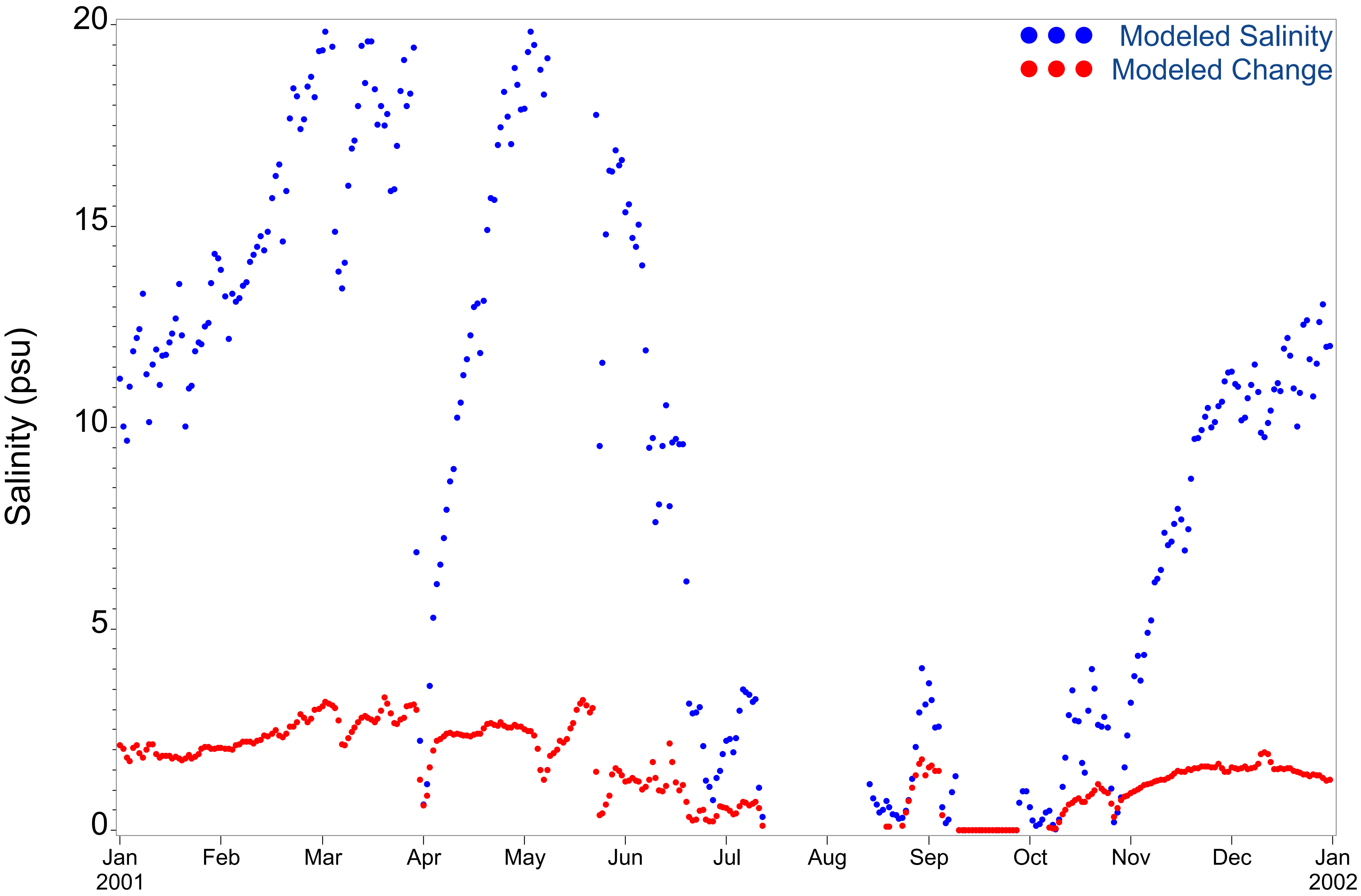


Figure 4.148 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 15.5 (2001)

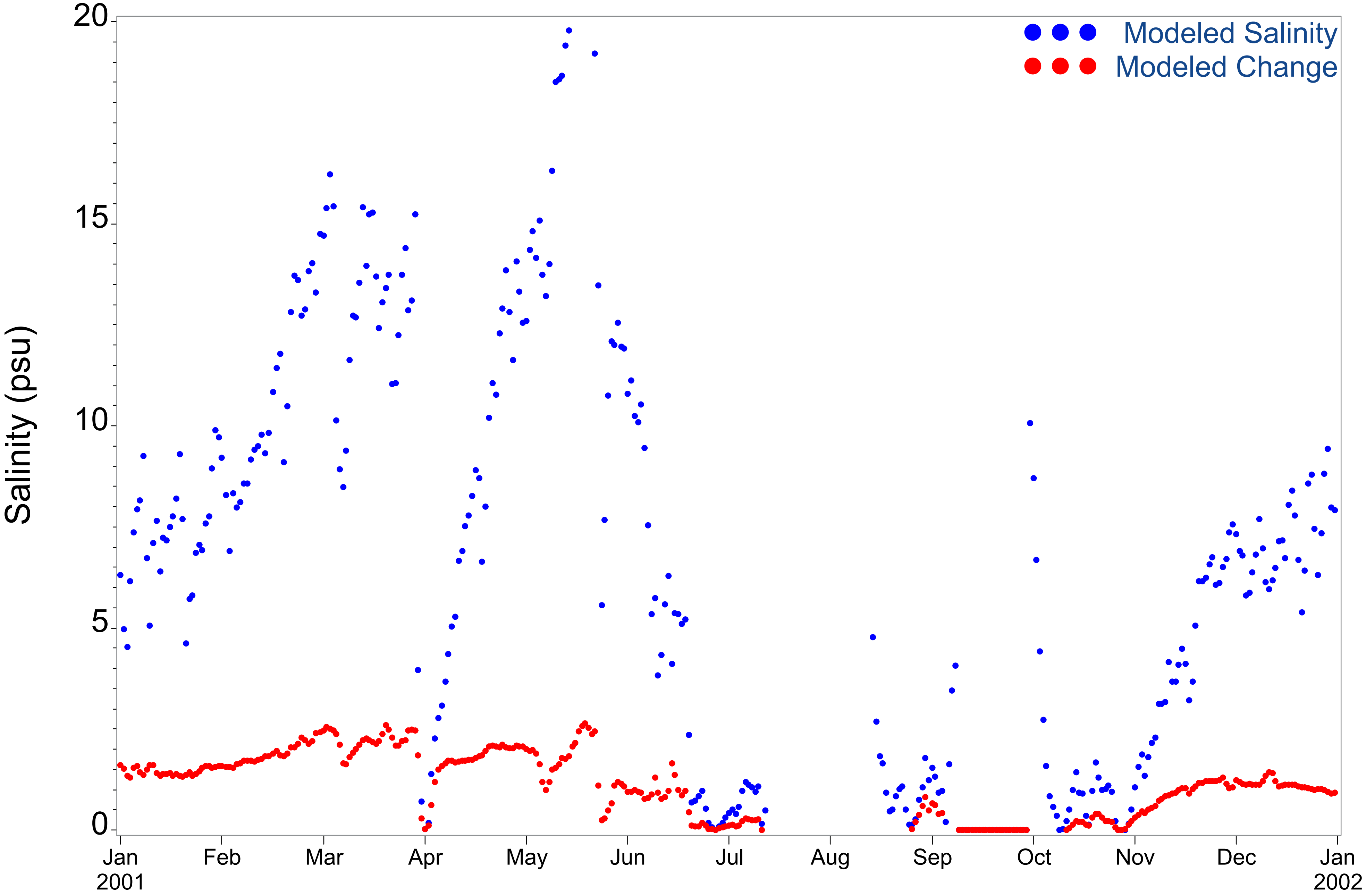


Figure 4.149 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.5 (2001)

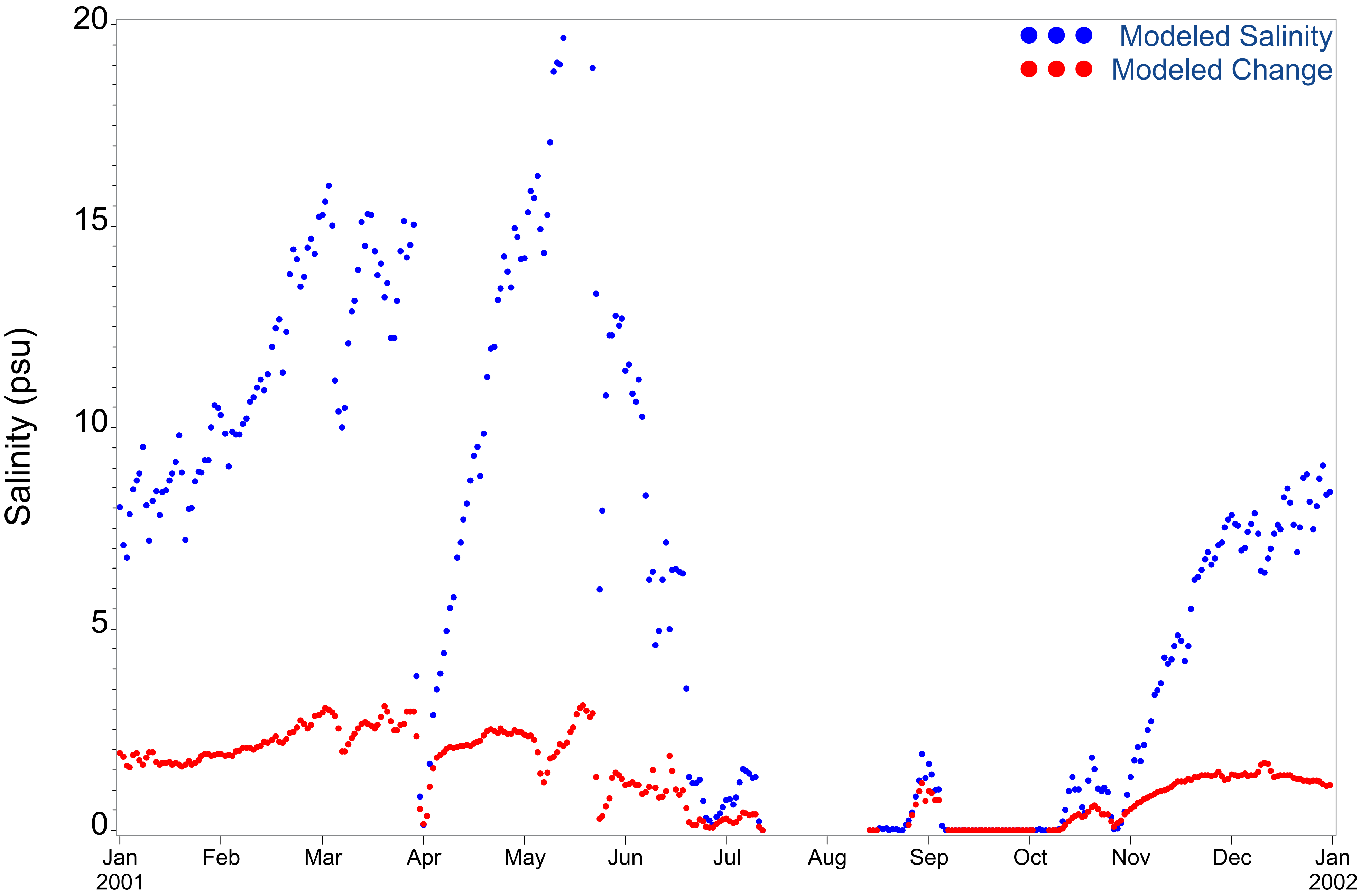


Figure 4.150 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.7 (2001)

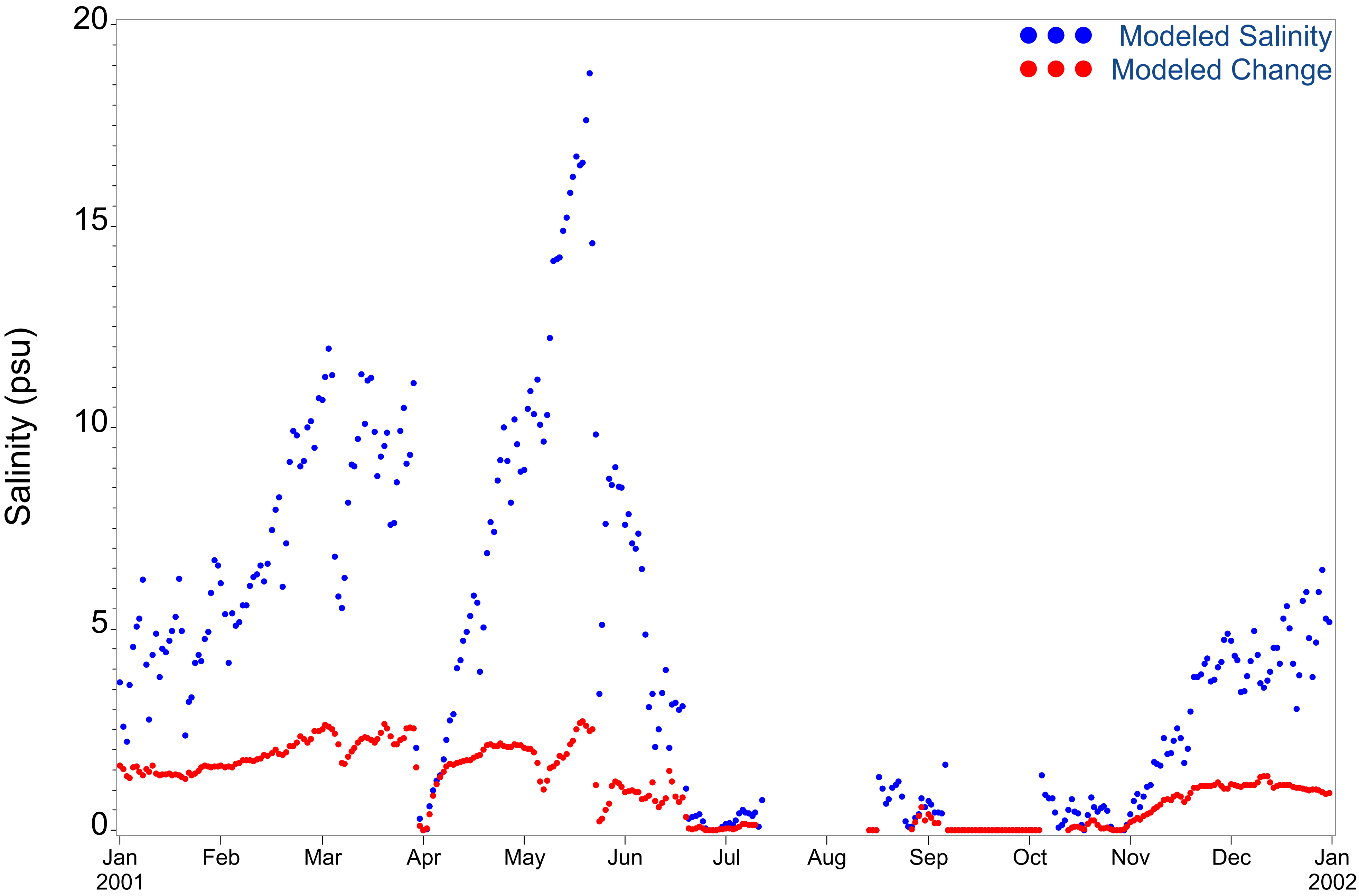


Figure 4.151 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 20.8 (2001)

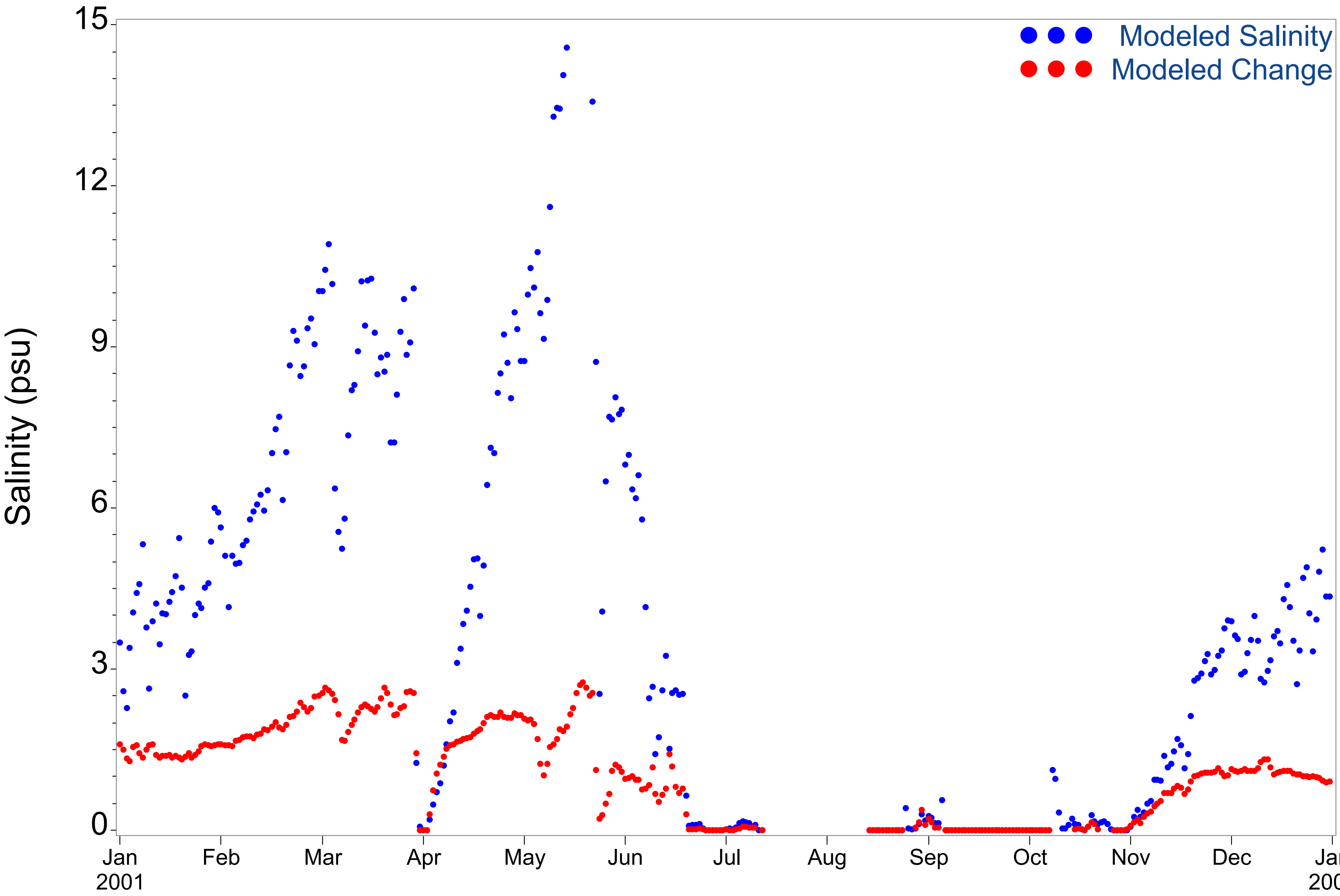


Figure 4.152 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 21.9 (2001)

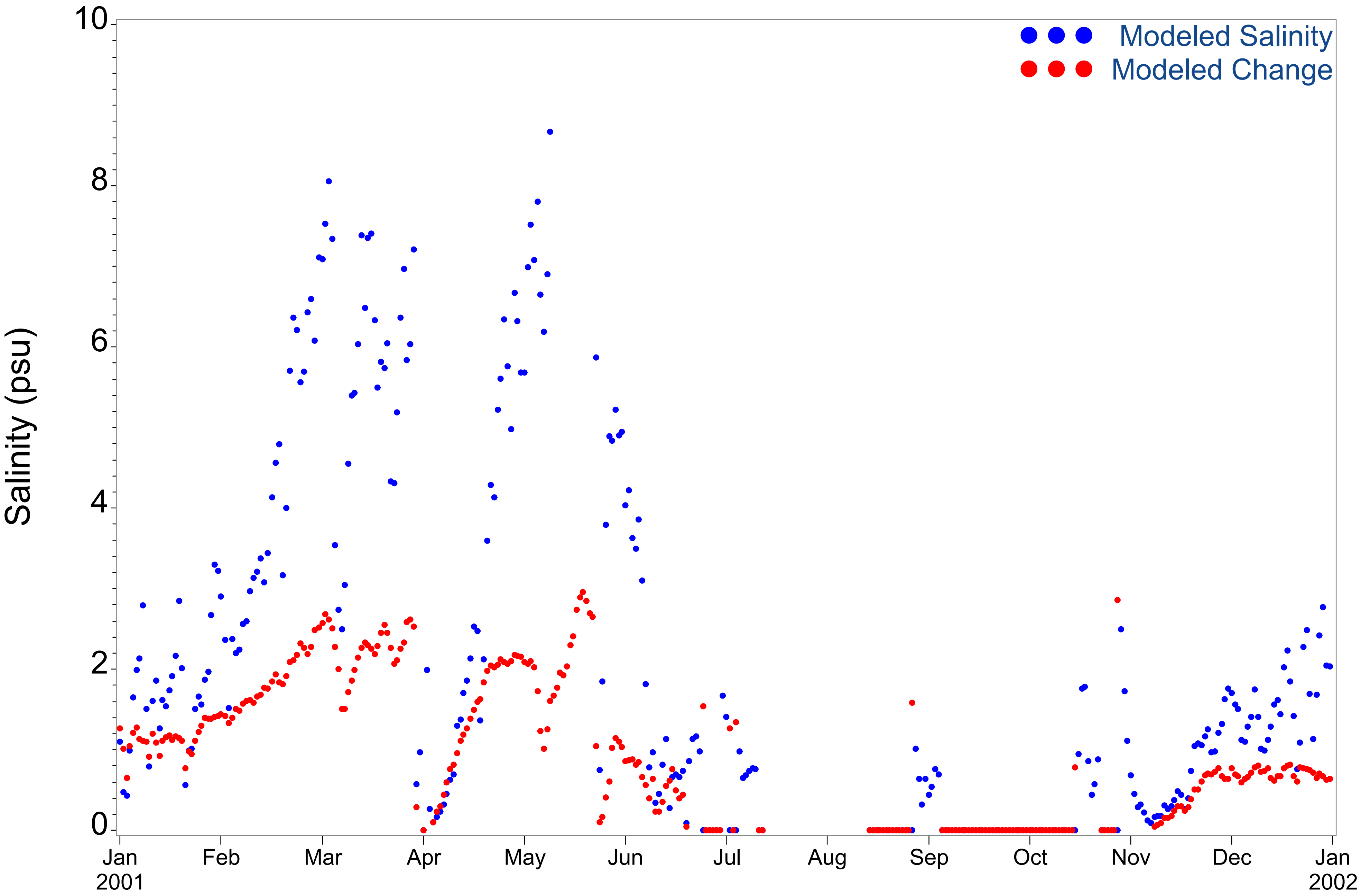


Figure 4.153 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 24.5 (2001)

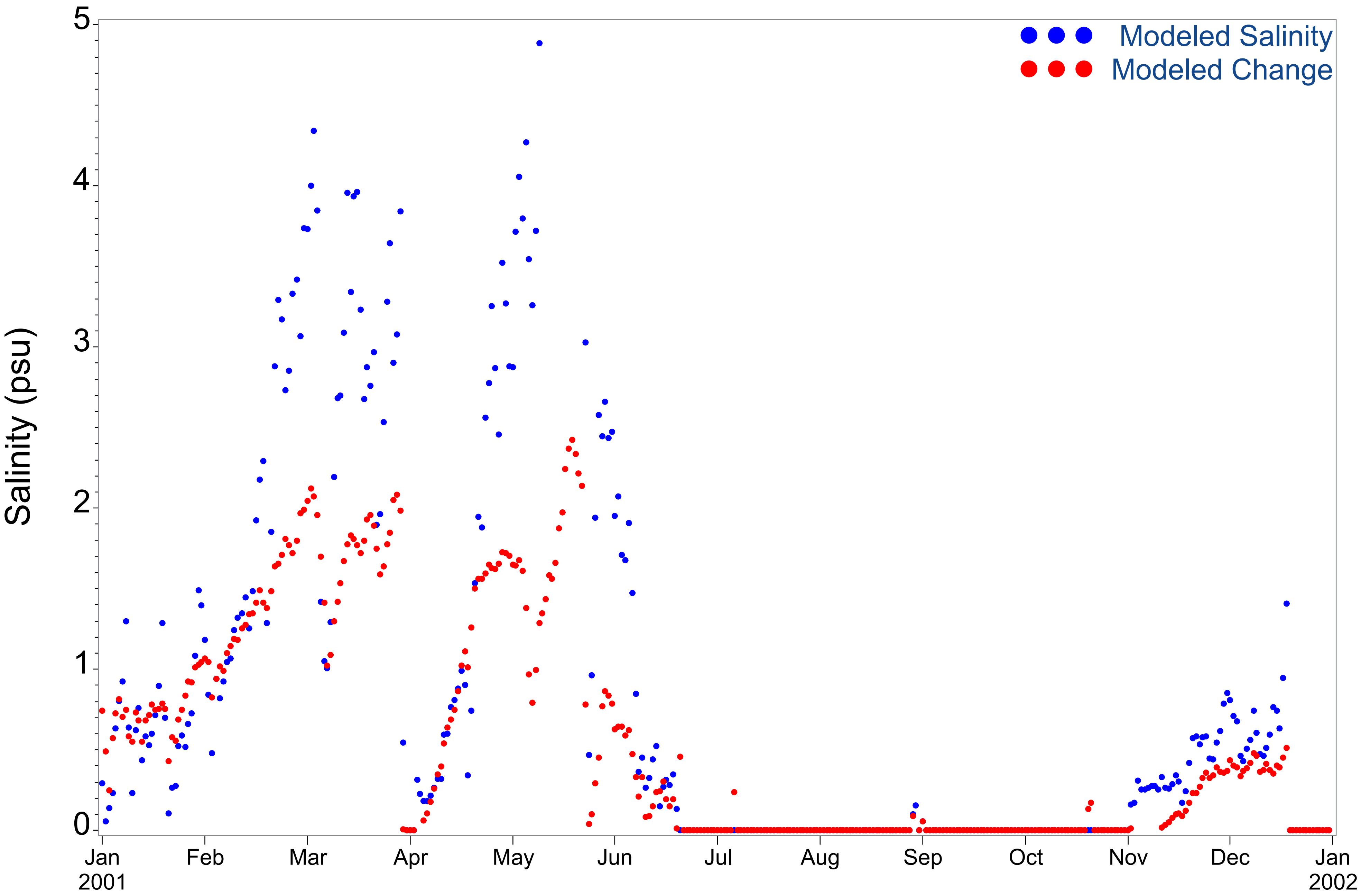


Figure 4.154 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 26.7 (2001)

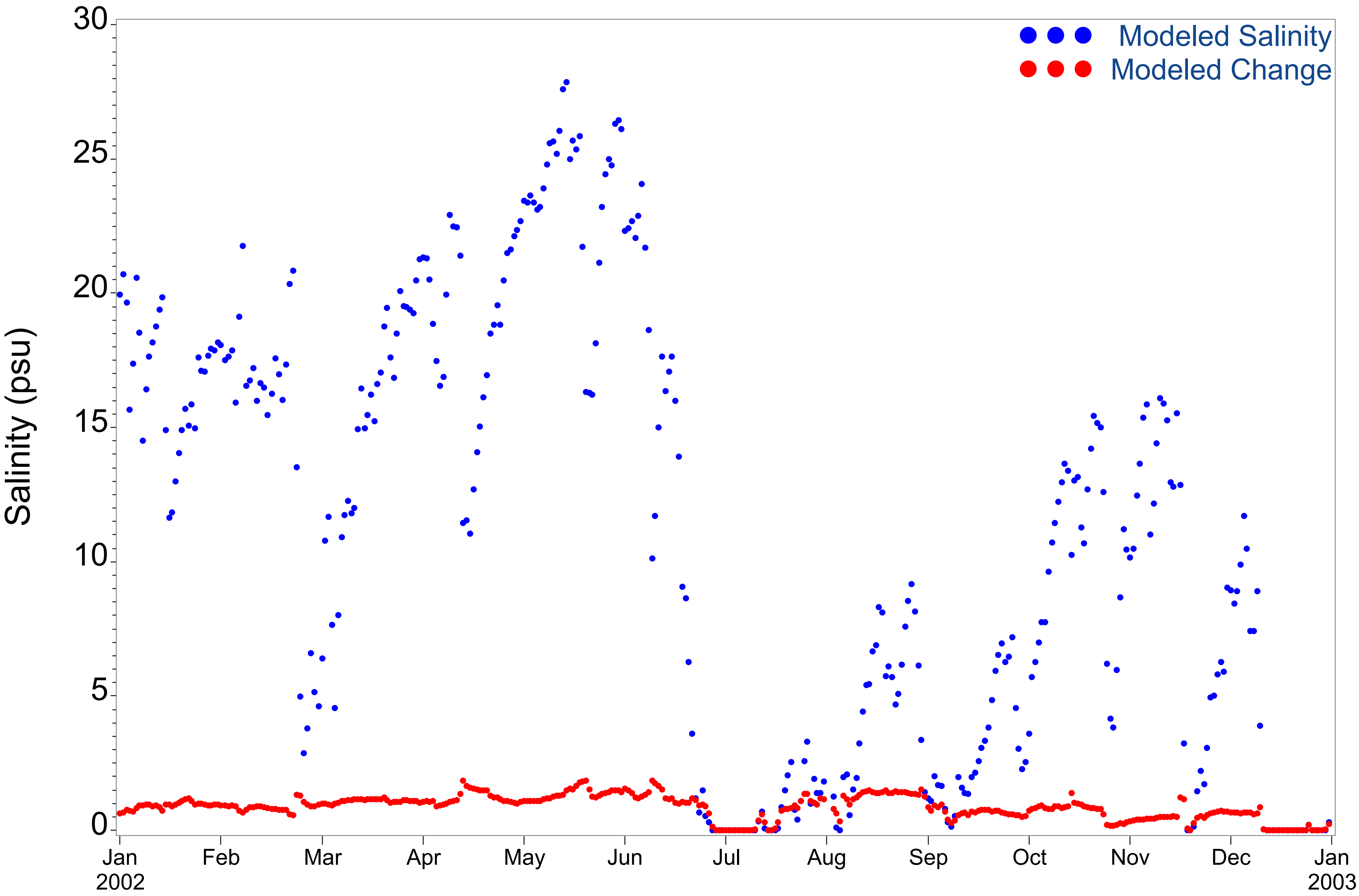


Figure 4.155 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 9.2 (2002)

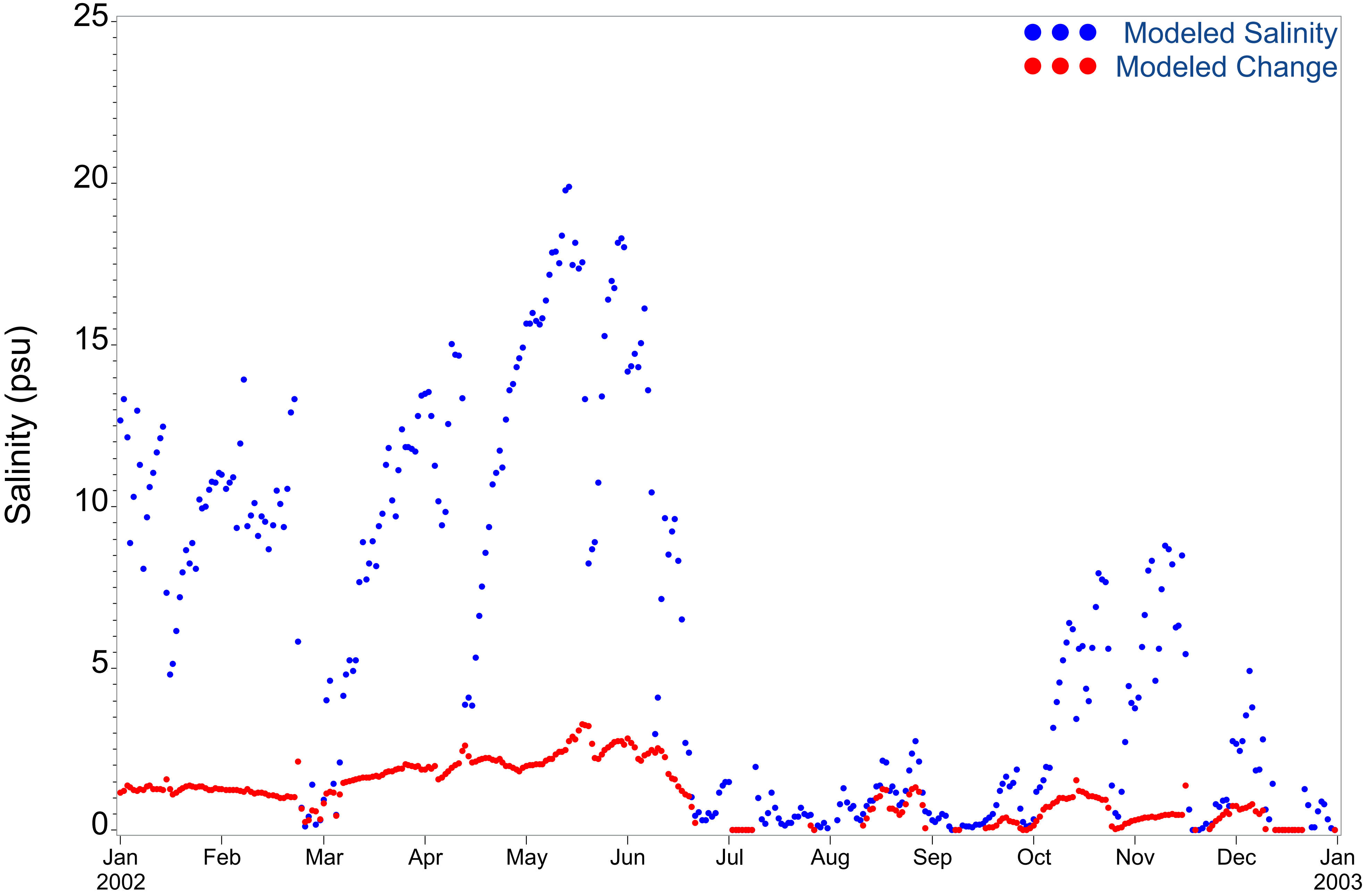


Figure 4.156 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 12.7 (2002)

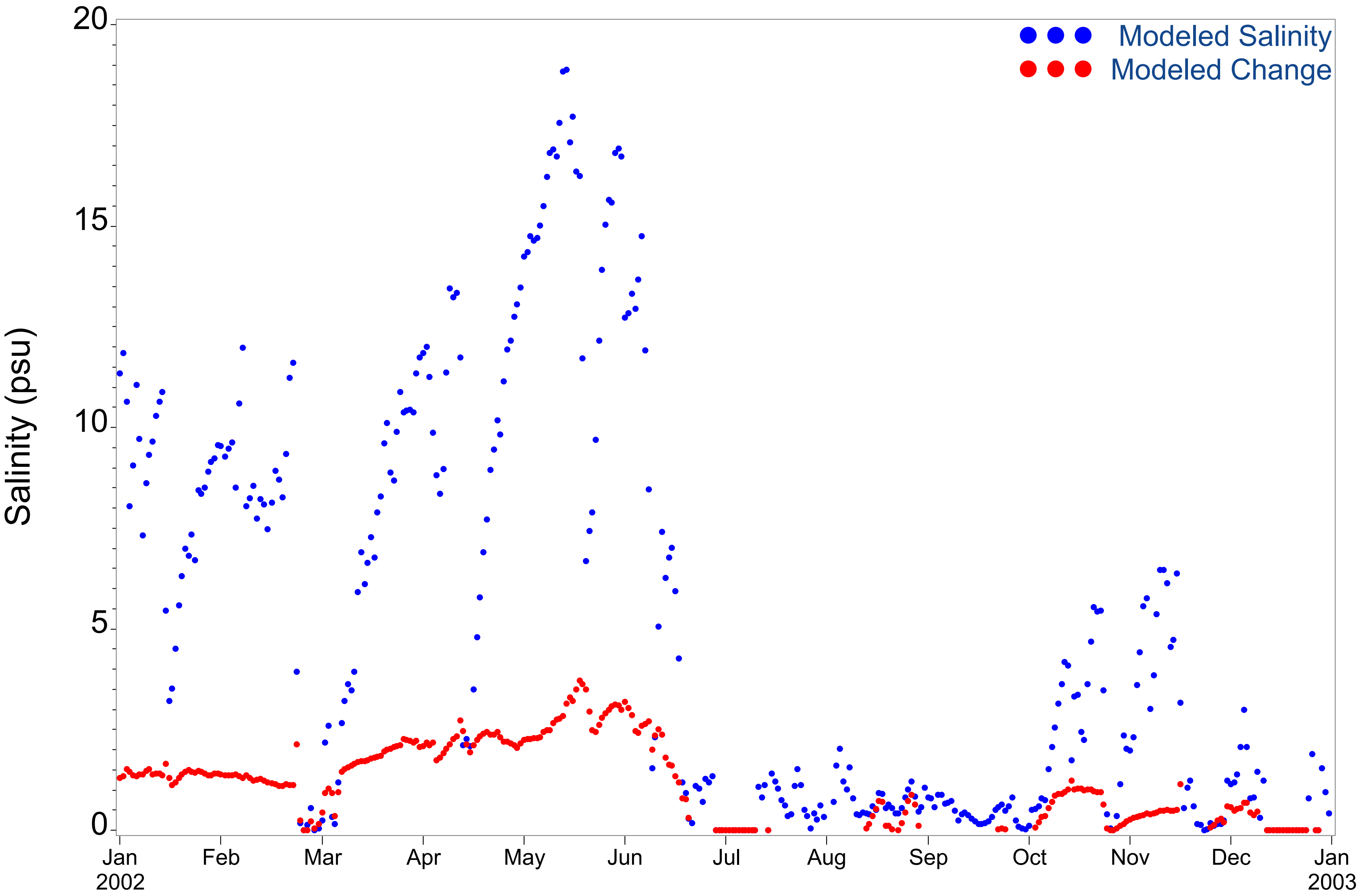


Figure 4.157 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 15.5 (2002)

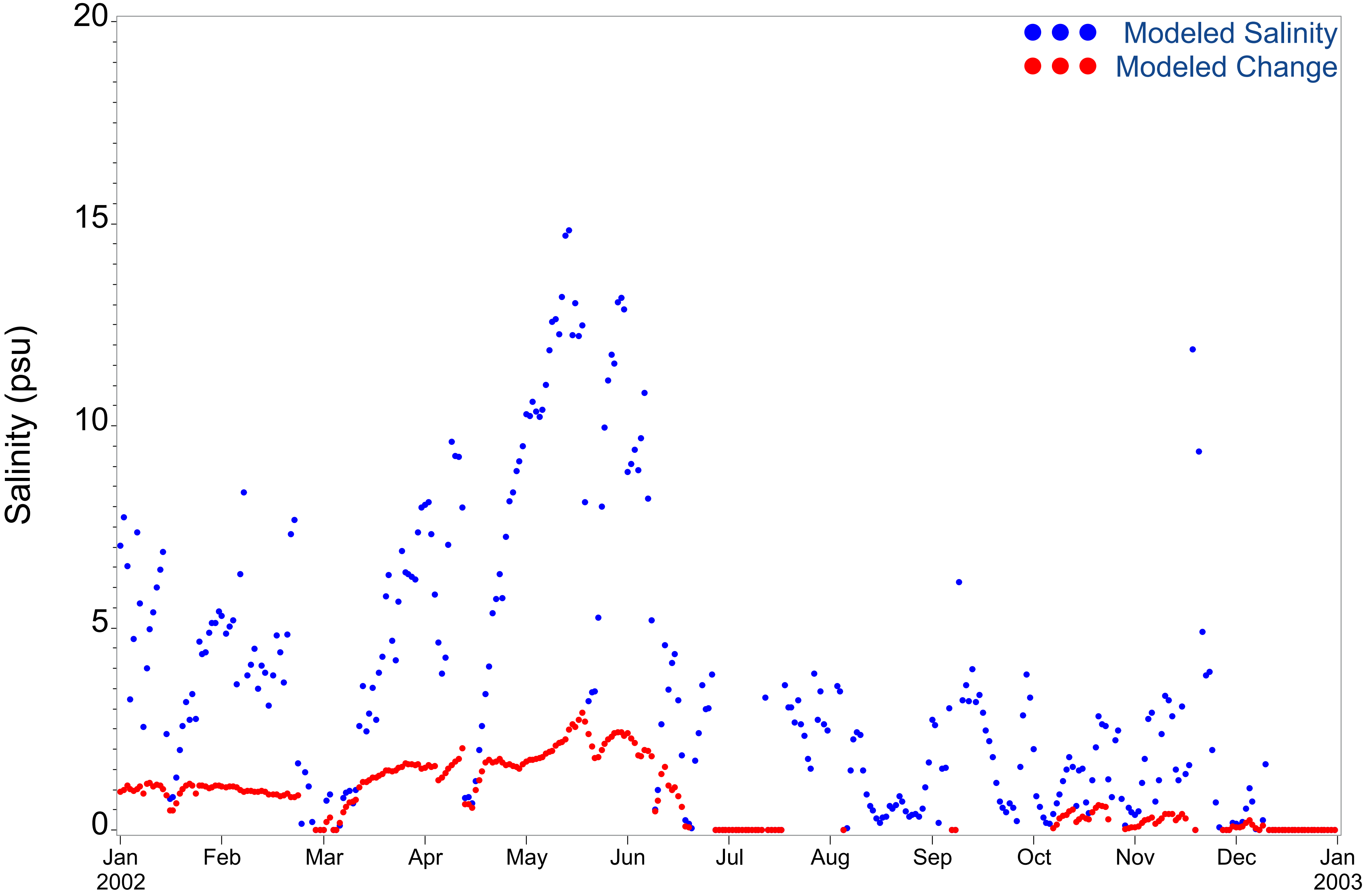


Figure 4.158 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.5 (2002)

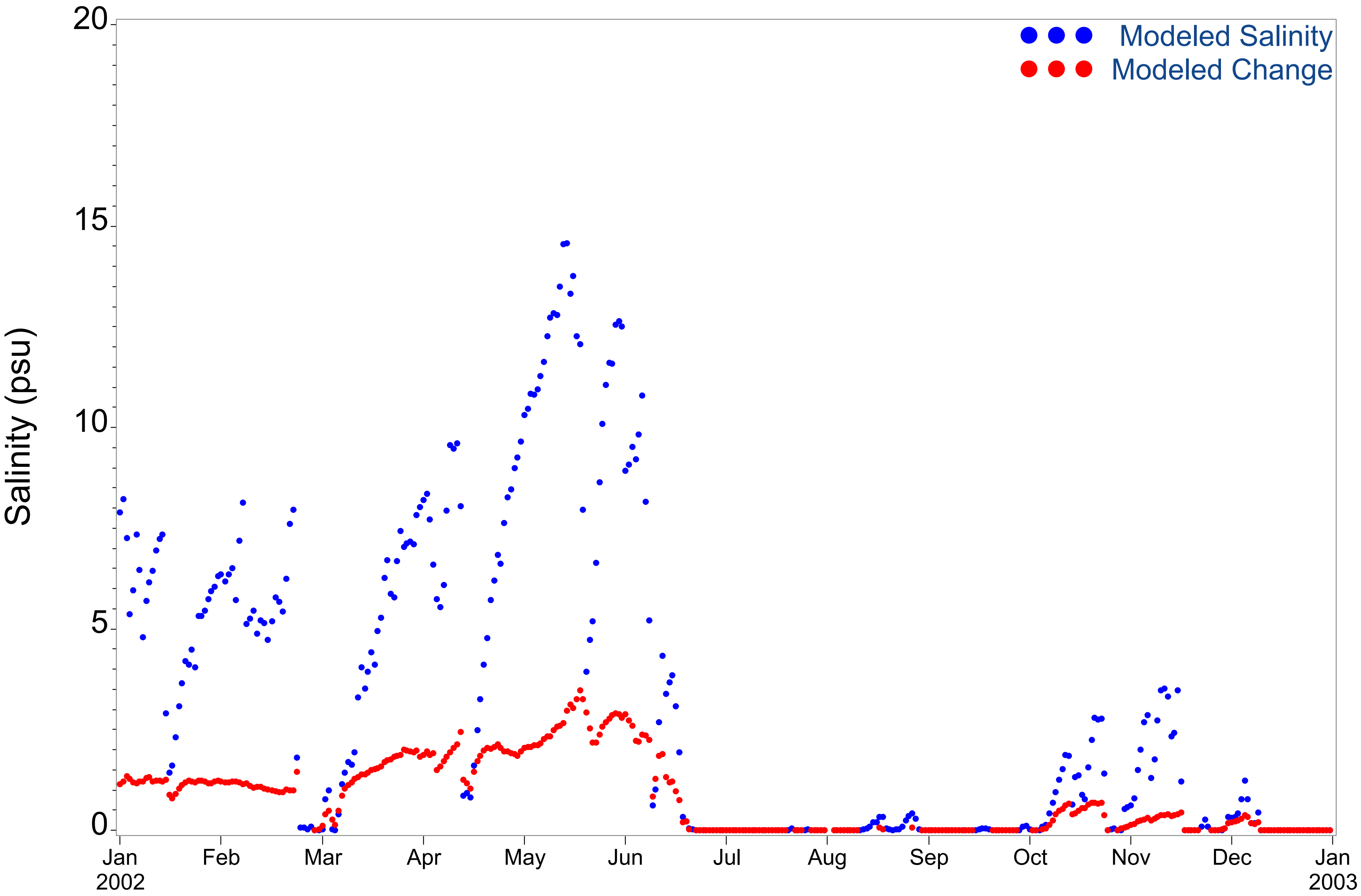


Figure 4.159 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.7 (2002)

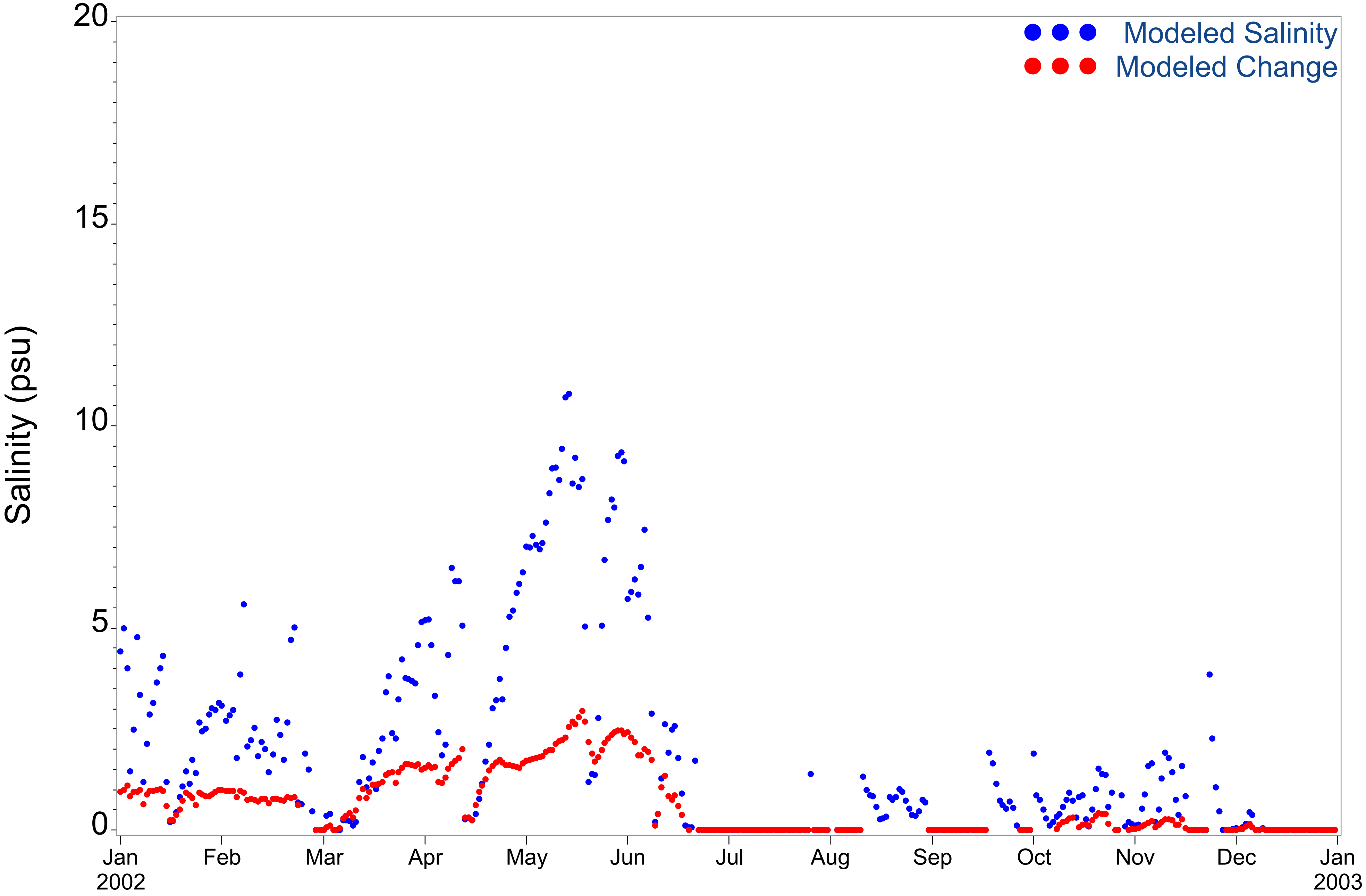


Figure 4.160 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 20.8 (2002)

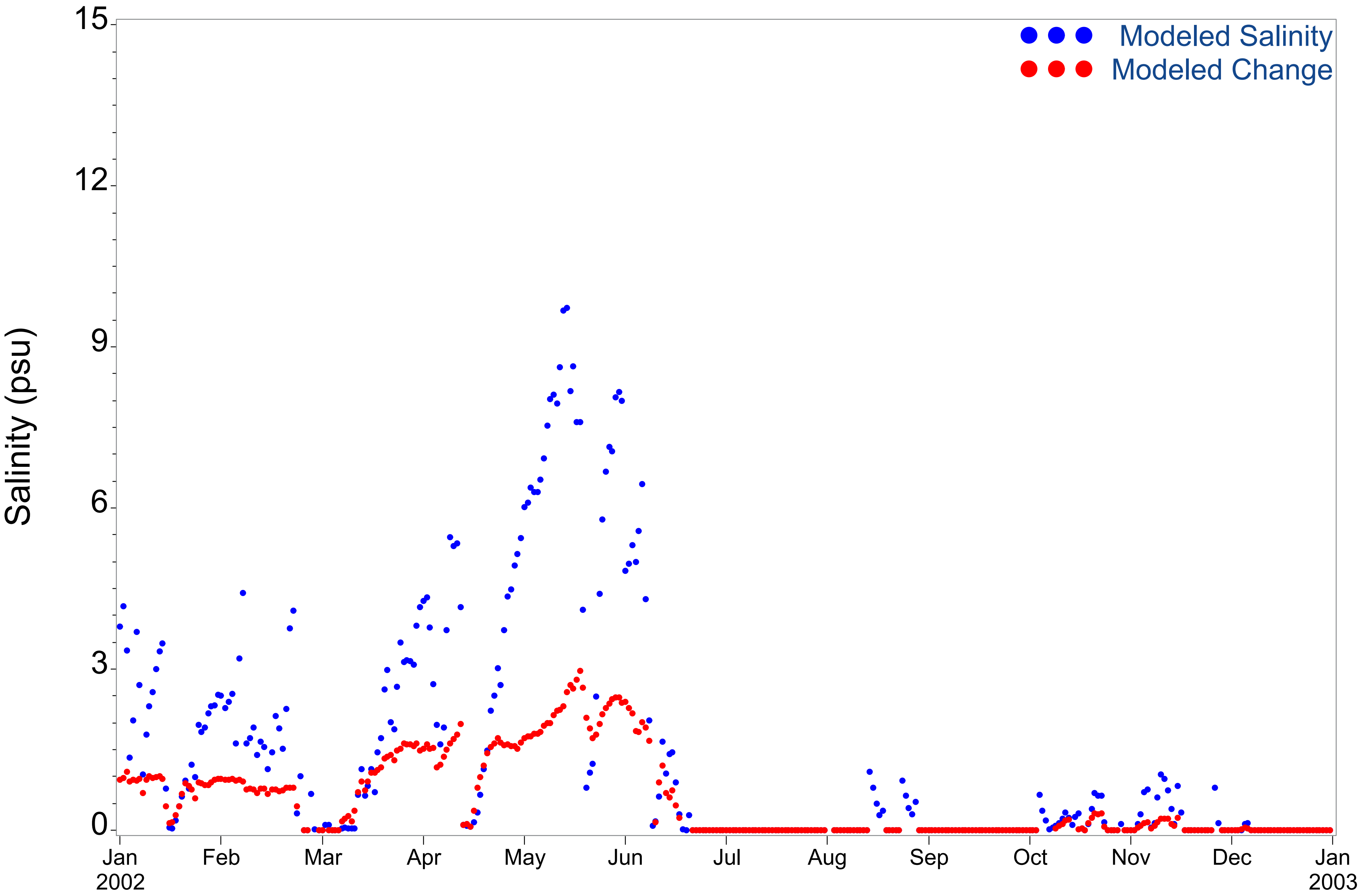


Figure 4.161 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 21.9 (2002)

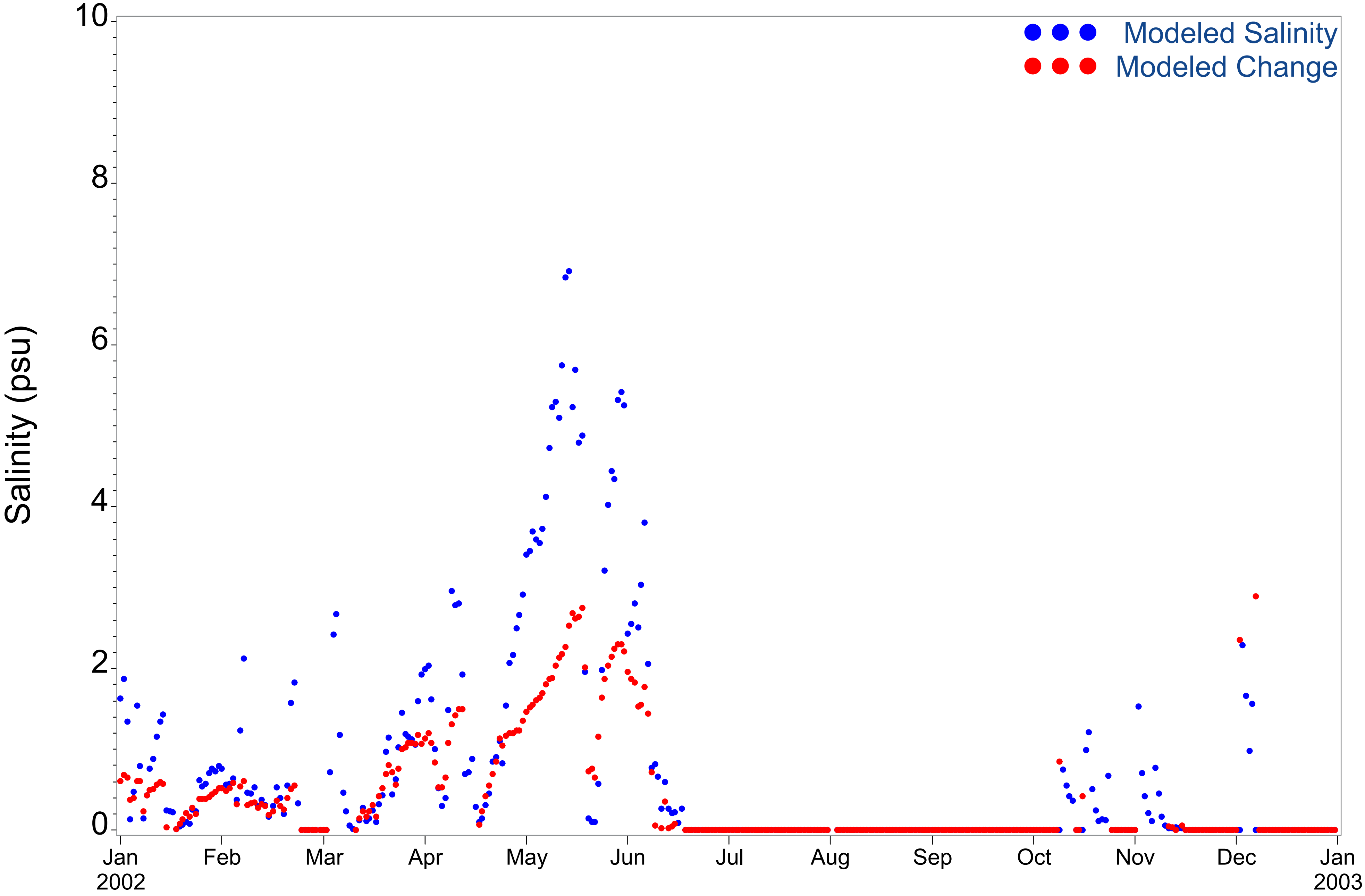


Figure 4.162 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 24.5 (2002)

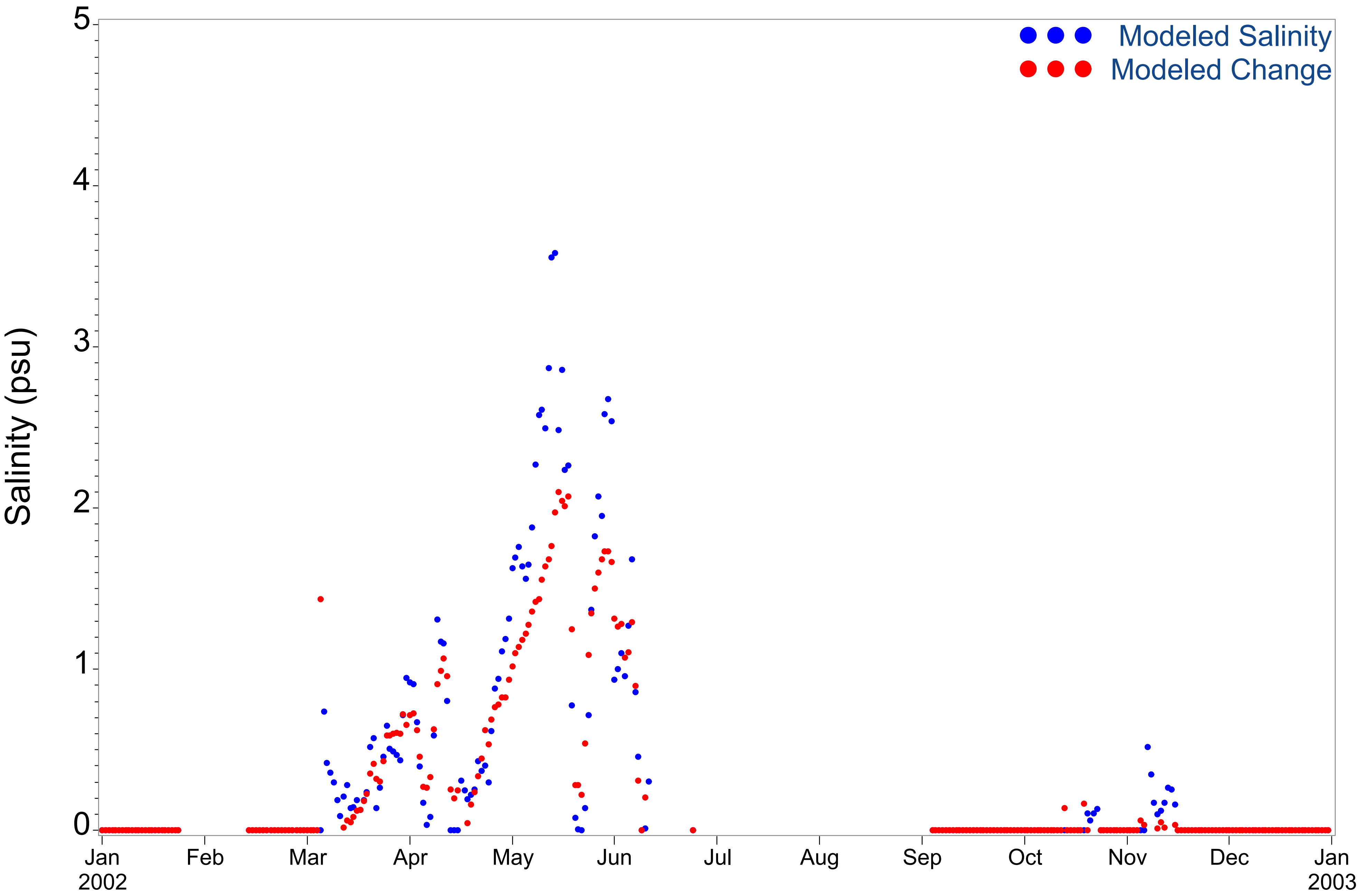


Figure 4.163 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 26.7 (2002)

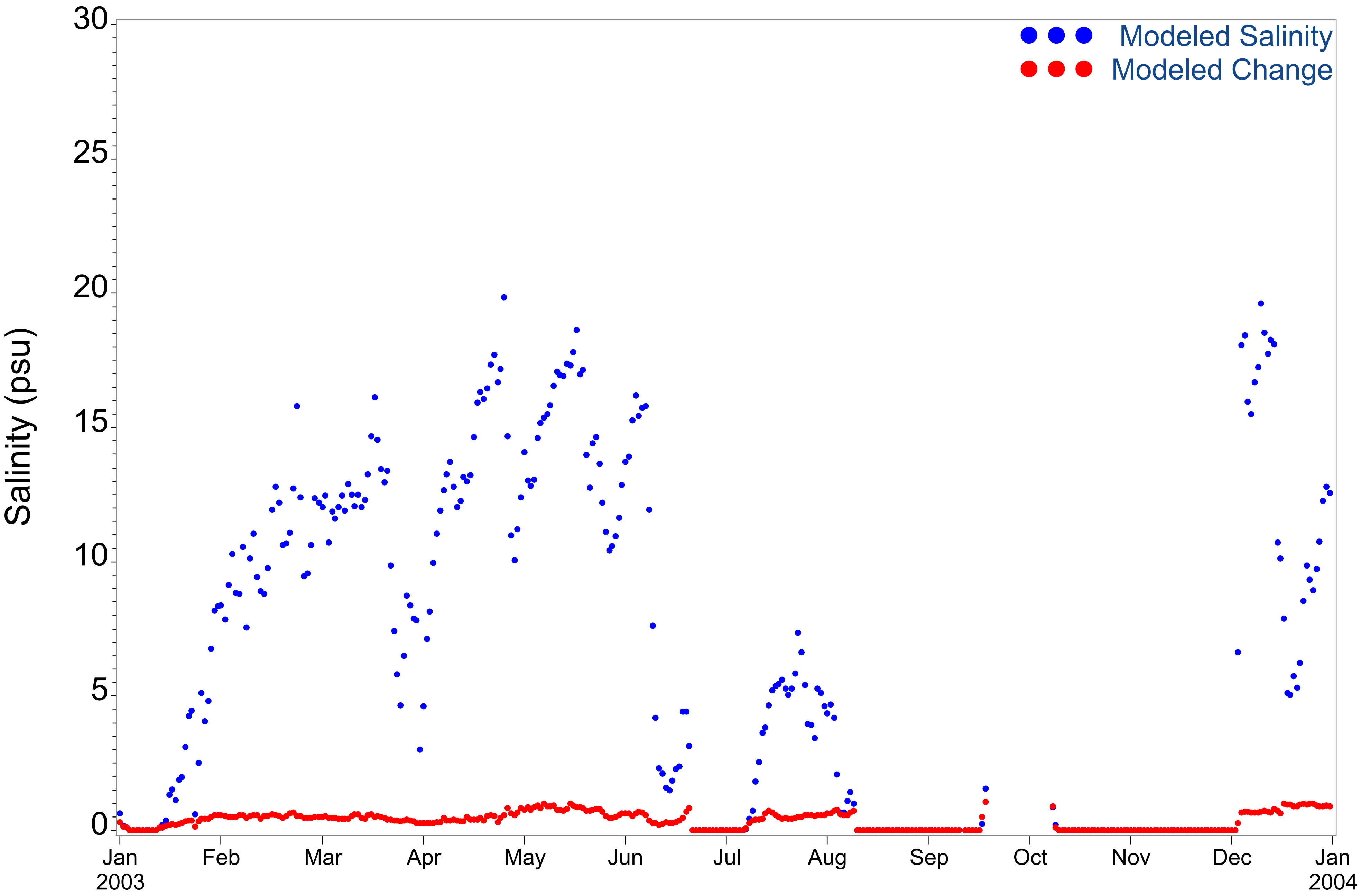


Figure 4.164 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 9.2 (2003)

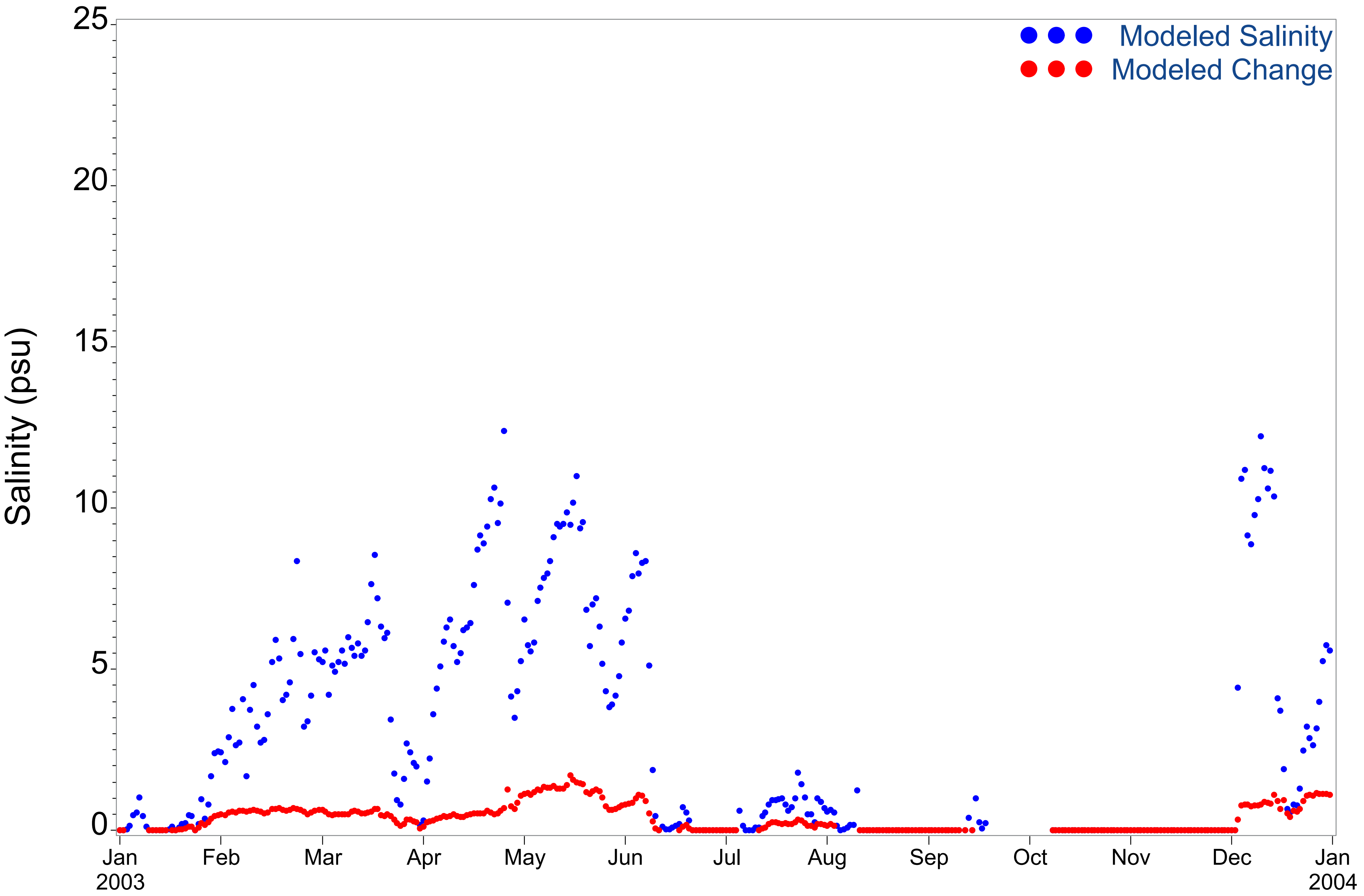


Figure 4.165 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 12.7 (2003)

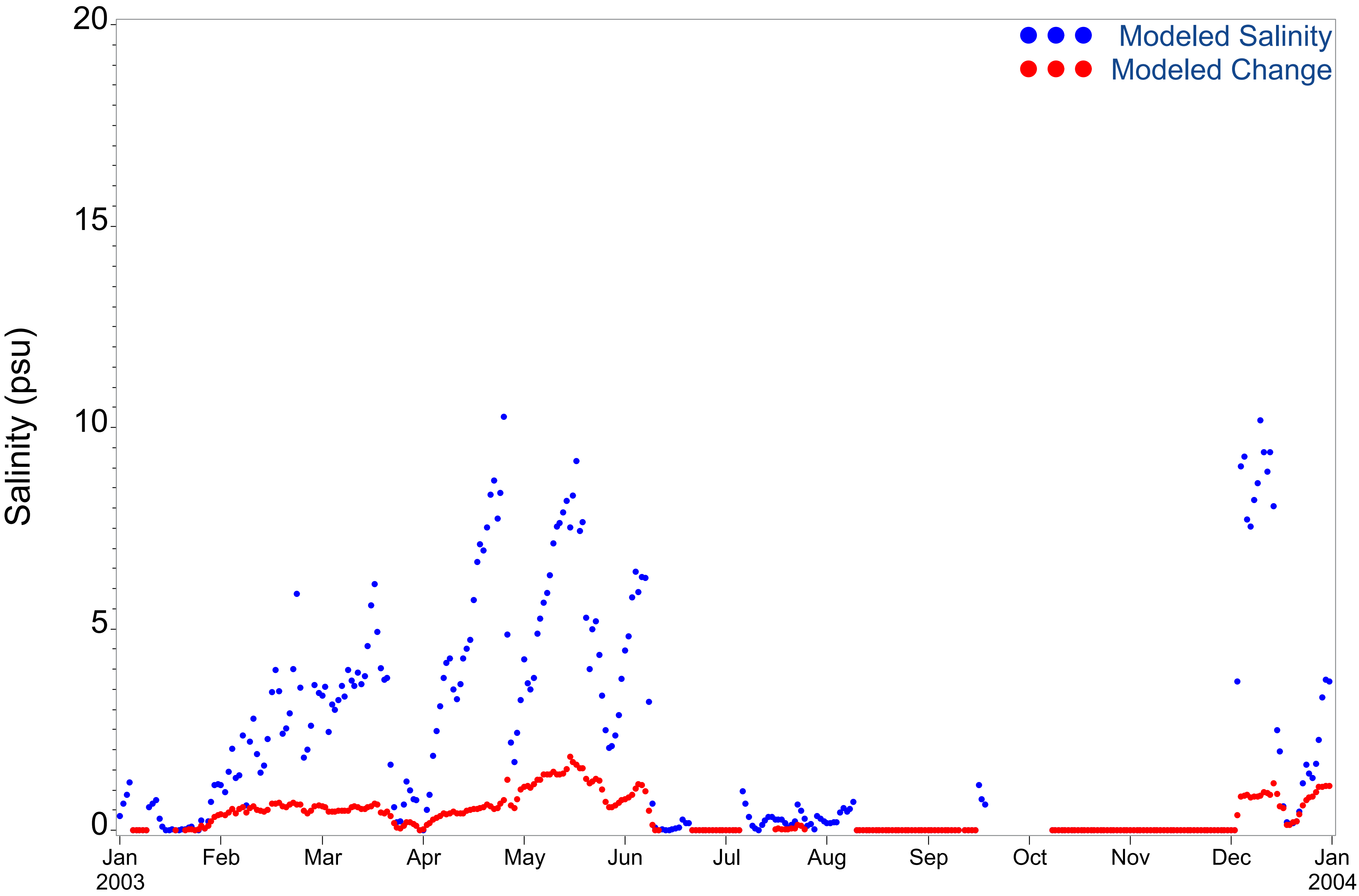


Figure 4.166 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 15.5 (2003)

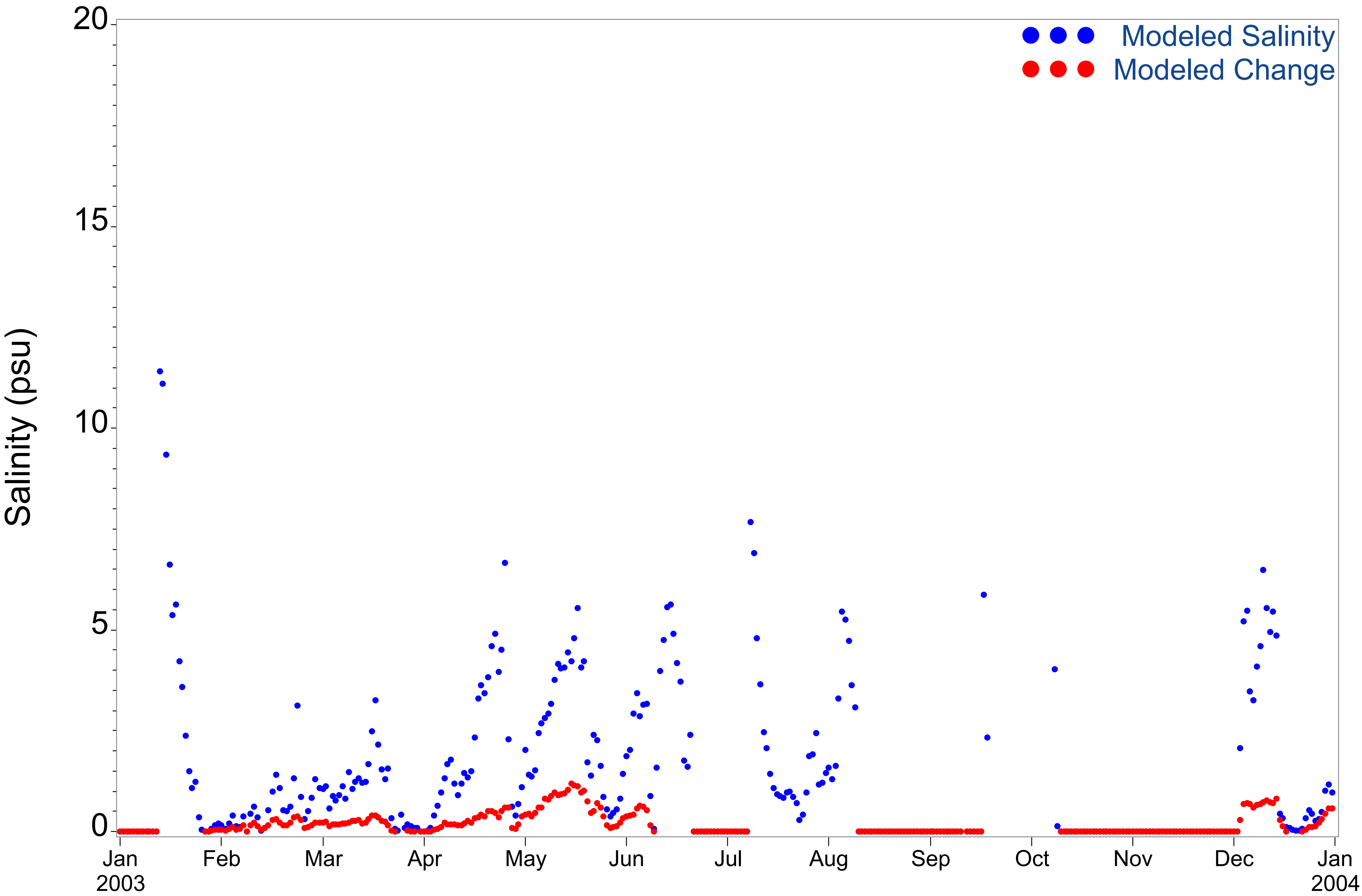


Figure 4.167 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.5 (2003)

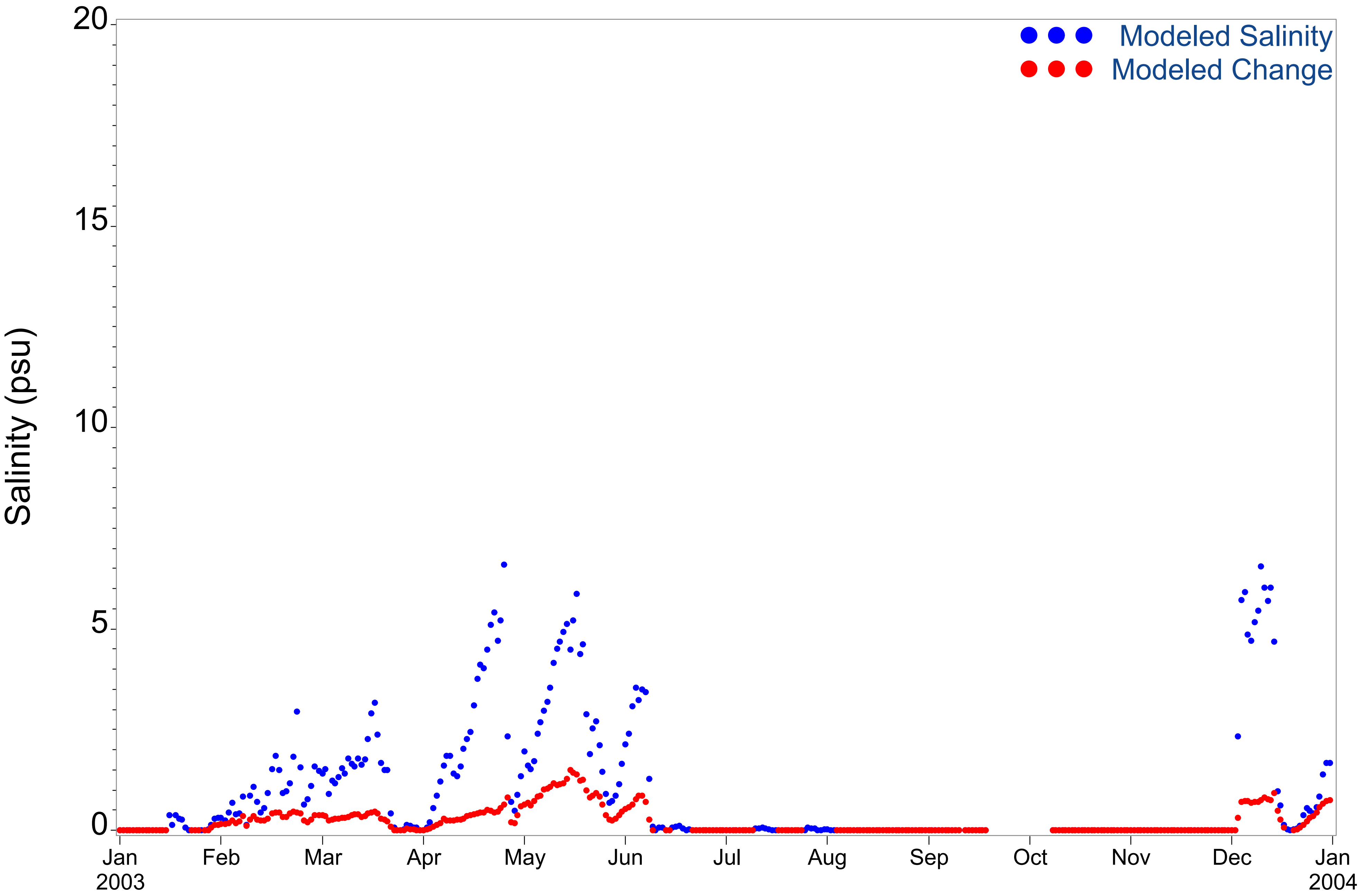


Figure 4.168 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.7 (2003)

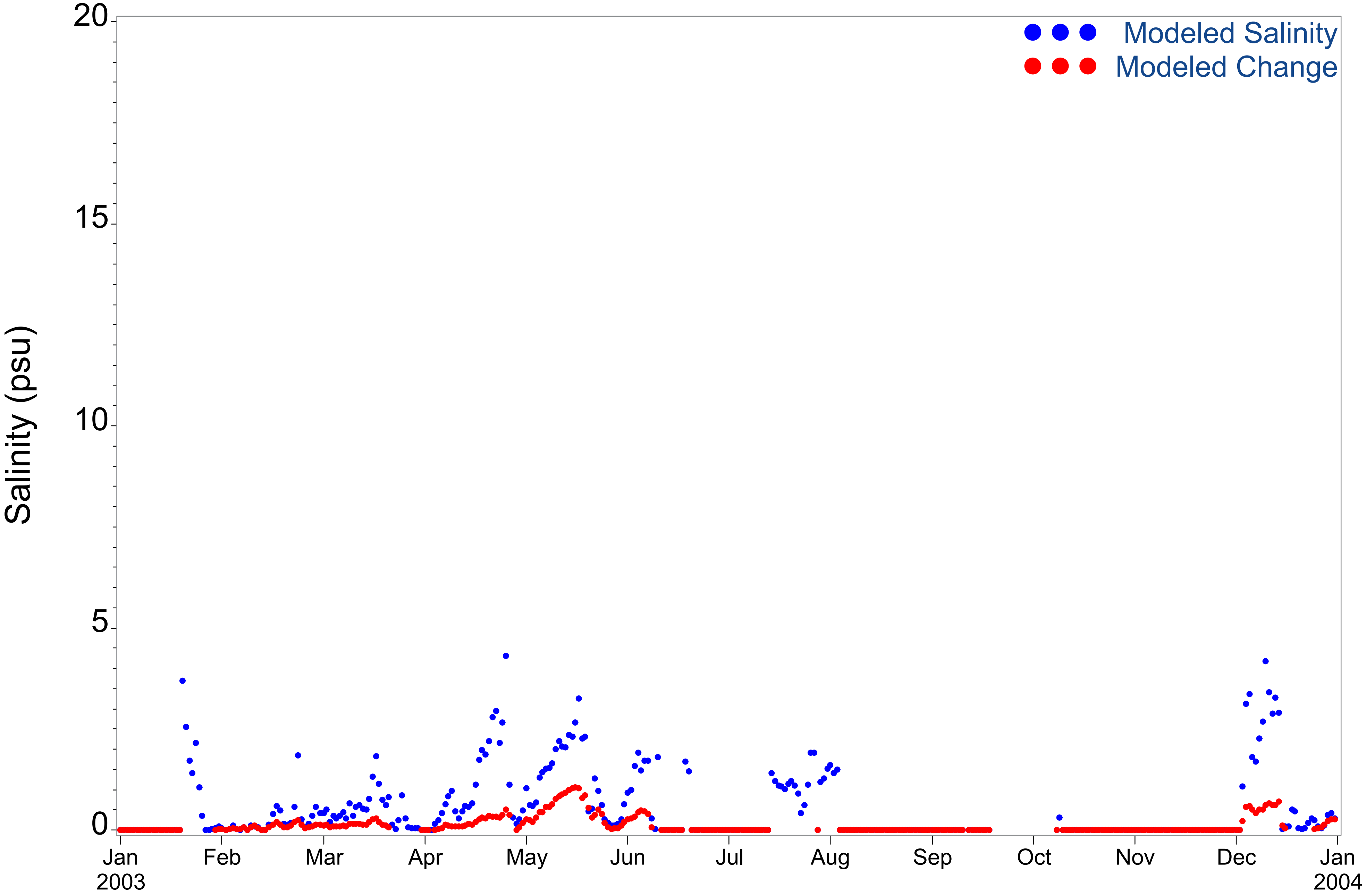


Figure 4.169 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 20.8 (2003)

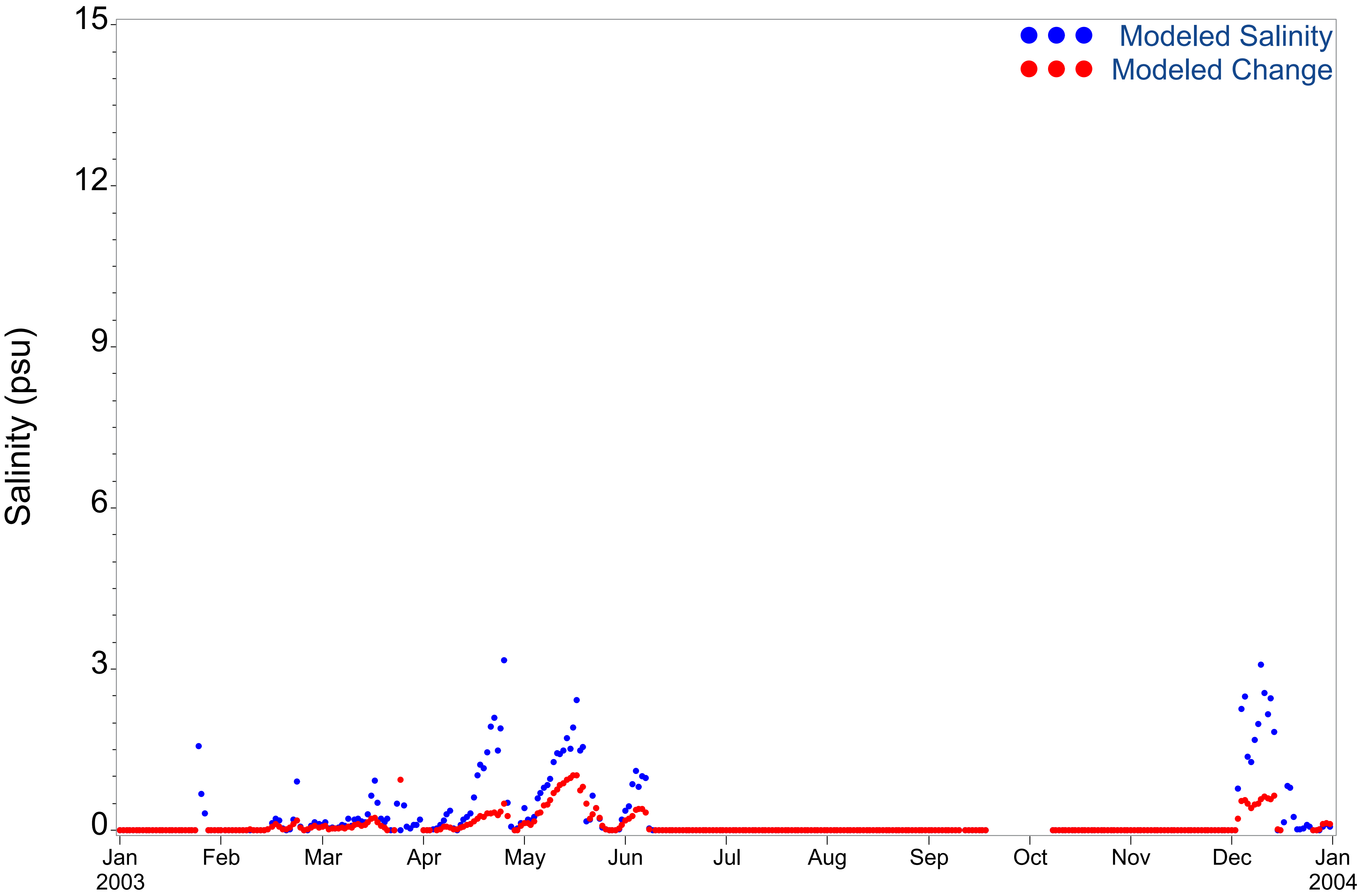


Figure 4.170 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 21.9 (2003)

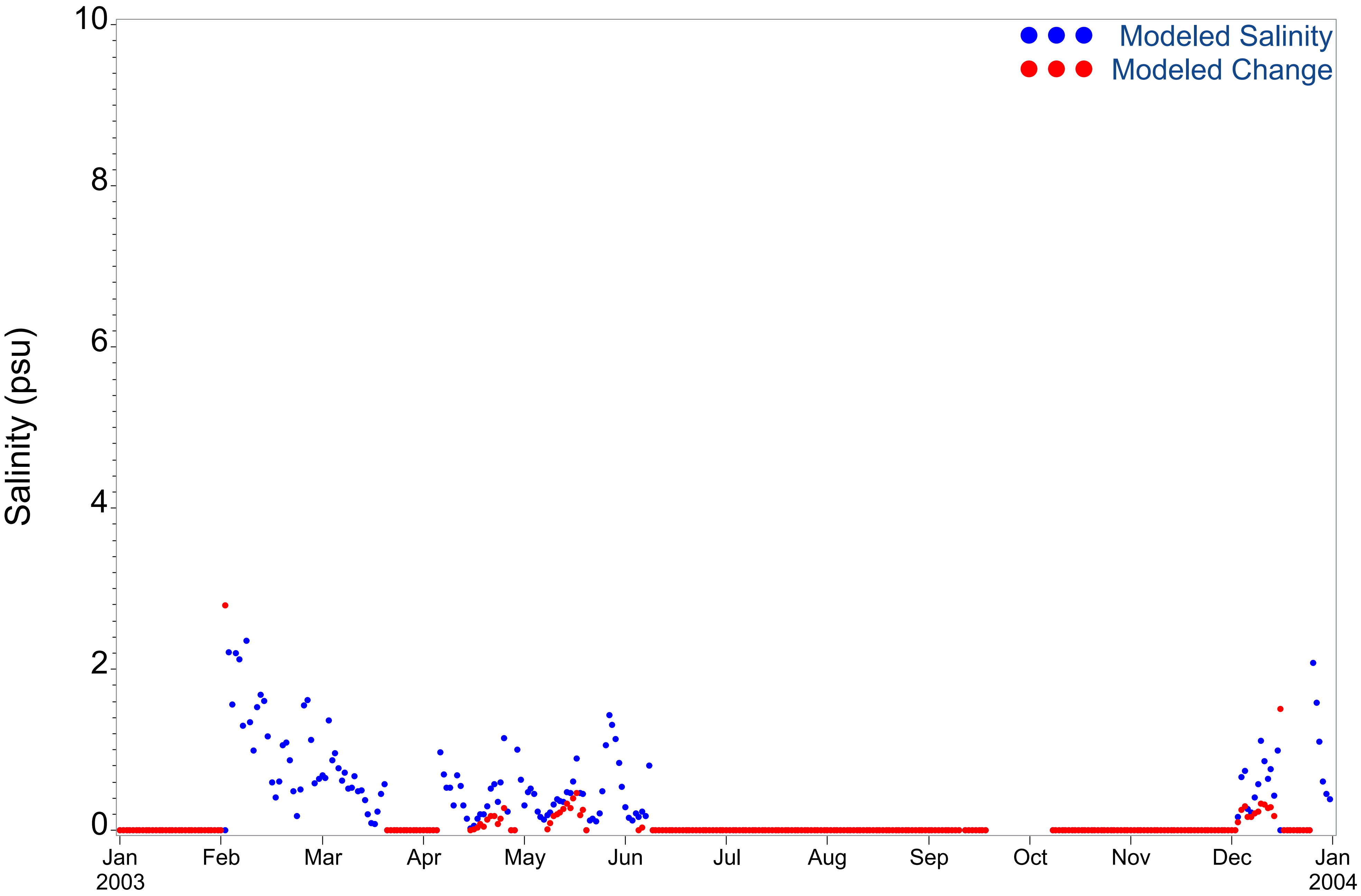


Figure 4.171 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 24.5 (2003)

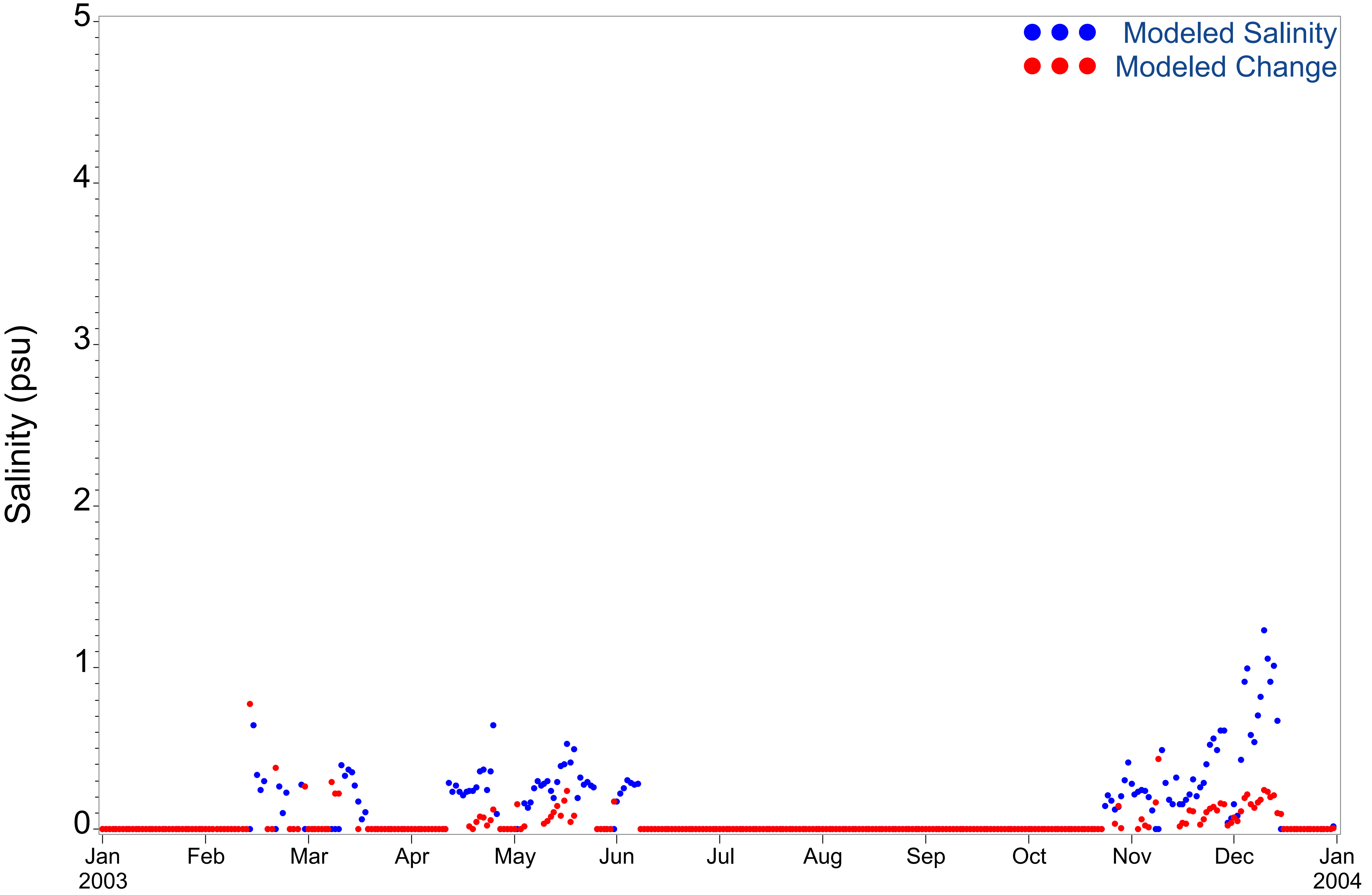


Figure 4.172 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 26.7 (2003)

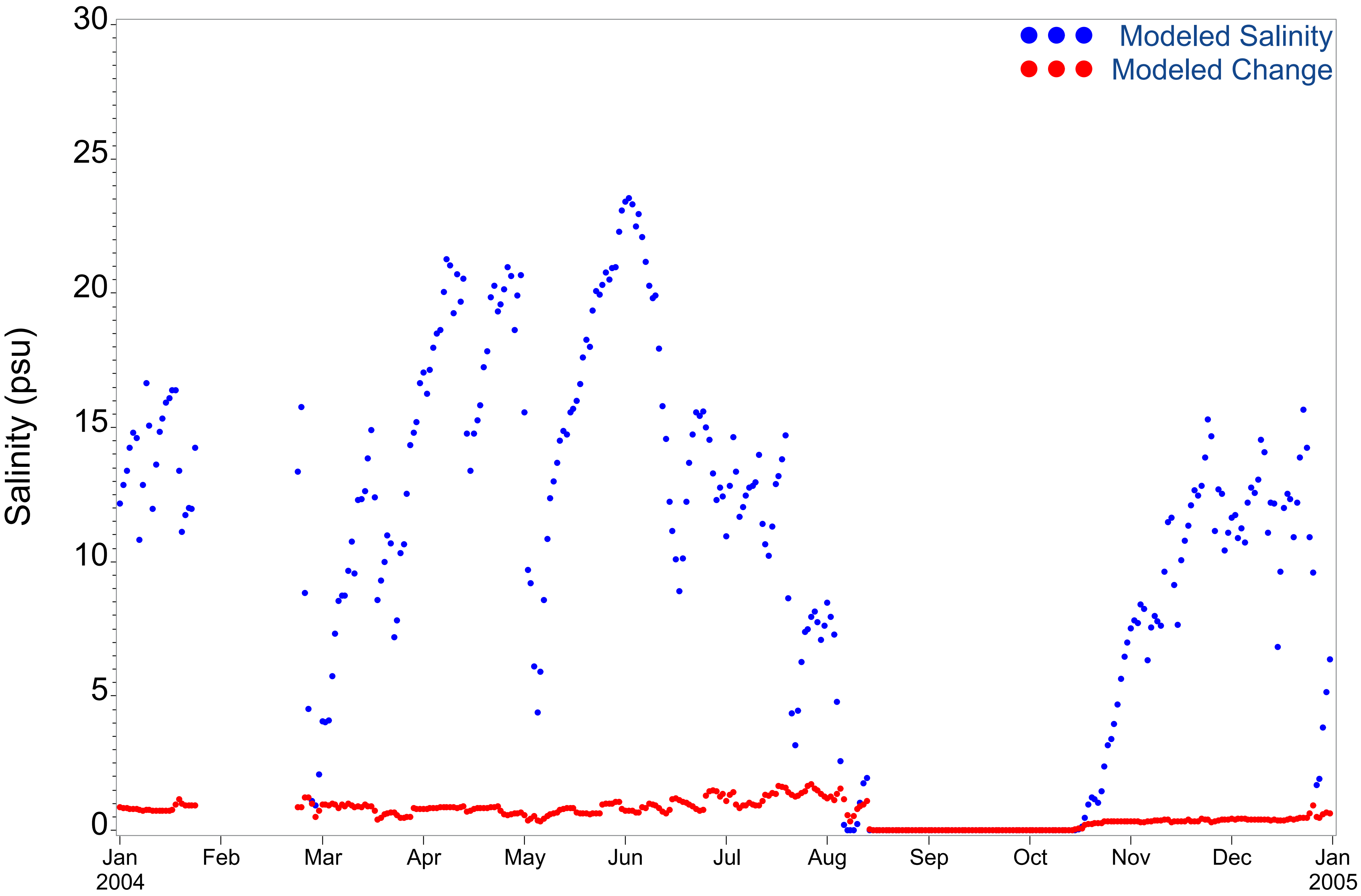


Figure 4.173 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 9.2 (2004)

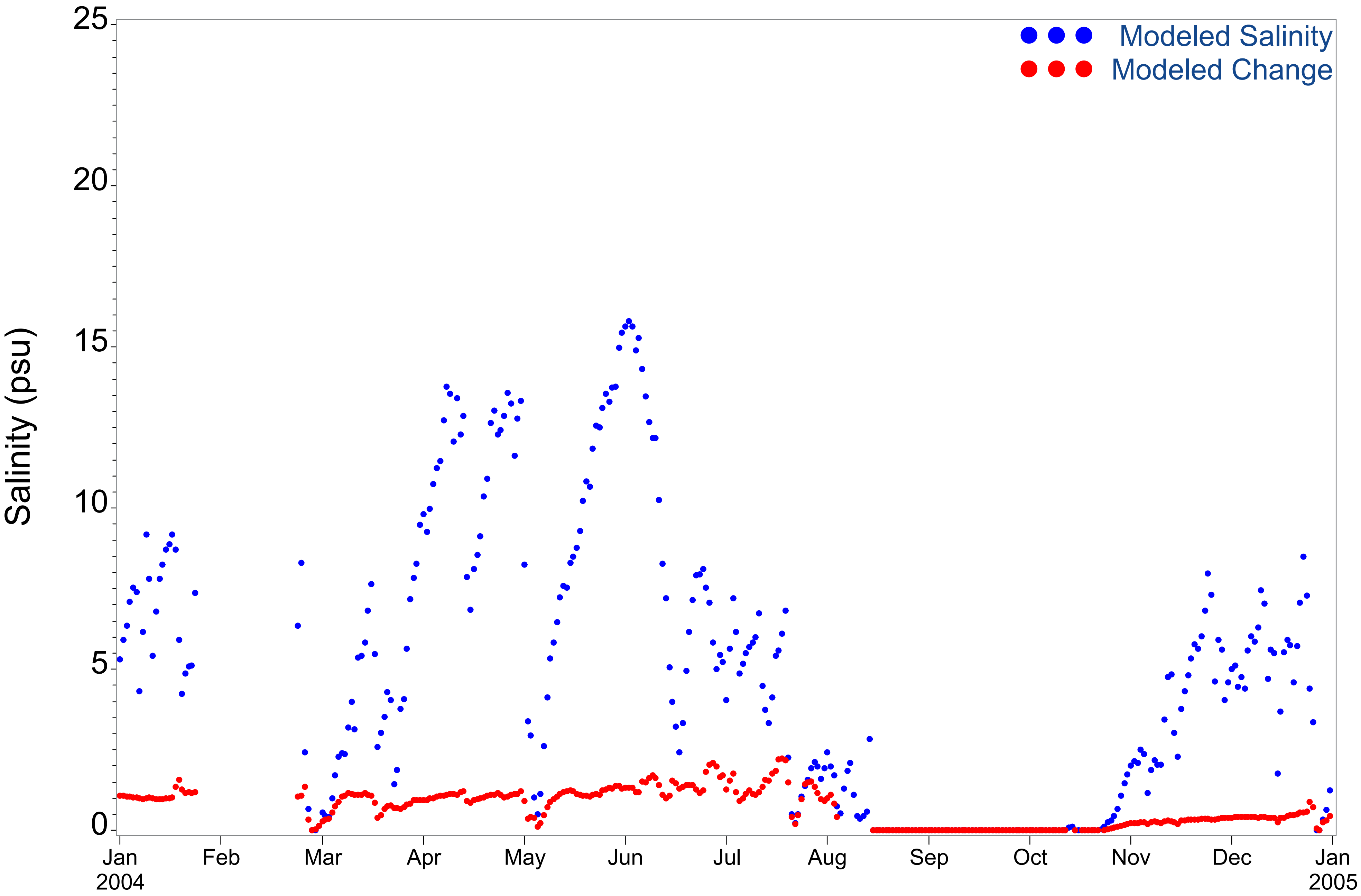


Figure 4.174 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 12.7 (2004)

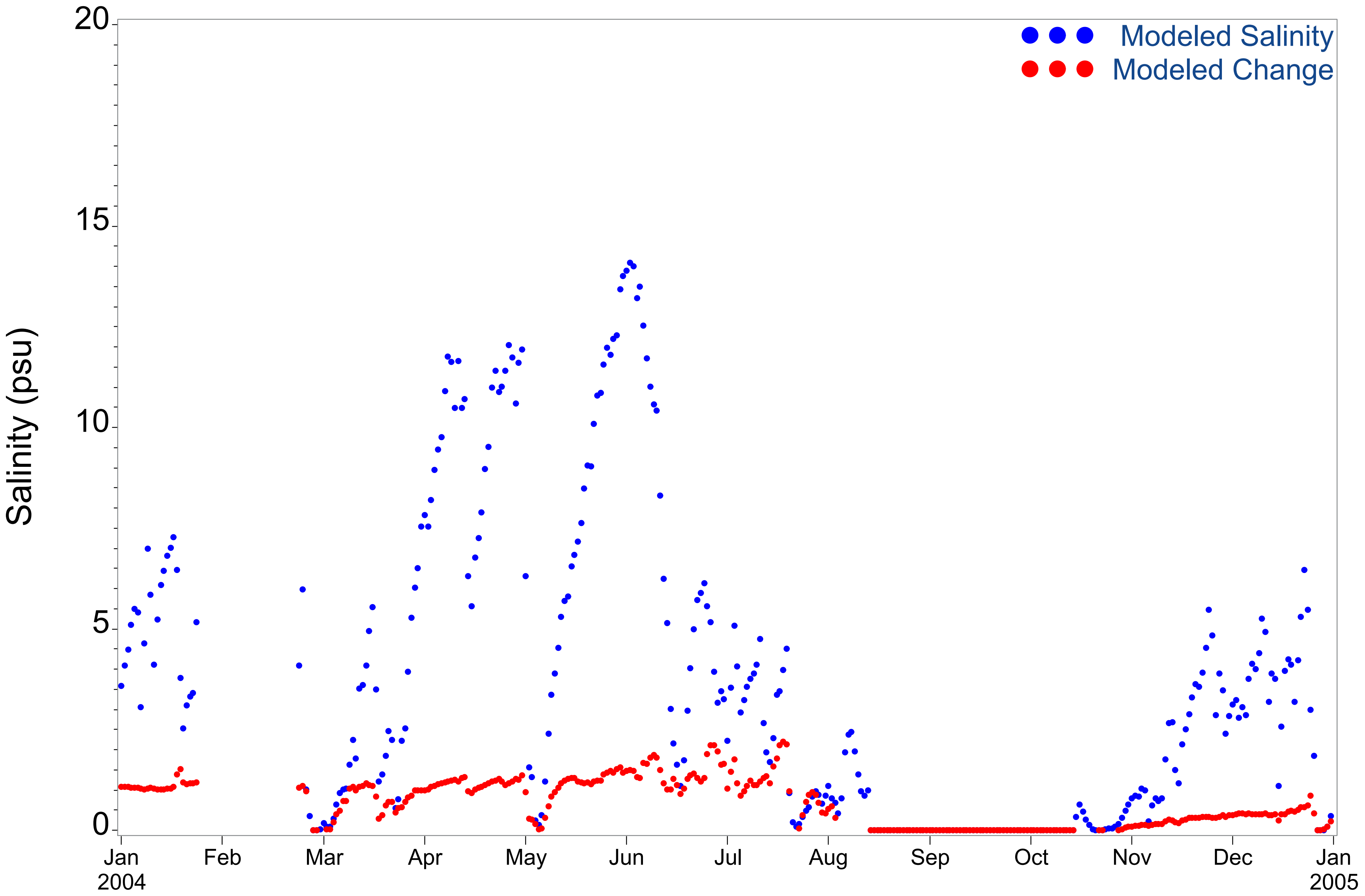


Figure 4.175 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 15.5 (2004)

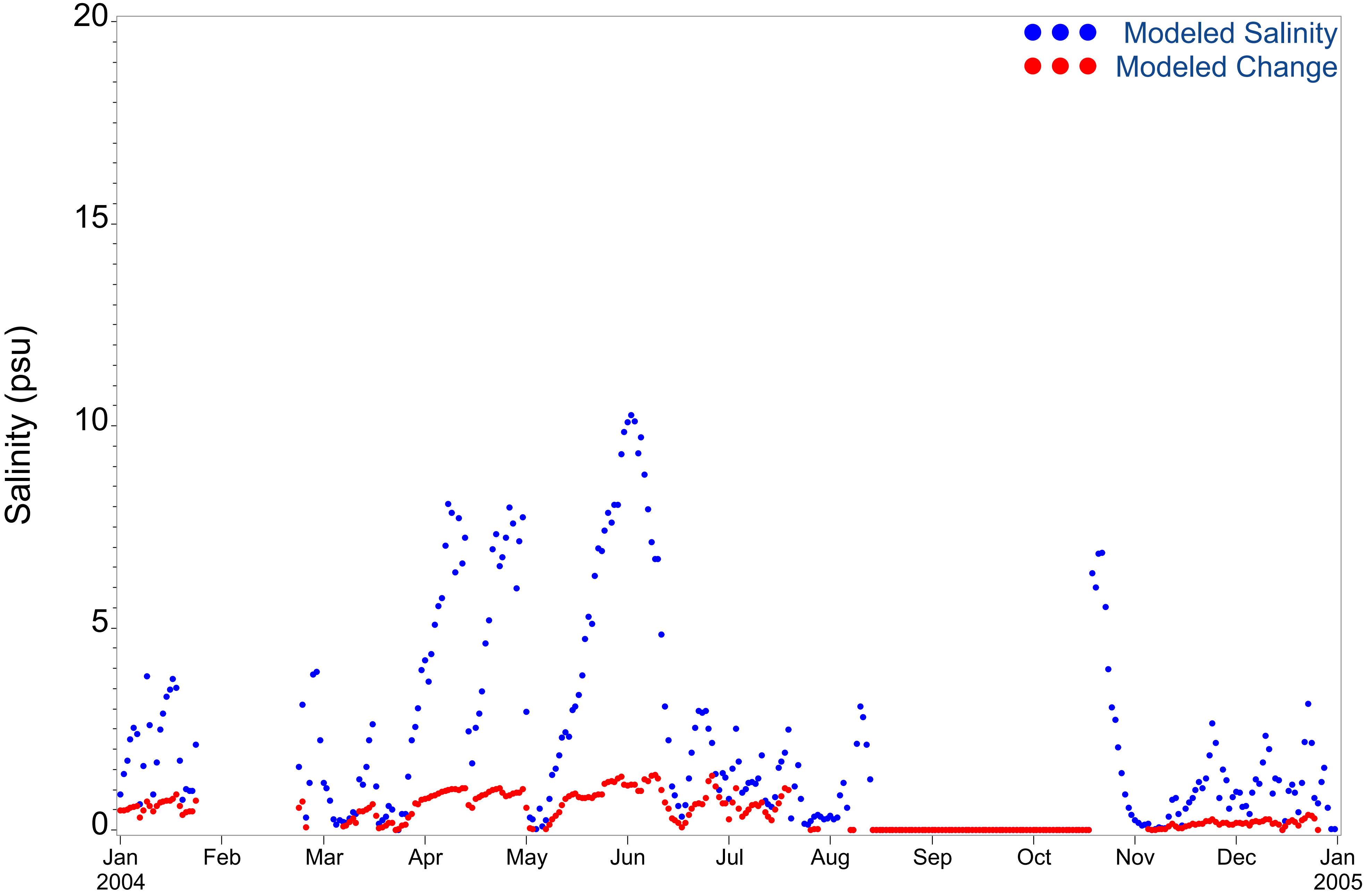


Figure 4.176 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.5 (2004)

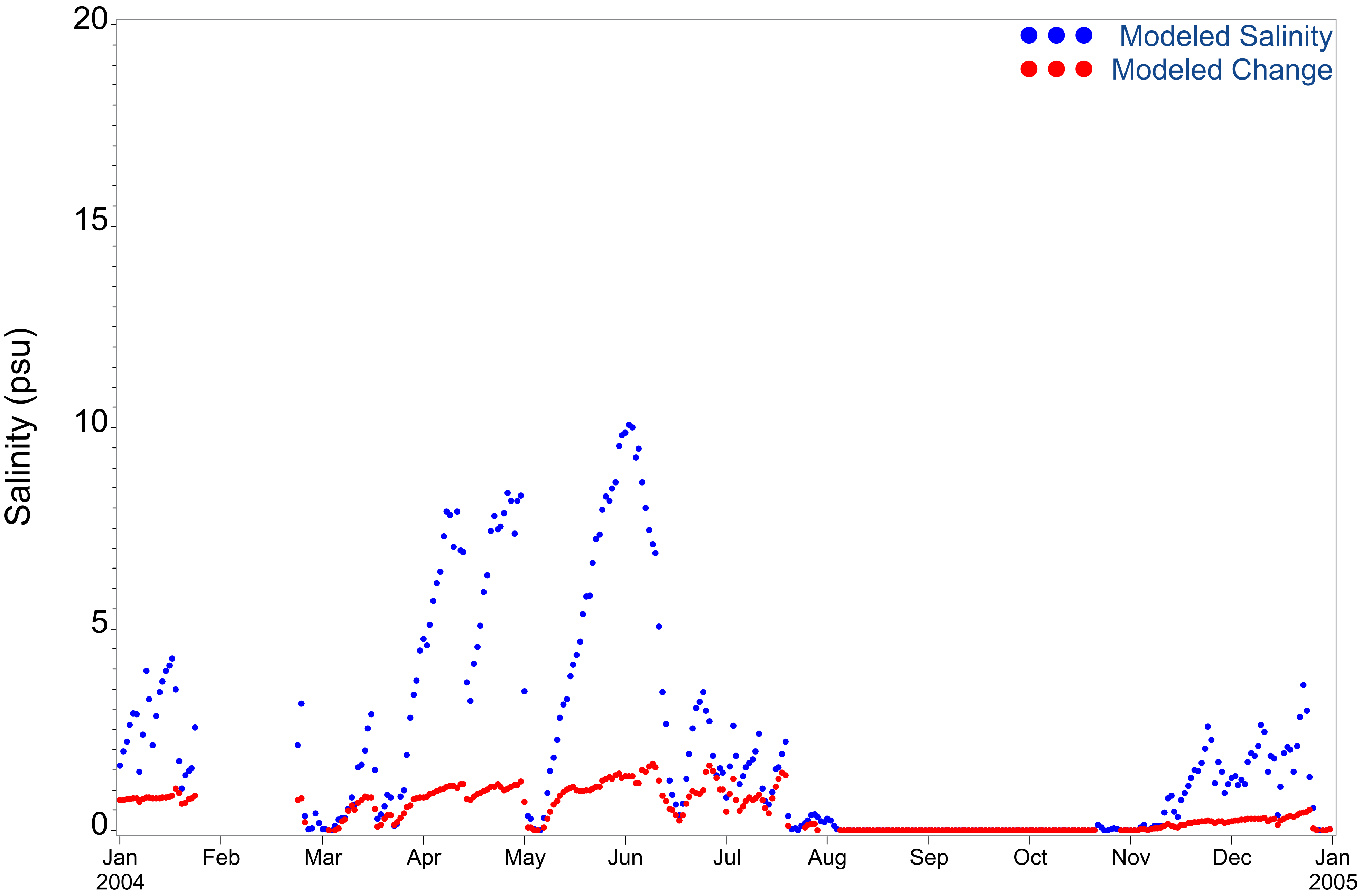


Figure 4.177 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.7 (2004)

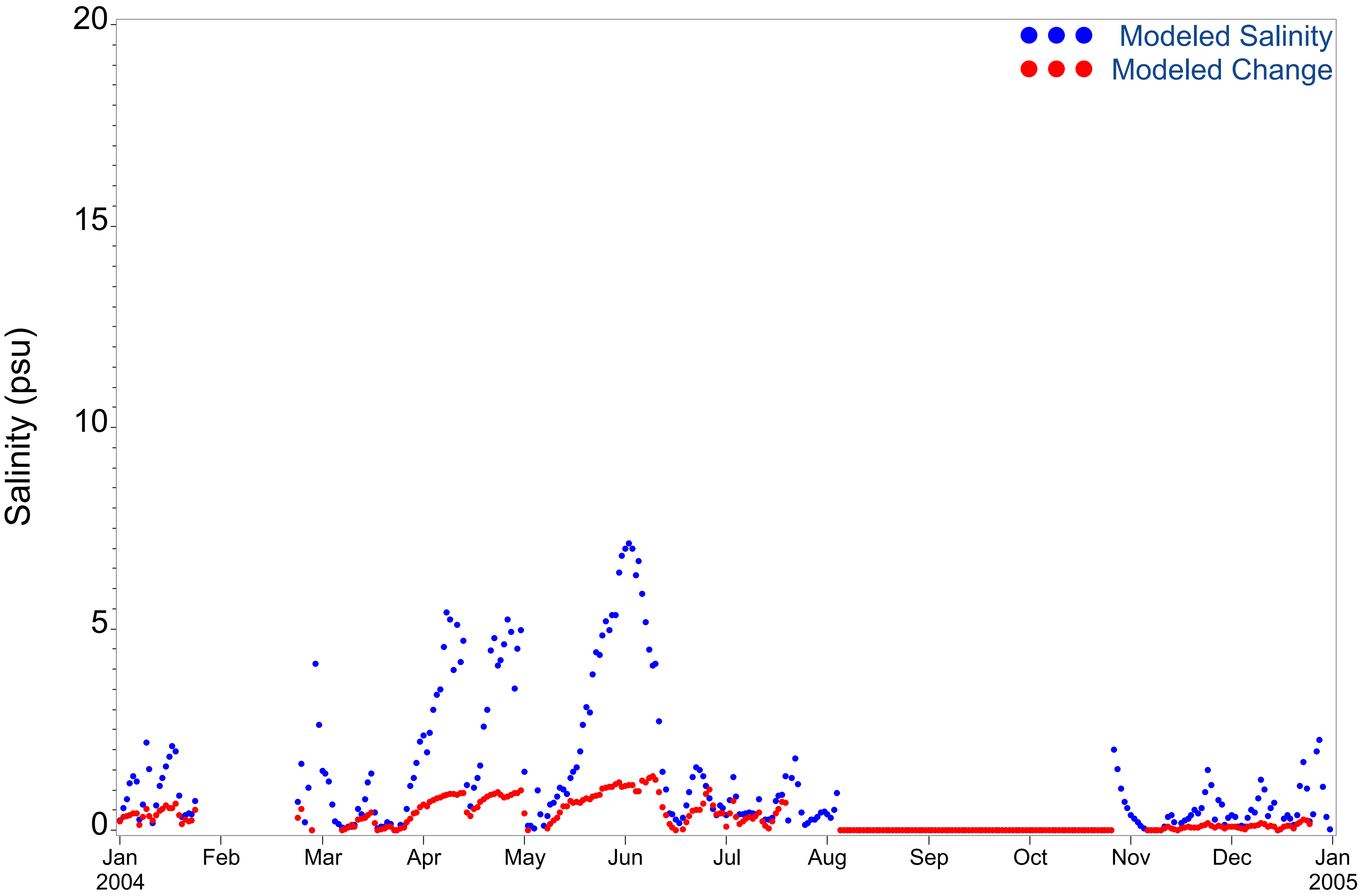


Figure 4.178 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 20.8 (2004)

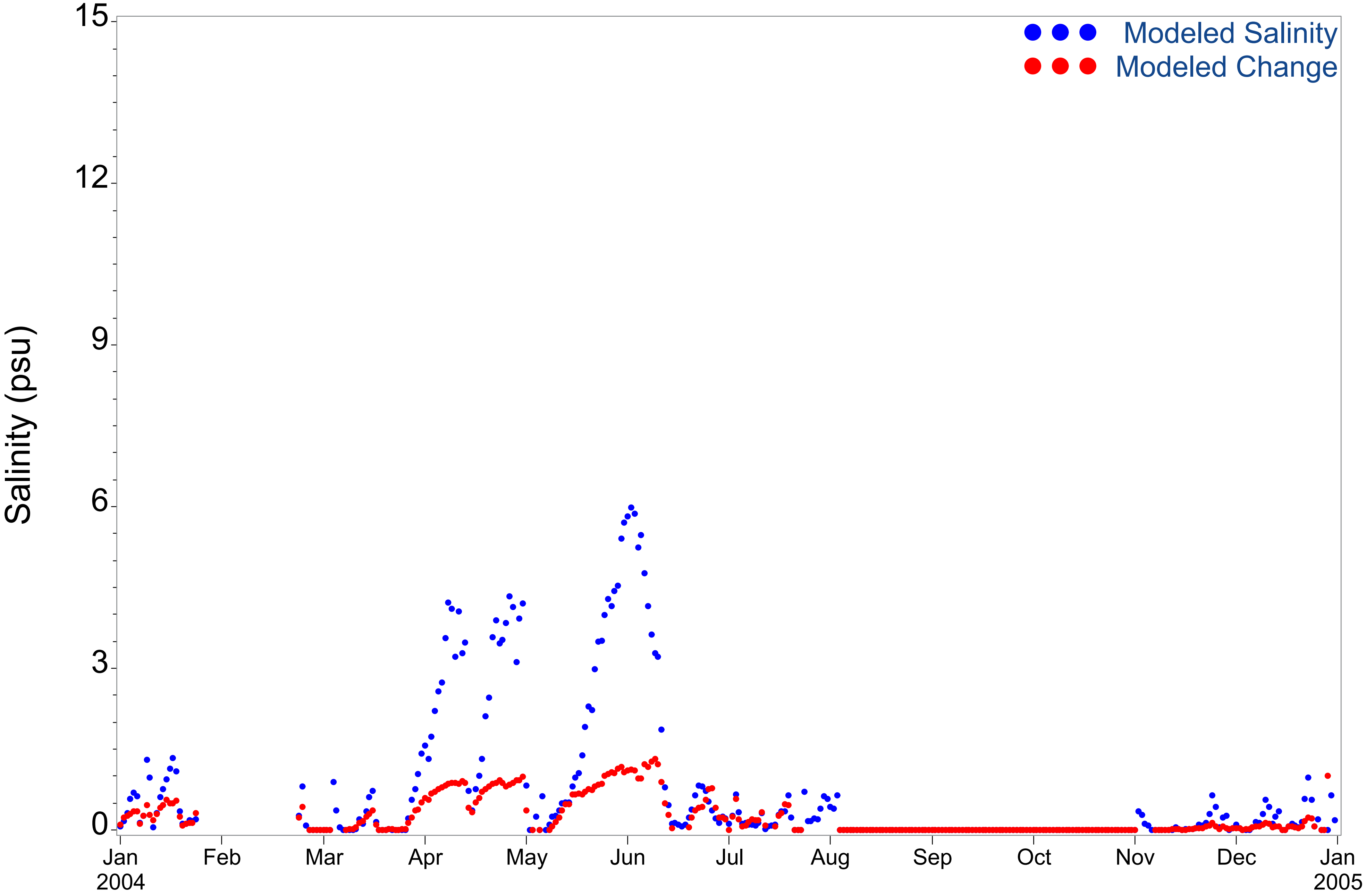


Figure 4.179 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 21.9 (2004)

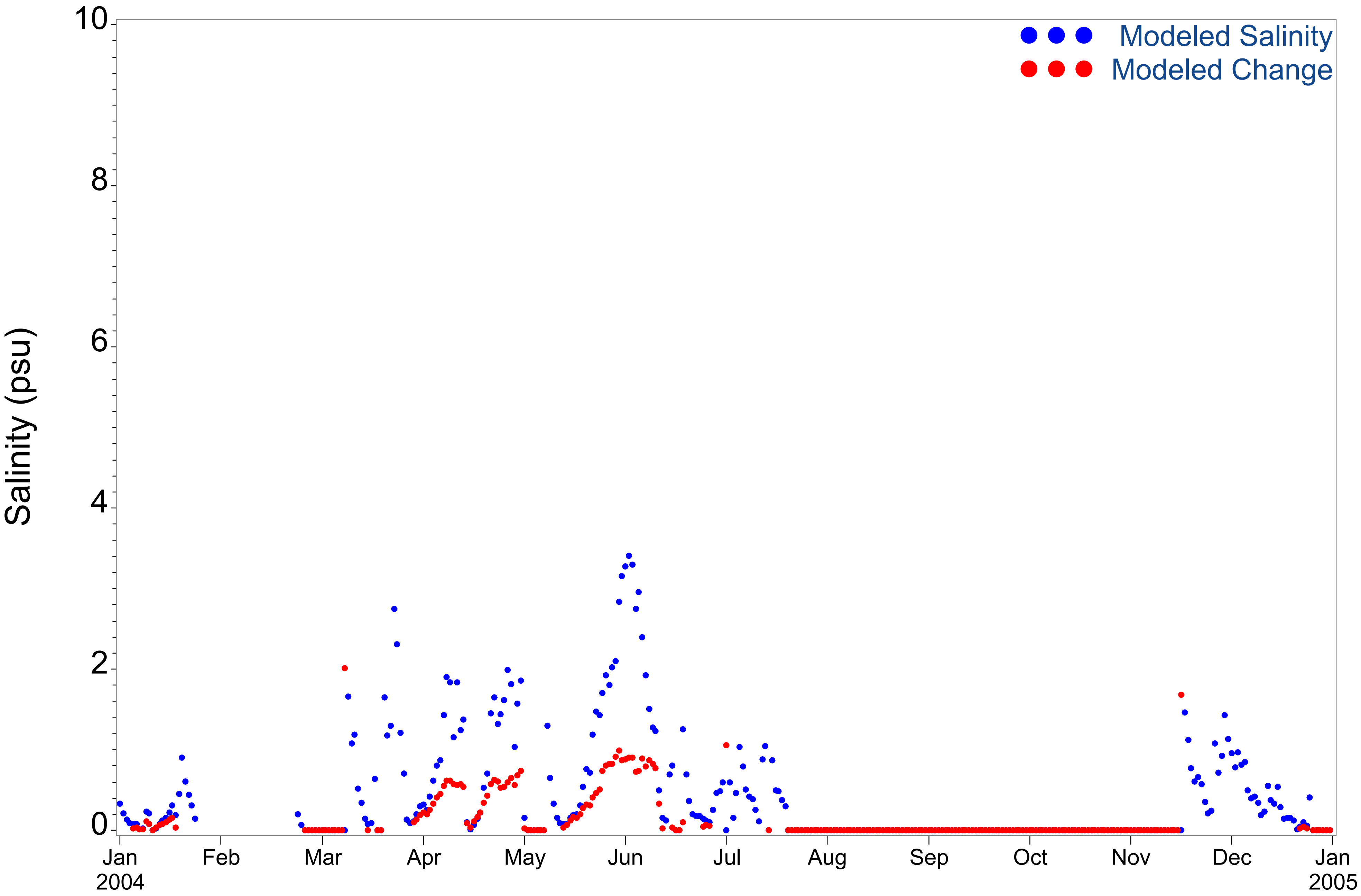


Figure 4.180 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 24.5 (2004)

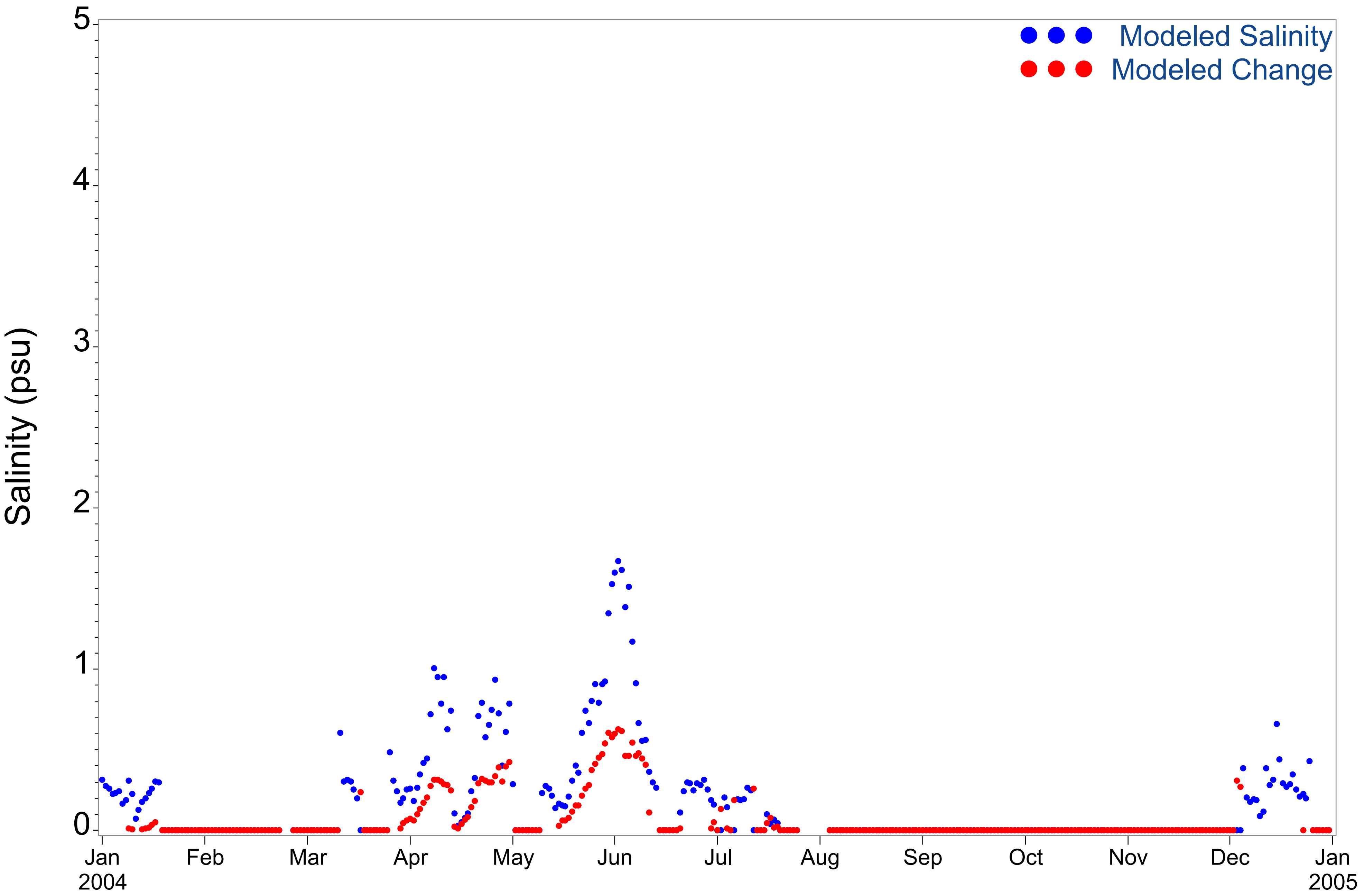


Figure 4.181 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 26.7 (2004)

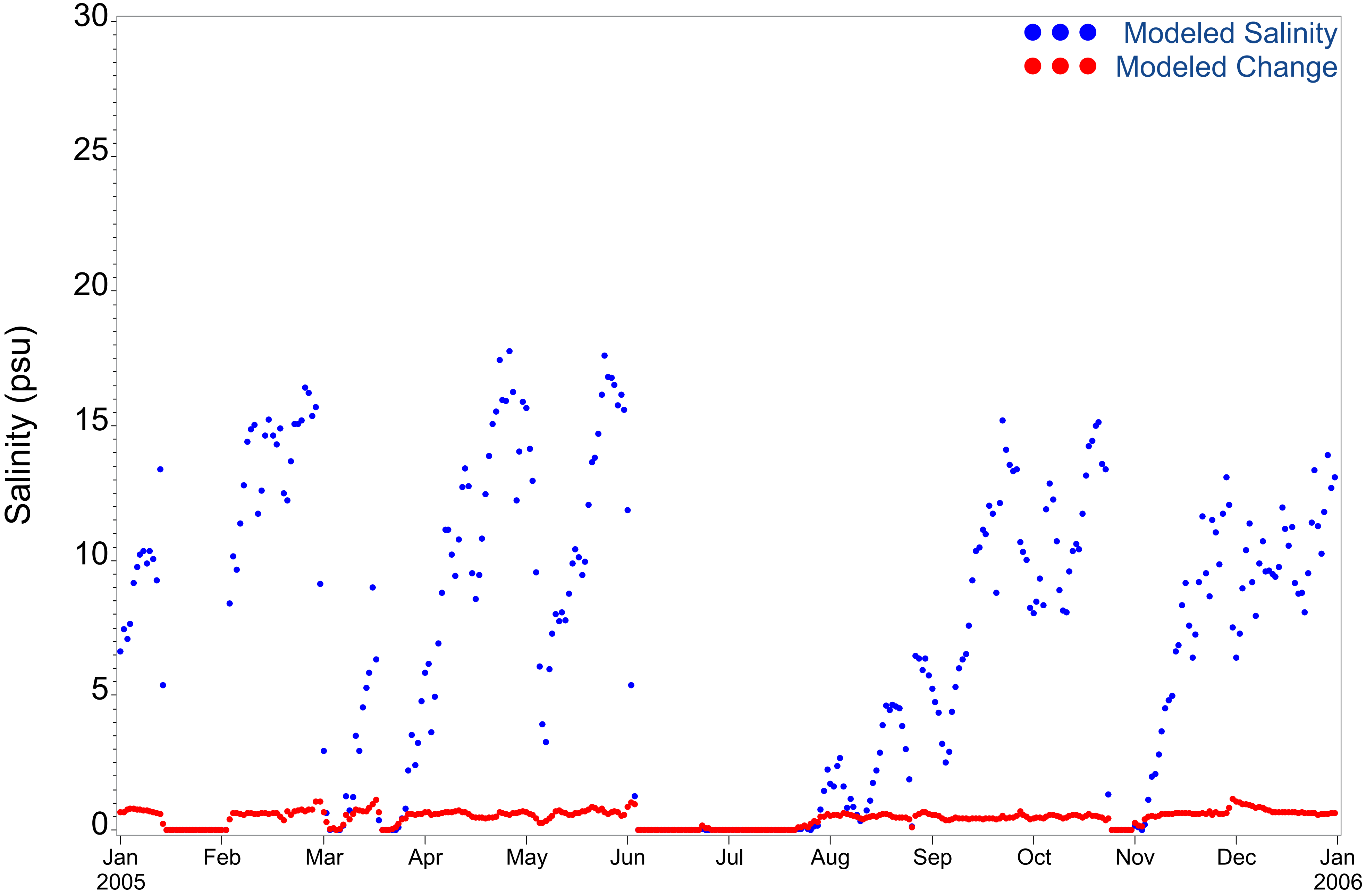


Figure 4.182 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 9.2 (2005)

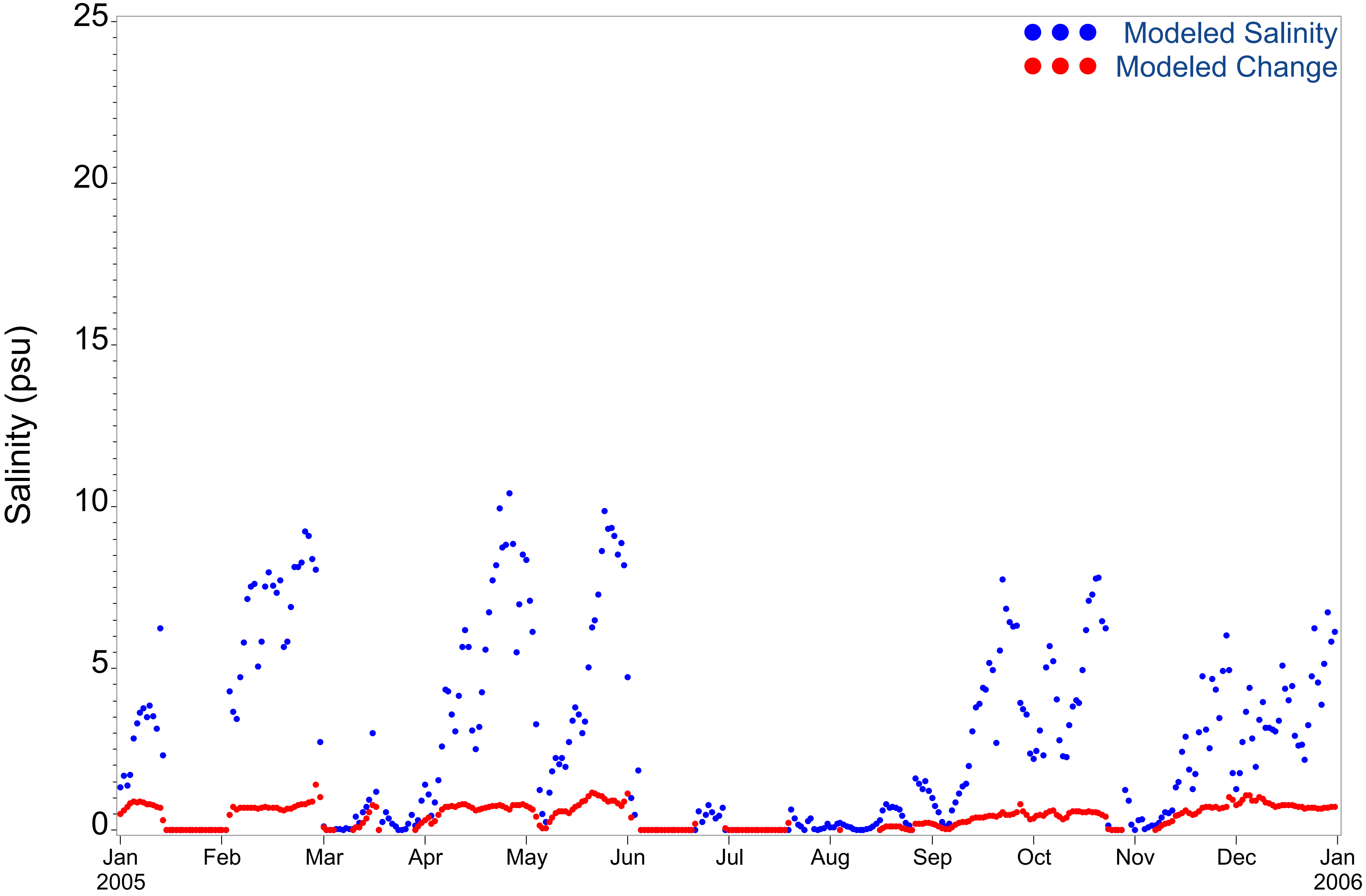


Figure 4.183 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 12.7 (2005)

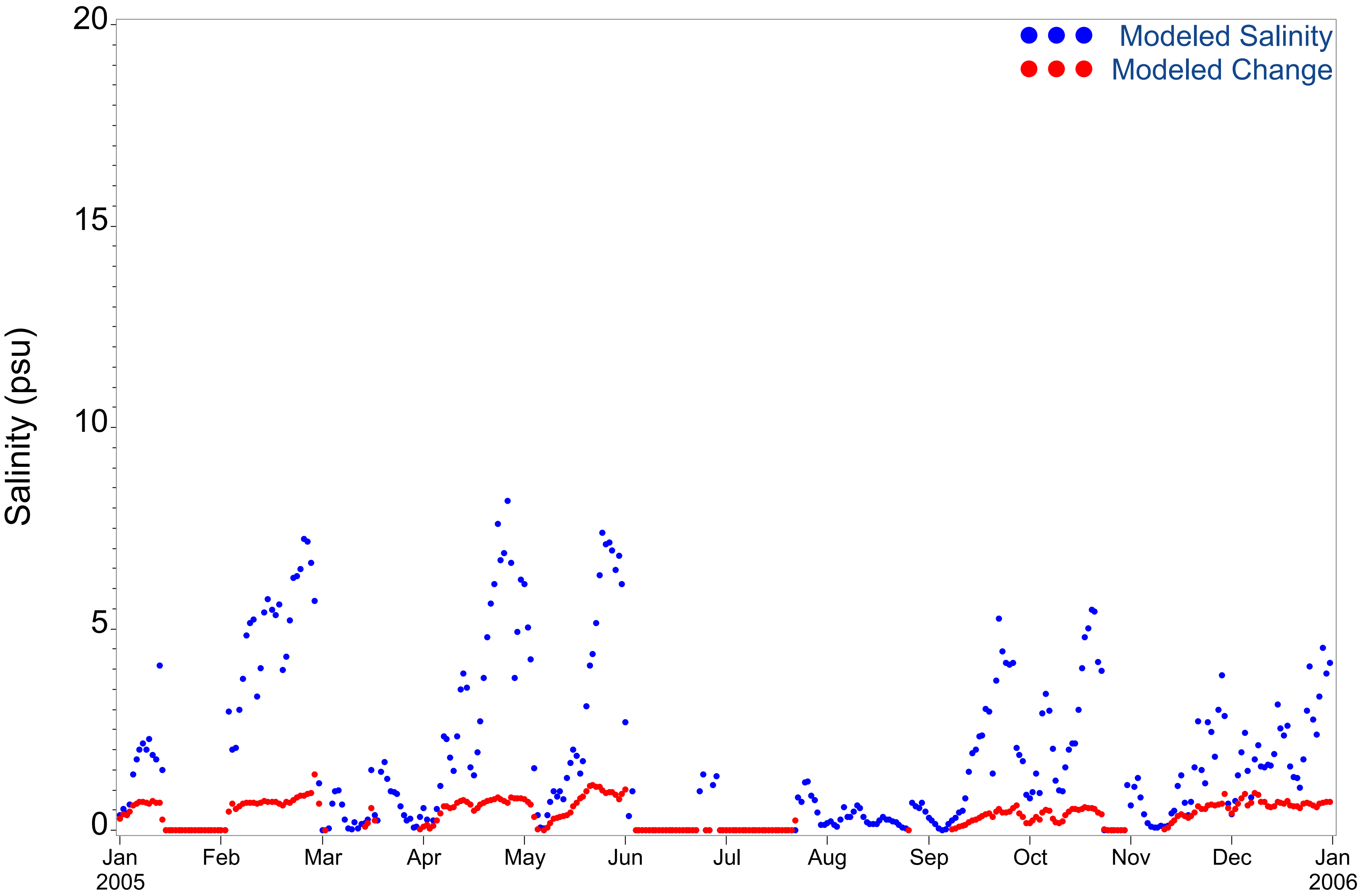


Figure 4.184 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 15.5 (2005)

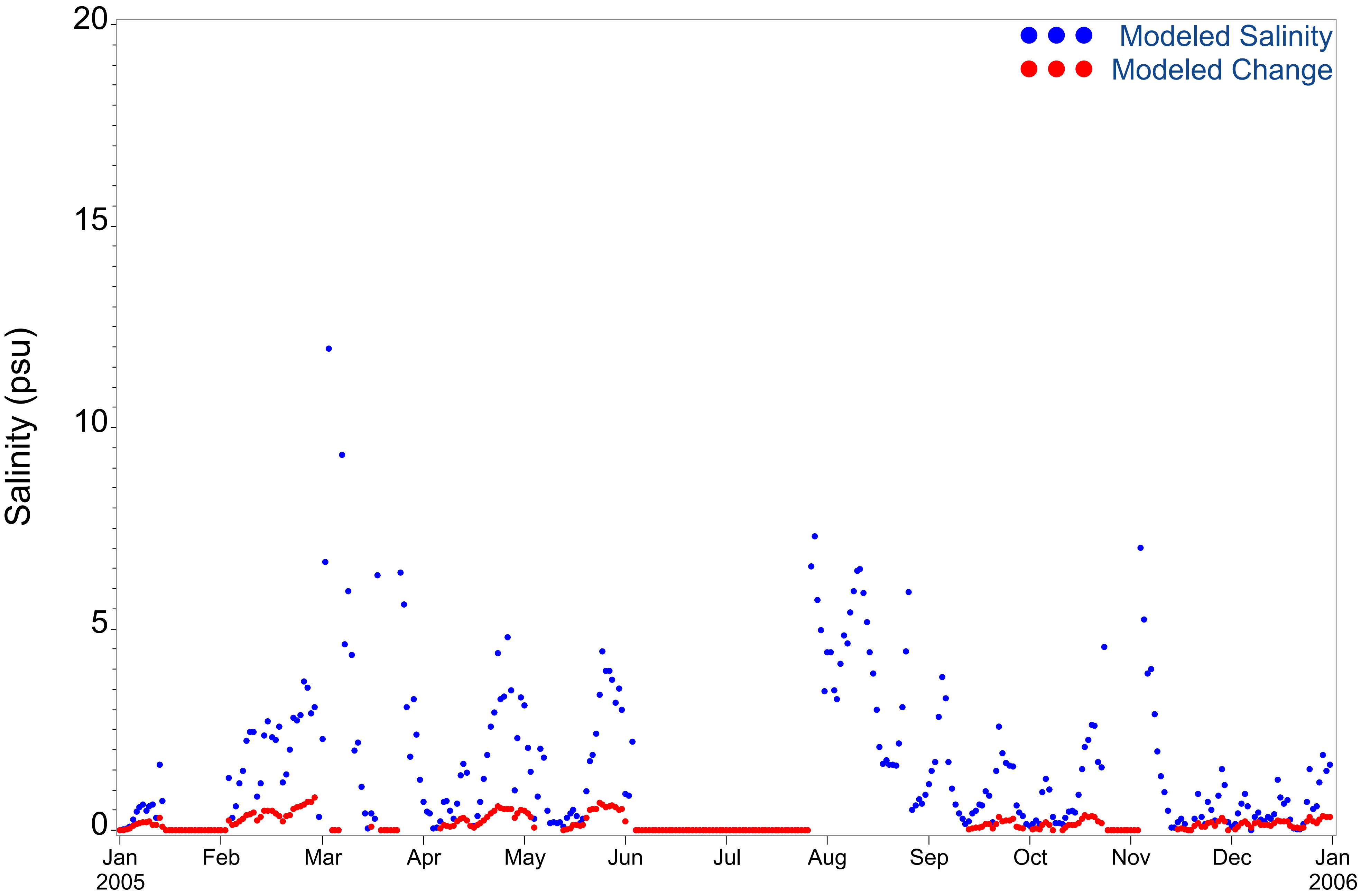


Figure 4.185 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.5 (2005)

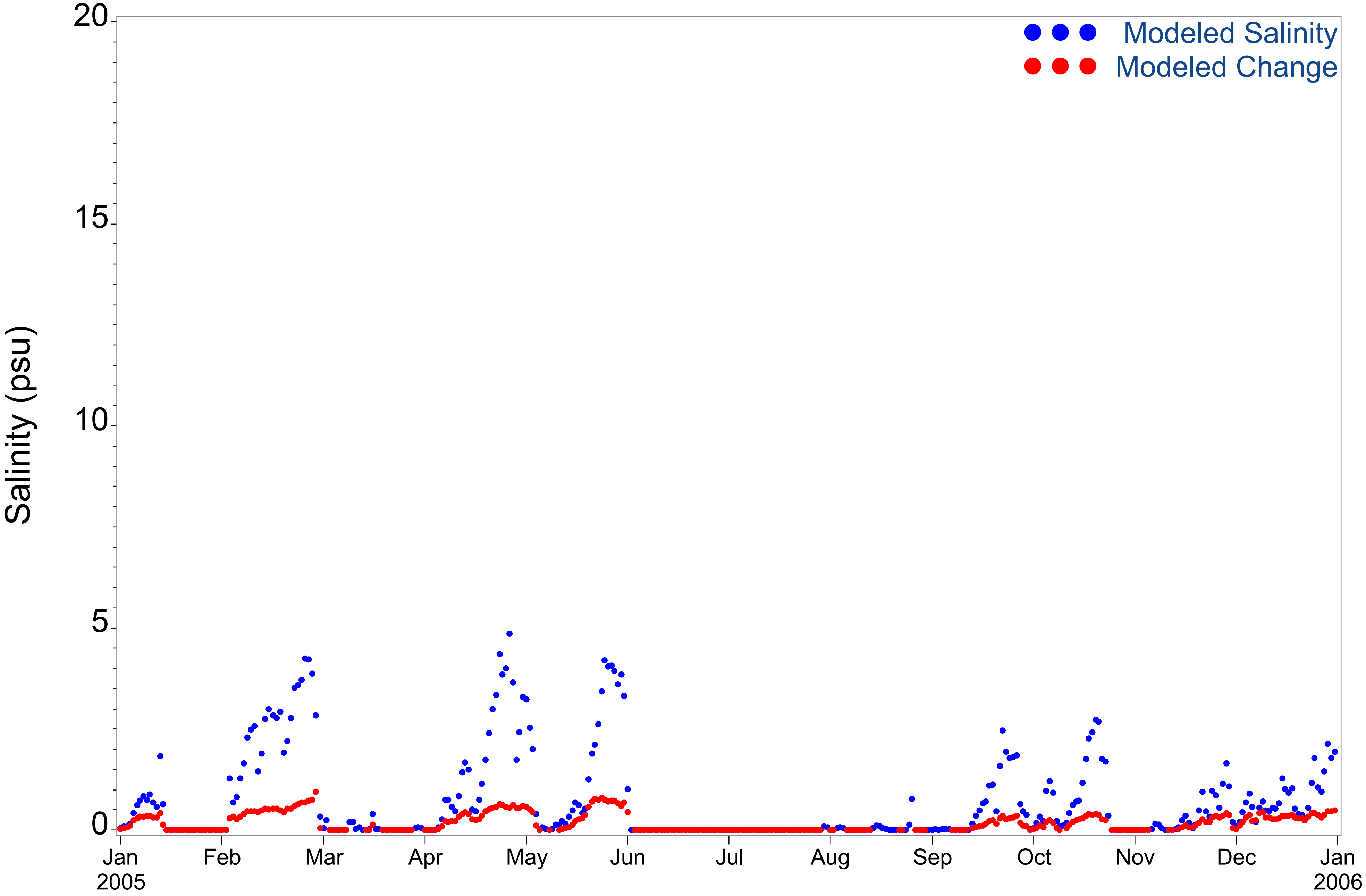


Figure 4.186 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.7 (2005)

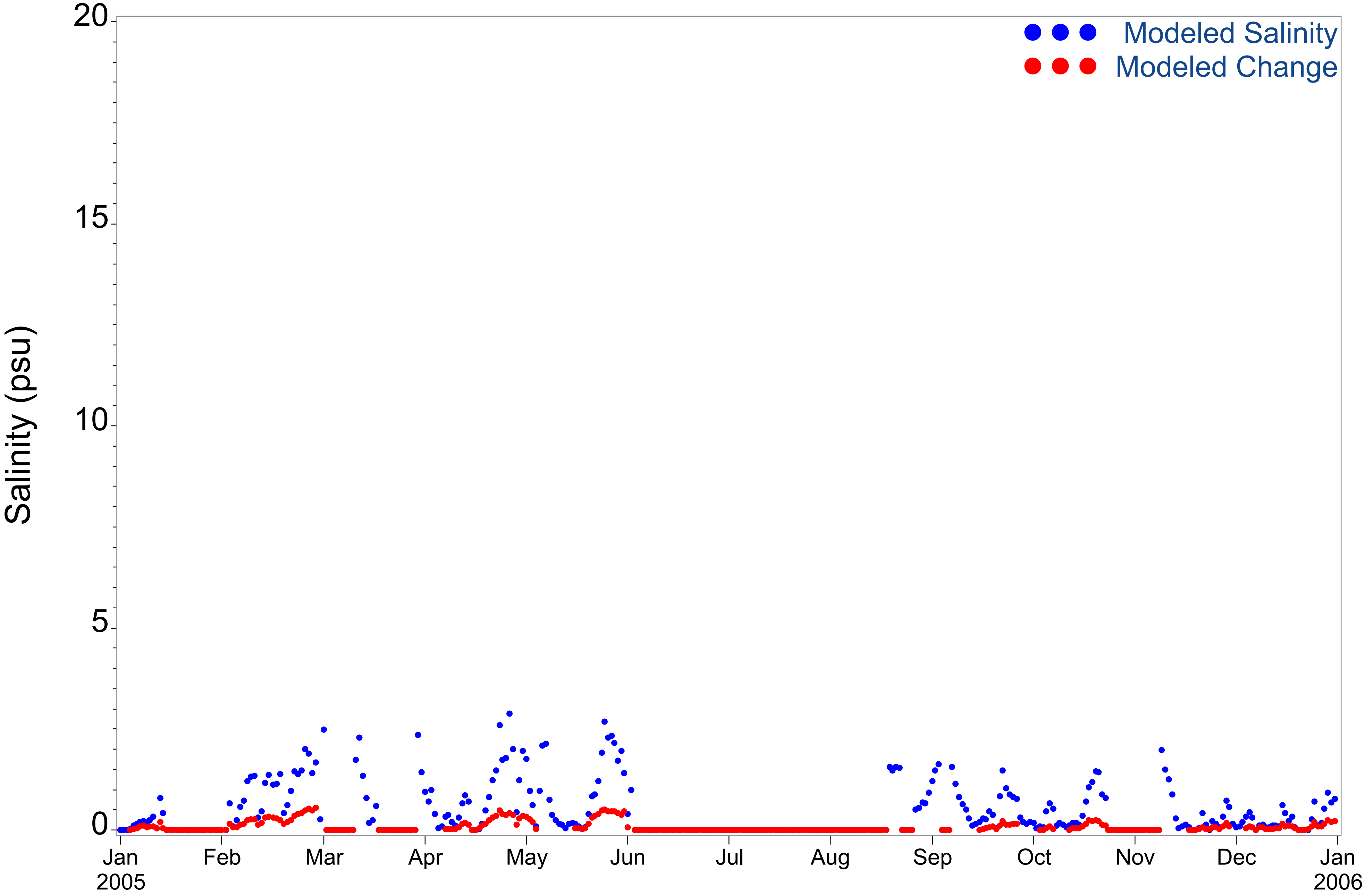


Figure 4.187 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 20.8 (2005)

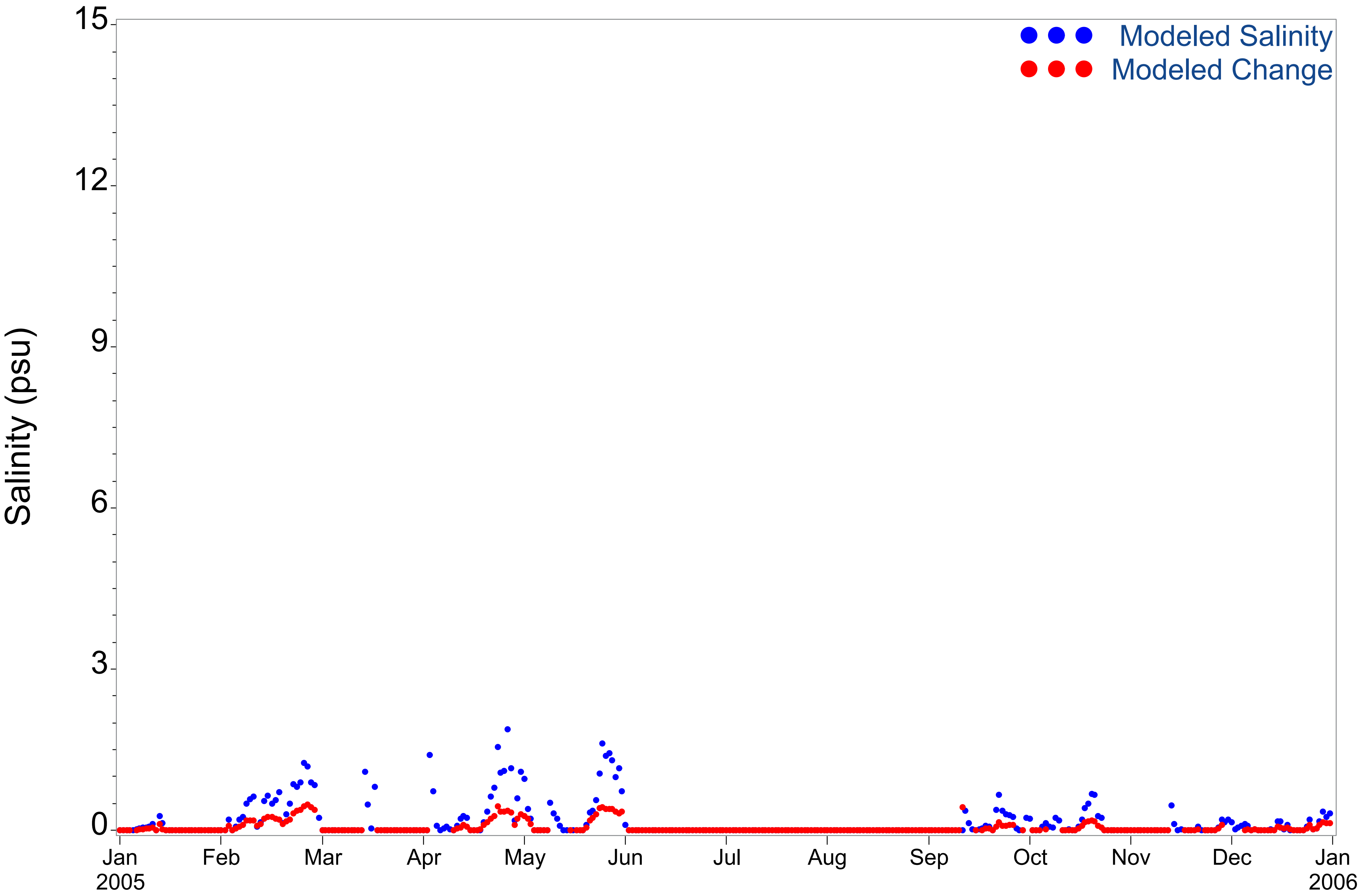


Figure 4.188 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 21.9 (2005)

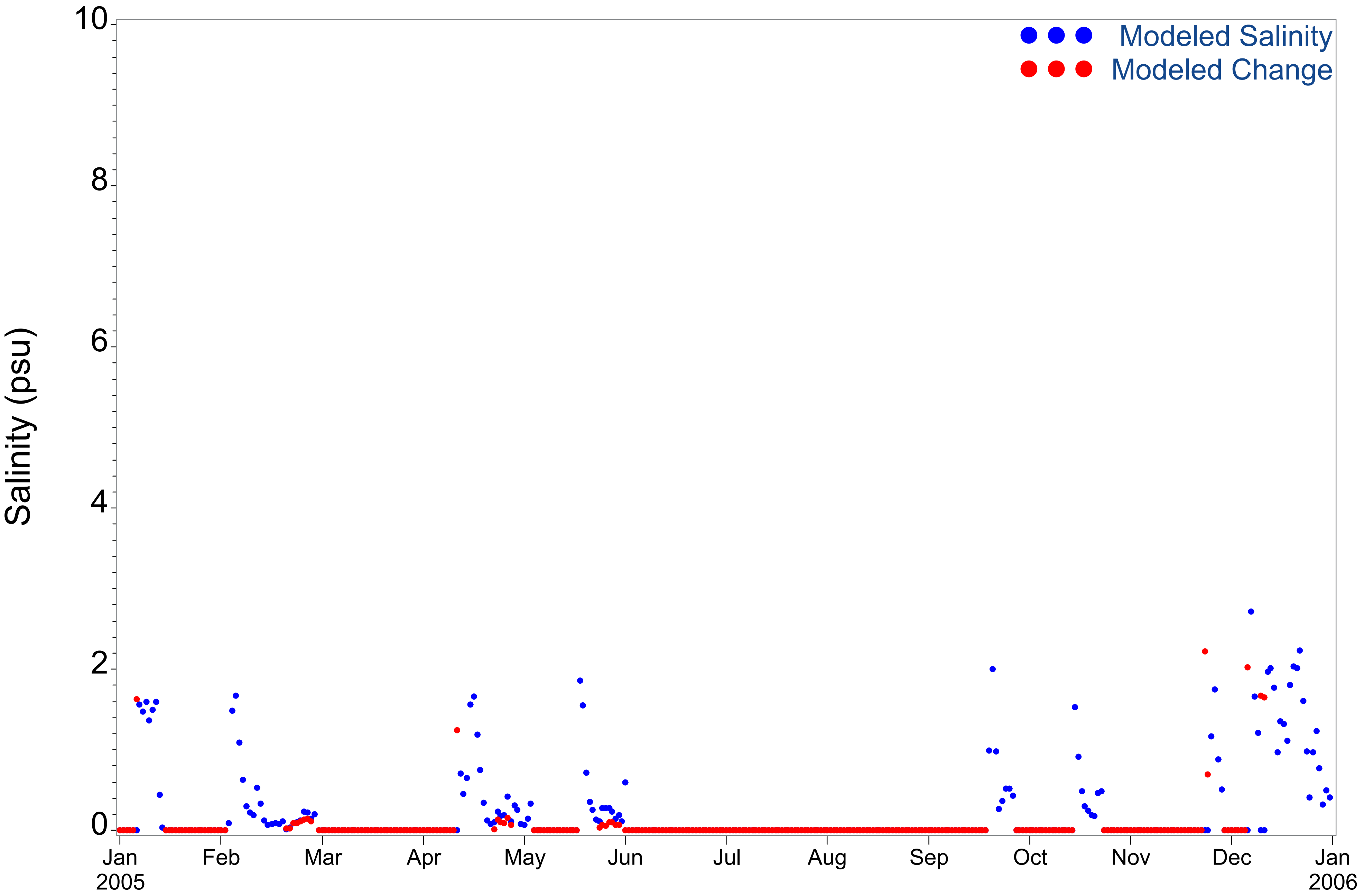


Figure 4.189 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 24.5 (2005)

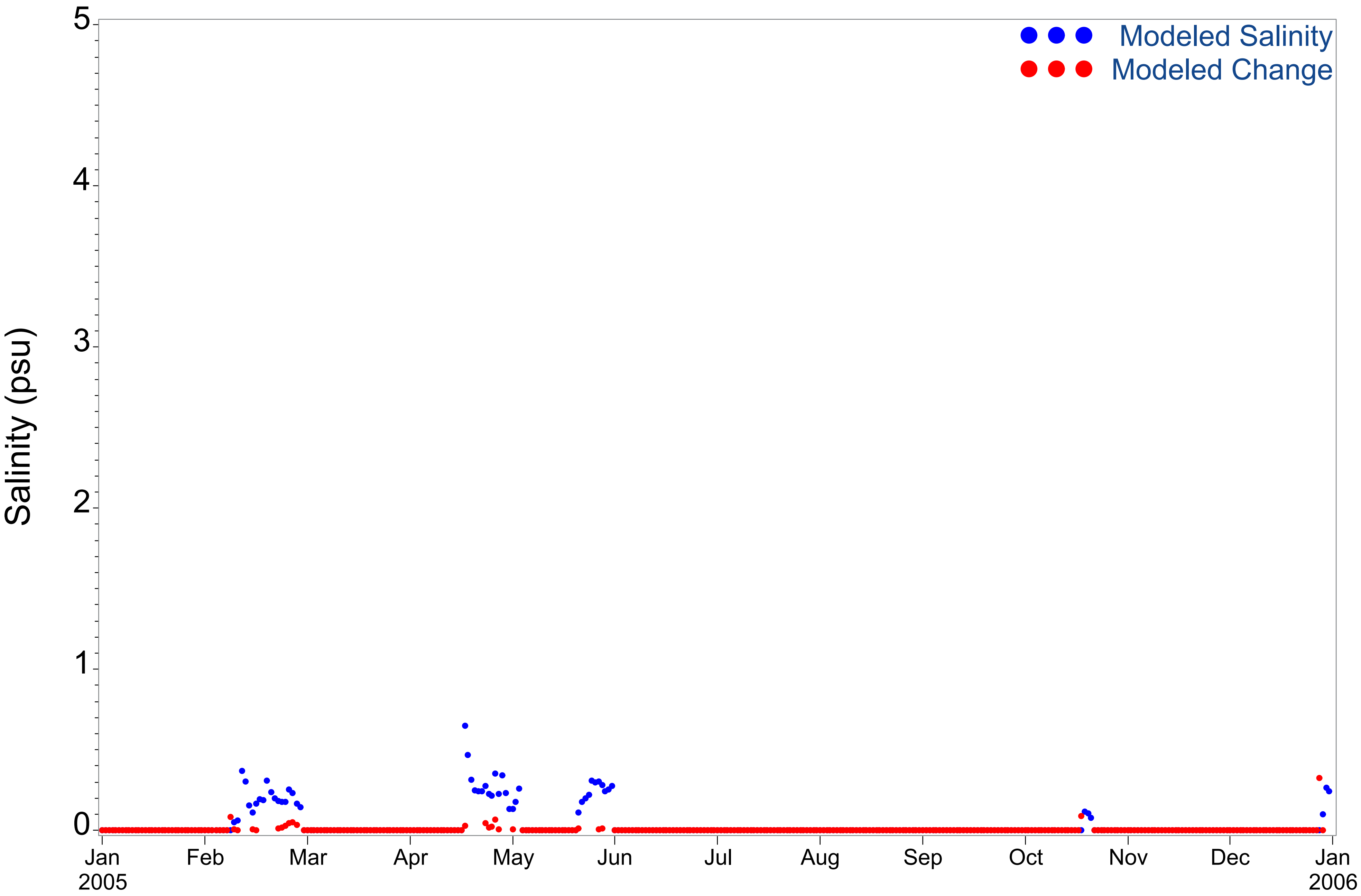


Figure 4.190 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 26.7 (2005)

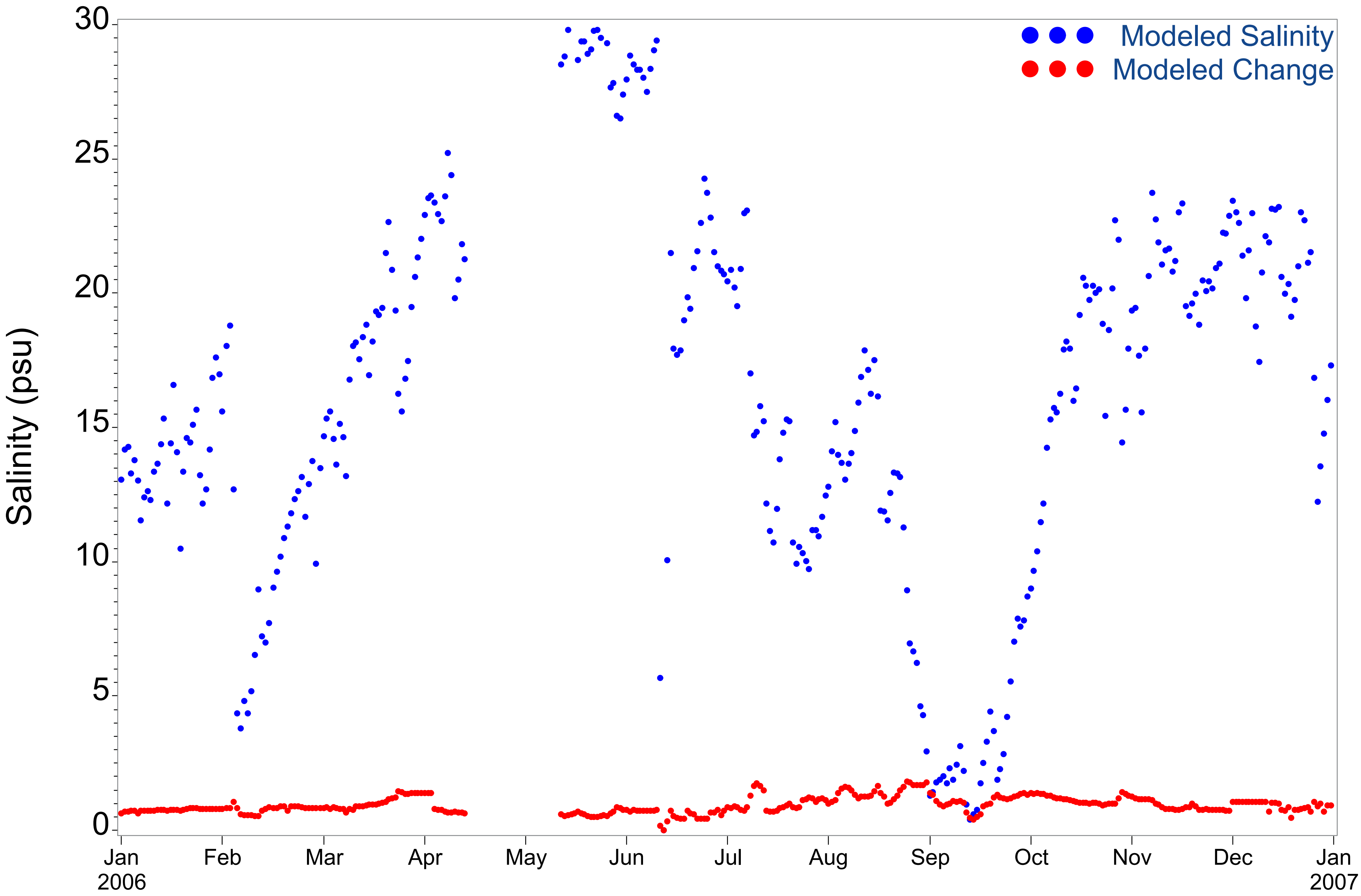


Figure 4.191 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 9.2 (2006)

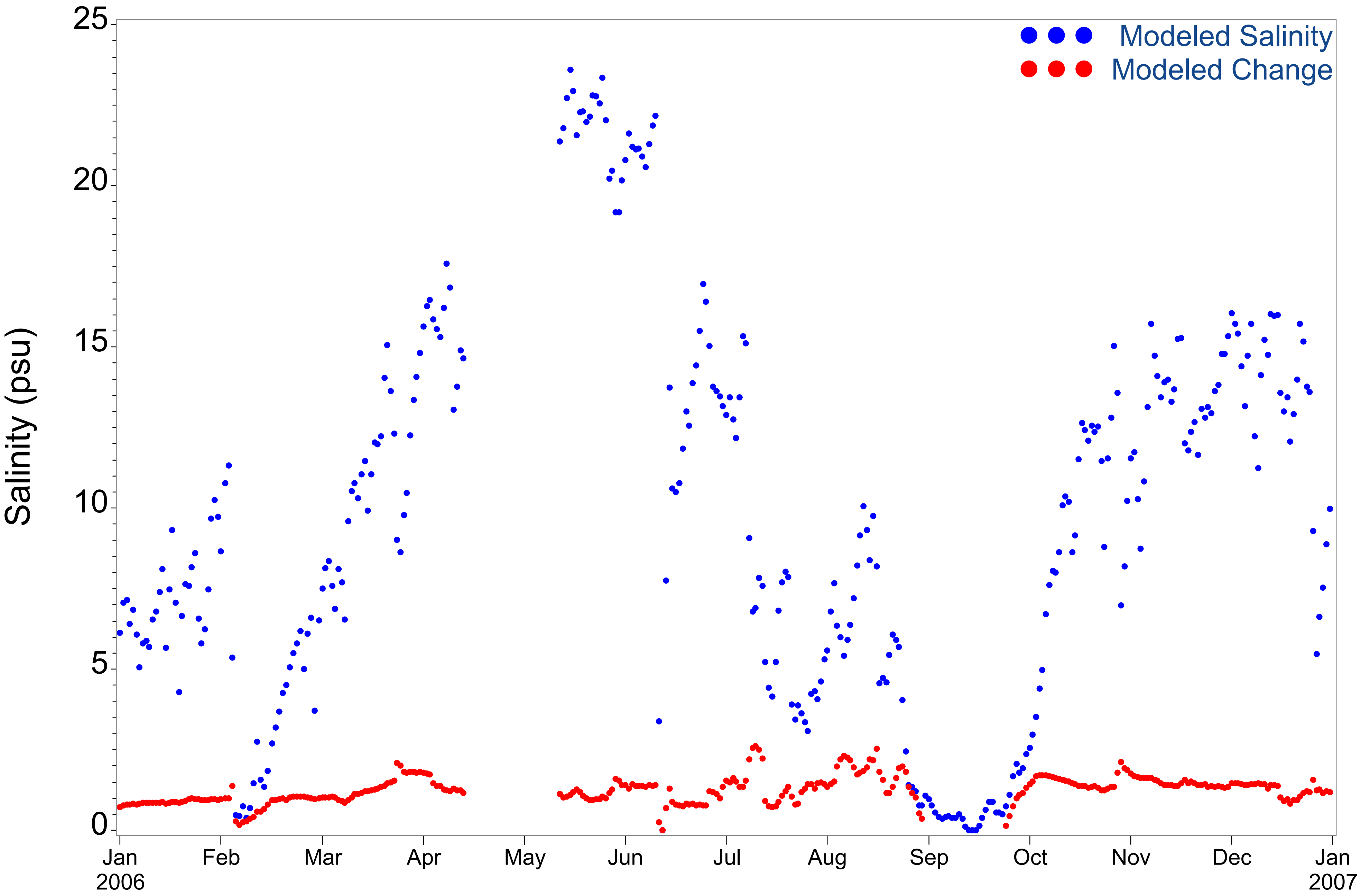


Figure 4.192 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 12.7 (2006)

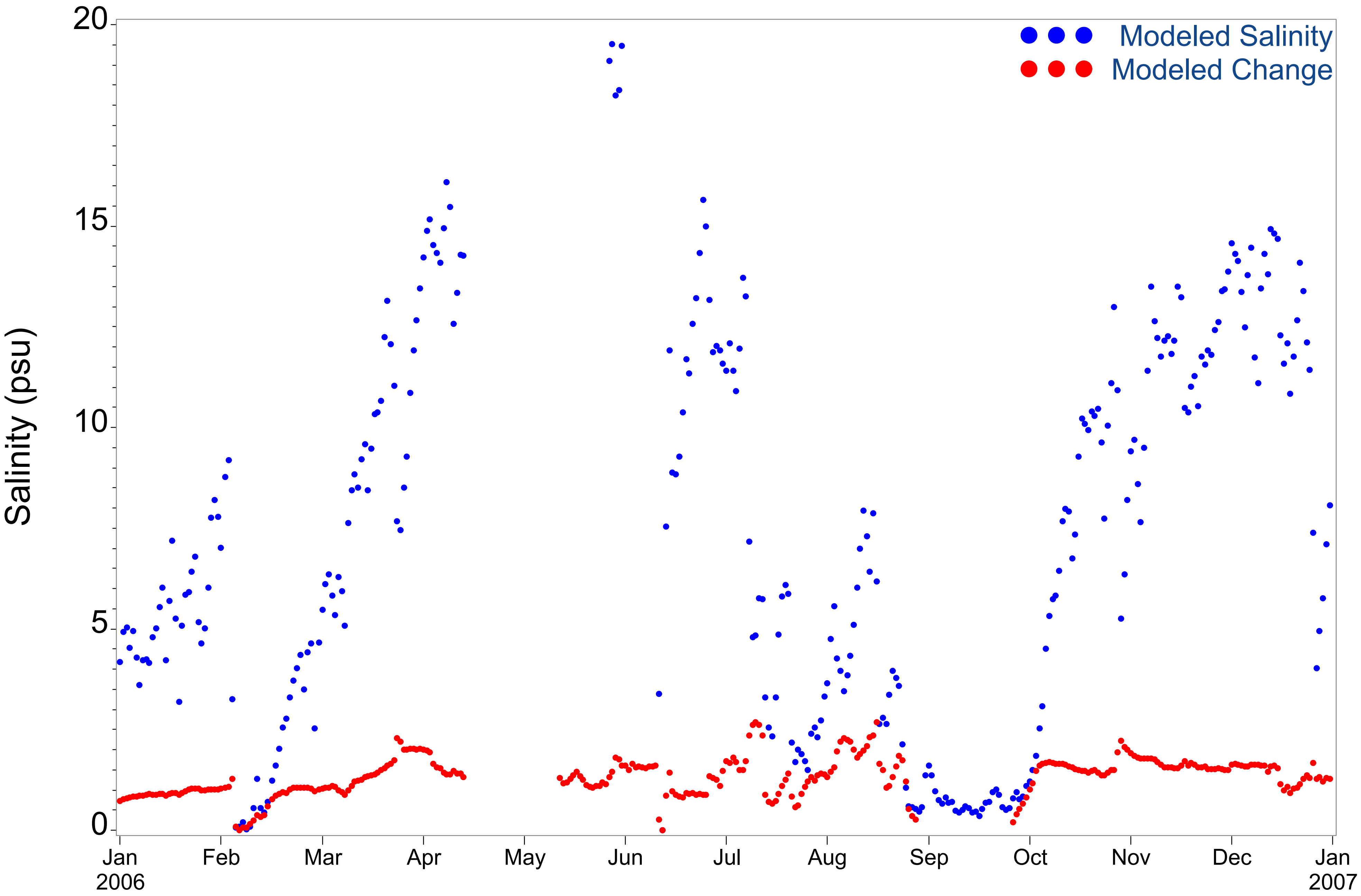
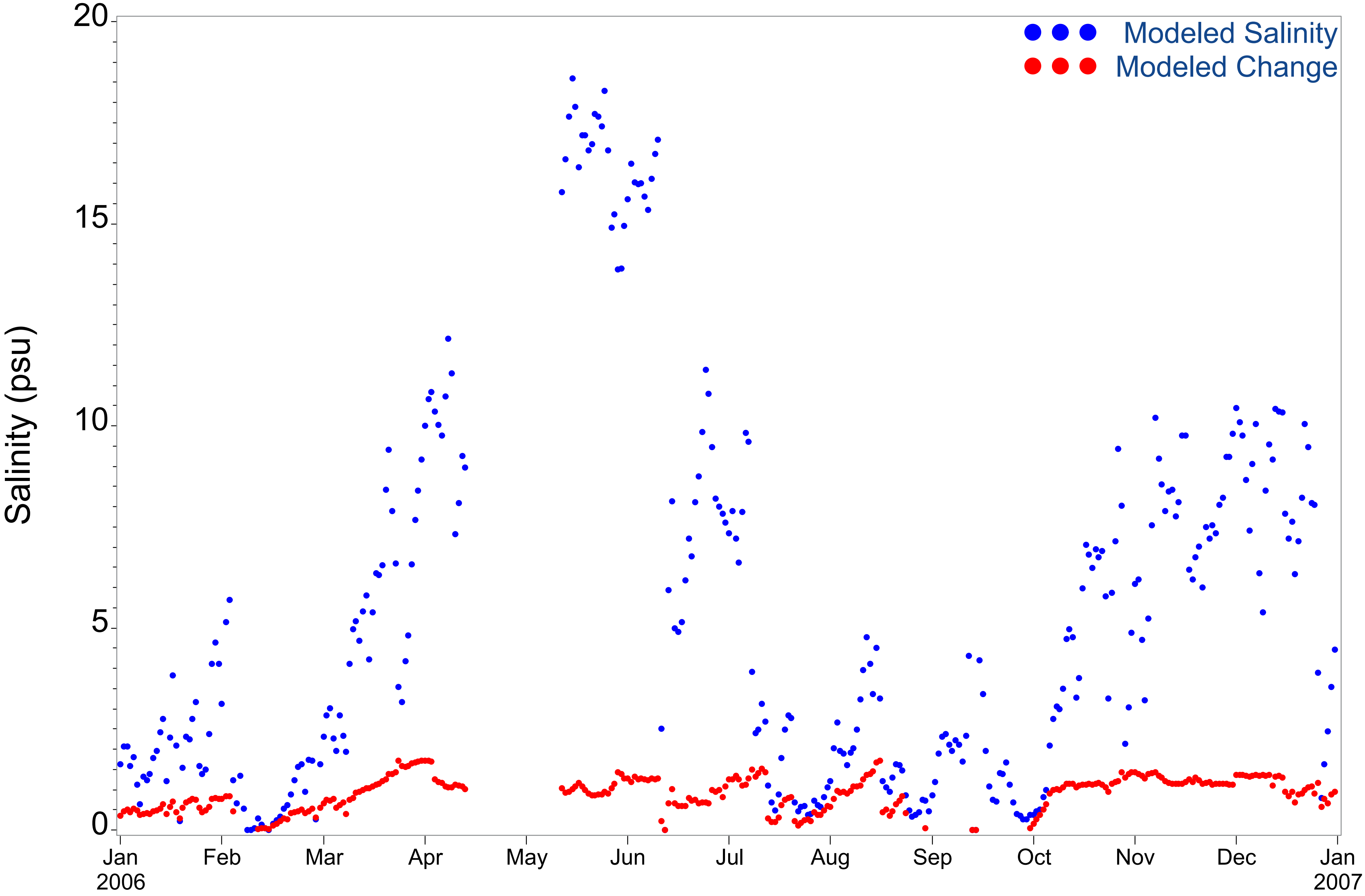


Figure 4.193 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 15.5 (2006)



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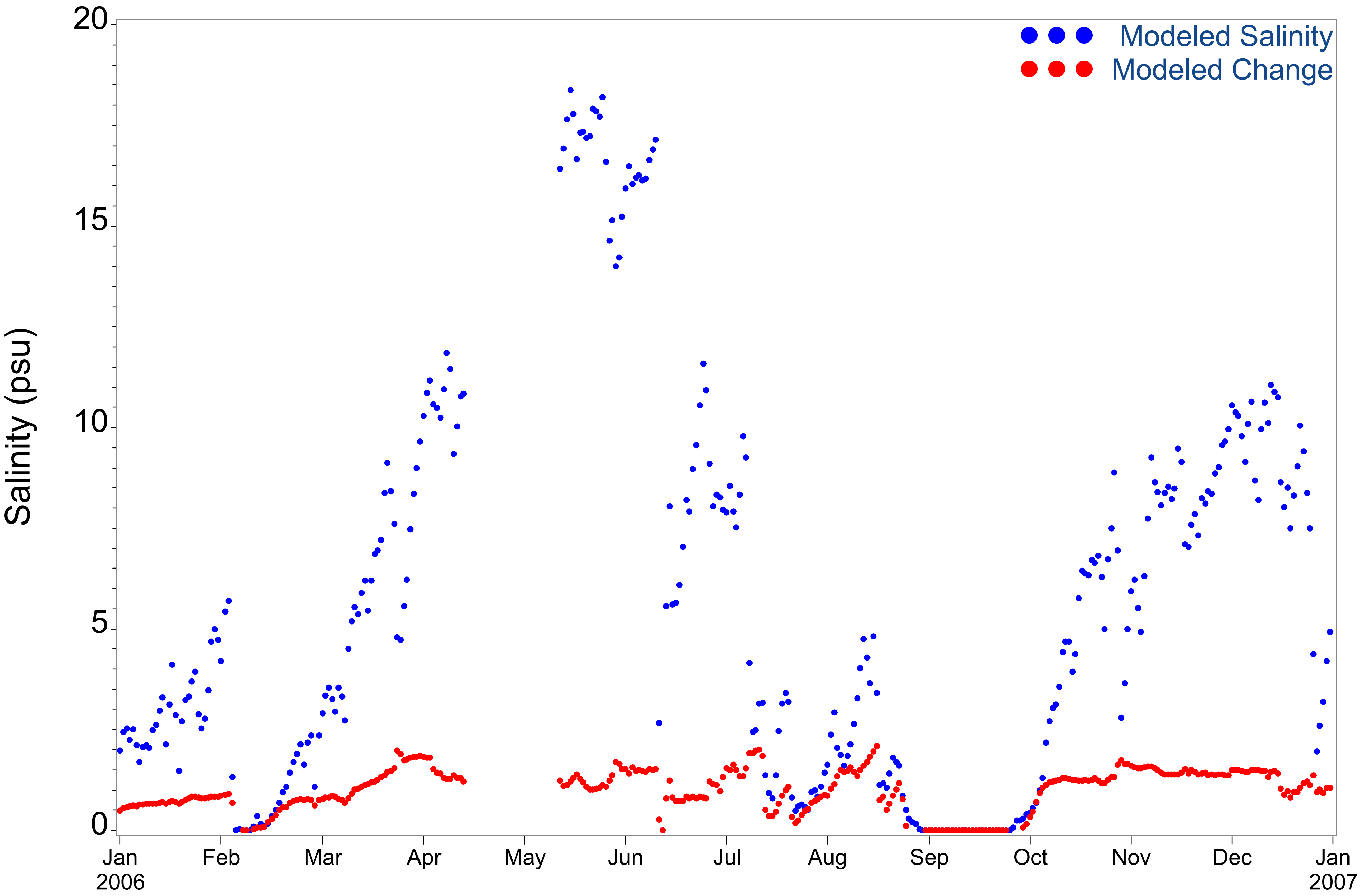


Figure 4.195 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.7 (2006)

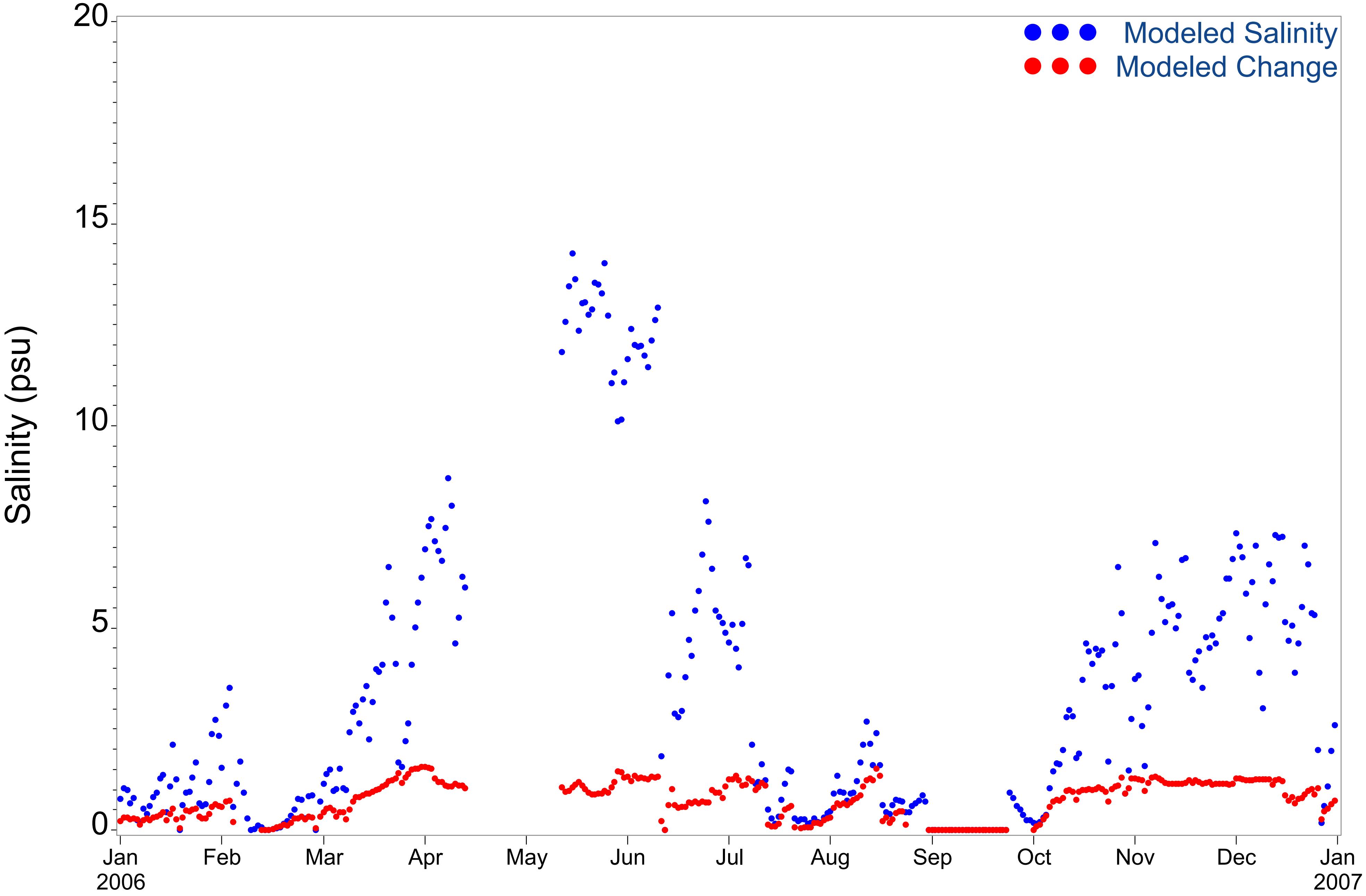


Figure 4.196 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 20.8 (2006)

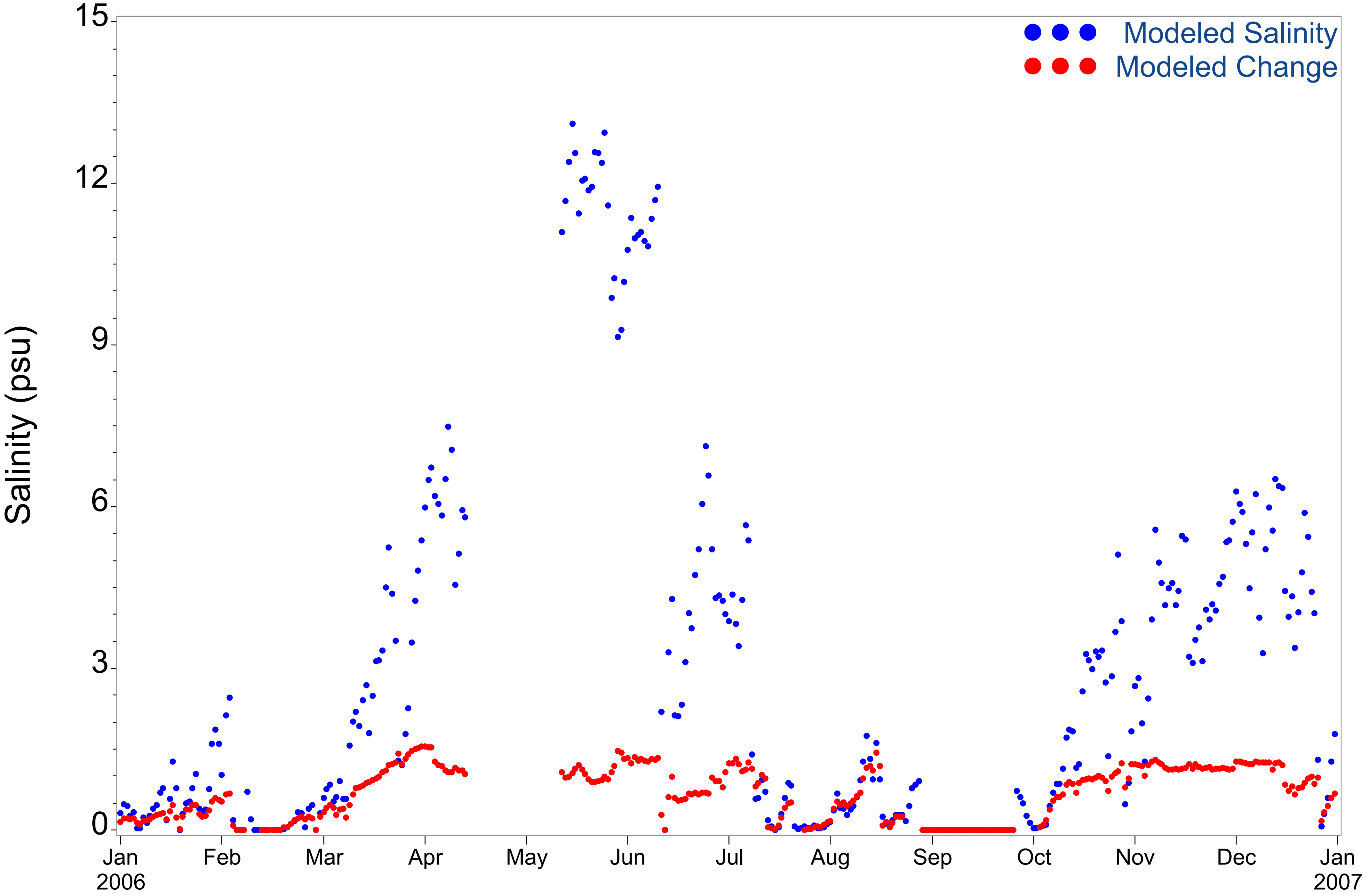


Figure 4.197 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 21.9 (2006)

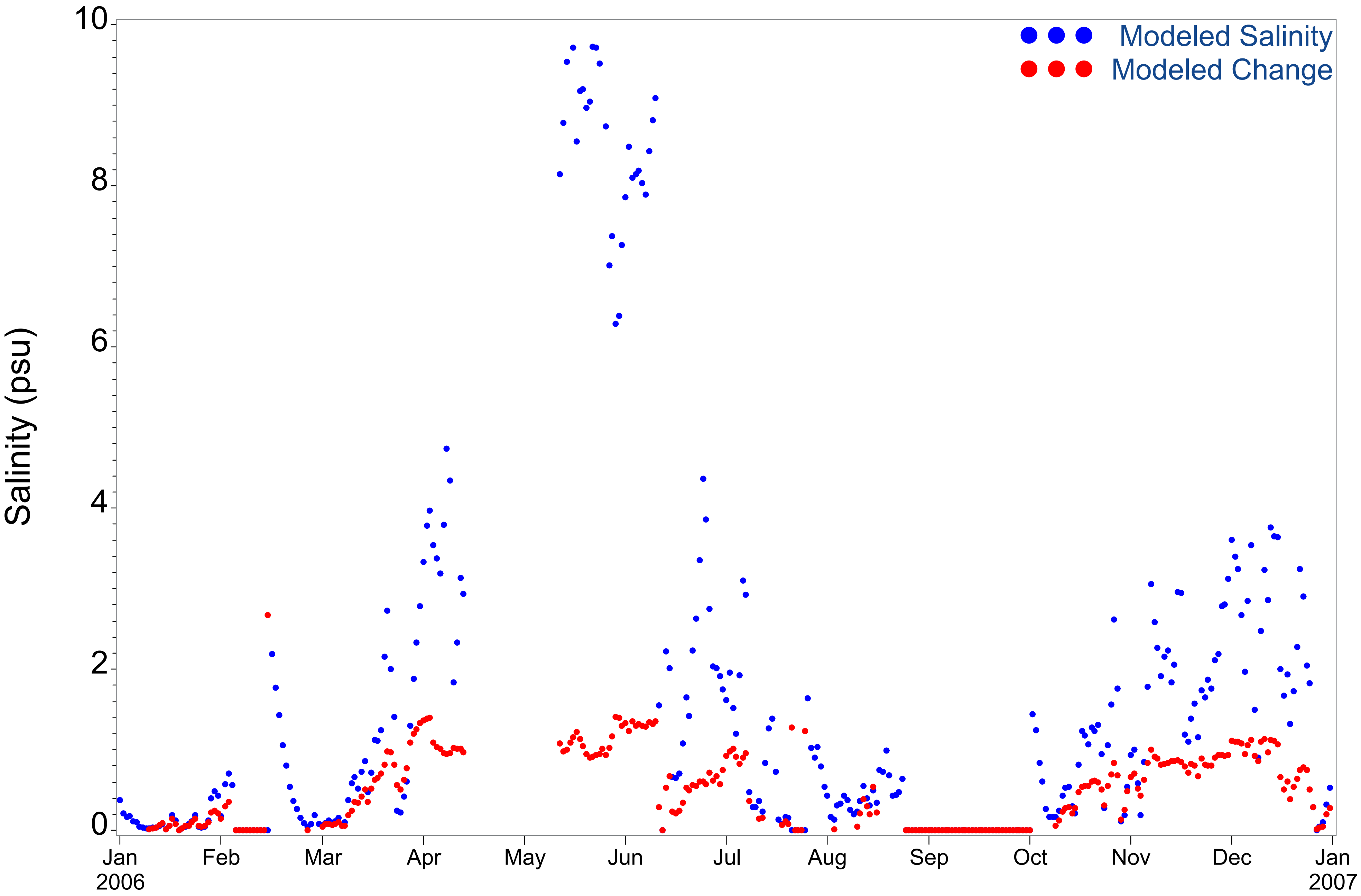


Figure 4.198 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 24.5 (2006)

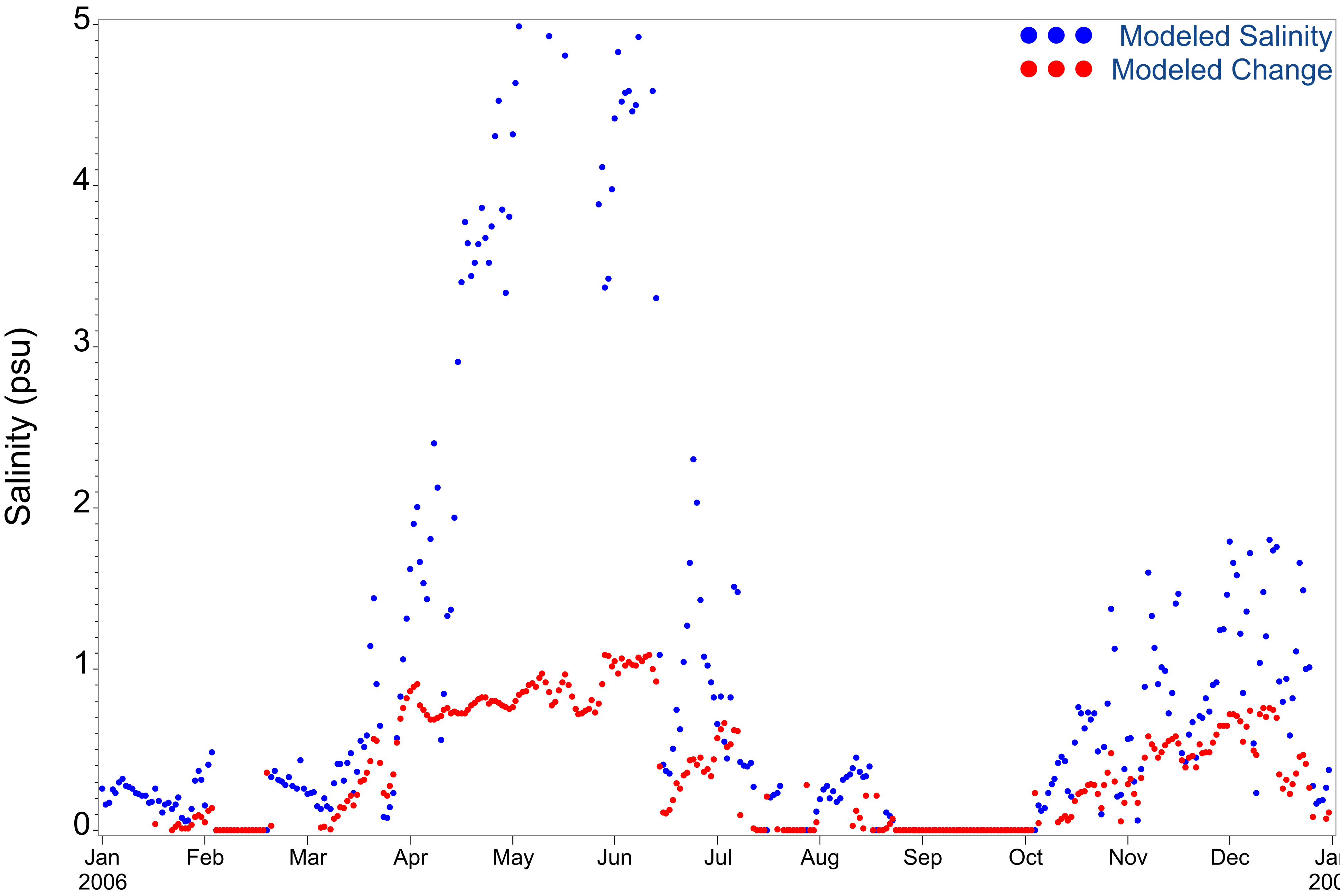


Figure 4.199 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 26.7 (2006)

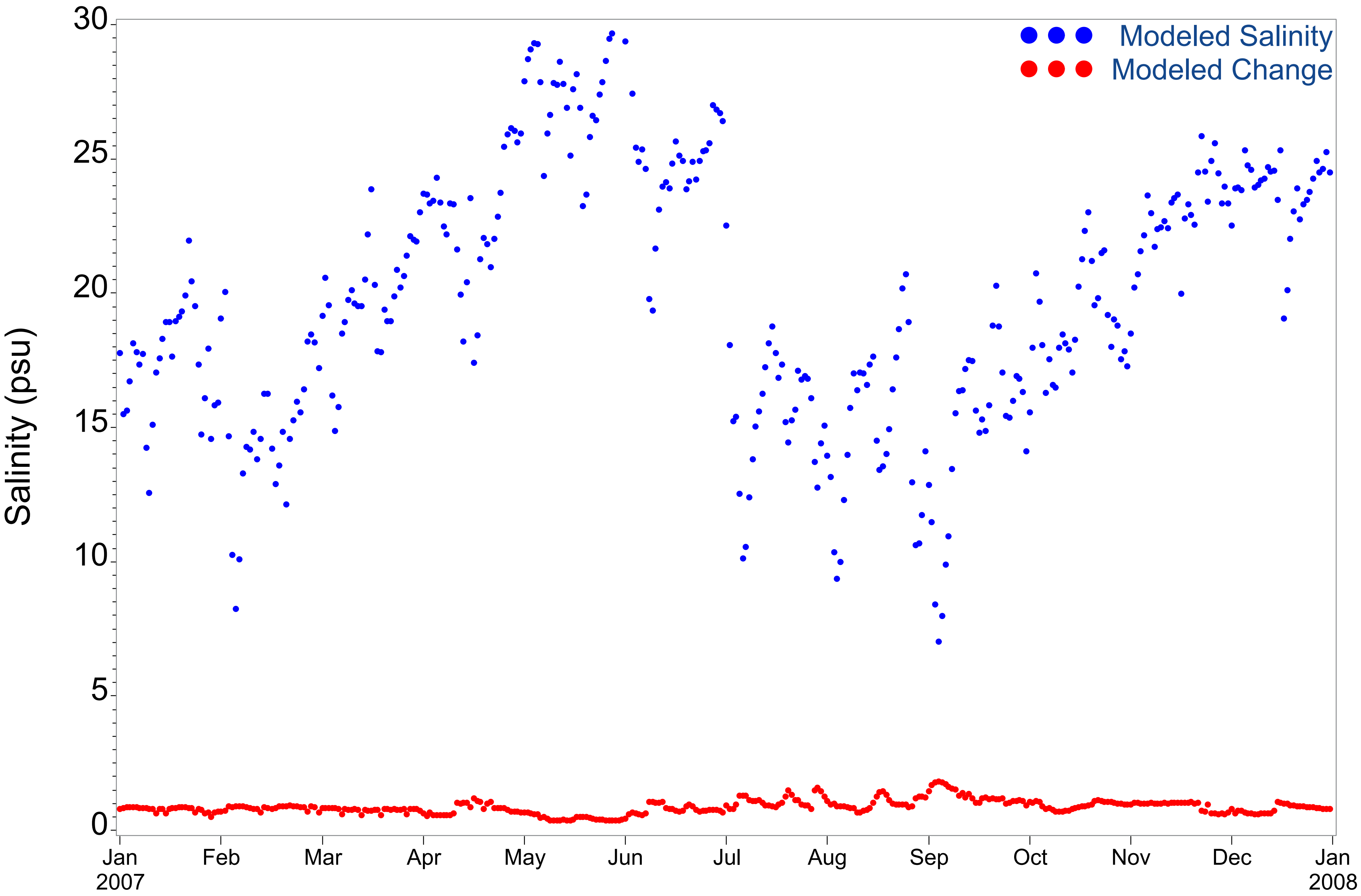


Figure 4.200 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 9.2 (2007)

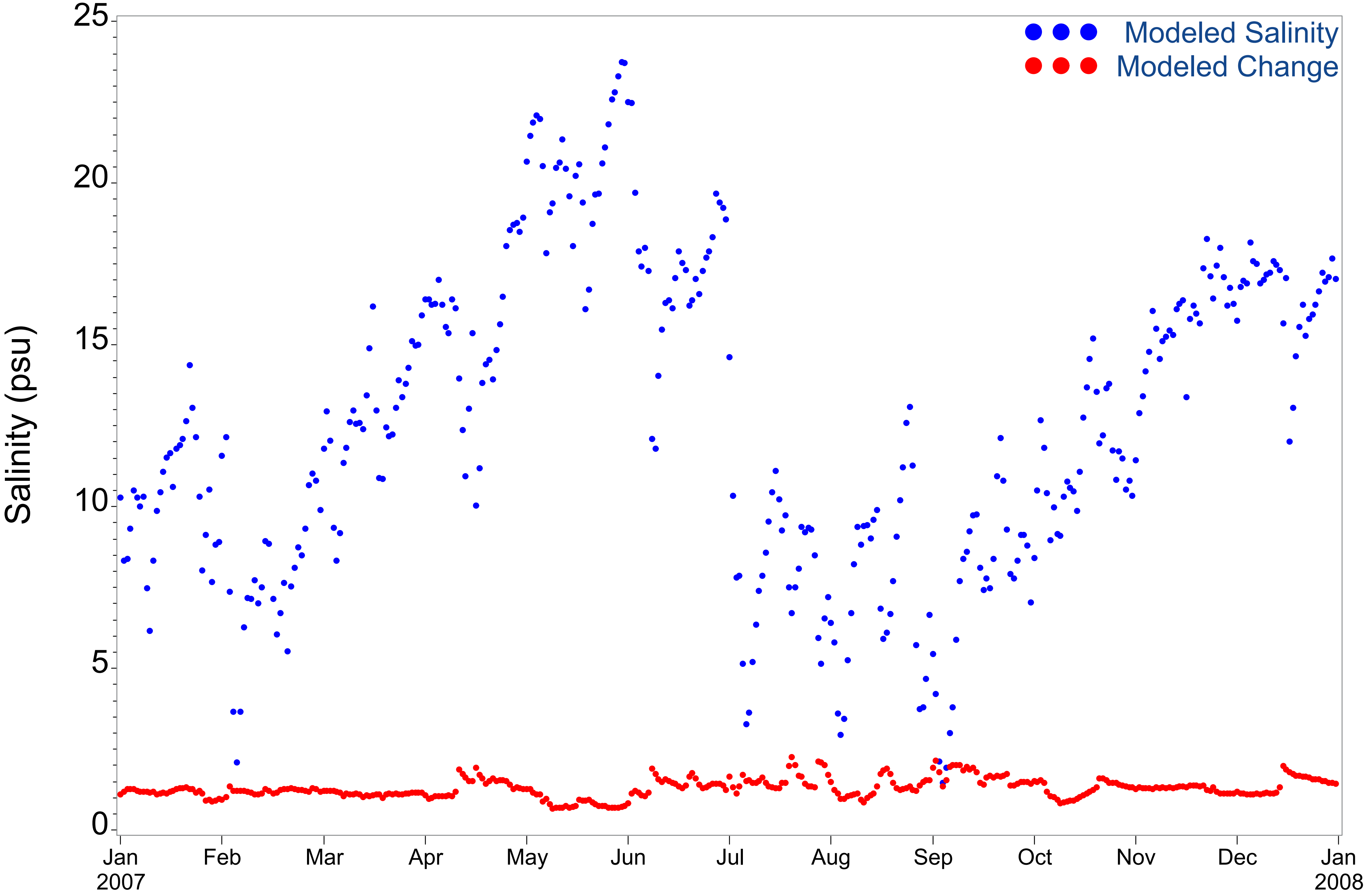


Figure 4.201 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 12.7 (2007)

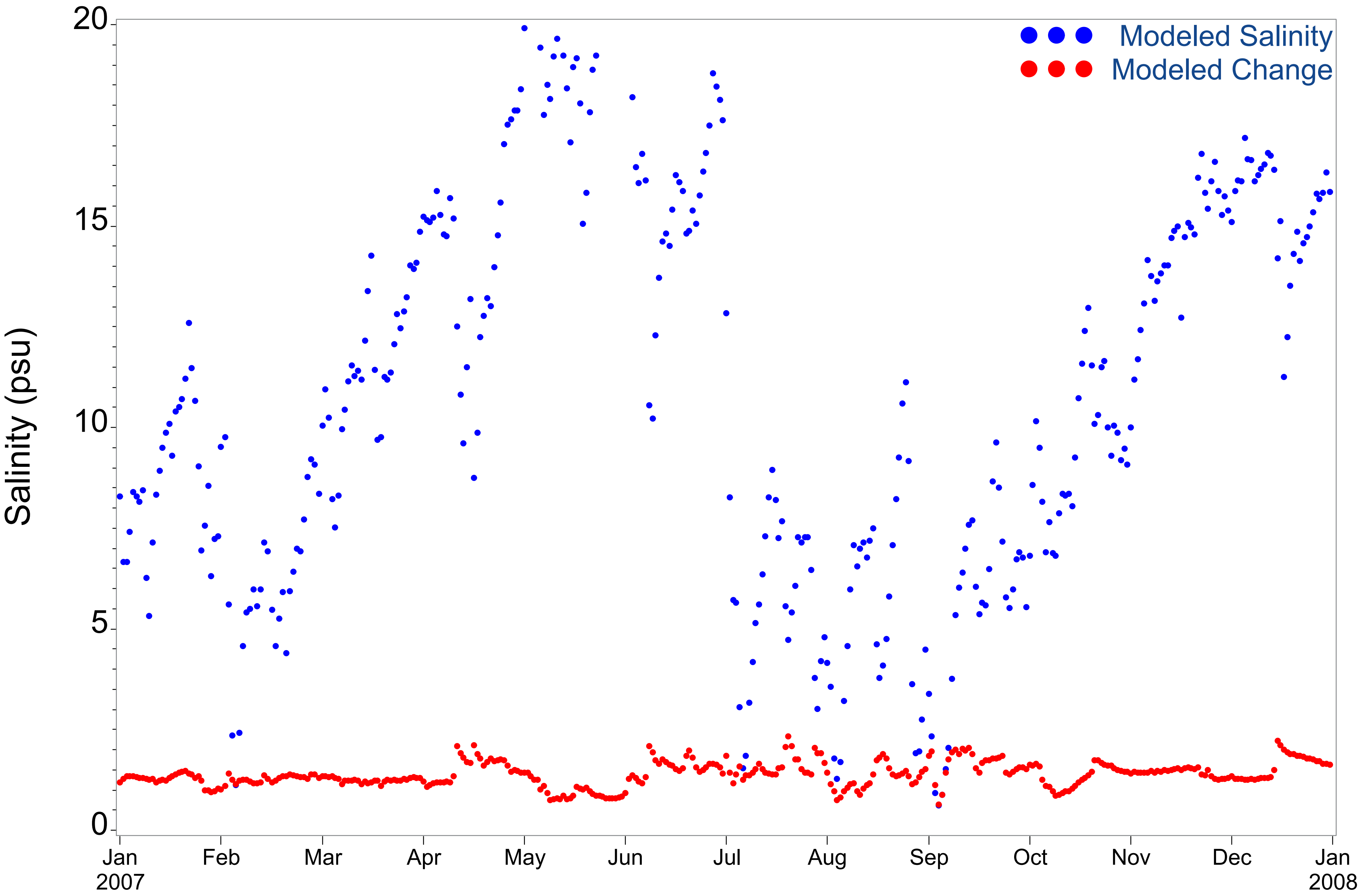


Figure 4.202 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 15.5 (2007)

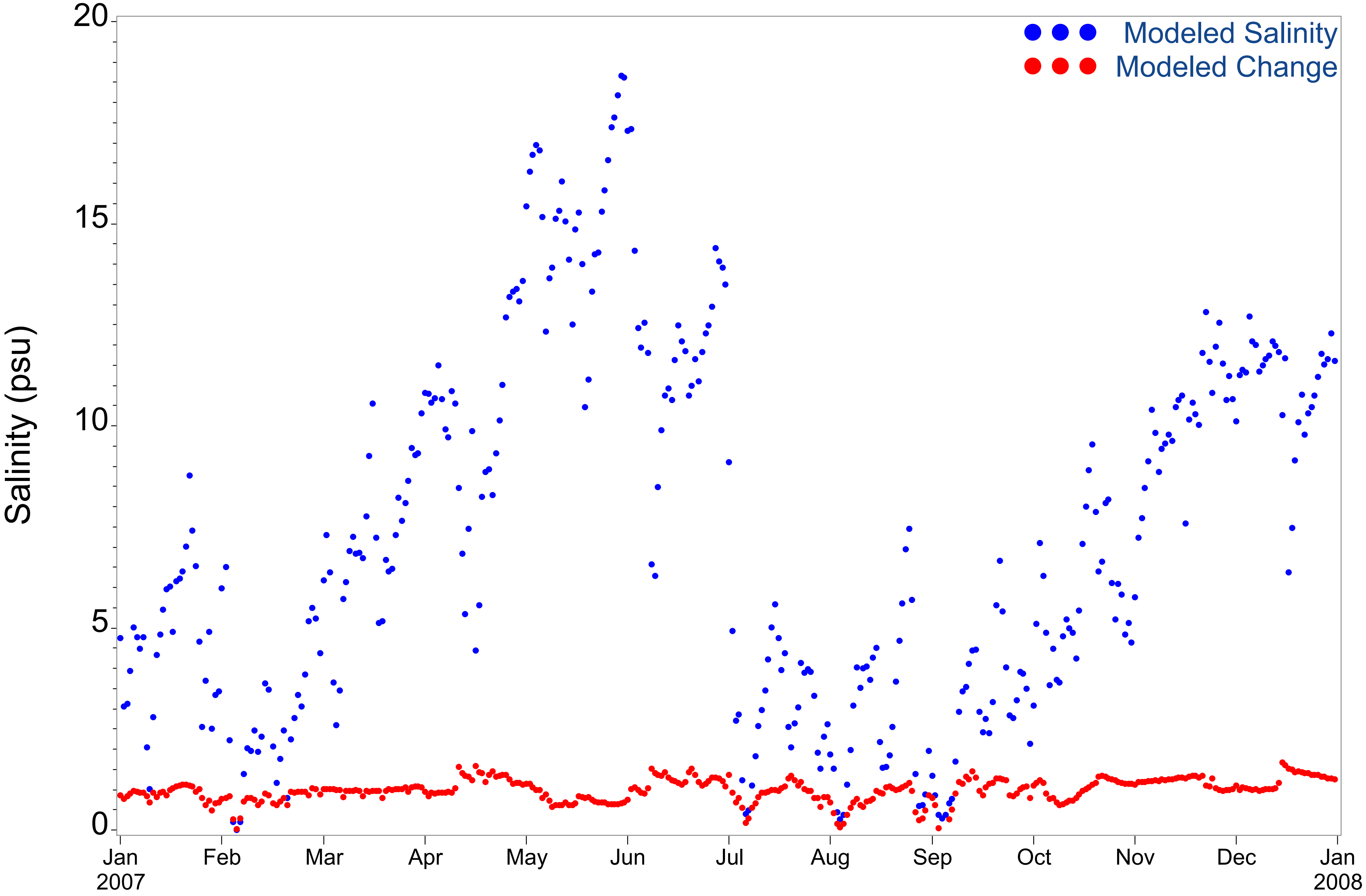


Figure 4.203 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.5 (2007)

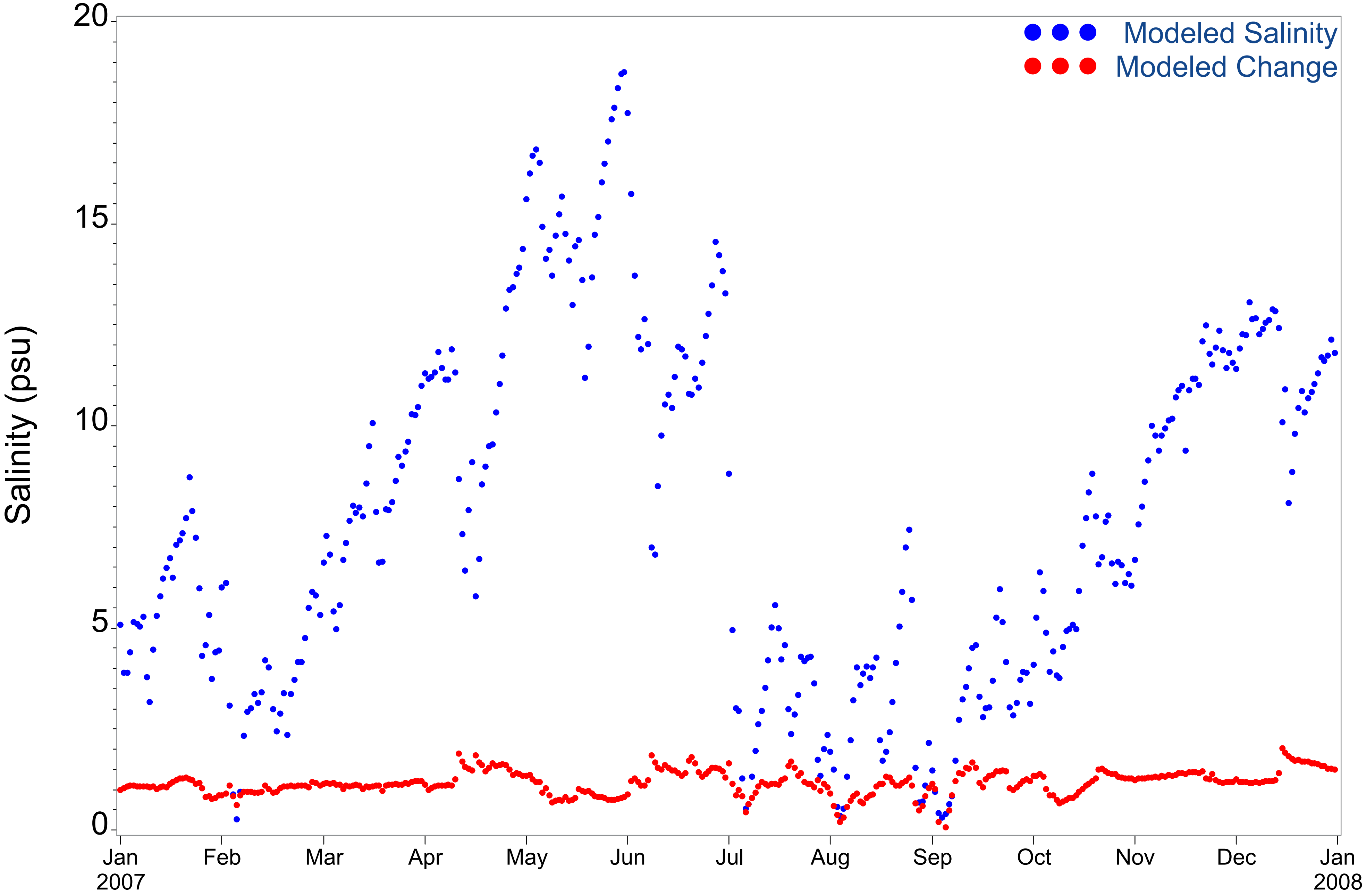


Figure 4.204 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.7 (2007)

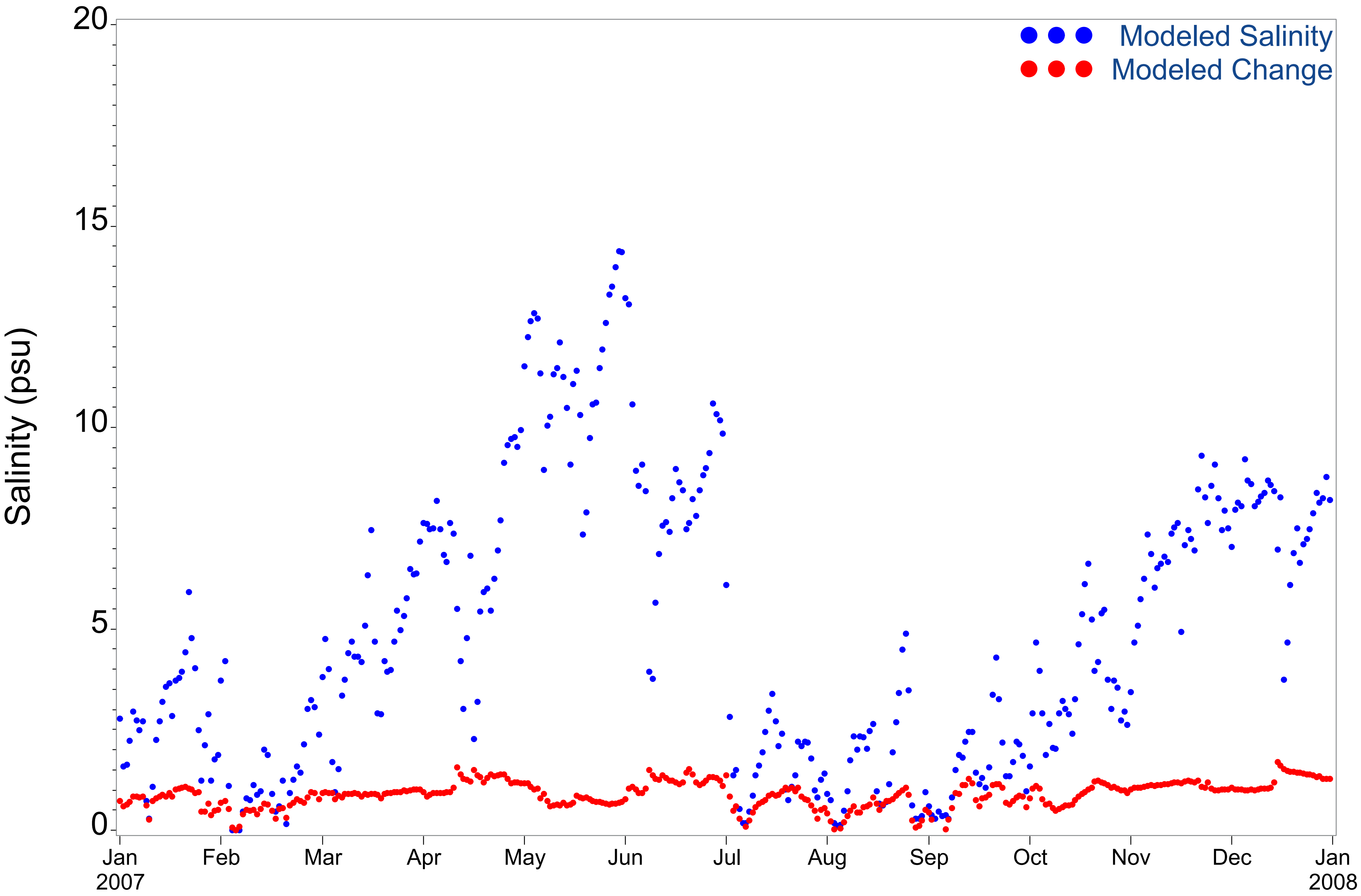


Figure 4.205 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 20.8 (2007)

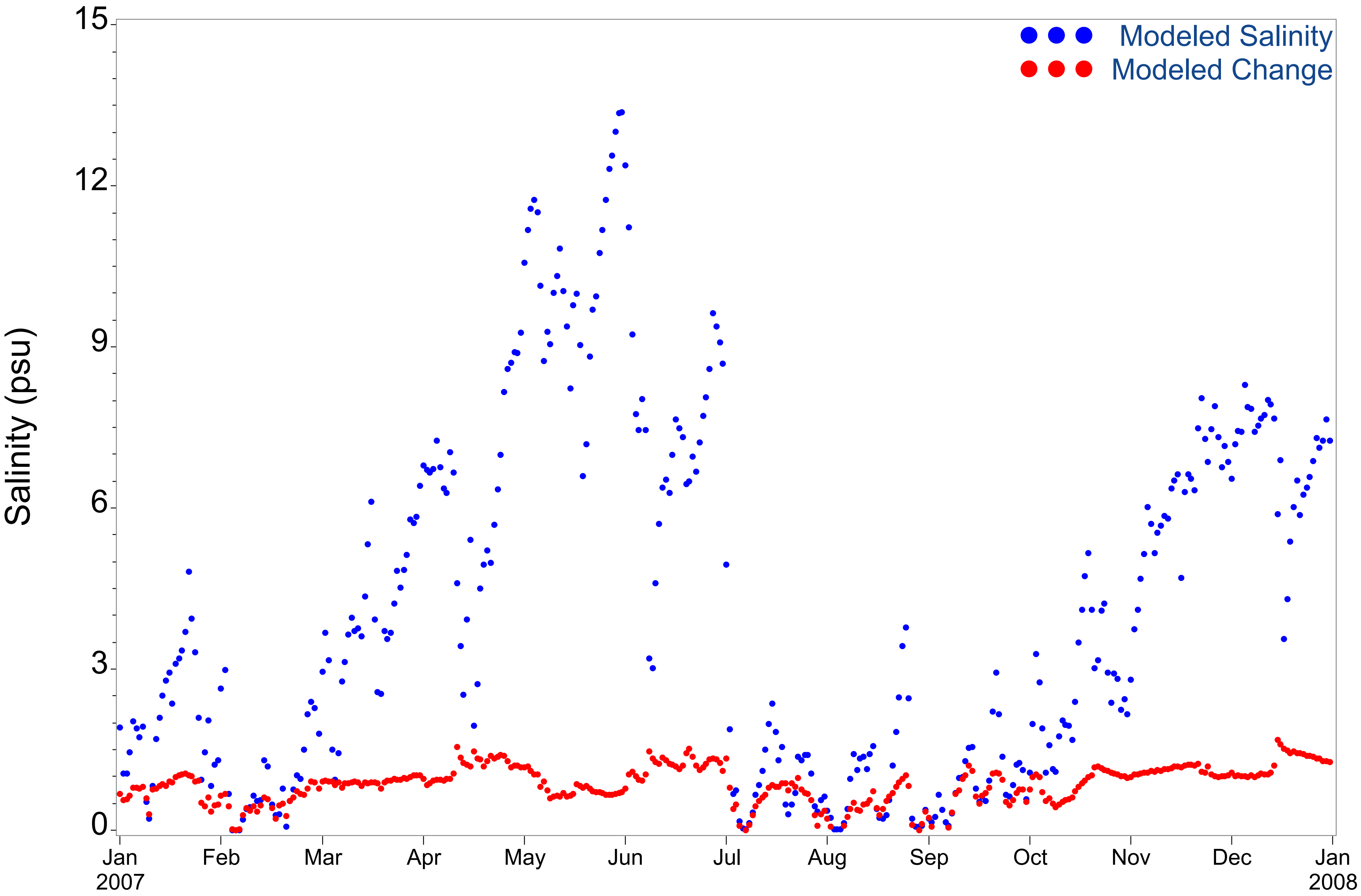


Figure 4.206 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 21.9 (2007)

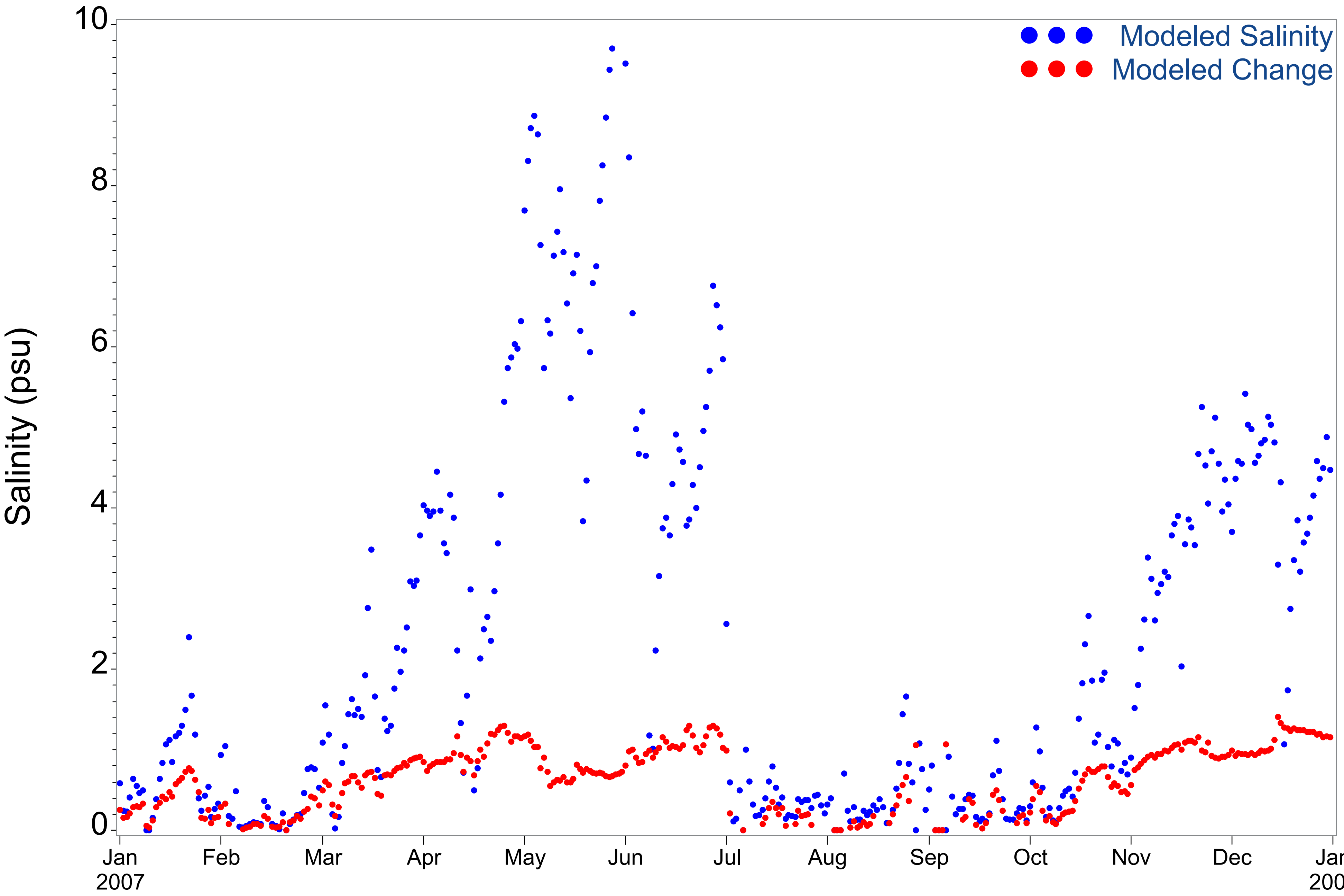


Figure 4.207 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 24.5 (2007)

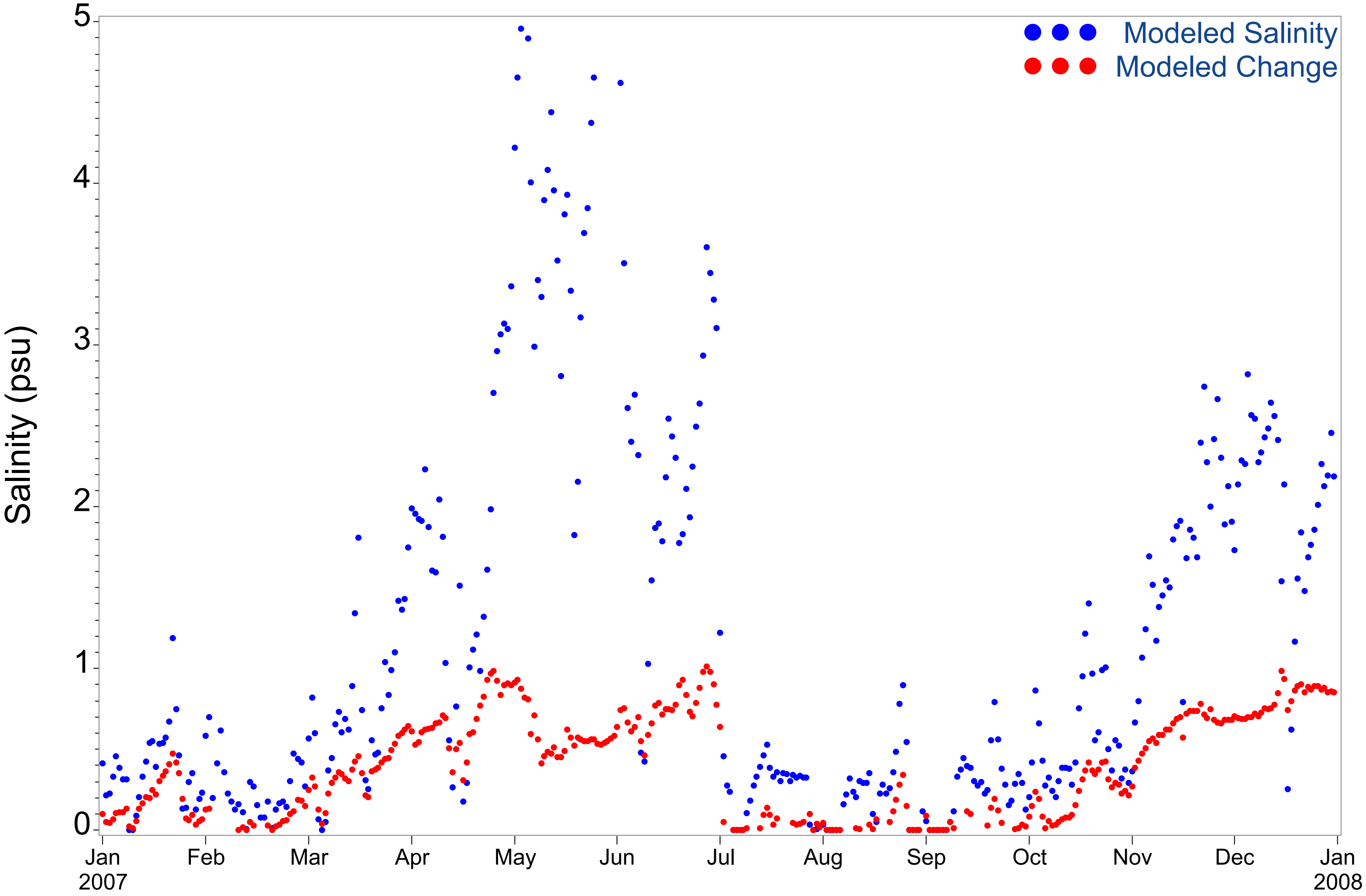


Figure 4.208 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 26.7 (2007)

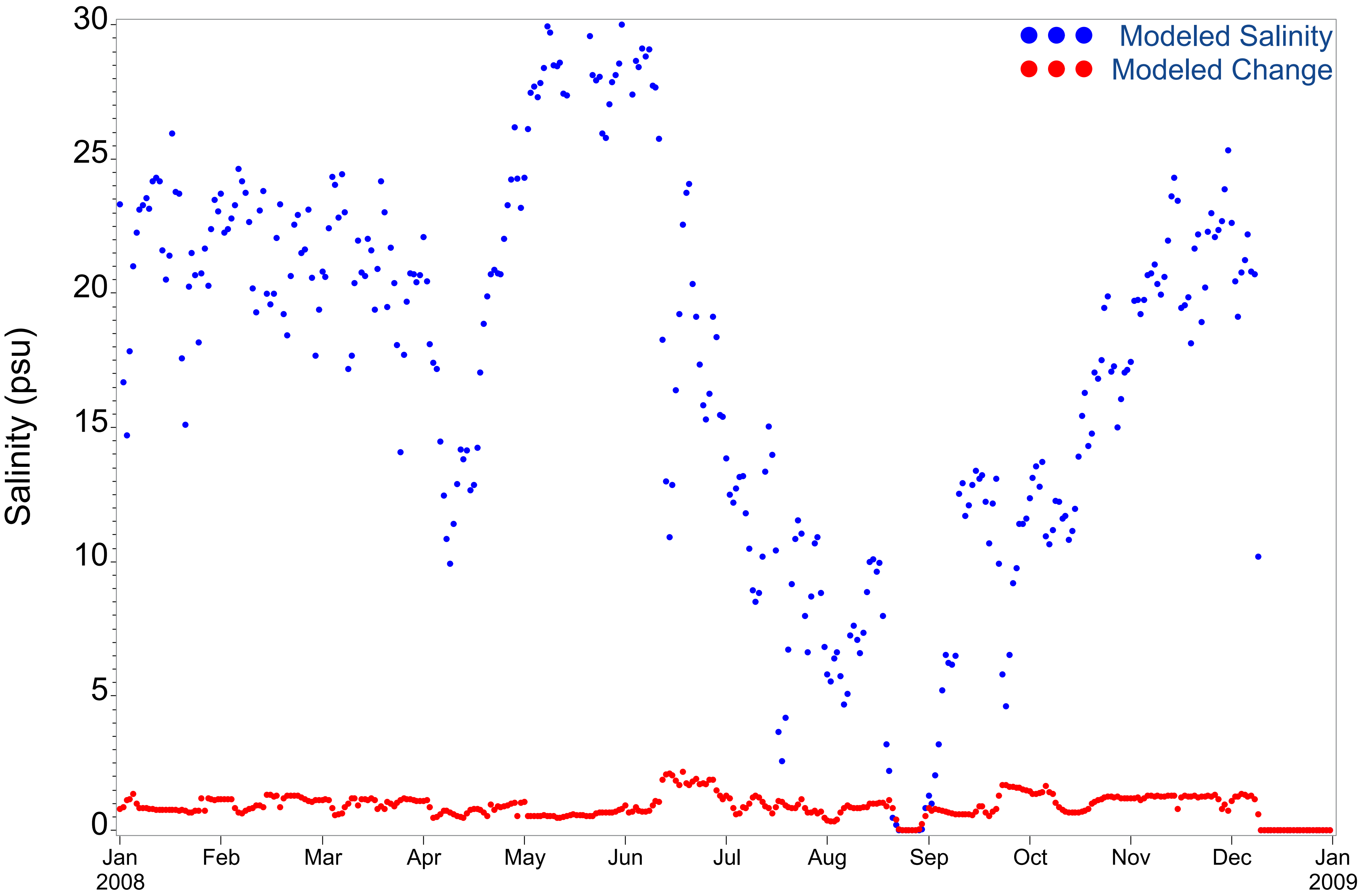


Figure 4.209 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 9.2 (2008)

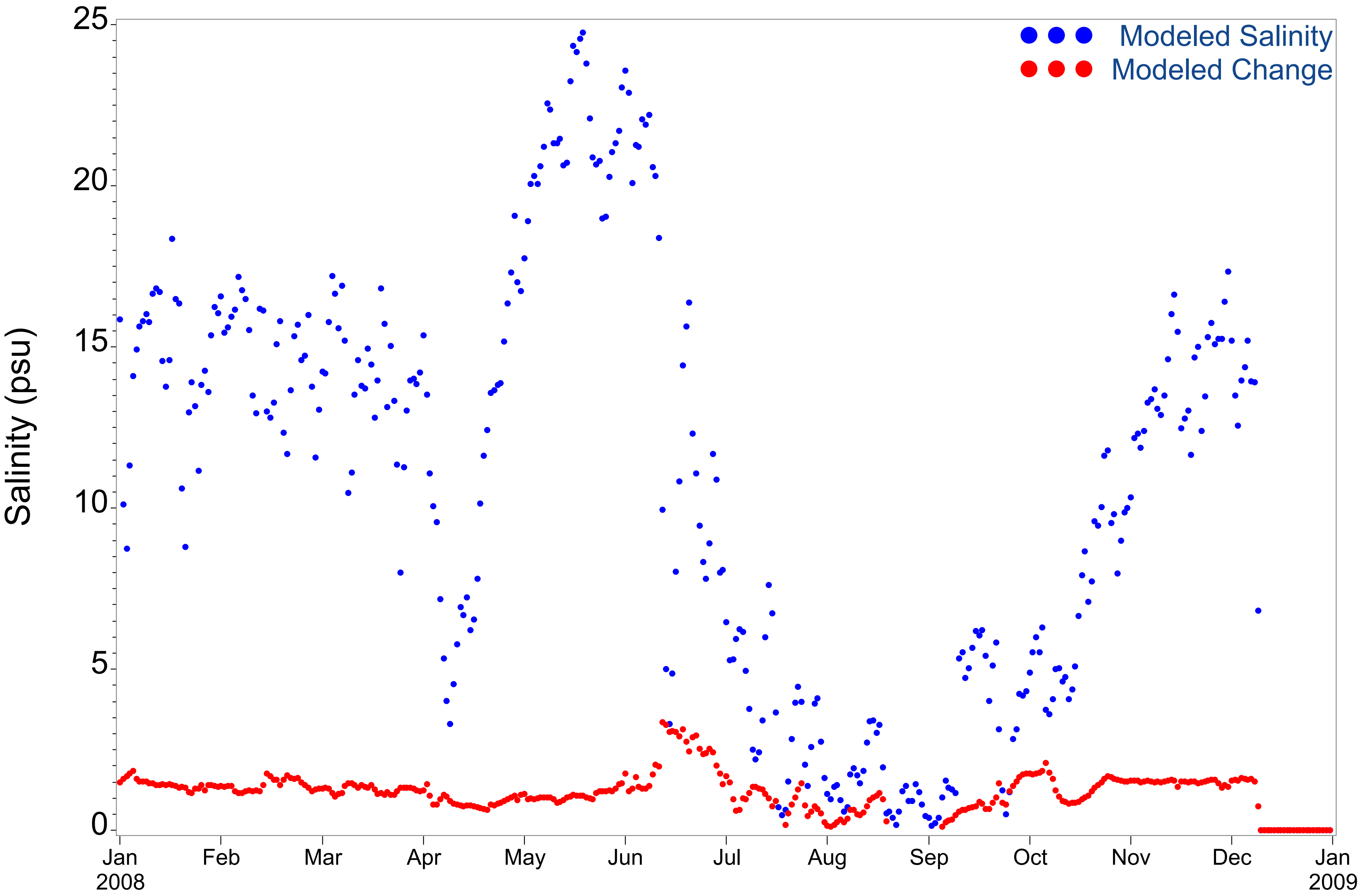


Figure 4.210 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 12.7 (2008)

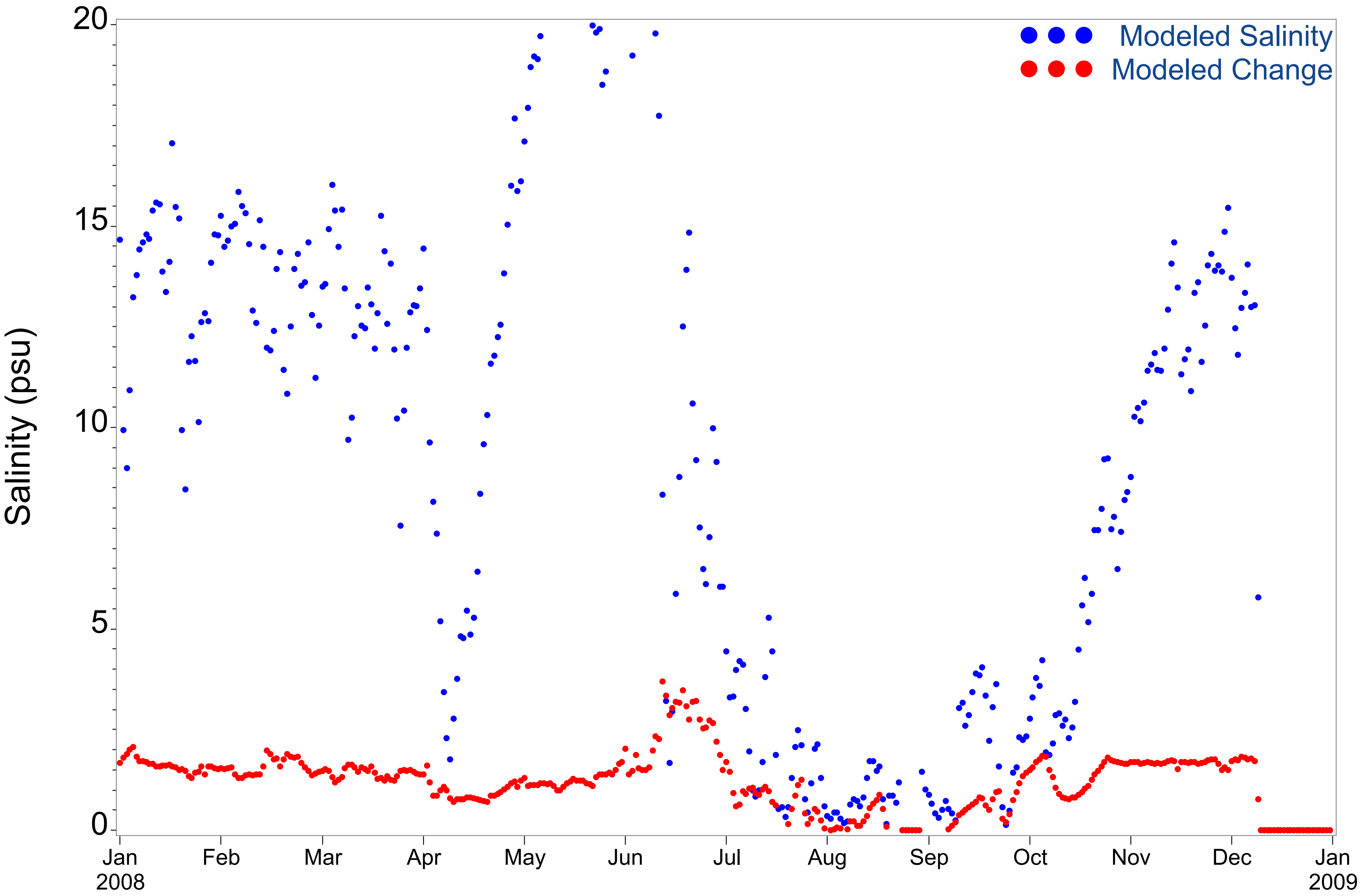


Figure 4.211 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 15.5 (2008)

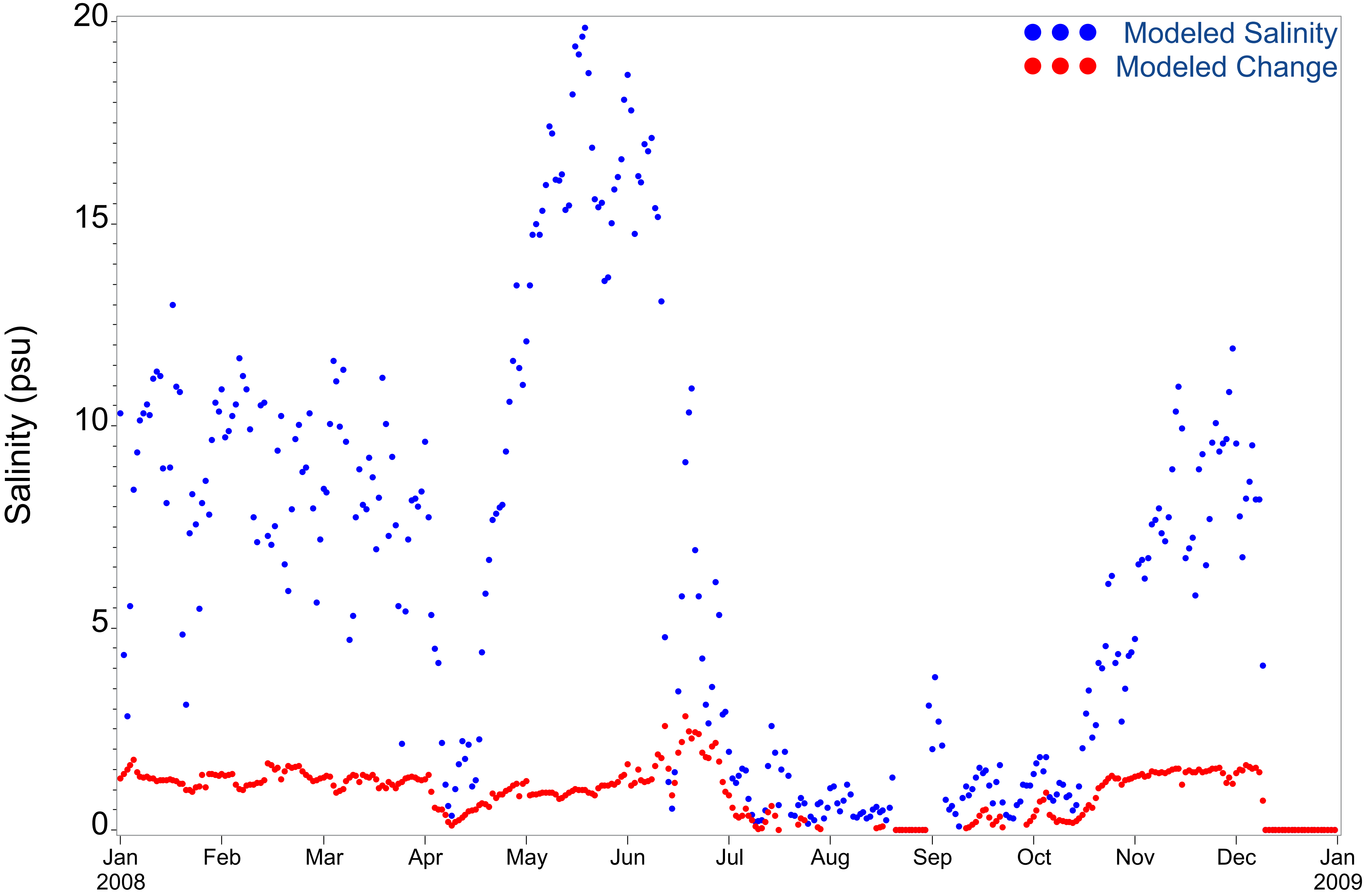


Figure 4.212 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.5 (2008)

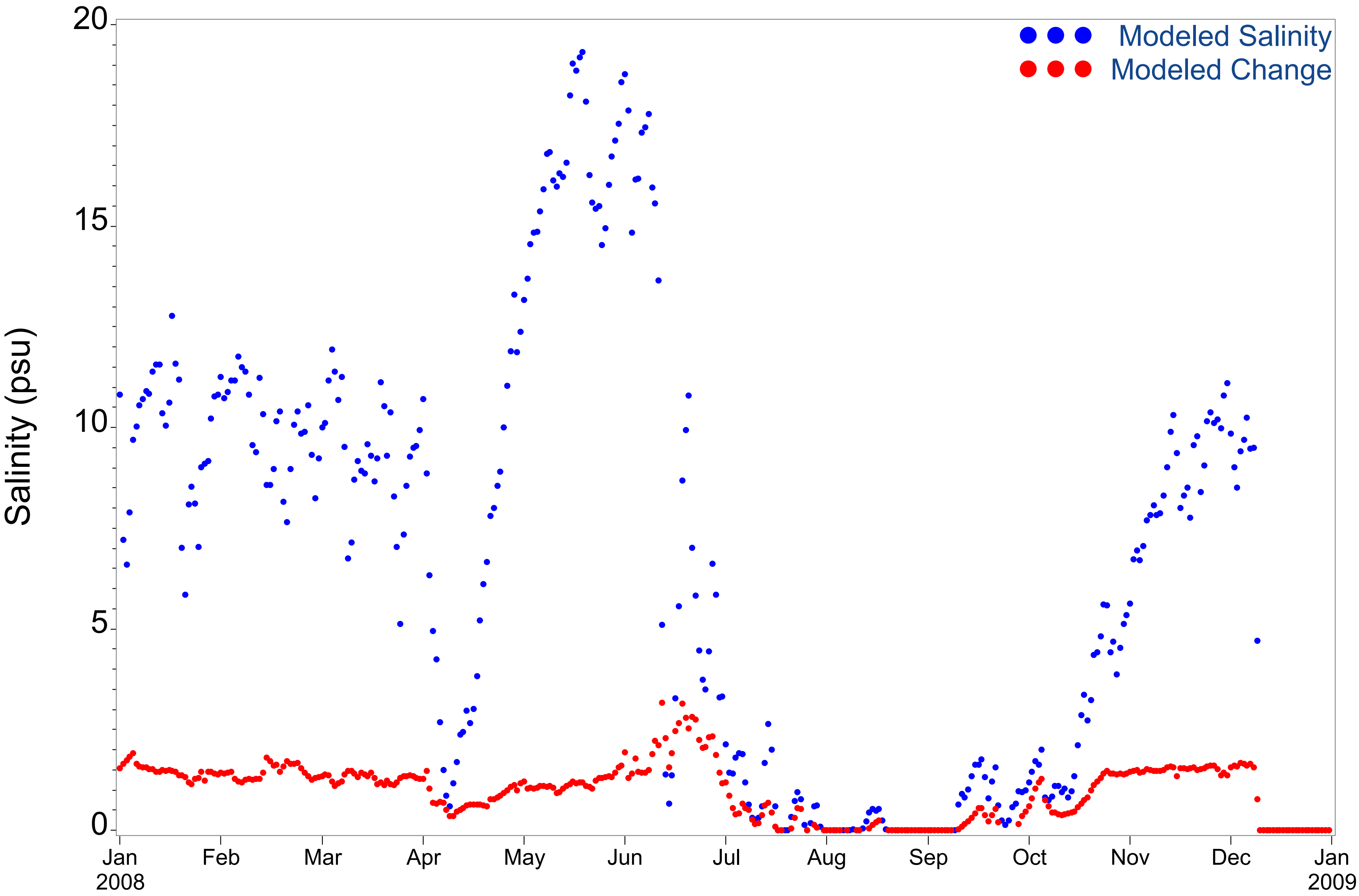


Figure 4.213 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.7 (2008)

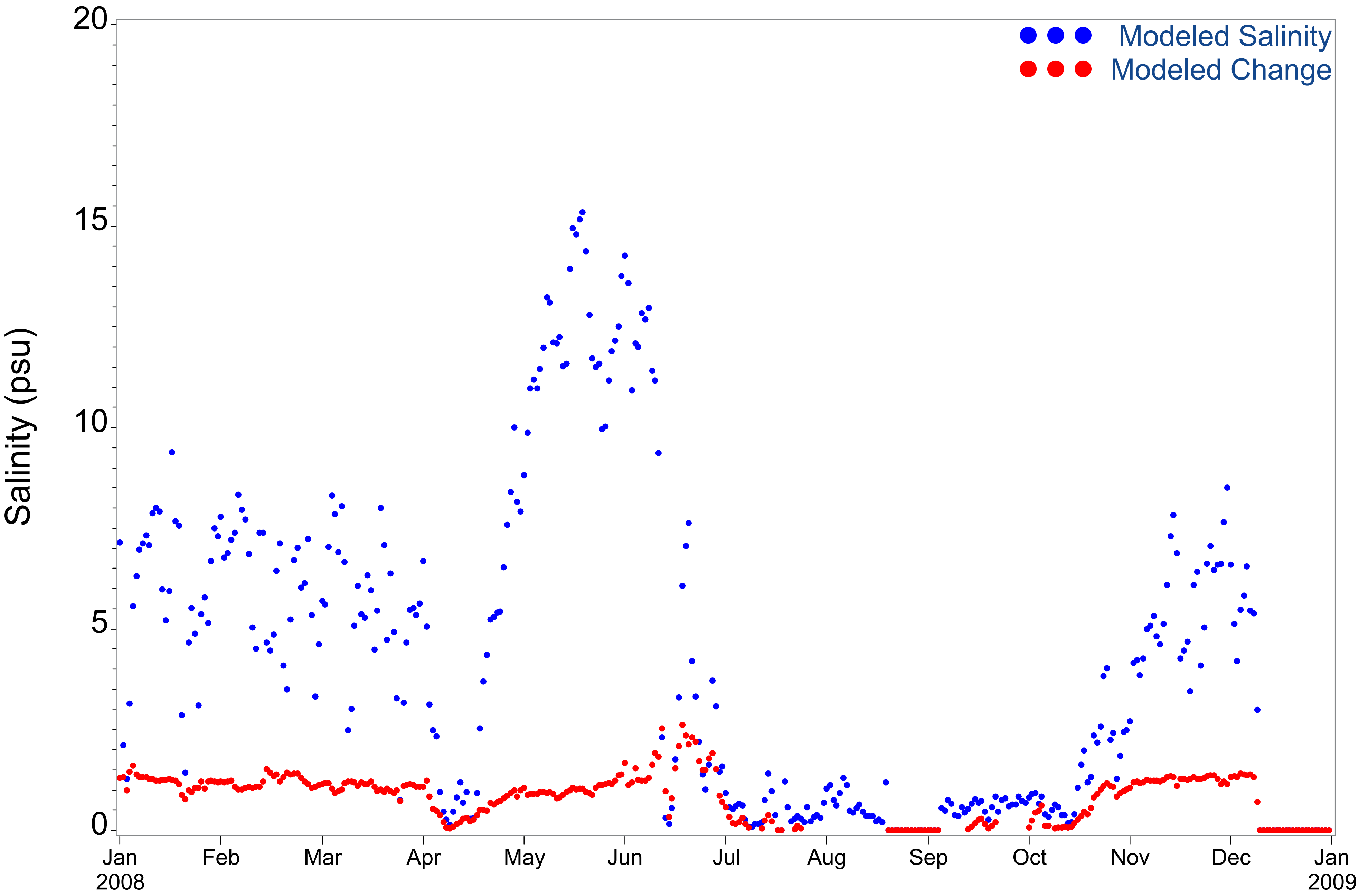


Figure 4.214 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 20.8 (2008)

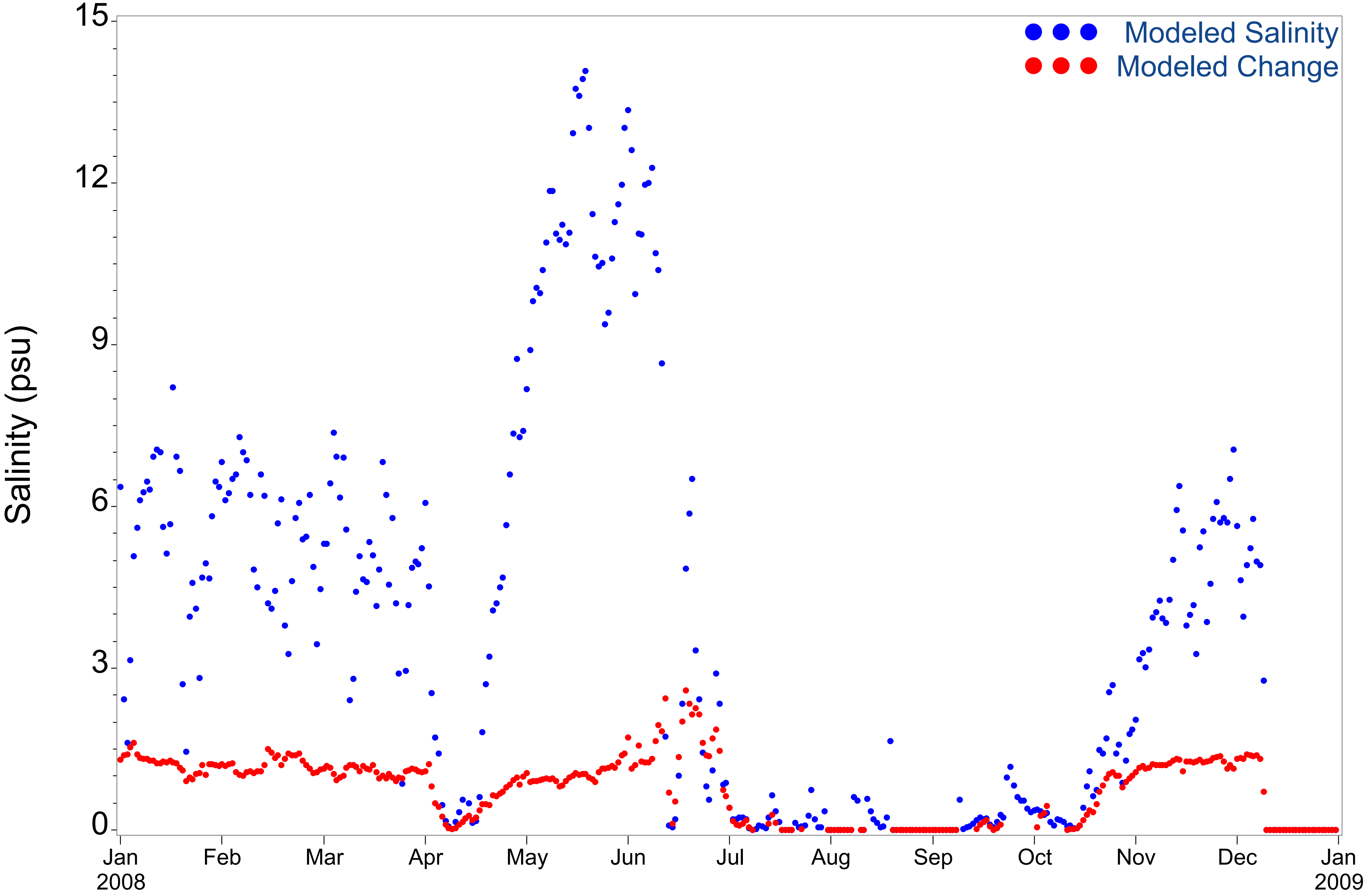


Figure 4.215 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 21.9 (2008)

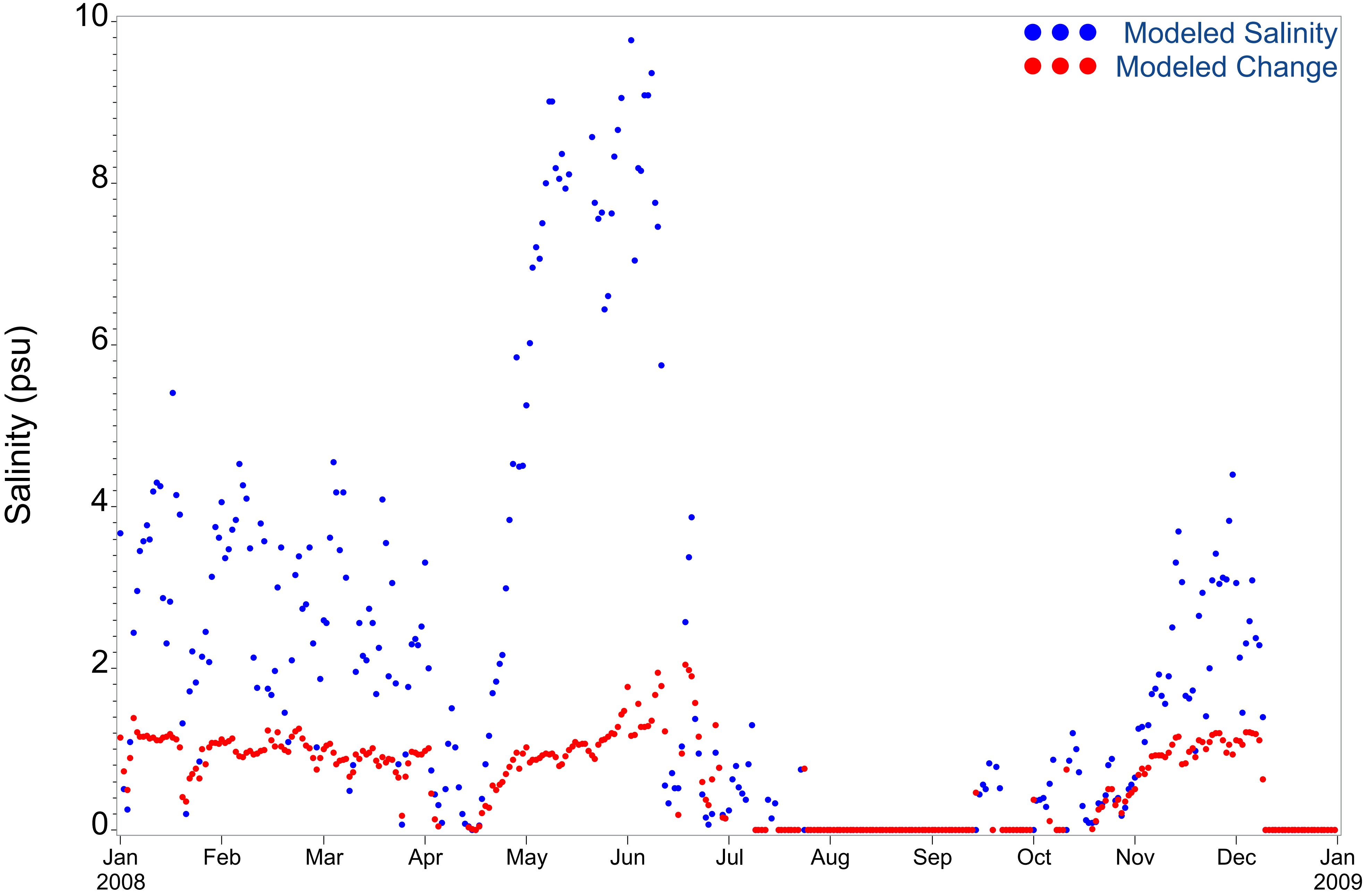


Figure 4.216 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 24.5 (2008)

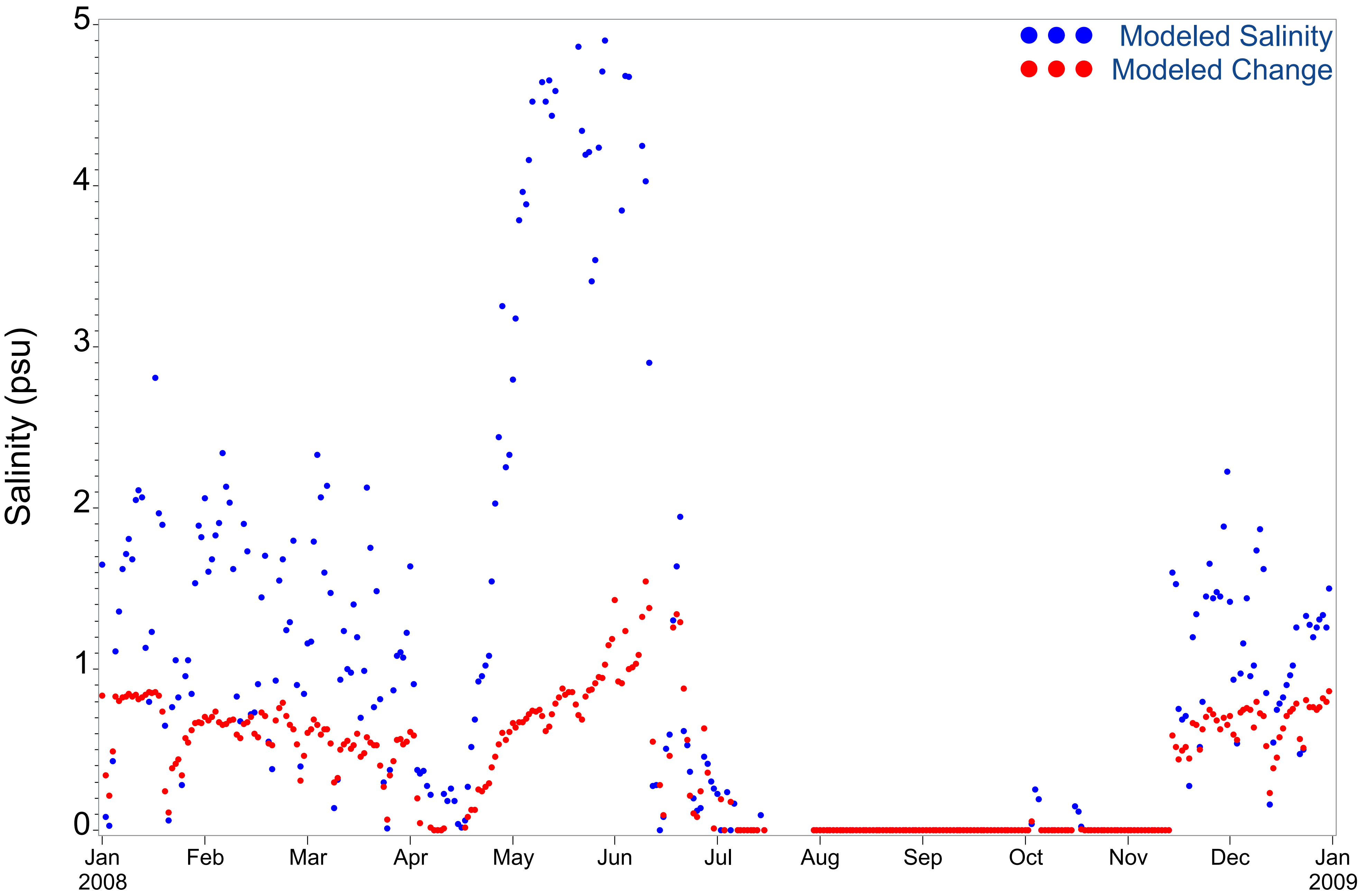


Figure 4.217 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 26.7 (2008)

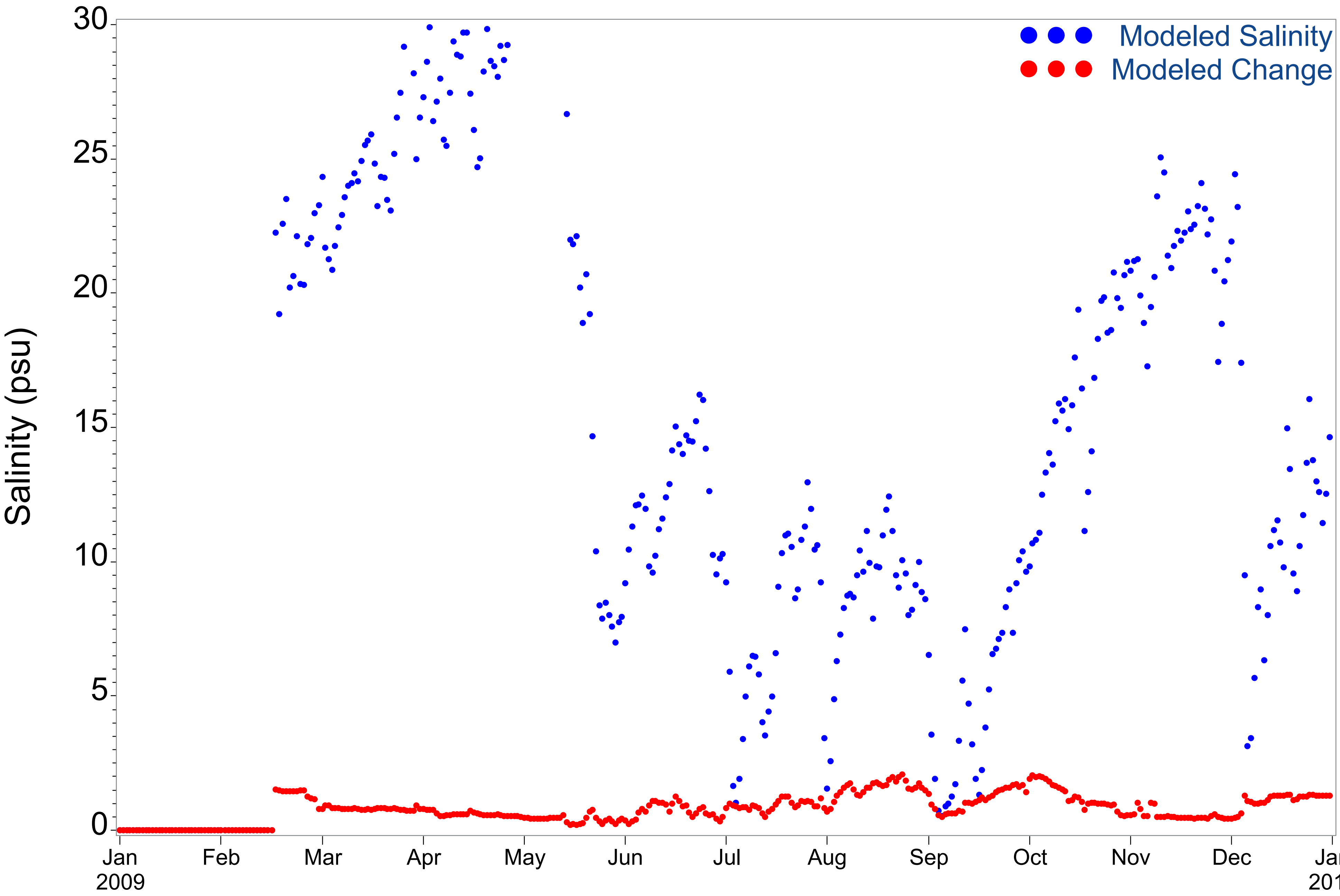


Figure 4.218 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 9.2 (2009)

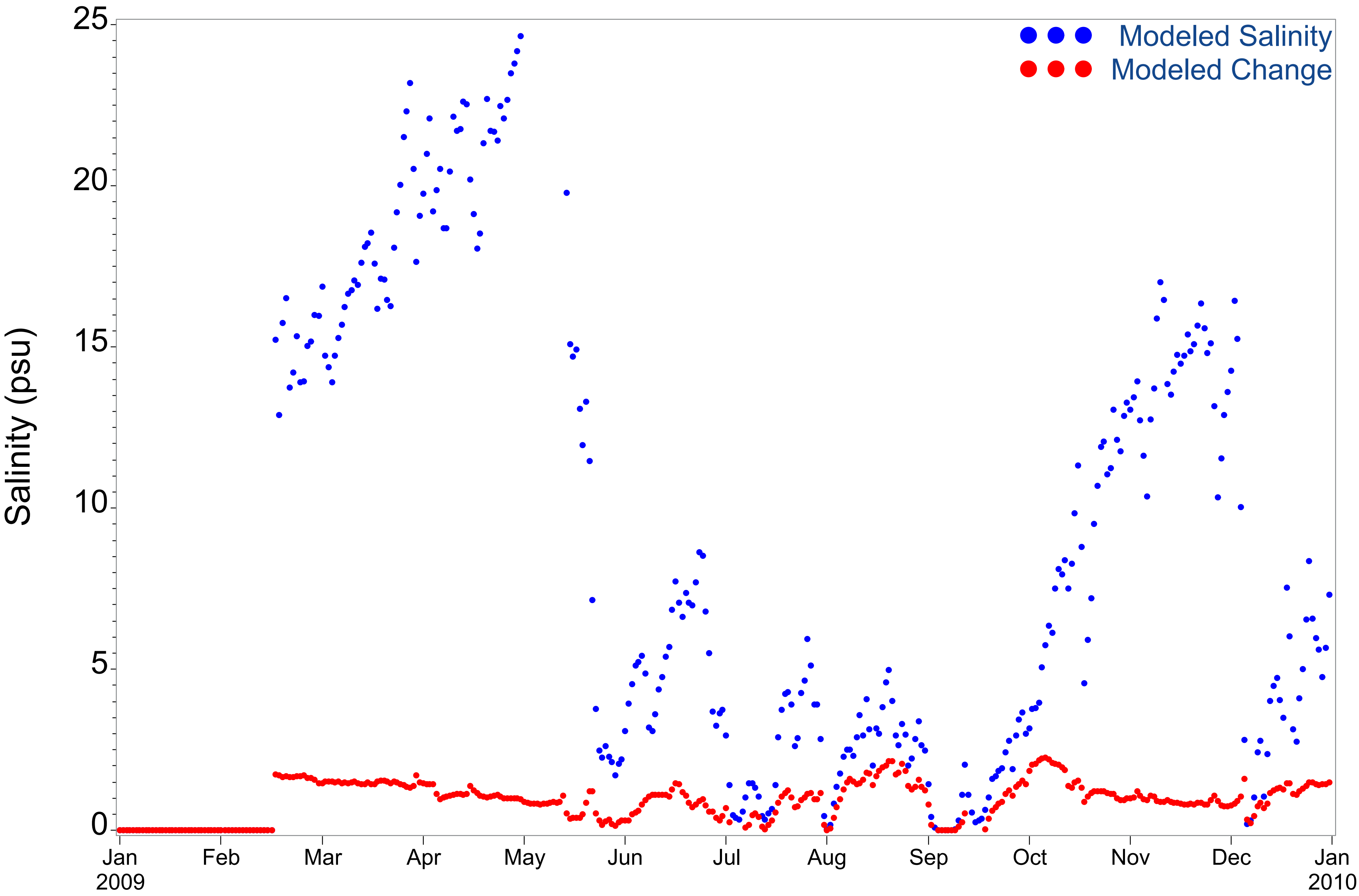


Figure 4.219 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 12.7 (2009)

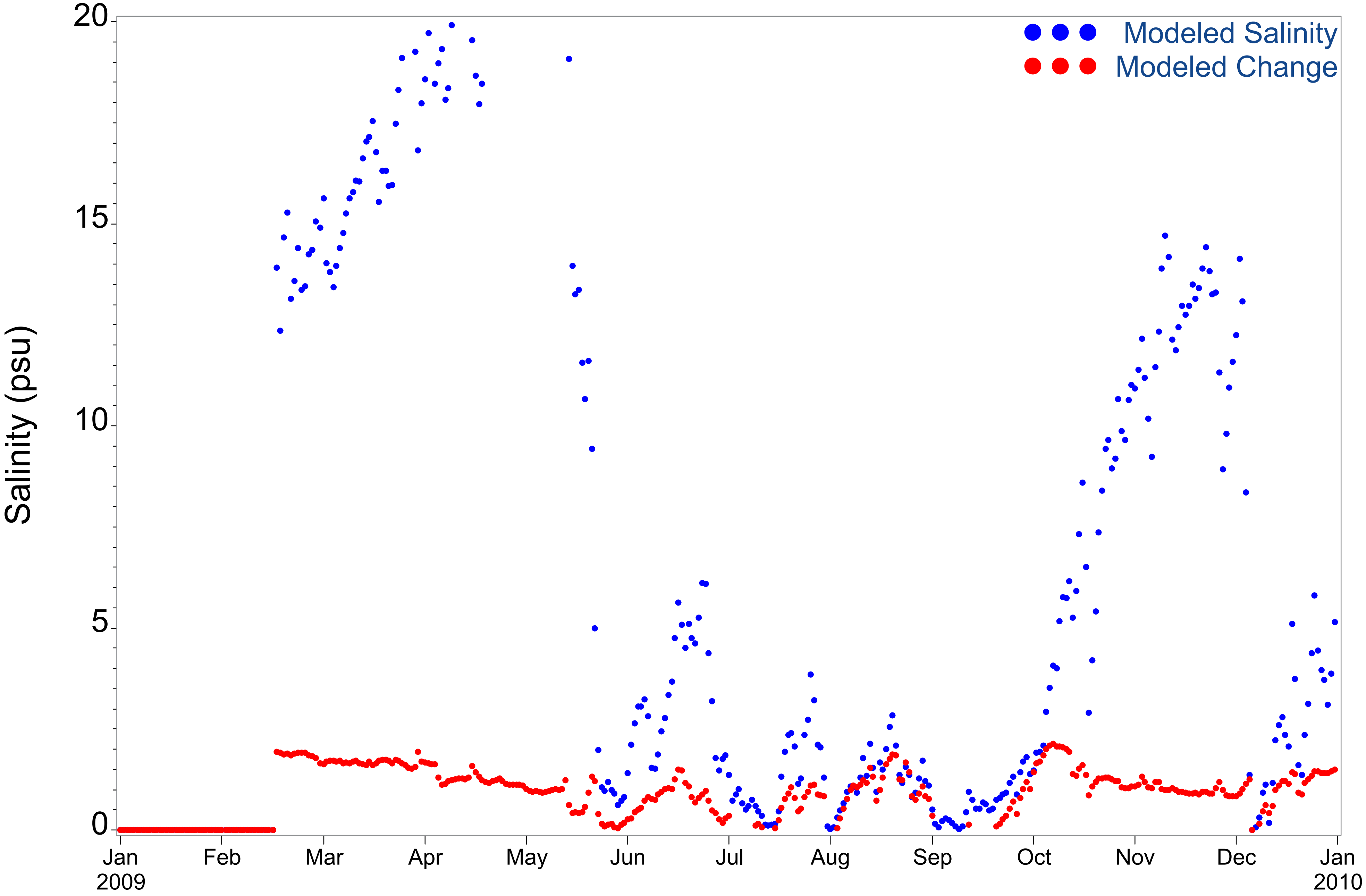


Figure 4.220 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 15.5 (2009)

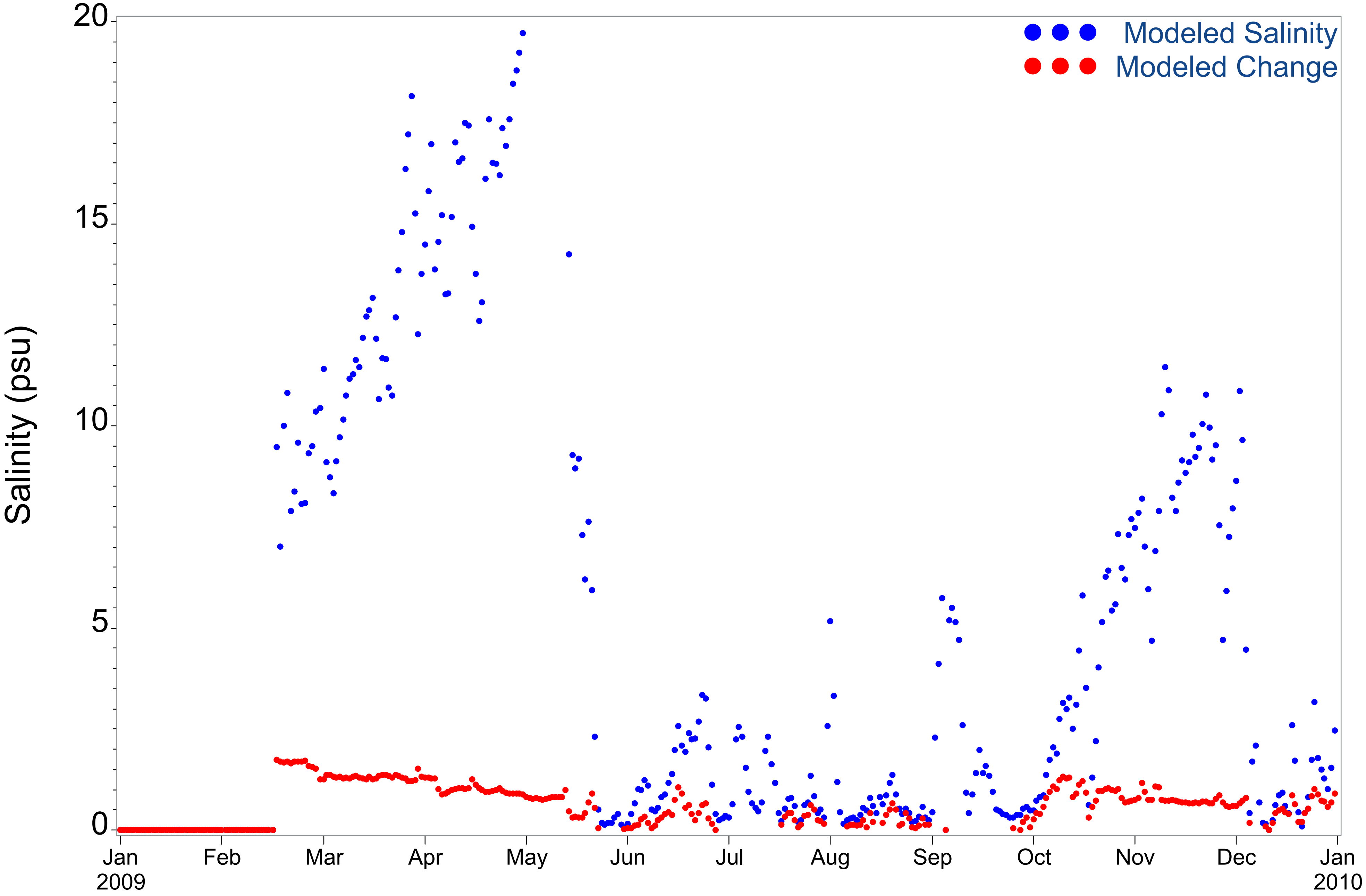


Figure 4.221 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.5 (2009)

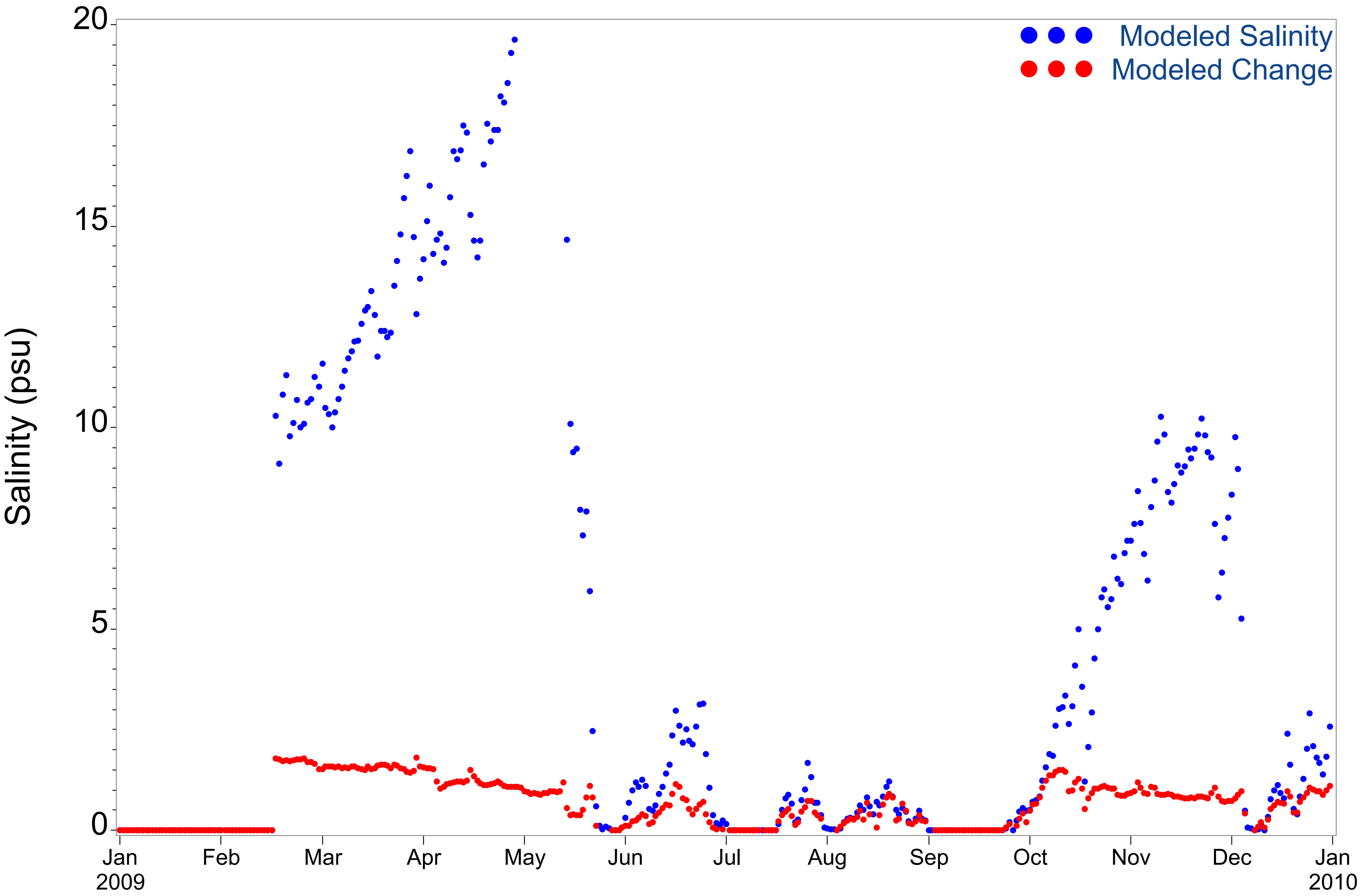


Figure 4.222 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.7 (2009)

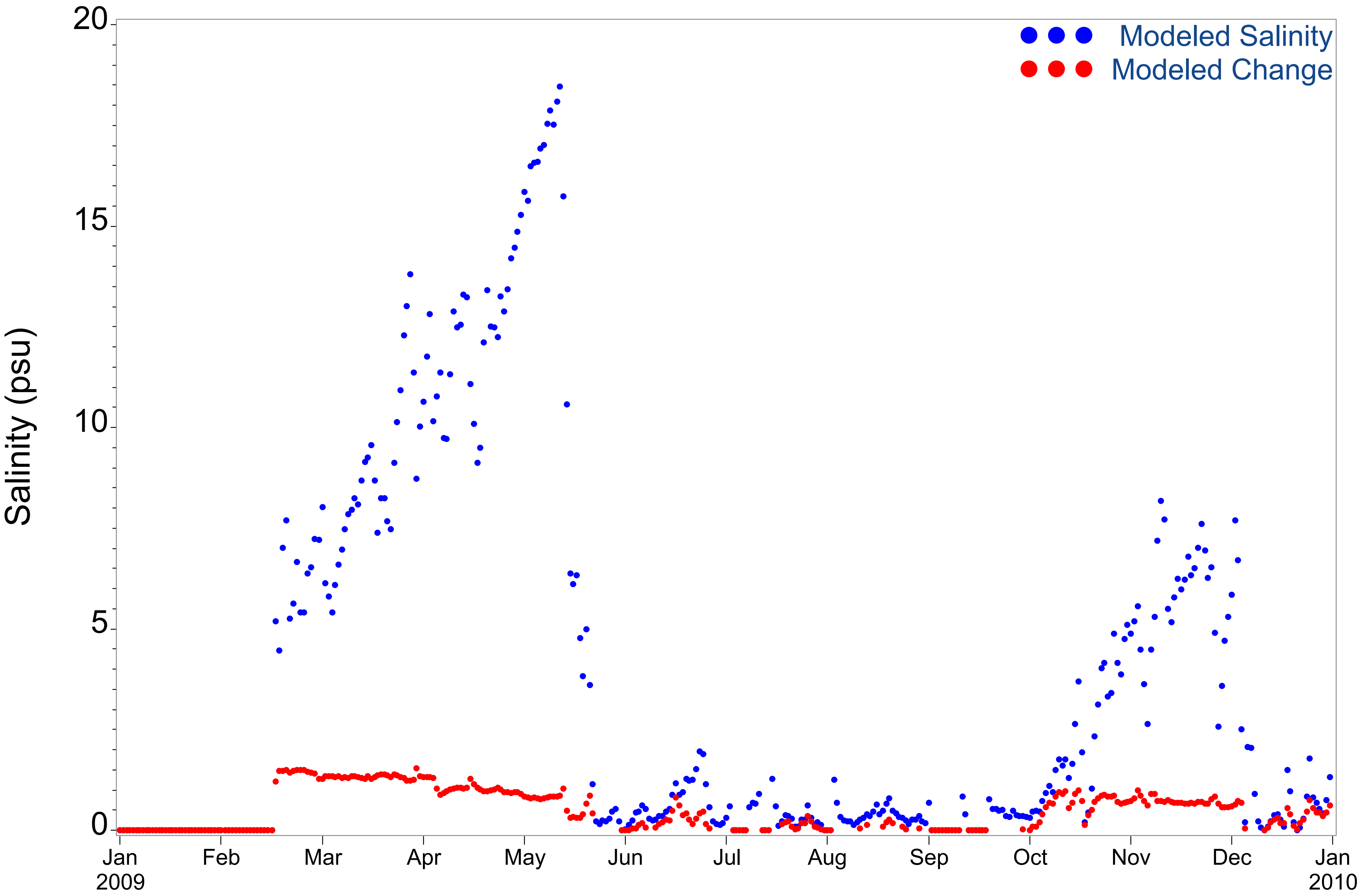


Figure 4.223 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 20.8 (2009)

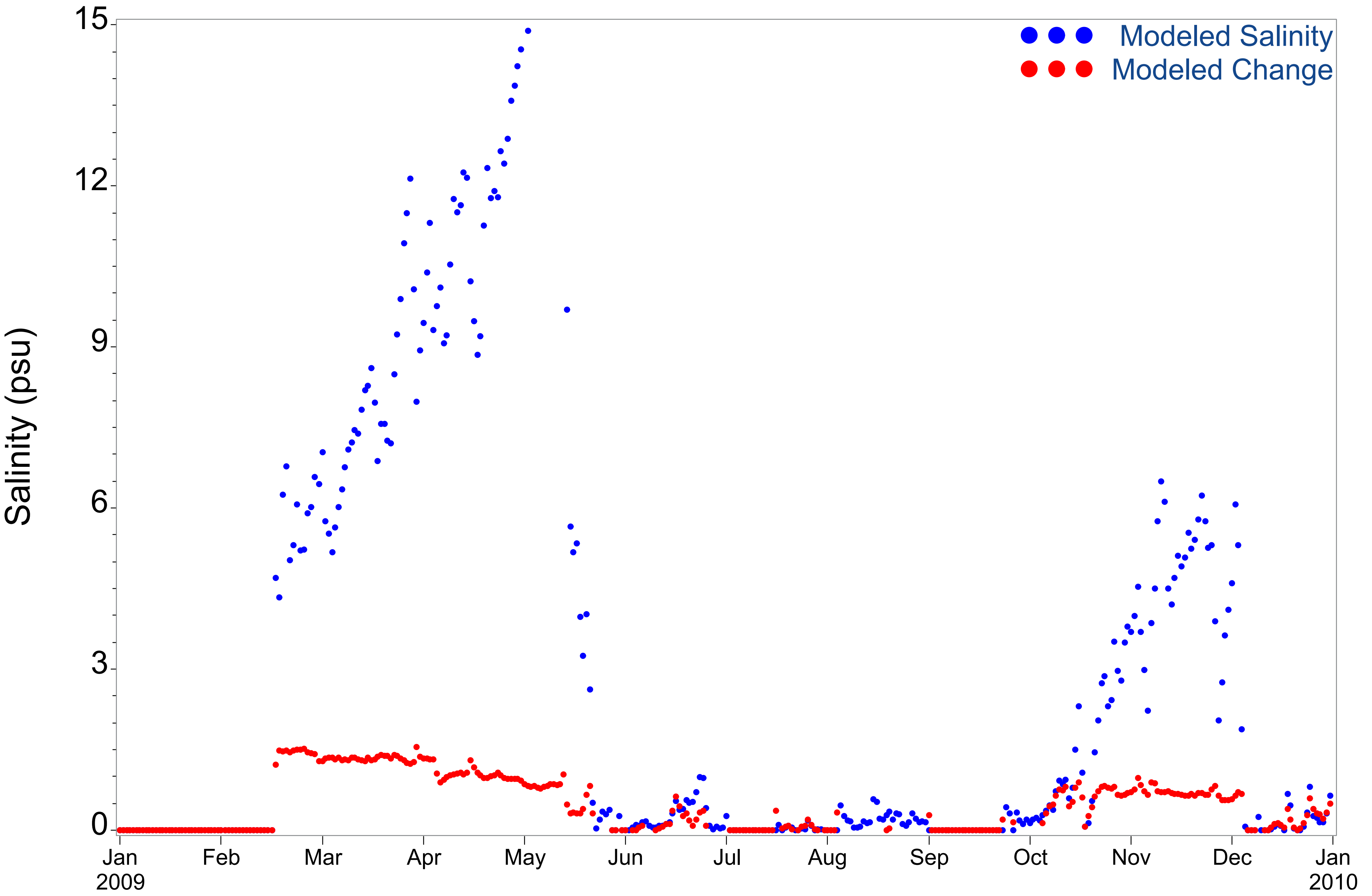


Figure 4.224 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 21.9 (2009)

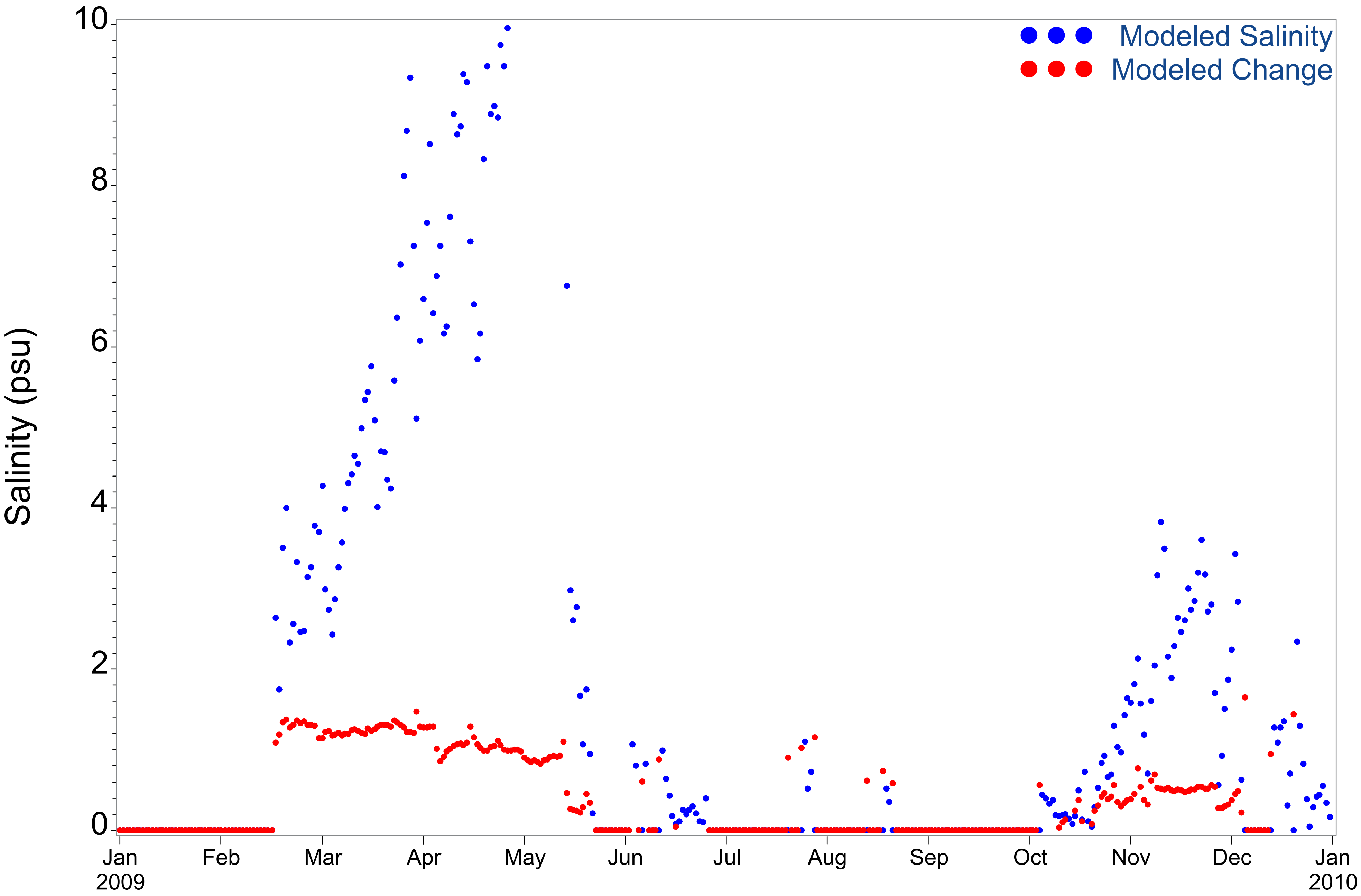


Figure 4.225 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 24.5 (2009)

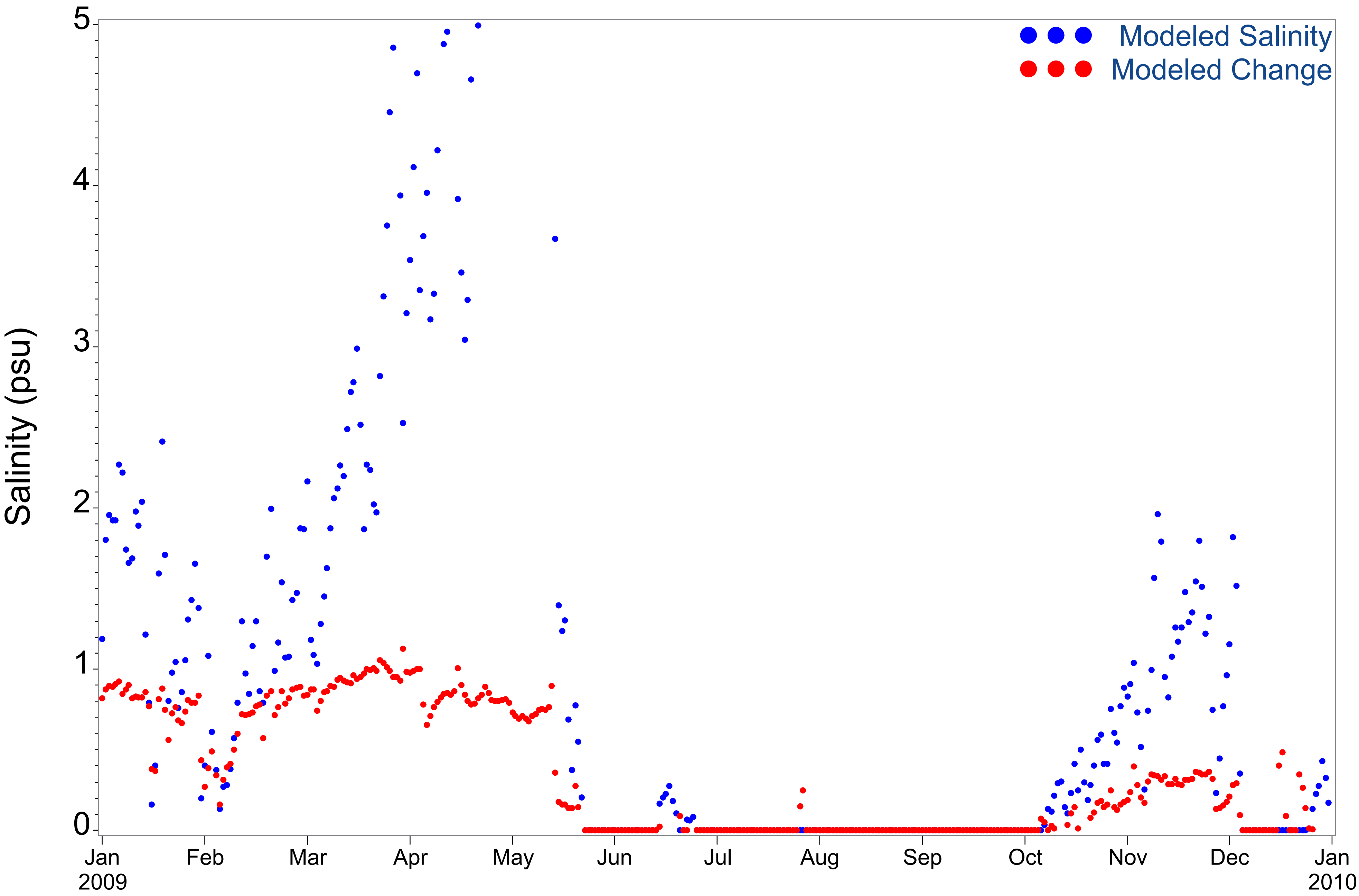


Figure 4.226 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 26.7 (2009)

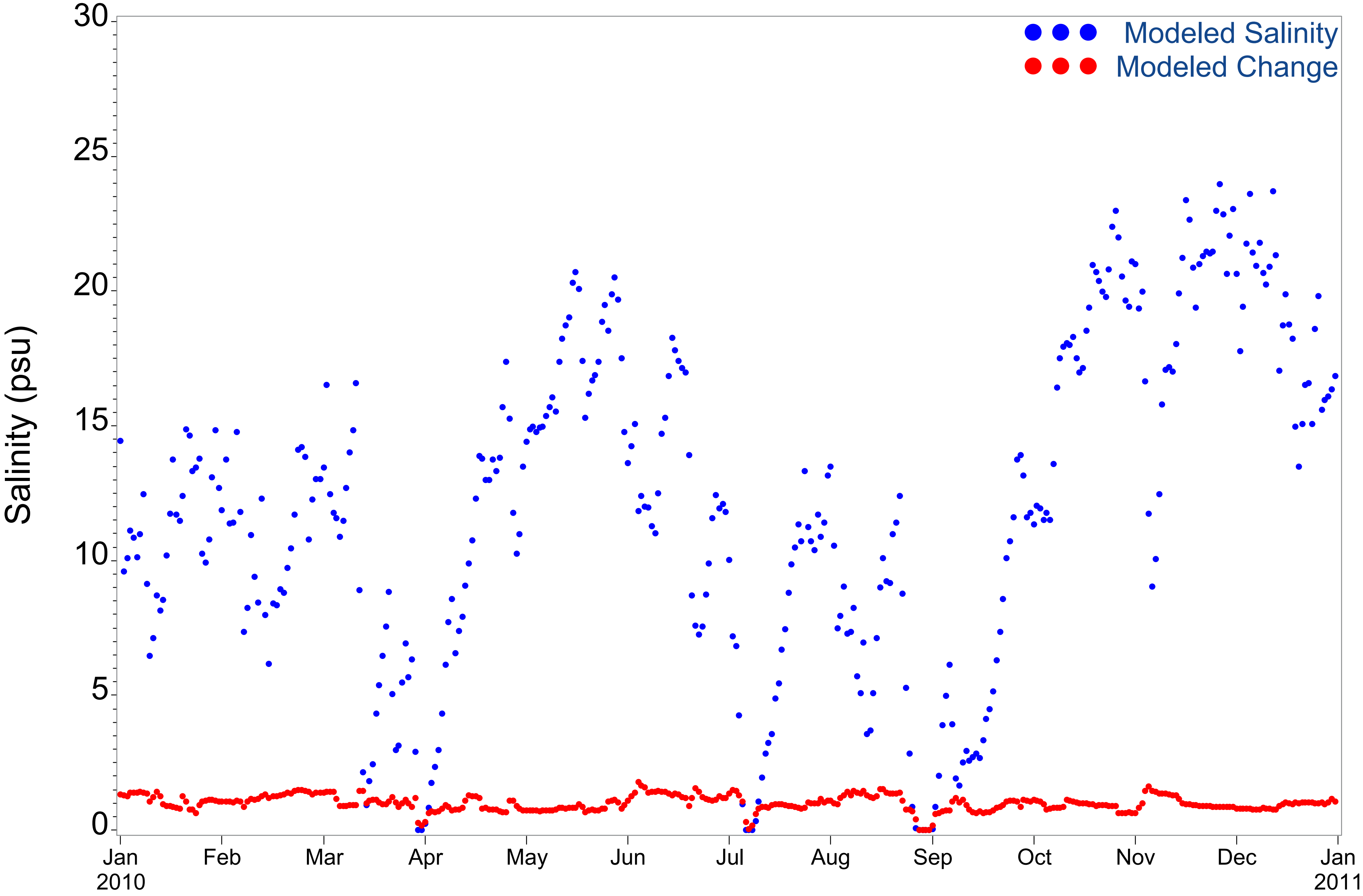


Figure 4.227 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 9.2 (2010)

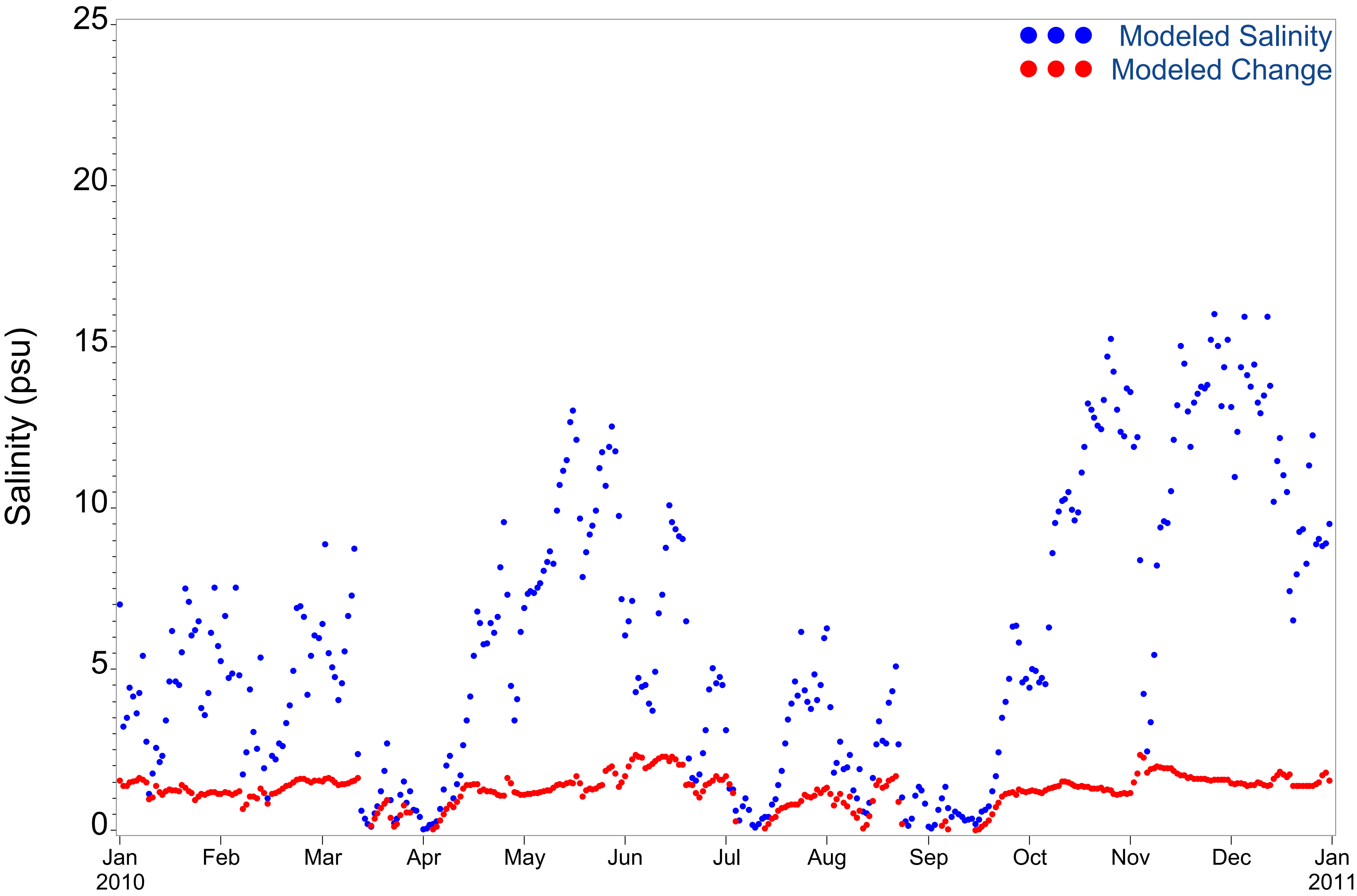


Figure 4.228 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 12.7 (2010)

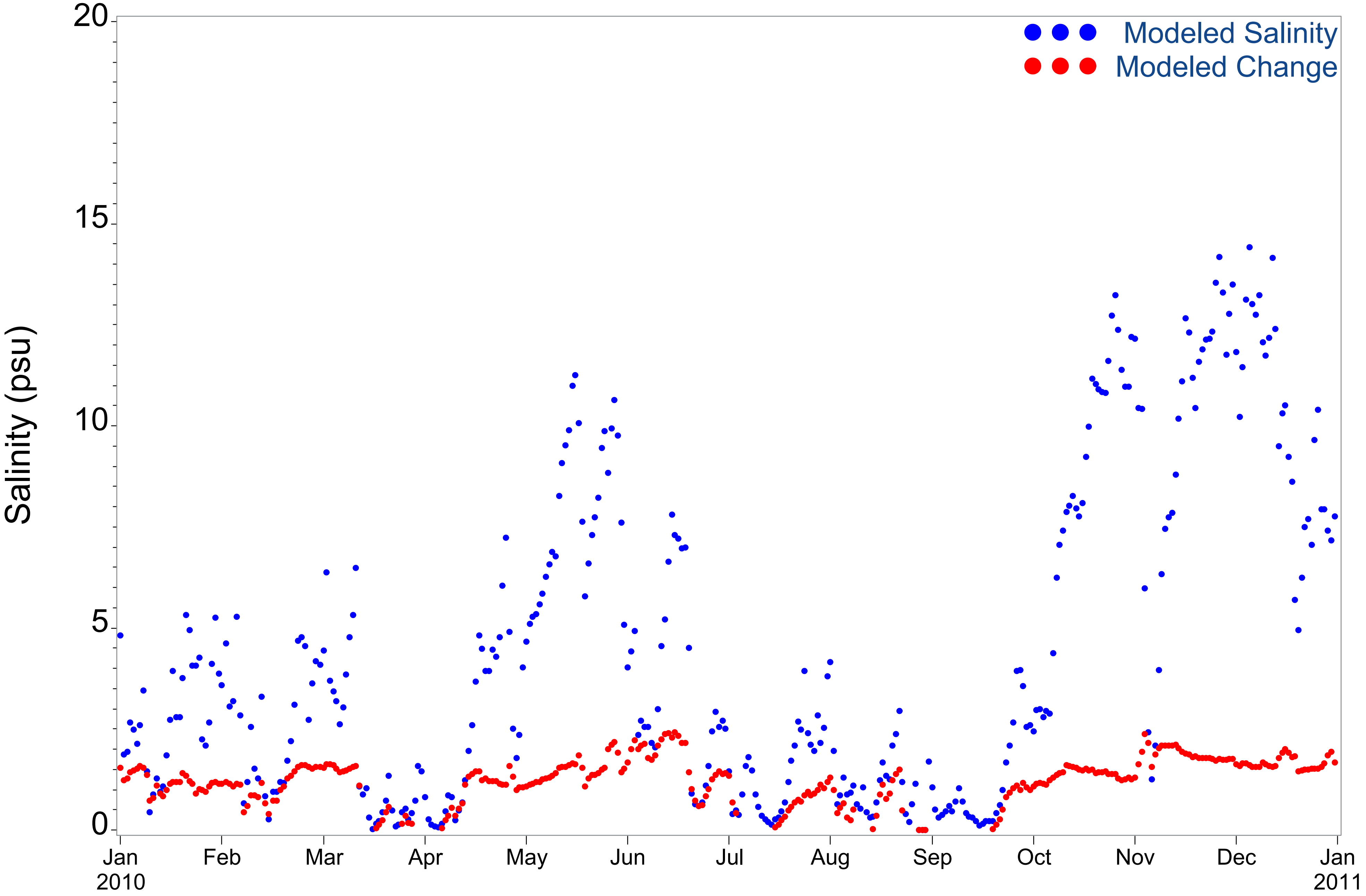


Figure 4.229 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 15.5 (2010)

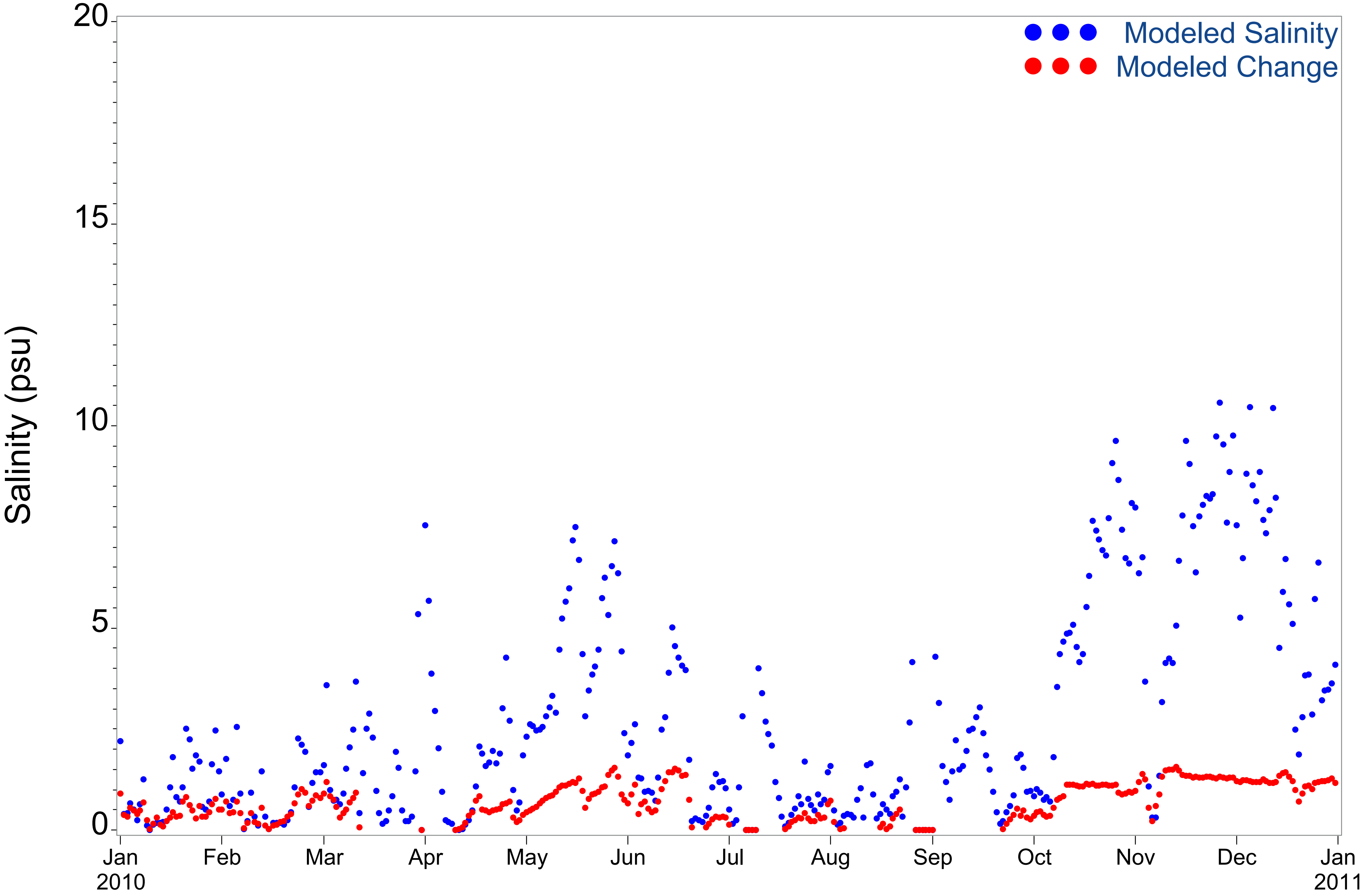


Figure 4.230 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.5 (2010)

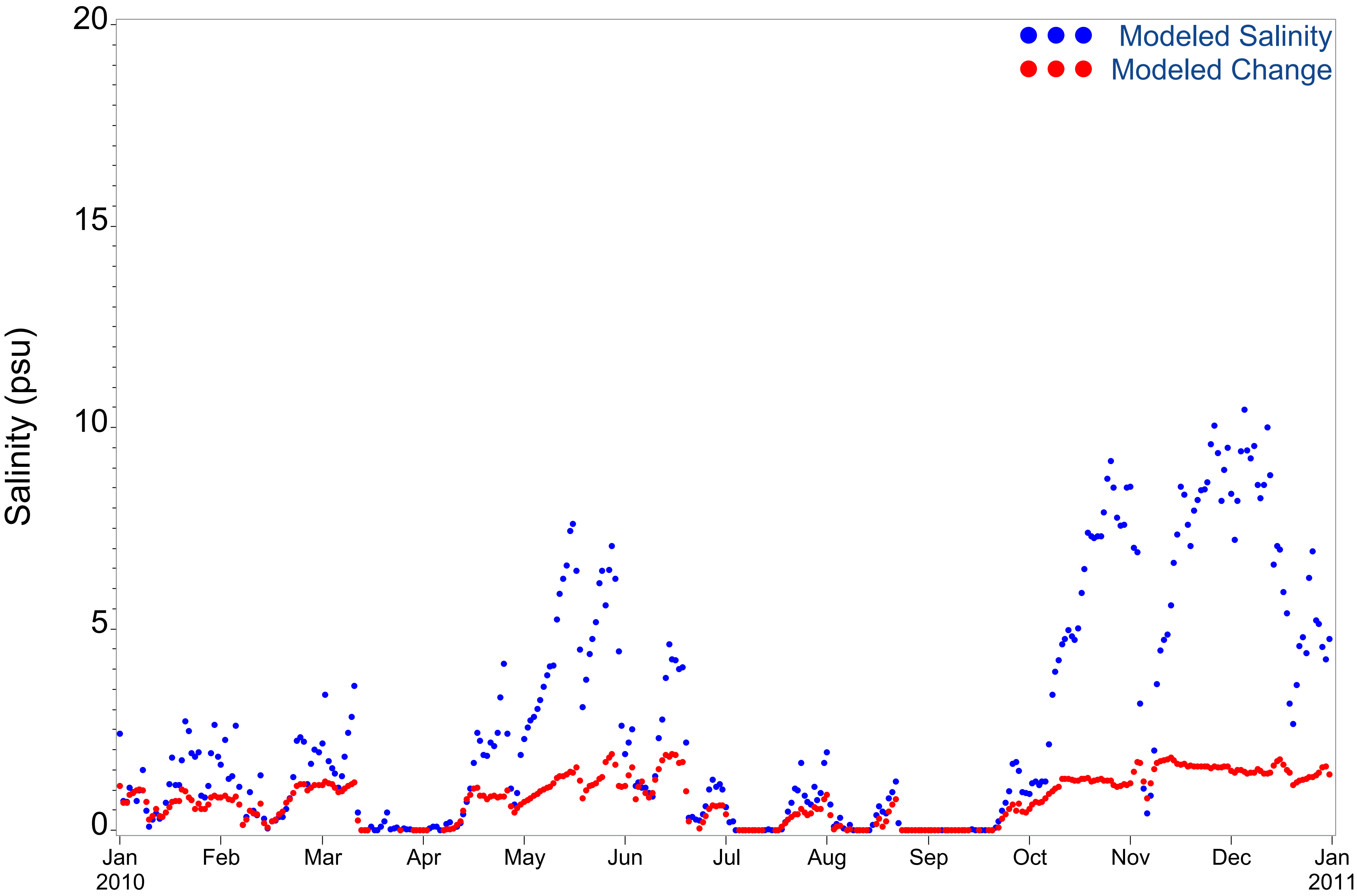


Figure 4.231 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.7 (2010)

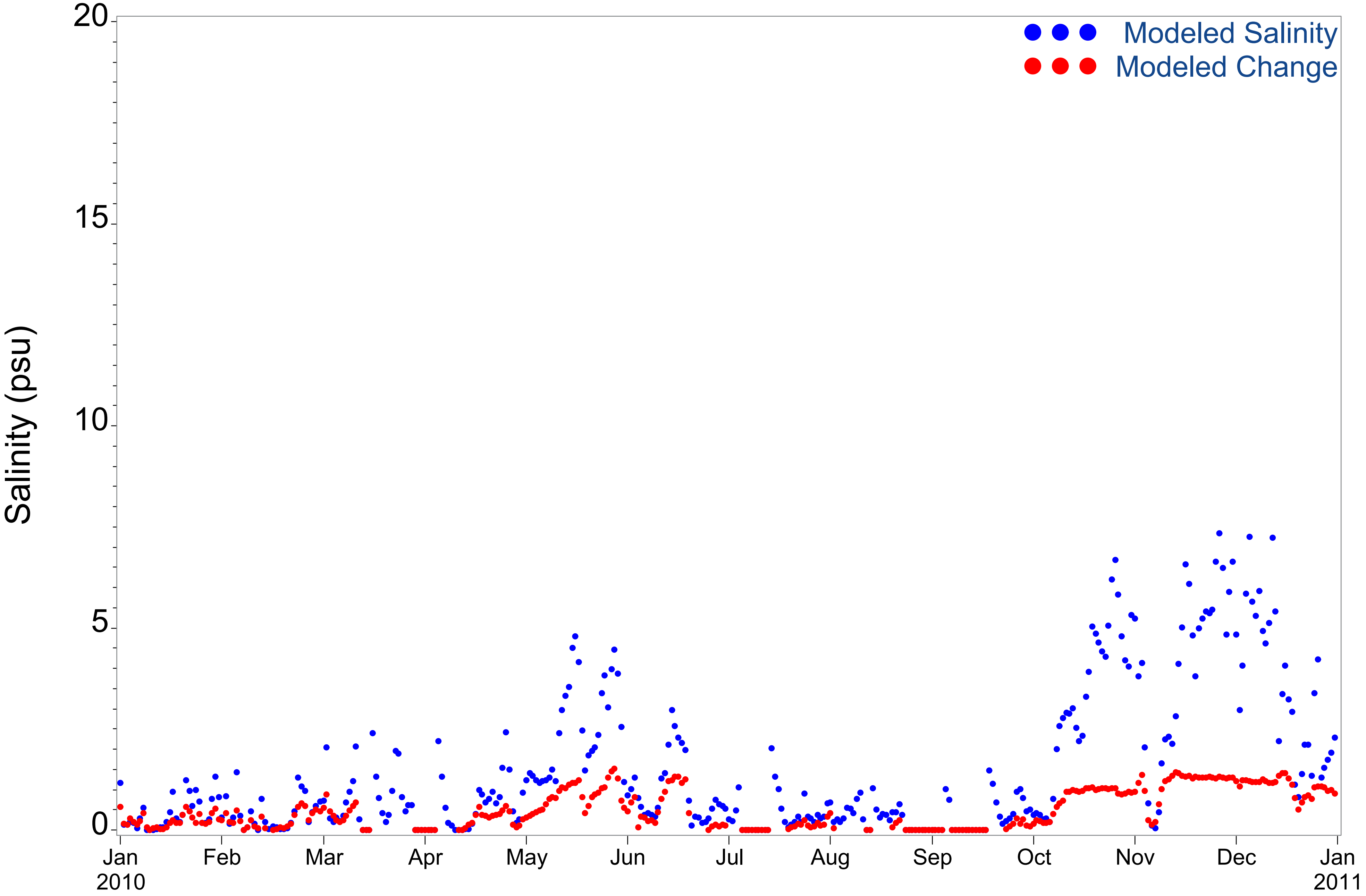


Figure 4.232 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 20.8 (2010)

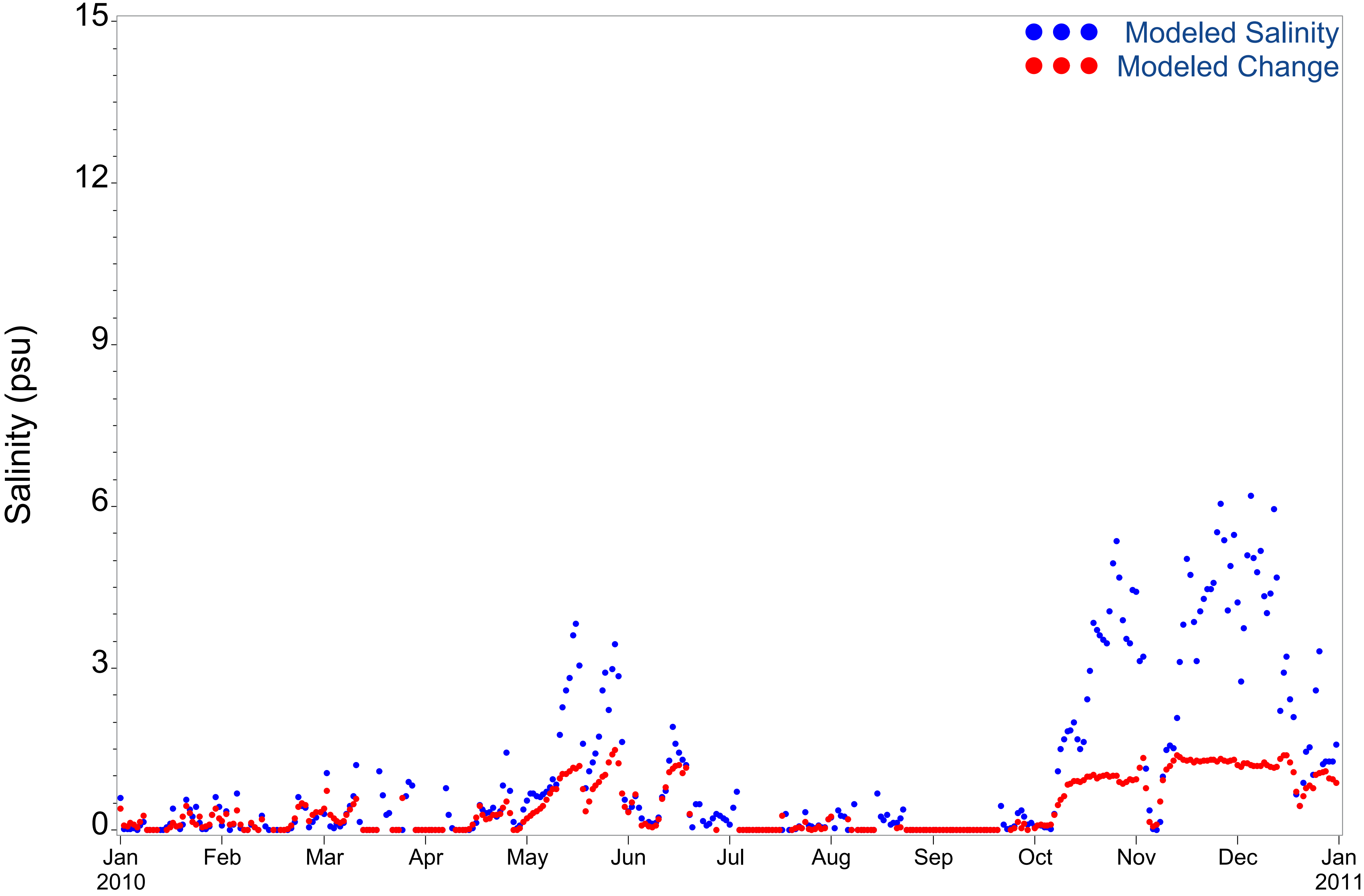


Figure 4.233 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 21.9 (2010)

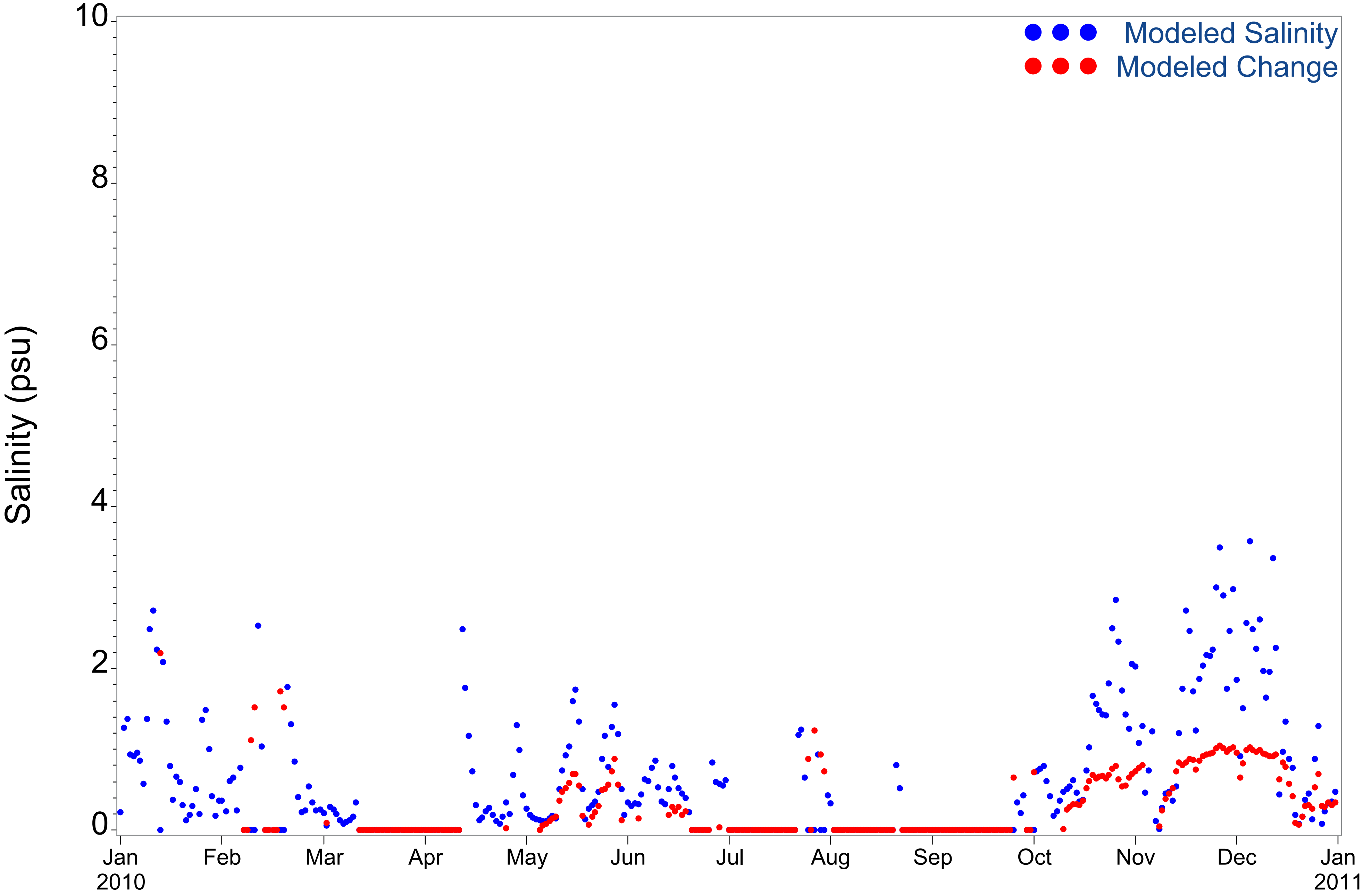
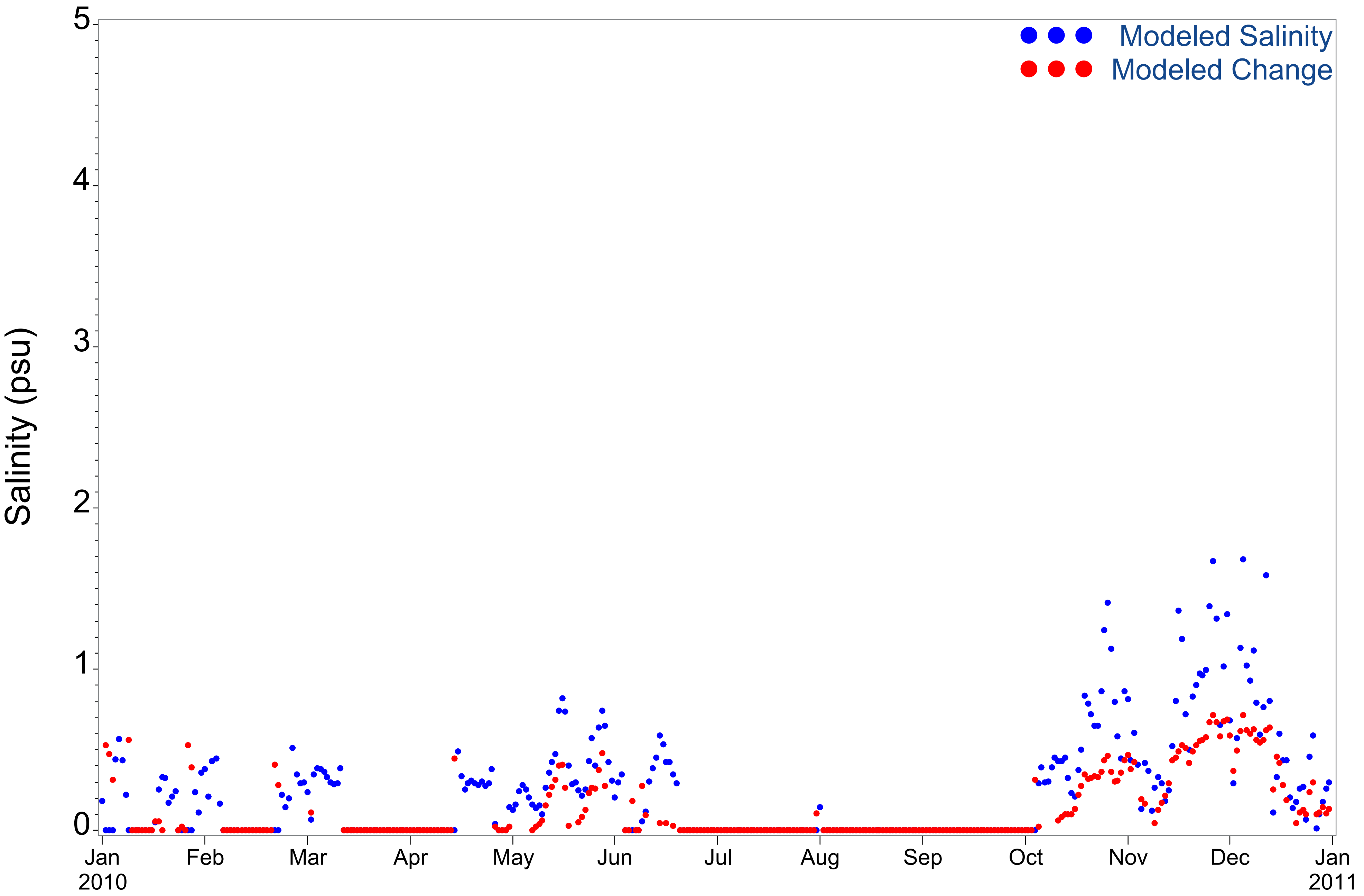


Figure 4.234 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 24.5 (2010)



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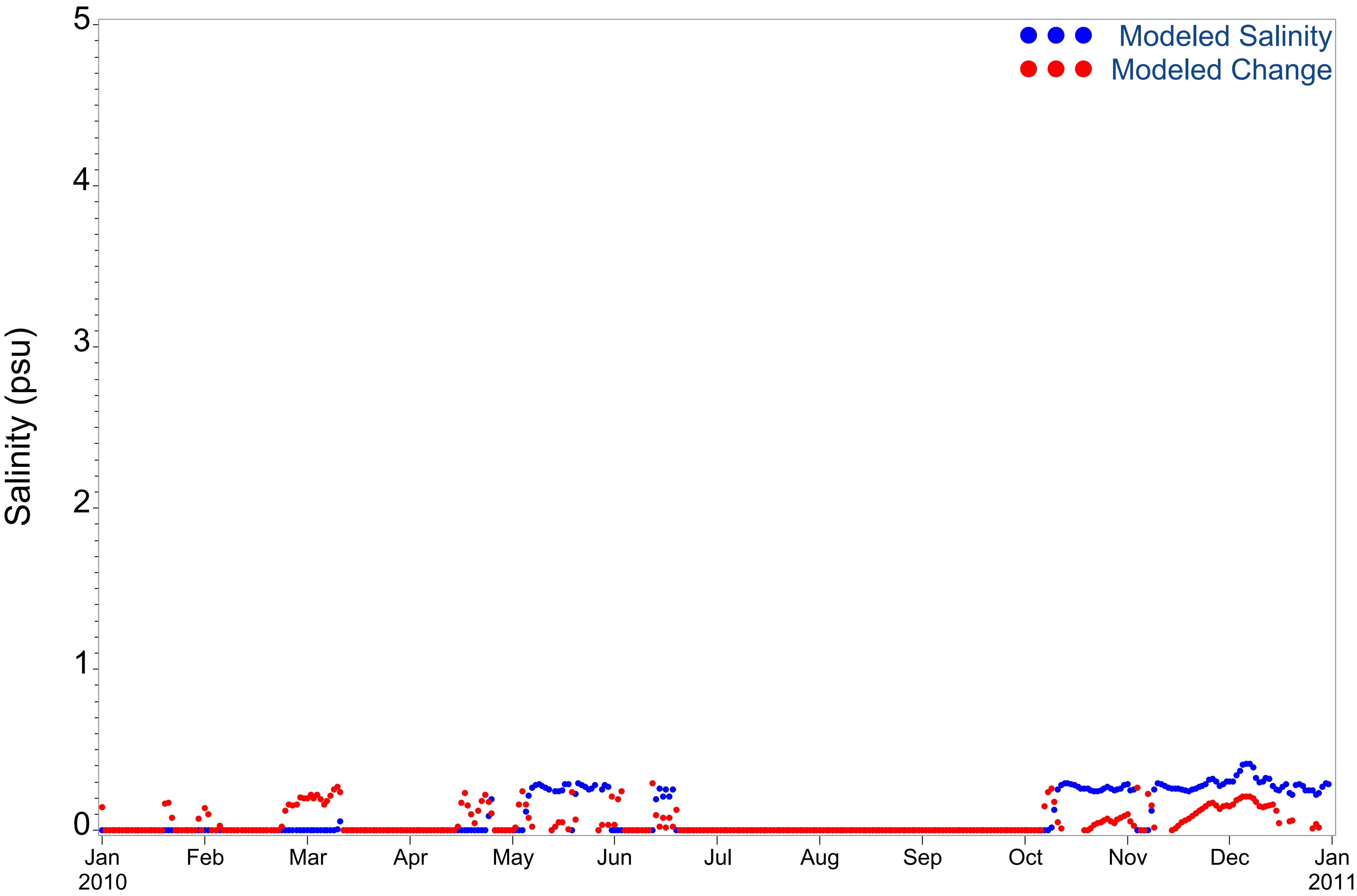


Figure 4.236 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 29.8 (2010)

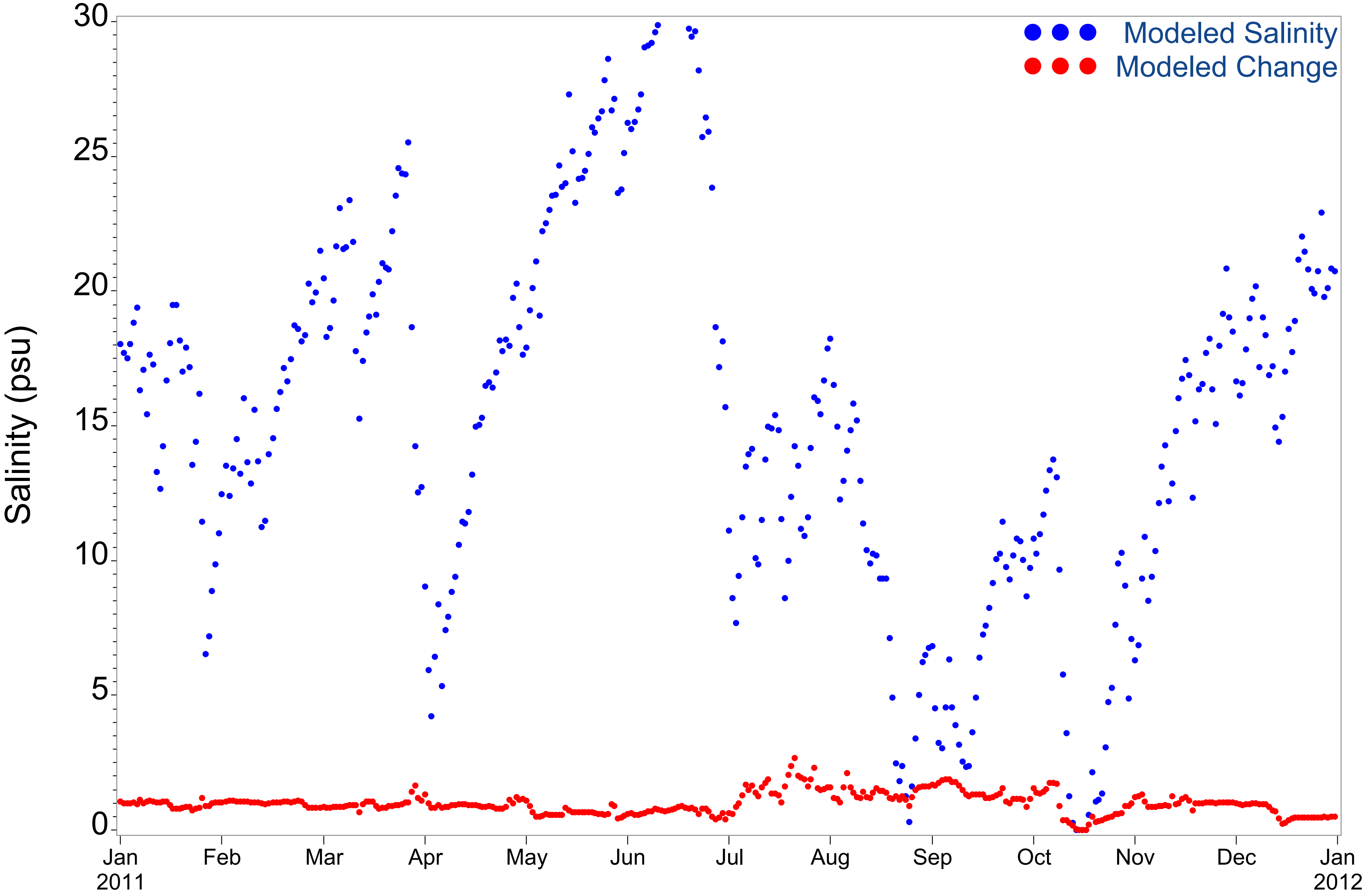


Figure 4.237 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 9.2 (2011)

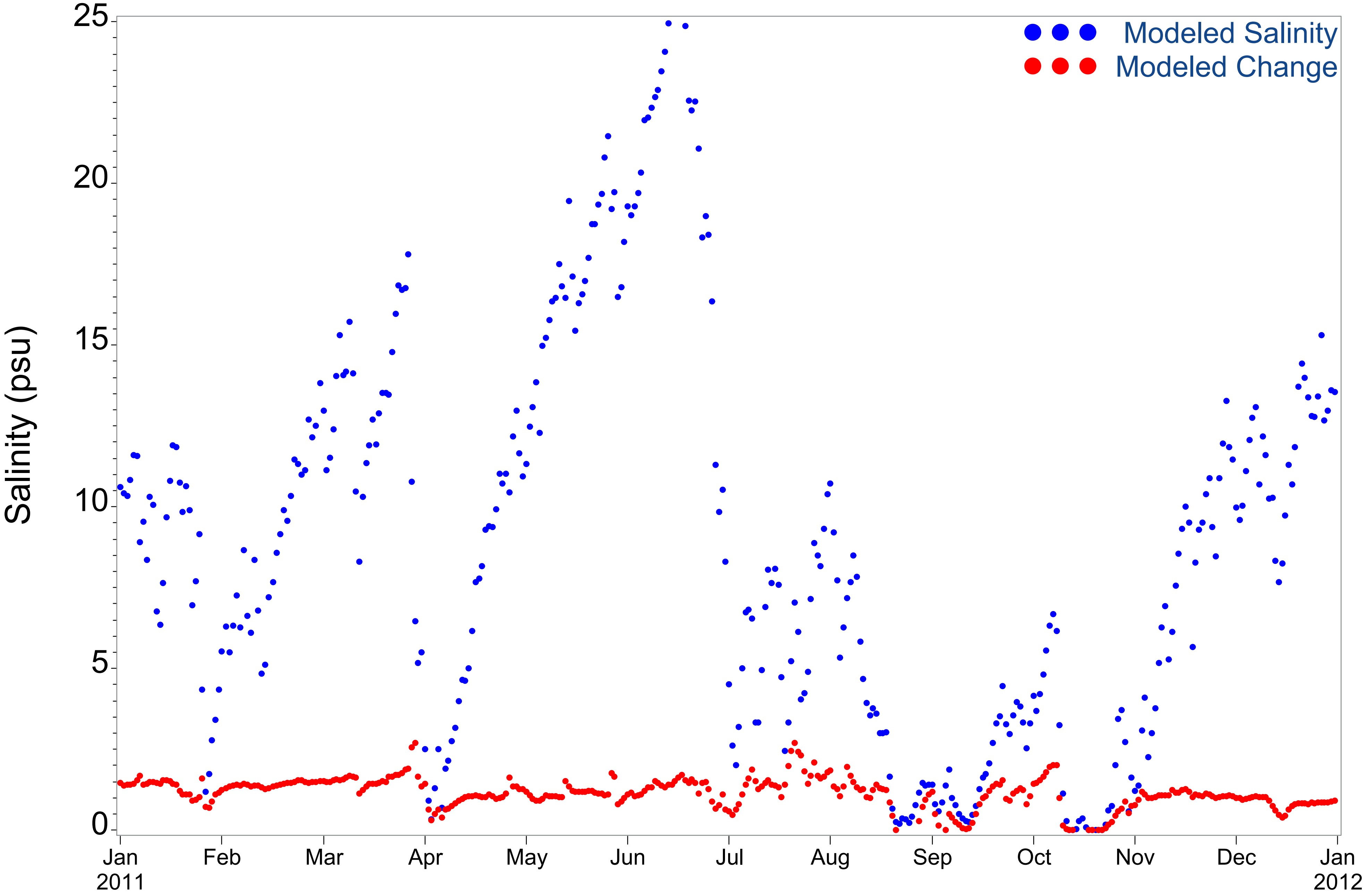


Figure 4.238 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 12.7 (2011)

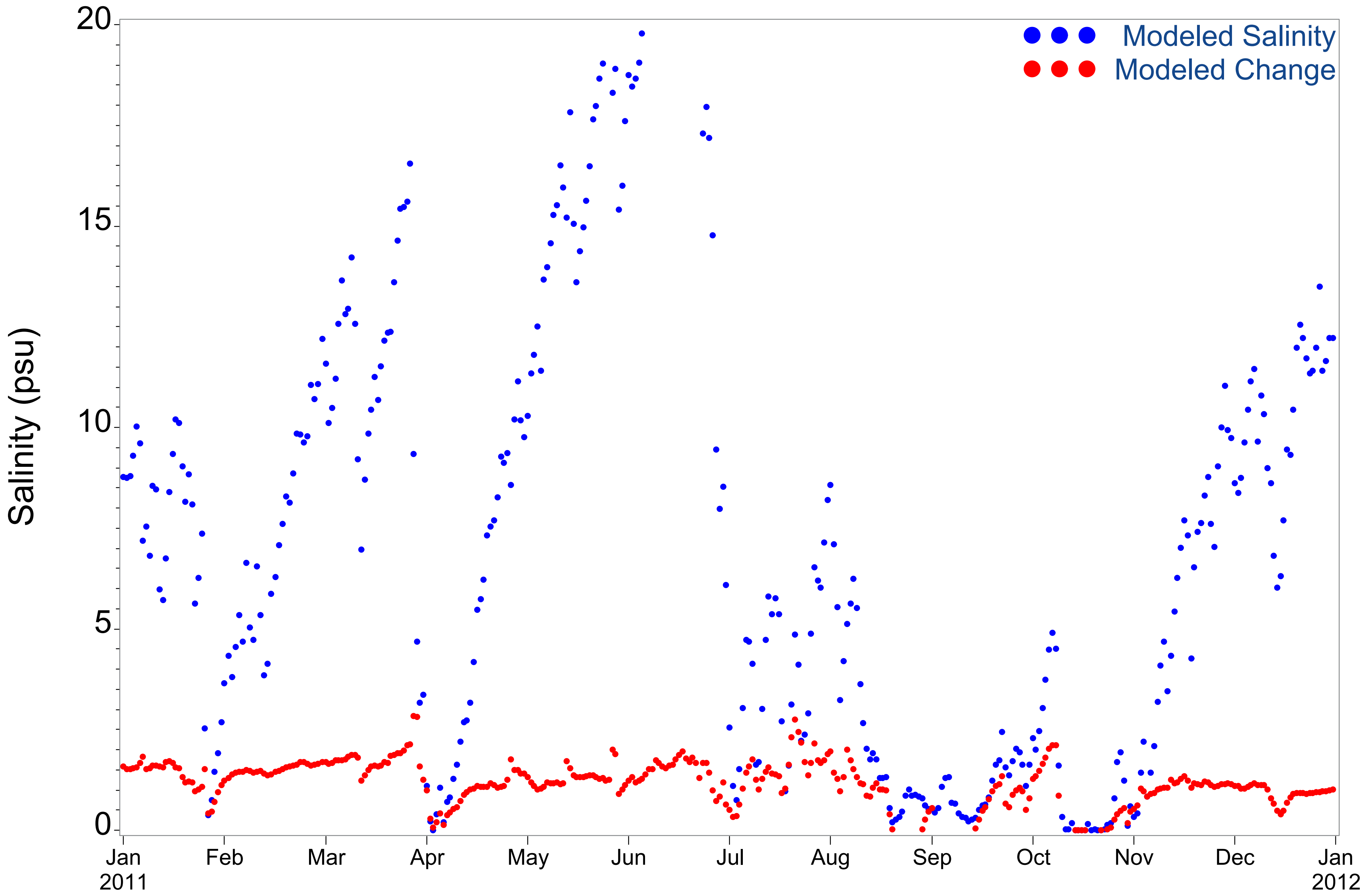
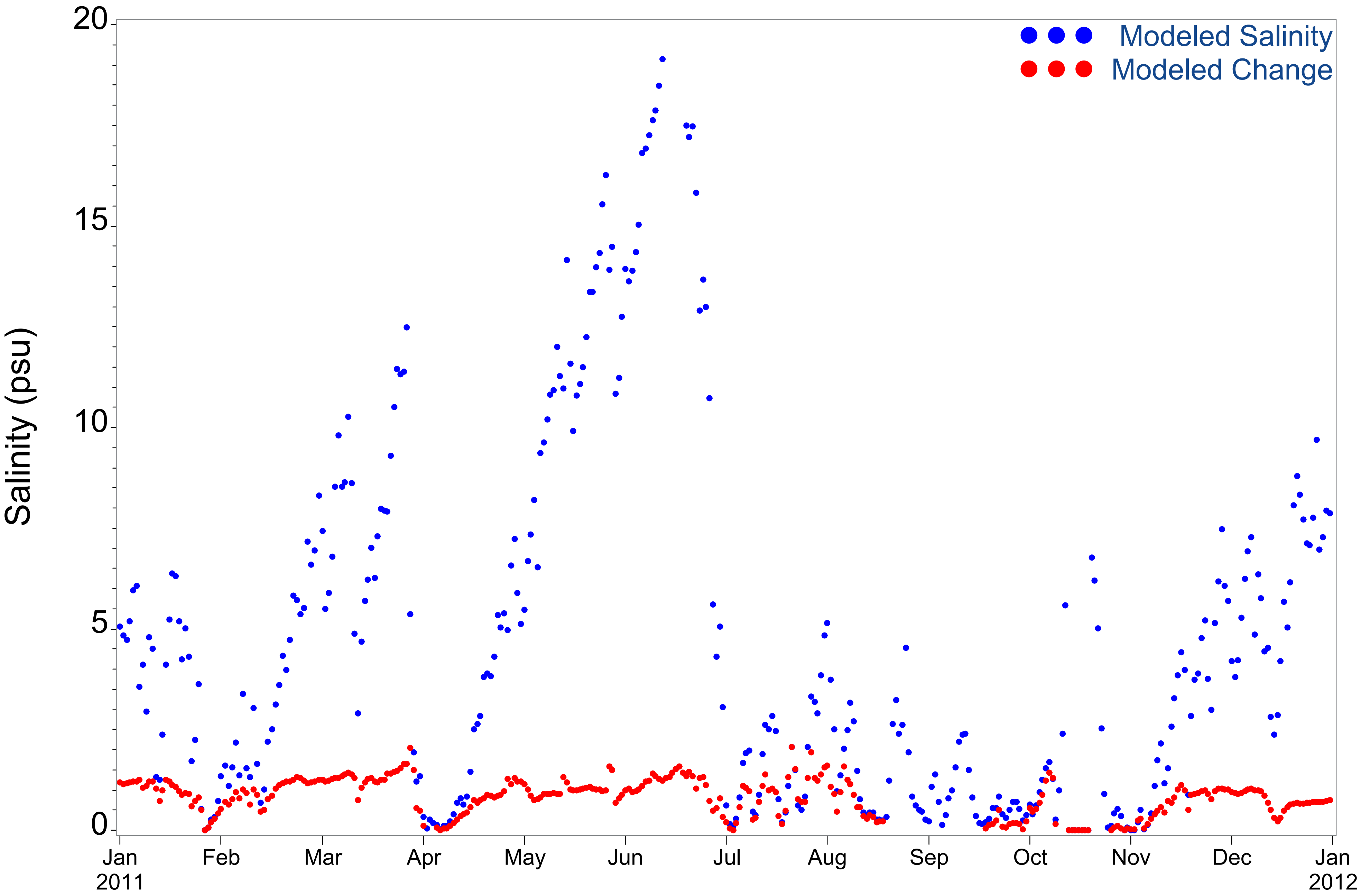


Figure 4.239 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 15.5 (2011)



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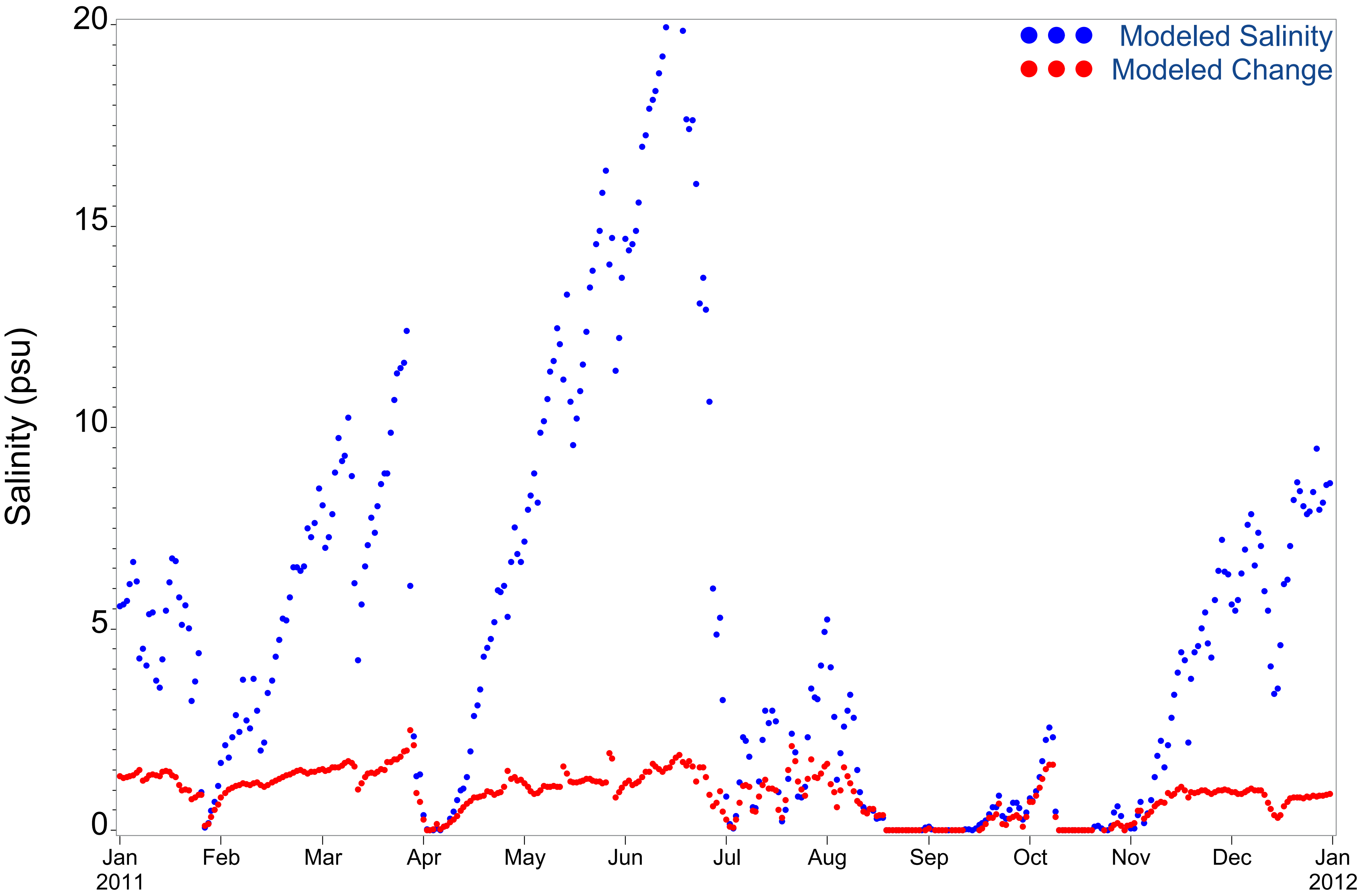


Figure 4.241 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.7 (2011)

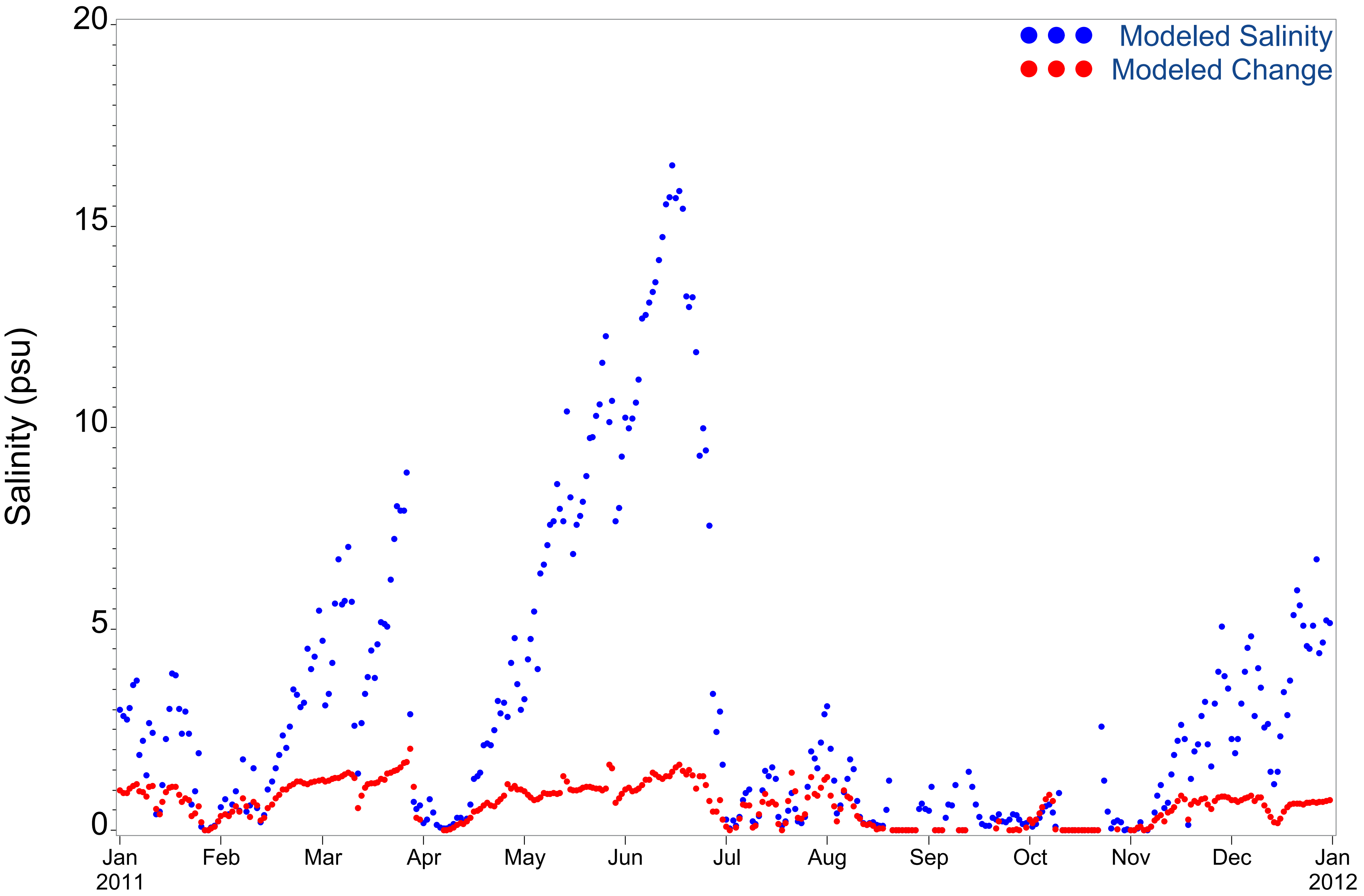


Figure 4.242 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 20.8 (2011)

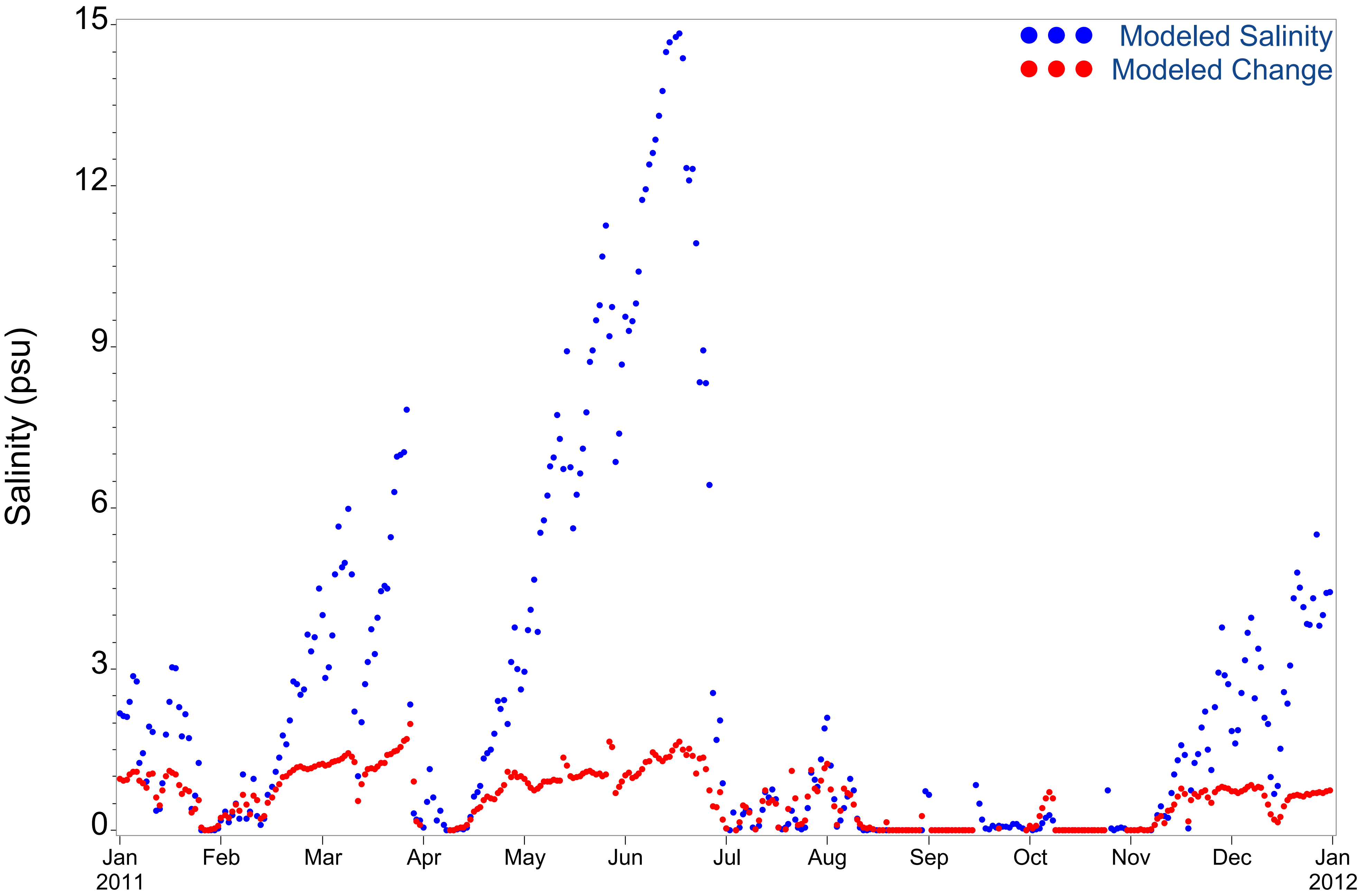


Figure 4.243 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 21.9 (2011)

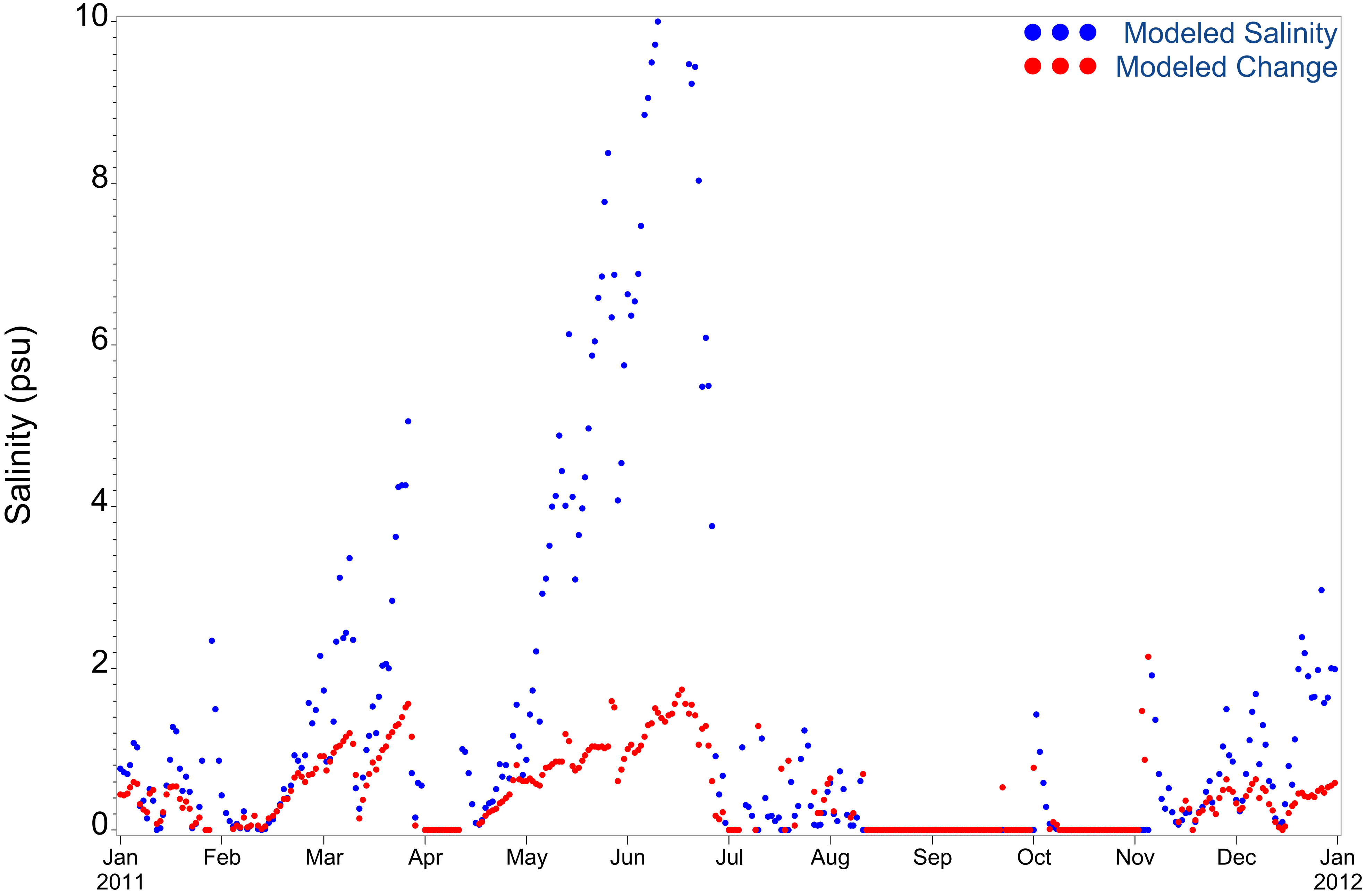


Figure 4.244 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 24.5 (2011)

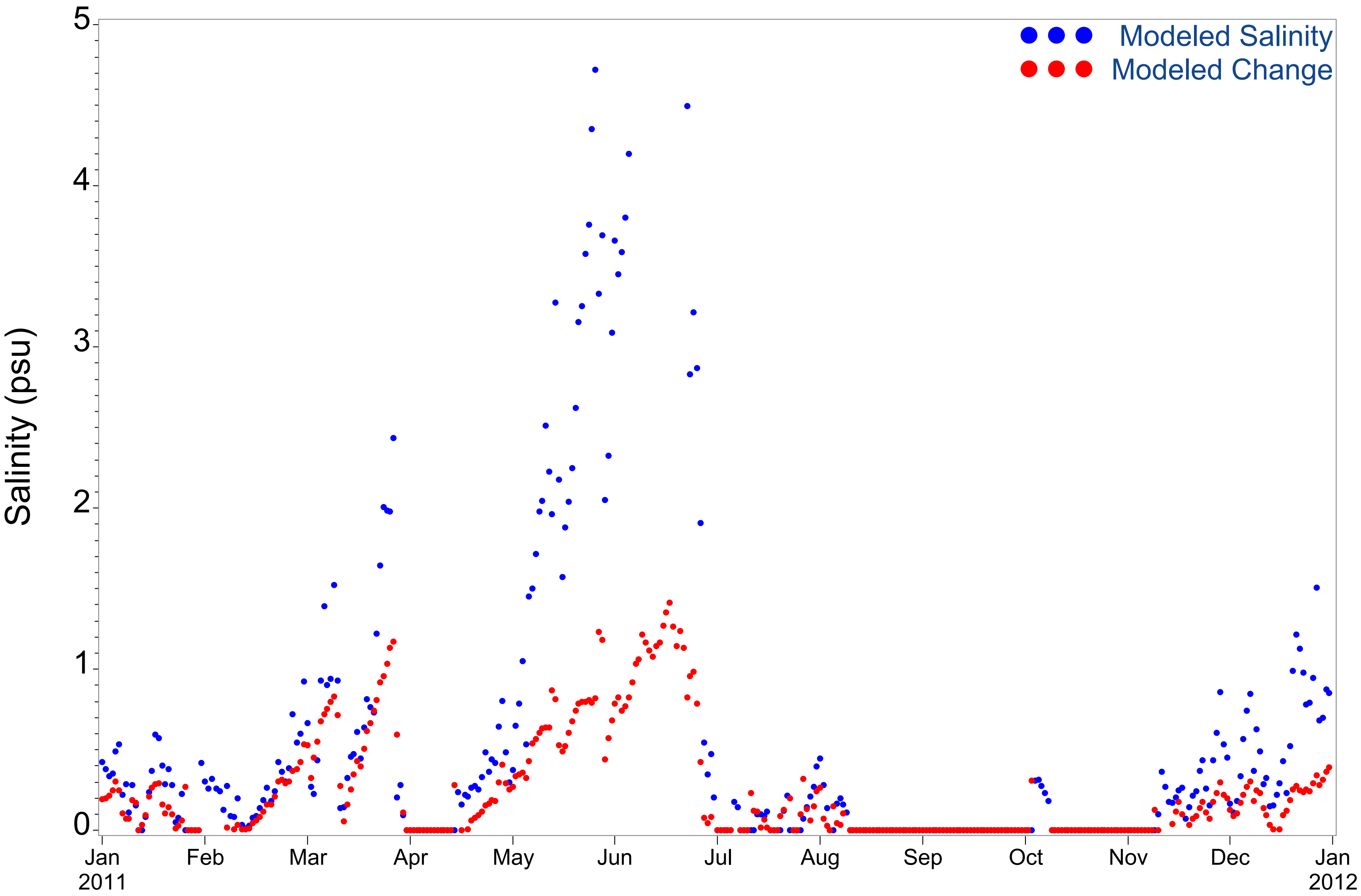


Figure 4.245 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 26.7 (2011)

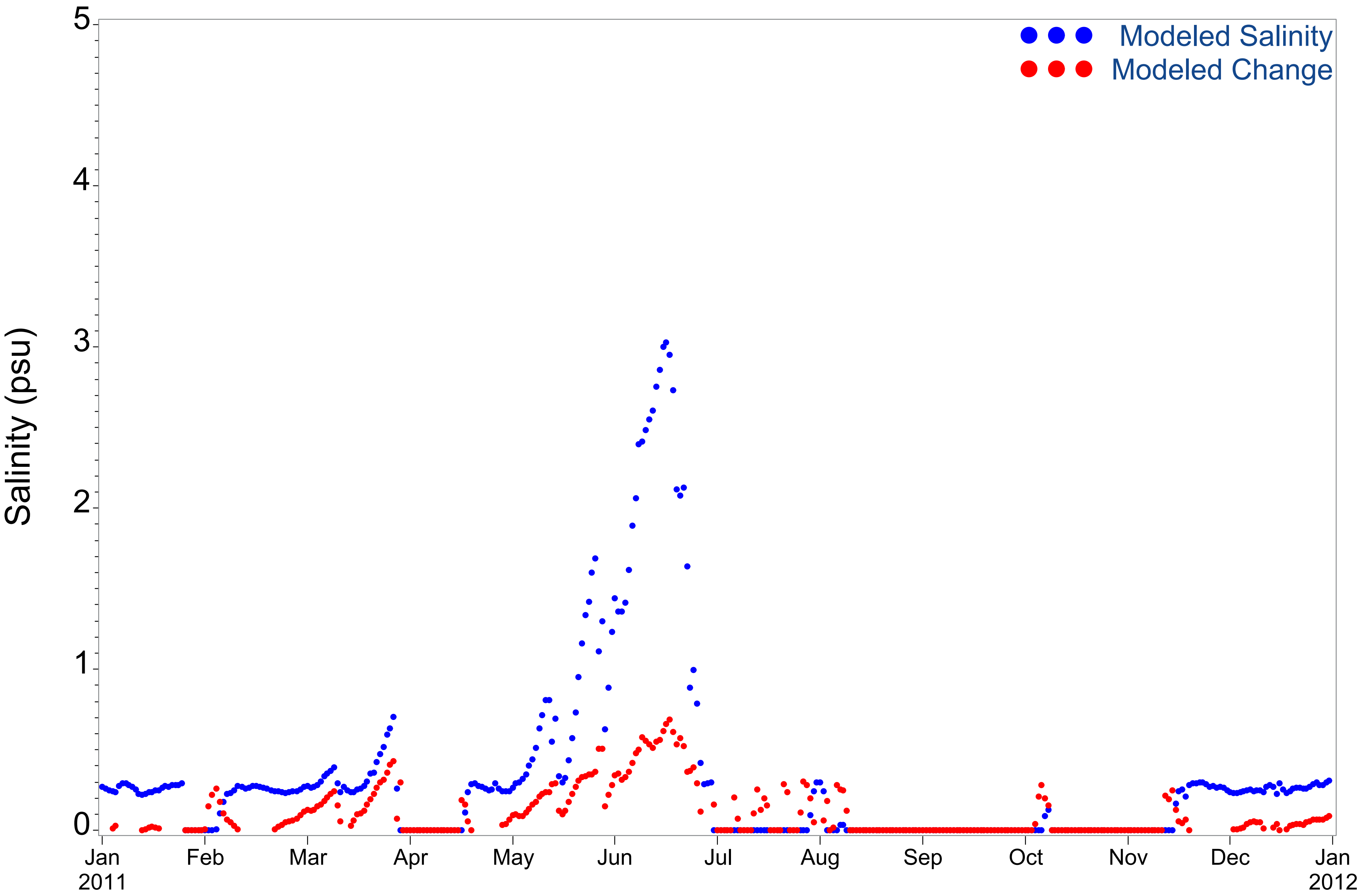


Figure 4.246 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 29.8 (2011)

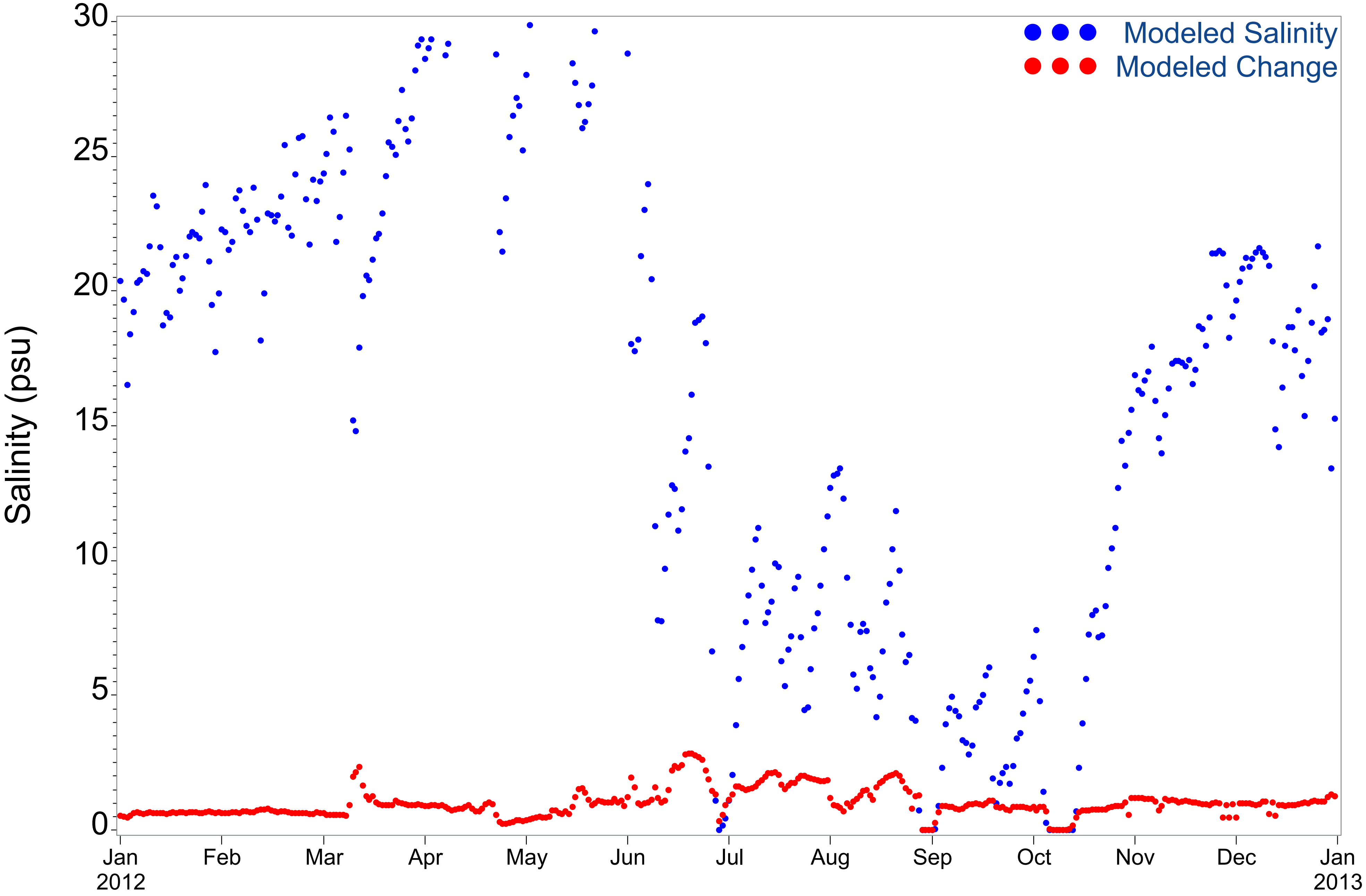


Figure 4.247 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 9.2 (2012)

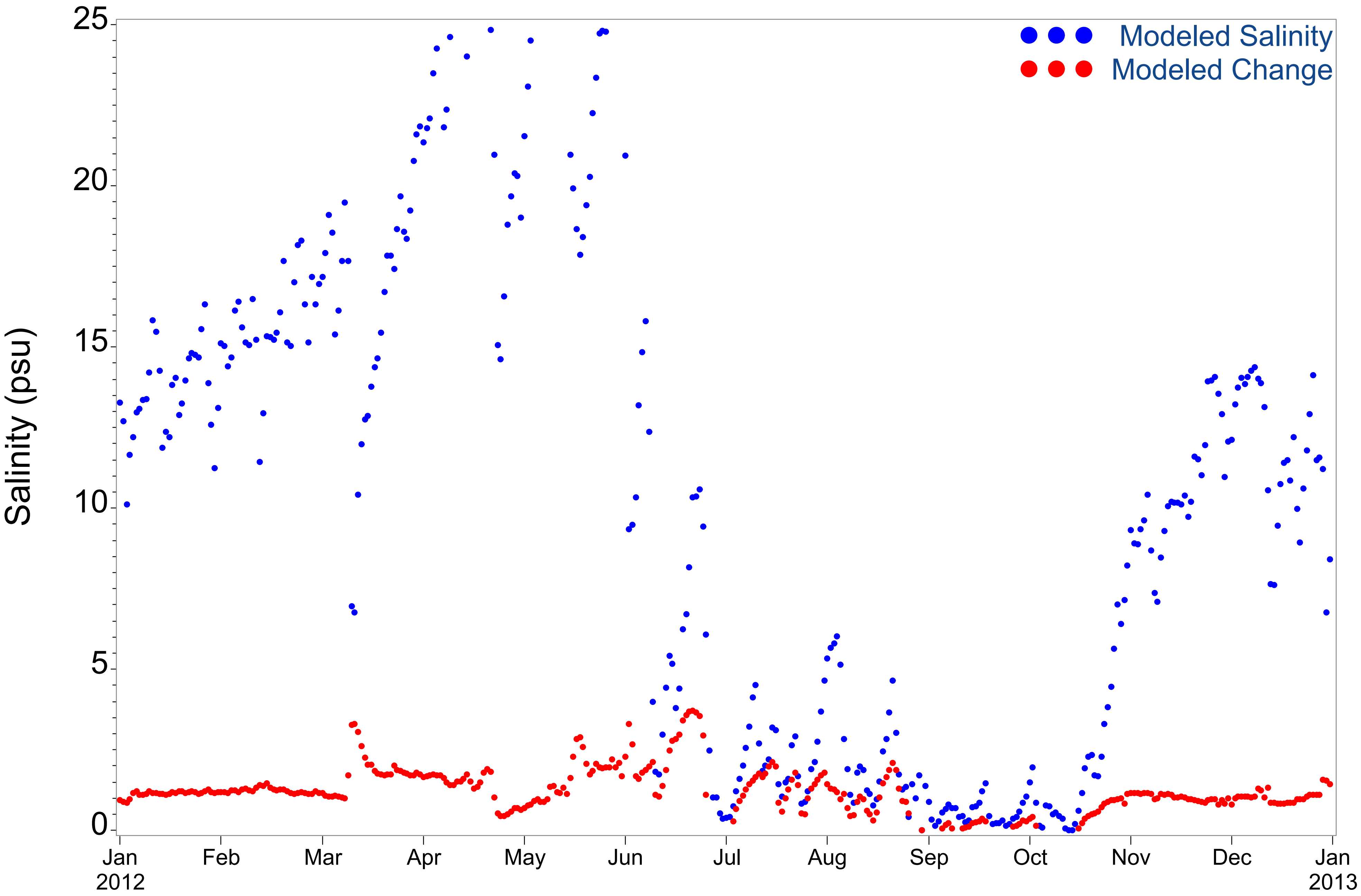
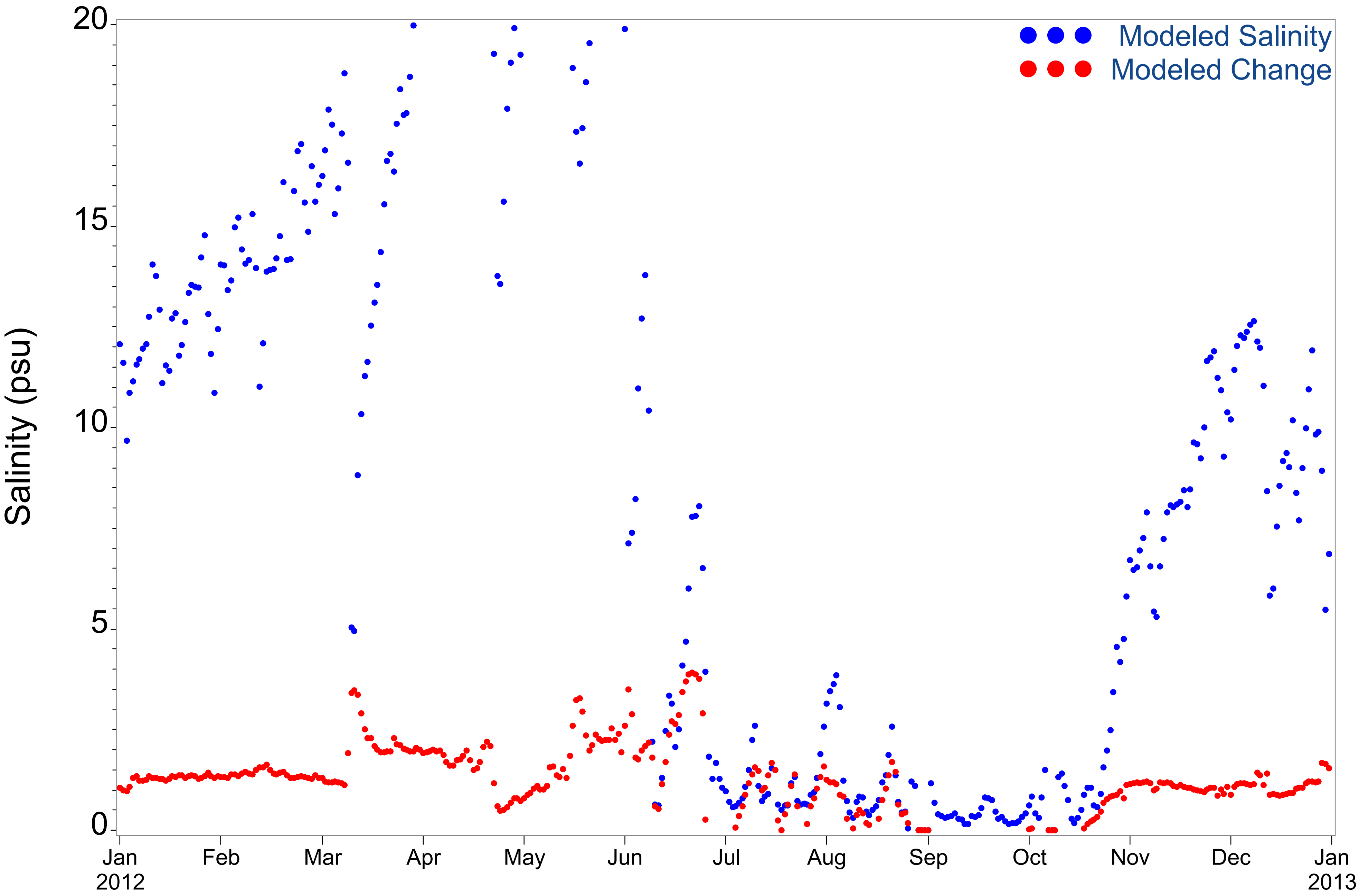


Figure 4.248 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 12.7 (2012)



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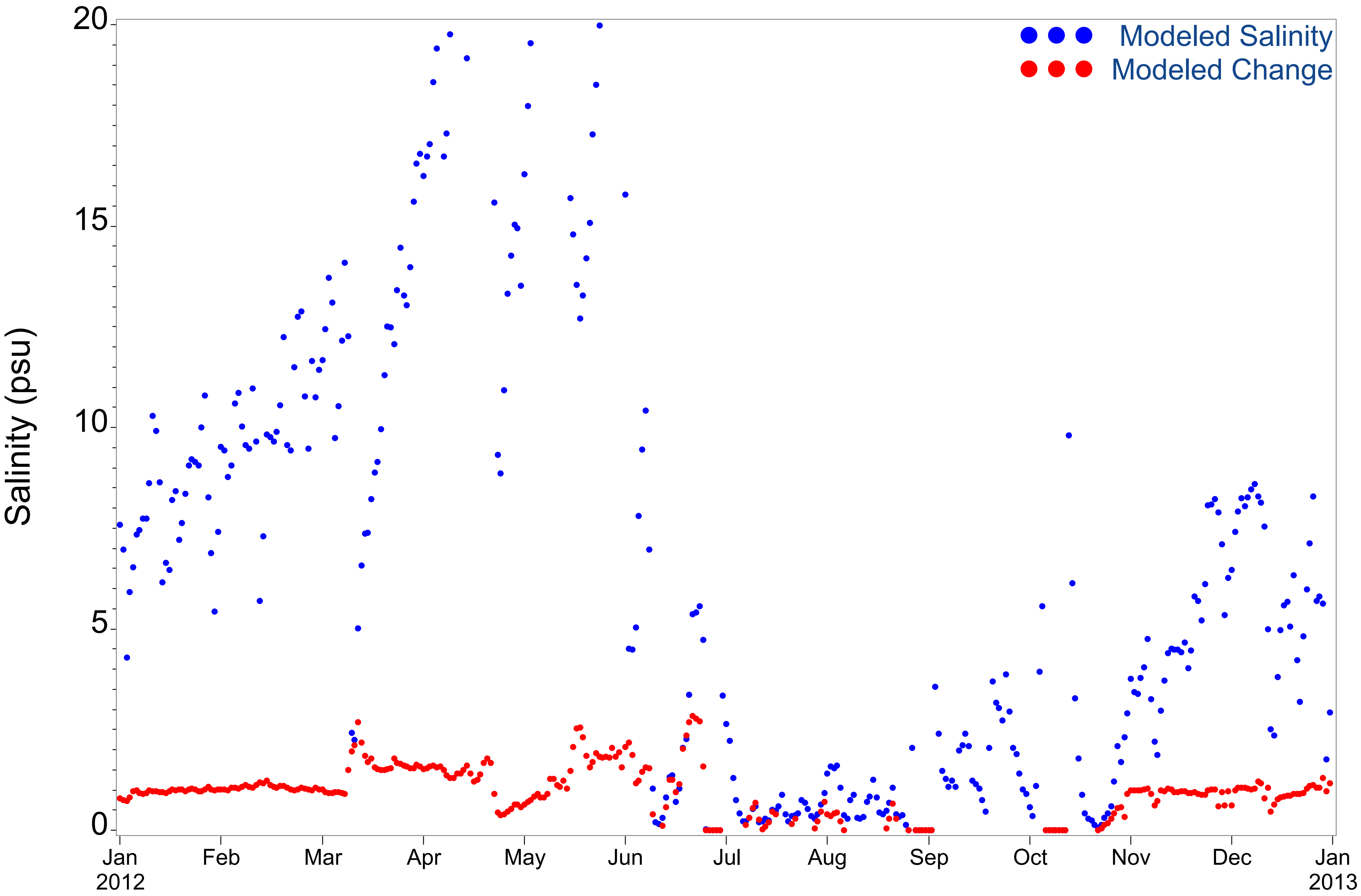

Figure 4.250 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.5 (2012)

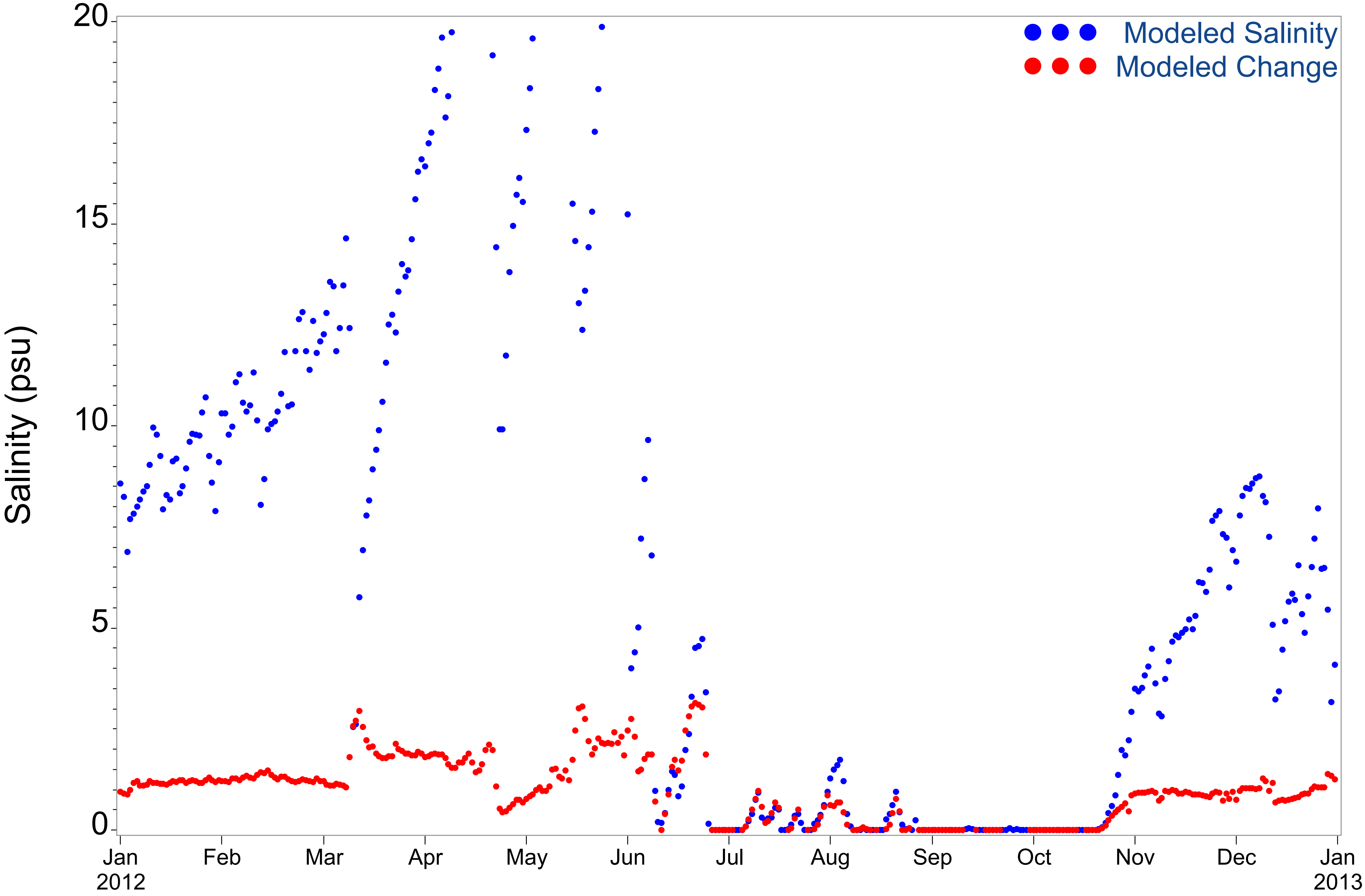

Figure 4.251 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.7 (2012)

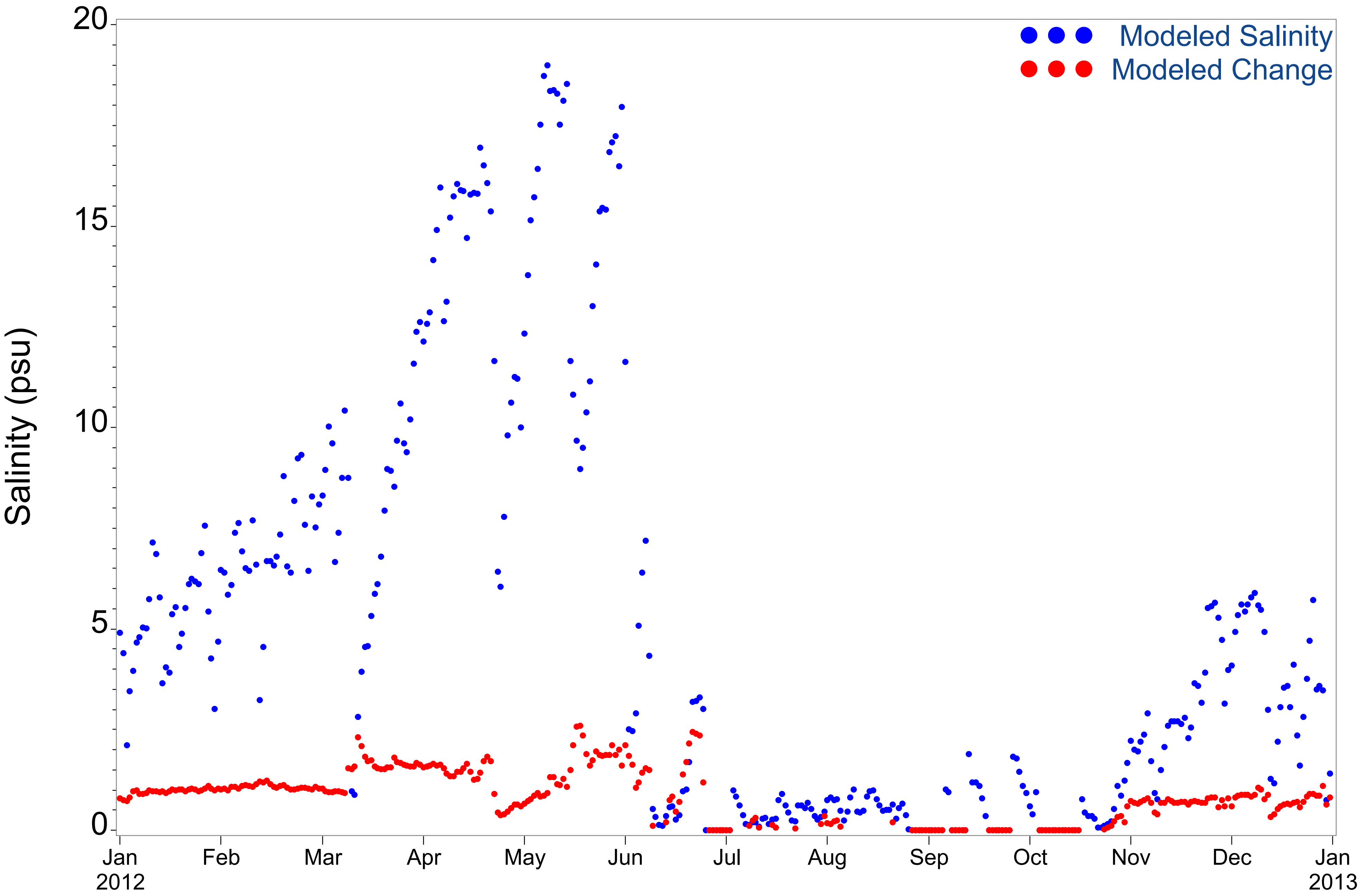

Figure 4.252 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 20.8 (2012)

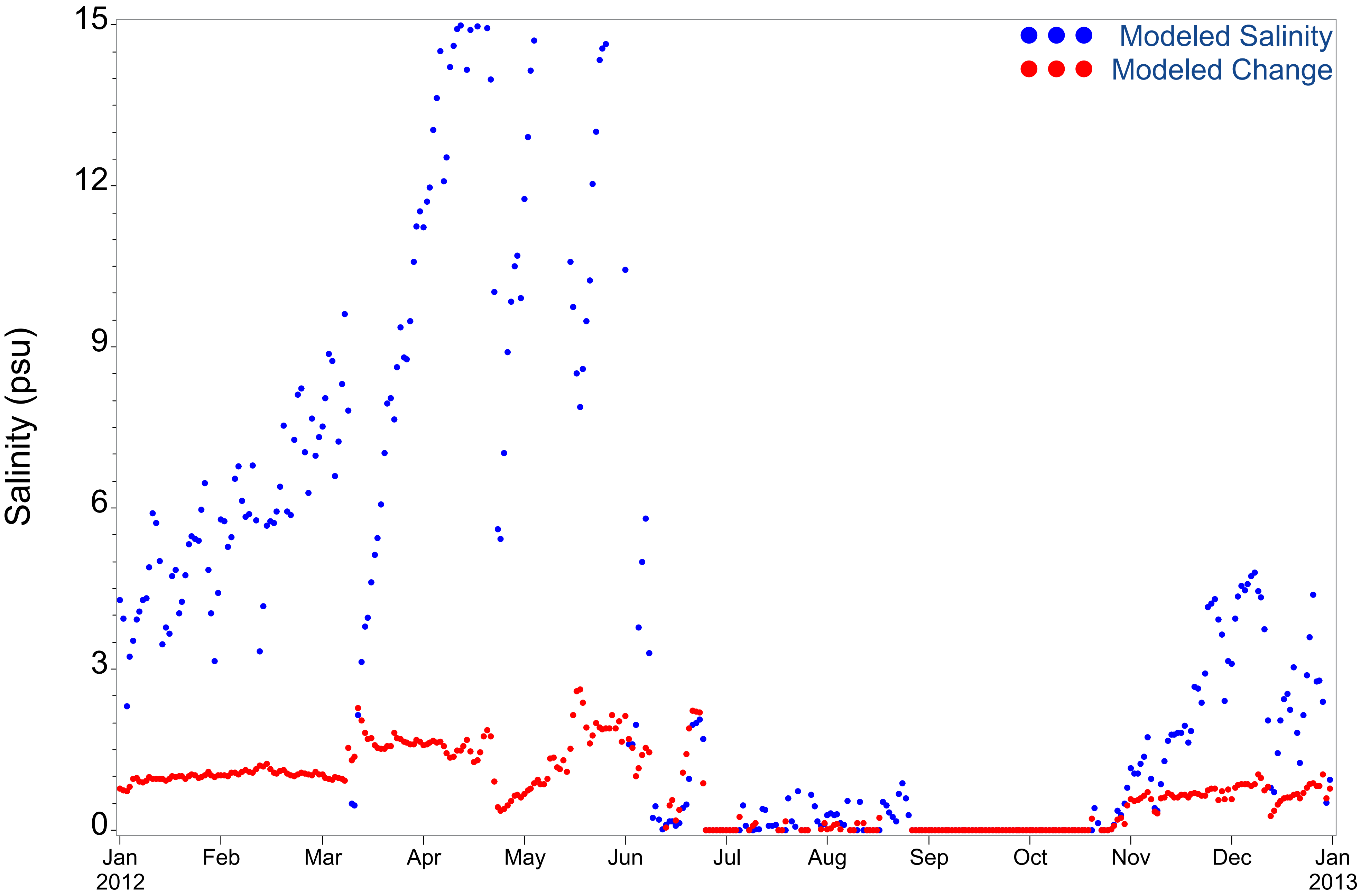

Figure 4.253 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 21.9 (2012)

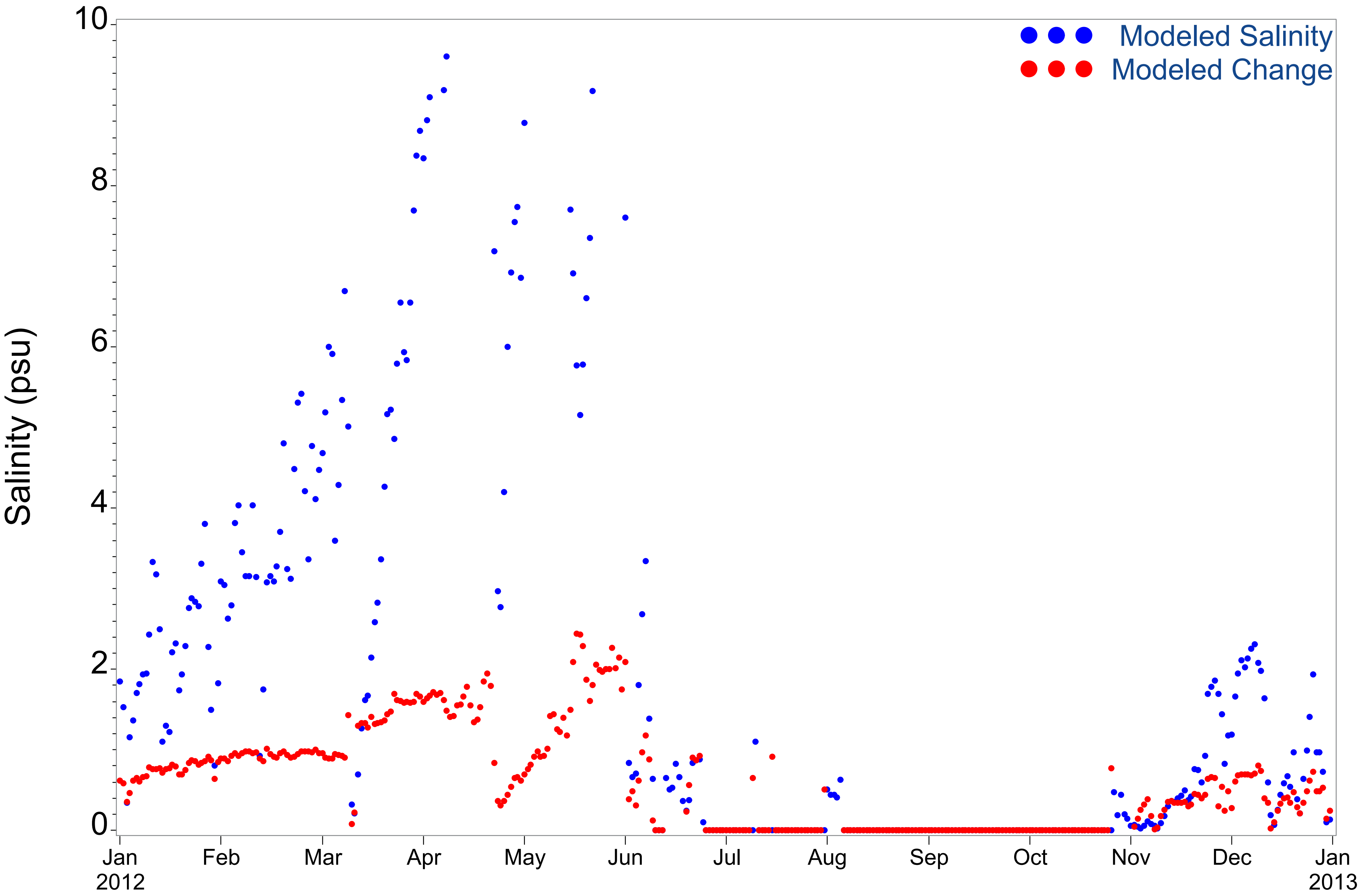

Figure 4.254 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 24.5 (2012)

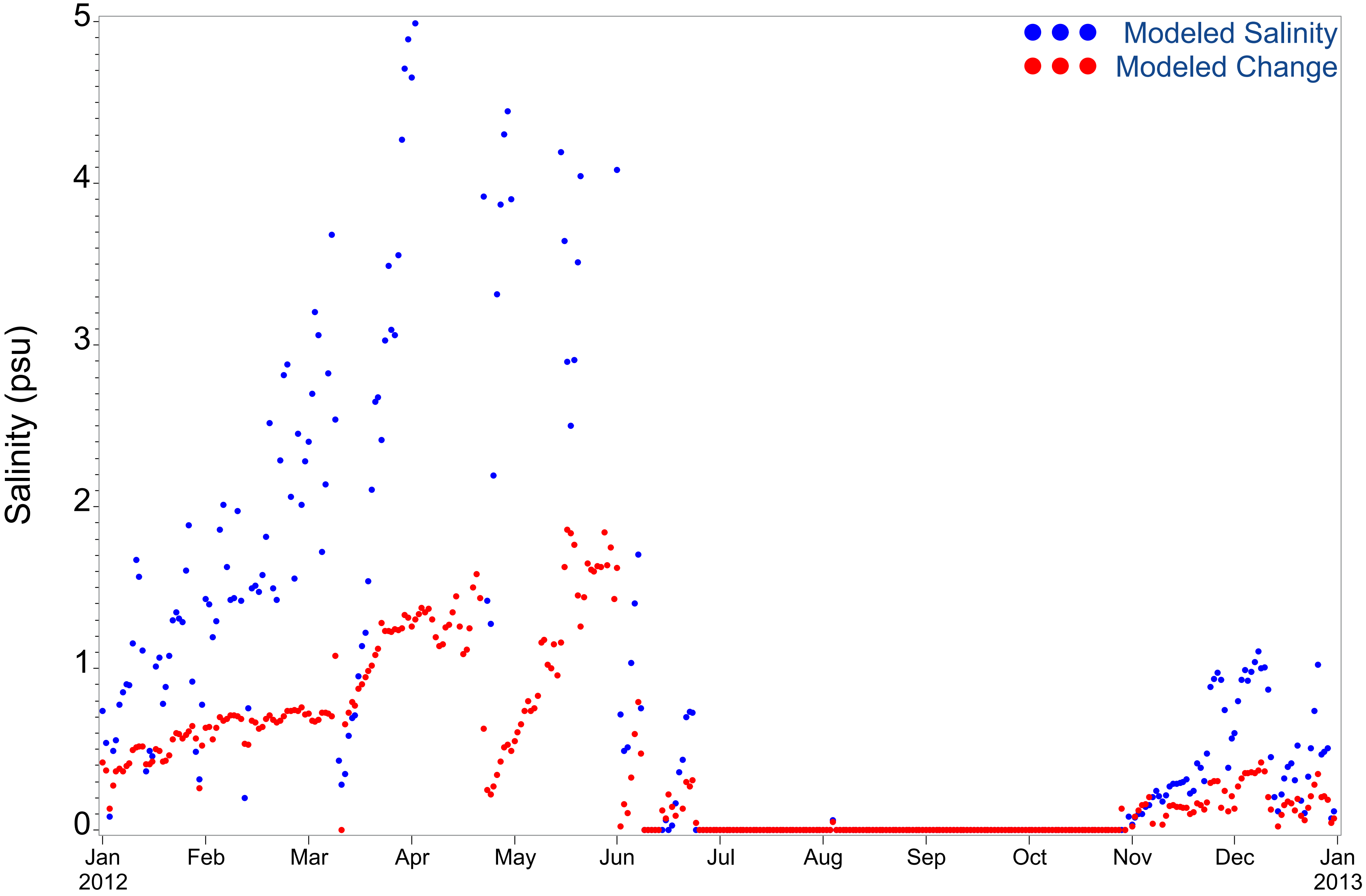

Figure 4.255 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 26.7 (2012)

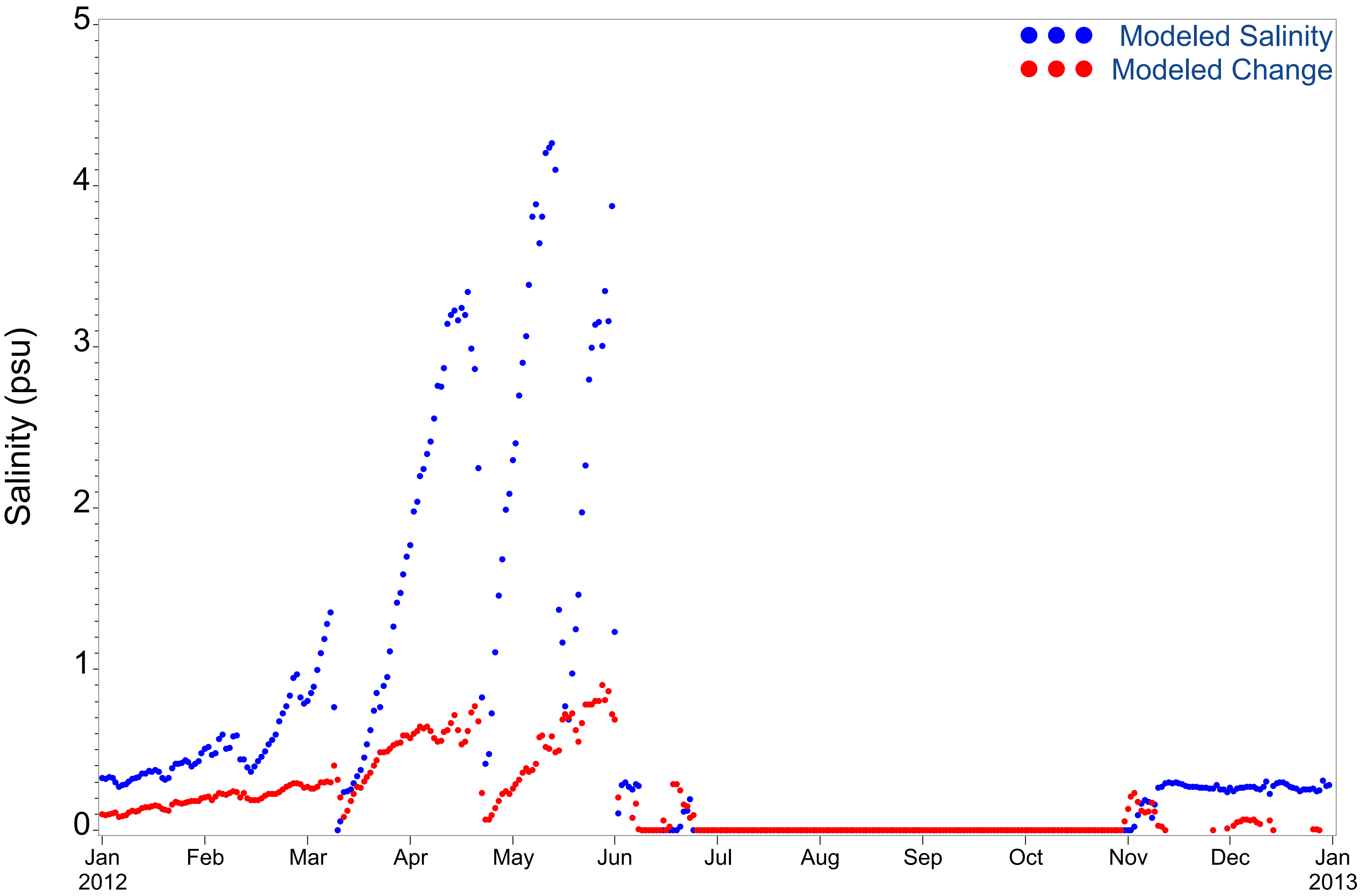

Figure 4.256 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 29.8 (2012)

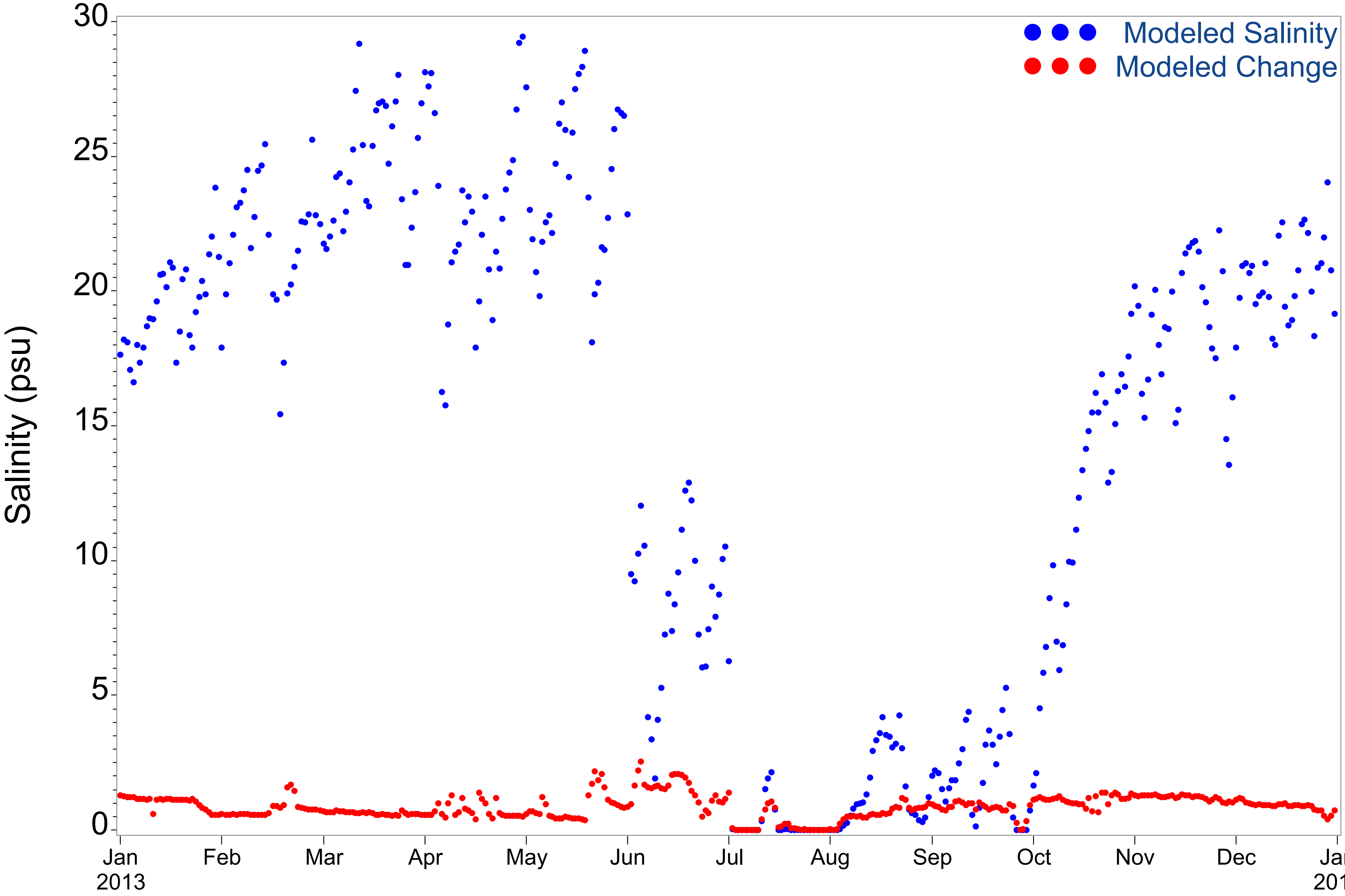

Figure 4.257 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 9.2 (2013)

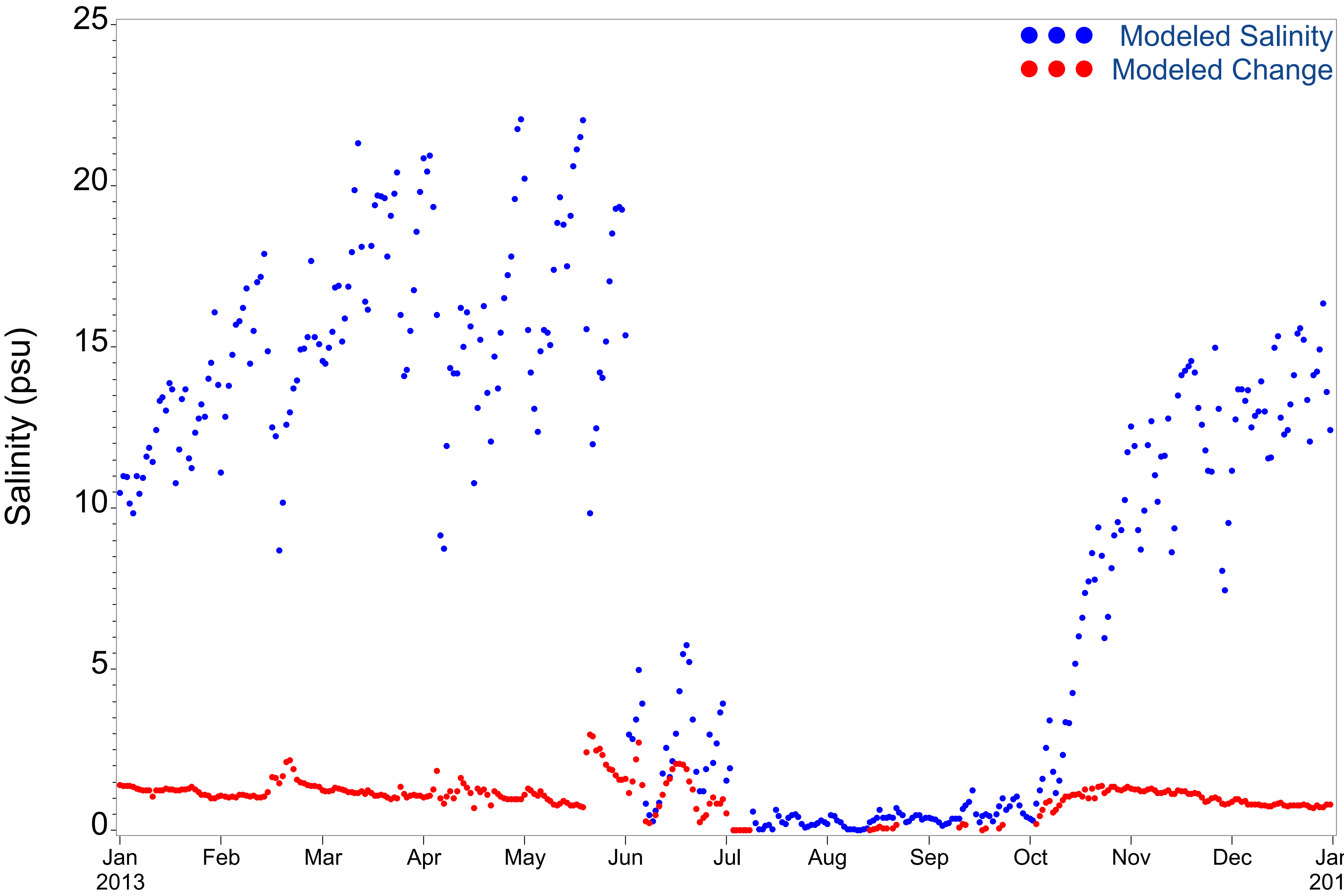

Figure 4.258 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 12.7 (2013)

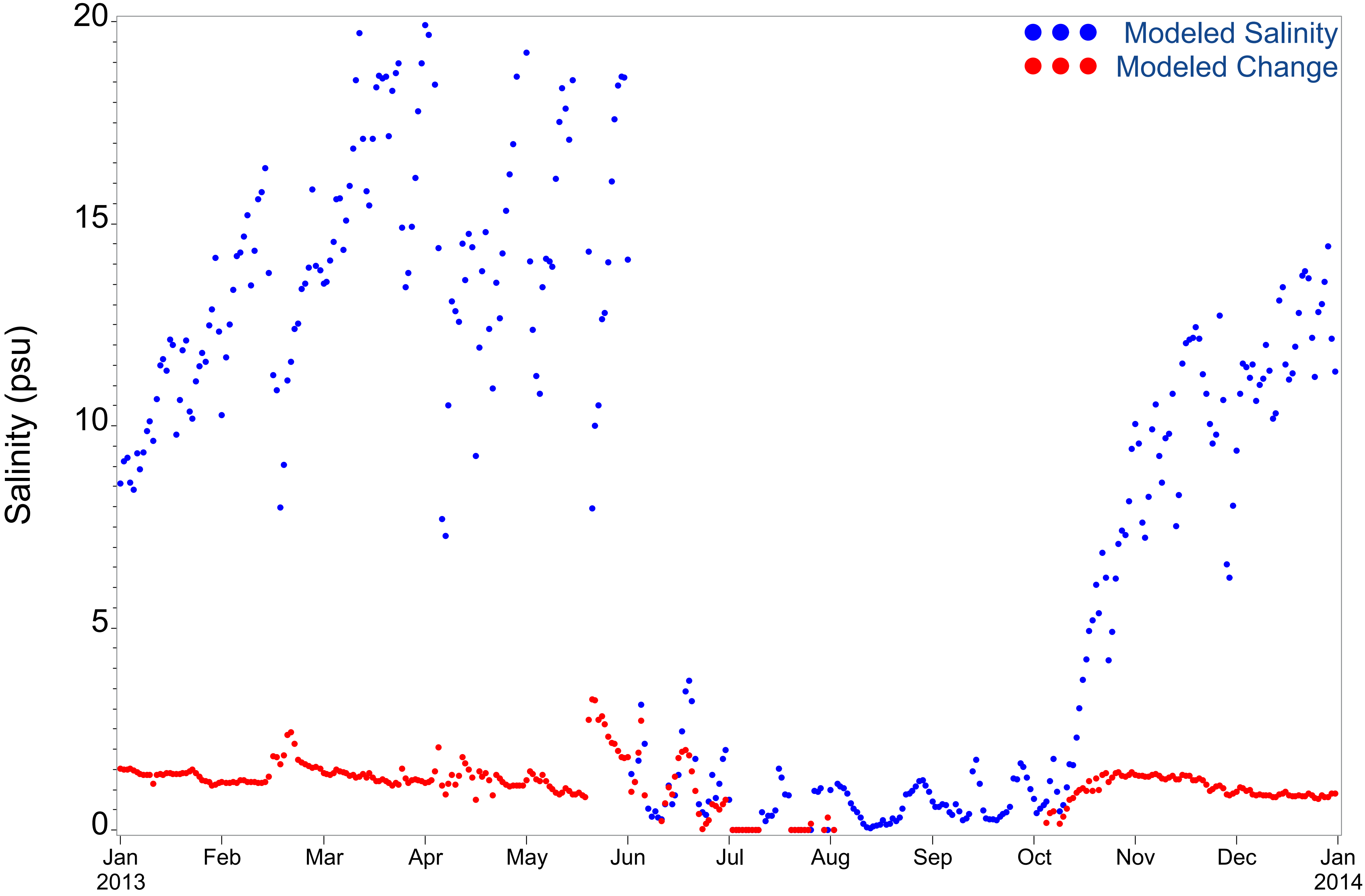

Figure 4.259 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 15.5 (2013)

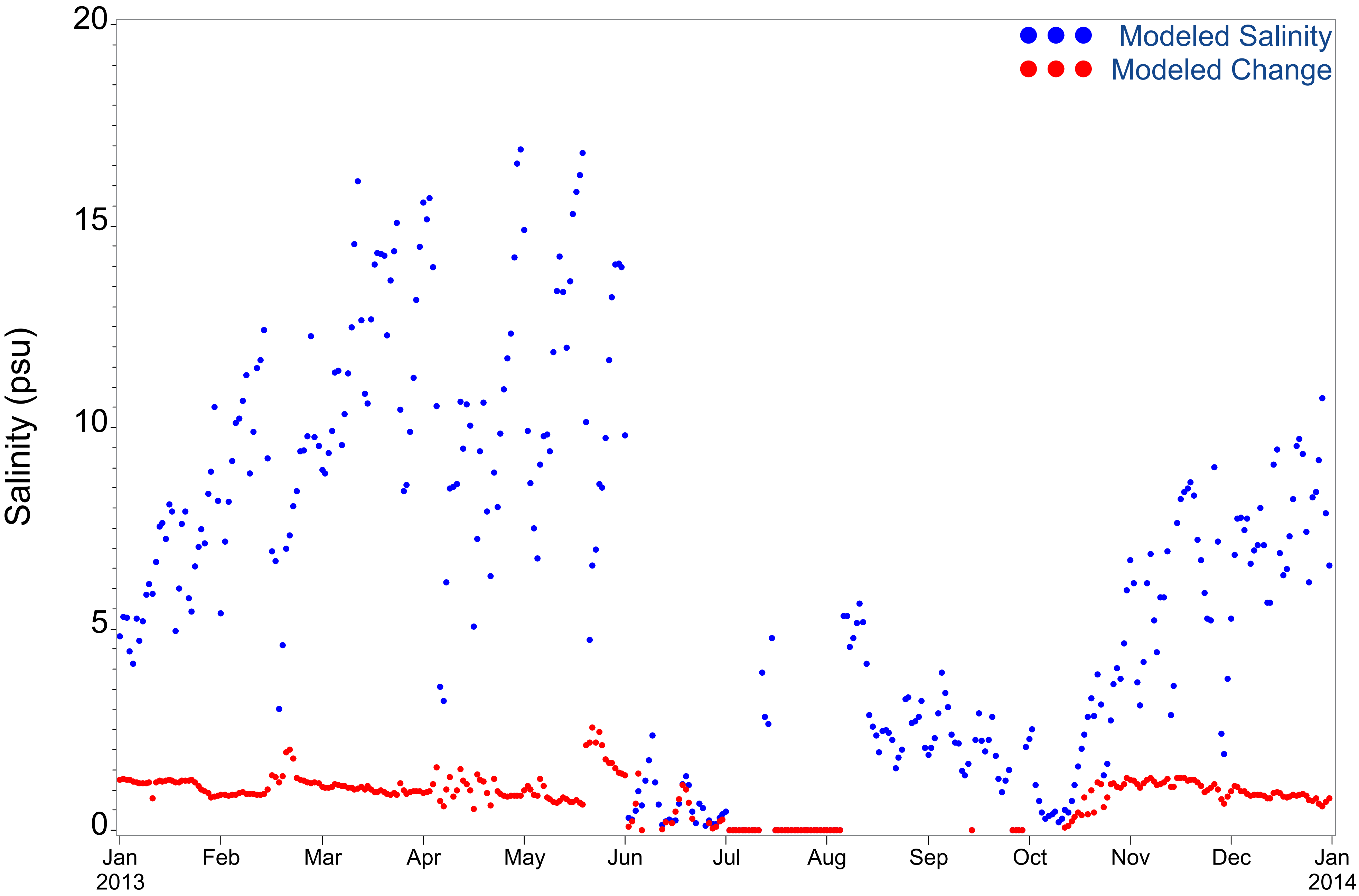

Figure 4.260 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.5 (2013)

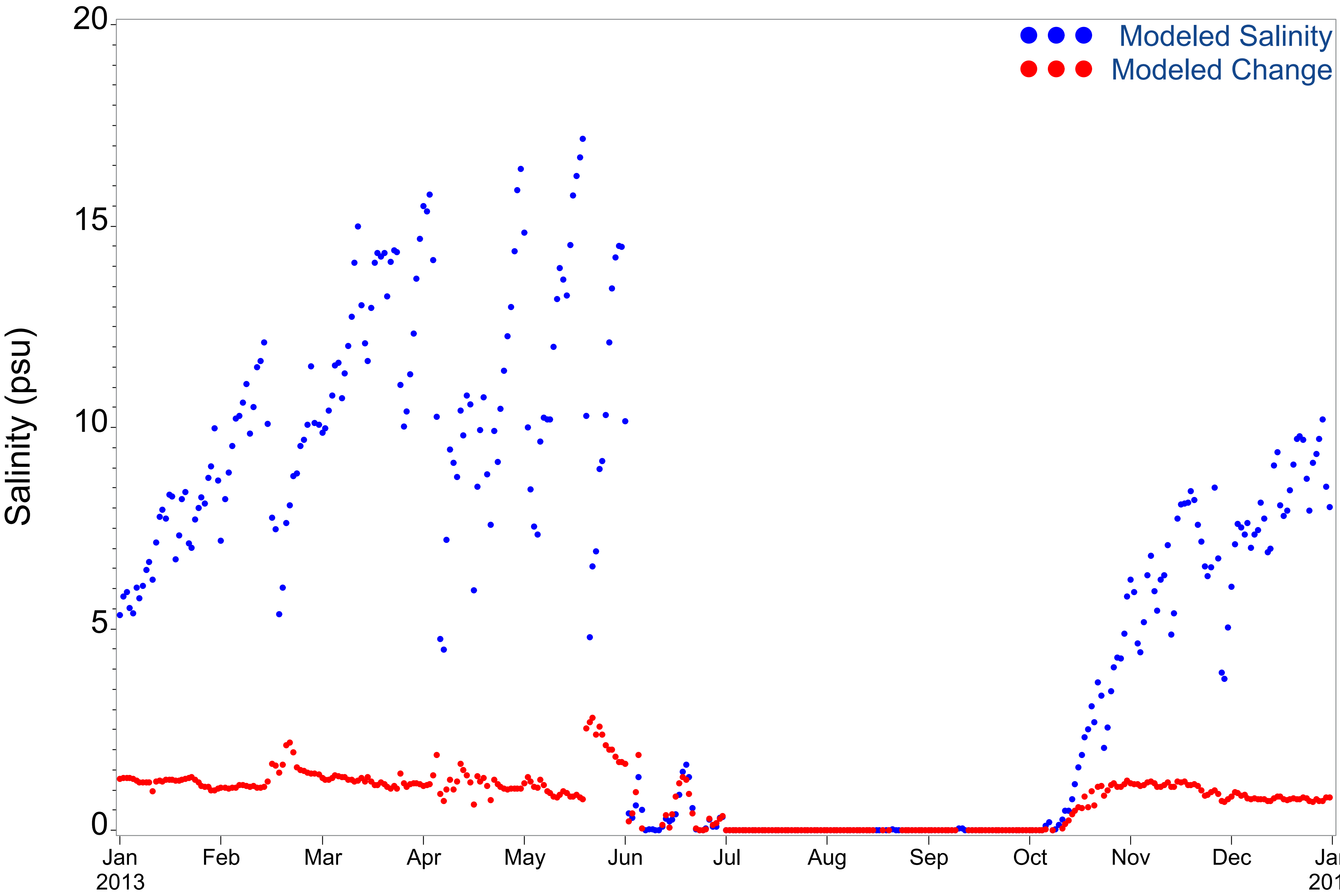

Figure 4.261 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.7 (2013)

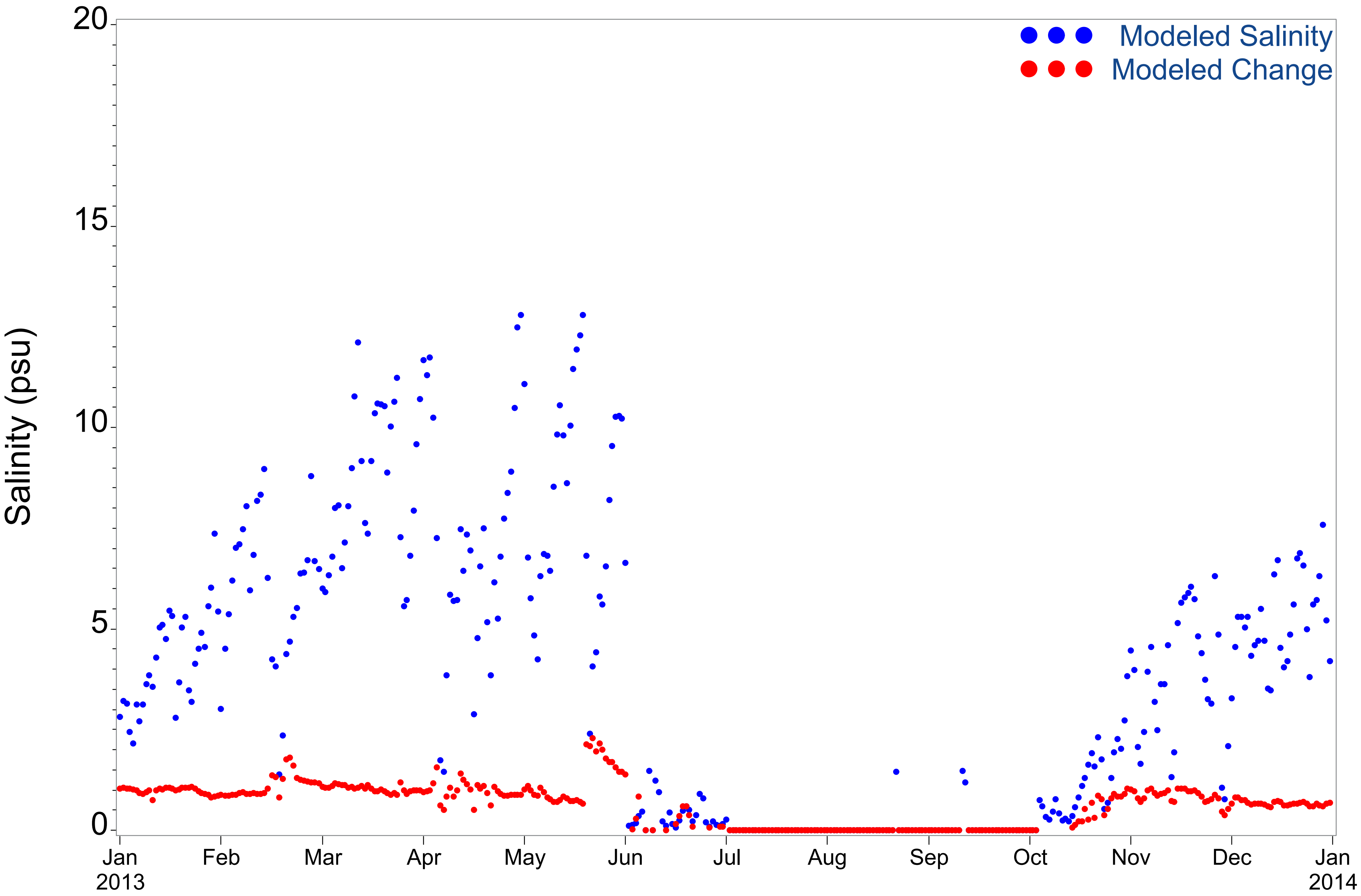

Figure 4.262 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 20.8 (2013)

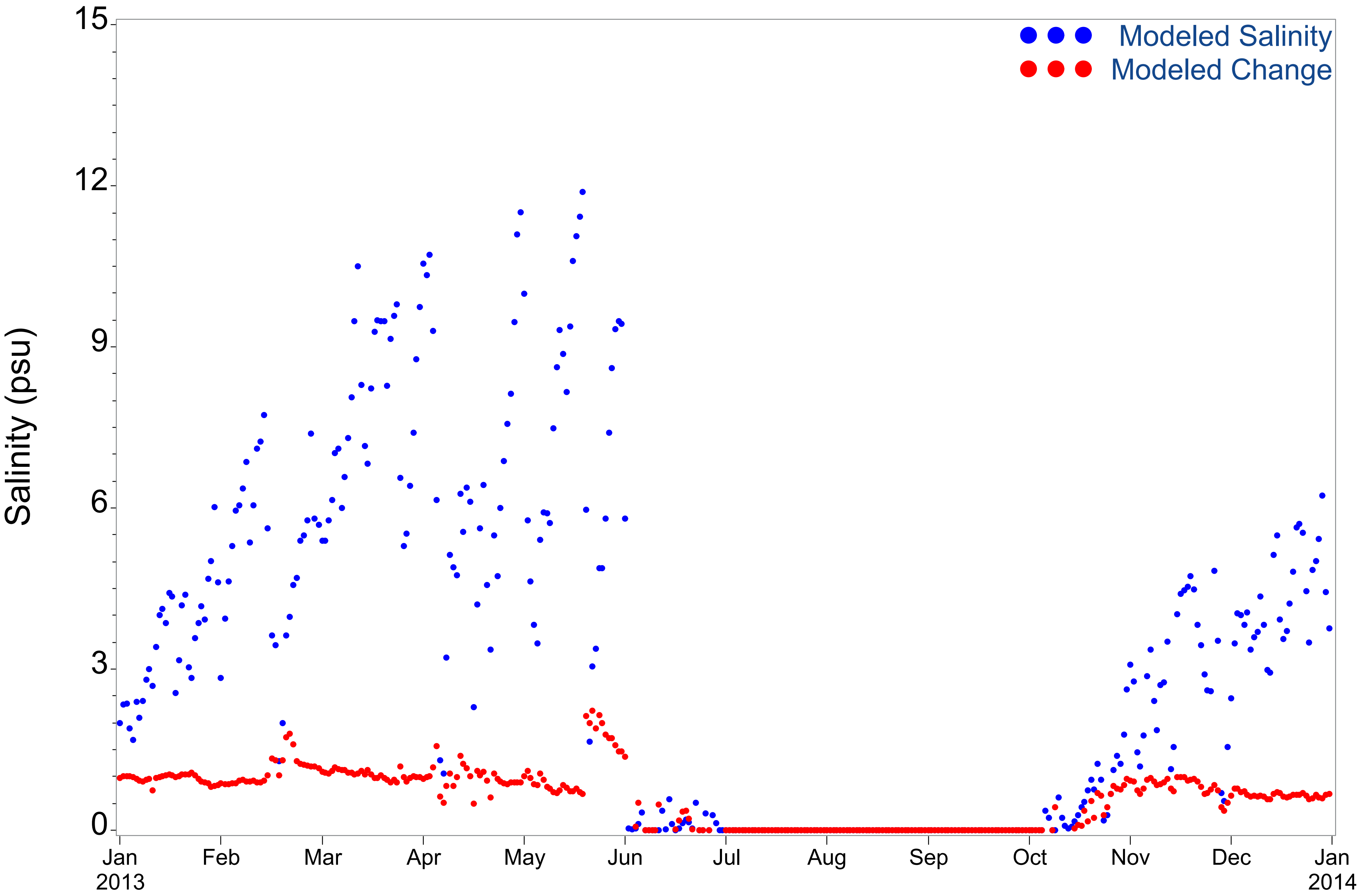

Figure 4.263 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 21.9 (2013)

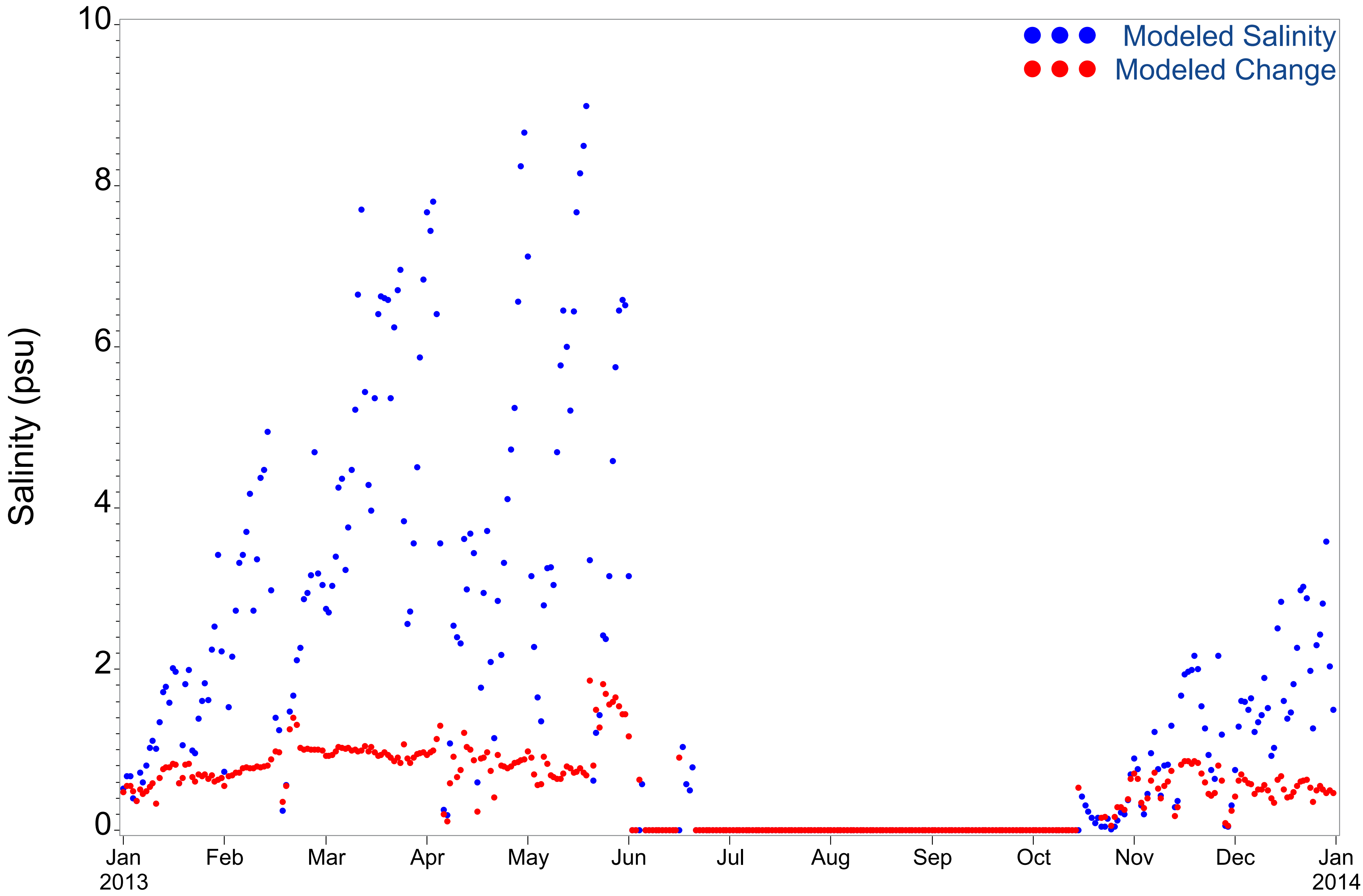

Figure 4.264 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 24.5 (2013)

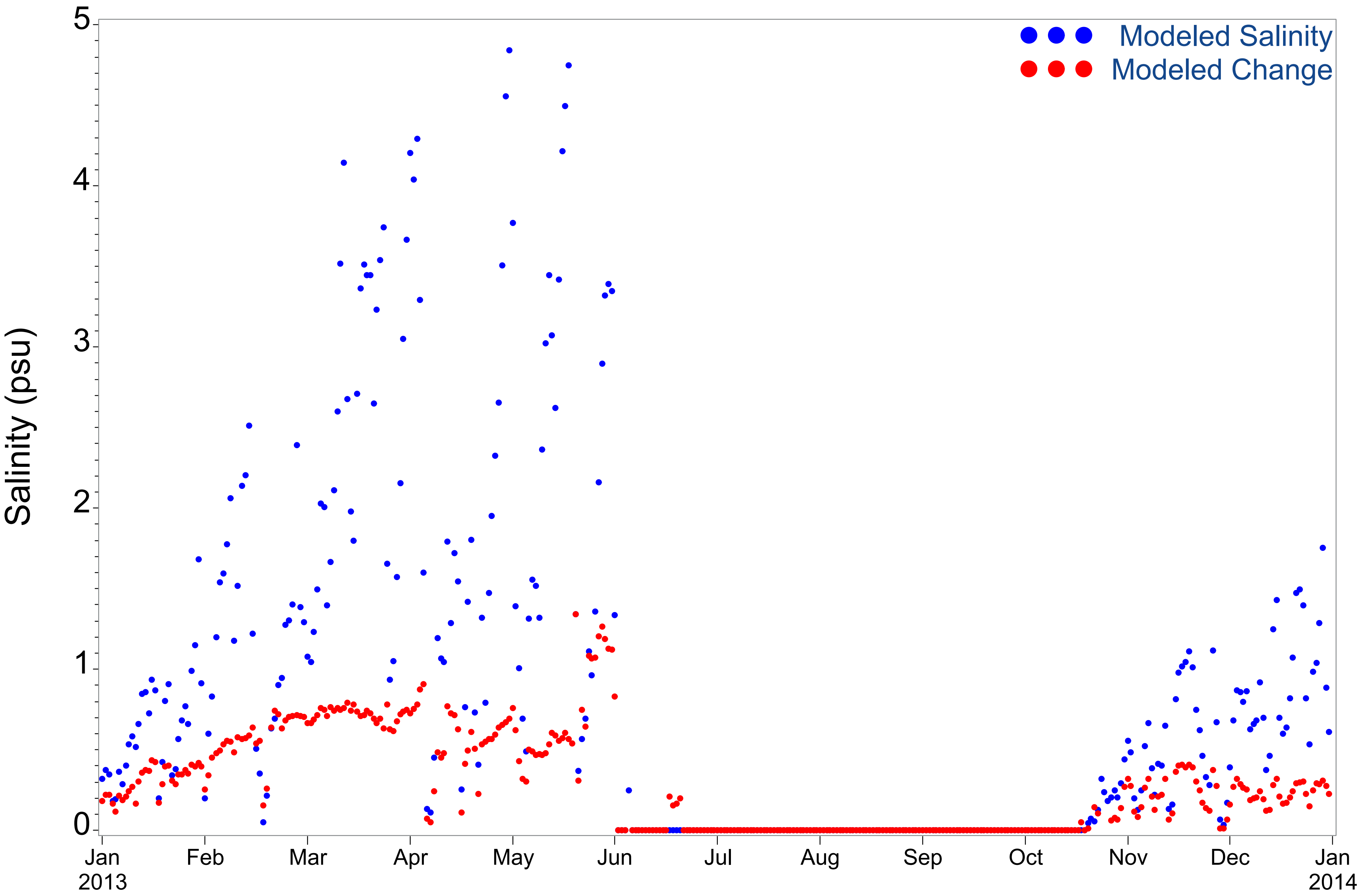

Figure 4.265 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 26.7 (2013)

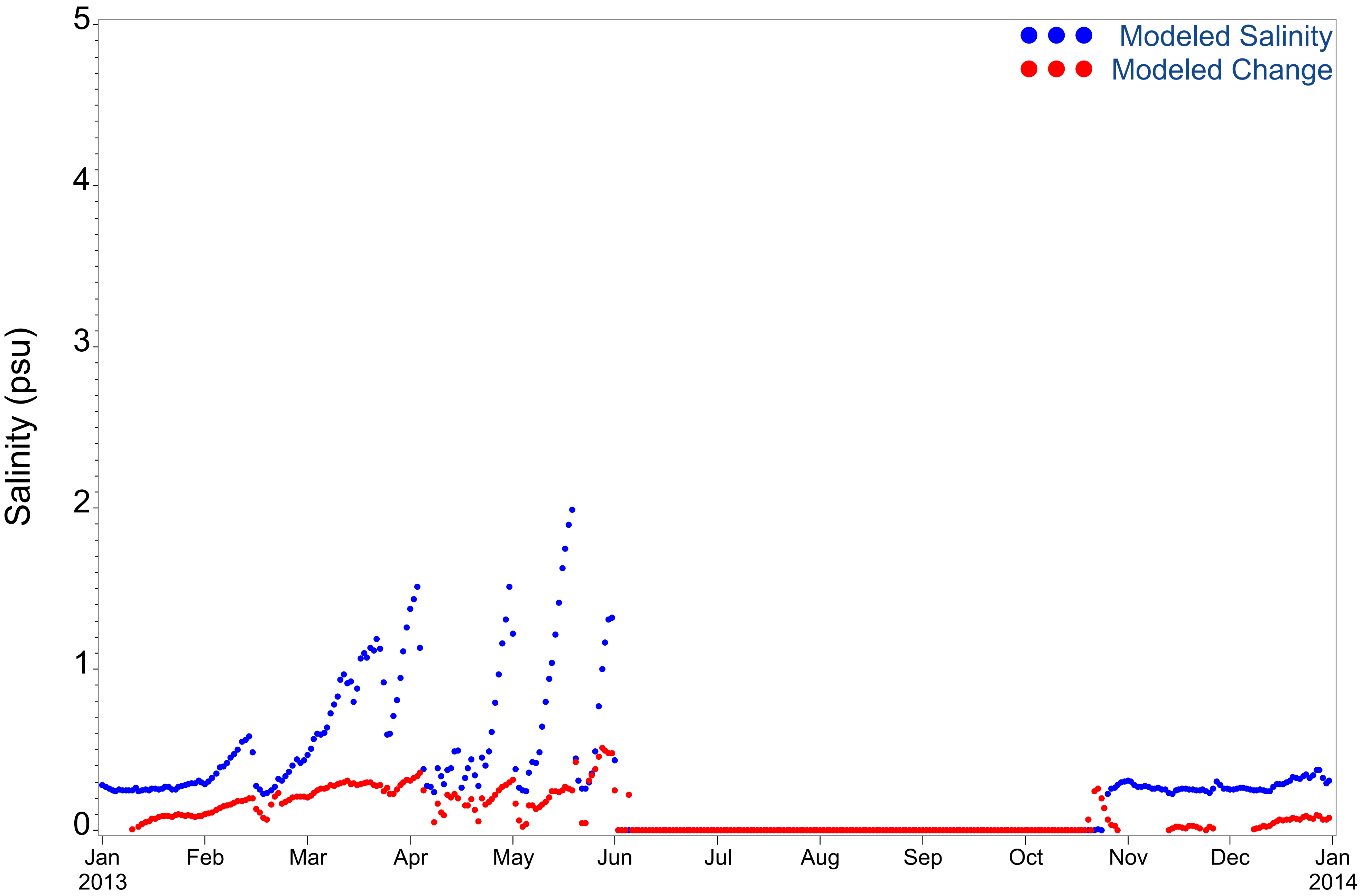

Figure 4.266 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 29.8 (2013)

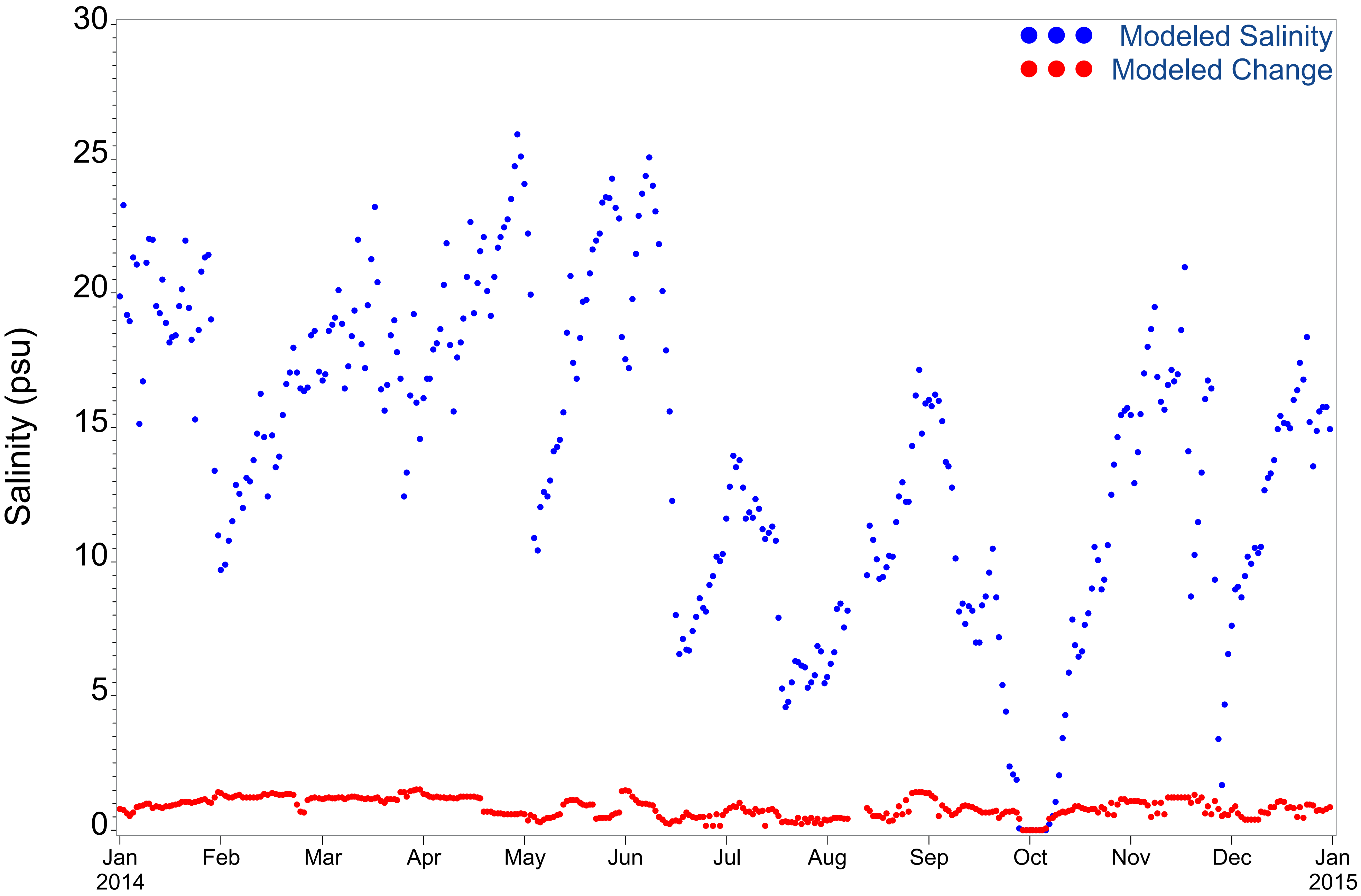

Figure 4.267 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 9.2 (2014)

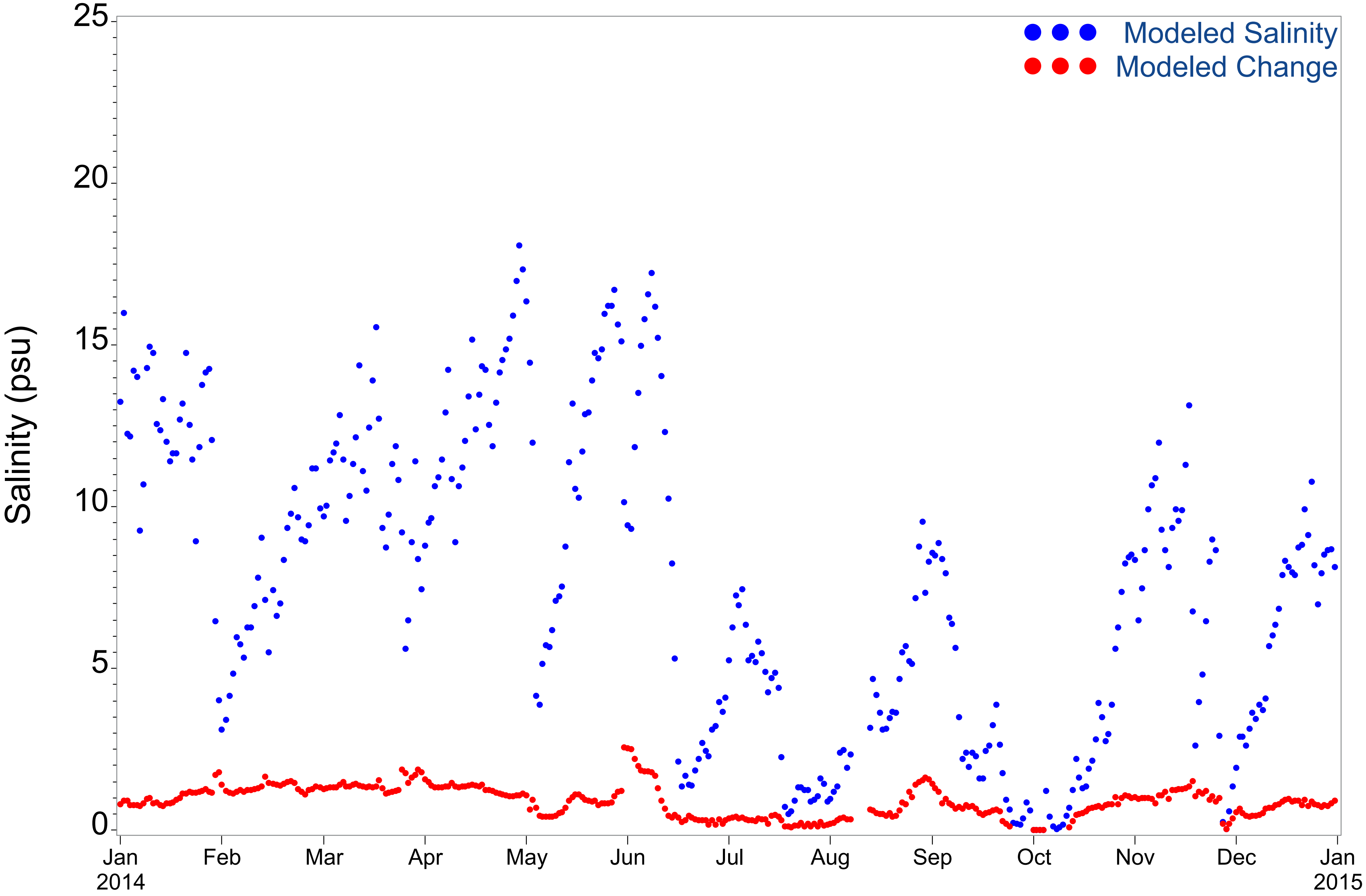

Figure 4.268 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 12.7 (2014)

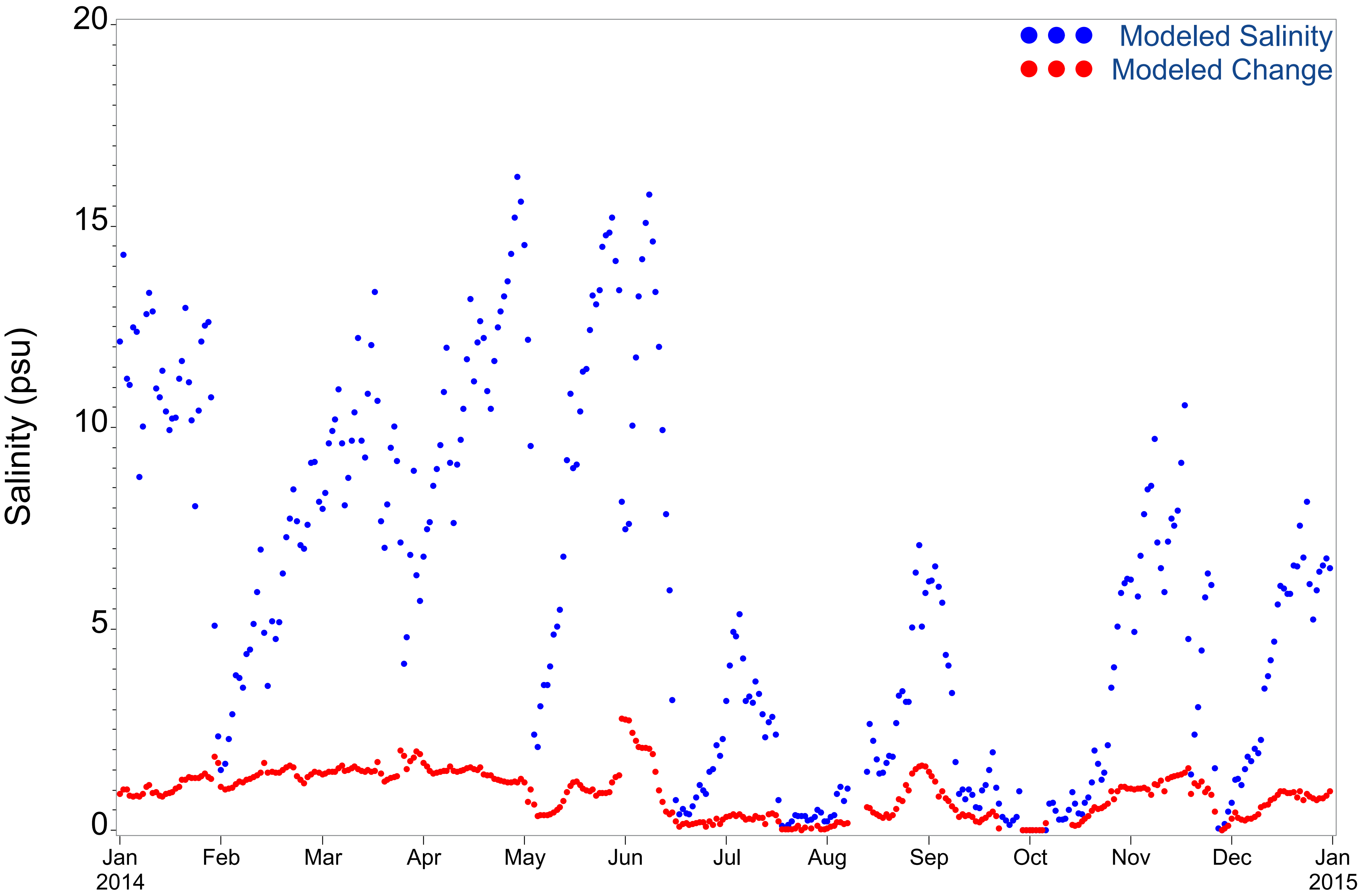

Figure 4.269 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 15.5 (2014)

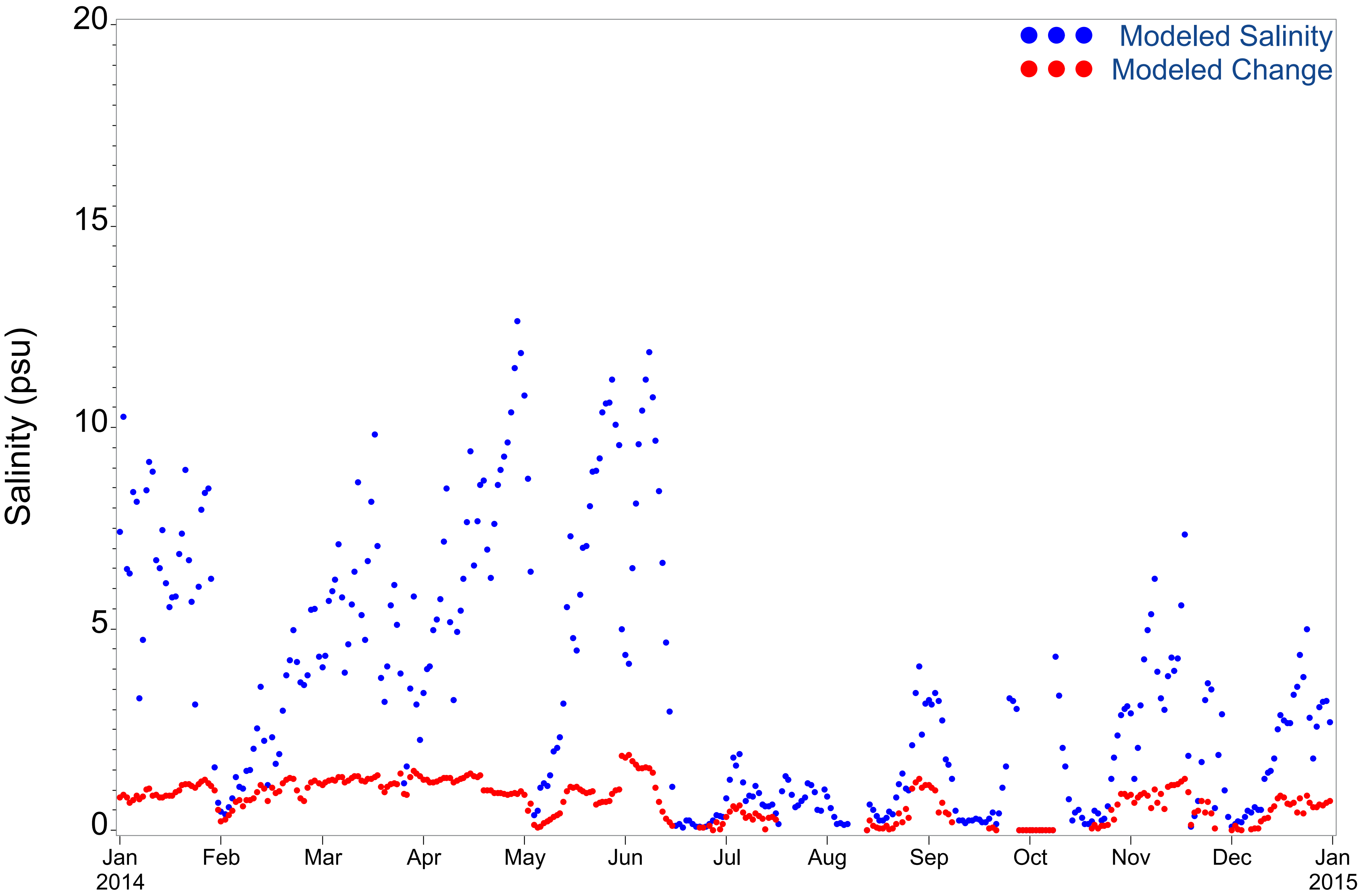

Figure 4.270 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.5 (2014)

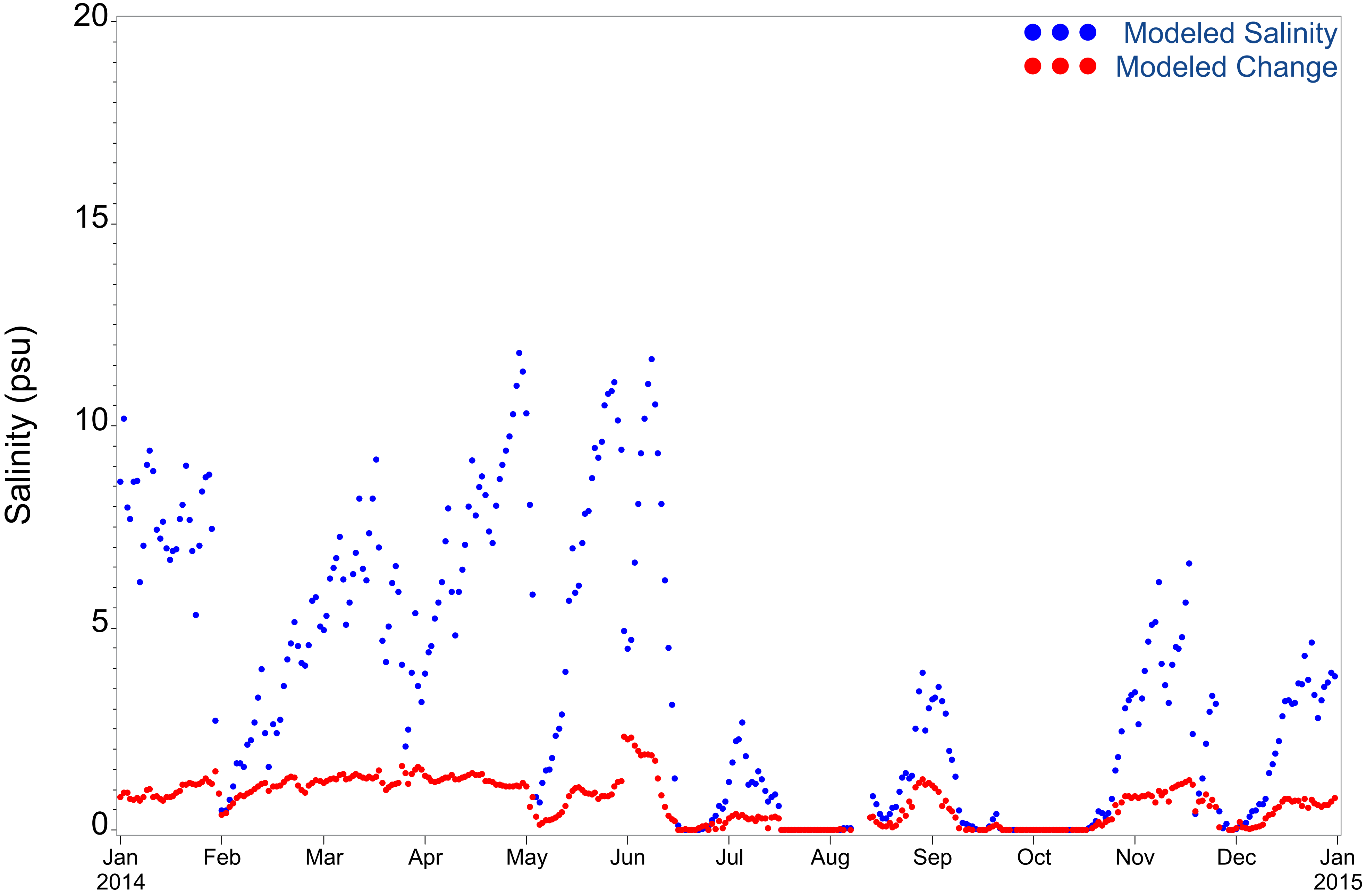

Figure 4.271 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.7 (2014)

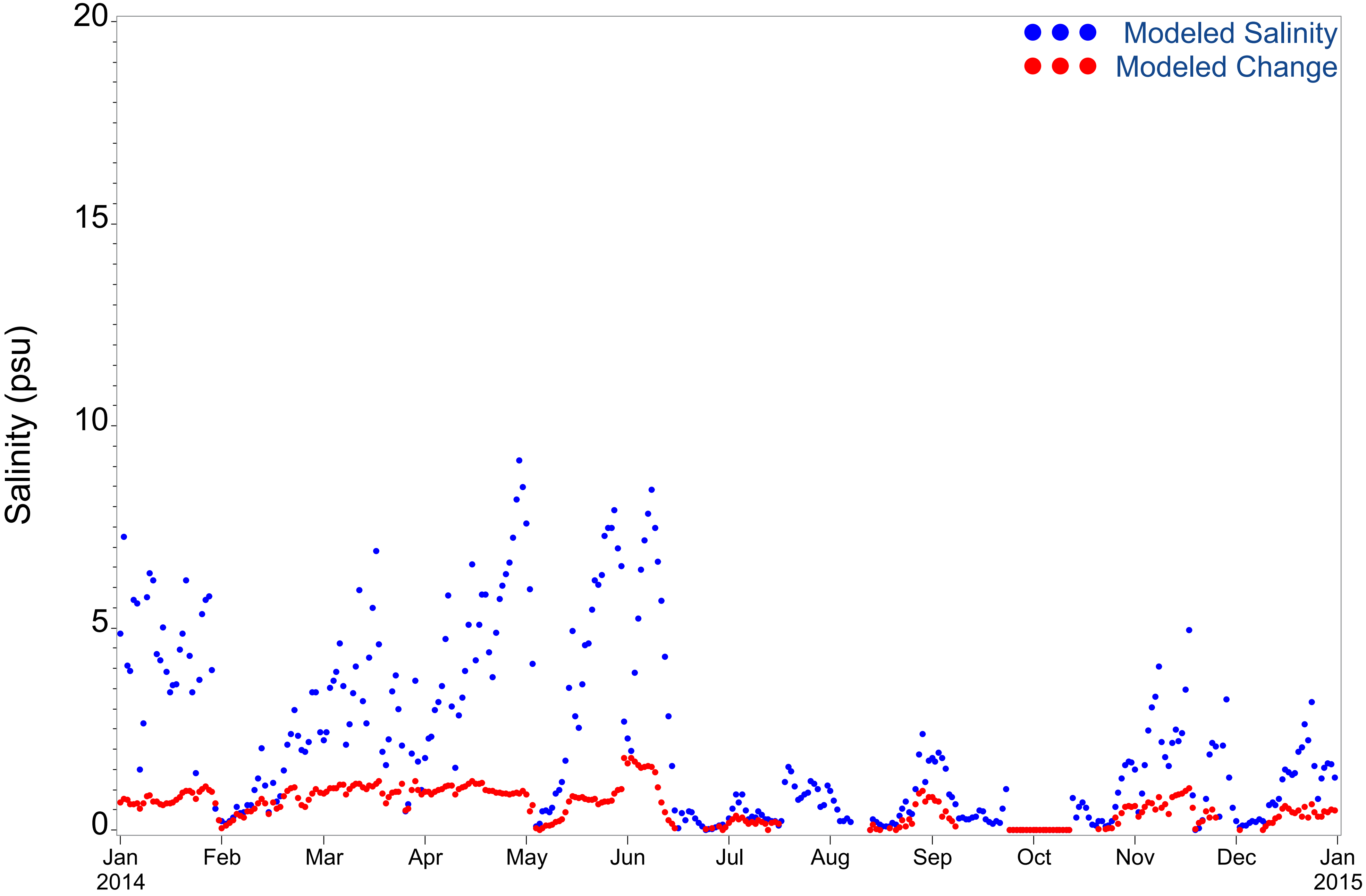

Figure 4.272 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 20.8 (2014)

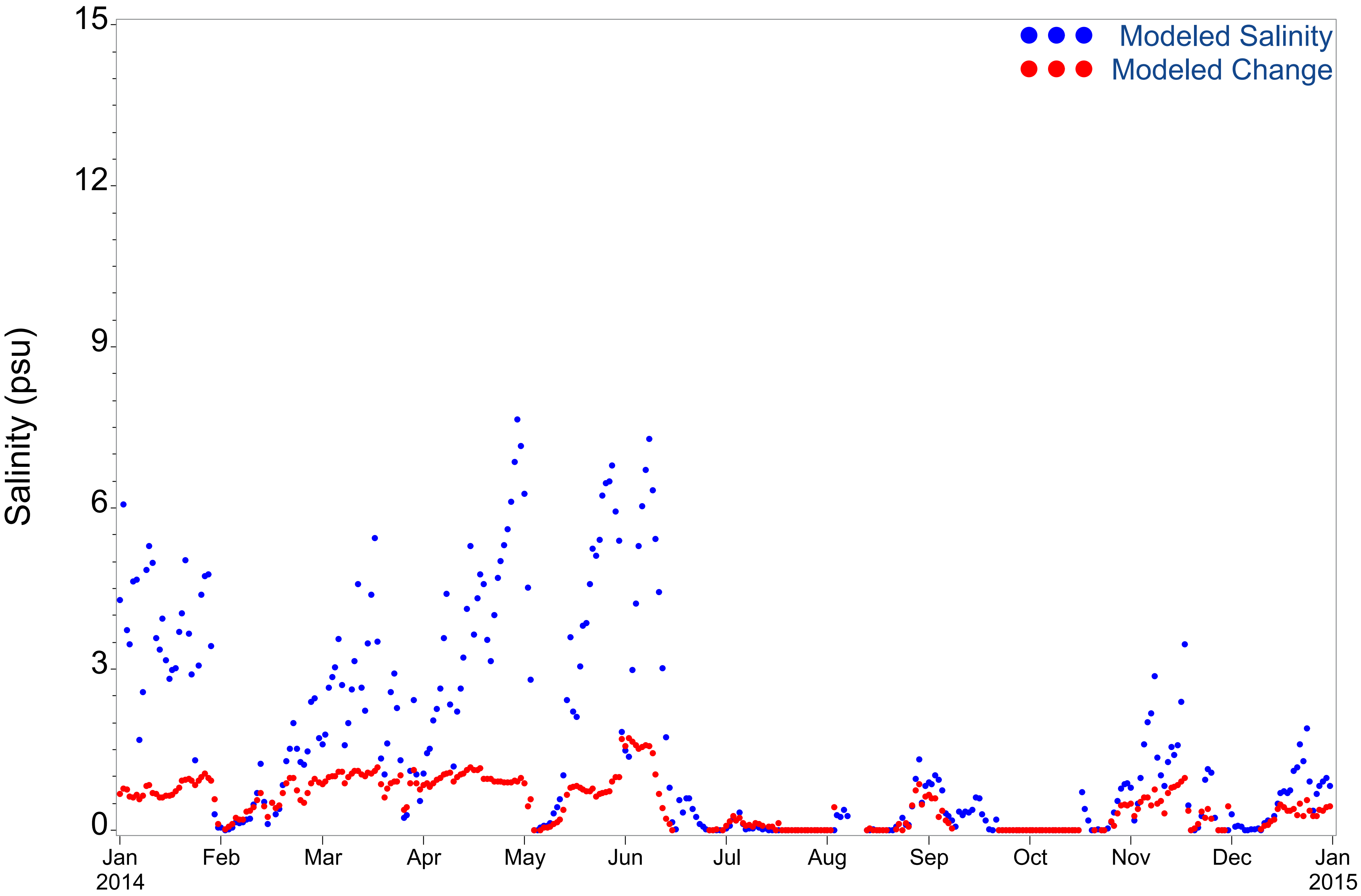

Figure 4.273 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 21.9 (2014)

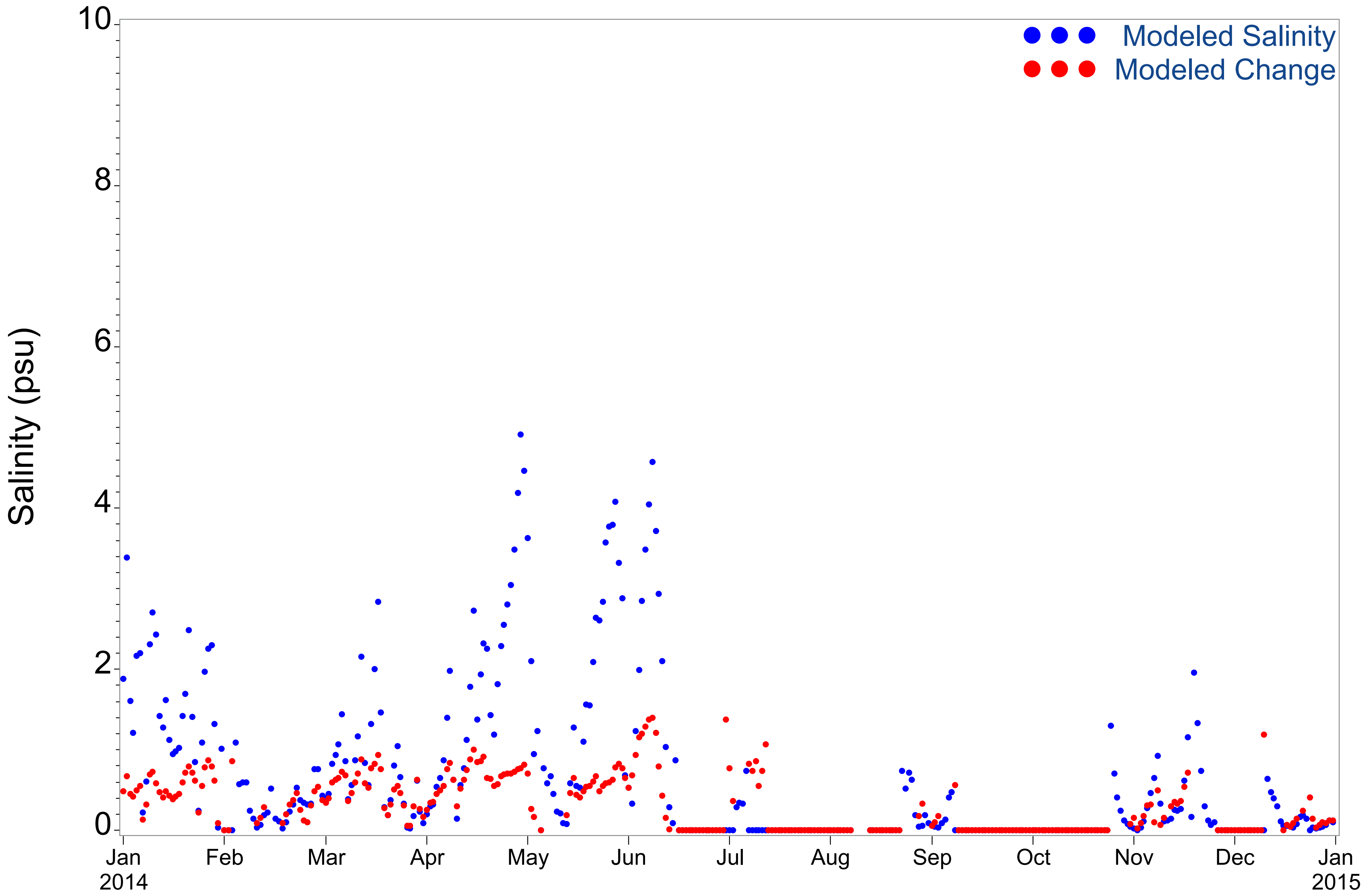

Figure 4.274 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 24.5 (2014)

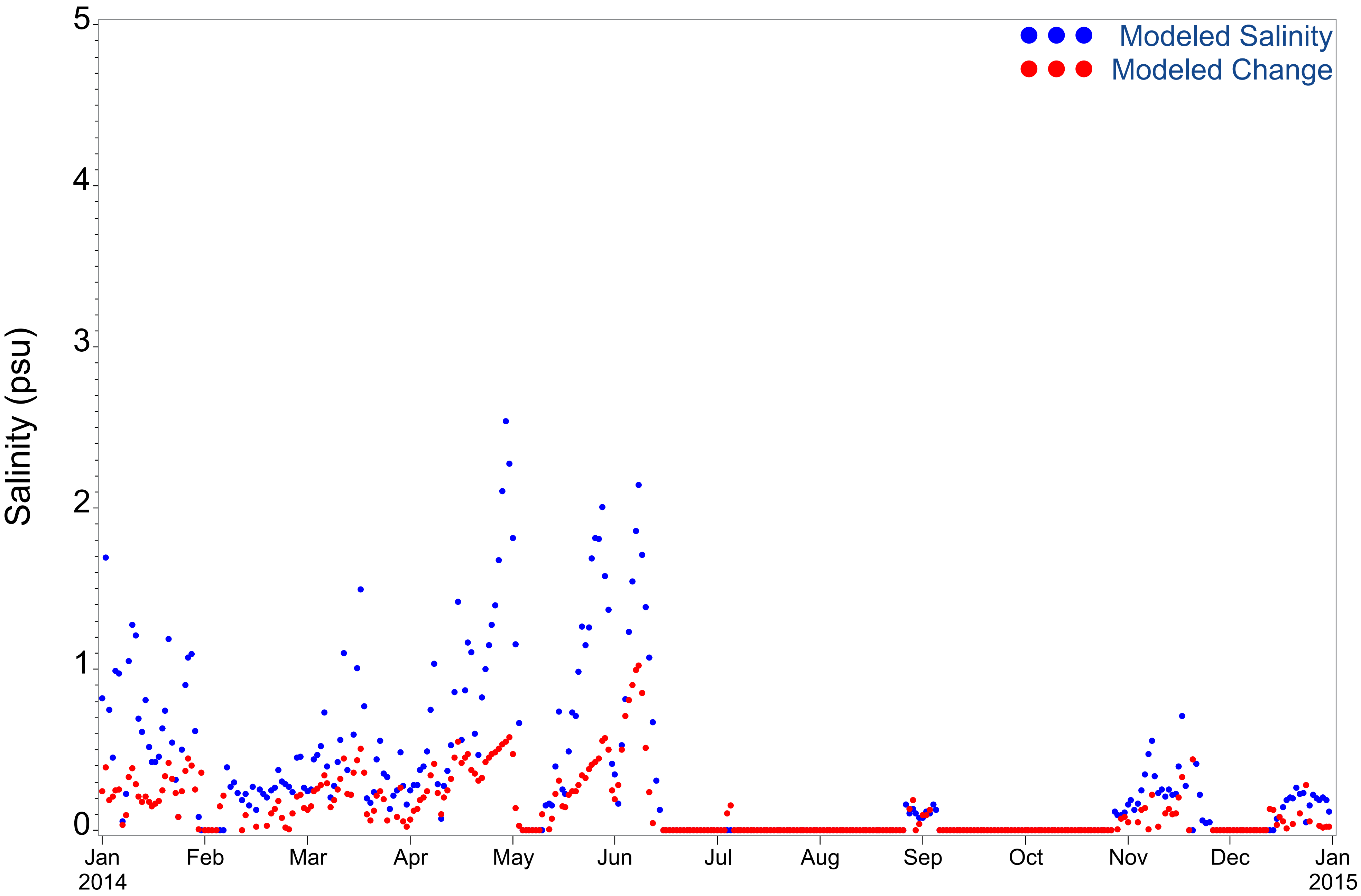

Figure 4.275 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 26.7 (2014)

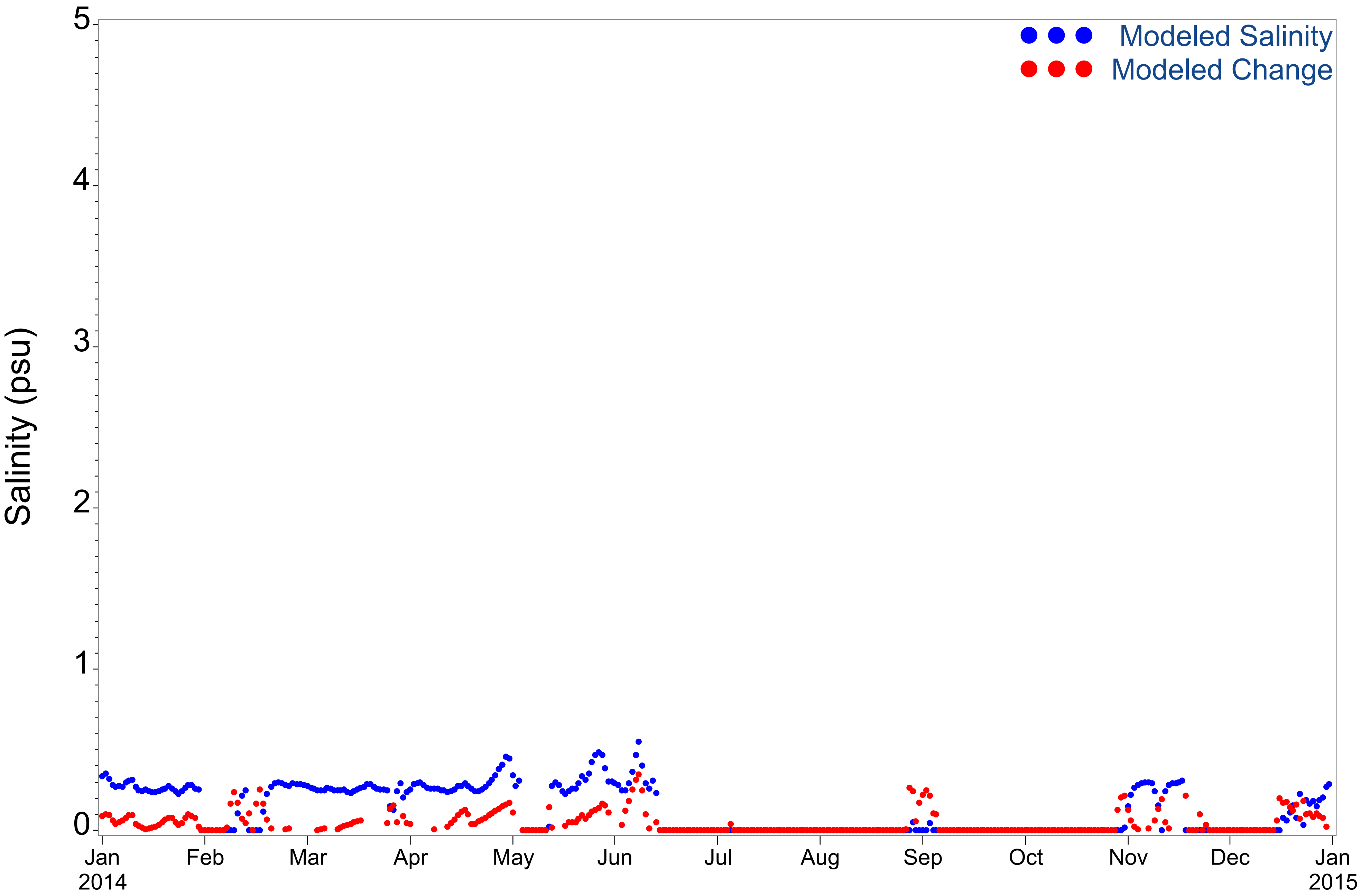

Figure 4.276 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 29.8 (2014)

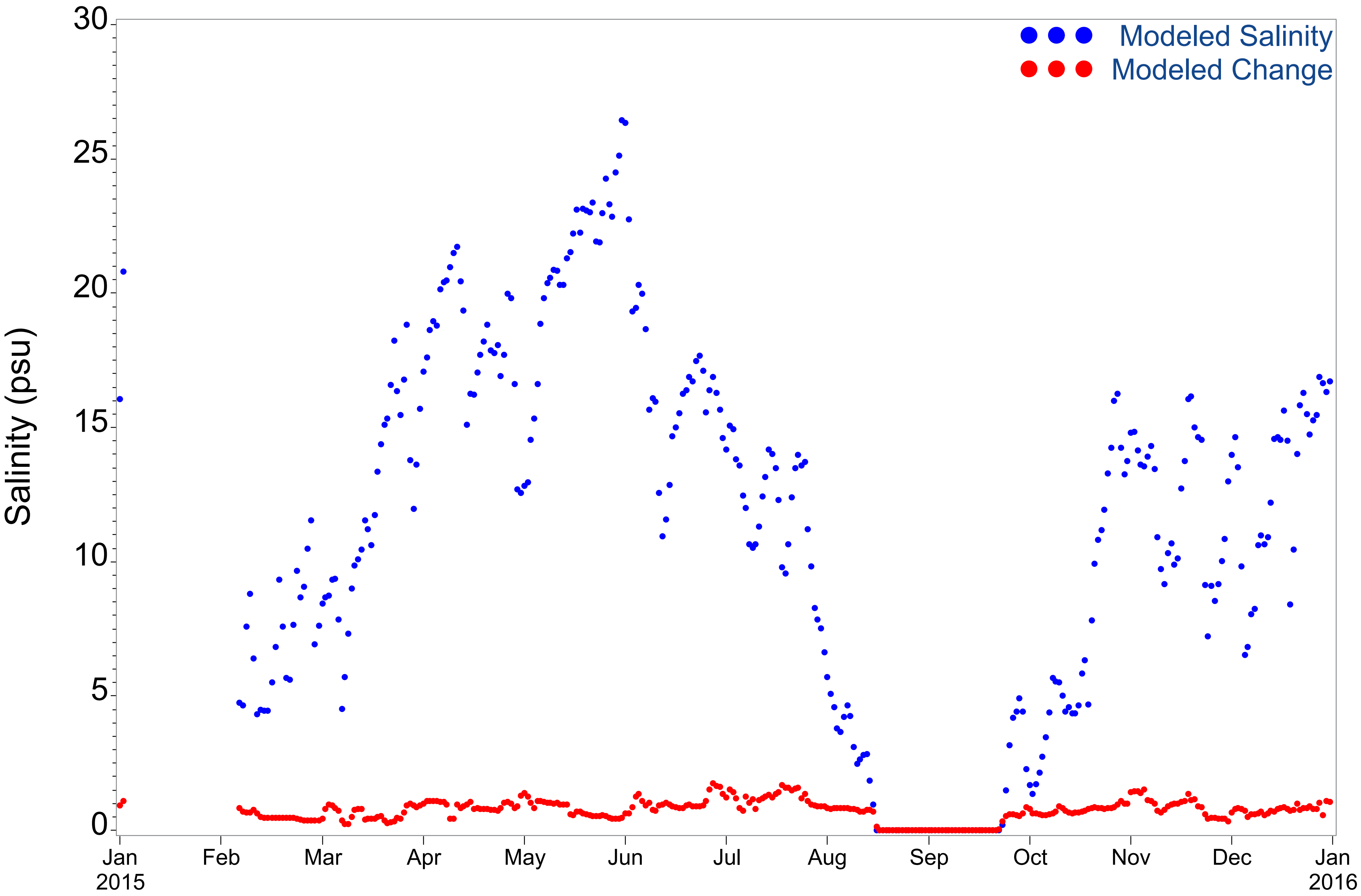

Figure 4.277 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 9.2 (2015)

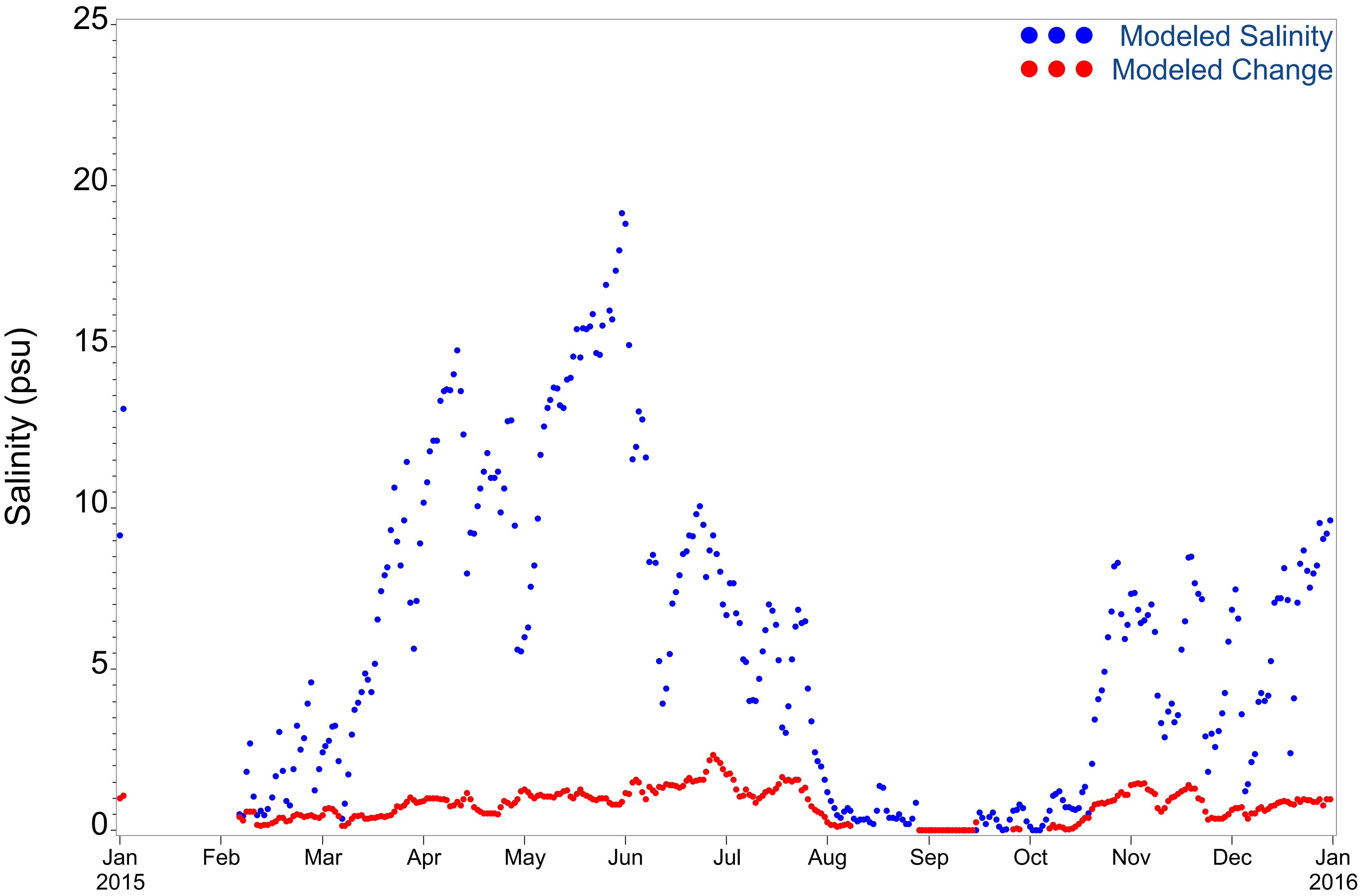

Figure 4.278 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 12.7 (2015)

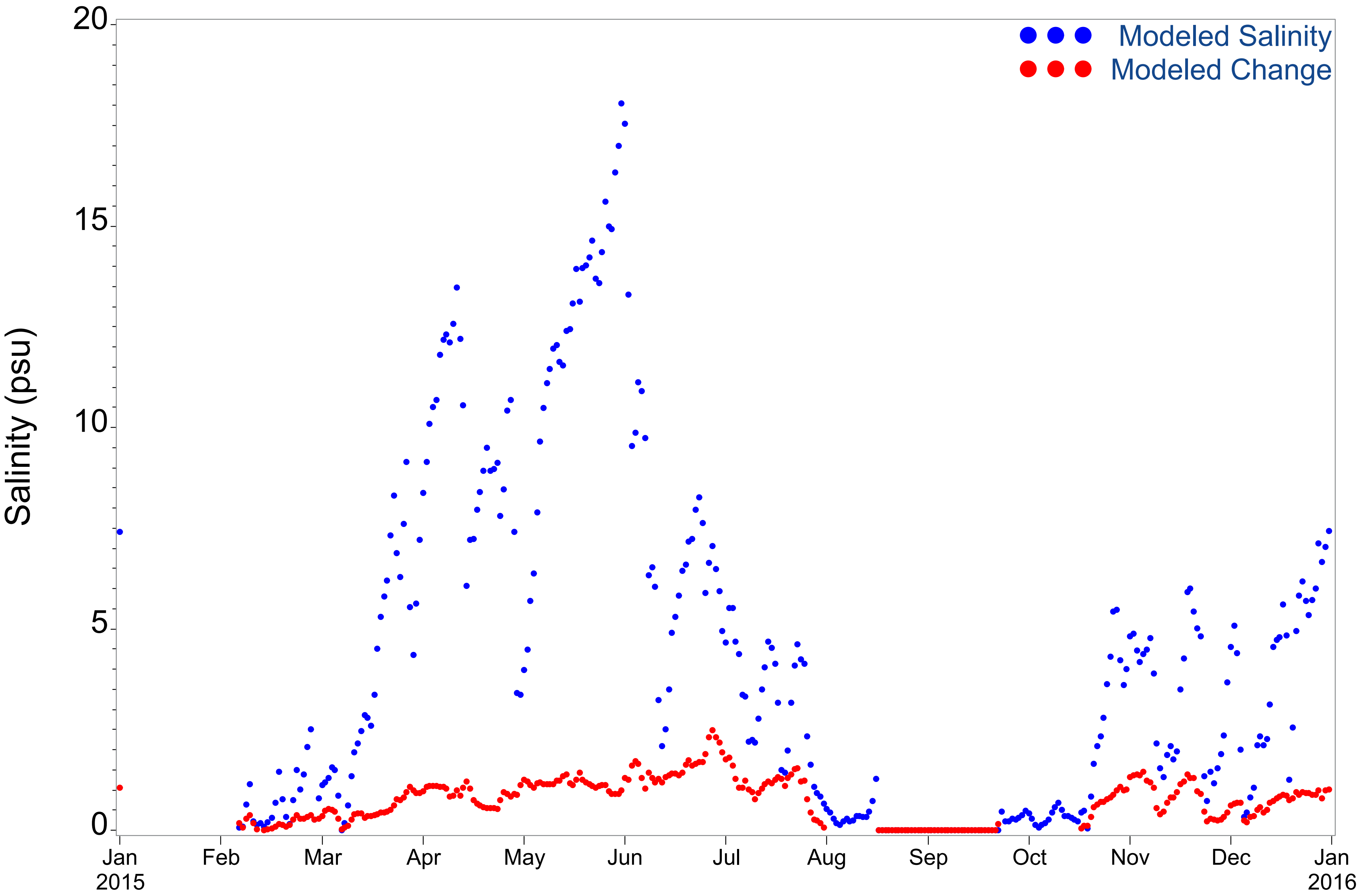

Figure 4.279 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 15.5 (2015)

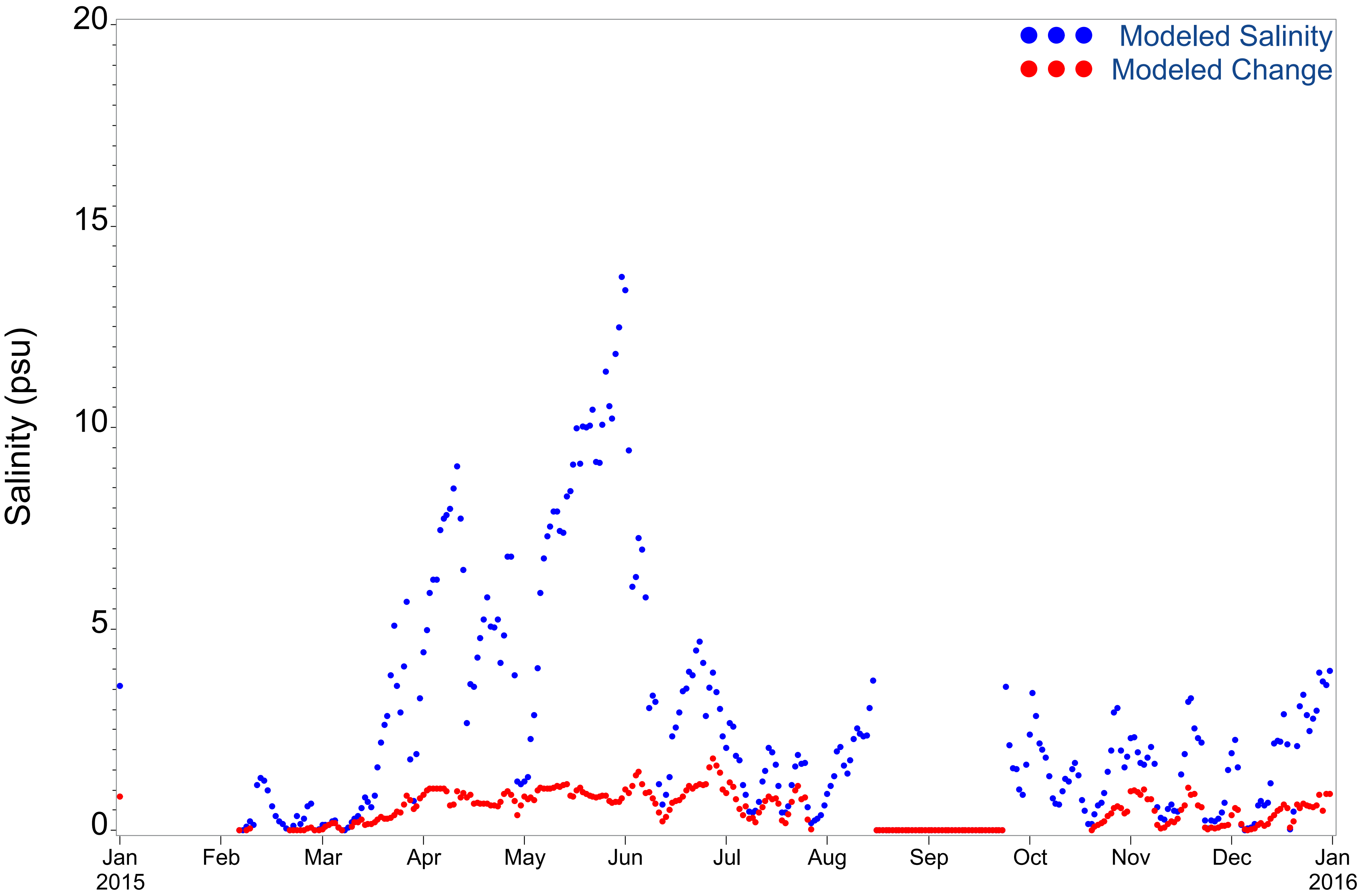

Figure 4.280 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.5 (2015)

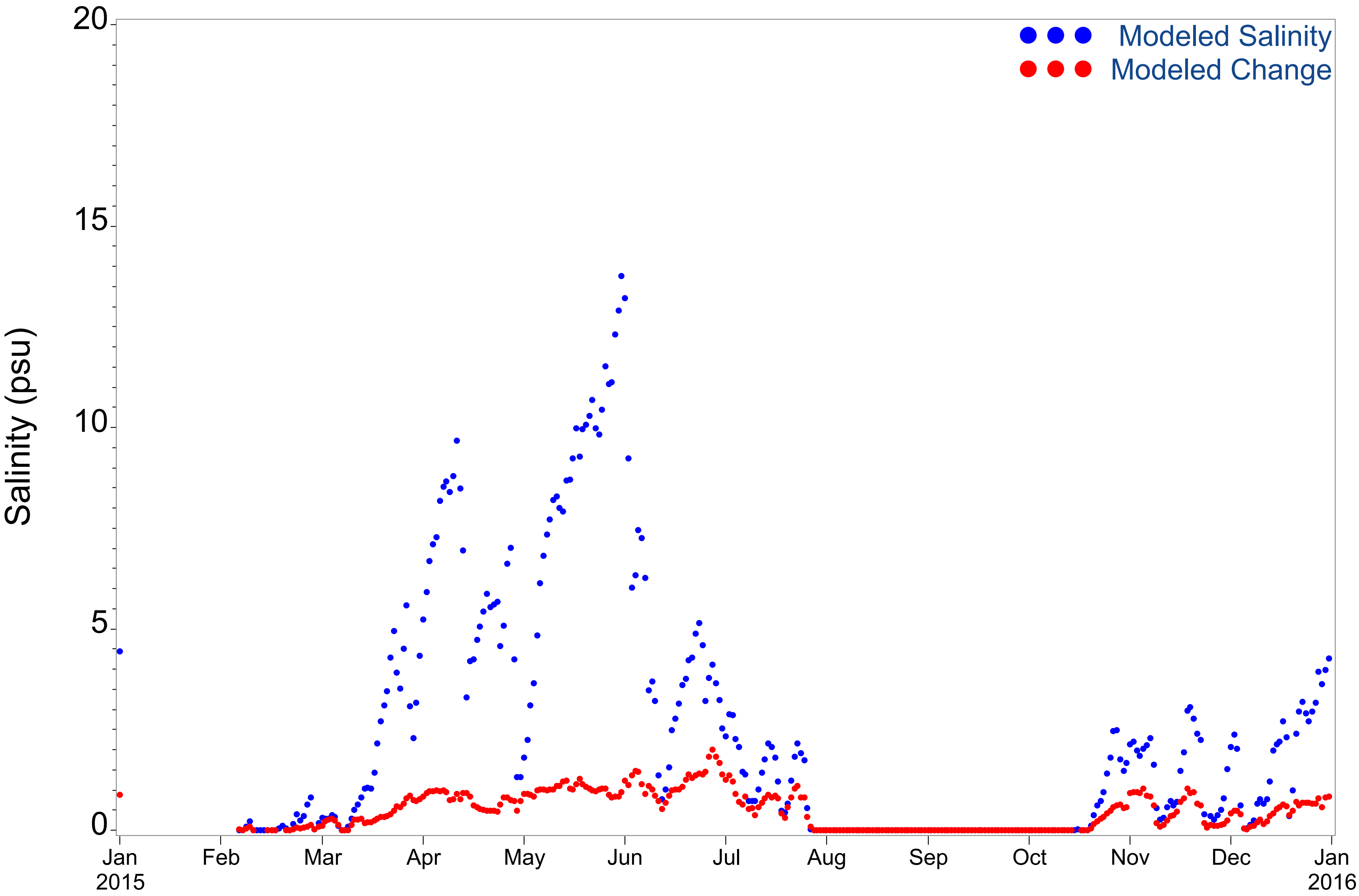

Figure 4.281 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.7 (2015)

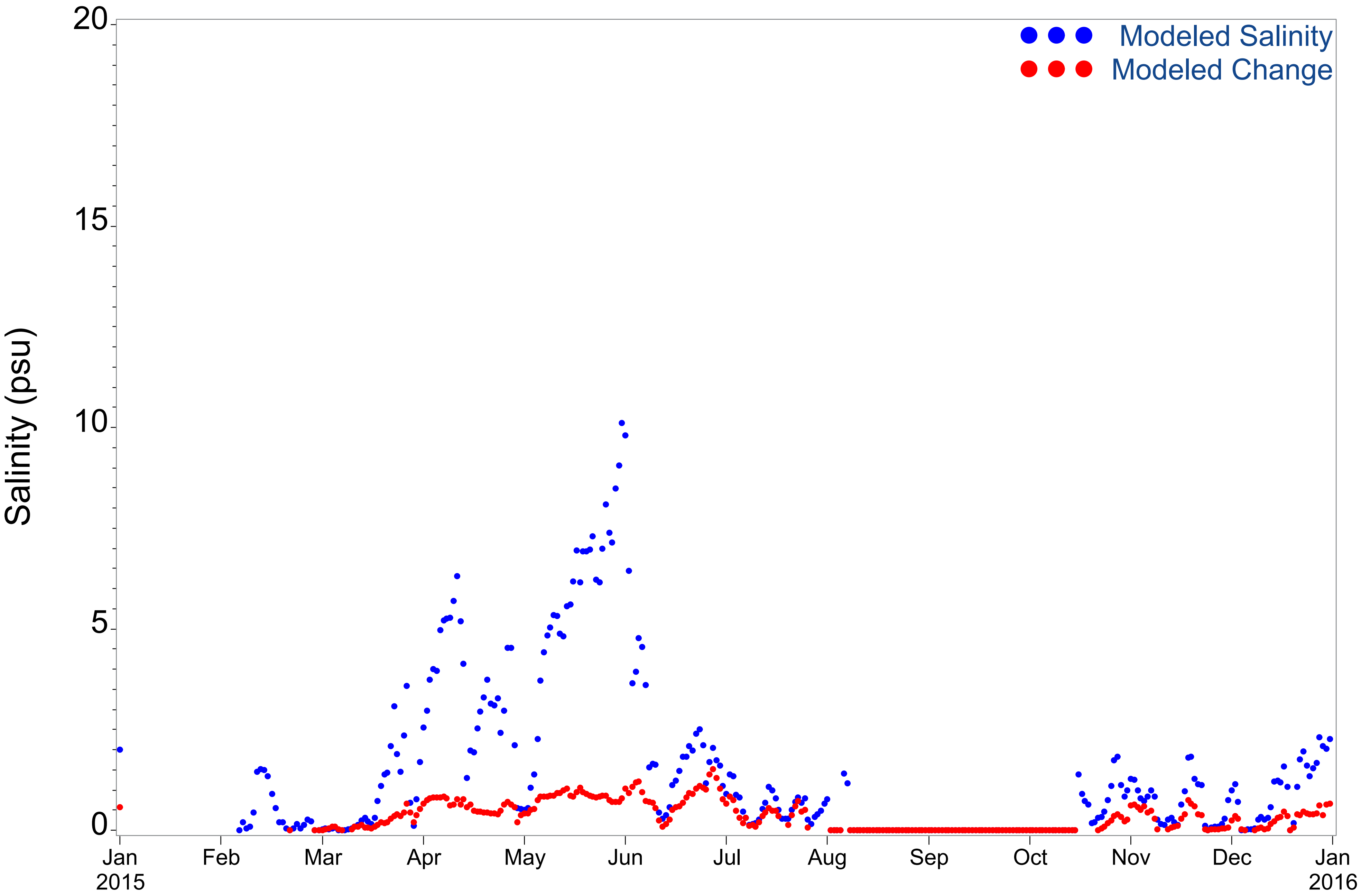

Figure 4.282 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 20.8 (2015)

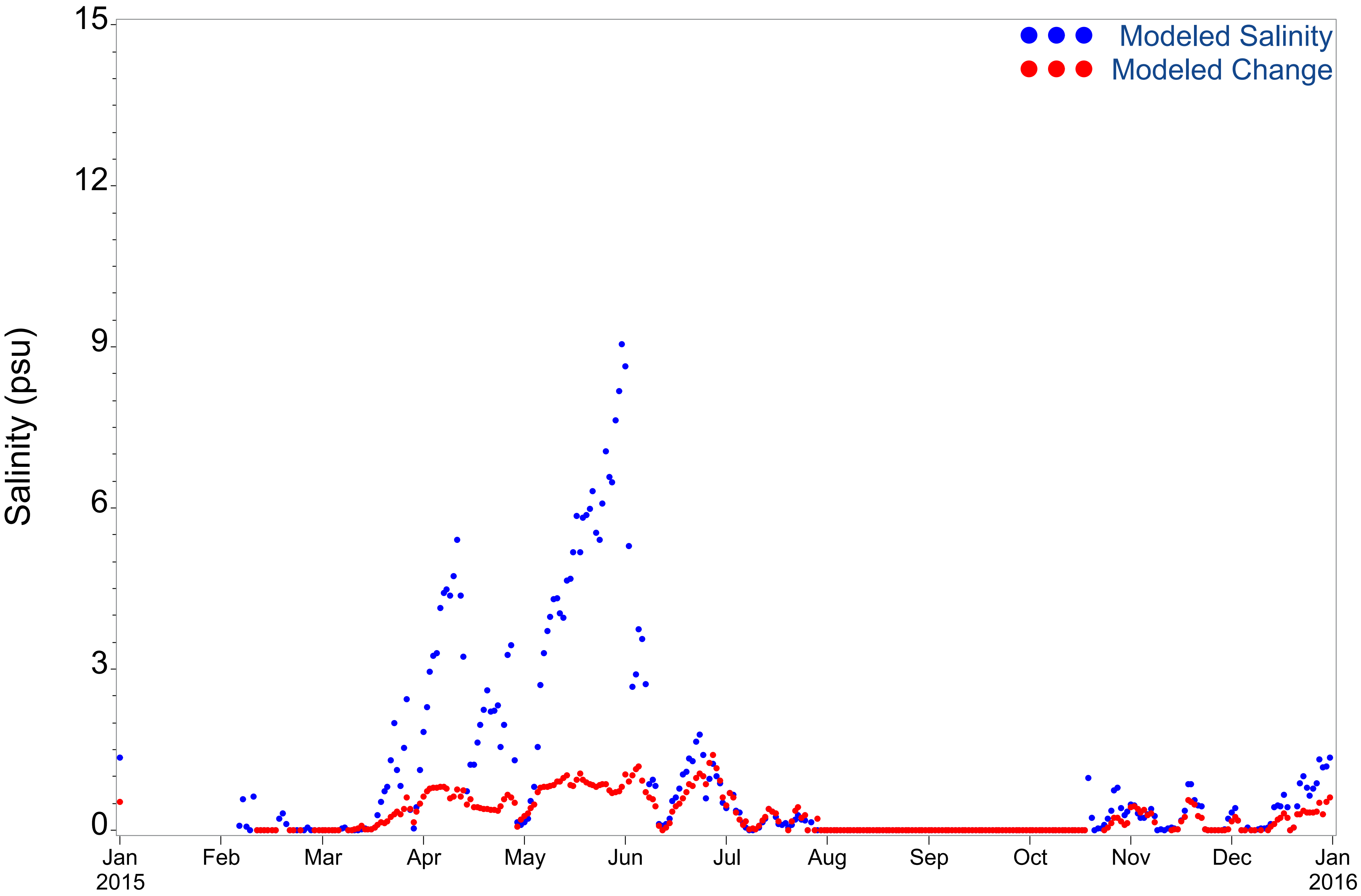

Figure 4.283 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 21.9 (2015)

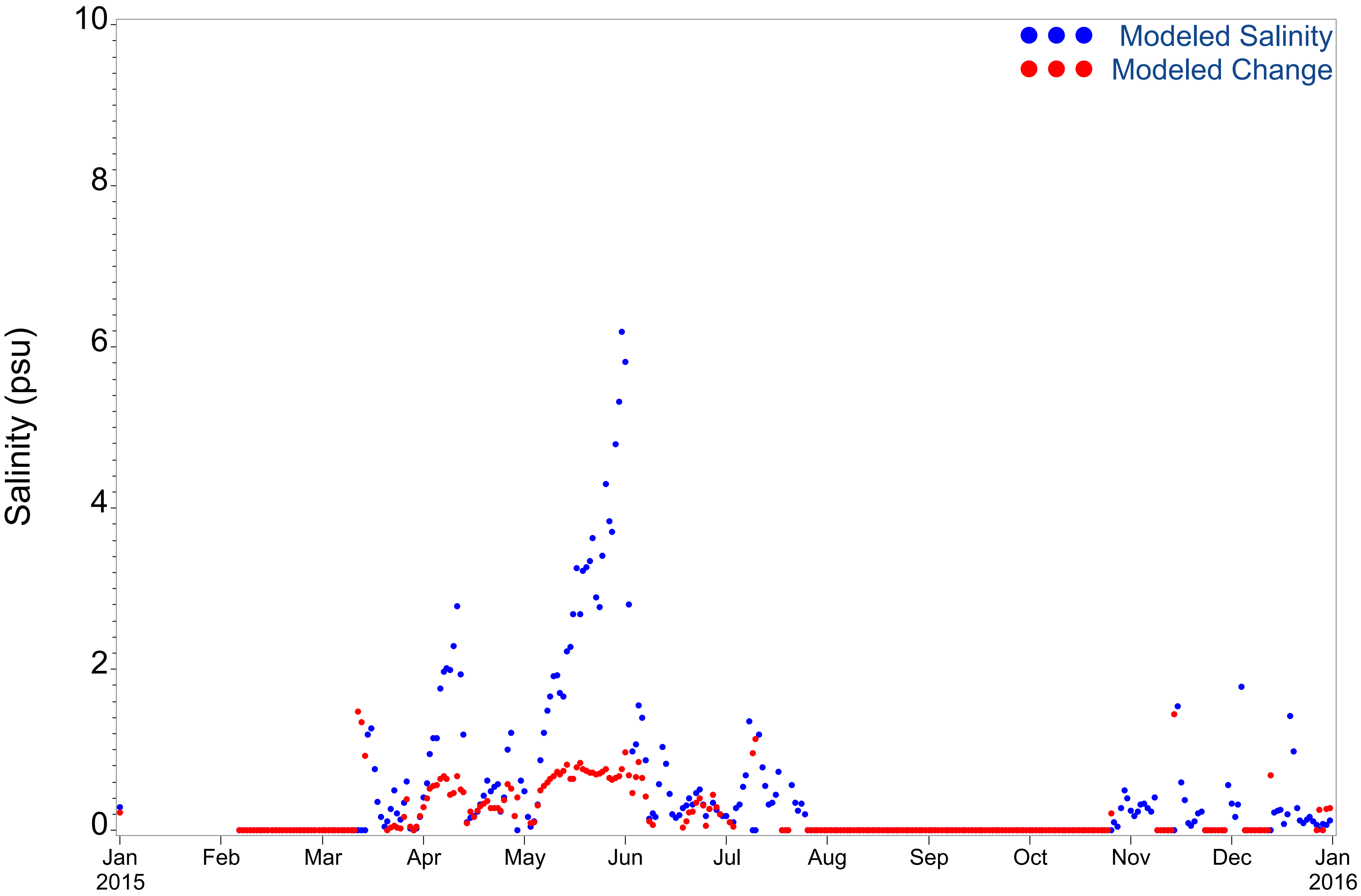

Figure 4.284 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 24.5 (2015)

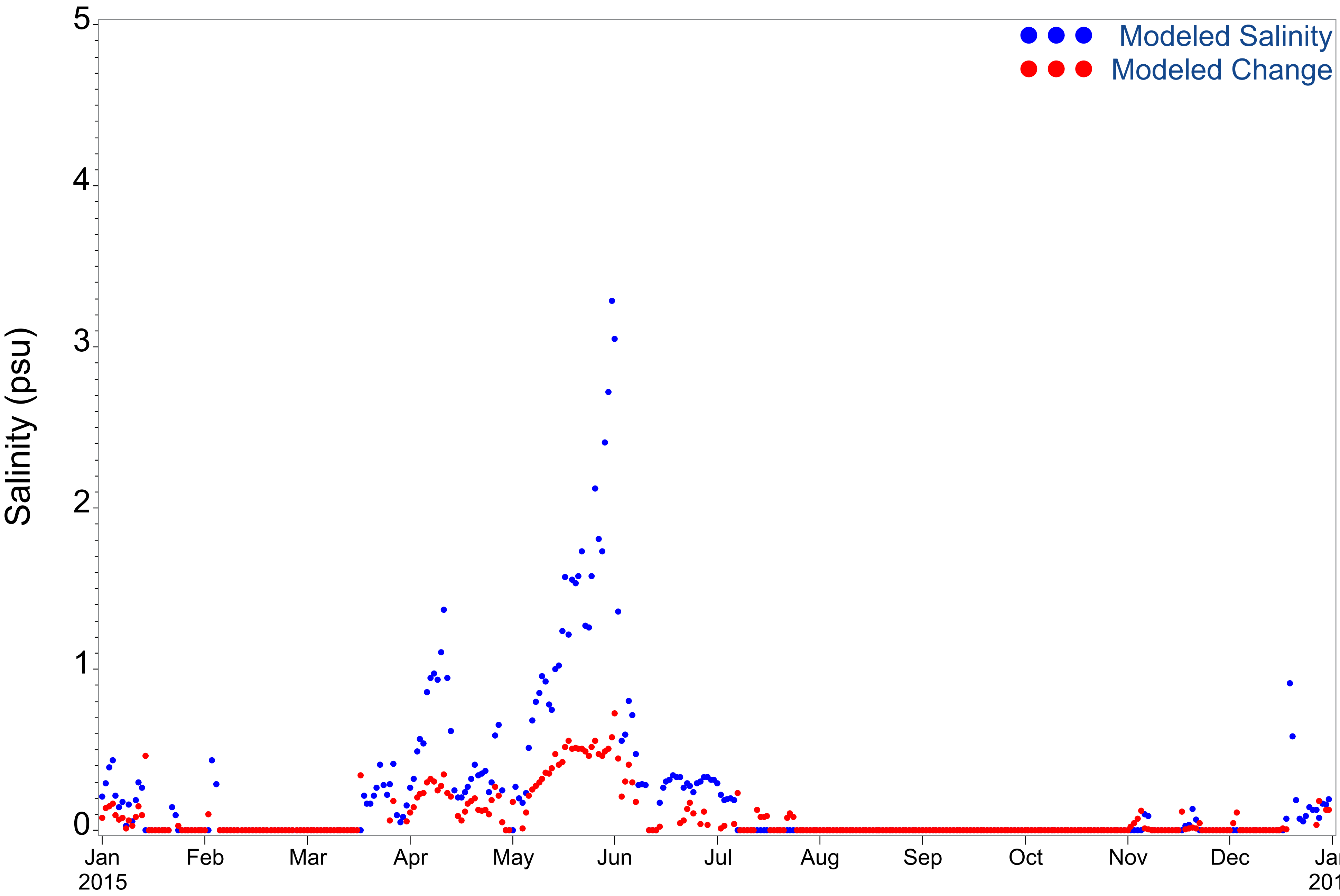

Figure 4.285 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 26.7 (2015)

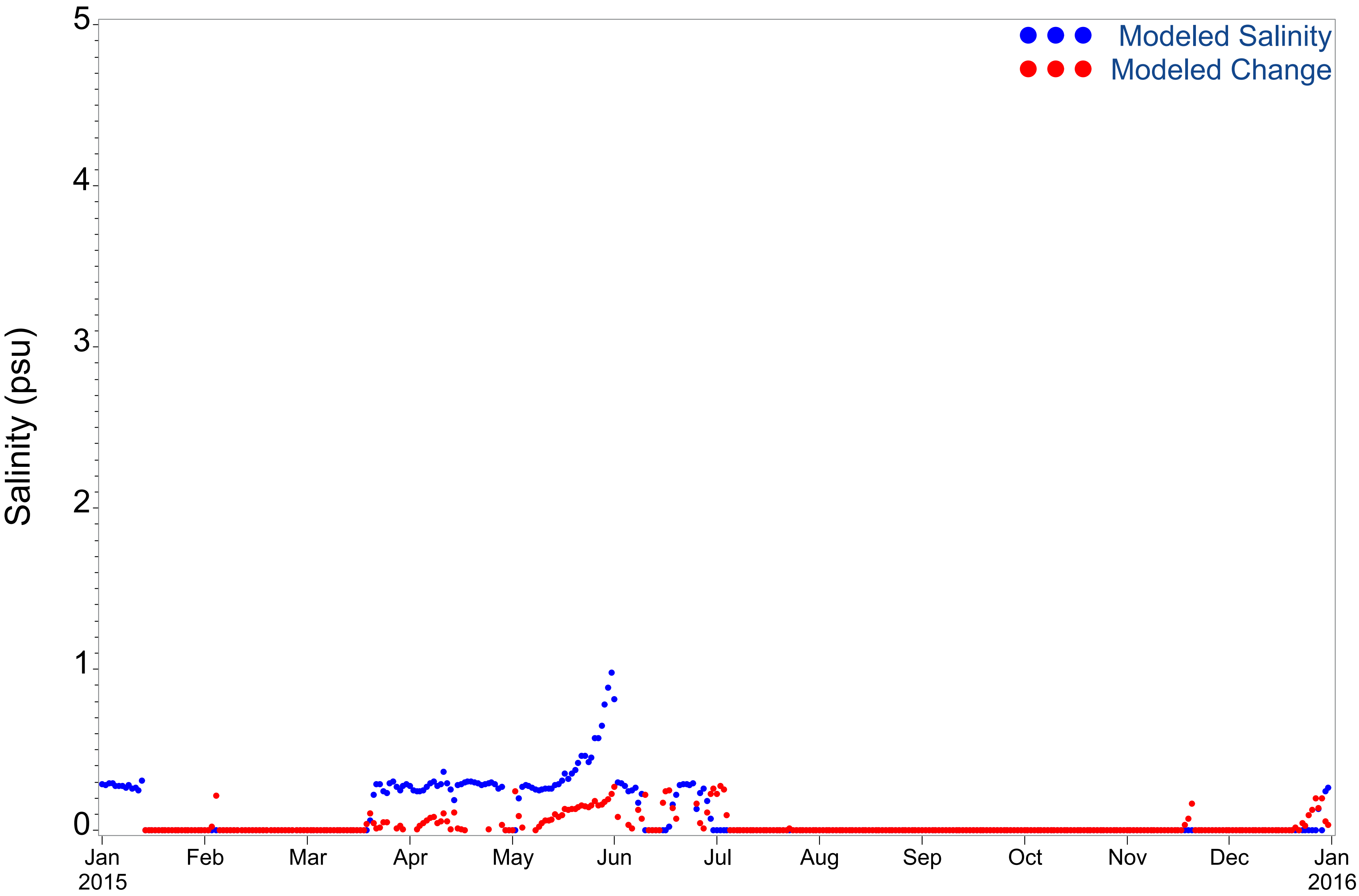

Figure 4.286 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 29.8 (2015)

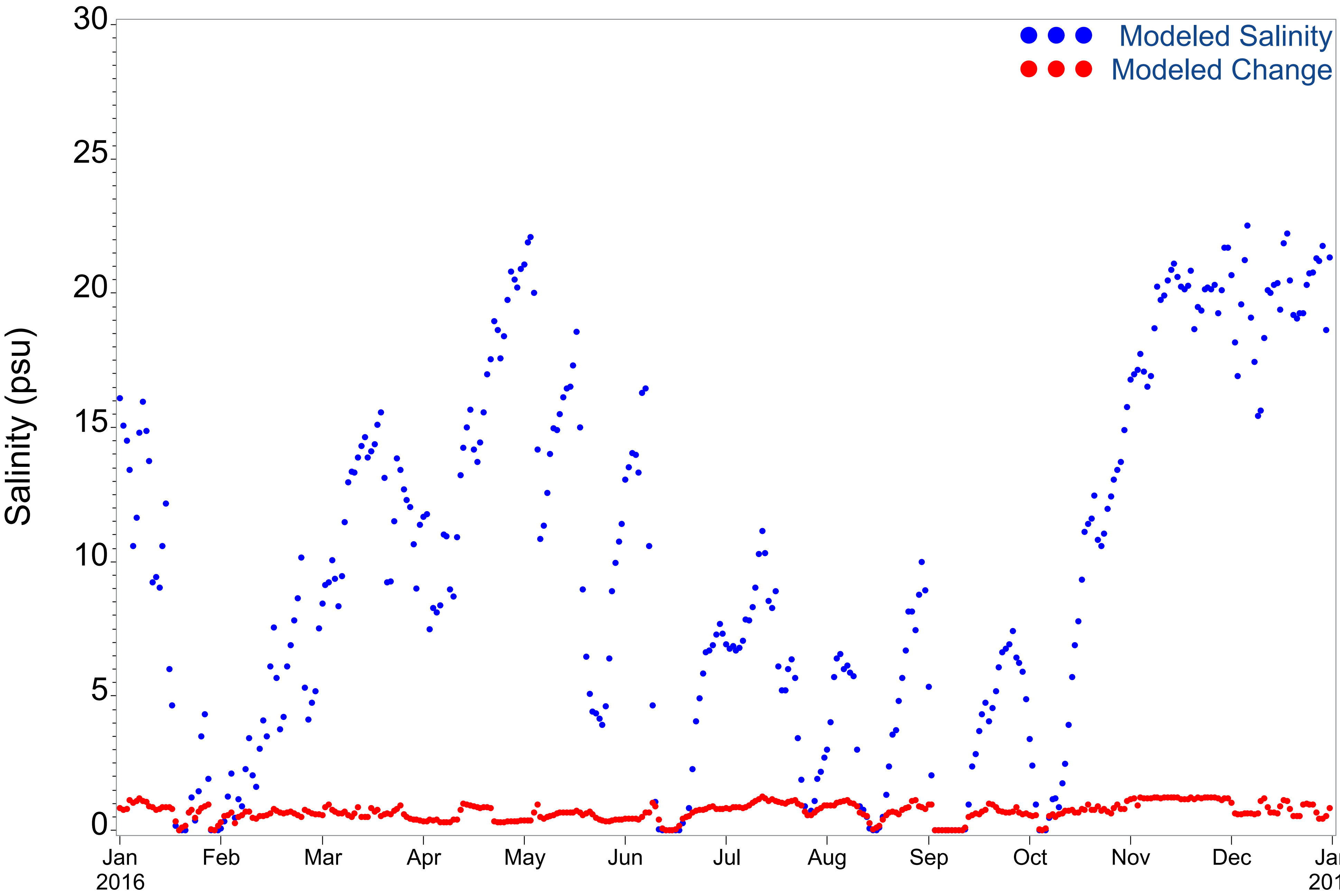

Figure 4.287 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 9.2 (2016)

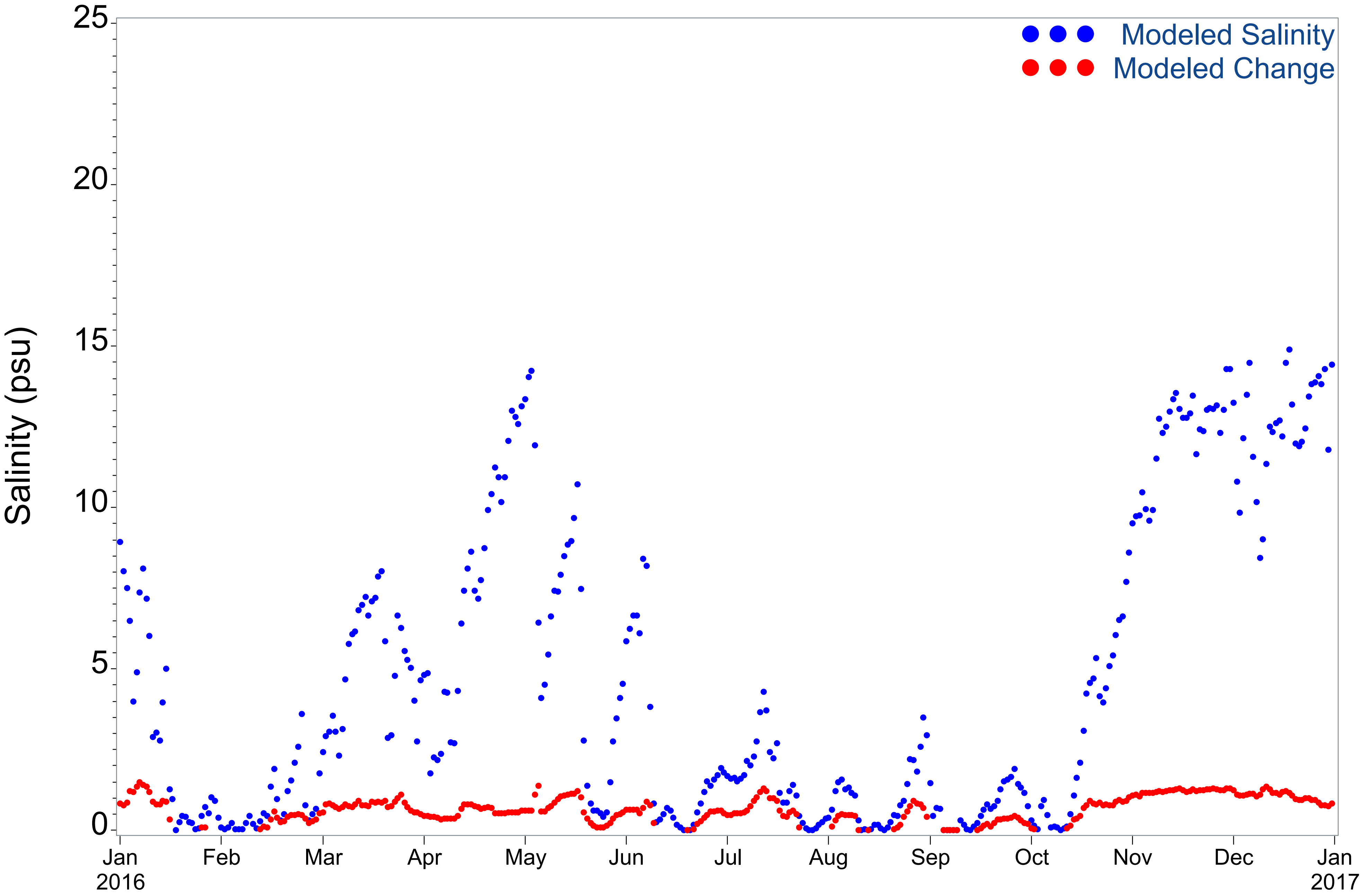

Figure 4.288 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 12.7 (2016)

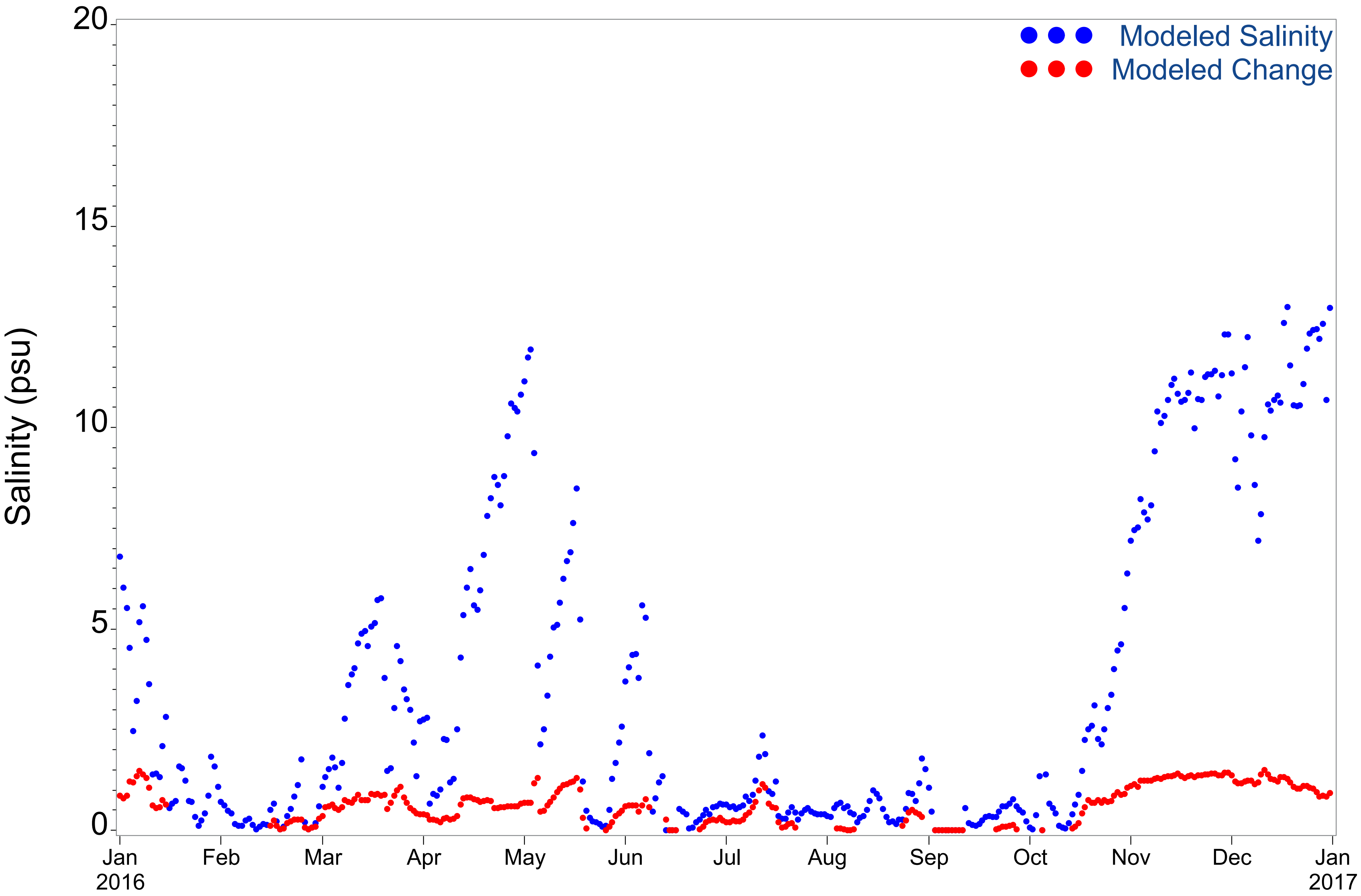

Figure 4.289 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 15.5 (2016)

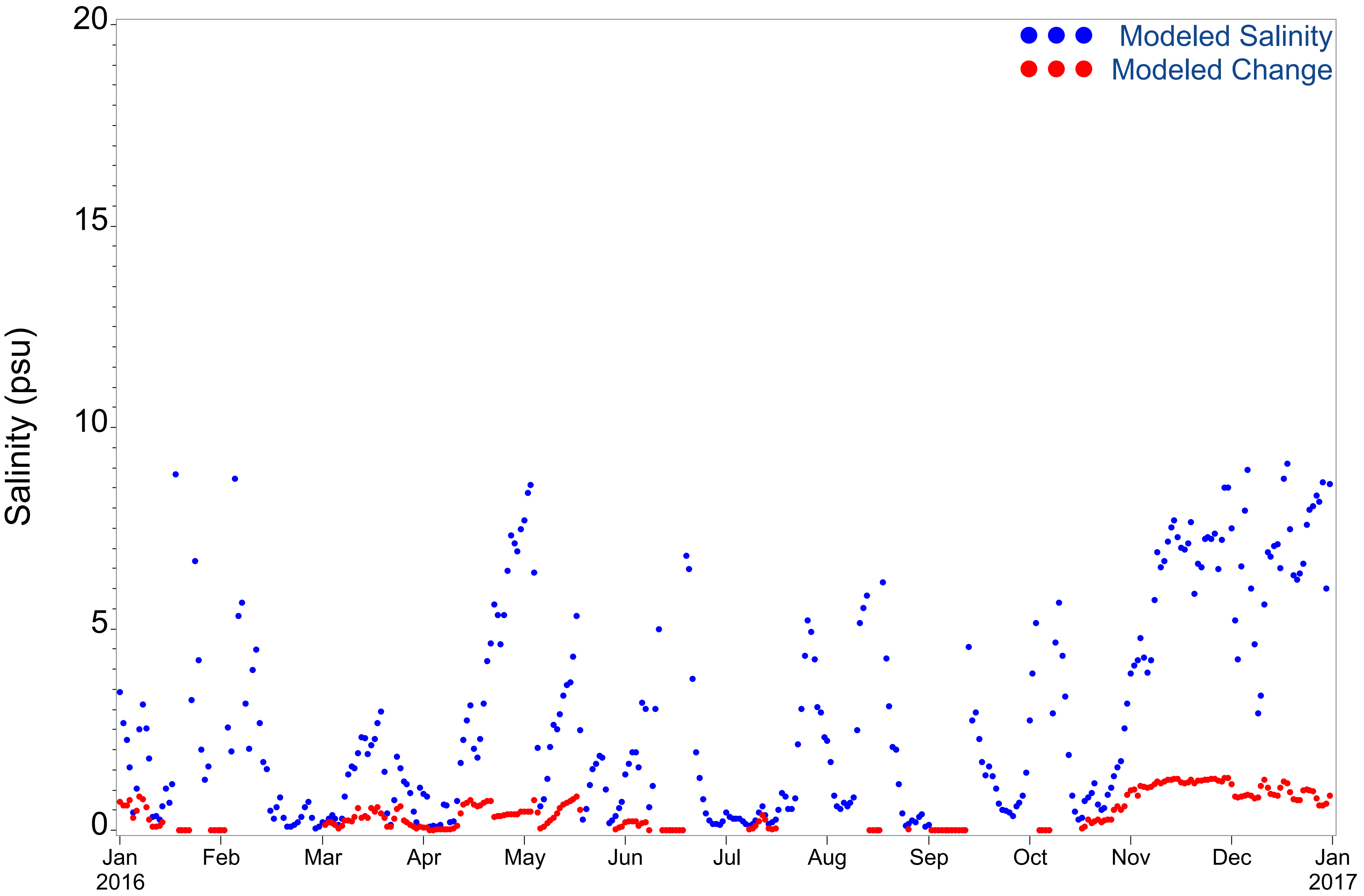

Figure 4.290 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.5 (2016)

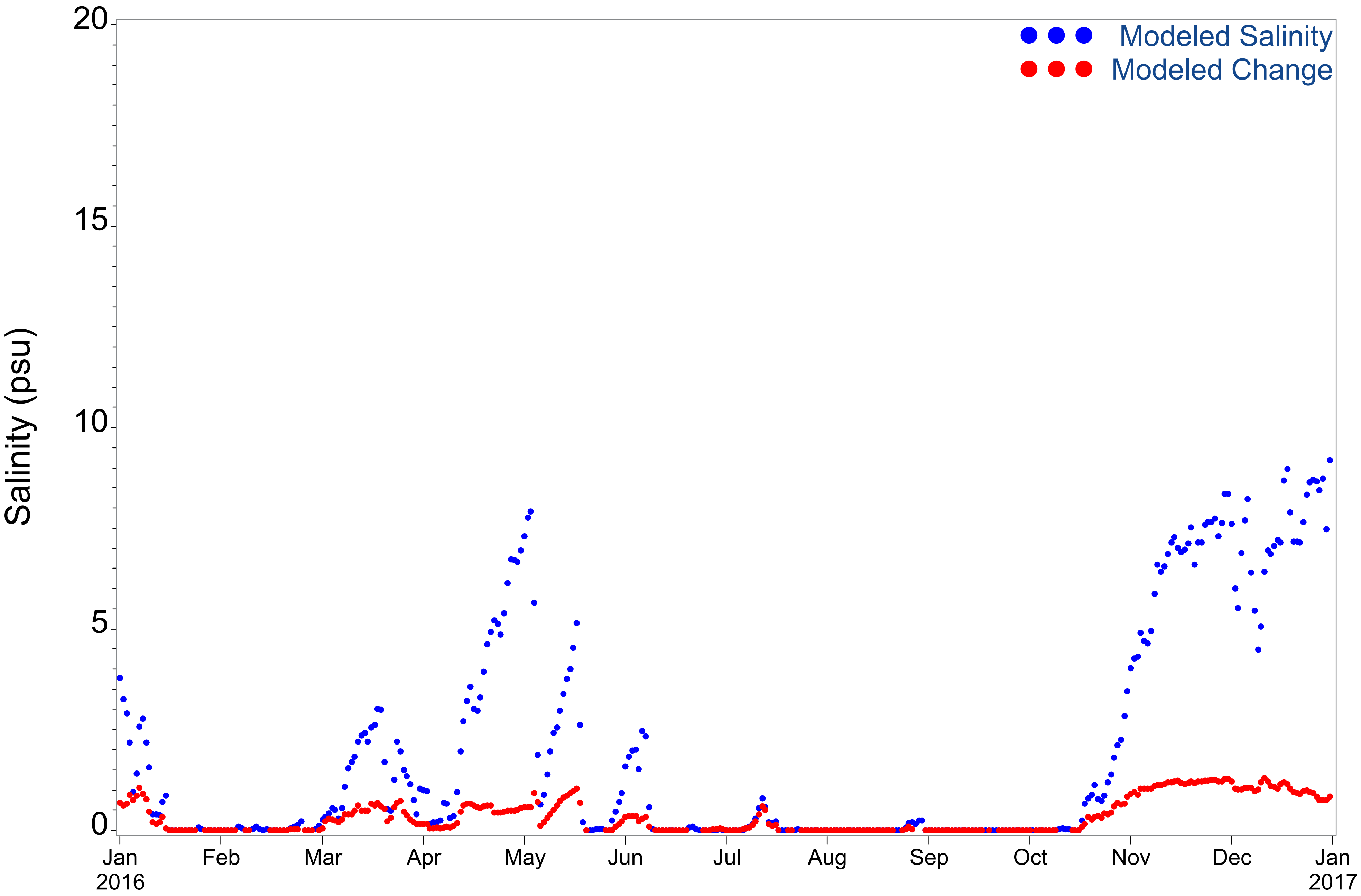

Figure 4.291 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 18.7 (2016)

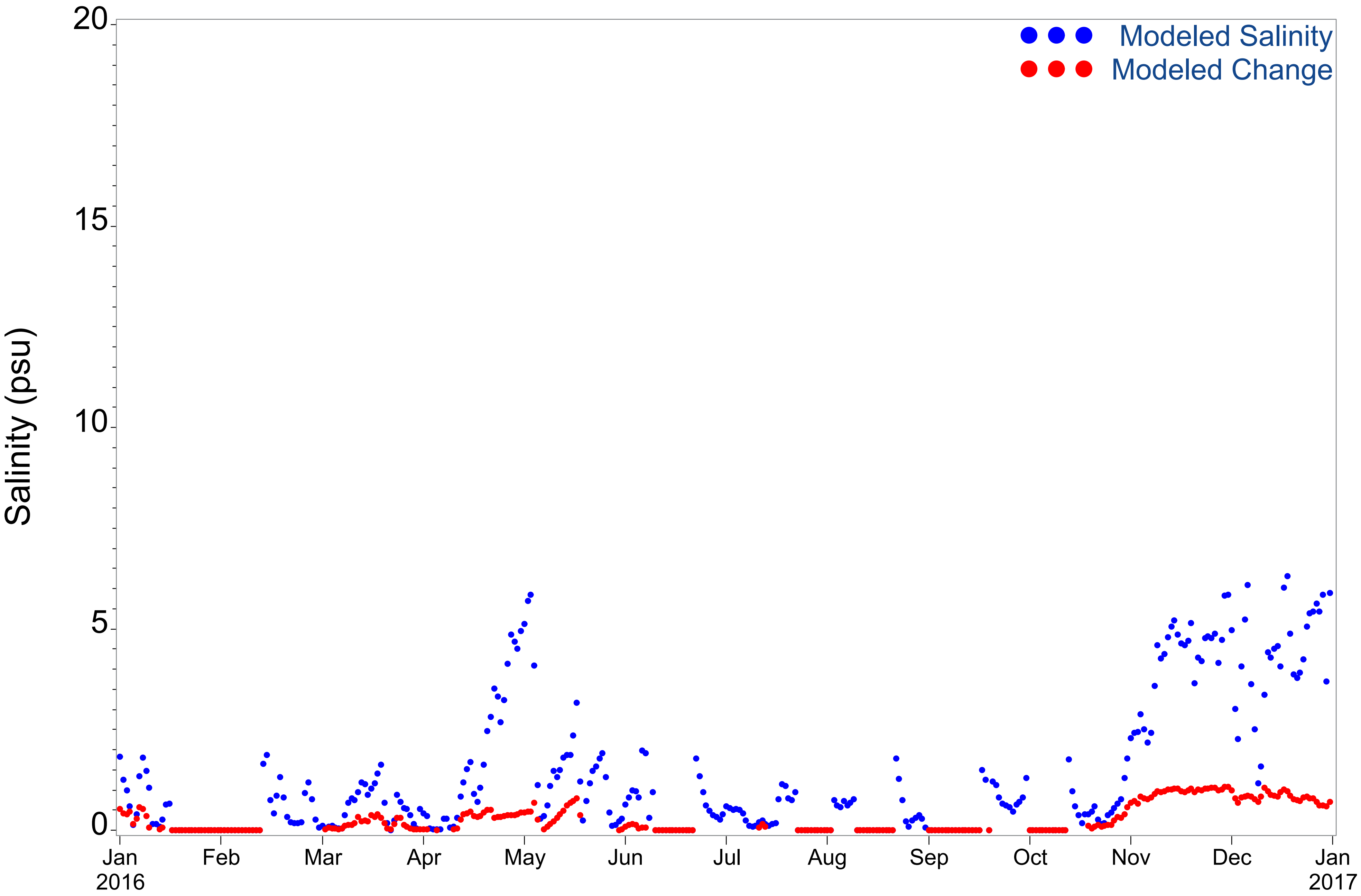

Figure 4.292 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 20.8 (2016)

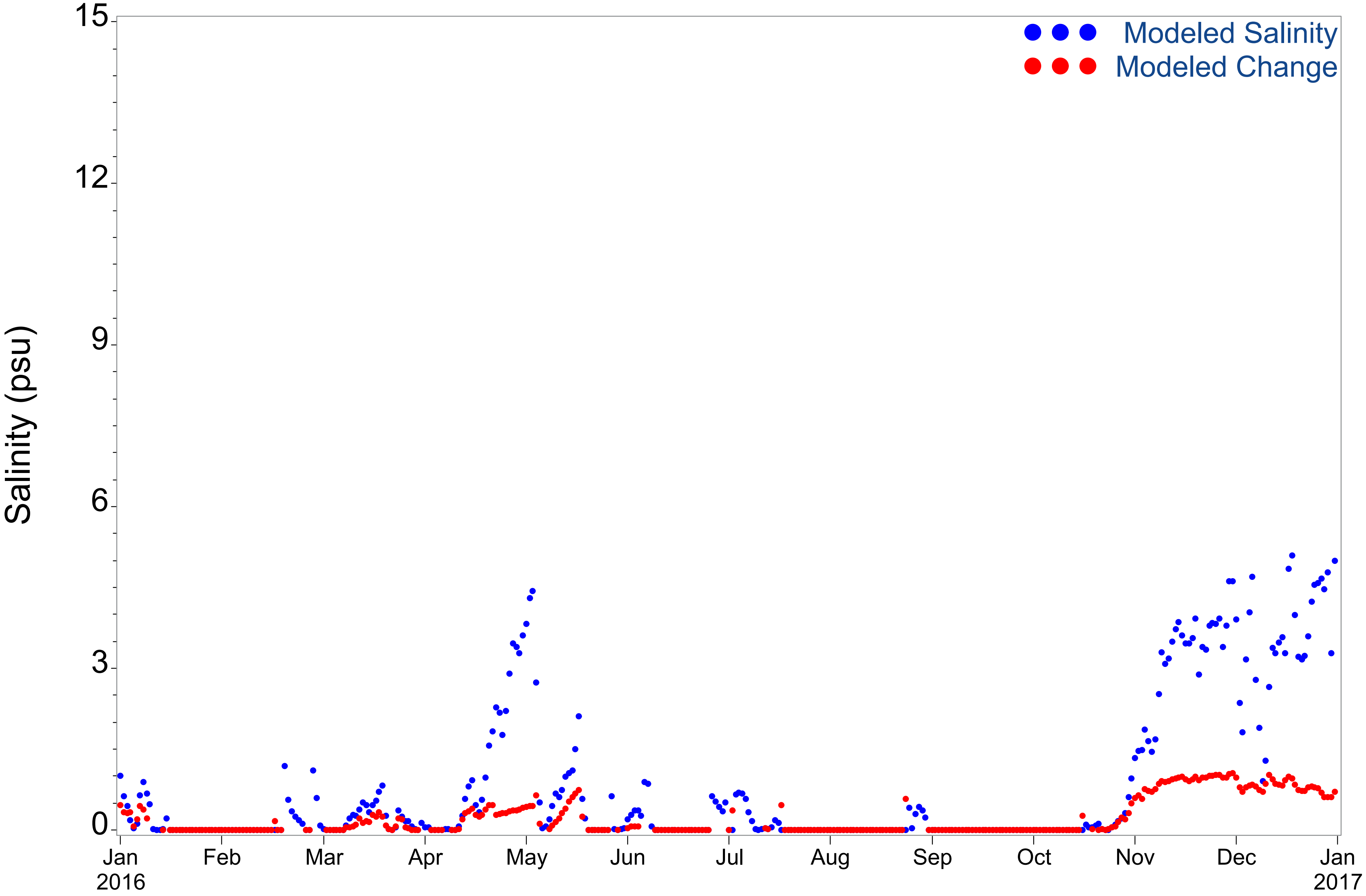

Figure 4.293 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 21.9 (2016)

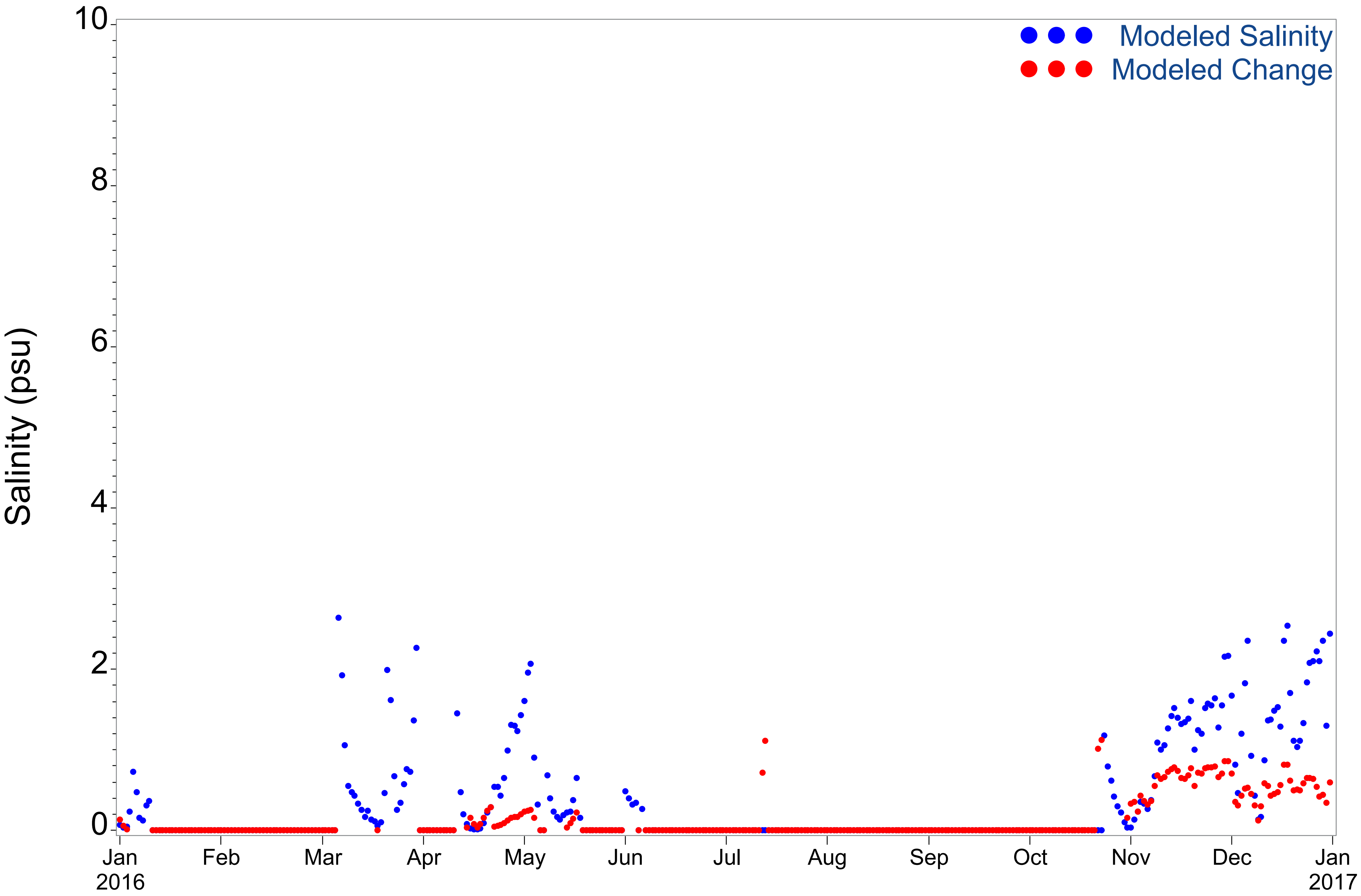

Figure 4.294 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 24.5 (2016)

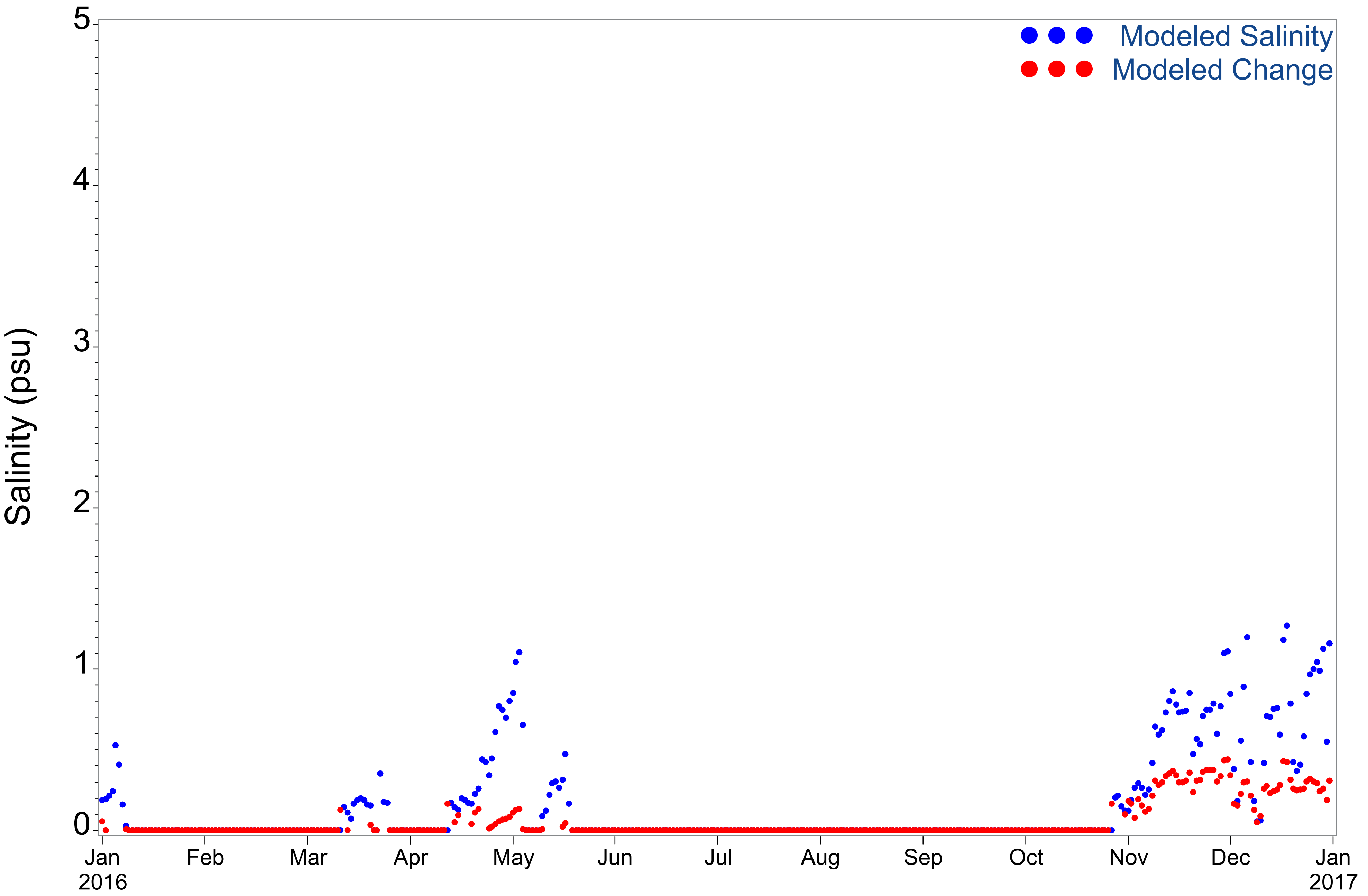

Figure 4.295 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 26.7 (2016)

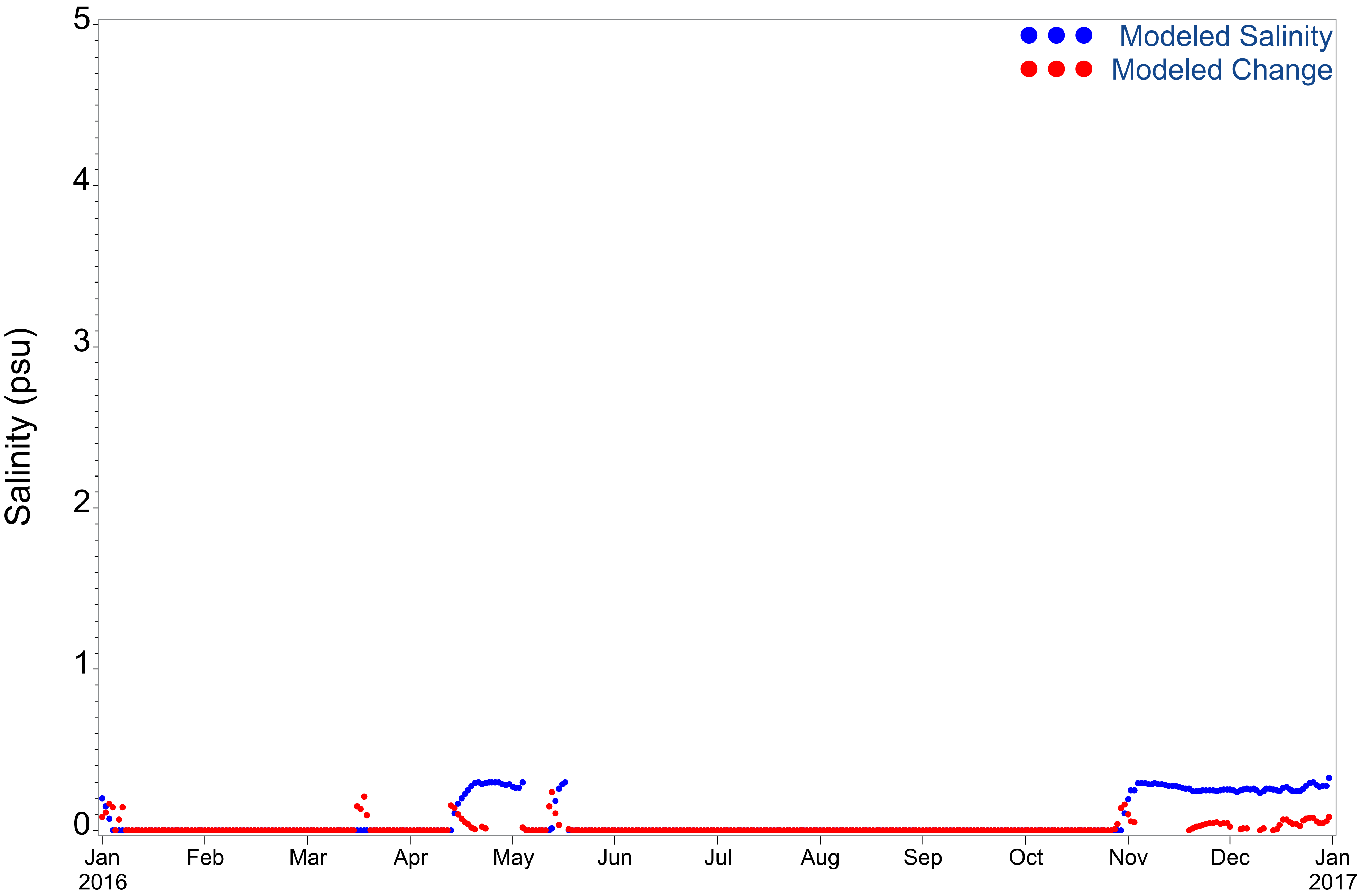

Figure 4.296 A comparison of estimated average daily differences in salinity due to Facility withdrawals and estimated average daily salinity at RK 29.8 (2016)

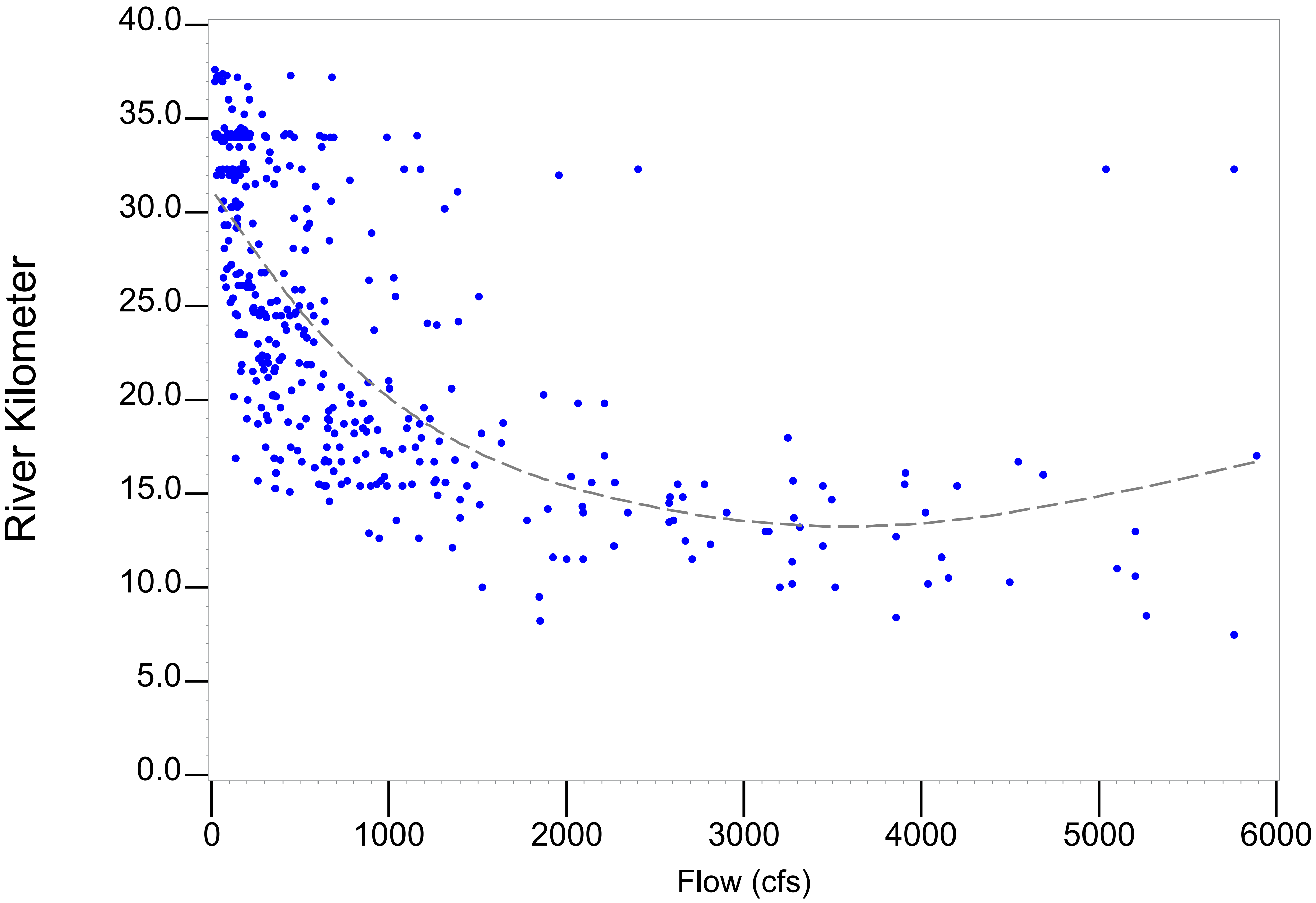

Figure 4.297. Movement of 0 psu isohaline relative to combined gaged flow upstream of the Peace River Facility

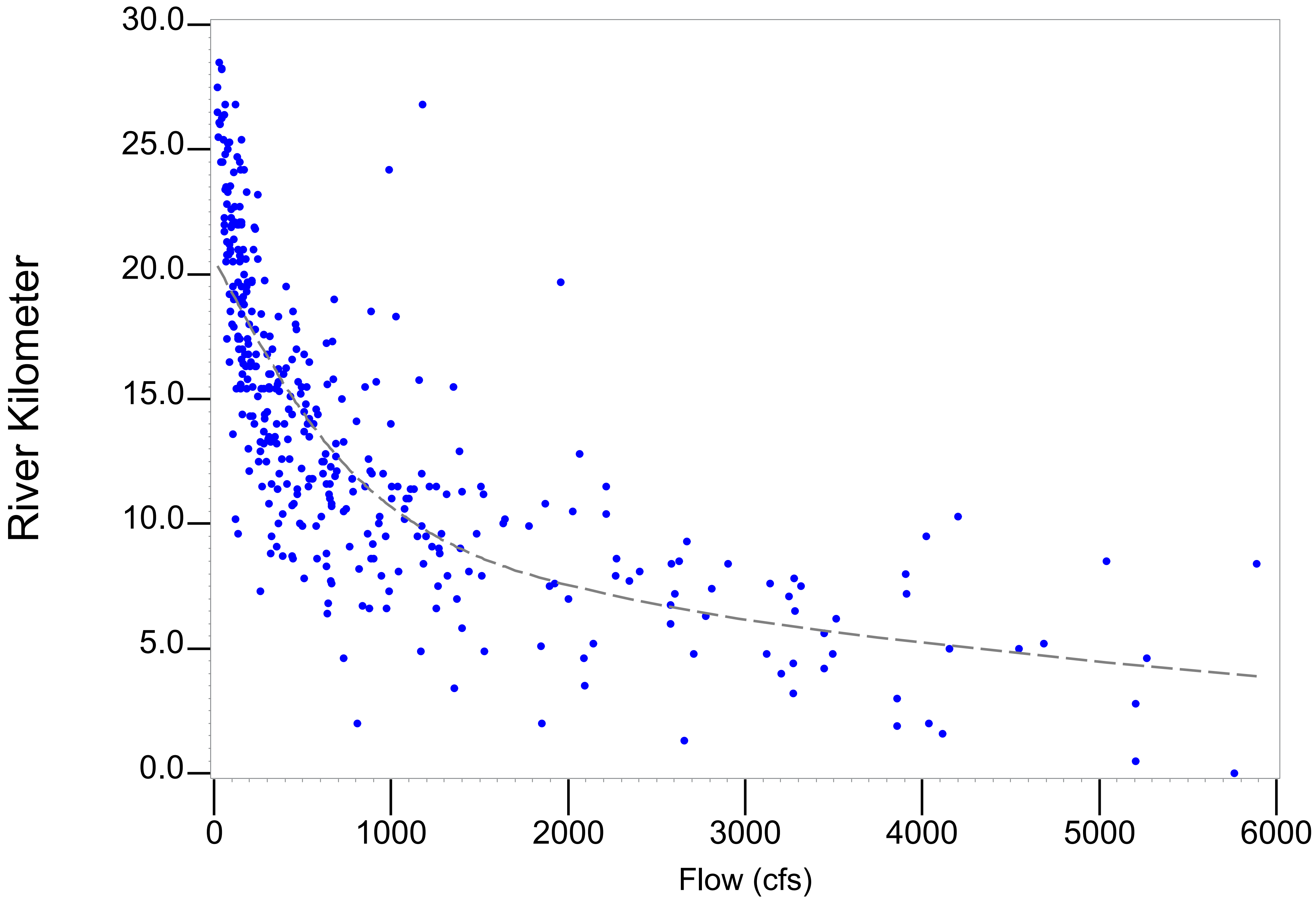

Figure 4.298. Movement of 6 psu isohaline relative to combined gaged flow upstream of the Peace River Facility

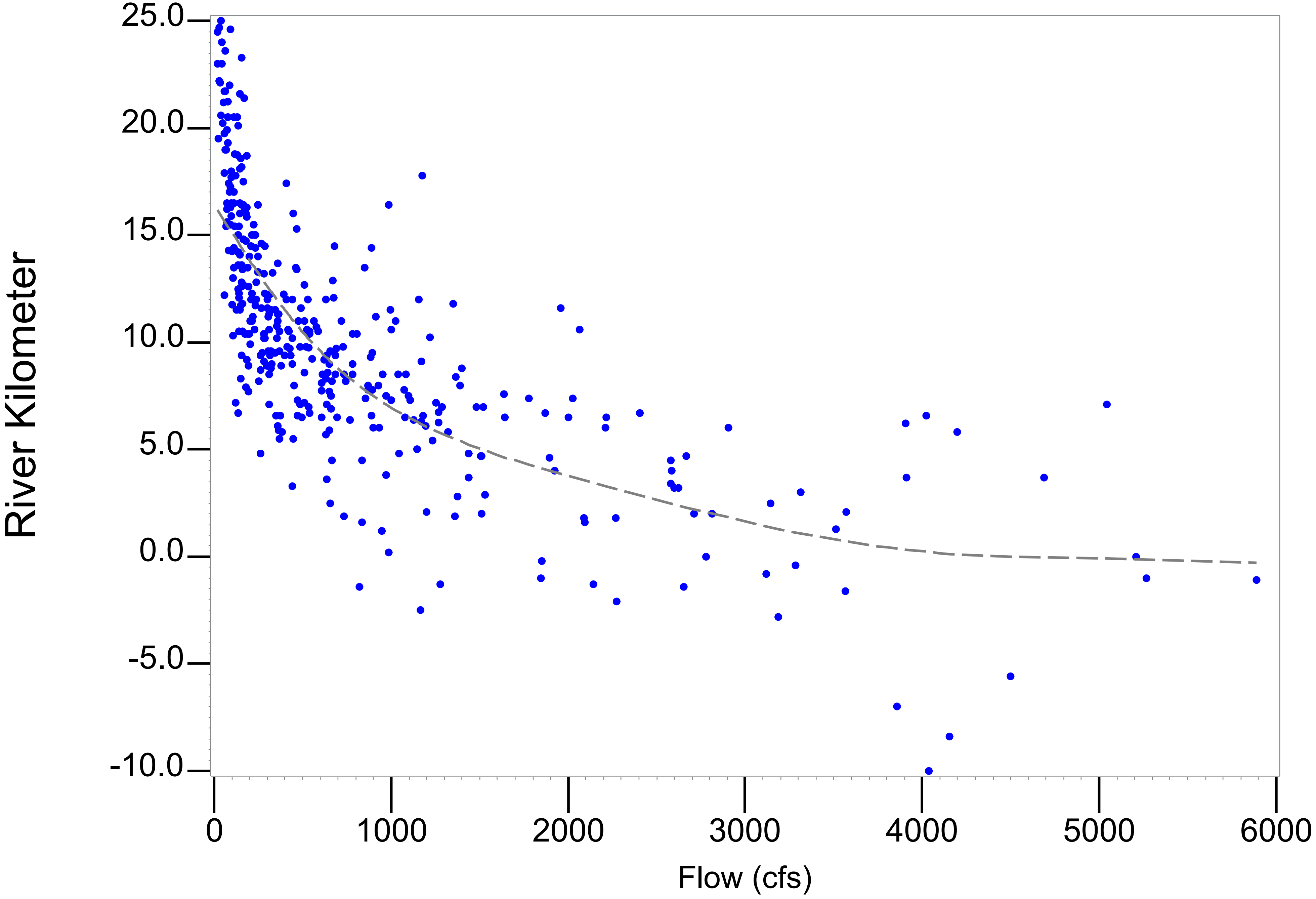

Figure 4.299. Movement of 12 psu isohaline relative to combined gaged flow upstream of the Peace River Facility

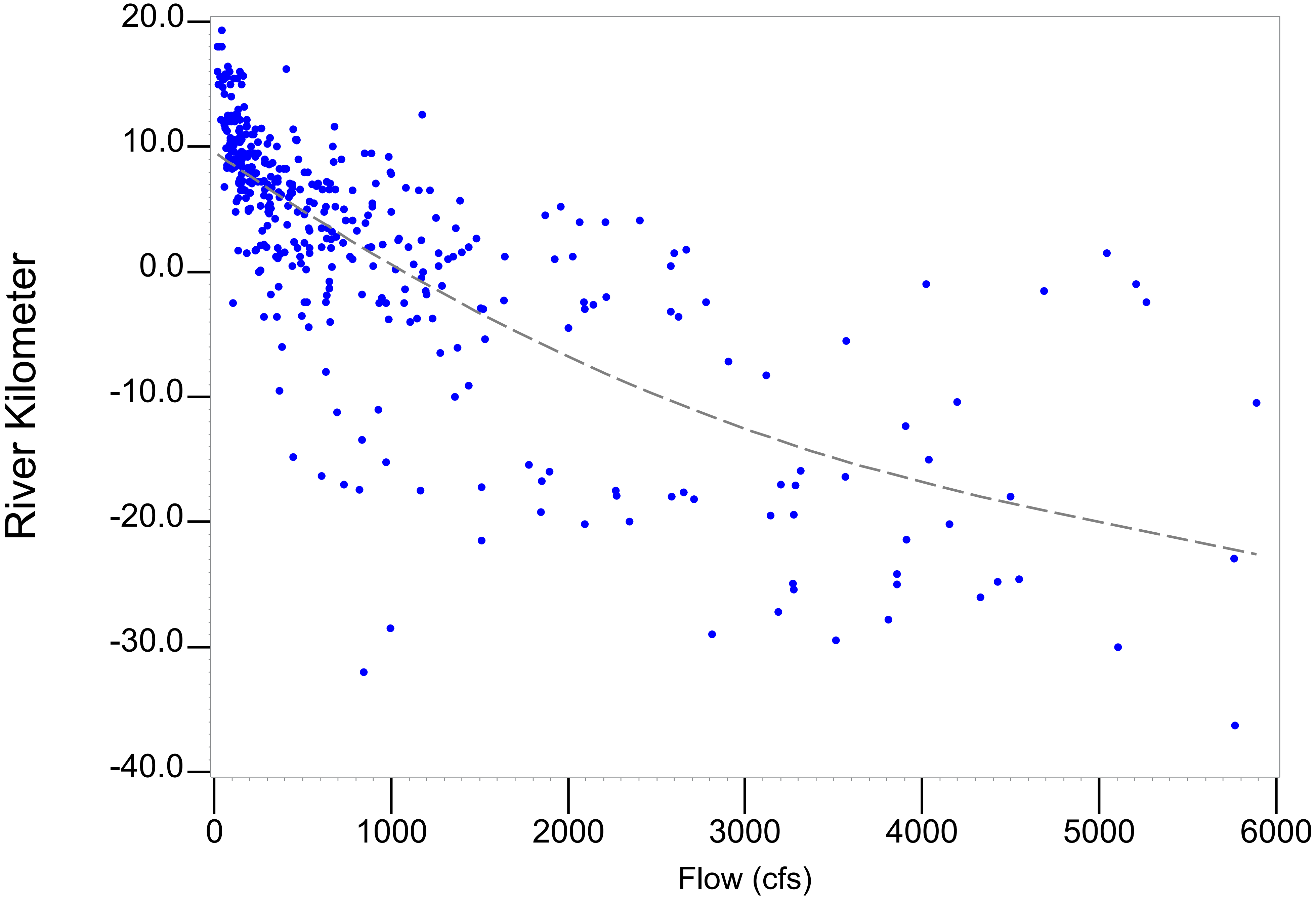

Figure 4.300. Movement of 20 psu isohaline relative to combined gaged flow upstream of the Peace River Facility

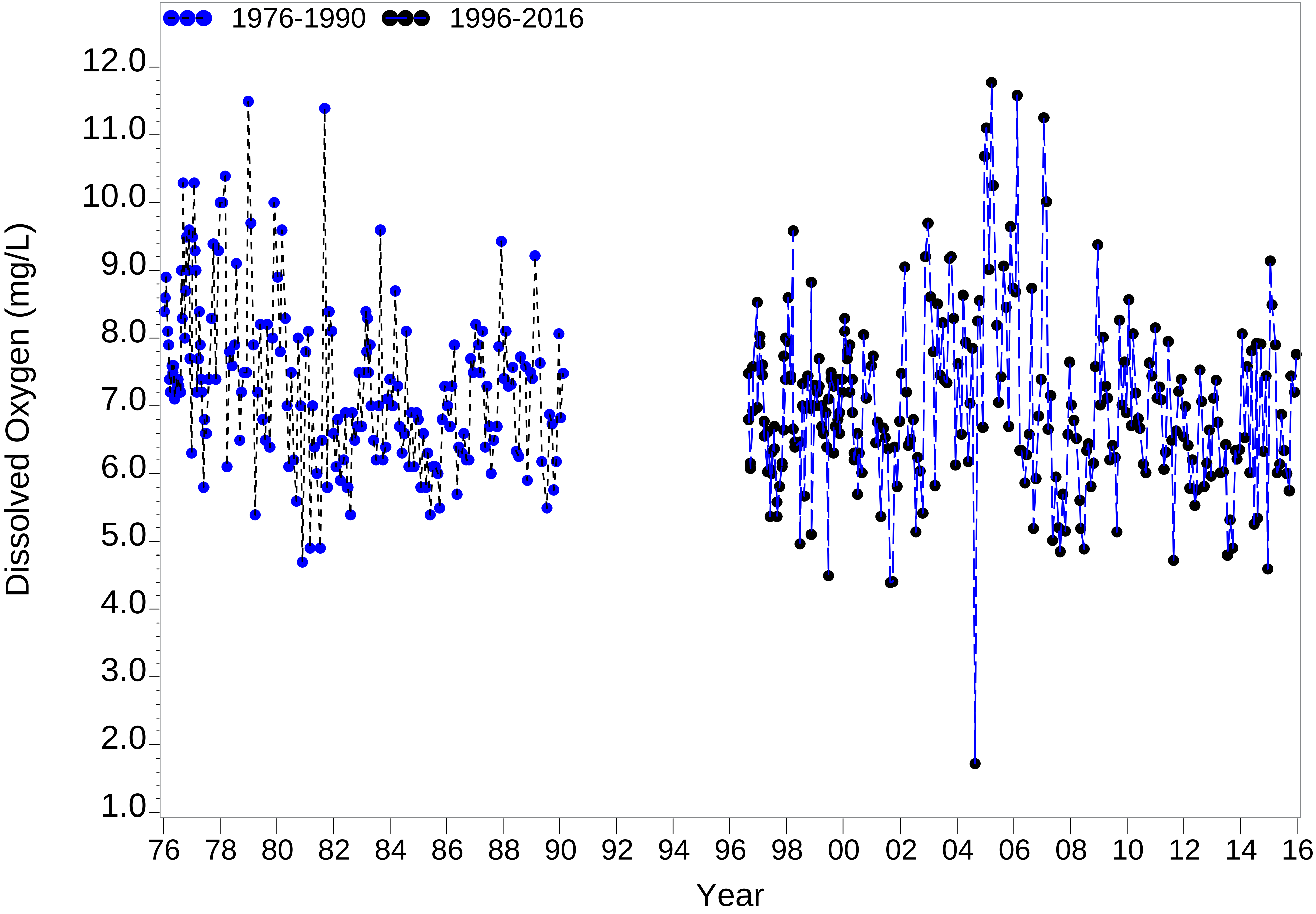

Figure 5.3. Monthly long-term Surface Dissolved Oxygen Levels at river kilometer -2.4

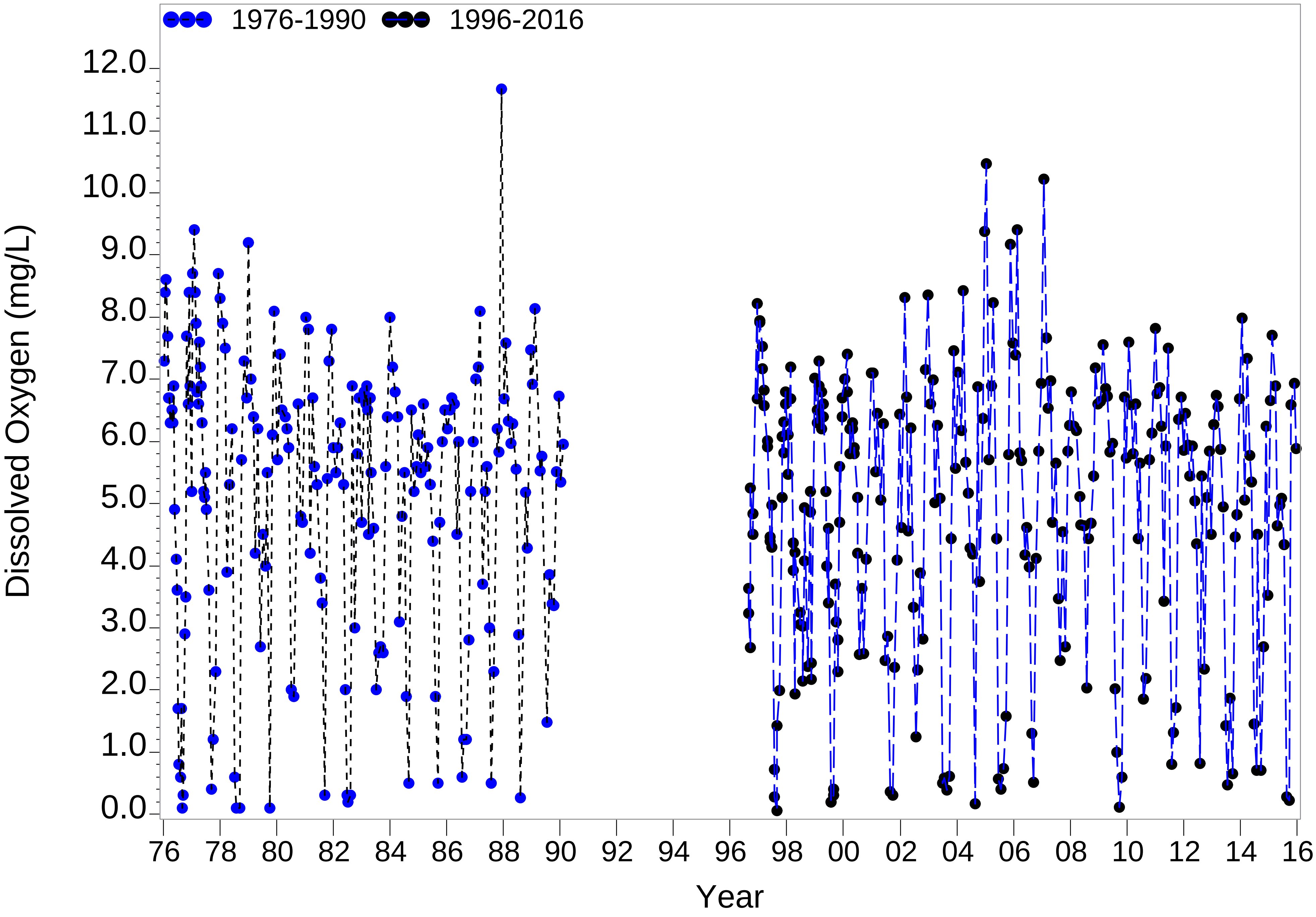

Figure 5.4. Monthly long-term Bottom Dissolved Oxygen Levels at river kilometer -2.4

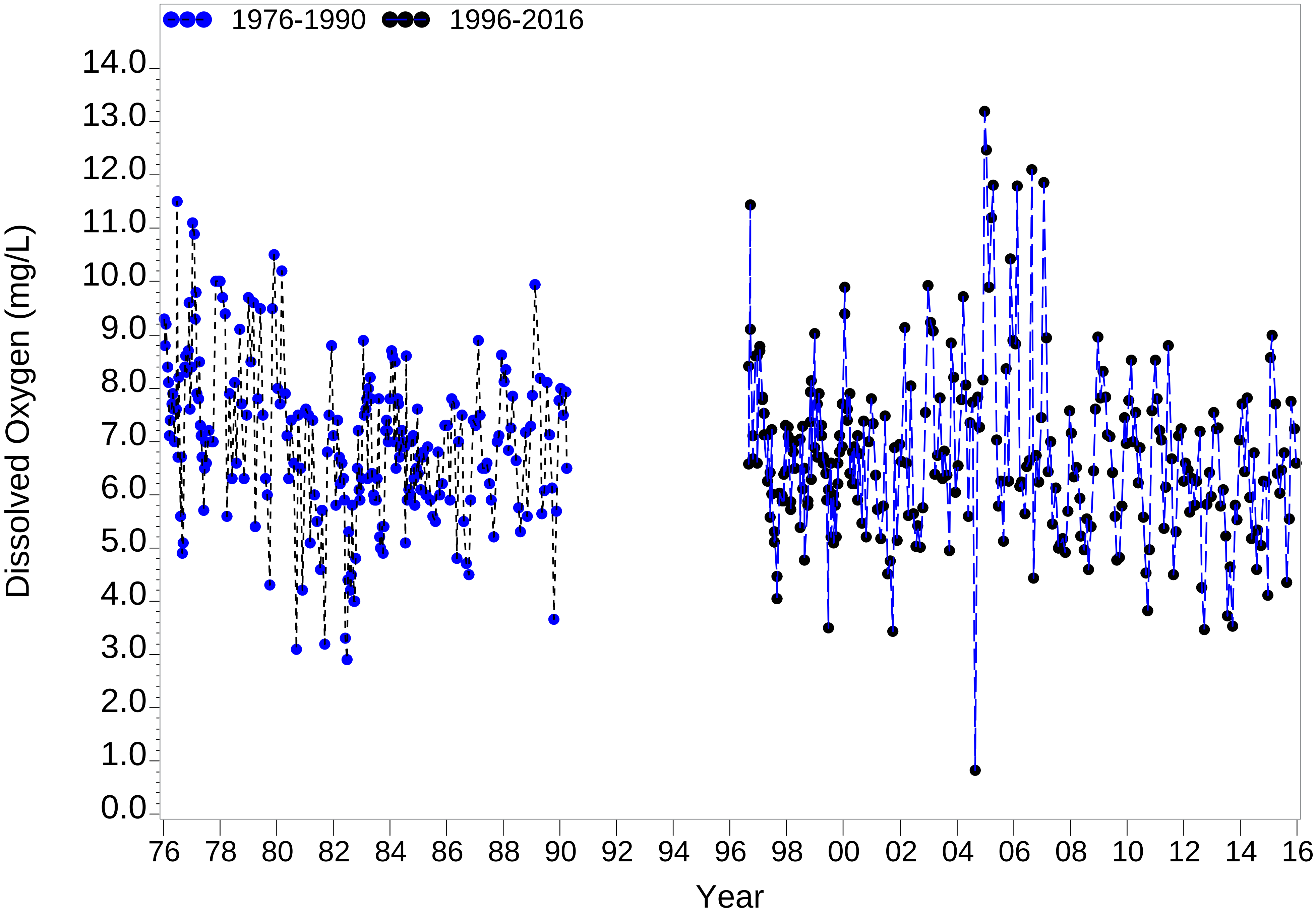

Figure 5.5. Monthly long-term Surface Dissolved Oxygen Levels at river kilometer 6.6

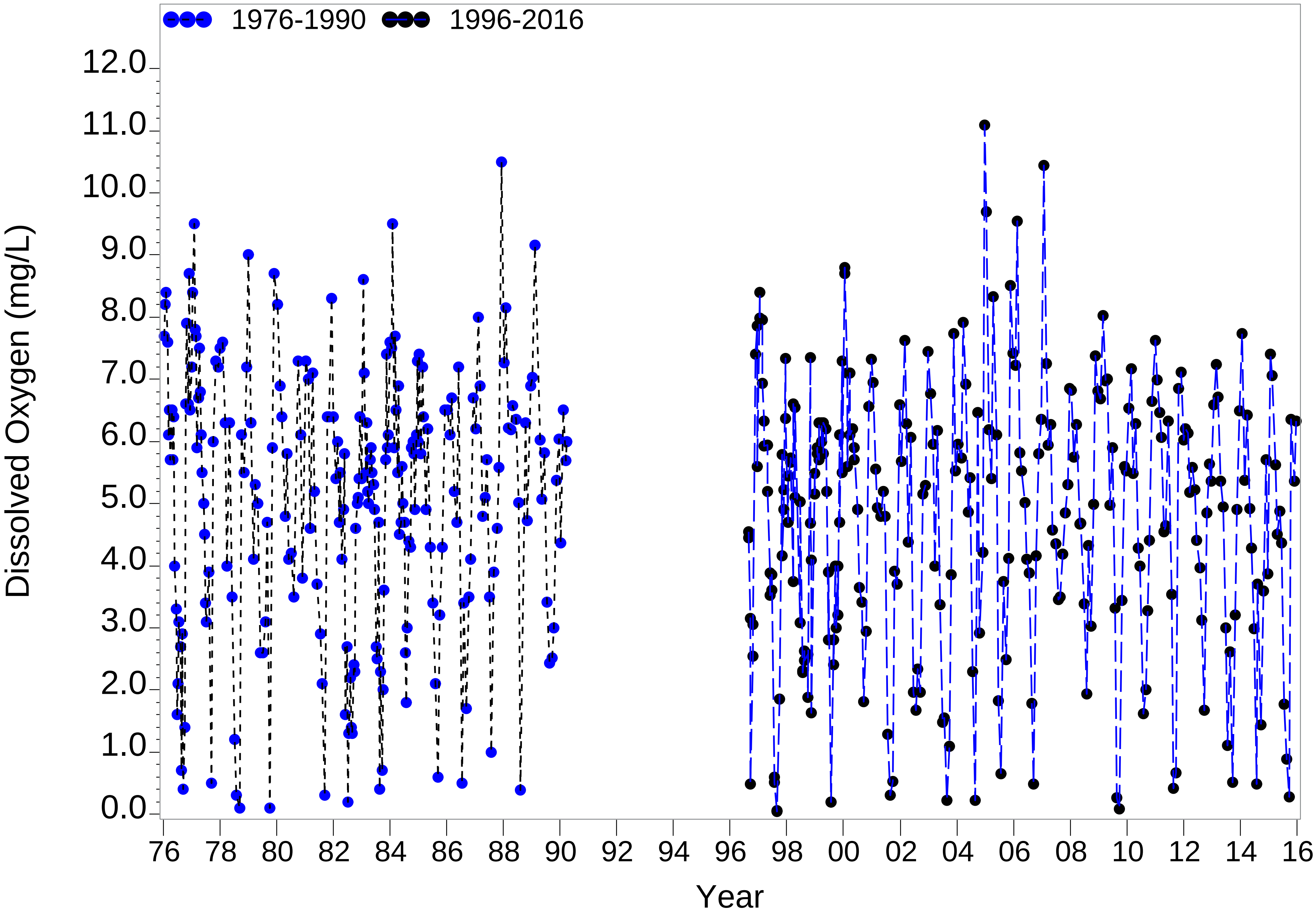

Figure 5.6. Monthly long-term Bottom Dissolved Oxygen Levels at river kilometer 6.6

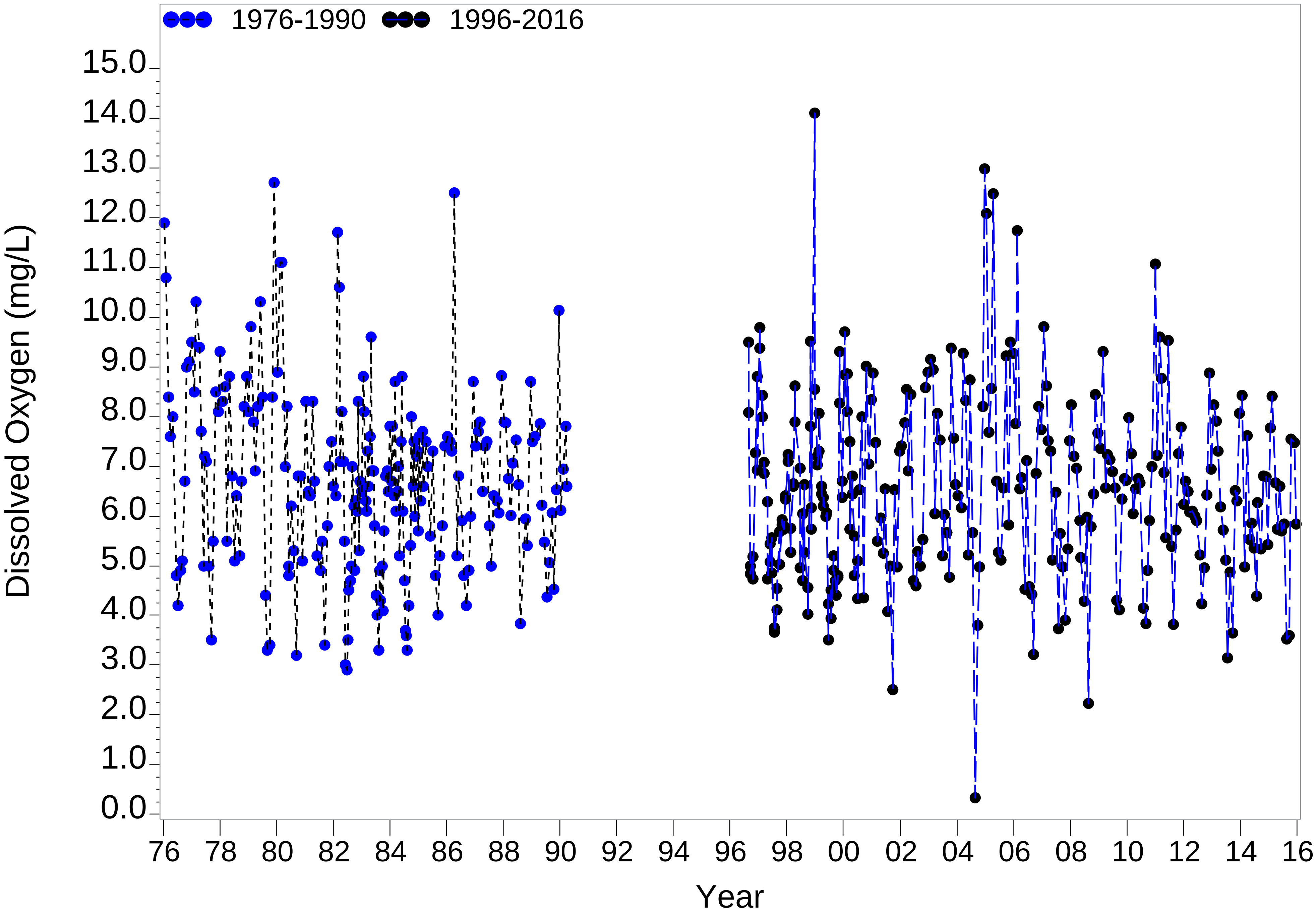

Figure 5.7. Monthly long-term Surface Dissolved Oxygen Levels at river kilometer 15.5

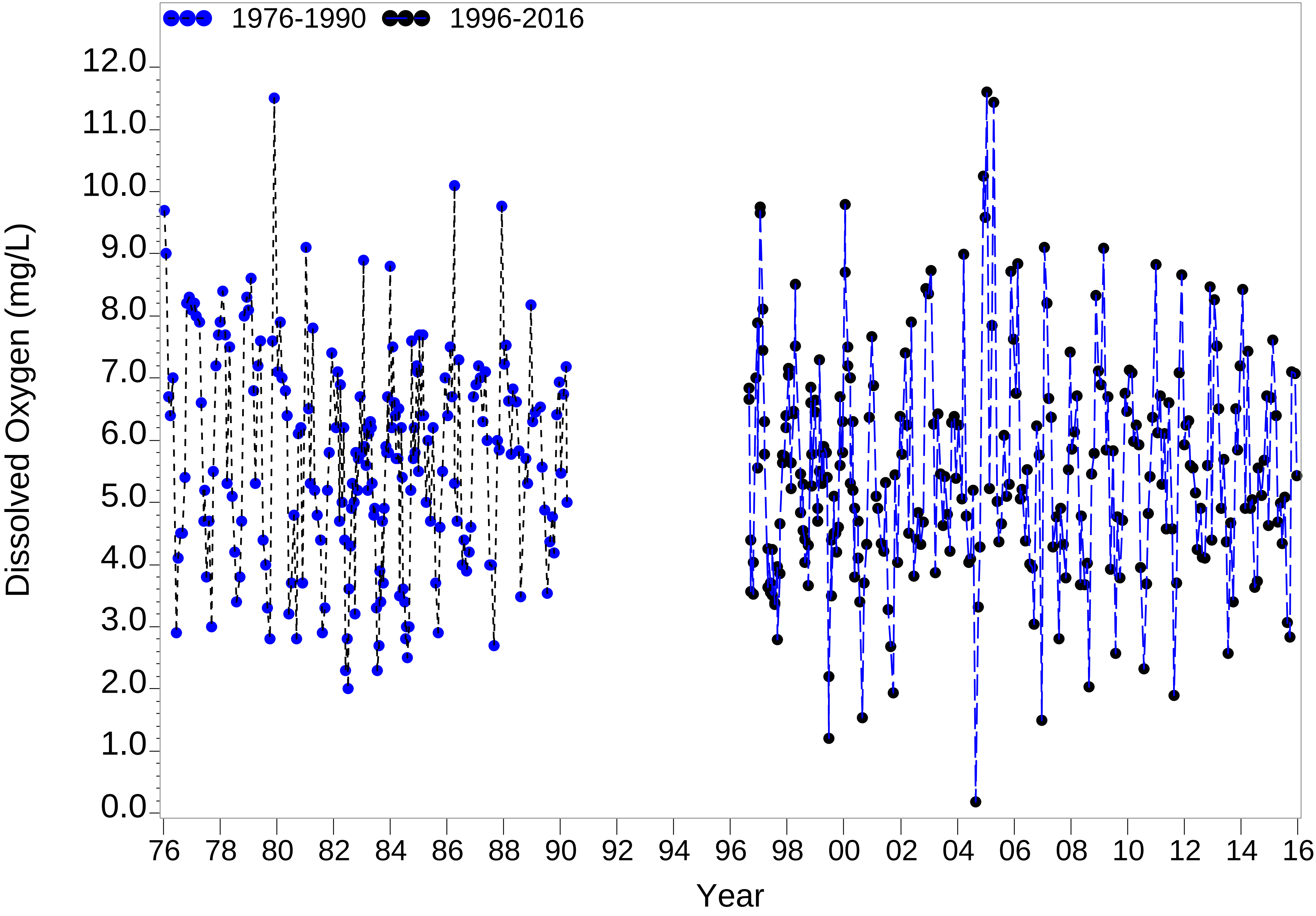

Figure 5.8. Monthly long-term Bottom Dissolved Oxygen Levels at river kilometer 15.5

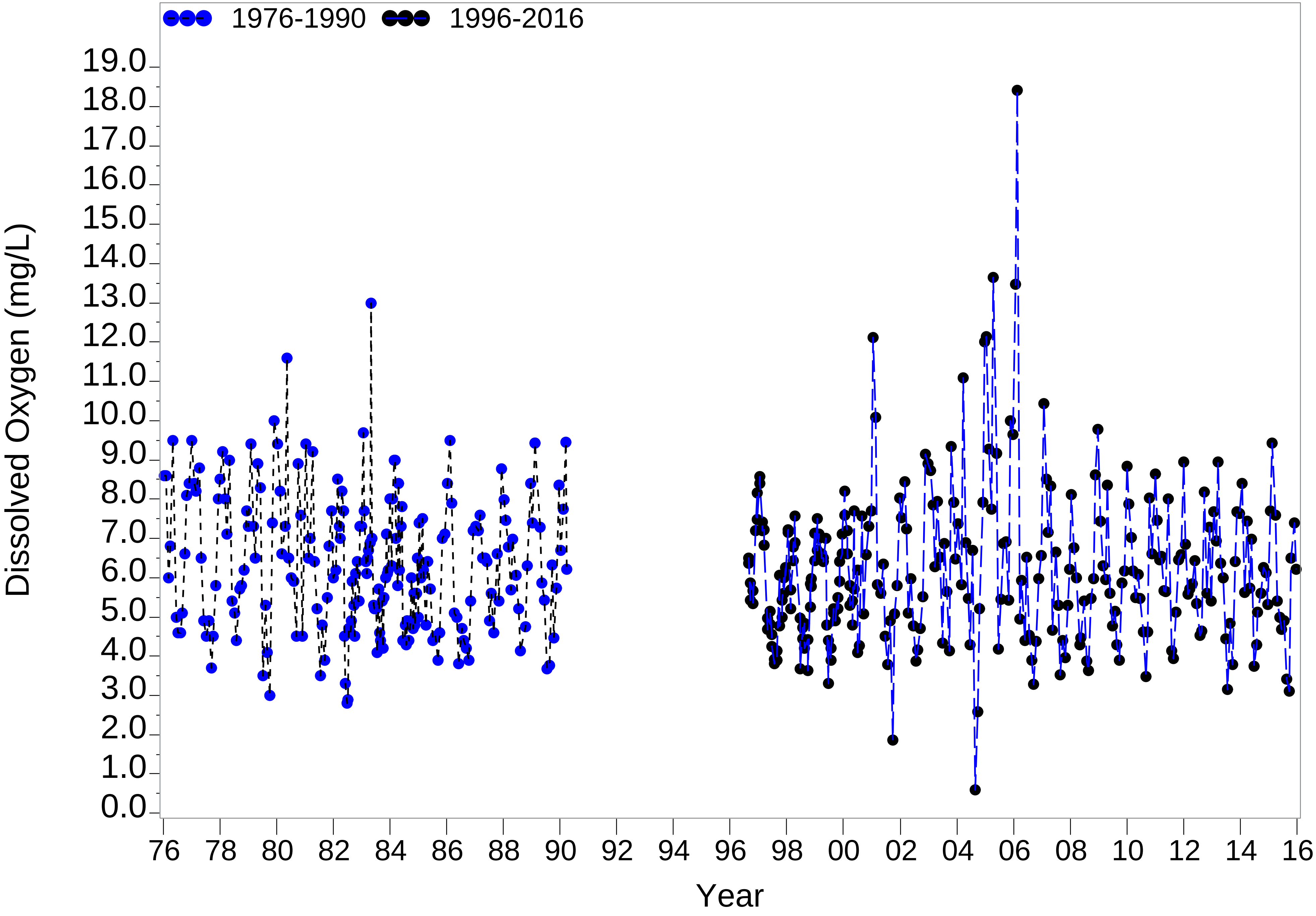

Figure 5.9. Monthly long-term Surface Dissolved Oxygen Levels at river kilometer 23.6

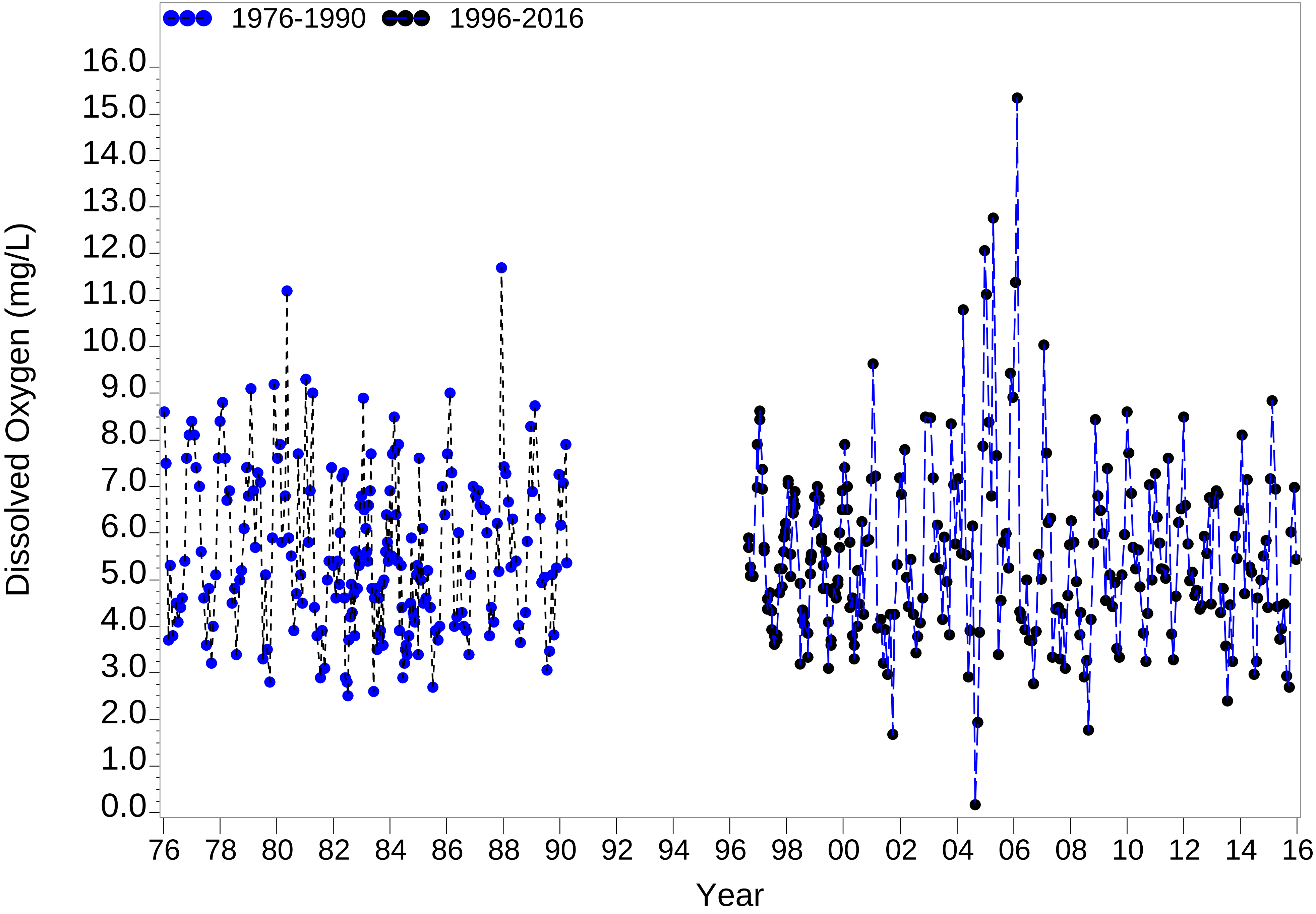

Figure 5.10. Monthly long-term Bottom Dissolved Oxygen Levels at river kilometer 23.6

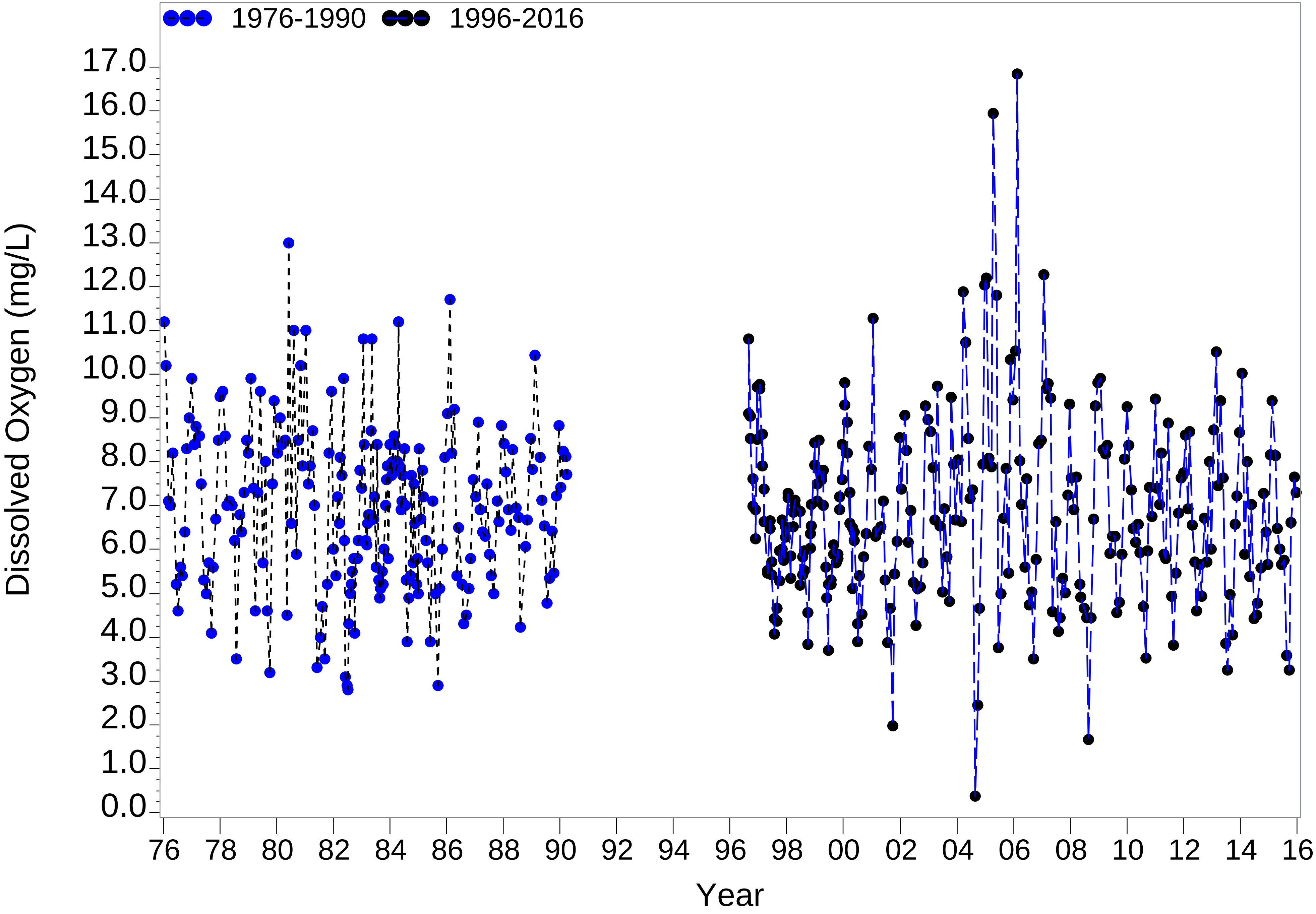

Figure 5.11. Monthly long-term Surface Dissolved Oxygen Levels at river kilometer 30.7

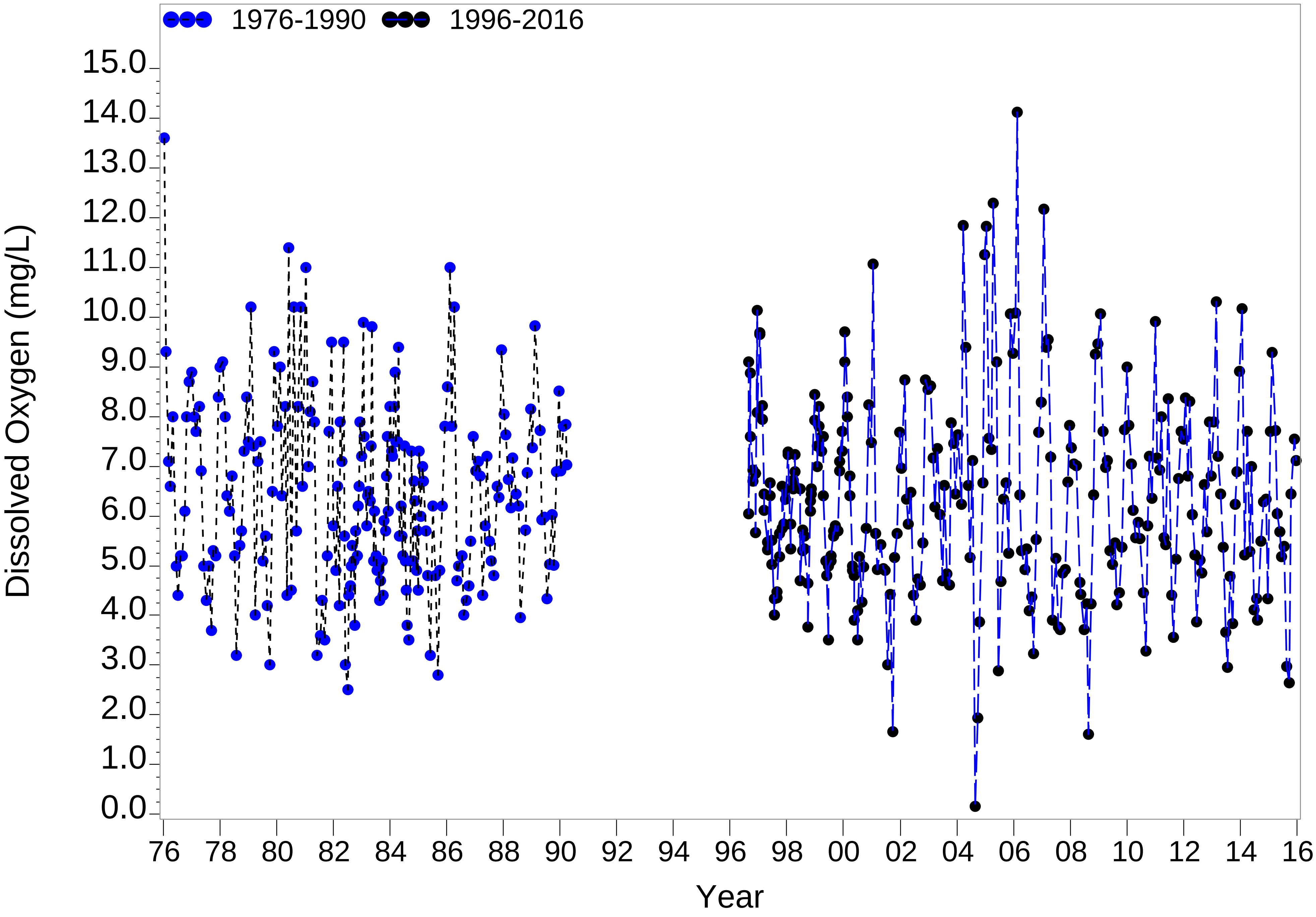

Figure 5.12. Monthly long-term Bottom Dissolved Oxygen Levels at river kilometer 30.7

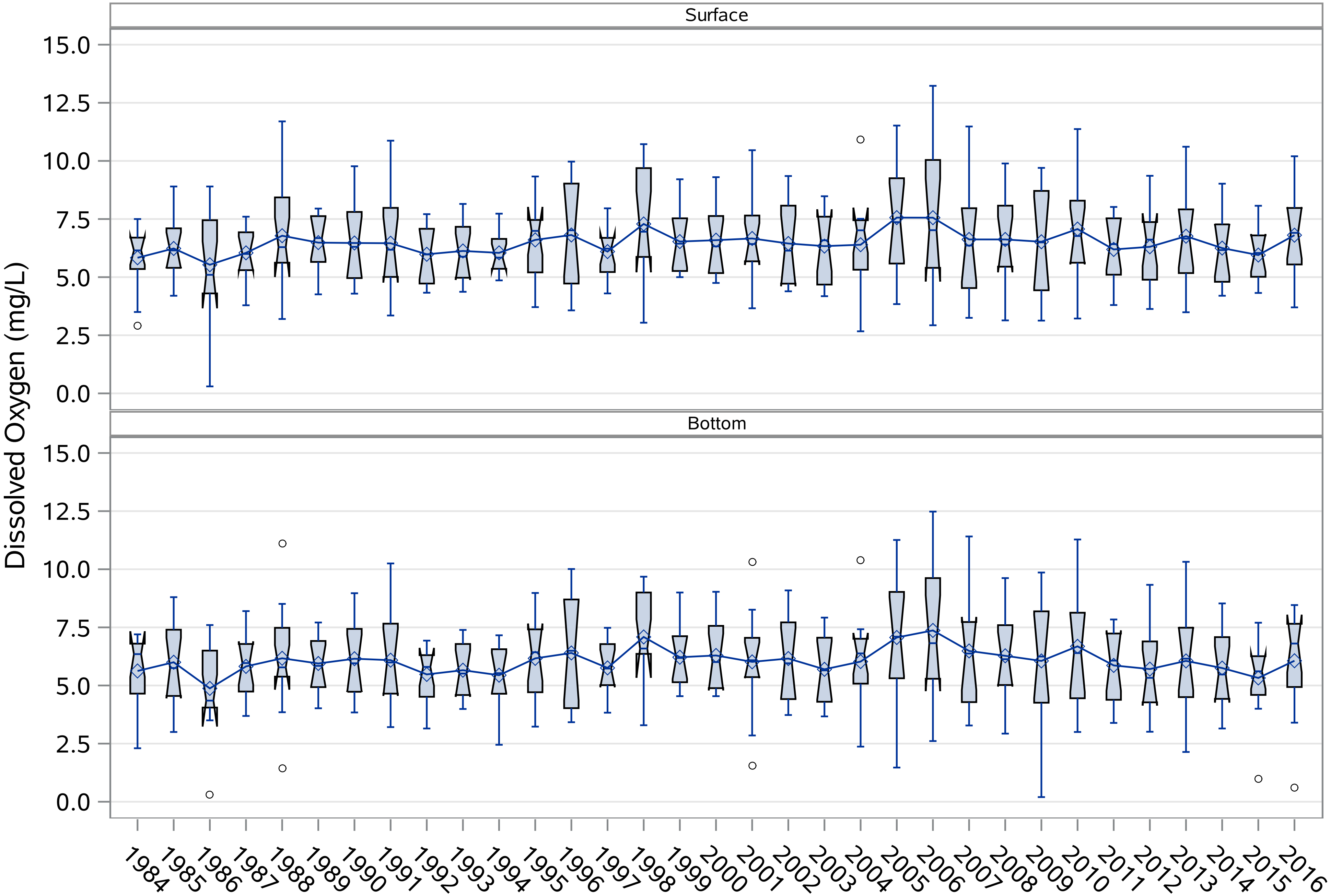

Figure 5.13. Annual boxplots of surface and bottom Dissolved Oxygen at the 0 psu isohaline (1984-2016)

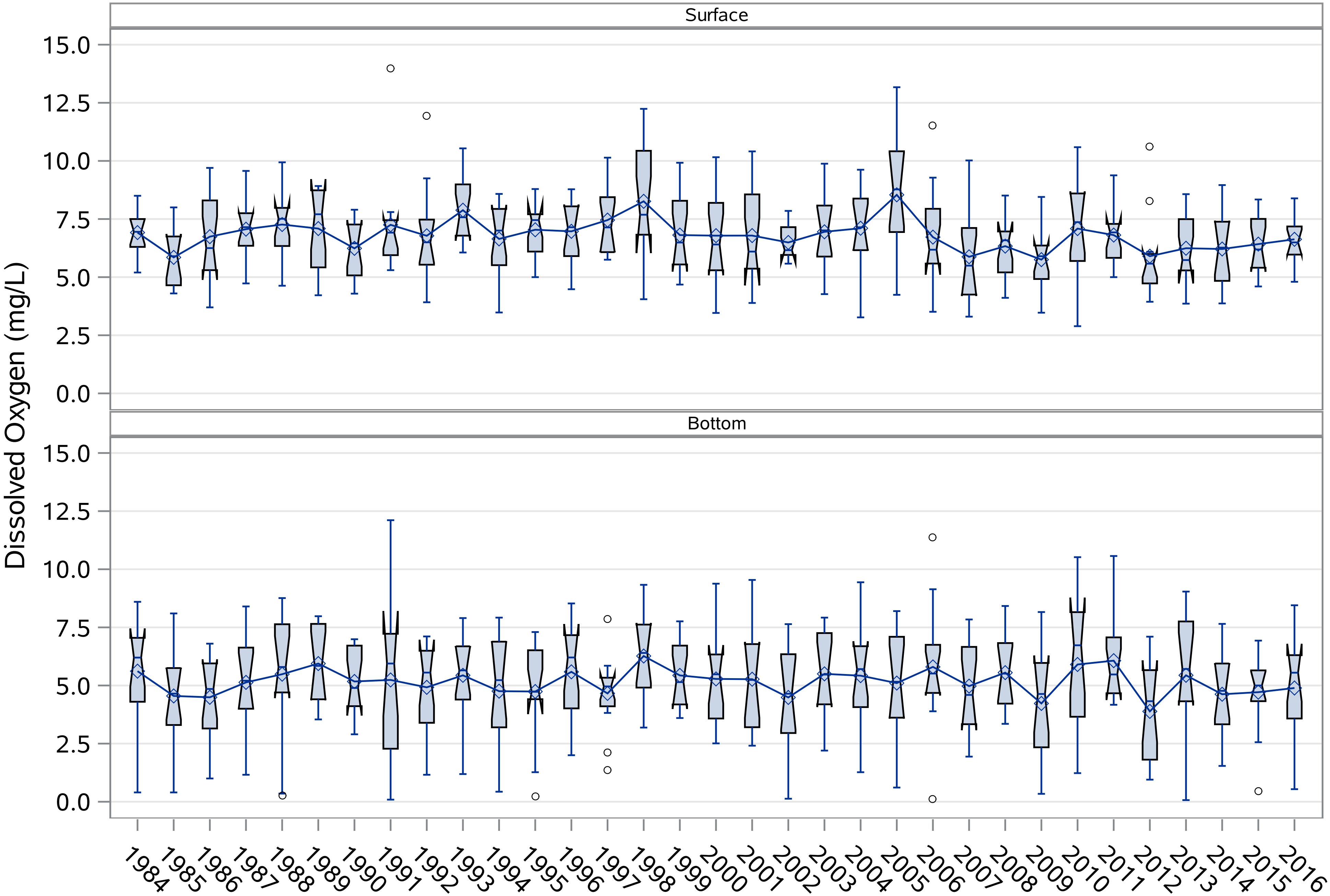

Figure 5.14. Annual boxplots of surface and bottom Dissolved Oxygen at the 6 psu isohaline (1984-2016)

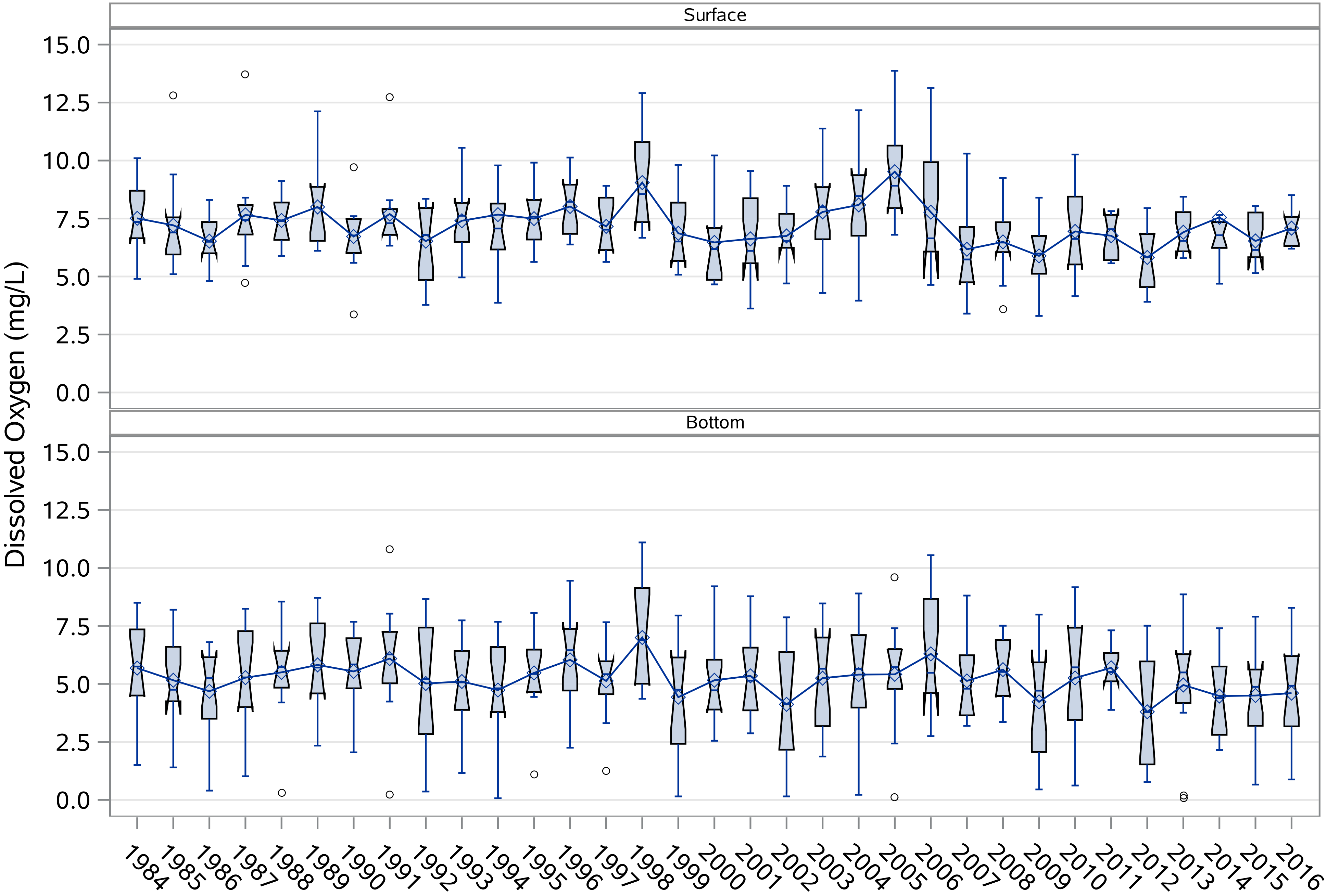

Figure 5.15. Annual boxplots of surface and bottom Dissolved Oxygen at the 12 psu isohaline (1984-2016)

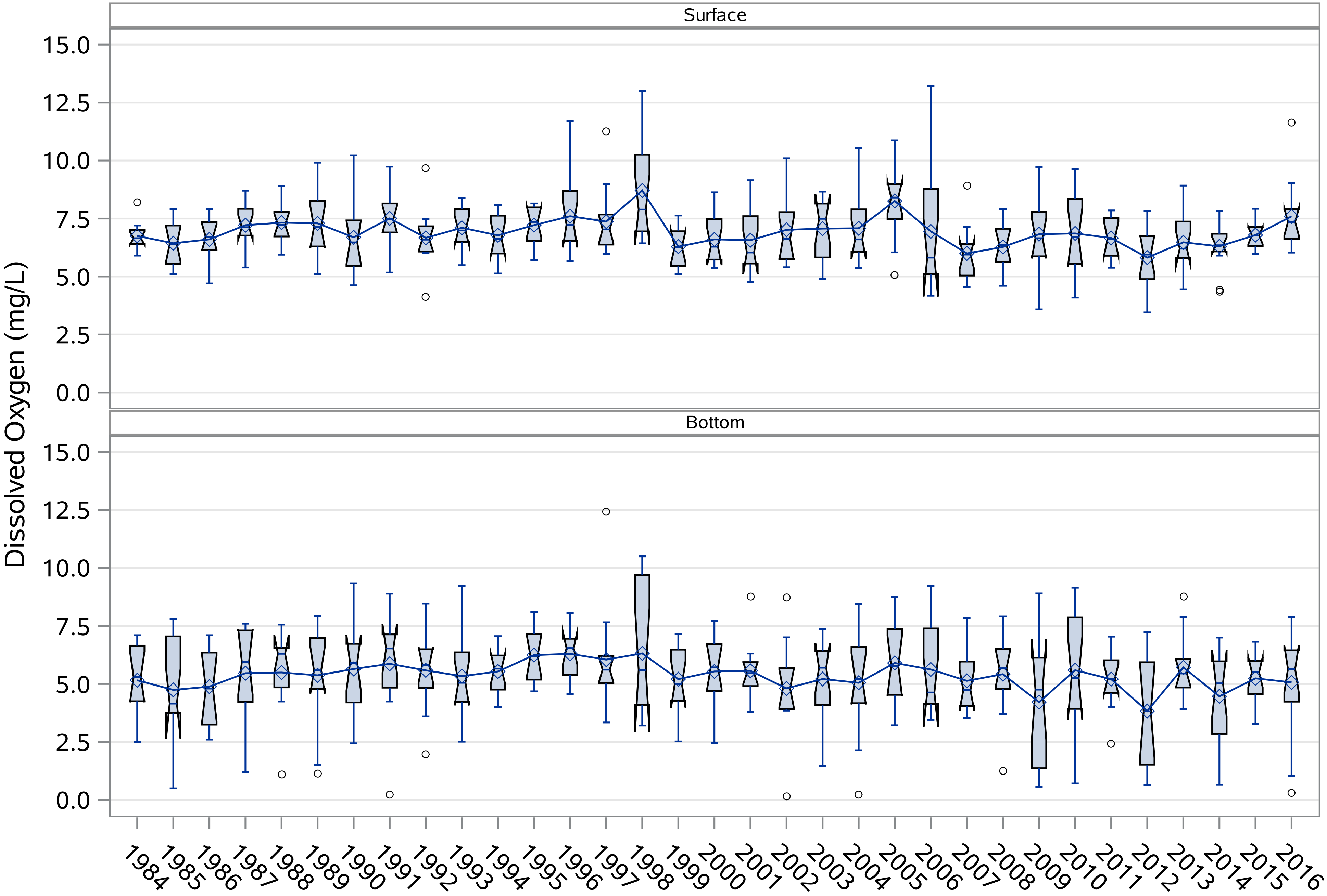

Figure 5.16. Annual boxplots of surface and bottom Dissolved Oxygen at the 20 psu isohaline (1984-2016)

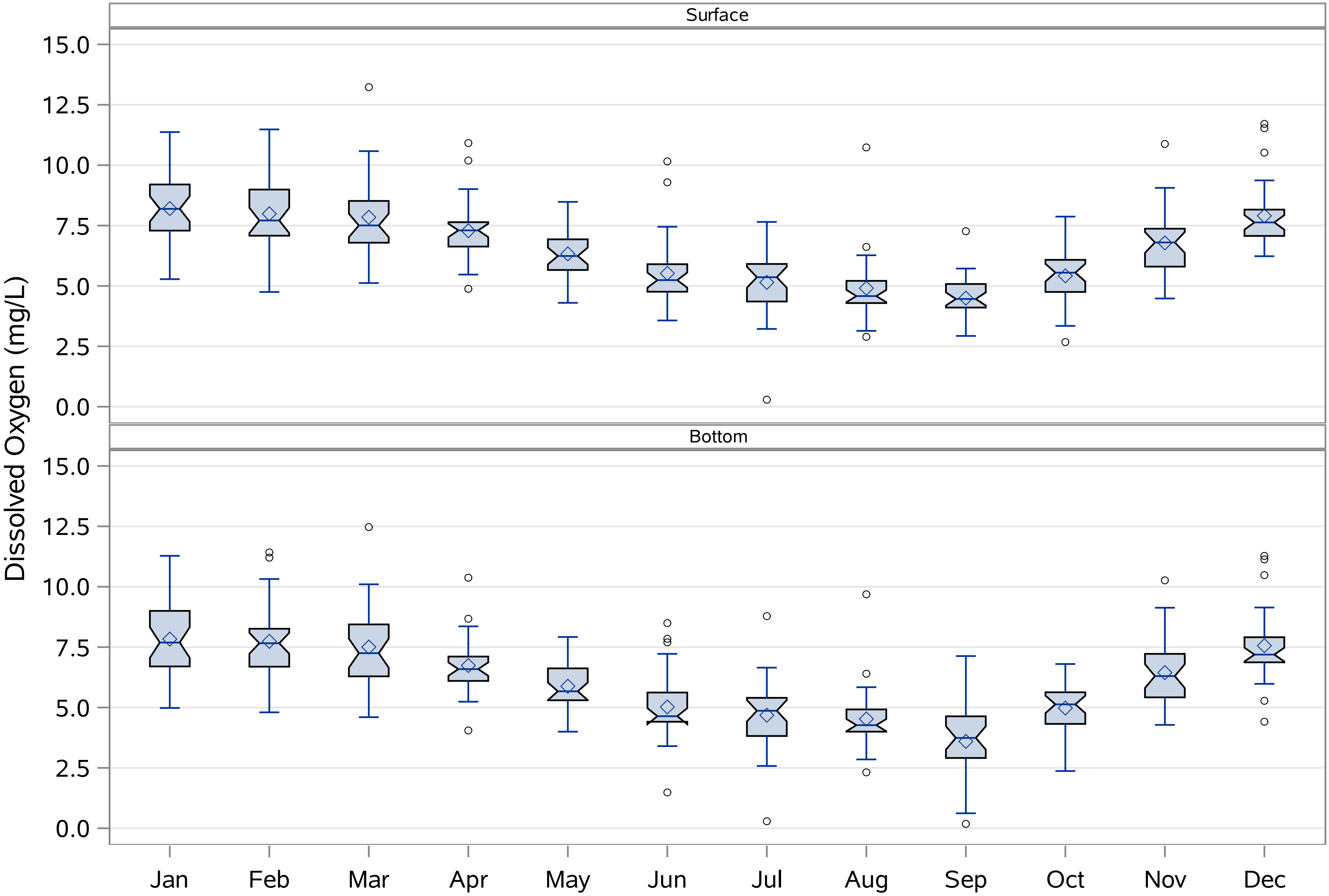

Figure 5.17. Mean monthly boxplots of surface and bottom Dissolved Oxygen at the 0 psu isohaline (1984-2016)

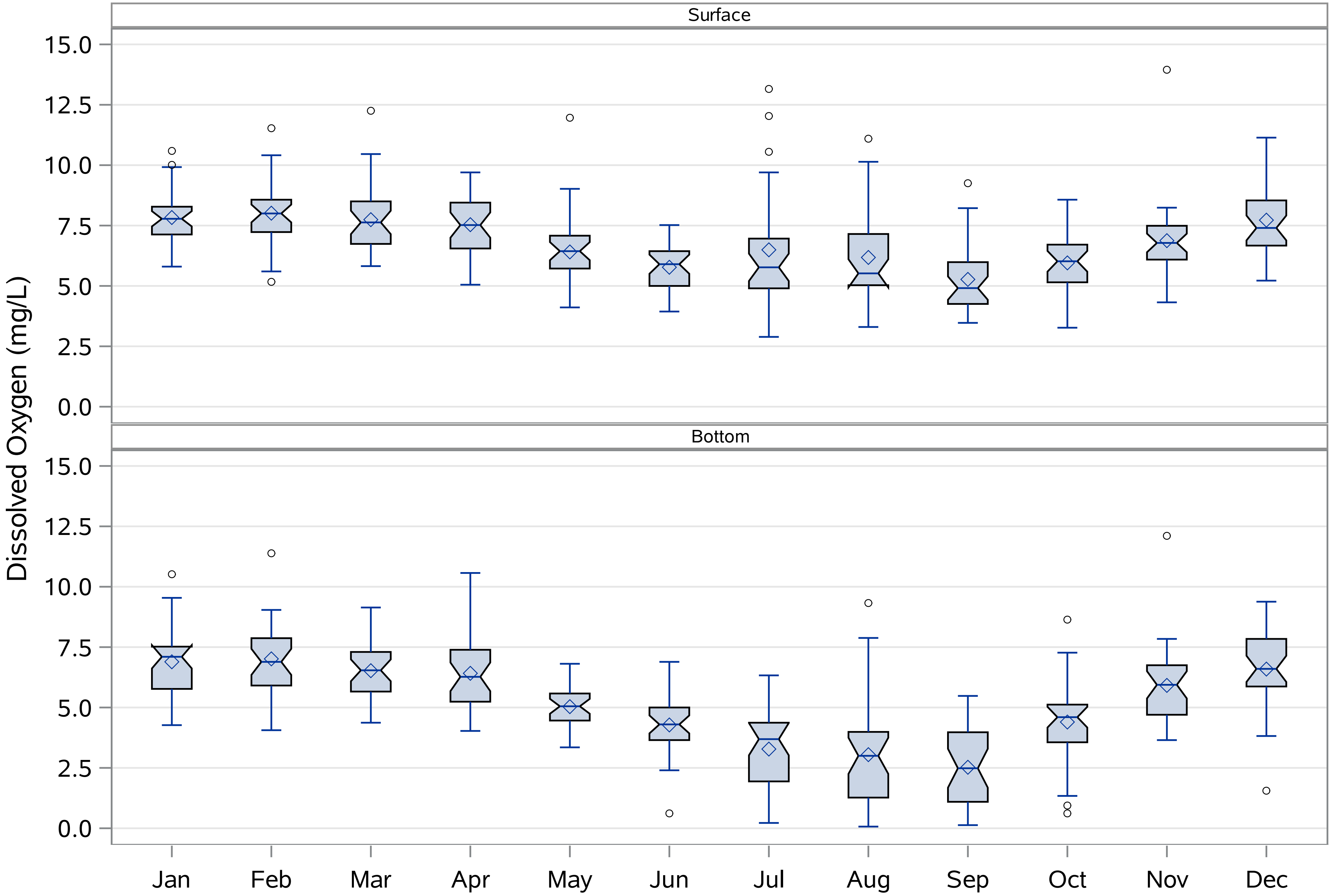

Figure 5.18. Mean monthly boxplots of surface and bottom Dissolved Oxygen at the 6 psu isohaline (1984-2016)

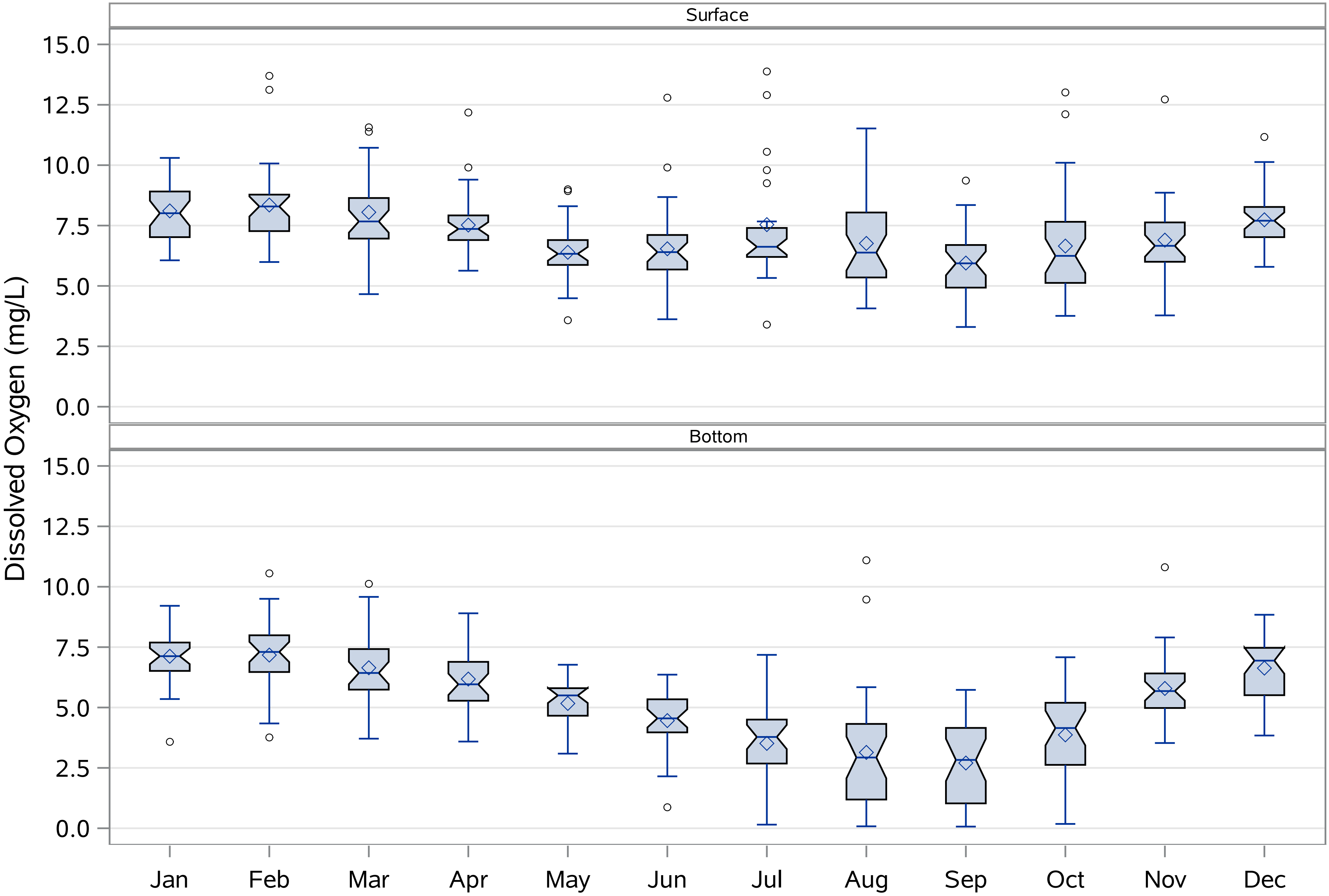

Figure 5.19. Mean monthly boxplots of surface and bottom Dissolved Oxygen at the 12 psu isohaline (1984-2016)

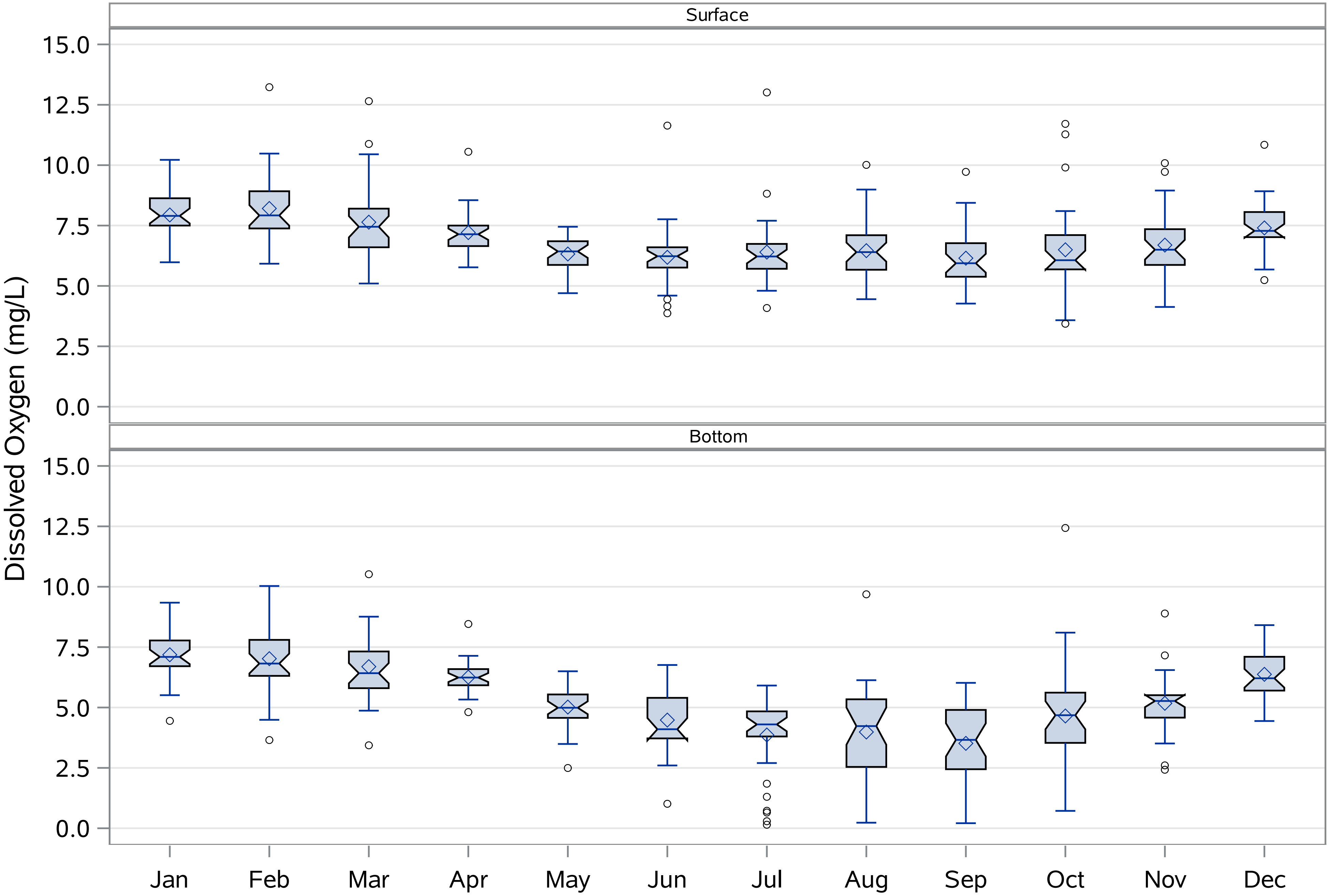

Figure 5.20. Mean monthly boxplots of surface and bottom Dissolved Oxygen at the 20 psu isohaline (1984-2016)

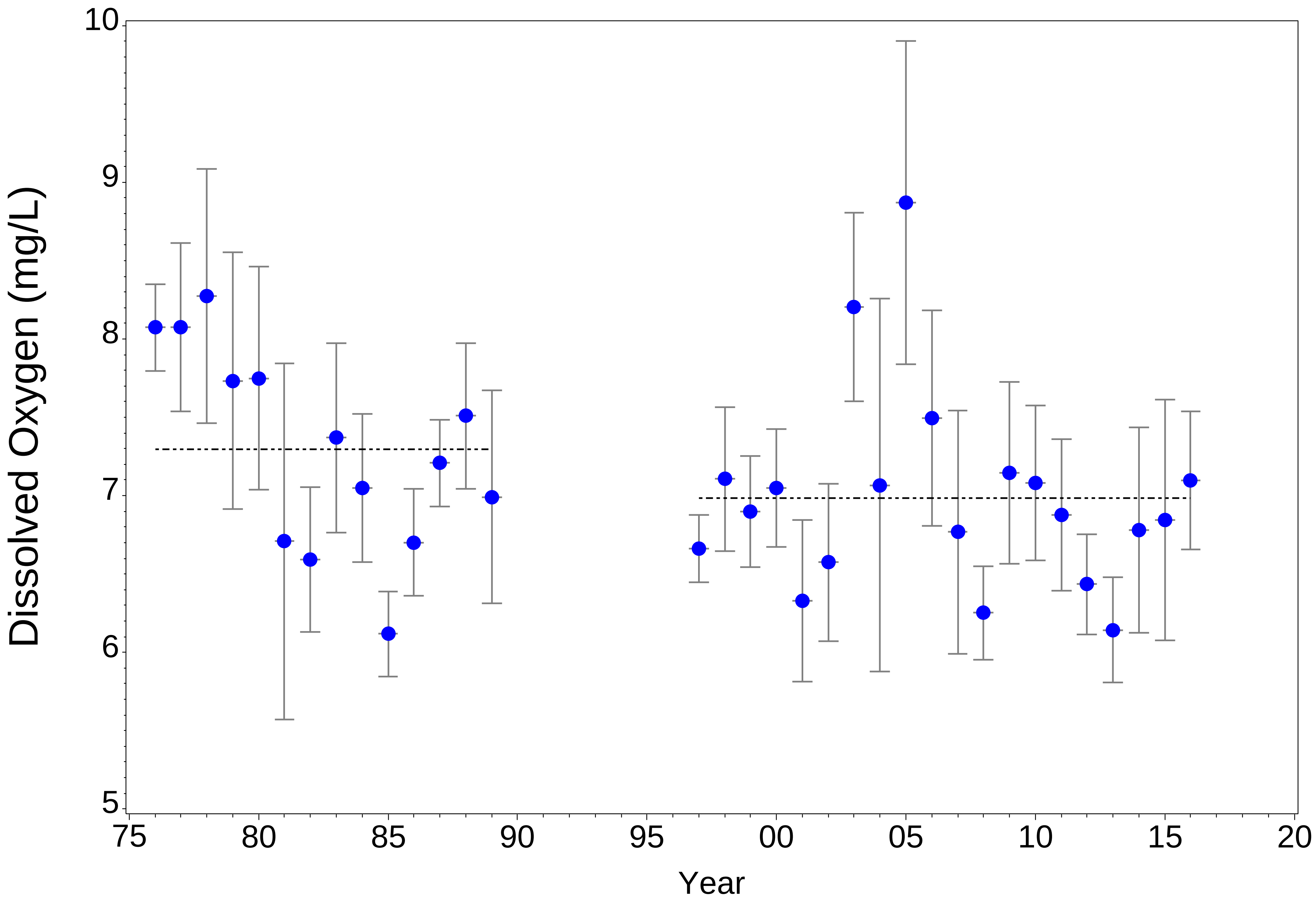

Figure 5.21. Long-term Station 9 Surface Dissolved Oxygen Levels at river kilometer -2.4

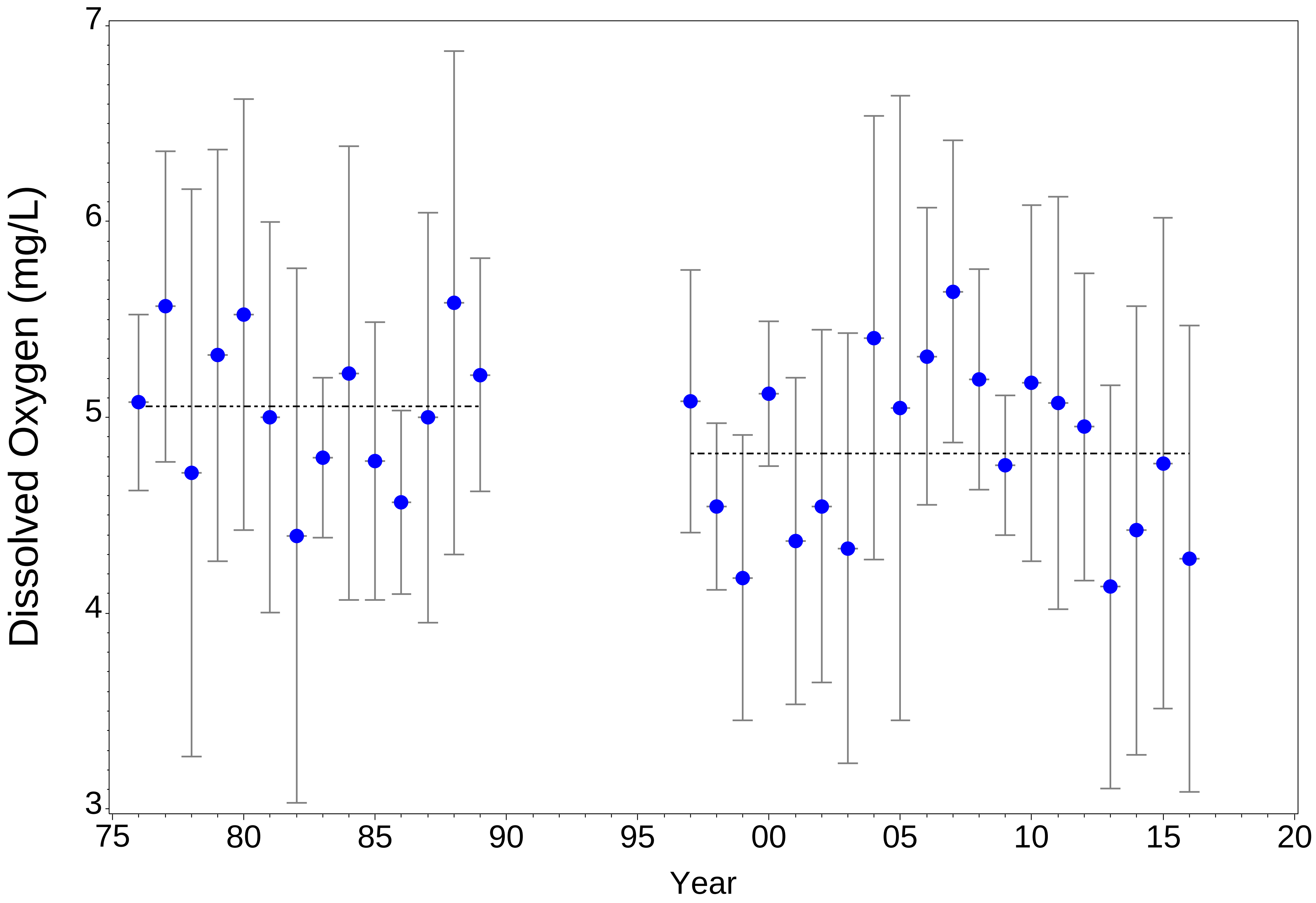

Figure 5.22. Long-term Station 9 Bottom Dissolved Oxygen Levels at river kilometer -2.4

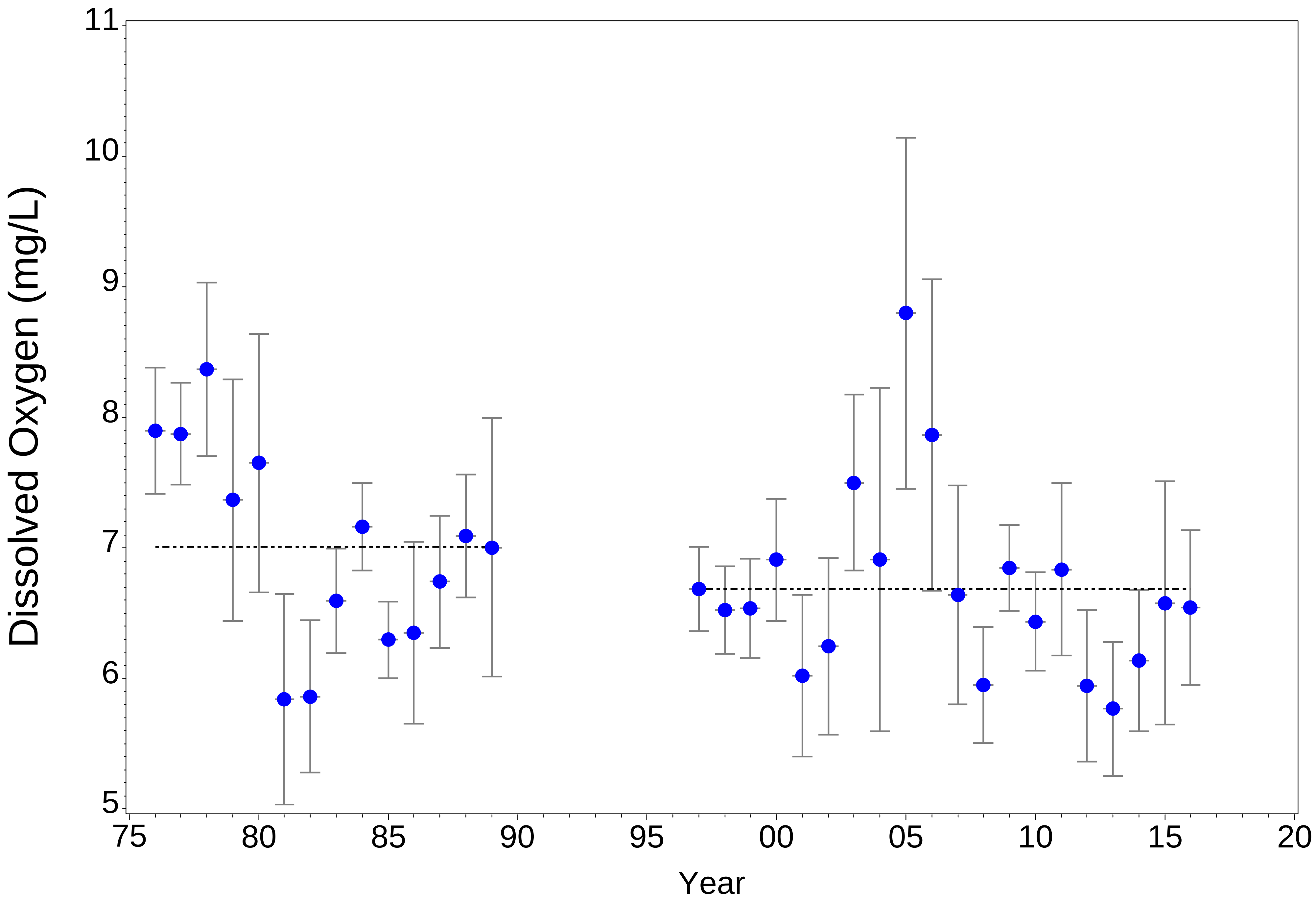

Figure 5.23. Long-term Station 10 Surface Dissolved Oxygen Levels at river kilometer 6.6

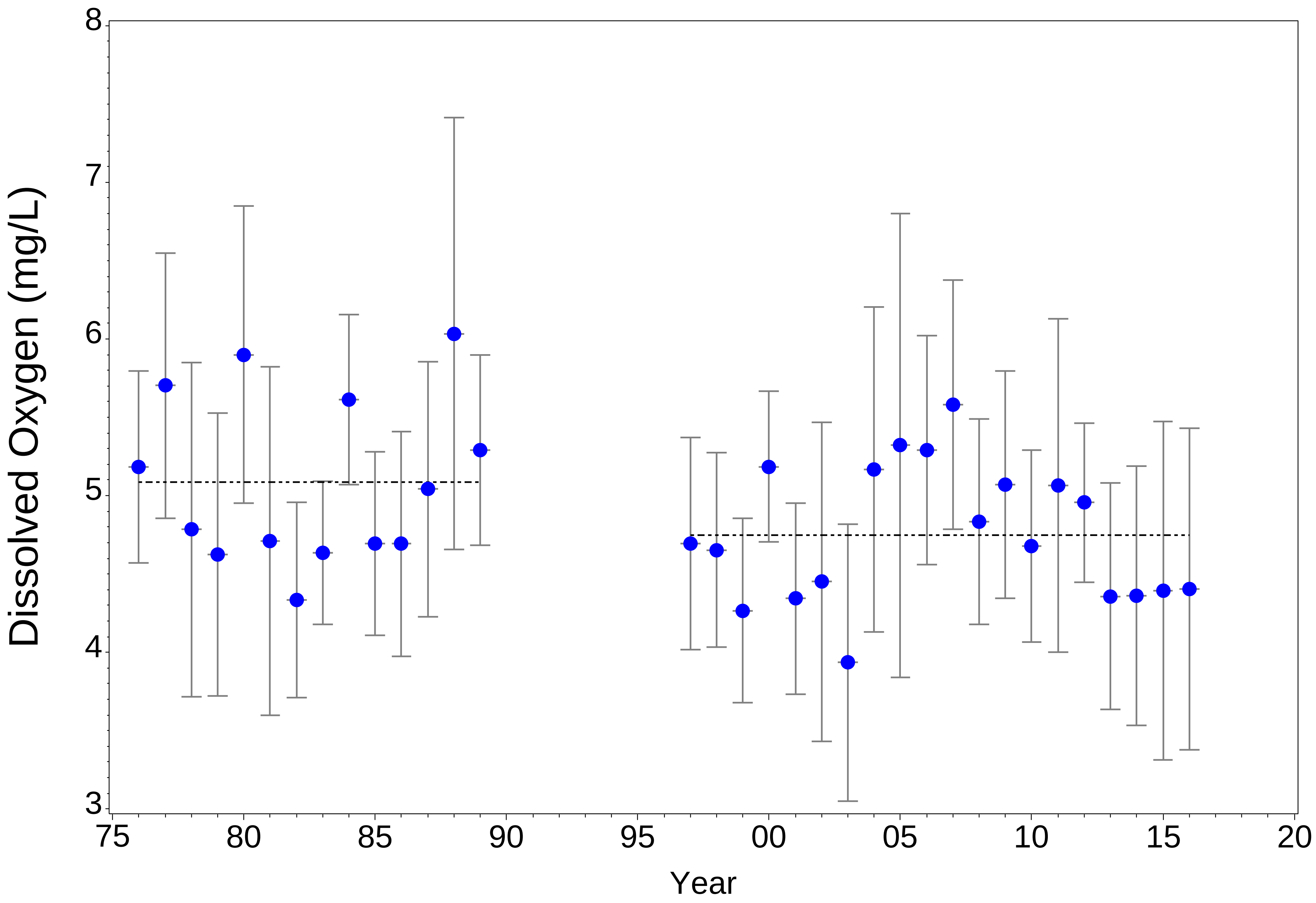

Figure 5.24. Long-term Station 10 Bottom Dissolved Oxygen Levels at river kilometer 6.6

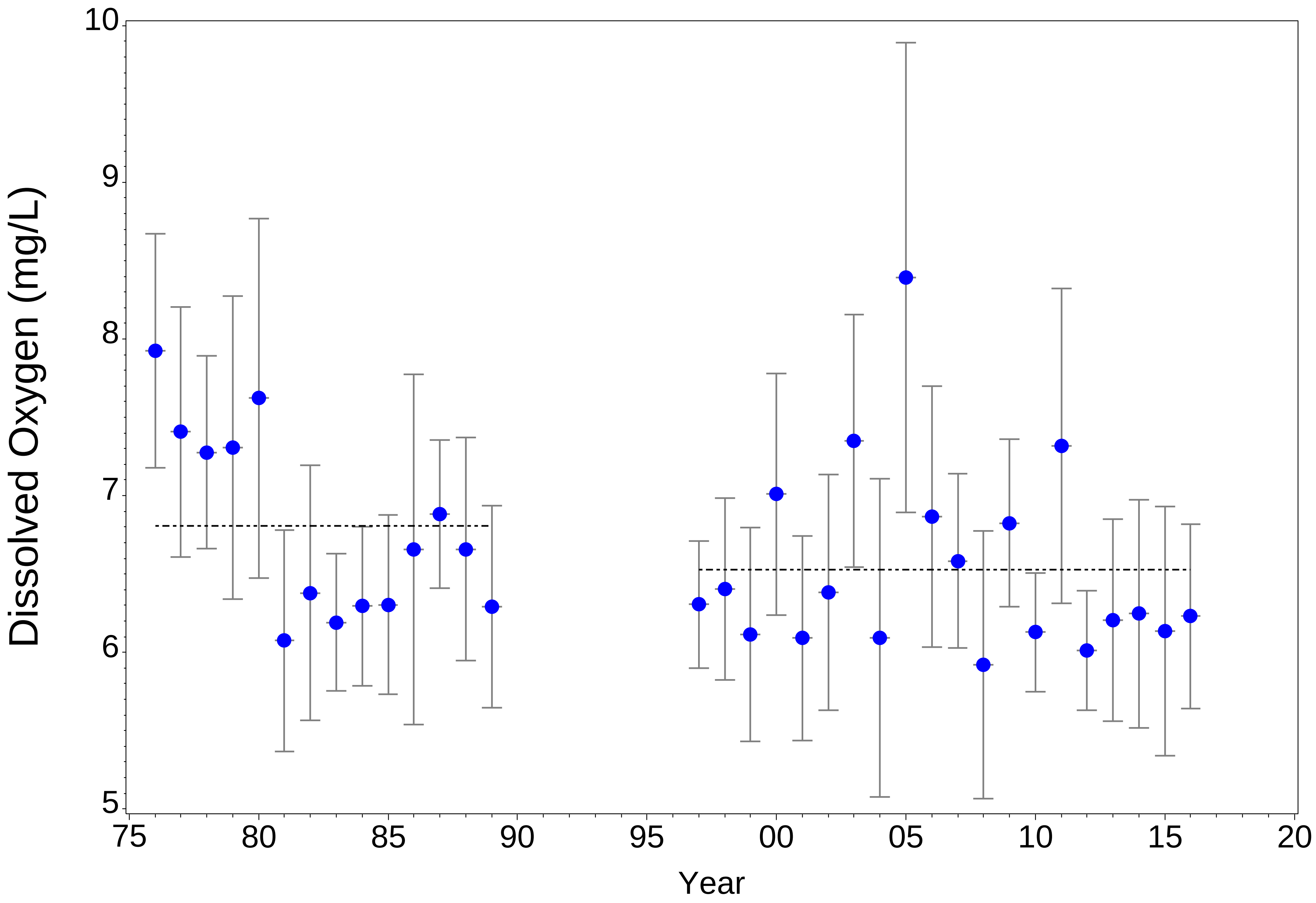

Figure 5.25. Long-term Station 12 Surface Dissolved Oxygen Levels at river kilometer 15.5

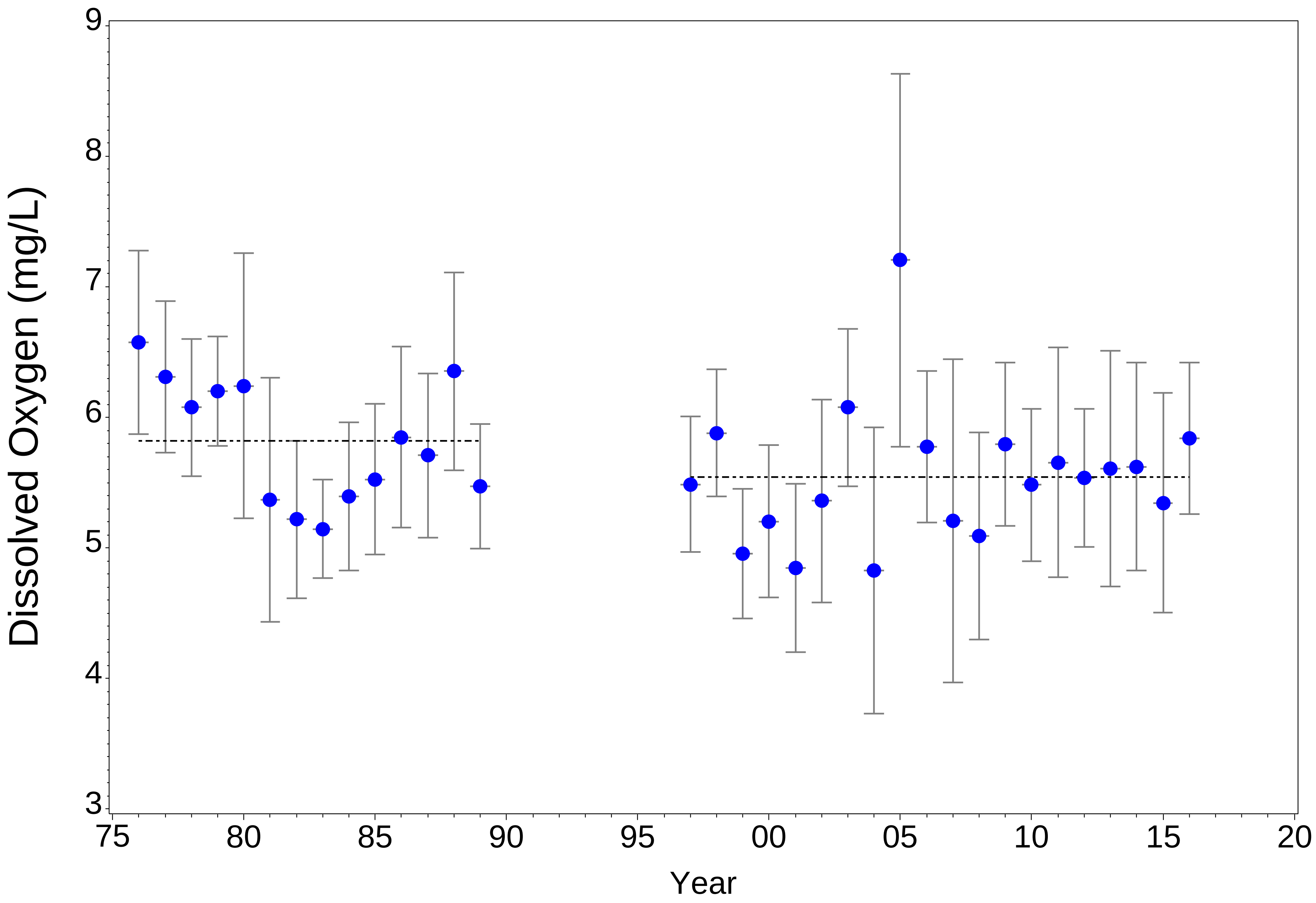

Figure 5.26. Long-term Station 12 Bottom Dissolved Oxygen Levels at river kilometer 15.5

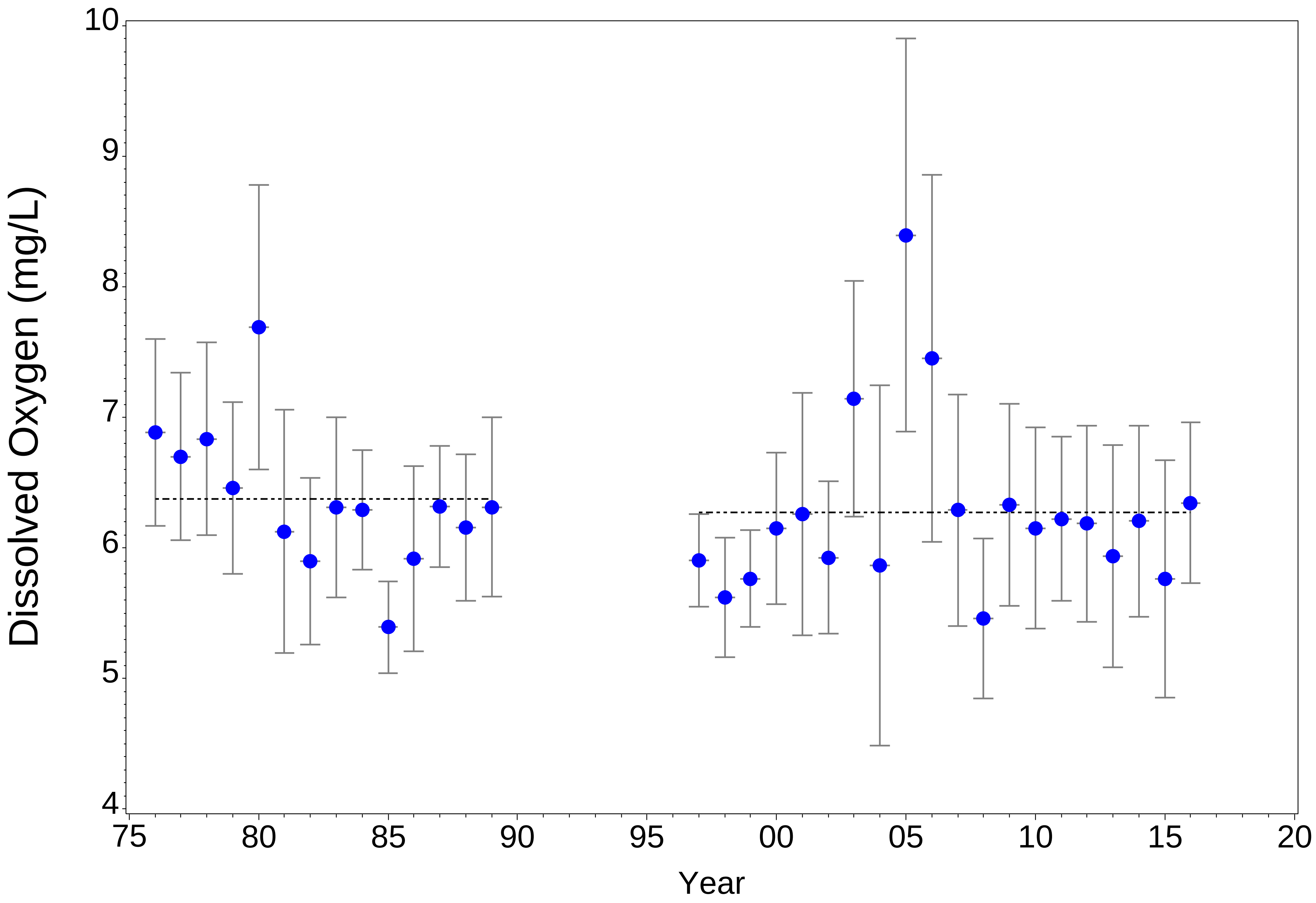

Figure 5.27. Long-term Station 14 Surface Dissolved Oxygen Levels at river kilometer 23.6

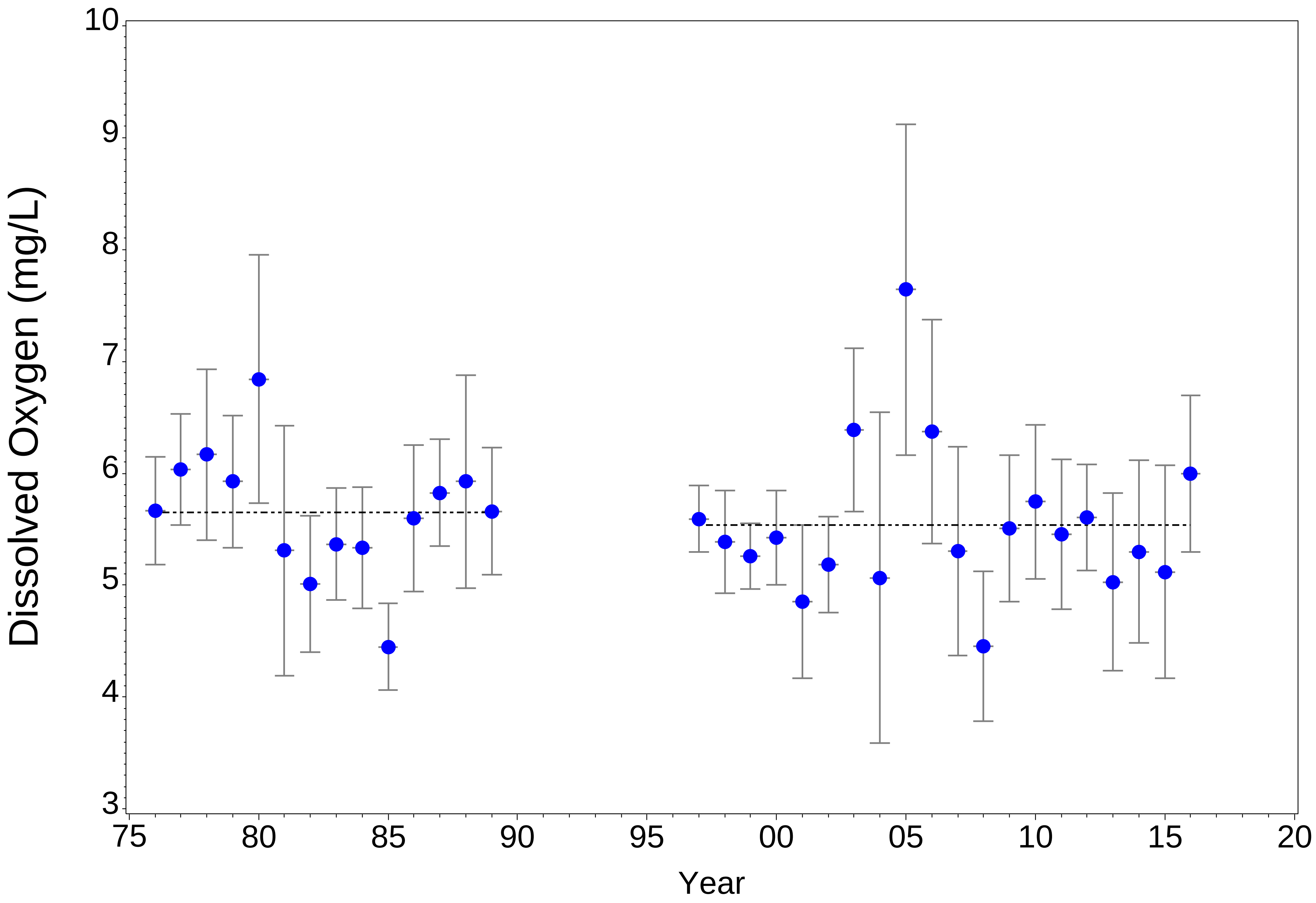

Figure 5.28. Long-term Station 14 Bottom Dissolved Oxygen Levels at river kilometer 23.6

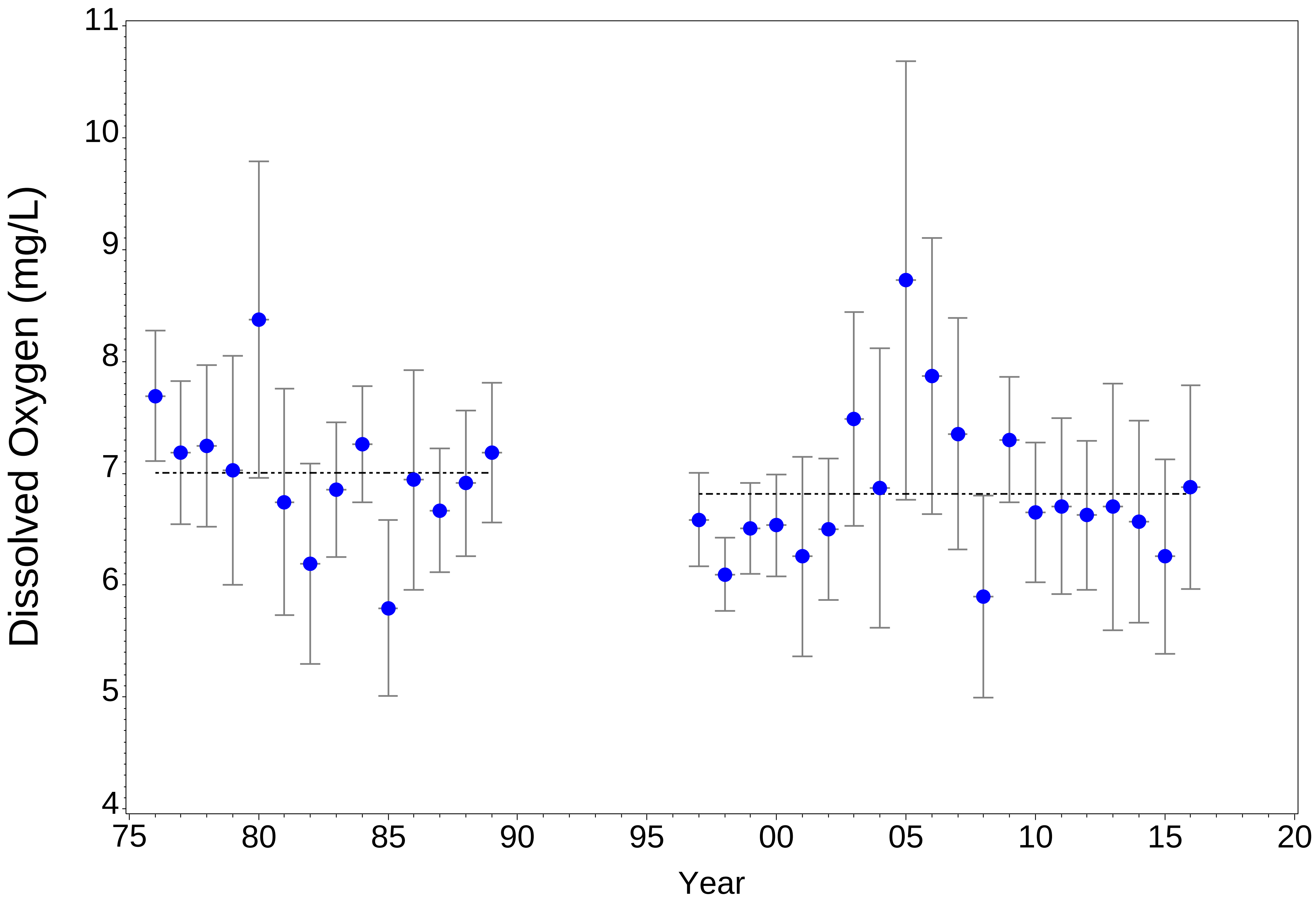

Figure 5.29. Long-term Station 18 Surface Dissolved Oxygen Levels at river kilometer 30.7

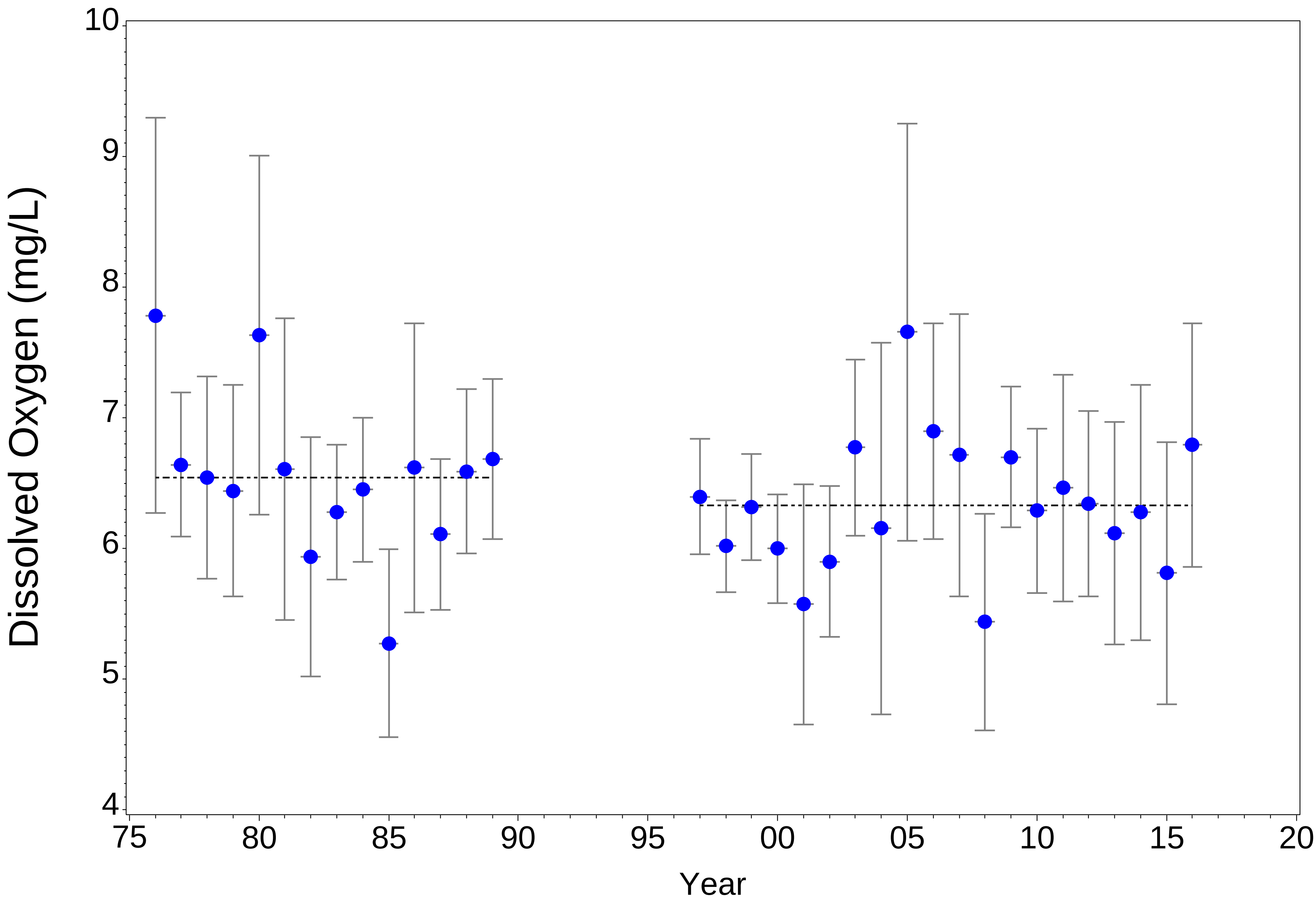

Figure 5.30. Long-term Station 18 Bottom Dissolved Oxygen Levels at river kilometer 30.7

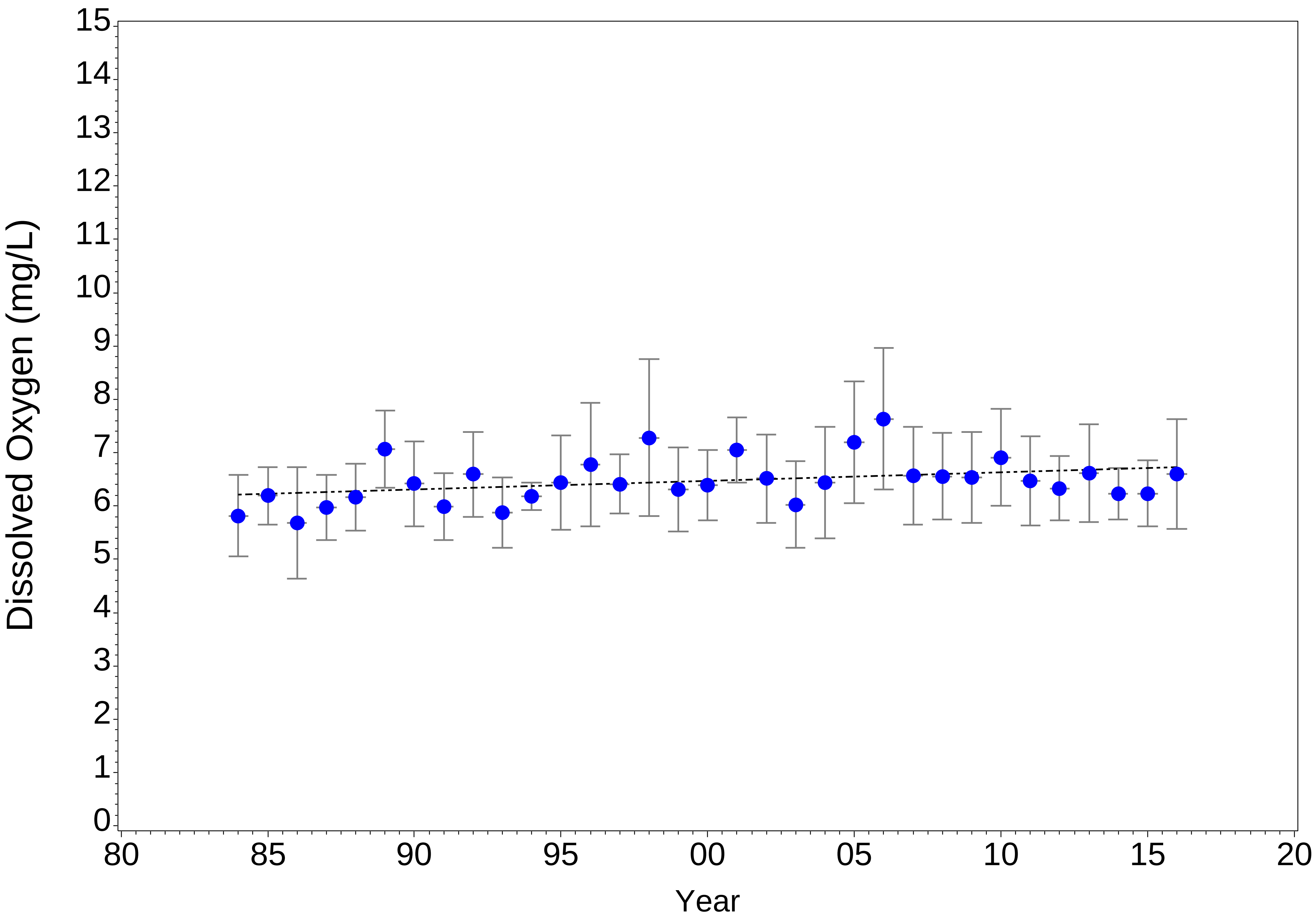

Figure 5.31. Annual monthly surface Dissolved Oxygen at 0 psu isohaline (1984-2016)

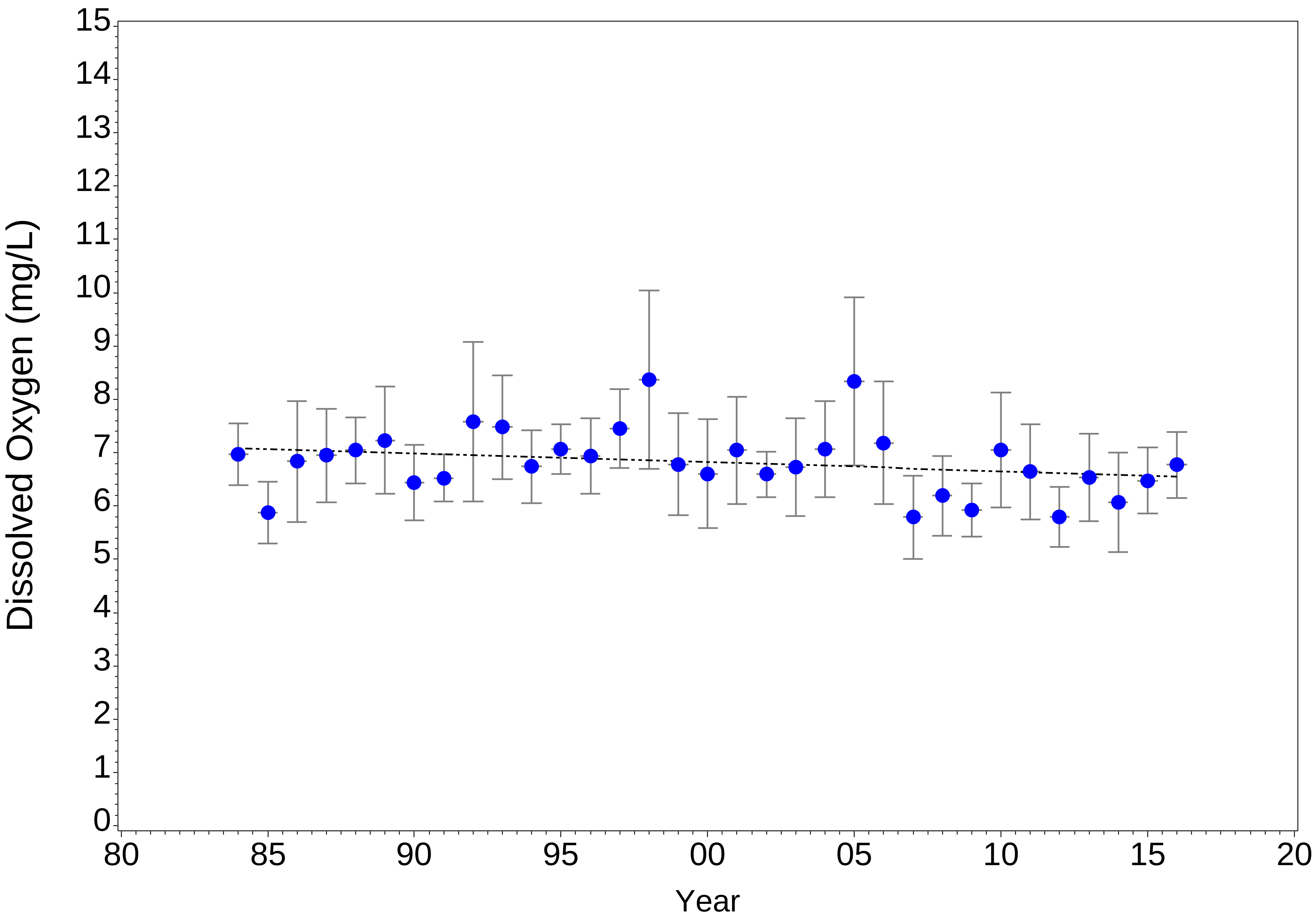

Figure 5.32. Annual monthly surface Dissolved Oxygen at 6 psu isohaline (1984-2016)

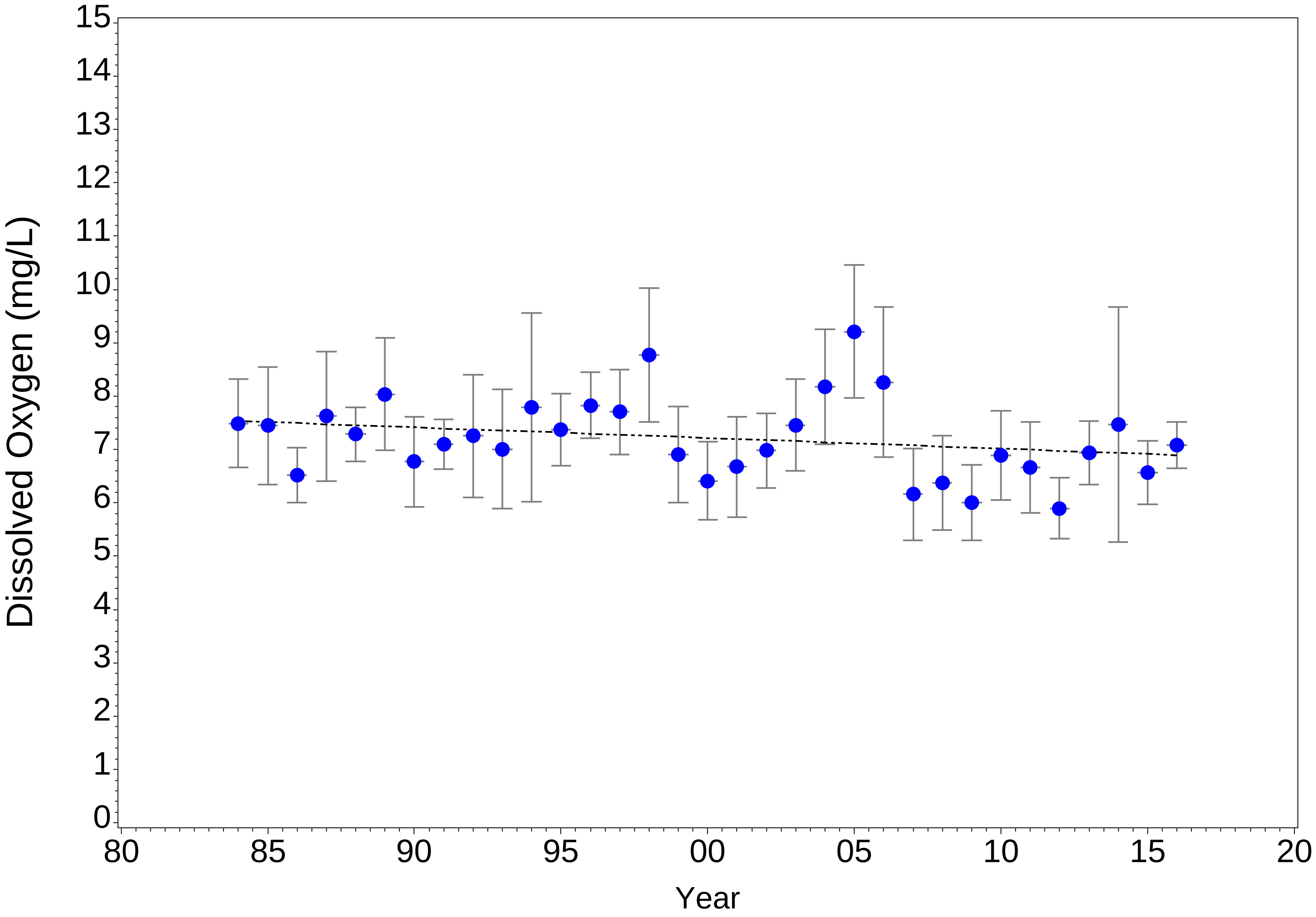

Figure 5.33. Annual monthly surface Dissolved Oxygen at 12 psu isohaline (1984-2016)

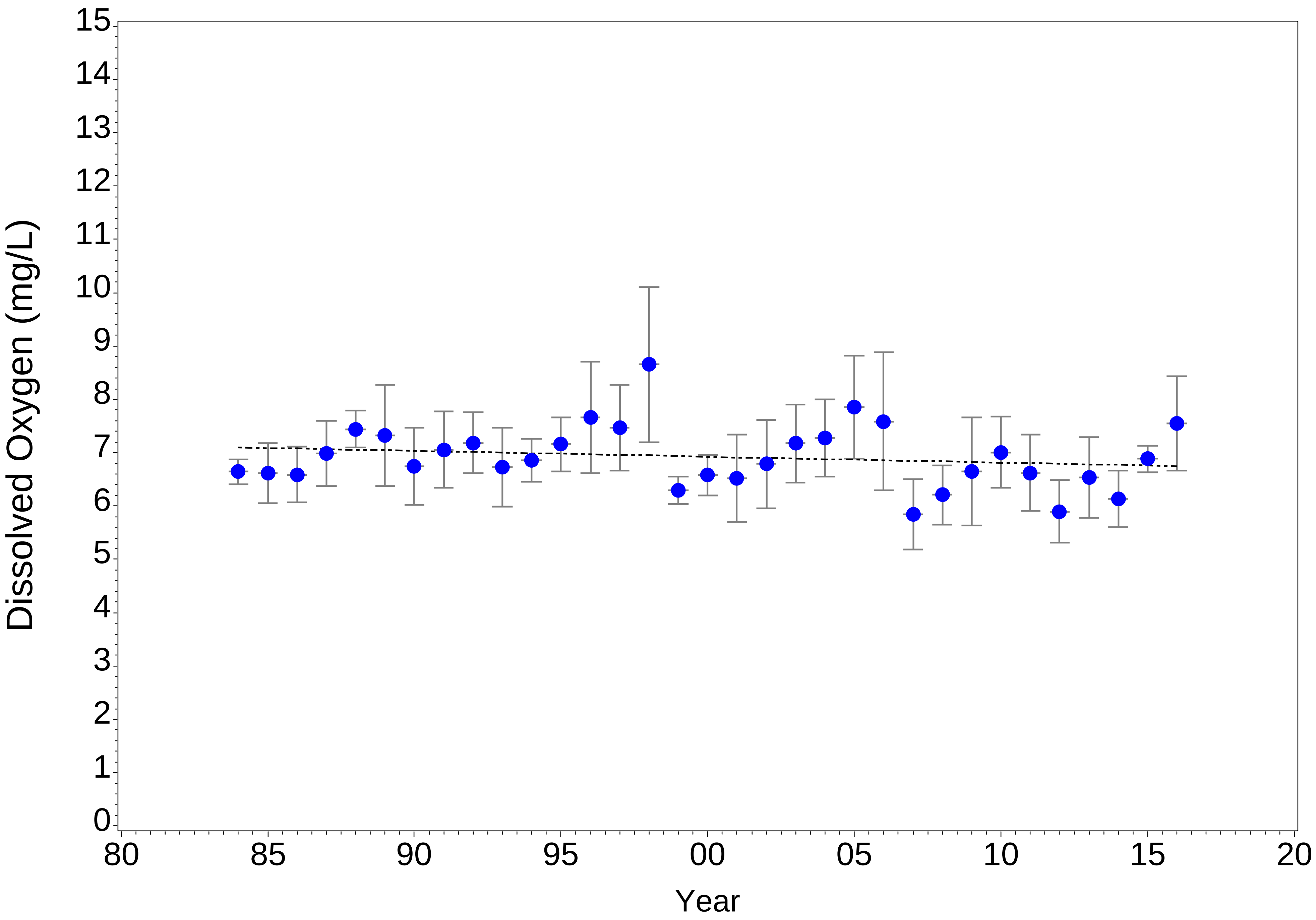

Figure 5.34. Annual monthly surface Dissolved Oxygen at 20 psu isohaline (1984-2016)

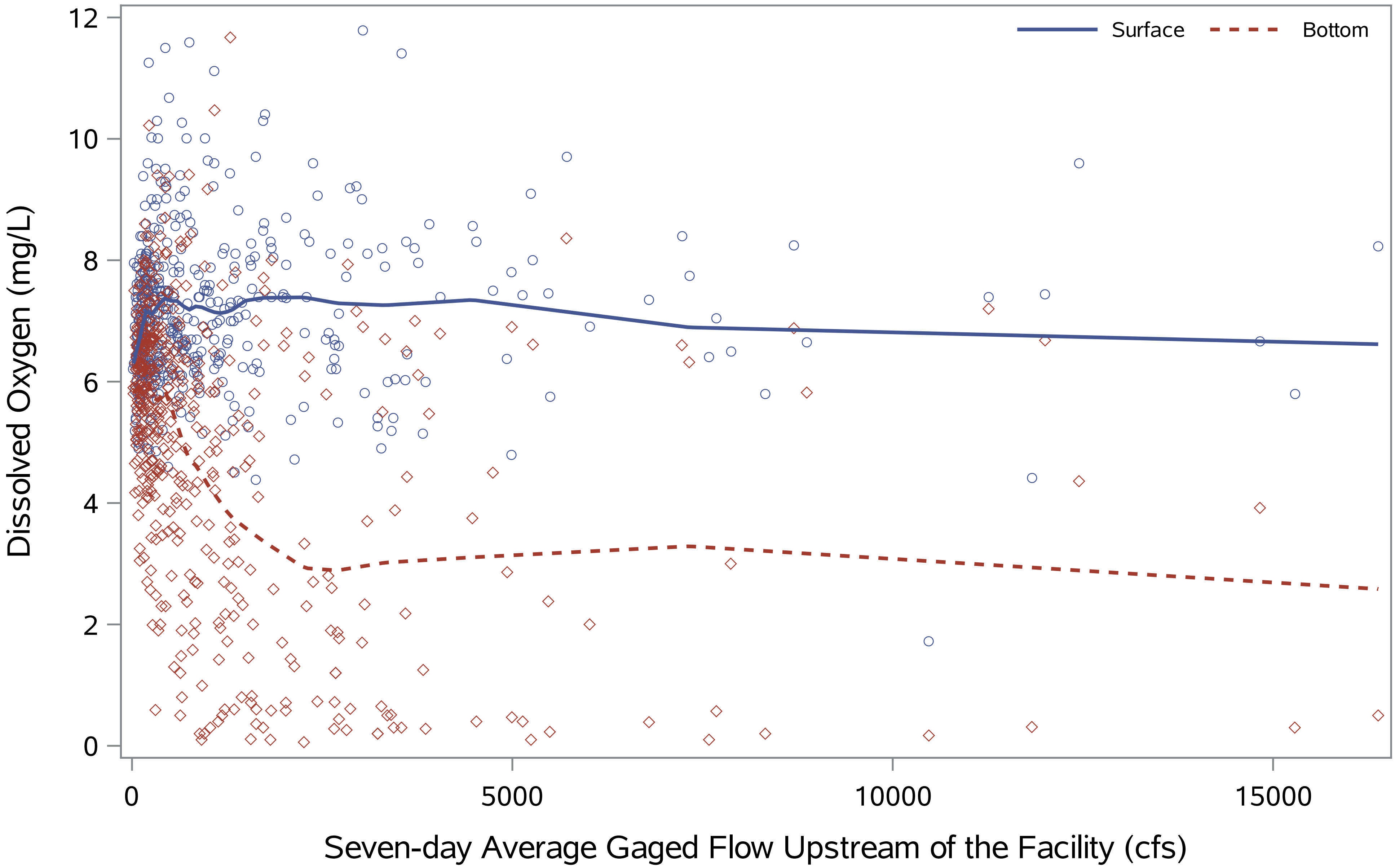

Figure 5.35. Dissolved Oxygen at river kilometer -2.4 versus flow

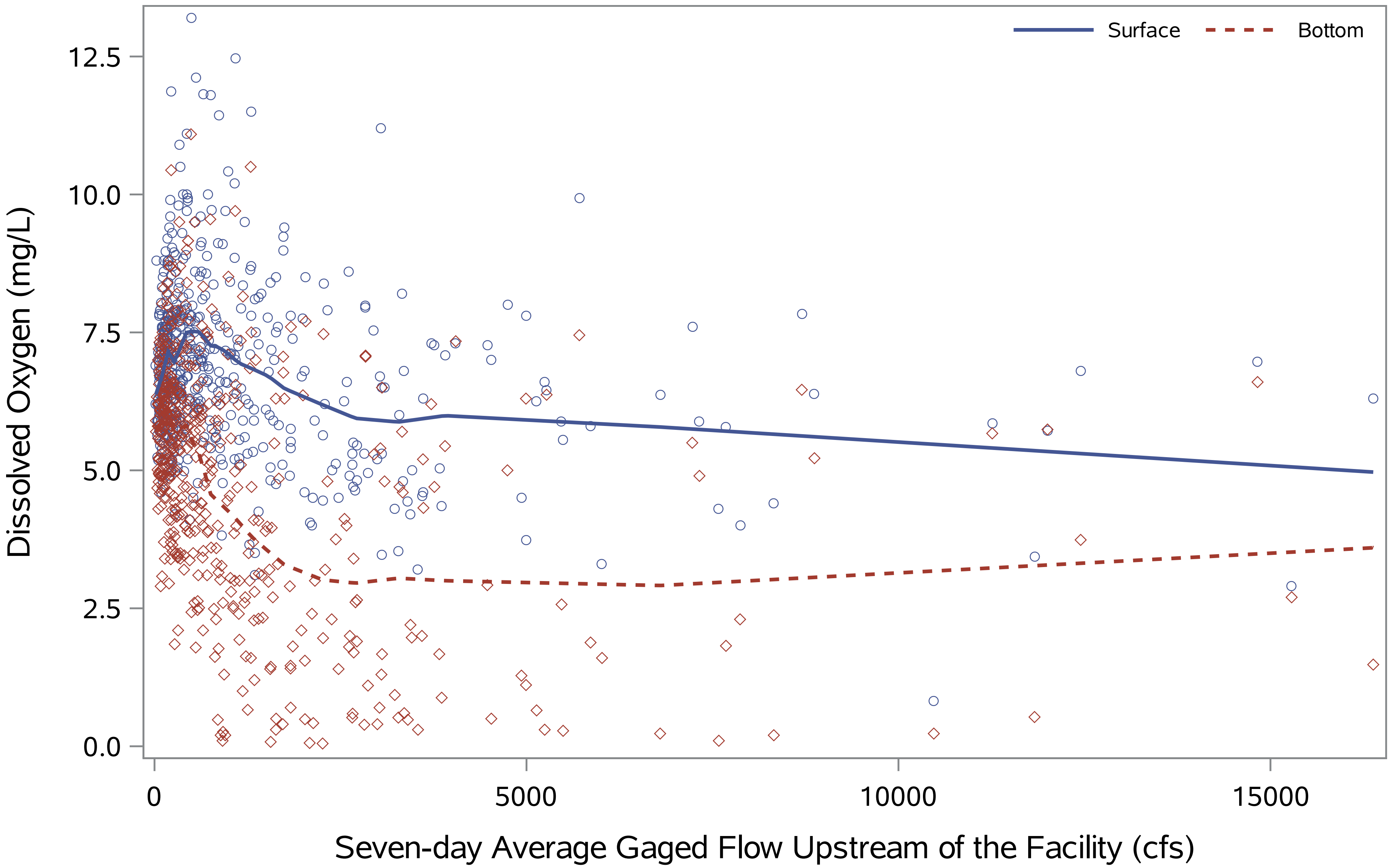

Figure 5.36. Dissolved Oxygen at river kilometer 6.6 versus flow

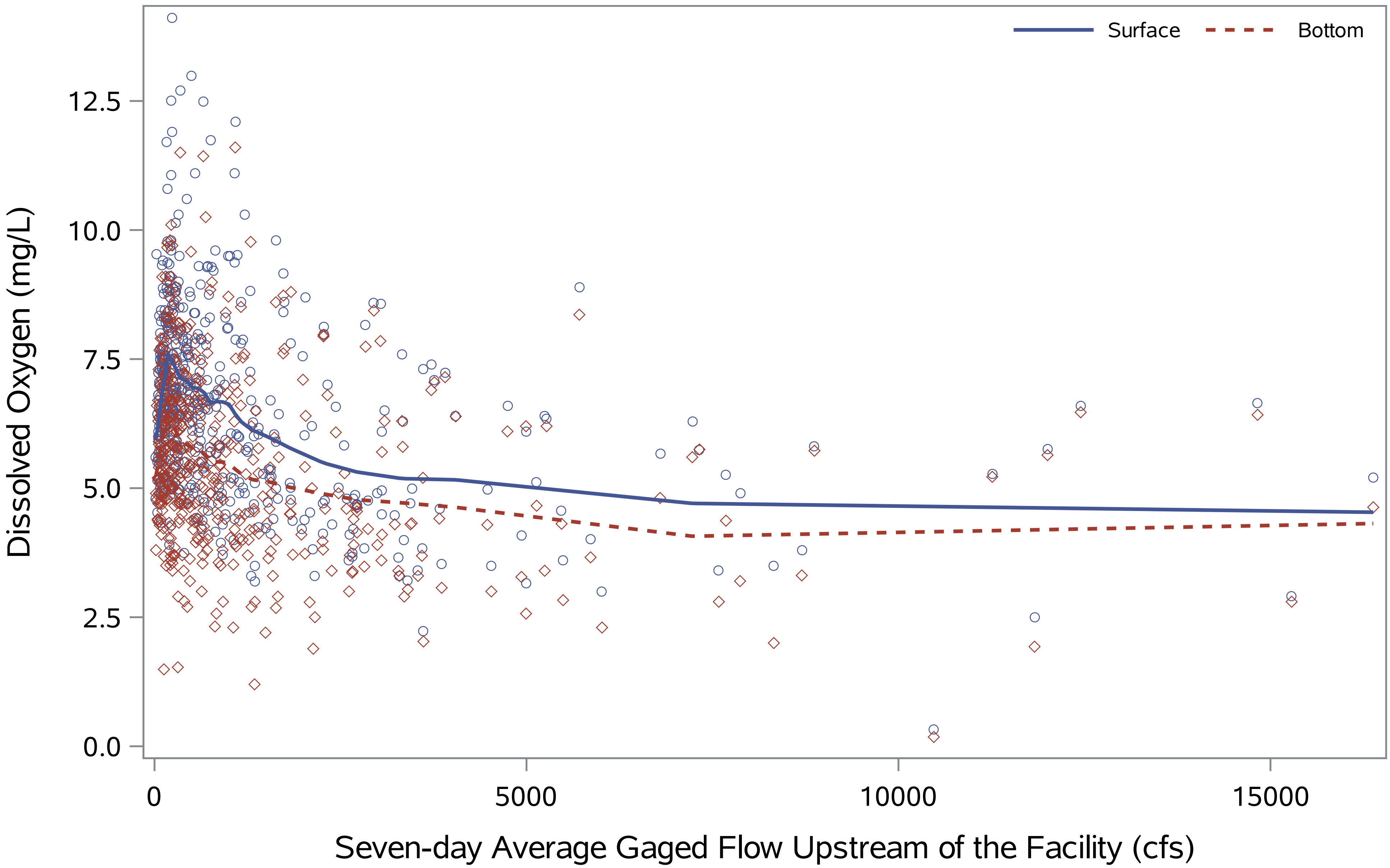

Figure 5.37. Dissolved Oxygen at river kilometer 15.5 versus flow

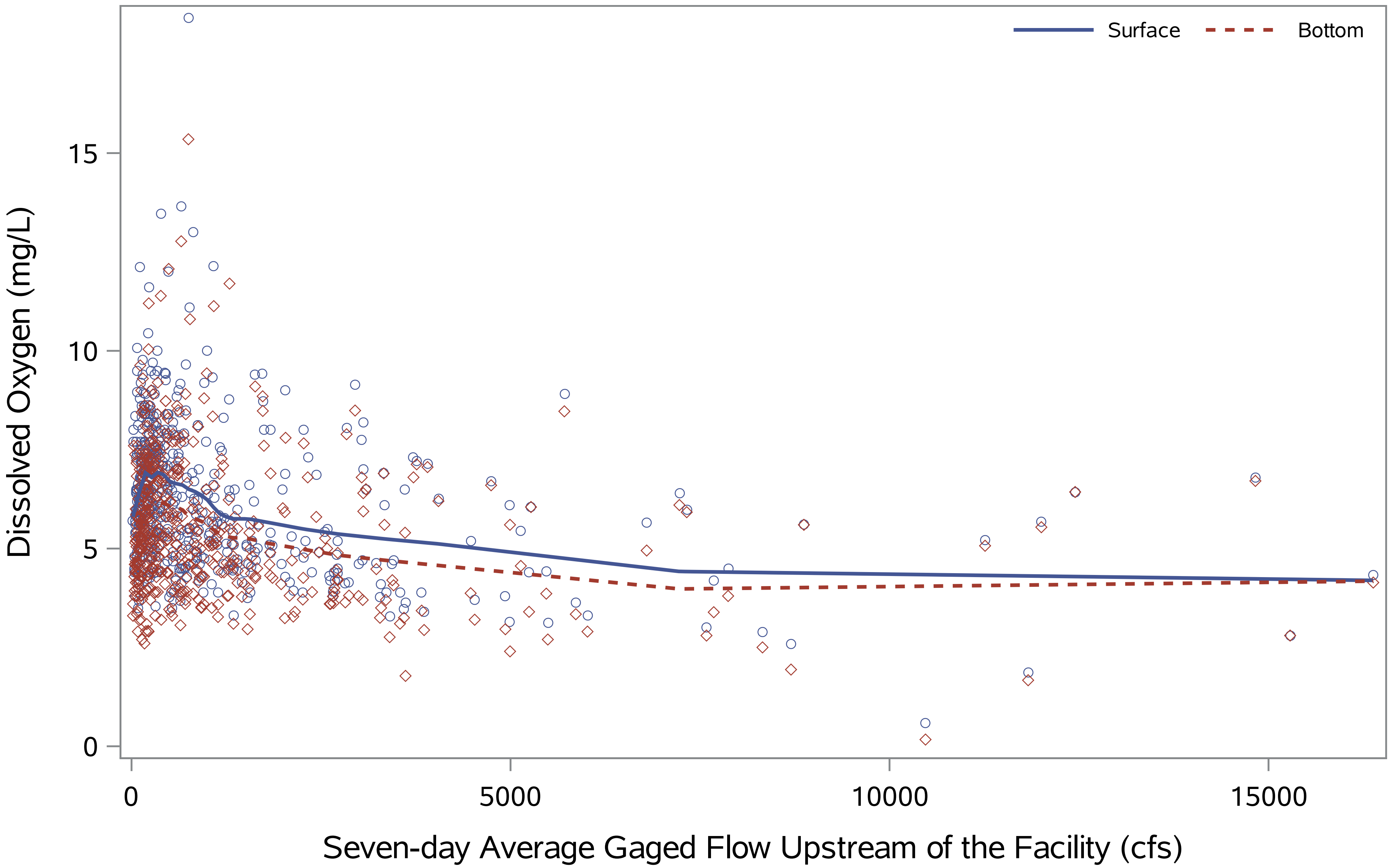

Figure 5.38. Dissolved Oxygen at river kilometer 23.6 versus flow

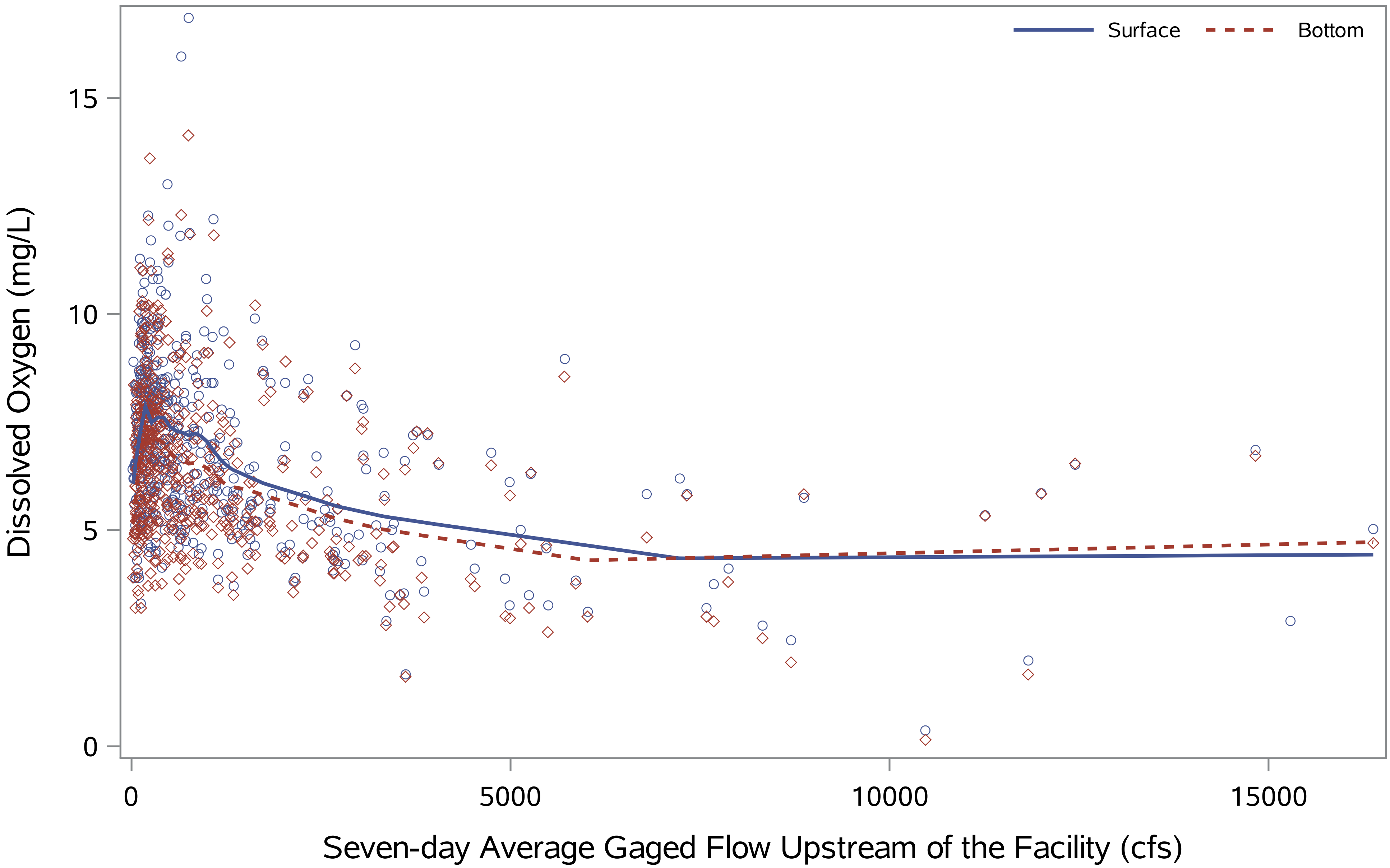

Figure 5.39. Dissolved Oxygen at river kilometer 30.7 versus flow

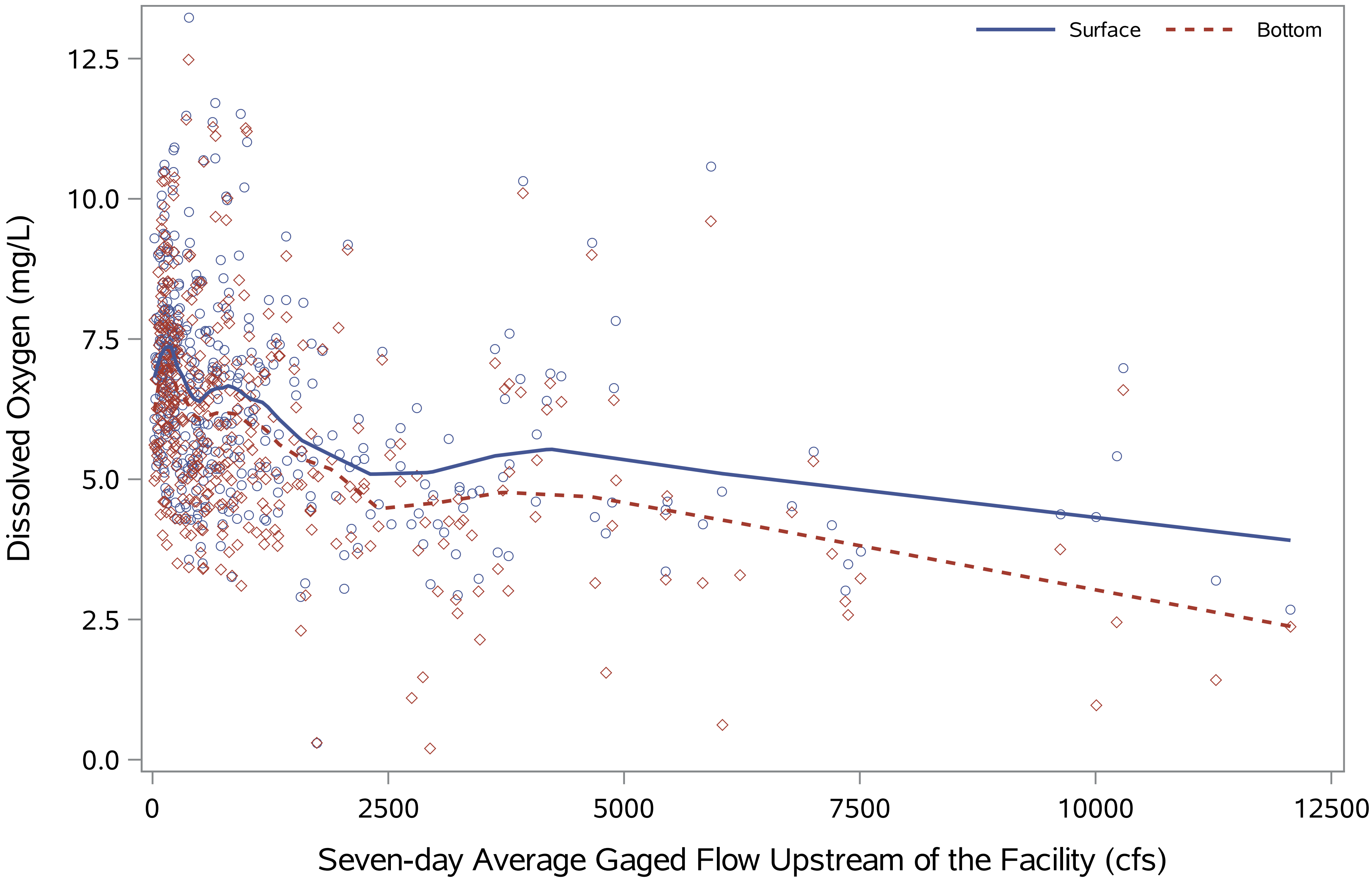

Figure 5.40. Dissolved Oxygen at the 0 psu isohaline versus flow

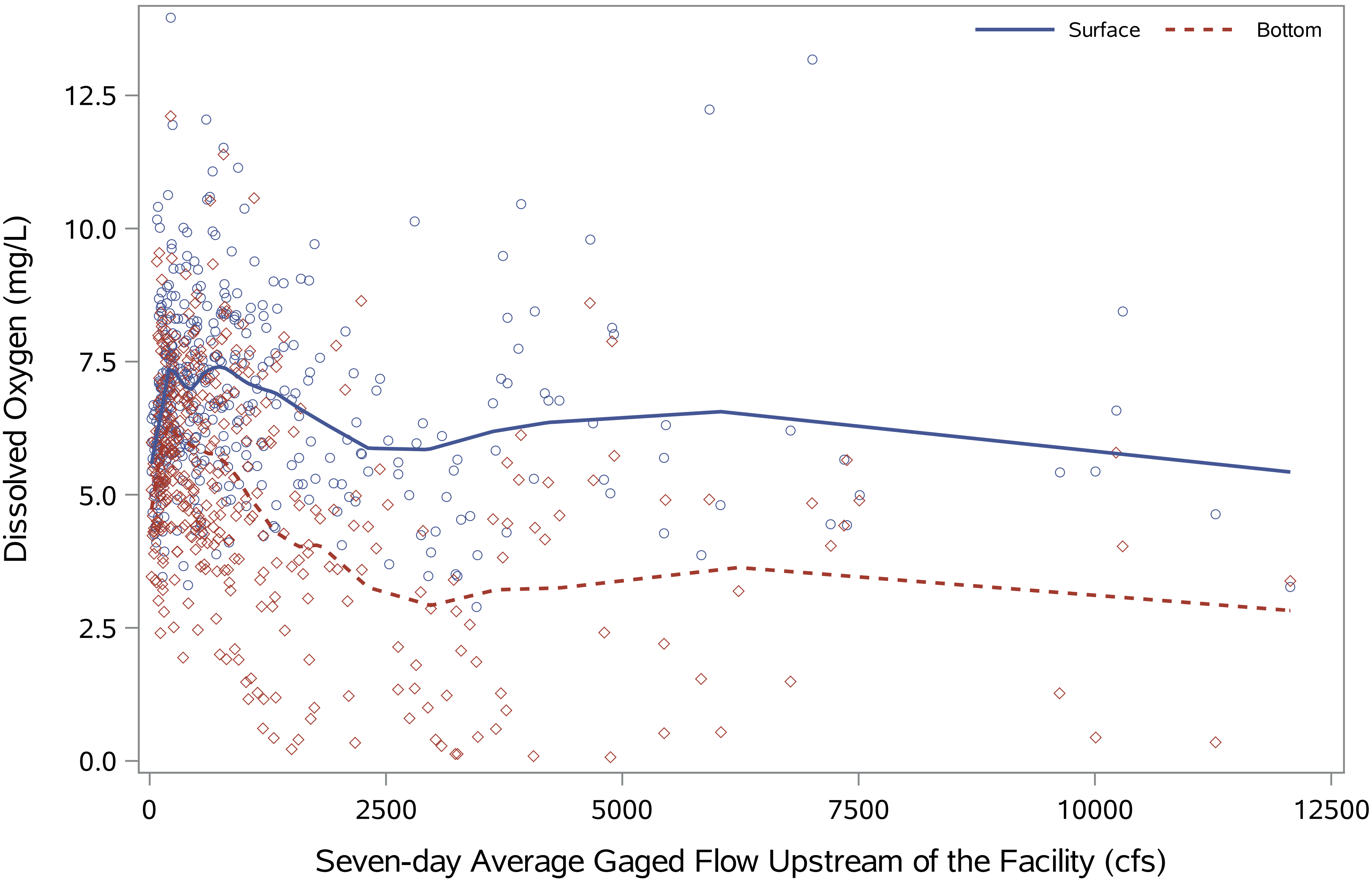

Figure 5.41. Dissolved Oxygen at the 6 psu isohaline versus flow

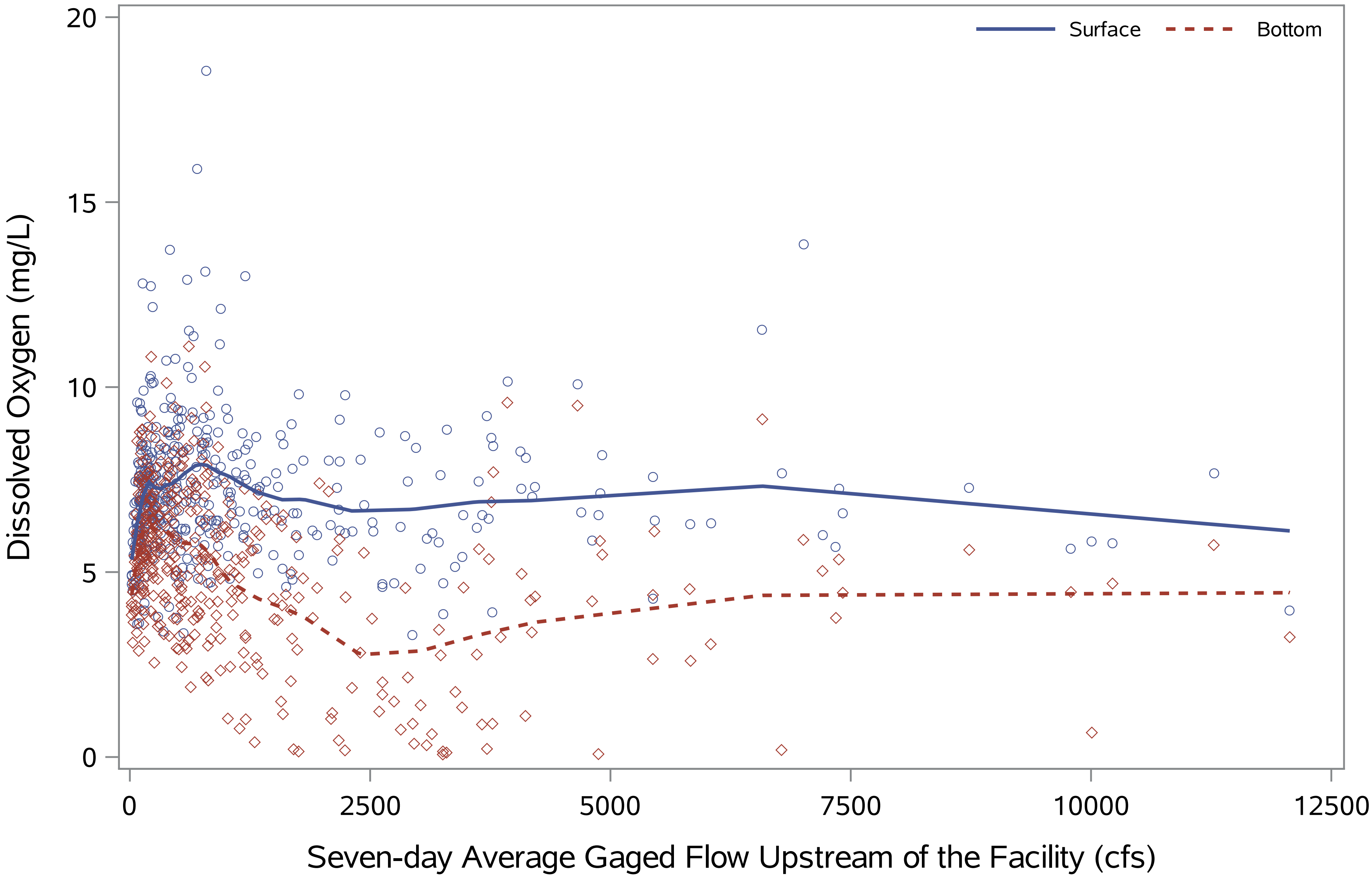

Figure 5.42. Dissolved Oxygen at the 12 psu isohaline versus flow

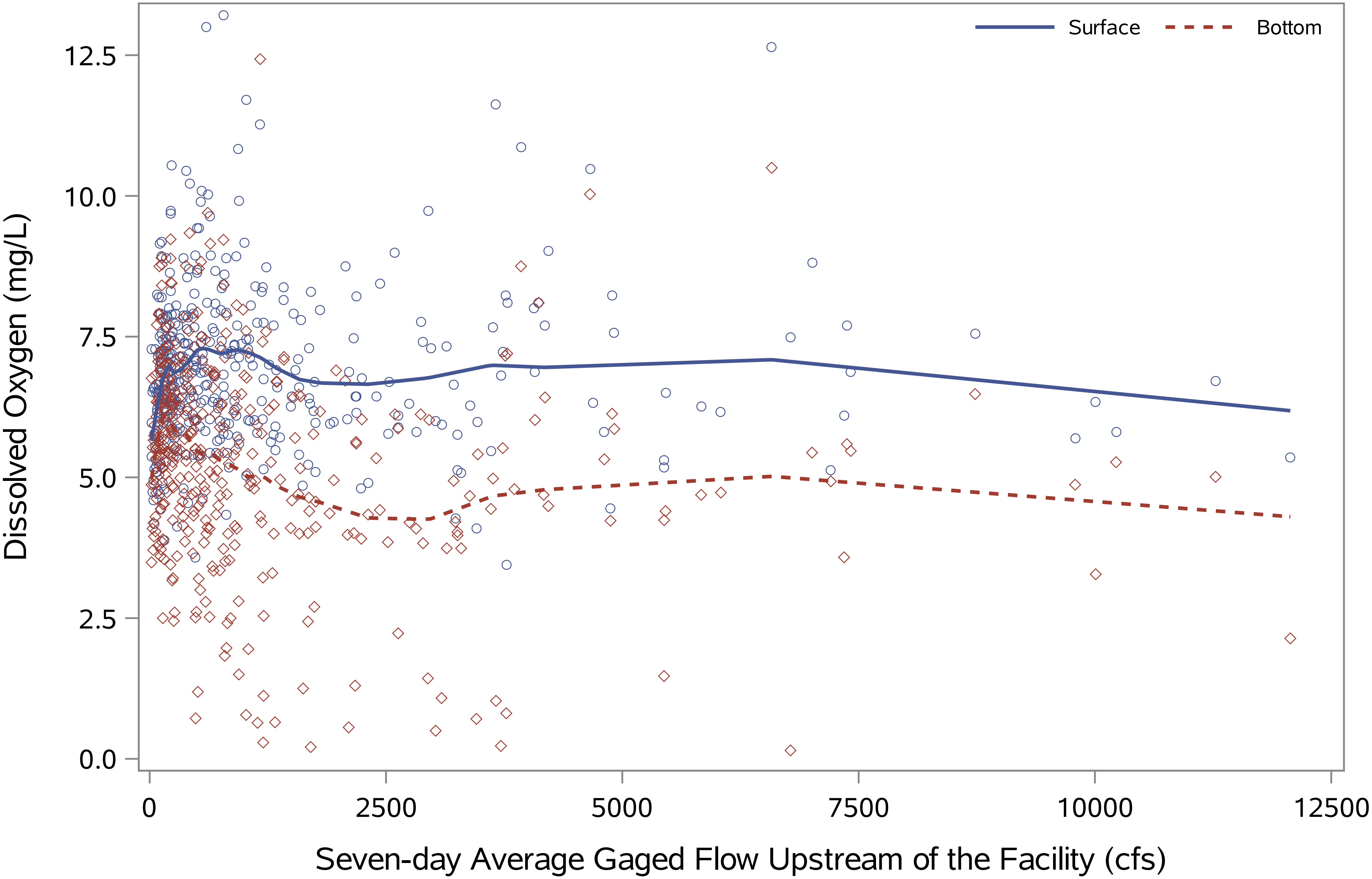

Figure 5.43. Dissolved Oxygen at the 20 psu isohaline versus flow

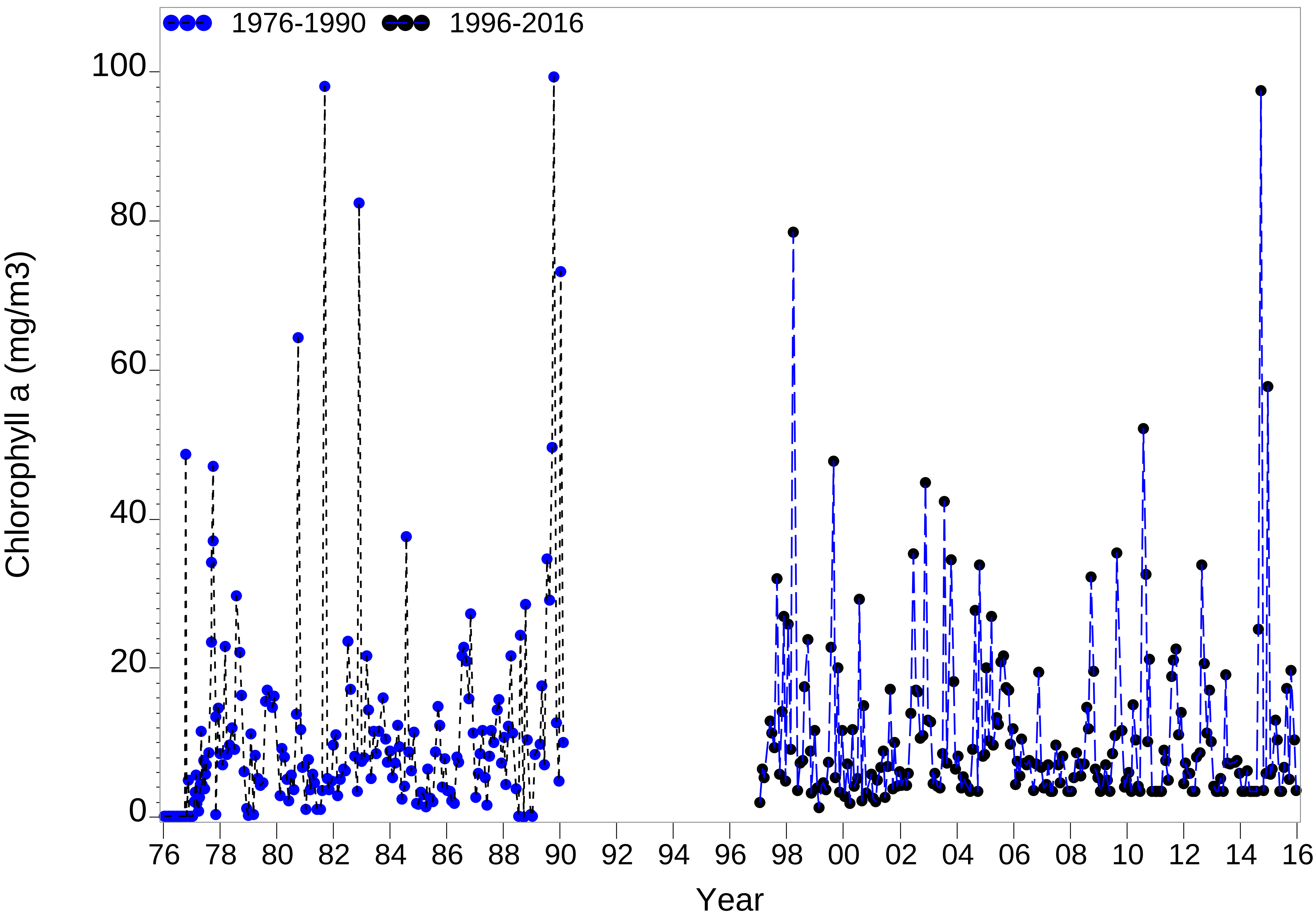

Figure 5.46. Monthly long-term Chlorophyll a at river kilometer -2.4

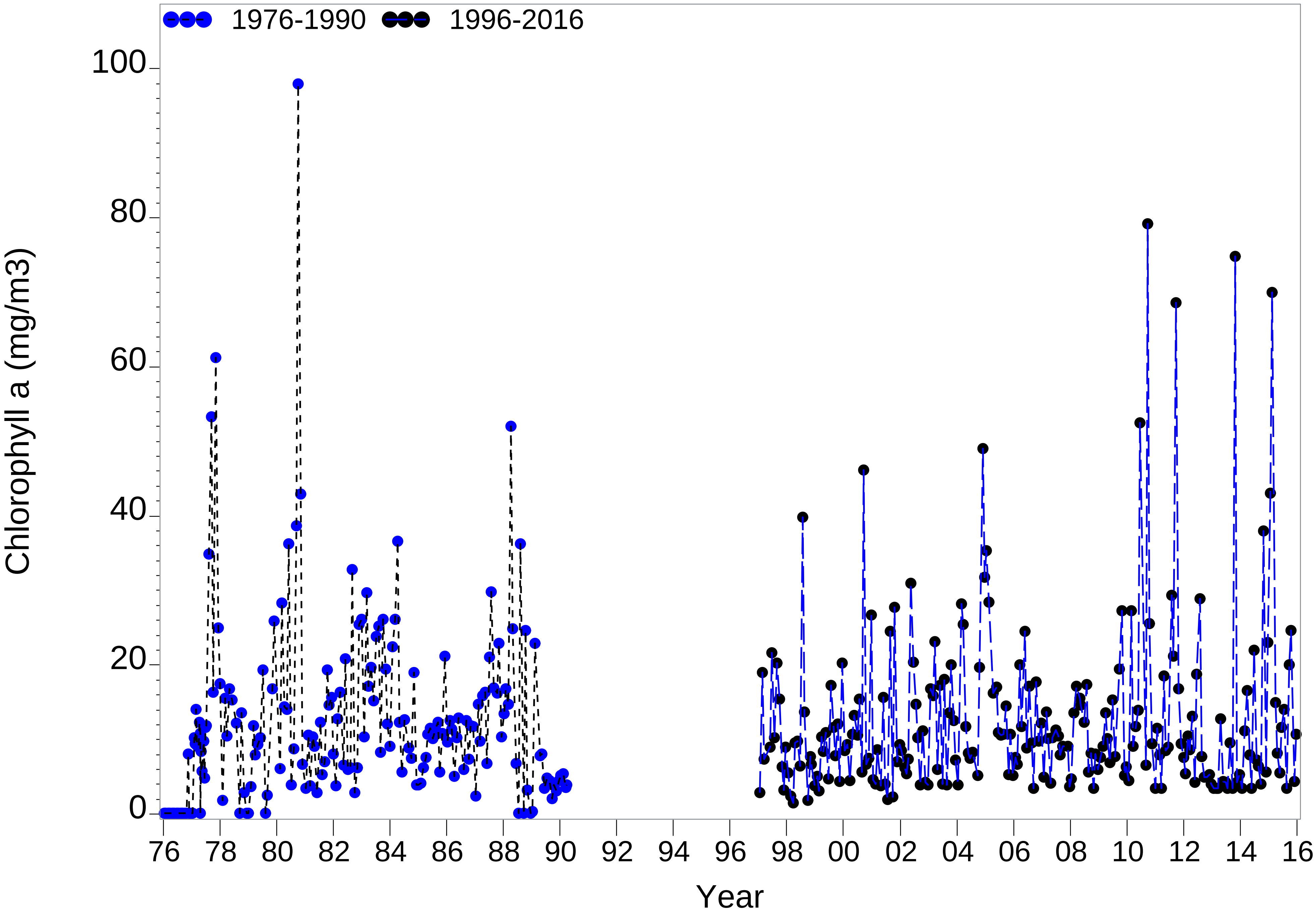

Figure 5.47. Monthly long-term Chlorophyll a at river kilometer 6.6

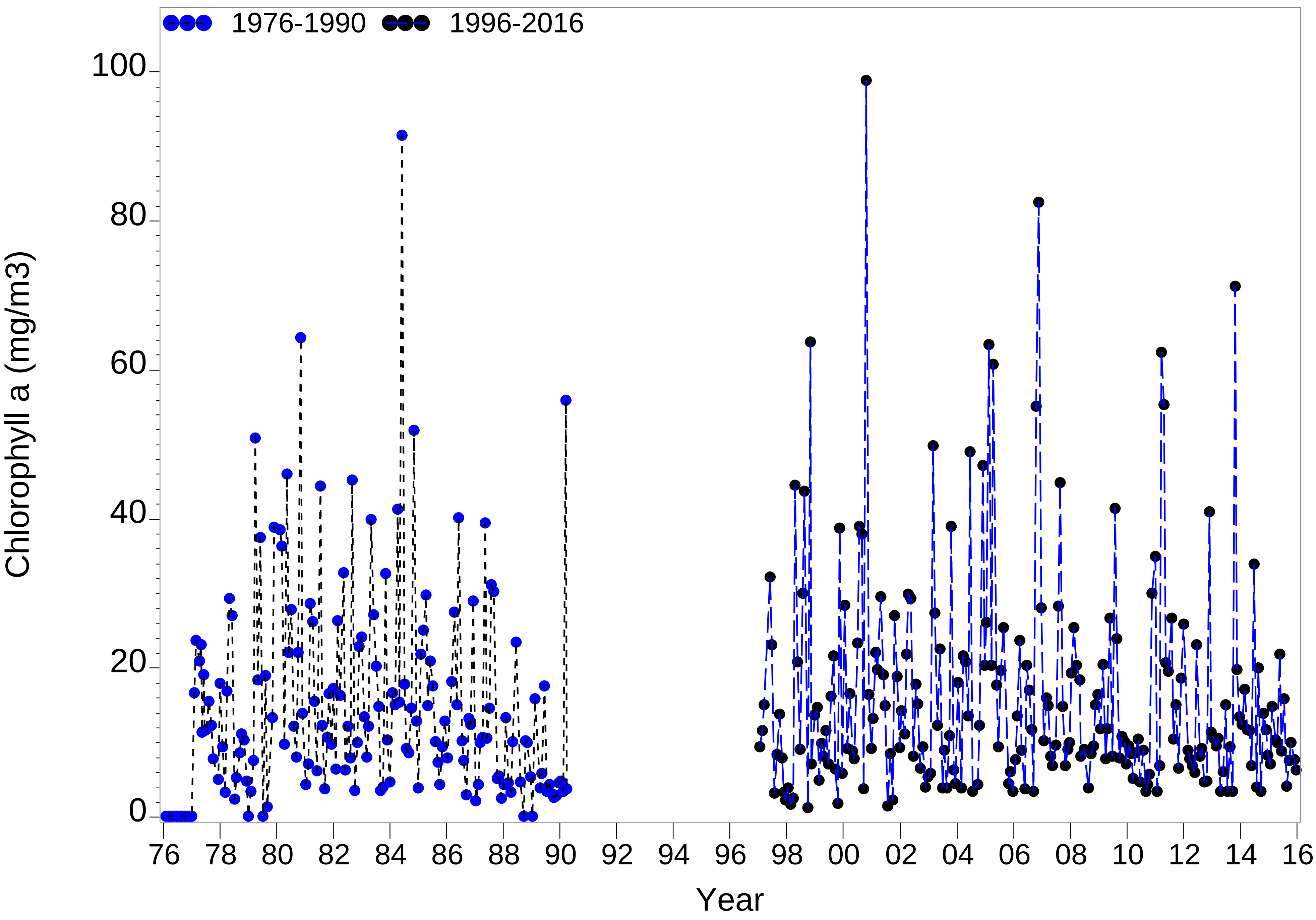

Figure 5.48. Monthly long-term Chlorophyll a at river kilometer 15.5

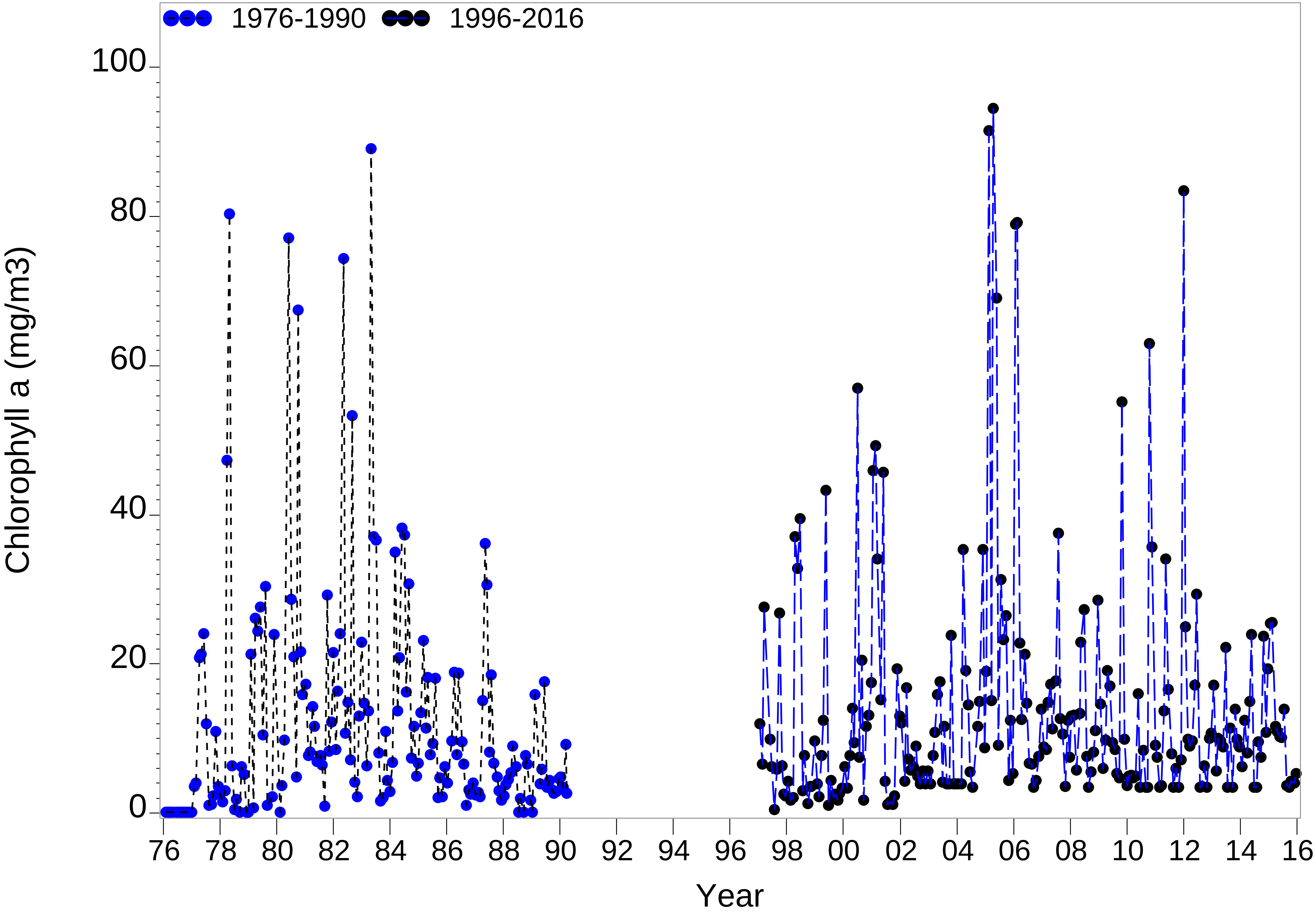

Figure 5.49. Monthly long-term Chlorophyll a at river kilometer 23.6

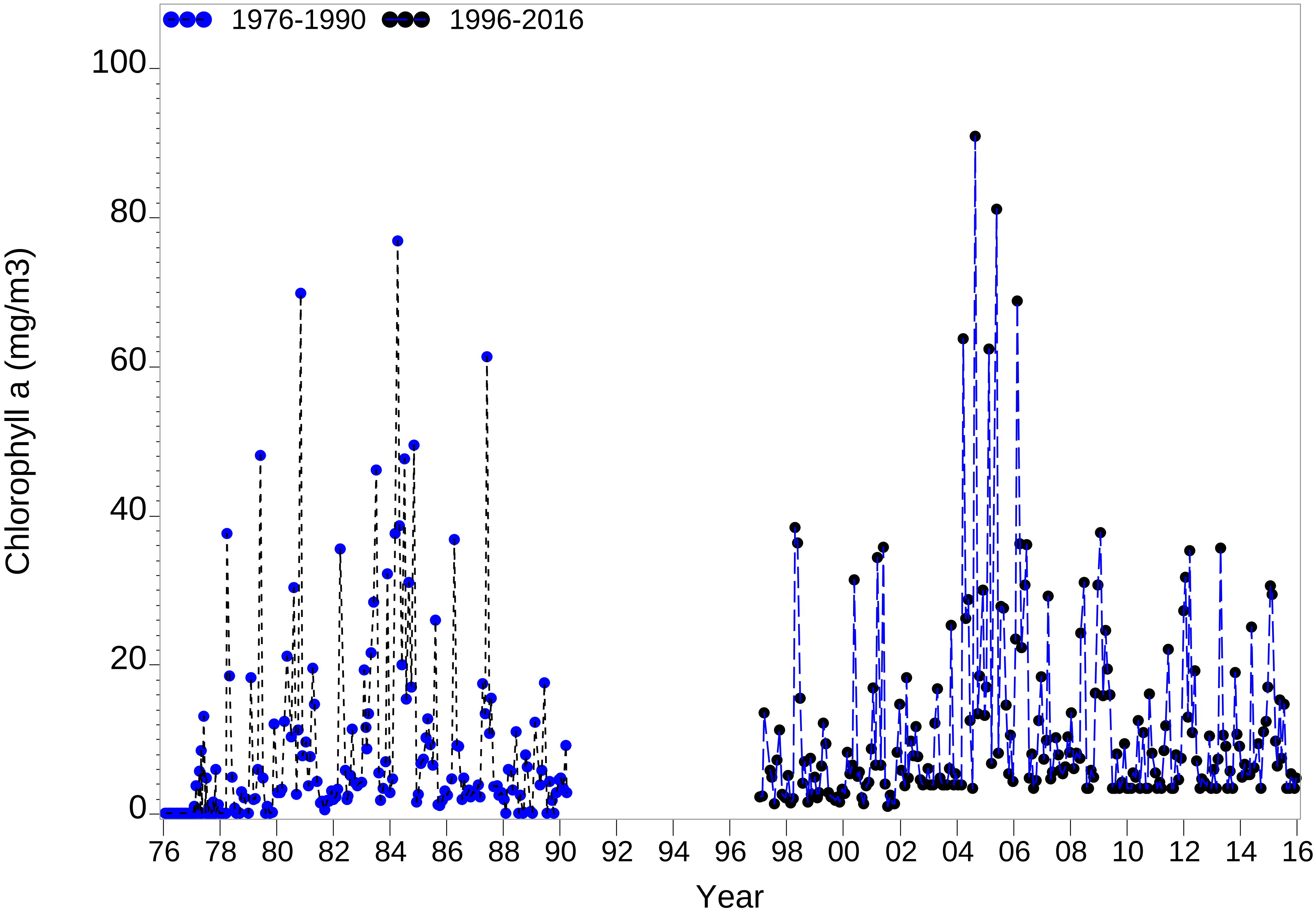

Figure 5.50. Monthly long-term Chlorophyll a at river kilometer 30.7

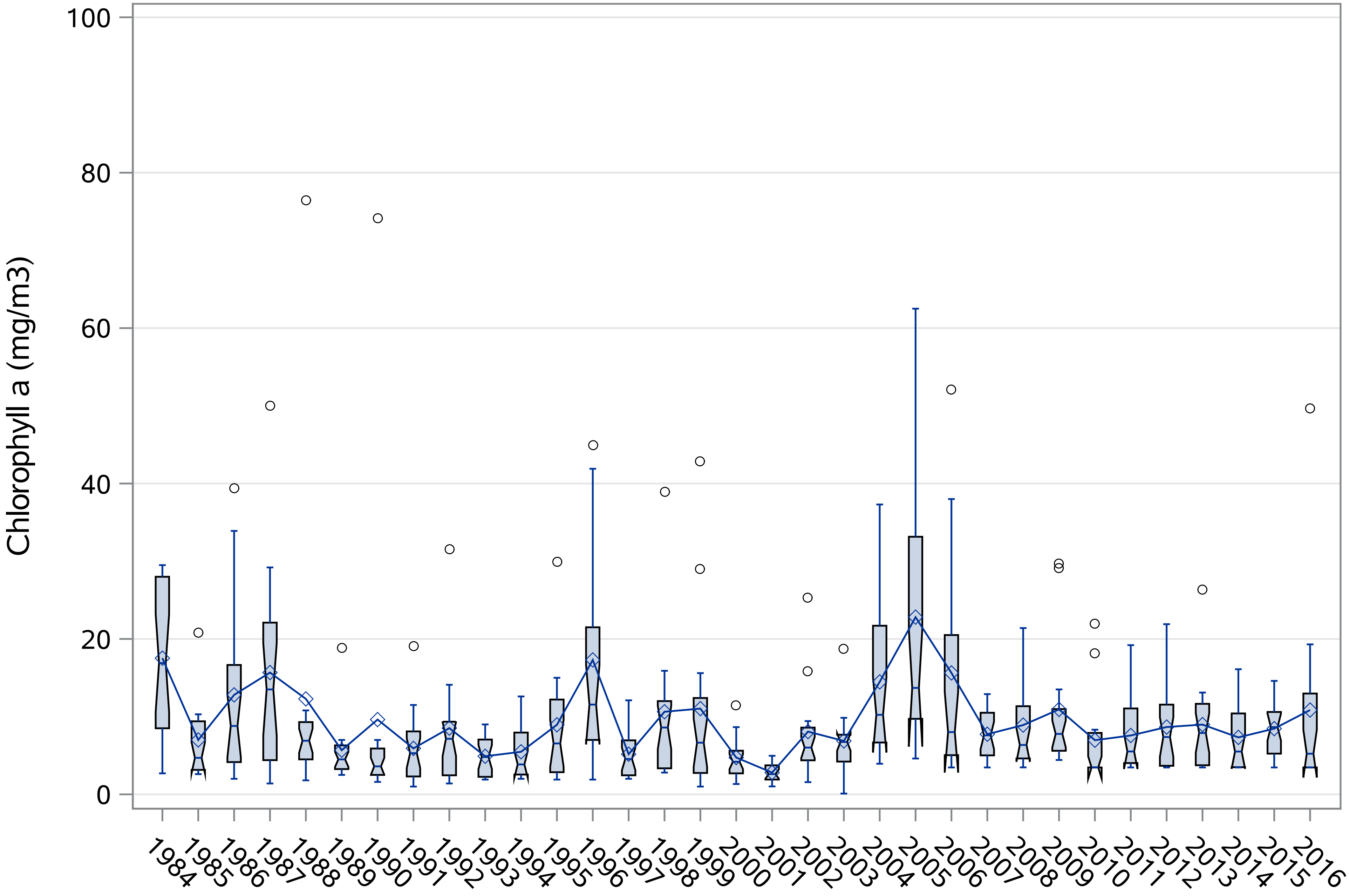

Figure 5.51. Annual boxplots of surface Chlorophyll a at the 0 psu isohaline (1984-2016)

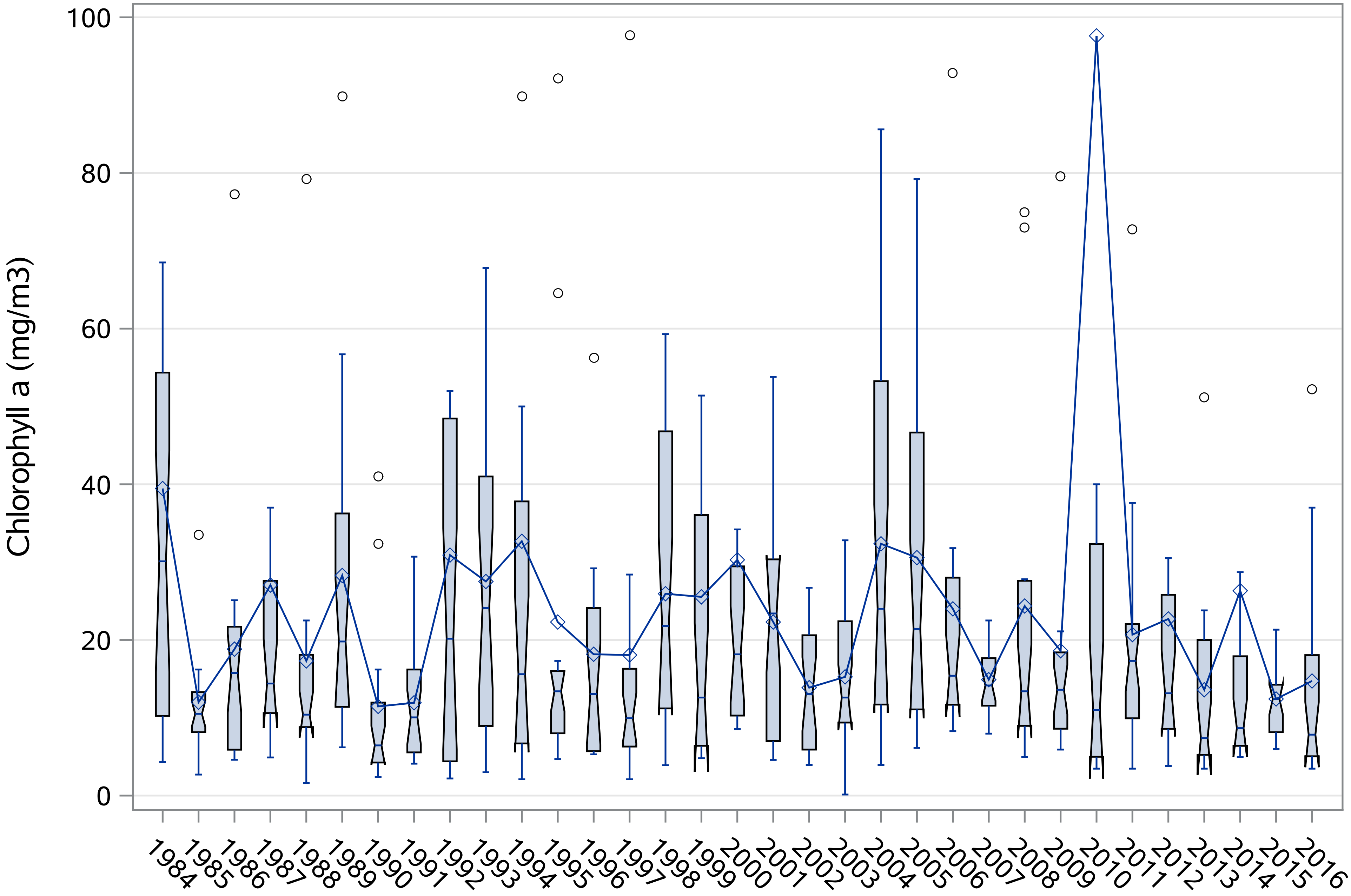

Figure 5.52. Annual boxplots of surface Chlorophyll a at the 6 psu isohaline (1984-2016)

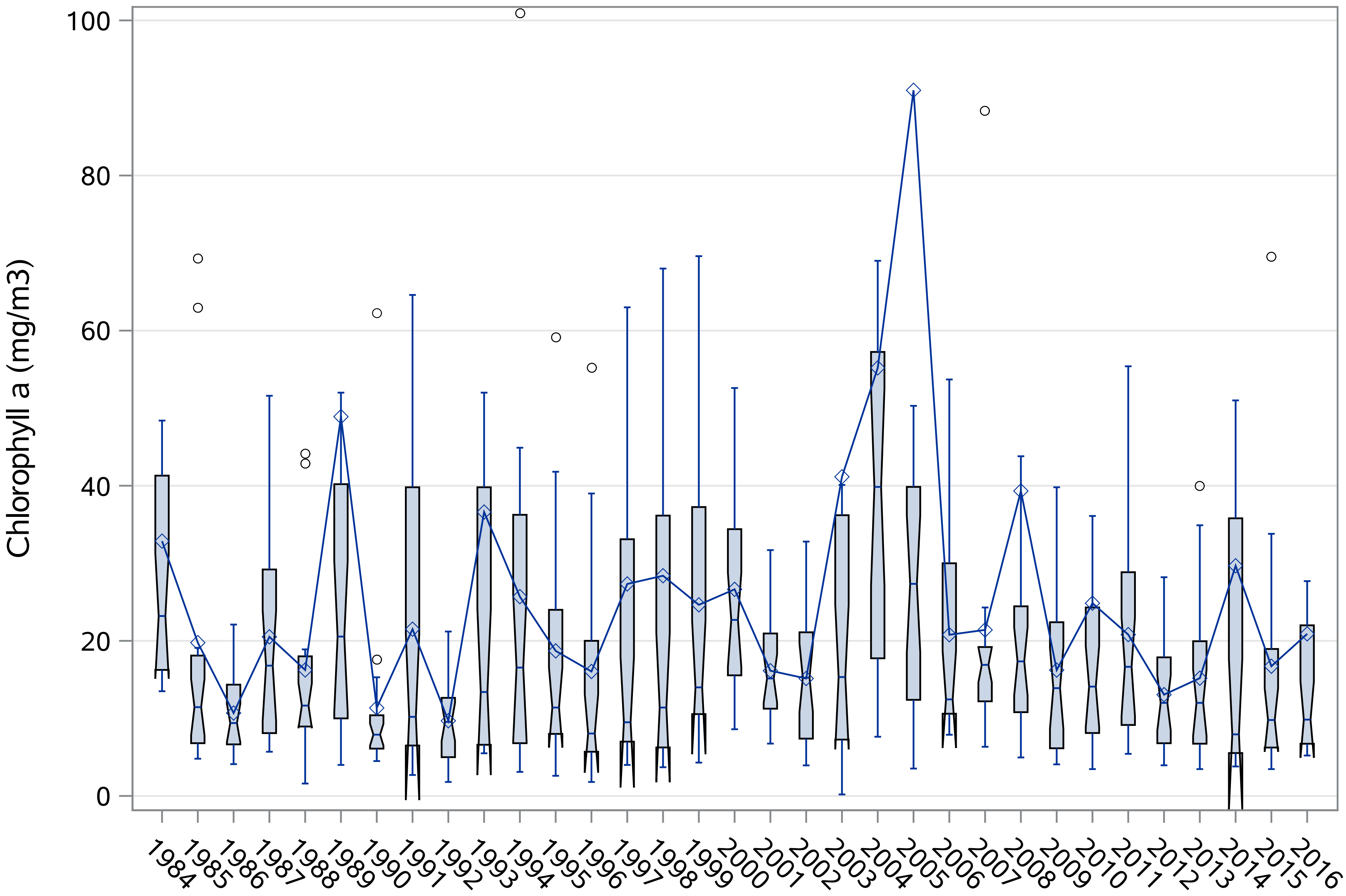

Figure 5.53. Annual boxplots of surface Chlorophyll a at the 12 psu isohaline (1984-2016)

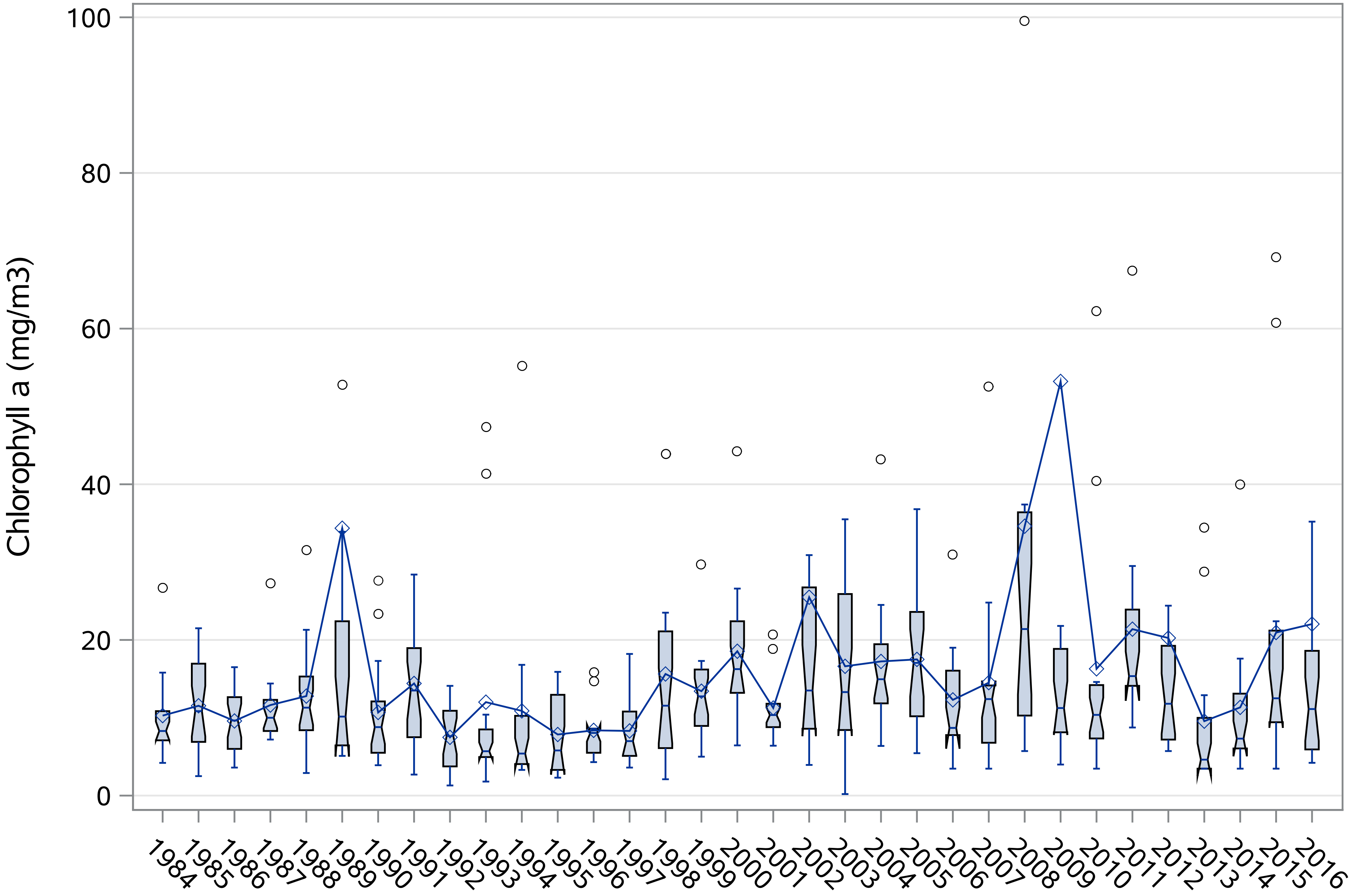

Figure 5.54. Annual boxplots of surface Chlorophyll a at the 20 psu isohaline (1984-2016)

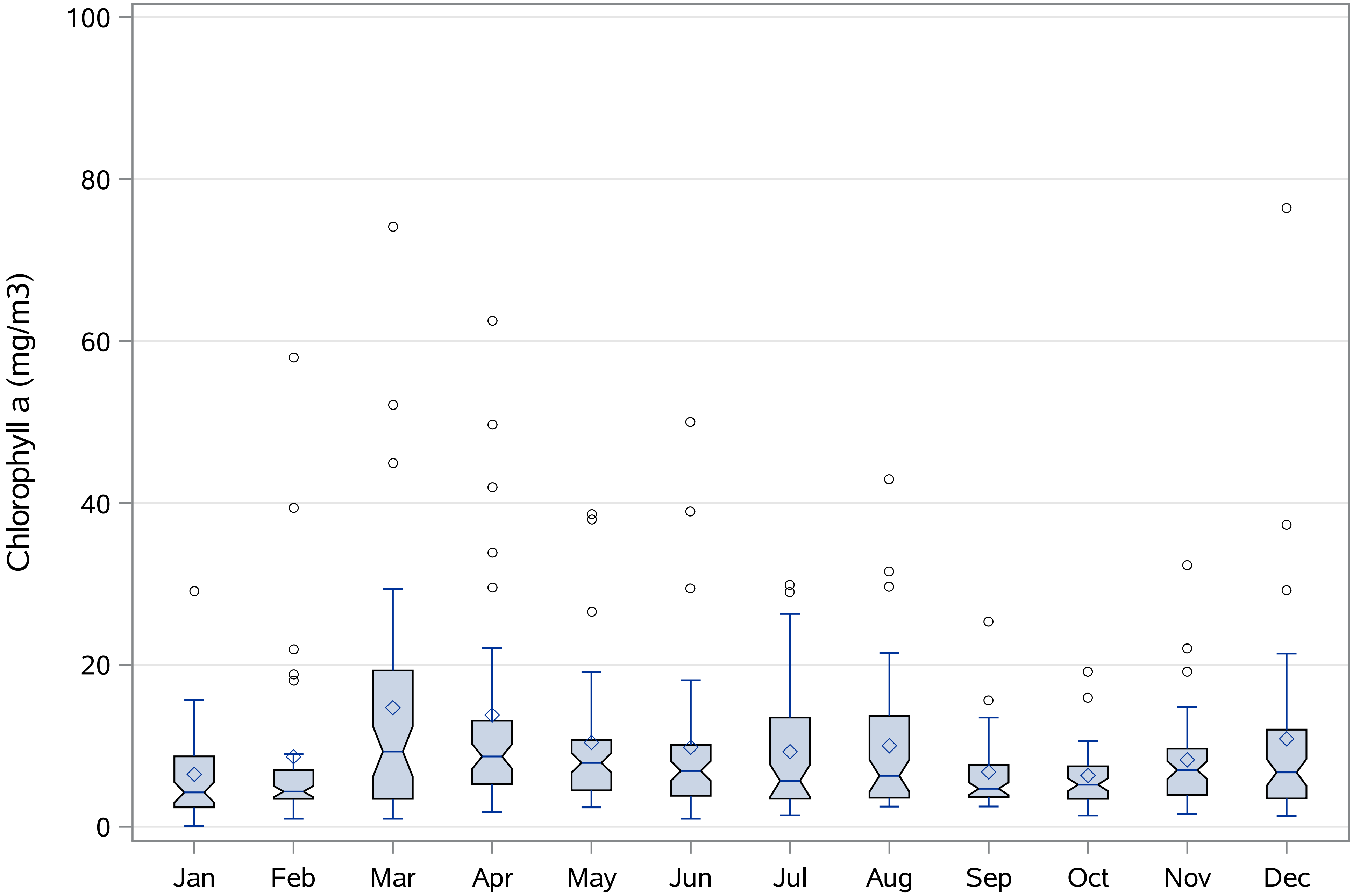

Figure 5.55. Mean monthly boxplots of surface Chlorophyll a at the 0 psu isohaline (1984-2016)

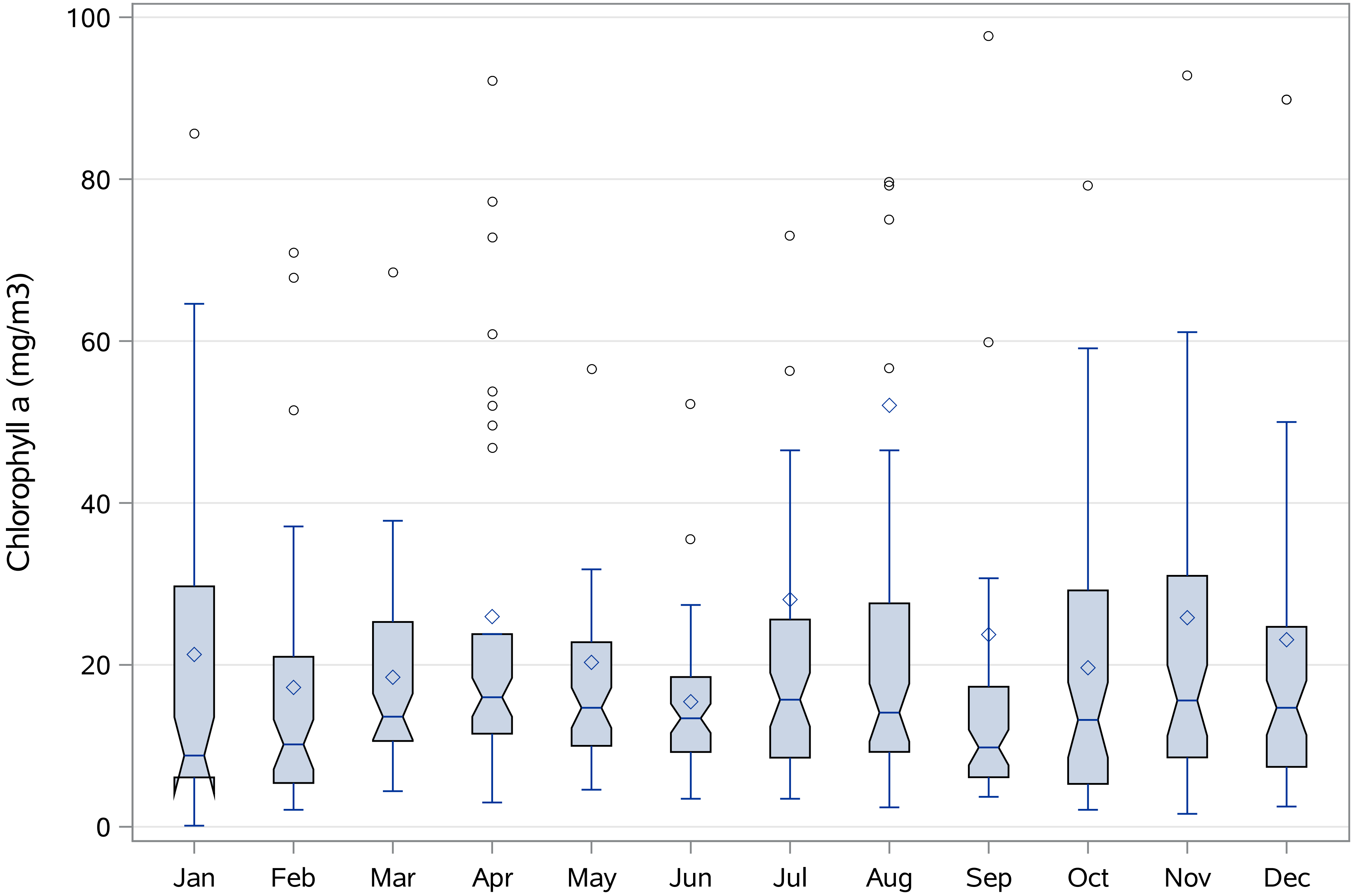

Figure 5.56. Mean monthly boxplots of surface Chlorophyll a at the 6 psu isohaline (1984-2016)

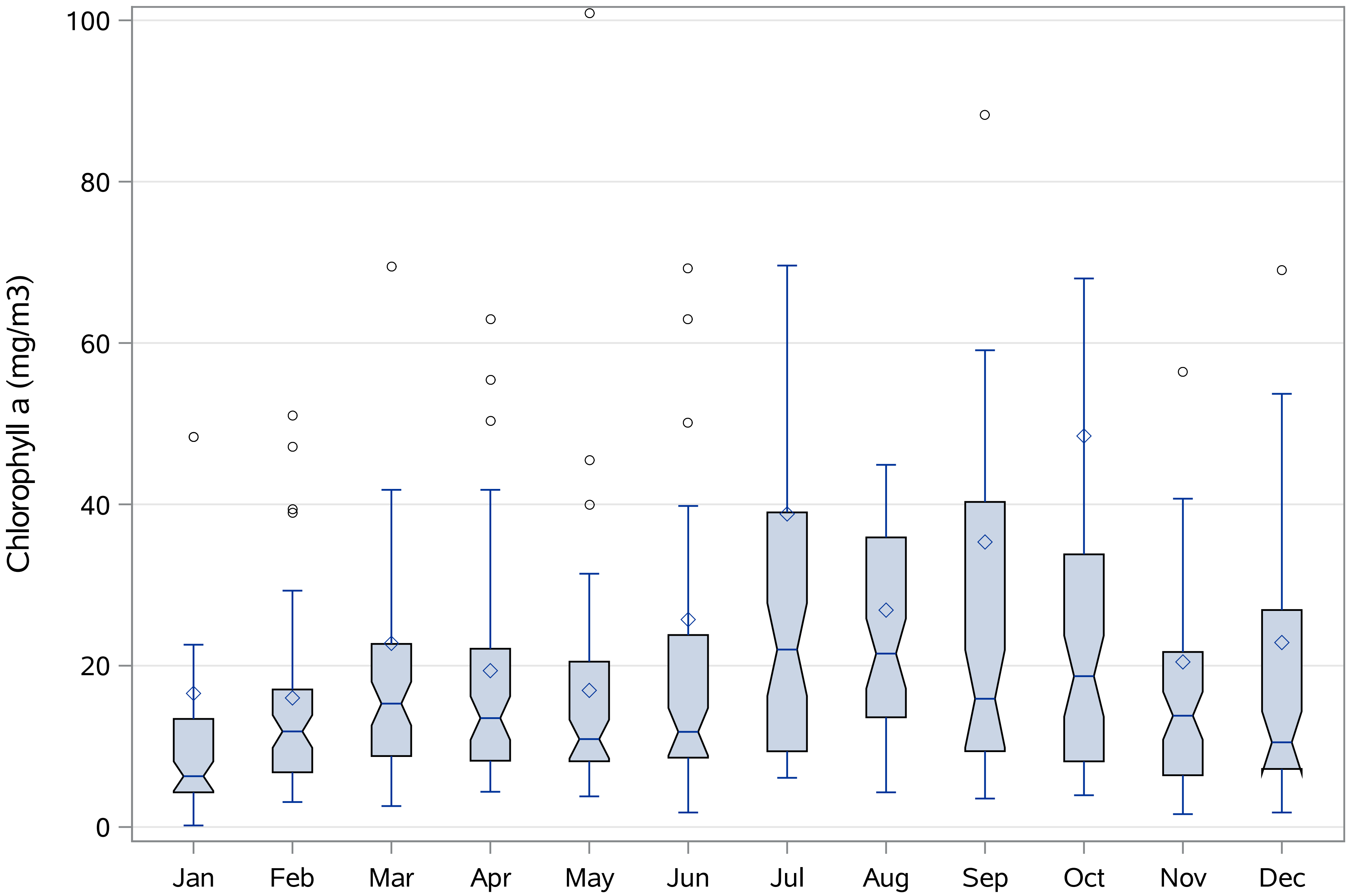

Figure 5.57. Mean monthly boxplots of surface Chlorophyll a at the 12 psu isohaline (1984-2016)

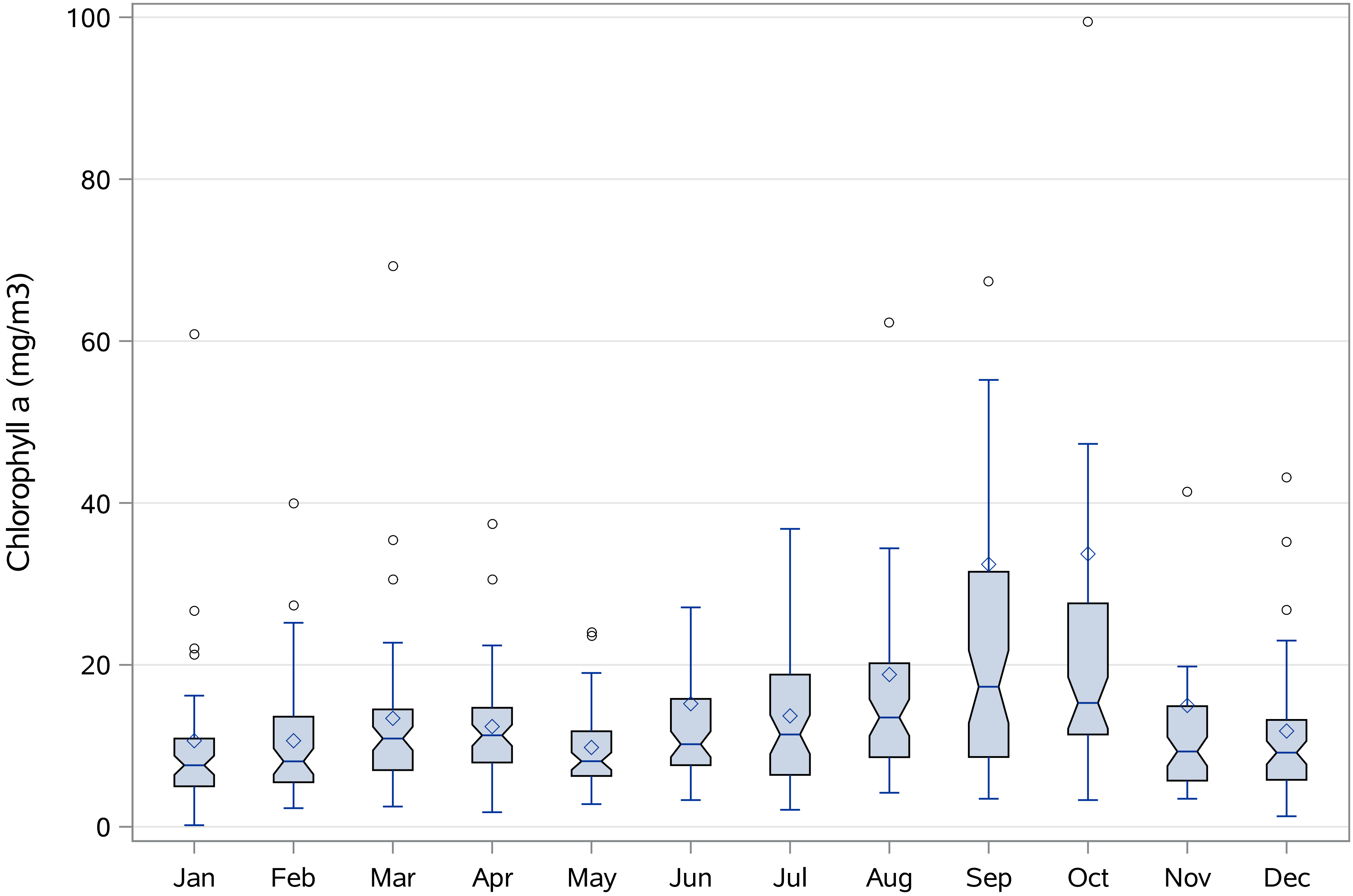

Figure 5.58. Mean monthly boxplots of surface Chlorophyll a at the 20 psu isohaline (1984-2016)

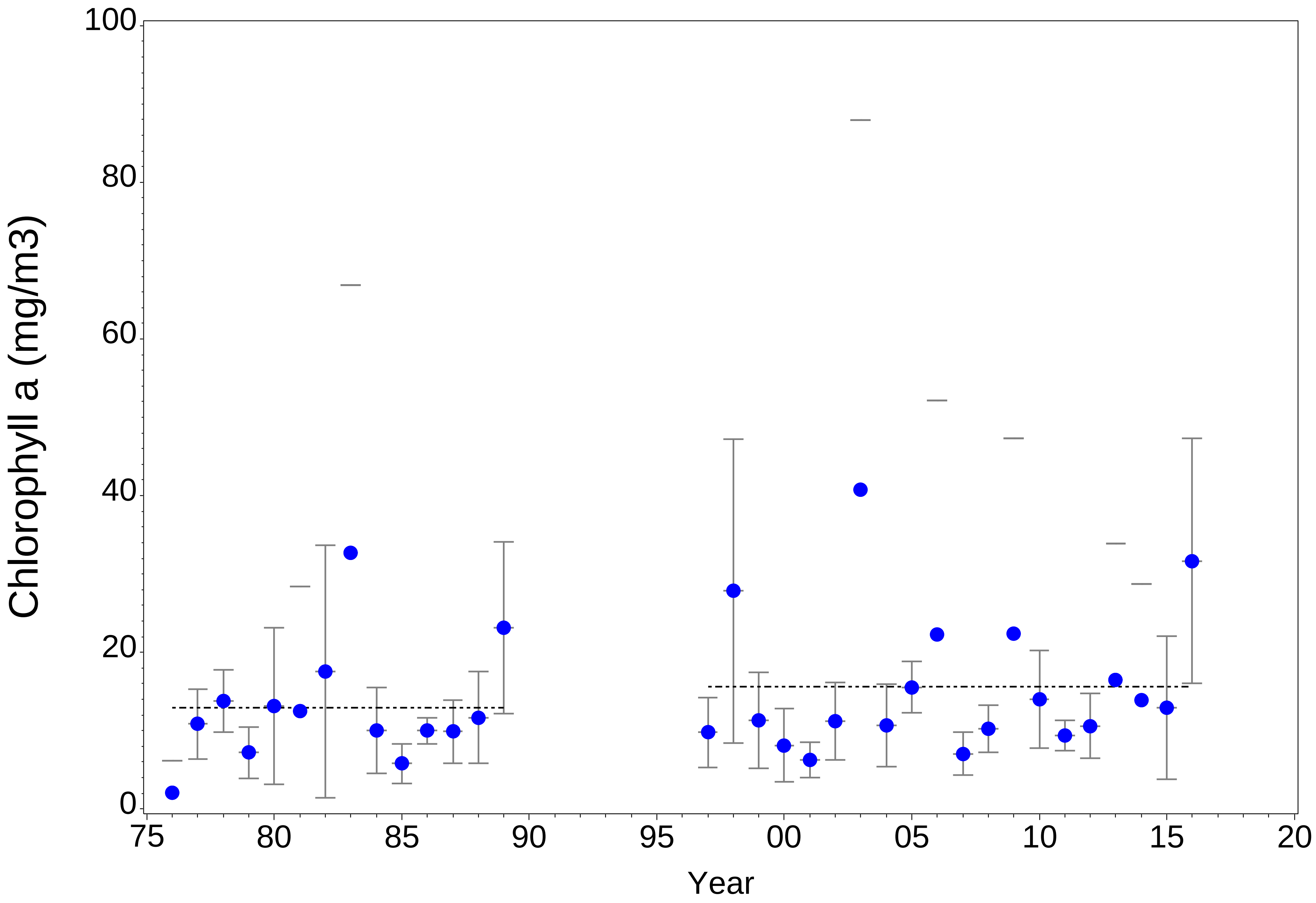

Figure 5.59. Long-term Station 9 surface Chlorophyll a at river kilometer -2.4

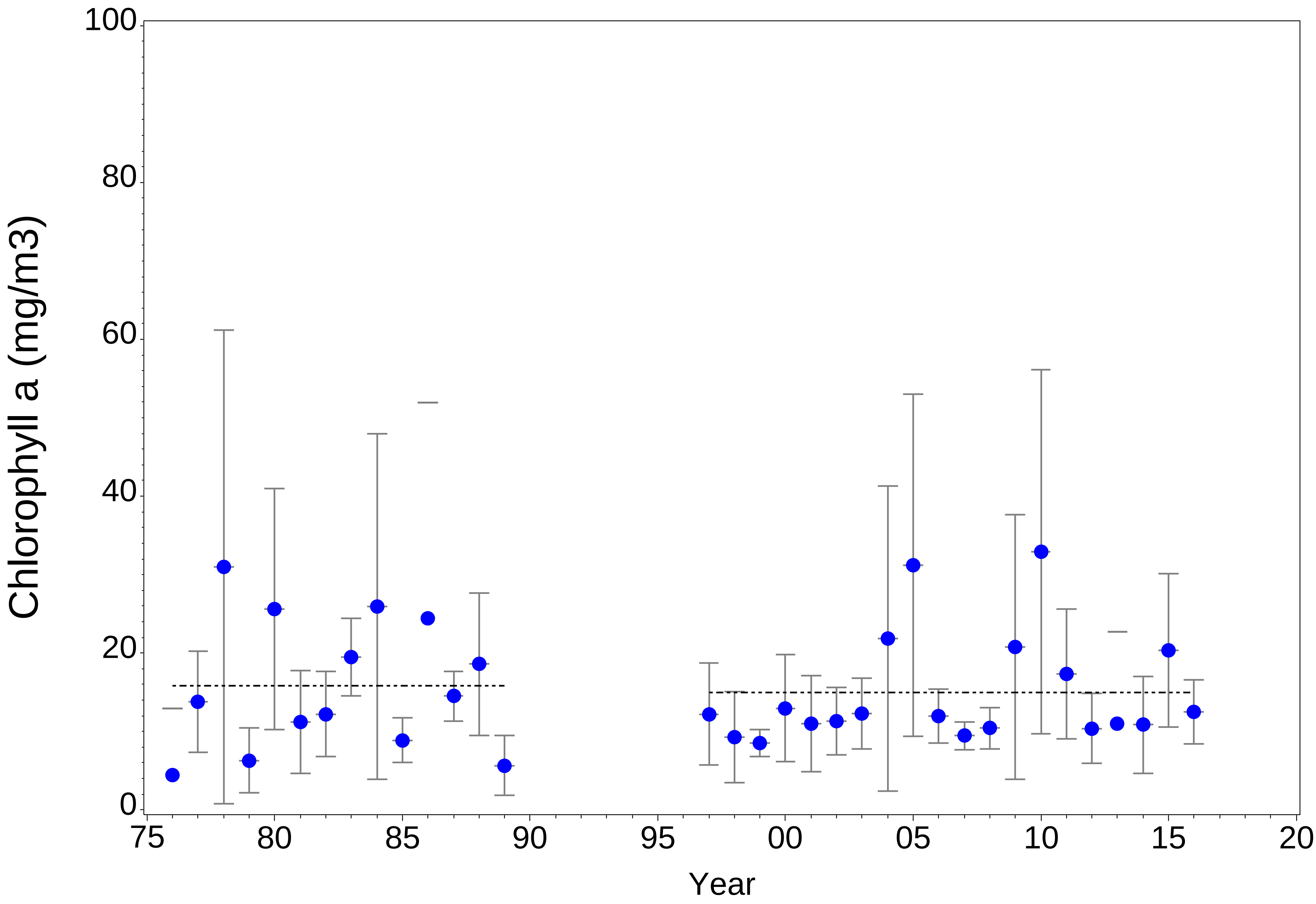

Figure 5.60. Long-term Station 10 surface Chlorophyll a at river kilometer 6.6

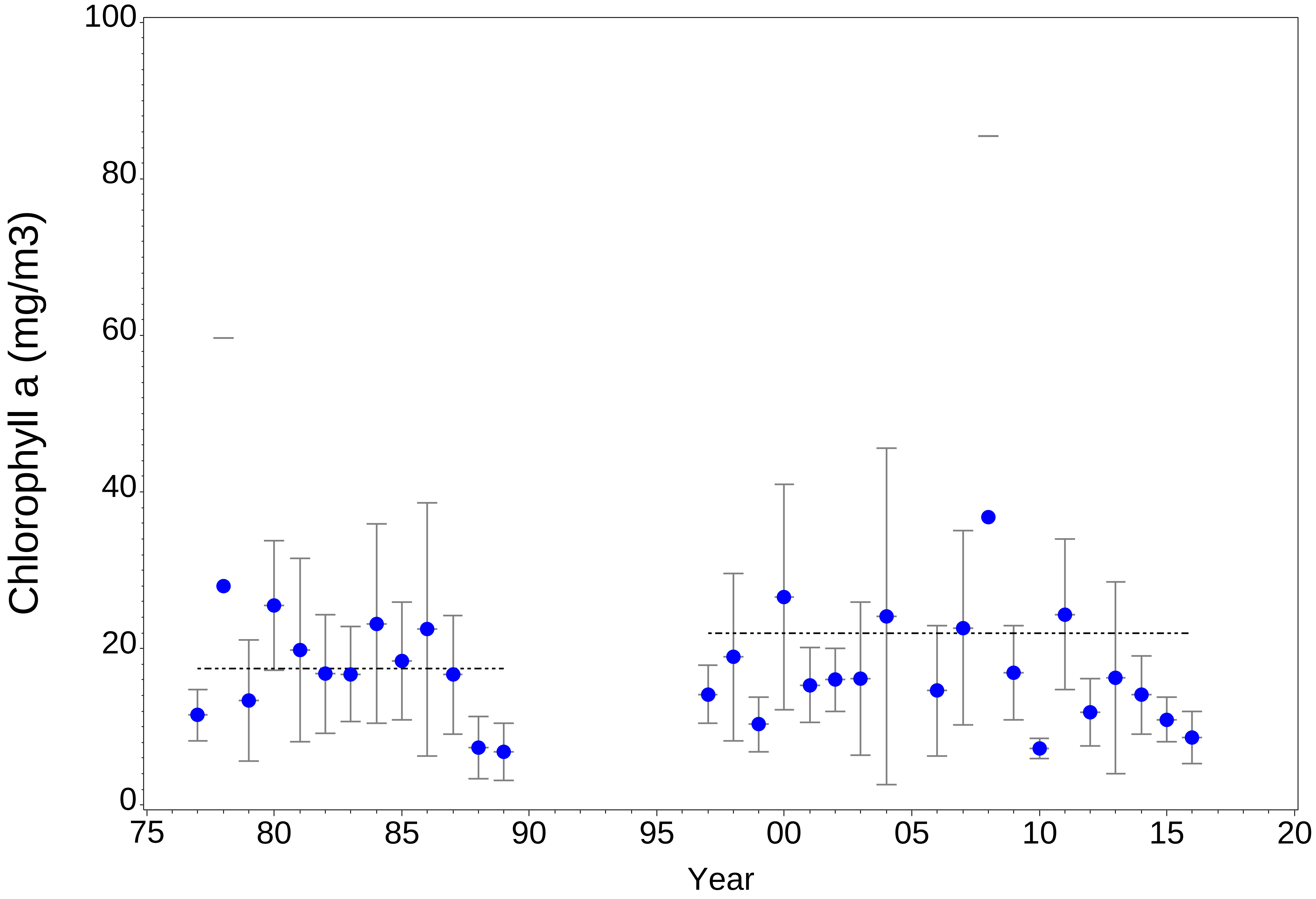

Figure 5.61. Long-term Station 12 surface Chlorophyll a at river kilometer 15.5

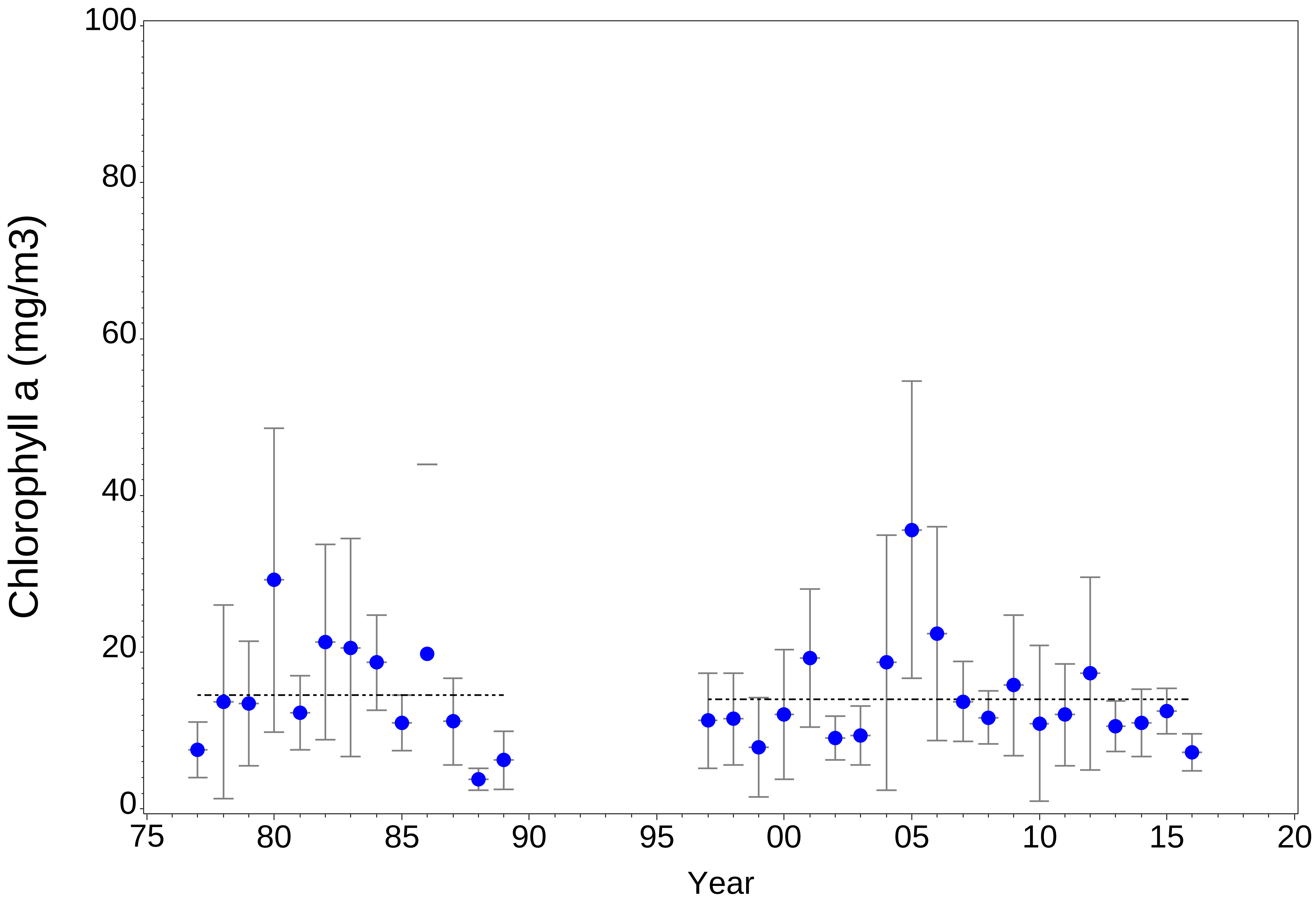

Figure 5.62. Long-term Station 14 surface Chlorophyll a at river kilometer 23.6

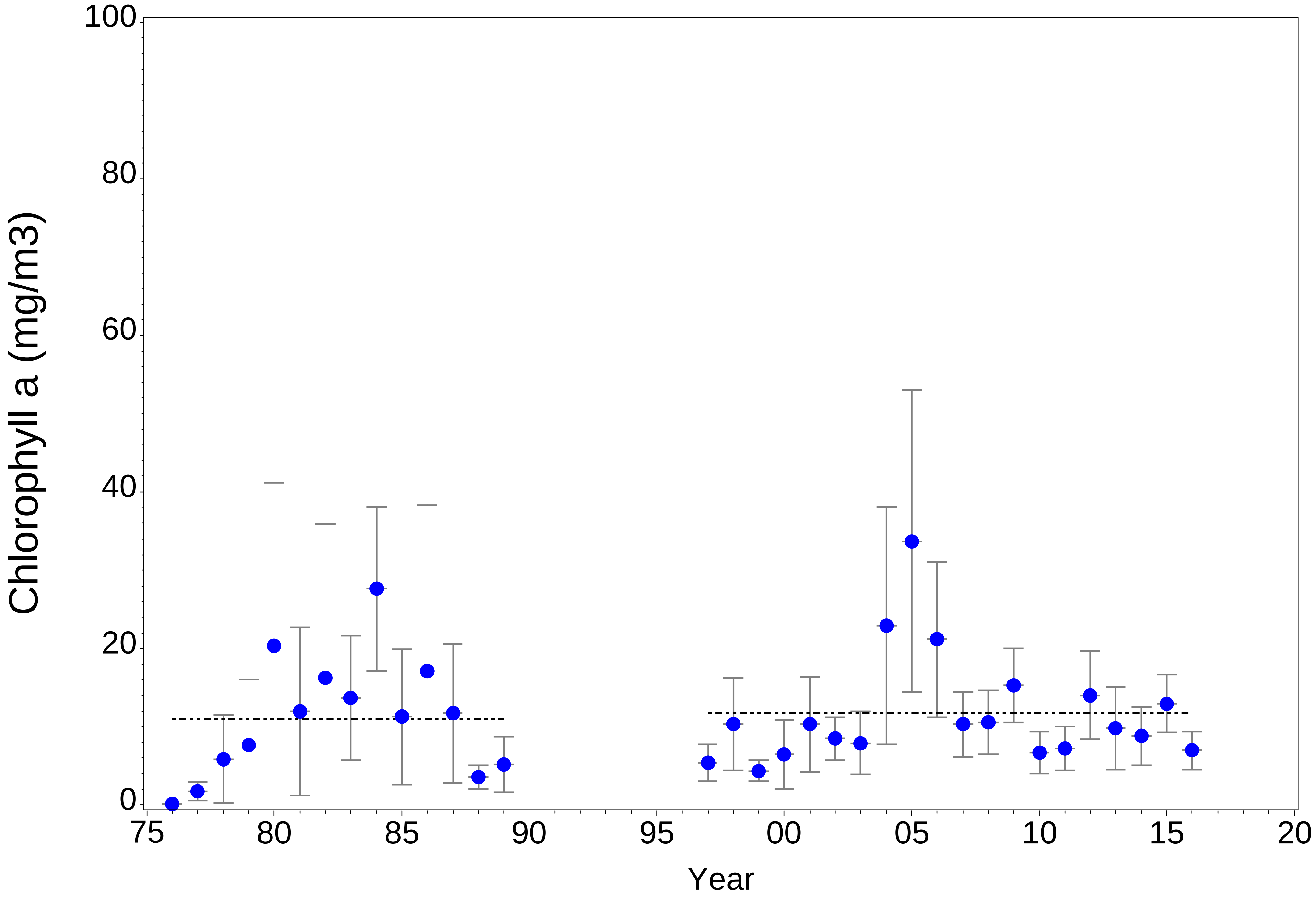

Figure 5.63. Long-term Station 18 surface Chlorophyll a at river kilometer 30.7

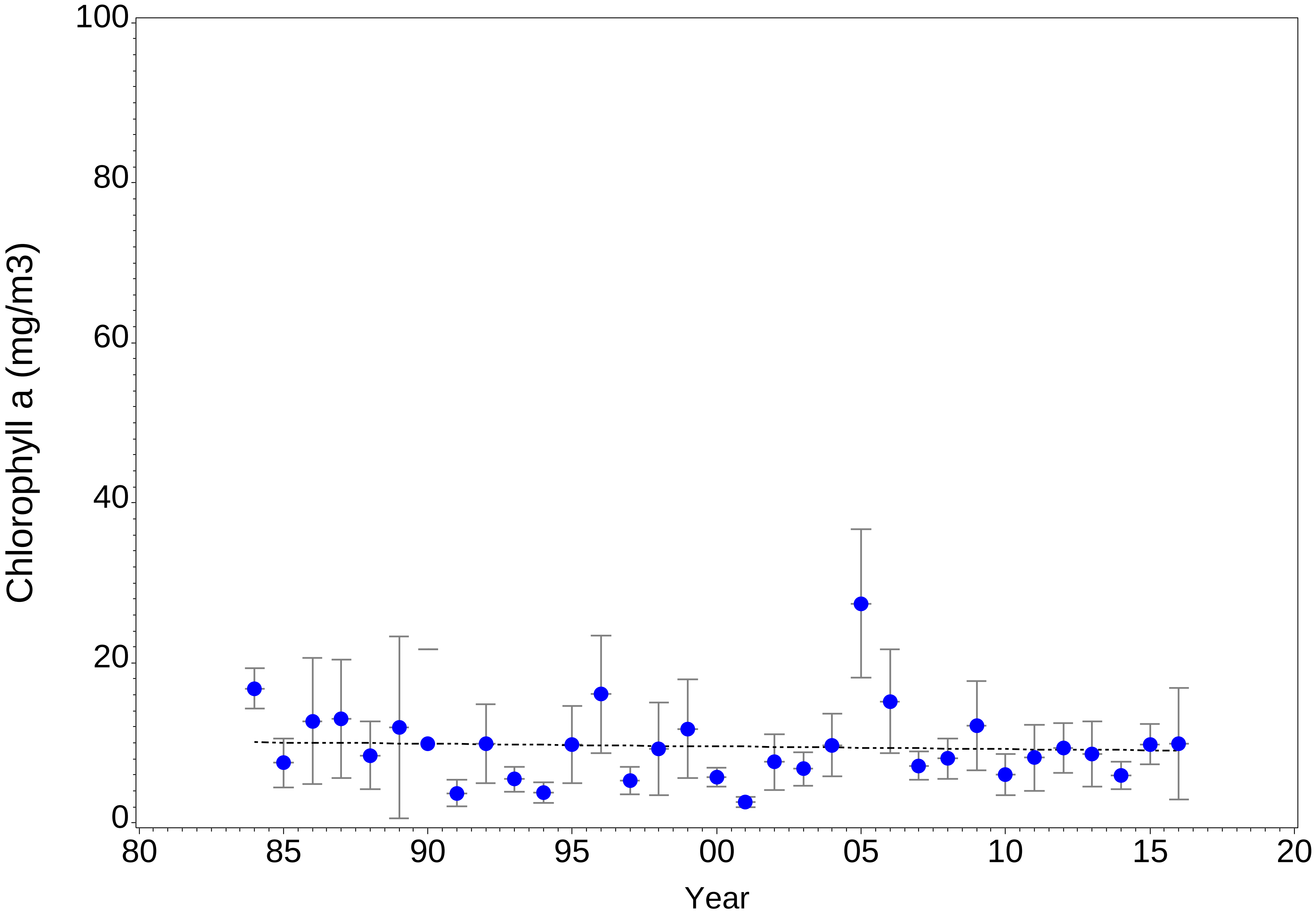

Figure 5.64. Annual monthly surface Chlorophyll a at 0 psu isohaline (1984-2016)

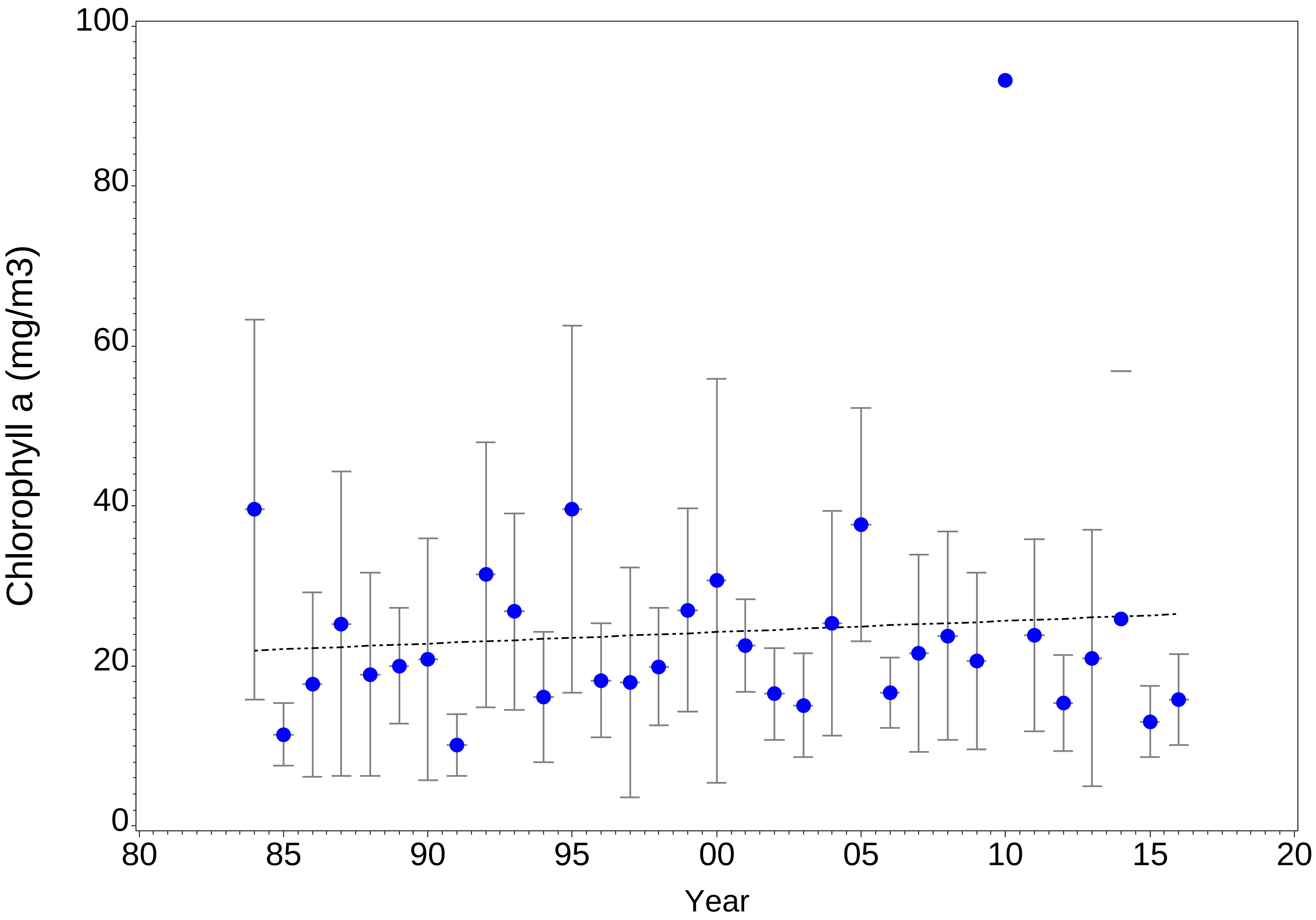

Figure 5.65. Annual monthly surface Chlorophyll a at 6 psu isohaline (1984-2016)

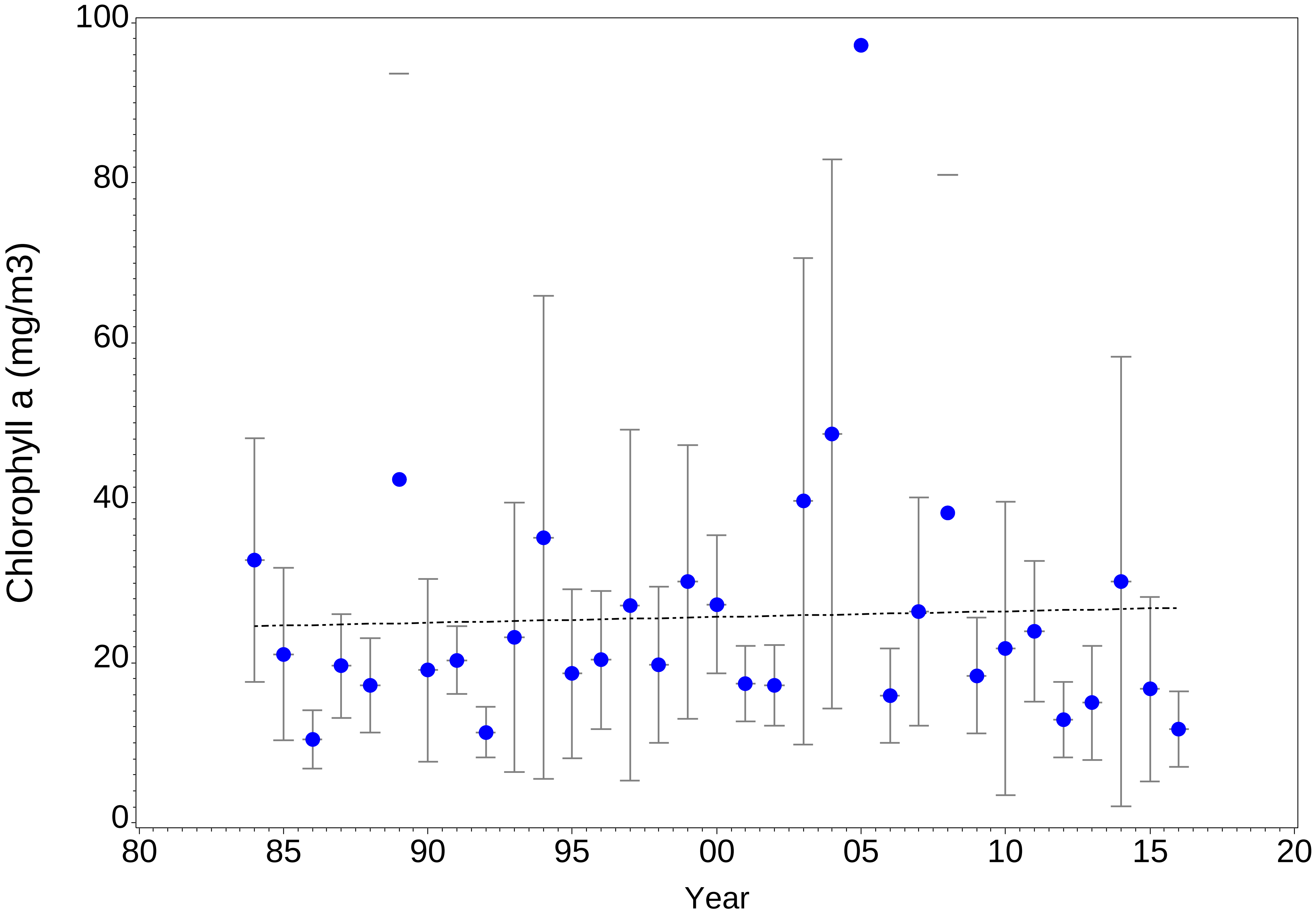

Figure 5.66. Annual monthly surface Chlorophyll a at 12 psu isohaline (1984-2016)

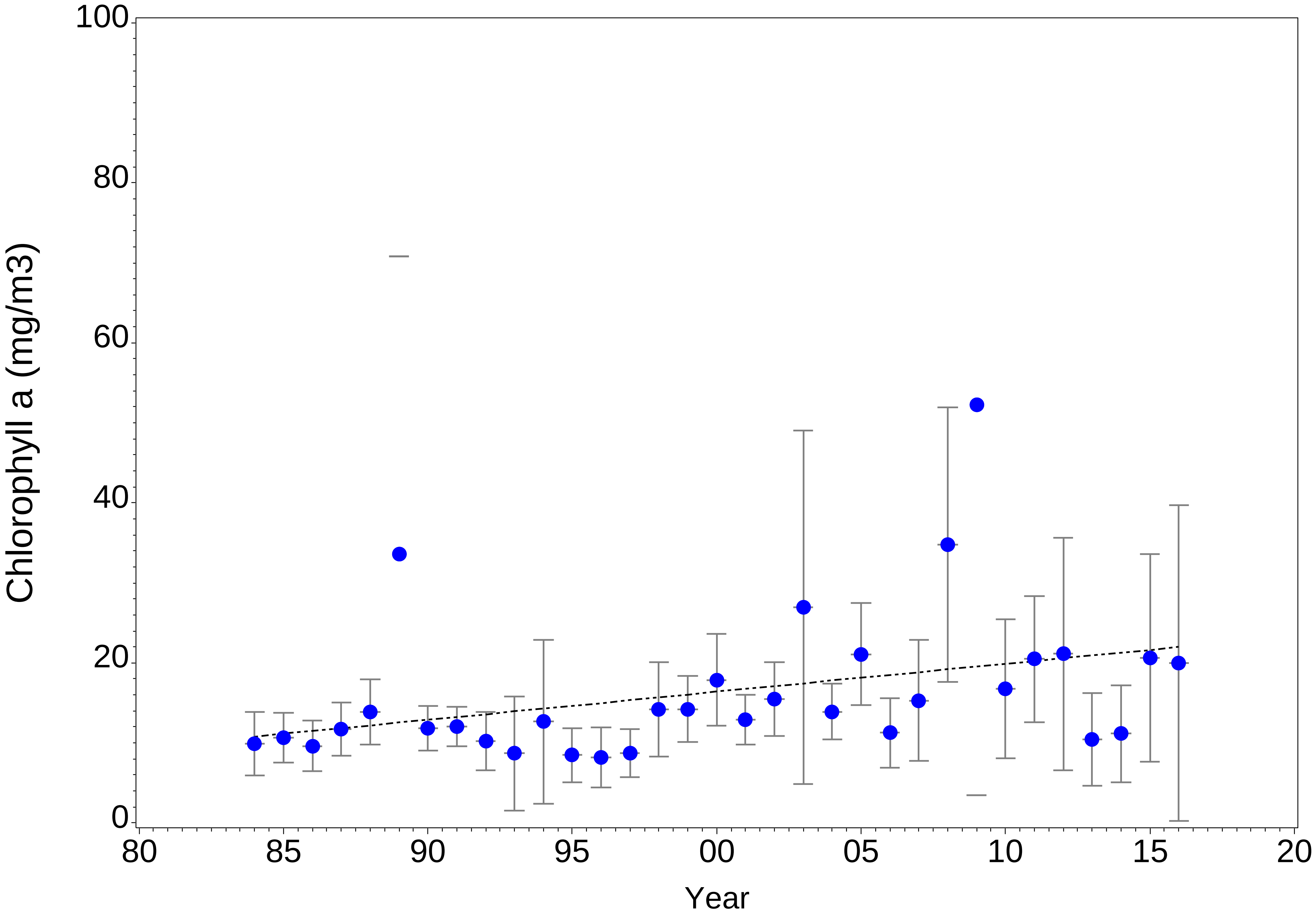

Figure 5.67. Annual monthly surface Chlorophyll a at 20 psu isohaline (1984-2016)

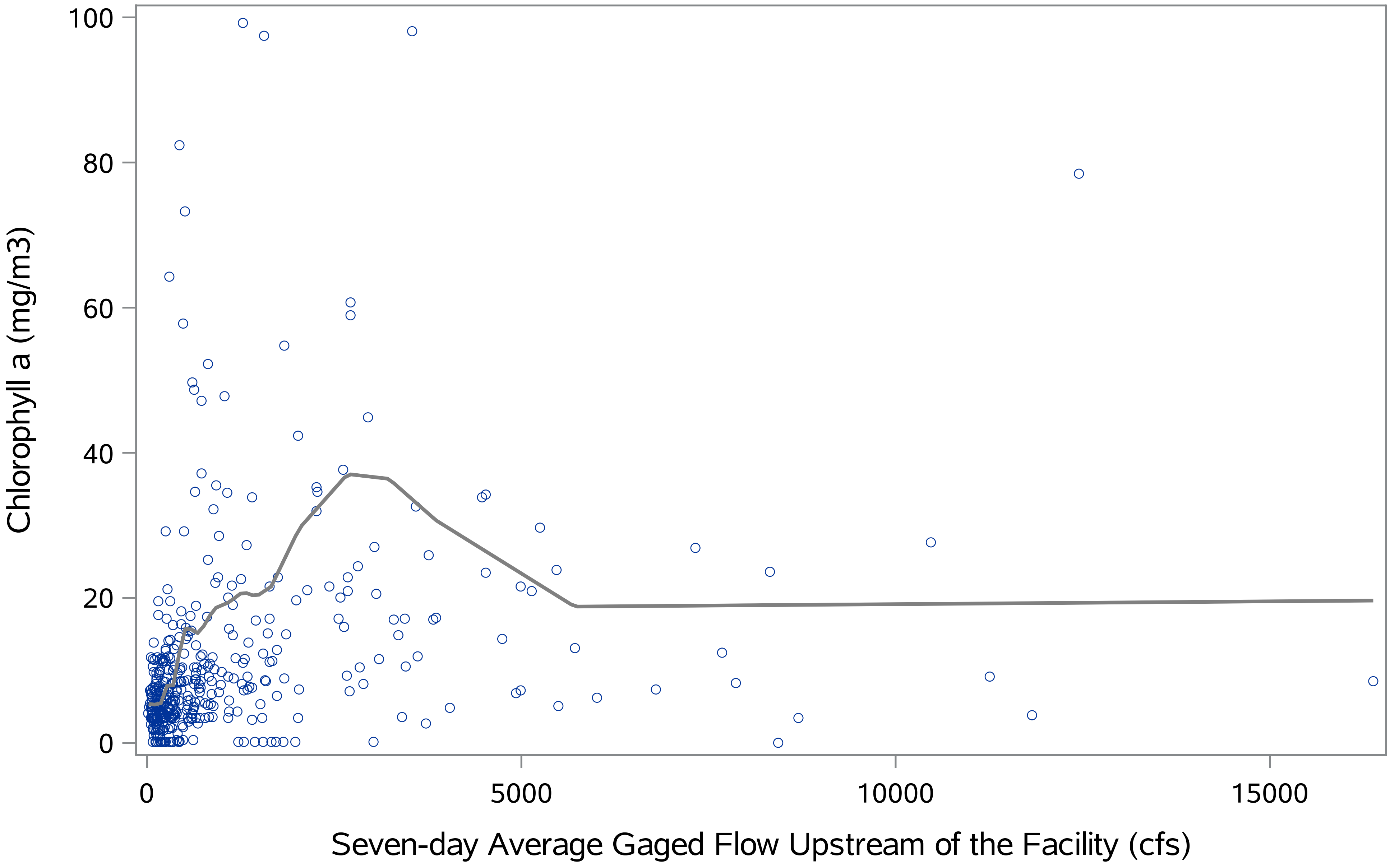

Figure 5.68. Surface Chlorophyll a at river kilometer -2.4 versus flow

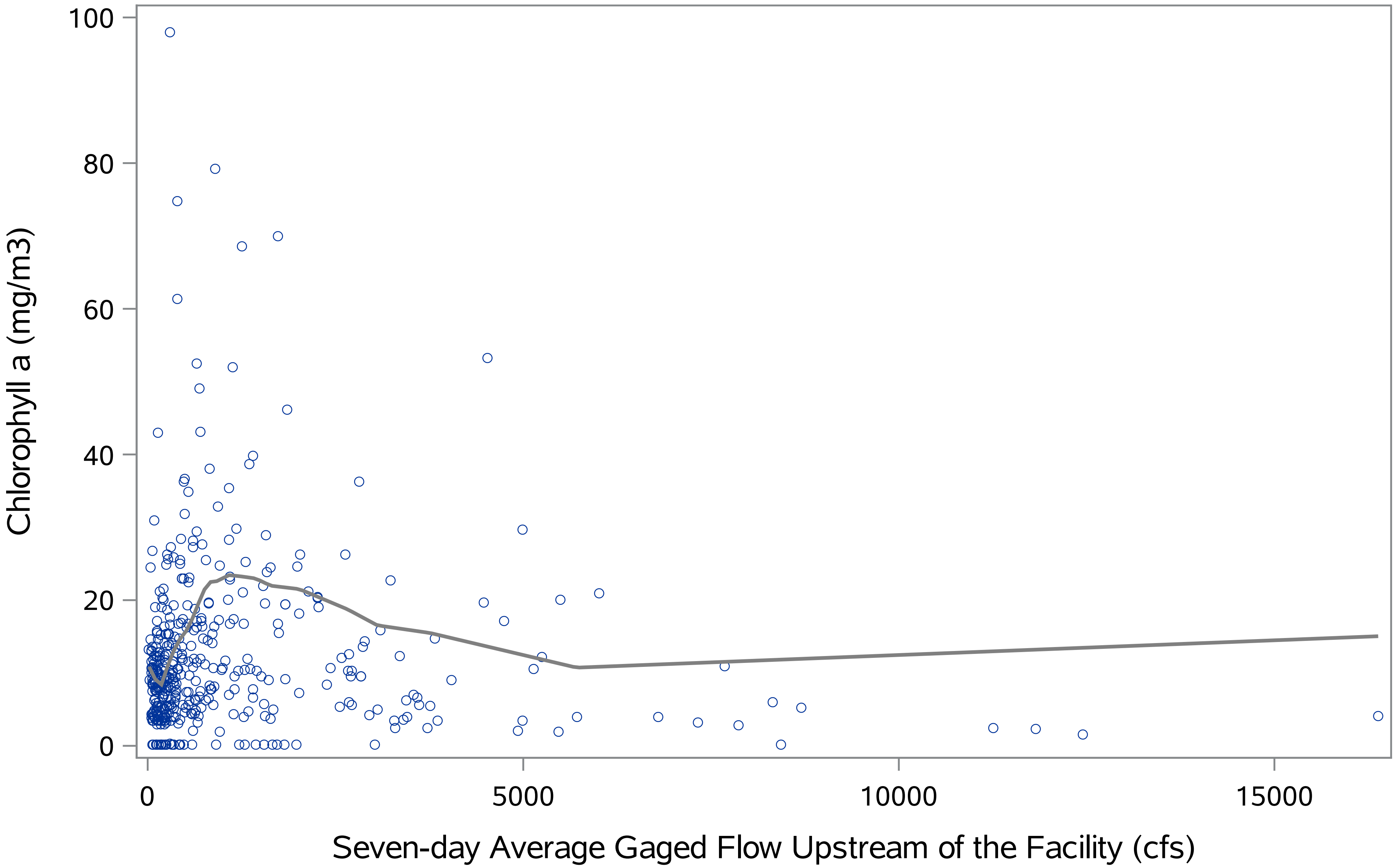

Figure 5.69. Surface Chlorophyll a at river kilometer 6.6 versus flow

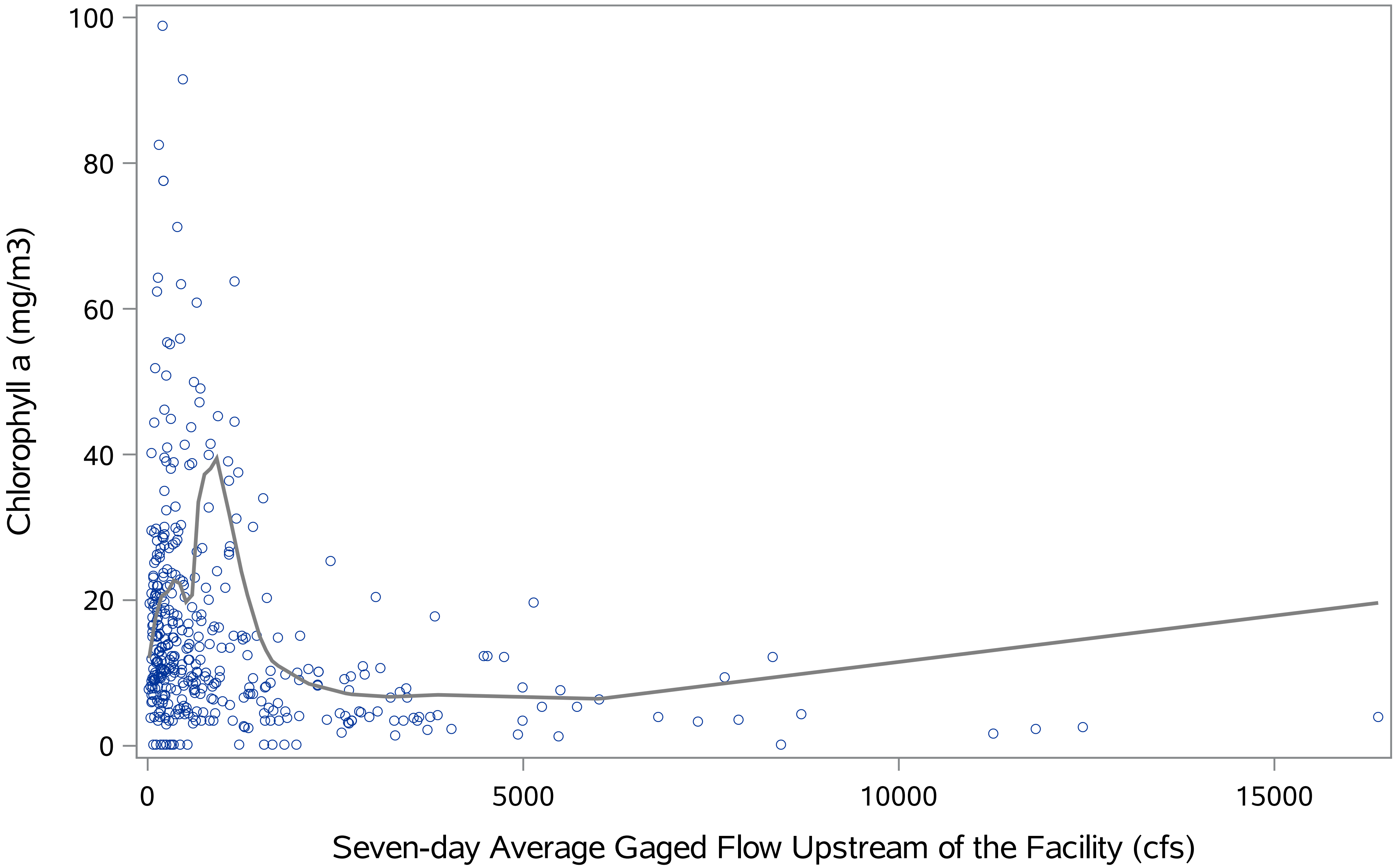

Figure 5.70. Surface Chlorophyll a at river kilometer 15.5 versus flow

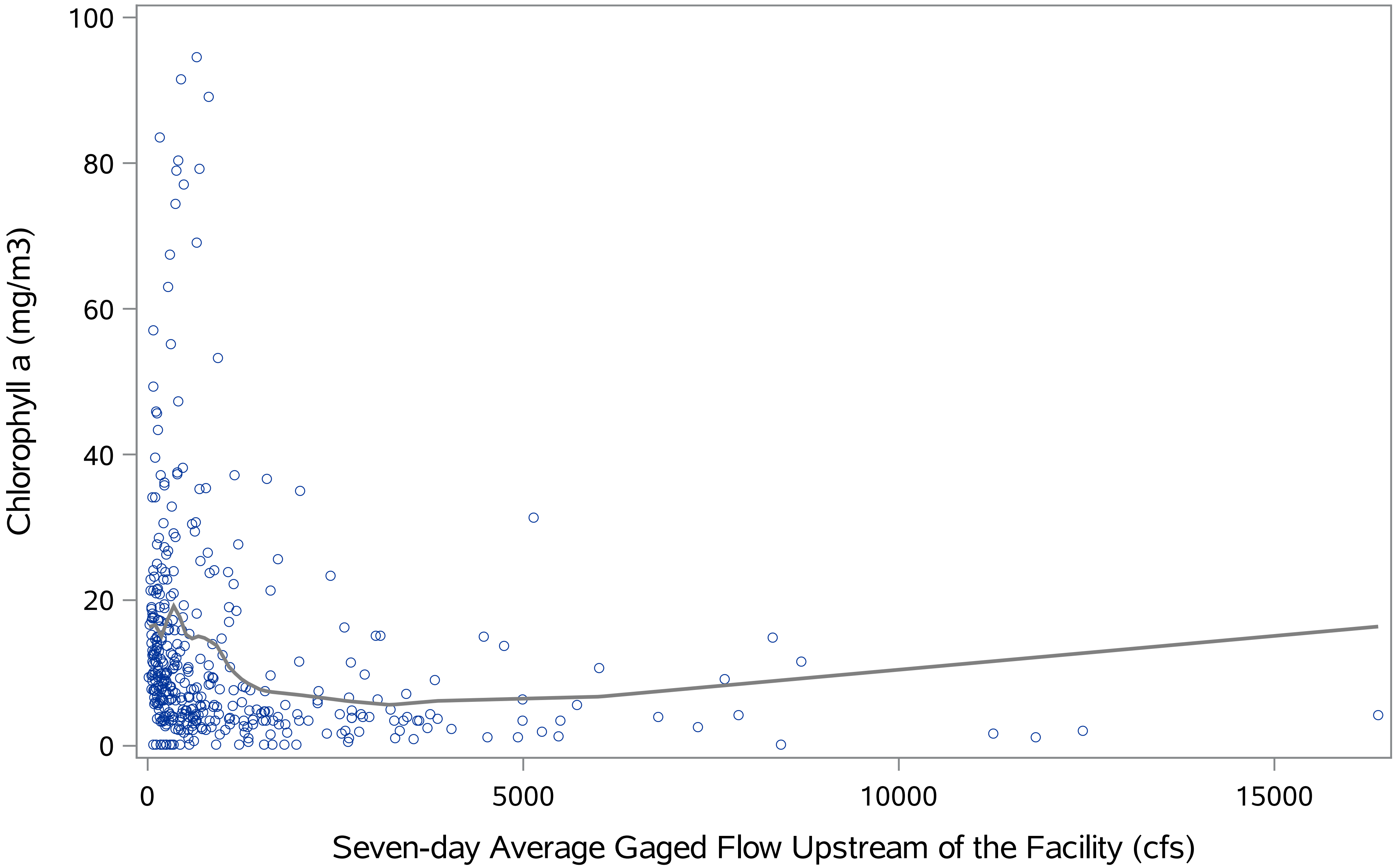

Figure 5.71. Surface Chlorophyll a at river kilometer 23.6 versus flow

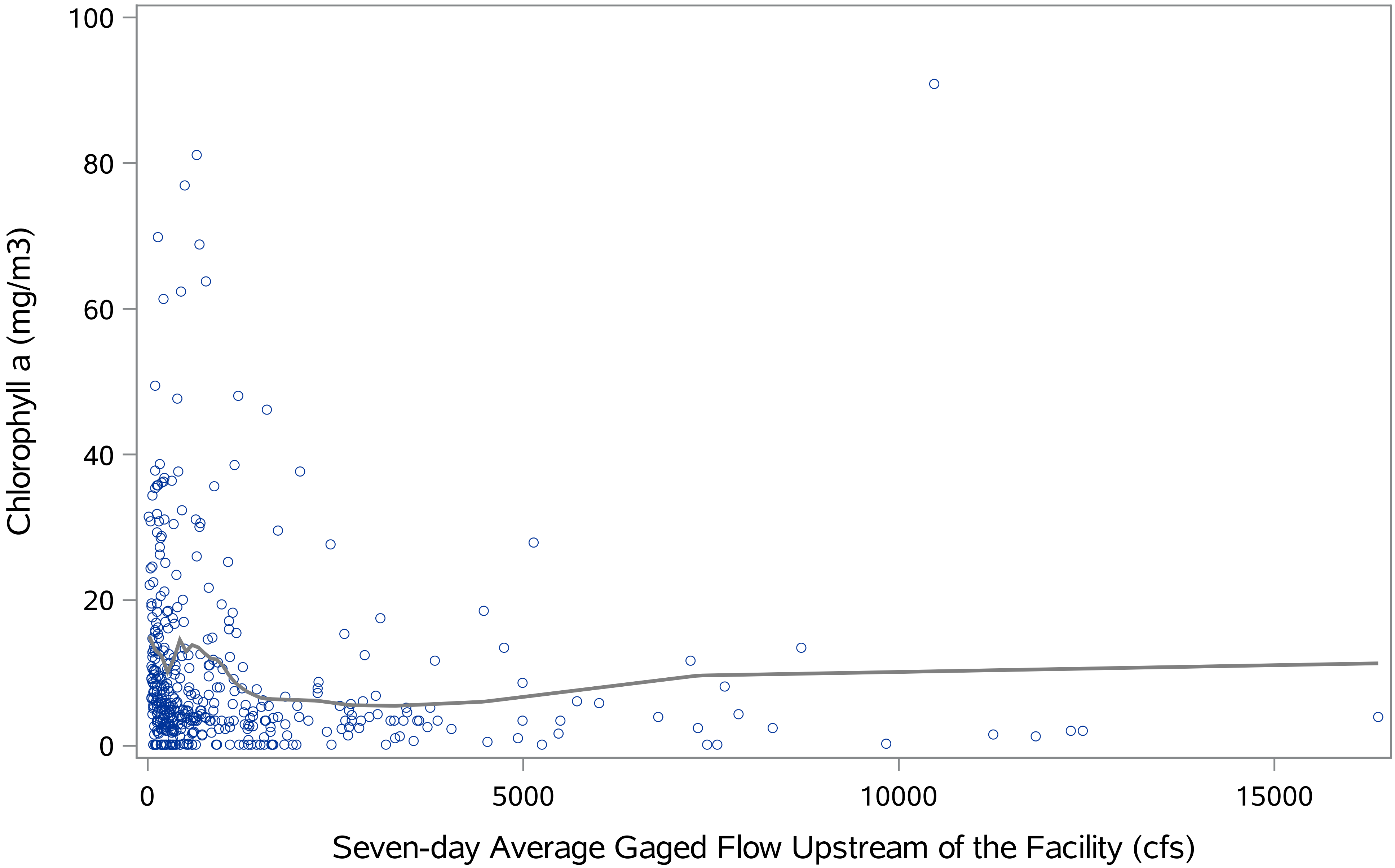

Figure 5.72. Surface Chlorophyll a at river kilometer 30.7 versus flow

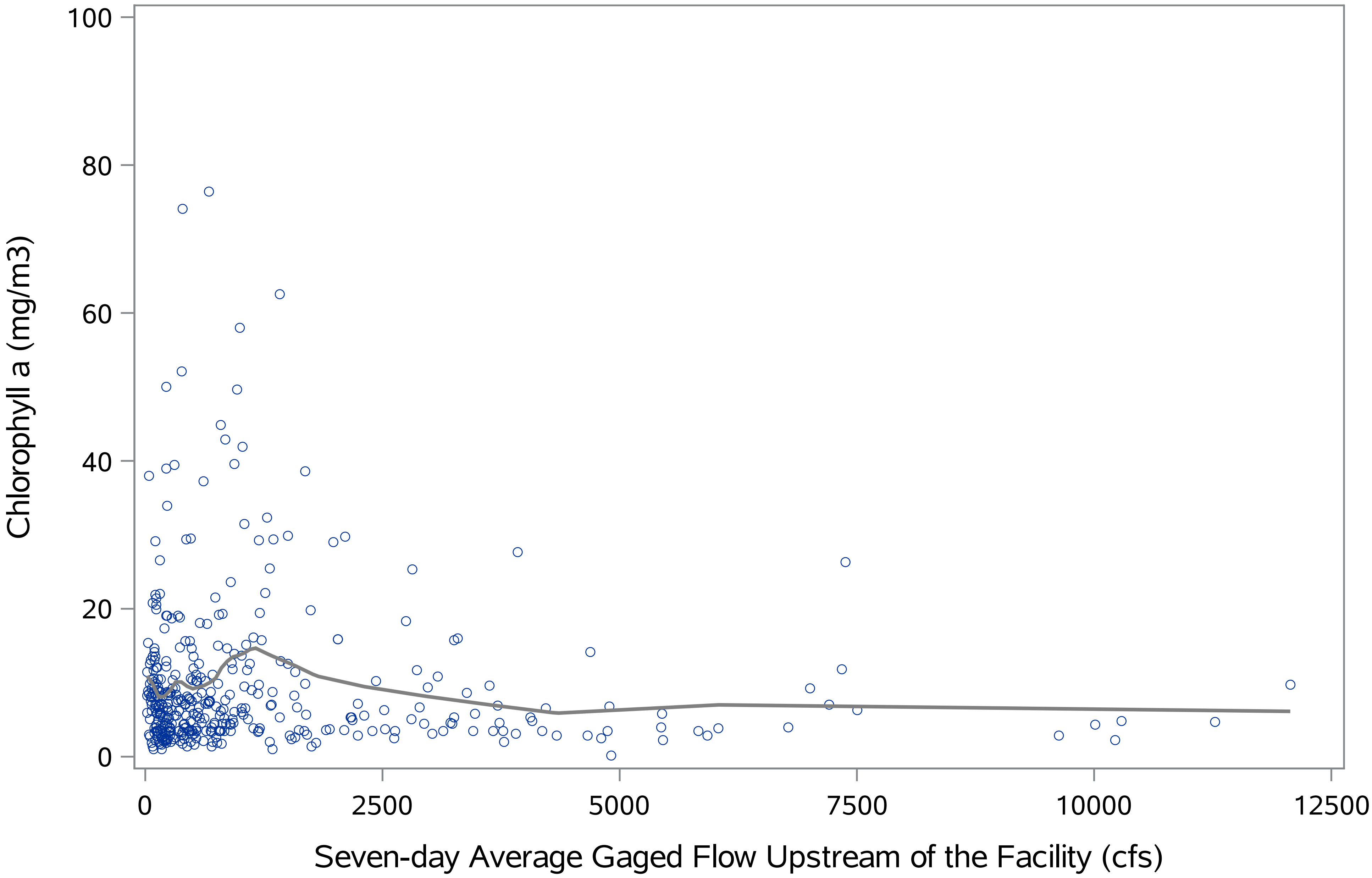

Figure 5.73. Chlorophyll a at the 0 psu isohaline versus flow

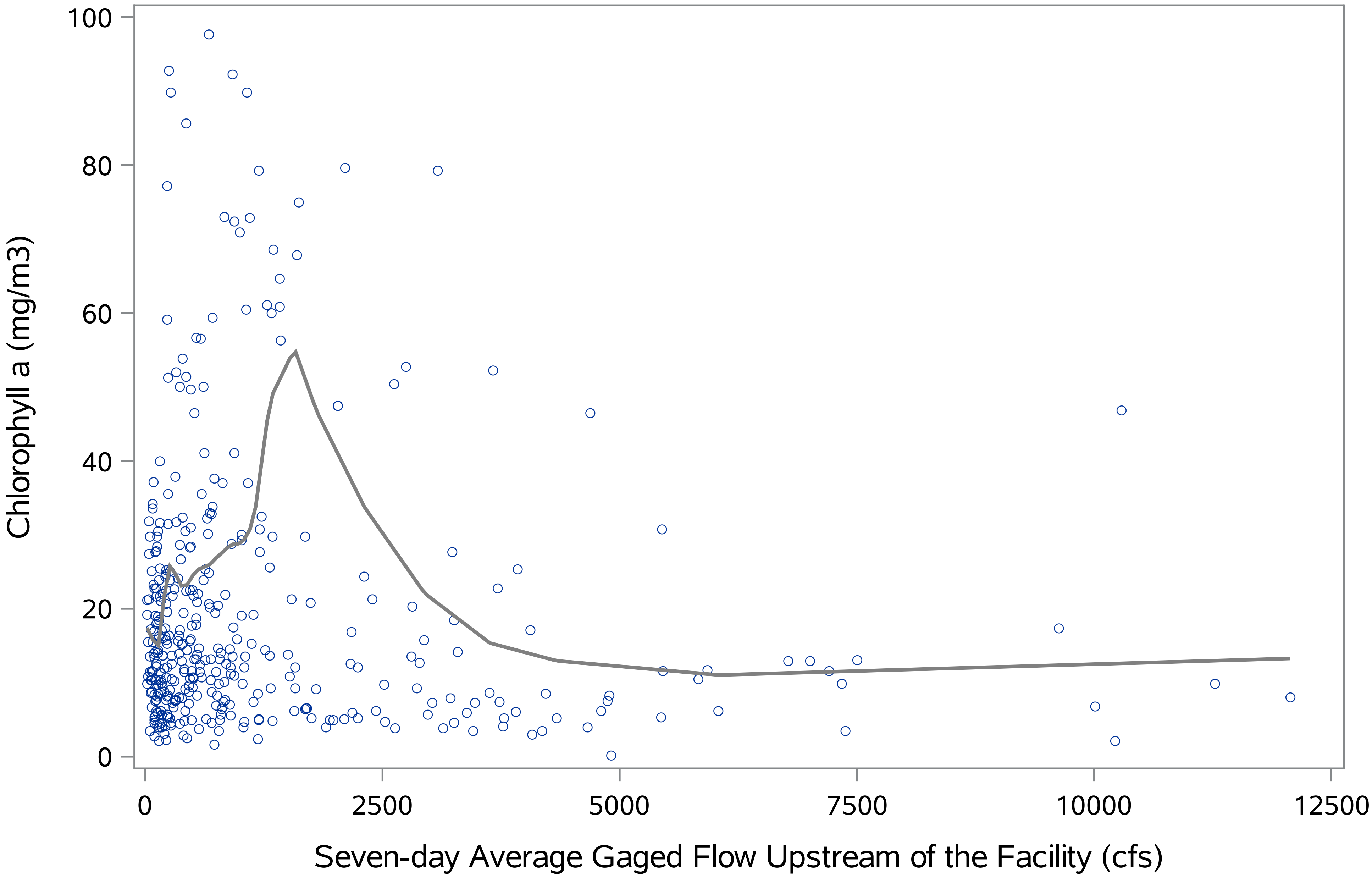

Figure 5.74. Chlorophyll a at the 6 psu isohaline versus flow

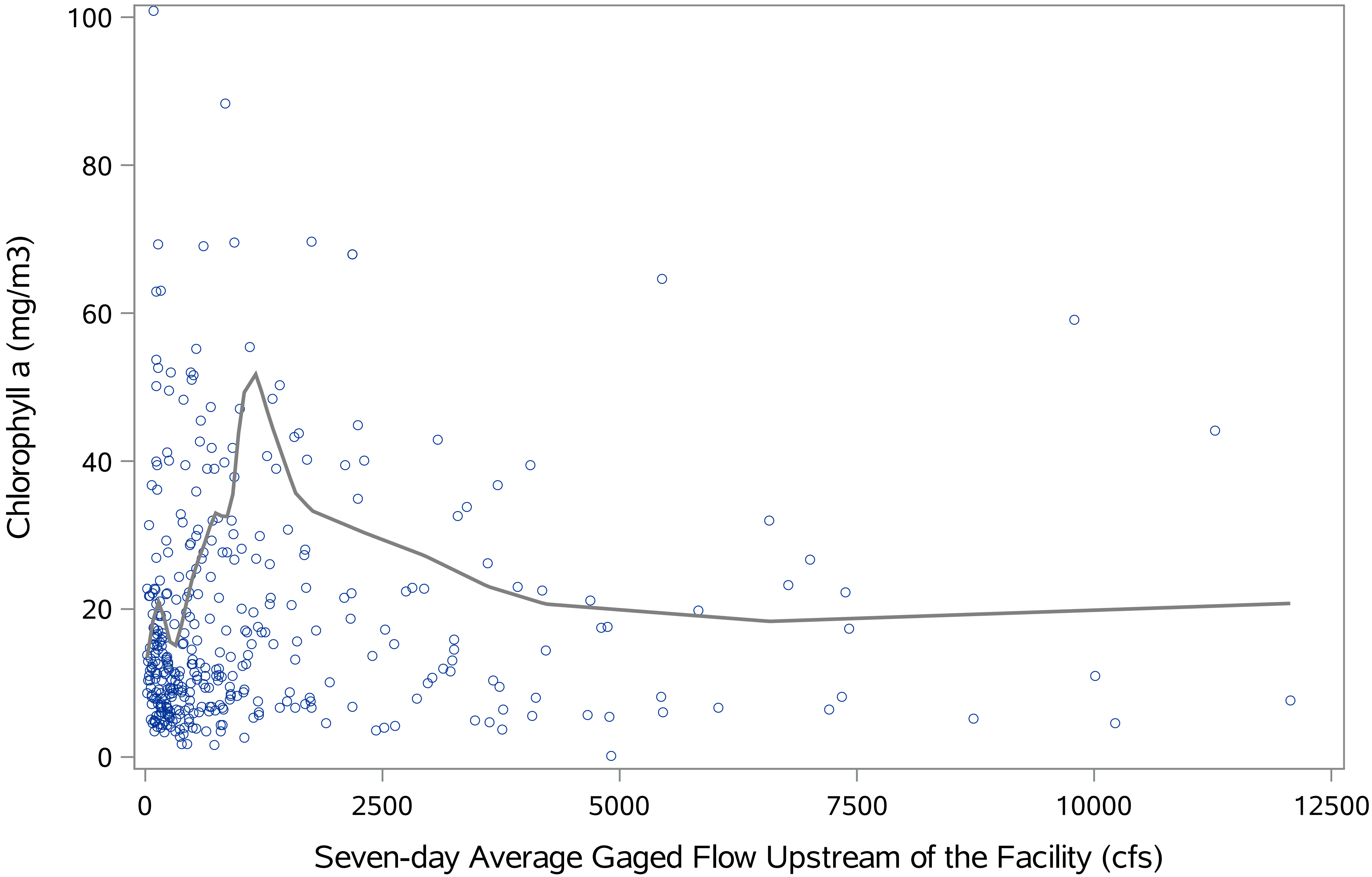

Figure 5.75. Chlorophyll a at the 12 psu isohaline versus flow

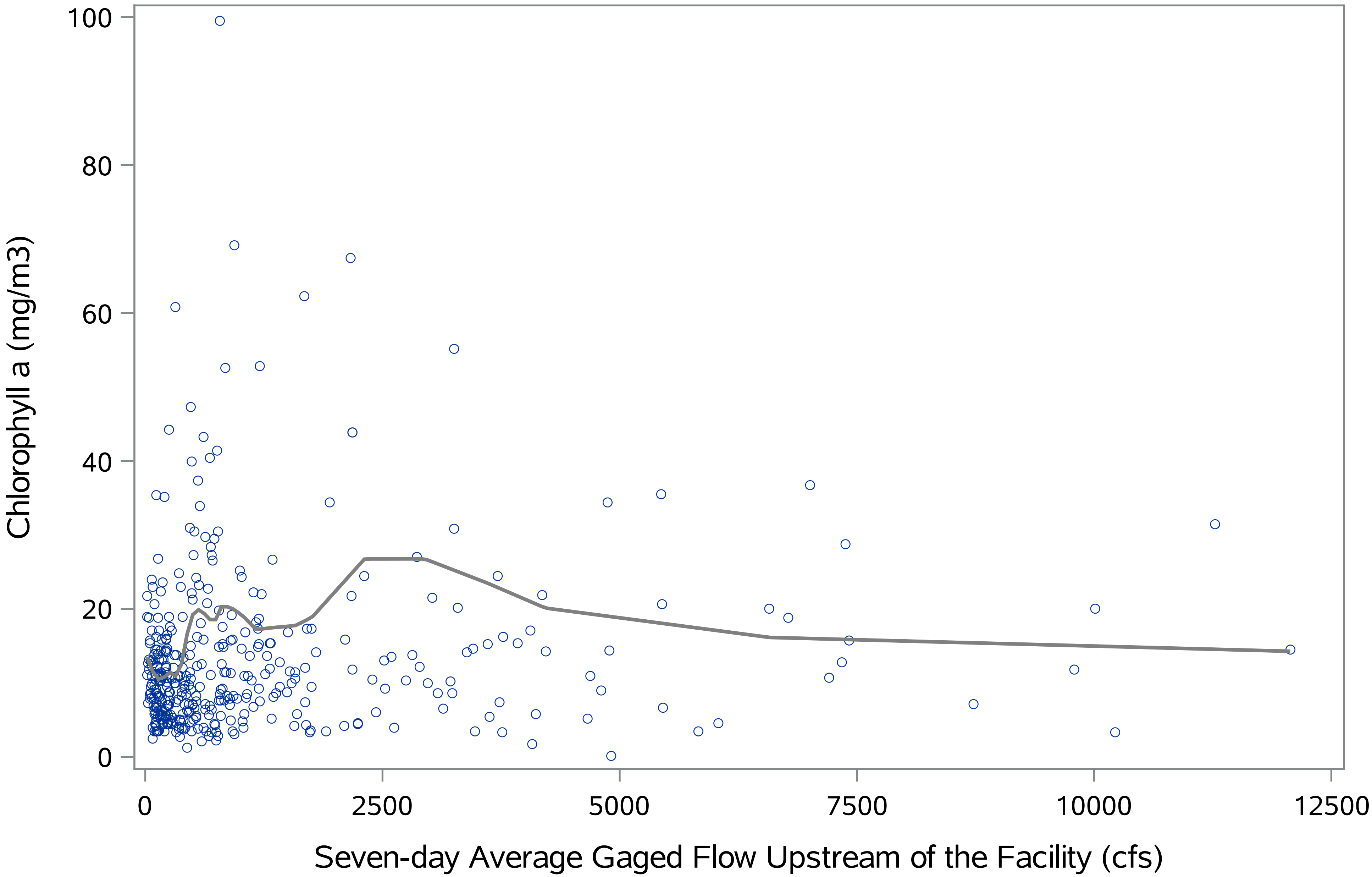

Figure 5.76. Chlorophyll a at the 20 psu isohaline versus flow

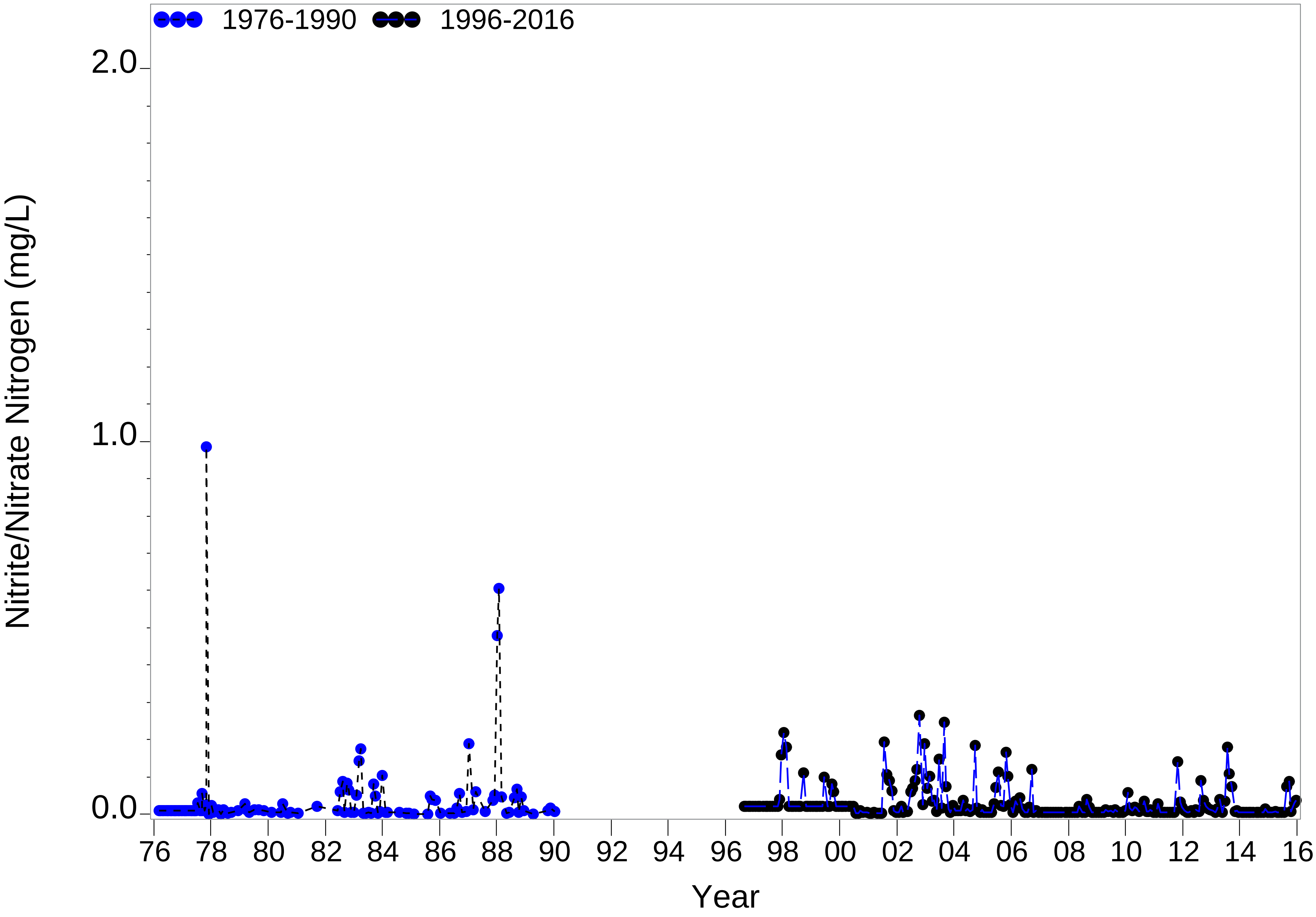

Figure 5.79. Monthly long-term Nitrite/Nitrate Nitrogen at river kilometer -2.4

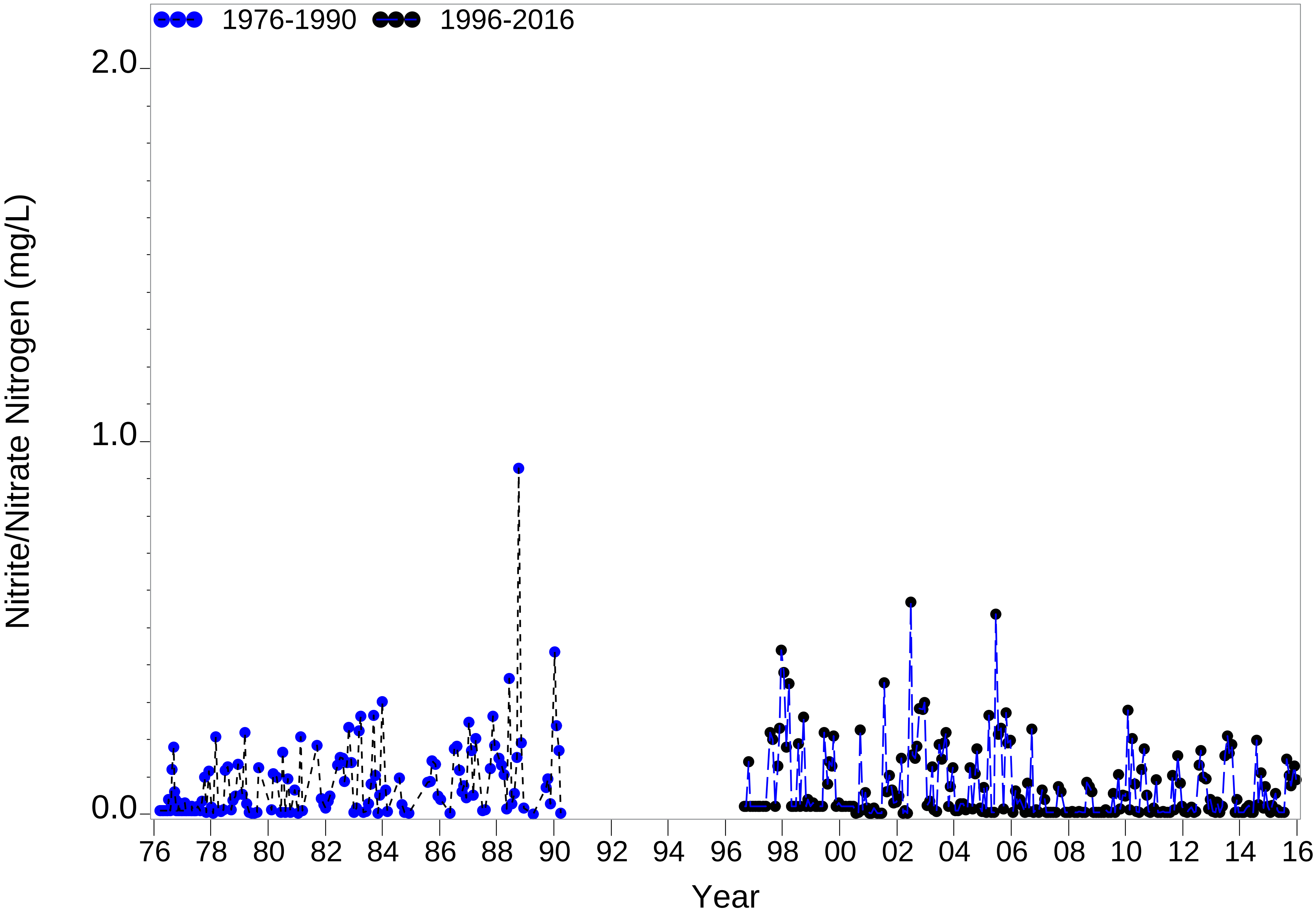

Figure 5.80. Monthly long-term Nitrite/Nitrate Nitrogen at river kilometer 6.6

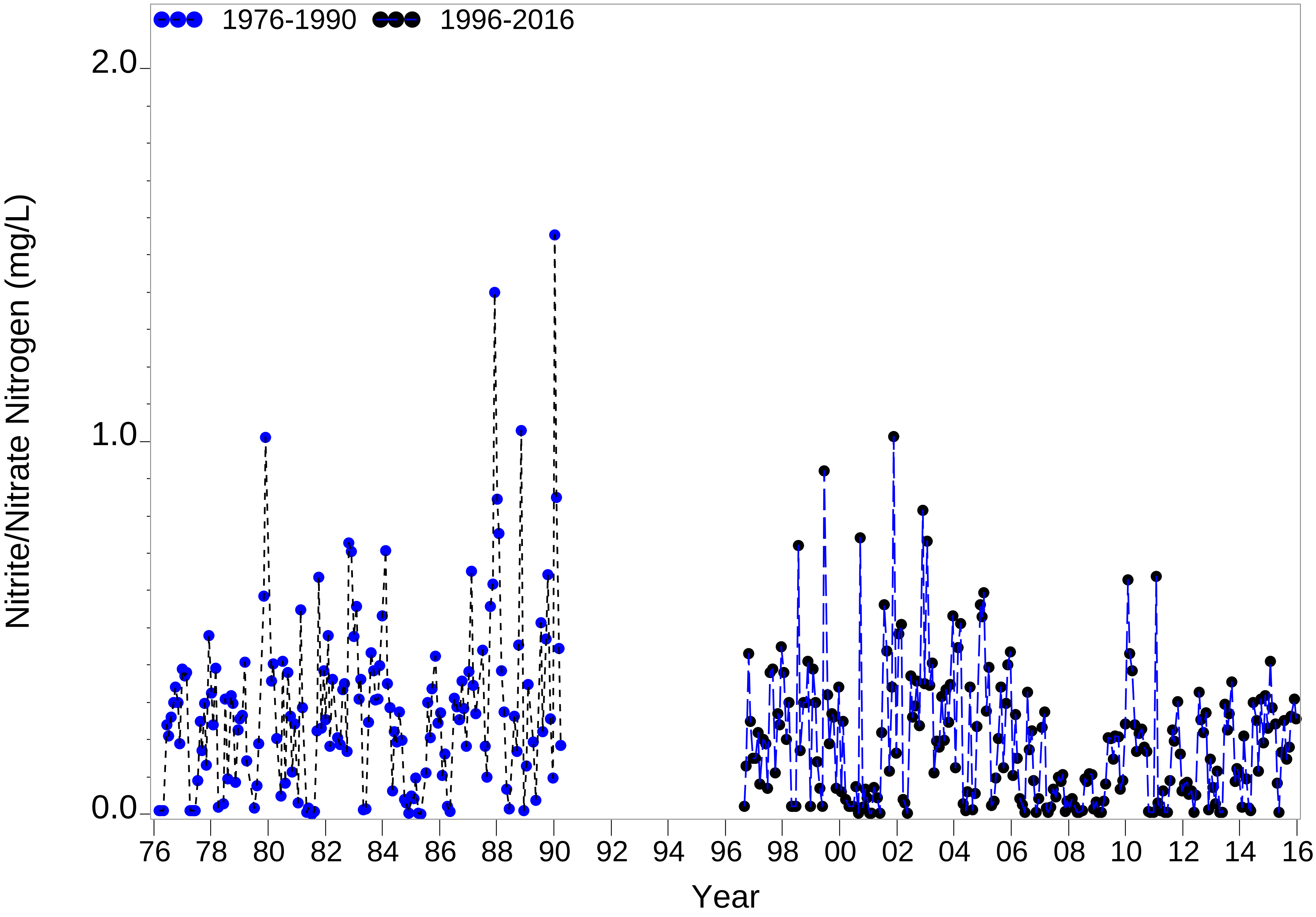

Figure 5.81. Monthly long-term Nitrite/Nitrate Nitrogen at river kilometer 15.5

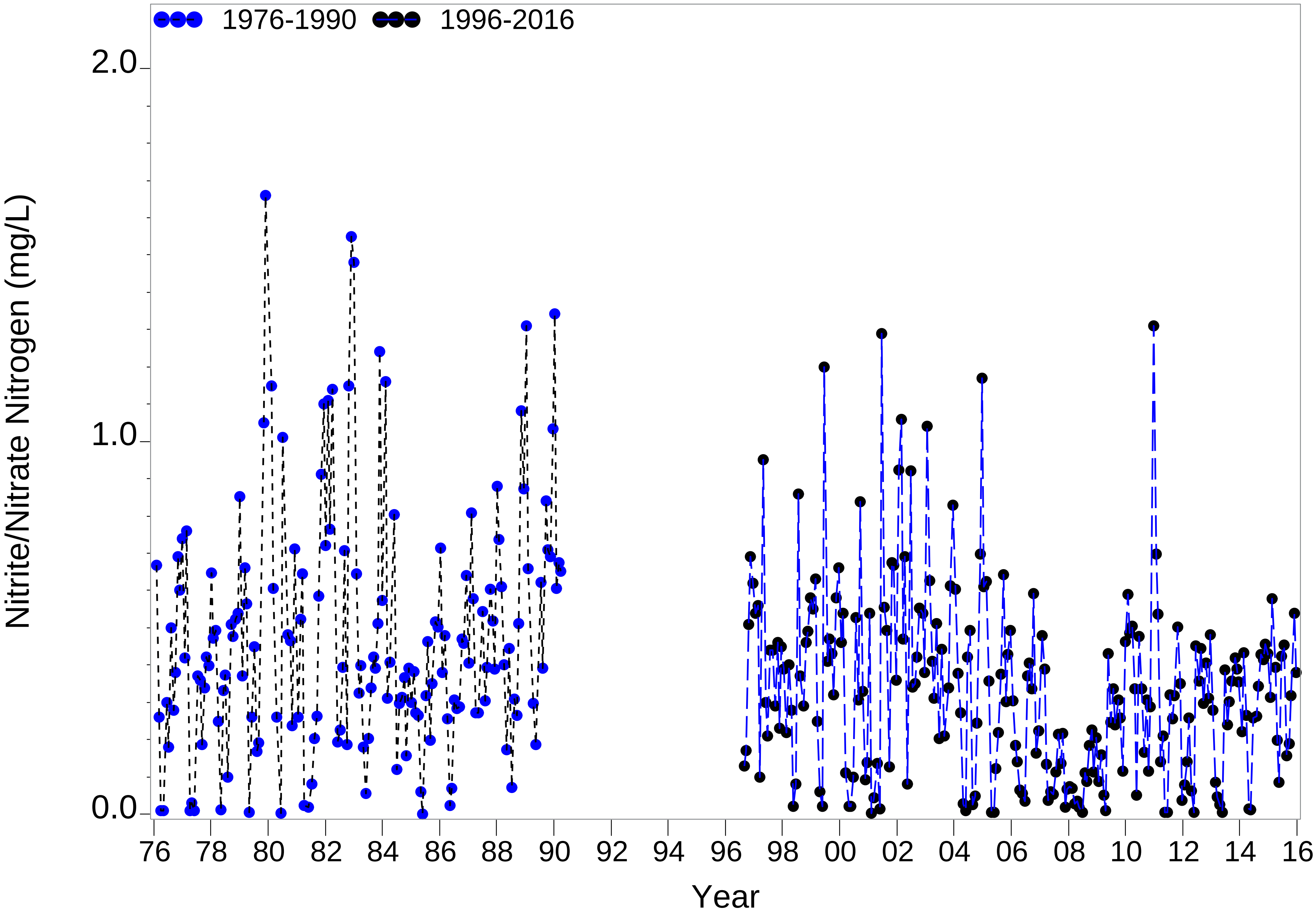

Figure 5.82. Monthly long-term Nitrite/Nitrate Nitrogen at river kilometer 23.6

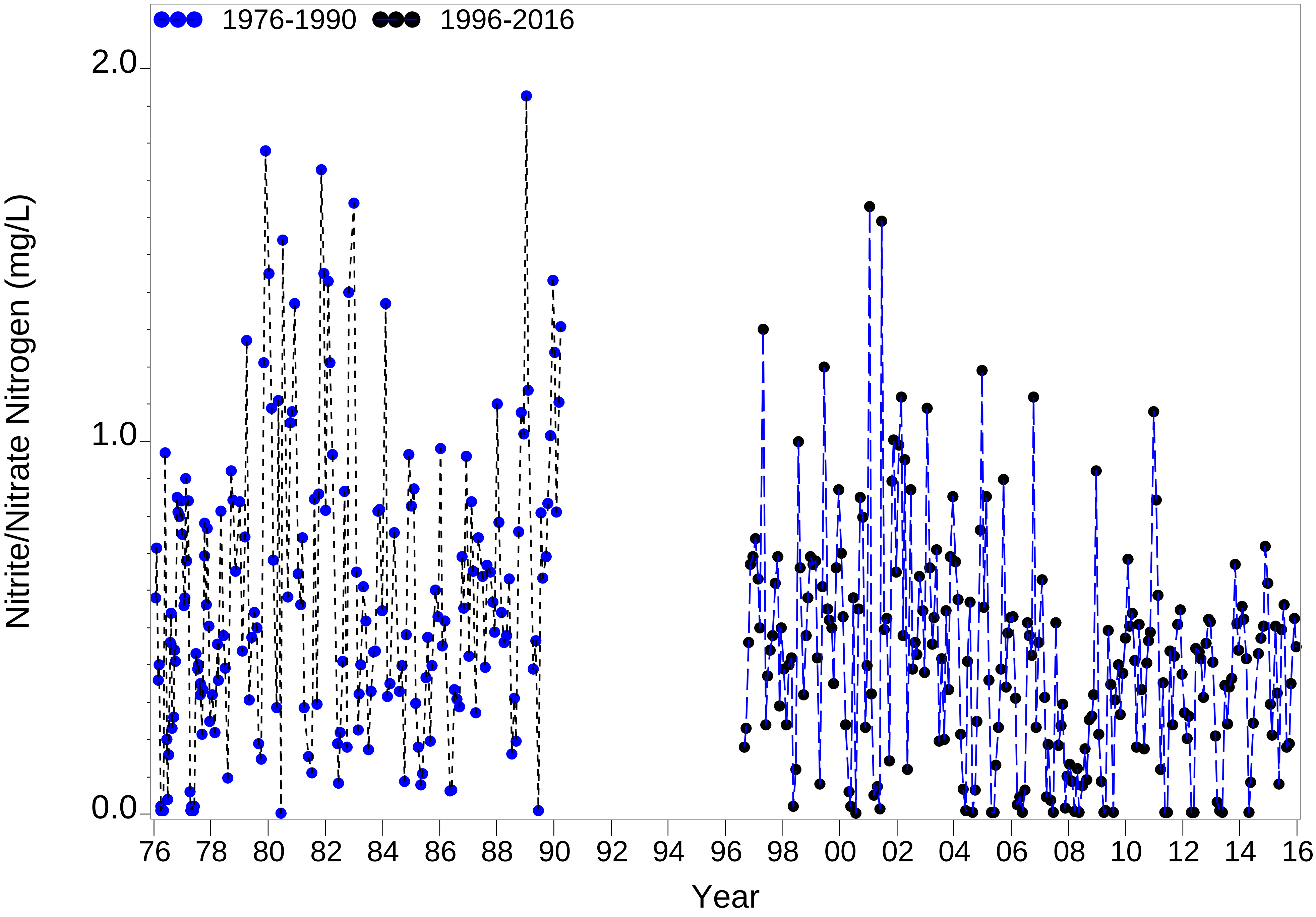

Figure 5.83. Monthly long-term Nitrite/Nitrate Nitrogen at river kilometer 30.7

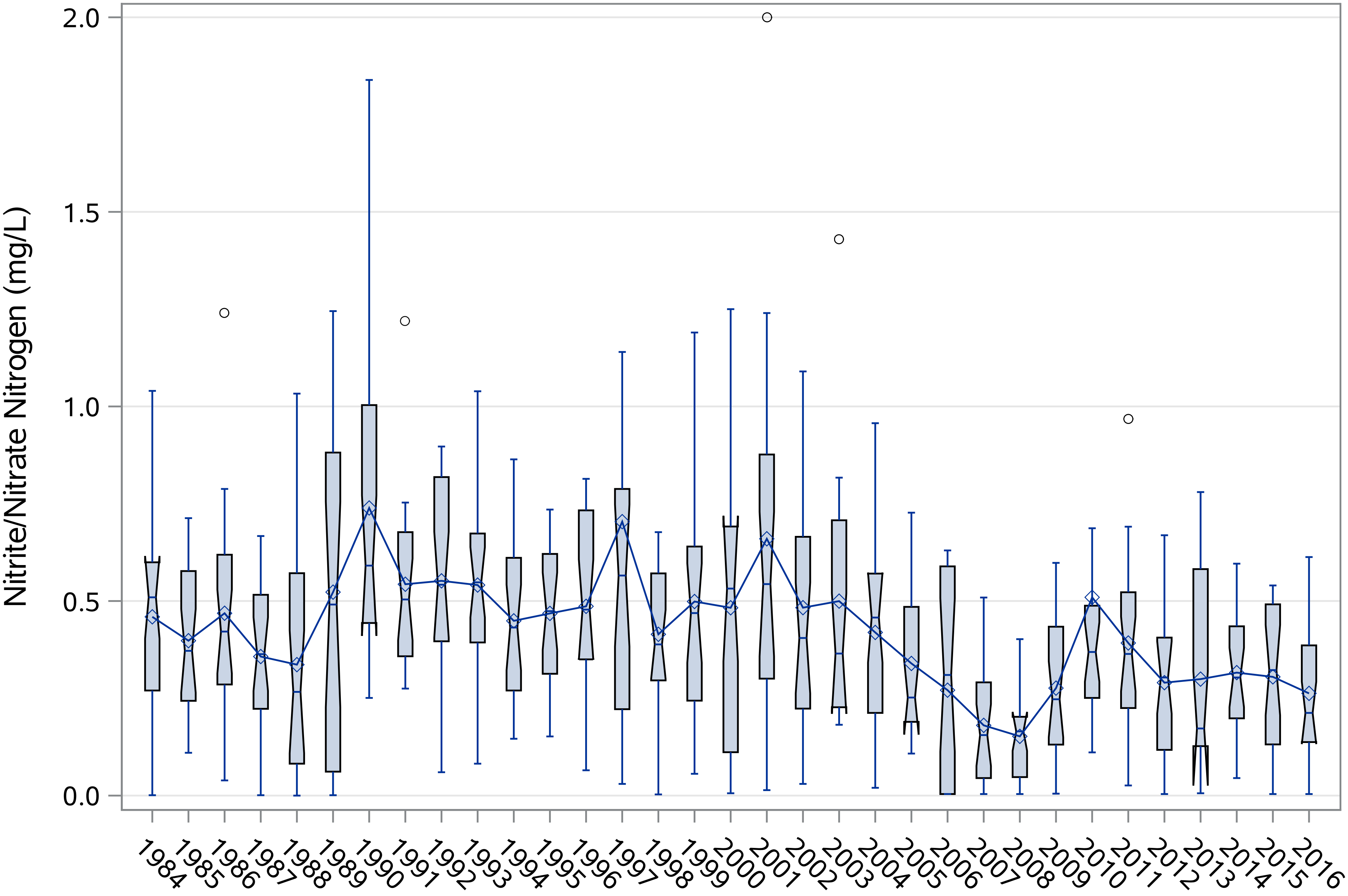

Figure 5.84. Annual boxplots of surface Nitrite/Nitrate Nitrogen at the 0 psu isohaline (1984-2016)

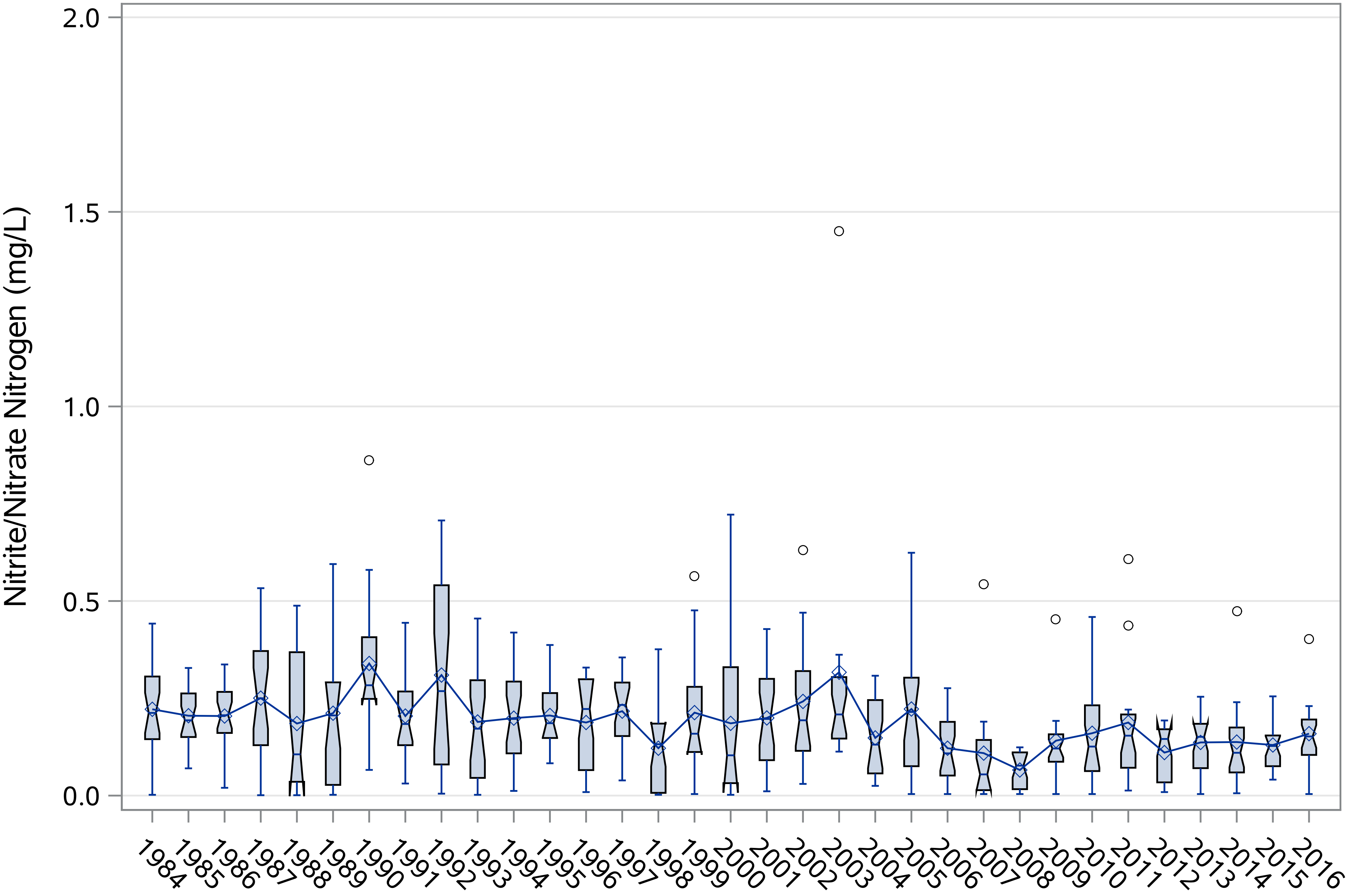

Figure 5.85. Annual boxplots of surface Nitrite/Nitrate Nitrogen at the 6 psu isohaline (1984-2016)

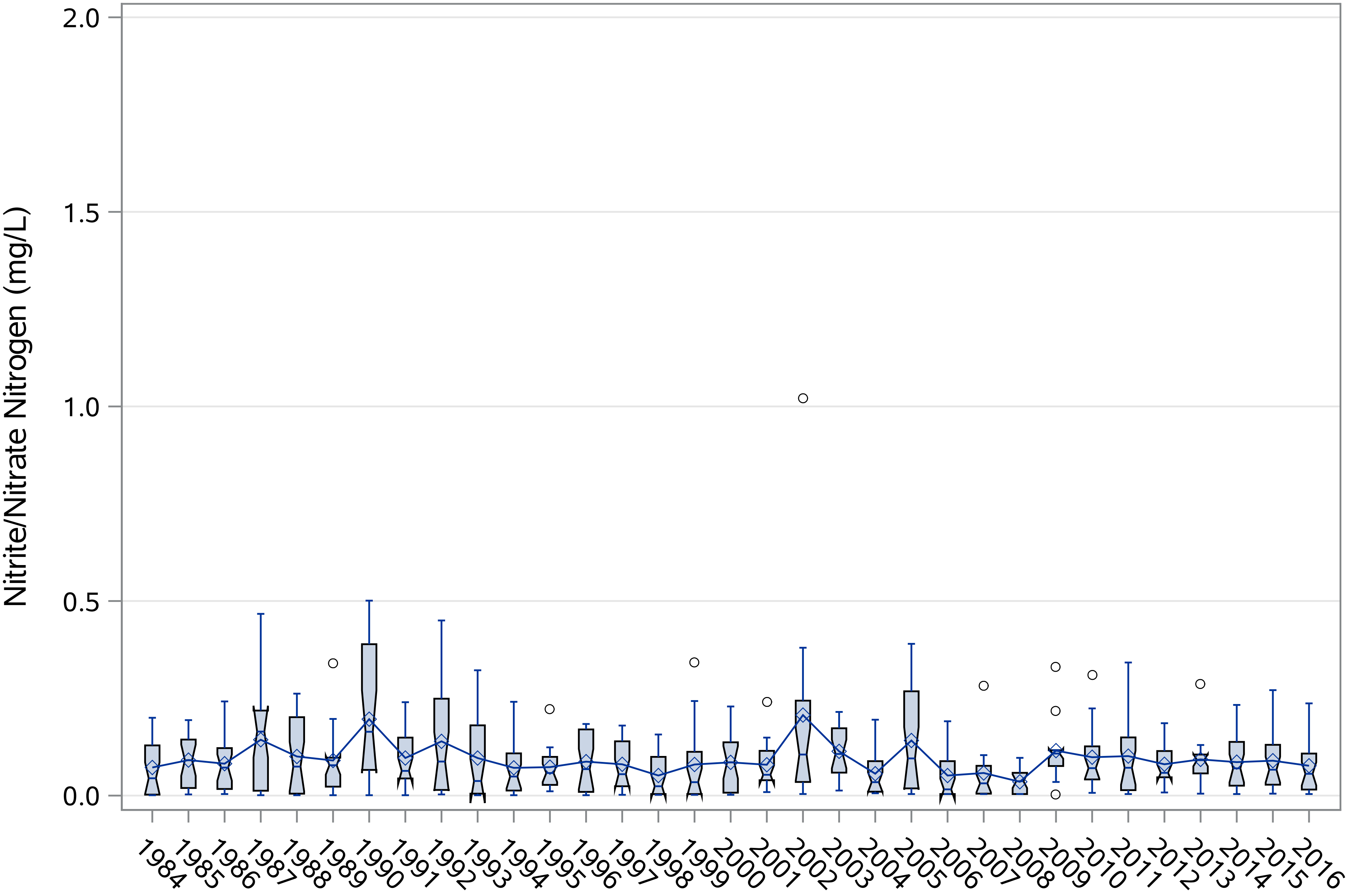

Figure 5.86. Annual boxplots of surface Nitrite/Nitrate Nitrogen at the 12 psu isohaline (1984-2016)

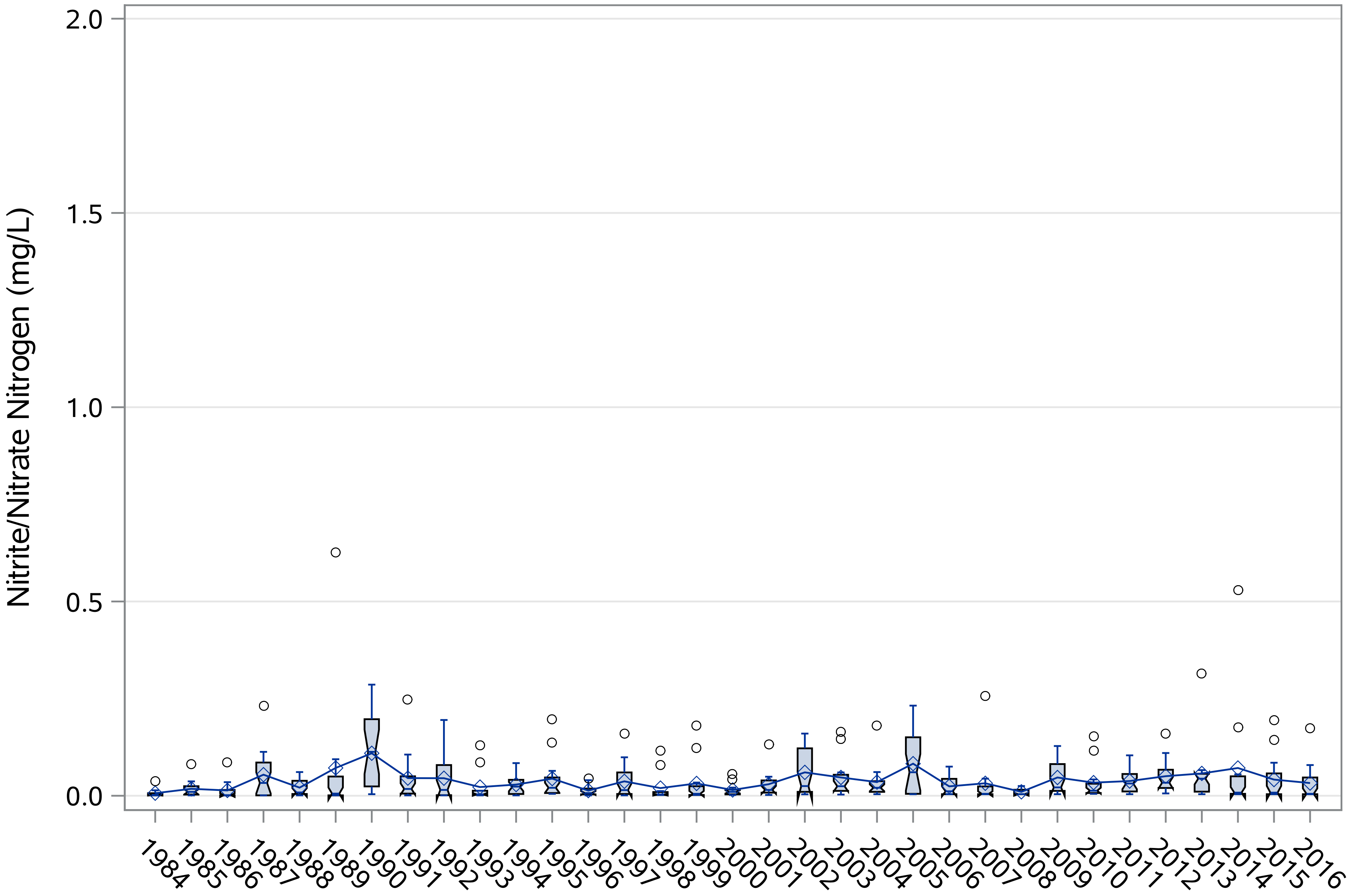

Figure 5.87. Annual boxplots of surface Nitrite/Nitrate Nitrogen at the 20 psu isohaline (1984-2016)

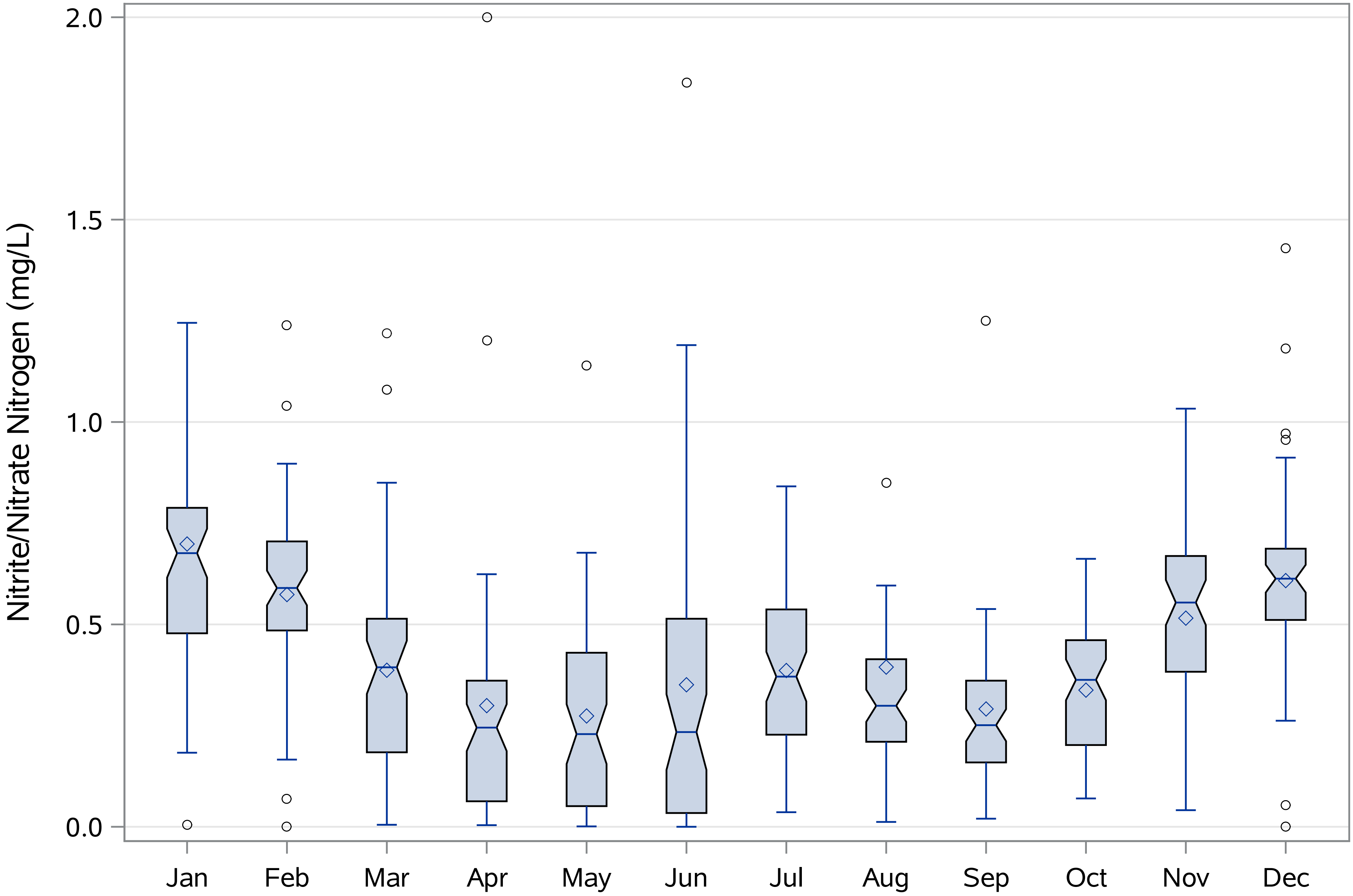

Figure 5.88. Mean monthly boxplots of surface Nitrite/Nitrate Nitrogen at the 0 psu isohaline (1984-2016)

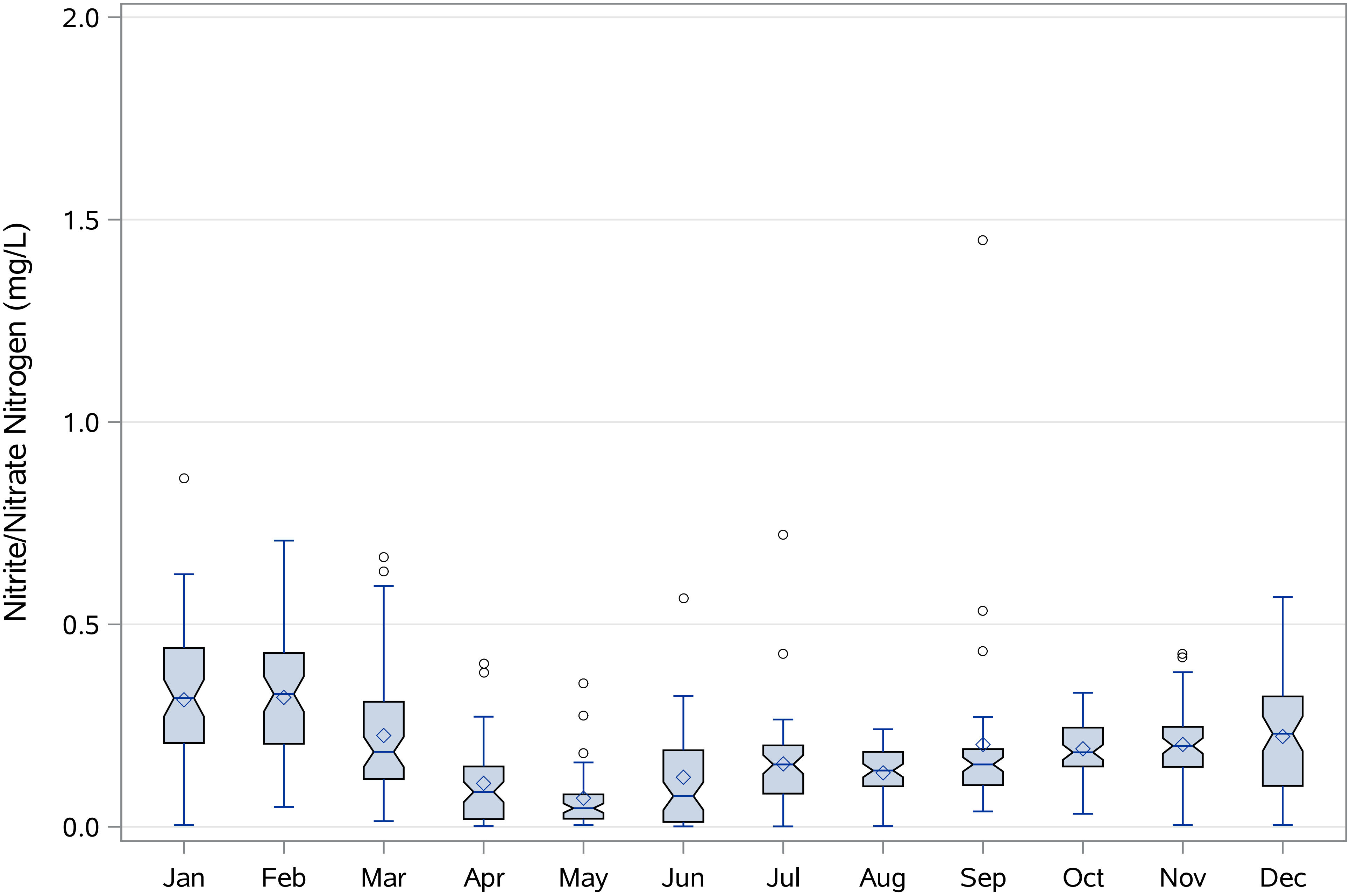

Figure 5.89. Mean monthly boxplots of surface Nitrite/Nitrate Nitrogen at the 6 psu isohaline (1984-2016)

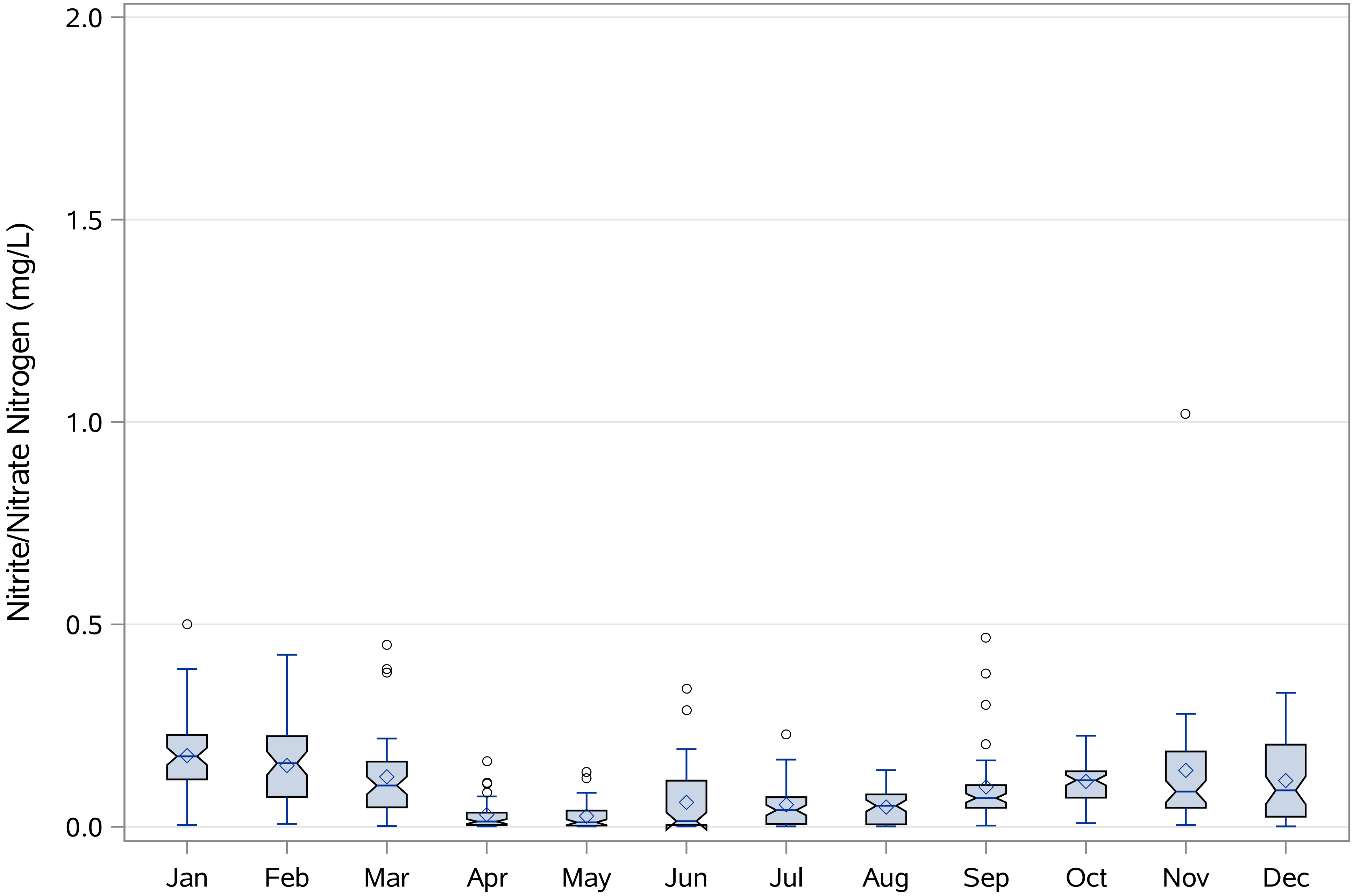

Figure 5.90. Mean monthly boxplots of surface Nitrite/Nitrate Nitrogen at the 12 psu isohaline (1984-2016)

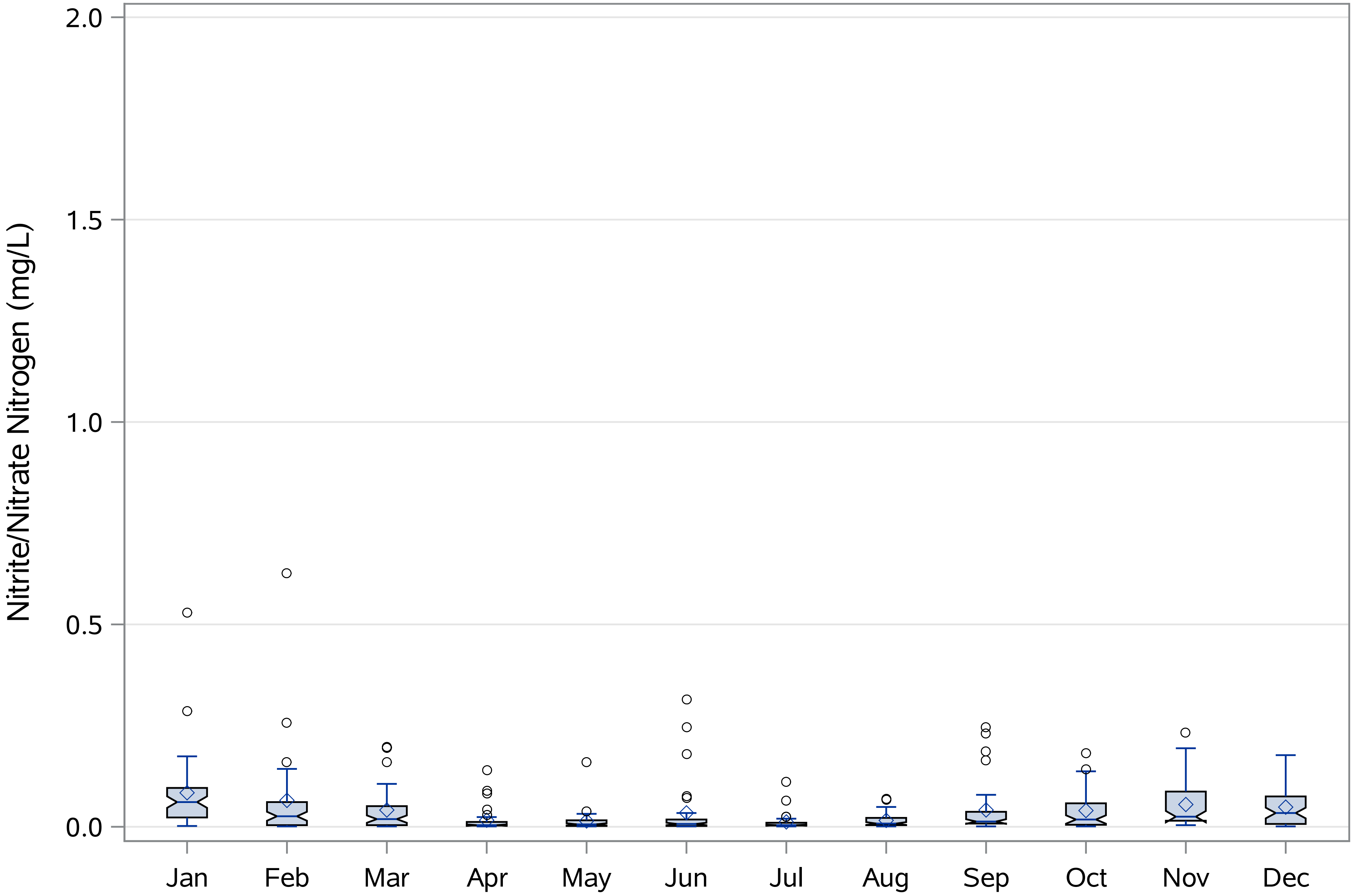

Figure 5.91. Mean monthly boxplots of surface Nitrite/Nitrate Nitrogen at the 20 psu isohaline (1984-2016)

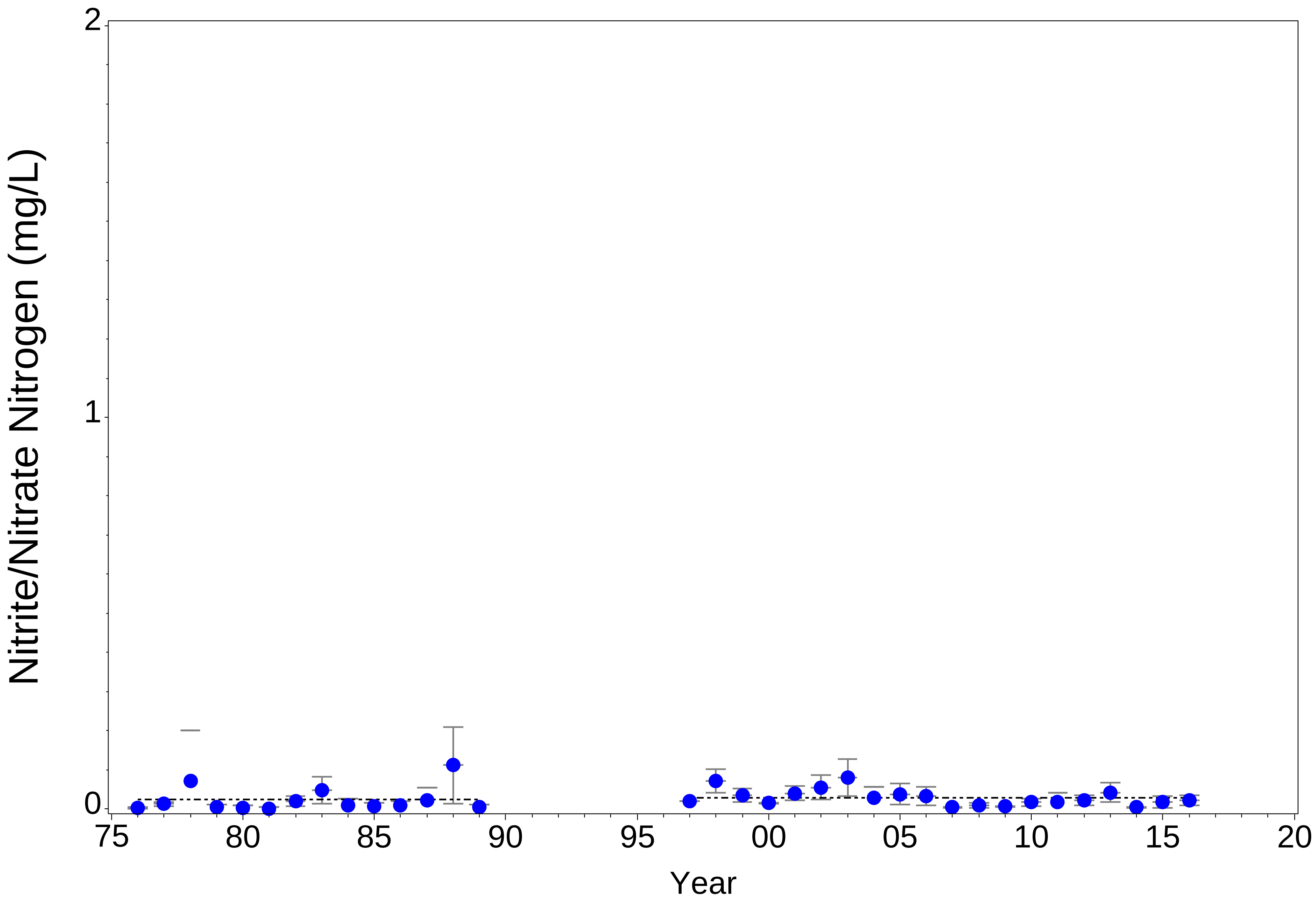

Figure 5.92. Long-term Station 9 surface Nitrite/Nitrate Nitrogen at river kilometer -2.4

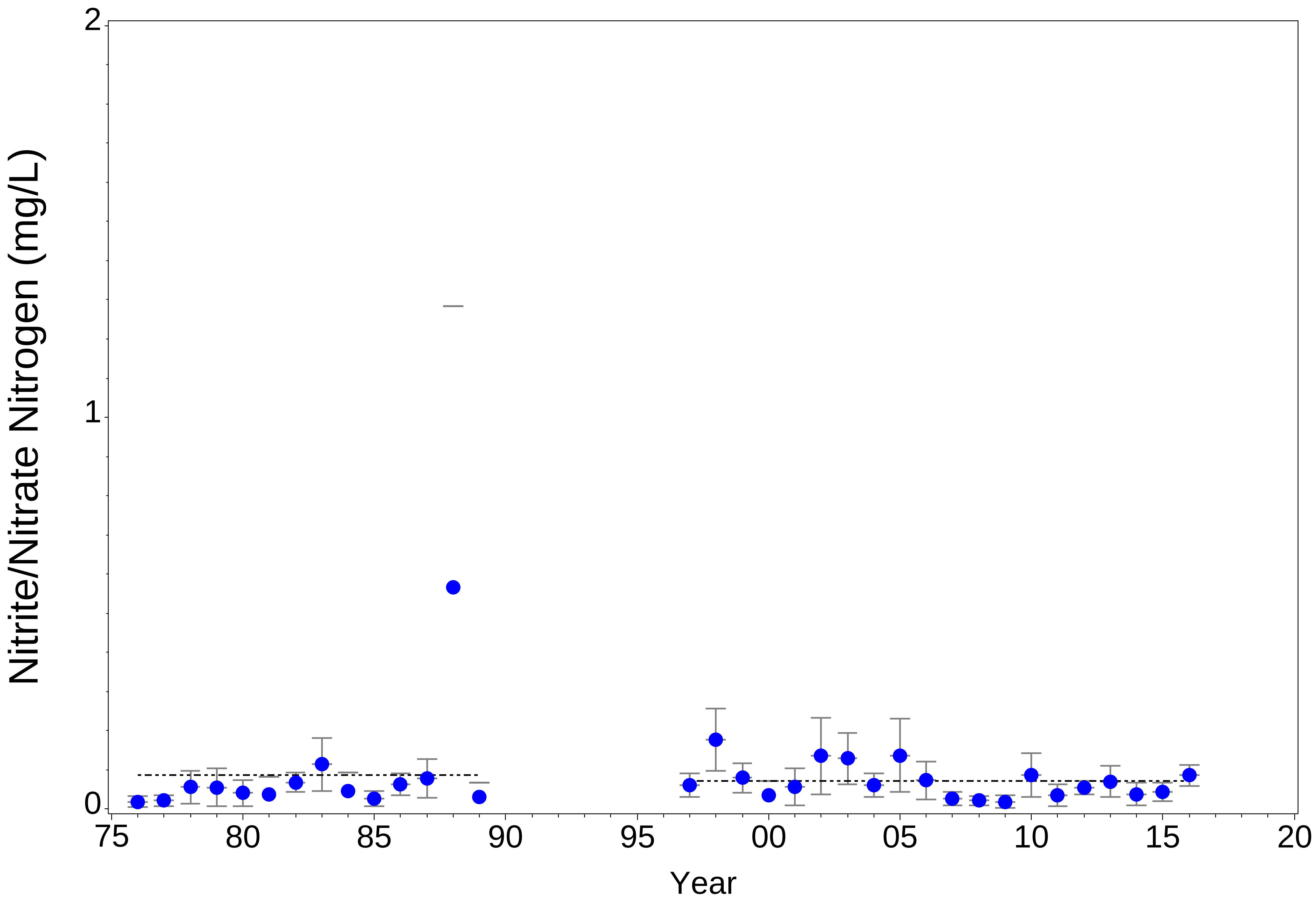

Figure 5.93. Long-term Station 10 surface Nitrite/Nitrate Nitrogen at river kilometer 6.6

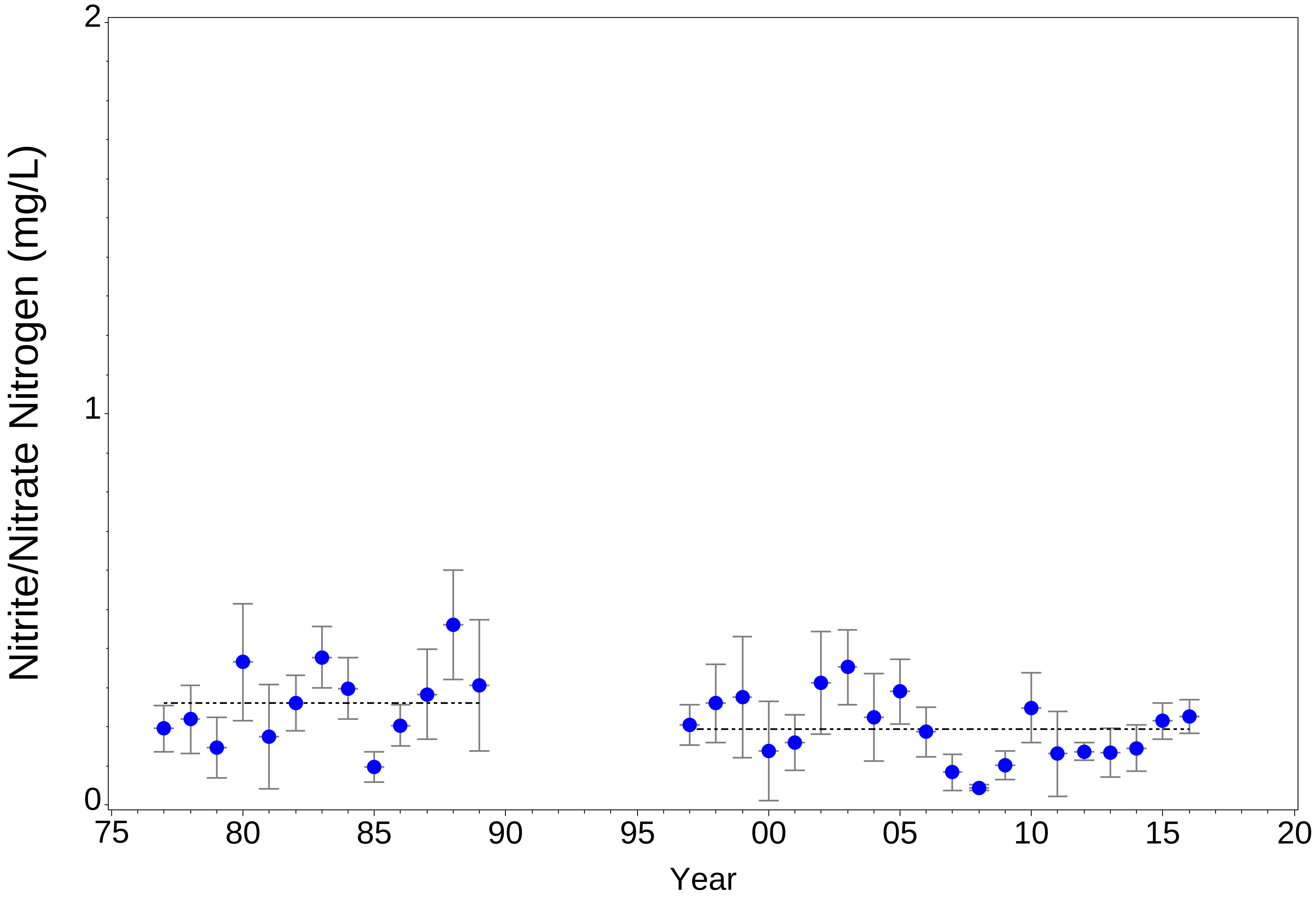

Figure 5.94. Long-term Station 12 surface Nitrite/Nitrate Nitrogen at river kilometer 15.5

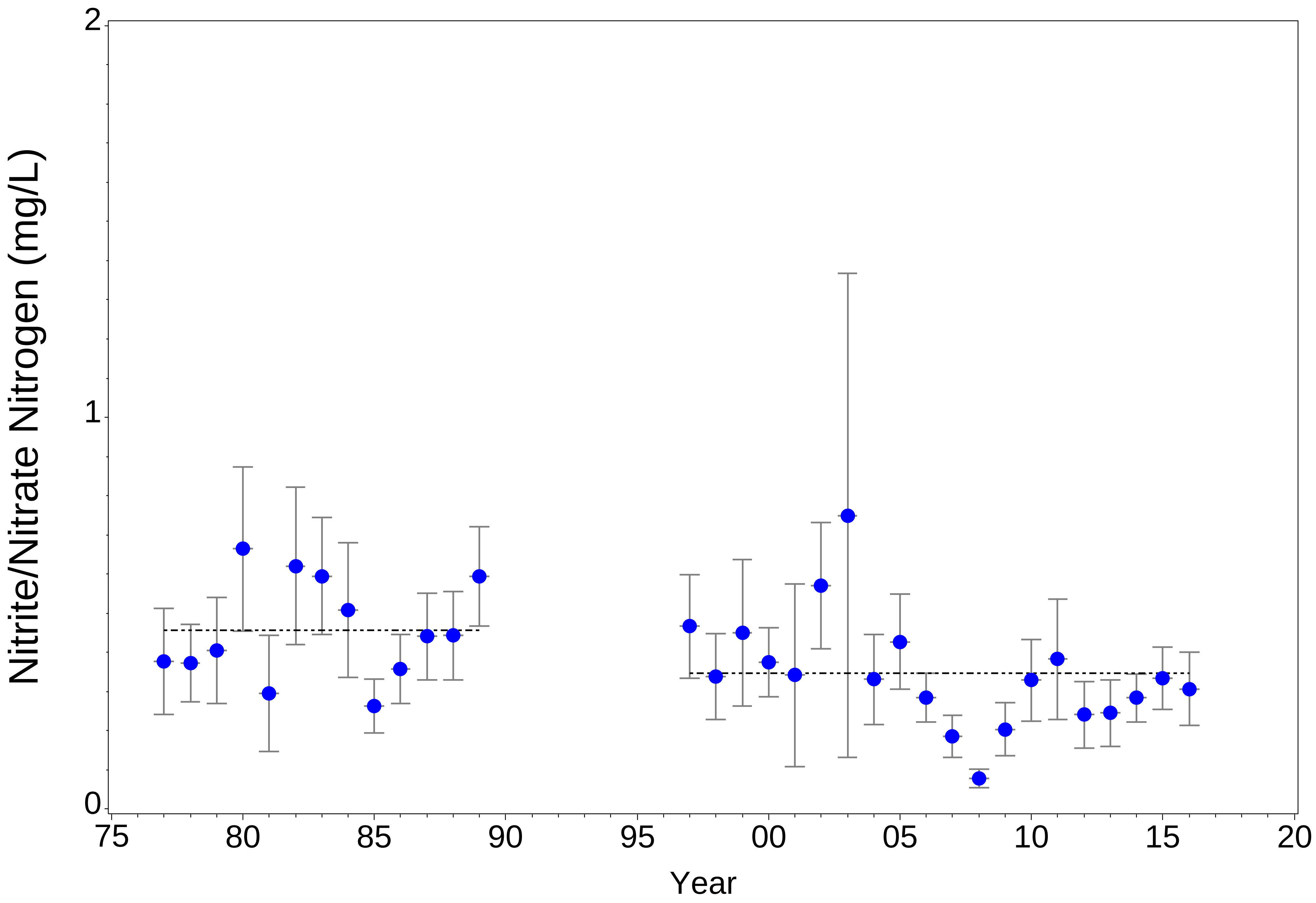

Figure 5.95. Long-term Station 14 surface Nitrite/Nitrate Nitrogen at river kilometer 23.6

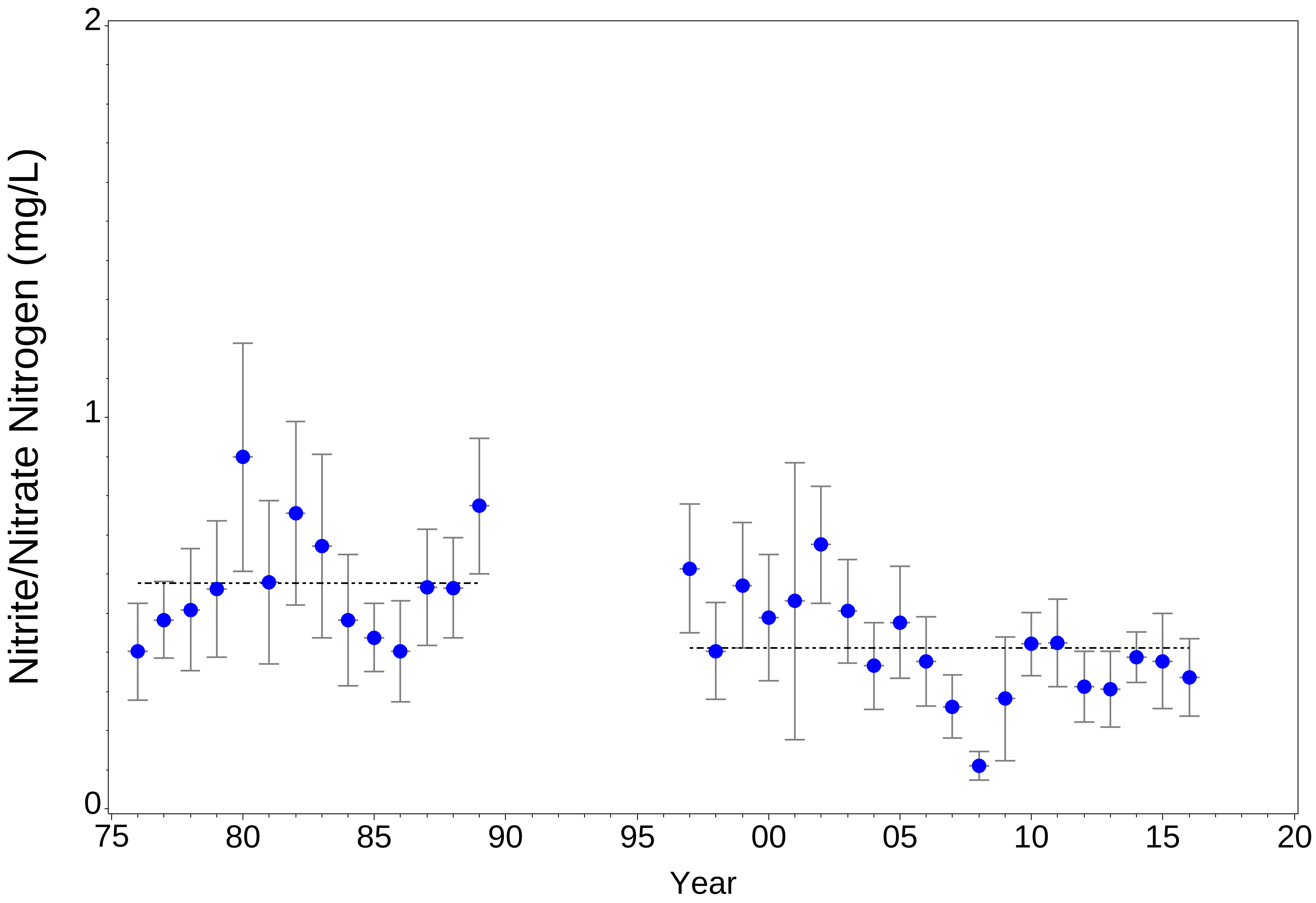

Figure 5.96. Long-term Station 18 surface Nitrite/Nitrate Nitrogen at river kilometer 30.7

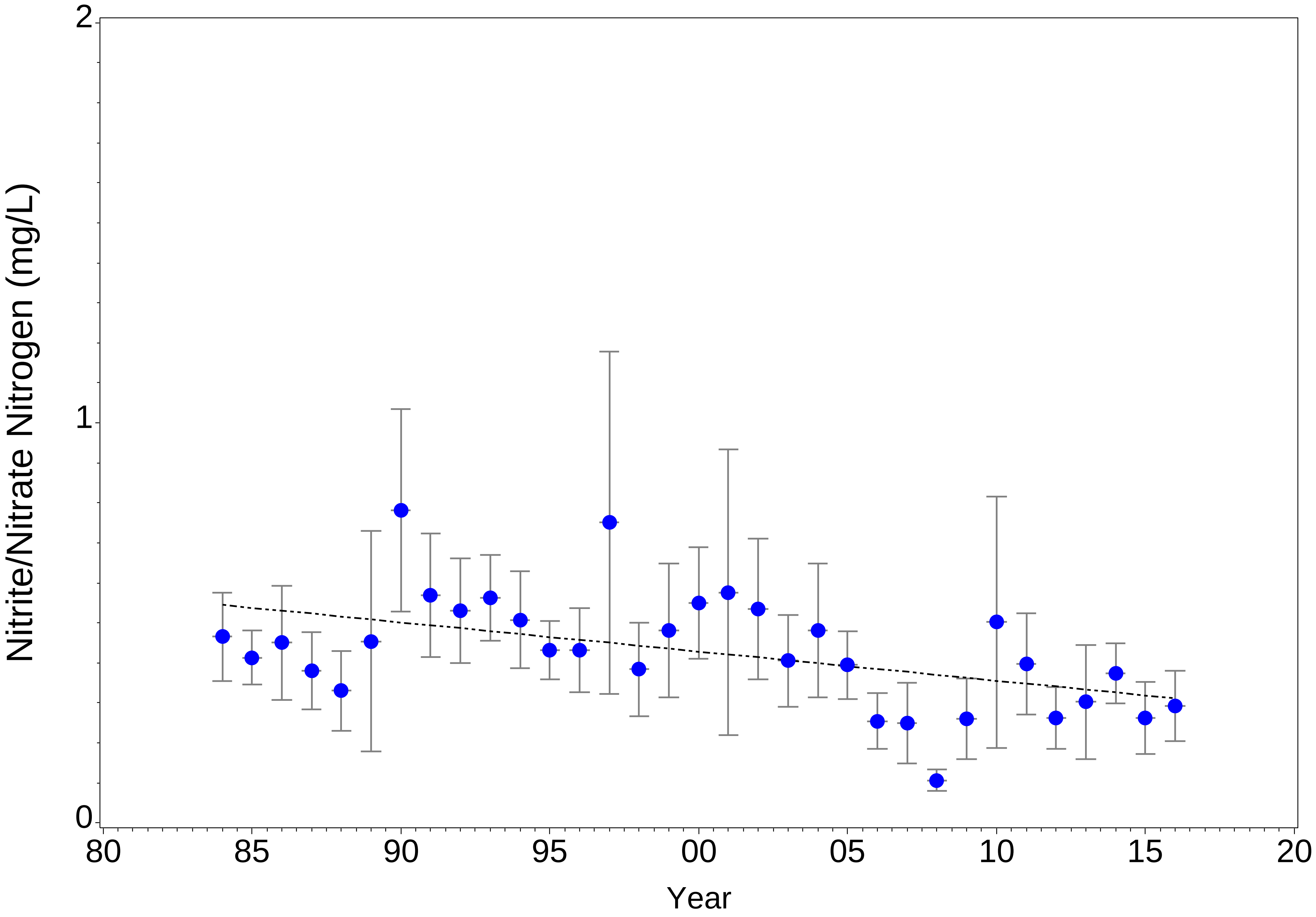

Figure 5.97. Annual monthly surface Nitrite/Nitrate Nitrogen at 0 psu isohaline (1984-2016)

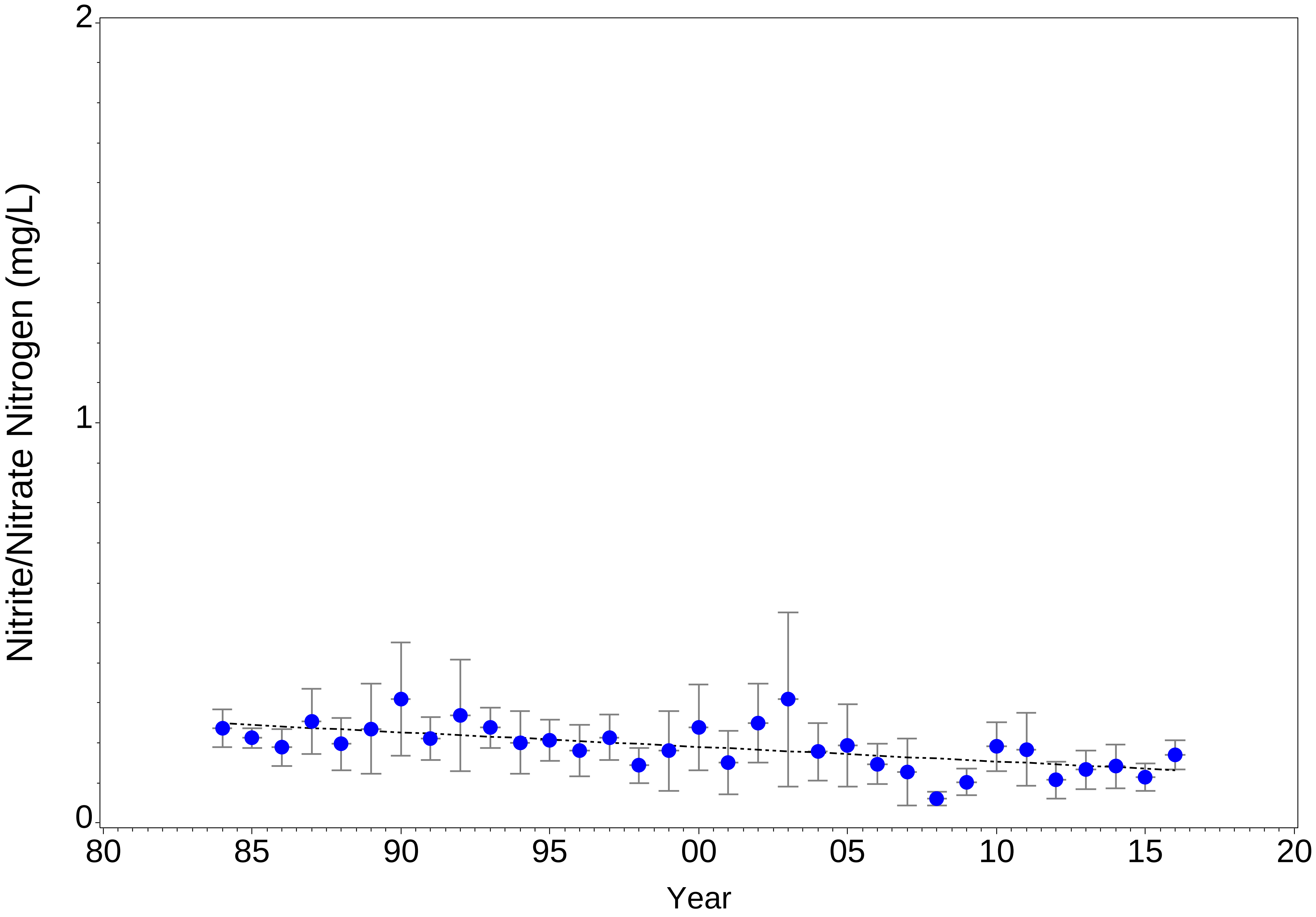

Figure 5.98. Annual monthly surface Nitrite/Nitrate Nitrogen at 6 psu isohaline (1984-2016)

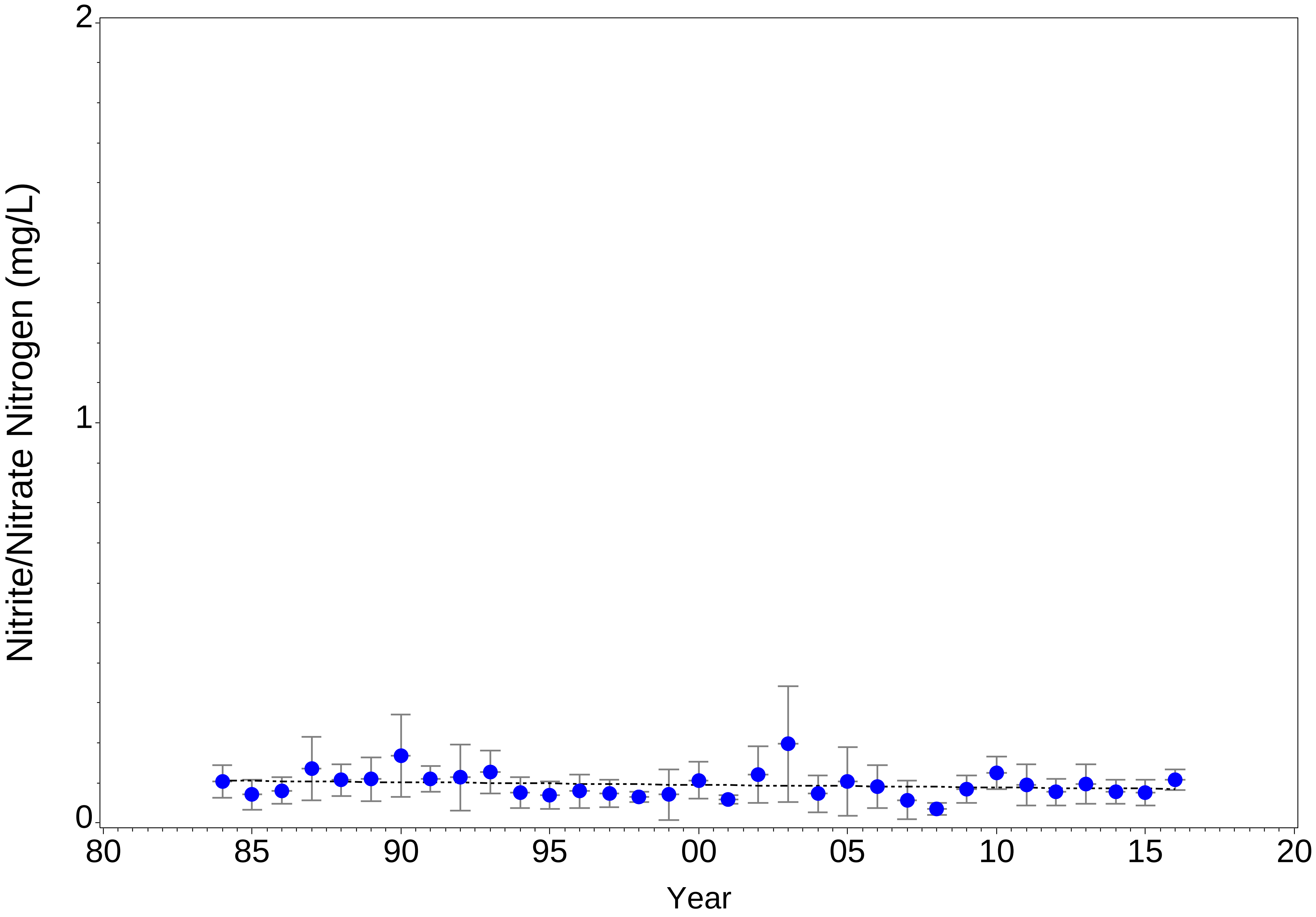

Figure 5.99. Annual monthly surface Nitrite/Nitrate Nitrogen at 12 psu isohaline (1984-2016)

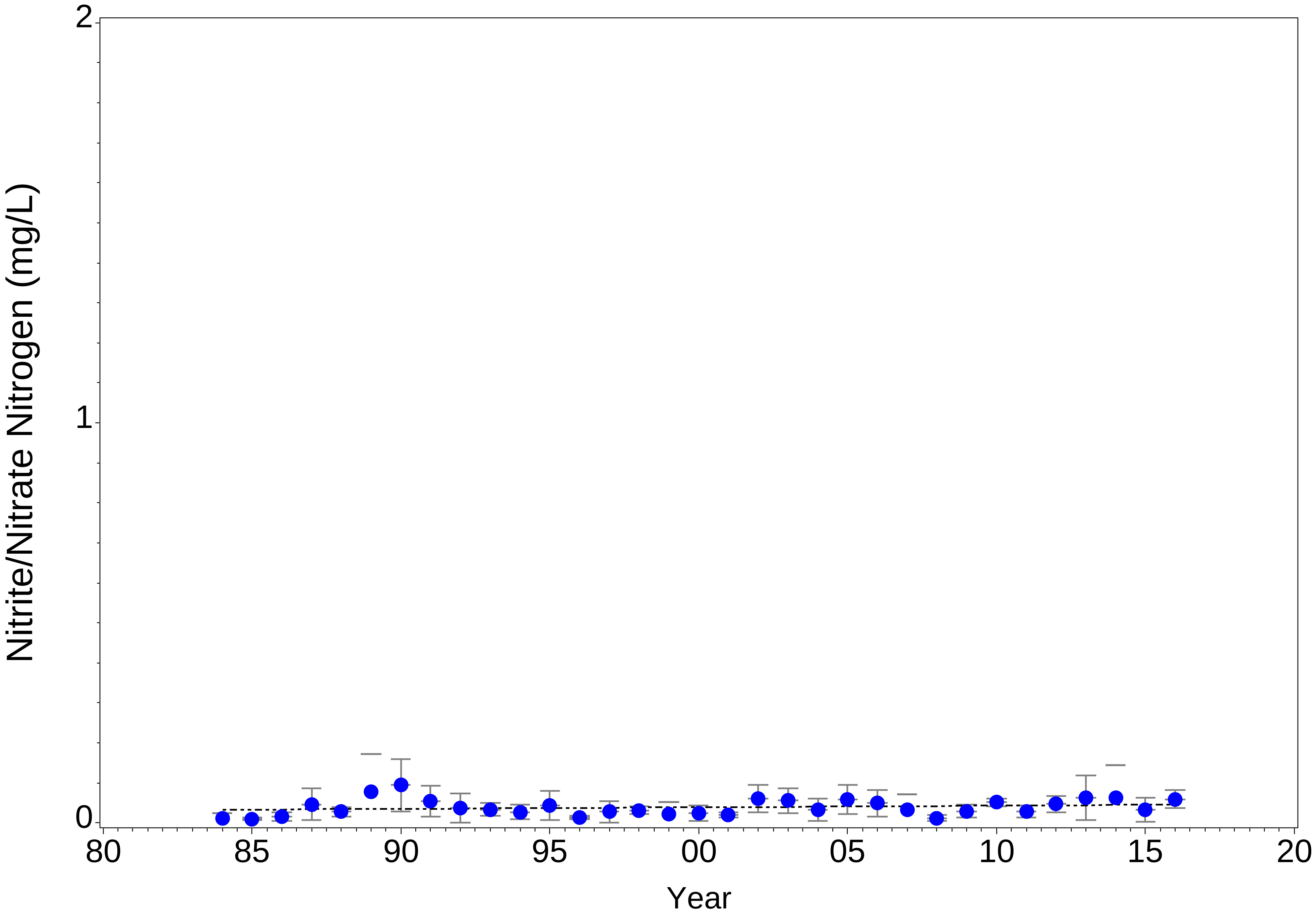

Figure 5.100. Annual monthly surface Nitrite/Nitrate Nitrogen at 20 psu isohaline (1984-2016)

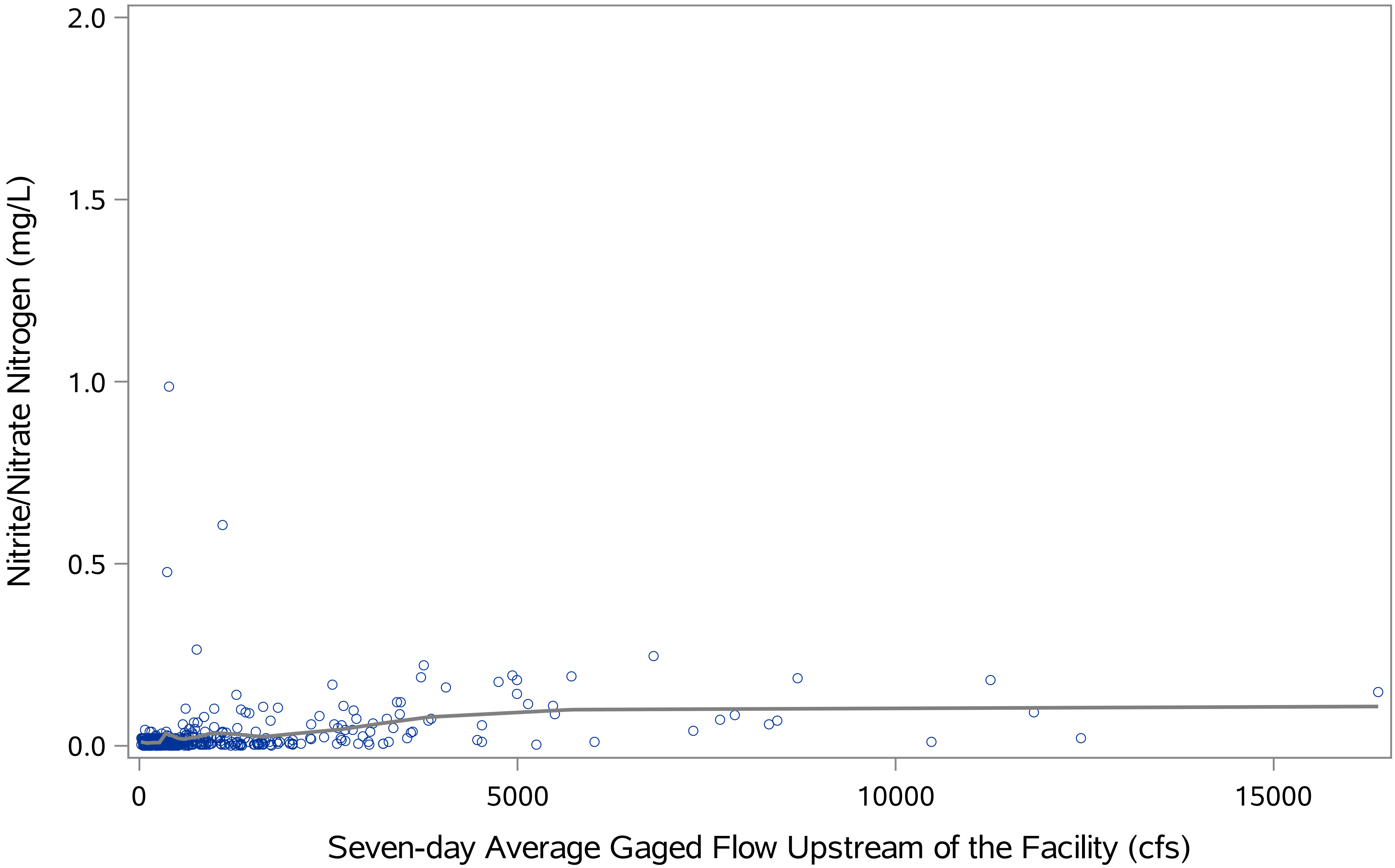

Figure 5.101. Surface Nitrite/Nitrate Nitrogen at river kilometer -2.4 versus flow

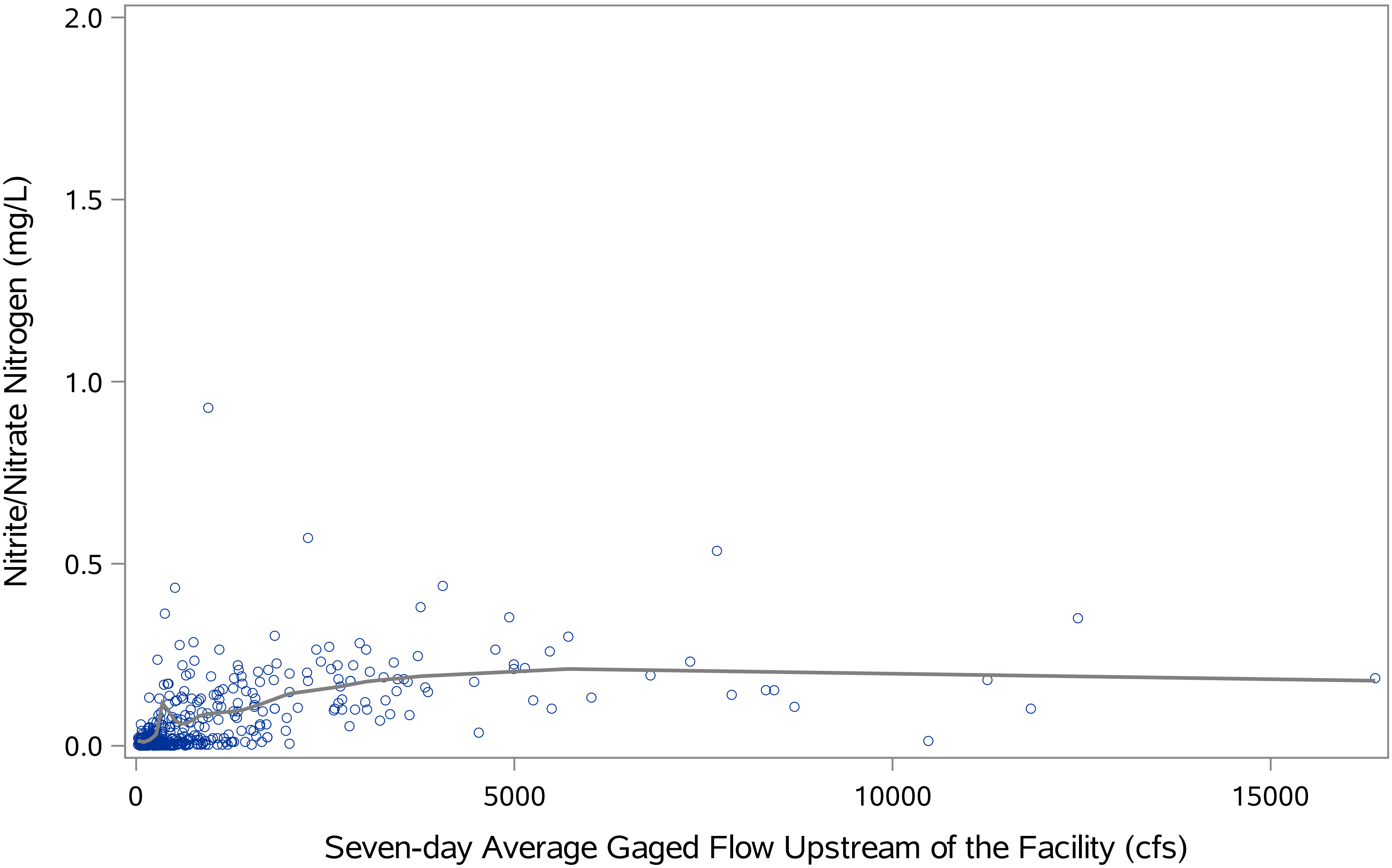

Figure 5.102. Surface Nitrite/Nitrate Nitrogen at river kilometer 6.6 versus flow

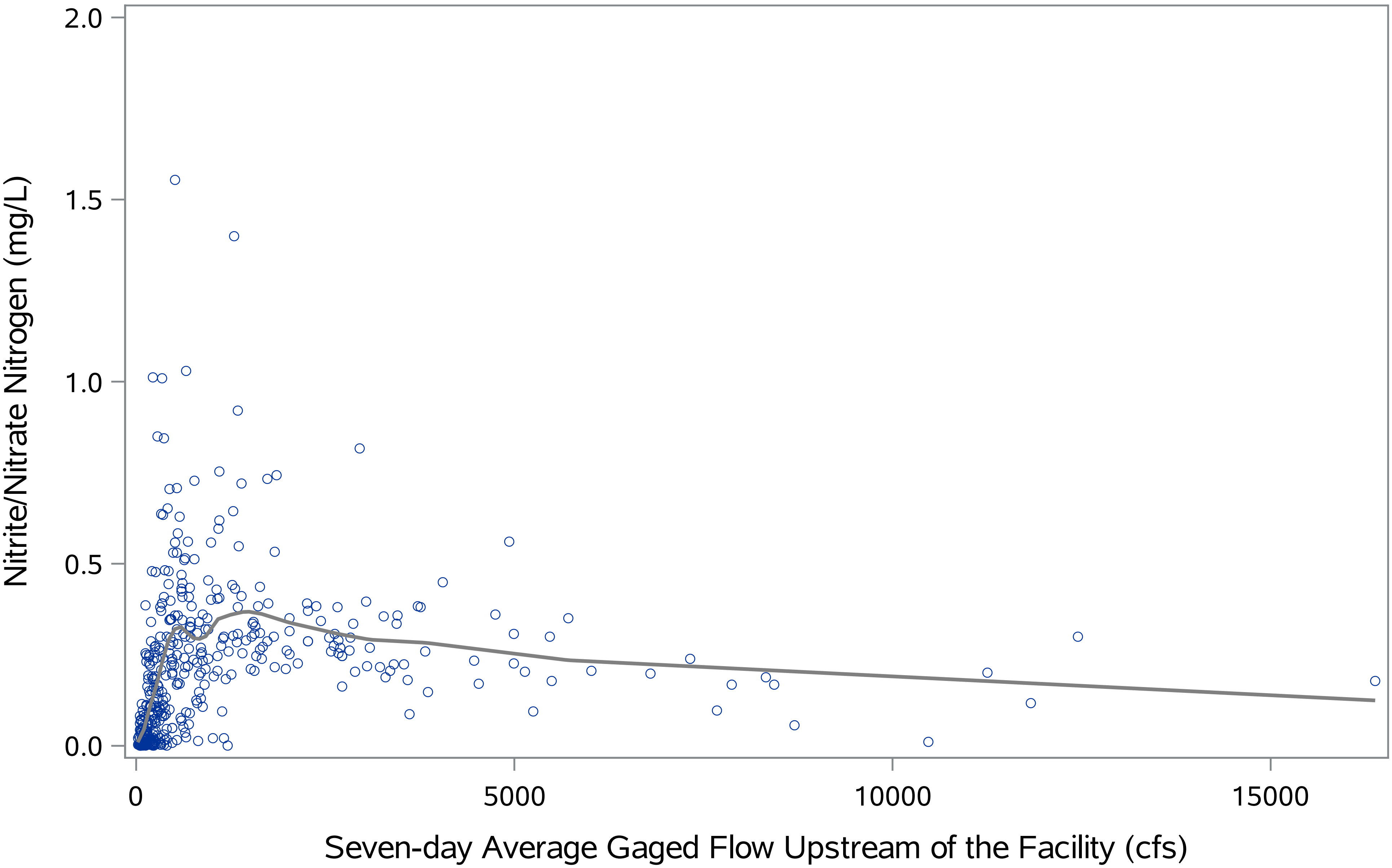

Figure 5.103. Surface Nitrite/Nitrate Nitrogen at river kilometer 15.5 versus flow

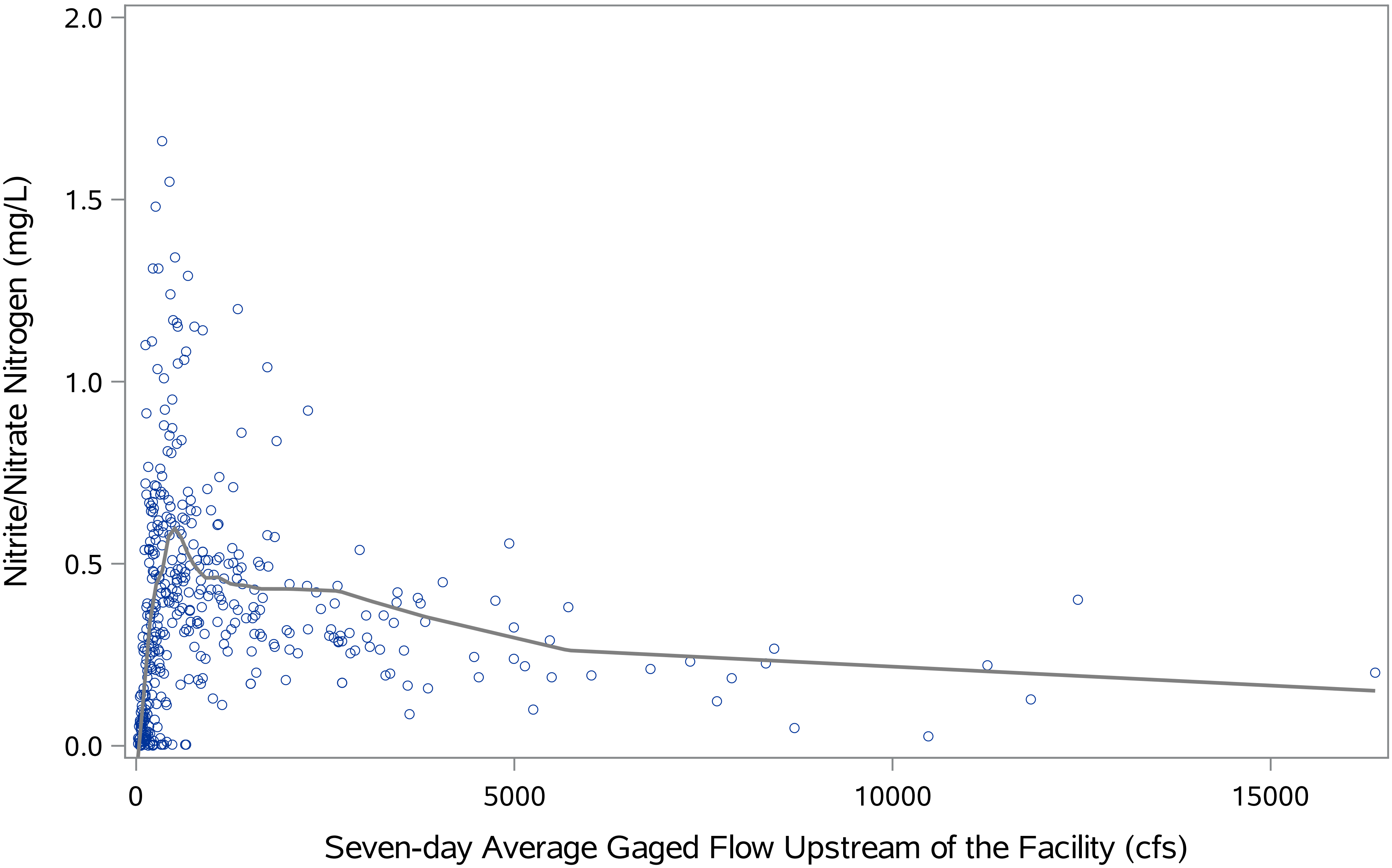

Figure 5.104. Surface Nitrite/Nitrate Nitrogen at river kilometer 23.6 versus flow

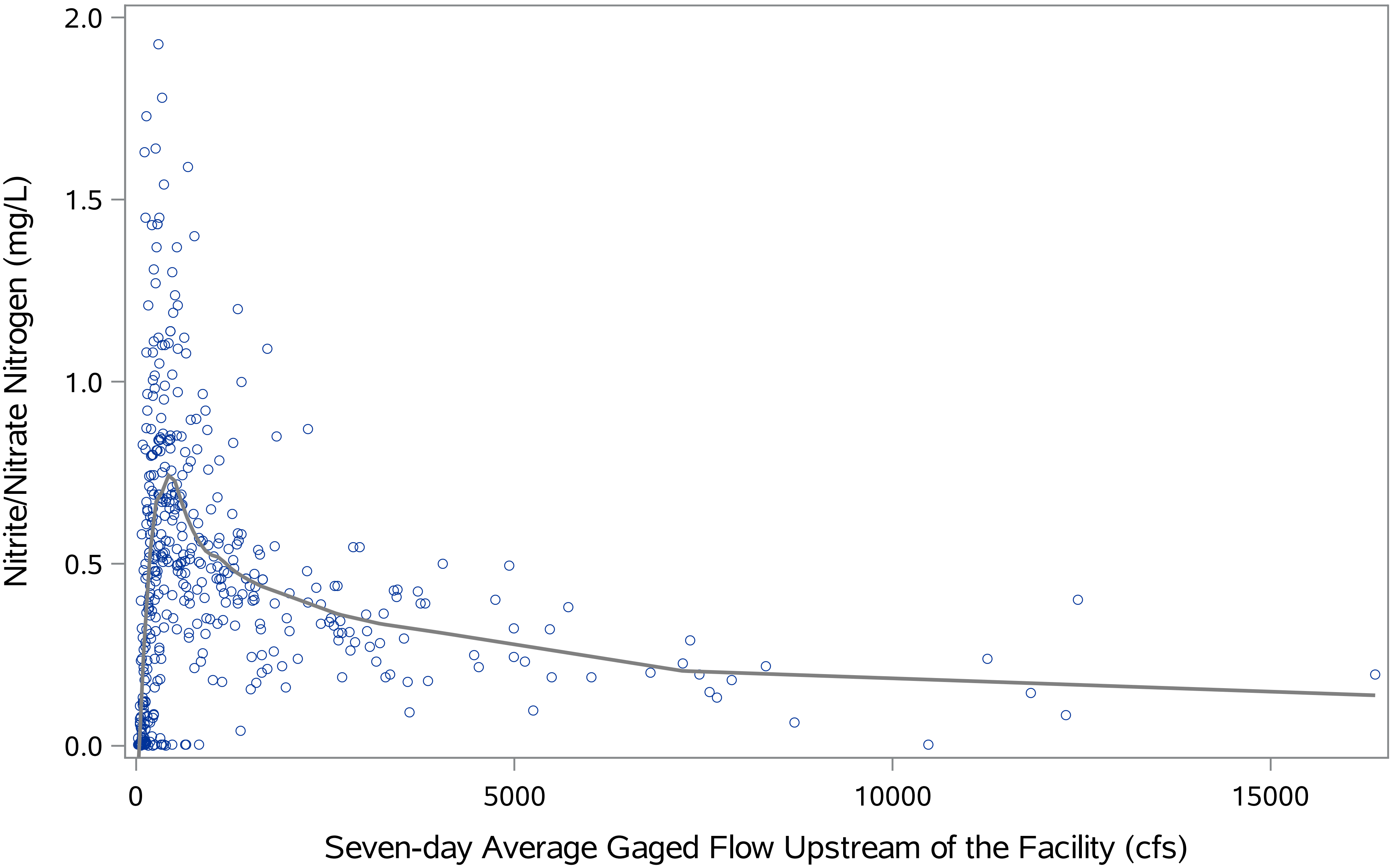

Figure 5.105. Surface Nitrite/Nitrate Nitrogen at river kilometer 30.7 versus flow

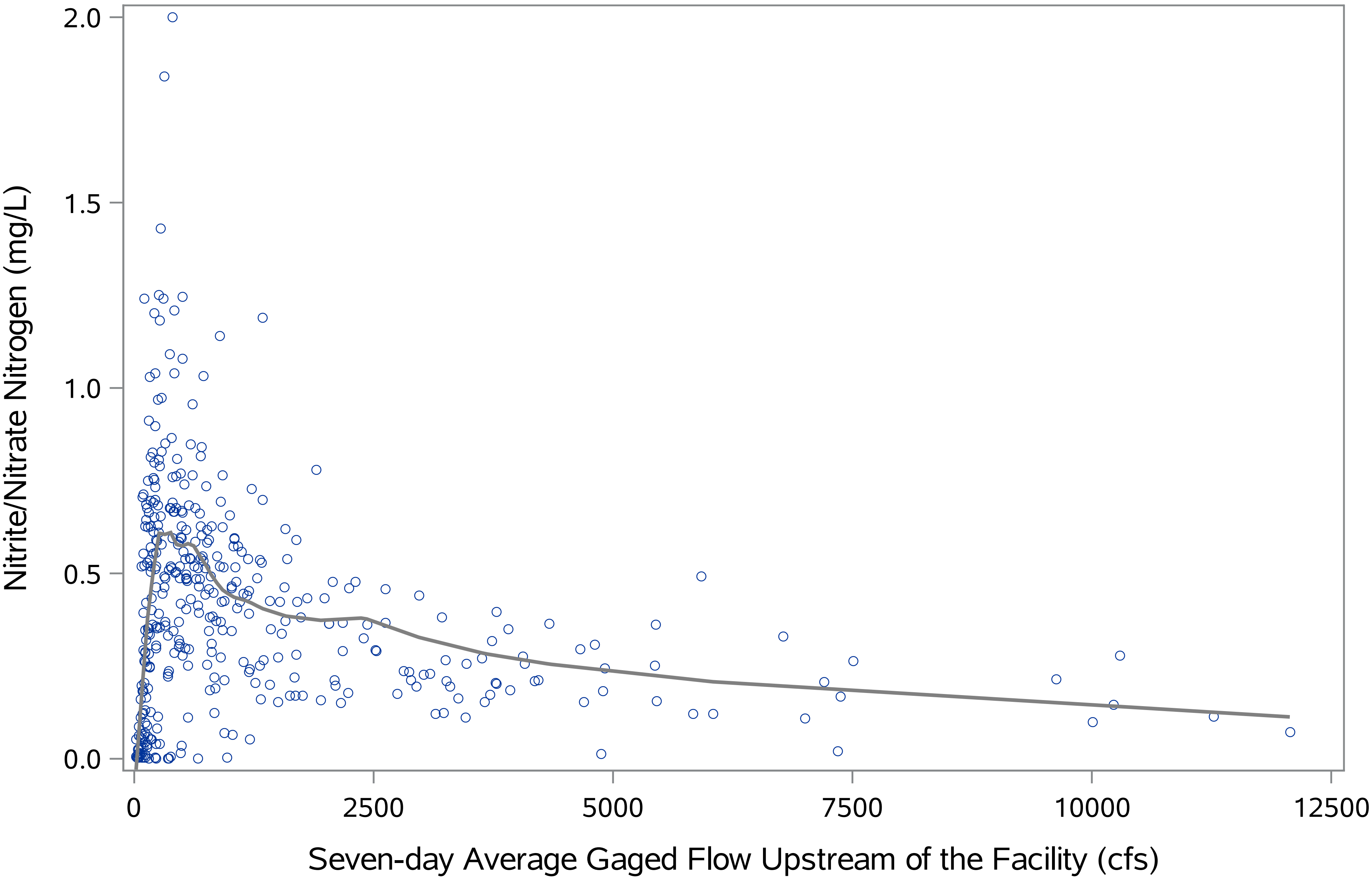

Figure 5.106. Nitrite/Nitrate Nitrogen at the 0 psu isohaline versus flow

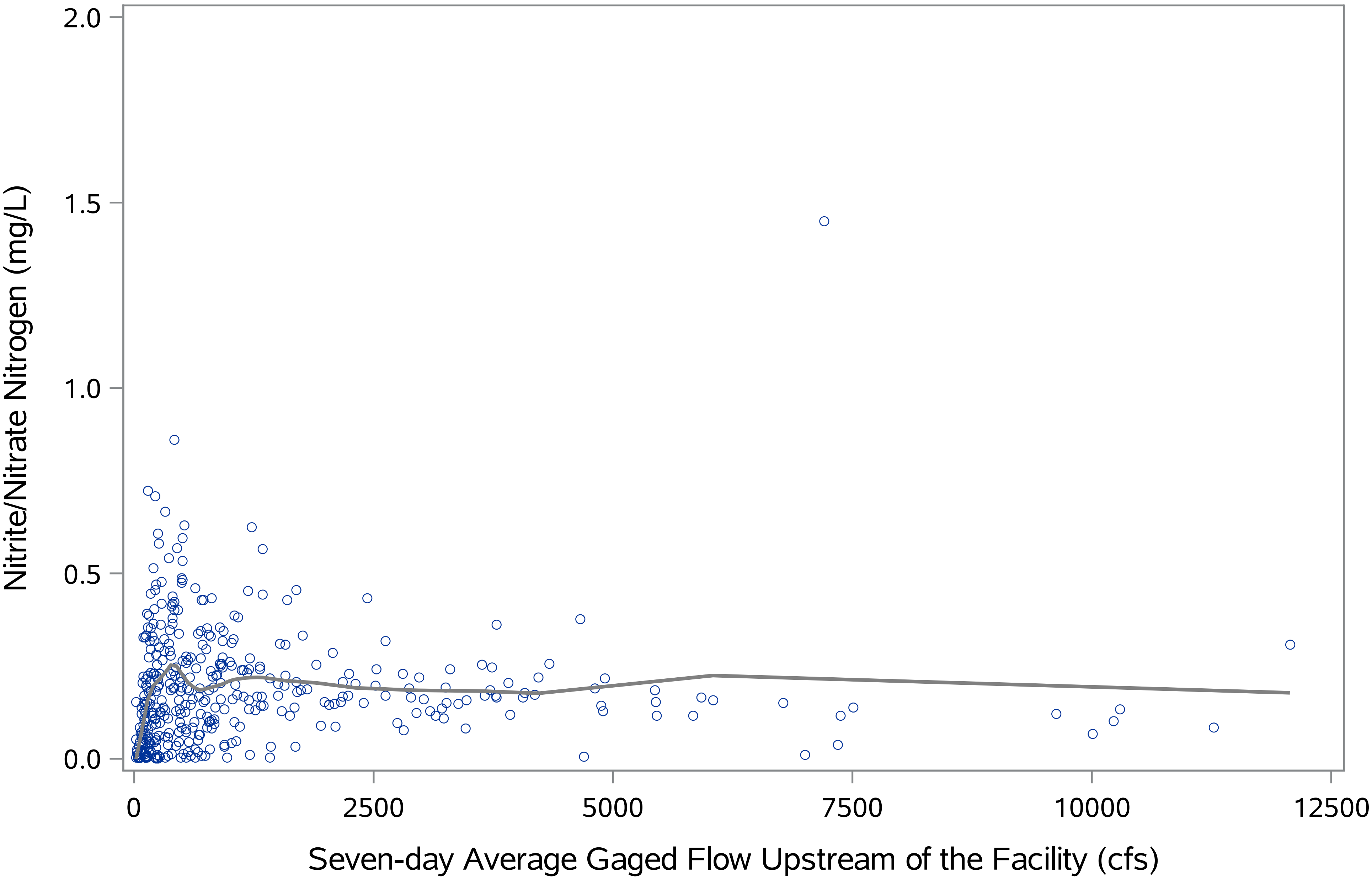

Figure 5.107. Nitrite/Nitrate Nitrogen at the 6 psu isohaline versus flow

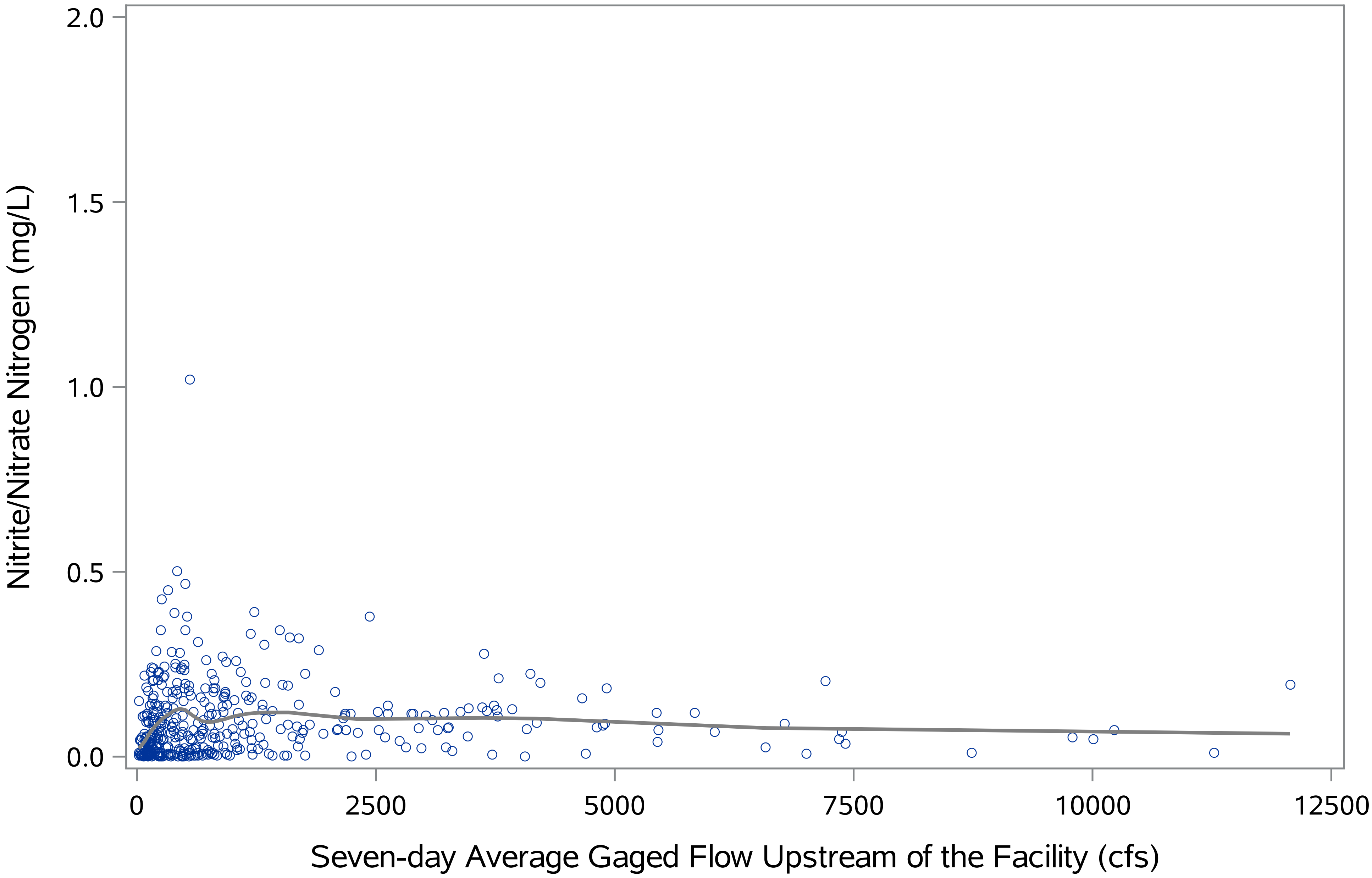

Figure 5.108. Nitrite/Nitrate Nitrogen at the 12 psu isohaline versus flow

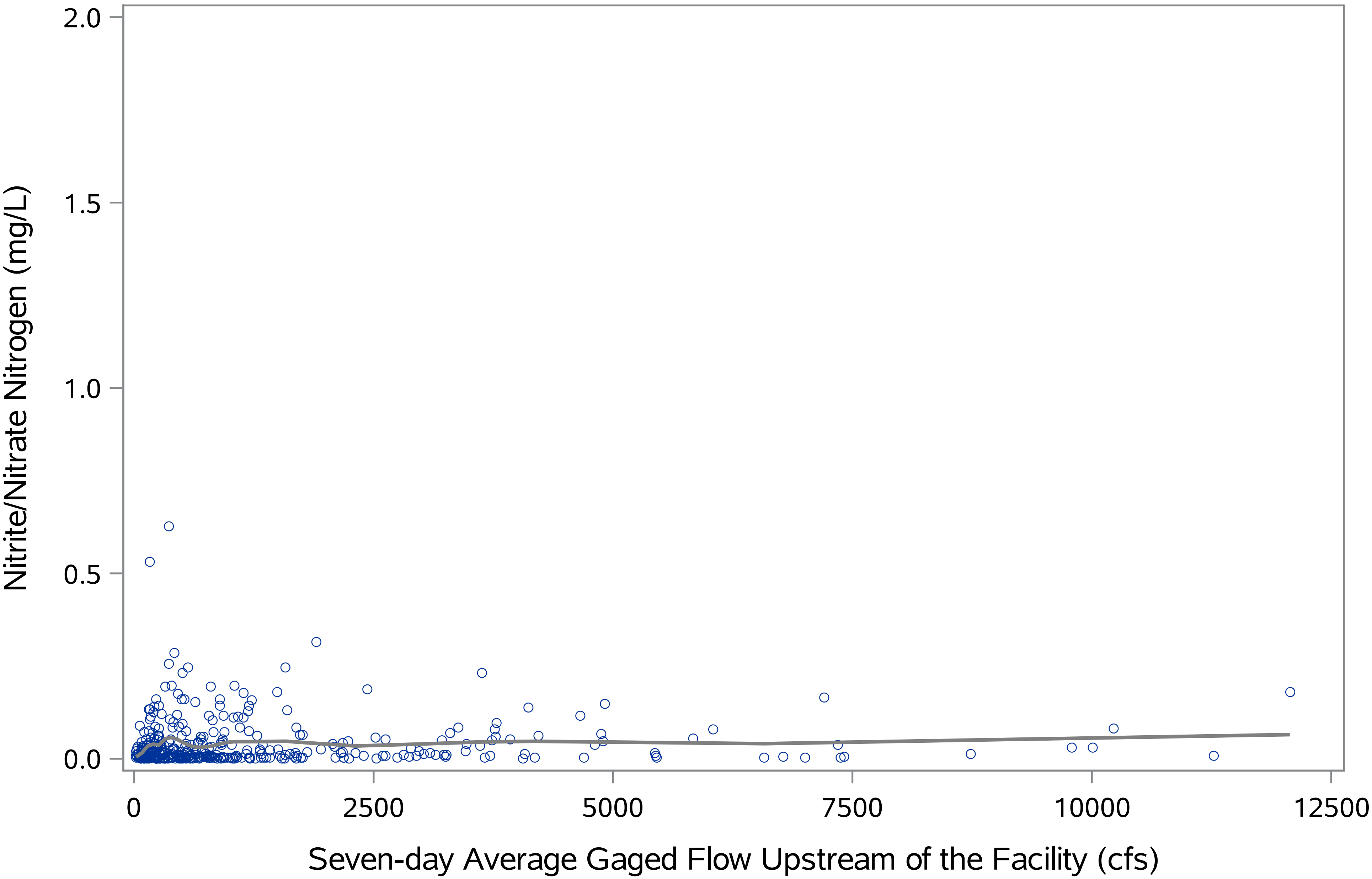

Figure 5.109. Nitrite/Nitrate Nitrogen at the 20 psu isohaline versus flow

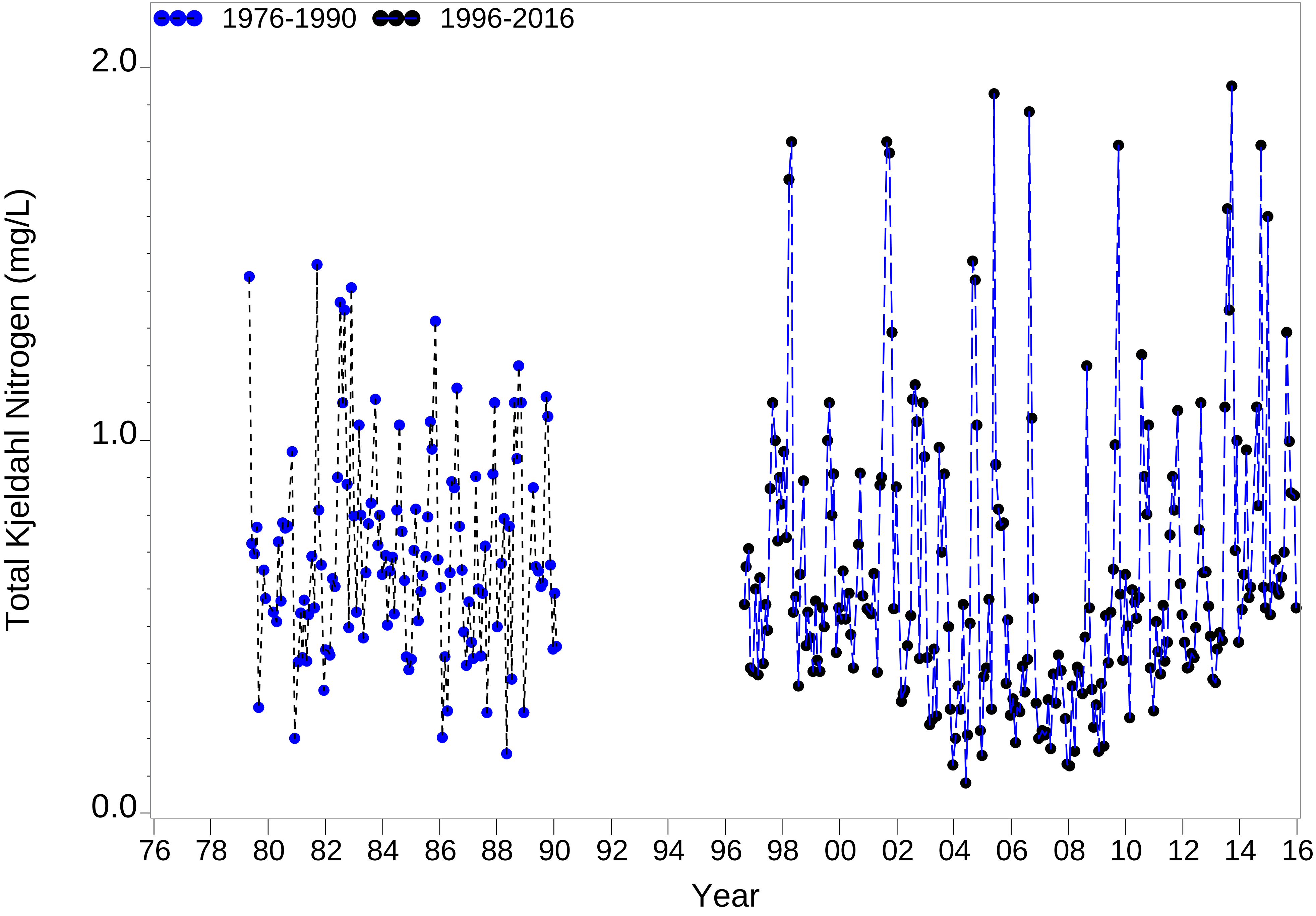

Figure 5.112. Monthly long-term Total Kjeldahl Nitrogen at river kilometer -2.4

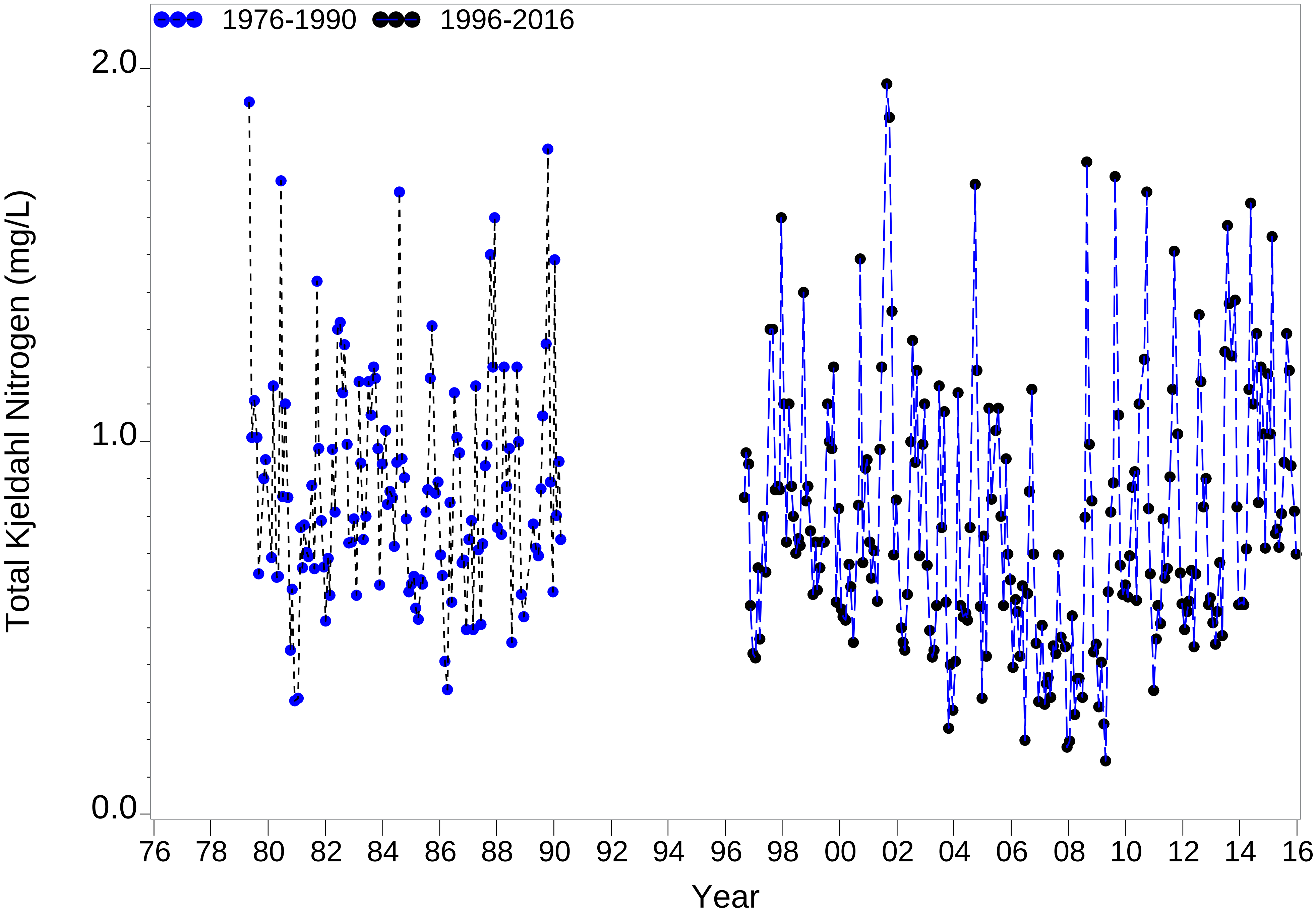

Figure 5.113. Monthly long-term Total Kjeldahl Nitrogen at river kilometer 6.6

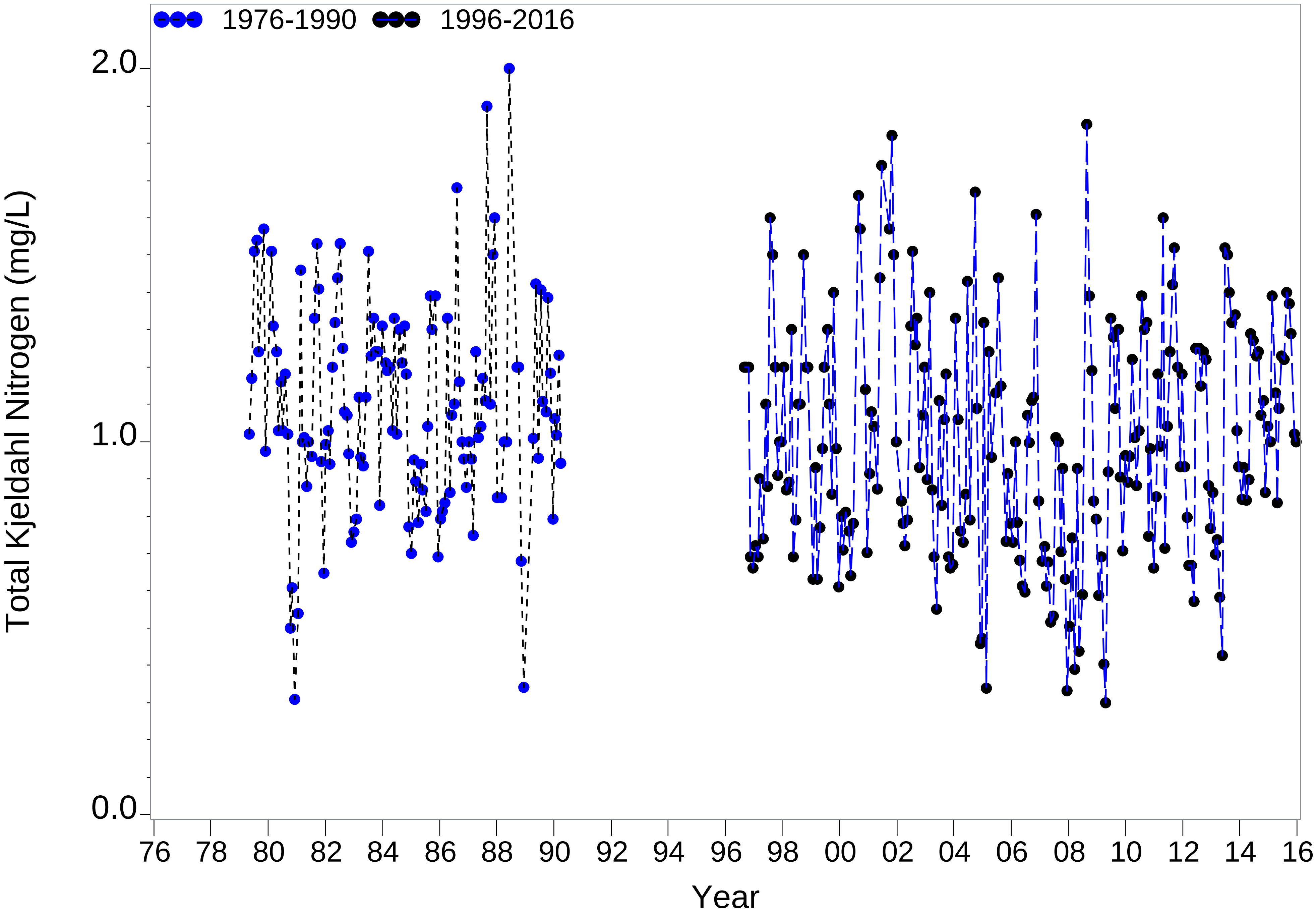

Figure 5.114. Monthly long-term Total Kjeldahl Nitrogen at river kilometer 15.5

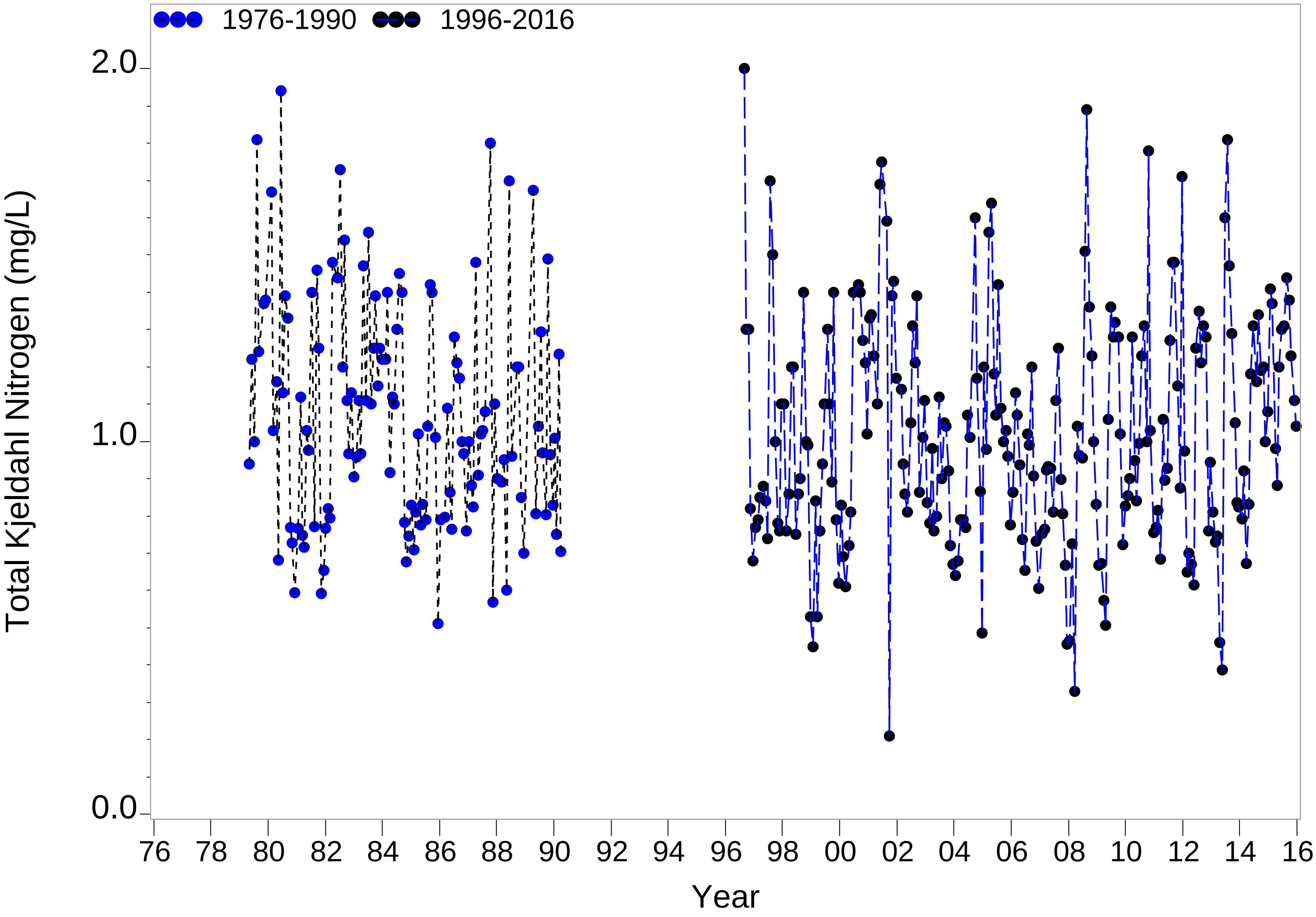

Figure 5.115. Monthly long-term Total Kjeldahl Nitrogen at river kilometer 23.6

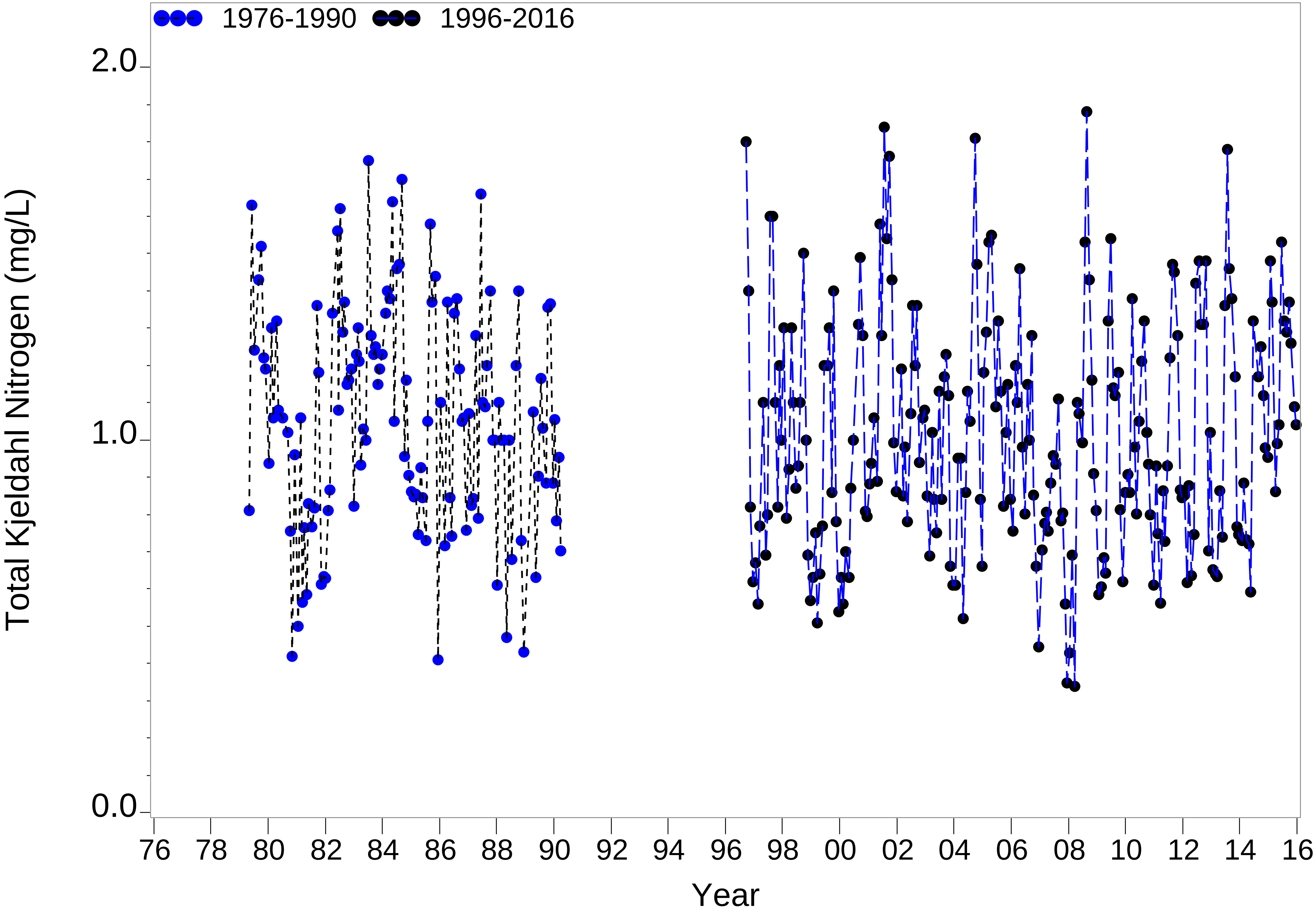

Figure 5.116. Monthly long-term Total Kjeldahl Nitrogen at river kilometer 30.7

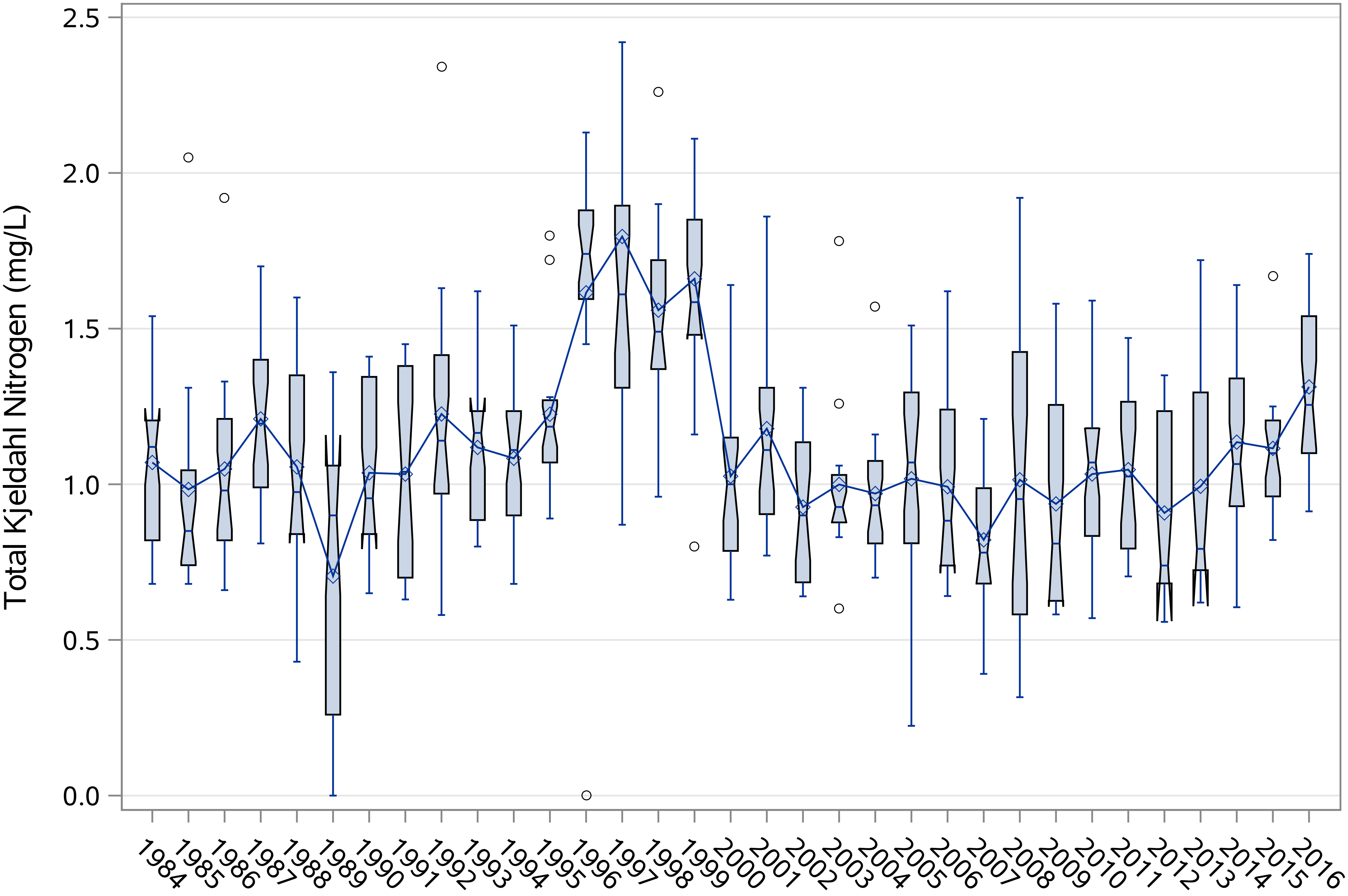

Figure 5.117. Annual boxplots of surface Total Kjeldahl Nitrogen at the 0 psu isohaline (1984-2016)

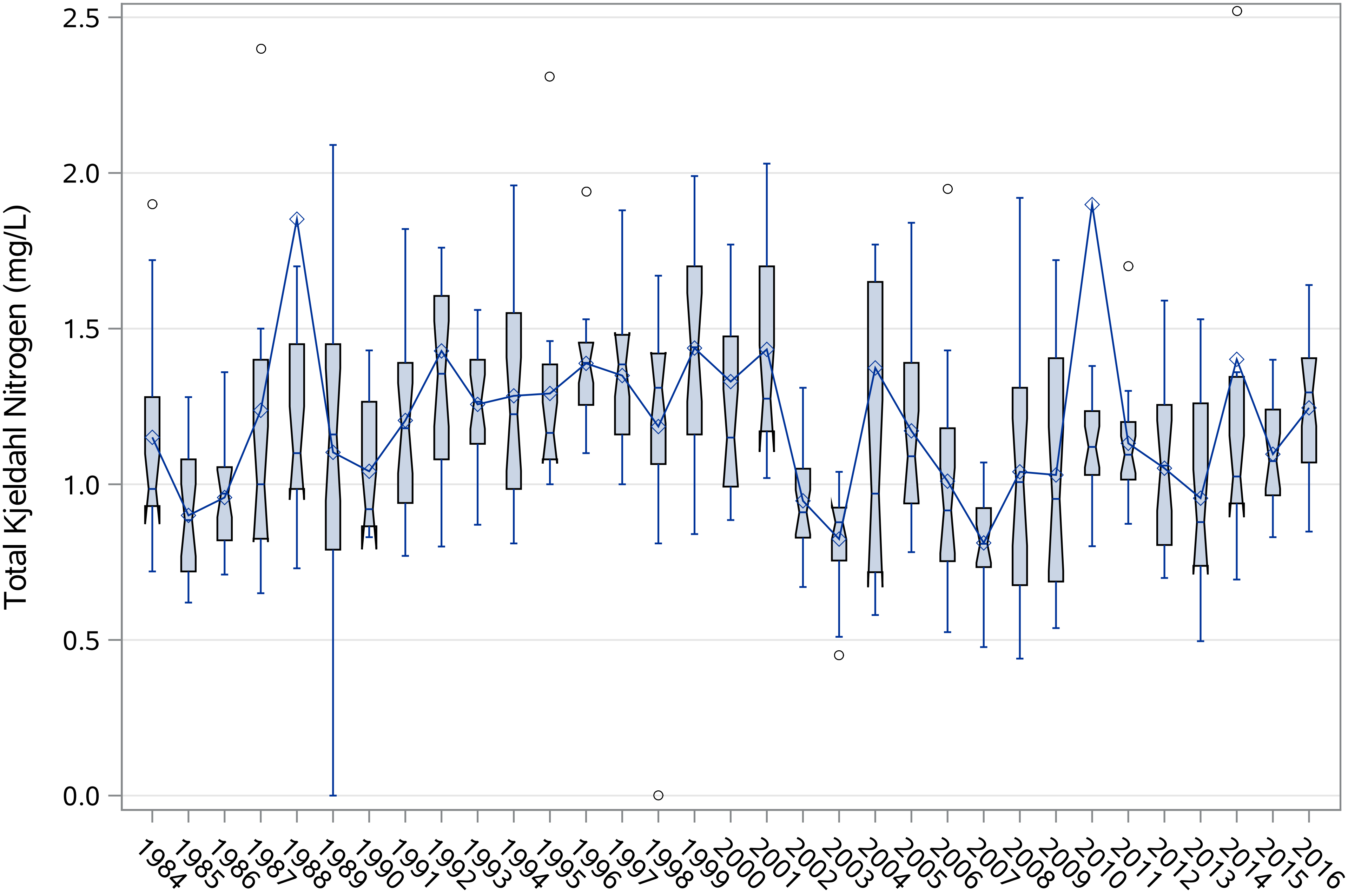

Figure 5.118. Annual boxplots of surface Total Kjeldahl Nitrogen at the 6 psu isohaline (1984-2016)

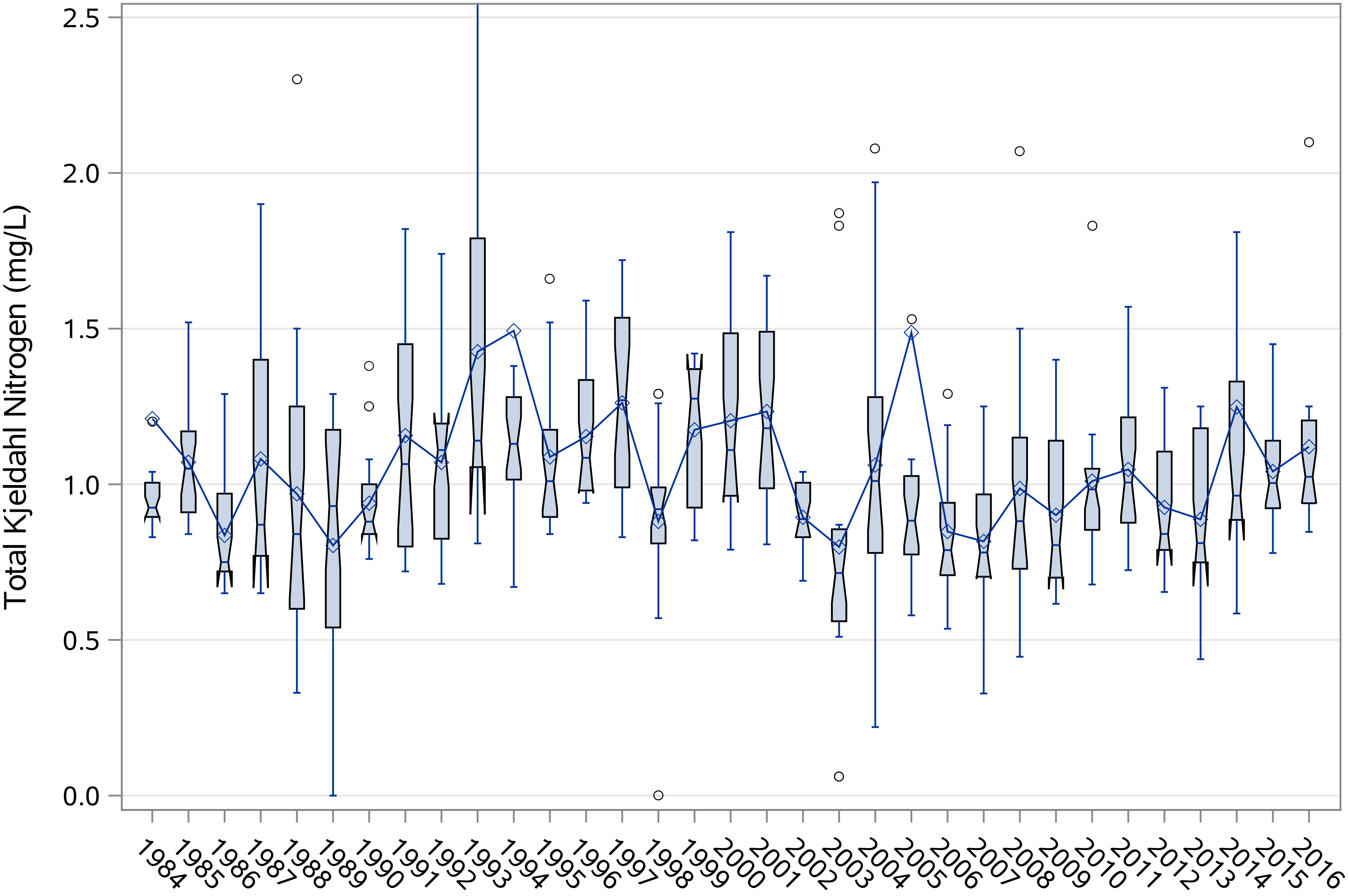

Figure 5.119. Annual boxplots of surface Total Kjeldahl Nitrogen at the 12 psu isohaline (1984-2016)

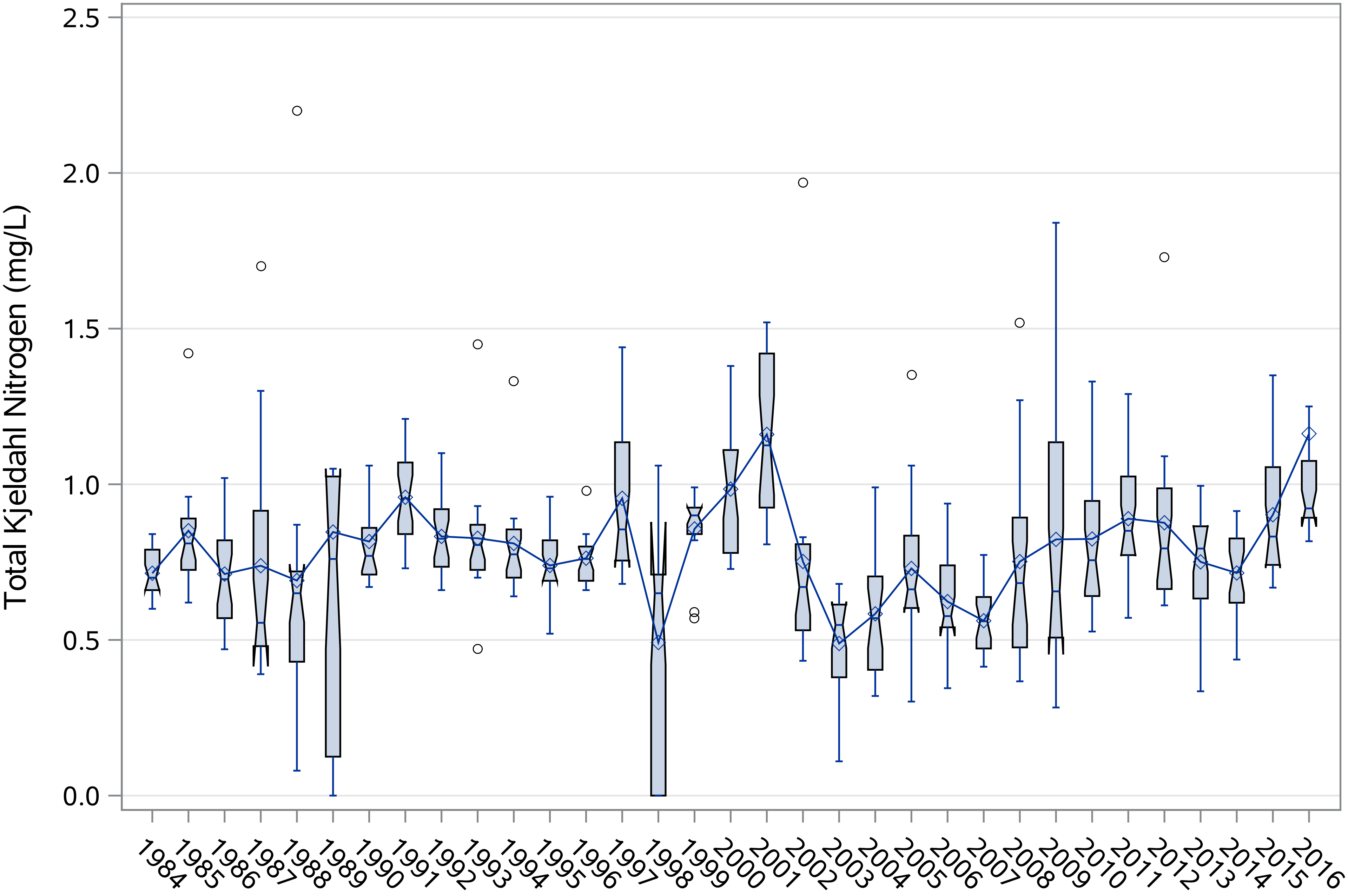

Figure 5.120. Annual boxplots of surface Total Kjeldahl Nitrogen at the 20 psu isohaline (1984-2016)

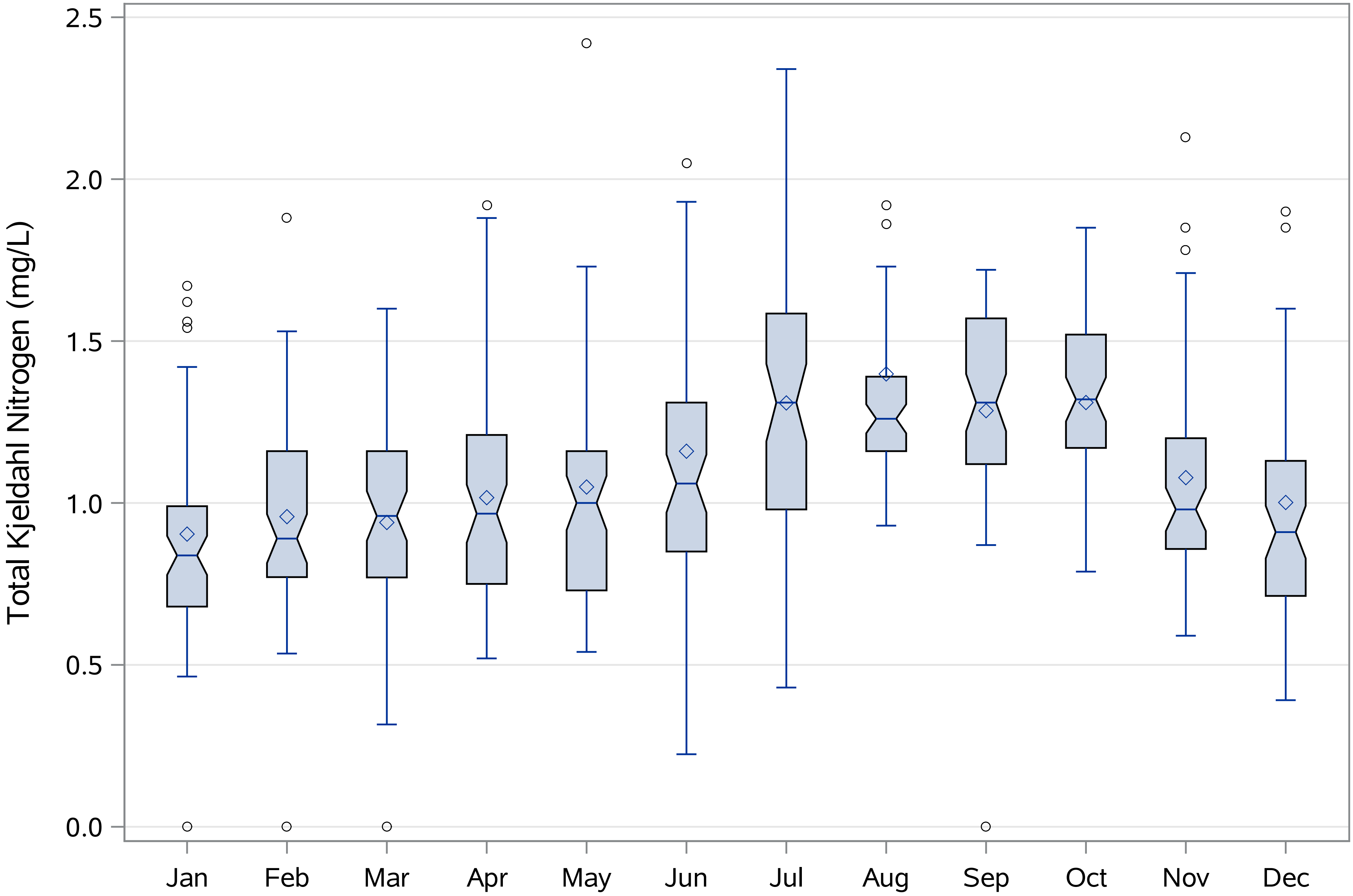

Figure 5.121. Mean monthly boxplots of surface Total Kjeldahl Nitrogen at the 0 psu isohaline (1984-2016)

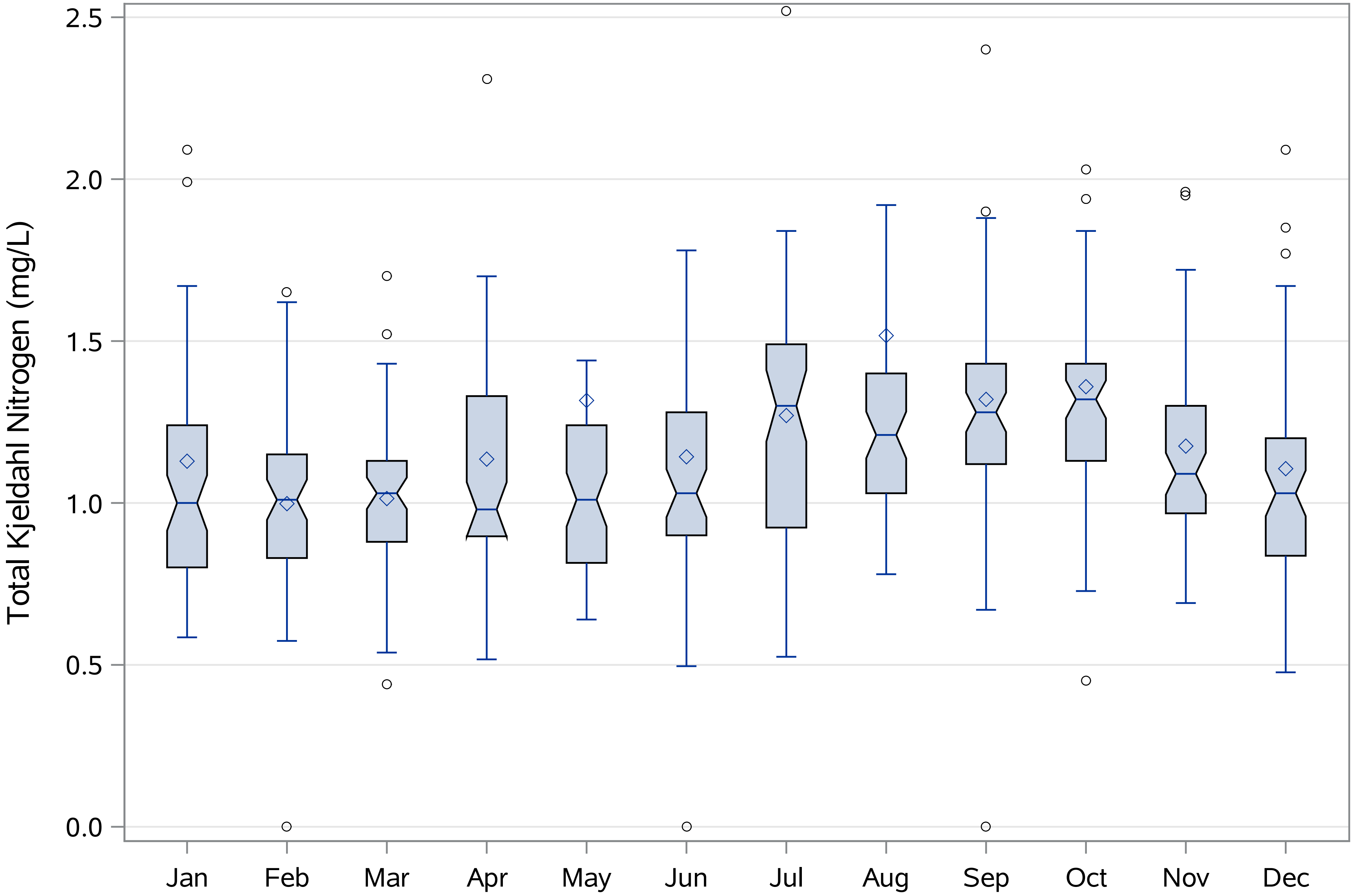

Figure 5.122. Mean monthly boxplots of surface Total Kjeldahl Nitrogen at the 6 psu isohaline (1984-2016)

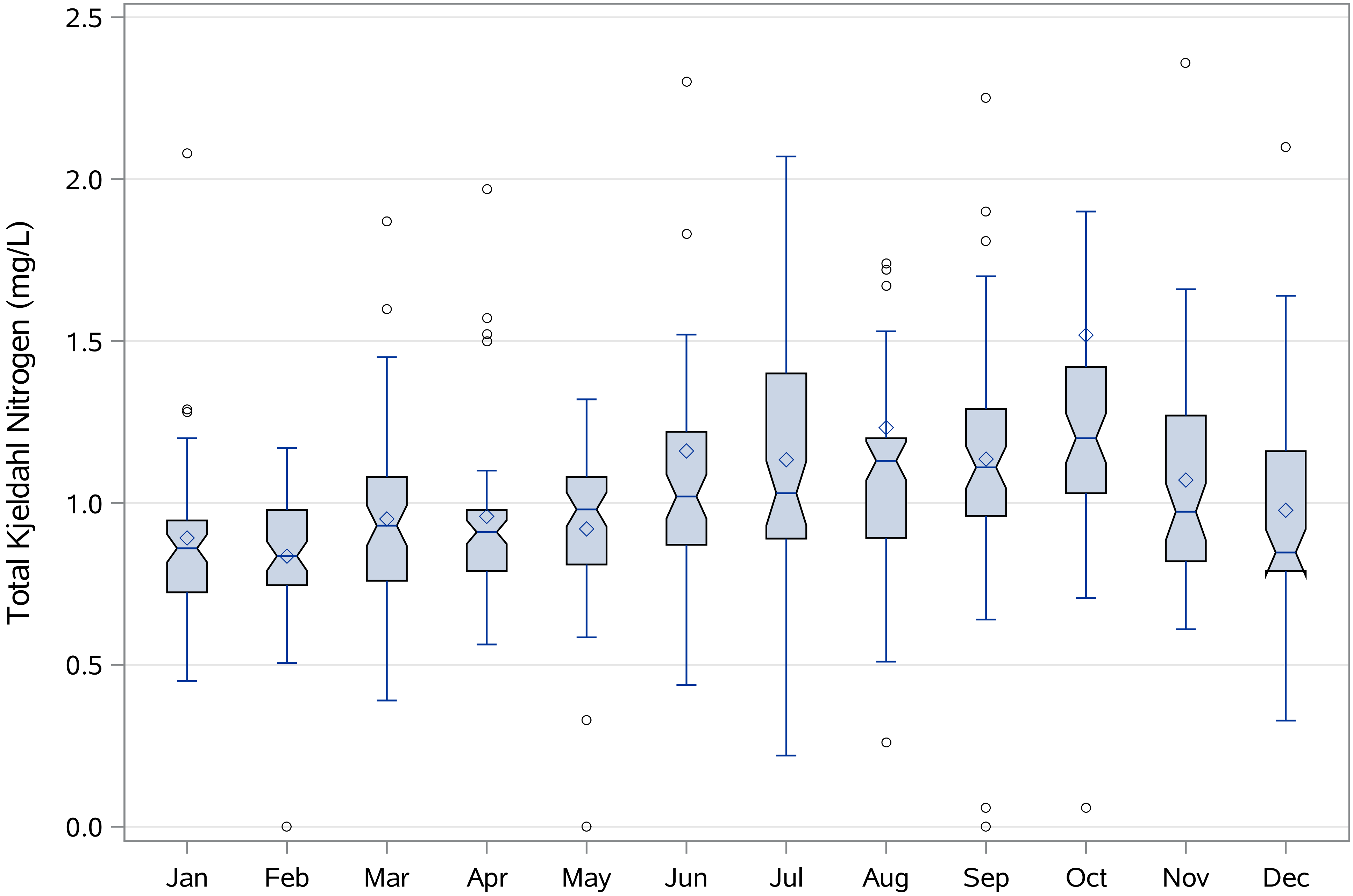

Figure 5.123. Mean monthly boxplots of surface Total Kjeldahl Nitrogen at the 12 psu isohaline (1984-2016)

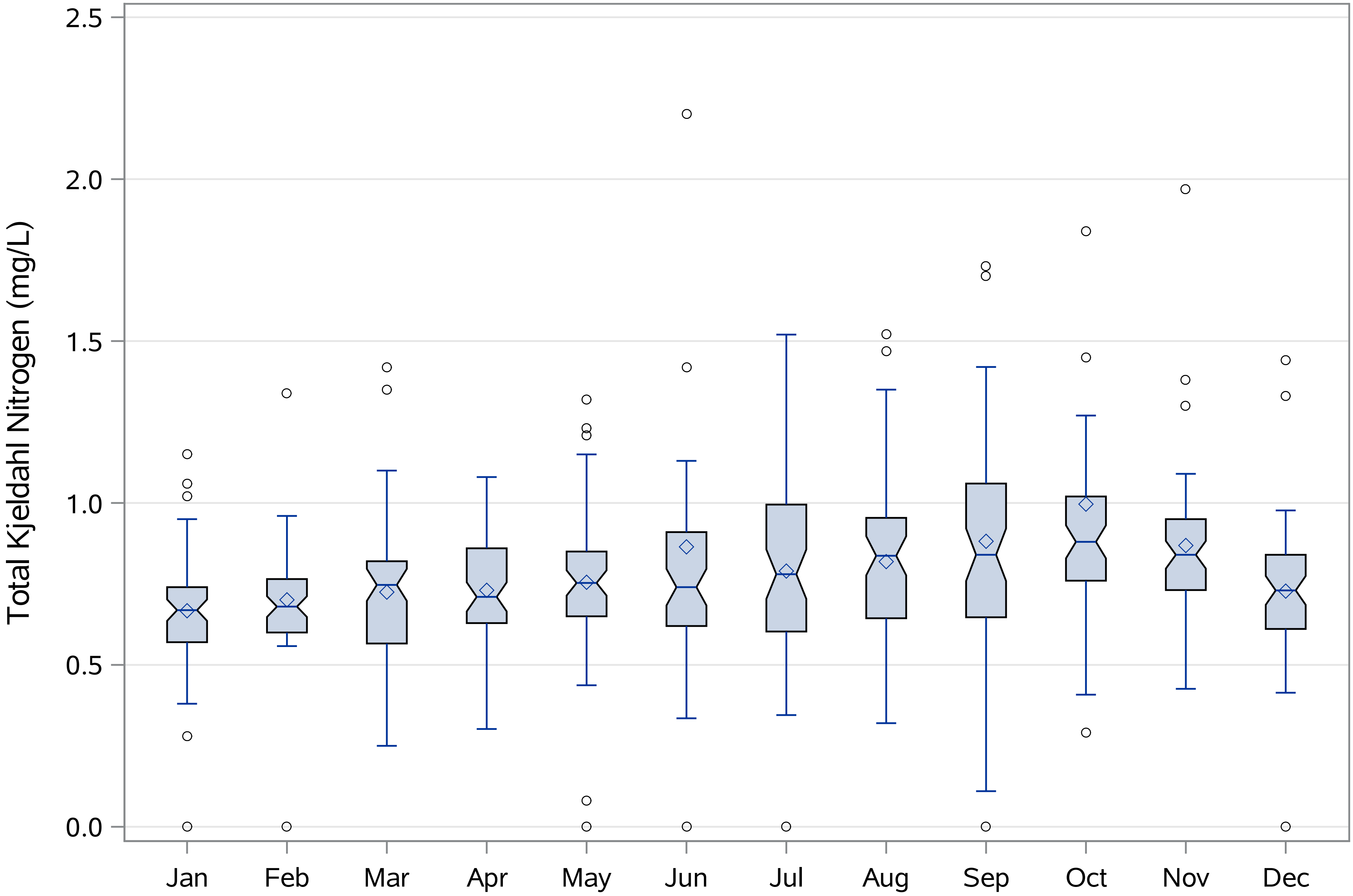

Figure 5.124. Mean monthly boxplots of surface Total Kjeldahl Nitrogen at the 20 psu isohaline (1984-2016)

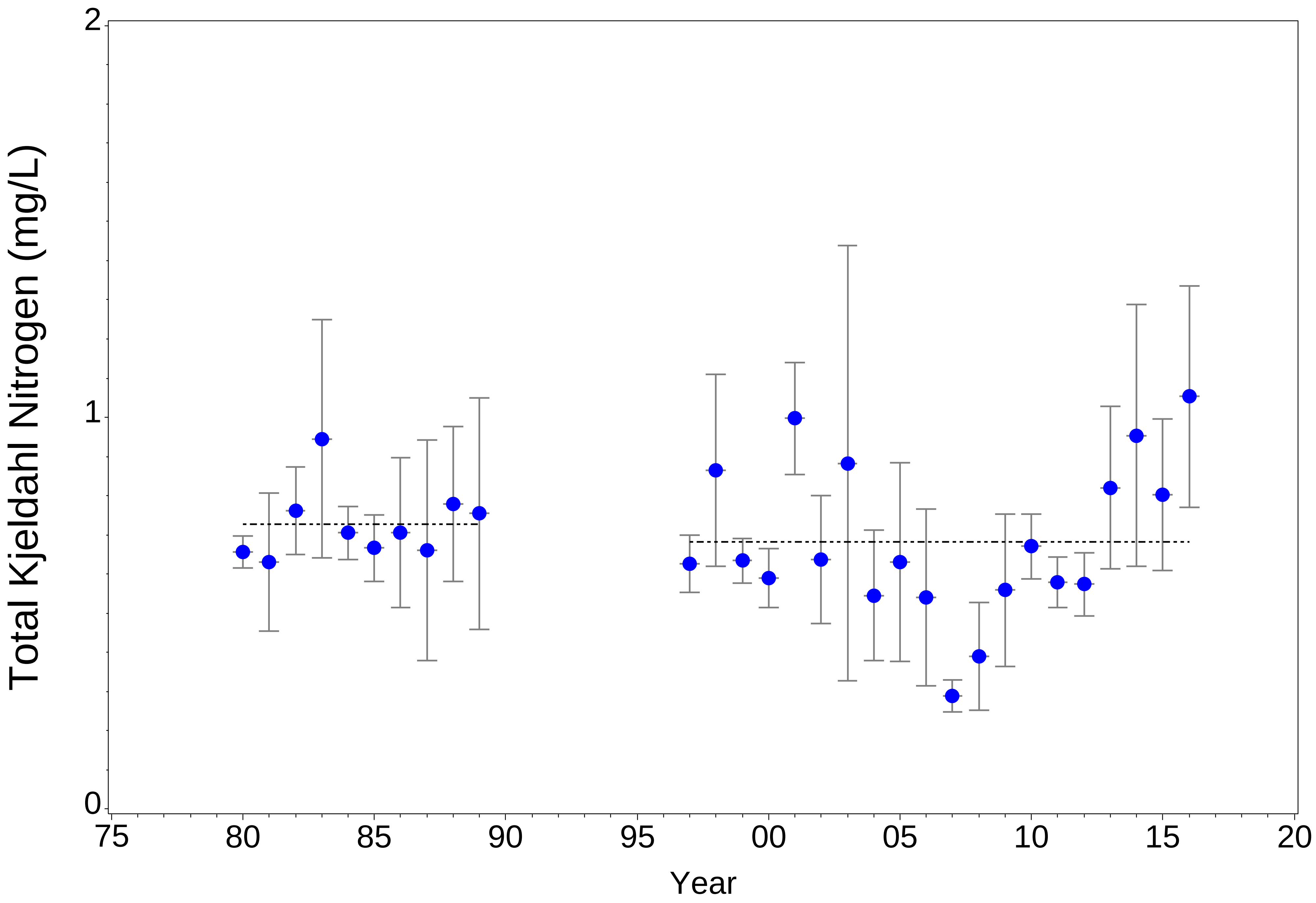

Figure 5.125. Long-term Station 9 surface Total Kjeldahl Nitrogen at river kilometer -2.4

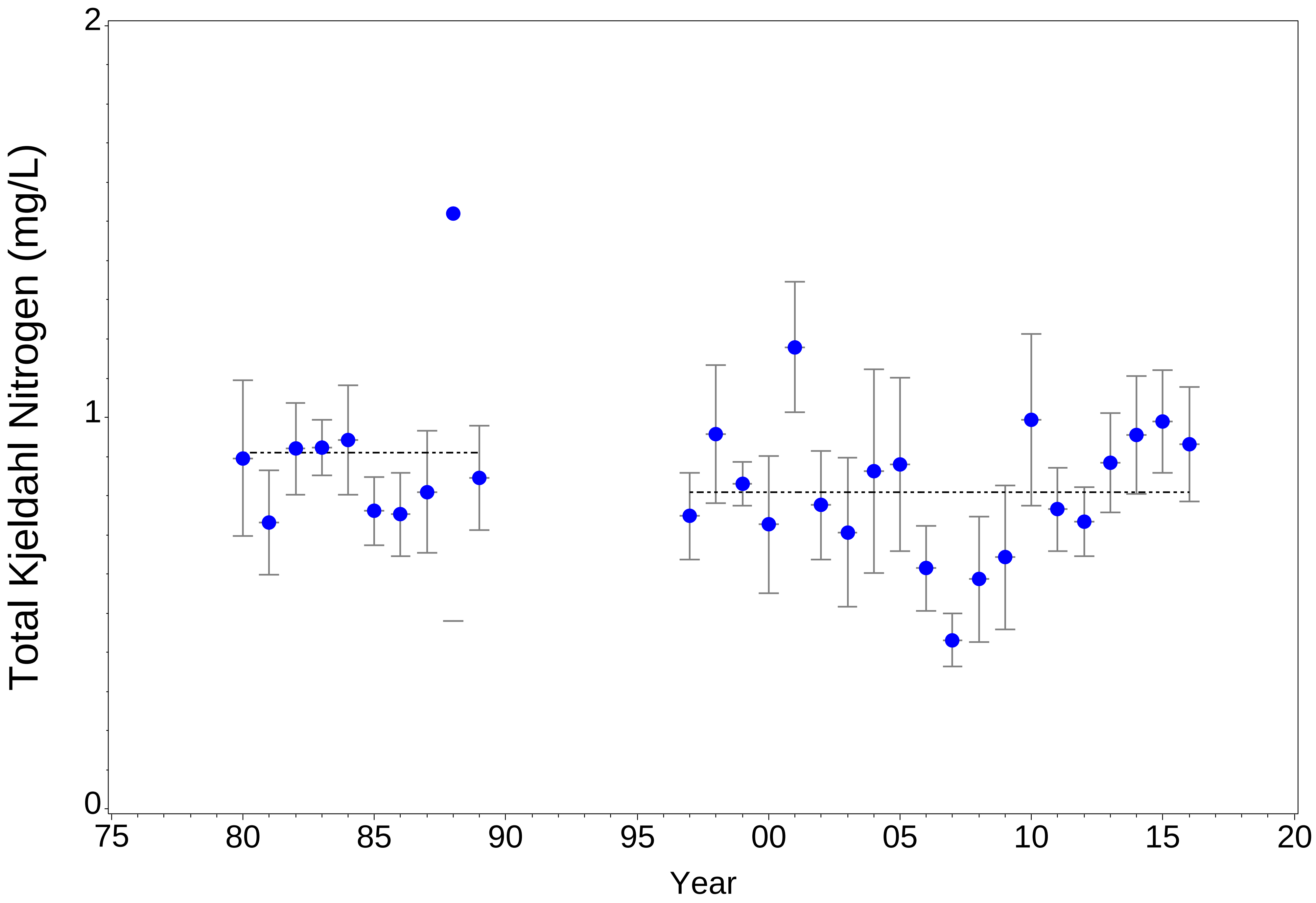

Figure 5.126. Long-term Station 10 surface Total Kjeldahl Nitrogen at river kilometer 6.6

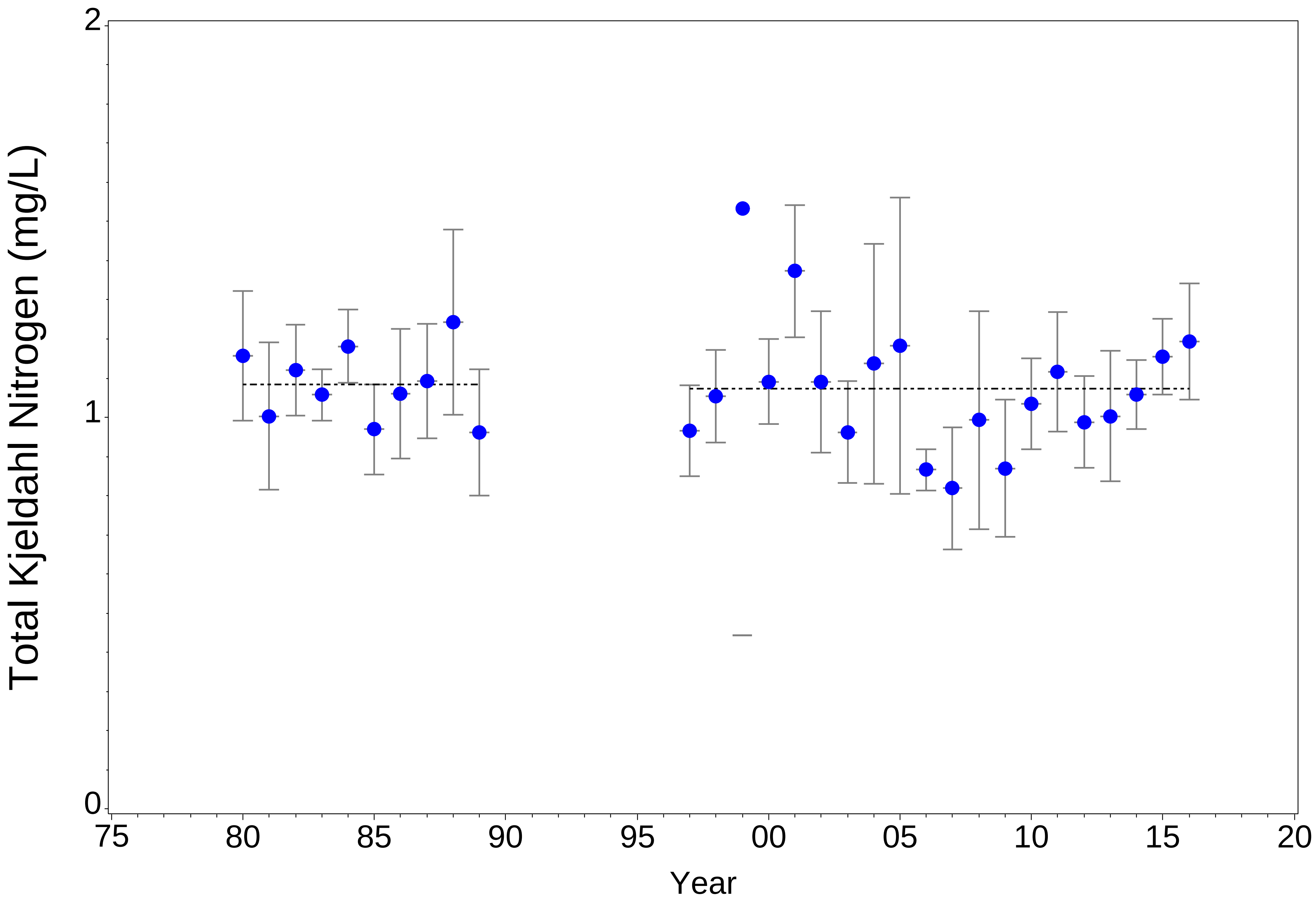

Figure 5.127. Long-term Station 12 surface Total Kjeldahl Nitrogen at river kilometer 15.5

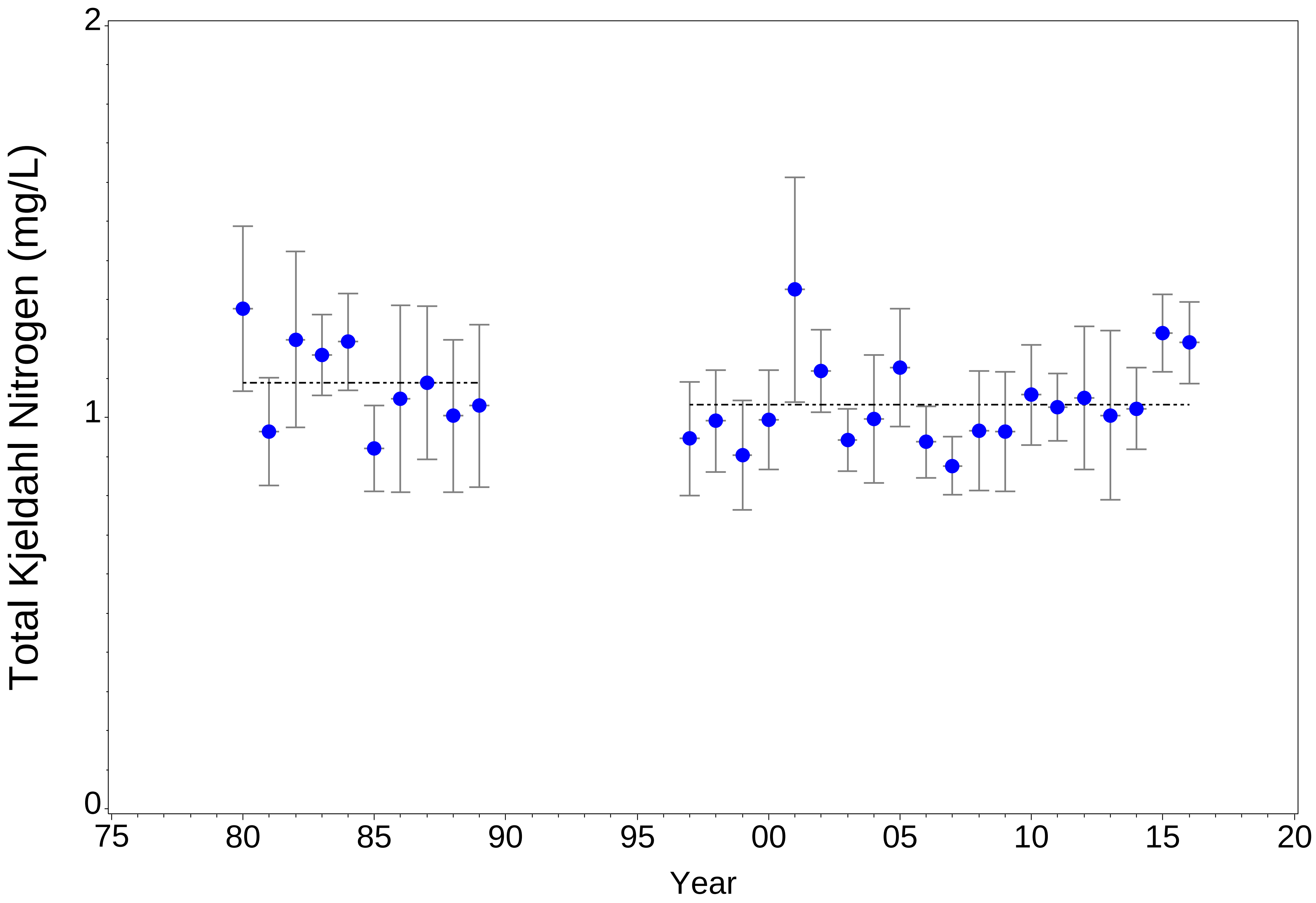

Figure 5.128. Long-term Station 14 surface Total Kjeldahl Nitrogen at river kilometer 23.6

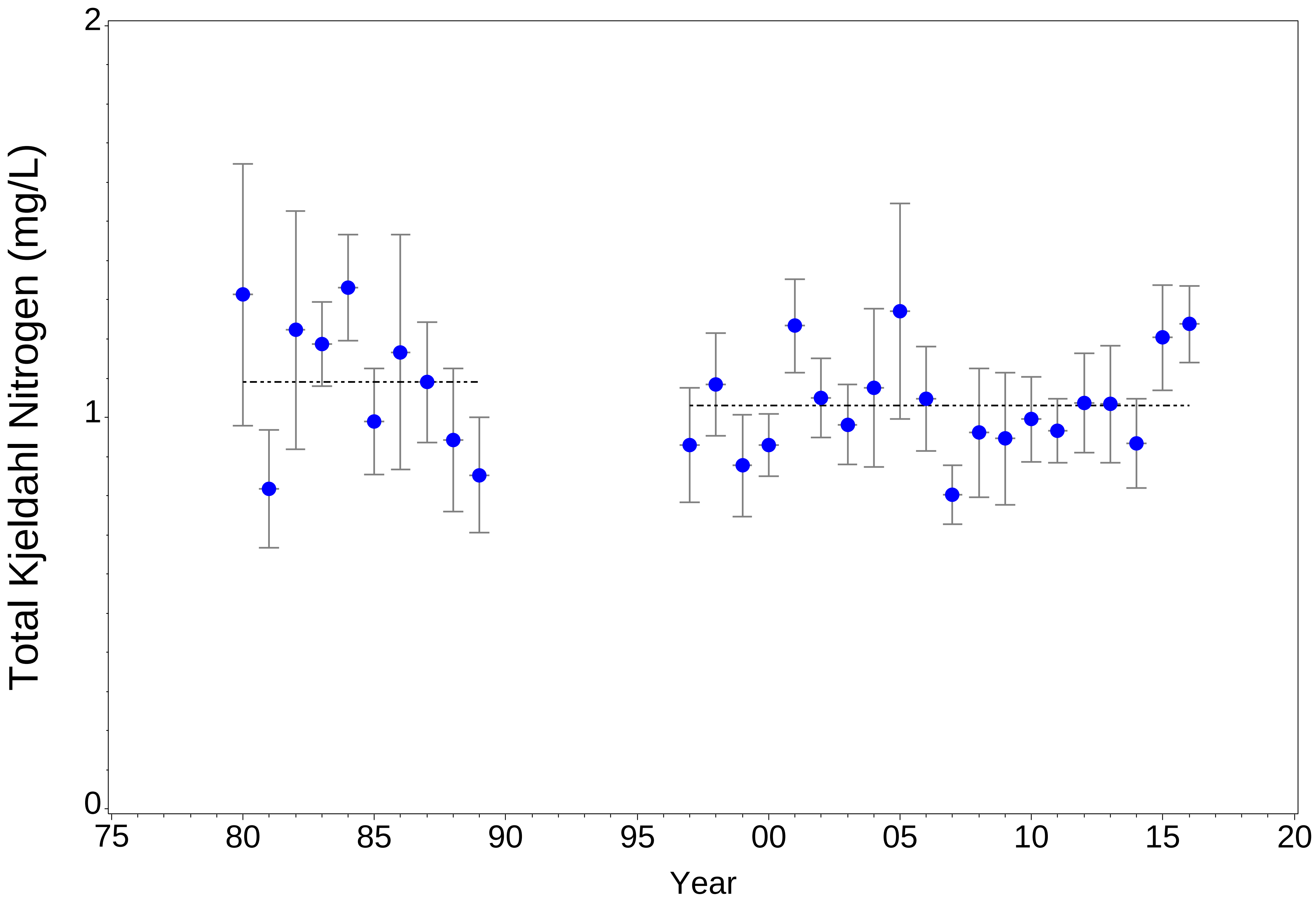

Figure 5.129. Long-term Station 18 surface Total Kjeldahl Nitrogen at river kilometer 30.7

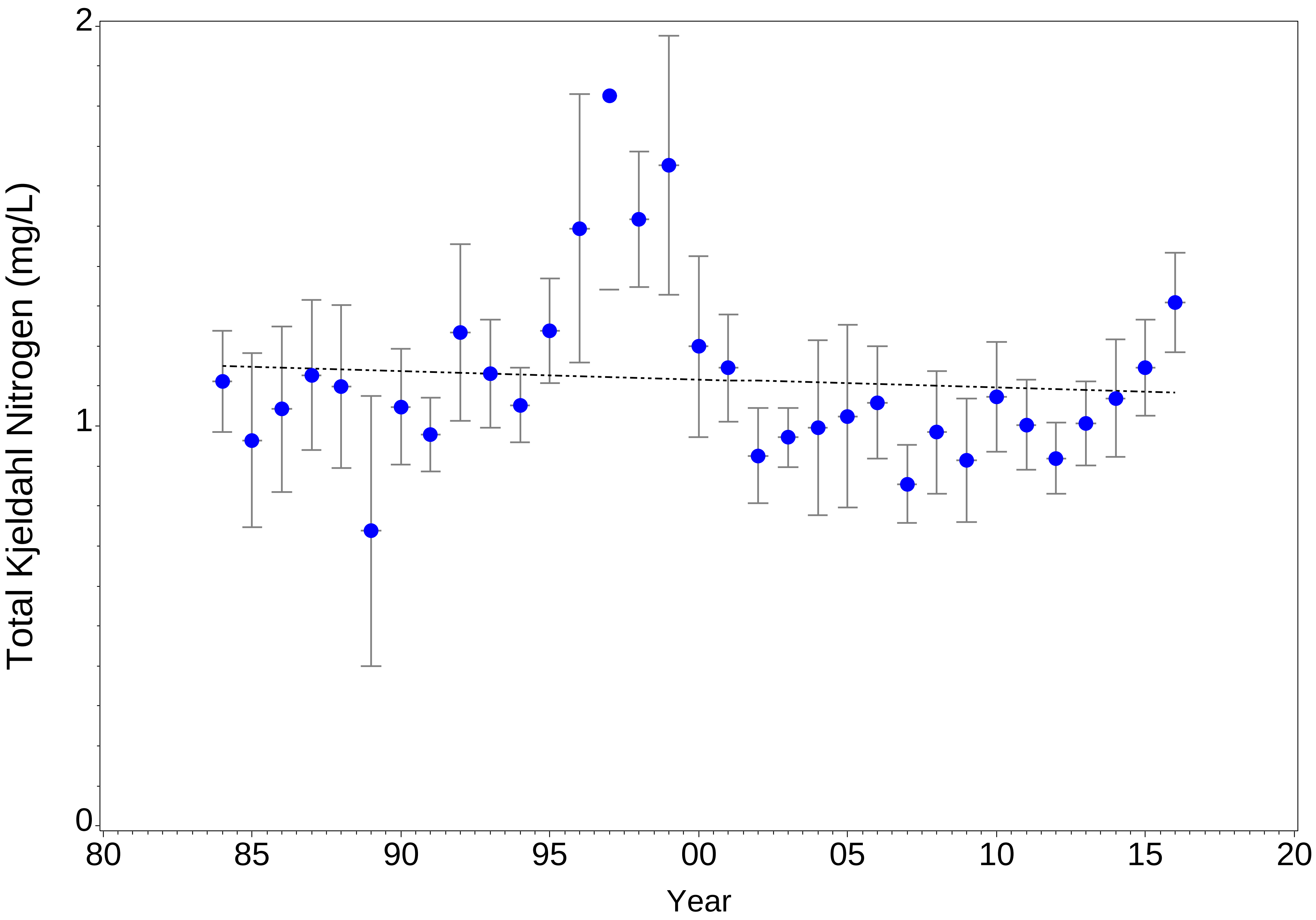

Figure 5.130. Annual monthly surface Total Kjeldahl Nitrogen at 0 psu isohaline (1984-2016)

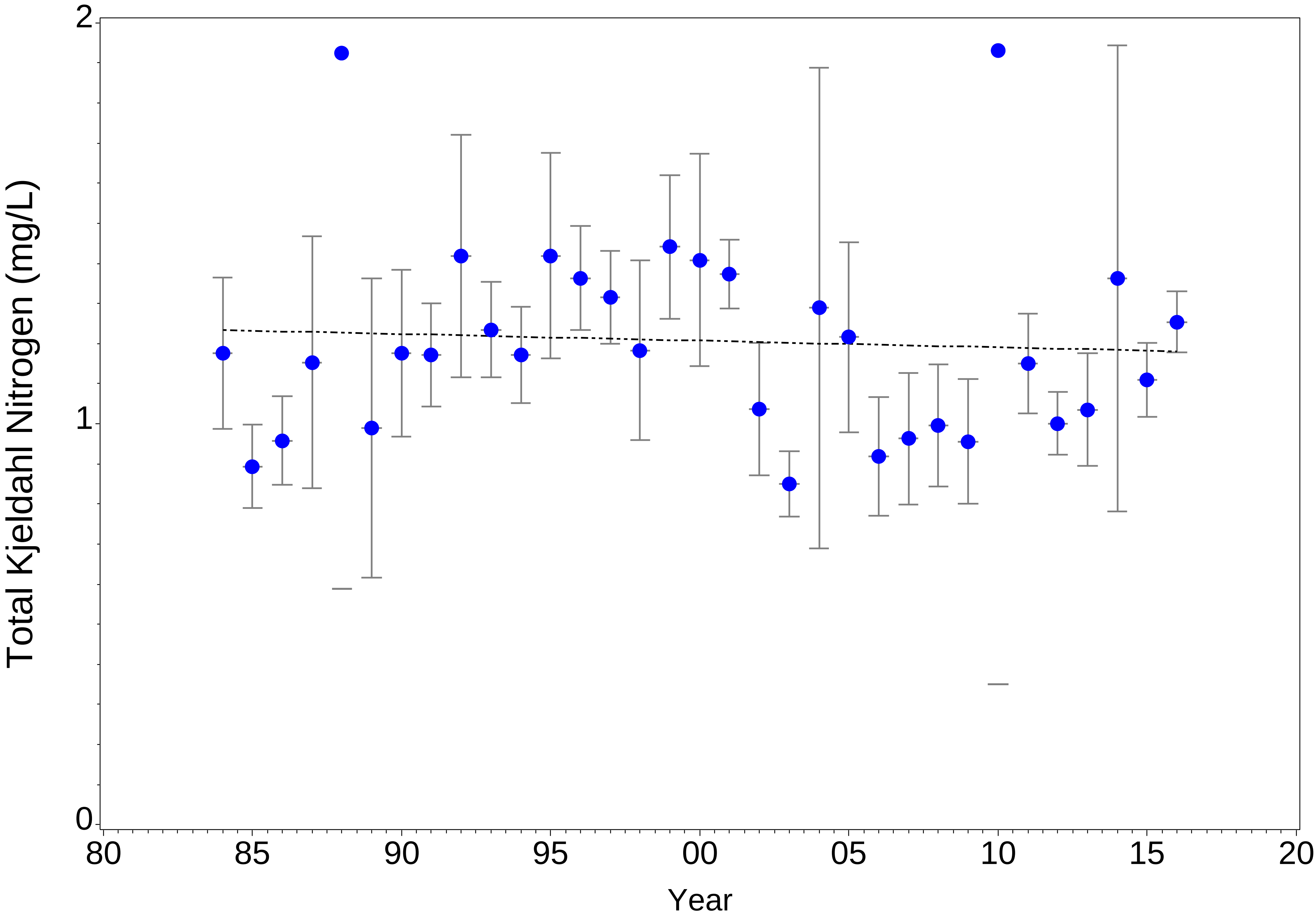

Figure 5.131. Annual monthly surface Total Kjeldahl Nitrogen at 6 psu isohaline (1984-2016)

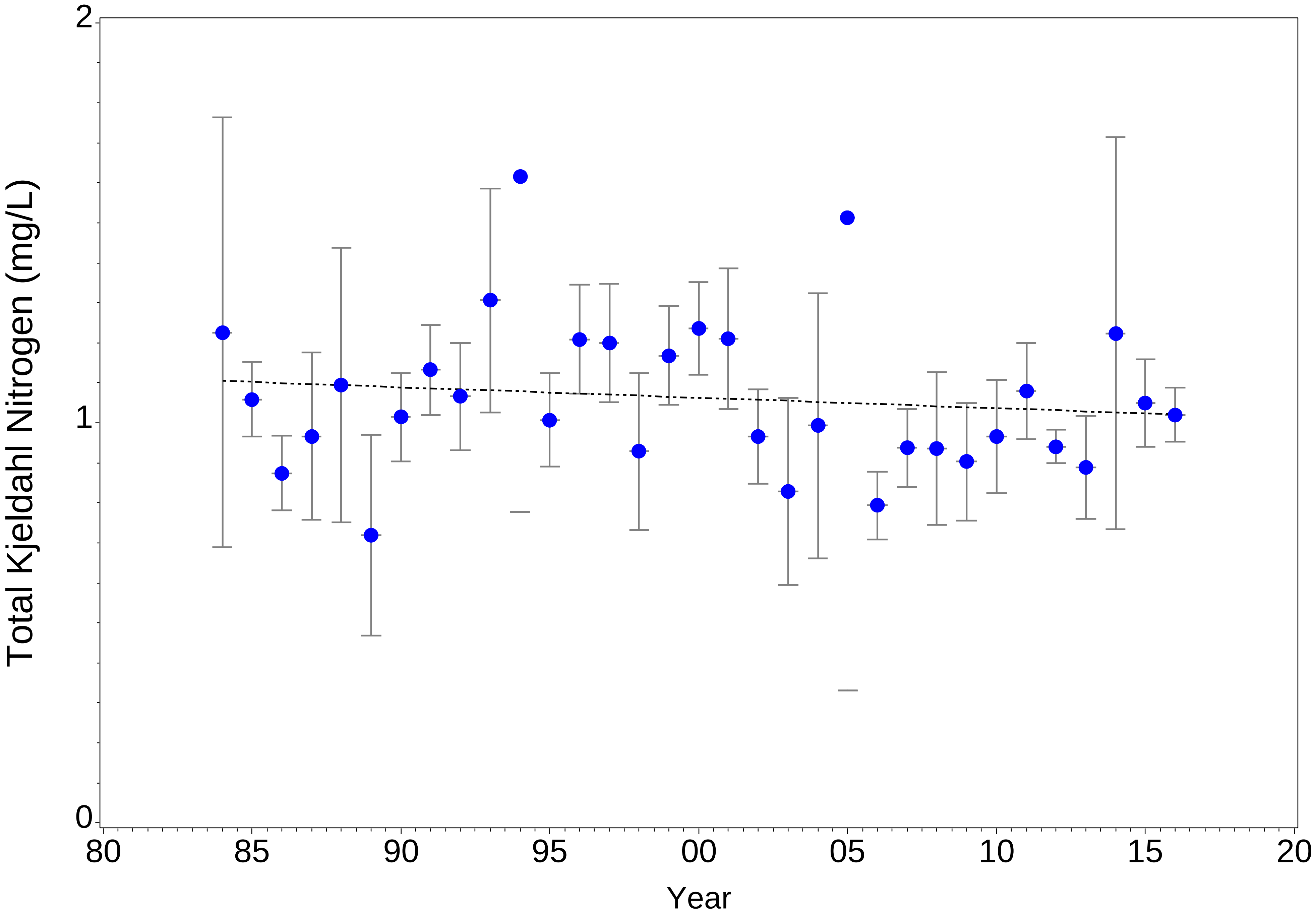

Figure 5.132. Annual monthly surface Total Kjeldahl Nitrogen at 12 psu isohaline (1984-2016)

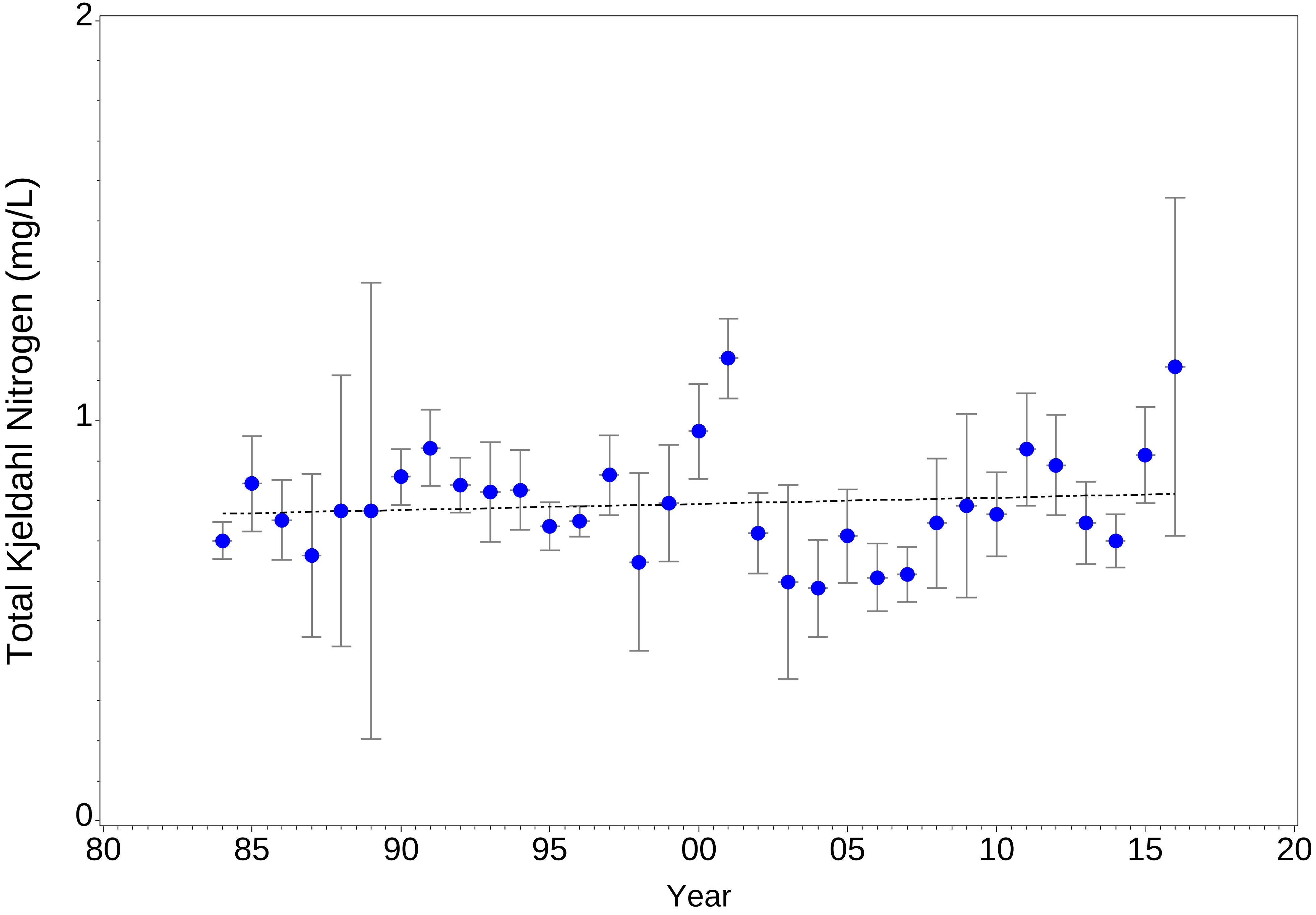

Figure 5.133. Annual monthly surface Total Kjeldahl Nitrogen at 20 psu isohaline (1984-2016)

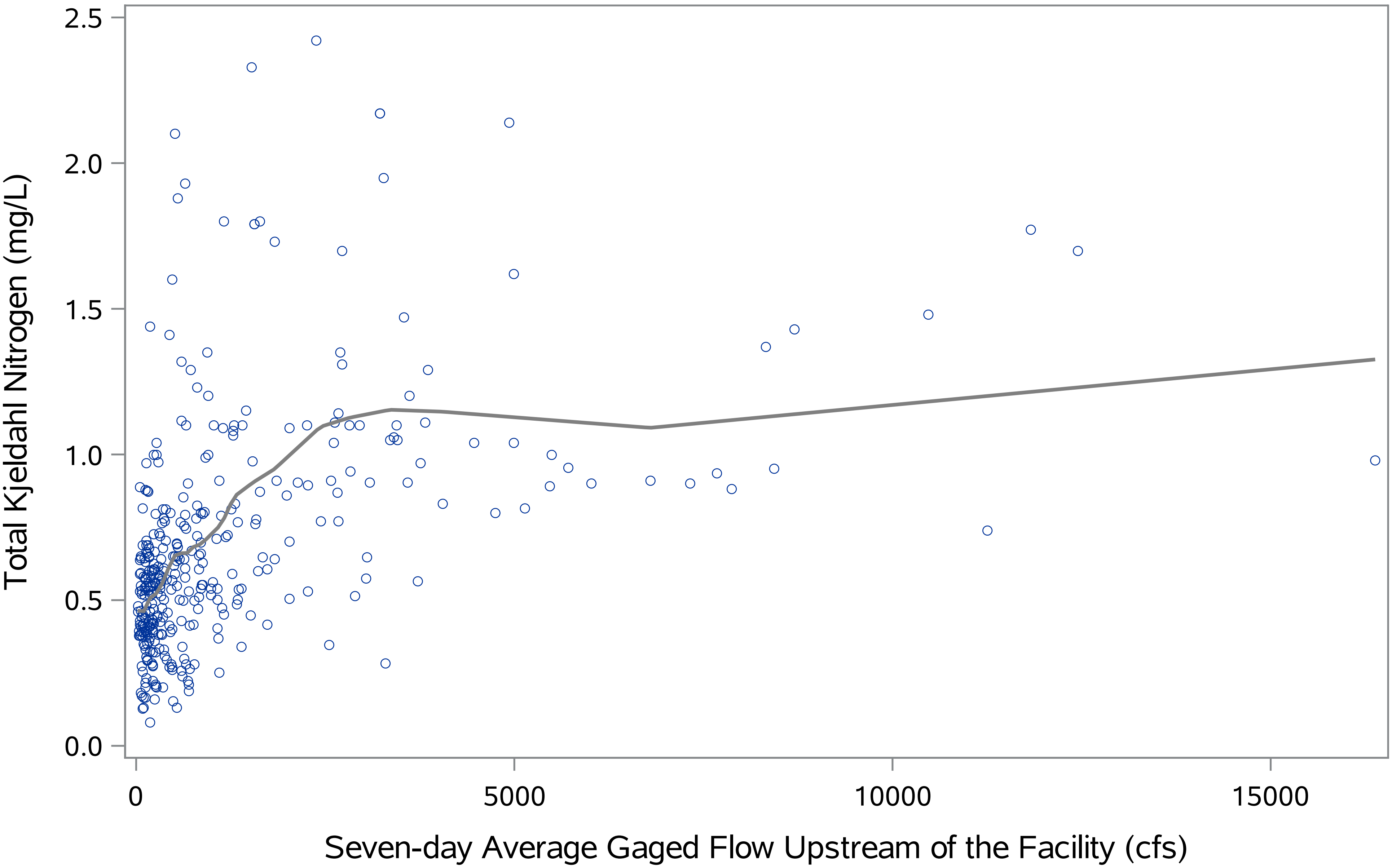

Figure 5.134. Surface Total Kjeldahl Nitrogen at river kilometer -2.4 versus flow

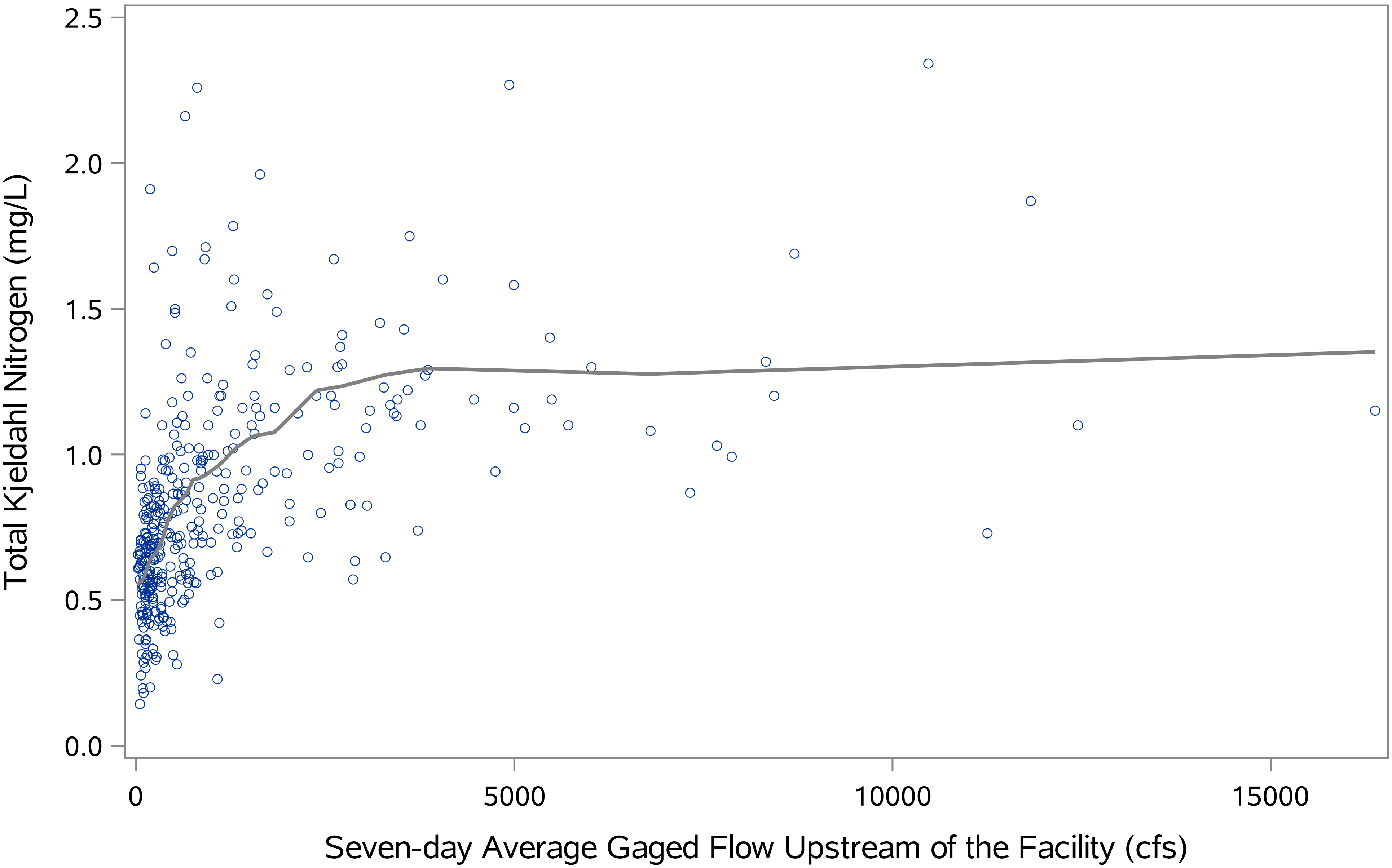

Figure 5.135. Surface Total Kjeldahl Nitrogen at river kilometer 6.6 versus flow

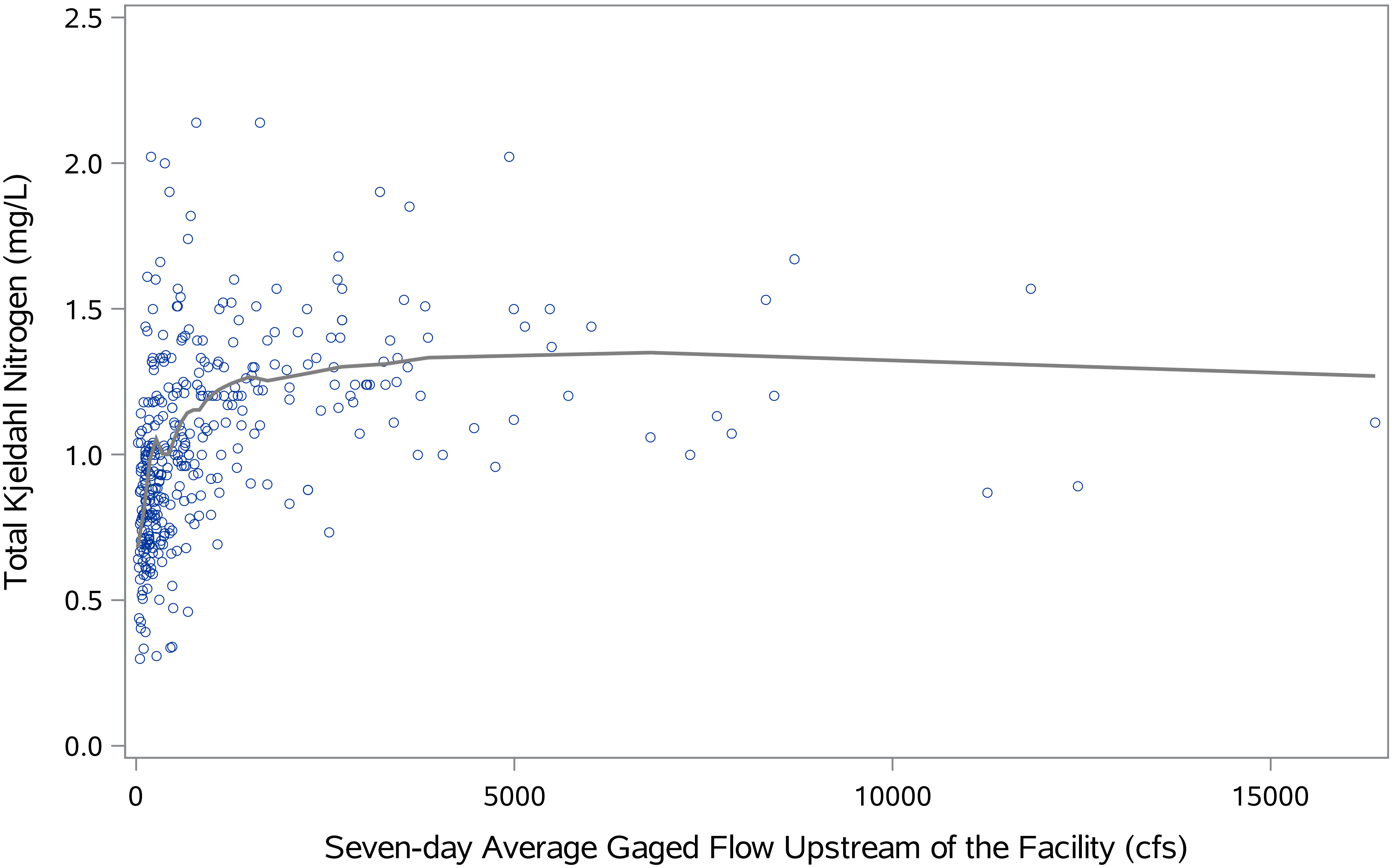

Figure 5.136. Surface Total Kjeldahl Nitrogen at river kilometer 15.5 versus flow

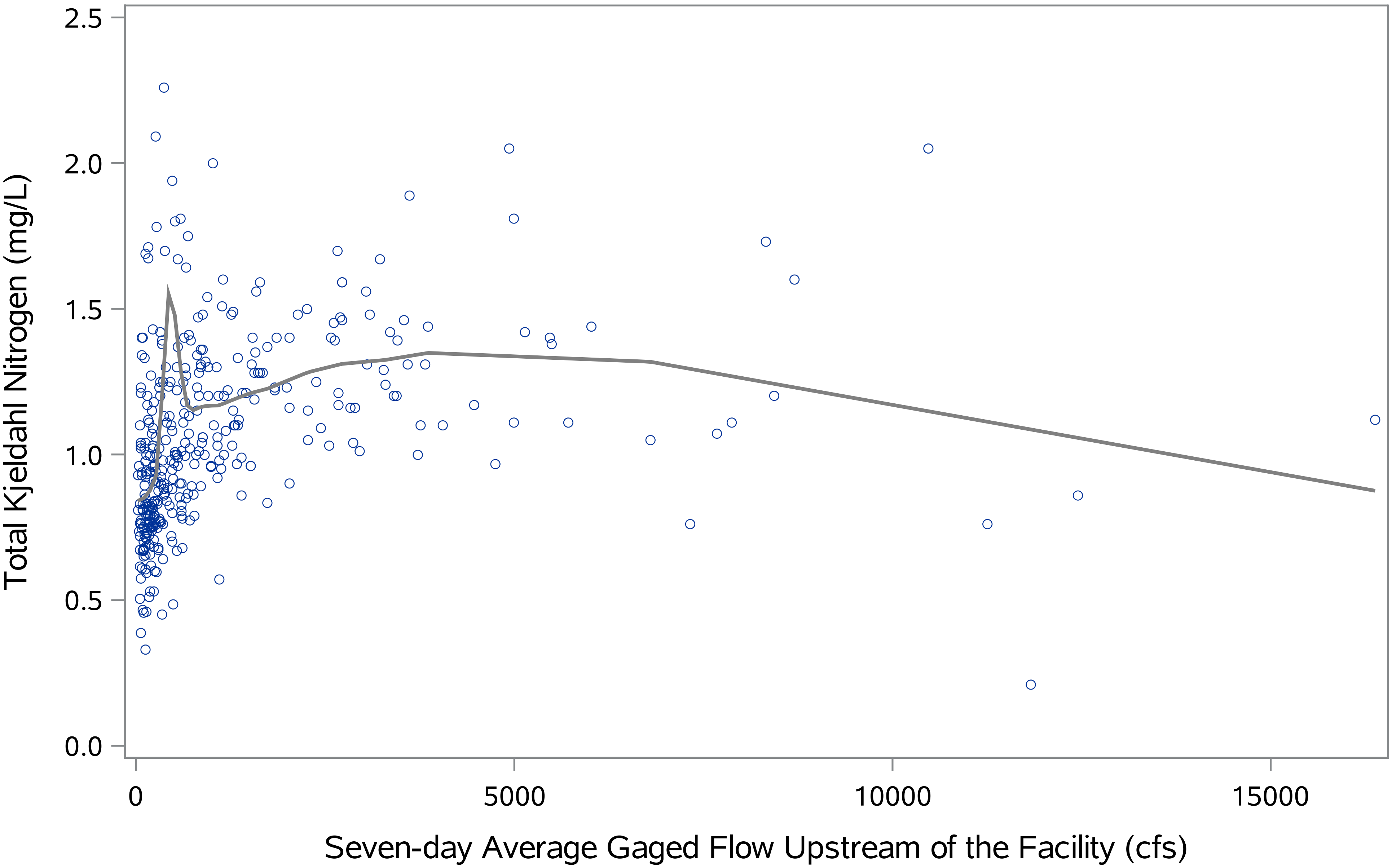

Figure 5.137. Surface Total Kjeldahl Nitrogen at river kilometer 23.6 versus flow

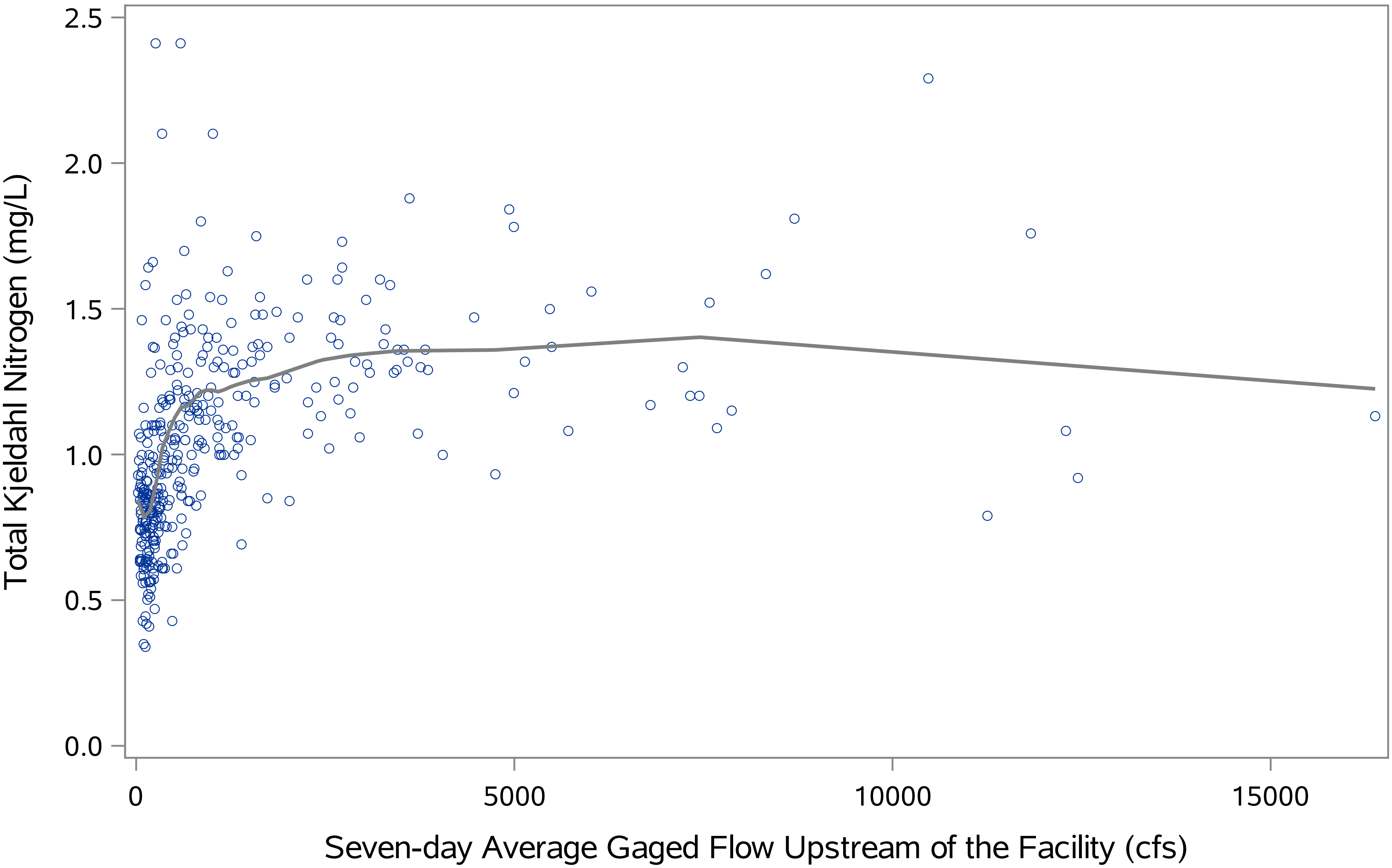

Figure 5.138. Surface Total Kjeldahl Nitrogen at river kilometer 30.7 versus flow

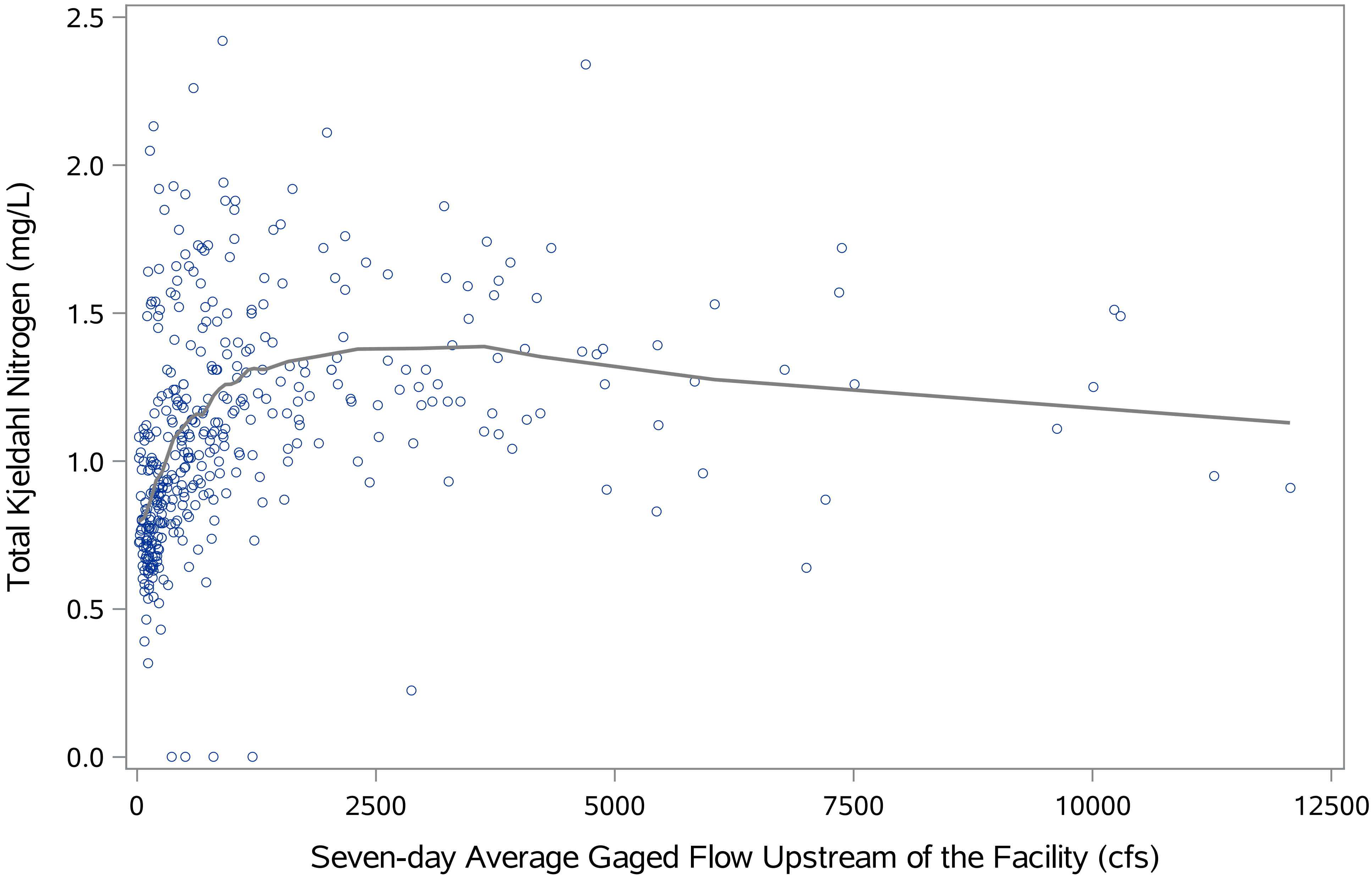

Figure 5.139. Total Kjeldahl Nitrogen at the 0 psu isohaline versus flow

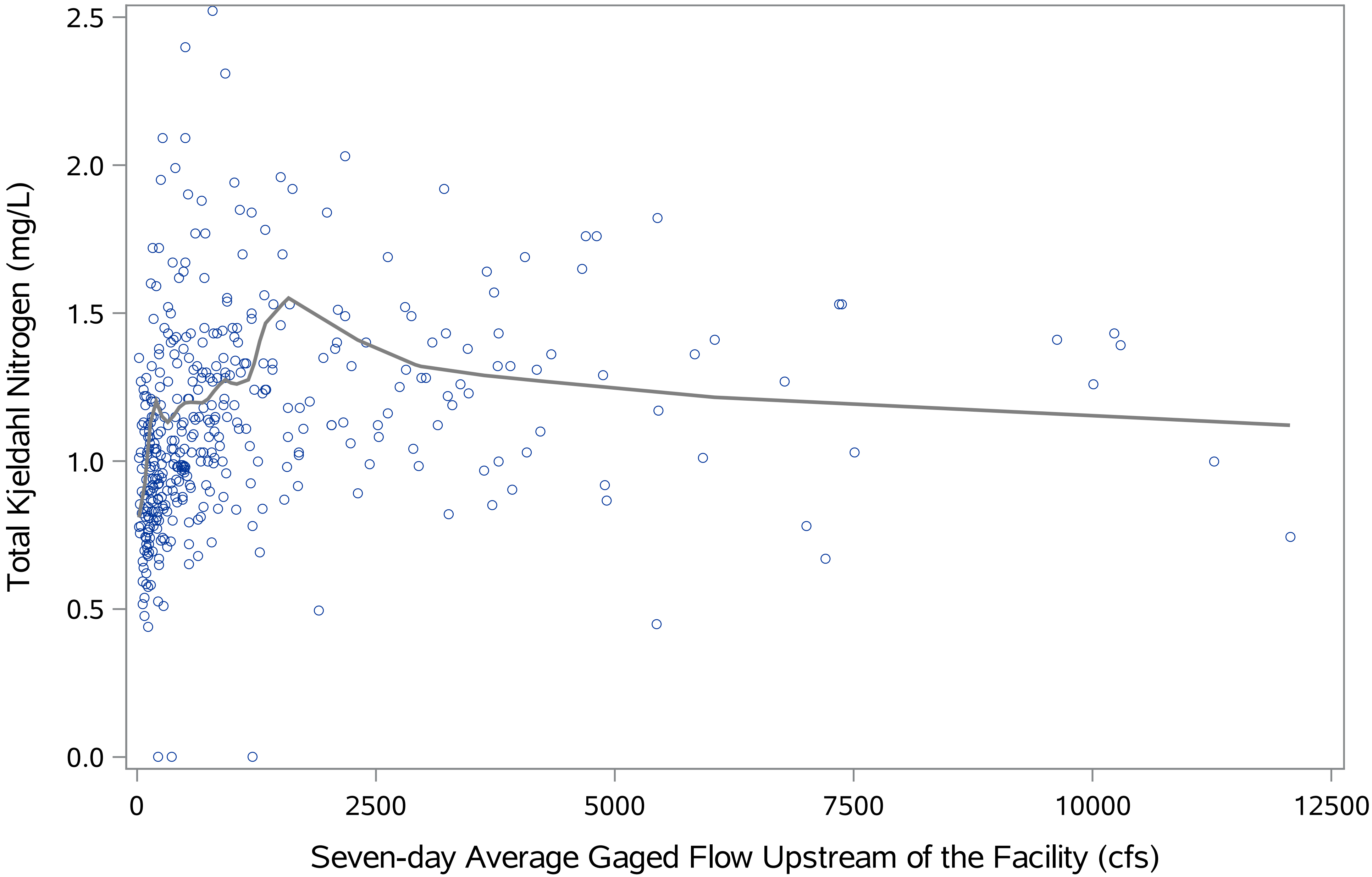

Figure 5.140. Total Kjeldahl Nitrogen at the 6 psu isohaline versus flow

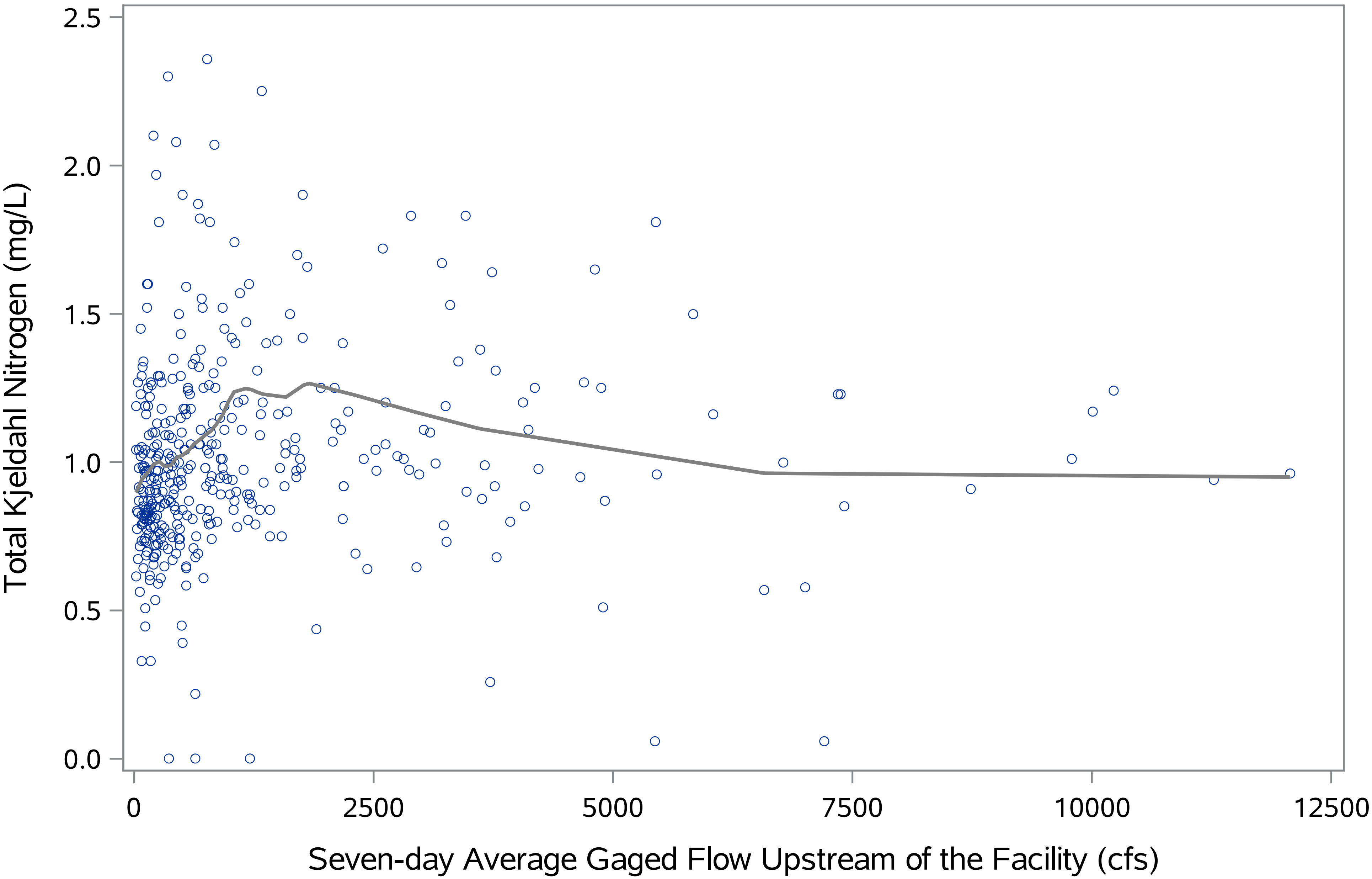

Figure 5.141. Total Kjeldahl Nitrogen at the 12 psu isohaline versus flow

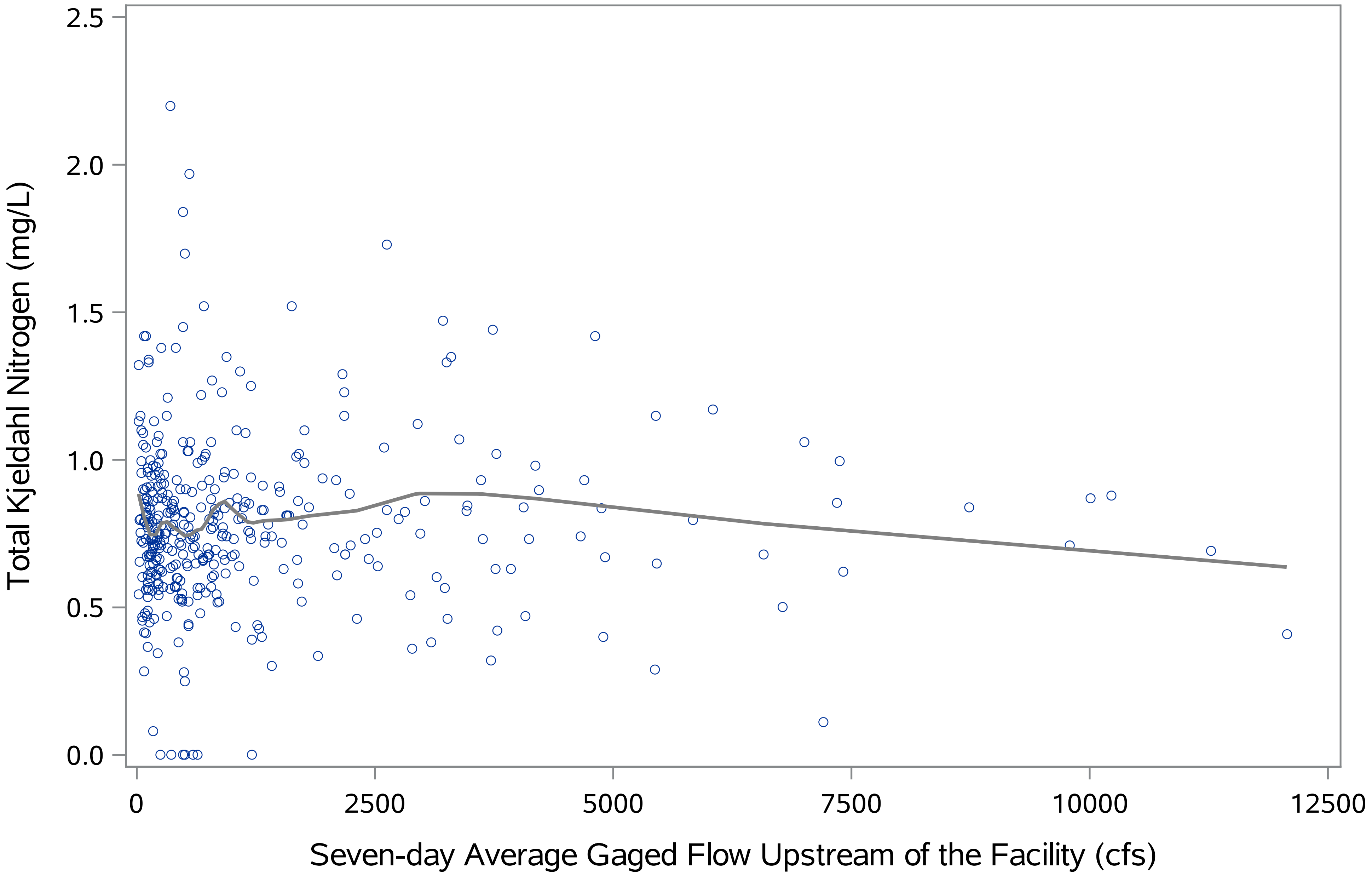

Figure 5.142. Total Kjeldahl Nitrogen at the 20 psu isohaline versus flow

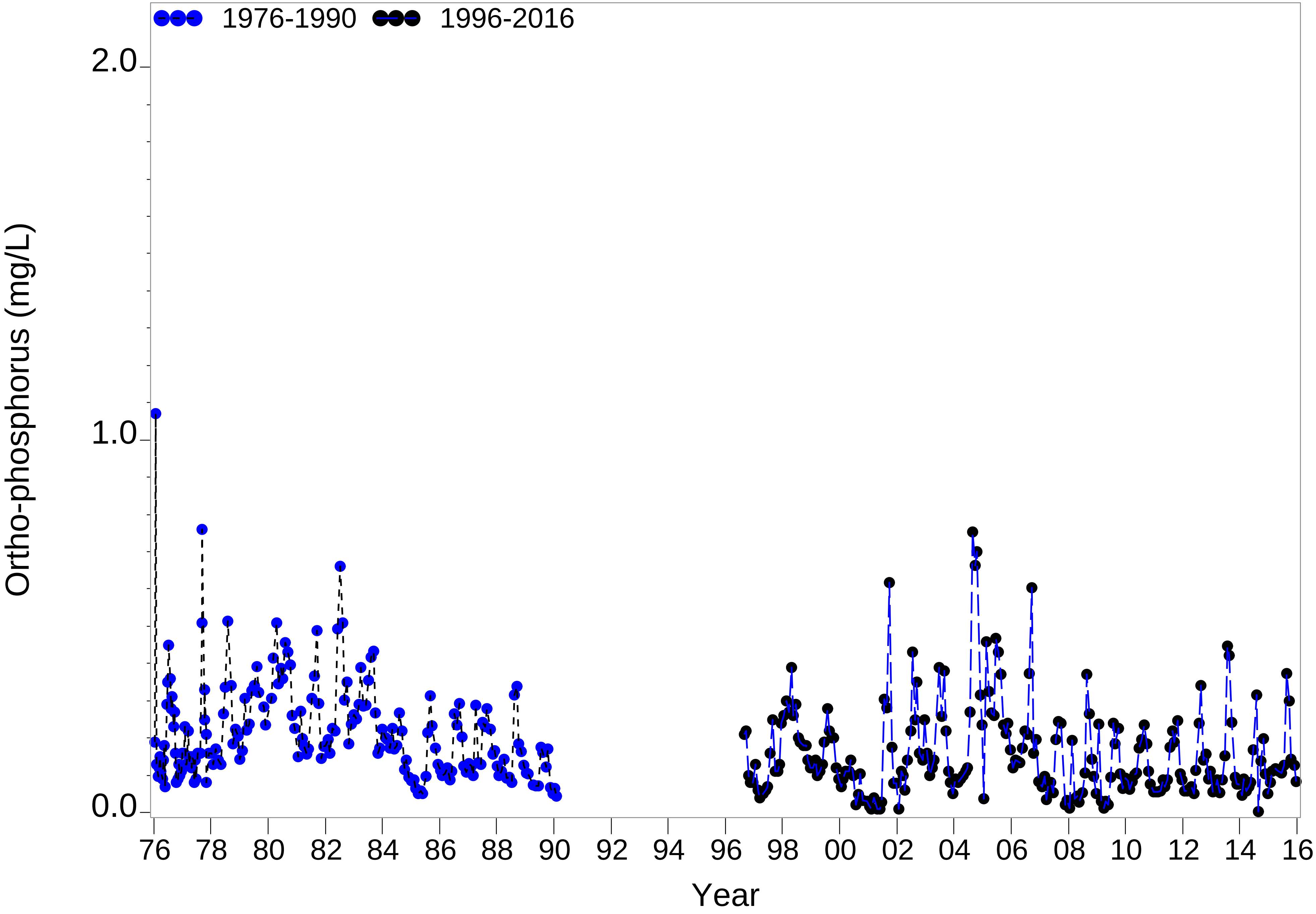

Figure 5.145. Monthly long-term Ortho-phosphorus at river kilometer -2.4

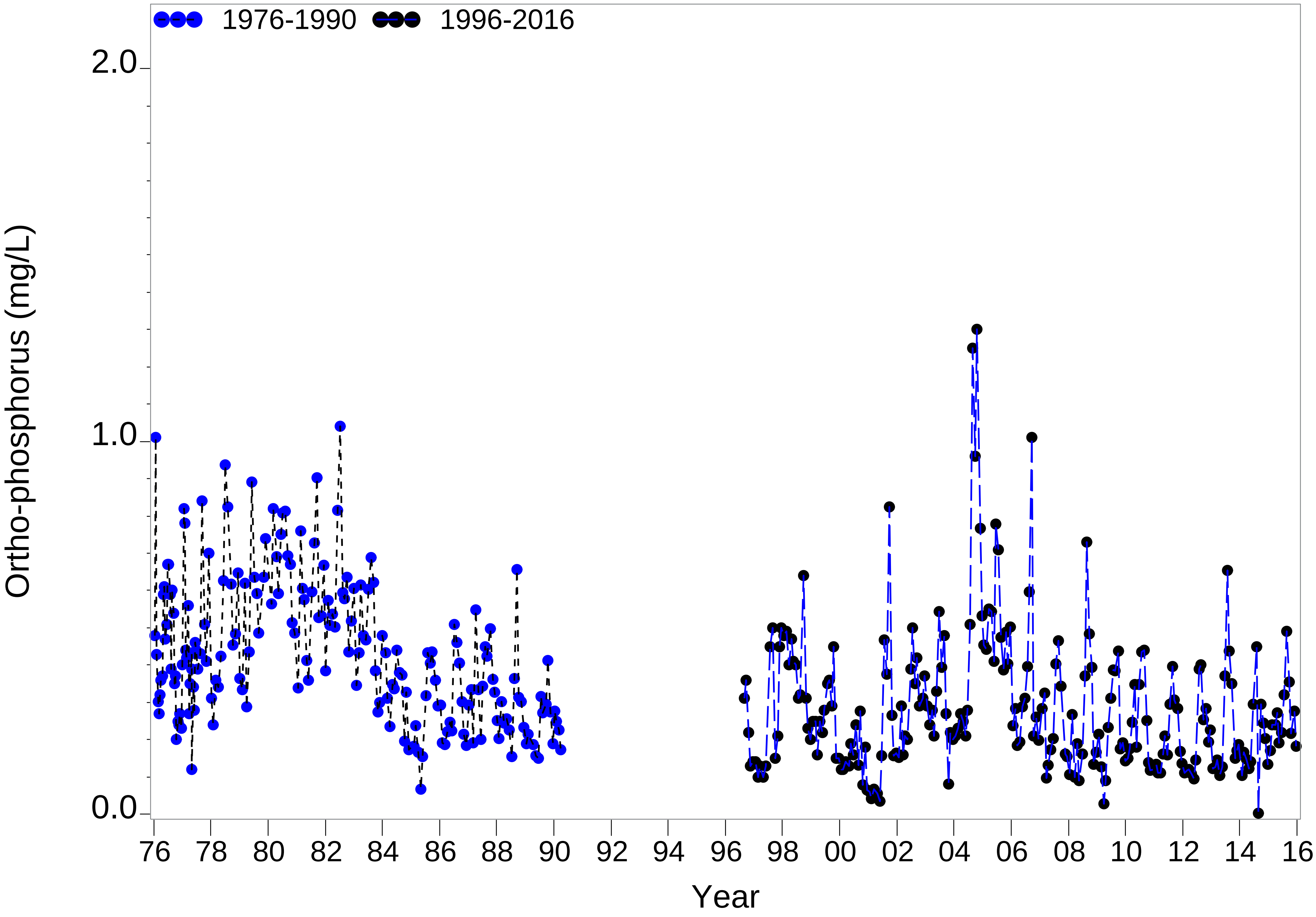

Figure 5.146. Monthly long-term Ortho-phosphorus at river kilometer 6.6

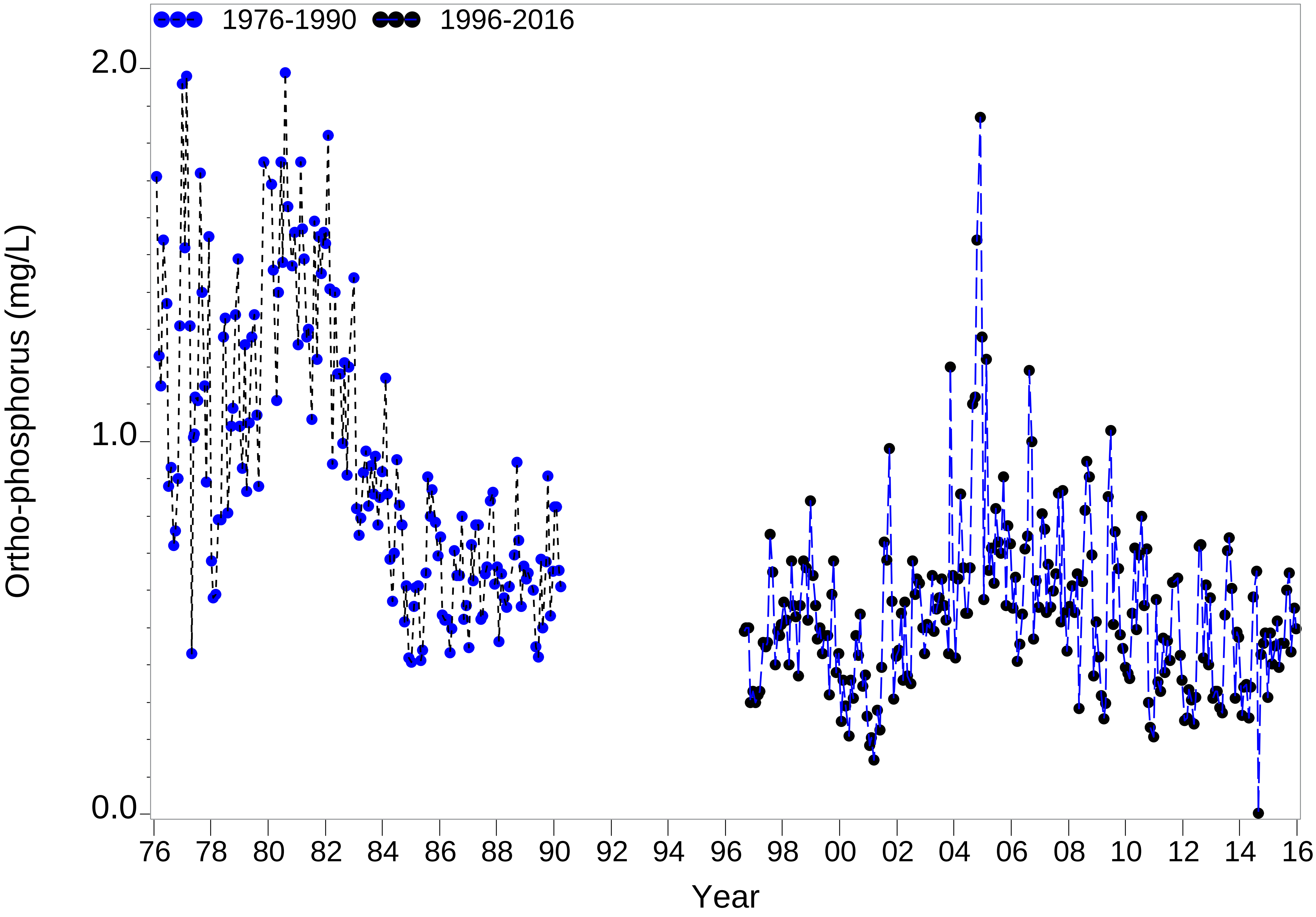

Figure 5.147. Monthly long-term Ortho-phosphorus at river kilometer 15.5

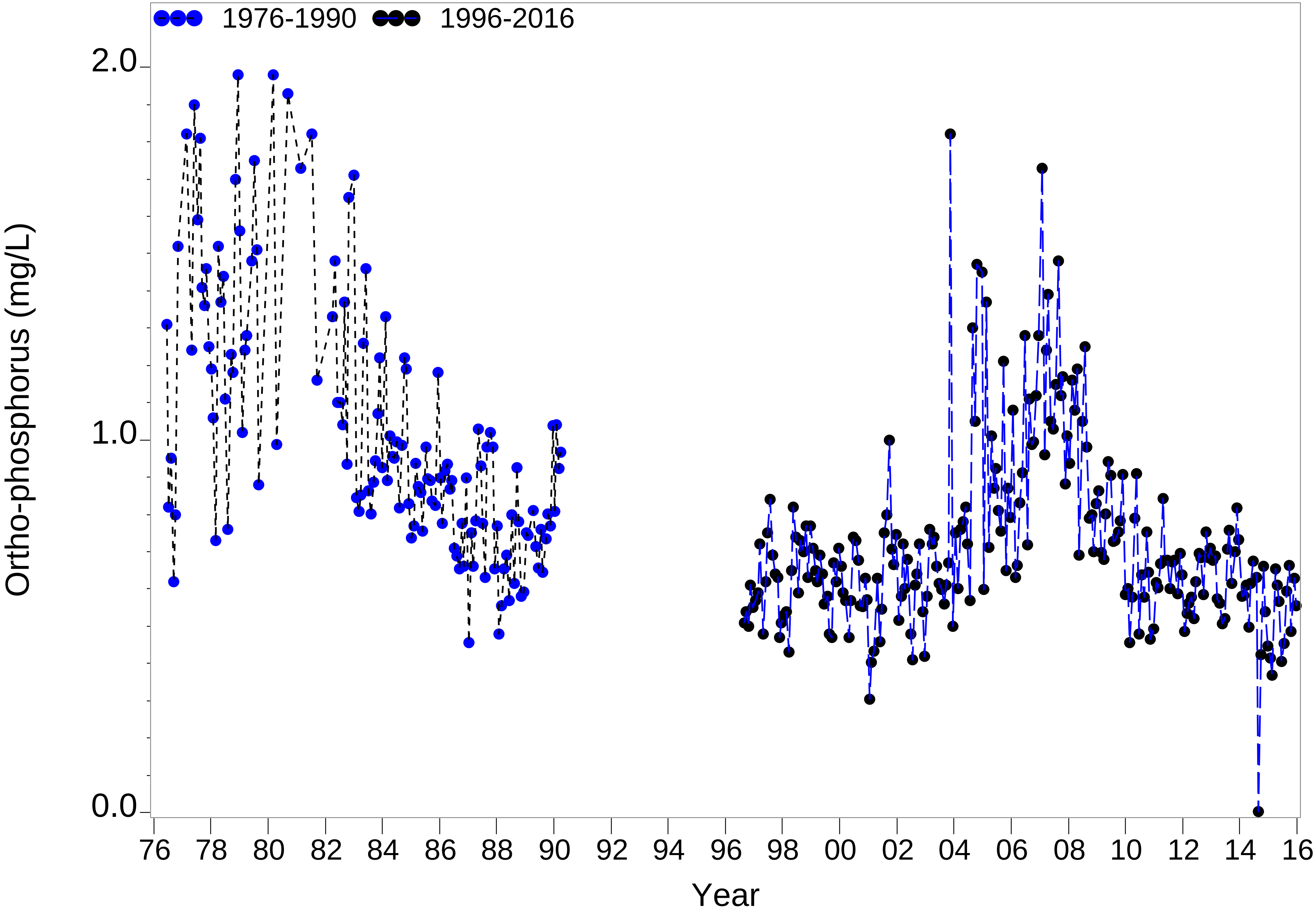

Figure 5.148. Monthly long-term Ortho-phosphorus at river kilometer 23.6

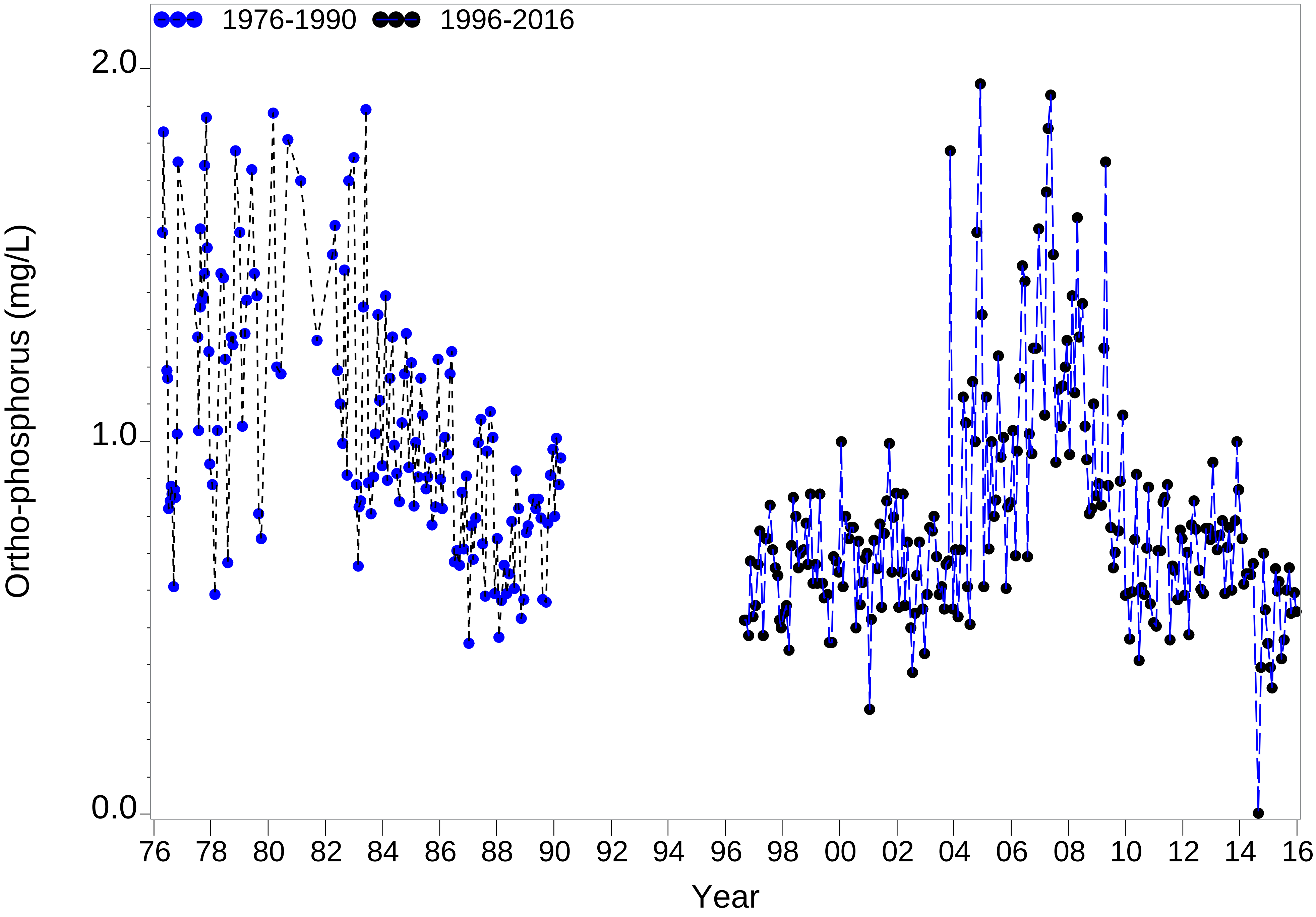

Figure 5.149. Monthly long-term Ortho-phosphorus at river kilometer 30.7

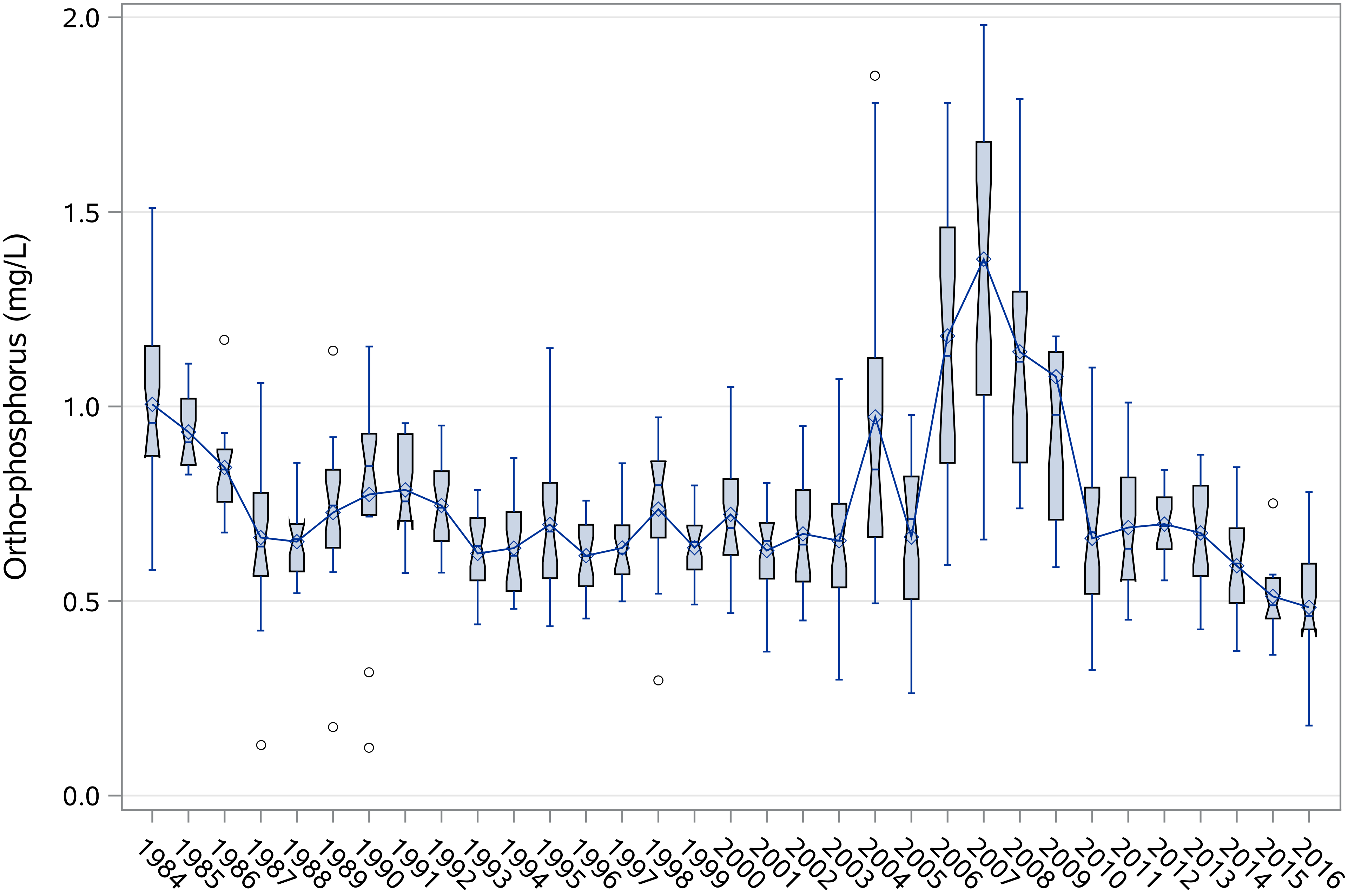

Figure 5.150. Annual boxplots of surface Ortho-phosphorus at the 0 psu isohaline (1984-2016)

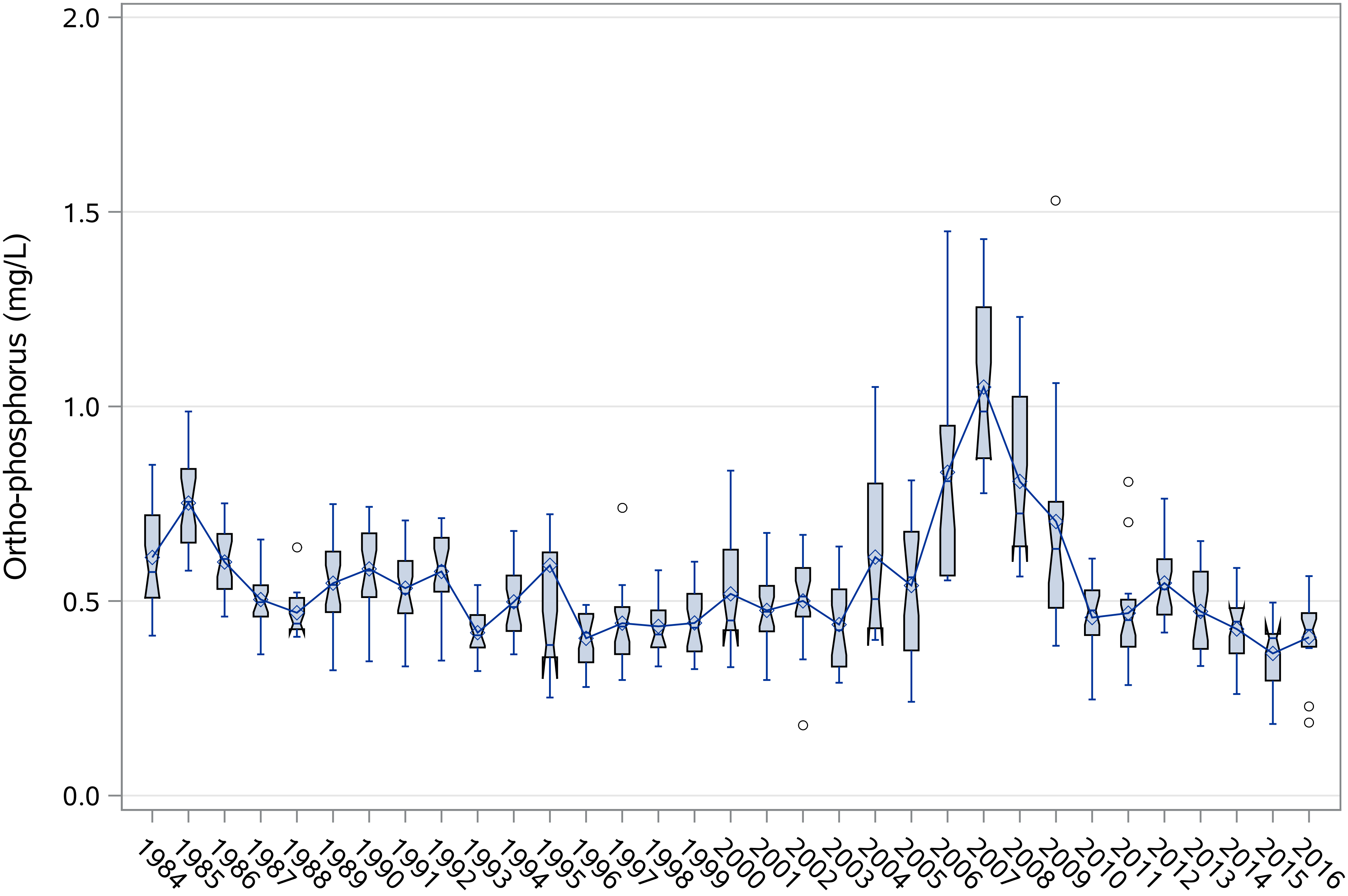

Figure 5.151. Annual boxplots of surface Ortho-phosphorus at the 6 psu isohaline (1984-2016)

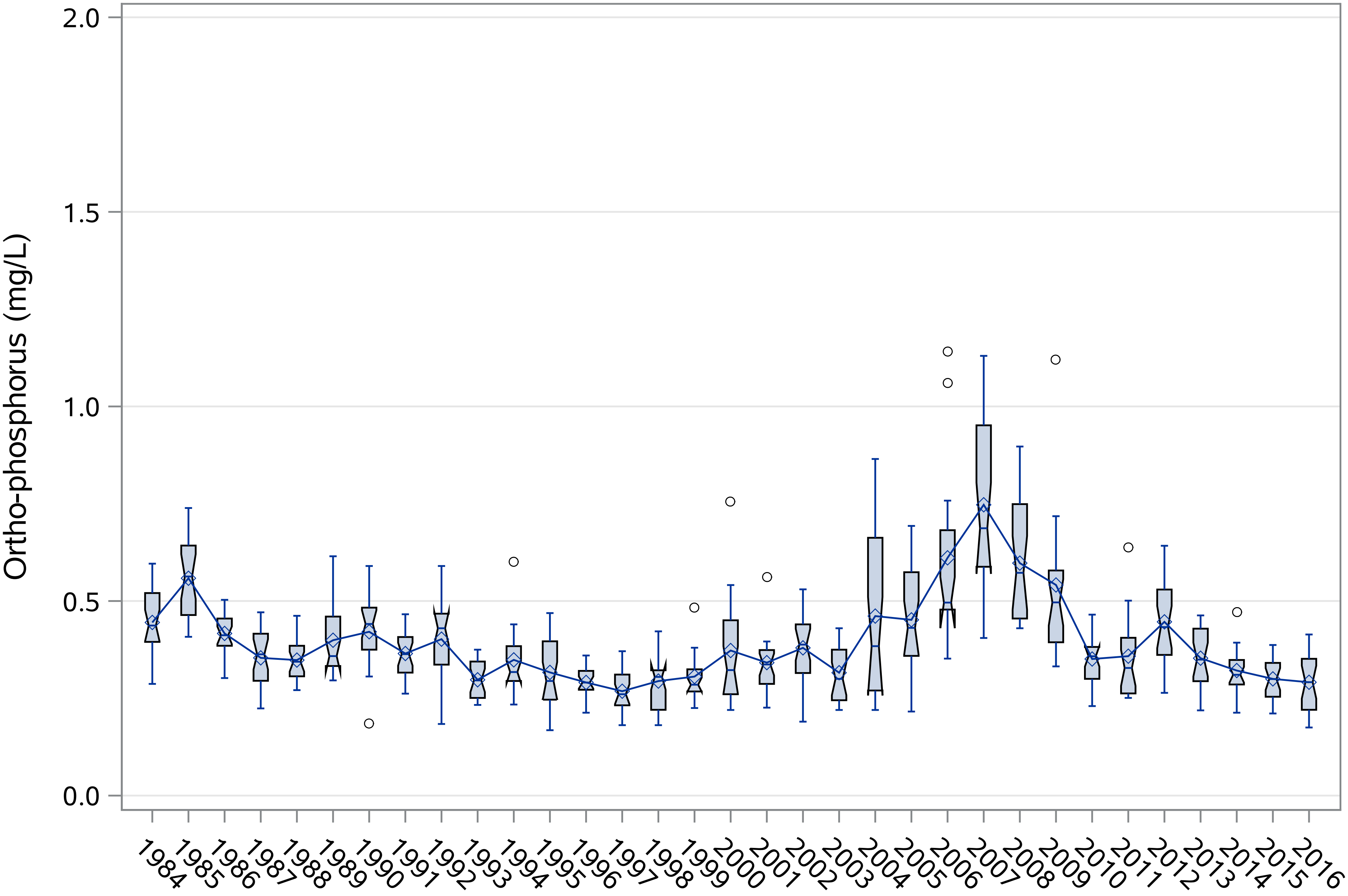

Figure 5.152. Annual boxplots of surface Ortho-phosphorus at the 12 psu isohaline (1984-2016)

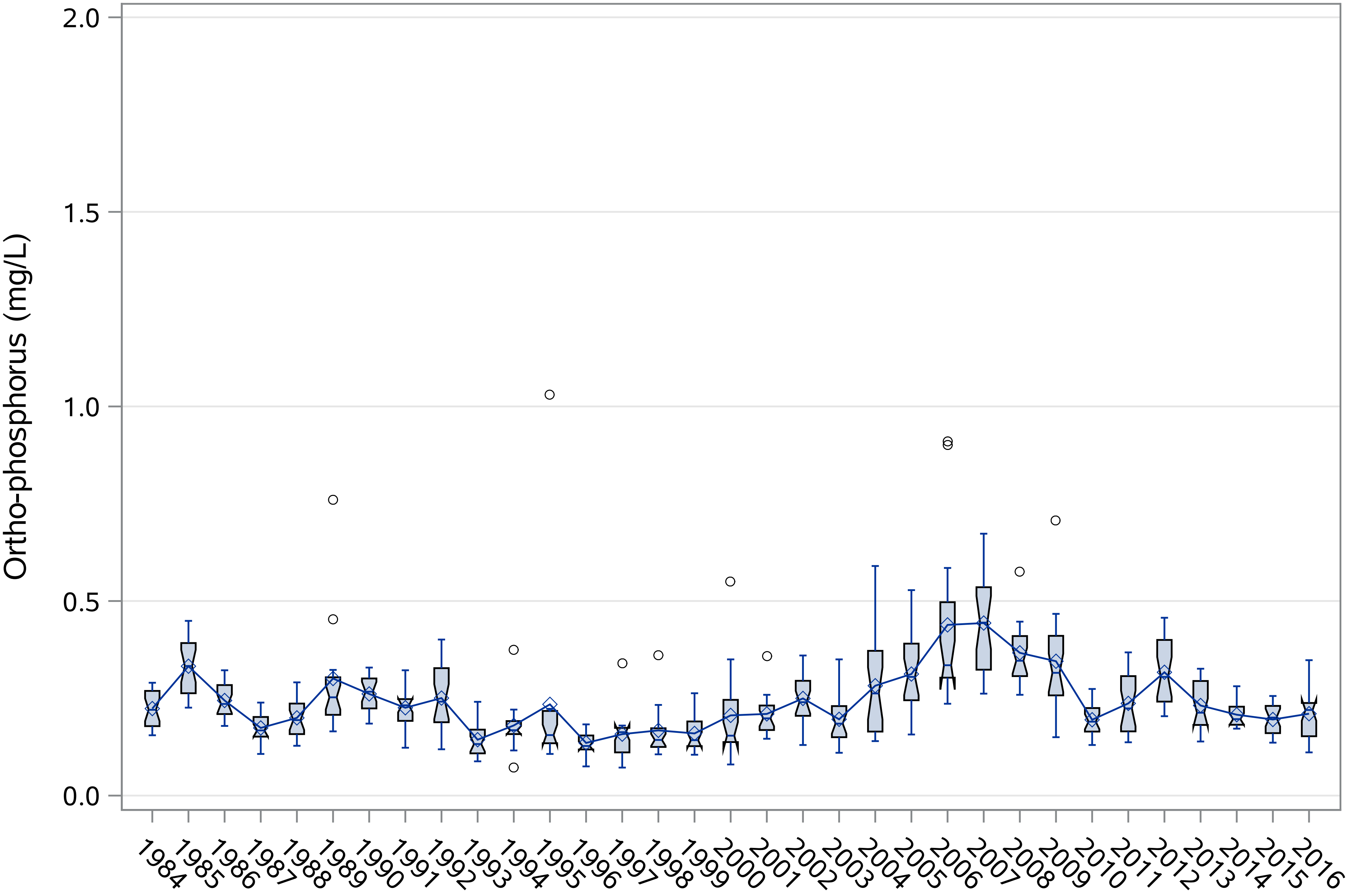

Figure 5.153. Annual boxplots of surface Ortho-phosphorus at the 20 psu isohaline (1984-2016)

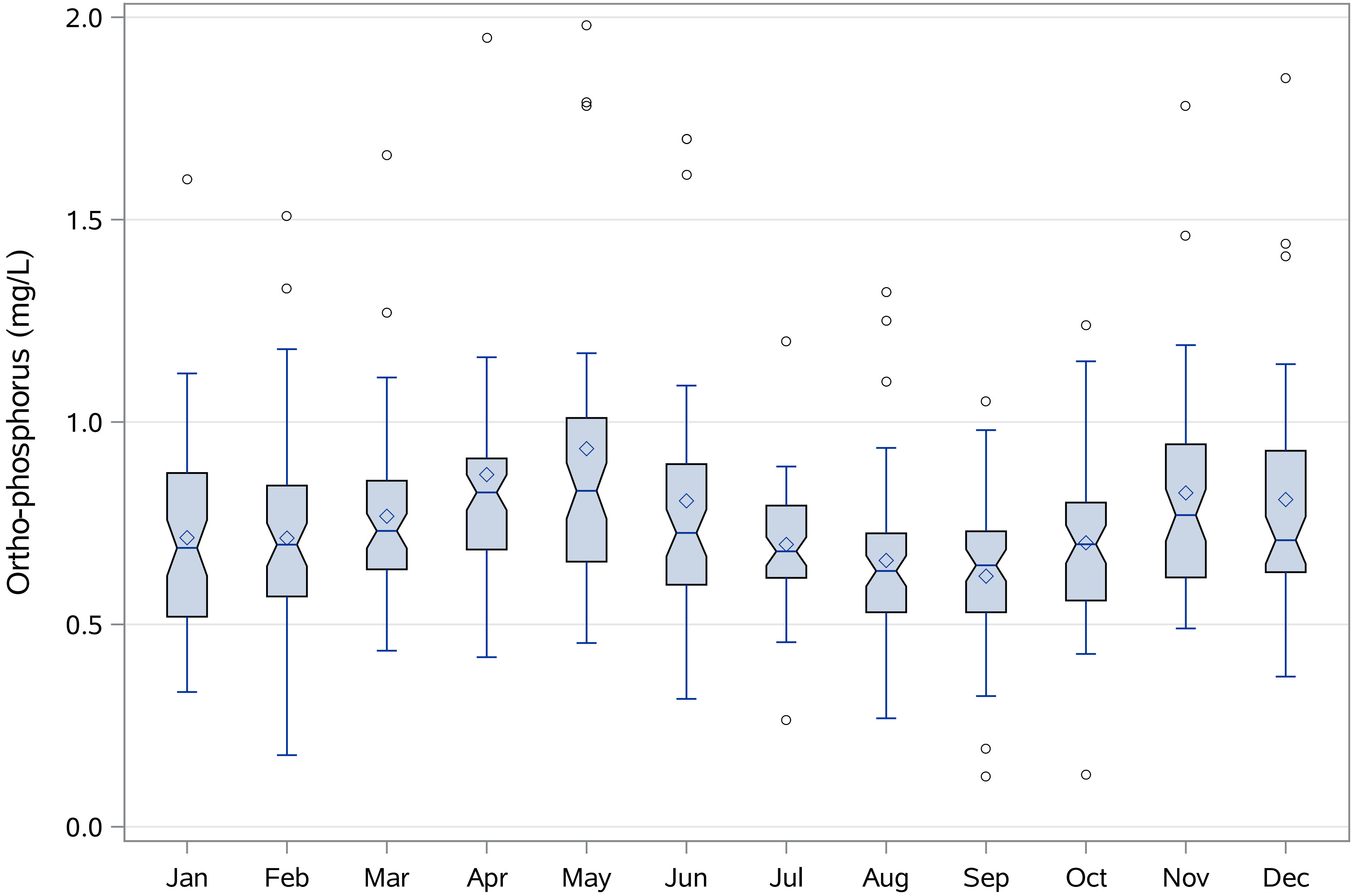

Figure 5.154. Mean monthly boxplots of surface Ortho-phosphorus at the 0 psu isohaline (1984-2016)

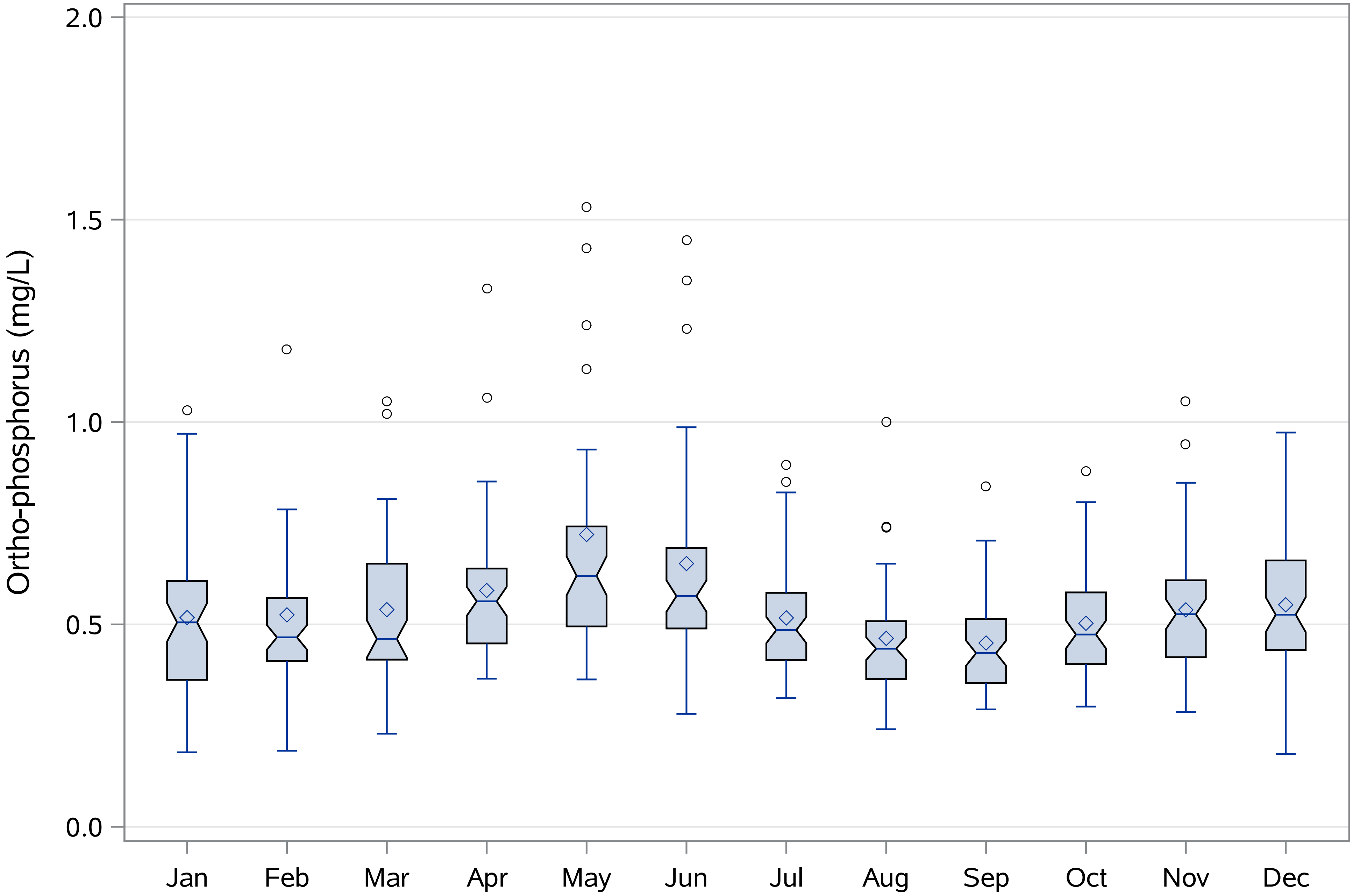

Figure 5.155. Mean monthly boxplots of surface Ortho-phosphorus at the 6 psu isohaline (1984-2016)

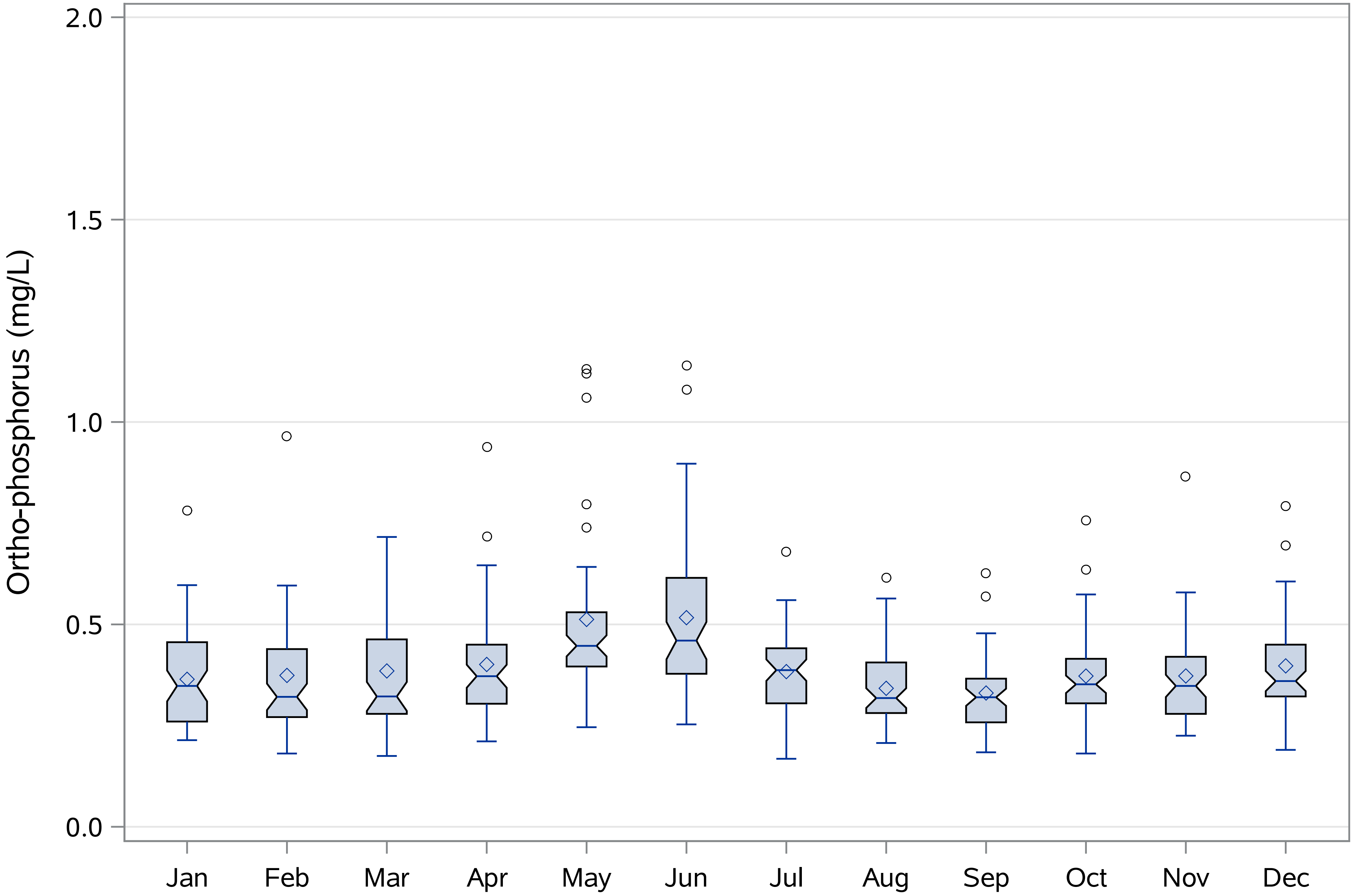

Figure 5.156. Mean monthly boxplots of surface Ortho-phosphorus at the 12 psu isohaline (1984-2016)

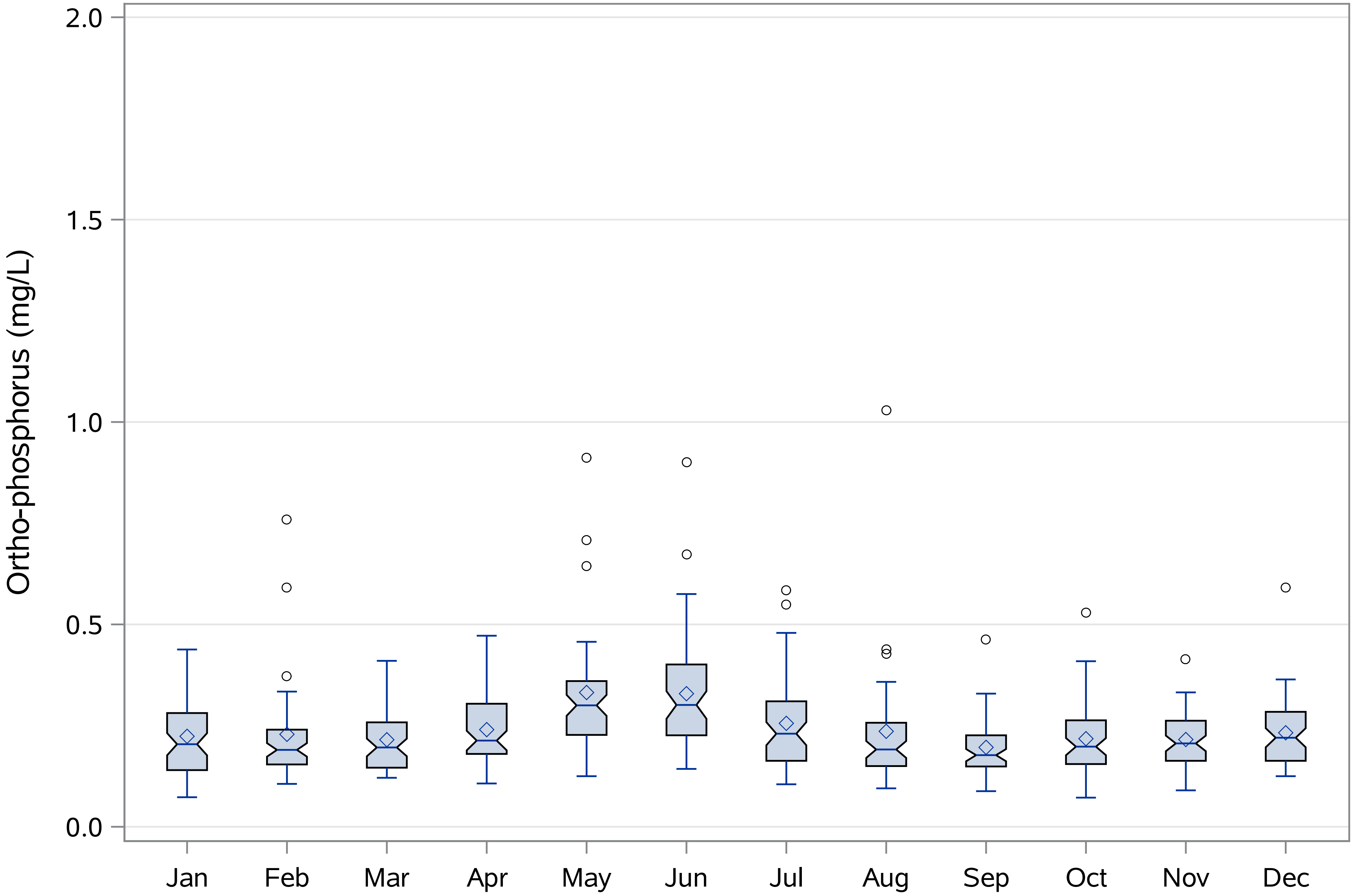

Figure 5.157. Mean monthly boxplots of surface Ortho-phosphorus at the 20 psu isohaline (1984-2016)

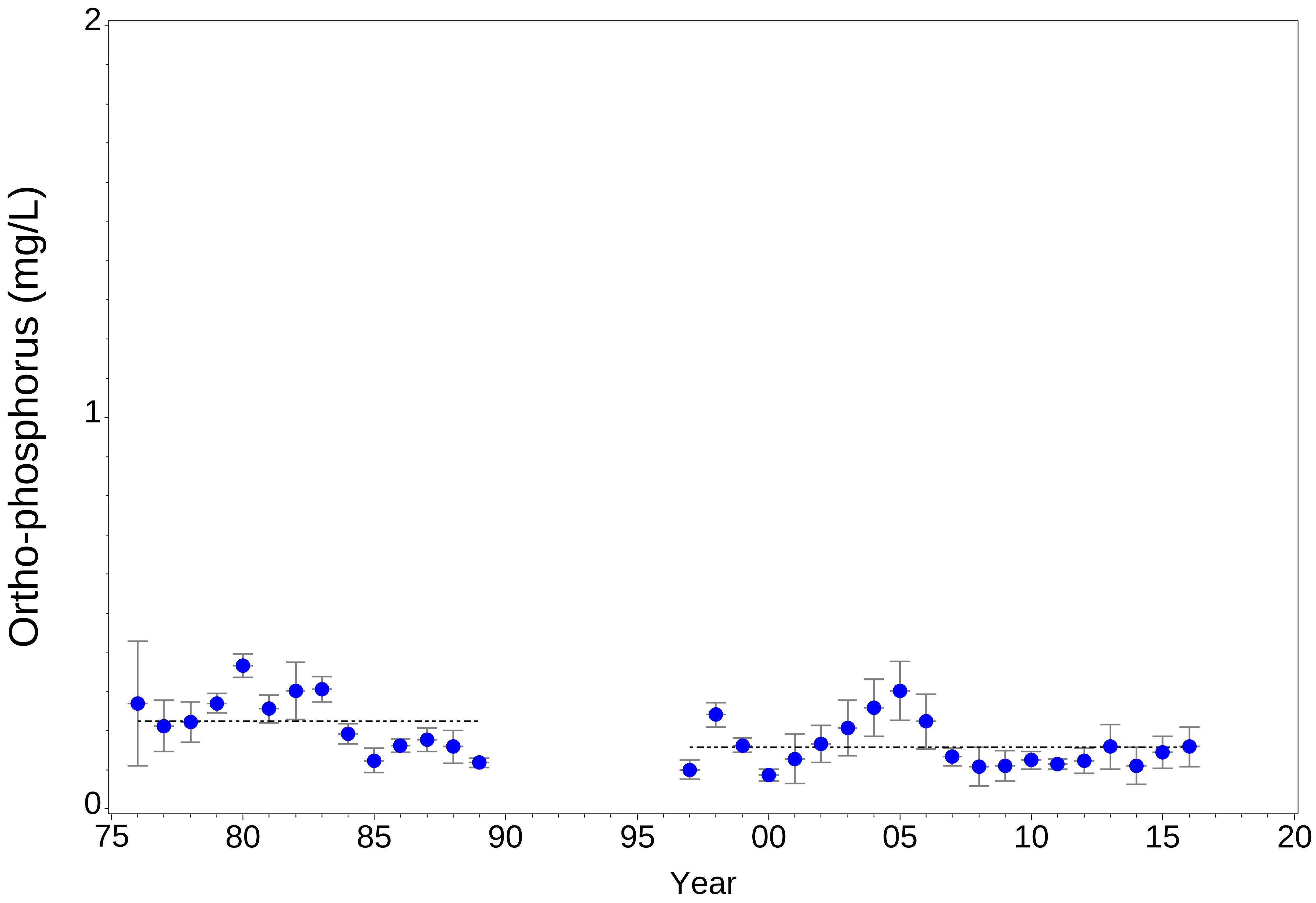

Figure 5.158. Long-term Station 9 surface Ortho-phosphorus at river kilometer -2.4

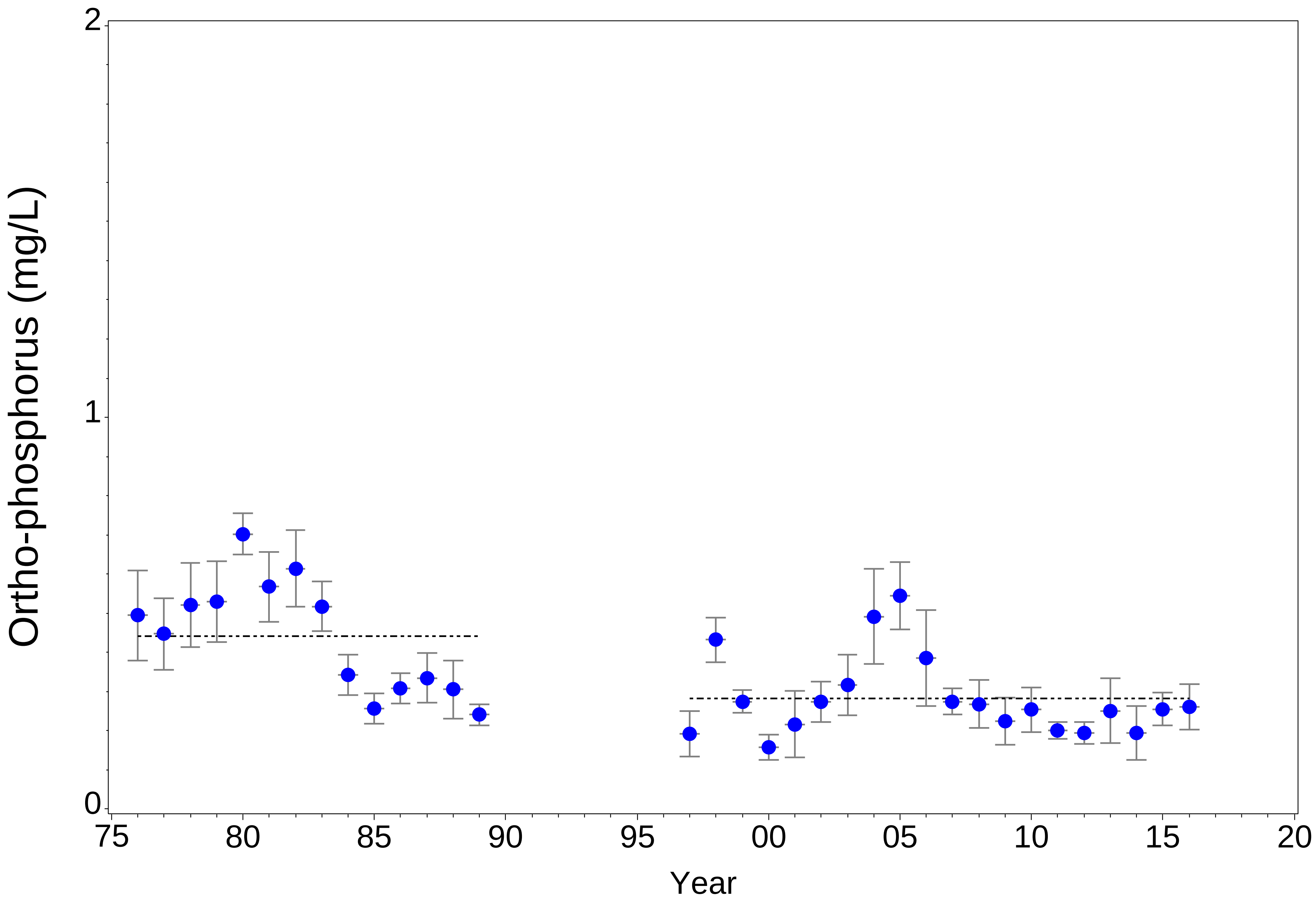

Figure 5.159. Long-term Station 10 surface Ortho-phosphorus at river kilometer 6.6

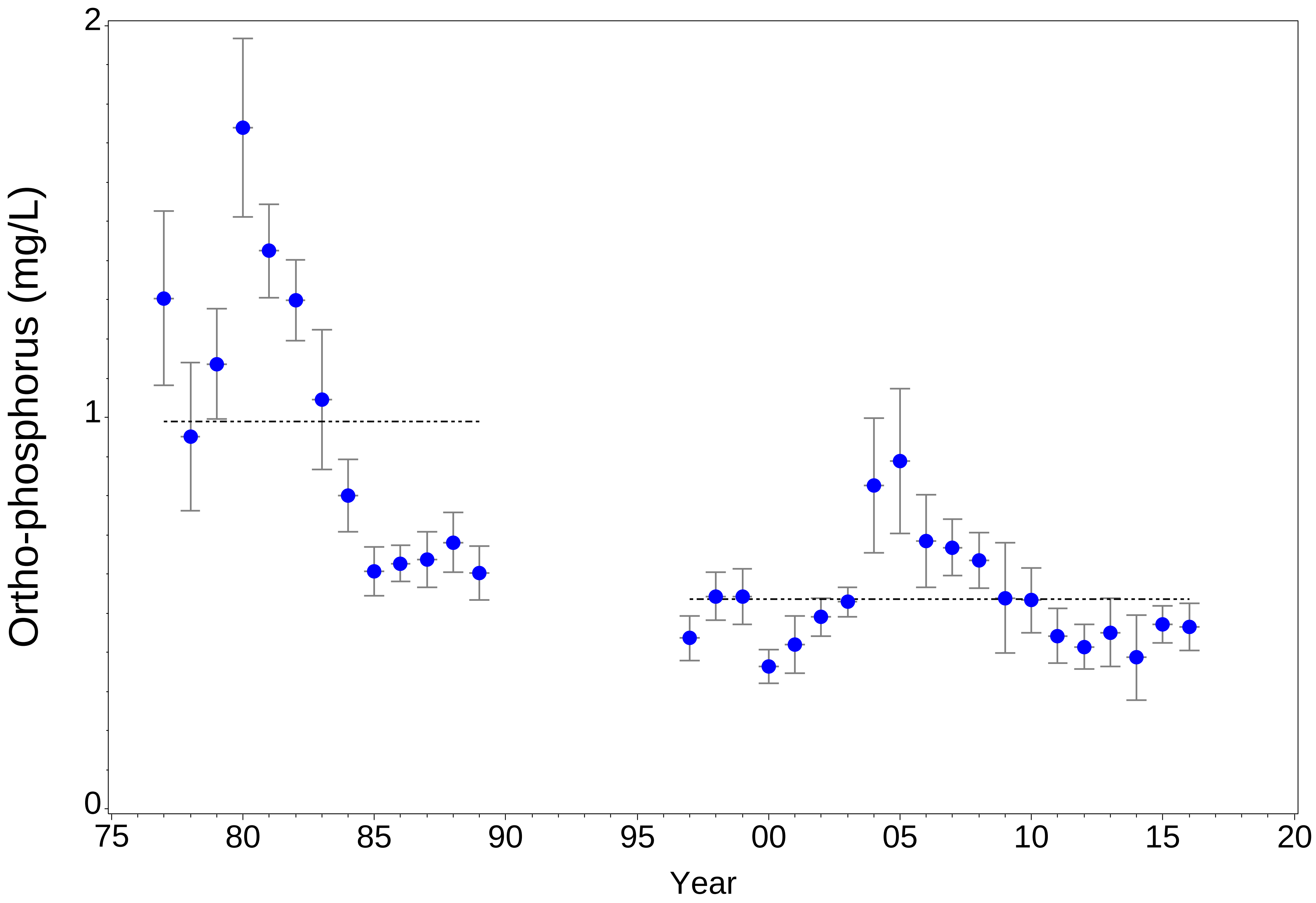

Figure 5.160. Long-term Station 12 surface Ortho-phosphorus at river kilometer 15.5

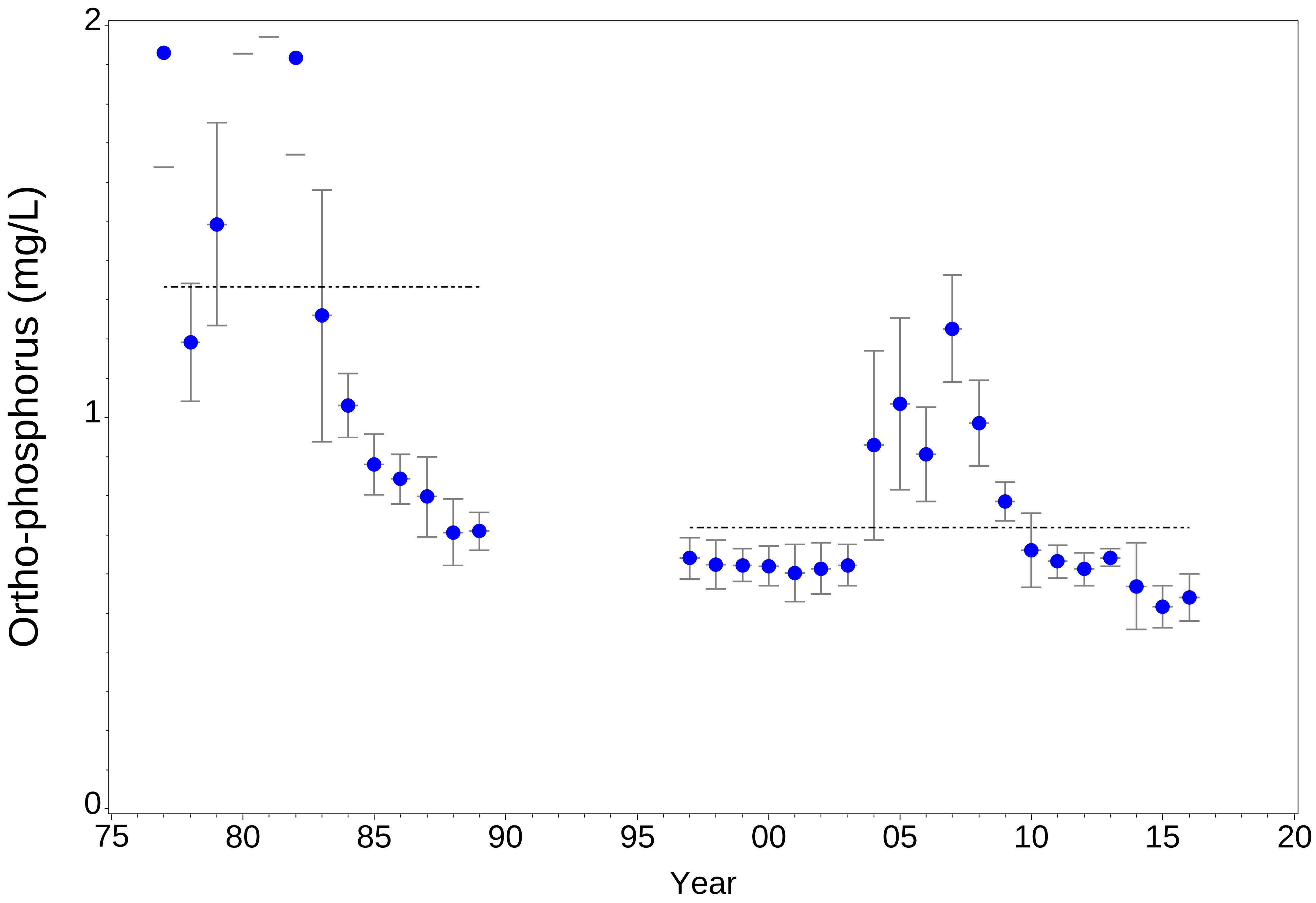

Figure 5.161. Long-term Station 14 surface Ortho-phosphorus at river kilometer 23.6

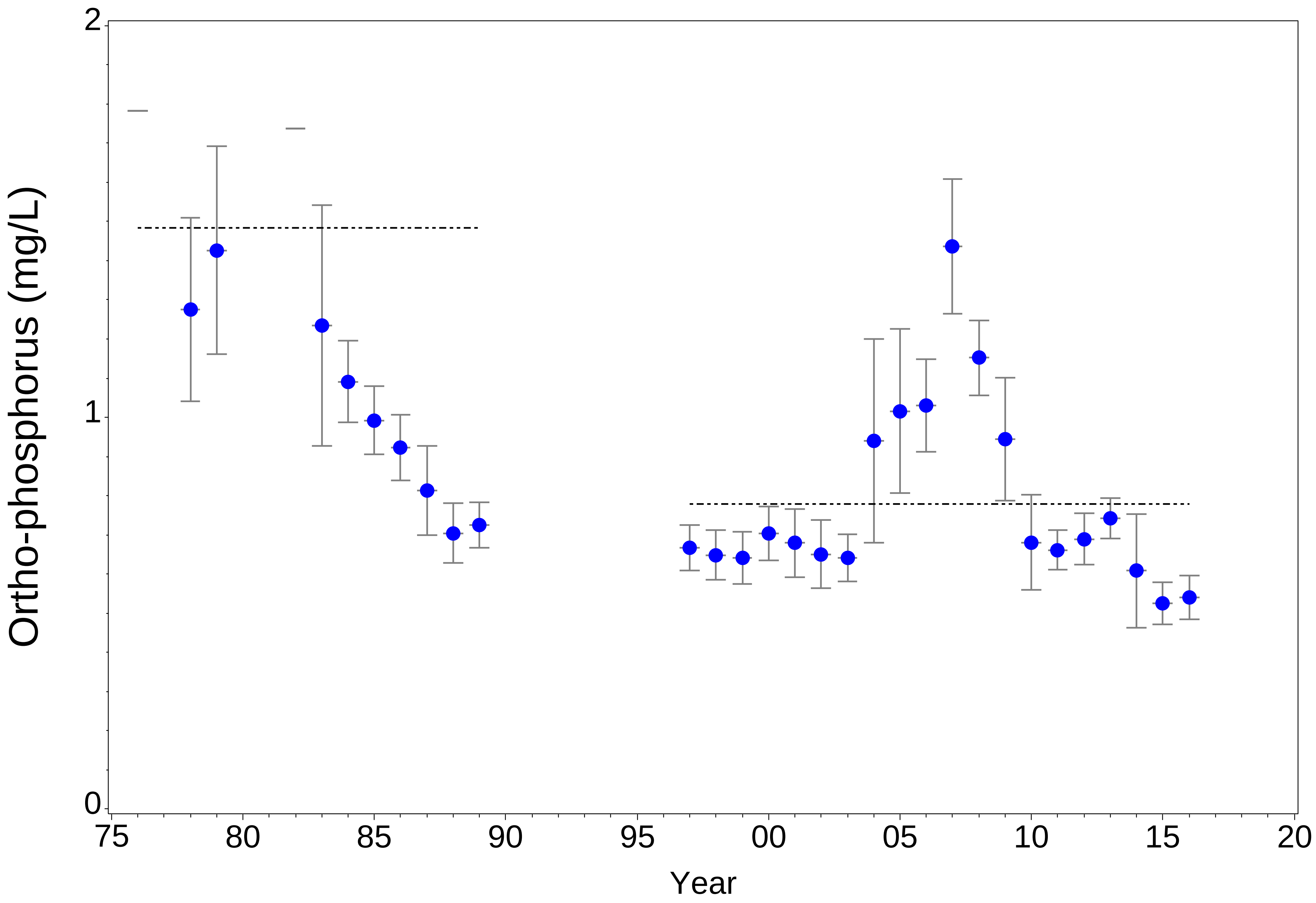

Figure 5.162. Long-term Station 18 surface Ortho-phosphorus at river kilometer 30.7

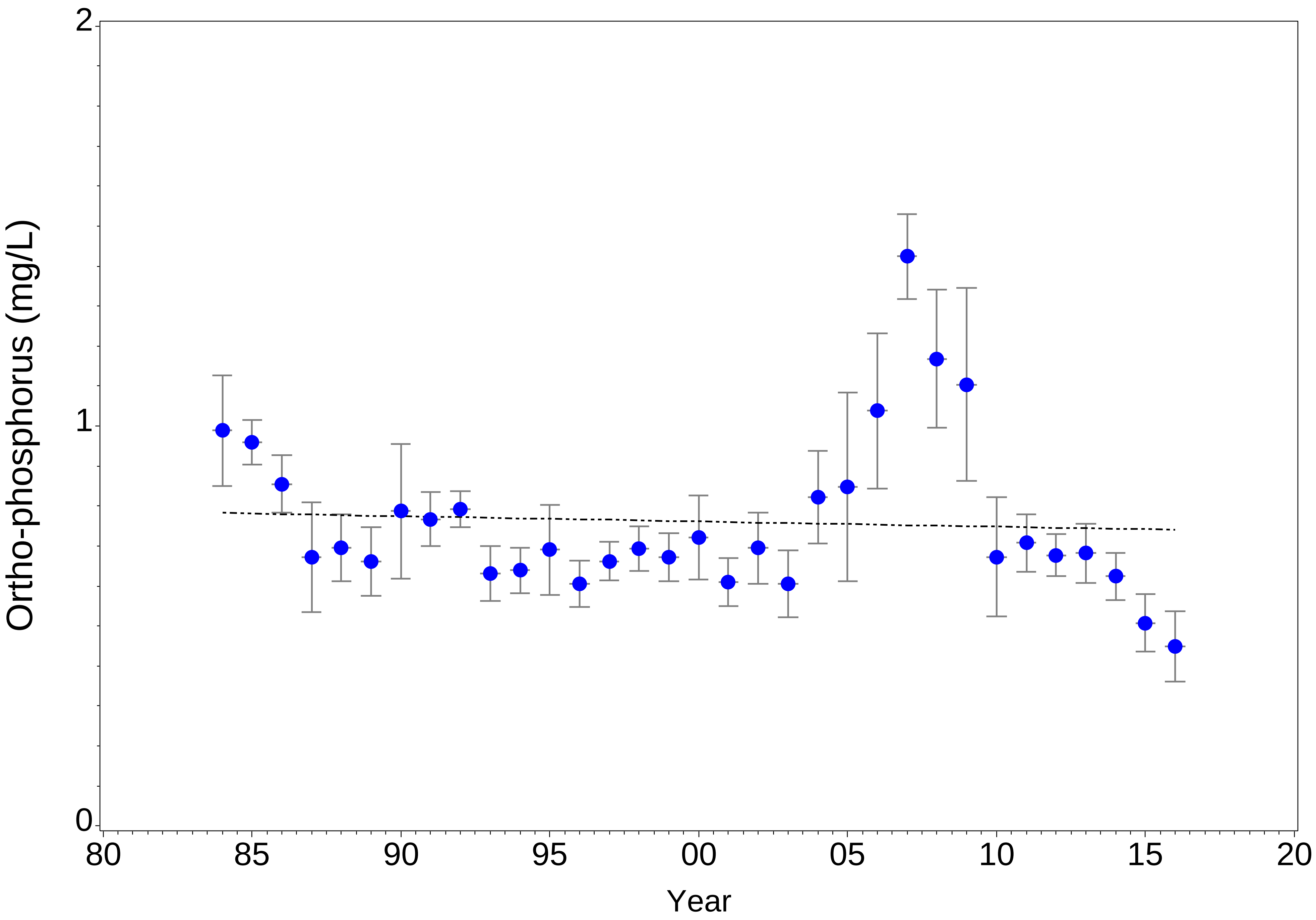

Figure 5.163. Annual monthly surface Ortho-phosphorus at 0 psu isohaline (1984-2016)

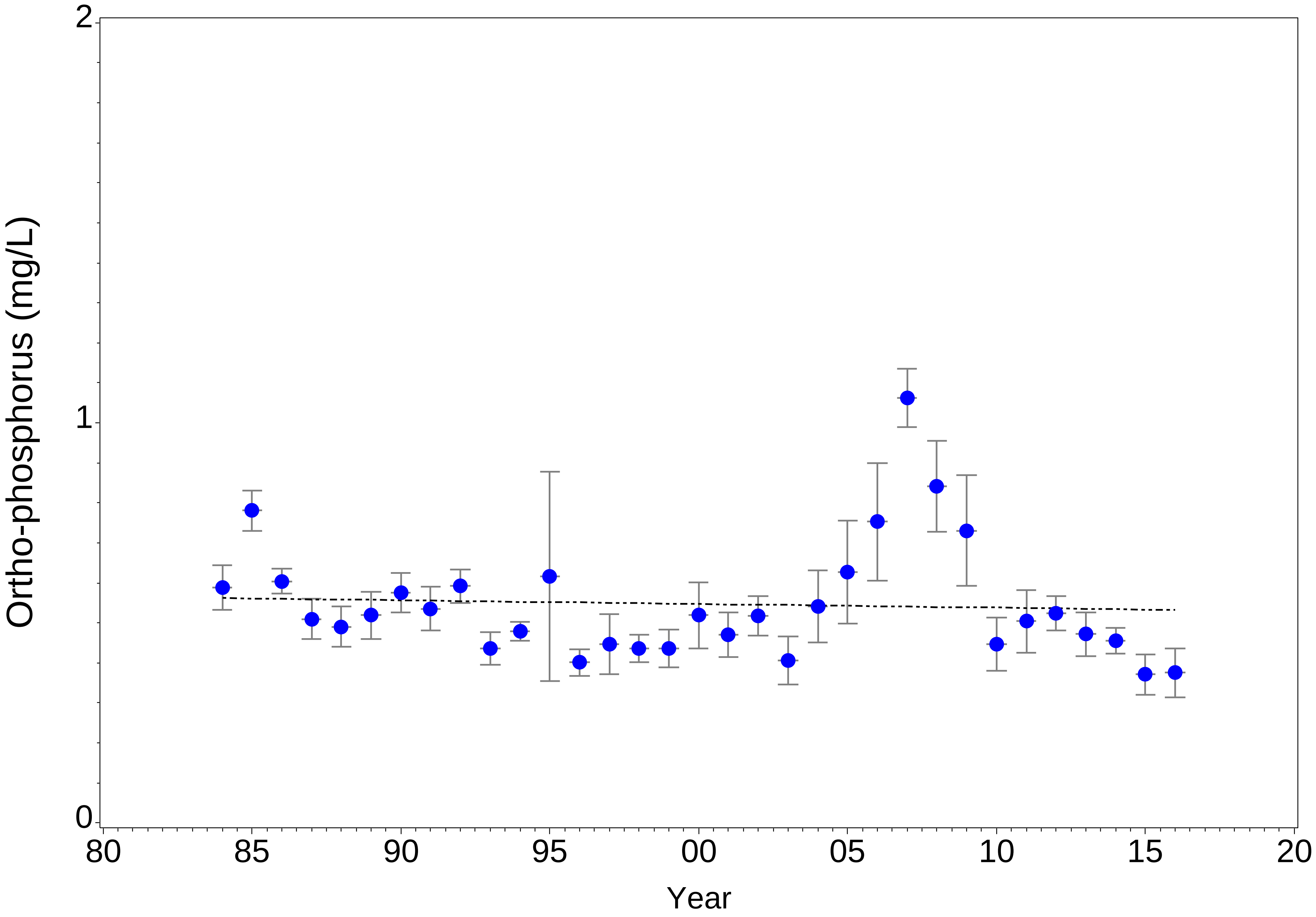

Figure 5.164. Annual monthly surface Ortho-phosphorus at 6 psu isohaline (1984-2016)

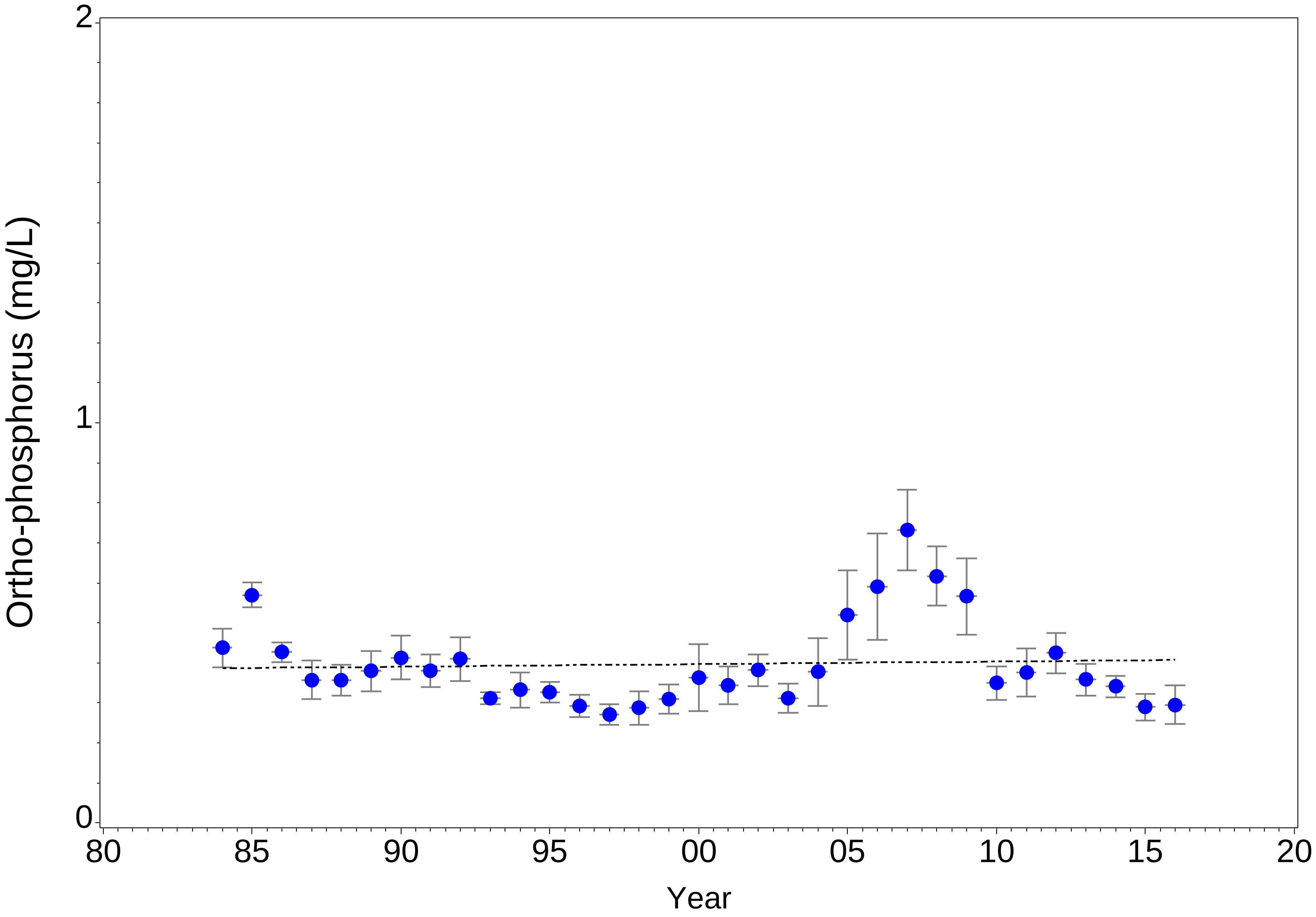

Figure 5.165. Annual monthly surface Ortho-phosphorus at 12 psu isohaline (1984-2016)

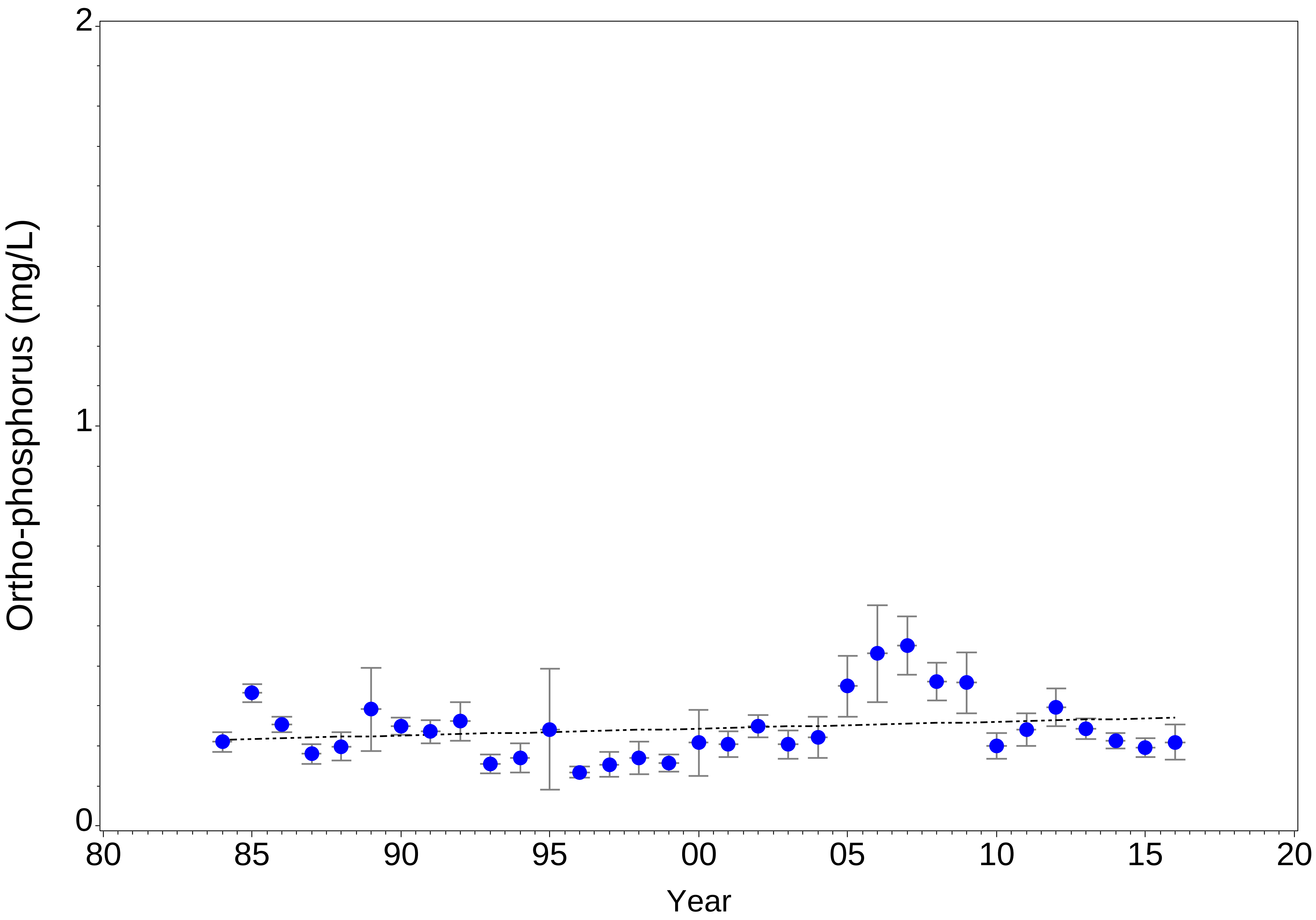

Figure 5.166. Annual monthly surface Ortho-phosphorus at 20 psu isohaline (1984-2016)

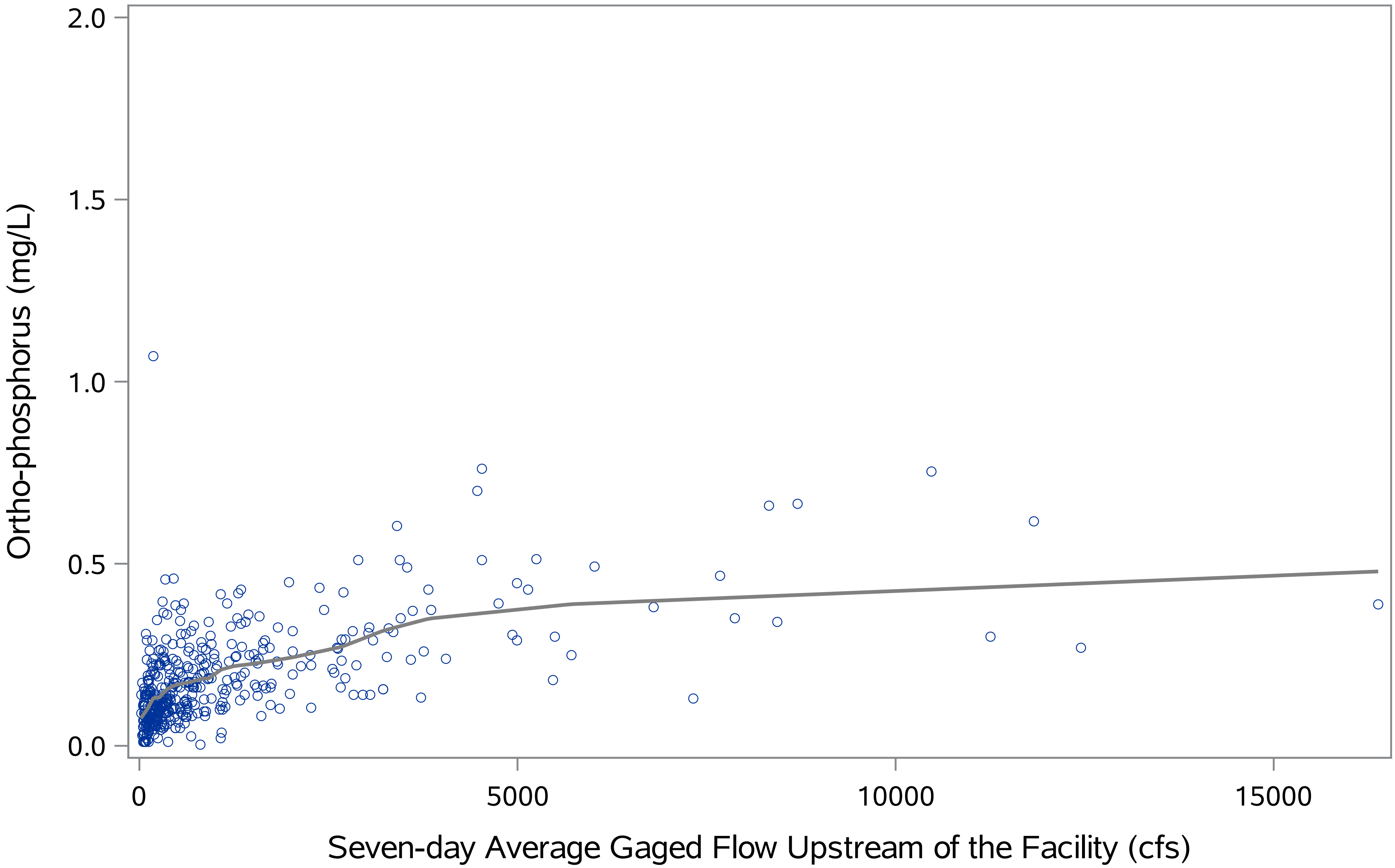

Figure 5.168. Surface Ortho-phosphorus at river kilometer -2.4 versus flow

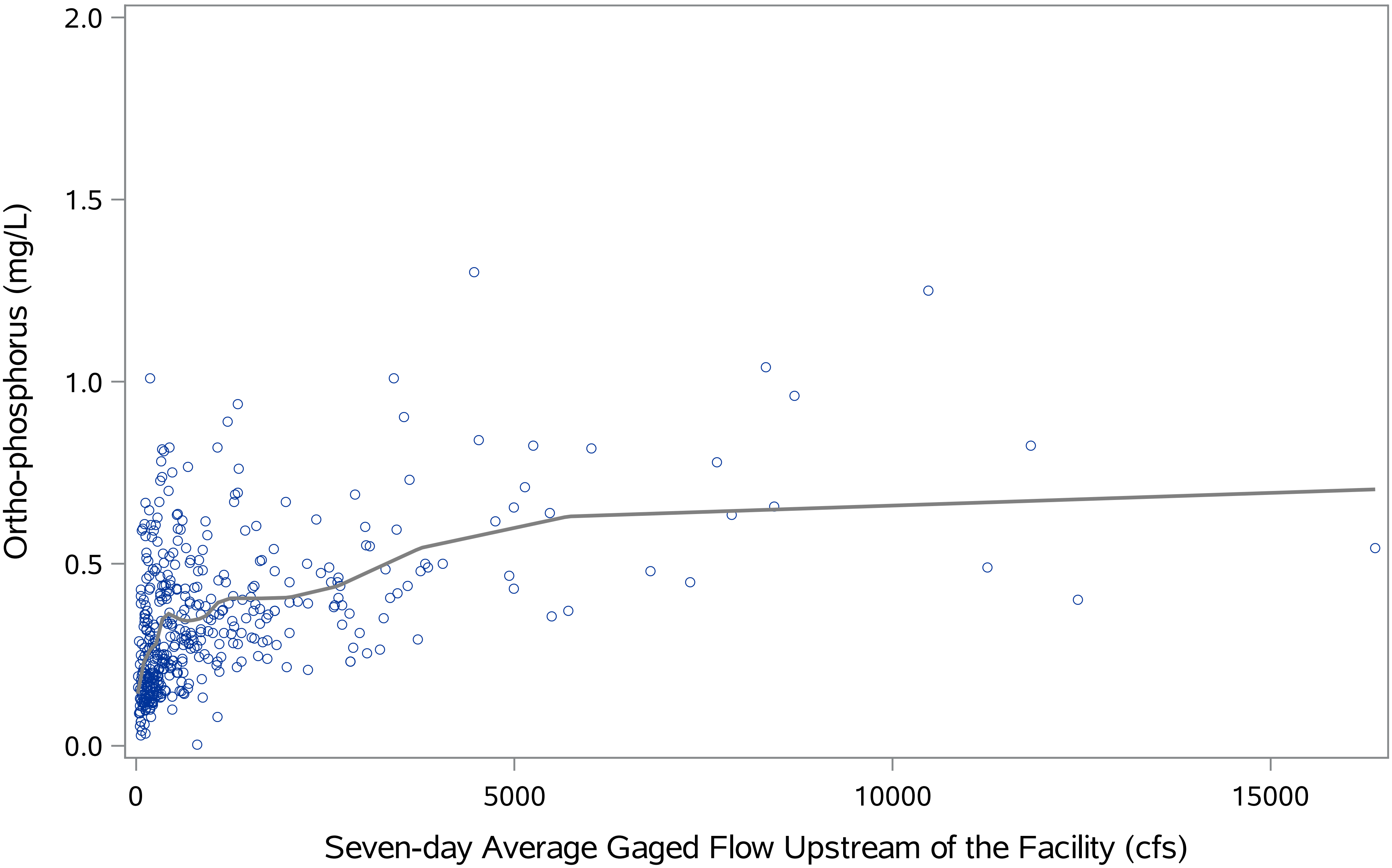

Figure 5.169. Surface Ortho-phosphorus at river kilometer 6.6 versus flow

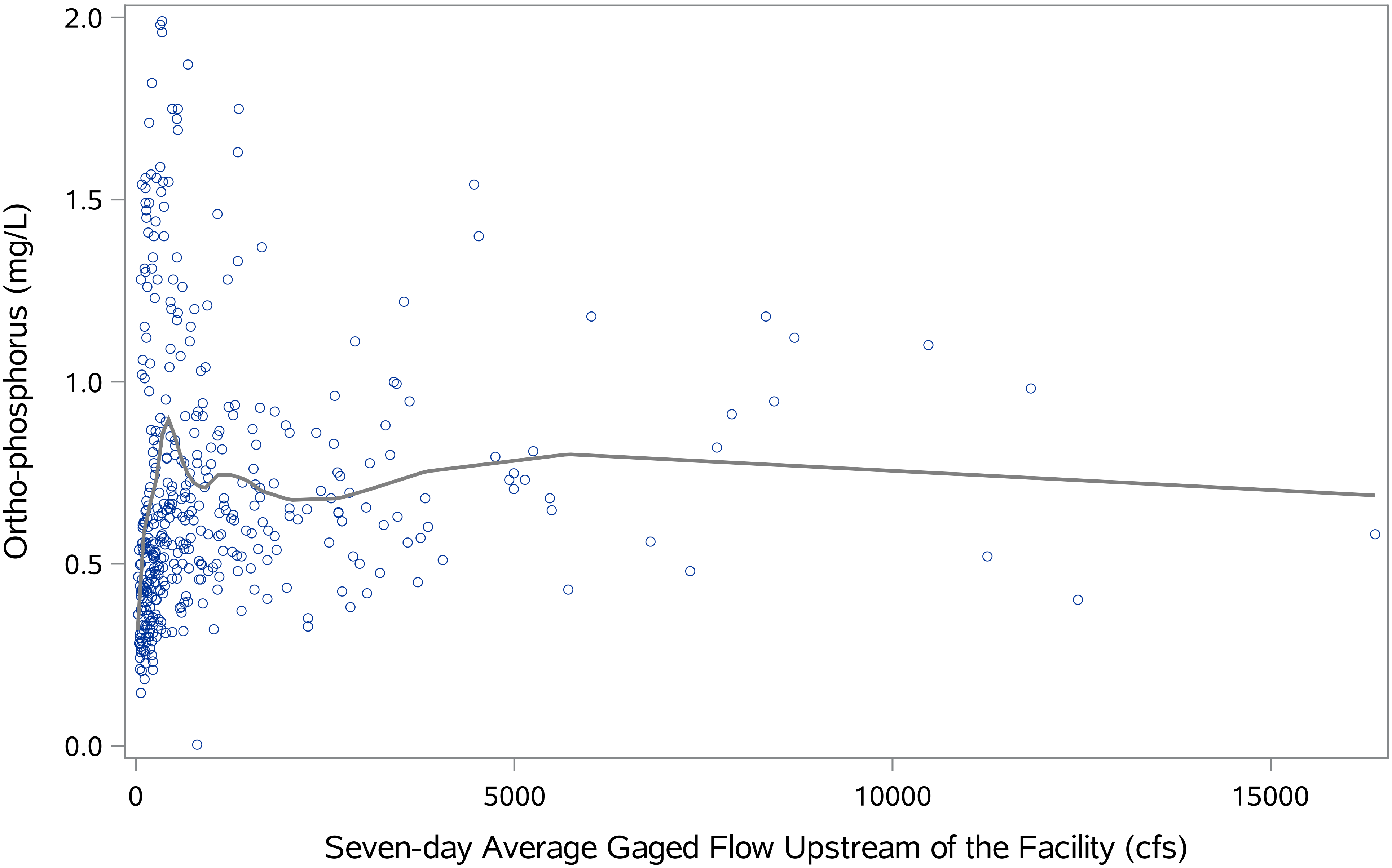

Figure 5.170. Surface Ortho-phosphorus at river kilometer 15.5 versus flow

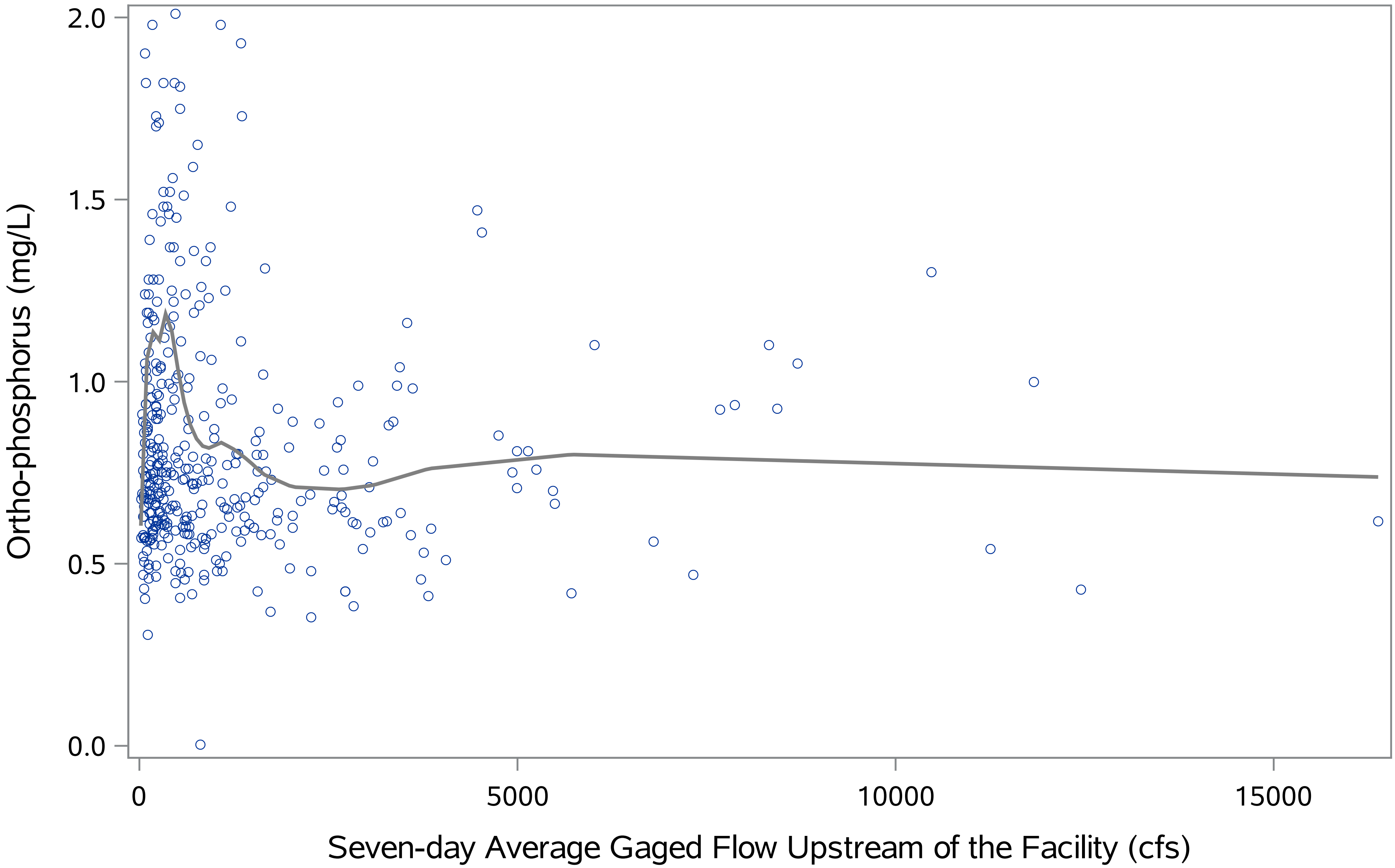

Figure 5.171. Surface Ortho-phosphorus at river kilometer 23.6 versus flow

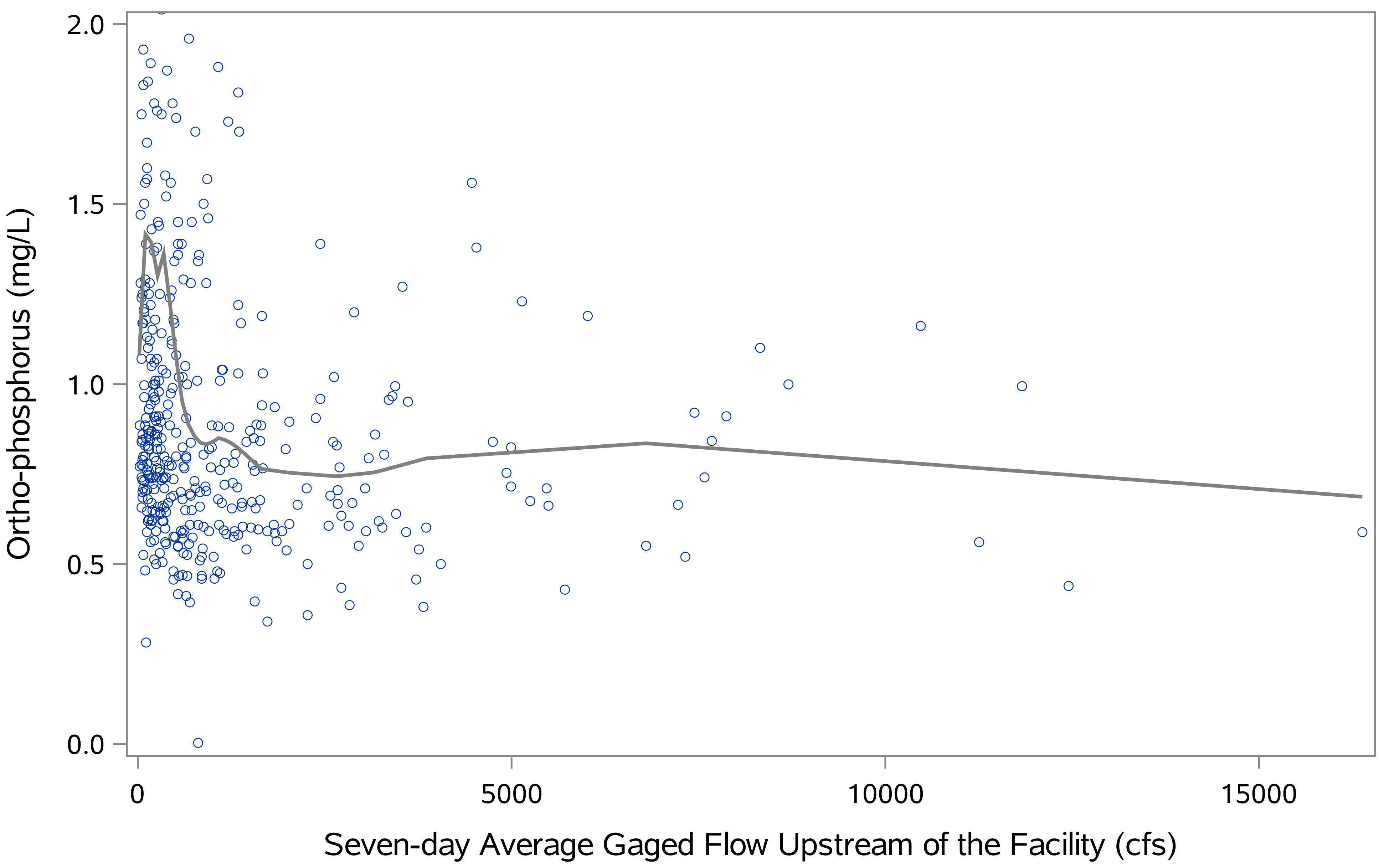

Figure 5.172. Surface Ortho-phosphorus at river kilometer 30.7 versus flow

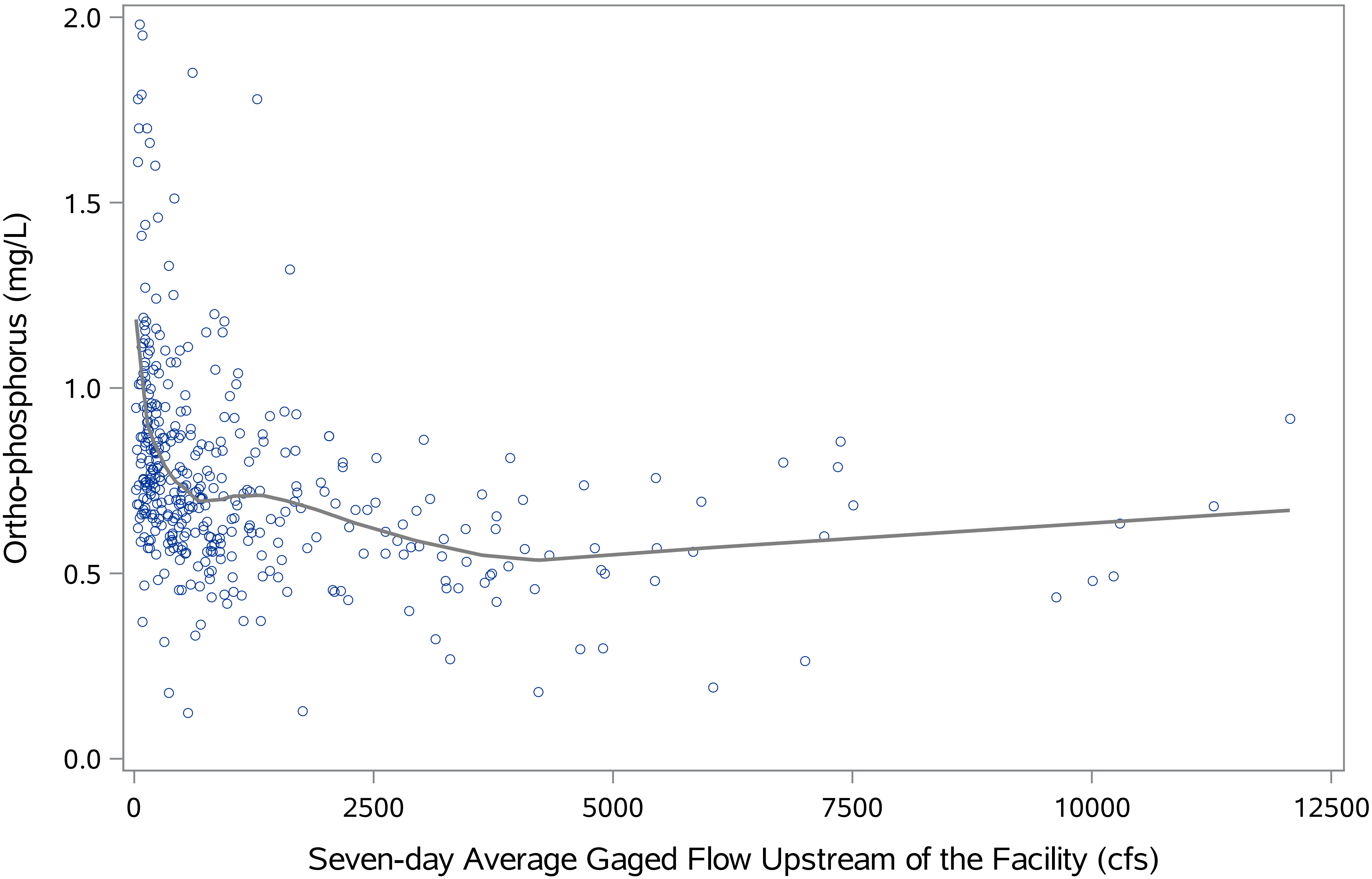

Figure 5.173. Ortho-phosphorus at the 0 psu isohaline versus flow

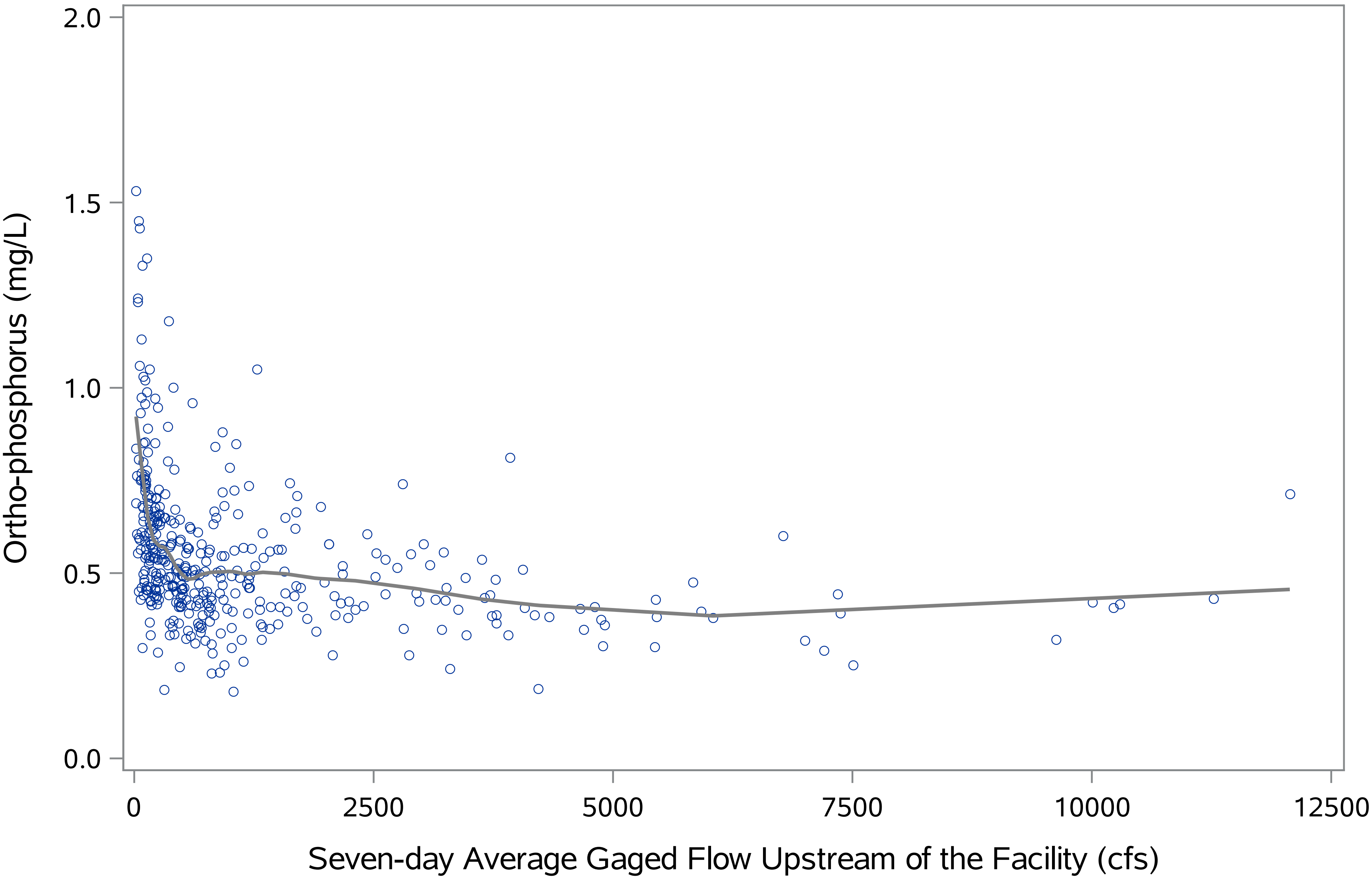

Figure 5.174. Ortho-phosphorus at the 6 psu isohaline versus flow

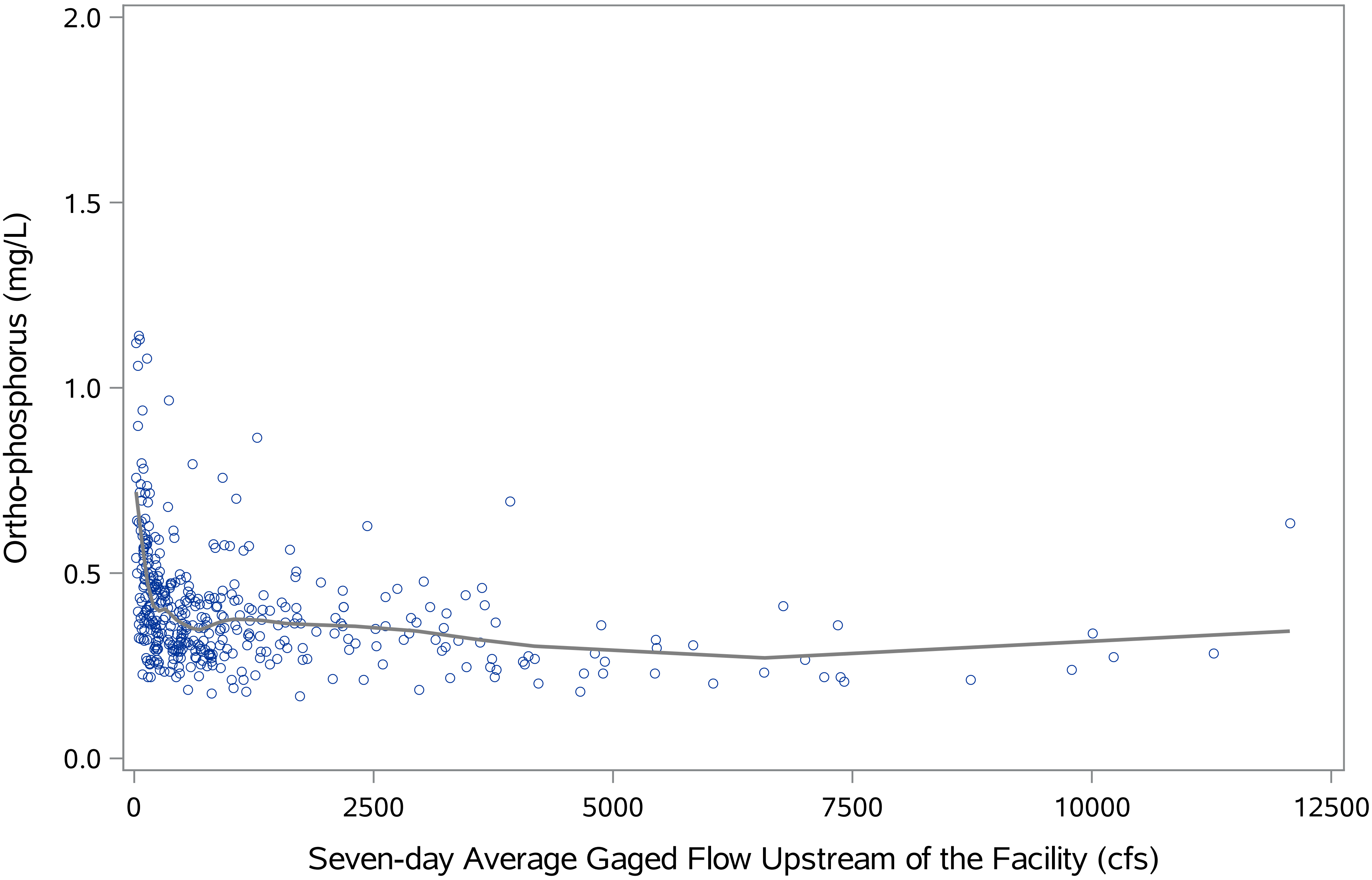

Figure 5.175. Ortho-phosphorus at the 12 psu isohaline versus flow

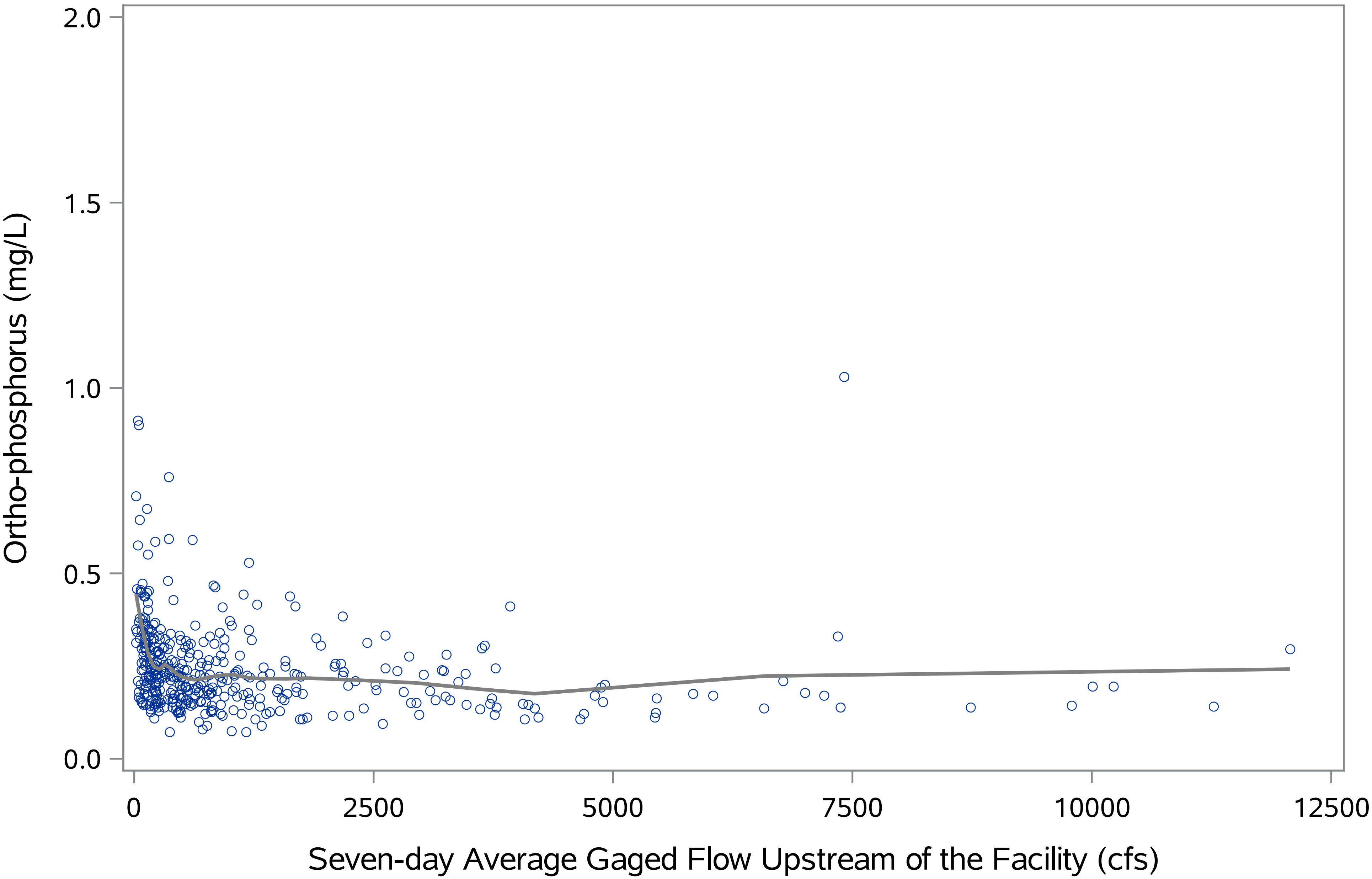

Figure 5.176. Ortho-phosphorus at the 20 psu isohaline versus flow

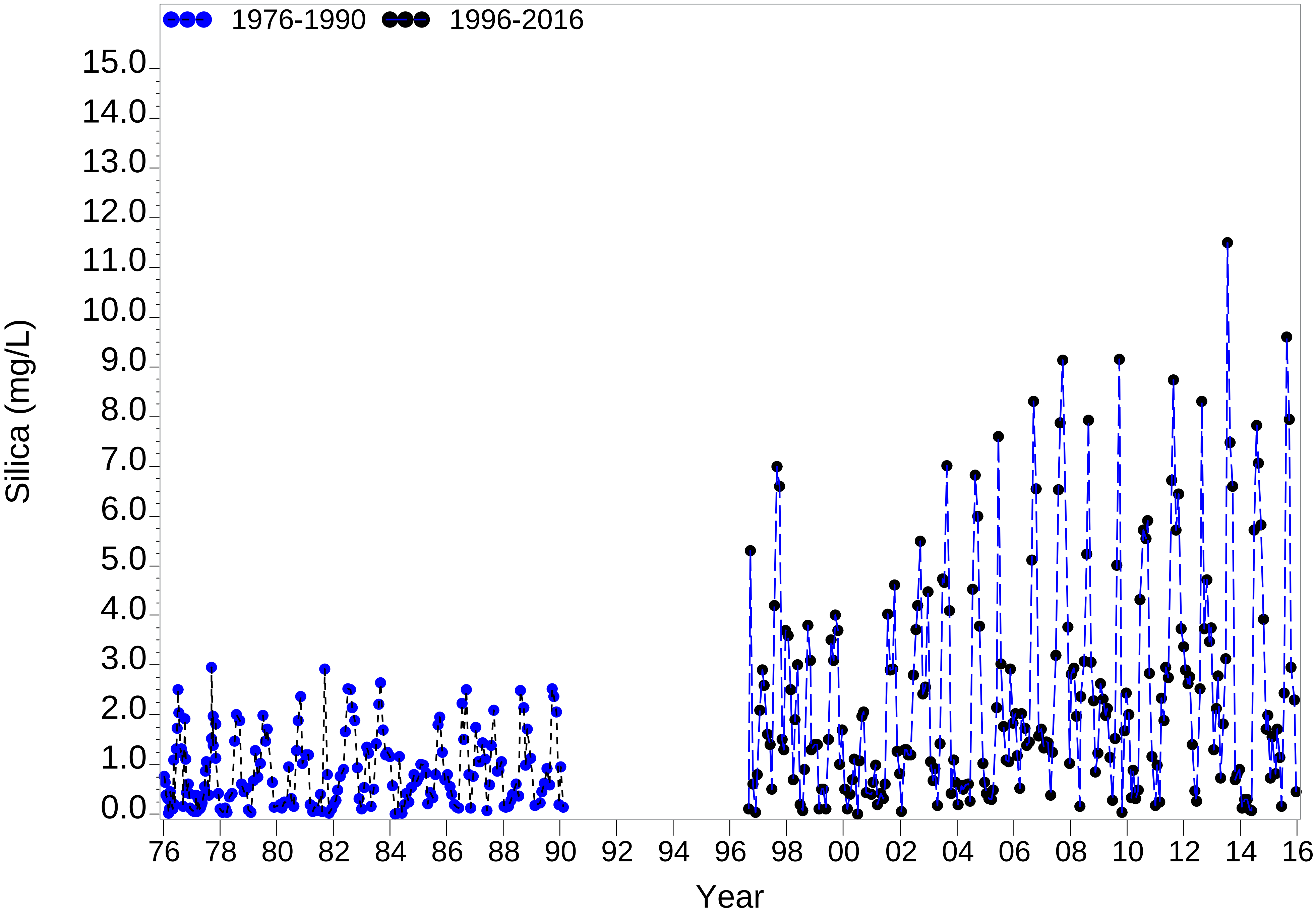

Figure 5.179. Monthly long-term Silica at river kilometer -2.4

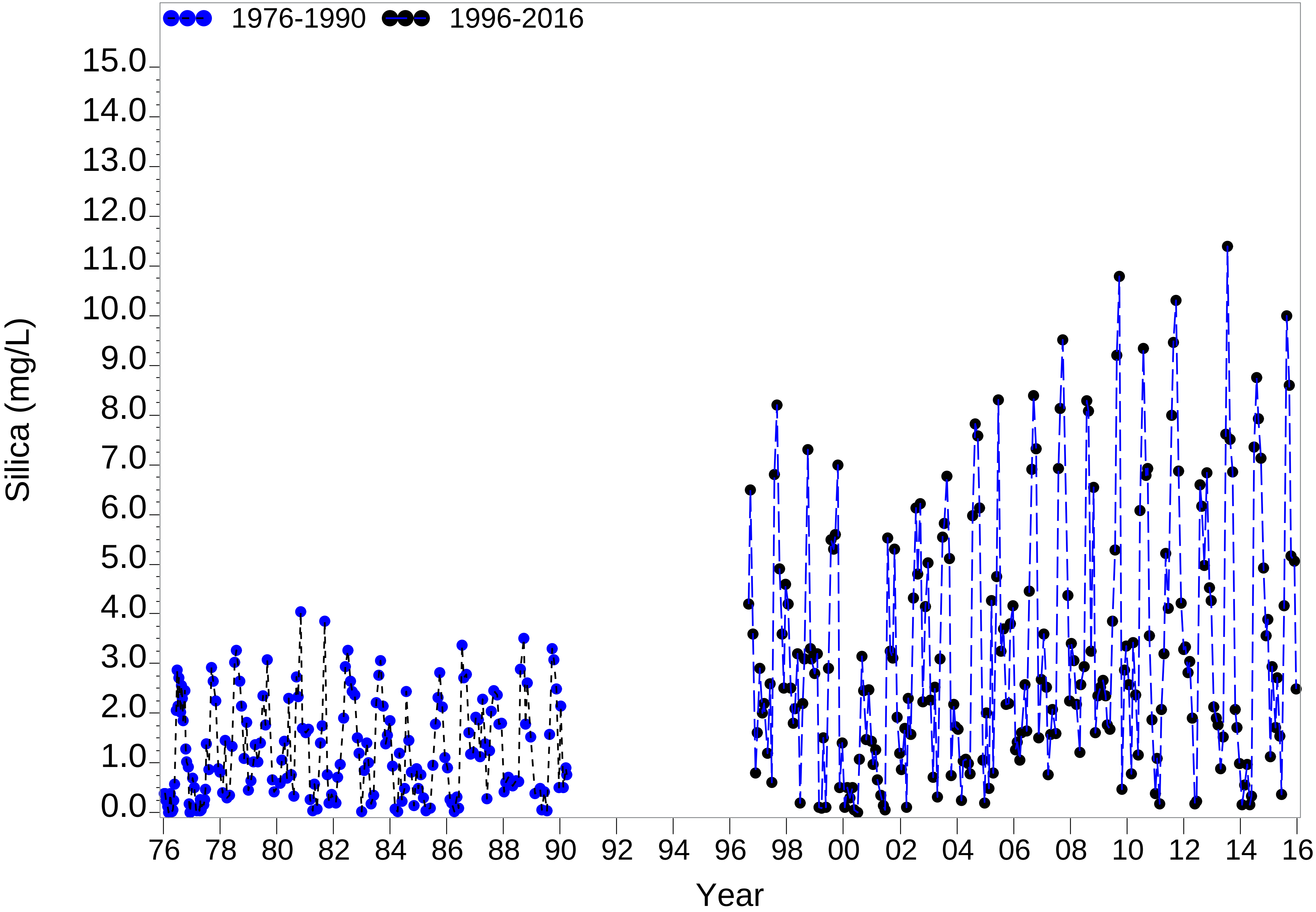

Figure 5.180. Monthly long-term Silica at river kilometer 6.6

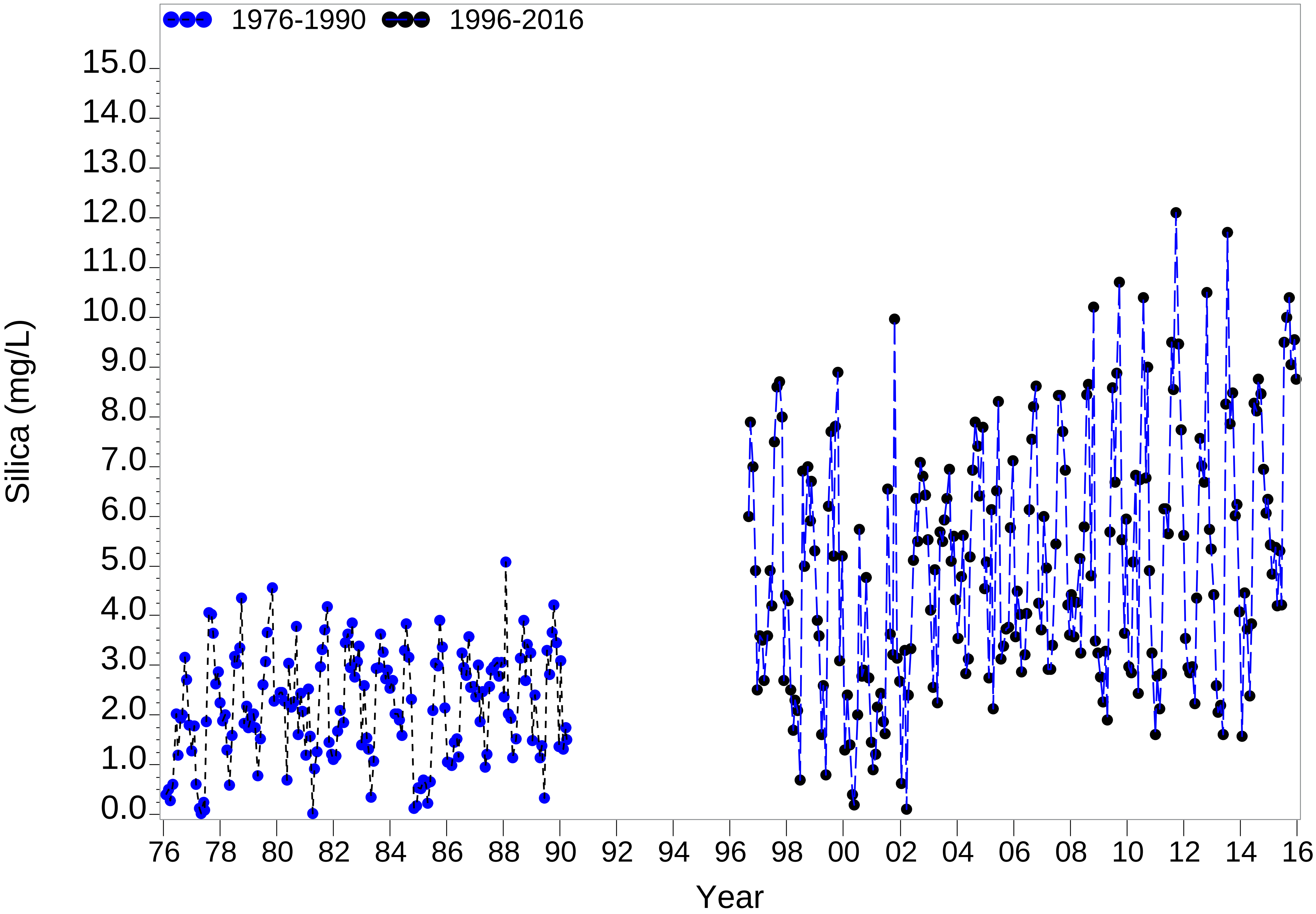

Figure 5.181. Monthly long-term Silica at river kilometer 15.5

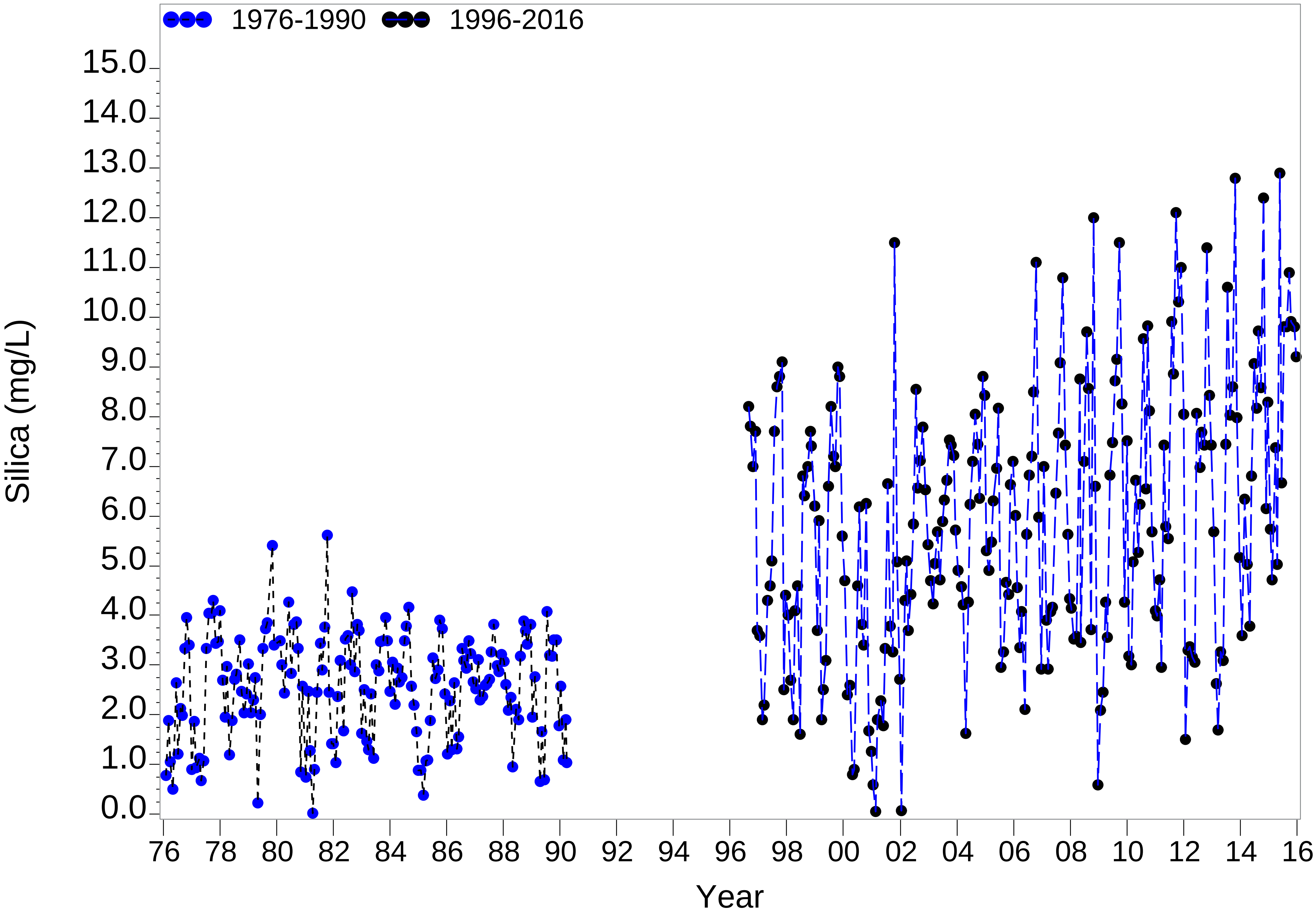

Figure 5.182. Monthly long-term Silica at river kilometer 23.6

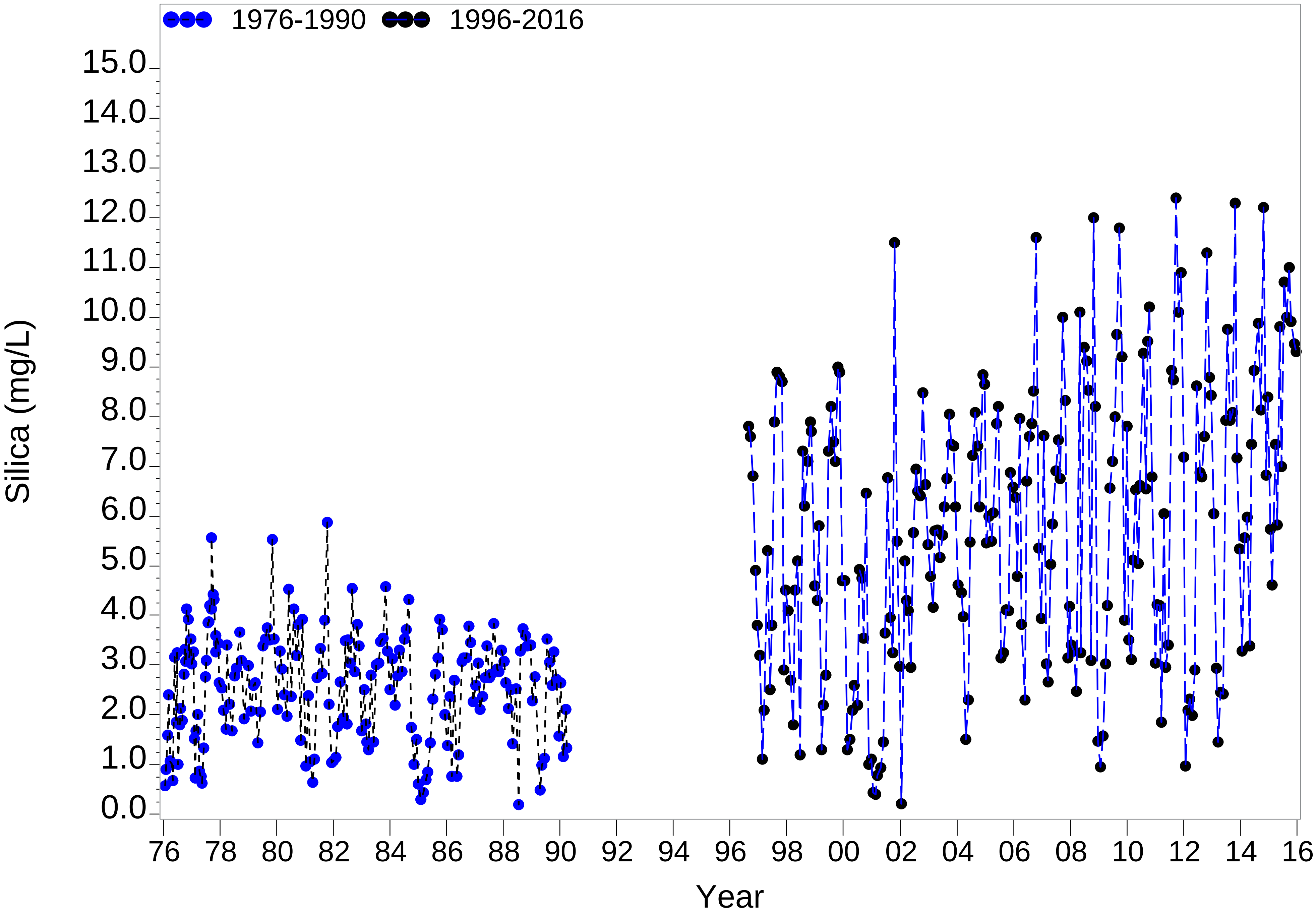

Figure 5.183. Monthly long-term Silica at river kilometer 30.7

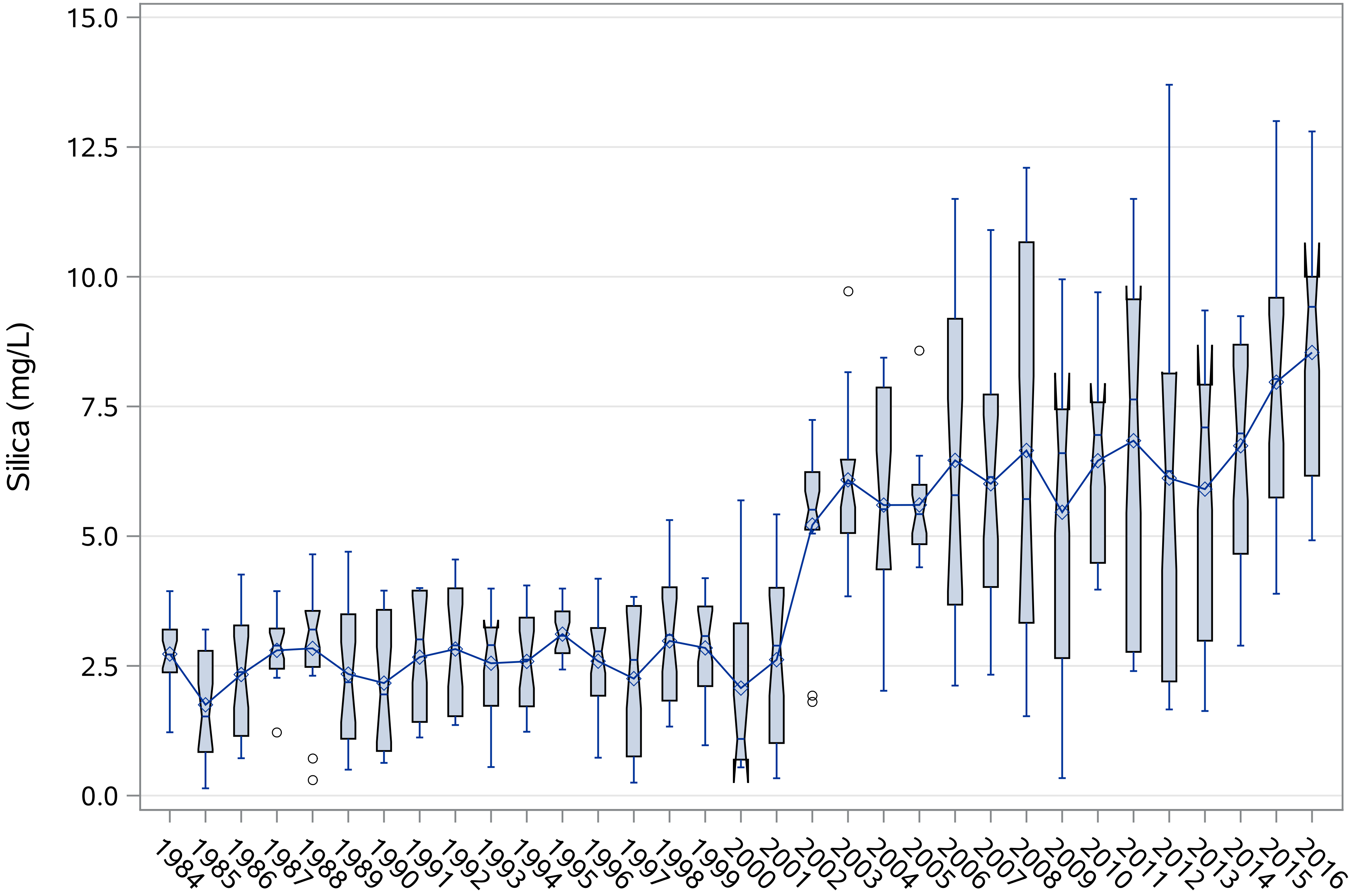

Figure 5.184. Annual boxplots of surface Silica at the 0 psu isohaline (1984-2016)

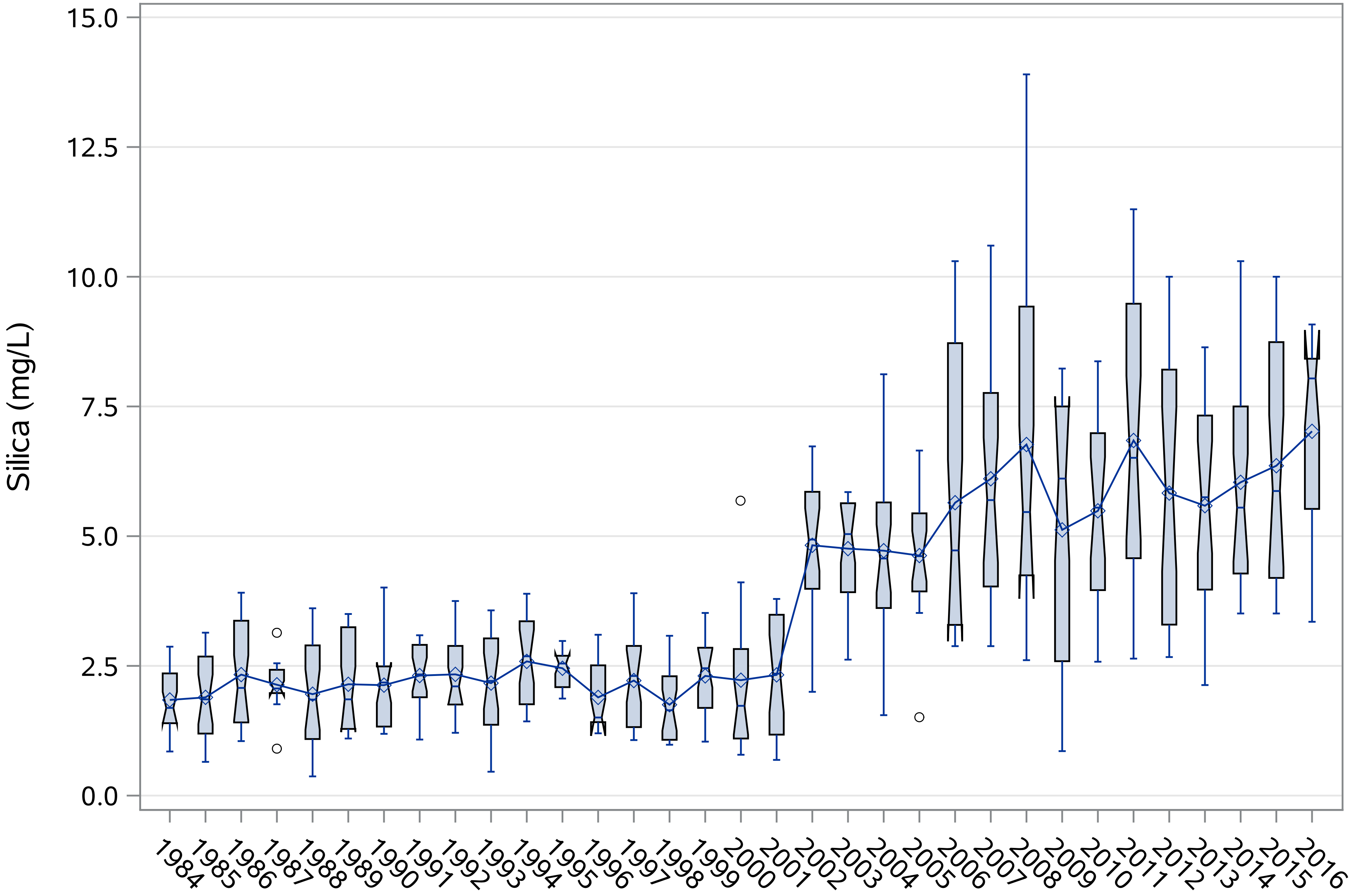

Figure 5.185. Annual boxplots of surface Silica at the 6 psu isohaline (1984-2016)

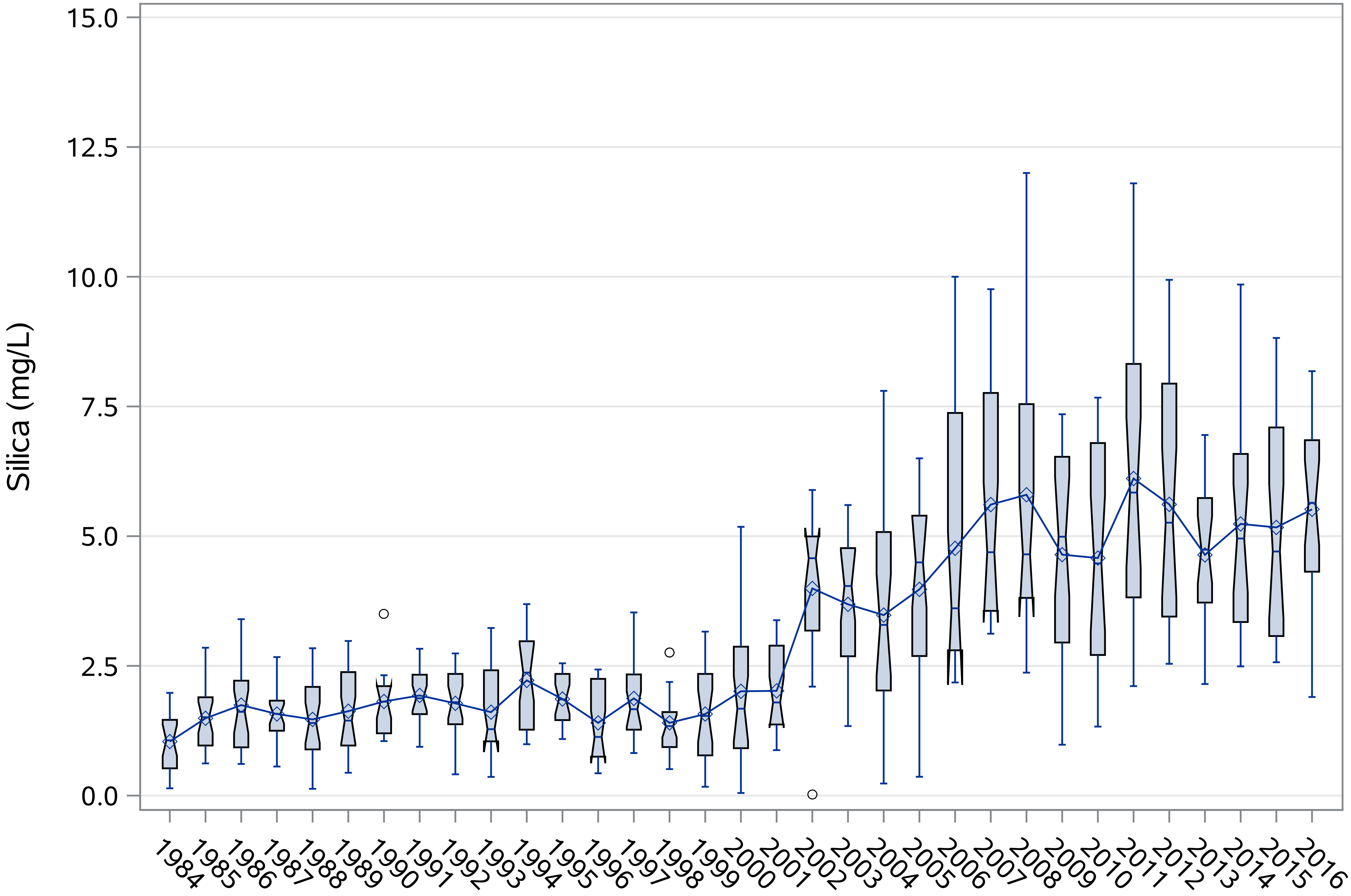

Figure 5.186. Annual boxplots of surface Silica at the 12 psu isohaline (1984-2016)

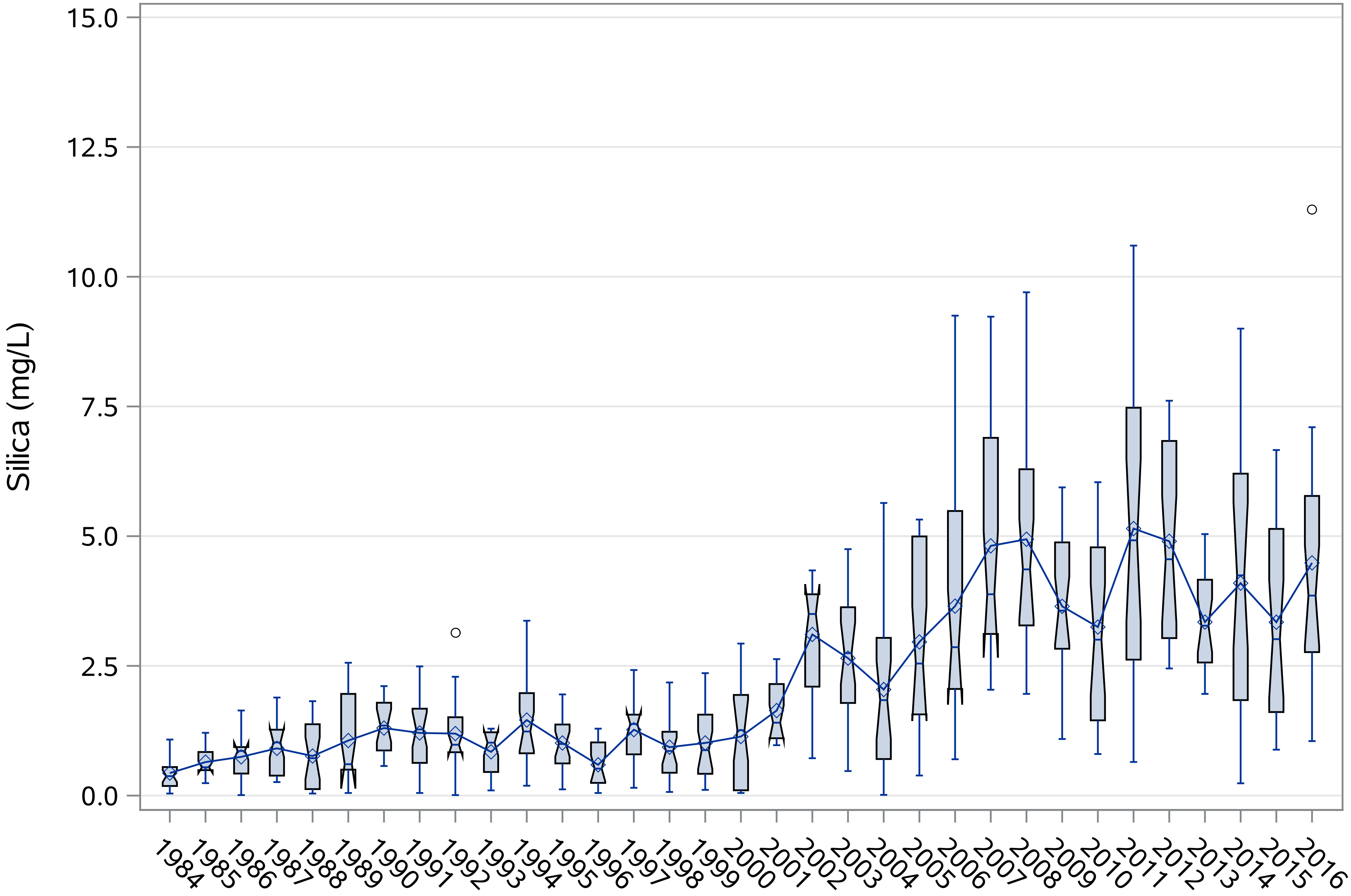

Figure 5.187. Annual boxplots of surface Silica at the 20 psu isohaline (1984-2016)

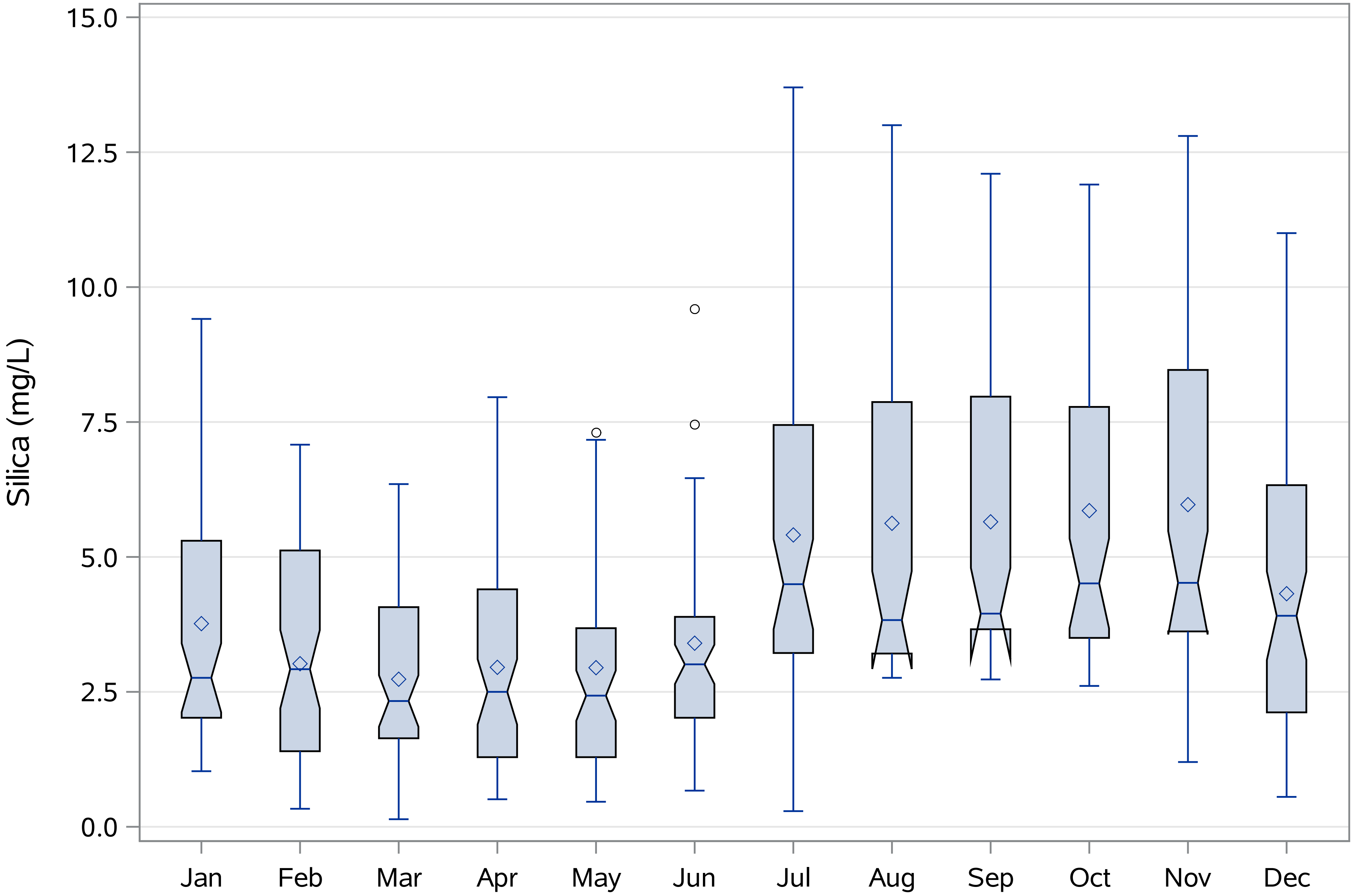

Figure 5.188. Mean monthly boxplots of surface Silica at the 0 psu isohaline (1984-2016)

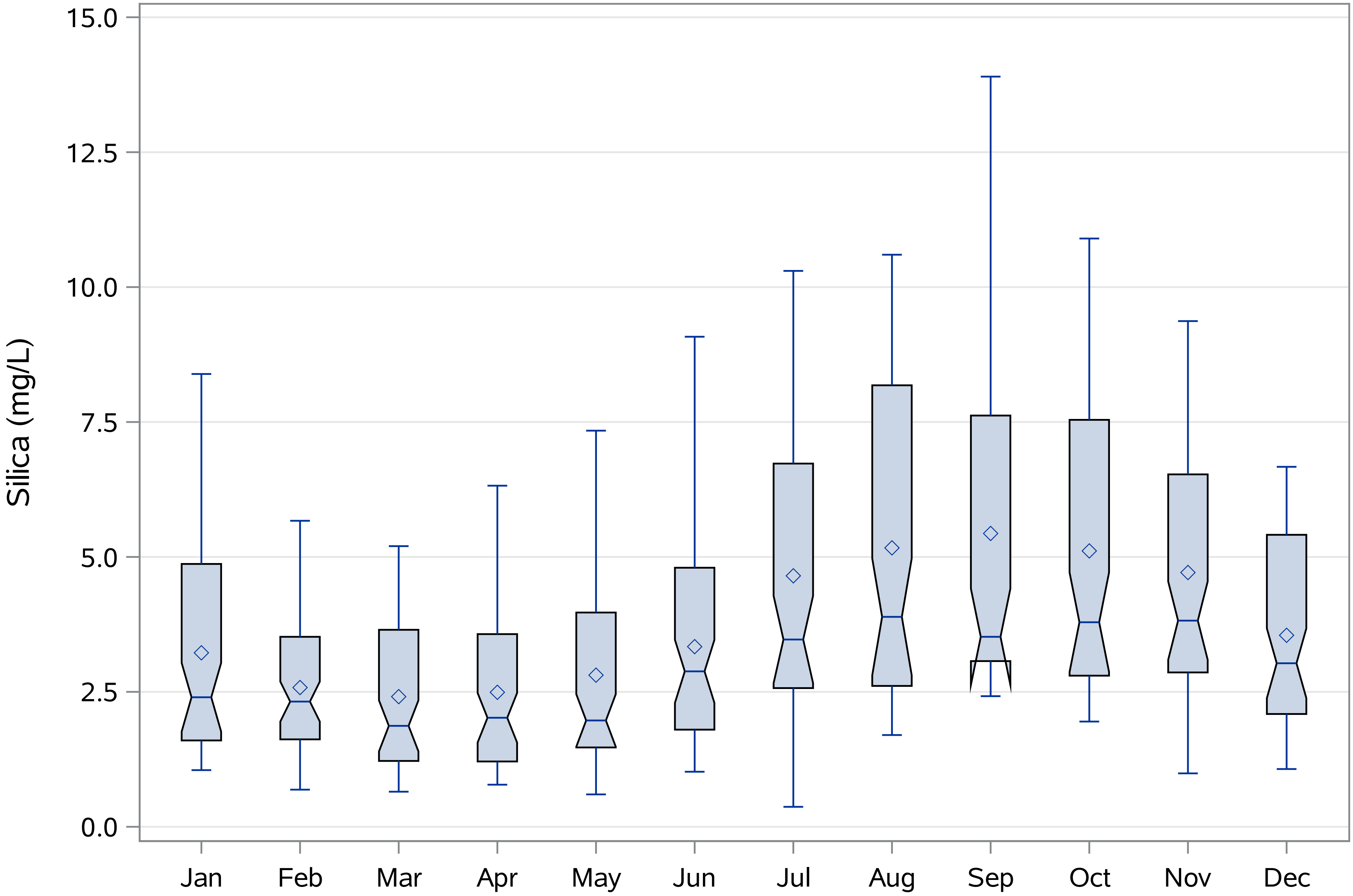

Figure 5.189. Mean monthly boxplots of surface Silica at the 6 psu isohaline (1984-2016)

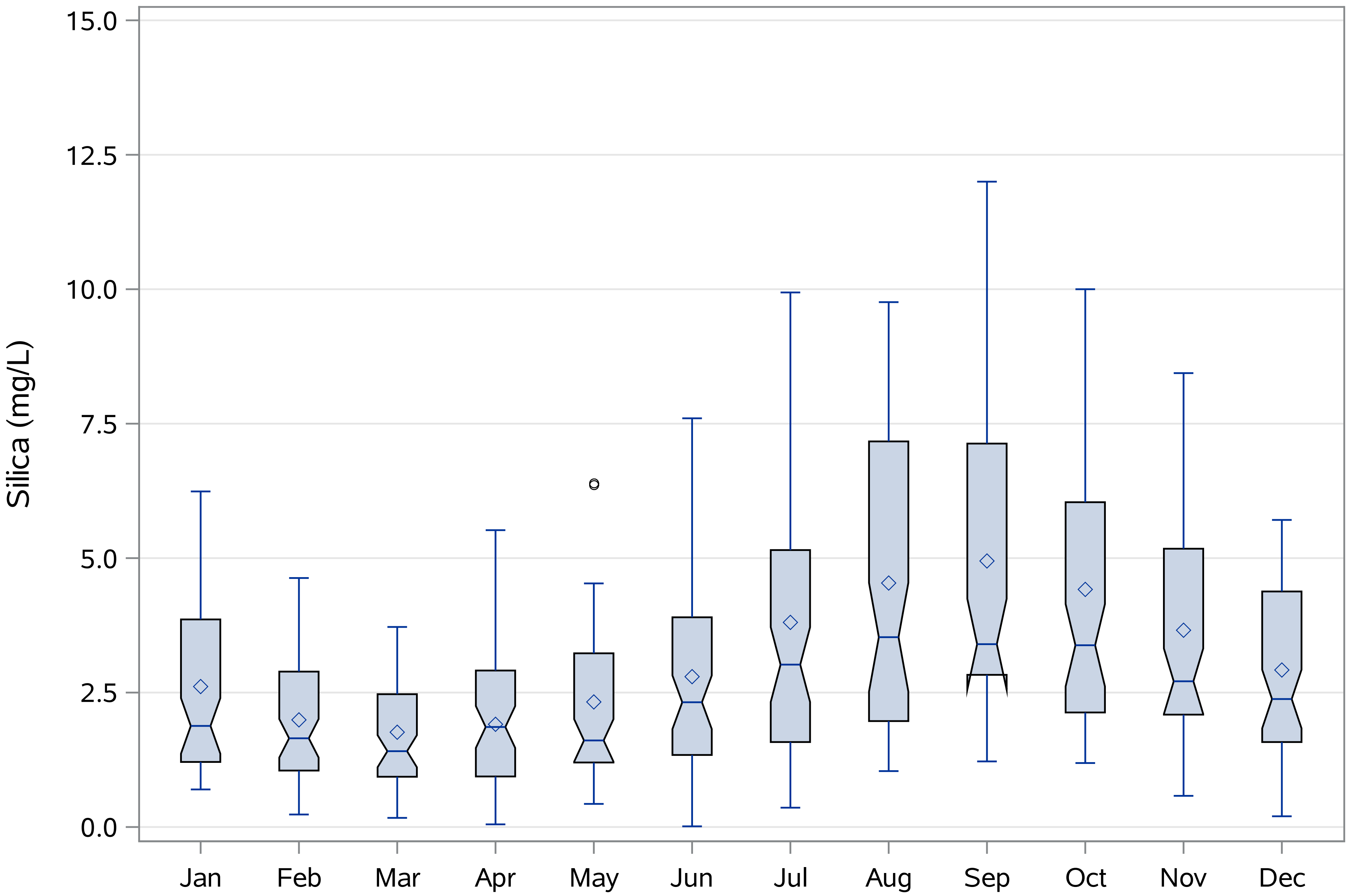

Figure 5.190. Mean monthly boxplots of surface Silica at the 12 psu isohaline (1984-2016)

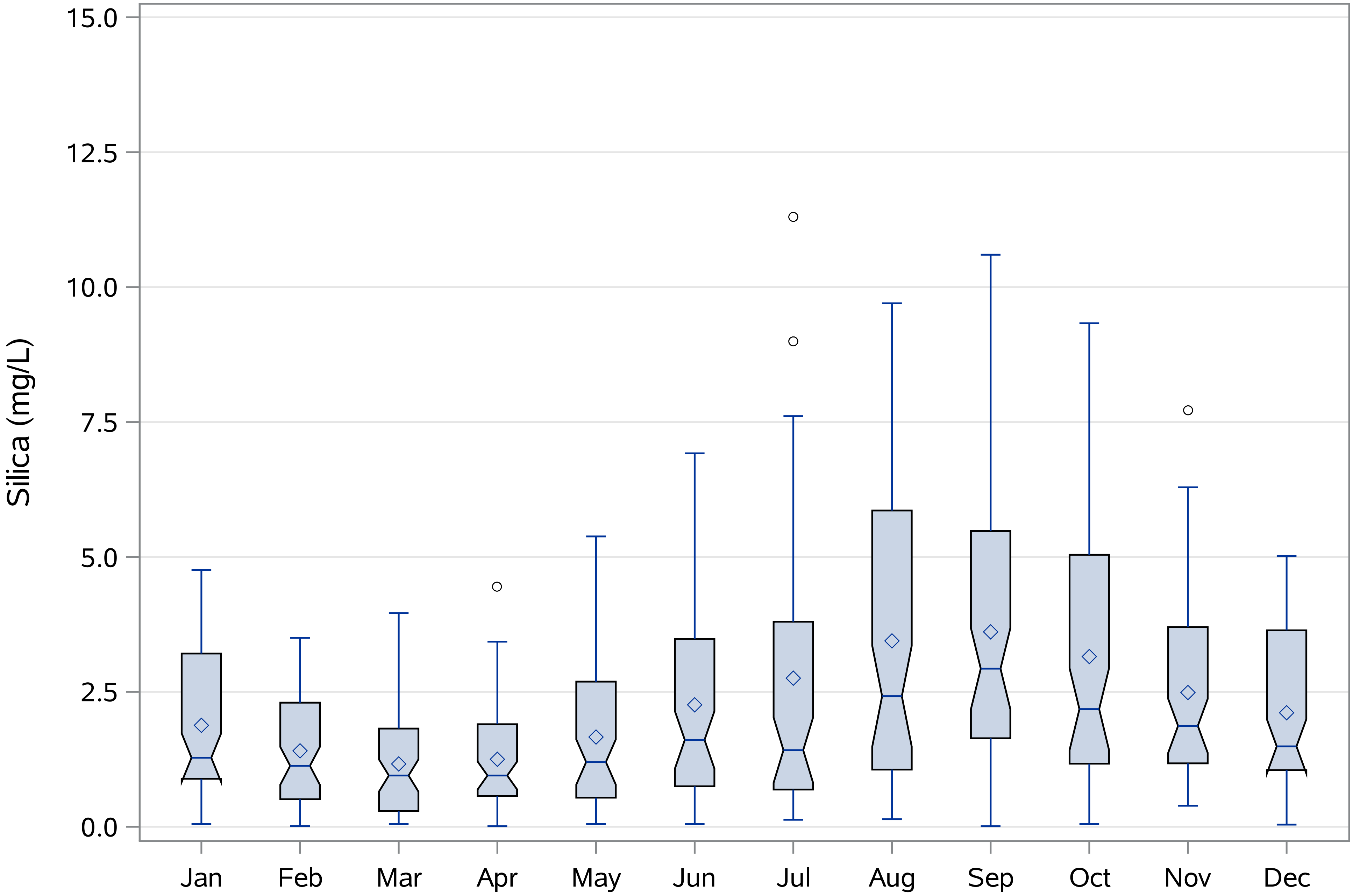

Figure 5.191. Mean monthly boxplots of surface Silica at the 20 psu isohaline (1984-2016)

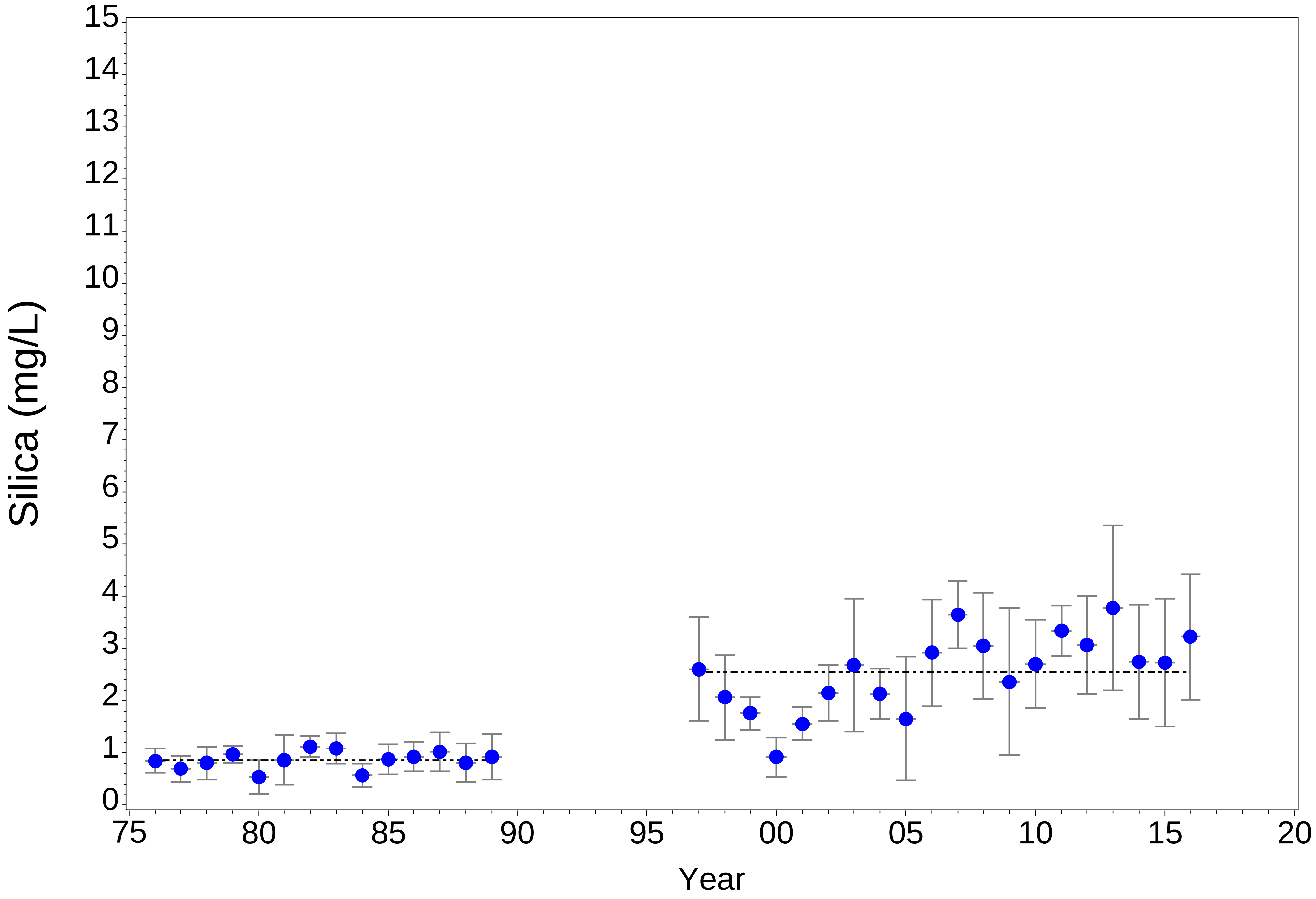

Figure 5.192. Long-term Station 9 surface Silica at river kilometer -2.4

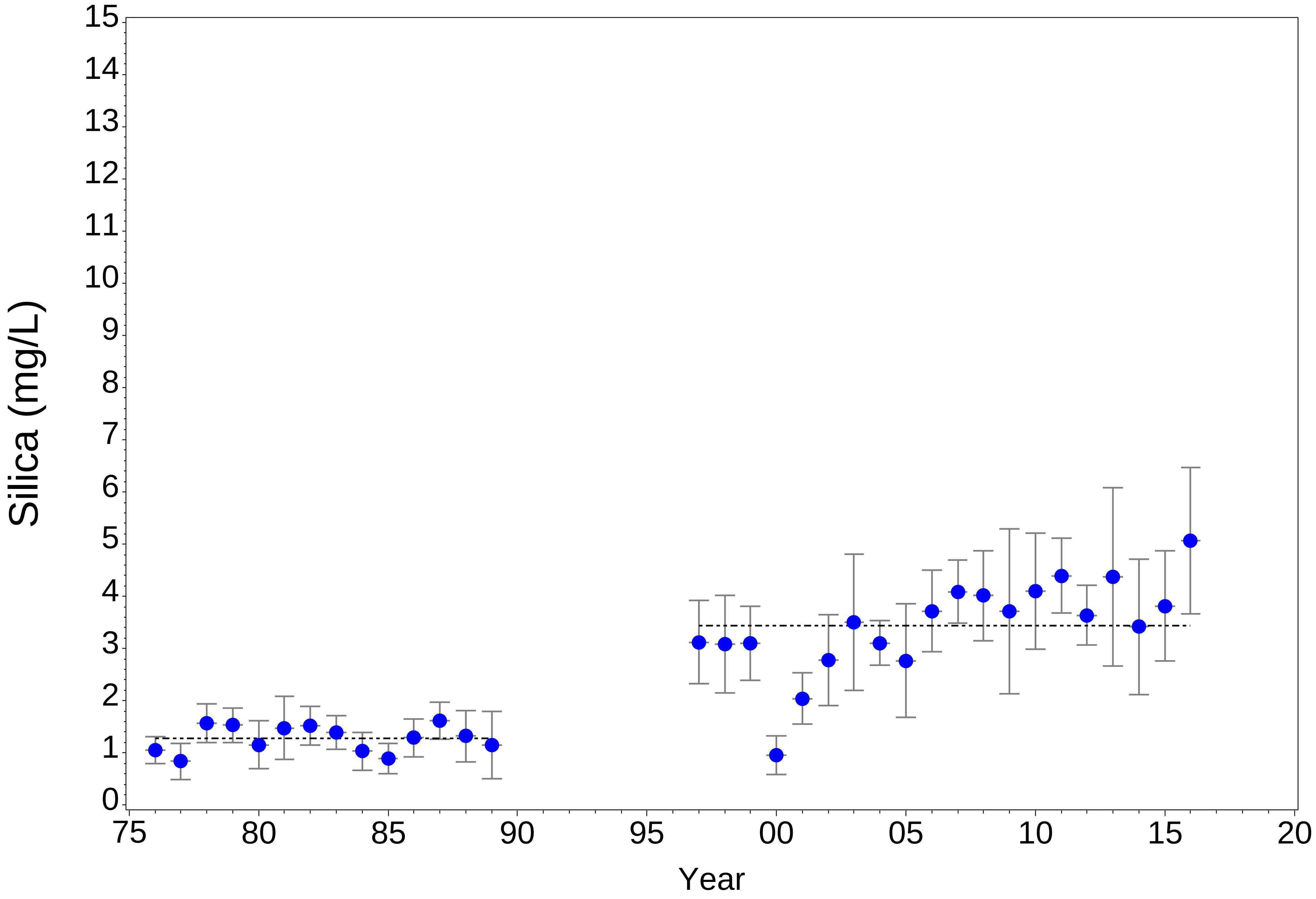

Figure 5.193. Long-term Station 10 surface Silica at river kilometer 6.6

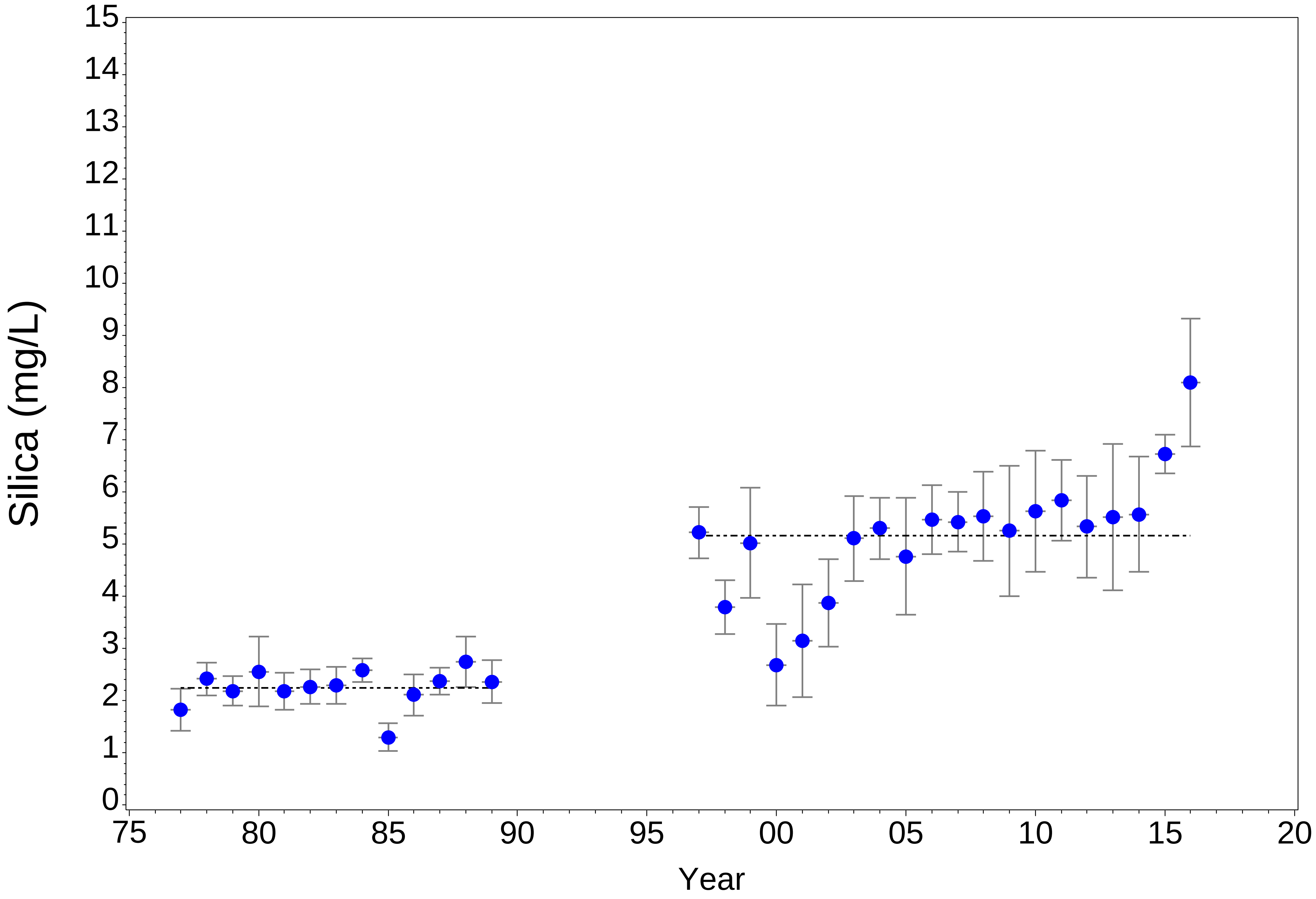

Figure 5.194. Long-term Station 12 surface Silica at river kilometer 15.5

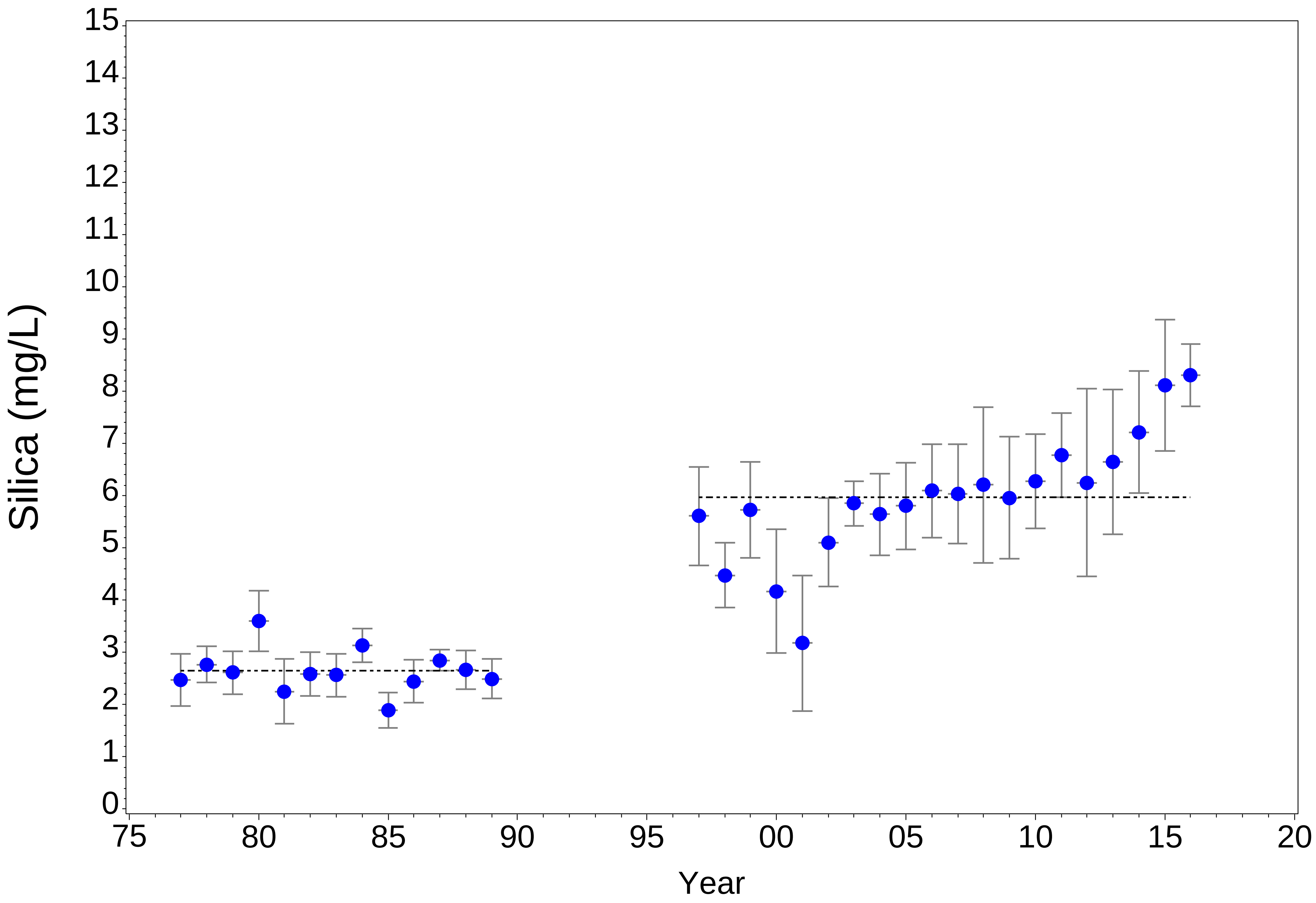

Figure 5.195. Long-term Station 14 surface Silica at river kilometer 23.6

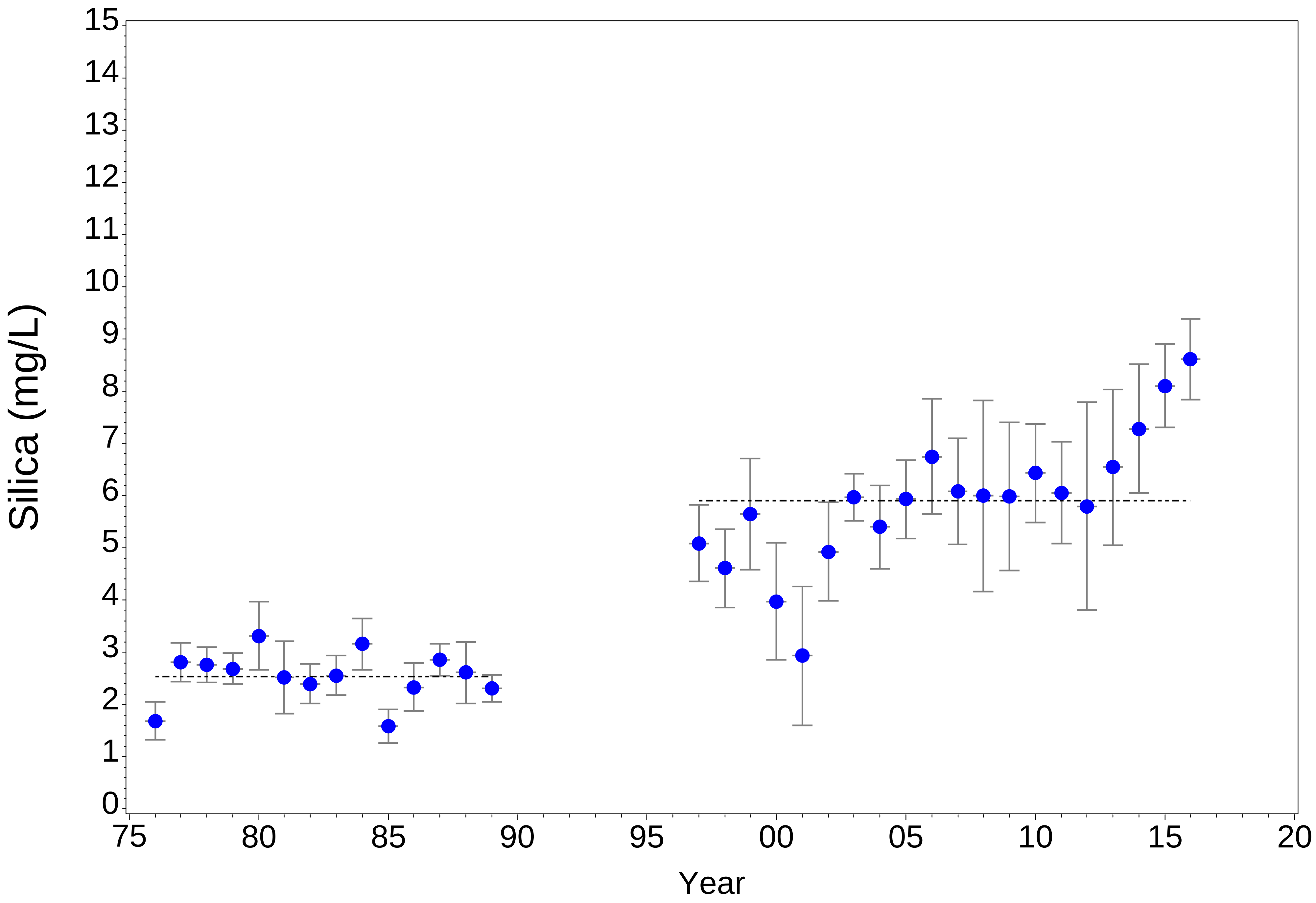

Figure 5.196. Long-term Station 18 surface Silica at river kilometer 30.7

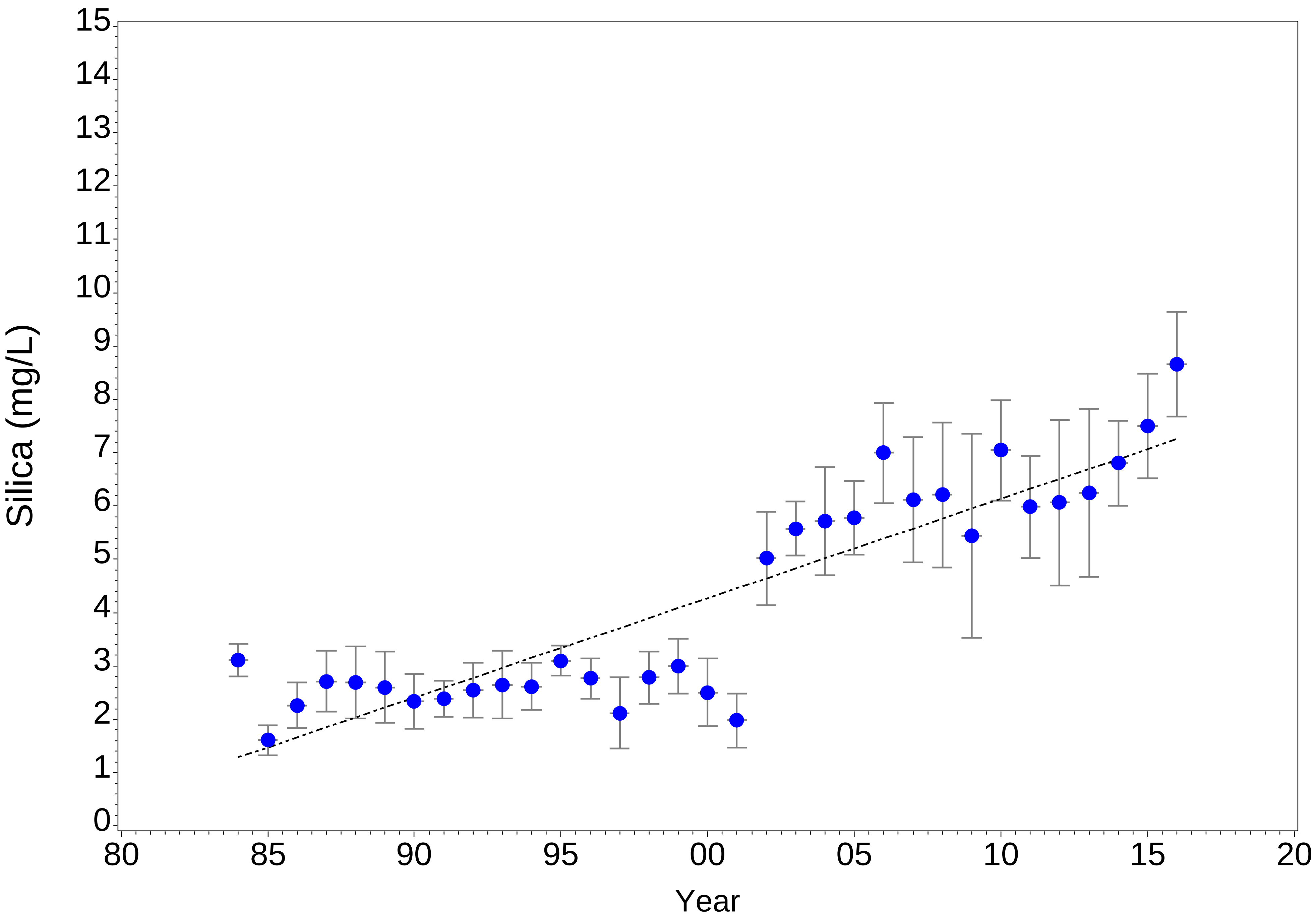

Figure 5.197. Annual monthly surface Silica at 0 psu isohaline (1984-2016)

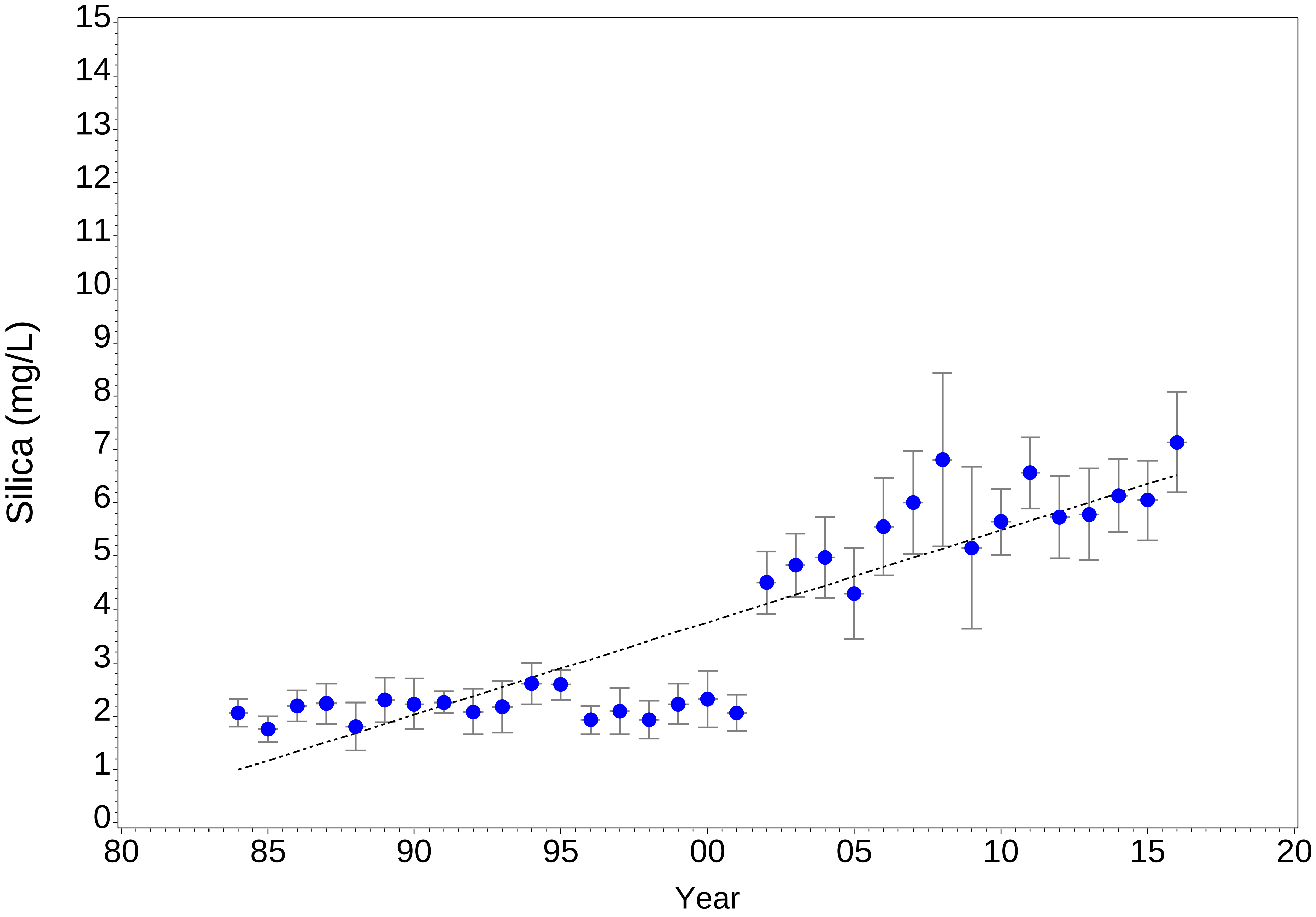

Figure 5.198. Annual monthly surface Silica at 6 psu isohaline (1984-2016)

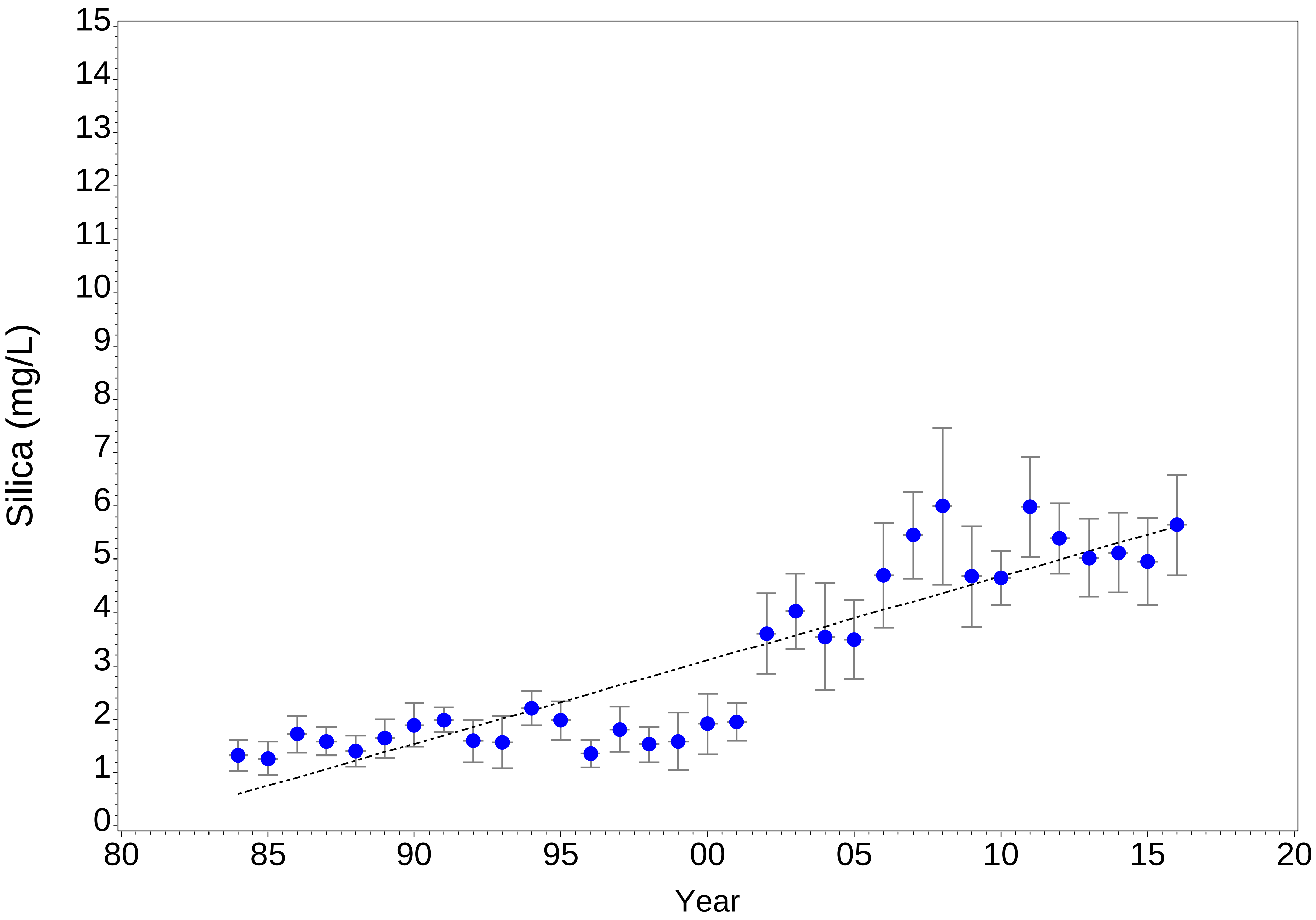

Figure 5.199. Annual monthly surface Silica at 12 psu isohaline (1984-2016)

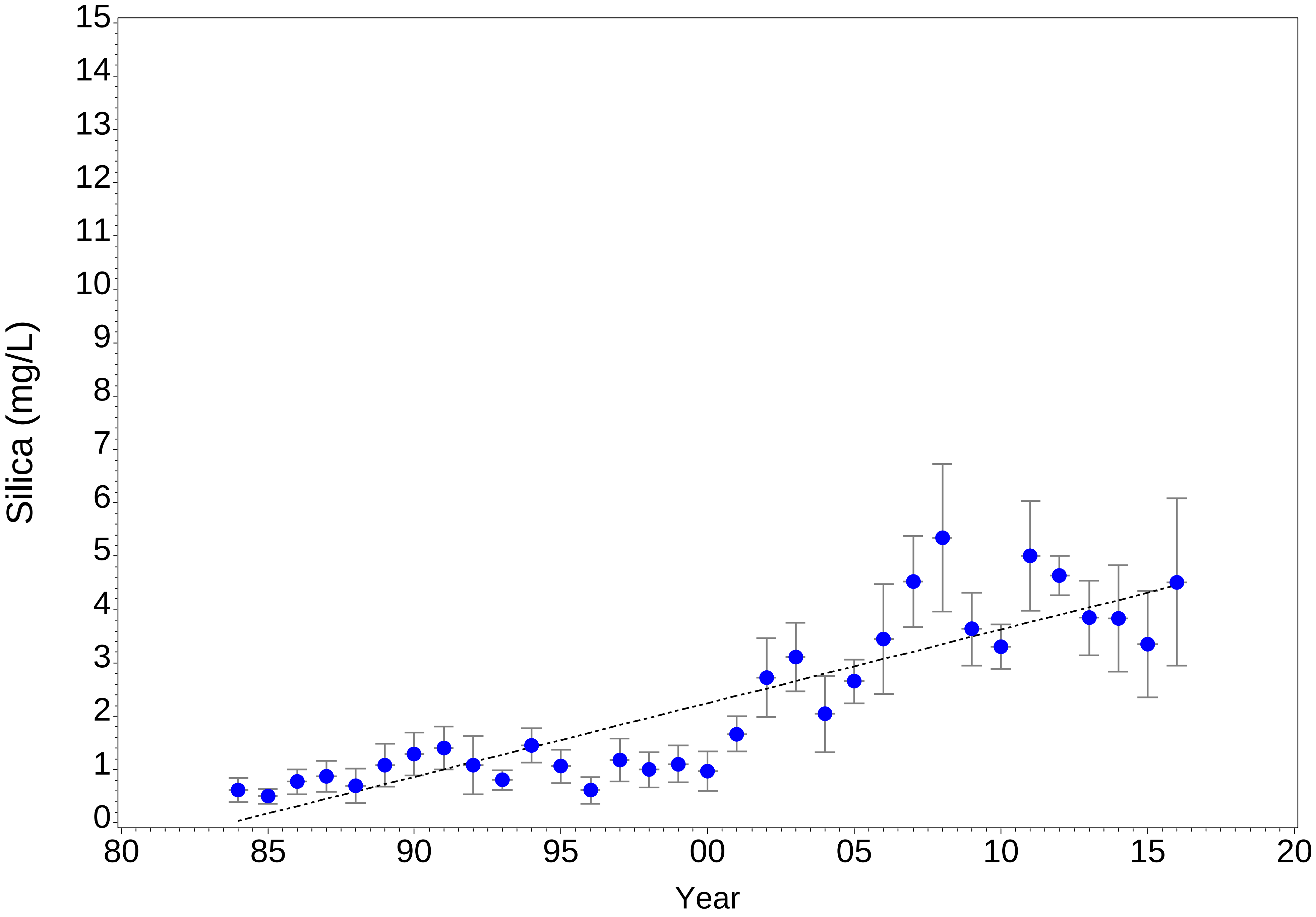

Figure 5.200. Annual monthly surface Silica at 20 psu isohaline (1984-2016)

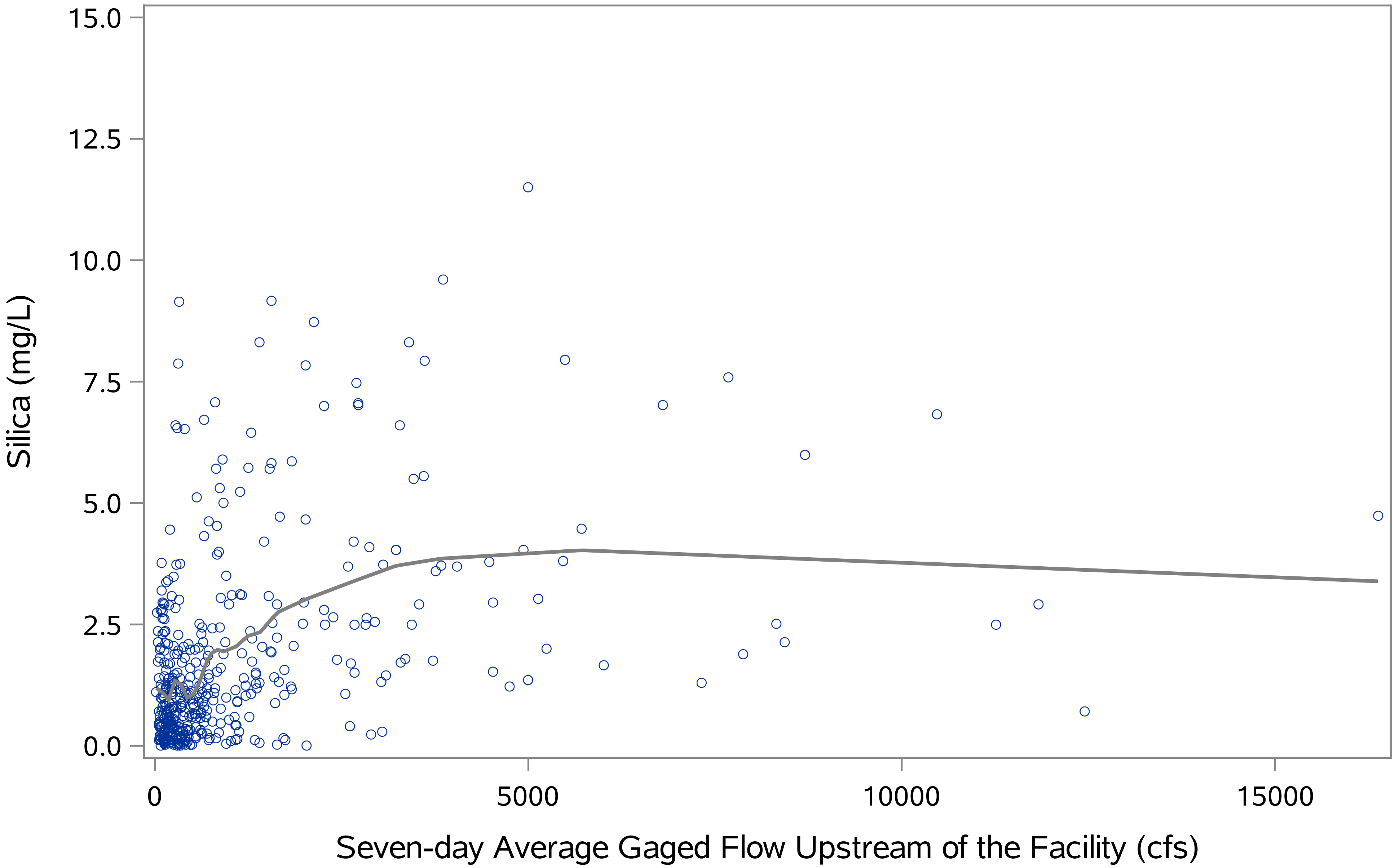

Figure 5.203. Surface Silica at river kilometer -2.4 versus flow

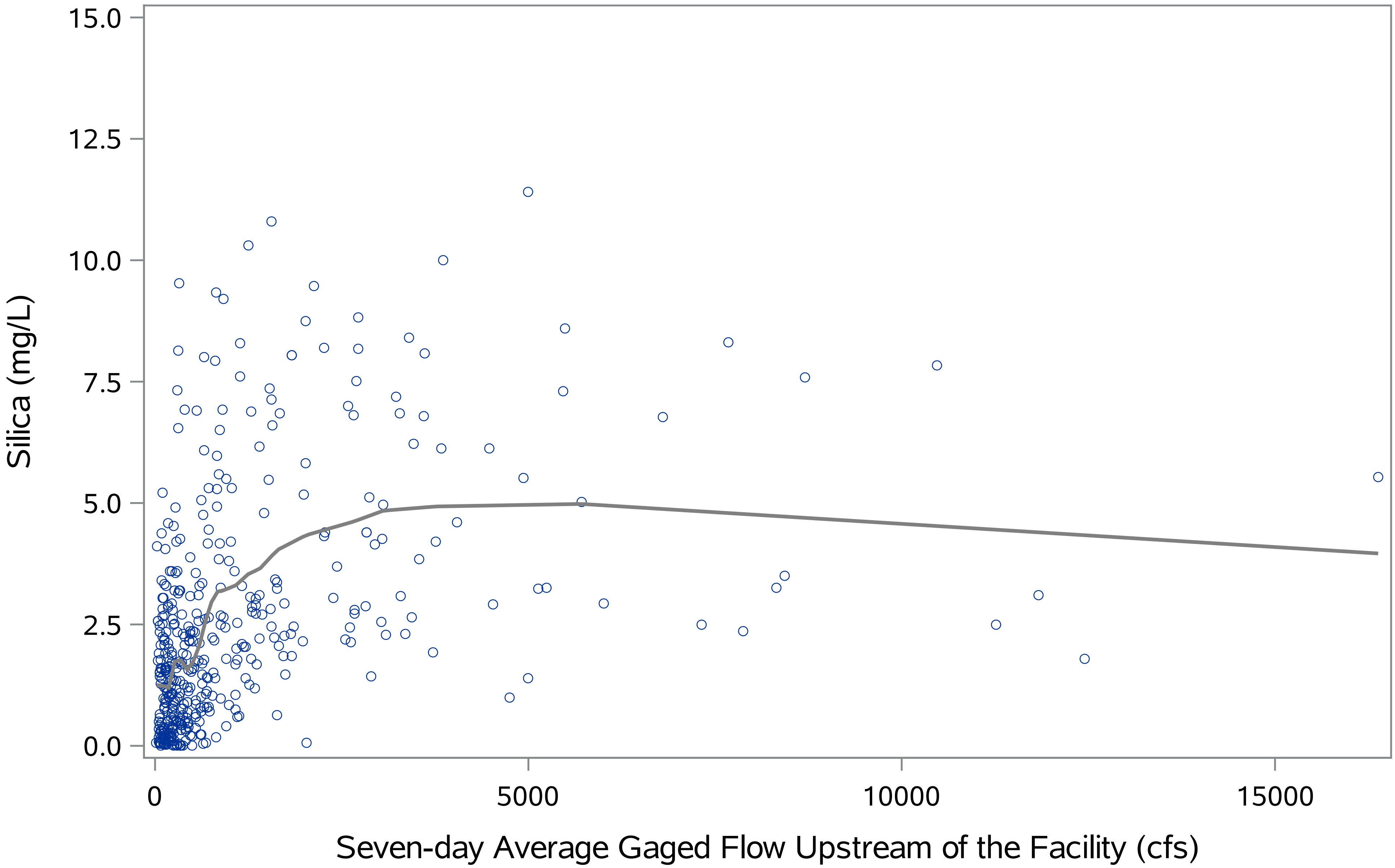

Figure 5.204. Surface Silica at river kilometer 6.6 versus flow

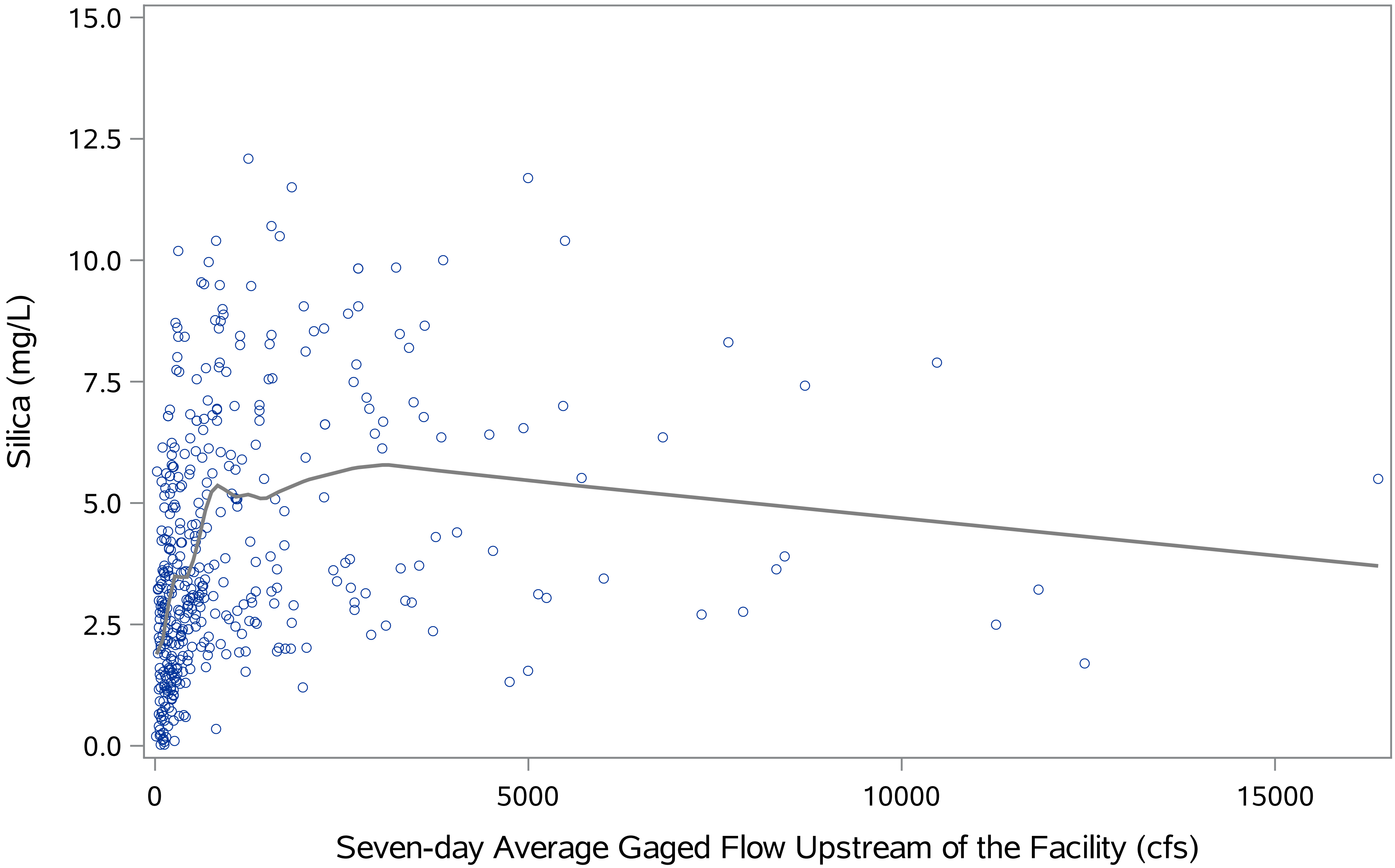

Figure 5.205. Surface Silica at river kilometer 15.5 versus flow

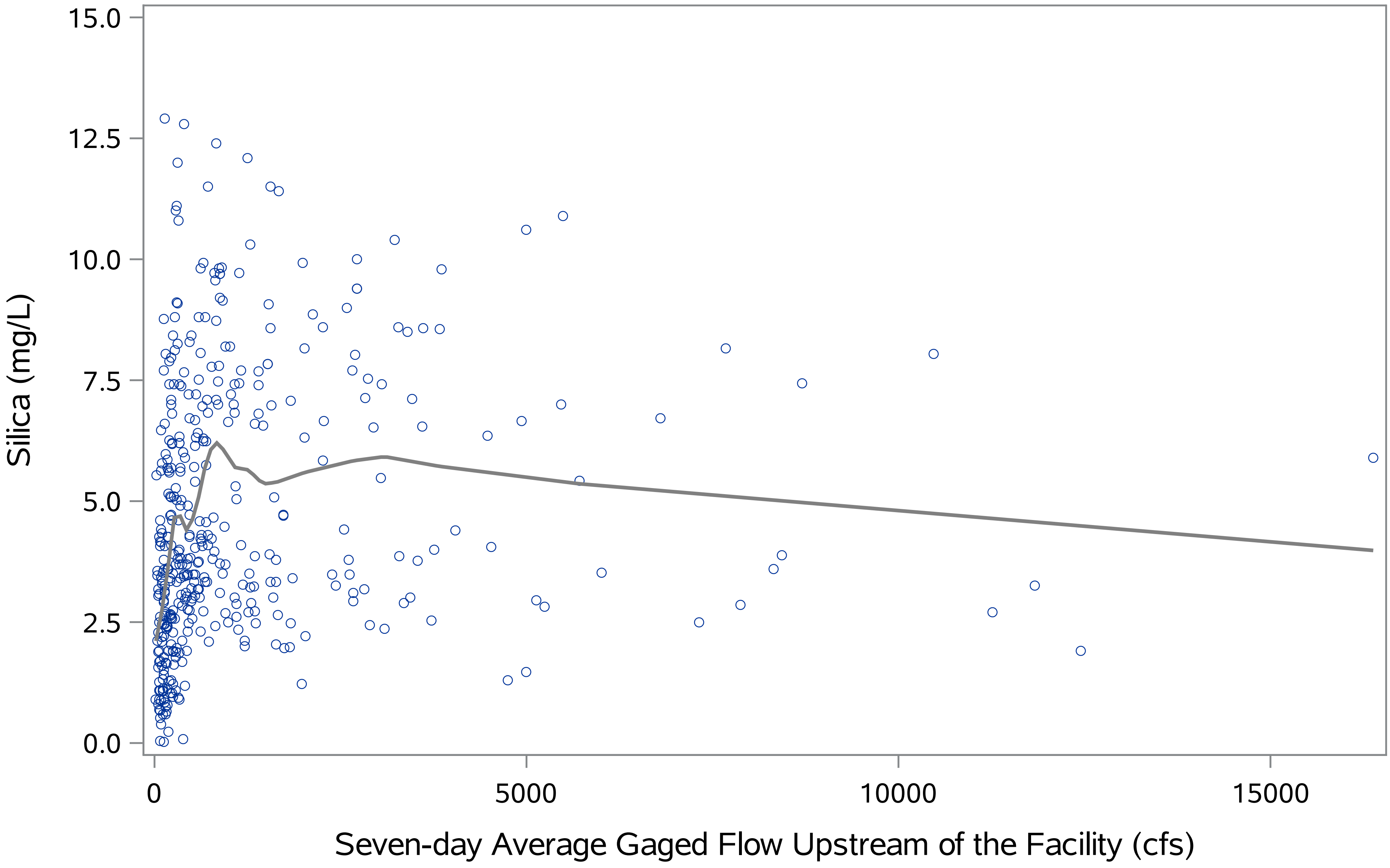

Figure 5.206. Surface Silica at river kilometer 23.6 versus flow

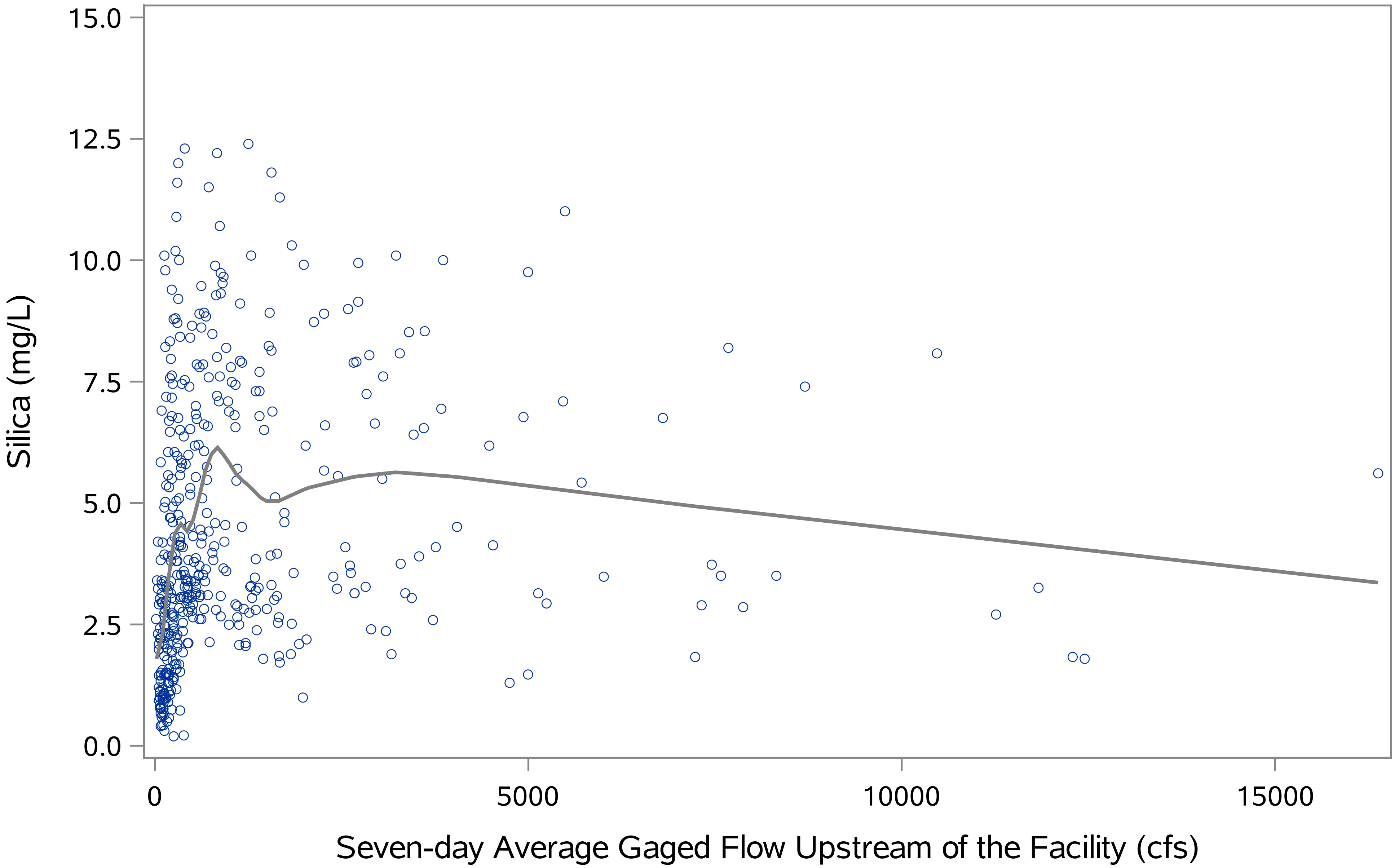

Figure 5.207. Surface Silica at river kilometer 30.7 versus flow

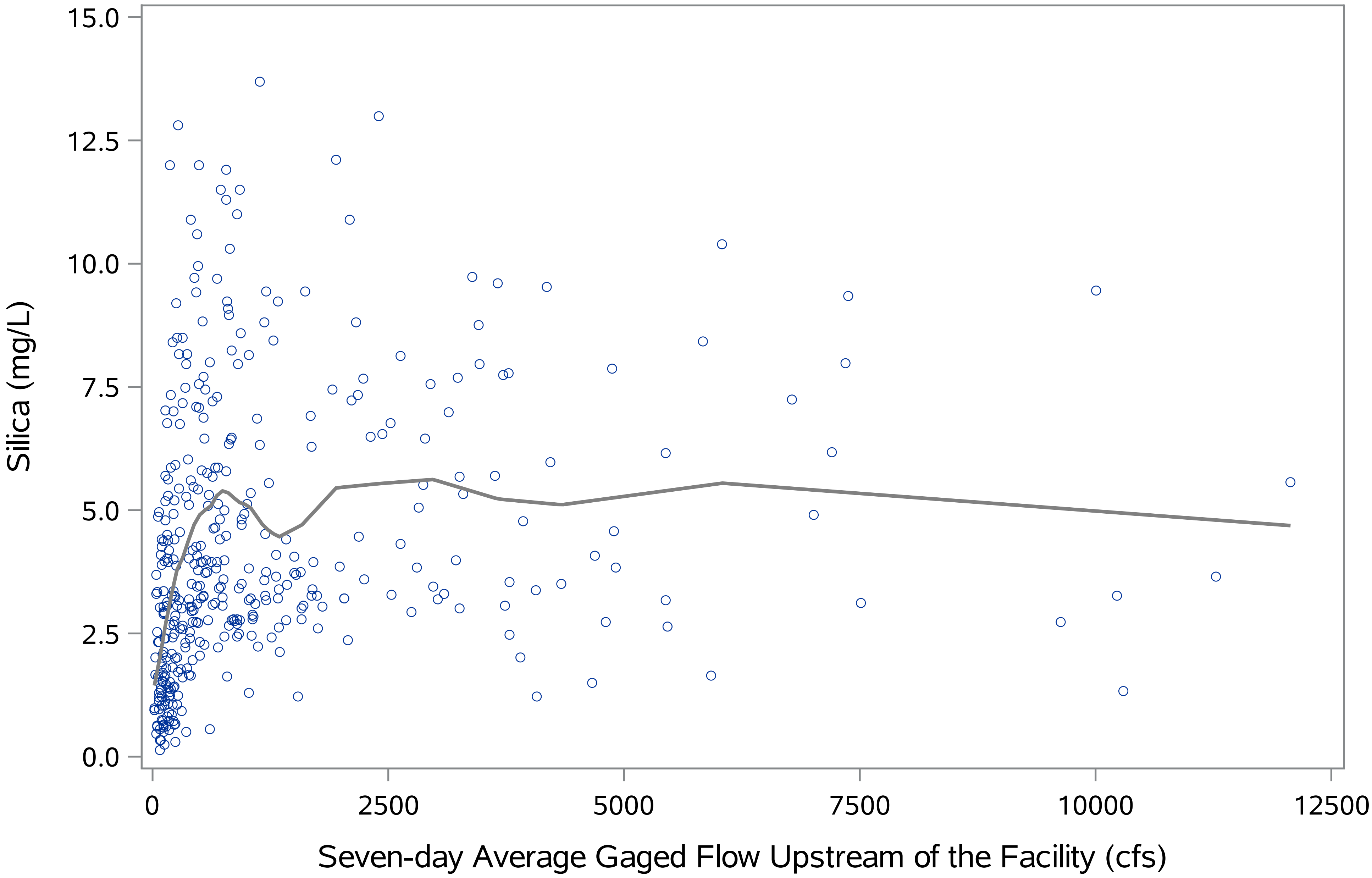

Figure 5.208. Silica at the 0 psu isohaline versus flow

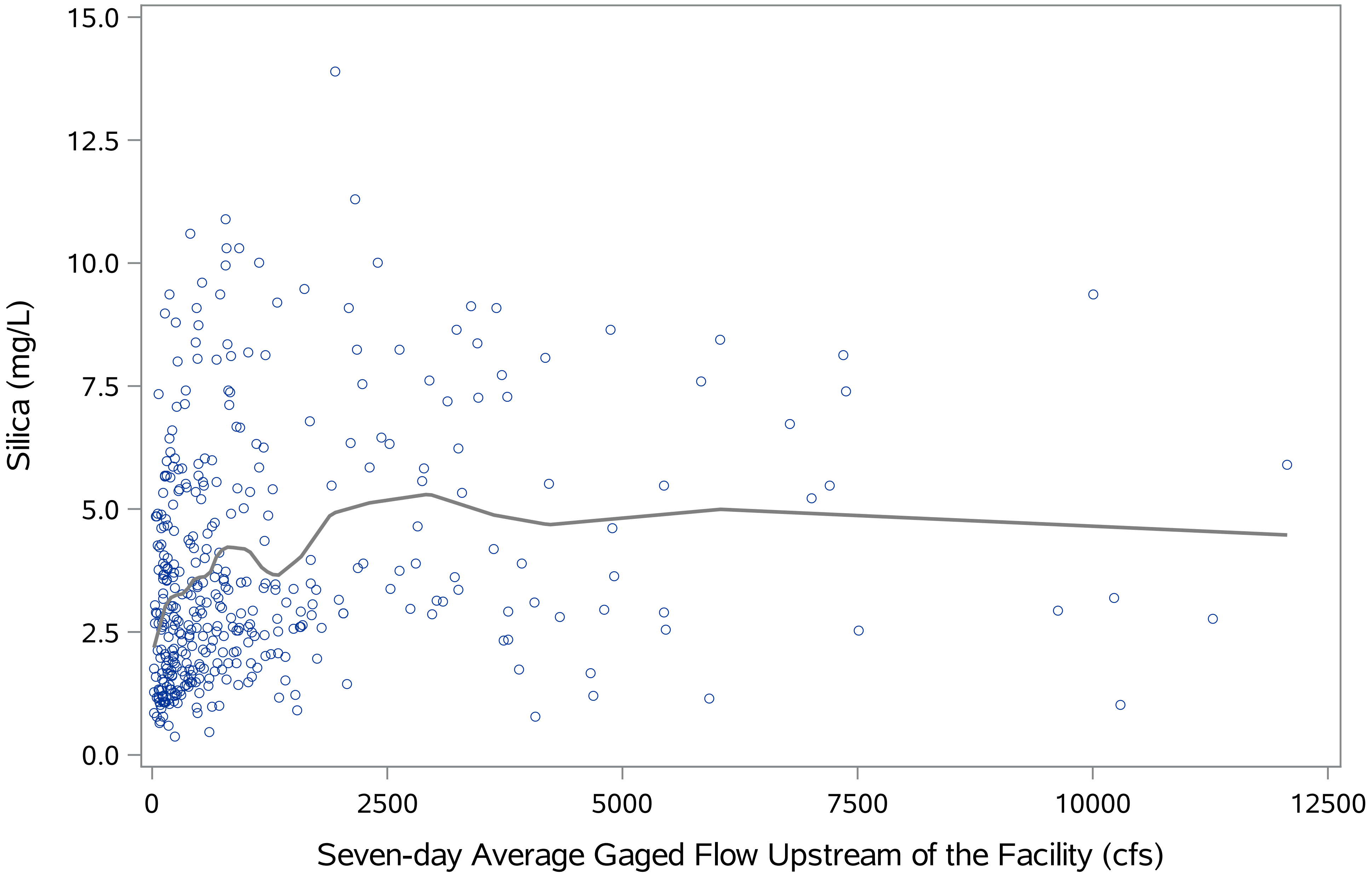

Figure 5.209. Silica at the 6 psu isohaline versus flow

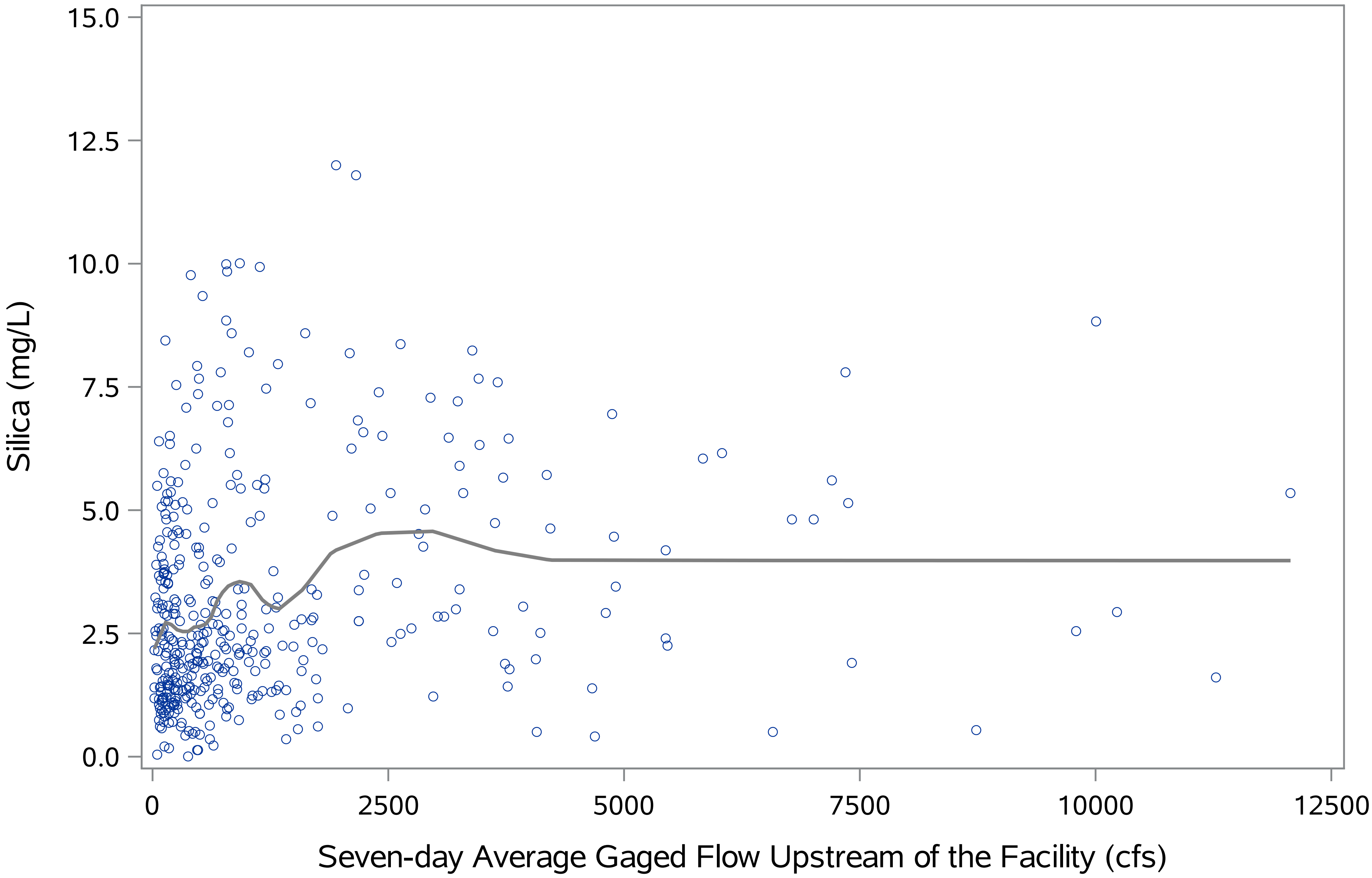

Figure 5.210. Silica at the 12 psu isohaline versus flow

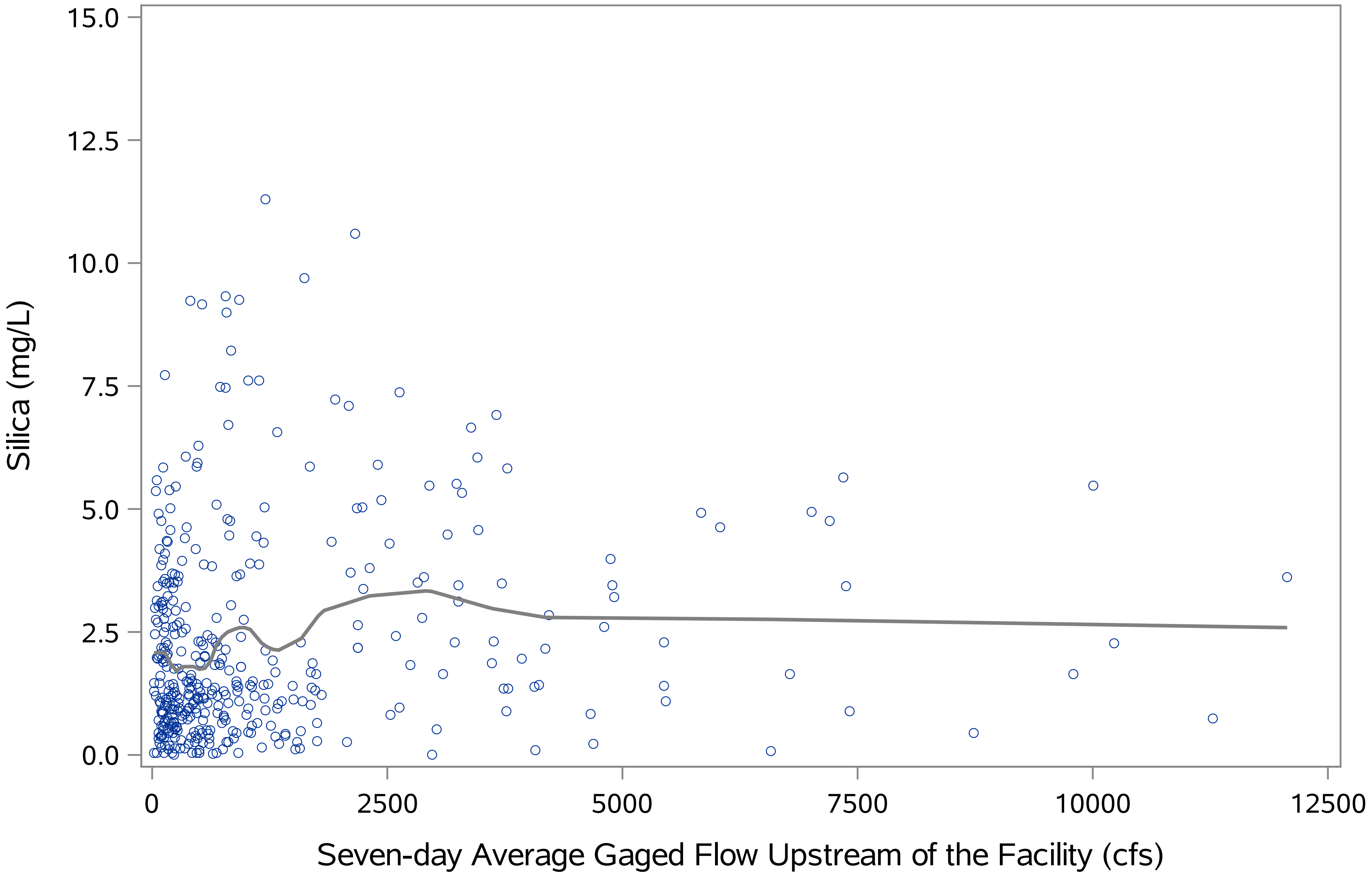

Figure 5.211. Silica at the 20 psu isohaline versus flow

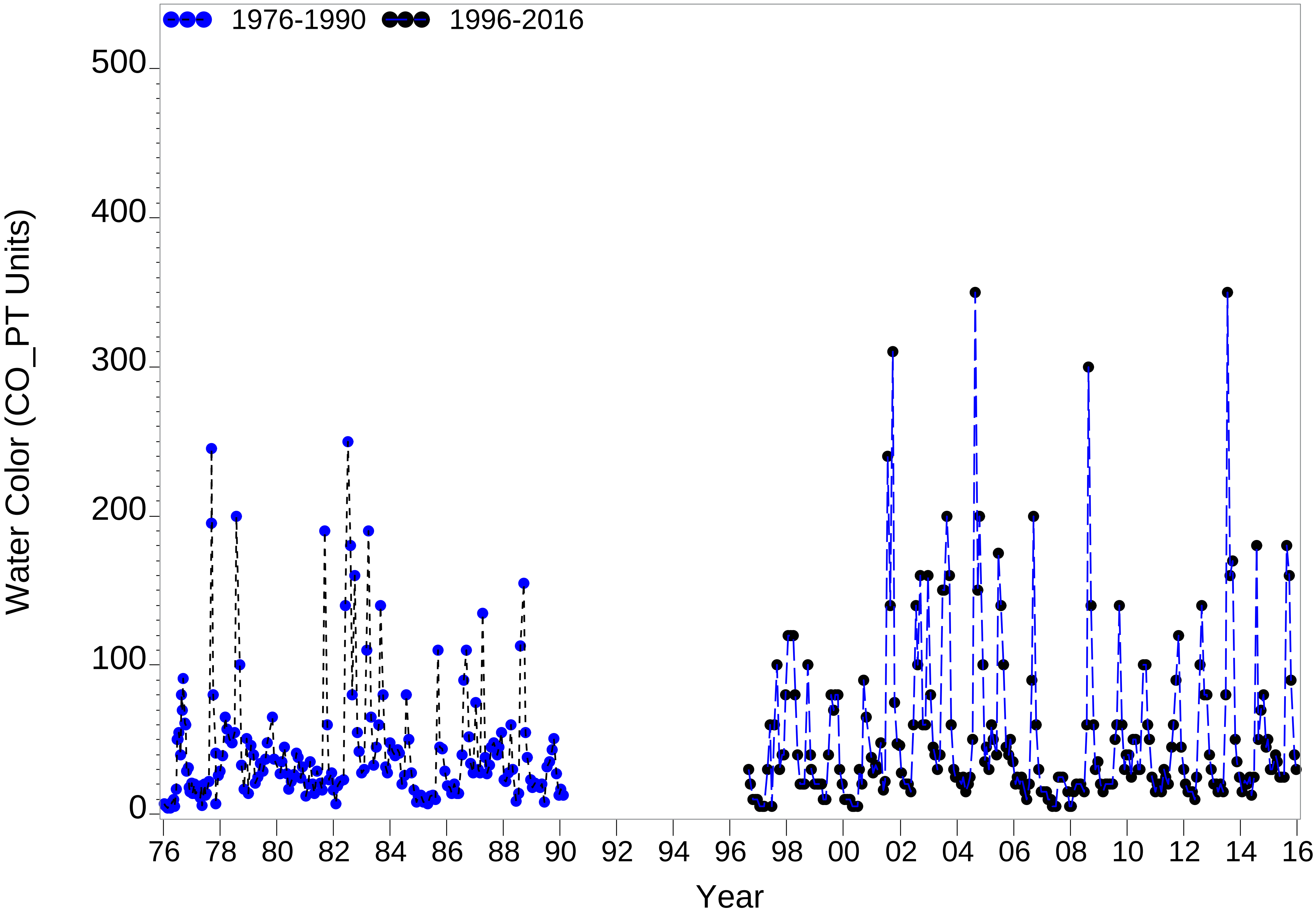

Figure 5.214. Monthly long-term Water Color at river kilometer -2.4

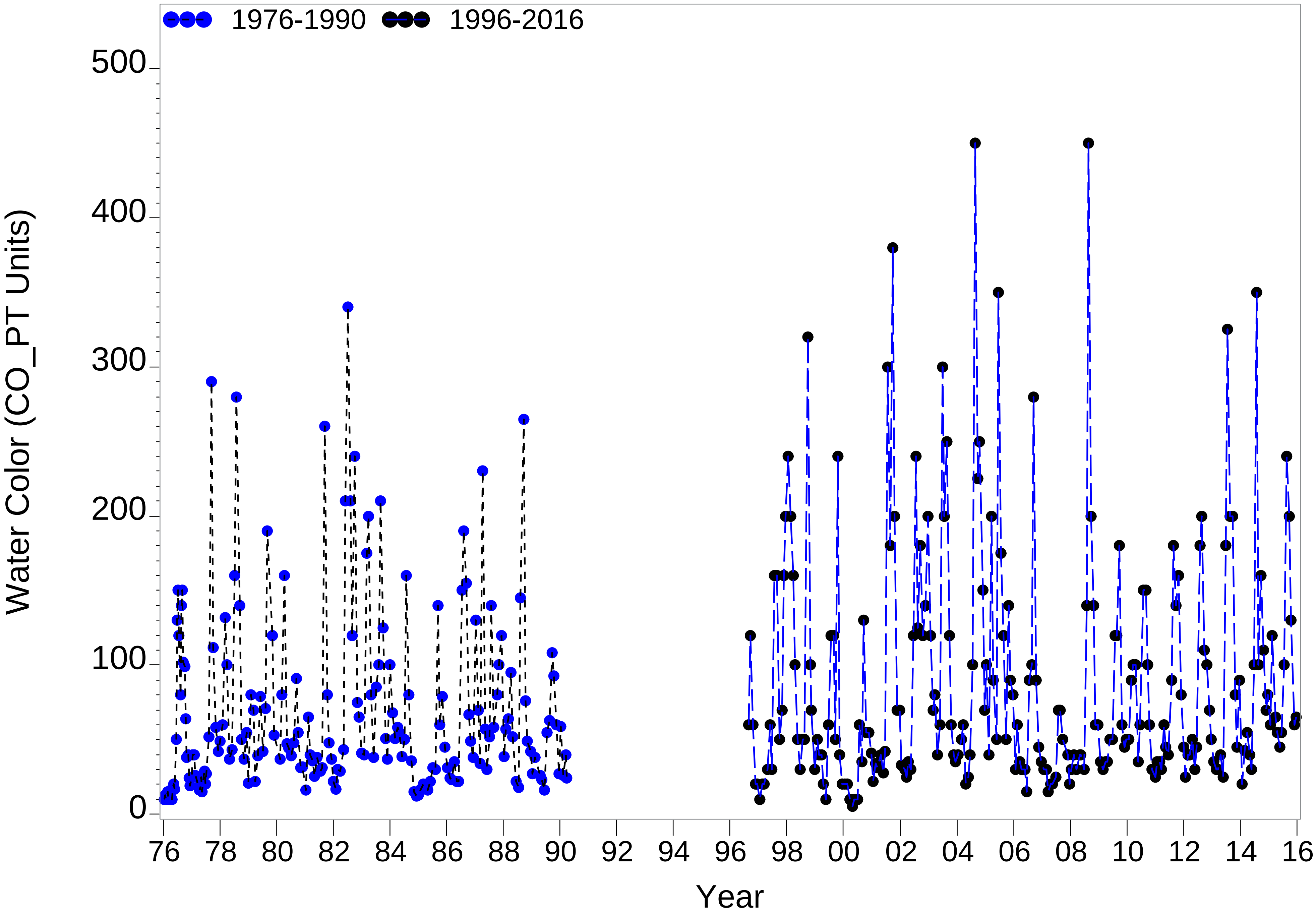

Figure 5.215. Monthly long-term Water Color at river kilometer 6.6

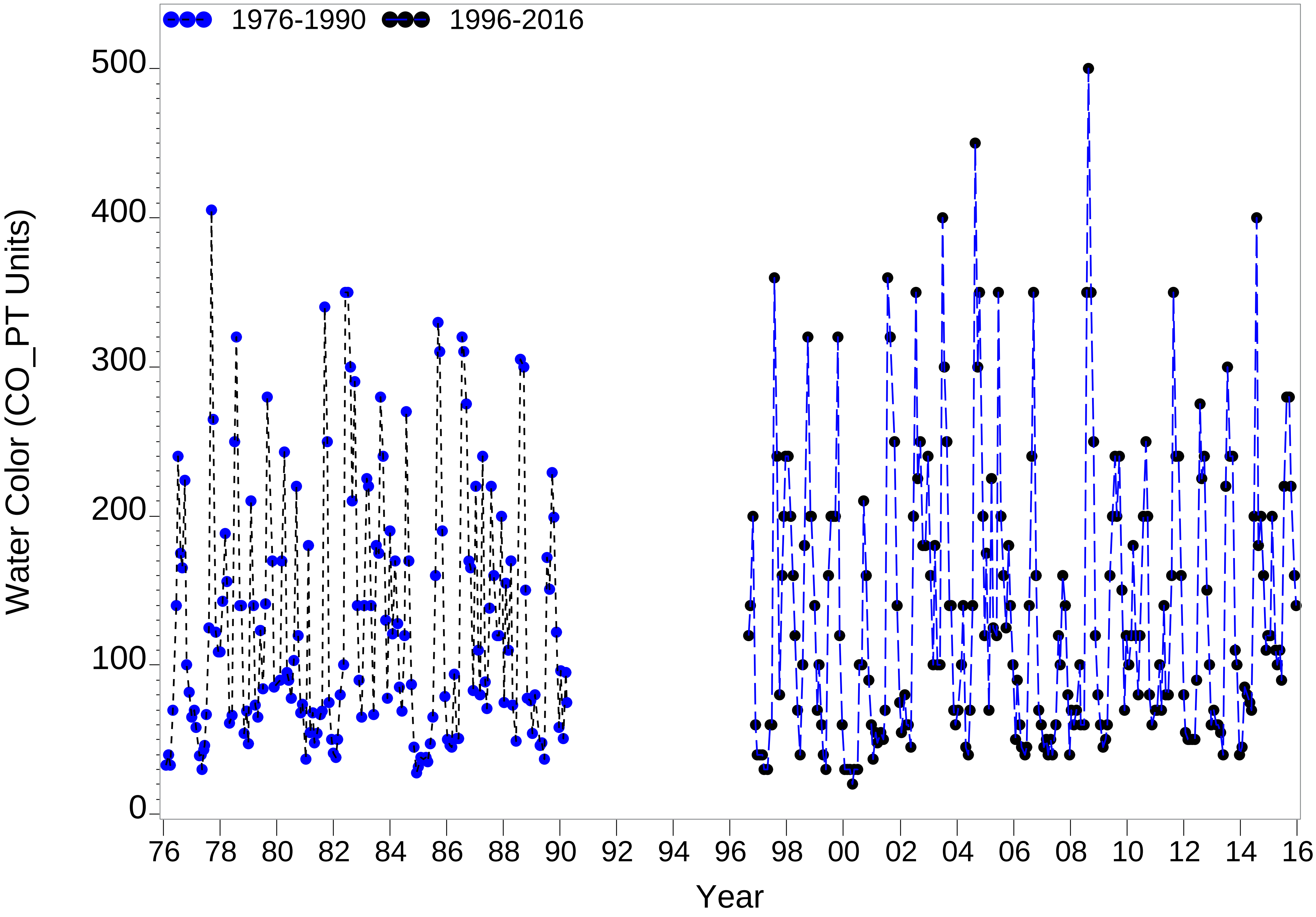

Figure 5.216. Monthly long-term Water Color at river kilometer 15.5

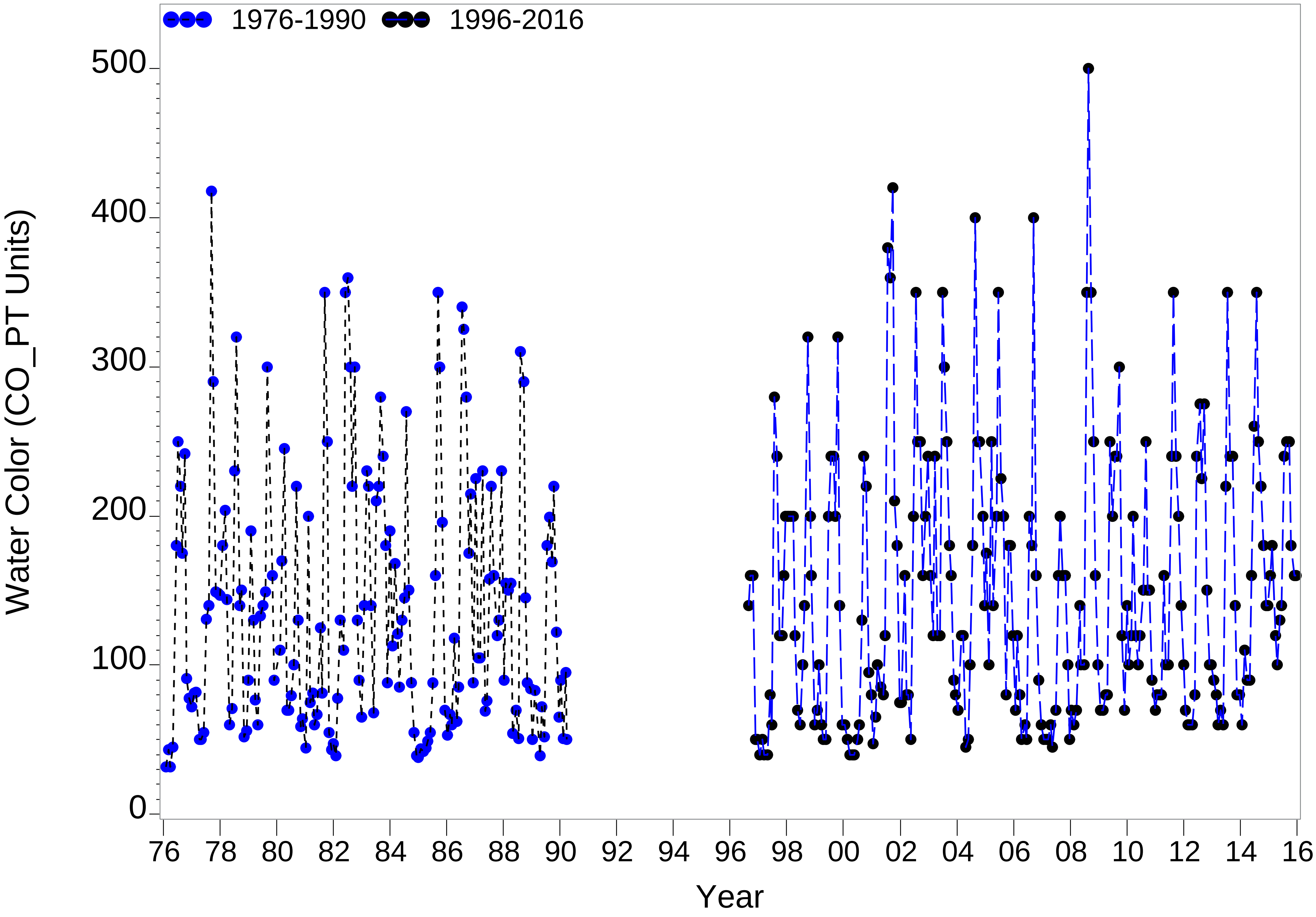

Figure 5.217. Monthly long-term Water Color at river kilometer 23.6

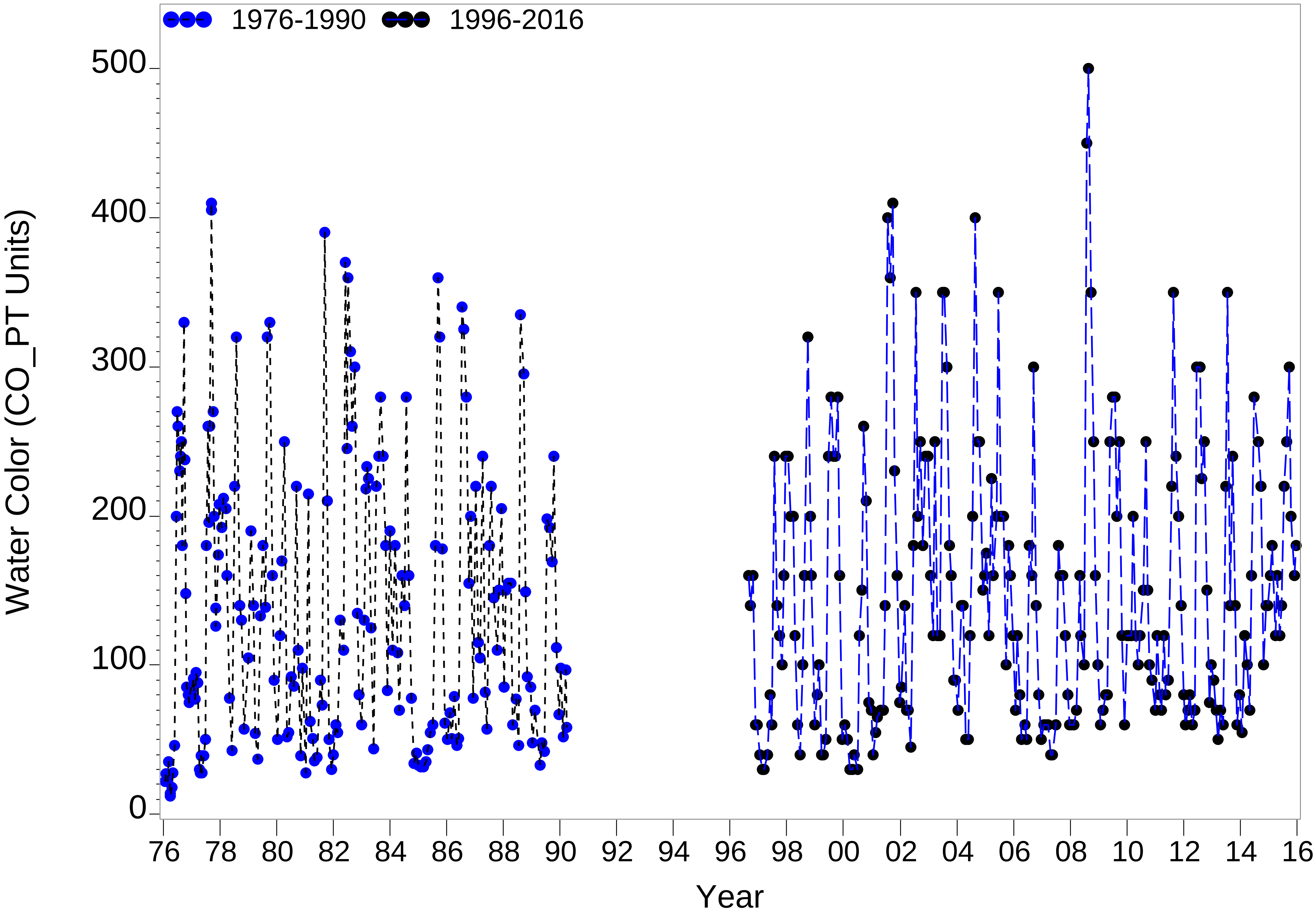

Figure 5.218. Monthly long-term Water Color at river kilometer 30.7

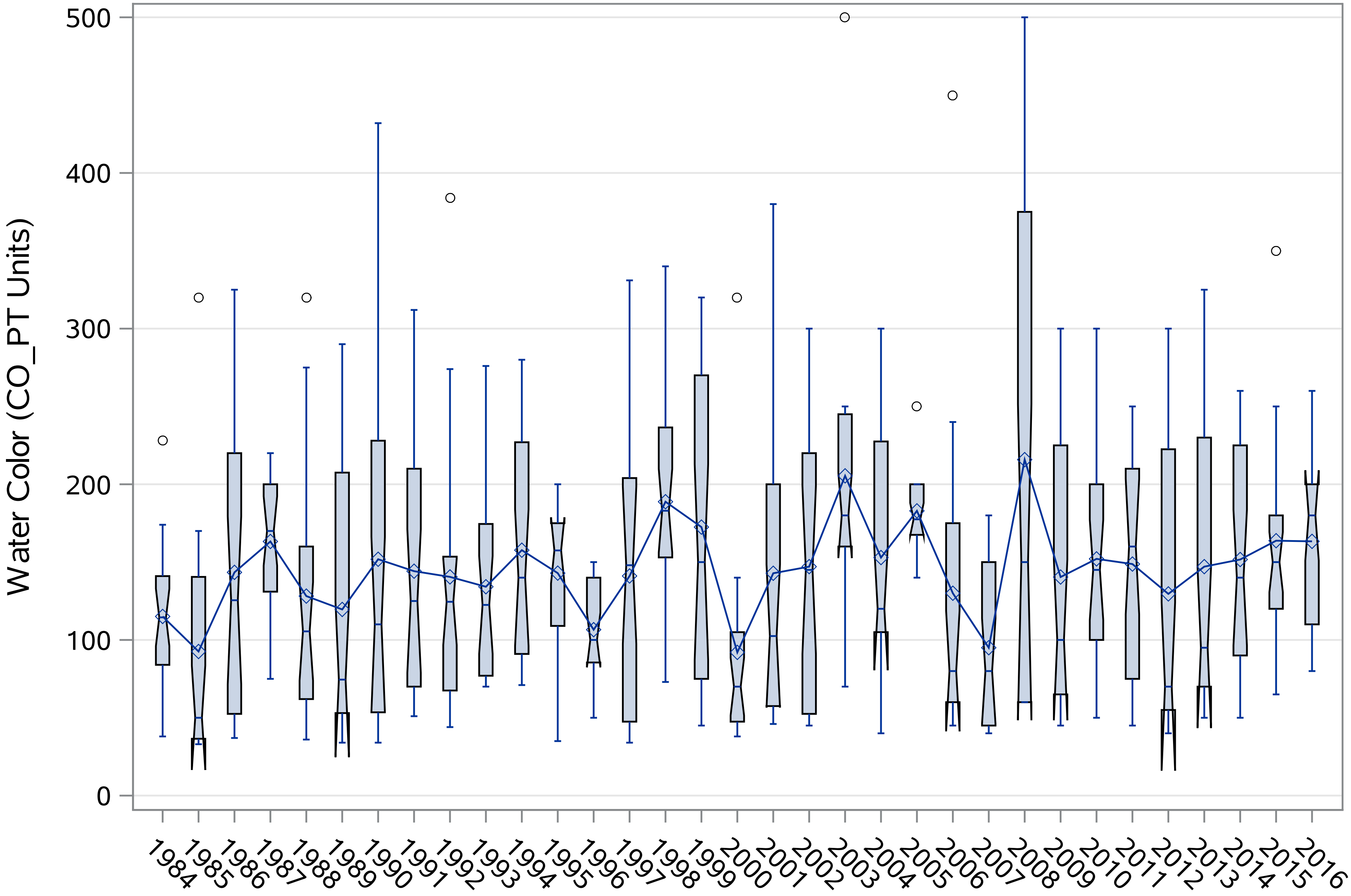

Figure 5.219. Annual boxplots of surface Water Color at the 0 psu isohaline (1984-2016)

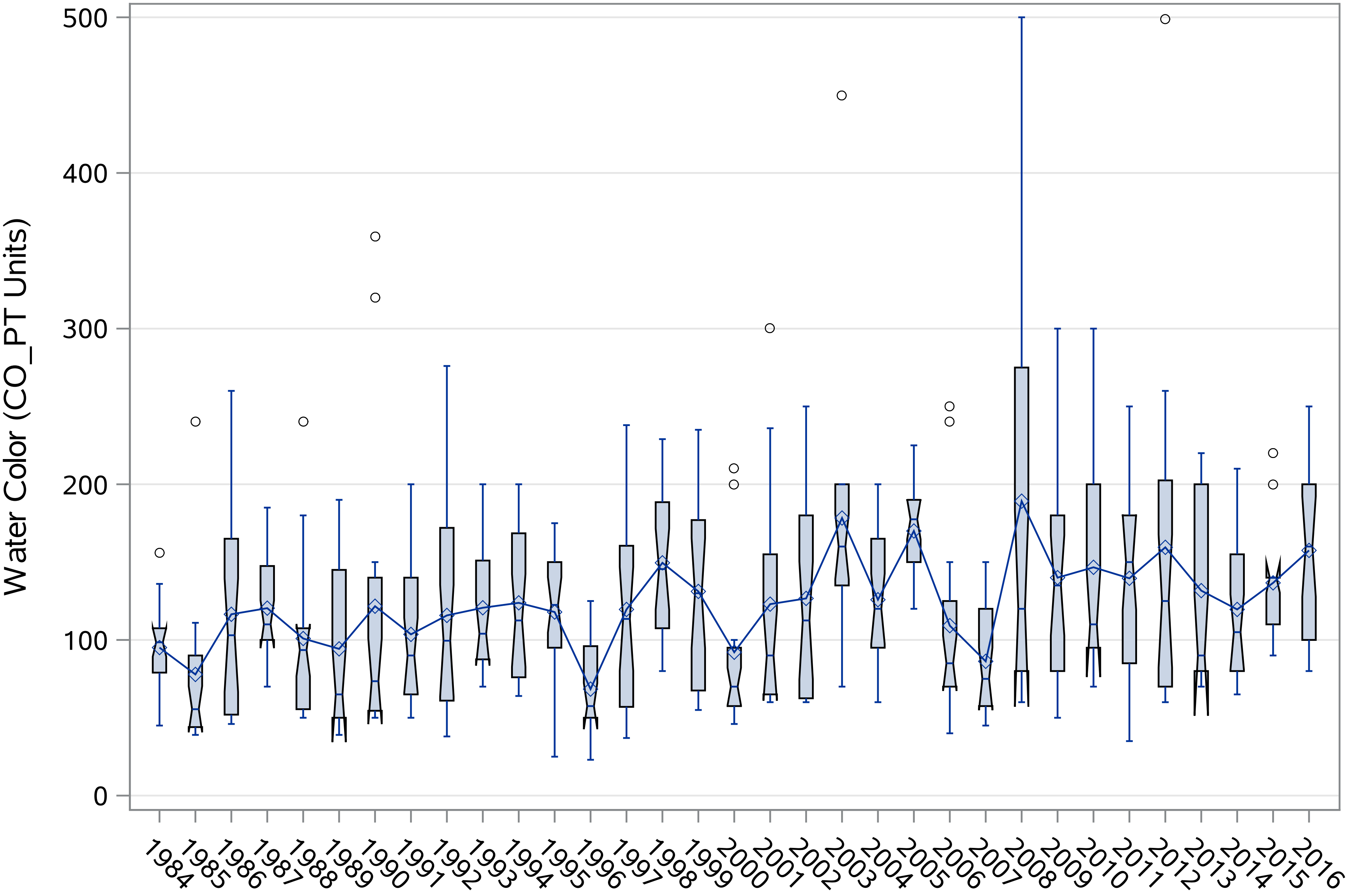

Figure 5.220. Annual boxplots of surface Water Color at the 6 psu isohaline (1984-2016)

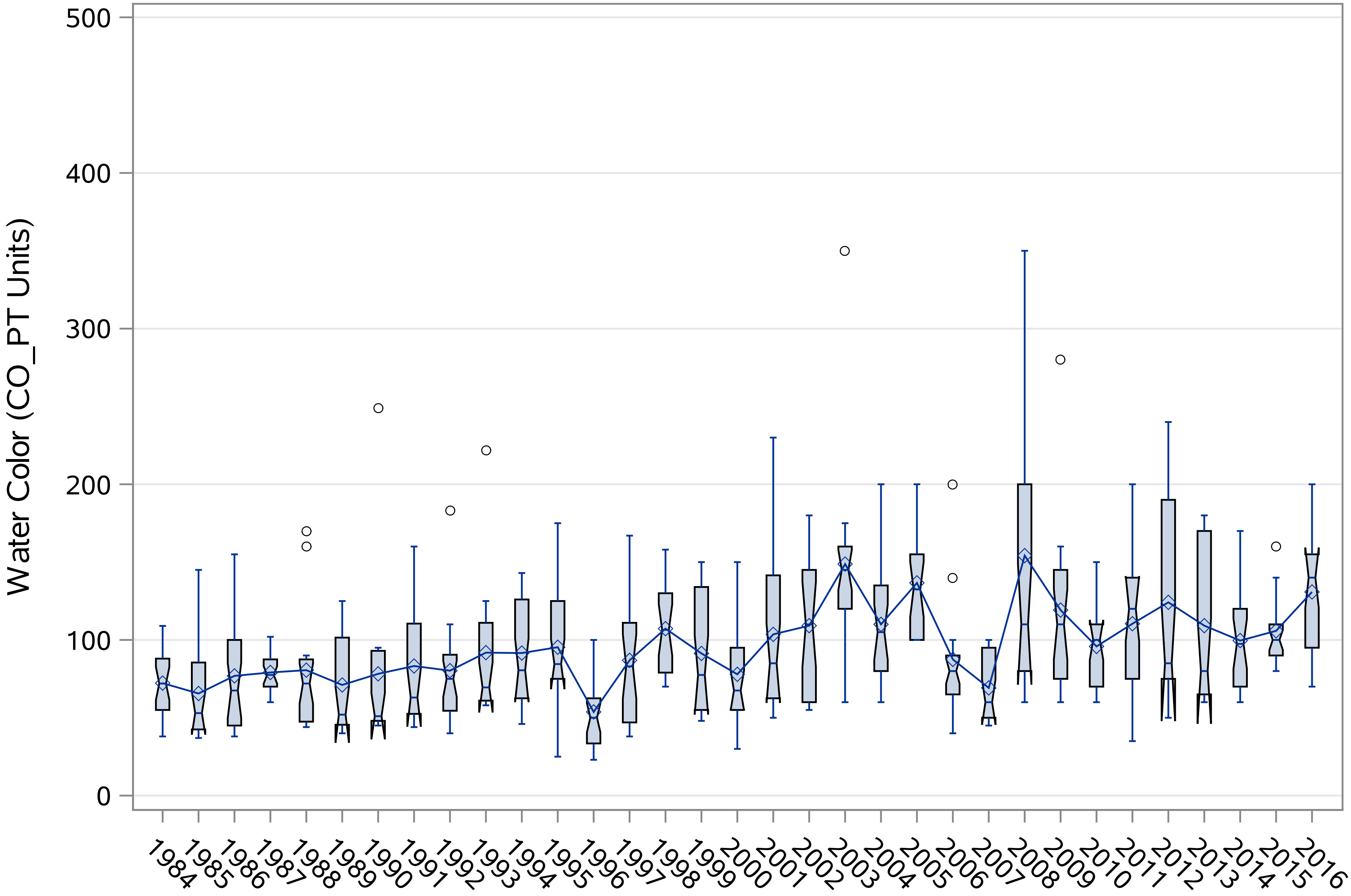

Figure 5.221. Annual boxplots of surface Water Color at the 12 psu isohaline (1984-2016)

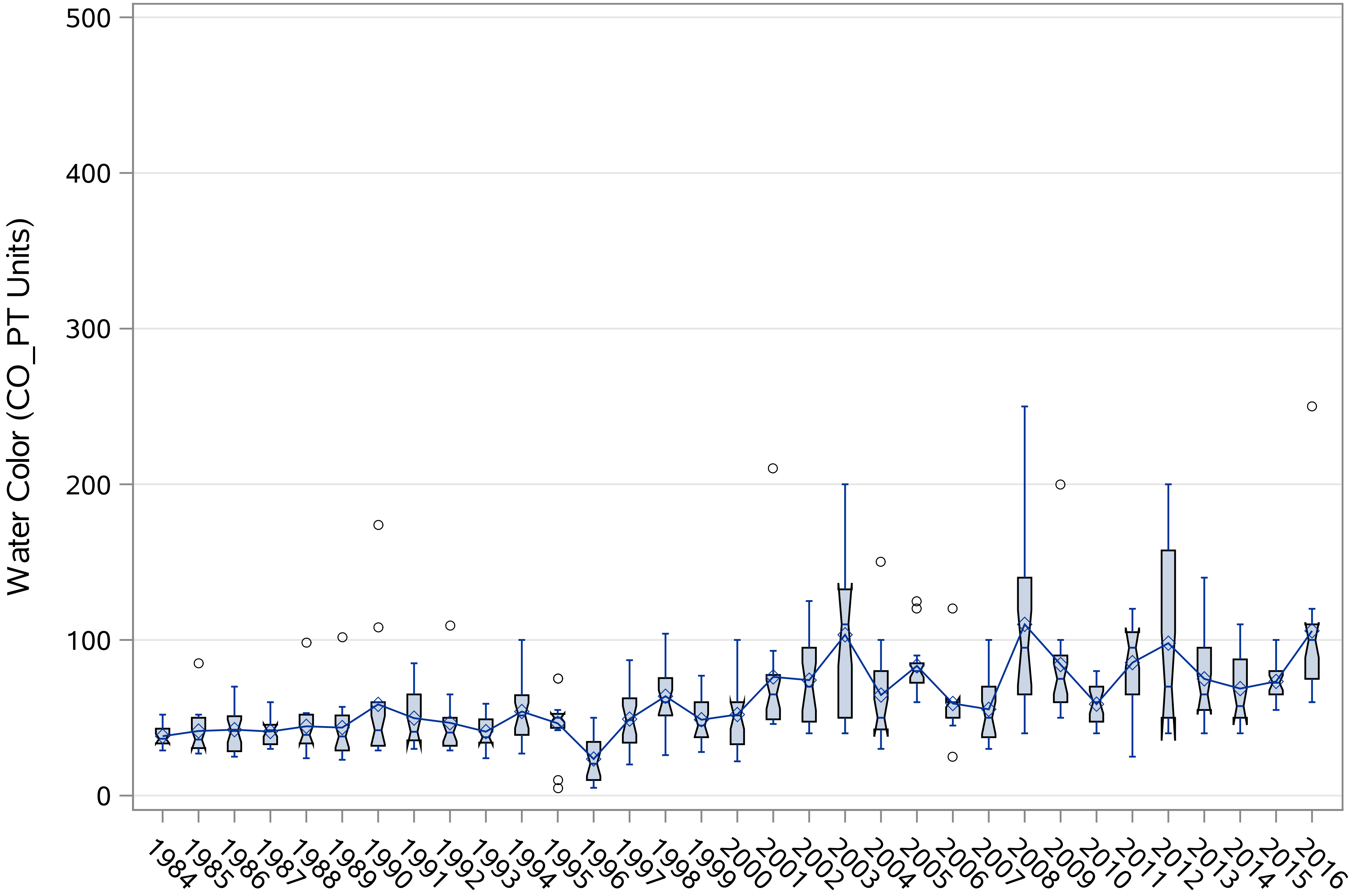

Figure 5.222. Annual boxplots of surface Water Color at the 20 psu isohaline (1984-2016)

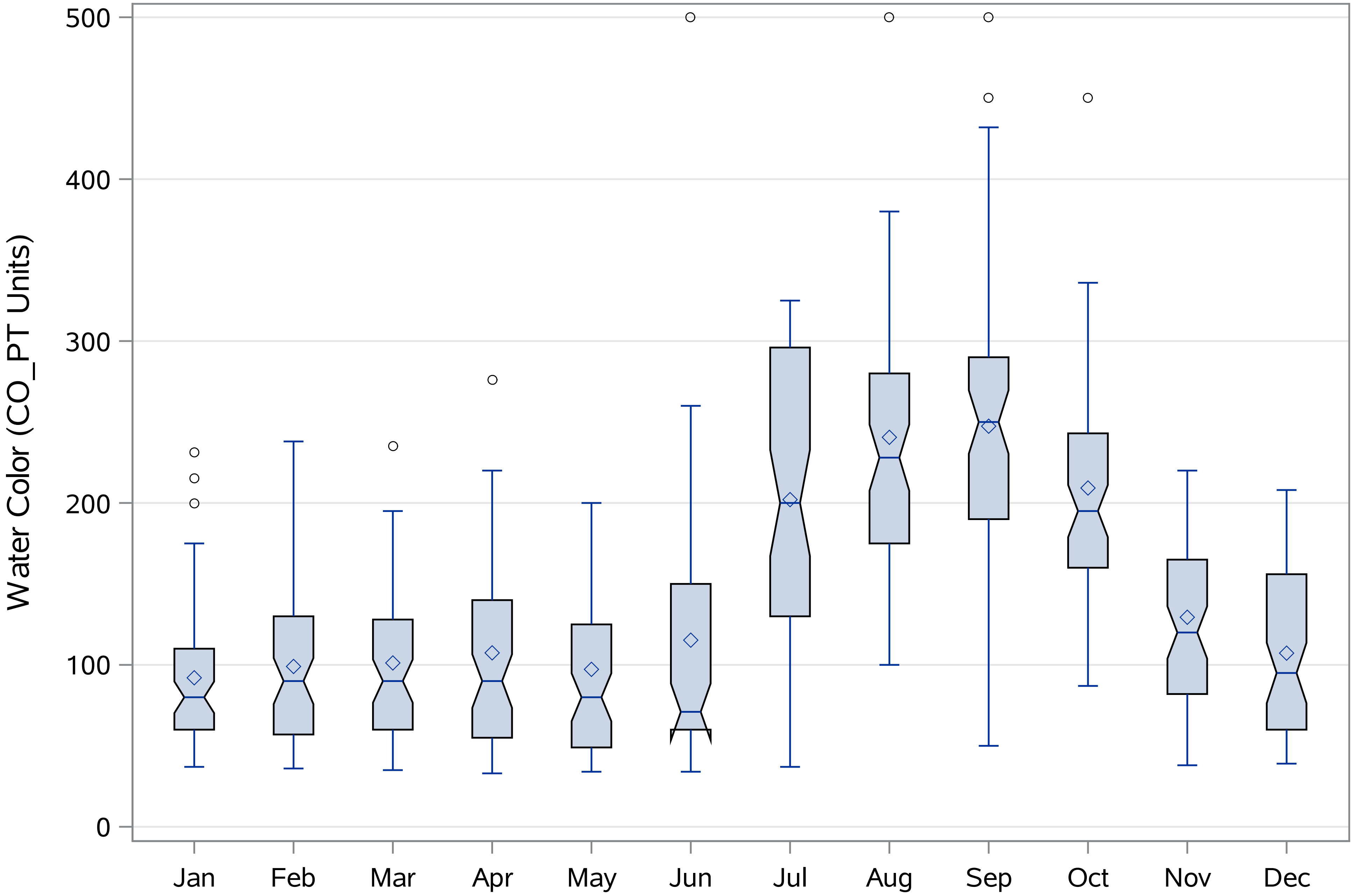

Figure 5.223. Mean monthly boxplots of surface Water Color at the 0 psu isohaline (1984-2016)

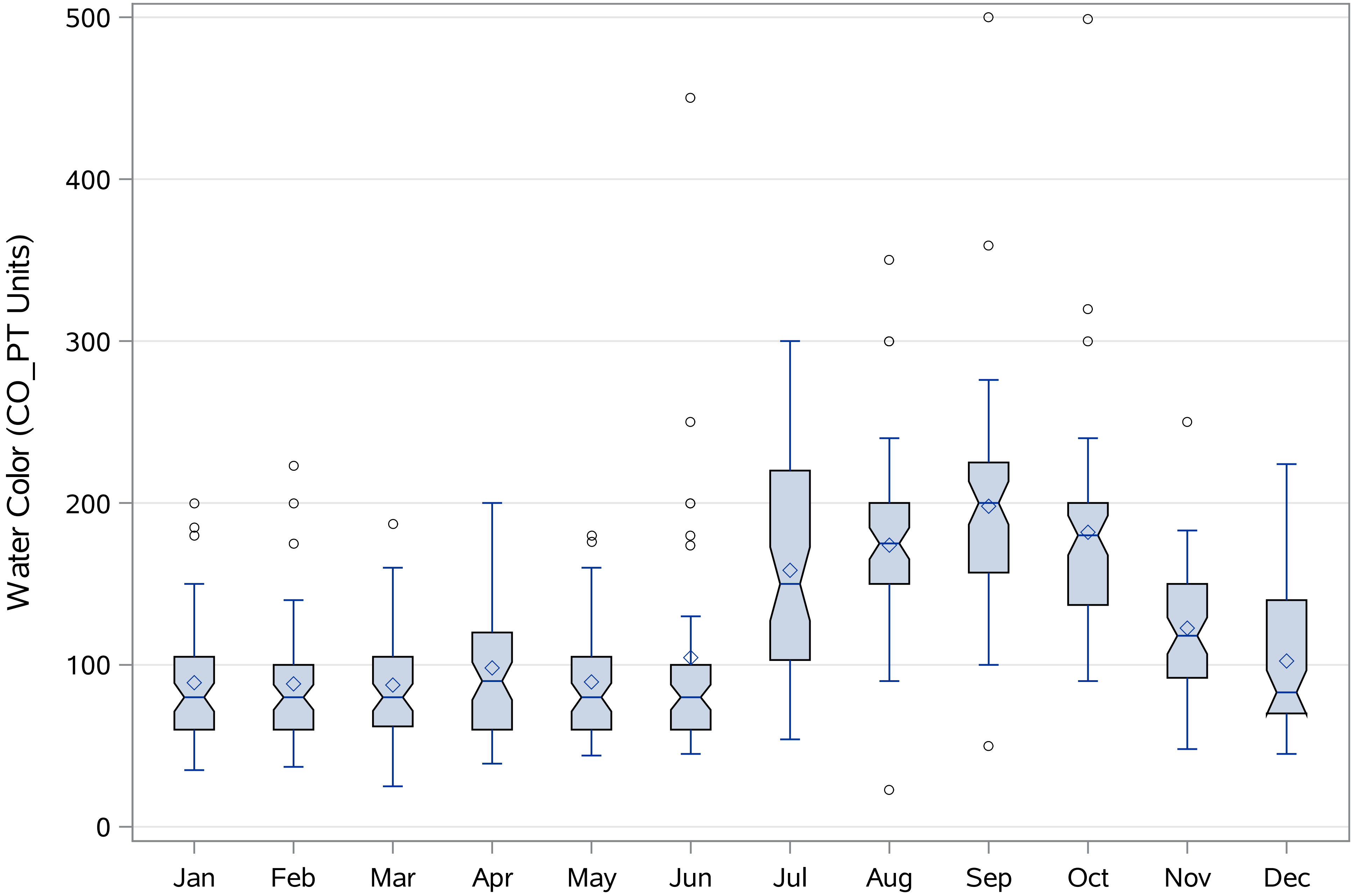

Figure 5.224. Mean monthly boxplots of surface Water Color at the 6 psu isohaline (1984-2016)

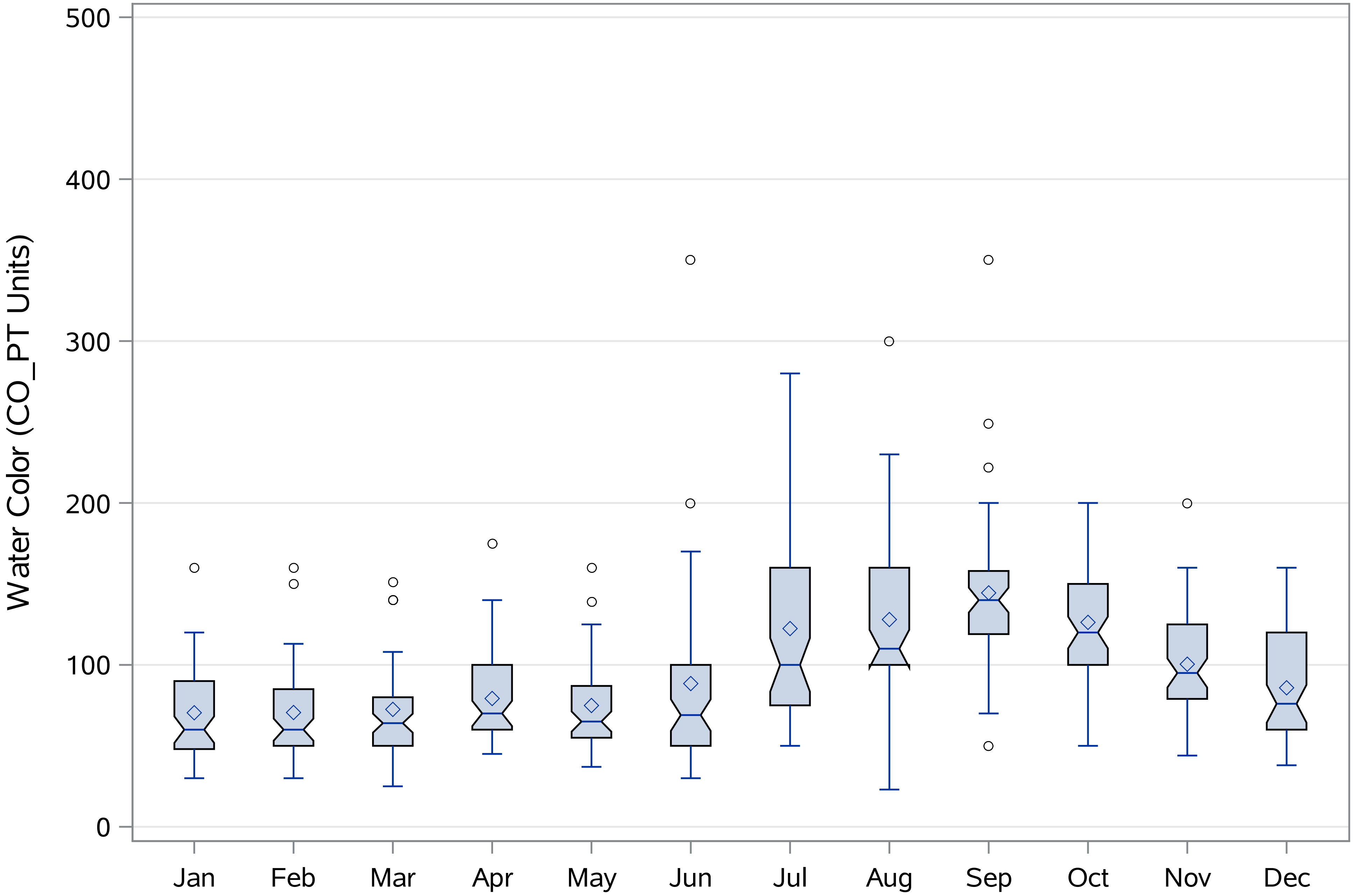

Figure 5.225. Mean monthly boxplots of surface Water Color at the 12 psu isohaline (1984-2016)

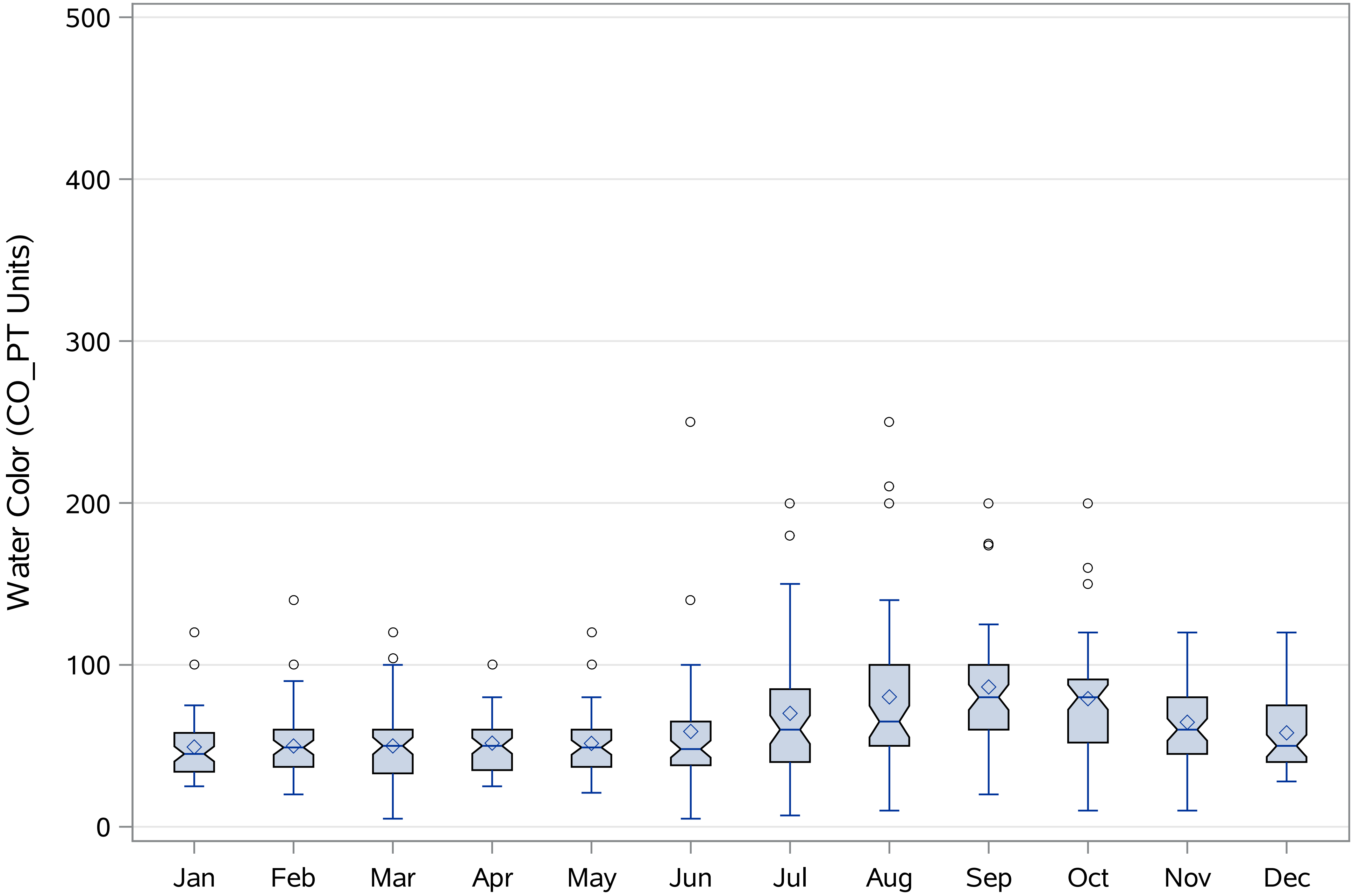

Figure 5.226. Mean monthly boxplots of surface Water Color at the 20 psu isohaline (1984-2016)

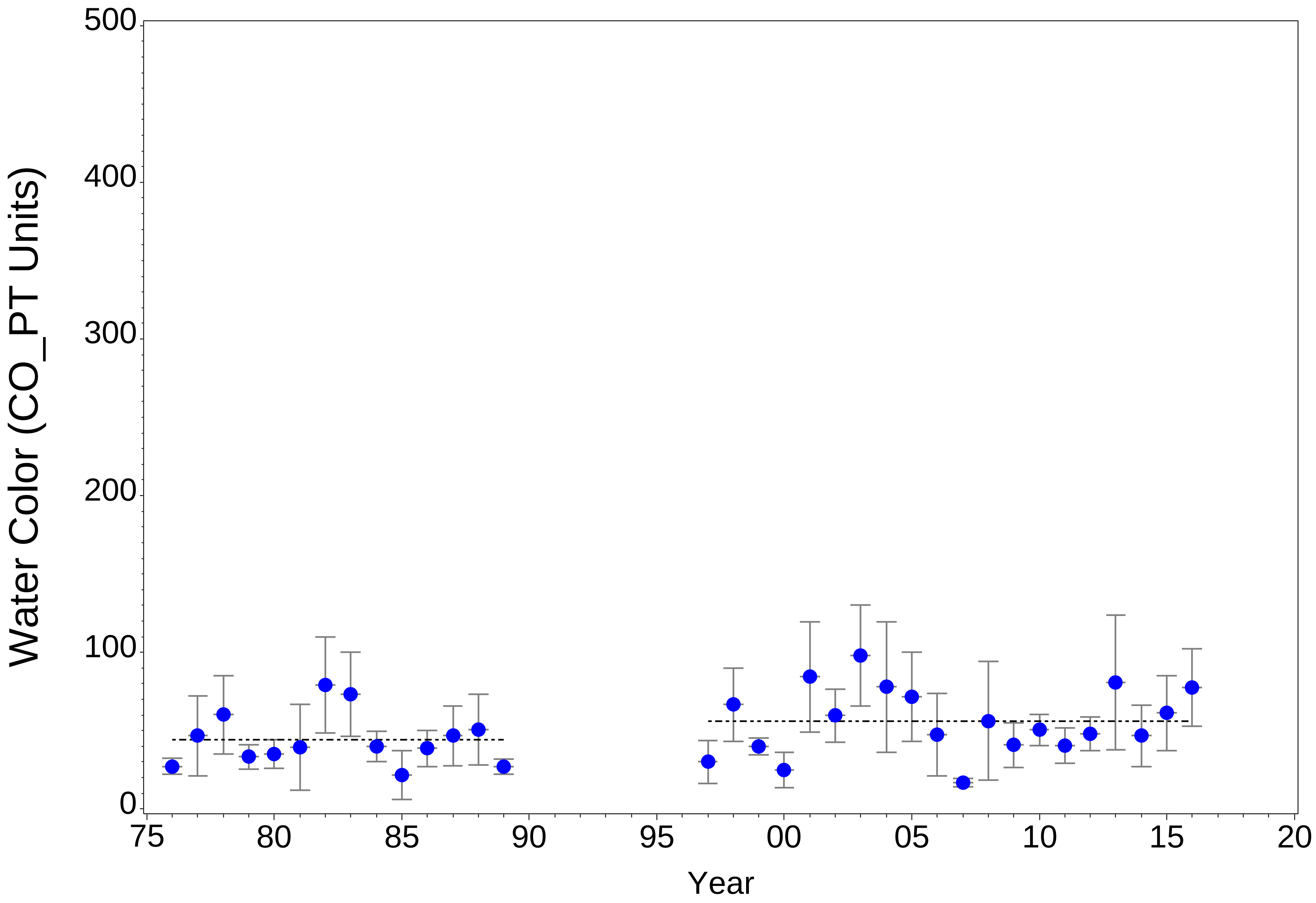

Figure 5.227. Long-term Station 9 surface Water Color at river kilometer -2.4

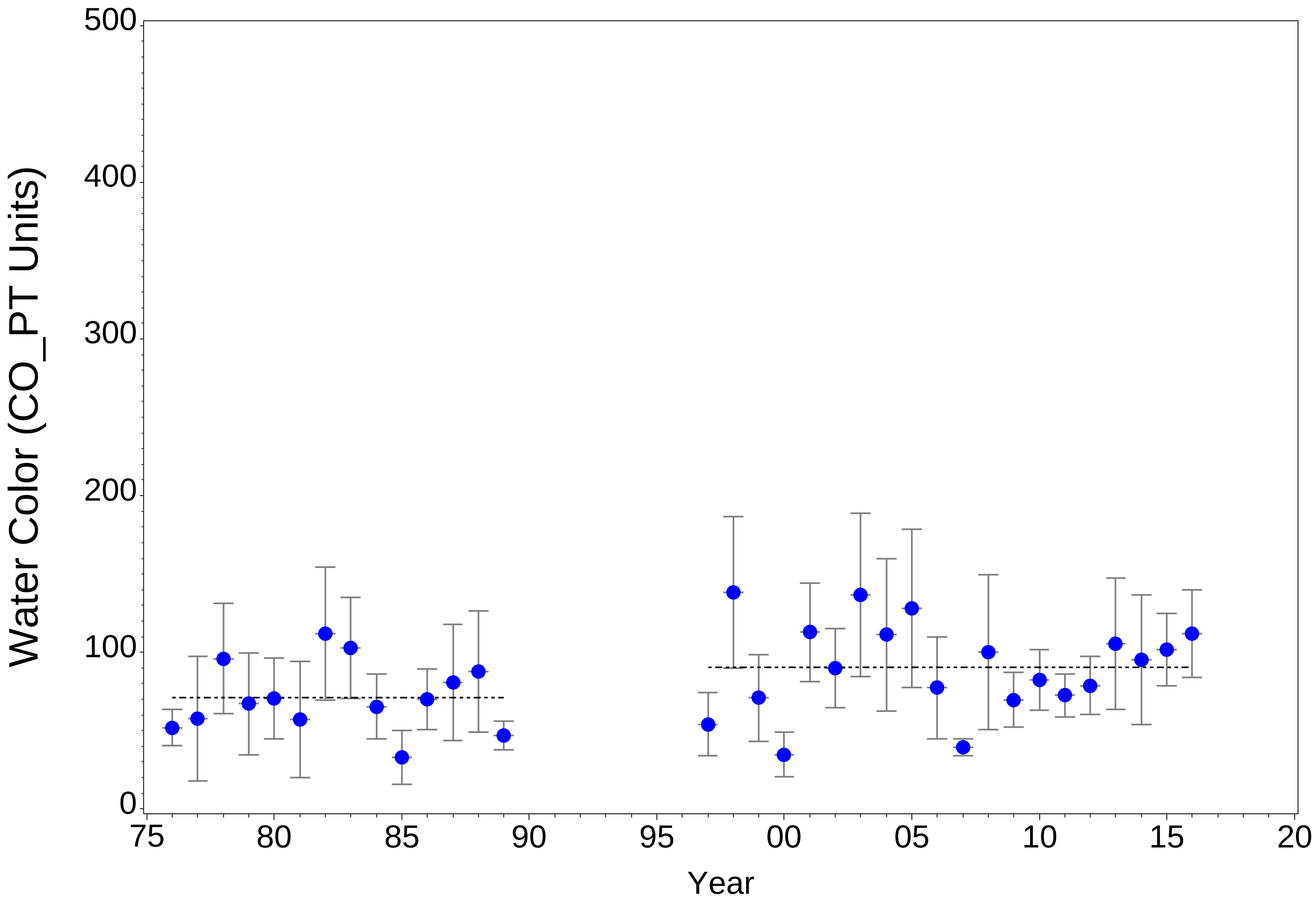

Figure 5.228. Long-term Station 10 surface Water Color at river kilometer 6.6

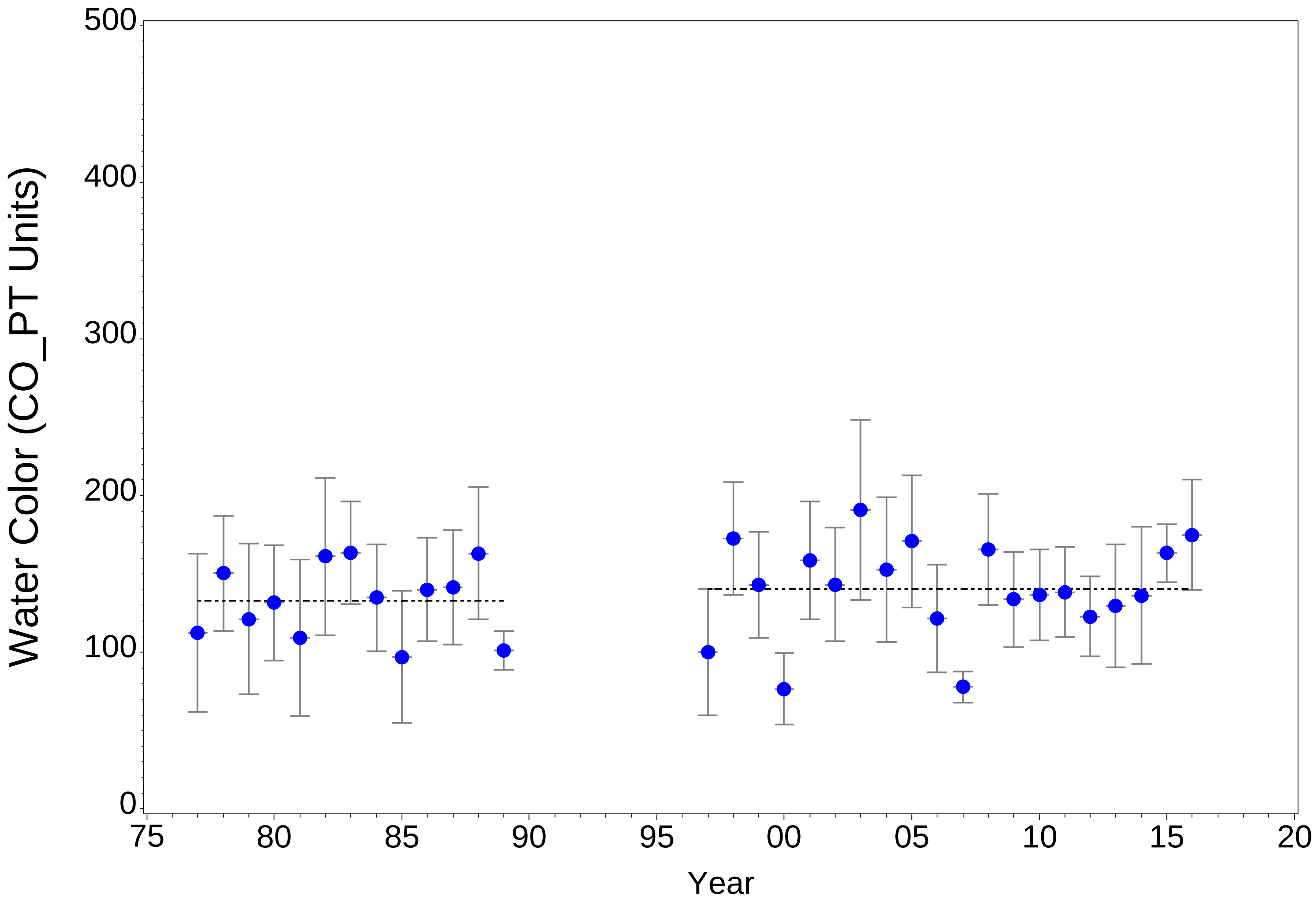

Figure 5.229. Long-term Station 12 surface Water Color at river kilometer 15.5

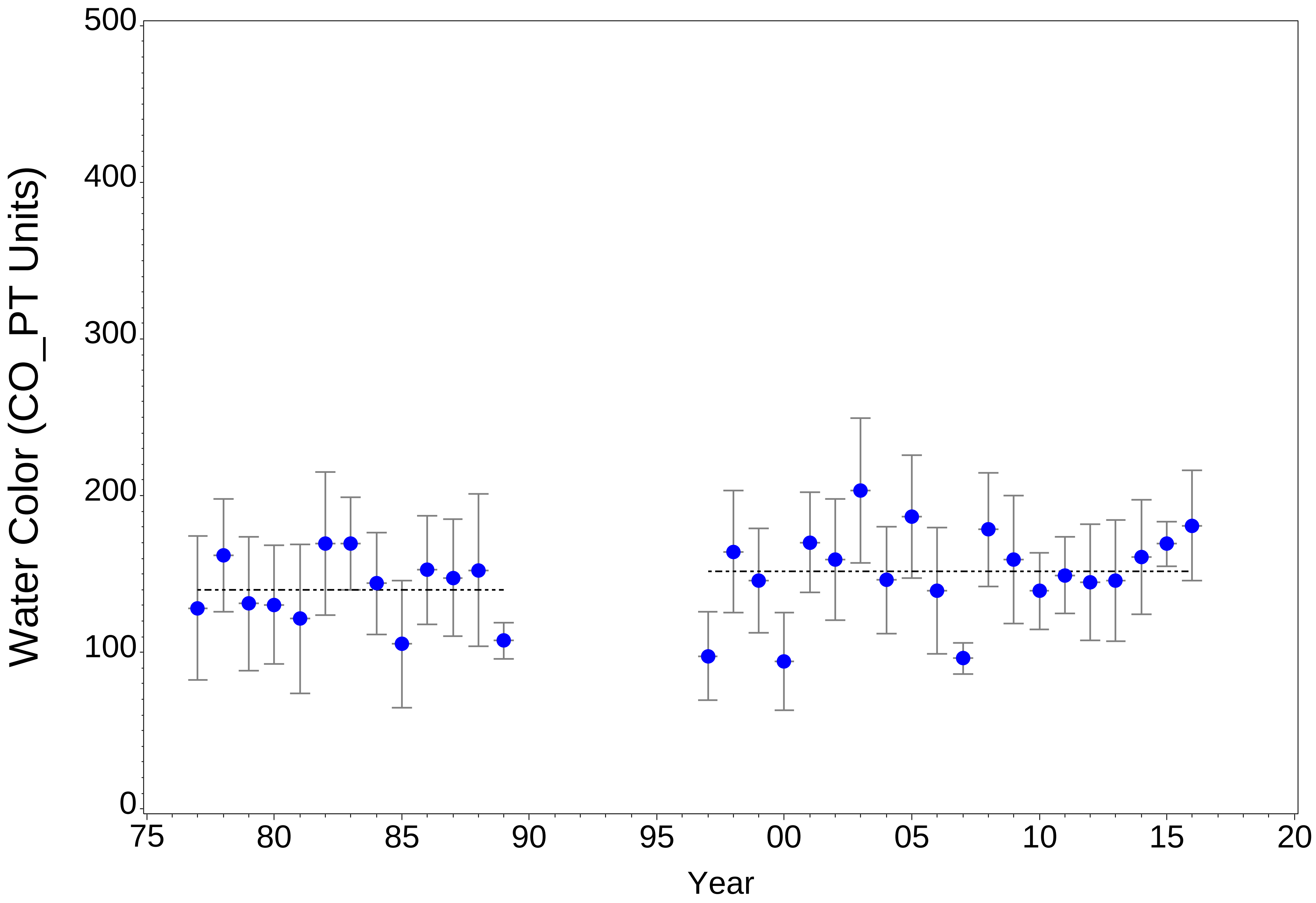

Figure 5.230. Long-term Station 14 surface Water Color at river kilometer 23.6

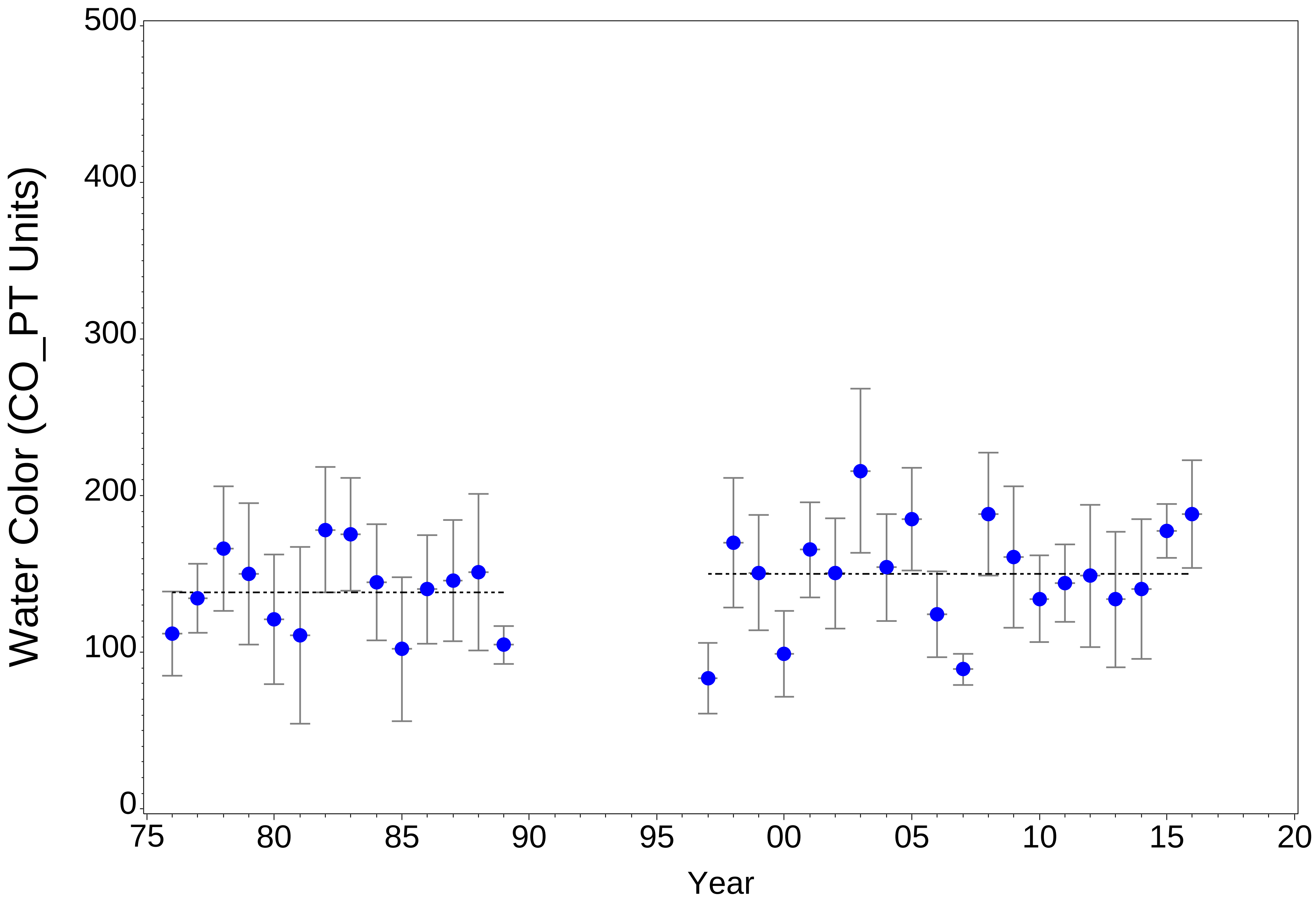

Figure 5.231. Long-term Station 18 surface Water Color at river kilometer 30.7

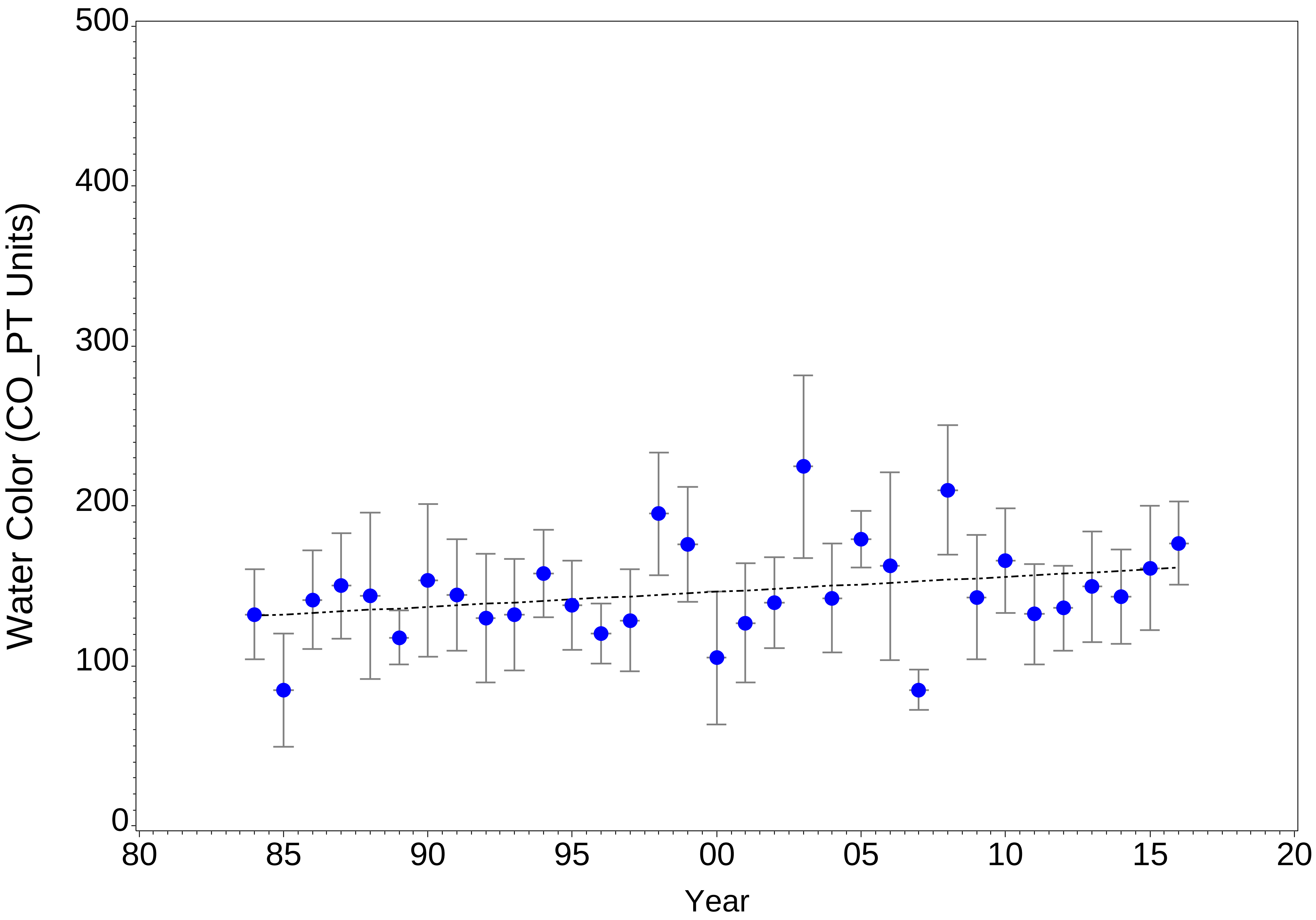

Figure 5.232. Annual monthly surface Water Color at 0 psu isohaline (1984-2016)

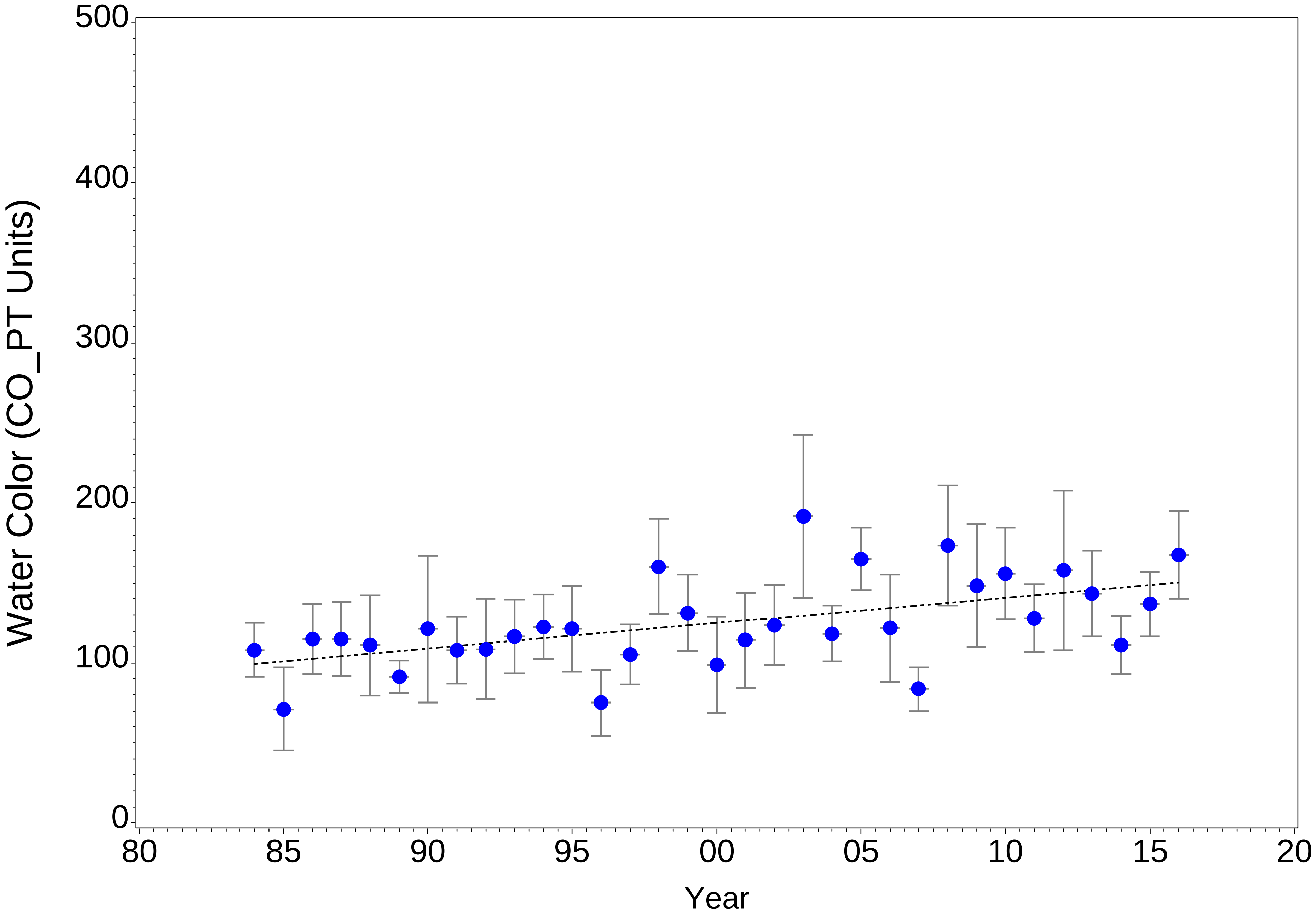

Figure 5.233. Annual monthly surface Water Color at 6 psu isohaline (1984-2016)

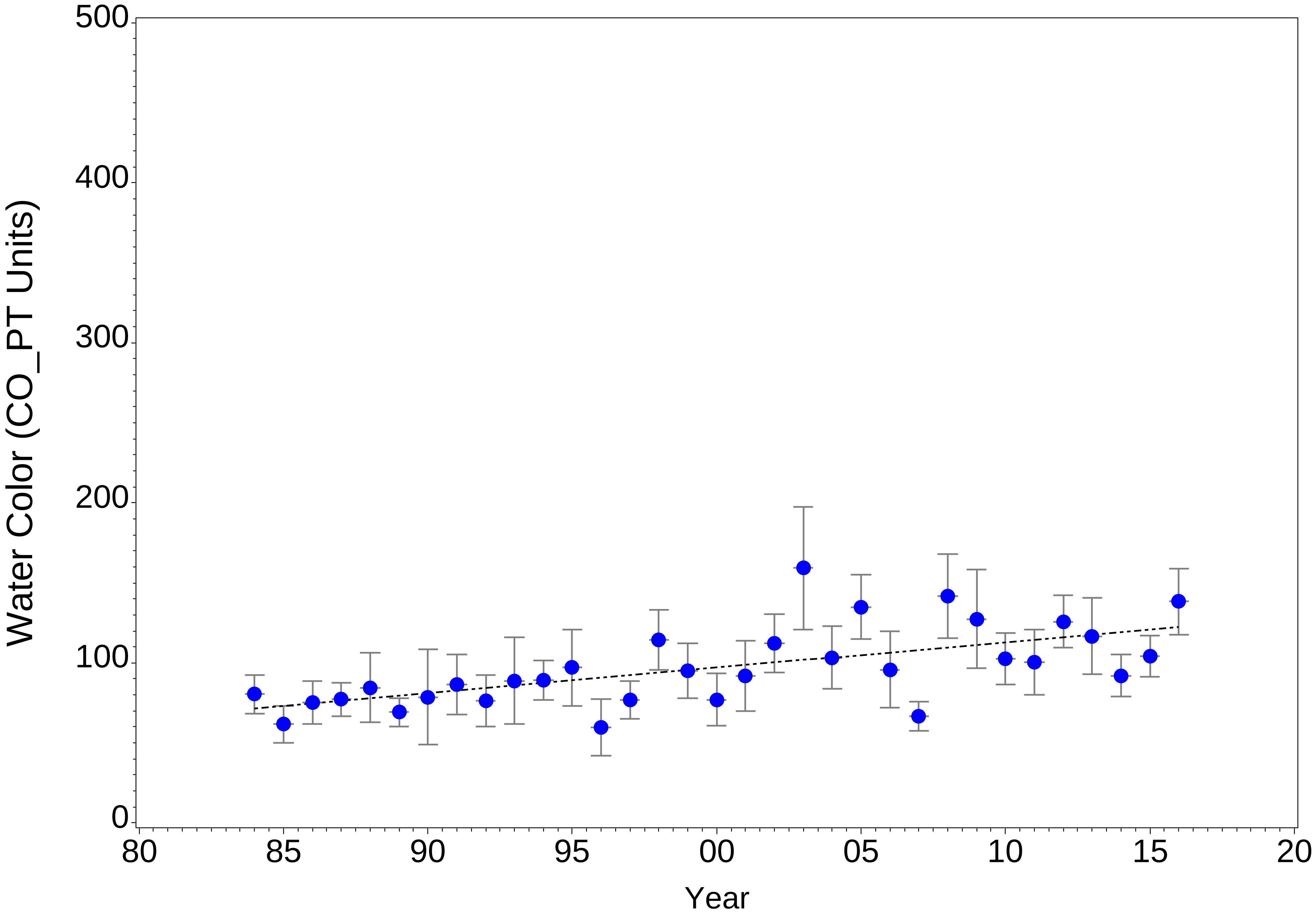

Figure 5.234. Annual monthly surface Water Color at 12 psu isohaline (1984-2016)

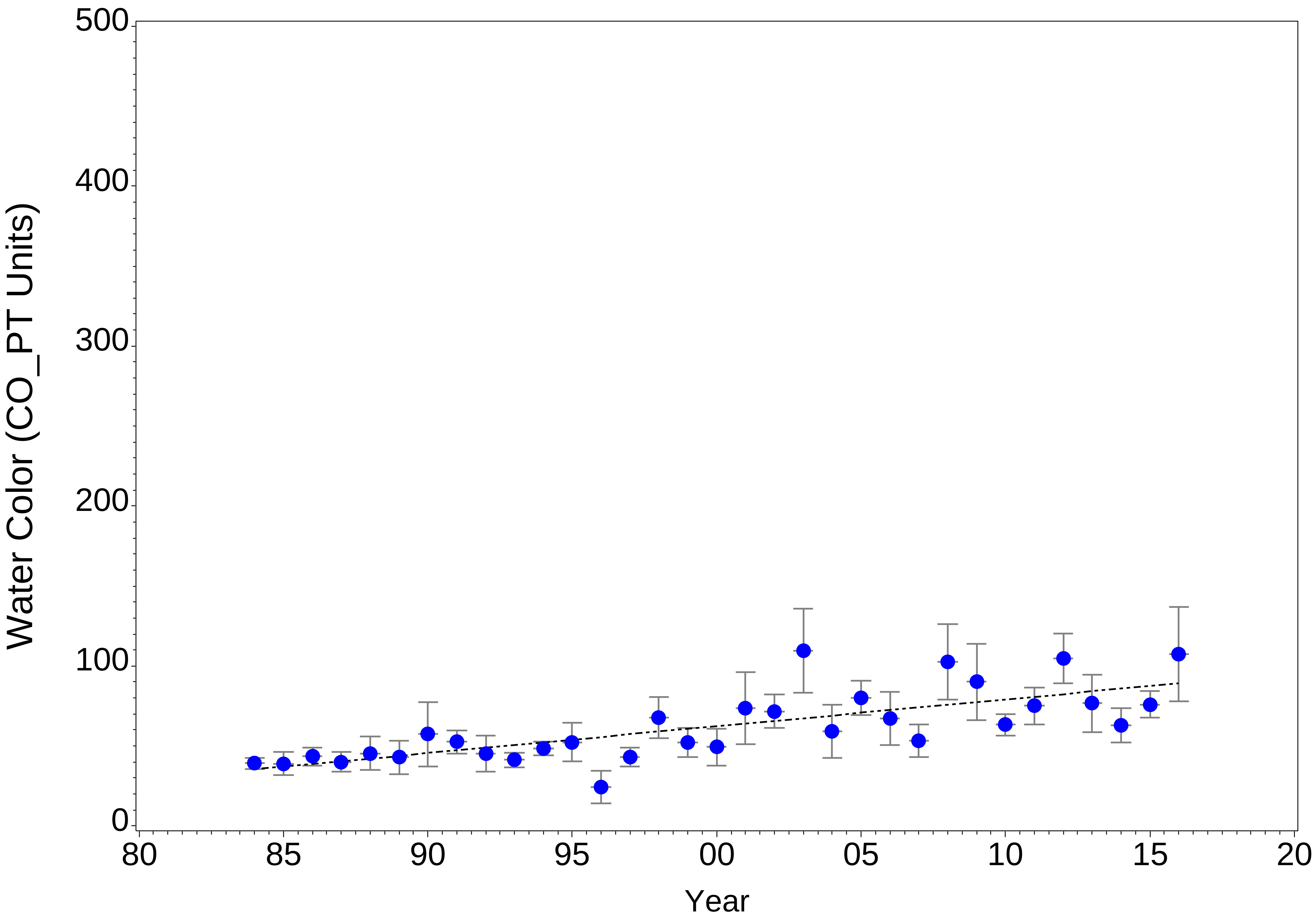

Figure 5.235. Annual monthly surface Water Color at 20 psu isohaline (1984-2016)

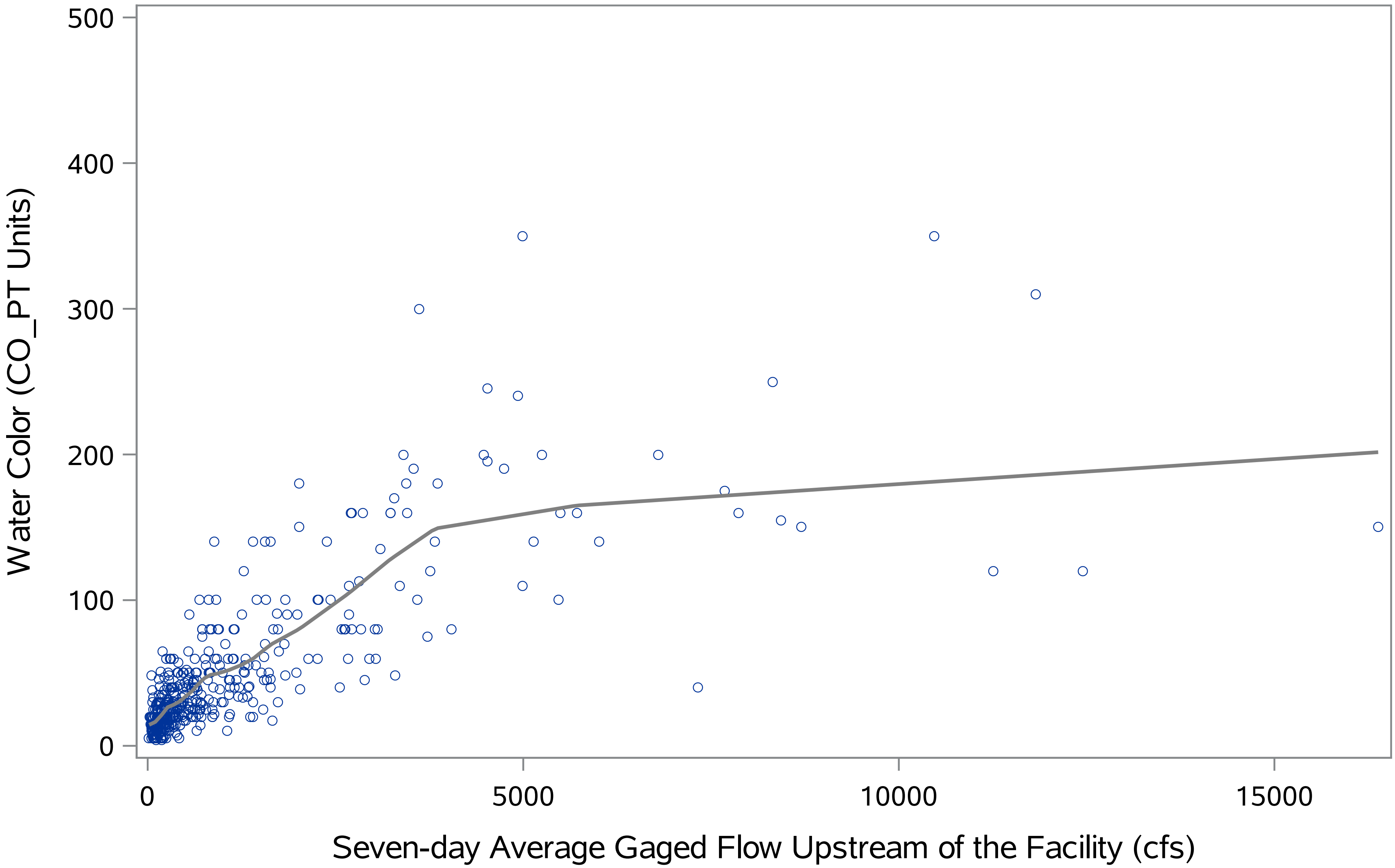

Figure 5.236. Surface Water Color at river kilometer -2.4 versus flow

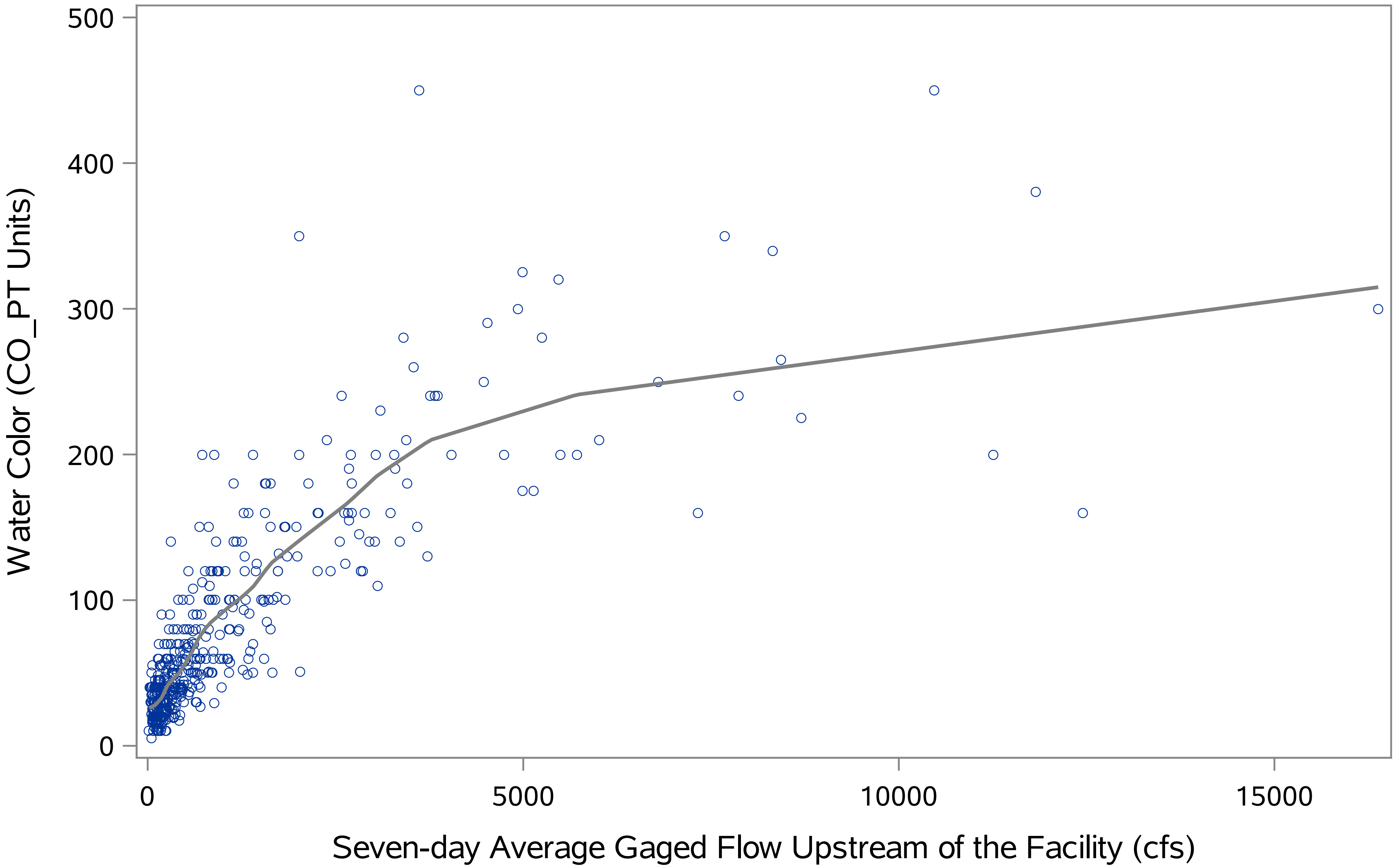

Figure 5.237. Surface Water Color at river kilometer 6.6 versus flow

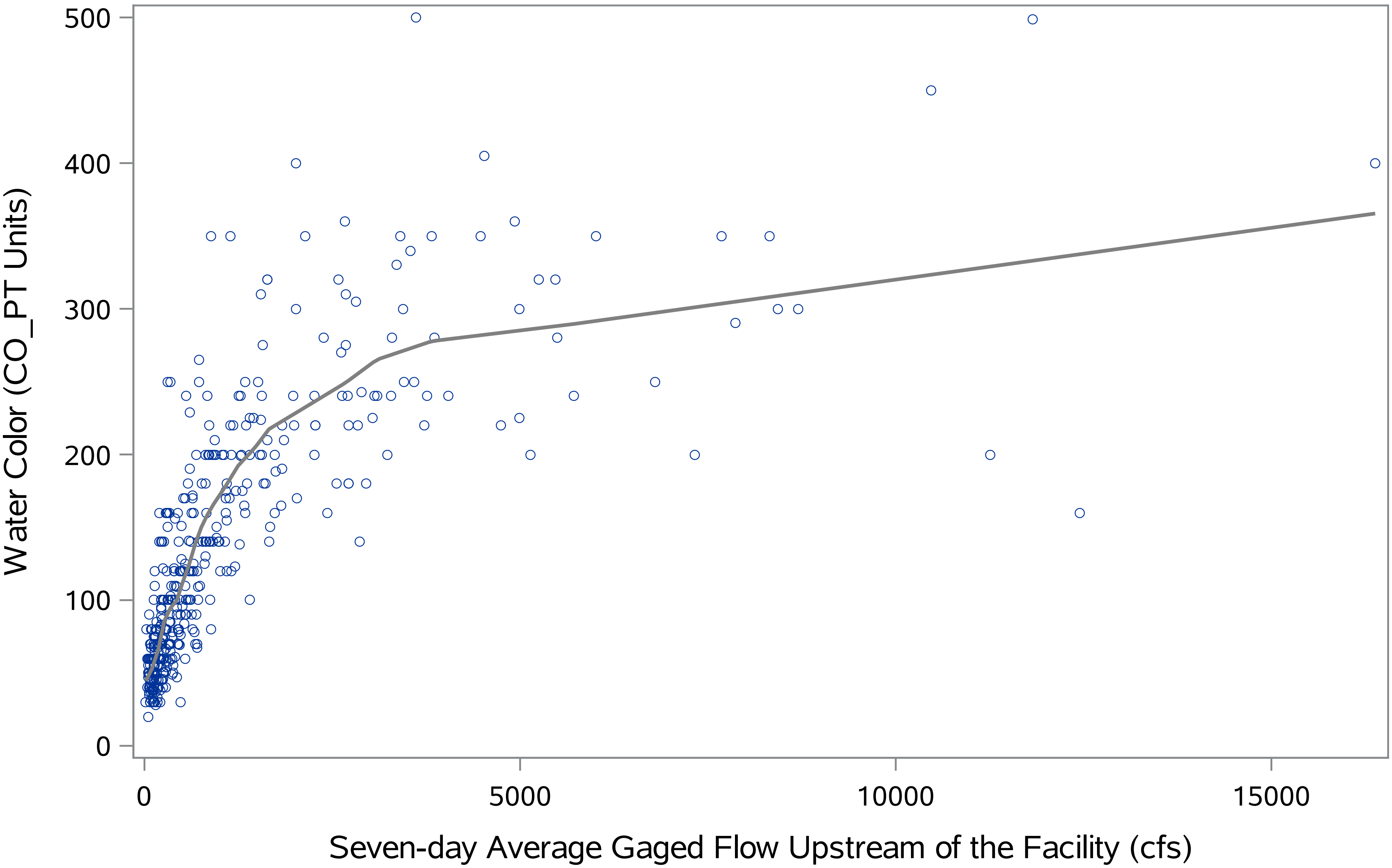

Figure 5.238. Surface Water Color at river kilometer 15.5 versus flow

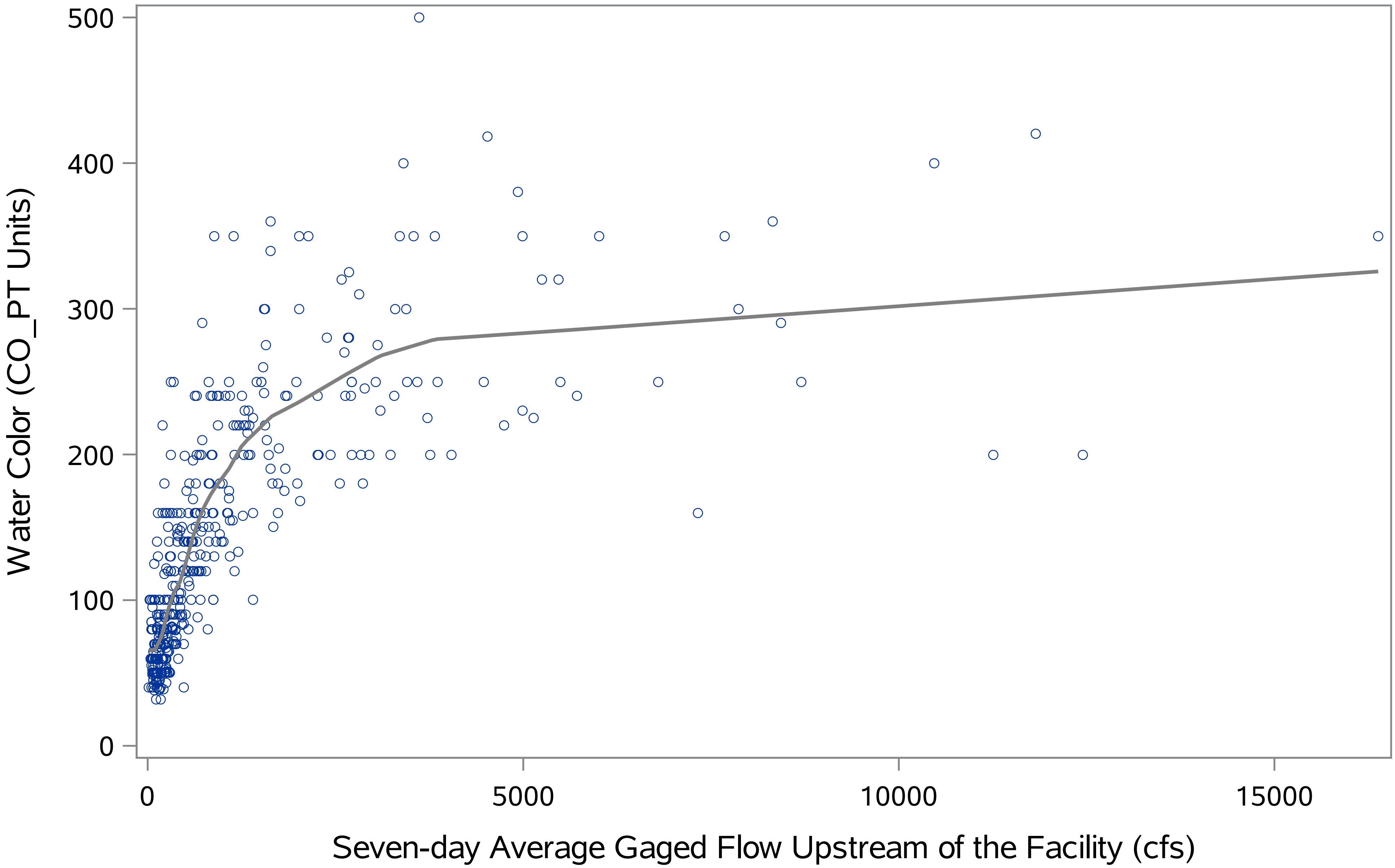

Figure 5.239. Surface Water Color at river kilometer 23.6 versus flow

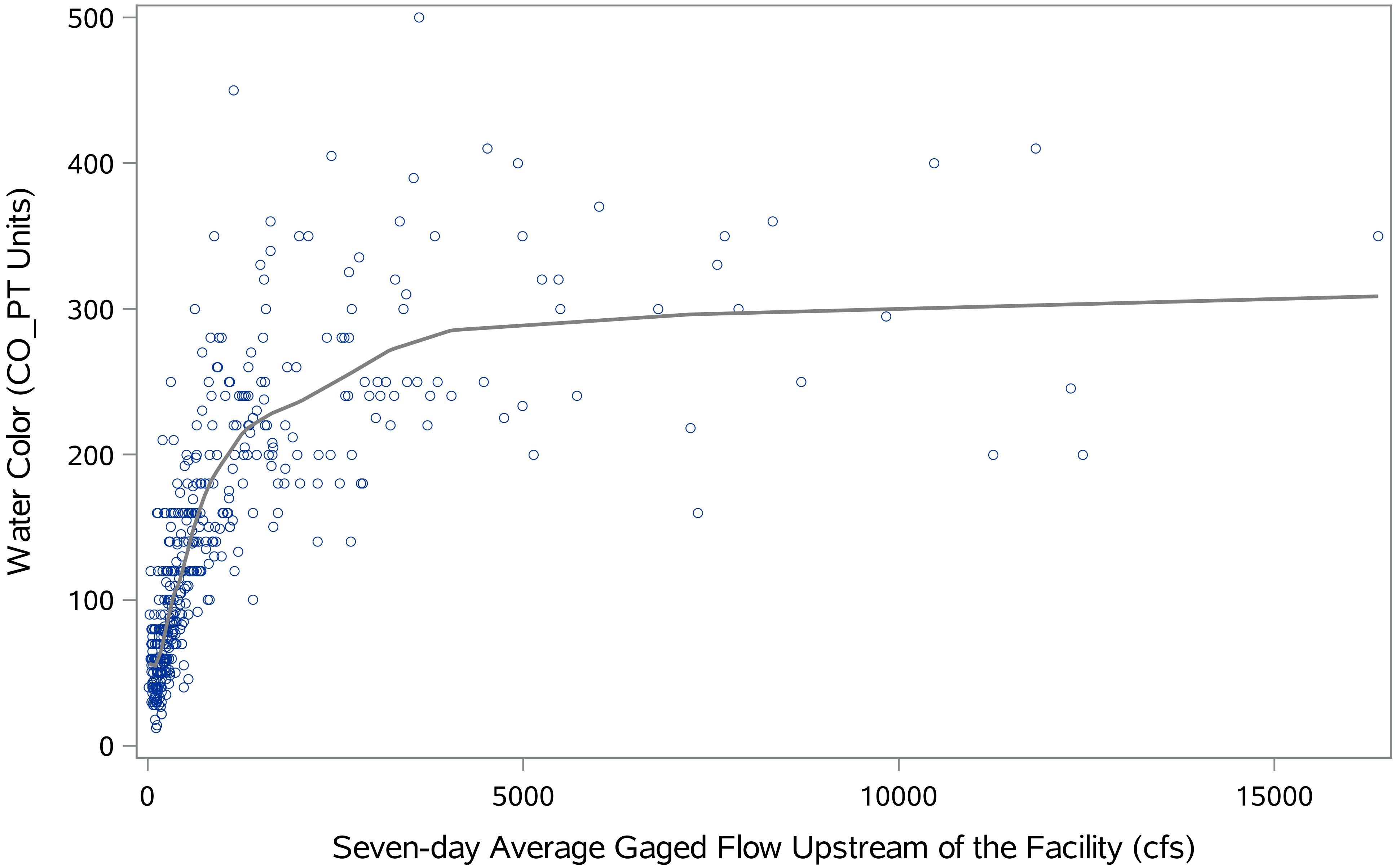

Figure 5.240. Surface Water Color at river kilometer 30.7 versus flow

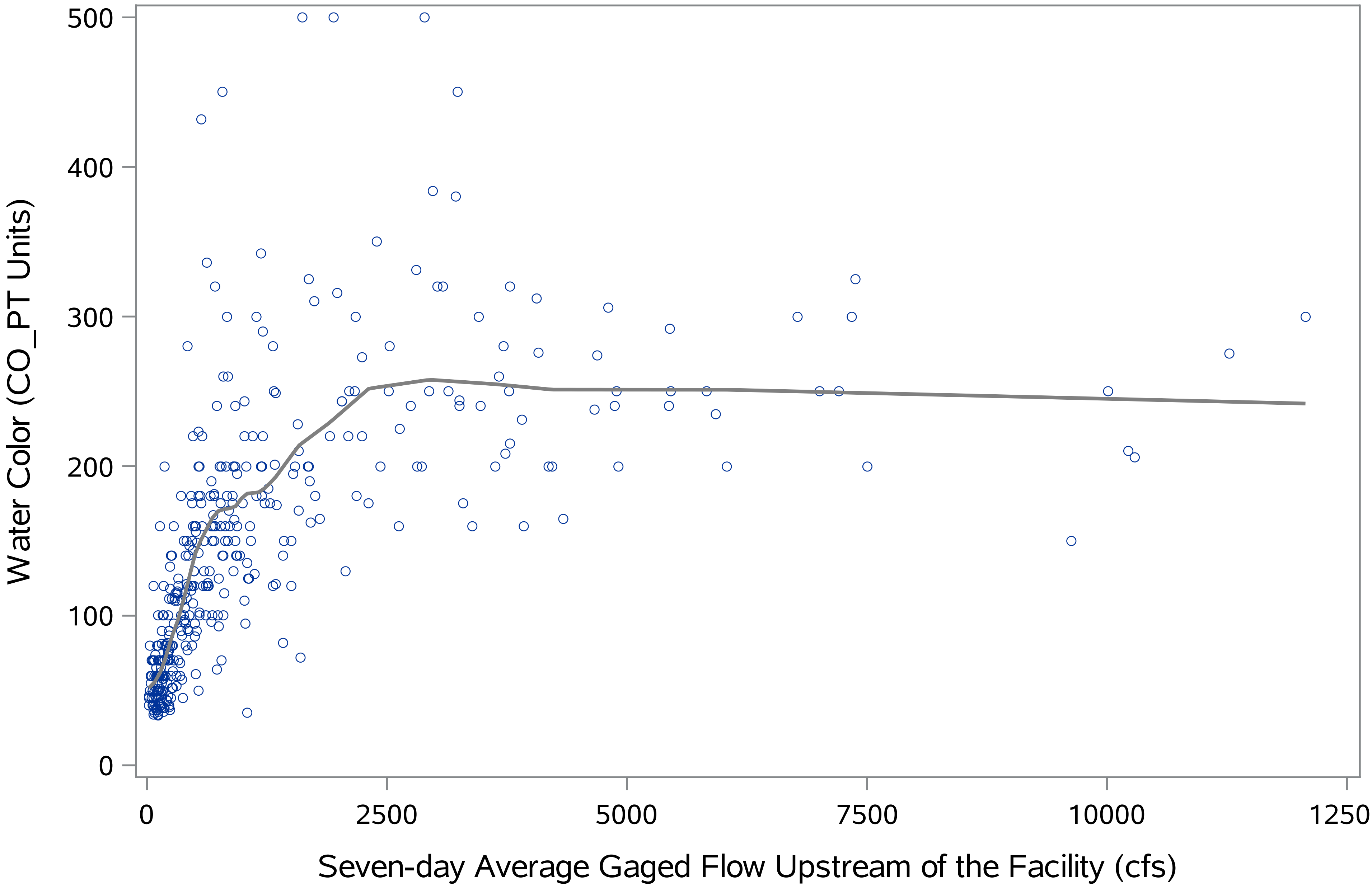

Figure 5.241. Water Color at the 0 psu isohaline versus flow

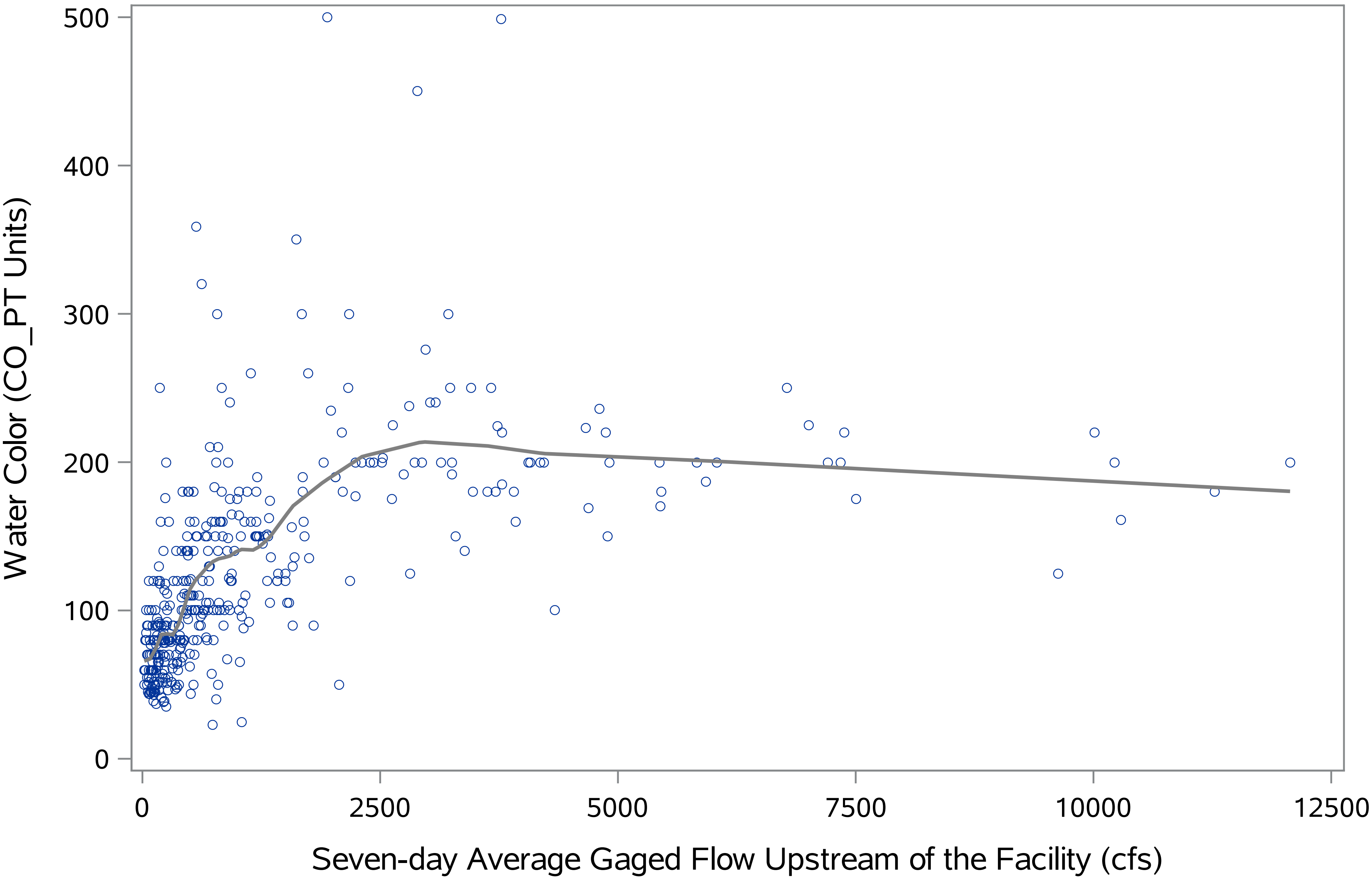

Figure 5.242. Water Color at the 6 psu isohaline versus flow

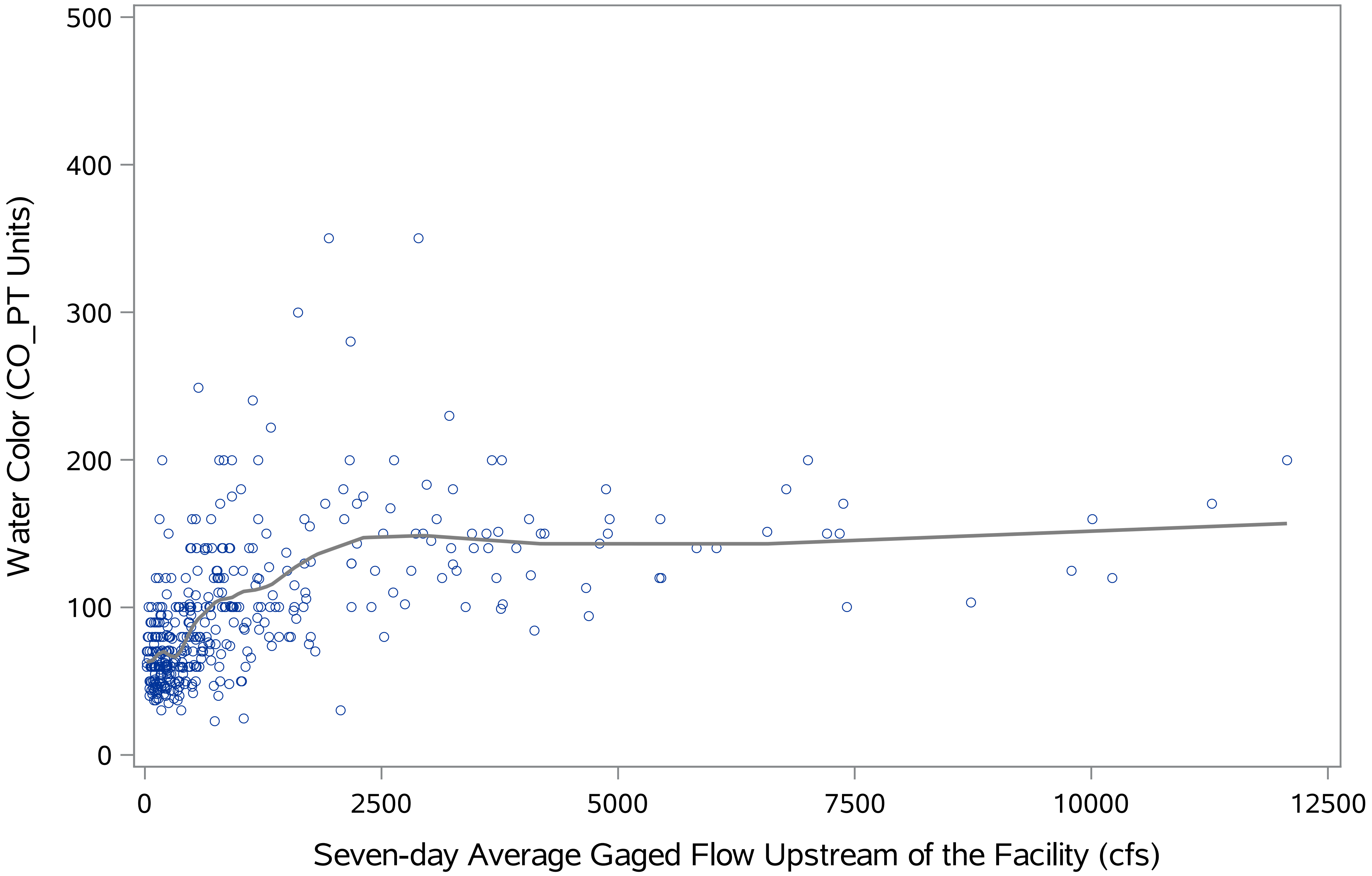

Figure 5.243. Water Color at the 12 psu isohaline versus flow

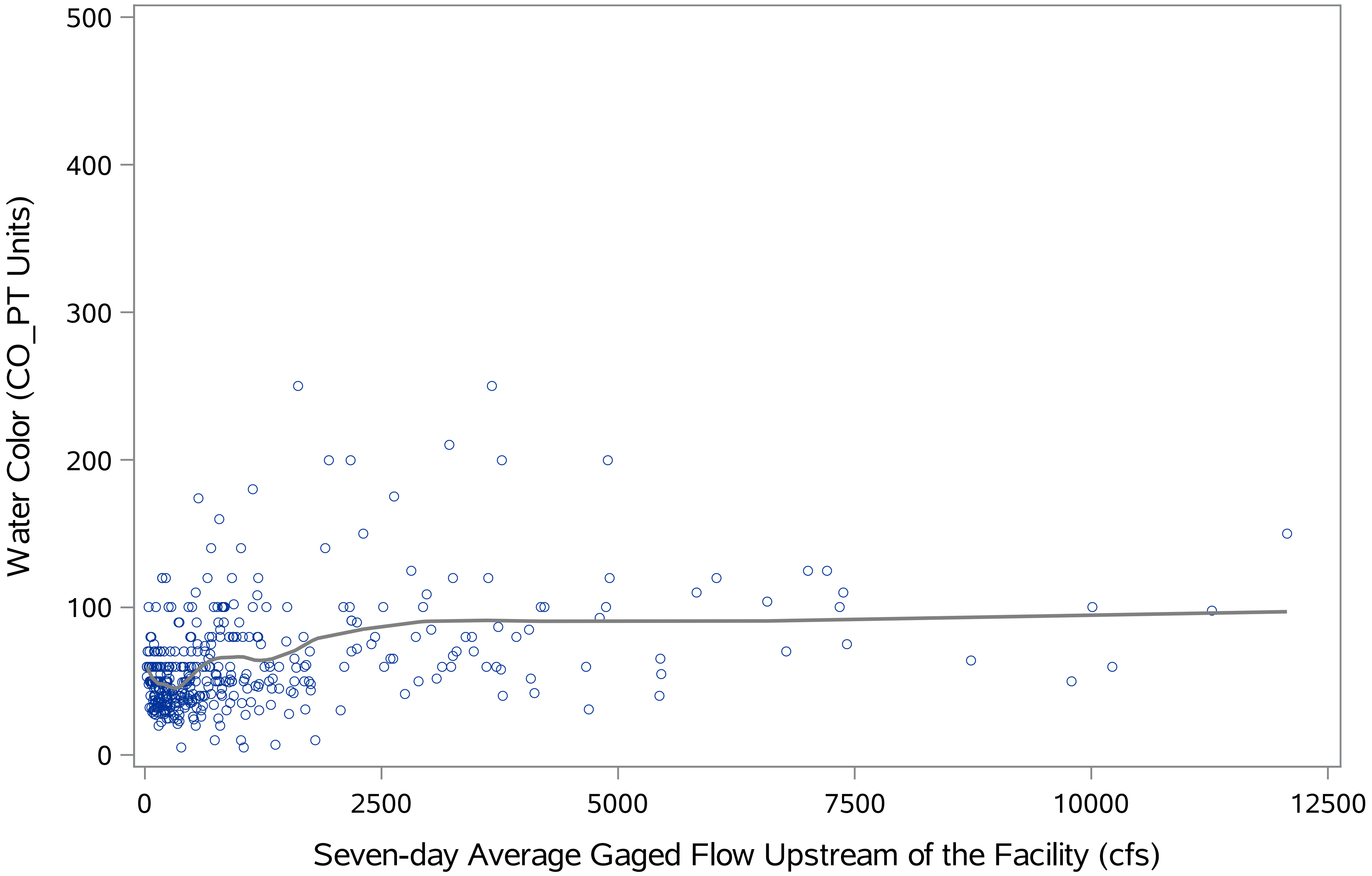

Figure 5.244. Water Color at the 20 psu isohaline versus flow

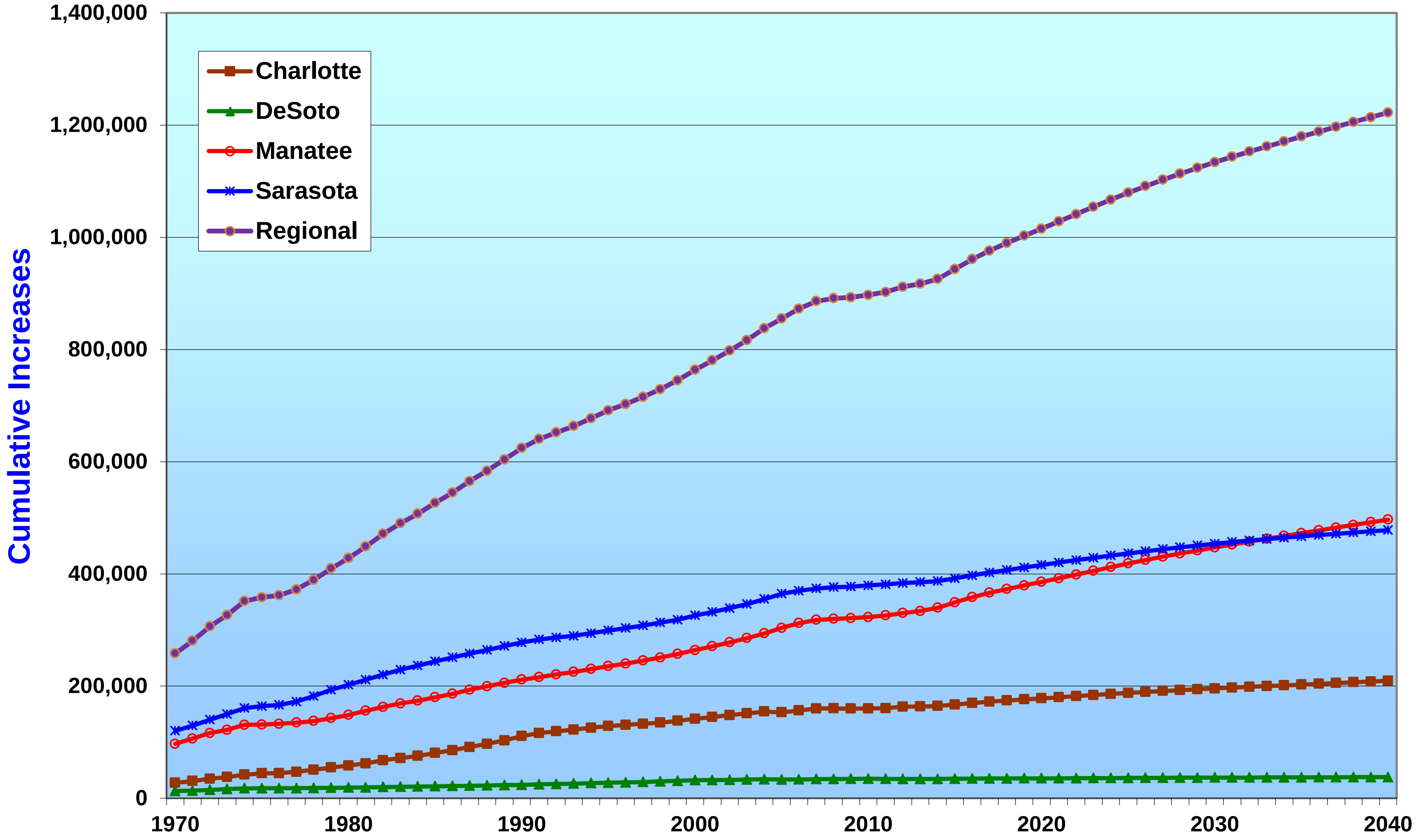

Figure 7.2 Projected potential population increase in the counties receiving water from the Peace River