Upper Peace River - Three Lakes Modeling Report Using WAM and WASP

WAM Setup and Results for the Development of a Total Maximum Daily Load (TMDL) estimation for Lakes Alfred, Arianna and Crystal in the Upper Peace River basin, Florida.

Completed For:

TETRA TECH

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SWET
Soil & Water Engineering Technology, Inc.

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Executive Summary

Soil and Water Engineering, Inc (SWET) contracted with Tetra-Tech, Inc. to assist the US Environmental Protection Agency (EPA) in the development of a Total Maximum Daily Load (TMDL) estimation for three Water Body Identification Numbers (WBID) in the Upper Peace River Basin, Central Florida. The three WBID's, listed below contained a total of five separate water bodies as listed below:

- 1488D – Lake Alfred, Lake Camp, Lake Grass;
- 1497A - Lake Crystal; and
- 1501B – Lake Ariana.

To develop the TMDL limits, SWET used the Watershed Assessment Model (WAM) to simulate the source loads of pollutants and water quantity originating on the land surrounding the three water bodies that drain to these WBIDs for two conditions. Existing (2007) and predevelopment (natural) conditions were run, where the natural condition was used to set the TMDL after the existing condition was used to calibrate the model. WAM has been linked to the Water Quality Analysis Simulation Program (WASP). The source load generated by WAM was used as the input parameters to WASP in order to accurately model the lake simulation processes.

Eutrophication processes in Lakes Alfred, Ariana, and Crystal were simulated using the program WASP (Water Quality Analysis Program) developed by the United States EPA. For this project, each lake was treated as a single "segment" in WASP, with a second segment used to accumulate recharge to the underlying aquifer. The lake segment was modeled using the standard eutrophication module in WASP, which contains a set of built-in routines to simulate nutrient enrichment and eutrophication. Mass loads (in Kg/day) of each of the state variables was determined by WAM and provided, together with water flows and volumes, as input data to WASP. The most abundant measured data in each of the lakes consisted of dissolved oxygen, total nitrogen, and total phosphorus, followed by ammonia, nitrate, orthophosphate, chlorophyll-a, and BOD.

An existing WASP calibration dataset developed by TetraTech for another study of lakes in central Florida was used as the starting point for calibration parameters. WASP was then calibrated to obtain reasonable fits with observed data for the lakes. Once a satisfactory fit was obtained for the lakes, the simulations were run again using loading values from WAM obtained by running a "natural conditions" scenario. The hydrologic conditions and internal WASP parameters were kept the same as the existing conditions calibration simulation. The external nutrient loads into the lake provided by WAM were greatly reduced over the scenario using existing conditions. From the data obtained from both scenarios, the Trophic State Index (TSI) was calculated. The most obvious point shown by the data is that the TSI is not significantly lowered by reducing the nutrient load to the lakes. This is due to the benthic nutrient fluxes being a significant fraction of the total nutrient load provided to the lakes. To show this effect, a series of model runs were performed using the external nutrient loadings provided by the natural conditions scenario and the same hydrologic conditions and WASP parameters, with the exception of lowering the benthic fluxes for NH4 and OPO4 by a set percentage for each run. Simulations with "natural" external loadings had benthic fluxes at 100%, 90%, 80%, 70%, 50%, and 25% of the original values determined in the calibration run. The results indicate that the residential effects of the buildup benthic communities will delay lake responses to reduced land source nutrient loads, so lake restoration will also need to focus on benthic flux sequestering processes.

Project Overview and Report Structure

The Peace River Basin is located in Central Florida, almost entirely within the South West Florida Water Management District (SWFWMD). The headwaters of the Peace River are characterized by predominantly urban land use types including the cities of Lakeland, Auburndale, Winter Haven and Lake Alfred in Polk County. These cities have experienced rapid population growth over the past decade. These upper Peace River reaches and the lakes of interest have internally drained lake hydrogeology or closed basins with many of the lakes not discharging under normal rainfall conditions. The three lake WBIDs are located in the very top of the Peace River which flows south from its headwaters through the predominantly rural counties of Hardee and Desoto until draining into the Gulf of Mexico in Charlotte County (Figure 1).

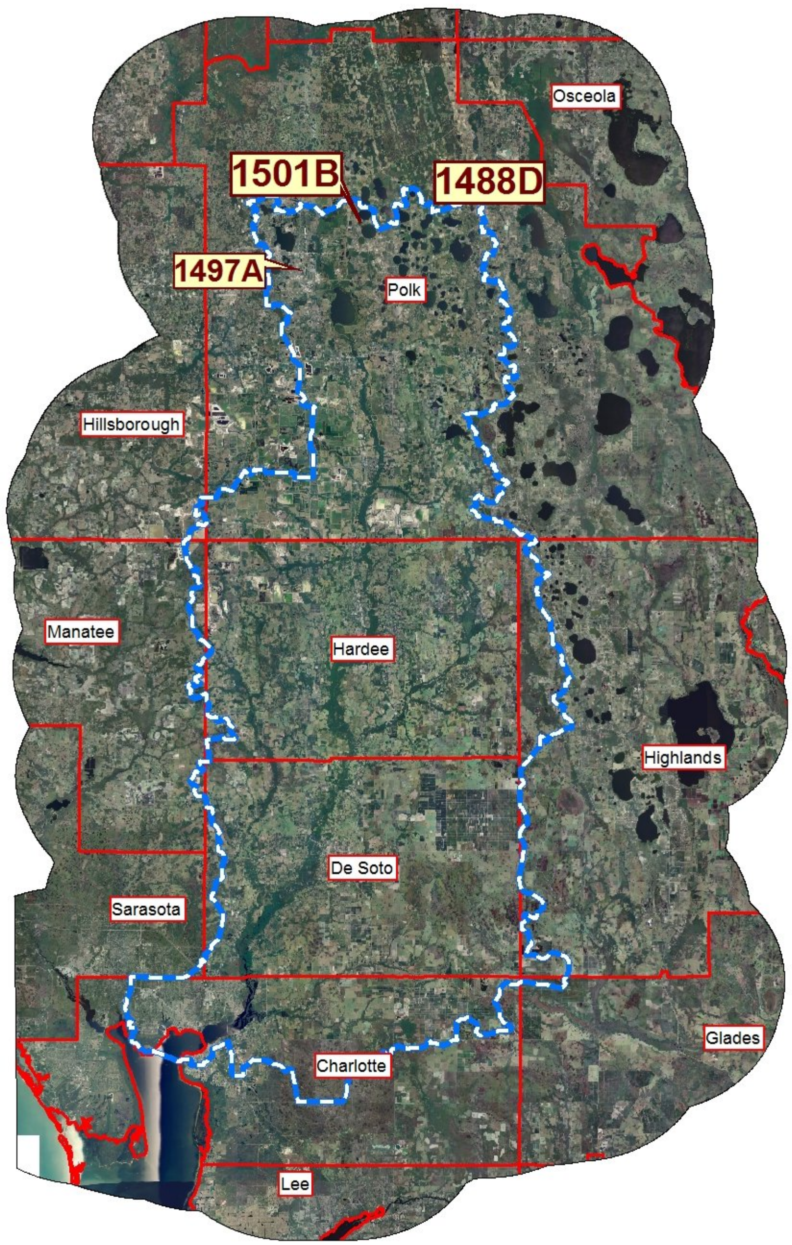


Figure 1: Peace River Basin, 2004 Aerial, Counties and Listed WBIDs

The three WBID's which were assessed in this project are all located in Polk County (Figure 2). Each of the WBIDs is a unique and hydrologically separate lake system that was studied through independent model simulation runs. A detailed description of each WBID modeled, the input data characteristics and a brief interpretation on the WAM and WASP modeling results are discussed individually in their respective sections of this report. The project overview section below, contains a summary of the WAM and WASP modeling processes and details on the data as a whole that was collected to be used as inputs to these models. It is essential that the reader have a general understanding of the processes that WAM and WASP utilize to model watersheds in order to better understand model limitations and interpret results.

A simulation period from 1980 through the end of 2008 was used with a three year spin-up period for model calibration and natural conditions simulations. WAM has previously been used for Lake Hancock TDML that was complete by the Florida Department of Environmental Protection. This project included two of the lake WBIDs being studied here, namely Crystal and Arianna. Where relevant, information gathered through this previous project was used for this project.

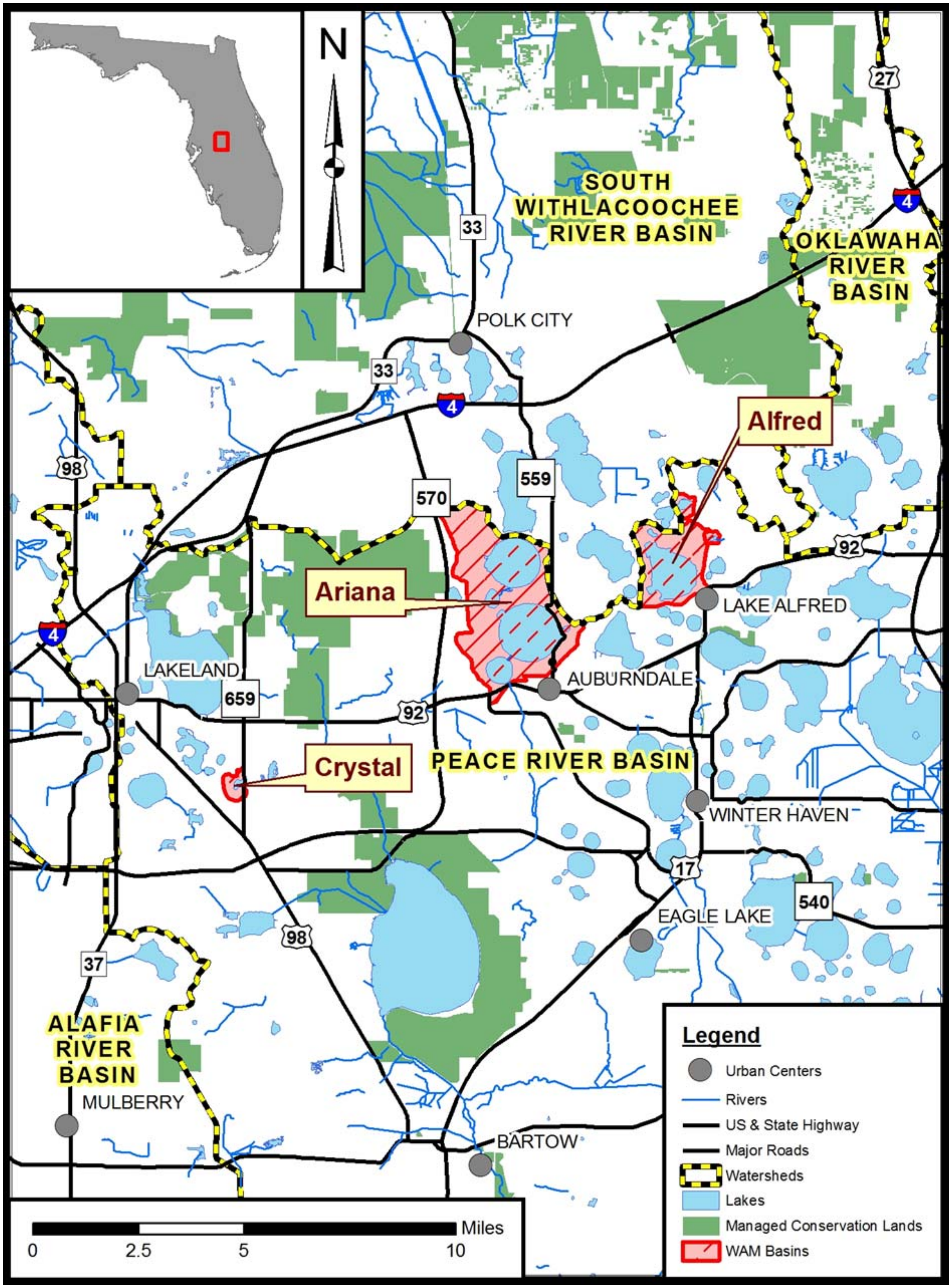


Figure 2: Project Locations

Overview of the Watershed Assessment Model

The Watershed Assessment Model (WAM) is a Geographical Information System (GIS) model that assesses the water quantity and quality responses to land use management practices within watersheds. WAM was developed to allow users to assess the water quantity and quality of both surface water and groundwater based on the detailed physical properties of the watershed and the underlying hydrogeological system. The model simulates the primary physical processes important for watershed hydrologic and pollutant transport, originating on individual fields or land uses and then dynamically routing the flows and constituents throughout the stream system.

WAM uses a GIS grid based (raster) representation to model the physical characteristics of the land surface. Depending on the combination of input GIS datasets (land use, soil type, presence of a wastewater service area, and rainfall zones), unique cells, or cell groupings, are determined that characterize distinctive conditions. Based on the land use and soil characteristics of the unique cell, an appropriate field-scale model is selected that will simulate the daily surface and groundwater constituents originating from the cell and will be transported to the respective stream reaches. Once the daily outputs from each cell, which includes surface and groundwater flows and constituent concentrations, are simulated they are routed to the nearest stream based on topological gradient flow path distances. While being routing to the nearest stream the constituents are attenuated based on features encountered such as wetlands and depressions. The attenuated flows are delivered to the appropriate stream reach within the watershed's hydrographic system using separate unit hydrographs and delay factors for surface and groundwater.

The water and constituents reaching a stream are routed hydrodynamically through the watershed stream network, to the ultimate basin outfall. WAM has the ability to model complex hydrology and can be set-up to routinely manage hydraulic structures and, looping, and tidally influenced boundary areas. In addition, shorelines can be assigned as reaches for a more precise delivery of constituents to large rivers, lakes and estuaries resulting in realistic modeling. Closed basins and depressions are handled routinely. An appropriate attenuation algorithm for the constituents is applied as water is being routed based on flow rate and land use conditions along the flow path.

The model outputs can be viewed in several formats (tables, graphs, and maps) including the daily time-series of source cell outputs or individual tributary reaches and source cells or subbasin constituent loading maps for surface and ground water for both attenuated and unattenuated loads. The user interface can also produce constituent load ranking tables of land uses and comparative displays of different BMP/Management Scenarios.

Overview of the Water Quality Analysis Simulation (WASP) Program

The Water Quality Analysis Simulation Program (WASP), helps users interpret and predict water quality responses to natural phenomena and man-made pollution for various pollution management decisions. It is a dynamic compartment-modeling program for aquatic systems, including both the water column and the underlying benthos. WASP allows the user to investigate 1, 2, and 3 dimensional systems, and a variety of pollutant types. The time-varying processes of advection, dispersion, point and diffuse mass loading and boundary exchange are represented in the model. WASP also can be linked with hydrodynamic and sediment transport models that can provide flows, depths velocities, temperature, salinity and sediment fluxes.

WASP was used to simulate the internal dynamics of the lakes because its biological, DO, and nutrient dynamic submodels are more robust than those currently available in WAM's stream routing algorithms. However, WAM is much more robust and comprehensive as to its prediction of upland source loads than WASP, which makes the coupling of the two models an ideal analysis tool.

Source: http://www.epa.gov/athens/wwqtsc/WASP.pdf

Data Collection

As in all models, the higher the quality of the input data, the more precise the outputs are expected to be. SWET took considerable steps to assure the accuracy of the input datasets and conducted quality control where possible. Below follows a description of the sources of data for each of the required modeled inputs.

Rainfall

The SWFWMD Water Management Information System (WMIS) and personal correspondence with District staff was used to collect and verify the accuracy of rainfall data. Rainfall monitoring locations in proximity to the project area were numerous, but limited in their temporal coverage through the simulation period. It was necessary to combine recordings from adjacent monitoring stations to have a complete rainfall period of record. Two stations were chosen to represent rainfall for the project area, and these are shown in Figure 3. The map also shows the Thiessen Polygons created from the monitoring stations that reflected the rainfall zones that were established for simulating rainfall as a WAM input parameter. Additionally, two graphical plots are provided that summarize the rainfall data by yearly cumulative total and monthly distribution for each station. It can be noted from the yearly cumulative rainfall chart that the both stations experienced unusually low rainfall, during the years of 1990, 2000 and 2006. After reviewing the daily data for those specific years and from correspondence with District staff, it was decided that this was an accurate representation of rainfall for the area. The daily data for those periods is continuous, which indicated that the recording instrument did not malfunction. It is assumed that a few significant localized convection thunderstorms missed the monitoring stations during these periods resulting in the low recorded values.

Other weather related values, such as temperature and solar radiation and wind, were taken from the Lake Hancock WAM parameter files.

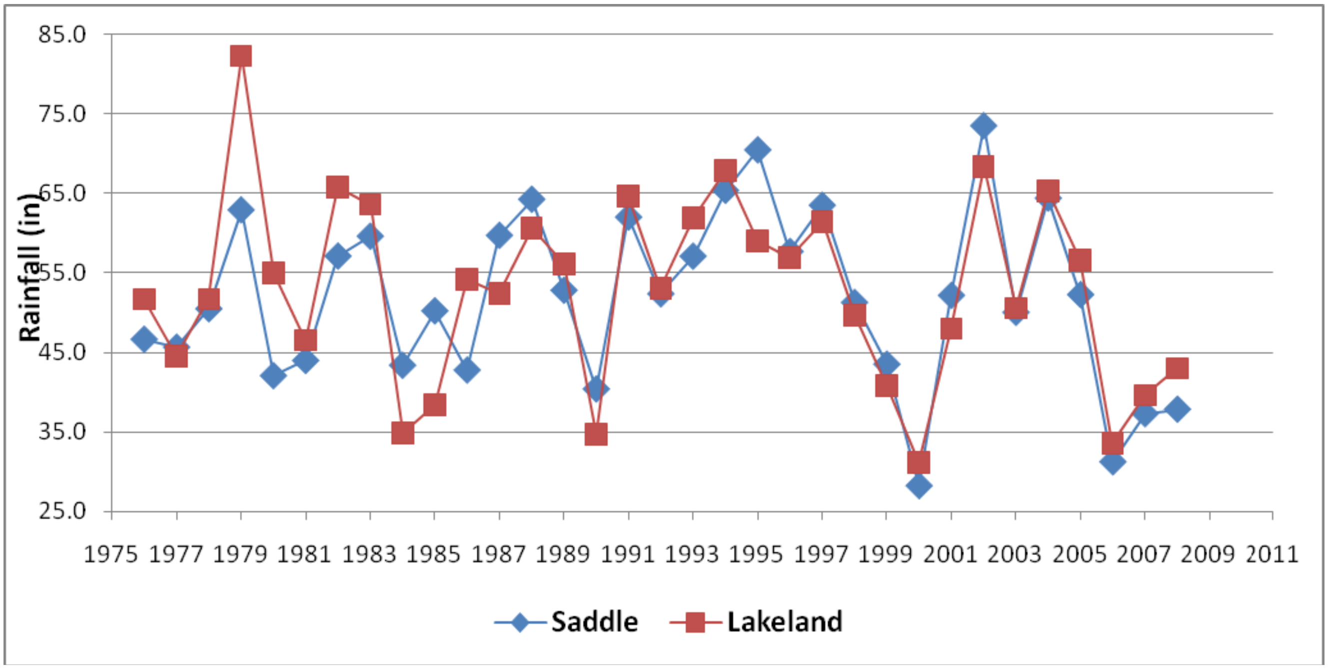


Figure 3: Yearly Cumulative Rainfall

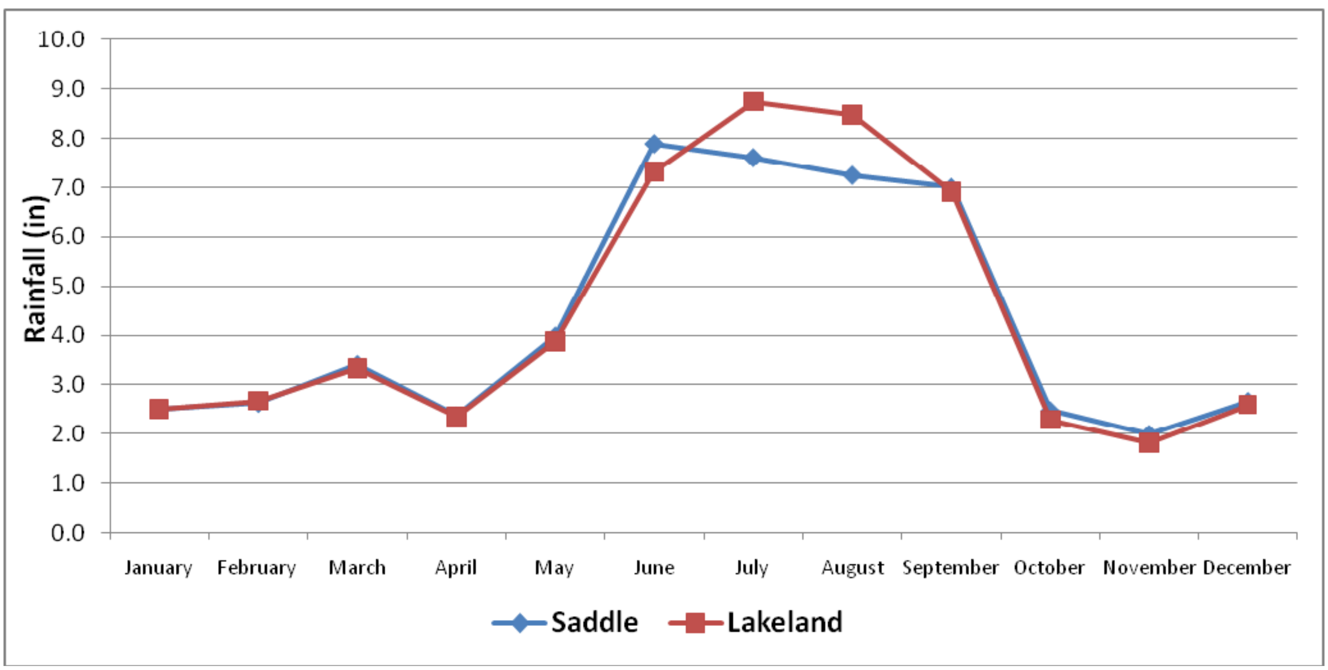


Figure 4: Monthly Rainfall Distribution

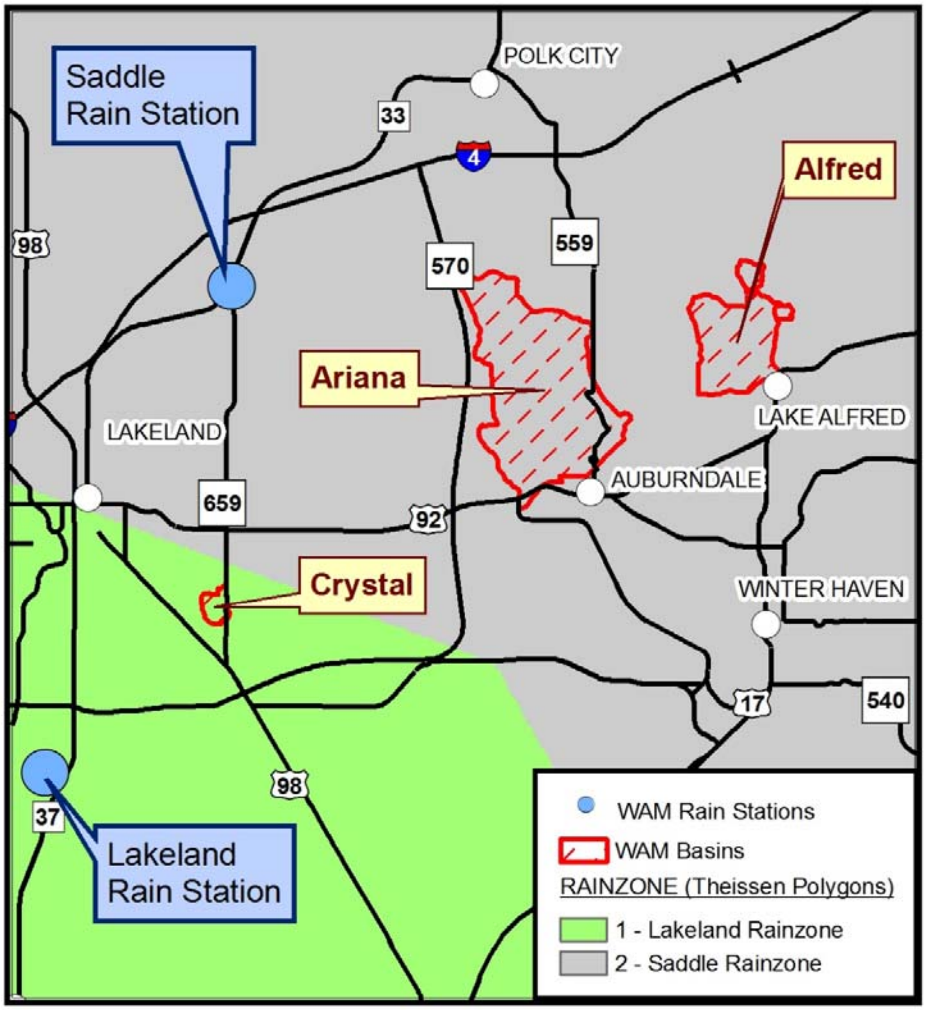


Figure 5: Rainfall Zones

Land Use

The SWFWMD 2007 land use/cover features categorized according to the Florida Land Use and Cover Classification System (FLUCCS) GIS data was used as the Land Use source. This data is the most accurate, available dataset for the area, with land use features being photointerpreted at a scale of 1:8,000 using 2007 1-ft color infrared (CIR) digital aerial photographs.

WAM uses FLUCCS codes and aggregates them based on predetermined similarities into a reduced number of land use categories for quicker simulation. The FLUCCS codes that were present in each simulated basin and the resultant aggregated categories are listed in Appendix B: Land Use tables. Additionally, maps that illustrate the spatial distribution of the land use types are shown in Appendix A for each basin.

Soils

The Soil Survey Geographic (SSURGO) GIS dataset was used as the soil coverage input. SSURGO is the most detailed level of soil mapping done by the Natural Resources Conservation Service (NRCS), and is the best available data for the project area. WAM's soil database includes the entire state's list of soil types by component name (compname). The soils located within each basin are illustrated in the provided map within Appendix A for each basin. Further details can be found on each soil type by referring to the NRCS soil survey book for Polk County.

Topography and Drainage Area

The USGS 5ft Contours from the 24,000 scale topographical quadrangle maps was used to delineate those areas that drained through overland run-off to the lakes under investigation. A Digital Elevation Model (DEM) was created from the contour data and overlaid with the Districts basin boundaries to identify those areas that would drain to each lake. The resultant drainage area for each lake is shown in the relevant maps within Appendix A. The DEM that was constructed was also used by WAM as an input dataset to calculate the overland flow distances of runoff to the destination reaches.

Utility Zones

Human waste, generated at the source cell, can be adjusted for in WAM depending on the waste treatment type that is present. If the service area of a waste water treatment plant is known, the waste generated within the source cells of that area will be directed to a point source discharge. If the service areas are not known, it assumed that waste is treated through a septic tank treatment system. The relevant County and Municipal staff were contacted to establish those areas under their jurisdiction that were serviced by a centralized waste water treatment facility, and those areas that were treated on-site through a septic system. There are no treatment facilities that discharge to water within the basins studied, thus including these areas in a centralized treatment system waste results in the loss of the nutrients and water to as they are transported out of the hydrologic system. The result of this research is displayed geographically in Appendix A.

Hydrology

The National Hydrography Dataset (NHD), high resolution aerials and other existing GIS dataset were consulted to develop a comprehensive hydrologic network for the lake systems. WAM requires specific details for each hydrographic segment or reach. These details include the reach number (CALCREACH), the reach(s) that the reach flows to, reach cross-section profile, and the type of the reach (Canal, Stream, Slough, Lake, Shoreline, etc.). The model uses this information to develop the hydrodynamic details of the reach network. Each of the lakes simulated in the project were assigned a unique number. The shoreline of each lake was assigned the same number as the lake itself, which allows for the time delay delivery of flow entering the lake to be as accurate as possible, and be handled robustly by the hydrodynamic nature of WAM.

The groundwater flow is handled by assigning a groundwater outflow reach to the associated land area that recharge waters will flow to, i.e. a groundwater basin or springshed is developed based on the potentiometric surface of the surficial aquifer. In some cases, the groundwater would not flow to the nearest stream or lake because the top of the surficial aquifer is below or down gradient of these features. In these cases, the groundwater recharge would flow away from the lake either out of the basin or to another reach. What exist near the lakes are two aquifers, a shallow surficial aquifer that is a perched aquifer above a semi-confining layer and a deeper aquifer below this perched aquifer that has a potentiometric head lower than the water levels in the lakes. For all of the lakes in this study the potentiometric surface of the regional deeper aquifer is about 10 to 20 feet below the water surface of the lakes, which means that downward leakage from these lakes occurs. The amount of leakage was estimated based on the lakes' water balances where surface and groundwater inflows and outflows plus rainfall and ET were taken into account. A more detailed description of each lake systems hydrology is provided in the description of each lake under section 2 of this report.

Observed Lake Levels and Water Quality Parameters

Measure (observed) hydrodynamic and constituent data were obtained, where available, from the SFWMD WMIS system and the Polk County Water Atlas (polkwateratlas.usf.edu). The observed data were used to calibrate the simulated WAM water levels, flows, and modeled constituents and the results of this calibration are shown in Appendix C with the simulated model results.

Natural Conditions Runs

In order to be able to compare the current state of impairment of each of the Lakes, it is important to gain an insight into what the historic conditions of the lakes would have been under natural land use conditions. This allows for a the TMDL reduction target to be set to a realistic level of what would be possible if no anthropogenic alterations had occurred within the basin. To do this, SWET has developed a lookup table that matches NRCS soil types with the most commonly occurring natural or vegetated land use type that is likely to be found growing in a particular soil type.   The lookup table for the soil types present within this project are displayed in Appendix B as Table 6. Additionally, where applicable, the hydro-geologic systems of each basin were altered to match natural (predevelopment) conditions.

Modeled Lake Descriptions for WAM-WASP

Each of the basins for the lakes modeled by WAM-WASP linked model is described below in detail. For each basin, maps of the WAM inputs are provided in Appendix A; land use acreage tables in Appendix B, Temporal graphs of simulated lake stages and flow in Appendix C, and source loads of Nitrogen (N) and Prosperous (P) in Appendix D. It was decided to separate these figures from the basin descriptions as they are numerous and if included in the body of the report could separate the text excessively. However, graphical depictions of the modeled reach layouts are included in the report body for easy reference. Additionally, items located in the appendix are referenced by number in the text.

Lake Alfred

Lake Alfred, the eastern most of the three lakes modeled, is listed as WBID 1488D. This WBID number actually contains three separate lakes; Camp Lake, Grass Lake and Lake Alfred. Lakes Camp and Grass are in separate sub-basins which drain eastward. While lakes Camp and Grass were simulated, the emphasis of the calibration work was on Lake Alfred, and its isolated system including two lakes that drain to Lake Alfred; Lakes Griffin and Eva. Lake Griffin, Eva and Alfred are located within the same closed drainage sub-basin as Lake Alfred and are thus modeled together (see Figure 2.1). Detailed land use tables, and simulated stage charts are provided for Lakes Camp and Grass in Appendix B and C respectively. Furthermore, the source loads of N and P are also included for these lakes in Appendix D maps for these sub-basins.

Base Condition WAM simulation

The Lake Alfred basin is very clearly defined by the surrounding topography, Figure A-2. The drainage basin is relatively small, at 1,775 acres, for the size of the lake (727 acres). The land use is mostly rural (Chart 2.1), but it does have a considerable proportion of land on the western shores that has been cleared for development, as shown in Figure A-4. The lake is located on the edge of the City of Lake Alfred. Most of the area within the municipal limit is on a central waste treatment facility, as displayed in Figure A-6.

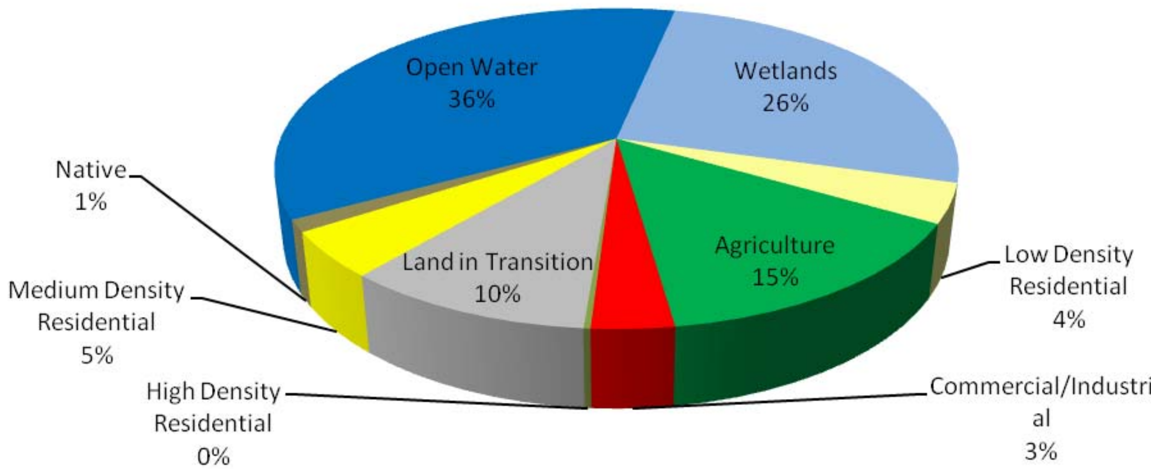


Figure 6: Lake Alfred Basin Land Use.

The Lake Alfred chain of lakes is comprised of three separate water bodies, linked together by a conveyance system of streams and canals. A graphical representation of the WAM reaches that were set-up to represent these lakes and conveyances is provided in Figure 2.1. At the top of the system is Lake Griffin (15.6 acres), which was assigned reach number 5. Lake Griffin was calibrated to only discharge, through reach 4, to Lake Alfred (reach 3), under high stage conditions. Lake Eva (20.5 acres), reach 7, is separated from Lake Alfred by a large wetland. A canal, reach 6, has been constructed between Eva and Alfred that links the lakes at all but the lowest lake levels. Lake Alfred itself is 727 acres, and reported by Lake Watch to be 14 feet deep with an average depth of 5 feet. Lake Alfred does not discharge but under very

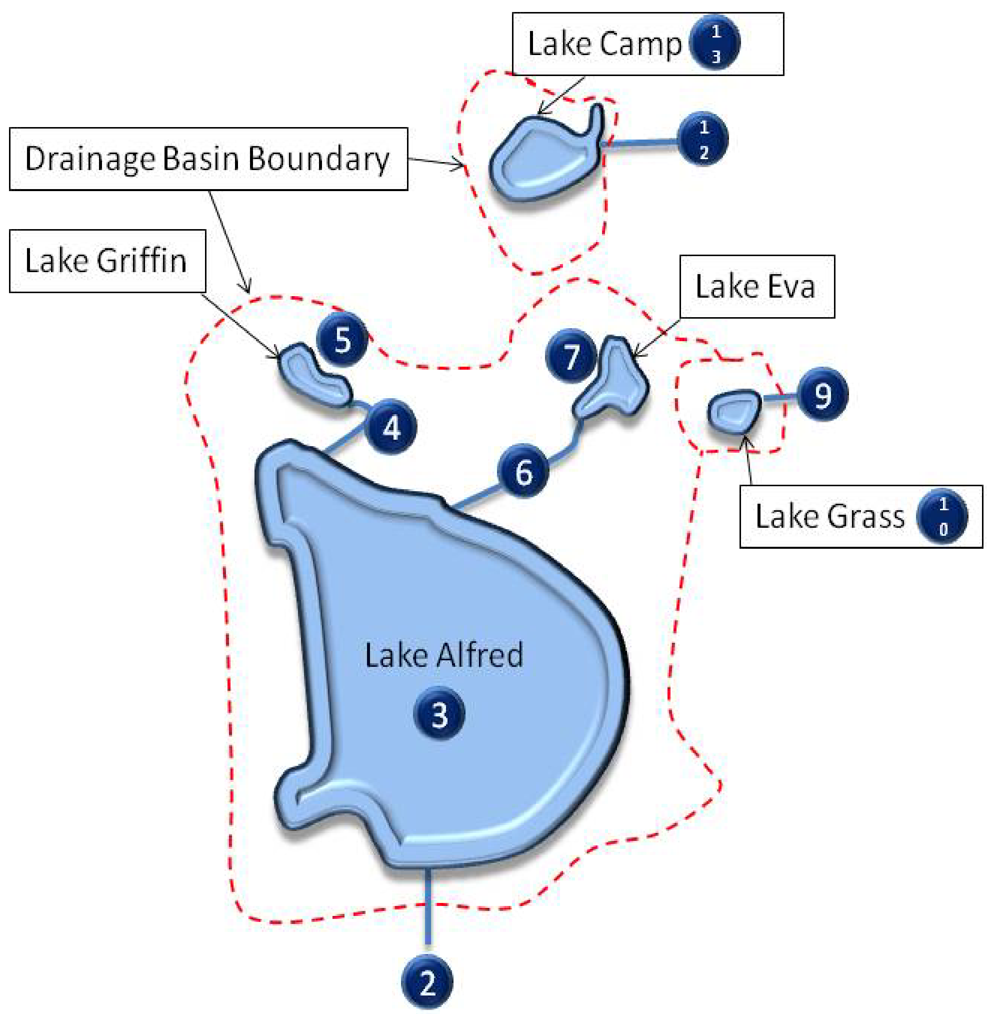


Figure 7: Lake Alfred WAM Reach Layout

extreme events, hence terming it a “closed” system. At no time during the simulation period did the lake discharge through a surface conveyance (reach 2). There was no water control structures added to the Lake Alfred system. All groundwater within the basin is directed to the appropriate surface water reaches (Figure A-7) with a specific groundwater time delay delivery curve.

The simulated stages and comparisons to observed conditions as well as the outflows of Lakes Alfred, Eva and Griffin are displayed in Appendix C, Figure C-1 and C-2 respectively. As can be seen the stages do track very closely, with the separations that occur being thought be a difference between actual rainfall observed at the lake and the recorded rainfall from the monitoring station located a few miles away.

The source loads of N and P, and the amount of overland attenuation each cell exhibits is shown in Appendix D, Figures D-1 and D-2. As can be seen more source load is generated on the more intensive land uses as is to be expected and the loads do not exhibit much attenuated within the flow conveyance systems due to the small spatial size of the basin. For the WASP model the TSI and Chlorophyll-a were calibrated further.

Natural Conditions WAM simulation

As described in the introduction, soil associations were used to create a Natural Conditions Land Use map (Appendix A, Figure 5). No change was made to the hydro geology of the system between simulation runs. The results of the natural condition runs as compared to existing condition runs are provided in Appendix E. The results clearly show a significant reduction of nitrogen and phosphorus loads for the natural conditions.

Lake Ariana

Lake Arianna, is listed as WBID 1501B. This WBID only includes the northern half of the Lake, but it was decided to treat the lake as a whole, instead of trying to separate the lake into halves as it is assumed that lake water mixes uniformly as would any lake of this size and location. Lakes Arietta, Whistler and Lena were modeled in this basin as a complete chain of lakes system as it appears that they either drain south to Lake Ariana or they are connected at high water level stages (Lake Lena). Thus the basin size modeled is approximately 5,458 acres. The City of Auburndale, surrounds Lakes Ariana and Lena and this area has undergone rapid population expansion in the previous few decades.

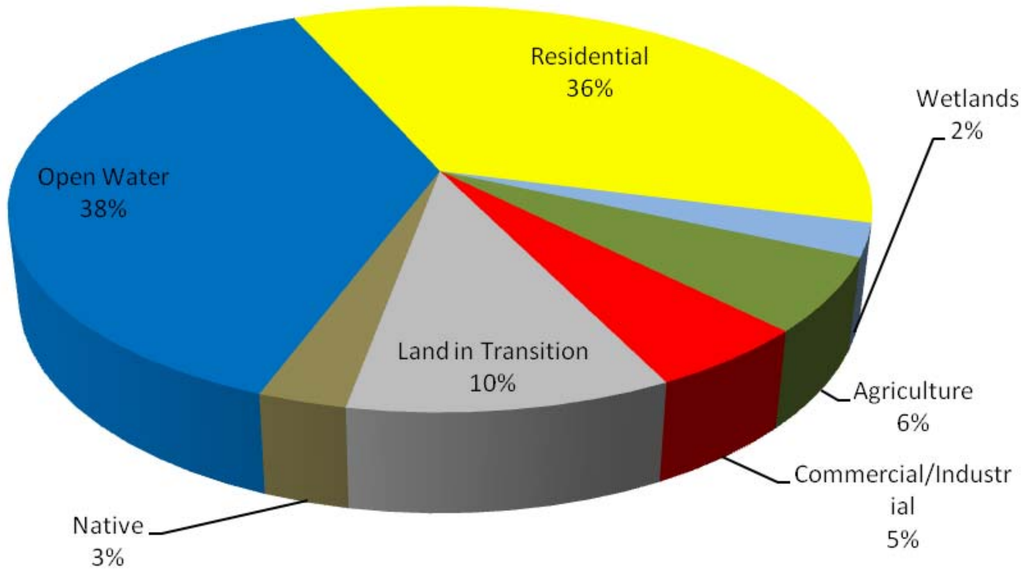


Figure 8: Lake Ariana Basin Land Use.

Base Condition WAM simulation

Due to its proximity to the City of Auburndale and that portion of Polk County that has been developed, much of the current land use can be described as either built-up, or in the process of being prepared for development. It can be seen from reviewing chart 2 below, and Table 5 in Appendix B that only 3% of the upland land surface has not been developed with an additional 6% under various agricultural practices. This is verified in the Aerial map provided as Figure A-8. Within the different WAM land use types, it is assumed that stormwater retention ponds are existing on certain types, e.g. Commercial and Services, while others are not assumed to have retention, e.g. Low Density residential. From reviewing the aerial, it could be seen that some developed land use areas had additional retention constructed. In order to reflect this, some land uses were changed to include a retention Best Management Practice (BMP) as included through the WAM. This change of BMP inclusion was not universal across the basin, but digitized using 2007 aerial photographs. Those areas that are included the stormwater retention BMP are mapped with the Utility Zones in Figure A-12. As it is assumed that the surface water lakes in this area are perched, it is also assumed that only a fraction of the precipitation that percolates ever gets into the lake systems. A buffer of approximately 200 meters from streams and 500 meters from lake shore was used to limit the groundwater flow into a surface water body. The WAM reaches that groundwater is delivered to is mapped in Figure A-13. Note, a separate groundwater specific reach (11) has been added. This reach is designed to collect all the deep recharge that percolates directly to the Floridian Aquifer and does not ever enter the surface water system.

As mentioned in the introduction paragraph for Lake Ariana, the four lakes present are inter-related in that water cascades down from Arietta, through Whistler, to Ariana and then ultimately out of the basin through an outfall on the southern shore of Lena. The WAM reaches were set-up during calibration to reflect this. Lakes Arietta (reach 9) and Whistler (reach 7) are separated by a culvert (on reach 8) which acts as a weir that stages the outflow of water to Lake Whistler. Lake Whistler is connected to Lake Ariatta (reach 5) by a narrow concrete drainage conveyance (reach 6), that also creates a weir to control the stage of water flowing down into Ariana. Ariana (reach 5) and Lena (reach 3) were setup to be connected at all but the driest of times, when they would separated by the stream that connects them (reach 4). A weir structure was placed on the outflow of Lake Lena to control the water upstream through the higher lakes, and it appears that this structure is completing the simulation accurately.

The stages and flows between the lakes can be seen by reviewing the figures provided in Appendix C (Figures C-5 through C-8). As can also be noted, the simulated stages closely resemble observed stages, indicating that the basin was accurately set-up and calibrated.

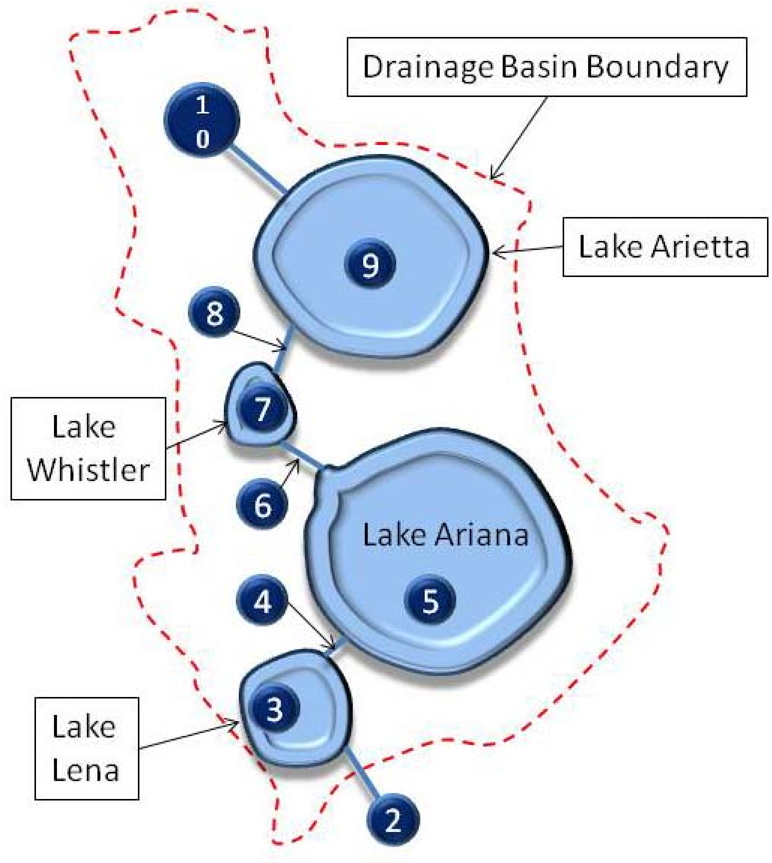


Figure 9: Lake Ariana WAM Reach Layout

Natural Conditions WAM simulation

Again, soil associations with natural land use types were used to map the natural, pre-development conditions (Figure A-11). Significant changes were made to the hydro geology, with reach 11, the deep groundwater recharge reach capturing the percolation from areas away from the reach being removed and all groundwater was delivered to the closest surface reach. This was done to simulate the higher potentiometric surface that was sure to have existed at a time the land use would have been under an unaltered state.

The results of the natural condition runs as compared to existing condition runs are provided in Appendix E. The results clearly show a significant reduction of nitrogen and phosphorus loads for the natural conditions.

Lake Crystal

The 27 acre Lake Crystal is the smallest of the three simulated lakes. Situated on the outskirts of the City of Lakeland and within a populated area of Polk County the lake has experienced significant pollutant loading over the past few decades. The drainage was delineated from the DEM (Figure A-16) to be 195 acres.

Base Condition WAM simulation

Based on the 2007 SWFWMD Land Use dataset (Figure A-18, Chart 2.3, Table B-4), there is no natural land use types left within the Lake Crystal drainage basin. This is evident from the Aerial map provided (Figure A-15). From correspondence with the City of Lakeland and Polk County staff, it was identified that only a small portion of the drainage area is on a centralized waste water treatment system and that most of the generated human water wastes were treated on-site through septic systems (Figure A-20).

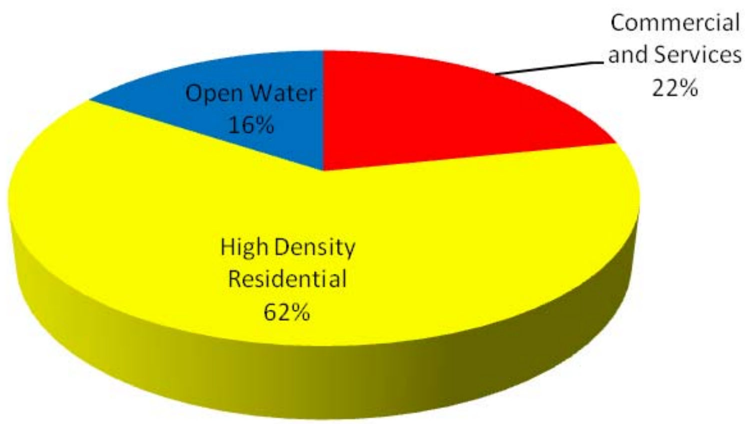


Figure 10: Lake Crystal Basin Land Use.

It was also identified from the Polk County records that a small storm water retention pond had been built on the northern shores of Lake Crystal. According to County staff, this area was once used as a swimming beach, but was retrofitted to treat storm water once the lake reached a certain level of degradation about 30 years ago. The retention area was included as a WAM reach (4) based on the as built specifications provided in the original permit to construct the retention area. The retention area is connected to Lake Crystal (reach 3) through an 18" x 28" grated overflow structure, and a 2 inch "bleed down" connection that allows the retention area to

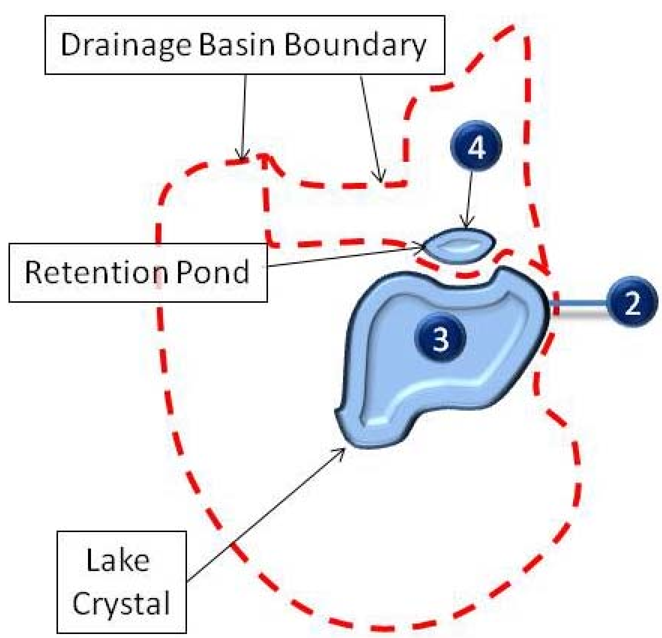


Figure 11: Lake Ariana WAM Reach Layout

continually discharge to the lake.   The drainage area of the retention pond was delineated based on aerials included in the permit drawings. Lake Crystal, drains to the East, through small culvert into a the stream (reach 2) that flows east and out of the sub-basin. Chart C-9, shows the simulated and observed stages of Lake Crystal, as well as the flow from the retention area to the lake, and the lake out flow. As can be seen from chart C-9, the bleed down between the retention area and the lake is working well to match observed stage in Lake Crystal because it continually drains the pond under normal conditions. However during large storm events water discharges through the 18” x 28” box culvert to prevent overtopping of the dike. Likewise, the lake flows and stages are well calibrated in that the lake only discharges during high stage periods. The simulated stages, closely matches the observed stage.

Natural Conditions WAM simulation

The soil to natural land use lookup table (Table 6) was used create the pre-development land use coverage, as shown in Figure A-19. The retention area included in the current land use simulation run as WAM reach 4 was removed. Additionally, groundwater that is currently thought to drain directly to the aquifer, was redirected to the surface water reaches due to the predevelopment condition of an elevated potentiometric surface that existed under natural hydro geological conditions, i.e. existing are much lower today than historic levels due to high groundwater pumping that has occurred in the area.

The results of the natural condition runs as compared to existing condition runs are provided in Appendix E. The results clearly show a significant reduction of nitrogen and phosphorus loads for the natural conditions.

WASP Calibration and Natural Condition Runs

Eutrophication processes in Lakes Alfred, Ariana, and Crystal were simulated using the program WASP (Water Quality Analysis Program) developed by the United States EPA. For this project, each lake was treated as a single "segment" in WASP, with a second segment used to accumulate recharge to the underlying aquifer. The lake segment was modeled using the standard eutrophication module in WASP, which contains a set of built-in routines to simulate nutrient enrichment and eutrophication. The state variables used by the module are

- Ammonia (NH4)
- Nitrate (NO3)
- Organic nitrogen (ON)
- Orthophosphate (OPO4)
- Organic phosphorus (OP)
- Dissolved oxygen (DO)
- Phytoplankton/Chlorophyll-a (PHYT/Chl-a)
- Carbonaceous Biochemical Oxygen Demand (CBOD)

Mass loads (in Kg/day) of each of the state variables was determined by WAM and provided, together with water flows and volumes, as input data to WASP. The most abundant measured data in each of the lakes consisted of dissolved oxygen, total nitrogen, and total phosphorus, followed by ammonia, nitrate, orthophosphate, chlorophyll-a, and BOD.

An existing WASP calibration dataset developed by TetraTech for another study of lakes in central Florida was used as the starting point for calibration parameters. Additionally, TetraTech provided time series values for air and water temperatures, solar radiation, fraction of daily light, and wind speed.

Initially, the sediment oxygen demand in the lake segment was adjusted to give a reasonable fit for the measured DO data. Once this value was determined, growth and death rates were adjusted for phytoplankton in an attempt to reproduce the observed values of measured Chl-a. It was quickly realized that the available supply of nutrients provided by the input loadings of nitrogen and phosphorus was not enough to fit either the available nutrient or phytoplankton data. Consequently, benthic flux terms for NH4 and OPO4 were added to the simulation to provide nutrients to match the observed values. These flux terms result from the build up over many years of organic material at the bottom of the lakes.

After the flux terms were adjusted to give reasonable values for simulated total nitrogen and phosphorus, parameters for phytoplankton growth, death, N:C and P:C ratios were adjusted, as were rates for nitrification, denitrification, organic nitrogen mineralization, and organic phosphorus mineralization. These adjustments were used to fine-tune the fit of the simulated values to the observed data. Parameters for light and BOD were used unchanged from the values given by TetraTech.

Once a satisfactory fit was obtained for Lakes Alfred, Arianna, and Crystal (see Appendices F and G, respectively), the simulation was run again using loading values from WAM obtained by running a "natural conditions" scenario. The hydrologic conditions and internal WASP parameters were kept the same as the existing conditions calibration simulation. The external nutrient loads into the lake provided by WAM were greatly reduced over the scenario using existing conditions. From the data obtained from both scenarios, the Trophic State Index (TSI) was calculated, with the results shown in Figures 12, 13, and 14. The most obvious point shown by the data is that the TSI is not significantly lowered by reducing the nutrient load to the lakes. This is due to the benthic nutrient fluxes being a significant fraction of the total nutrient load provided to the lakes. To show this effect, a series of model runs were performed using the external nutrient loadings provided by the natural conditions scenario and the same hydrologic conditions and WASP parameters, with the exception of lowering the benthic fluxes for NH4 and OPO4 by a set percentage for each run. Simulations with "natural" external loadings had benthic fluxes at 100%, 90%, 80%, 70%, 50%, and 25% of the original values determined in the calibration run.

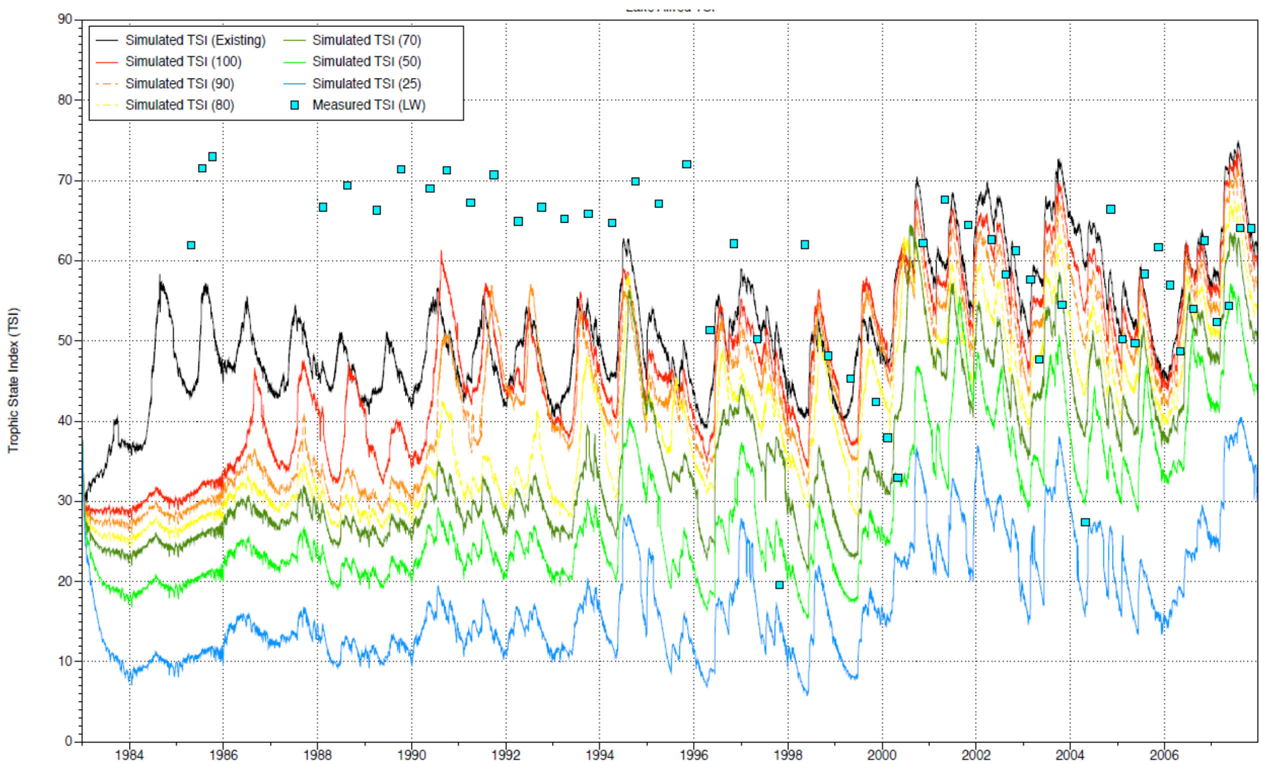


Figure 12. Trophic State Index (TSI) calculated for Lake Alfred. The simulation for existing conditions is shown together with a set of results for a set of model runs using external loads obtained from "natural conditions" land use. Each simulation for the natural conditions has the internal nutrient load from benthic fluxes set at 100%, 90%, 80%, 70%, 50%, and 25% of the fluxes determined from the existing condition calibration run. The heavier black line shows lake depths, and the filled squares show TSI calculated from measured values of Chl-a, total N, and Total P.

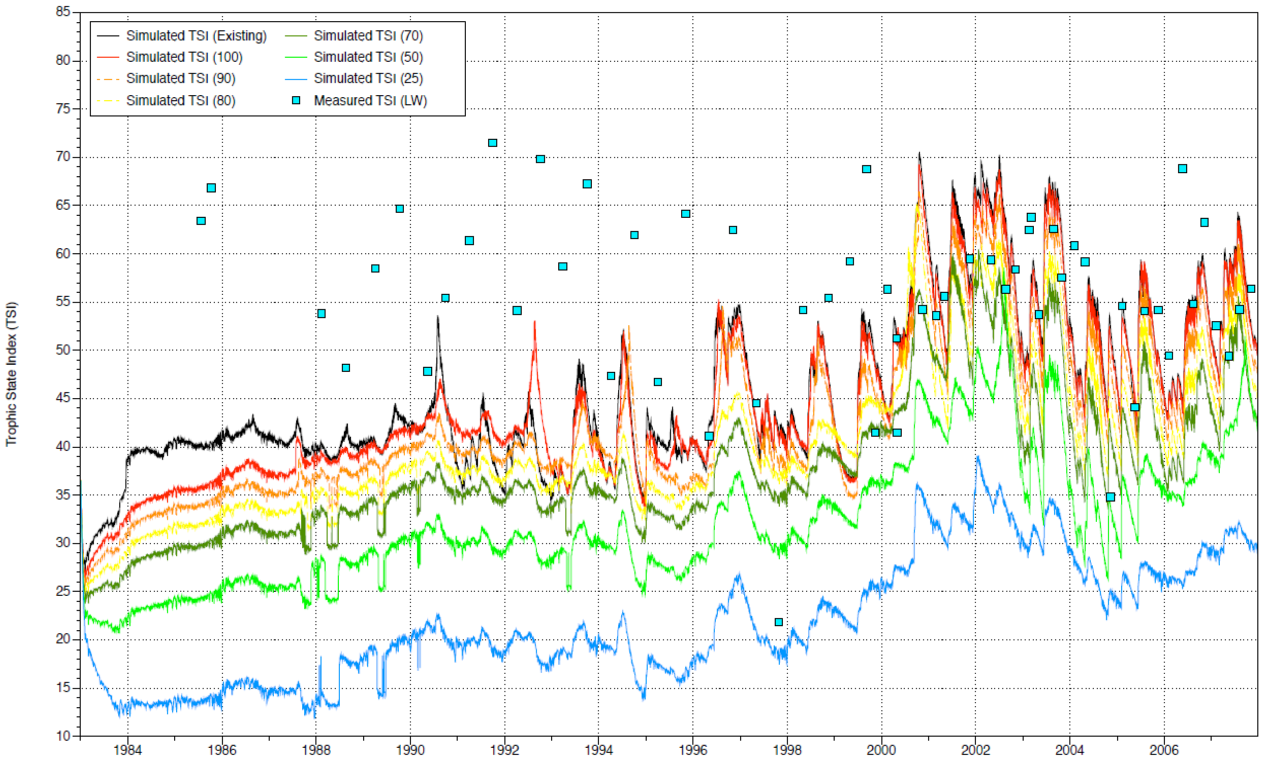
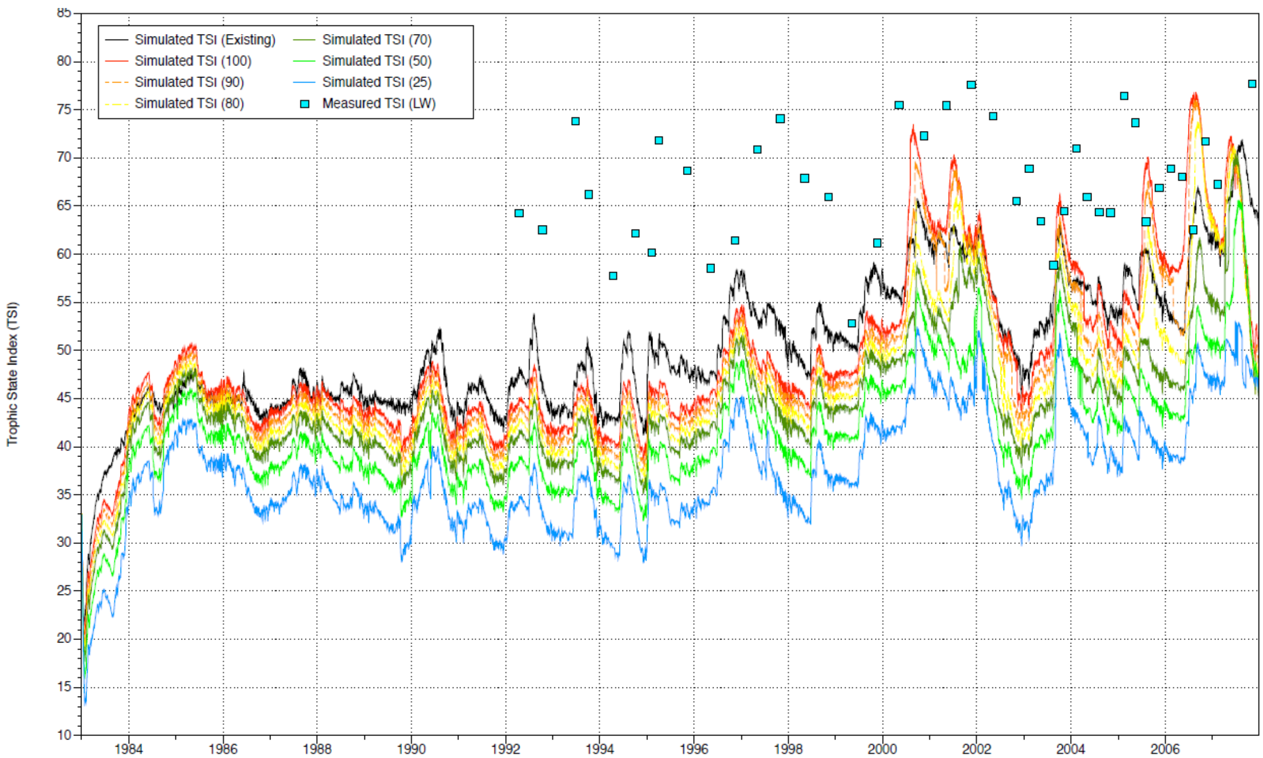


Figure 13. Trophic State Index (TSI) calculated for Lake Ariana. The simulation for existing conditions is shown together with a set of results for a set of model runs using external loads obtained from "natural conditions" land use. Each simulation for the natural conditions has the internal nutrient load from benthic fluxes set at 100%, 90%, 80%, 70%, 50%, and 25% of the fluxes determined from the existing condition calibration run. The heavier black line shows lake depths, and the filled squares show TSI calculated from measured values of Chl-a, total N, and Total P.



Fi

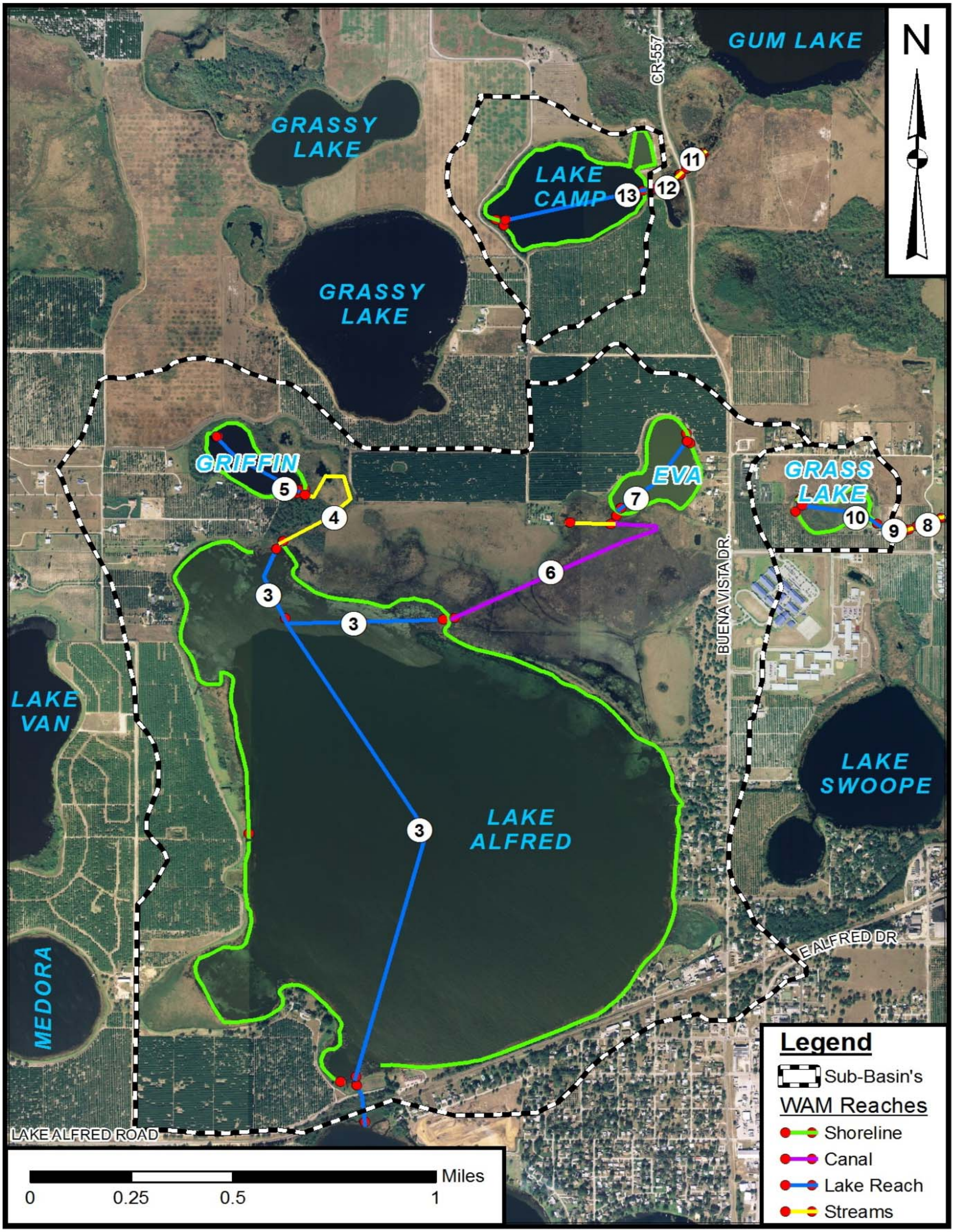
Figure 14. Trophic State Index (TSI) calculated for Lake Crystal. The simulation for existing conditions is shown together with a set of results for a set of model runs using external loads obtained from "natural conditions" land use. Each simulation for the natural conditions has the internal nutrient load from benthic fluxes set at 100%, 90%, 80%, 70%, 50%, and 25% of the fluxes determined from the existing condition calibration run. The heavier black line shows lake depths, and the filled squares show TSI calculated from measured values of Chl-a, total N, and Total P.

Appendix A

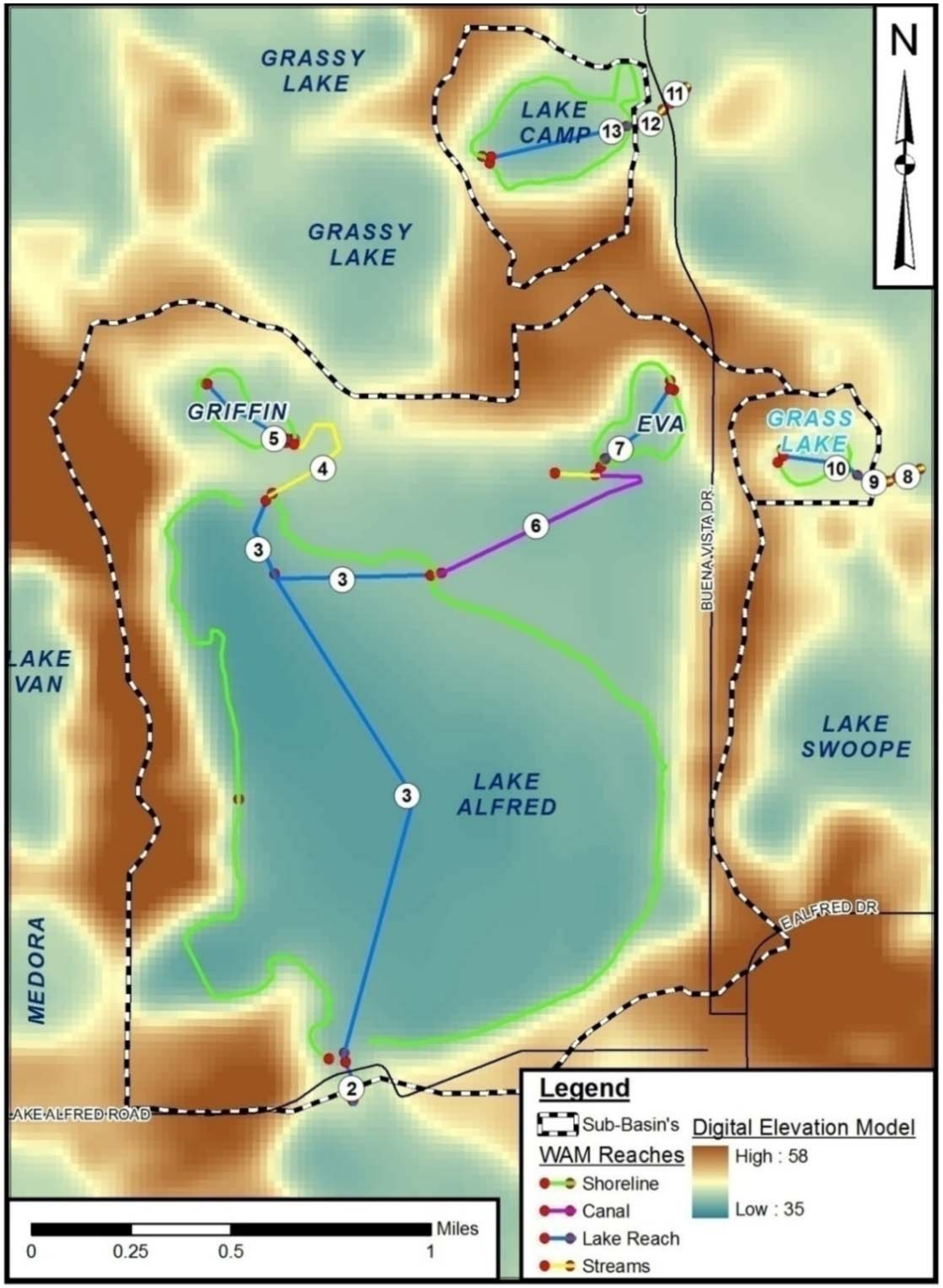
Upper Peace River - Three Lakes

Watershed Assessment Model (WAM)

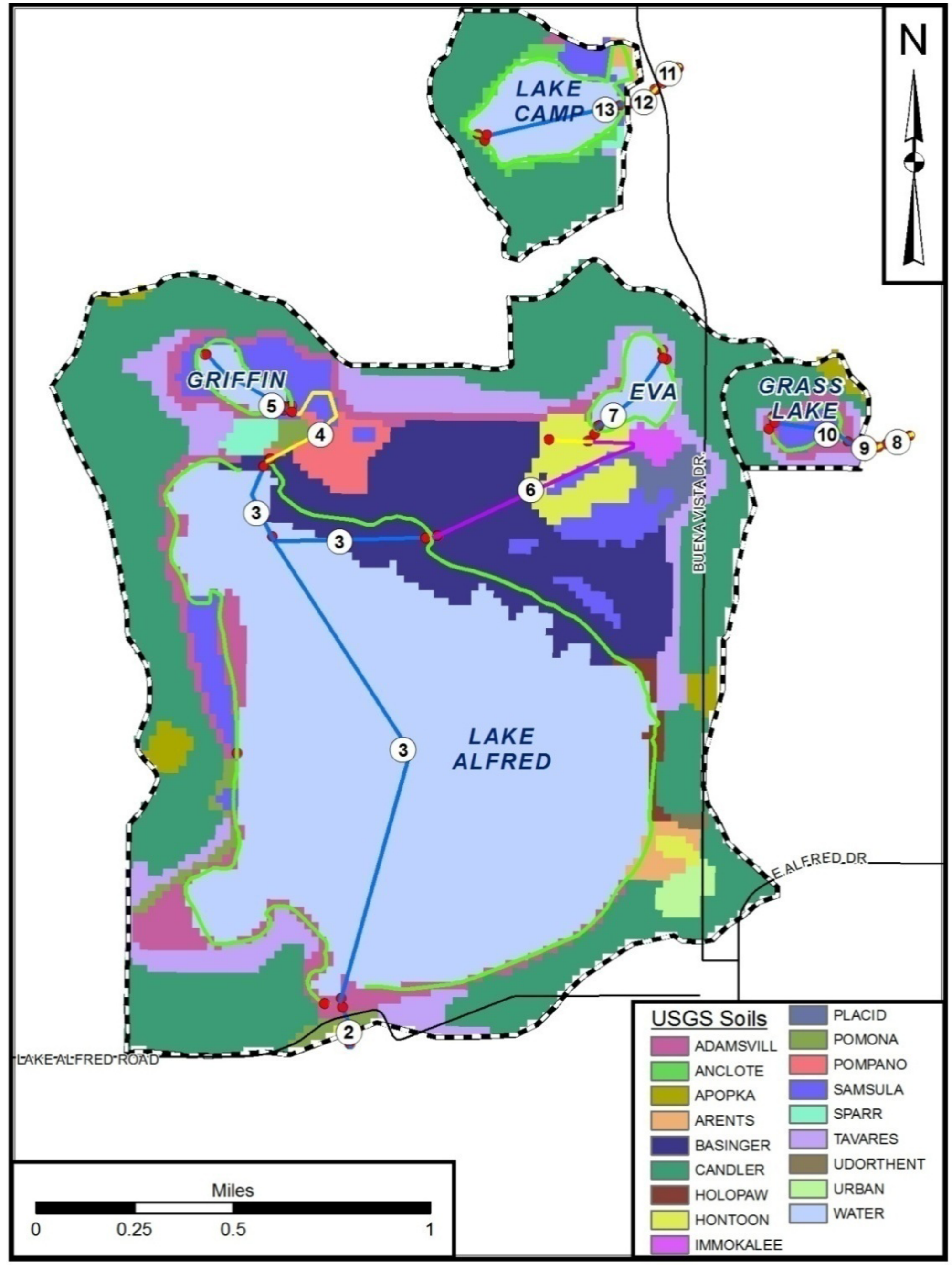
GIS Input Data Maps



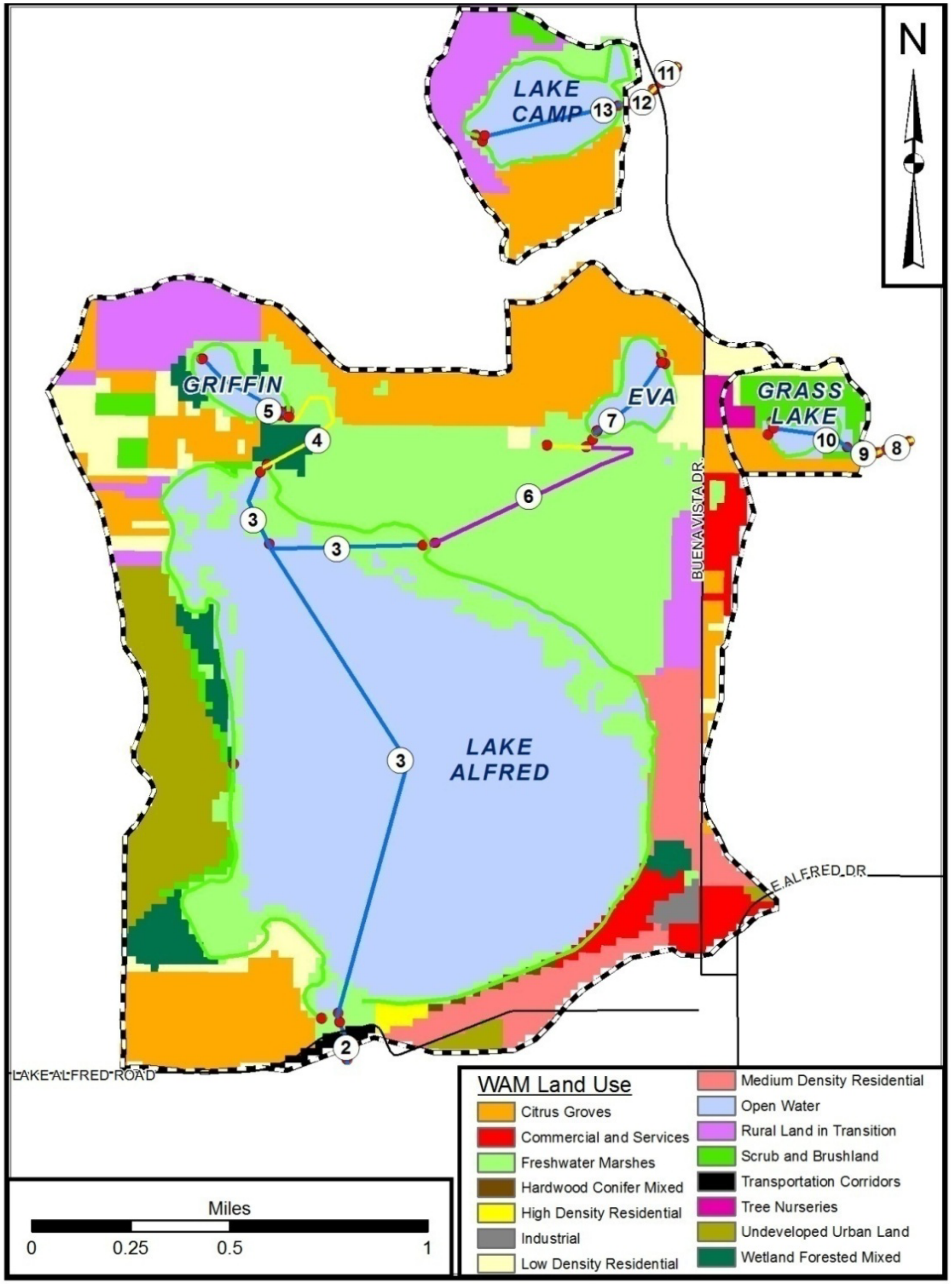
A - 1: Lake Alfred 2007 True Color Aerial:



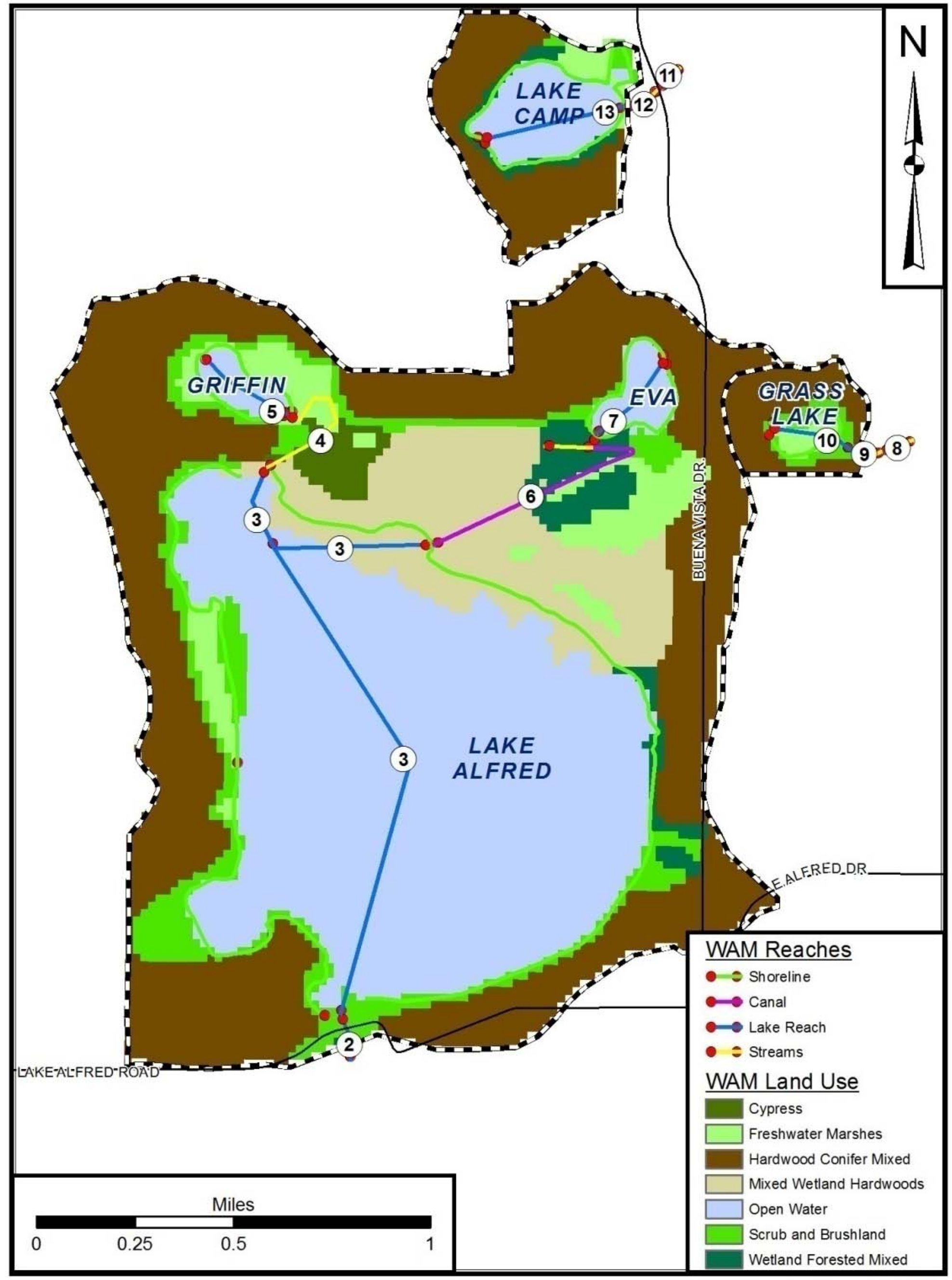
A - 3: Lake Alfred Topography



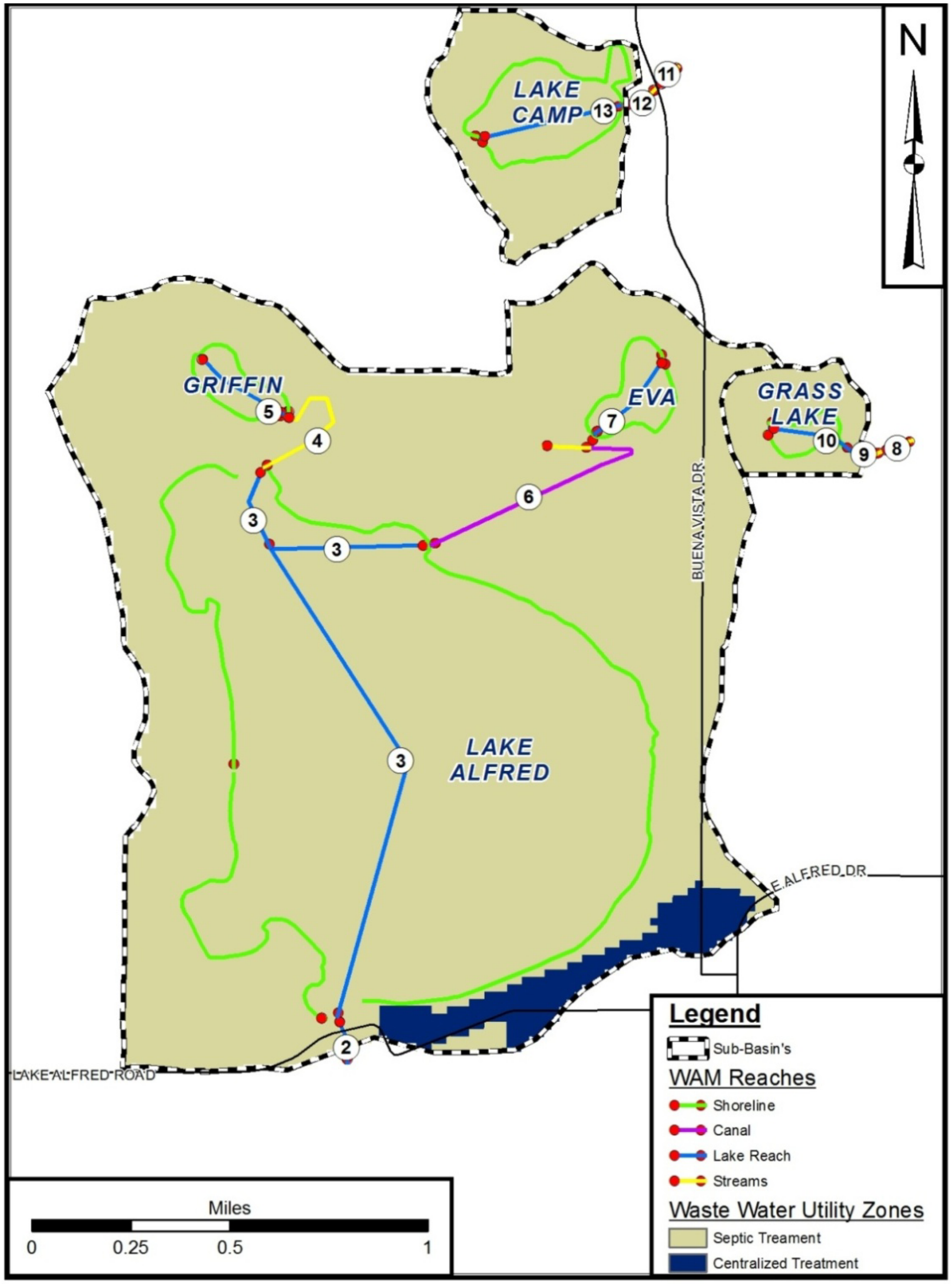
A - 2: Lake Alfred USGS Soils



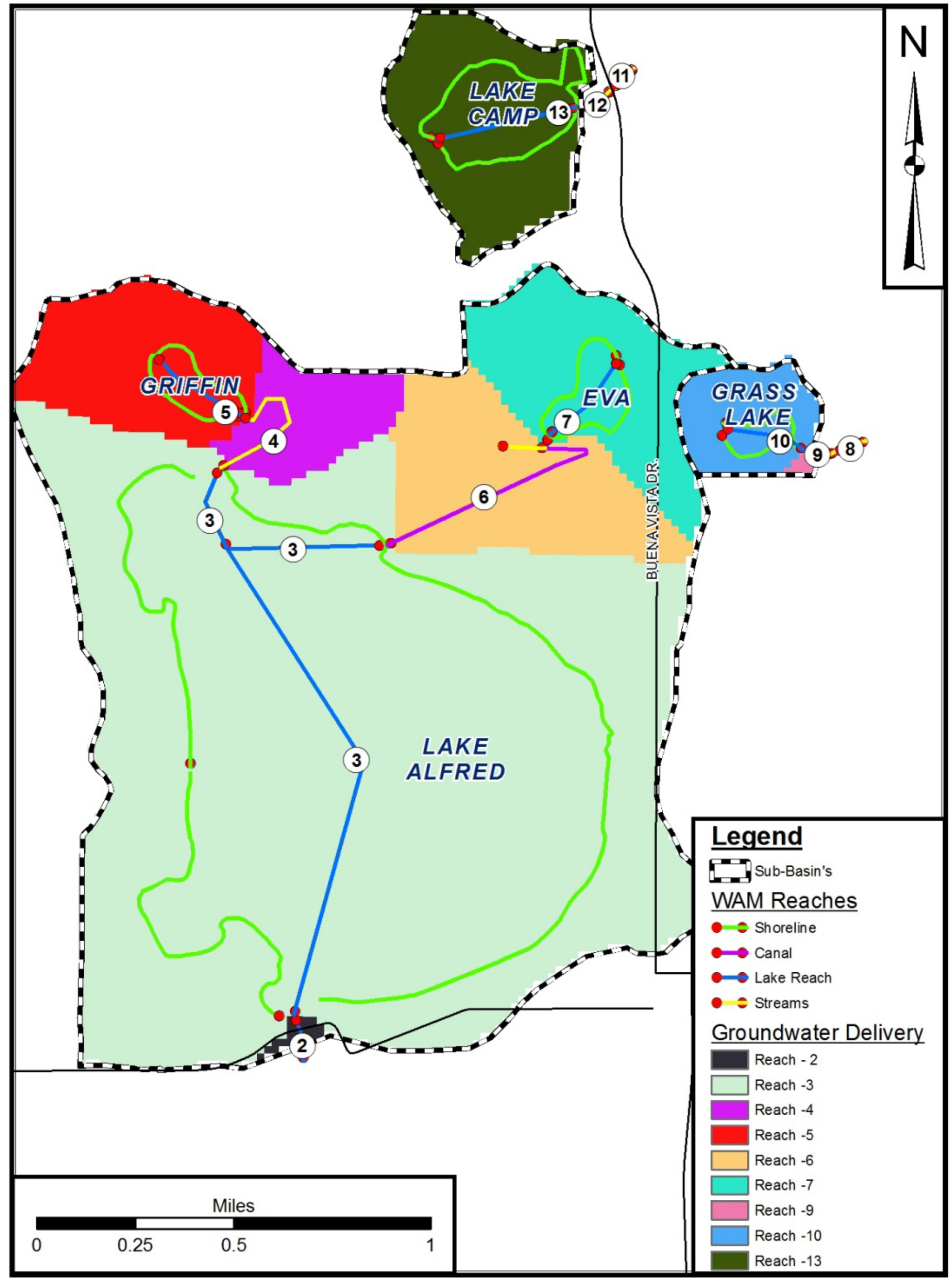
A - 5: Lake Alfred Current Land Use



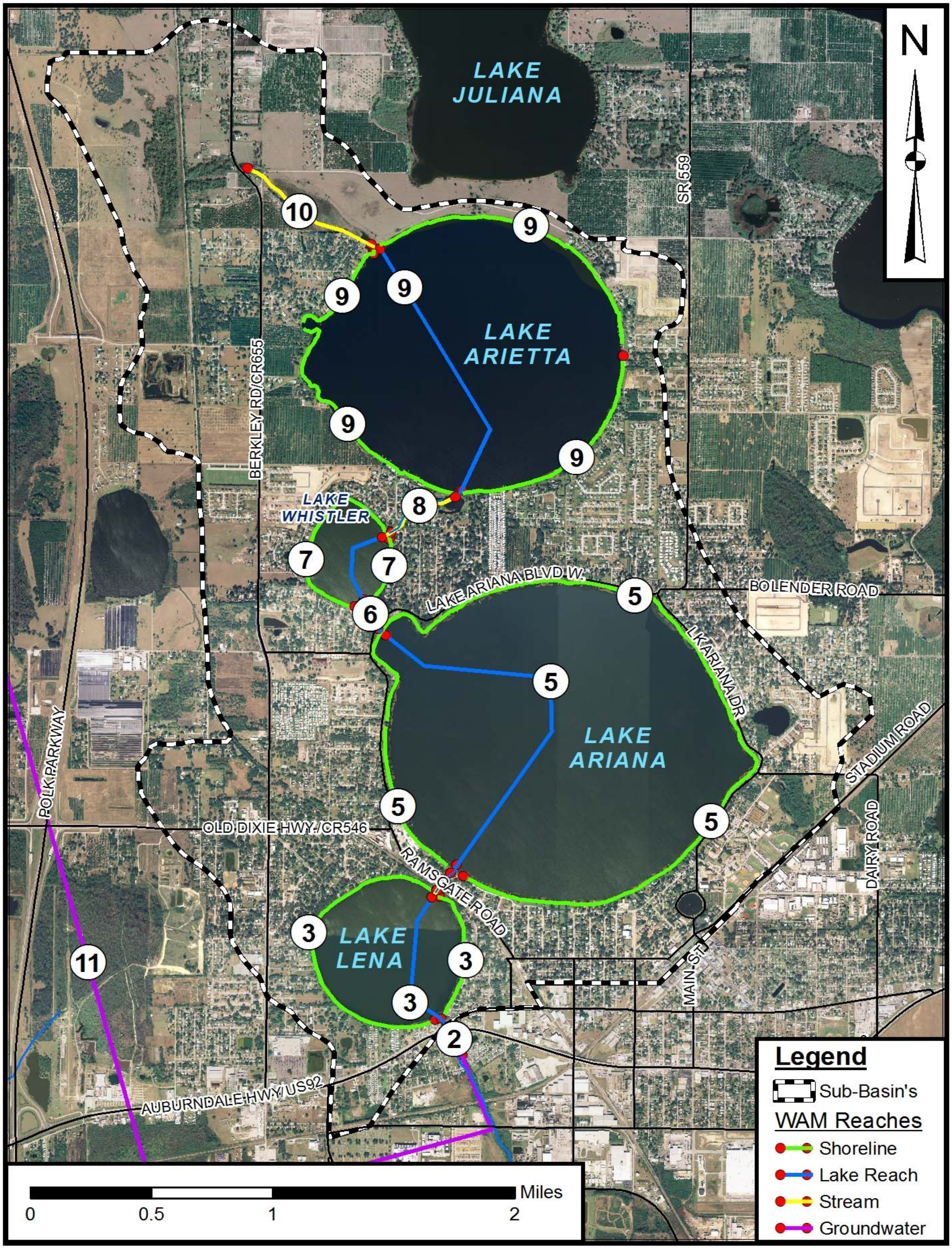
A - 4: Lake Alfred Natural Land Use Condition



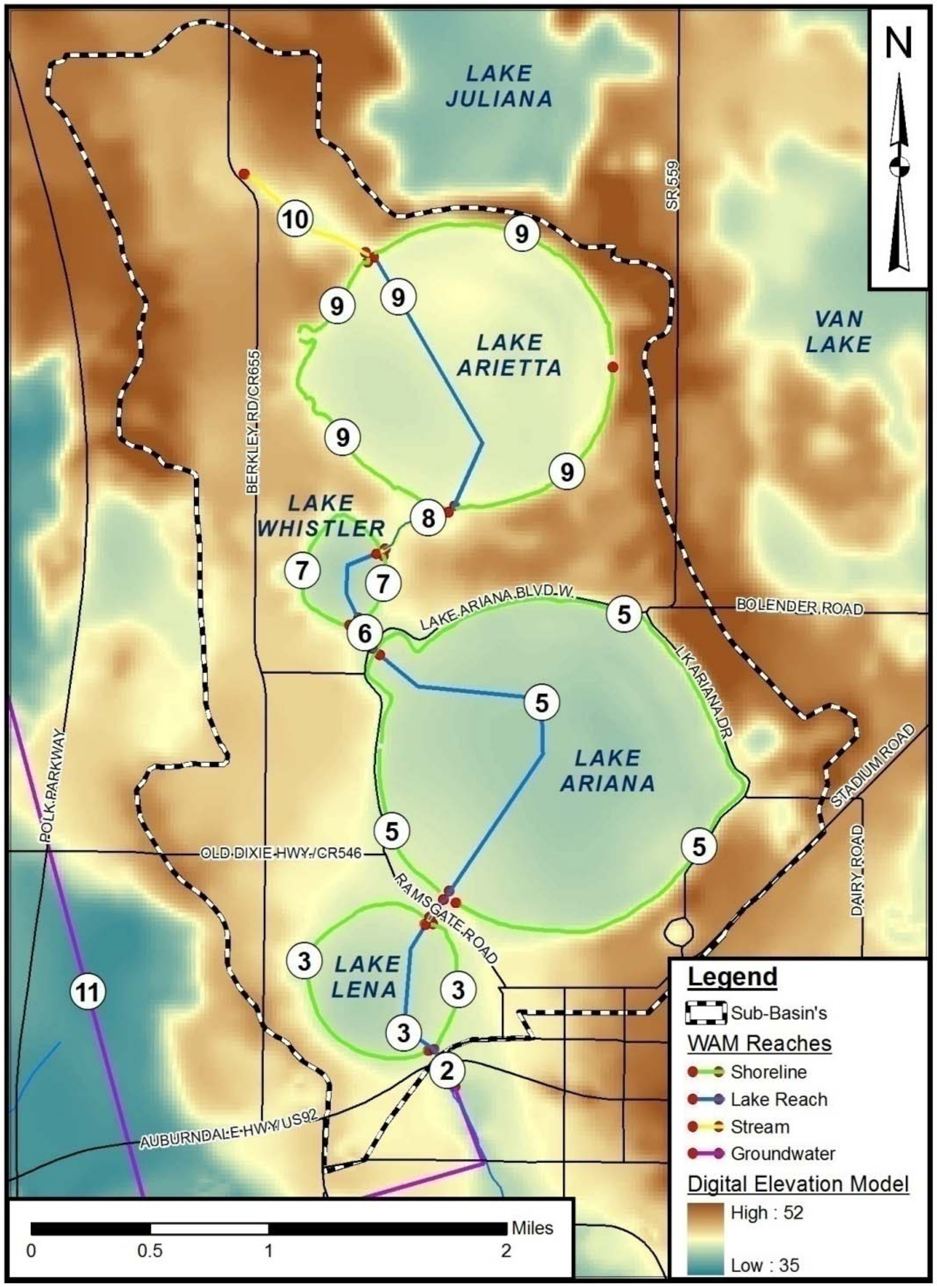
A - 6: Lake Alfred Waste Water Utility Zones



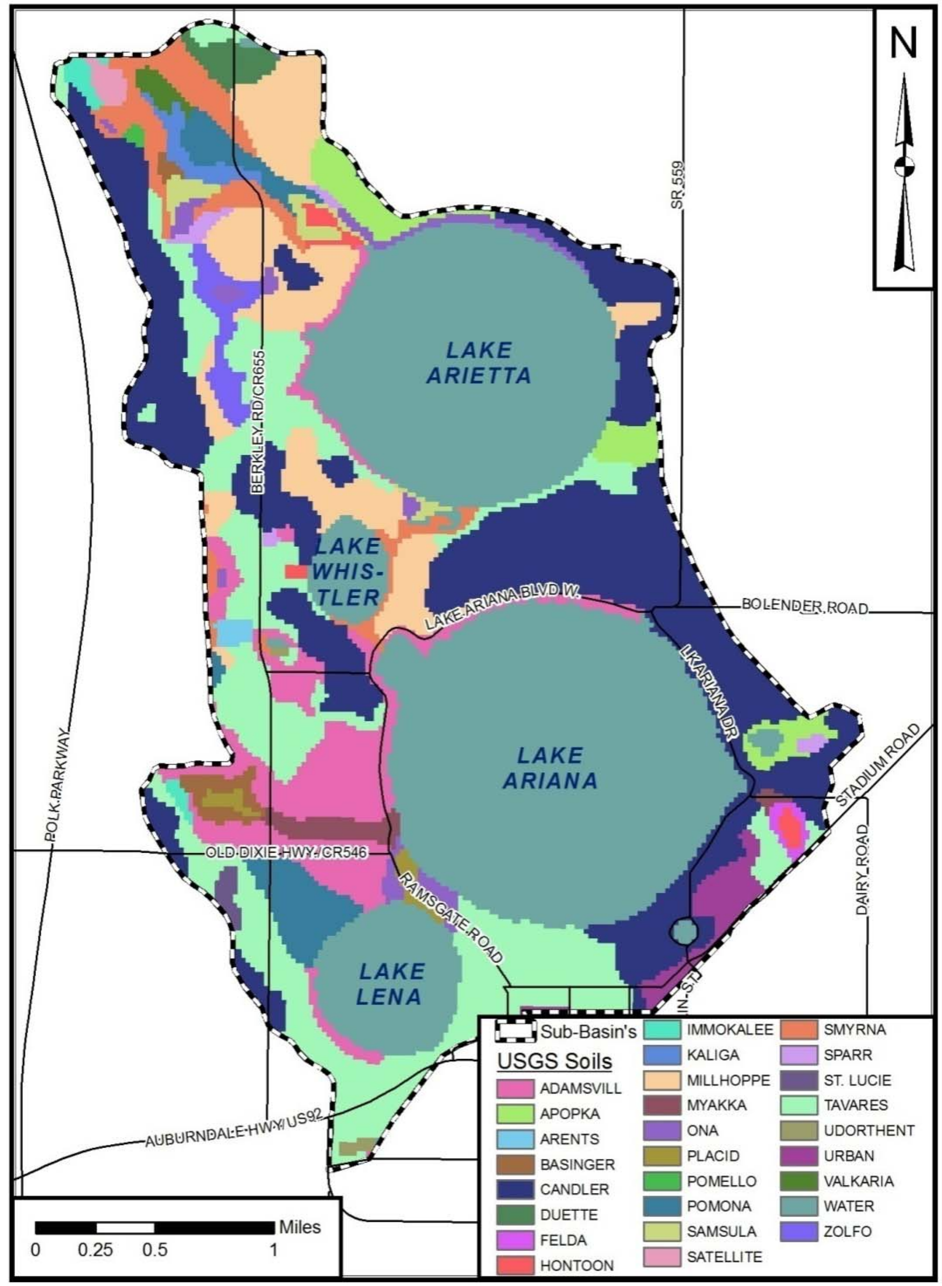
A - 7: Lake Alfred Groundwater Delivery Reach Zones



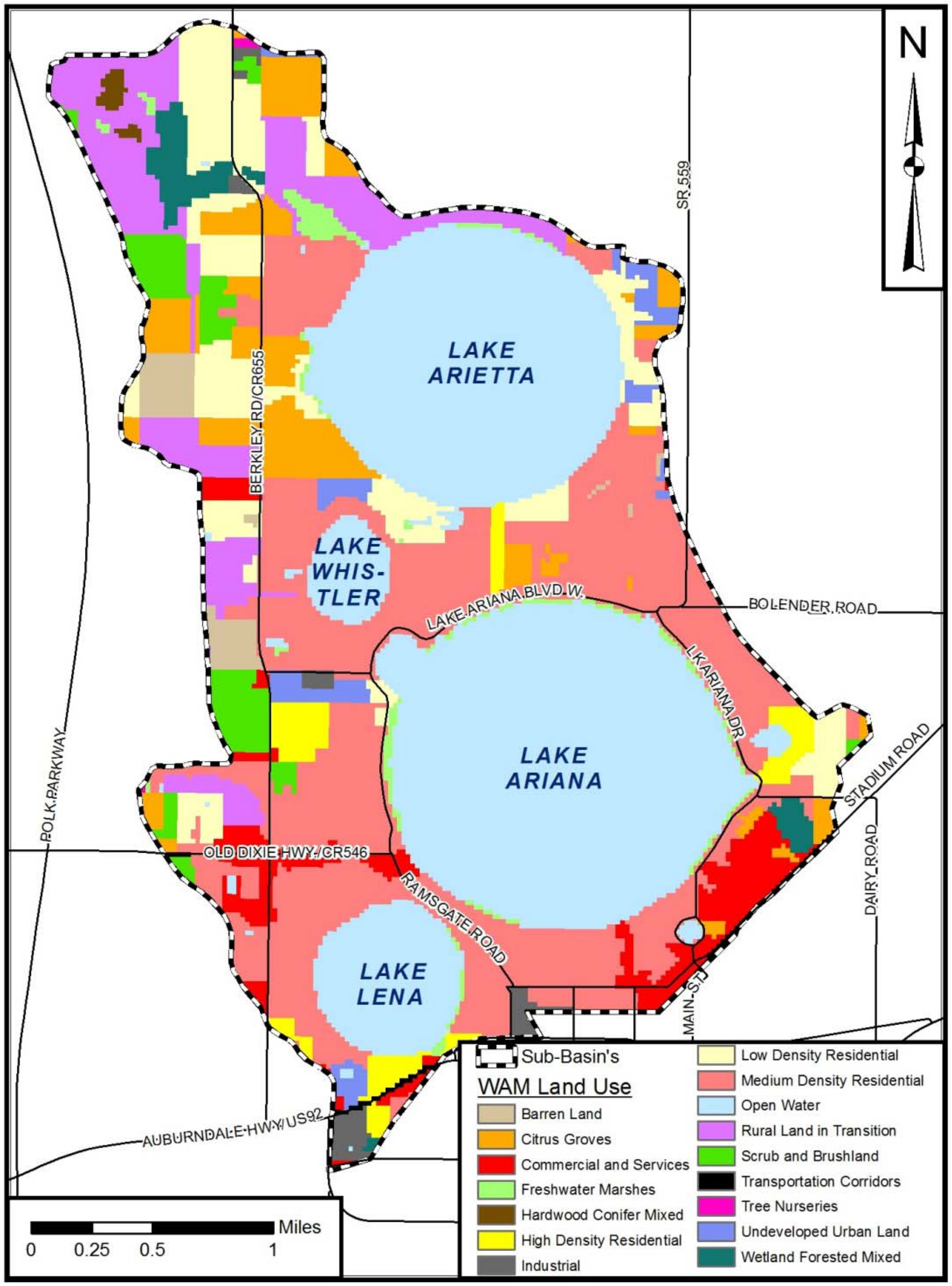
A - 8: Lake Arianna 2007 True Color Aerial



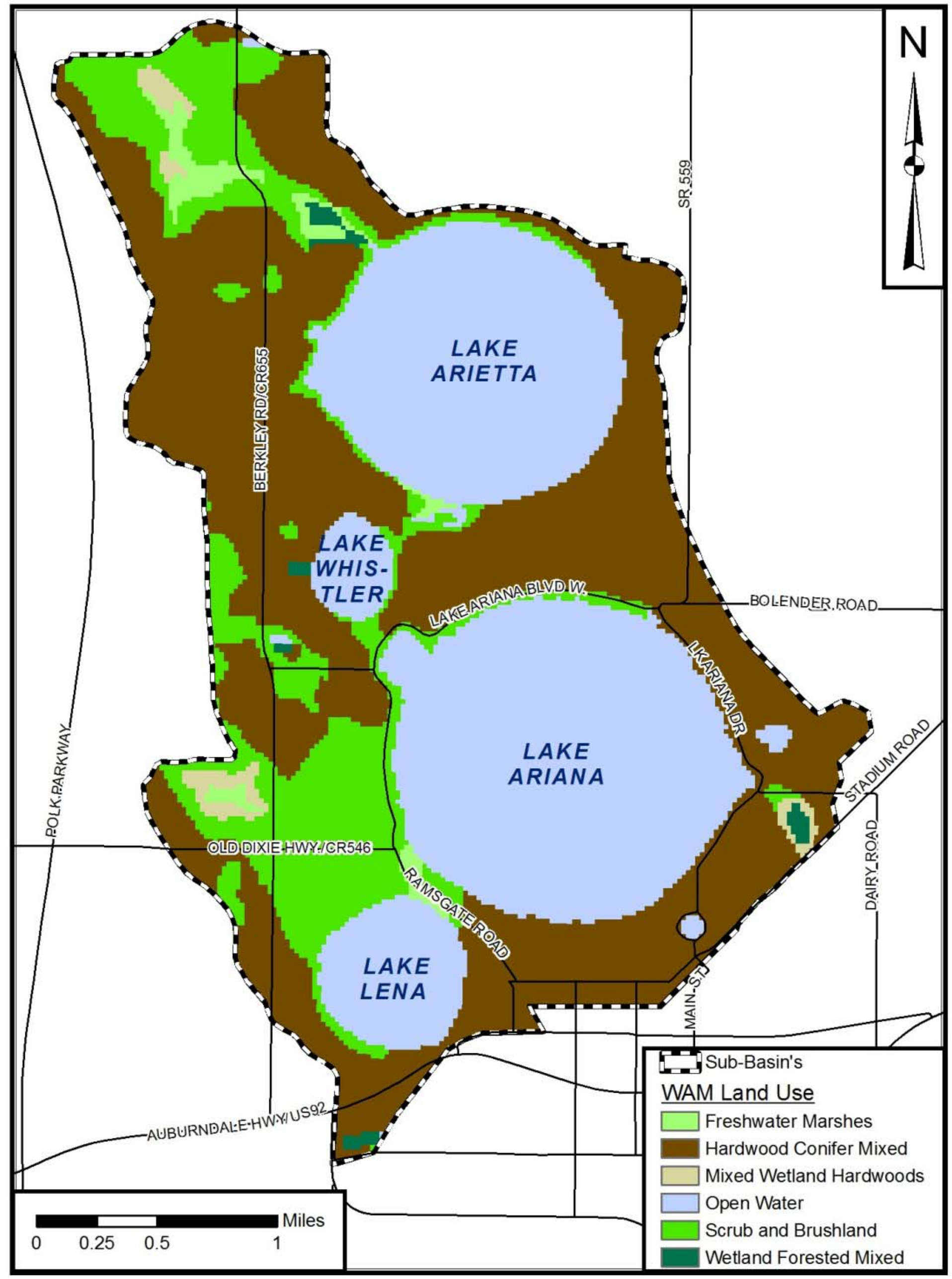
A - 10: Lake Ariana Topography



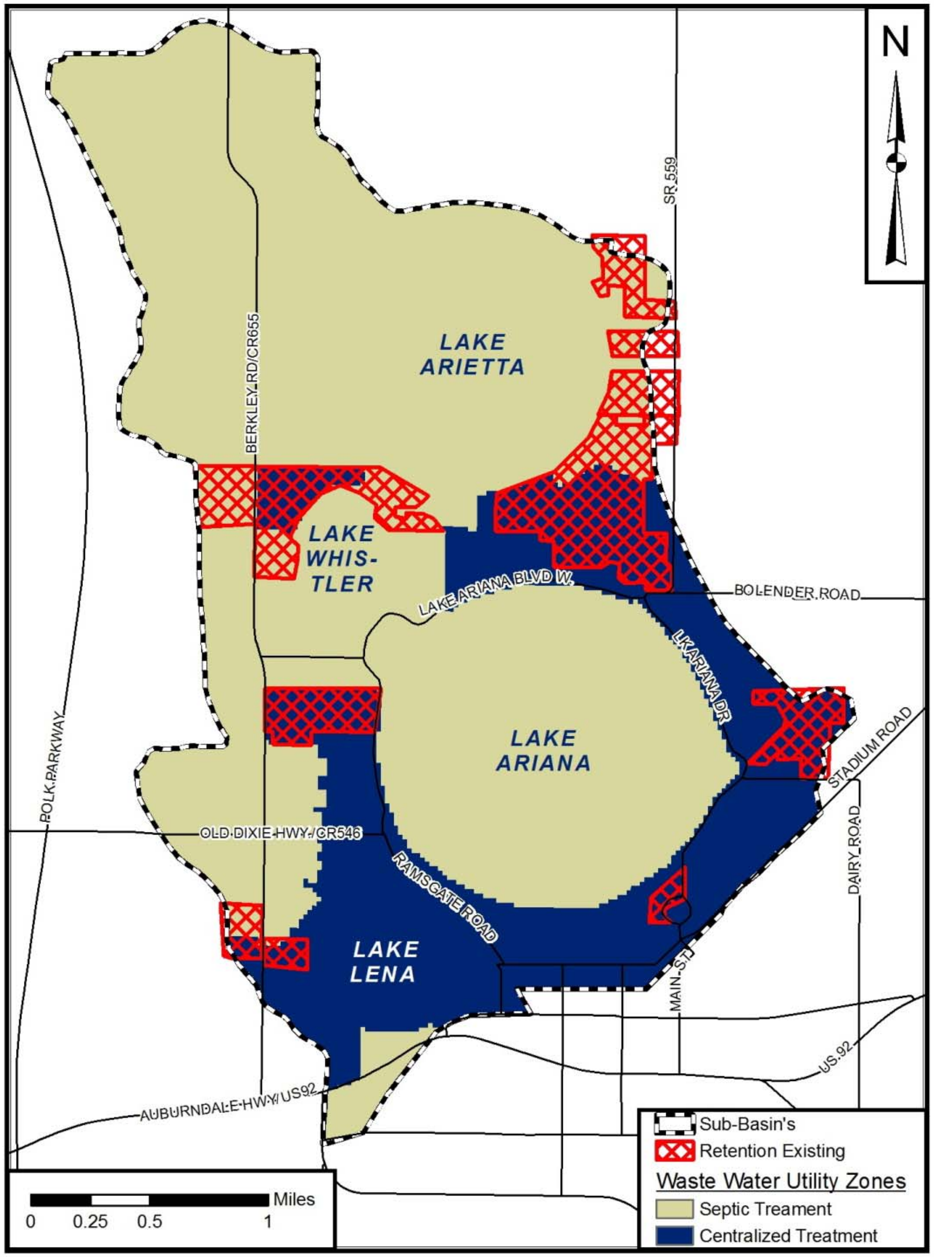
A - 9: Lake Ariana USGS Soils



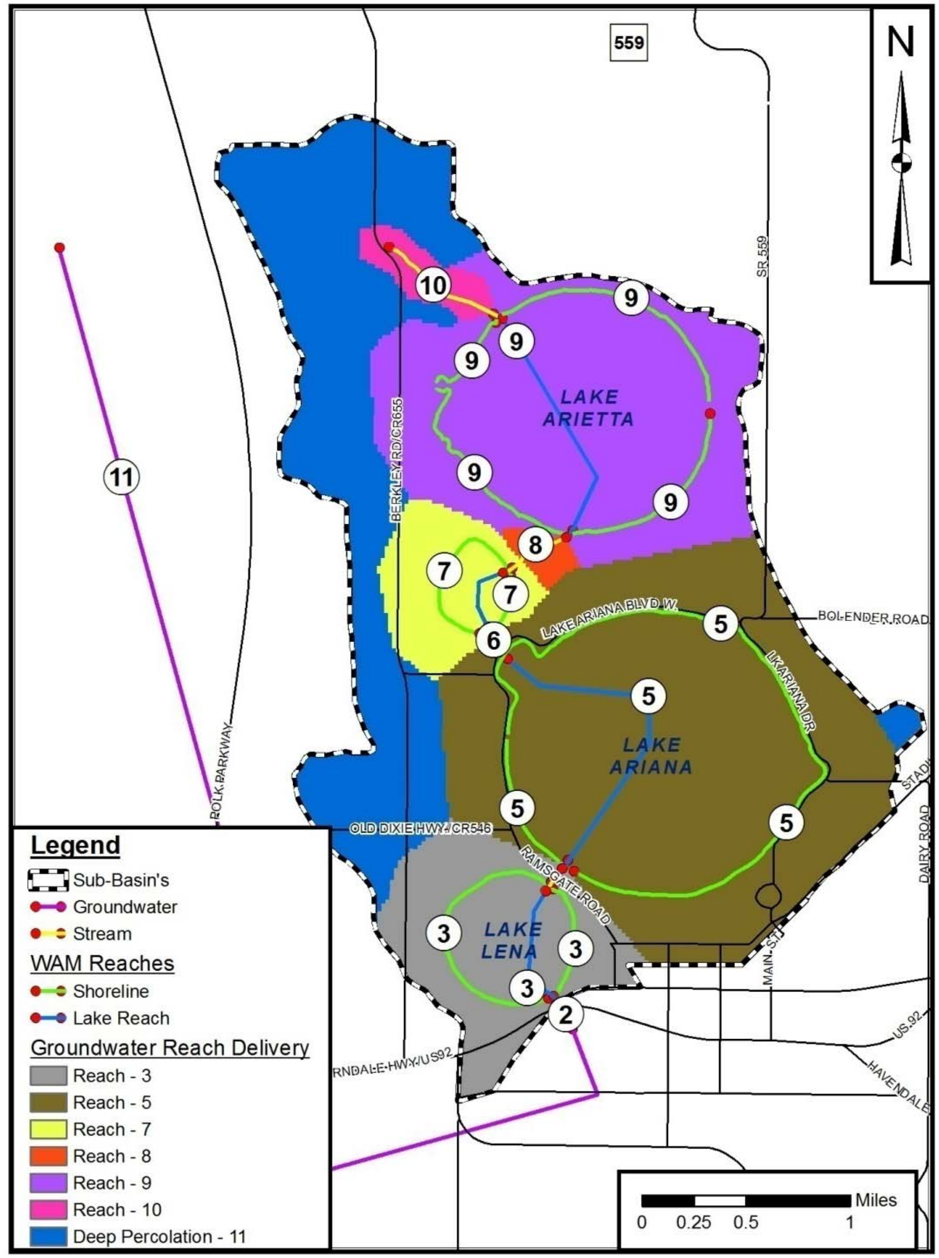
A - 12: Lake Ariana Current Land Use Condition



A - 11: Lake Ariana Natural Land Use Condition



A - 13: Lake Ariana Waste Water Utility Zones and Area under Retention



A - 14: Lake Ariana Groundwater Delivery Reach Zones

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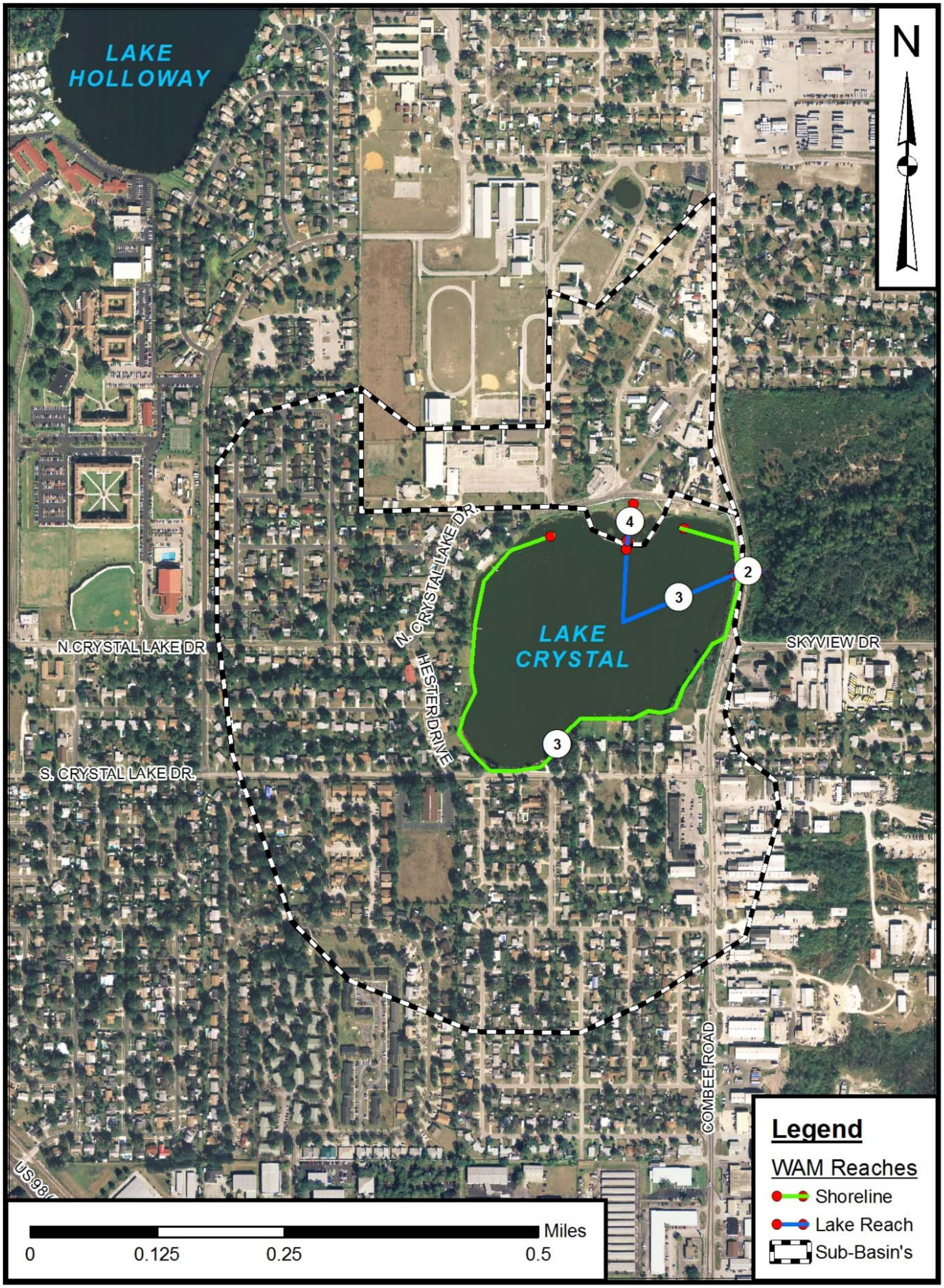
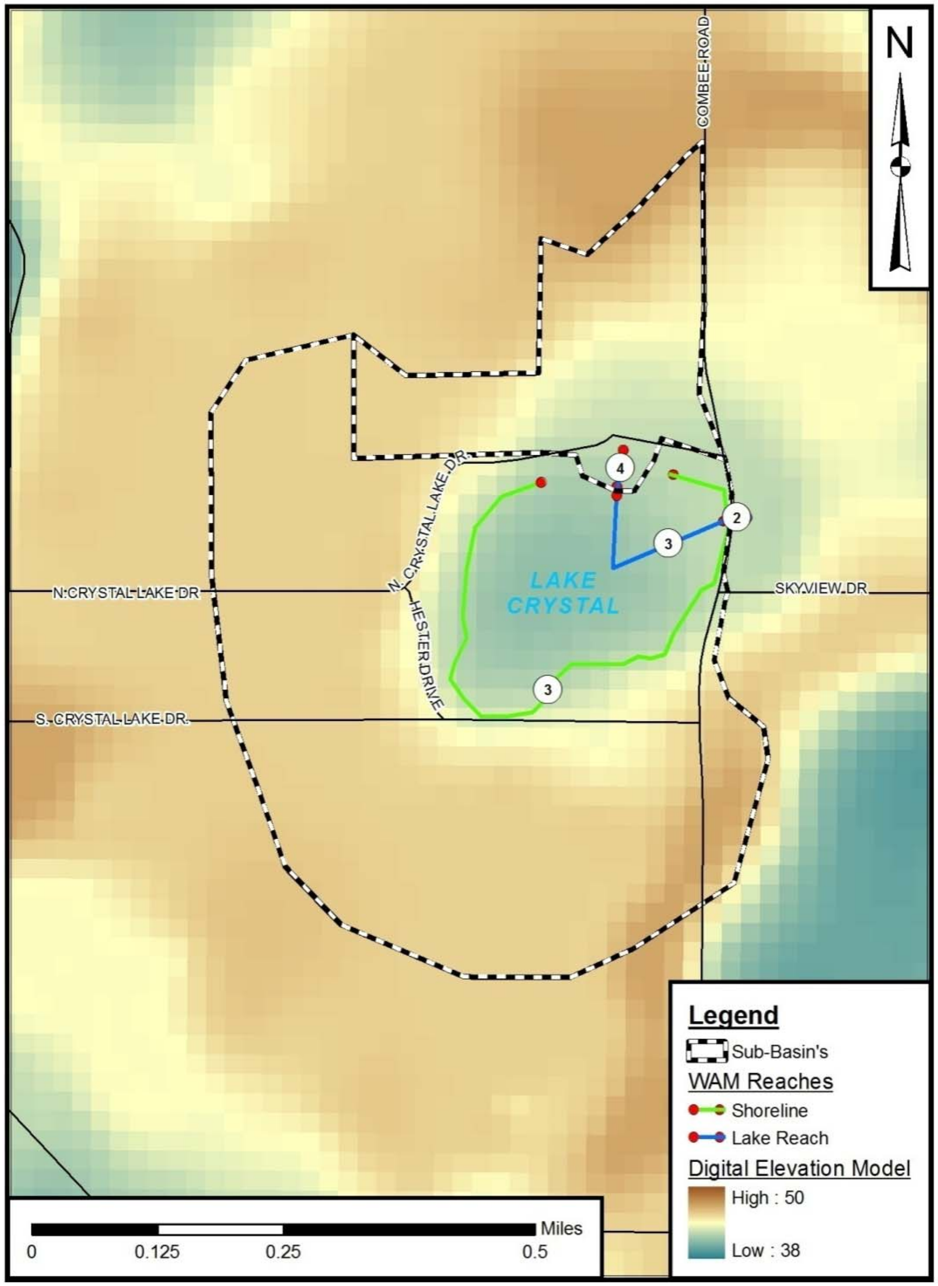
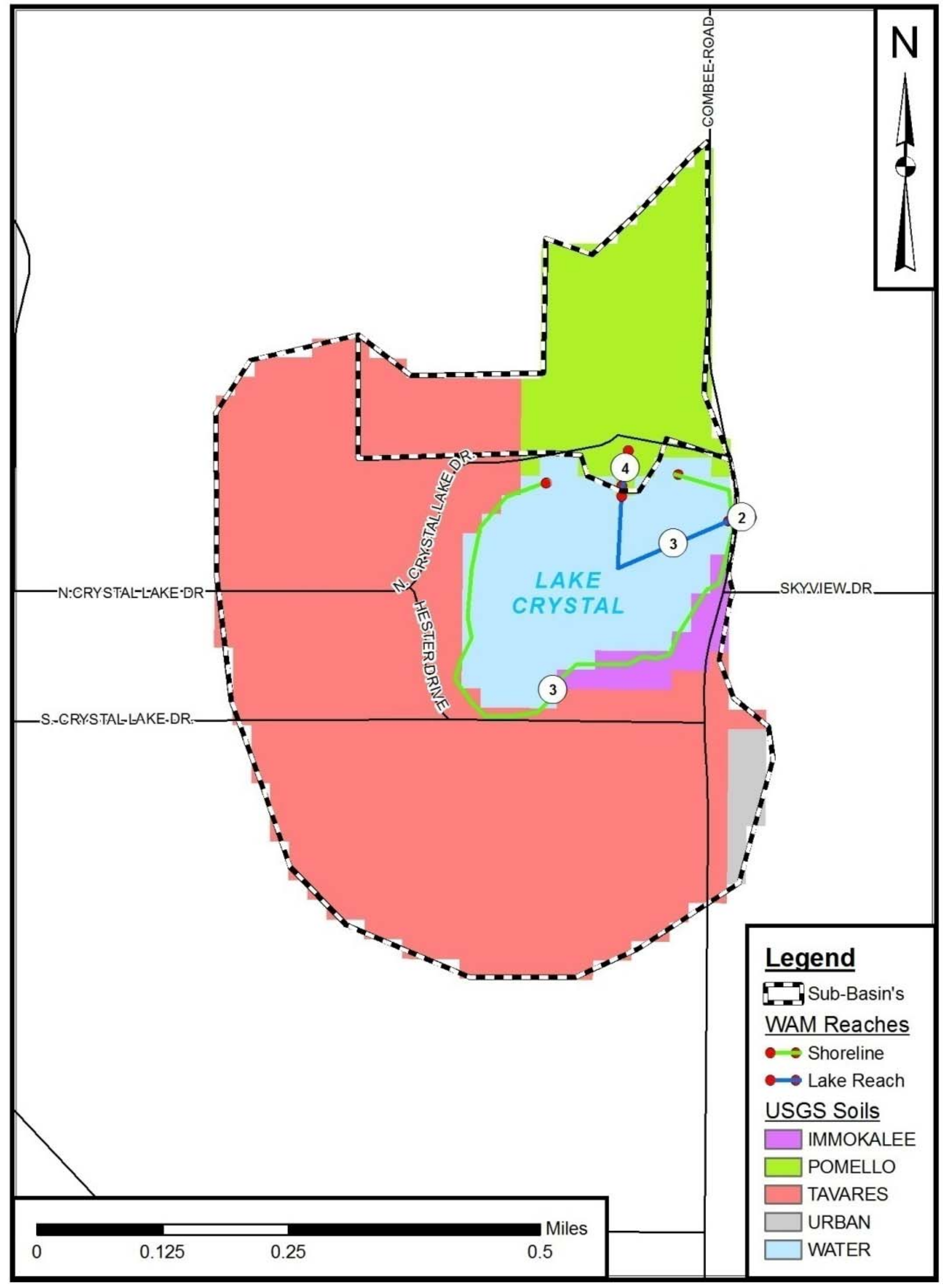


A - 15: Lake Crystal 2007 True Color Aerial

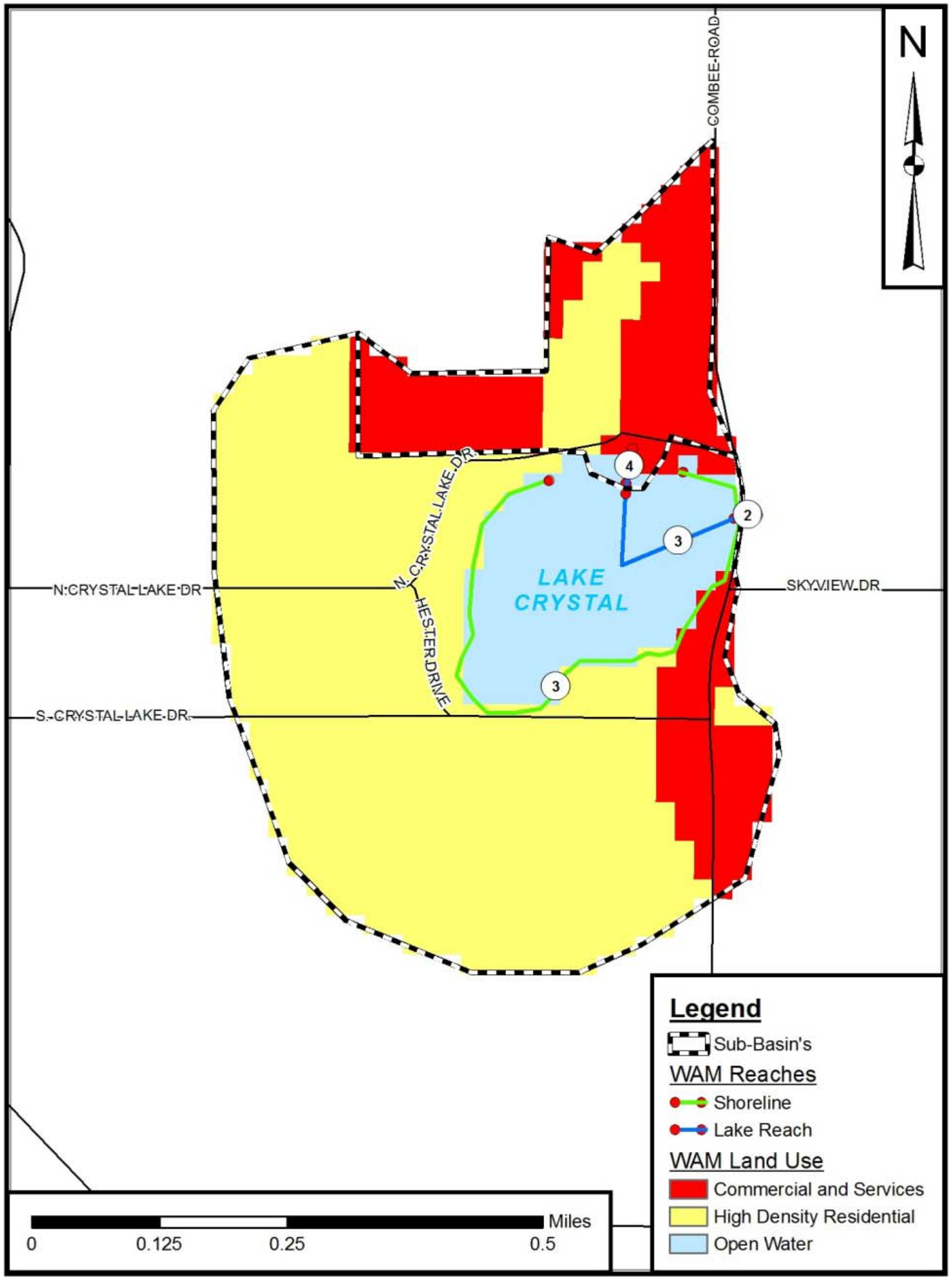
A-15



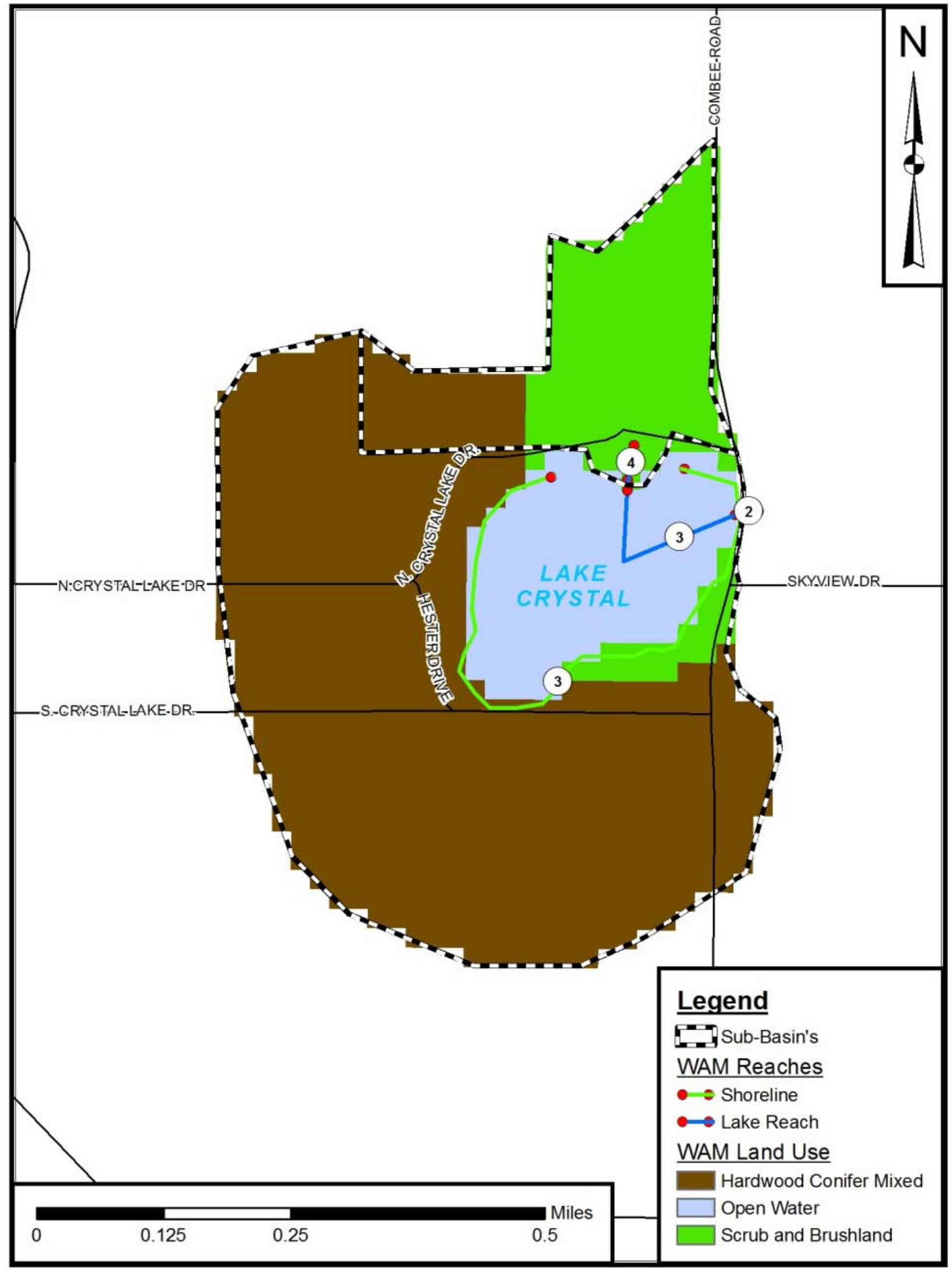
A - 16: Lake Crystal Topography



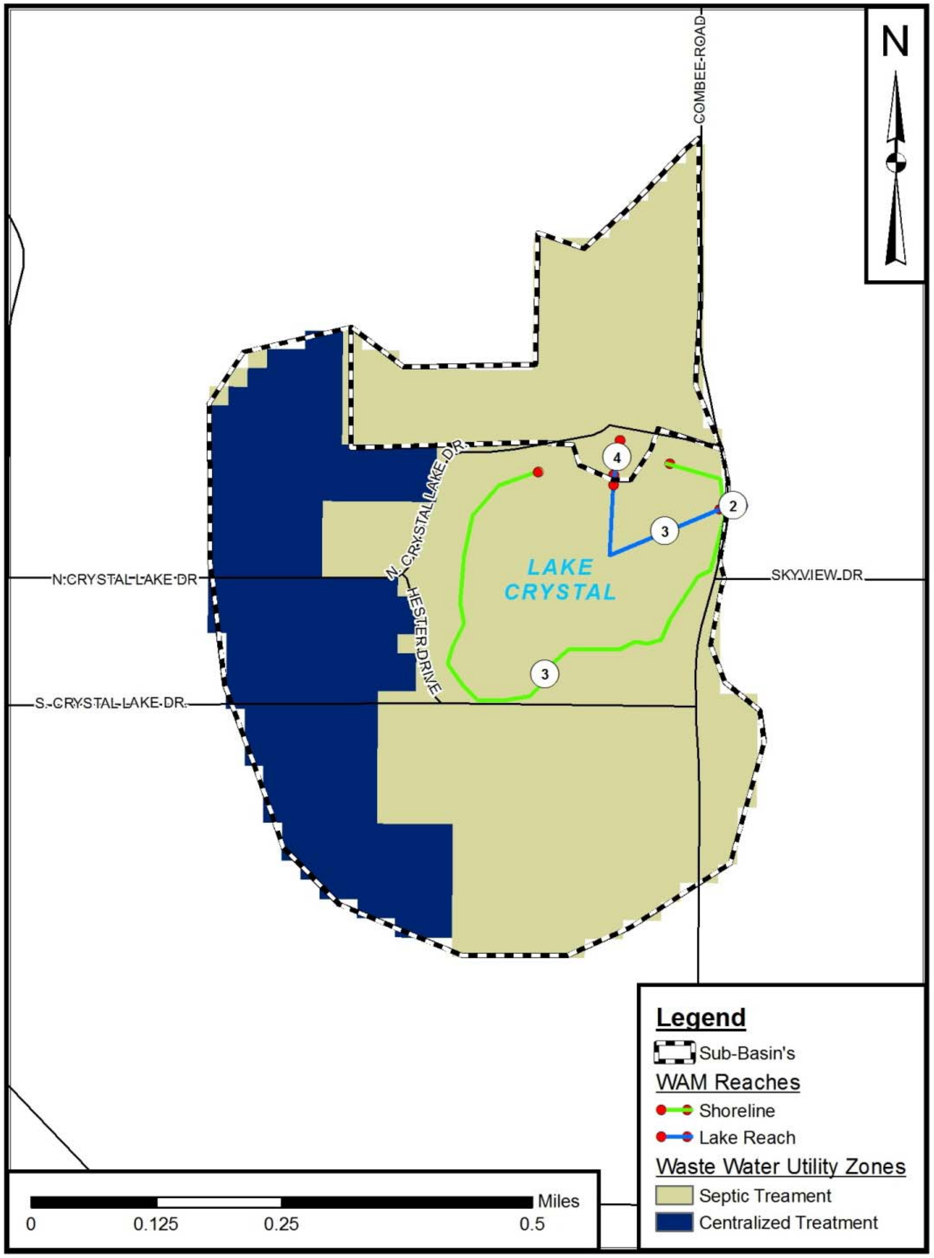
A - 17: Lake Crystal USGS Soils



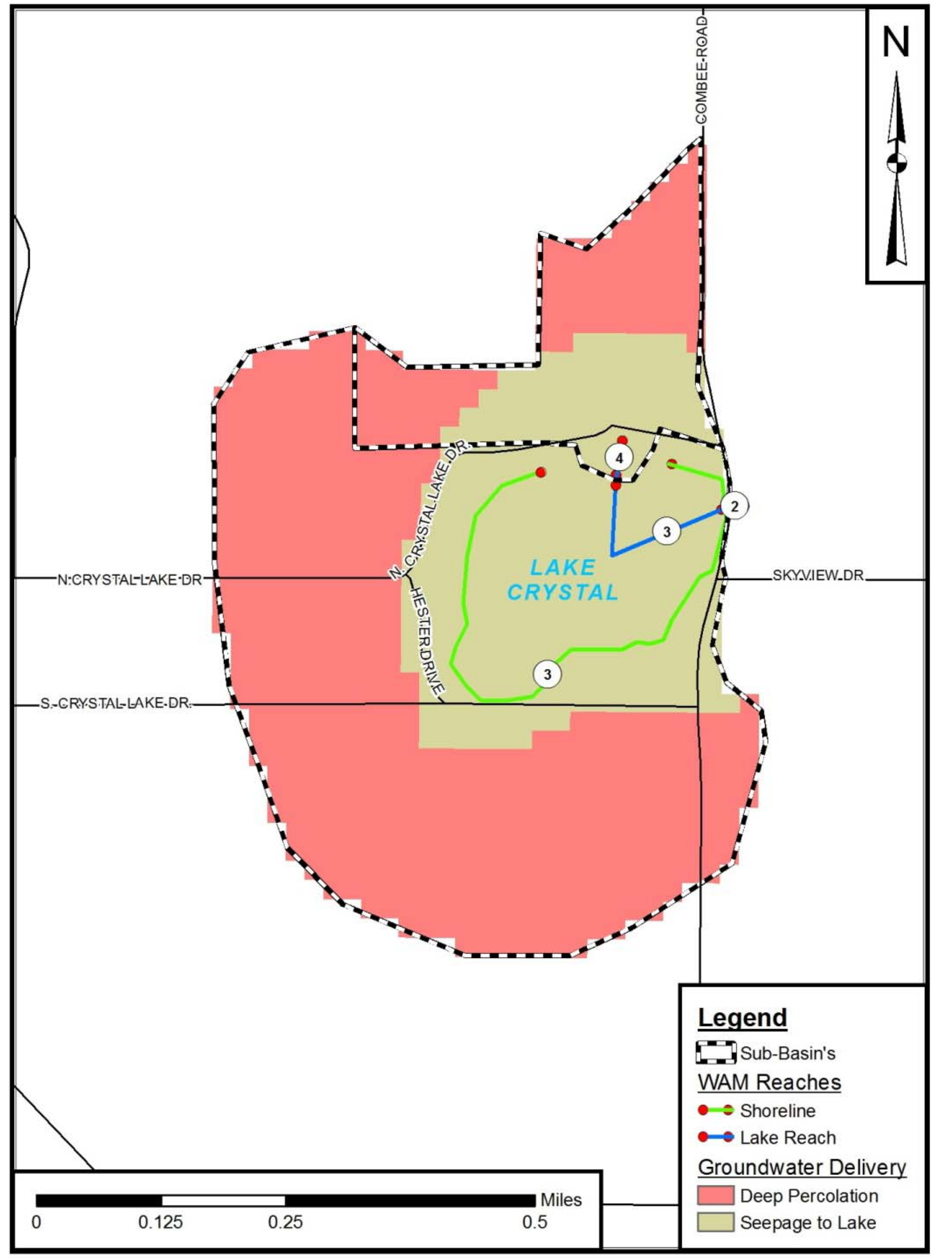
A - 18: Lake Crystal Current Land Use Condition



A - 19: Lake Crystal Natural Land Use Condition



A - 20: Lake Crystal Waste Water Utility Zones



A - 21: Lake Crystal Groundwater Delivery Reach Zones

Appendix B:

Upper Peace River - Three Lakes

Watershed Assessment Model (WAM)

Land Use Tables

Table B-1: Lake Alfred Land Use

FLUCCS	FLUCCS Description	WAM Land Use Group Code	WAM Land Use Group Description	Acres
1100	Low Density Residential, Fixed Single Family Units	2	Low Density Residential	70.0
1400	Commercial and Services	3	Commercial and Services	13.5
1700	Educational Facilities	3	Commercial and Services	17.2
1800	Recreation	3	Commercial and Services	16.3
2100	Pastures and Fields	4	Rural Land in Transition	76.2
2600	Old Field	5	Scrub and Brushland	18.6
4340	Hardwood - Conifer Mixed	7	Hardwood Conifer Mixed	3.0
5200	Lakes	9	Open Water	6.9
5300	Reservoirs	9	Open Water	0.2
5201	Interconnected Lakes	92	Open Water	636.1
6150	Stream and Lake Swamps (Bottomland)	15	Wetland Forested Mixed	31.4
6300	Wetland Forested Mixed	15	Wetland Forested Mixed	17.0
6410	Freshwater Marshes	16	Freshwater Marshes	224.3
6430	Wet Prairies	16	Freshwater Marshes	76.9
6440	Emergent Aquatic Vegetation	16	Freshwater Marshes	113.6
8100	Transportation	18	Transportation Corridors	5.0
1200	Medium Density Residential, Fixed Single Family Units	19	Medium Density Residential	81.7
1300	High Density Residential	20	High Density Residential	4.8
1500	Industrial	22	Industrial	6.2
2400	Nurseries and Vineyards	35	Tree Nurseries	4.6
1900	Undeveloped Land	70	Undeveloped Urban Land	101.1
2200	Tree Crops	84	Citrus Groves	250.9
			Lake Alfred Sub-Basin Total	1775.6

Table B-2: Lake Camp Land Use

FLUCCS	FLUCCS Description	WAM Land Use Group Code	WAM Land Use Group Description	Acres
1100	Low Density Residential, Fixed Single Family Units	2	Low Density Residential	0.8
2100	Pastures and Fields	4	Rural Land in Transition	36.8
2600	Old Field	5	Scrub and Brushland	3.6
5200	Lakes	9	Open Water	2.8
5201	Interconnected Lakes	92	Open Water	46.6
6410	Freshwater Marshes	16	Freshwater Marshes	12.1
2200	Tree Crops	84	Citrus Groves	38.6
			Lake Camp Sub-Basin Total	141.3

Table B-3: Grass Lake Land Use

FLUCCS	FLUCCS Description	WAM Land Use Group Code	WAM Land Use Group Description	Acres
1100	Low Density Residential, Fixed Single Family Units	2	Low Density Residential	5.0
2600	Old Field	5	Scrub and Brushland	21.6
2400	Nurseries and Vineyards	35	Tree Nurseries	3.9
2200	Tree Crops	84	Citrus Groves	12.9
5201	Interconnected Lakes	92	Open Water	13.3
			Grass Lake Sub-Basin Total	56.6

Table B-4: Lake Crystal Land Use

FLUCCS	FLUCCS Description	WAM Land Use Group Code	WAM Land Use Group Description	Acres
1300	High Density Residential	20	High Density Residential	122.1
1400	Commercial and Services	3	Commercial and Services	30.3
1700	Educational Facilities	3	Commercial and Services	12.2
5201	Interconnected Lakes	92	Open Water	30.8
			Lake Crystal Sub-Basin Total	195.4

Table B-5: Lake Ariana **Land Use**

FLUCCS	FLUCCS Description	WAM Land Use Group Code	WAM Land Use Group Description	Acres
1100	Low Density Residential, Fixed Single Family Units	2	Low Density Residential	294.1
11100	Low Density Residential, Fixed Single Family Units - storm ret	102	Low Density Residential - Storm Retention	132.9
1400	Commercial and Services	3	Commercial and Services	105.4
1700	Educational Facilities	3	Commercial and Services	91.8
1800	Recreation	3	Commercial and Services	4.1
11800	Recreation - storm ret	103	Commercial and Services - Storm Retention	16.1
2100	Pastures and Fields	4	Rural Land in Transition	399.4
2600	Old Field	5	Scrub and Brushland	140.3
4340	Hardwood - Conifer Mixed	7	Hardwood Conifer Mixed	12.9
5200	Lakes	9	Open Water	14.2
5300	Reservoirs	9	Open Water	9.9
5201	Interconnected Lakes	92	Open Water	2033.3
6150	Stream and Lake Swamps	15	Wetland Forested Mixed	19.5
6300	Wetland Forested Mixed	15	Wetland Forested Mixed	55.1
6400	Vegetated Non-Forested Wetlands	16	Freshwater Marshes	28.7
6410	Freshwater Marshes	16	Freshwater Marshes	0.2
6440	Emergent Aquatic Vegetation	16	Freshwater Marshes	40.2
6530	Inland Shores/Ephemeral Ponds	17	Barren Land	4.8
7400	Barren Land	17	Barren Land	67.0
8100	Transportation	18	Transportation Corridors	14.2
1200	Medium Density Residential, Fixed Single Family Units	19	Medium Density Residential	1082.6
11200	Medium Density Residential, Fixed Single Family Units - storm ret	119	Medium Density Residential - Storm Retention	319.3
1300	High Density Residential	20	High Density Residential	62.4
11300	High Density Residential - storm ret	120	High Density Residential - Storm Retention	53.9
1500	Industrial	22	Industrial	45.7
8300	Utilities	22	Industrial	4.1
2400	Nurseries and Vineyards	35	Tree Nurseries	3.0
1900	Undeveloped Land	70	Undeveloped Urban Land	43.2
11900	Undeveloped Land - storm ret	170	Undeveloped Urban Land - Storm Retention	42.7

2200	Tree Crops	84	Citrus Groves	317.3
			Lake Ariana Sub-Basin Total	5458.4

Table B-6: Soil Type to Natural Land Use Lookup Table

NRCS Soils (COMPNAME)	WAM Soilcode	Associated Natural Land Use	FLUCCS	WAM land use code
ADAMSVILL	1	Dry Prairie or Pine Flatwoods	4110	5
ANCLOTE	7	Forested Wetland	6220	15
APOPKA	11	Pine-Xeric Oak Forest	4340	7
ARENTS	18	Community Undetermined	4110	5
BASINGER	26	Sloughs or Hydric Flatwoods	6172	12
CANDLER	62	Pine-Xeric Oak Forest	4340	7
DUETTE	102	Xeric Scrub	3200	5
FELDA	129	Sloughs or Hydric Flatwoods	6172	12
HOLOPAW	164	Cypress - Pine - Cabbage Palm	6240	15
HONTOON	166	Forested Wetland	6220	15
IMMOKALEE	171	Dry Prairie or Pine Flatwoods	4110	5
KALIGA	183	Herbaceous Wetland	6410	16
MILLHOPPE	243	Oak - Pine - Hickory	4230	7
MYAKKA	250	Dry Prairie or Pine Flatwoods	4110	5
ONA	275	Dry Prairie or Pine Flatwoods	4110	5
PLACID	311	Herbaceous Wetland	6410	16
POMELLO	315	Xeric Scrub	3200	5
POMONA	316	Dry Prairie or Pine Flatwoods	4110	5
POMPANO	317	Cypress - with wet prairies	6219	14
SAMSULA	340	Herbaceous Wetland	6410	16
SATELLITE	344	Xeric Scrub	3200	5
SMYRNA	355	Dry Prairie or Pine Flatwoods	4110	5
SPARR	357	Oak - Pine - Hickory	4230	7
ST. LUCIE	360	Xeric Scrub	3200	5
TAVARES	374	Pine-Xeric Oak Forest	4340	7
UDORTHENT	395	Wetland Forested Mixed	6300	15
URBAN	396	Pine-Xeric Oak Forest	4340	7
VALKARIA	398	Sloughs or Hydric Flatwoods	6172	12
WATER	408	Open Water	5100	9
ZOLFO	427	Oak - Pine - Hickory	4230	7

Appendix C

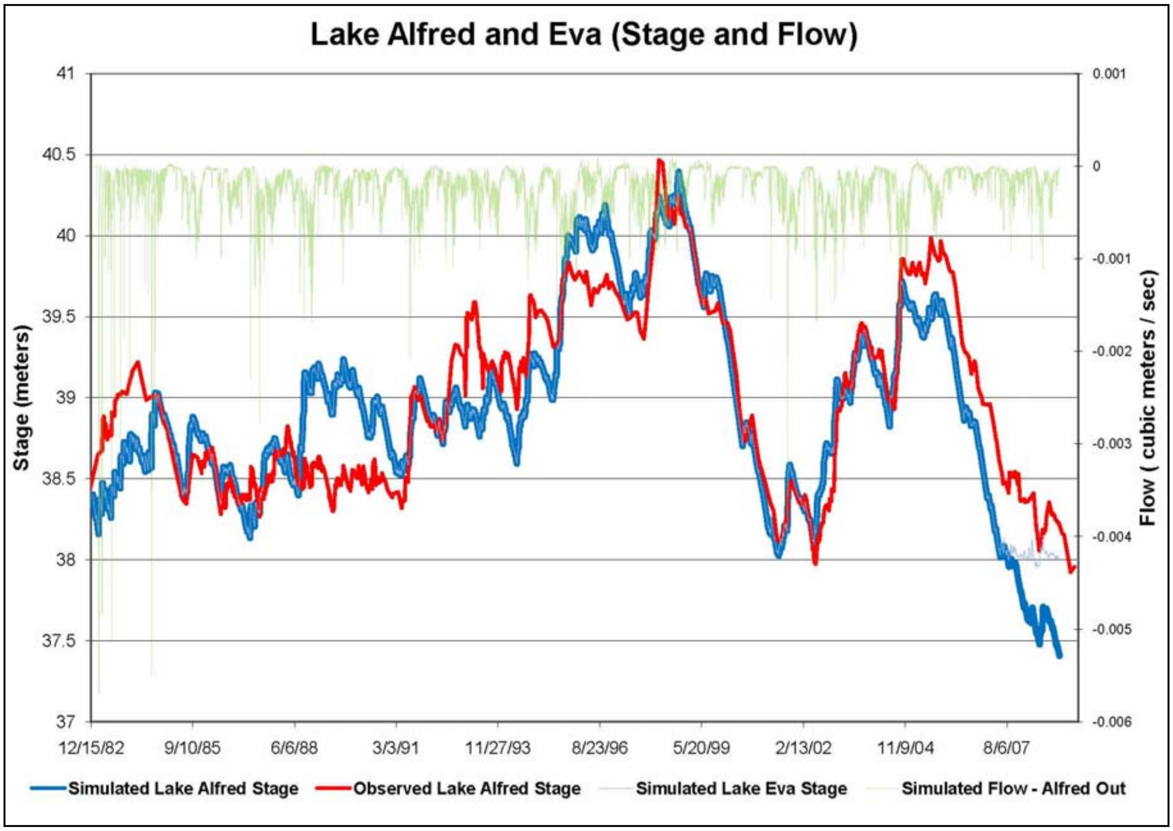
Upper Peace River - Three Lakes

Watershed Assessment Model (WAM)

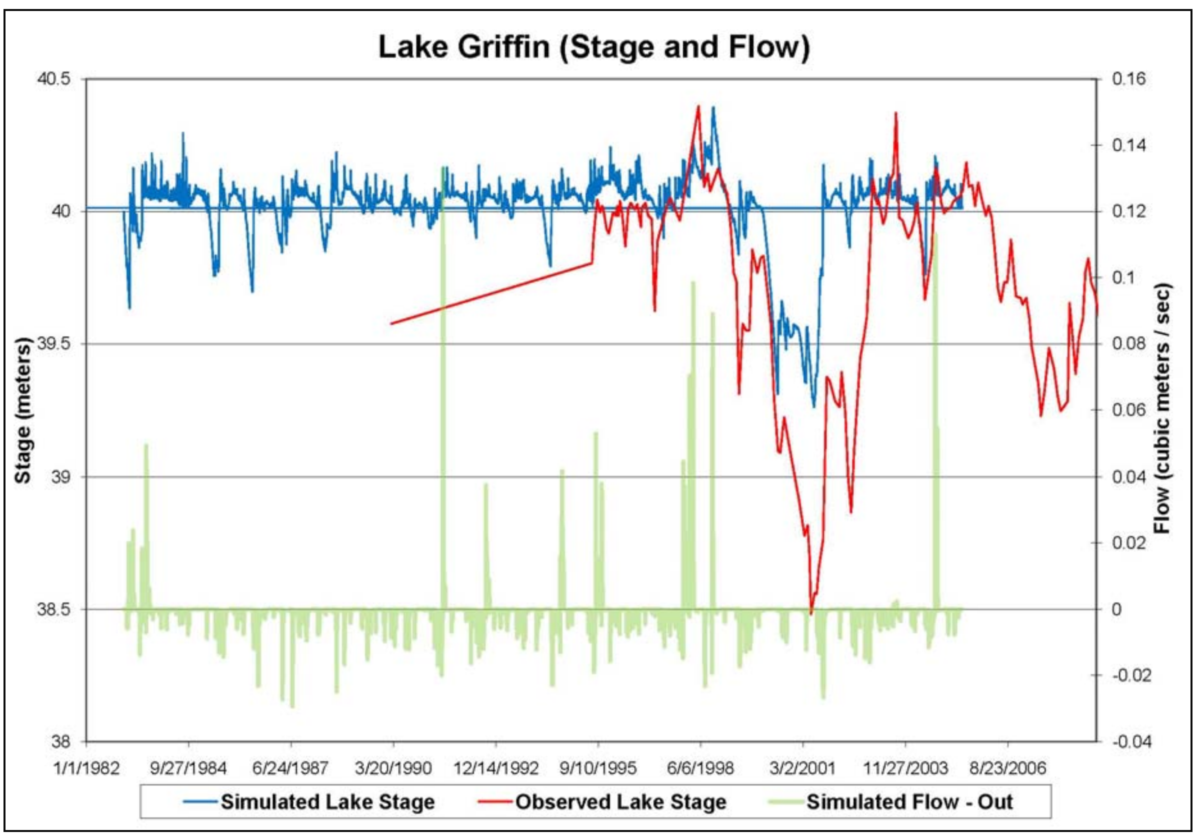
Current Land use Condition

Temporal Flow and Stage Simulation Value

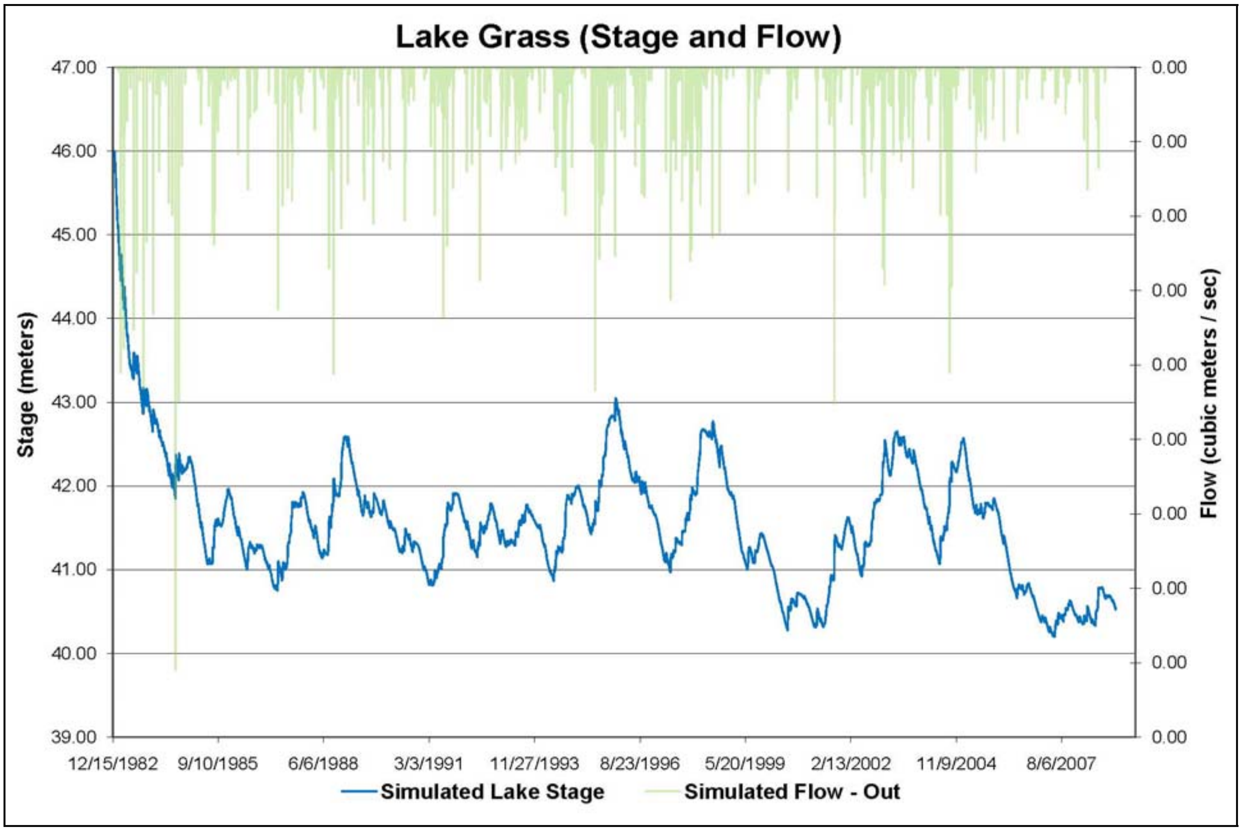
Comparisons to Observed Values.



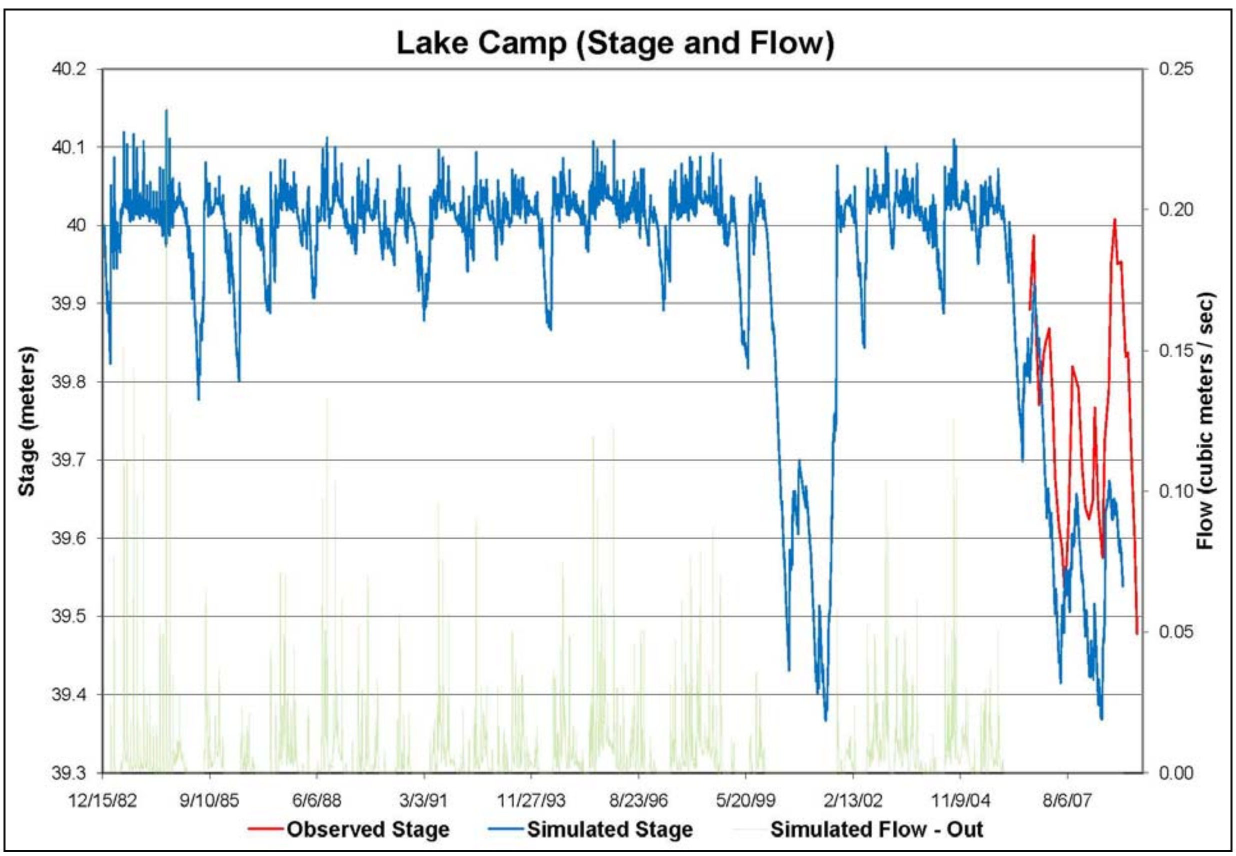
C - 1: Lake Alfred and Lake Eva Temporal Stage and Flow



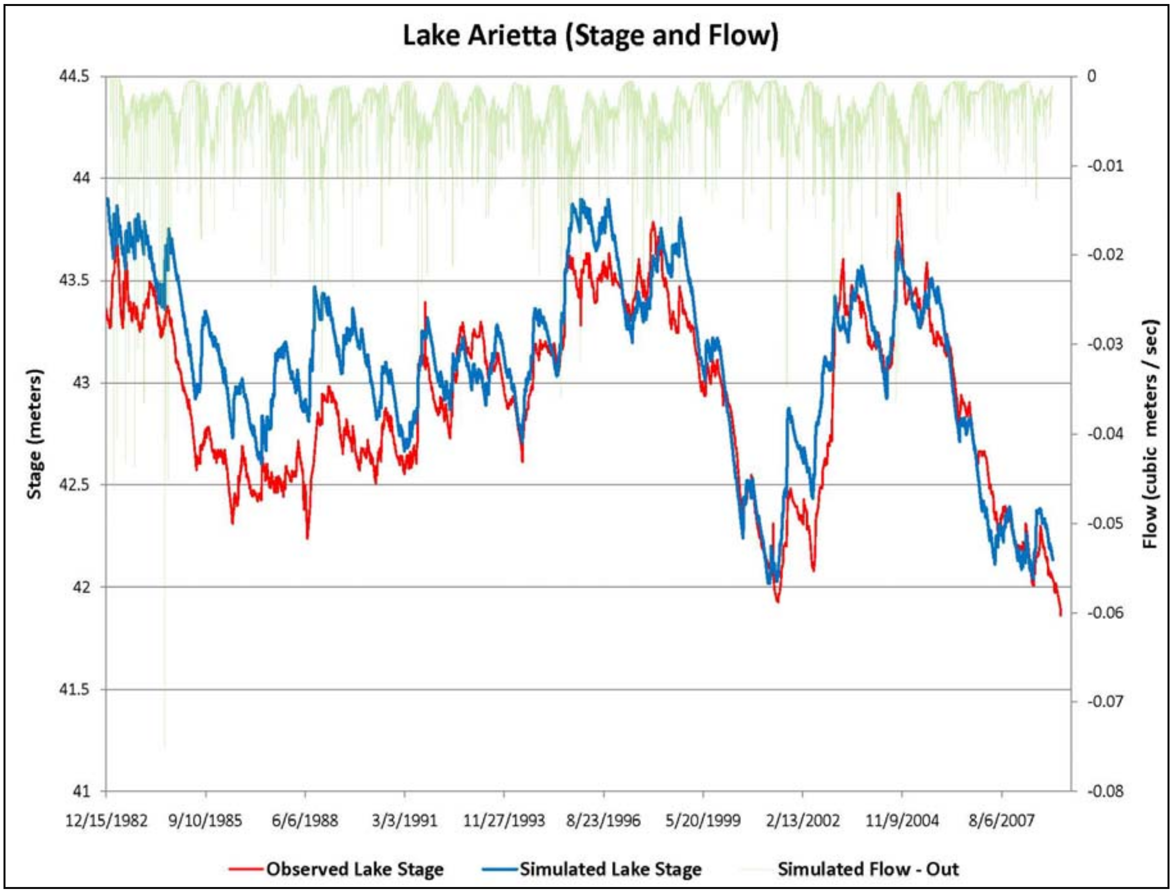
C - 2: Lake Griffin Temporal Stage and Flow



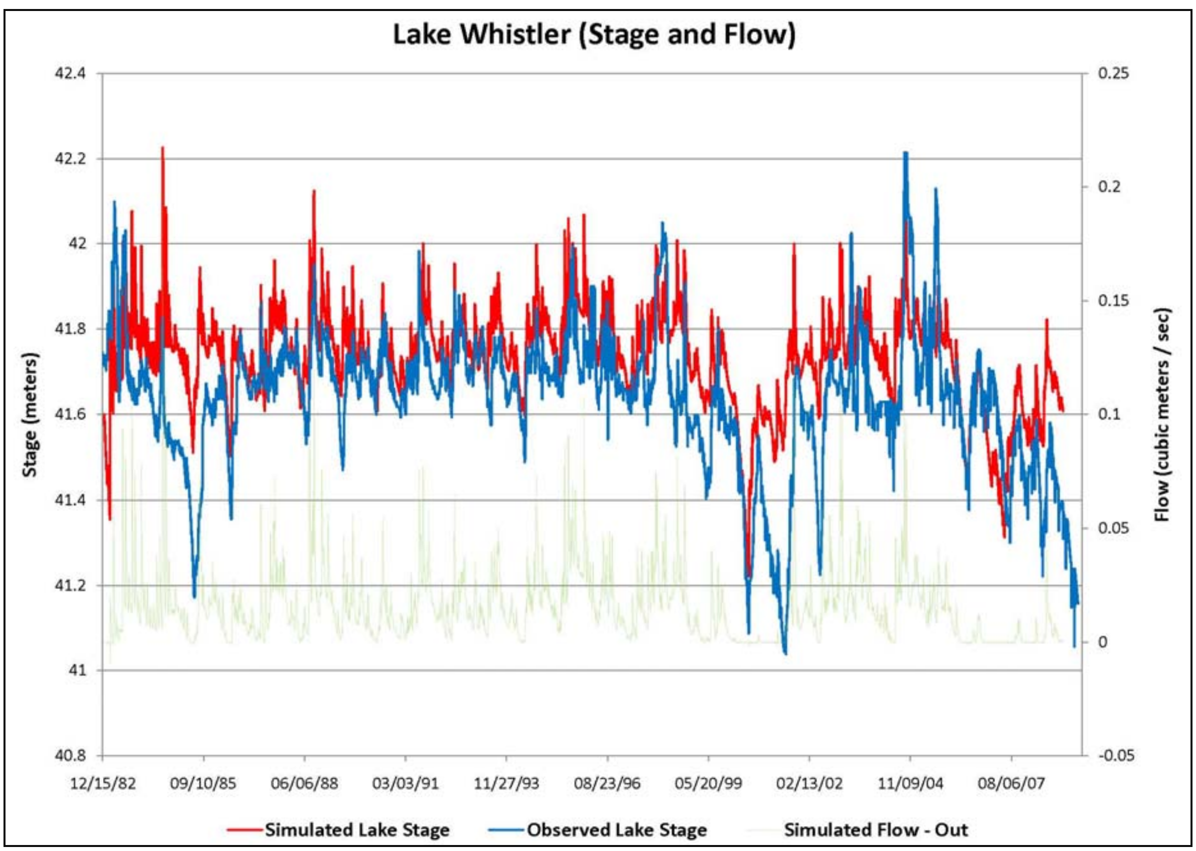
C - 3: Lake Grass Temporal Stage and Flow



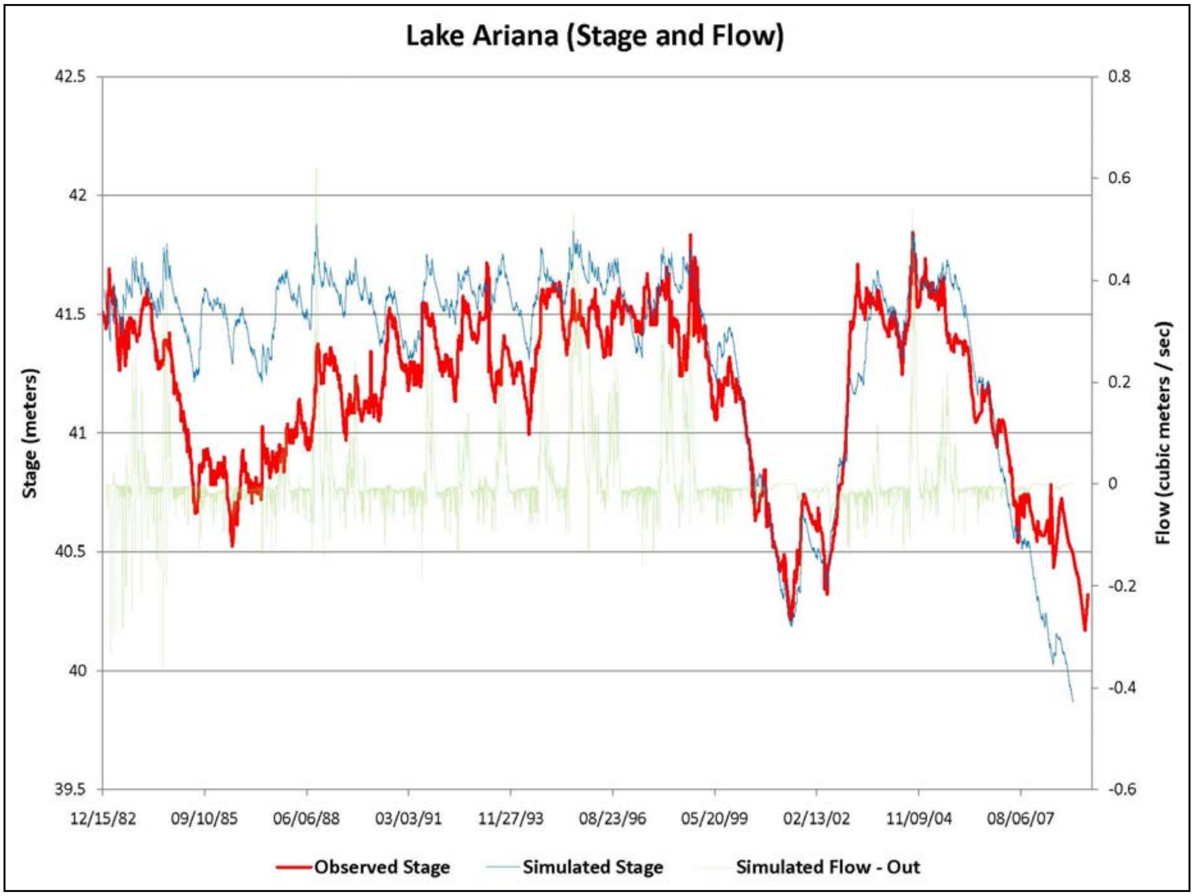
C - 4: Lake Camp Temporal Stage and Flow



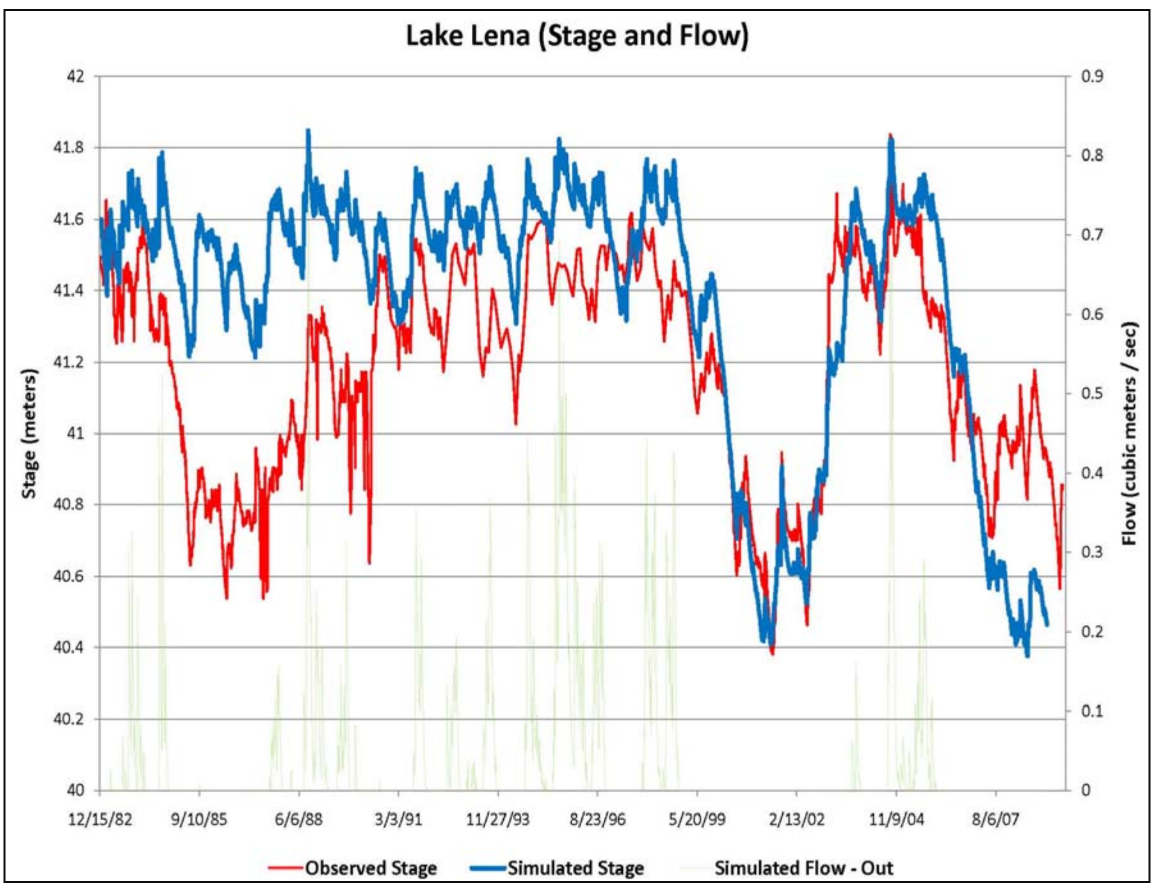
C - 5: Lake Arietta Temporal Stage and Flow



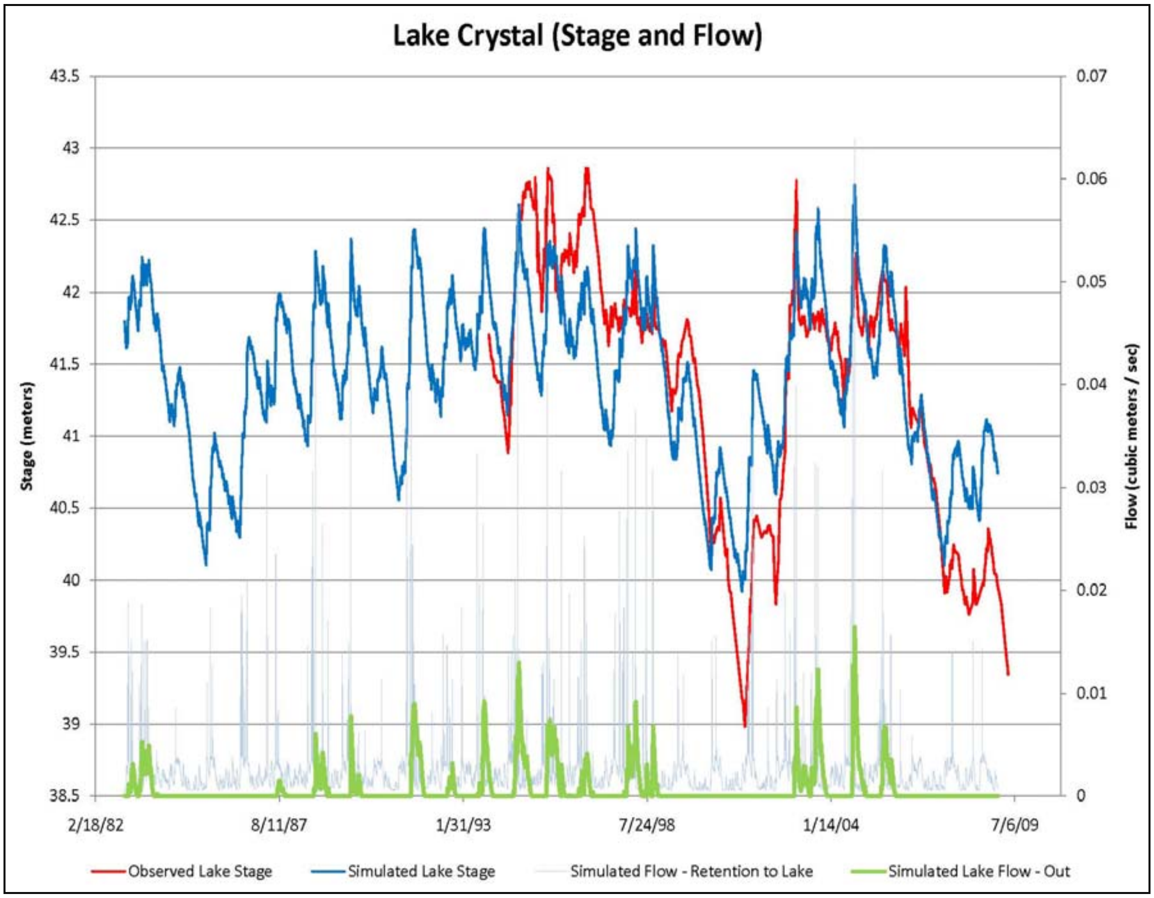
C - 6: Lake Whistler Stage and Flow



C - 7: Lake Ariana Temporal Stage and Flow



C - 8: Lake Lena Temporal Stage and Flow



C - 9: Lake Crystal Temporal Stage and Flow

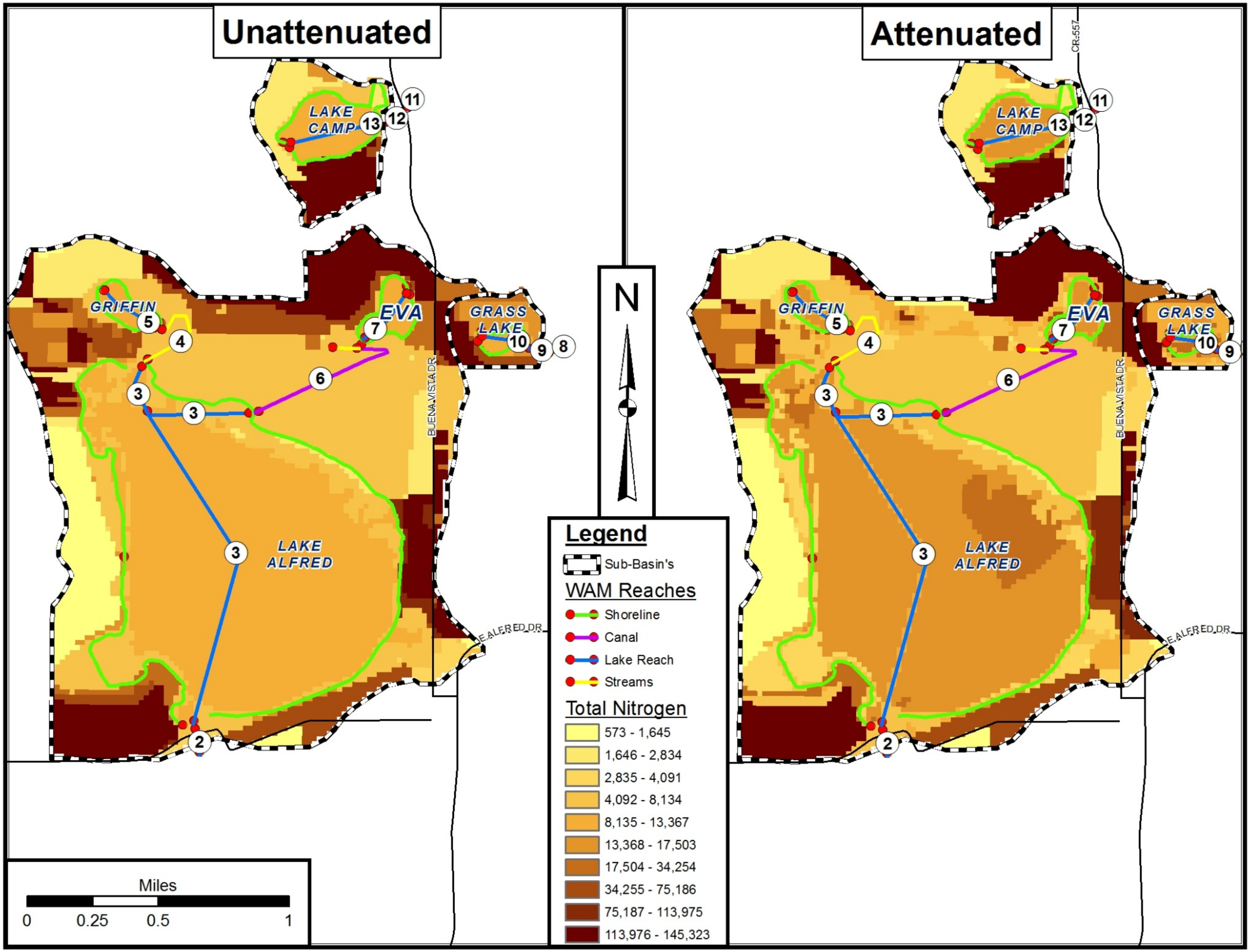
Appendix D

Upper Peace River - Three Lakes

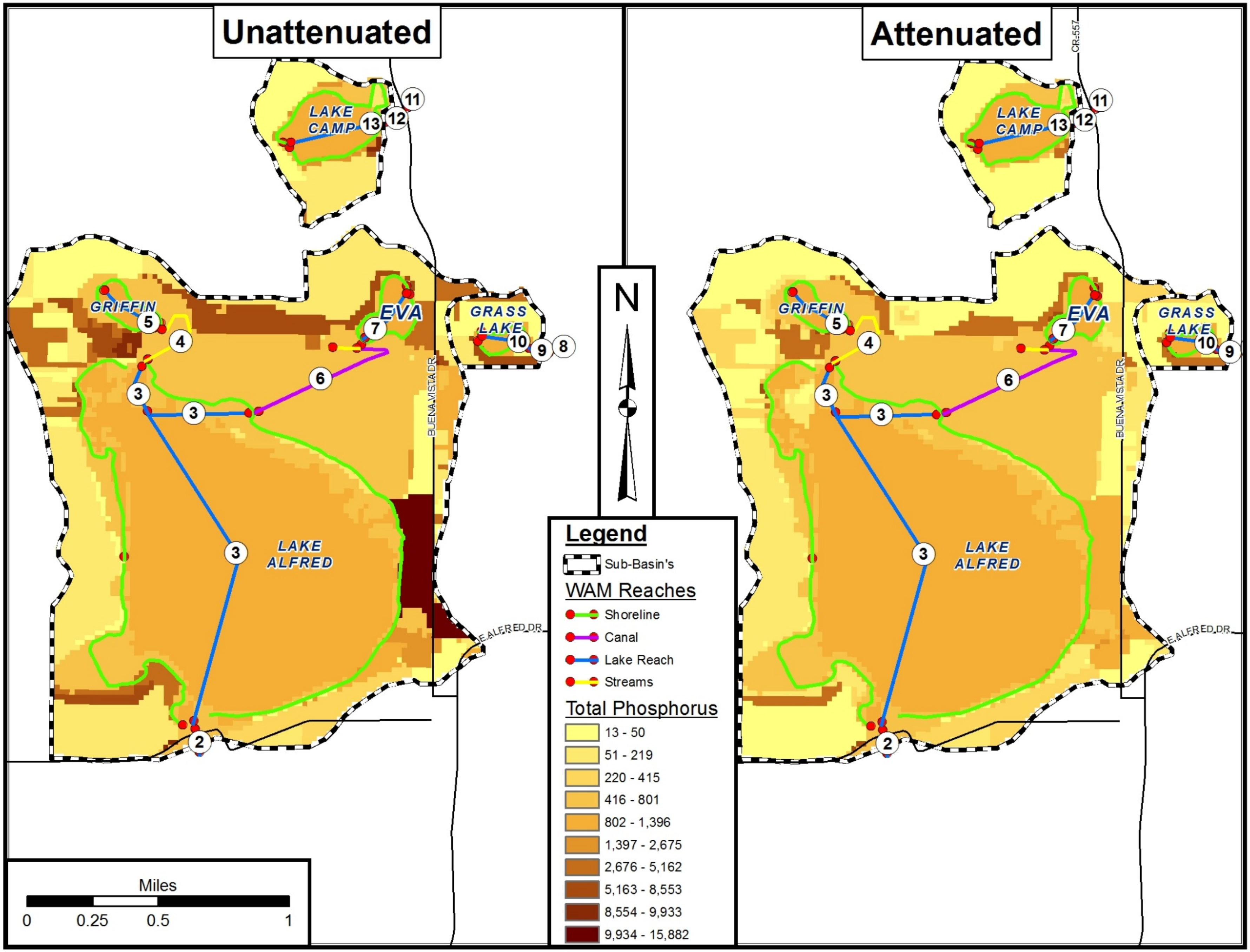
Watershed Assessment Model (WAM)

Simulated Attenuated and Unattenuated

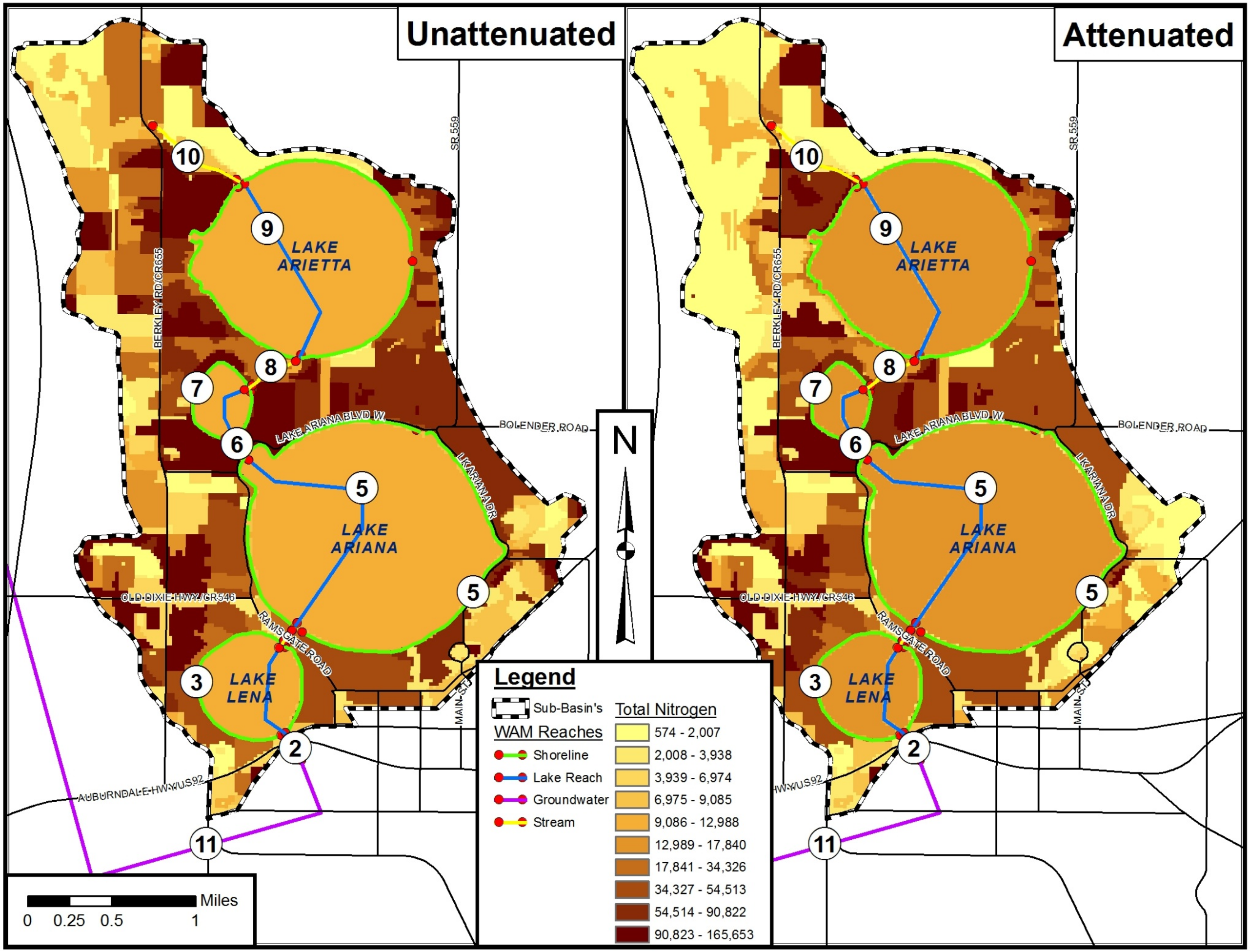
Source Loads



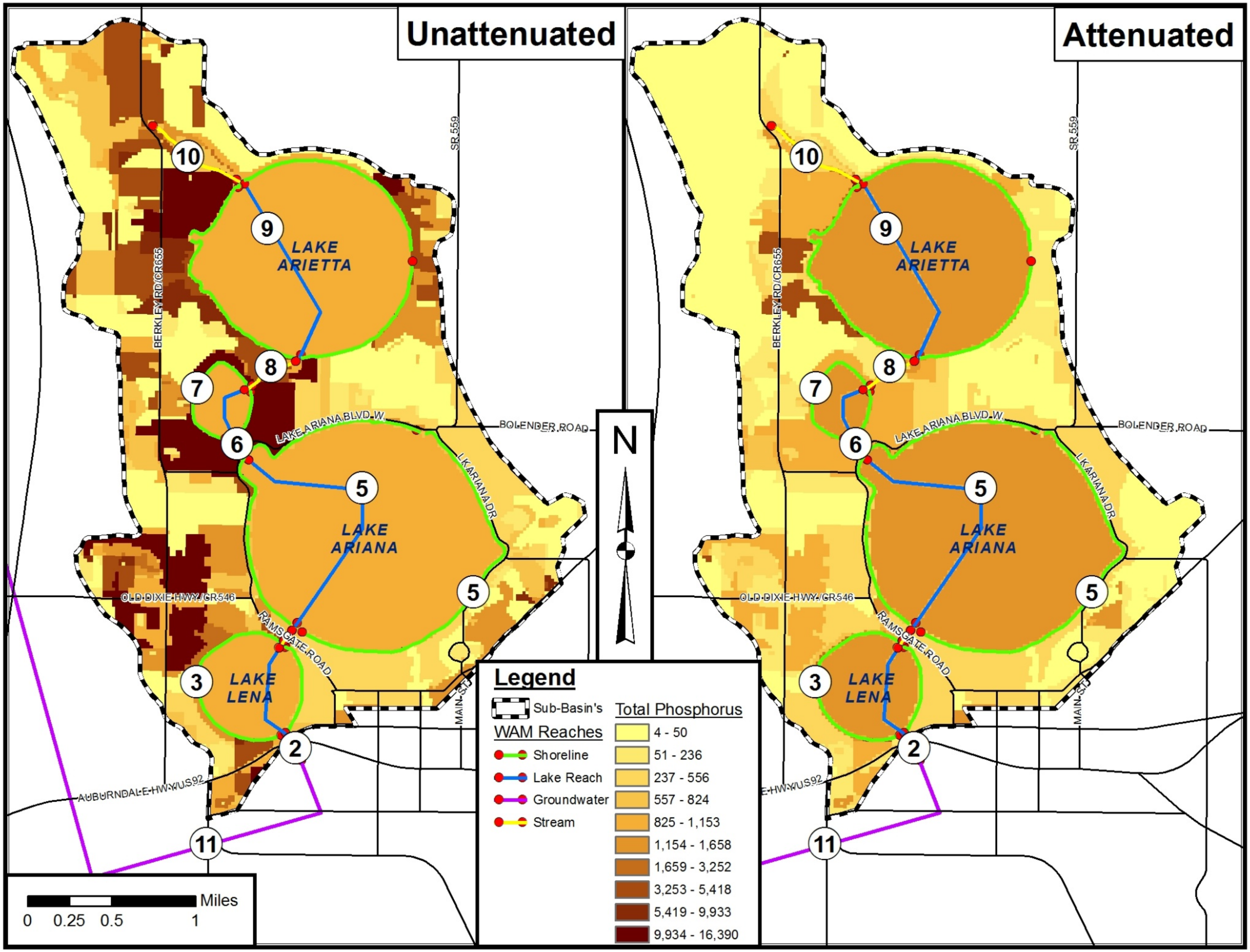
D - 1: Lake Alfred Total Nitrogen Source Loads (kg/ha)



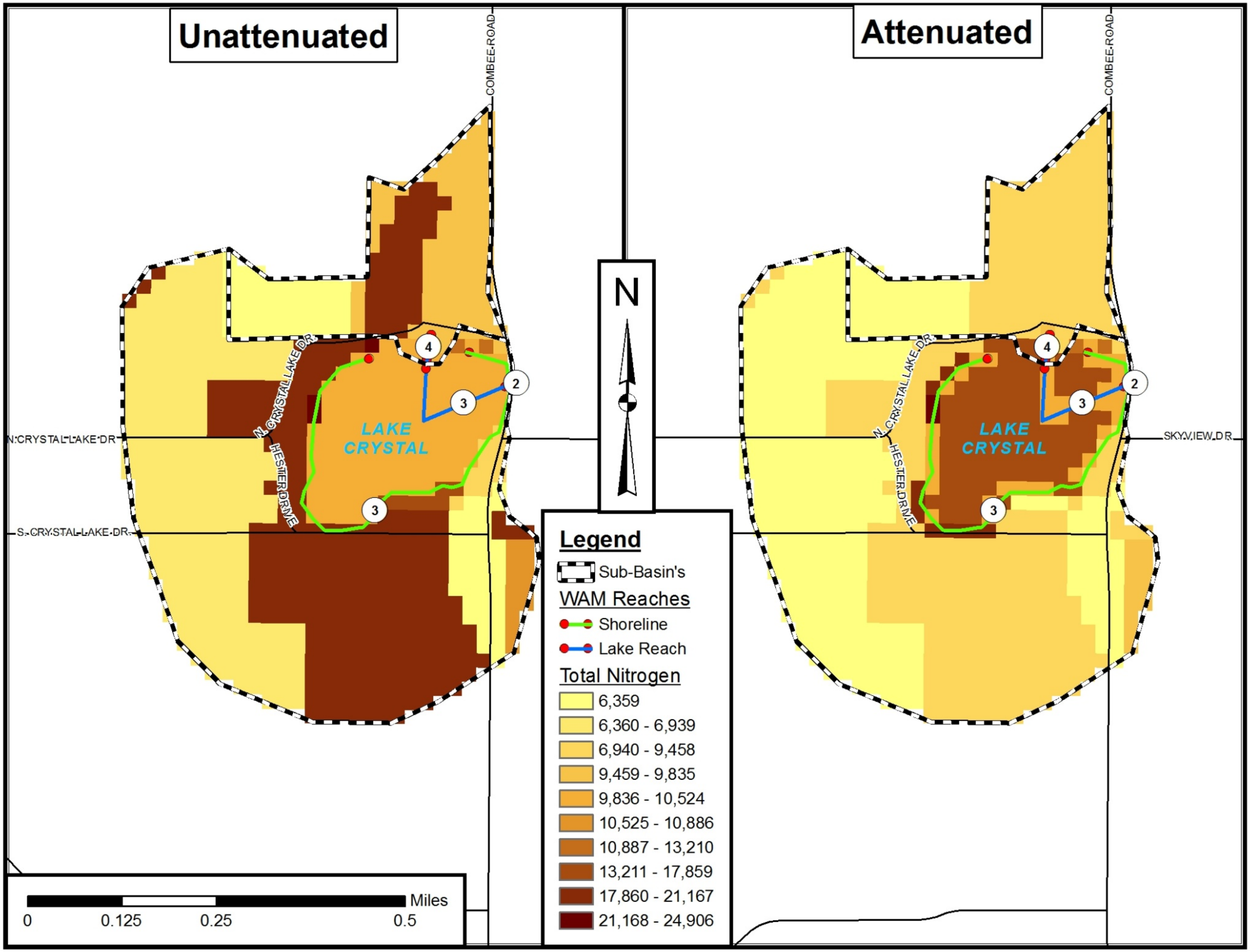
D - 2: Lake Alfred Total Phosphorus Source Loads (kg/ha)



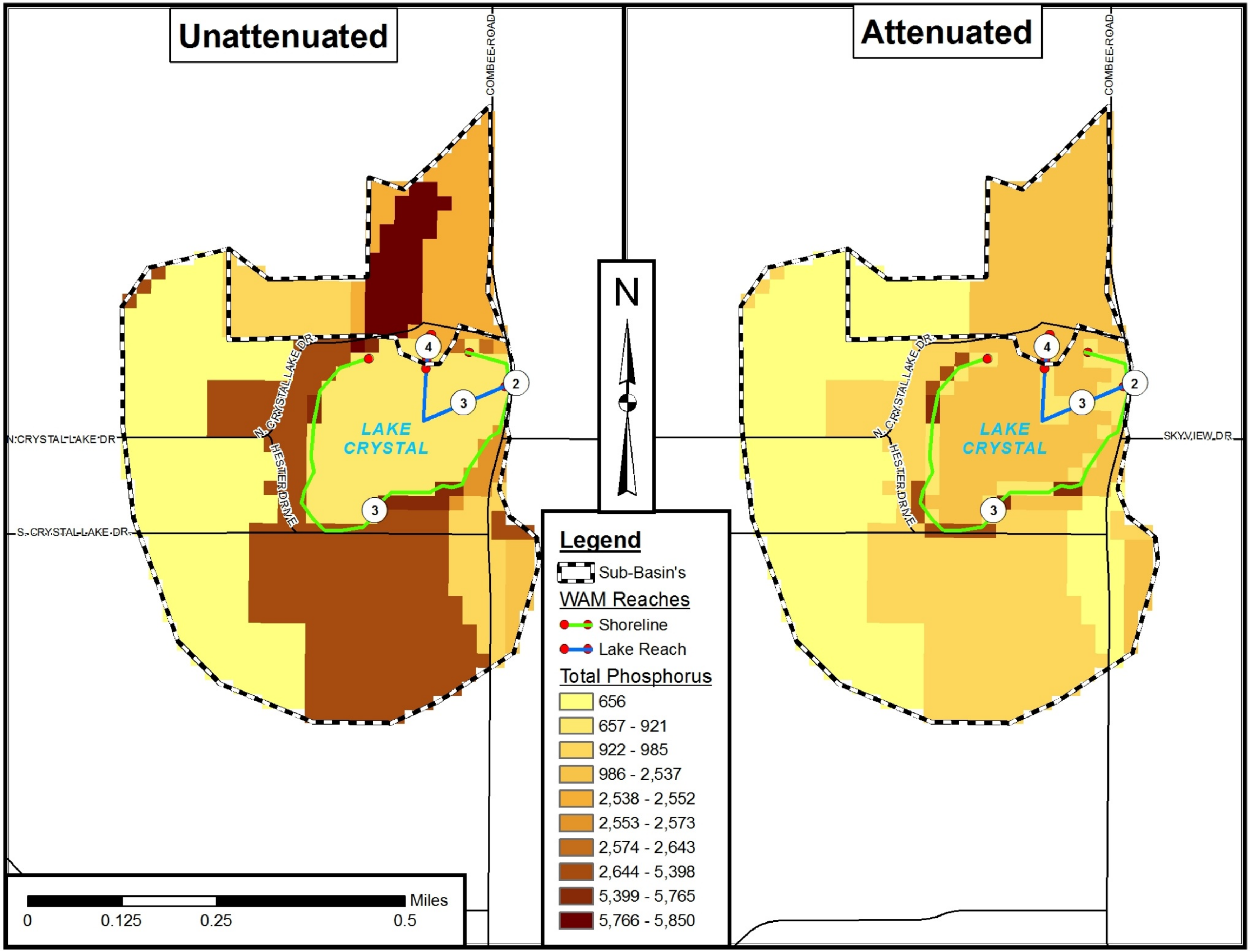
D - 3: Lake Ariana Total Nitrogen Source Loads (kg/ha)



D - 4: Lake Ariana Total Phosphorus Source Loads (kg/ha)



D - 5: Lake Crystal Total Nitrogen Source Loads (kg/ha)



D - 6: Lake Crystal Total Phosphorus Source Loads (kg/ha)

Appendix E

Upper Peace River - Three Lakes

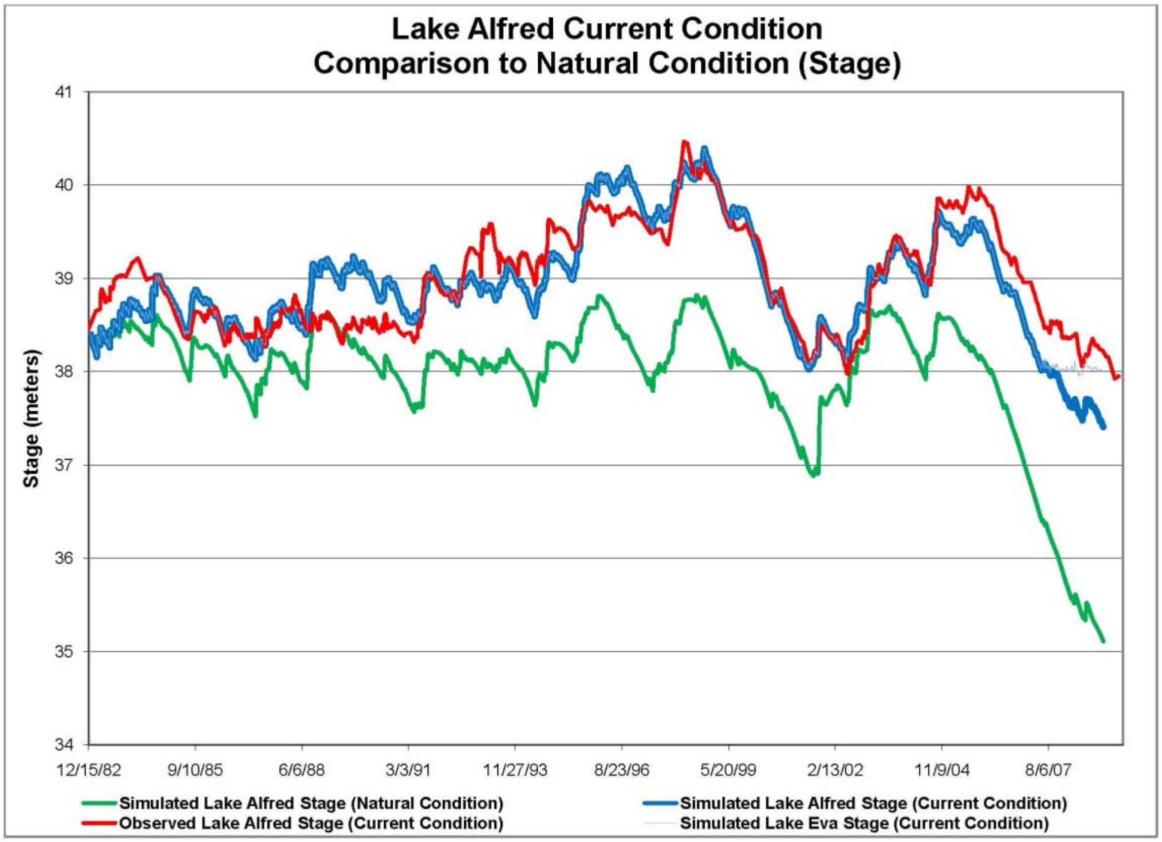
Watershed Assessment Model (WAM)

Natural Condition to Current Condition Comparisons

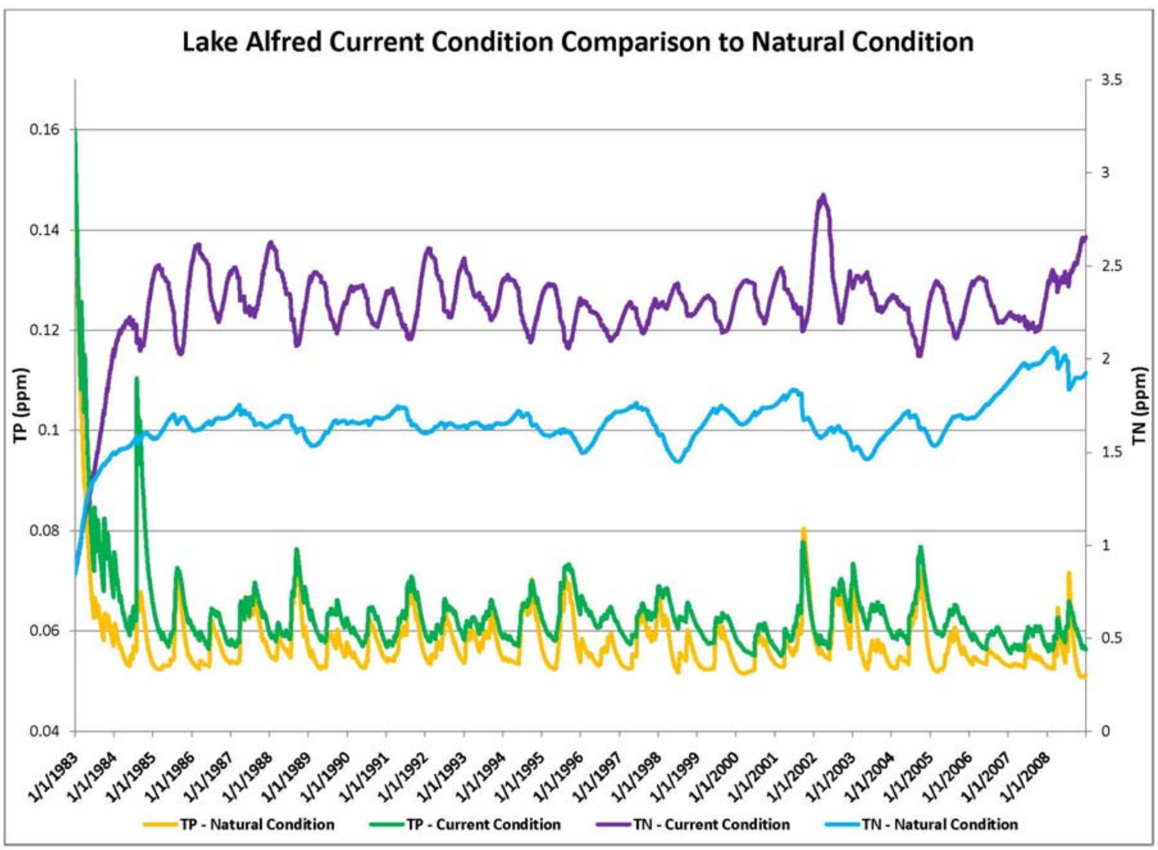
Temporal Stage, Total Nitrogen and

Total Phosphorous simulated value

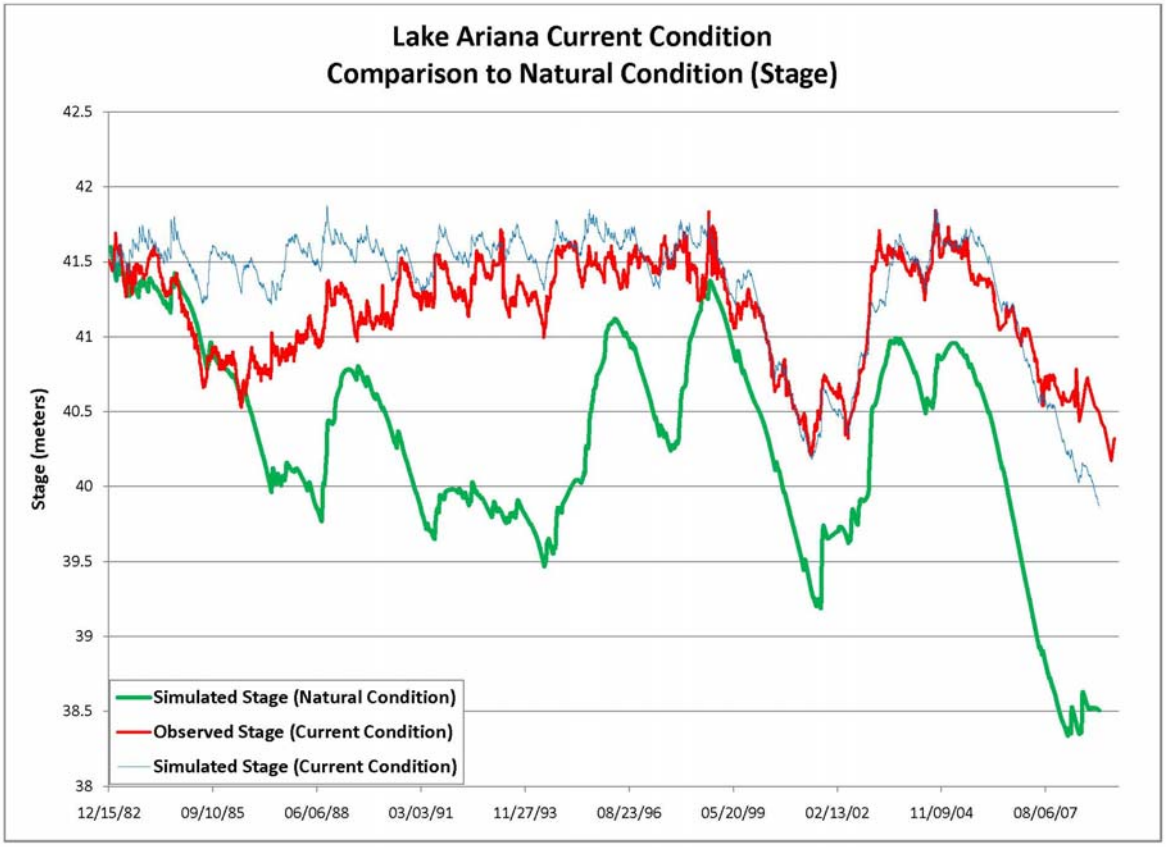
Comparisons.



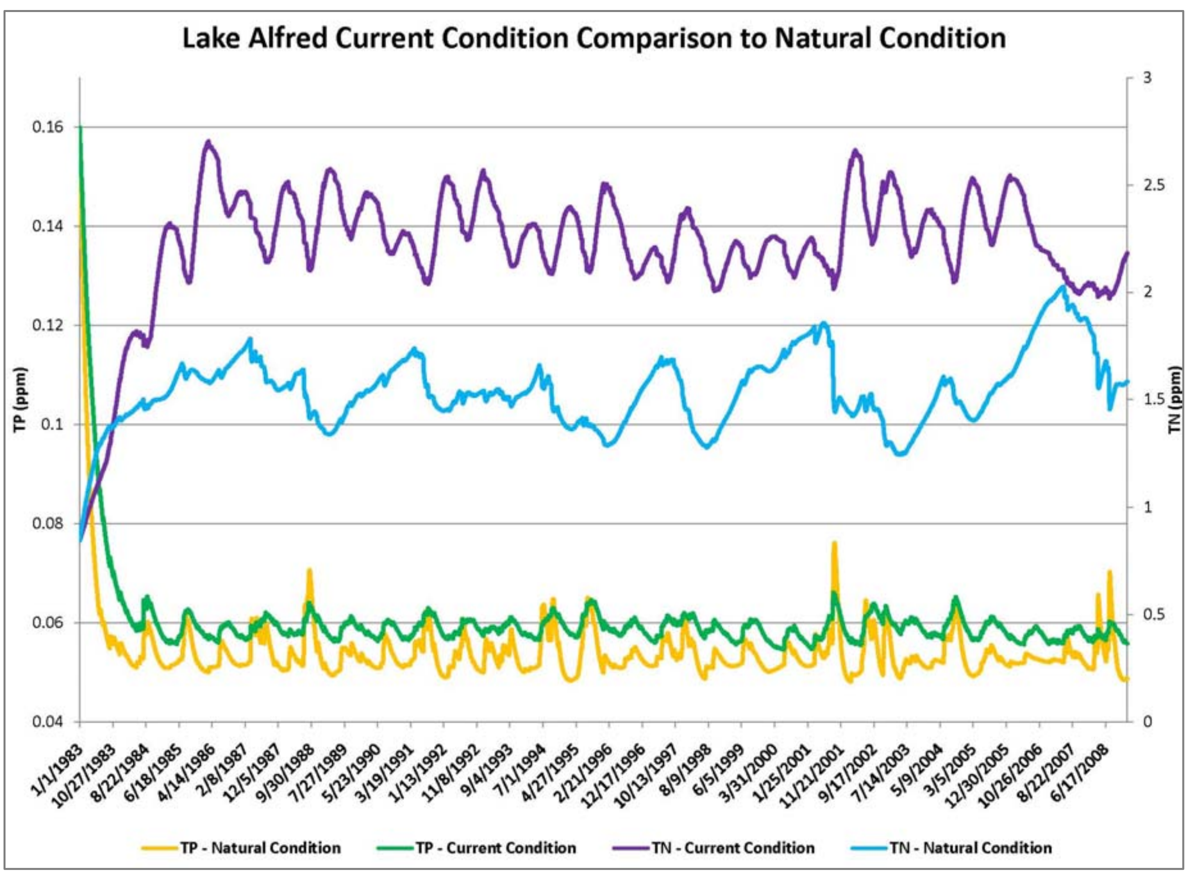
E - 1: Lake Alfred Stage Condition Comparison



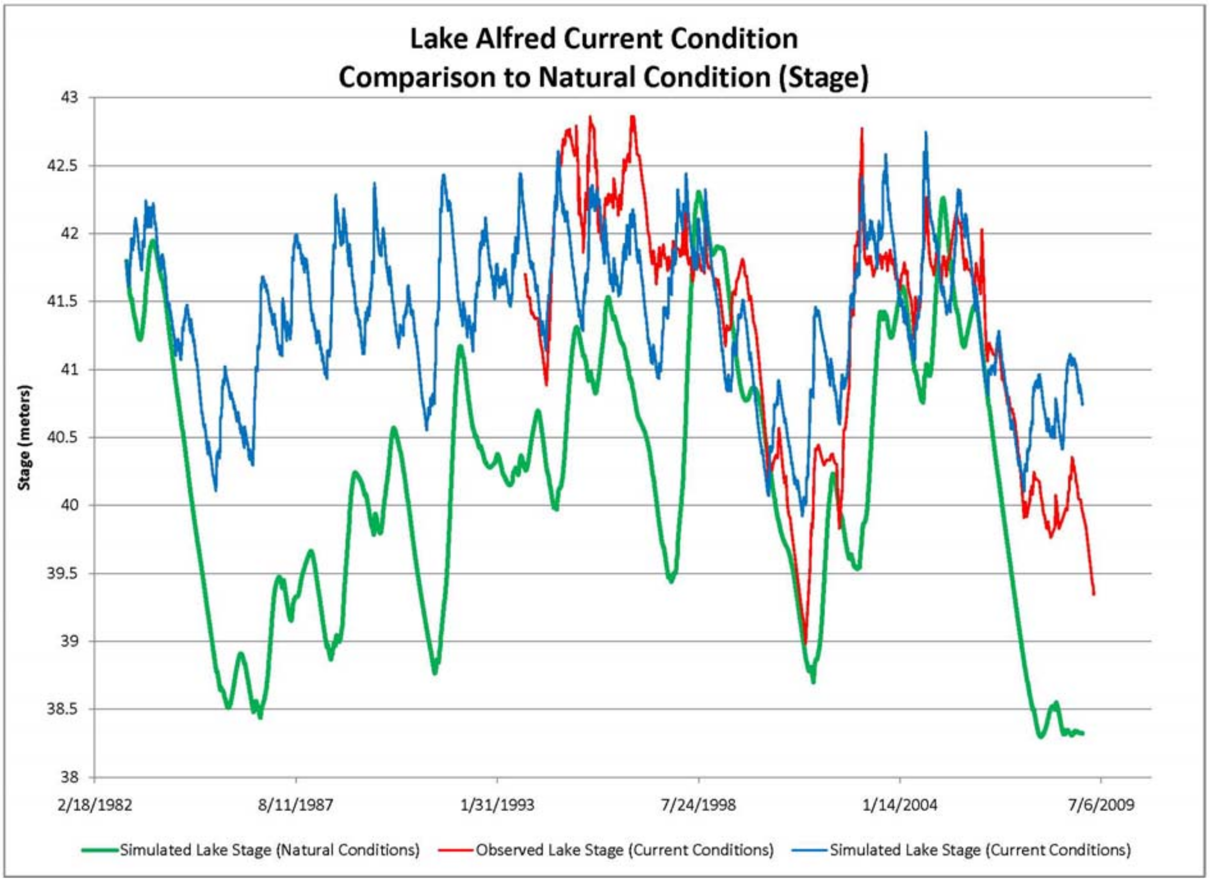
E - 2: Lake Alfred Total Nitrogen and Total Phosphorous Condition Comparisons



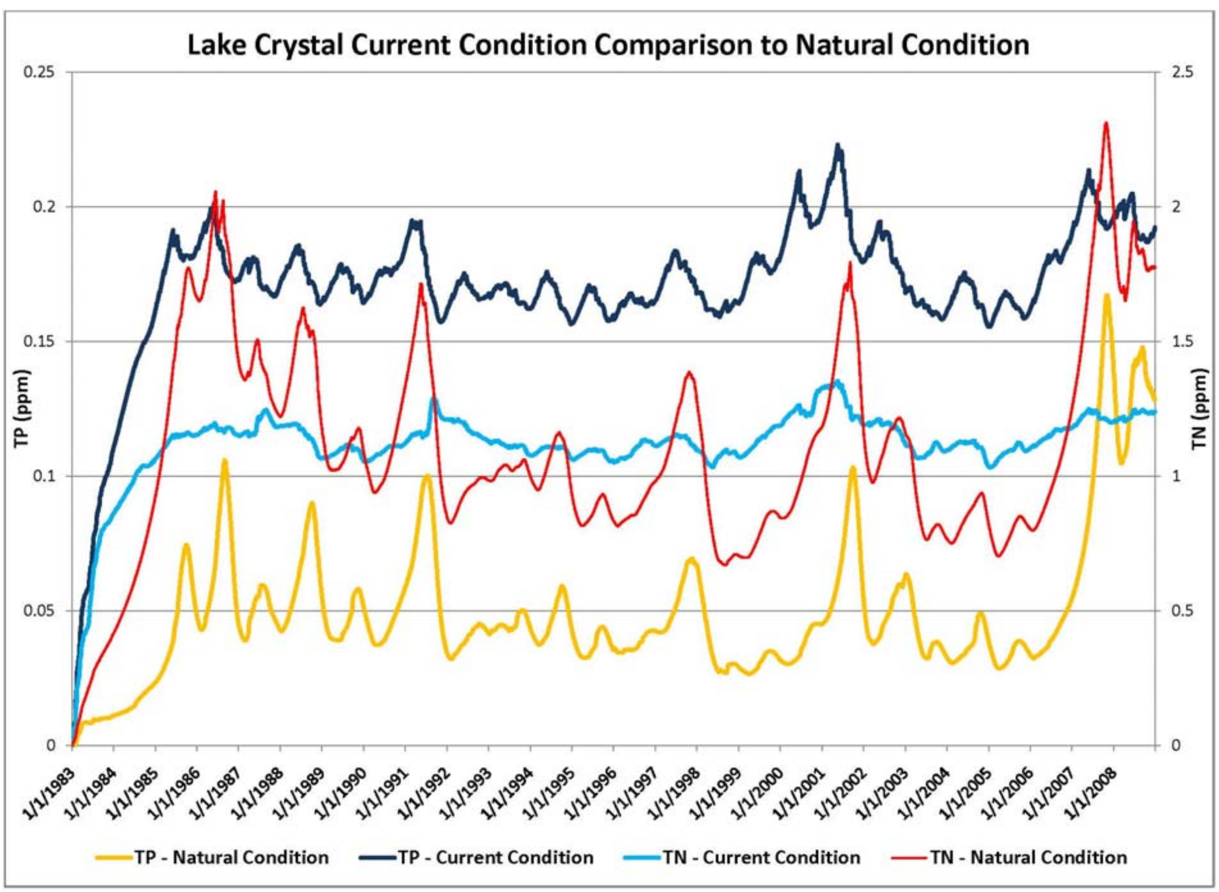
E - 3: Lake Ariana Stage Condition Comparison



E - 4: Lake Ariana Total Nitrogen and Total Phosphorous Condition Comparisons



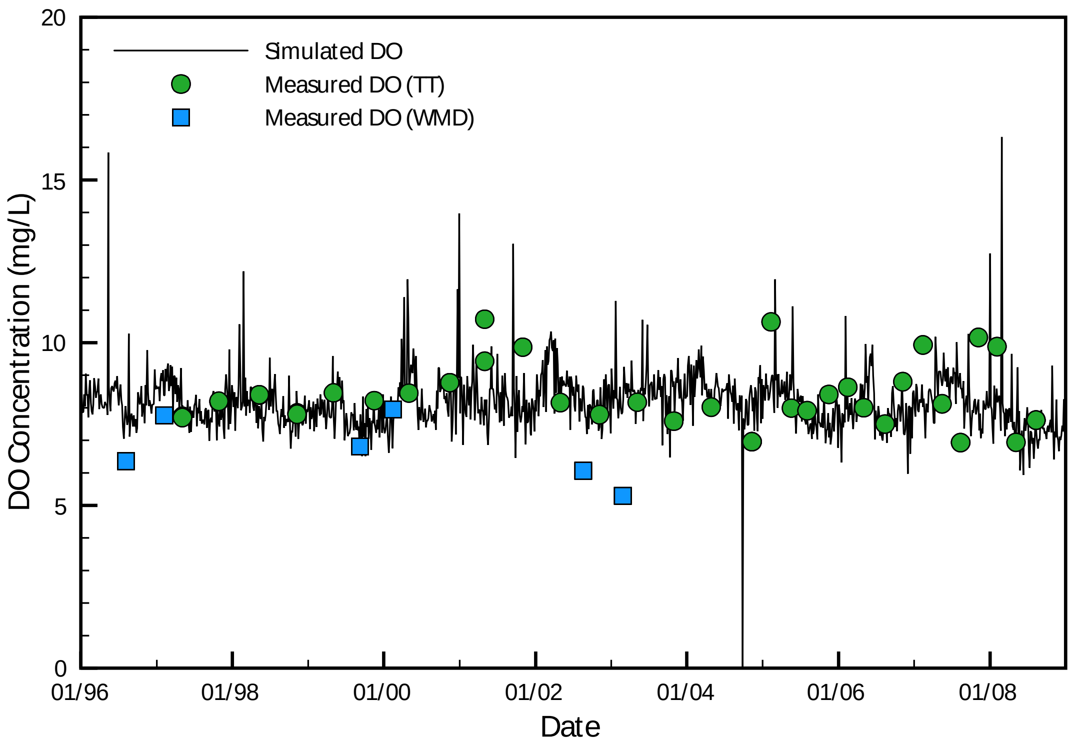
E - 5: Lake Crystal Stage Condition Comparison

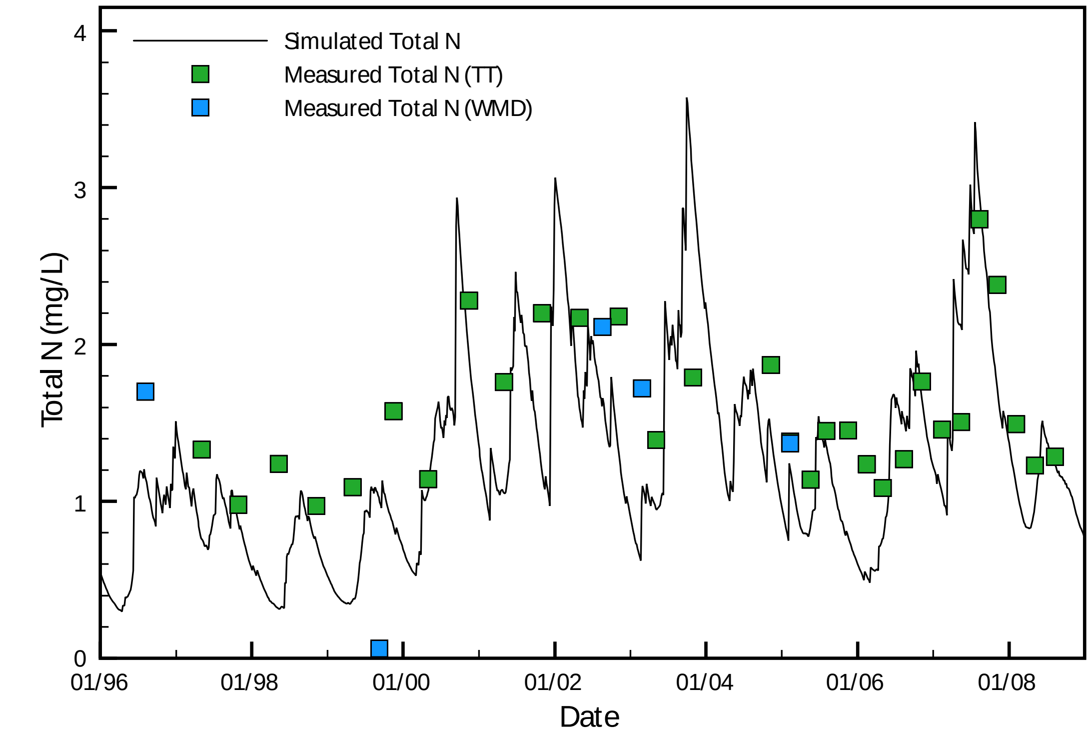


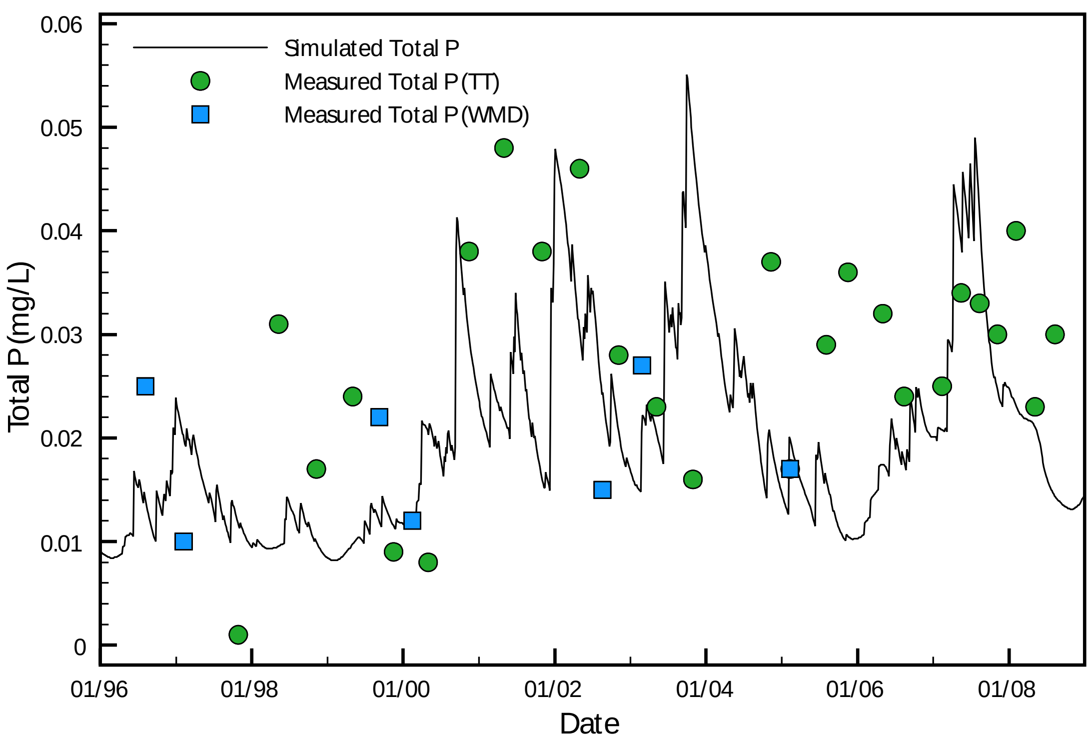
E - 6: Lake Crystal Total Nitrogen and Total Phosphorous Condition Comparisons

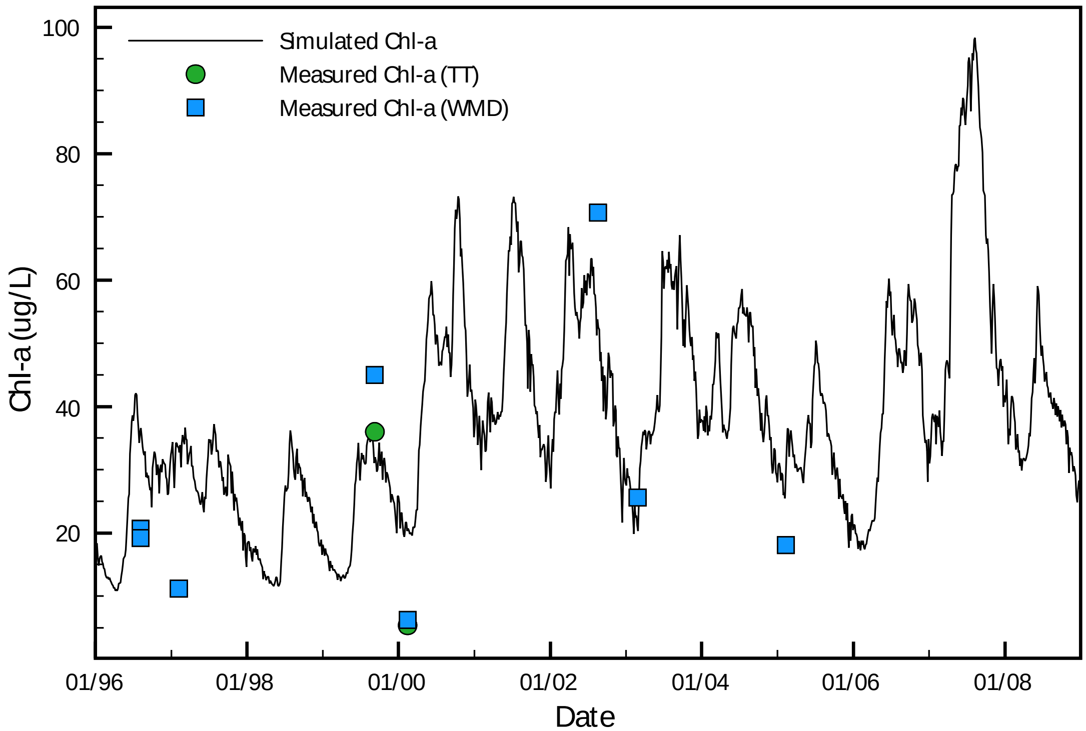
Appendix F

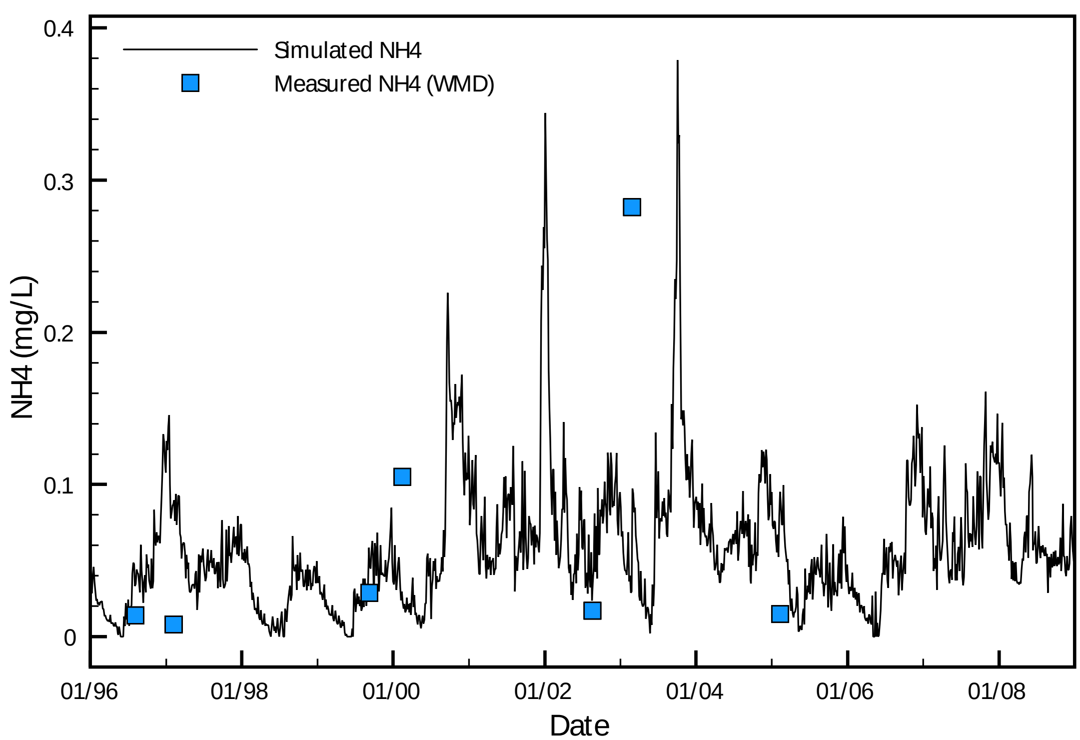
Calibration Charts for Lake Alfred. In the key for each figure, "TT" indicates measured data provided by TetraTech, while "WMD" indicates data obtained from SWET from the Southwest Florida Water Management District.

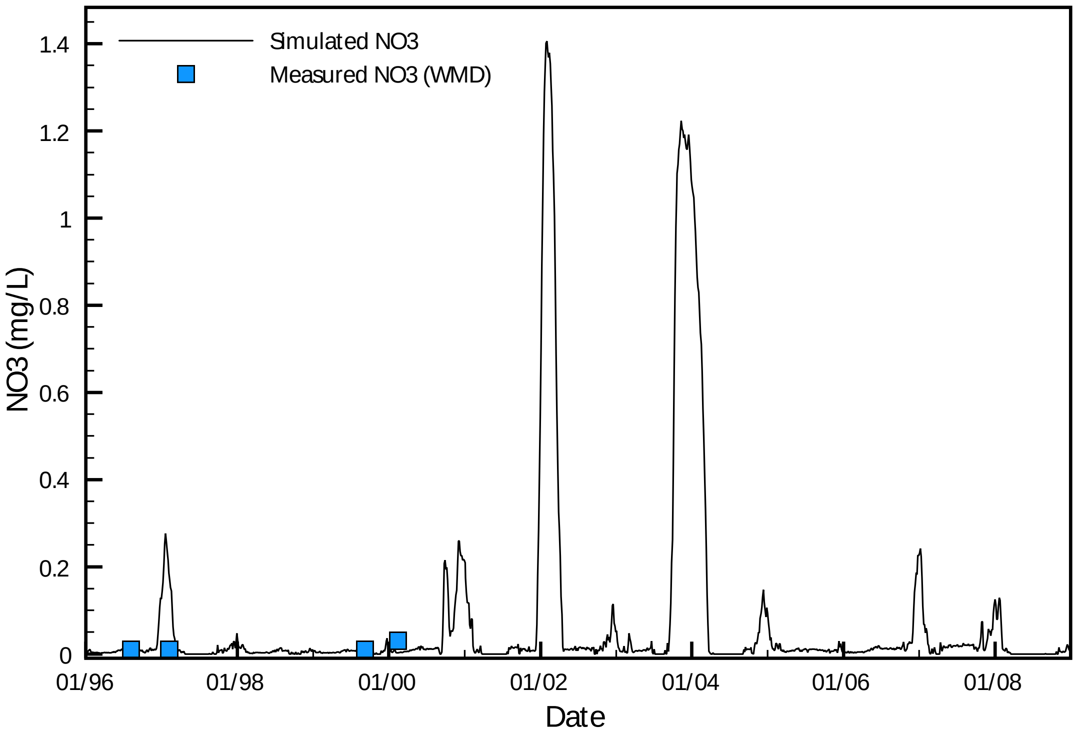



Simulated Total N
Measured Total N (TT)
Measured Total N (WMD)
Total N (mg/L)
Date
0
1
2
3
4
01/96
01/98
01/00
01/02
01/04
01/06
01/08


Simulated Total P
Measured Total P (TT)
Measured Total P (WMD)
Total P (mg/L)
Date
0
0.01
0.02
0.03
0.04
0.05
0.06
01/96
01/98
01/00
01/02
01/04
01/06
01/08

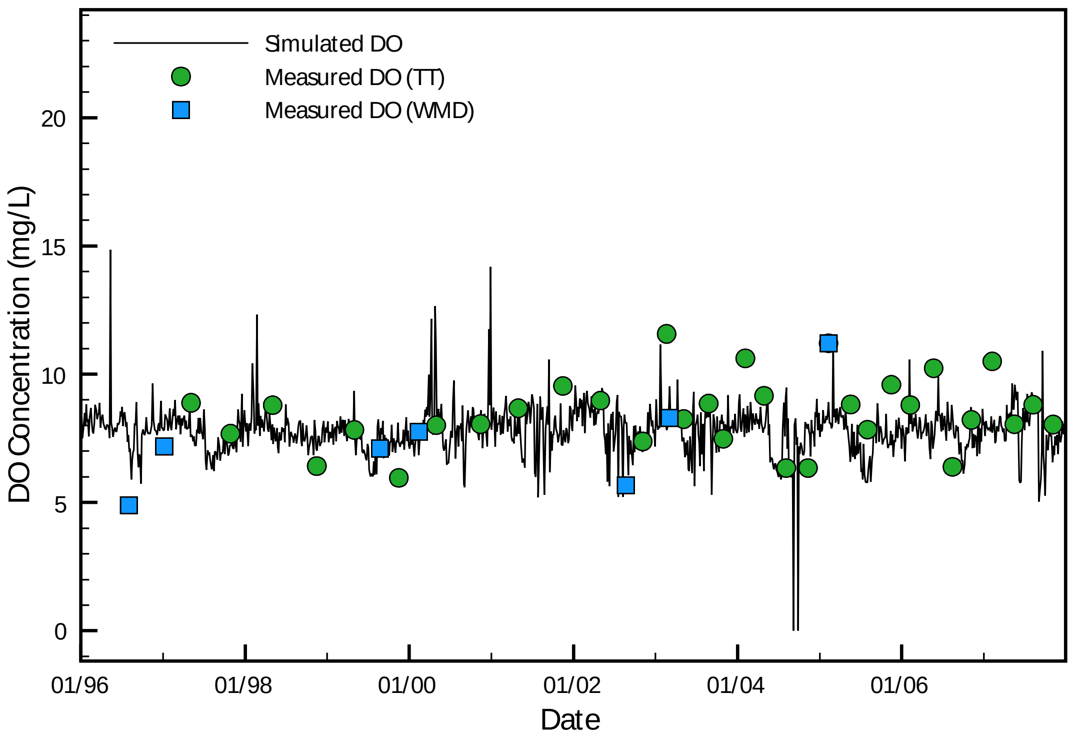

Simulated Chl-a
Measured Chl-a (TT)
Measured Chl-a (WMD)
Chl-a (ug/L)
100
80
60
40
20
01/96
01/98
01/00
01/02
01/04
01/06
01/08
Date

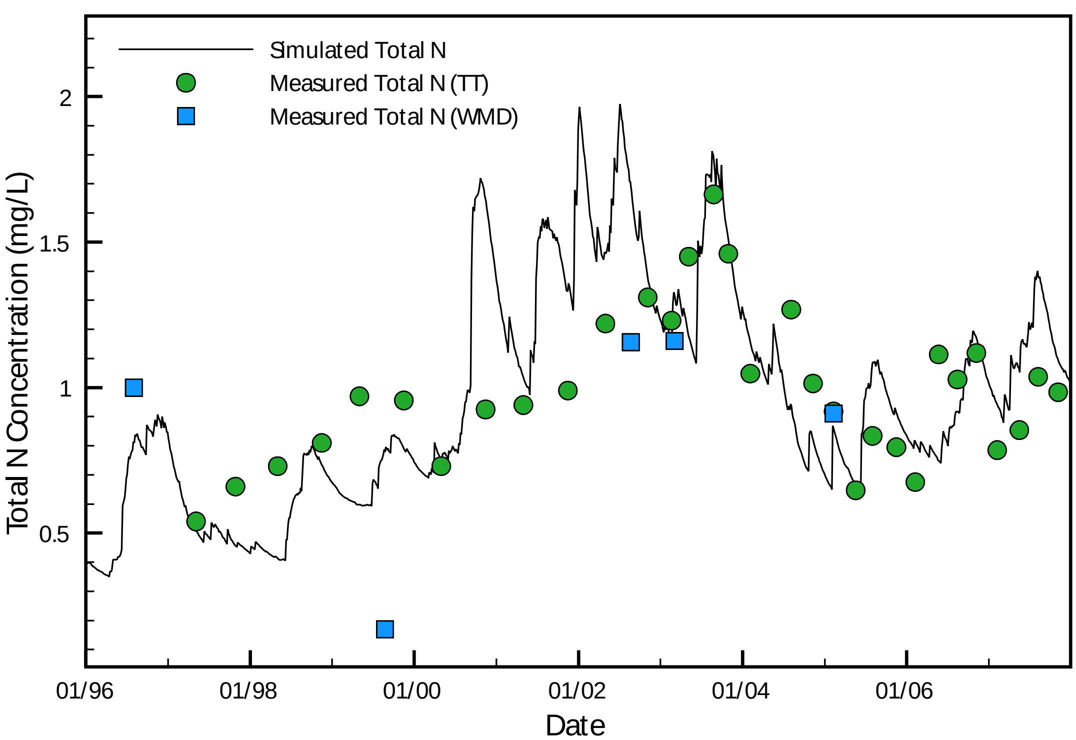

Simulated NH4
Measured NH4 (WMD)
NH4 (mg/L)
0.4
0.3
0.2
0.1
0
01/96
01/98
01/00
01/02
01/04
01/06
01/08
Date

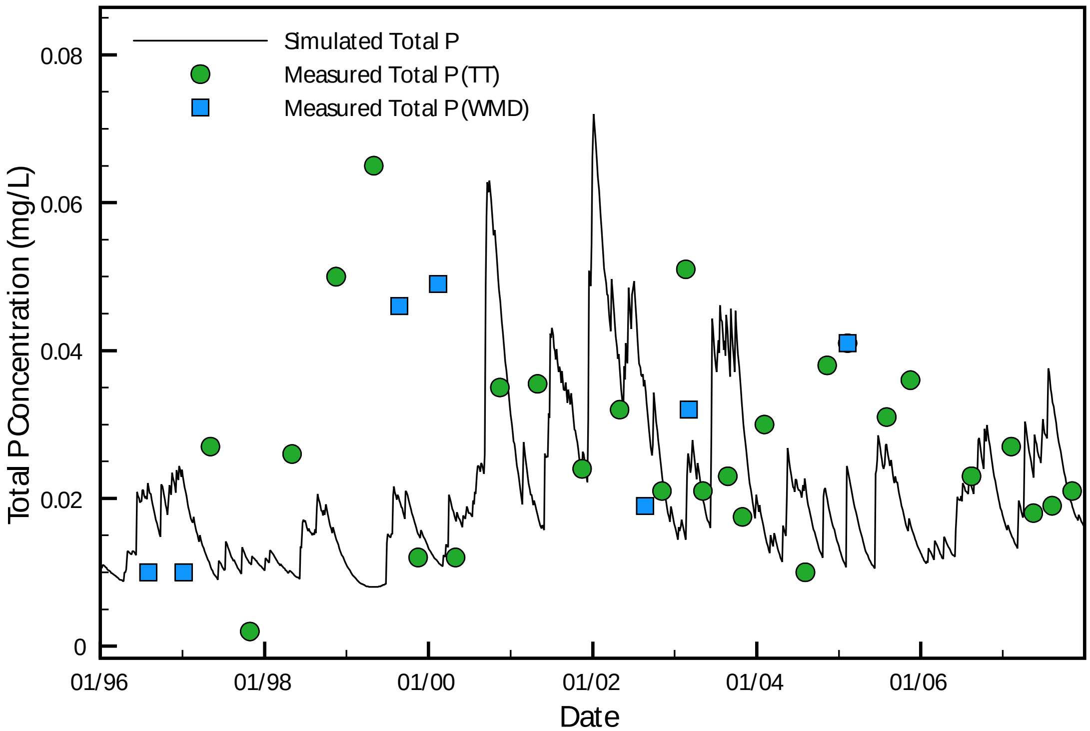

Simulated NO3
Measured NO3 (WMD)
NO3 (mg/L)
Date
0
0.2
0.4
0.6
0.8
1
1.2
1.4
01/96
01/98
01/00
01/02
01/04
01/06
01/08

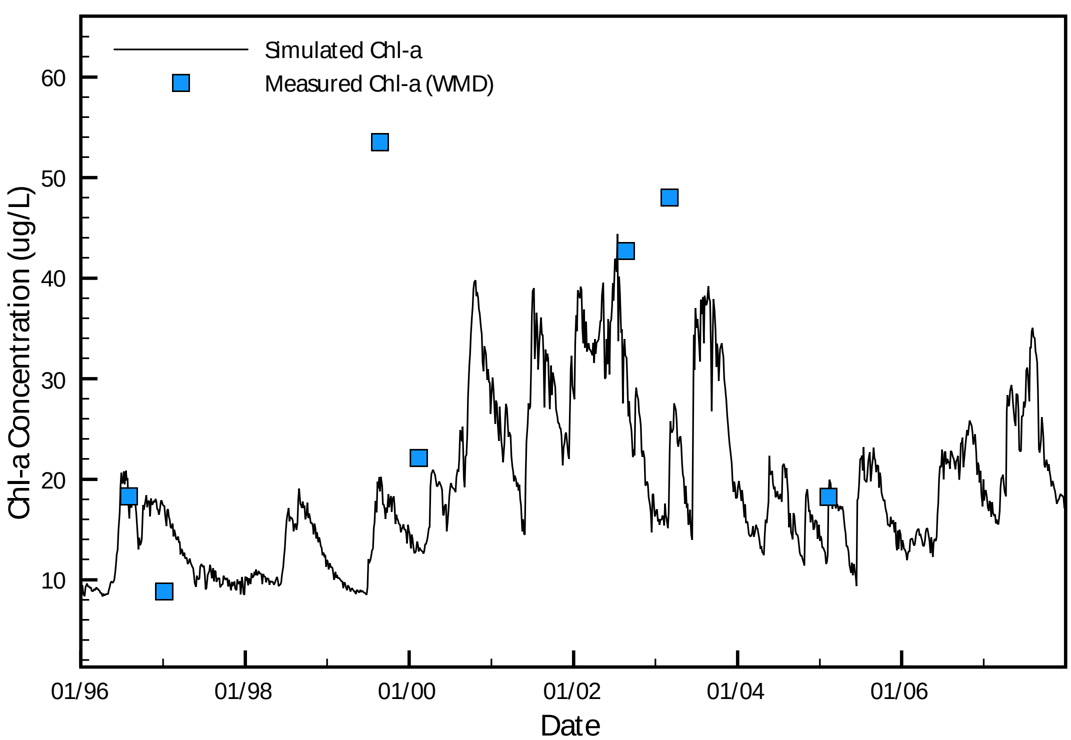
Appendix G

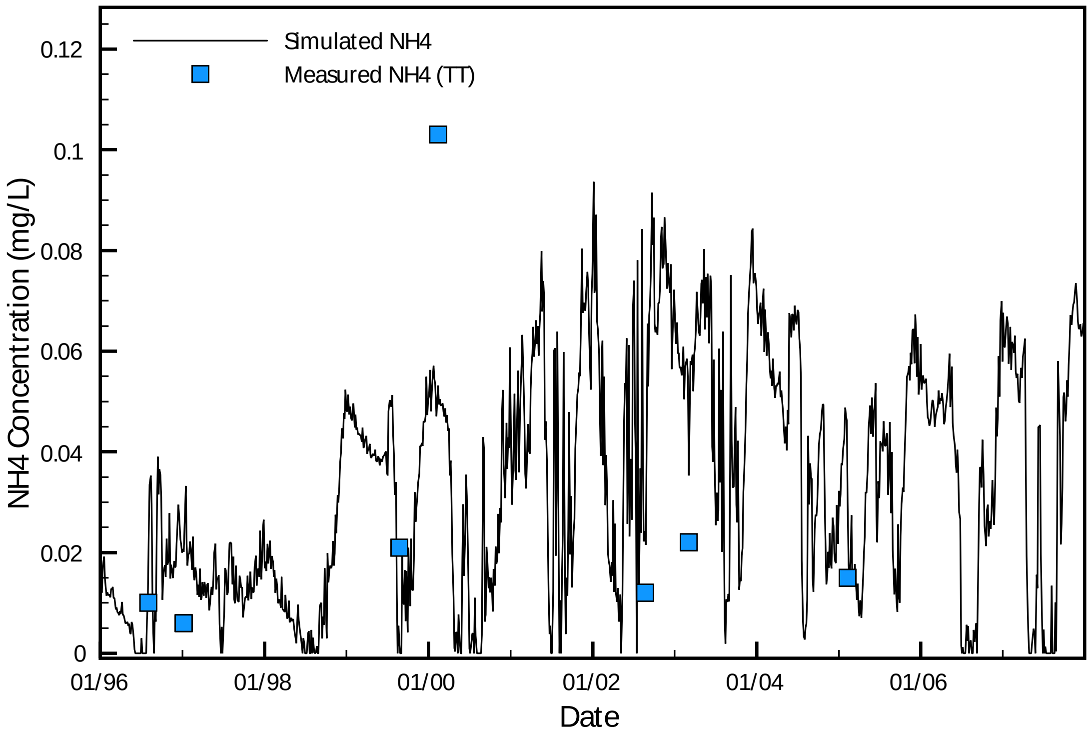
Calibration Charts for Lake Ariana. . In the key for each figure, "TT" indicates measured data provided by TetraTech, while "WMD" indicates data obtained from SWET from the Southwest Florida Water Management District.



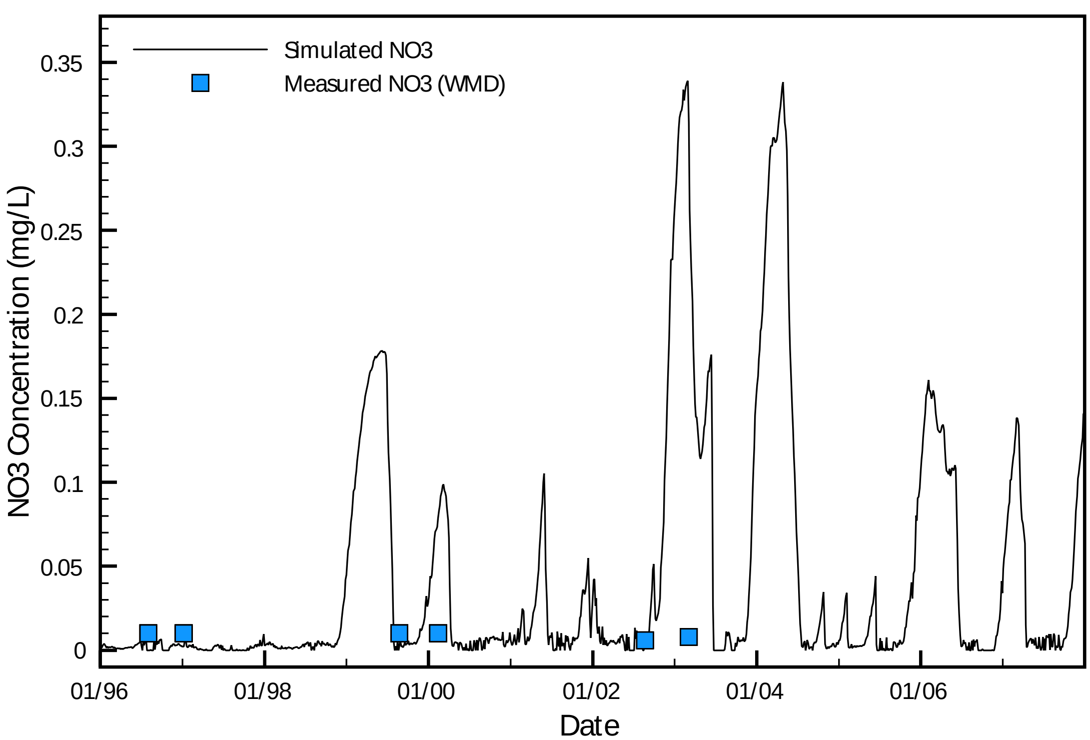



Simulated Total P
Measured Total P (TT)
Measured Total P (WMD)
Total P Concentration (mg/L)
0.08
0.06
0.04
0.02
0
01/96
01/98
01/00
01/02
01/04
01/06
Date


Simulated Chl-a
Measured Chl-a (WMD)
Chl-a Concentration (ug/L)
60
50
40
30
20
10
01/96
01/98
01/00
01/02
01/04
01/06
Date



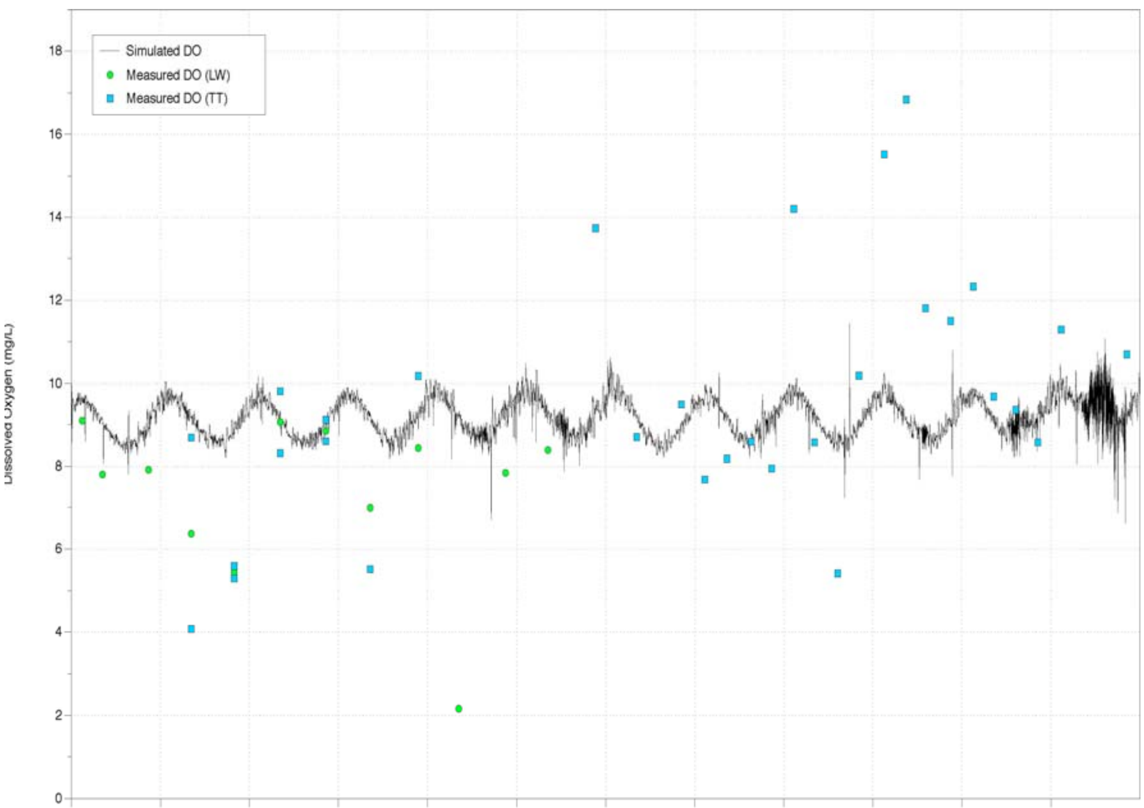
Simulated NH4
Measured NH4 (TT)
0.12
0.1
0.08
0.06
0.04
0.02
0
NH4 Concentration (mg/L)
01/96
01/98
01/00
01/02
01/04
01/06
Date

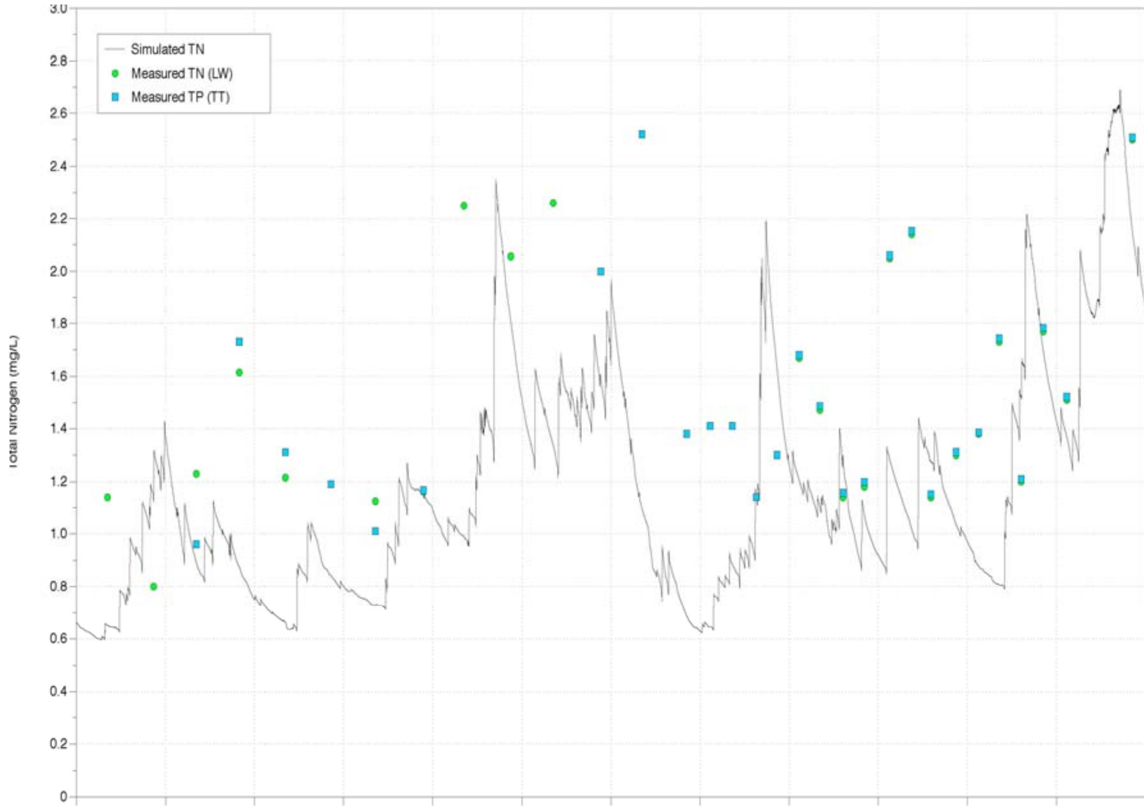


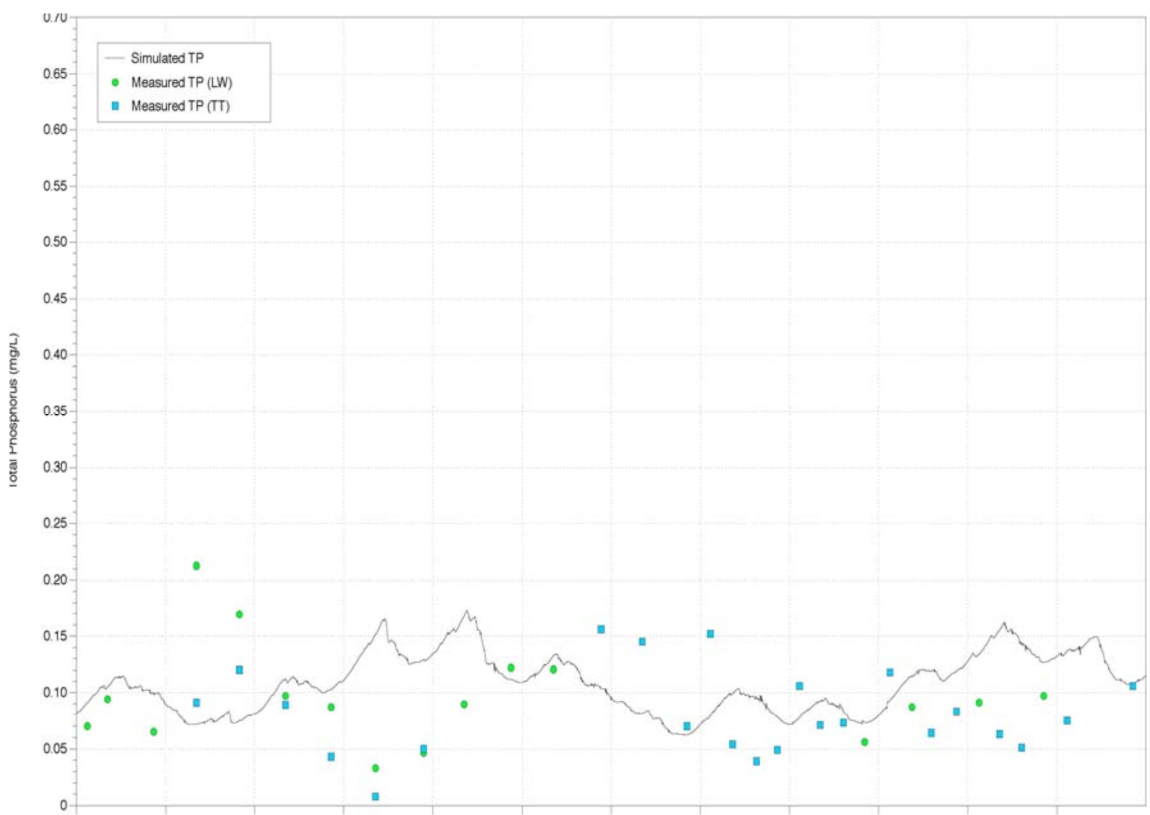
Simulated NO3
Measured NO3 (WMD)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
NO3 Concentration (mg/L)
01/96
01/98
01/00
01/02
01/04
01/06
Date

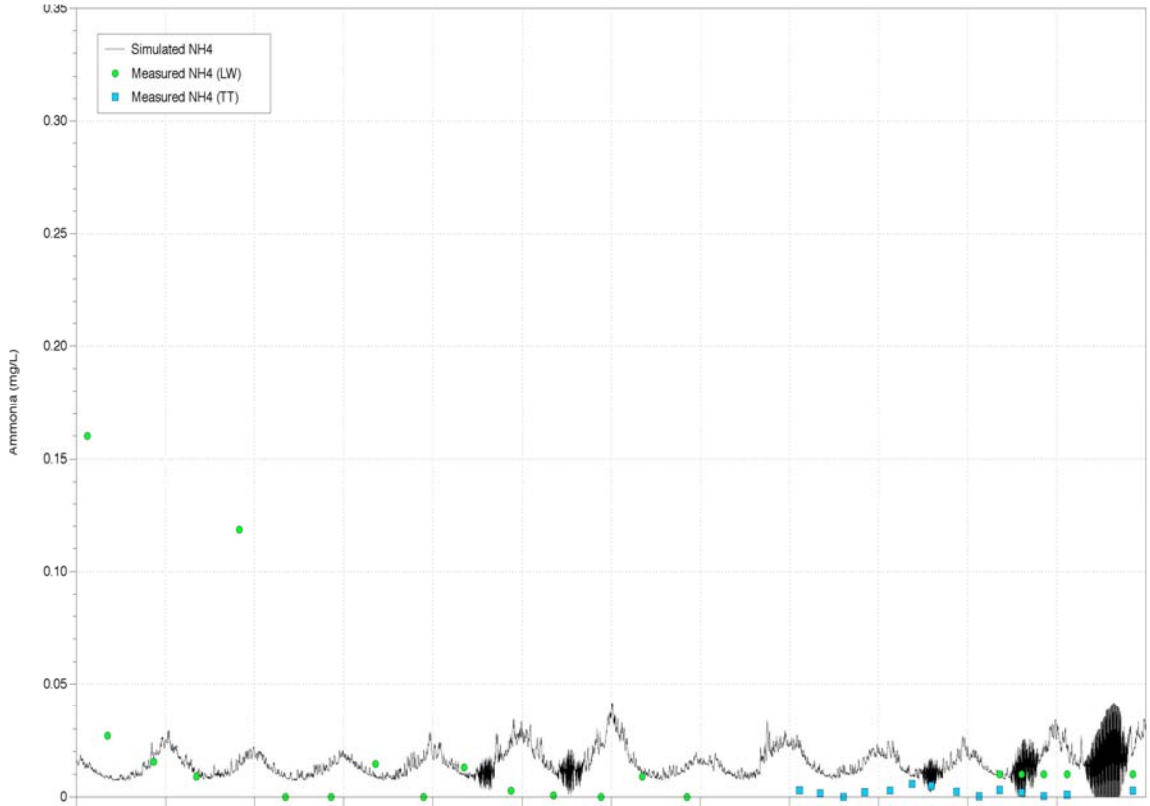
Appendix H

Calibration Charts for Lake Crystal . In the key for each figure, "TT" indicates measured data provided by TetraTech, while "WMD" indicates data obtained from SWET from the Southwest Florida Water Management District.




Simulated TN
Measured TN (LW)
Measured TP (TT)
Total Nitrogen (mg/L)
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0


Simulated TP
Measured TP (LW)
Measured TP (TT)
Total Phosphorus (mg/L)
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0


Simulated NH4
Measured NH4 (LW)
Measured NH4 (TT)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
Ammonia (mg/L)