Banana Lake
Sediment Characterization and Inactivation Study

Final Report

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SECTION 1
INTRODUCTION

This report provides a summary of work efforts performed by Environmental Research and Design, Inc. (ERD) for the Polk County Natural Resources Division (Polk County) to perform a sediment characterization study for Banana Lake. The primary purpose of this study is to evaluate the potential for sediment phosphorus release within Banana Lake and the feasibility for sediment phosphorus inactivation using alum. Banana Lake is a 242-acre lake located west of Lake Hancock and south of the City of Lakeland in unincorporated Polk County. Also included in this evaluation is Stahl Lake, a 30.6-acre waterbody located northwest of Banana Lake and connected to Banana Lake by a navigable channel. A location map for Banana Lake and Stahl Lake is given in Figure 1-1. Banana Lake forms the headwaters of Banana Creek which discharges into Lake Hancock and ultimately the Peace River.

Over the past several decades, Banana Lake has been characterized by elevated levels of total phosphorus, chlorophyll-a, and total nitrogen, combined with poor water column clarity. According to the Polk County Water Atlas, the historic average Trophic State Index (TSI) for Banana Lake from 1984-2005 is 83.7, indicating hypereutrophic conditions. Phosphorus release and recycling from nutrient-rich sediments is thought to be a contributing factor to the ongoing poor water quality characteristics within the lake. An aerial overview of Banana Lake and Stahl Lake is given in Figure 1-2.

Field monitoring and laboratory analyses were conducted by ERD from September 2005-January 2006 to evaluate bathymetric and sediment characteristics in Banana Lake and Stahl Lake. Field measurements were performed for development of water depth contour maps for the two lakes, along with estimated depths of unconsolidated organic sediments. A sediment monitoring program was also performed to quantify the physical and chemical characteristics of

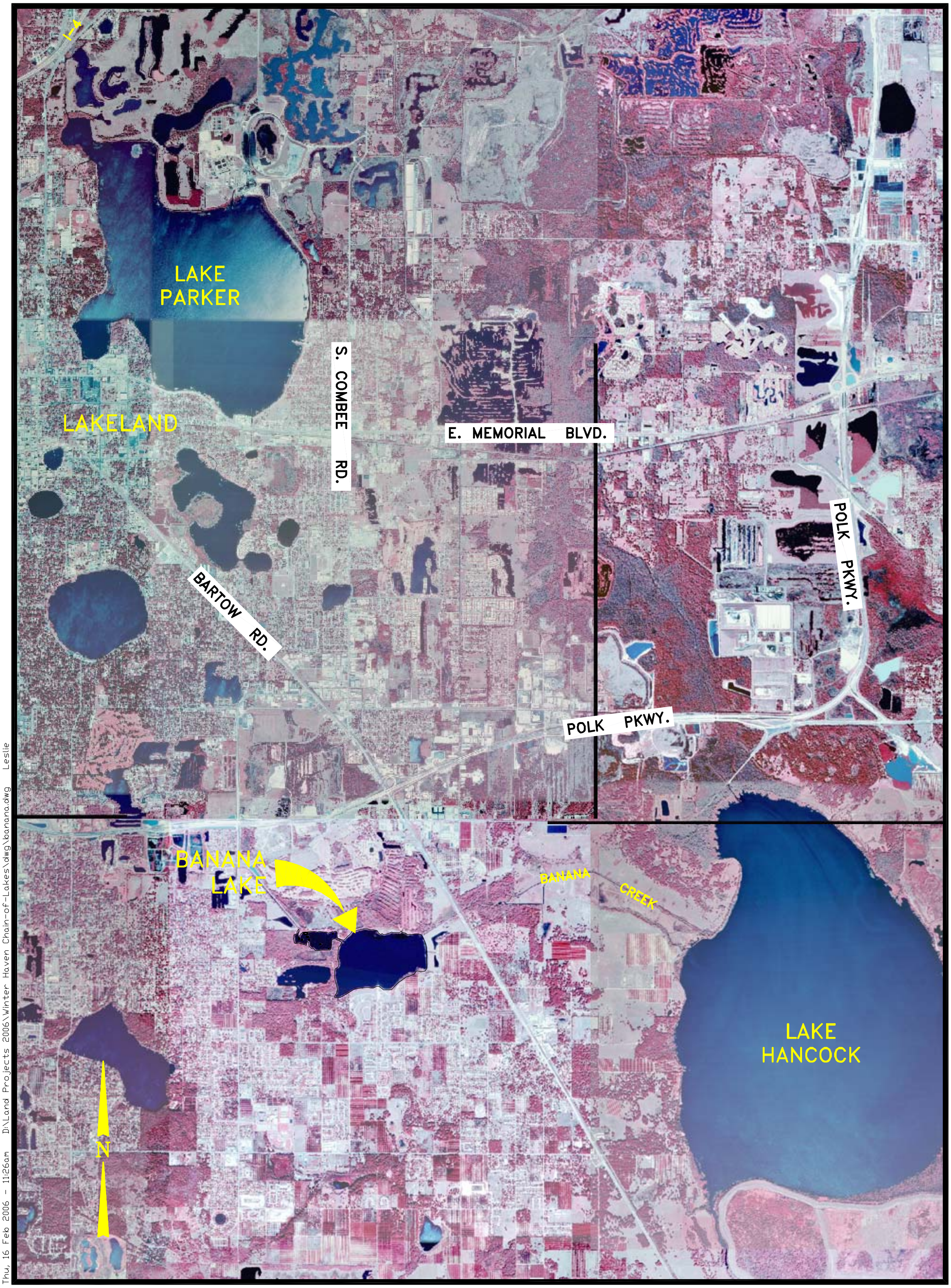

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Figure 1-1. Location Map for Banana Lake.

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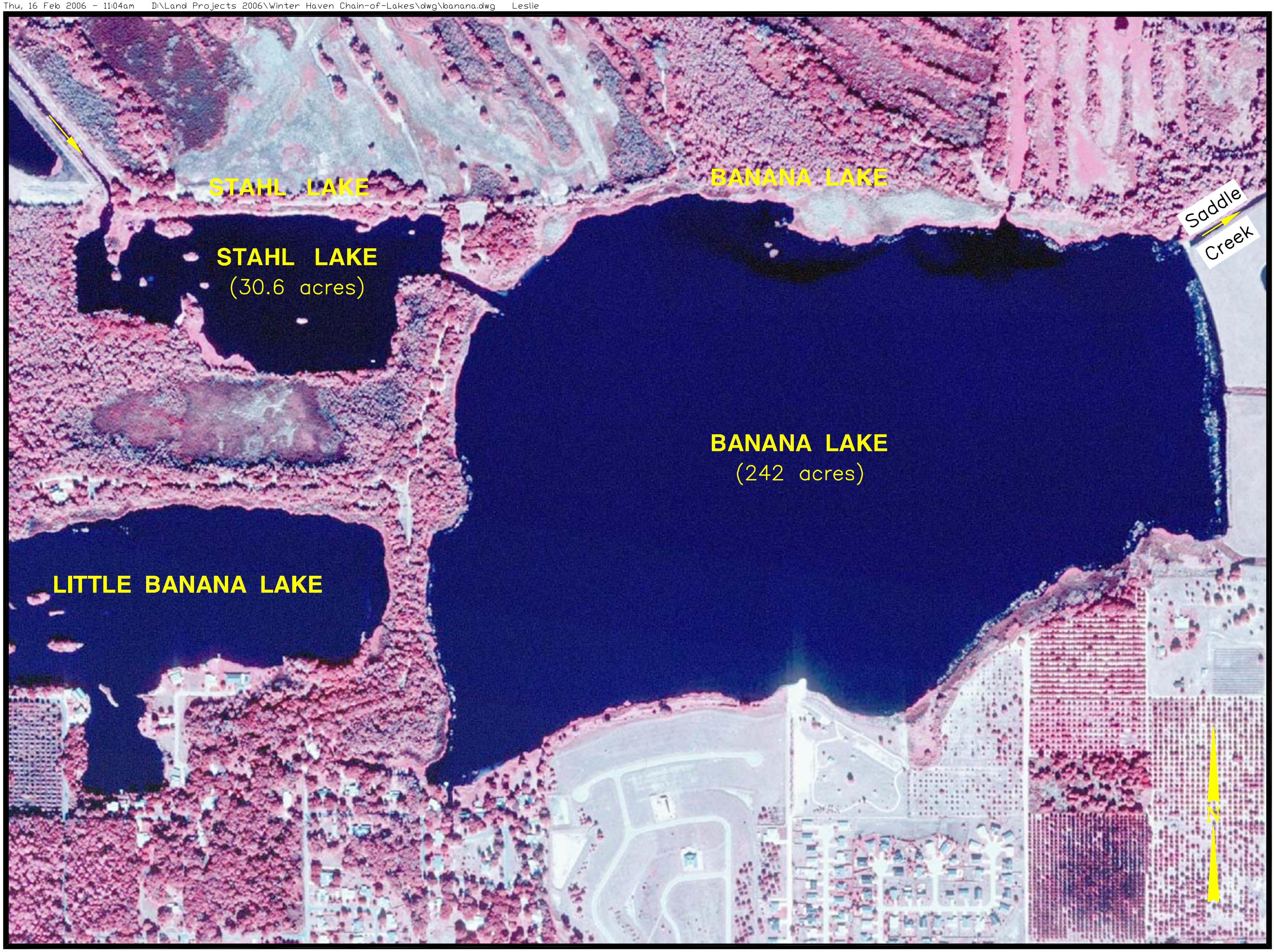

Figure 1-2. Overview of Banana Lake and Stahl Lake.

existing sediments within the lakes and to evaluate the potential for internal recycling of phosphorus from sediments into the overlying water column.

This report is divided into four separate sections. Section 1 contains an introduction to the report and provides a brief summary of the work efforts performed by ERD. Section 2 contains a description of the field and laboratory activities conducted by ERD. The results of the field and laboratory activities are summarized in Section 3. An evaluation of the feasibility of sediment inactivation using alum is given in Section 4.

SECTION 2

FIELD AND LABORATORY ACTIVITIES

Field and laboratory activities were performed to develop bathymetric contour maps for water depth and unconsolidated organic sediments in Banana Lake and Stahl Lake. Sediment core samples were also collected and evaluated for a variety of physical and chemical characteristics to assist in evaluating the potential for internal recycling of phosphorus from the sediments into the overlying water column of the lake. Field and laboratory activities used to perform these assessments are described in the following sections.

2.1 Bathymetric Surveys

Bathymetric surveys were performed in Banana Lake and Stahl Lake during January 2006 to evaluate water column depth as well as thickness of unconsolidated sediments within each lake. Bathymetric measurements of water depth and sediment thickness were conducted at 250 individual sites, with 197 sites in Banana Lake and 53 sites in Stahl Lake. Data collection sites used for the bathymetric study are indicated on Figure 2-1. Each of the data collection sites was identified in the field by longitude and latitude coordinates which were recorded using a portable GPS device.

Water depth at each of the data collection sites was determined by lowering a 20 cm diameter Secchi Disk, attached to a graduated line, until resistance from the surficial sediment layer was encountered. The depth on the graduated line was recorded in the field and defined as the water depth at each site.

After the water depth is defined at each site, a 1-1/2 inch diameter graduated aluminum pole is then lowered into the water column and forced into the sediments until a firm bottom material, typically sand or clay, is encountered. This depth is defined as the depth to the firm

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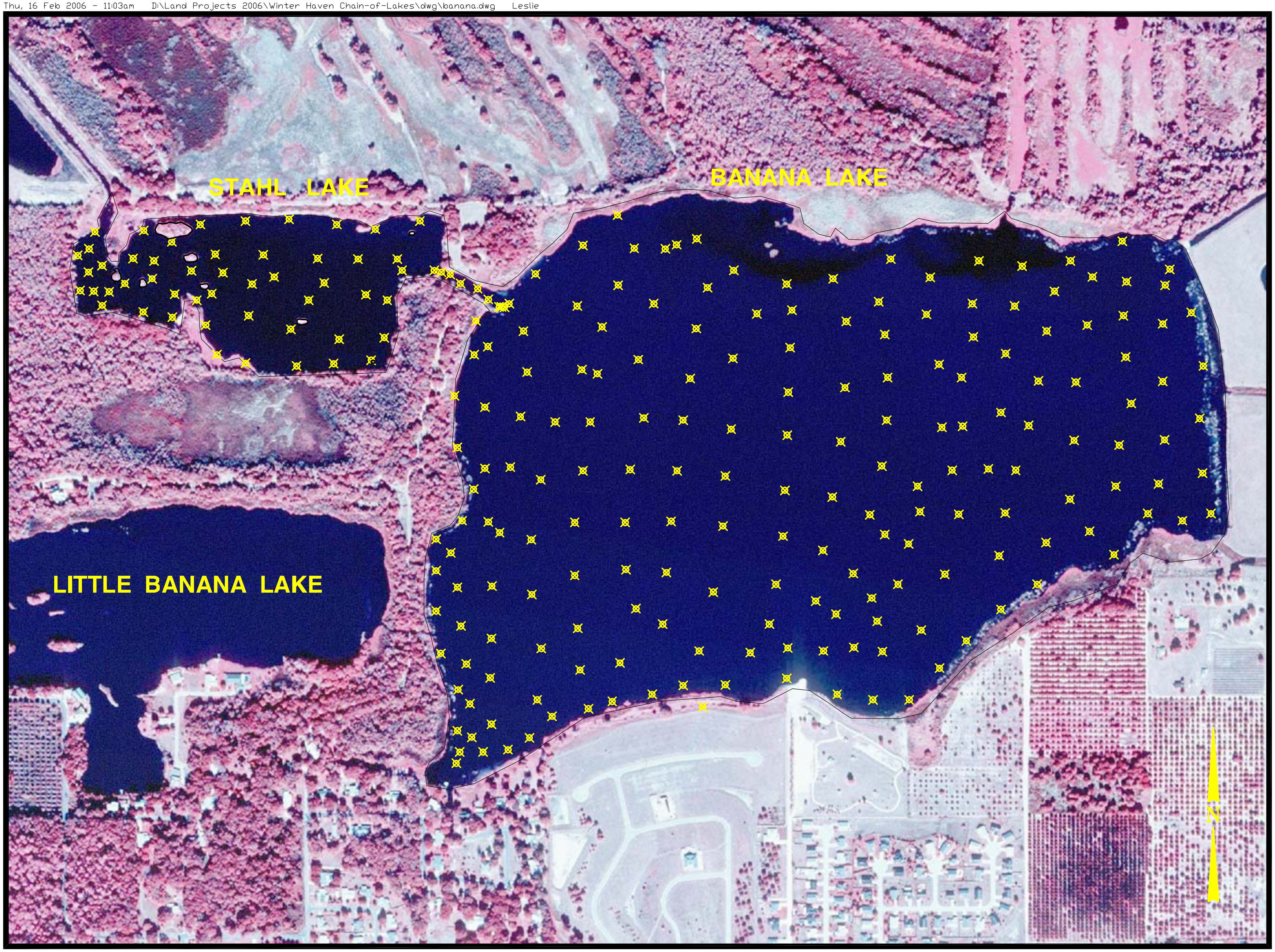

Figure 2-1. Data Collection Sites for Bathymetric Studies.

lake bottom. The difference between the depth to the firm lake bottom and the water depth is defined as the depth of unconsolidated sediments at each site.

The generated field data was converted into bathymetric maps for both water depth and unconsolidated sediment depth in Banana Lake and Stahl Lake using Autodesk Land Desktop 2006. Estimates of water volume and unconsolidated sediment volume within the lakes were also generated.

2.2 Collection of Sediment Core Samples

Sediment core samples were also collected by ERD to assist in evaluating the significance of sediments for impacting water quality in Banana Lake. Sediment core samples were collected at 40 separate locations in Banana Lake and 7 locations in Stahl Lake on November 1-2, 2005. The geographic coordinates of the sediment sample sites, referenced as UTM NAD83 coordinates, were recorded in the field. Locations of sediment sampling sites in the two lakes are illustrated on Figure 2-2. Sediment samples could not be collected in the center of Stahl Lake due to the unconsolidated nature of the sediments and the water depth which exceeded 30 ft in several locations.

Sediment samples were collected at each of the 47 sites using a stainless steel split-spoon core device which was penetrated into the sediments at each location to a minimum distance of approximately 0.5 m. After retrieval of the sediment sample, any overlying water was carefully decanted before the split-spoon device was opened to expose the collected sample. Visual characteristics of each sediment core sample were recorded, and the 0-10 cm layer was carefully sectioned off and placed into a polyethylene container for transport to the ERD laboratory. Duplicate core samples were collected at each site, and the 0-10 cm layers were combined together to form a single composite sample for each of the 47 sites. The polyethylene containers utilized for storage of the collected samples were filled completely so that no air space was present in the storage container above the composite sediment sample. Each of the collected samples was stored on ice and returned to the ERD laboratory for physical and chemical characterization.

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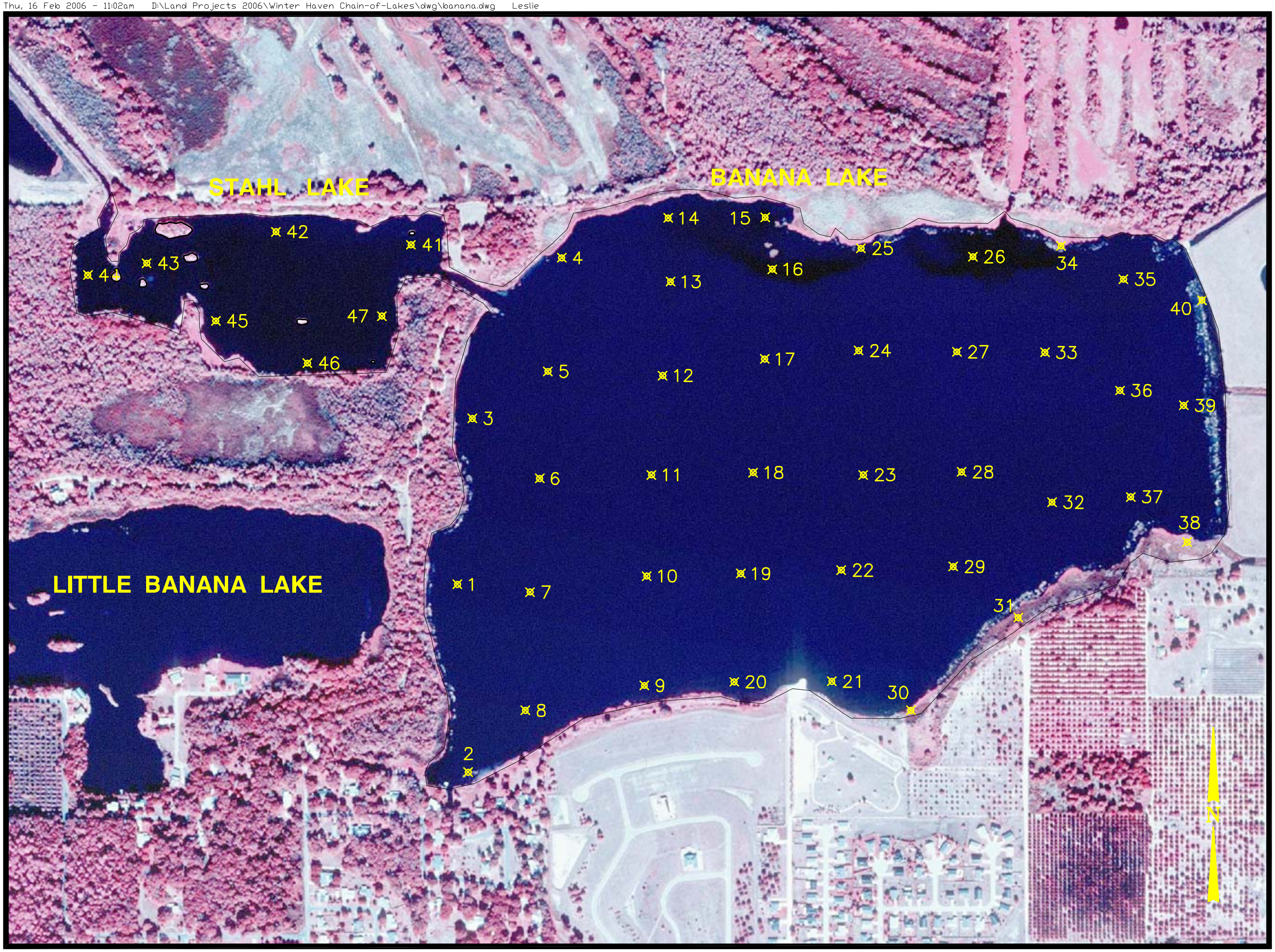

Figure 2-2. Locations of Sediment Collection Sites in Banana Lake and Stahl Lake.

2.3 Sediment Characterization and Speciation Studies

Each of the 47 collected sediment core samples was analyzed for a variety of general parameters, including moisture content, organic content, sediment density, total nitrogen, and total phosphorus. Methodologies utilized for preparation and analysis of the sediment samples for these parameters are outlined in Table 2-1.

TABLE 2-1

ANALYTICAL METHODS FOR SEDIMENT ANALYSES

MEASUREMENT PARAMETER	SAMPLE PREPARATION	ANALYSIS REFERENCE	REFERENCE PREP./ANAL.	METHOD DETECTION LIMITS (MDLs)
pH	EPA 9045	EPA 9045	3/3	0.01 pH units
Moisture Content	p. 3-54	p. 3-58	1/1	0.1%
Organic Content (Volatile Solids)	p. 3-52	pp. 3-52 to 3-53	1/1	0.1%
Total Phosphorus	pp. 3-227 to 3-228 (Method C)	EPA 365.4	½	0.005 mg/kg
Total Nitrogen	p. 3-201	pp. 3-201 to 3-204	1/1	0.010 mg/kg
Specific Gravity (Density)	p. 3-61	pp. 3-61 to 3-62	1/1	NA

REFERENCES:

1. Procedures for Handling and Chemical Analysis of Sediments and Water Samples, EPA/Corps of Engineers, EPA/CE-81-1, 1981.

2. Methods for Chemical Analysis of Water and Wastes, EPA 600/4-79-020, Revised March 1983.

3. Test Methods for Evaluating Solid Wastes, Physical-Chemical Methods, Third Edition, EPA-SW-846, Updated November 1990.

In addition to general sediment characterization, a fractionation procedure for inorganic soil phosphorus was conducted on each of the 47 collected sediment samples. The modified Chang and Jackson Procedure, as proposed by Peterson and Corey (1966), was used for phosphorus fractionation. The Chang and Jackson Procedure allows the speciation of sediment phosphorus into saloid-bound phosphorus (defined as the sum of soluble plus easily exchangeable sediment phosphorus), iron-bound phosphorus, and aluminum-bound phosphorus. Although not used in this project, subsequent extractions of the Chang and Jackson procedure also provide calcium-bound and residual organic fractions.

Saloid-bound phosphorus is considered to be available under all conditions at all times. Iron-bound phosphorus is relatively stable under aerobic environments, generally characterized by redox potentials greater than 200 mv (E_h), while unstable under anoxic conditions, characterized by redox potential less than 200 mv. Aluminum-bound phosphorus is considered to be stable under all conditions of redox potential and natural pH conditions. A schematic of the Chang and Jackson Speciation Procedure for evaluating soil phosphorus bounding is given in Figure 2-3.

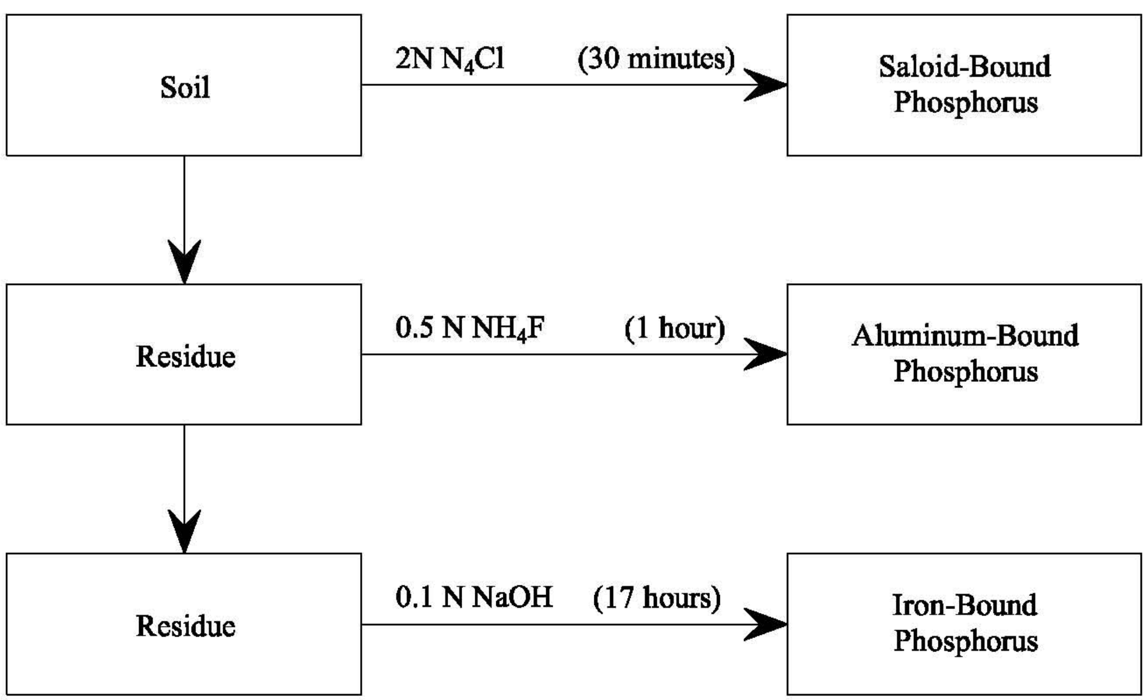

Figure 2-3. Schematic of Chang and Jackson Speciation Procedure for Evaluating Soil Phosphorus Bonding.

For purposes of evaluating release potential, ERD typically assumes that potentially available inorganic phosphorus in soils/sediments, particularly those which exhibit a significant potential to develop highly reduced conditions below the sediment-water interface, is represented by the sum of the soluble inorganic phosphorus and easily exchangeable phosphorus fractions (collectively termed saloid-bound phosphorus), plus iron-bound phosphorus, which can become solubilized under reduced conditions. Aluminum-bound phosphorus is generally considered to be unavailable in the pH range of approximately 5.5-7.5 under a wide range of redox conditions.

SECTION 3

RESULTS

3.1 Bathymetric Surveys

A bathymetric survey was conducted in Banana Lake and Stahl Lake on January 9, 2006 with measurements collected at 250 sites to generate information for use in developing water depth and unconsolidated sediment contours for the lakes. Water depth contour maps for Banana Lake and Stahl Lake, based upon the field monitoring program performed by ERD, are given in Figure 3-1. The maximum water depth in Banana Lake is approximately 6 ft in central and southern portions of the lake. Water depth contours in Stahl Lake are highly irregular, with a maximum depth which reaches approximately 30 ft.

Stage-storage relationships for Banana Lake and Stahl Lake are summarized in Table 3-1. At the water surface elevation present on January 9, 2006, the surface area of Banana Lake is approximately 241.6 acres. The lake volume at this surface area is 995.8 ac-ft which corresponds to a mean water depth of 4.6 ft. This value is relatively shallow for a Central Florida lake. At the water surface elevation present in January 9, 2006, the surface area of Stahl Lake is approximately 30.6 acres. The lake volume at this surface area is 298.8 ac-ft which corresponds to a mean water depth of 9.8 ft.

Bathymetric contour maps of the depth of unconsolidated organic sediments in Banana Lake and Stahl Lake are given in Figure 3-2. Consolidated organic sediments in Banana Lake are relatively shallow, ranging from 0-1 ft through most portions of the lake. However, sediment accumulations in Stahl Lake are considerably greater than observed in Banana Lake. The depth of organic sediments in Stahl Lake exceeds 12 ft in northwestern and western portions of the lake. Sediment depth in remaining portions of Stahl Lake ranges from 1-6 ft in most areas.

A summary of estimated organic muck volumes in Banana Lake and Stahl Lake is given in Table 3-2. In Banana Lake, approximately 91% of the lake surface area is covered by muck

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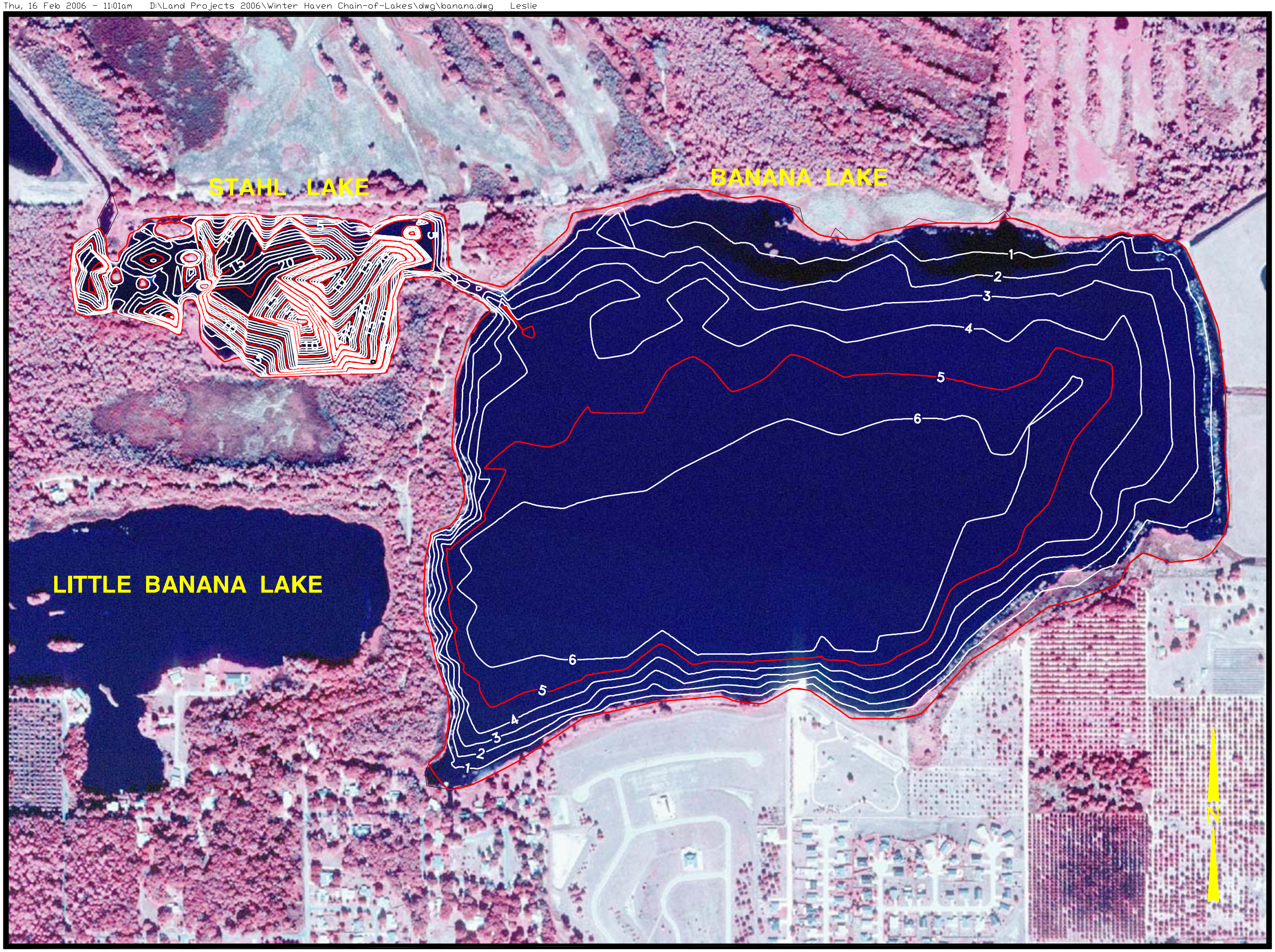

Figure 3-1. Water Depth Contours (ft.) in Banana Lake and Stahl Lake on January 9, 2006.

TABLE 3-1

STAGE-STORAGE RELATIONSHIPS FOR BANANA LAKE AND STAHL LAKE

Banana Lake

DEPTH (ft)	AREA (ac)	VOLUME (ac-ft)	DEPTH (ft)	AREA (ac)	VOLUME (ac-ft)
0.0	241.6	995.8	4.0	145.8	212.8
1.0	218.0	766.0	5.0	106.6	86.6
2.0	196.7	558.5	6.0	66.4	0.0
3.0	174.4	373.0			

Stahl Lake

DEPTH (ft)	AREA (ac)	VOLUME (ac-ft)	DEPTH (ft)	AREA (ac)	VOLUME (ac-ft)
0.0	30.6	298.8	15.0	8.15	32.3
1.0	28.9	269.1	16.0	7.05	24.7
2.0	26.5	241.4	17.0	5.96	18.2
3.0	24.4	215.9	18.0	4.88	12.8
4.0	22.1	192.6	19.0	3.80	8.41
5.0	20.4	171.3	20.0	2.73	5.15
6.0	18.8	151.7	21.0	1.48	3.05
7.0	17.3	133.6	22.0	0.87	1.87
8.0	16.1	116.9	23.0	0.60	1.14
9.0	14.9	101.4	24.0	0.39	0.65
10.0	13.7	87.1	25.0	0.24	0.33
11.0	12.6	73.9	26.0	0.14	0.14
12.0	11.6	61.8	27.0	0.06	0.05
13.0	10.4	50.8	28.0	0.02	0.01
14.0	9.27	41.0	29.0	0.00	0.00

Figure 3-2. Muck Depth Contours (ft.) in Banana Lake and Stahl Lake on January 9, 2006.

accumulations of 1 ft in depth or less. Approximately 9% of the lake is covered with muck accumulations ranging from 1-2 ft. Overall, Banana Lake contains approximately 6,791,996 ft^3 of unconsolidated organic sediments. The volume of unconsolidated sediments in Banana Lake is sufficient to cover the entire lake bottom to a depth of 0.65 ft (7.8 inches).

TABLE 3-2

SUMMARY OF UNCONSOLIDATED ORGANIC SEDIMENT ACCUMULATIONS IN BANANA LAKE AND STAHL LAKE

Banana Lake

MUCK DEPTH (ft)	AREA IN LAKE (ac)	PERCENTAGE OF LAKE AREA	MUCK VOLUME (ft^3)
0-1	220.4	91	5,406,788
1-2	21.2	9	1,385,208
Total:	**241.6**	**100**	**6,791,996**

Stahl Lake

MUCK DEPTH (ft)	AREA IN LAKE (ac)	PERCENTAGE OF LAKE AREA	MUCK VOLUME (ft^3)
0-1	11.27	37	245,461
1-2	7.56	25	493,970
2-3	5.31	17	578,259
3-4	2.81	9	428,413
4-5	1.17	4	229,343
5-6	0.74	2	177,289
6-7	0.43	1	121,750
7-8	0.33	1	107,811
8-9	0.30	1	111,078
9-10	0.27	< 1	111,731
10-11	0.21	< 1	96,050
11-12	0.11	< 1	55,103
Total:	**30.6**	**100**	**2,756,259**

In Stahl Lake, approximately 37% of the lake surface area is covered by organic sediments to a depth of approximately 1 ft or less, with 25% of the lake covered by sediments ranging from 1-2 ft, 17% of the lake covered by sediments ranging from 2-3 ft, and 9% of the lake area covered by sediments ranging from 3-4 ft. Approximately 10% of the lake surface area is covered by sediments at depths of 4 ft or greater. Overall, Stahl Lake contains approximately 2,756,259 ft^3 of organic muck sediments, sufficient to cover the entire lake bottom to a mean depth of 2.07 ft.

3.2 Sediment Characteristics

3.2.1 Visual Characteristics

Visual characteristics of sediment core samples were recorded for each of the 47 sediment samples collected in Banana Lake and Stahl Lake during November 2005. A summary of visual characteristics of sediment core samples is given in Table 3-3. In general, northern and northern central portions of Banana Lake are characterized by sandy sediments consisting primarily of light brown fine sand, extending to depths of approximately 5-15 cm below the water-sediment interface. Southern and southern central portions of Banana Lake are characterized by muck-type sediments consisting primarily of dark brown unconsolidated and consolidated organic muck at depths ranging from 4-48 cm. This unconsolidated layer is comprised primarily of fresh organic material, such as dead algal cells, which have accumulated onto the bottom of the lake. This organic material is easily disturbed by wind action or boating activities. As the sediment depth increases, the organic layer becomes more consolidated with a consistency similar to pudding. These deeper layers typically do not resuspend into the water column except during relatively vigorous mixing action within the lake.

A similar pattern is apparent in the sediment samples collected in Stahl Lake. Northern portions of Stahl Lake appear to have sediments composed primarily of light brown fine sand, extending from 5->35 cm below the water-sediment interface. Southern portions of Stahl Lake appear to have sediments dominated by organic muck, with unconsolidated organic muck layers ranging from 4->48 cm in thickness.

3.2.2 General Sediment Characteristics

After return to the ERD laboratory, the collected sediment core samples were evaluated for a variety of general characteristics including pH, moisture content, organic content, sediment density, total nitrogen, and total phosphorus. A summary of general characteristics measured in each of the 47 collected sediment core samples is given in Table 3-4. In general, sediments in the two lakes were found to be approximately neutral in pH, with measured sediment pH values ranging from 6.10-7.85 and an overall mean of 6.73. These values are typical of pH measurements commonly observed in hypereutrophic urban lakes.

TABLE 3-3

VISUAL CHARACTERISTICS OF SEDIMENT CORE SAMPLES COLLECTED IN BANANA LAKE AND STAHL LAKE DURING NOVEMBER 2005

Banana Lake

SITE NO.	LAYER (cm)	VISUAL APPEARANCE
1	0-6	Dark brown unconsolidated organic muck
	6-11	Dark brown consolidated organic muck
	11-22	Brown fine sand with organics
	>22	Dark gray fine sand with organics
2	0->12	Light brown fine sand
3	0-7	Light brown fine sand
	7-13	Light brown fine sand with light gray clay
	13-26	Dark brown consolidated organic muck
	>26	Brown fine sand with organics
4	0->13	Light brown fine sand with vegetation
5	0-15	Light brown fine sand
	>15	Dark gray clay
6	0->15	Light brown fine sand
7	0-16	Dark brown unconsolidated organic muck
	16-21	Consolidated organic muck
	>21	Brown fine sand with organics
8	0-6	Light brown fine sand
	>6	Brown fine sand with organics
9	0-5	Dark brown unconsolidated organic muck
	5-8	Consolidated organic muck
	5-11	Light brown fine sand
	>11	Brown fine sand with organics
10	0-5	Dark brown unconsolidated organic muck
	5->25	Dark brown consolidated organic muck
11	0->17	Light brown fine sand
12	0->16	Light brown fine sand
13	0-8	Dark brown unconsolidated organic muck
	8-14	Dark brown consolidated organic muck
	14-27	Light brown fine sand
	>27	Light gray clay
14	0-5	Light brown fine sand with algae
	>5	Light brown fine sand
15	0-4	Light brown fine sand with algae
	>4	Light brown fine sand
16	0-5	Light brown fine sand with algae
	>5	Light brown fine sand
17	0->10	Light brown fine sand
18	0-4	Dark brown unconsolidated organic muck
	4-9	Brown fine sand with organics
	>9	Dark gray clay

TABLE 3-3 – CONTINUED

VISUAL CHARACTERISTICS OF SEDIMENT CORE SAMPLES COLLECTED IN BANANA LAKE AND STAHL LAKE DURING NOVEMBER 2005

Banana Lake (Continued)

SITE NO.	LAYER (cm)	VISUAL APPEARANCE
19	0-7 7-17 >17	Dark brown unconsolidated organic muck Dark brown consolidated organic muck Dark gray clay
20	0->13	Light brown fine sand
21	0-4 >4	Light brown fine sand Brown fine sand with organics
22	0-4 >4	Dark brown unconsolidated organic muck Dark brown consolidated organic muck
23	0-3 3-15 >15	Dark brown unconsolidated organic muck Dark brown consolidated organic muck Brown fine sand with organics
24	0-6 6-9 >9	Light brown fine sand with algae Light brown fine sand with vegetation Brown fine sand with organics
25	0-6 >6	Light brown fine sand with algae Light brown fine sand
26	0-8 >8	Light brown fine sand with algae Light brown fine sand
27	0-7 >7	Brown fine sand with organics Light brown fine sand
28	0-8 >8	Dark brown unconsolidated organic muck Dark gray clay
29	0-8 8-24 >24	Dark brown unconsolidated organic muck Dark brown consolidated organic muck Light brown fine sand
30	0-1 1-8 >8	Light brown fine sand with algae Light brown fine sand with vegetation Brown fine sand with organics
31	0-4 4-14 >14	Light brown fine sand with vegetation Light brown fine sand Brown fine sand with organics
32	0-10 >10	Dark brown unconsolidated organic muck Dark brown consolidated organic muck
33	0-7 7-12 >12	Light brown fine sand Brown fine sand with organics Light brown fine sand
34	0-5 >5	Light brown fine sand with algae Light brown fine sand
35	0-5 >5	Light brown fine sand Brown fine sand with organics

TABLE 3-3 – CONTINUED

VISUAL CHARACTERISTICS OF SEDIMENT CORE SAMPLES COLLECTED IN BANANA LAKE AND STAHL LAKE DURING NOVEMBER 2005

Banana Lake (Continued)

SITE NO.	LAYER (cm)	VISUAL APPEARANCE
36	0-11 >11	Light brown fine sand Brown fine sand with organics
37	0-6 >6	Light brown fine sand Brown fine sand with organics
38	0-5 >5	Light brown fine sand Brown fine sand with organics
39	0->6	Light brown fine sand
40	0-3 >3	Light brown fine sand with algae Light brown fine sand

Stahl Lake

SITE NO.	LAYER (cm)	VISUAL APPEARANCE
41	0-10 >10	Brown fine sand with organics Dark gray clay
42	0-5 >5	Light brown fine sand with algae Dark gray clay
43	0-25 25-33 >33	Brown fine sand with organics Light brown fine sand Brown fine sand with organics
44	0-4 4->40	Dark brown unconsolidated organic muck Dark brown consolidated organic muck
45	0-7 7-20 >20	Brown fine sand with organics Dark brown consolidated organic muck Brown fine sand with organics
46	0-48 >48	Dark brown consolidated organic muck Dark gray clay
47	0-21 >21	Dark brown consolidated organic muck Dark gray clay

TABLE 3-4

GENERAL CHARACTERISTICS OF SEDIMENT CORE SAMPLES COLLECTED IN BANANA LAKE AND STAHL LAKE DURING NOVEMBER 2005

Banana Lake

SAMPLE SITE	pH	MOISTURE CONTENT (%)	ORGANIC CONTENT (%)	DENSITY (g/cm^3)	TOTAL NITROGEN (µg/cm^3)	TOTAL PHOSPHORUS (µg/cm^3)
1	6.37	86.5	20.5	1.16	2,747	1,878
2	6.75	24.0	0.6	2.13	1,324	1,116
3	6.67	27.0	1.6	2.08	1,002	4,174
4	6.59	30.2	1.6	2.03	1,510	1,764
5	6.78	22.2	0.4	2.16	669	343
6	6.68	22.9	0.3	2.15	650	266
7	6.37	93.5	33.3	1.07	2,526	1,381
8	6.95	34.2	0.8	1.98	1,316	473
9	6.38	57.7	3.4	1.61	2,889	1,448
10	6.18	78.7	15.8	1.27	3,550	2,287
11	6.91	22.6	0.3	2.16	687	364
12	6.66	21.8	0.3	2.17	731	289
13	6.23	89.5	22.1	1.12	2,769	1,759
14	6.51	22.8	0.4	2.15	799	2,120
15	6.65	22.5	0.4	2.16	851	4,551
16	6.61	22.8	0.5	2.15	797	1,204
17	6.93	22.5	0.4	2.16	960	507
18	6.10	49.7	4.0	1.72	3,108	3,390
19	6.16	89.3	26.1	1.12	3,932	2,602
20	6.90	24.7	0.7	2.12	920	2,279
21	7.18	24.8	2.0	2.11	1,029	1,714
22	6.25	89.9	31.4	1.10	4,072	2,990
23	6.41	90.9	27.2	1.10	3,040	2,072
24	6.84	22.7	0.5	2.15	715	1,126
25	7.16	21.4	0.4	2.17	642	2,199
26	6.21	30.1	0.8	2.04	977	1,207
27	6.88	22.4	0.3	2.16	677	1,313
28	6.15	74.0	9.1	1.35	3,056	2,299
29	6.28	93.3	35.0	1.07	2,997	1,413
30	6.7	34.0	2.8	1.96	1,079	864
31	6.73	27.2	1.2	2.08	610	725
32	6.39	88.5	26.4	1.13	5,675	3,700
33	6.91	24.4	0.7	2.13	1,482	1,252
34	6.6	23.2	0.6	2.15	871	1,469
35	6.99	39.7	4.1	1.87	3,784	436
36	6.87	25.2	0.5	2.12	1,158	507
37	6.94	23.0	0.6	2.15	724	454
38	7.85	24.0	0.8	2.13	1,108	707
39	6.67	27.8	0.3	2.08	633	284
40	7.57	23.1	0.5	2.15	597	707
Mean	**6.68**	**42.3**	**7.0**	**1.84**	**1,717**	**1,541**
Minimum	**6.10**	**21.4**	**0.3**	**1.07**	**597**	**266**
Maximum	**7.85**	**93.5**	**35.0**	**2.17**	**5,675**	**4,551**

TABLE 3-4 -- CONTINUED

GENERAL CHARACTERISTICS OF SEDIMENT CORE SAMPLES COLLECTED IN BANANA LAKE AND STAHL LAKE DURING NOVEMBER 2005

Stahl Lake

SAMPLE SITE	pH	MOISTURE CONTENT (%)	ORGANIC CONTENT (%)	DENSITY (g/cm^3)	TOTAL NITROGEN ($\mu g/cm^3$)	TOTAL PHOSPHORUS ($\mu g/cm^3$)
41	7.54	28.1	1.4	2.06	1,423	4,327
42	7.15	22.7	1.8	2.14	1,010	5,168
43	7.04	36.2	6.7	1.89	4,000	770
44	6.86	83.1	16.8	1.21	3,740	1,279
45	7.08	31.0	2.6	2.01	1,739	1,559
46	6.75	77.1	13.5	1.30	3,705	2,675
47	6.79	78.5	16.3	1.27	3,231	2,568
Mean	**7.03**	**60.0**	**8.4**	**1.82**	**2,693**	**2,621**
Minimum	**6.75**	**22.7**	**1.4**	**1.21**	**1,010**	**770**
Maximum	**7.54**	**83.1**	**16.8**	**2.14**	**4,000**	**5,168**

Isopleths of sediment pH in Banana Lake and Stahl Lake are summarized in Figure 3-3 based upon the information provided in Table 3-4. In general, sediment pH values appear to be slightly lower in central portions of the lake, with more elevated values measured in perimeter shoreline areas. Sediment pH values appear to be slightly greater in Stahl Lake than observed within Banana Lake.

Measurements of sediment moisture content and organic content in Banana Lake and Stahl Lake were found to be highly variable throughout each lake. Sediment samples with relatively low moisture contents are often comprised largely of fine sand and are also characterized by a relatively low organic content. In contrast, sediments which exhibit a high moisture content are often comprised primarily of organic muck and are also associated with a high organic content.

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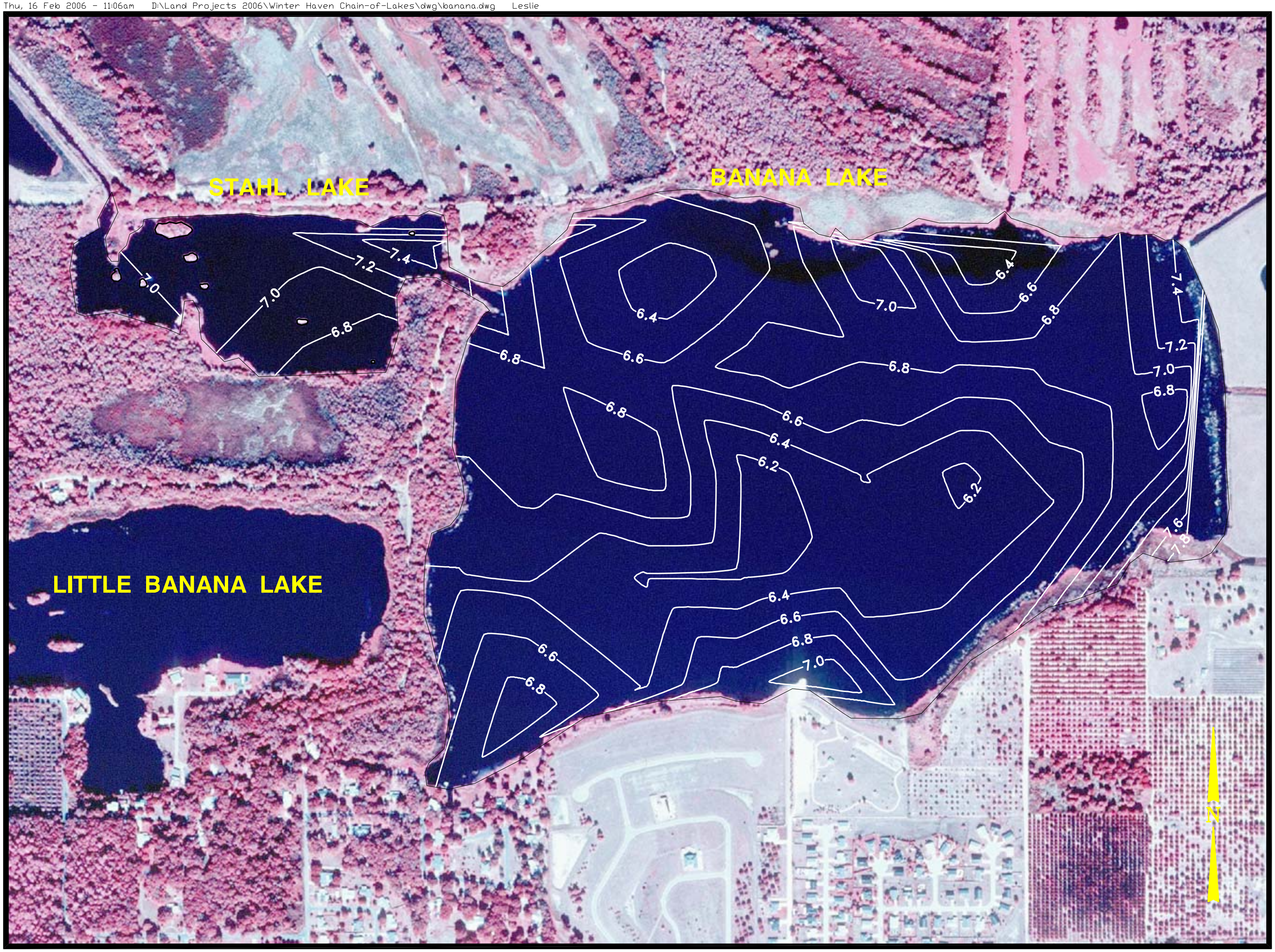

Figure 3-3. Isopleths of Sediment pH in Banana Lake and Stahl Lake.

Isopleths of sediment moisture content in Banana Lake and Stahl Lake are summarized in Figure 3-4 based upon the information provided in Table 3-4. Areas of elevated moisture content are present in the northwestern, southwestern, and southeastern portions of Banana Lake and the southwestern and southeastern portions of Stahl Lake. Sediment moisture contents in access of 50-70% are often indicative of highly organic sediments, with moisture contents less than 50% reflecting mixtures of sand and muck.

Isopleths of sediment organic content in Banana Lake and Stahl Lake are illustrated on Figure 3-5 based upon the information provided in Table 3-4. In general, sediment organic contents in excess of 20% are often indicative of organic muck-type sediments, with values less than 20% representing mixtures of muck and sand. Based upon these criteria, areas of concentrated organic muck are apparent in southeastern and southwestern portions of Banana Lake. This area corresponds well with the area of accumulated organic muck deposits indicated on Figure 3-2. Measured organic sediment content within the two lakes range from 0.3-35.0% with an overall mean of 7.2%.

Values of sediment density are also useful in evaluating the general characteristics of sediments within the lake. Sediments with calculated densities between 1.0 and 1.5 are often indicative of highly organic muck-type sediments, while sediment densities of approximately 2.0 or greater are often indicative of sandy sediment conditions. Measured sediment densities in the two lakes range from 1.07-2.17 g/cm^3 with an overall mean of 1.82 g/cm^3.

Isopleths of sediment density in Banana Lake and Stahl Lake are presented in Figure 3-6. Areas of relatively sandy sediment conditions are apparent in perimeter areas of Banana Lake and northern portions of Stahl Lake, as indicated by sediment densities of approximately 2.0 g/cm^3 or greater. Sediment densities of approximately 1.5 g/cm^3 or less are apparent in southern central portions of both lakes, suggesting muck type sediments in these areas.

Measured concentrations of total phosphorus in Banana Lake and Stahl Lake sediments were found to be highly variable. Measured total phosphorus concentrations in the two lakes range from 266-5168 μg/cm^3 (wet weight basis), with a mean sediment phosphorus

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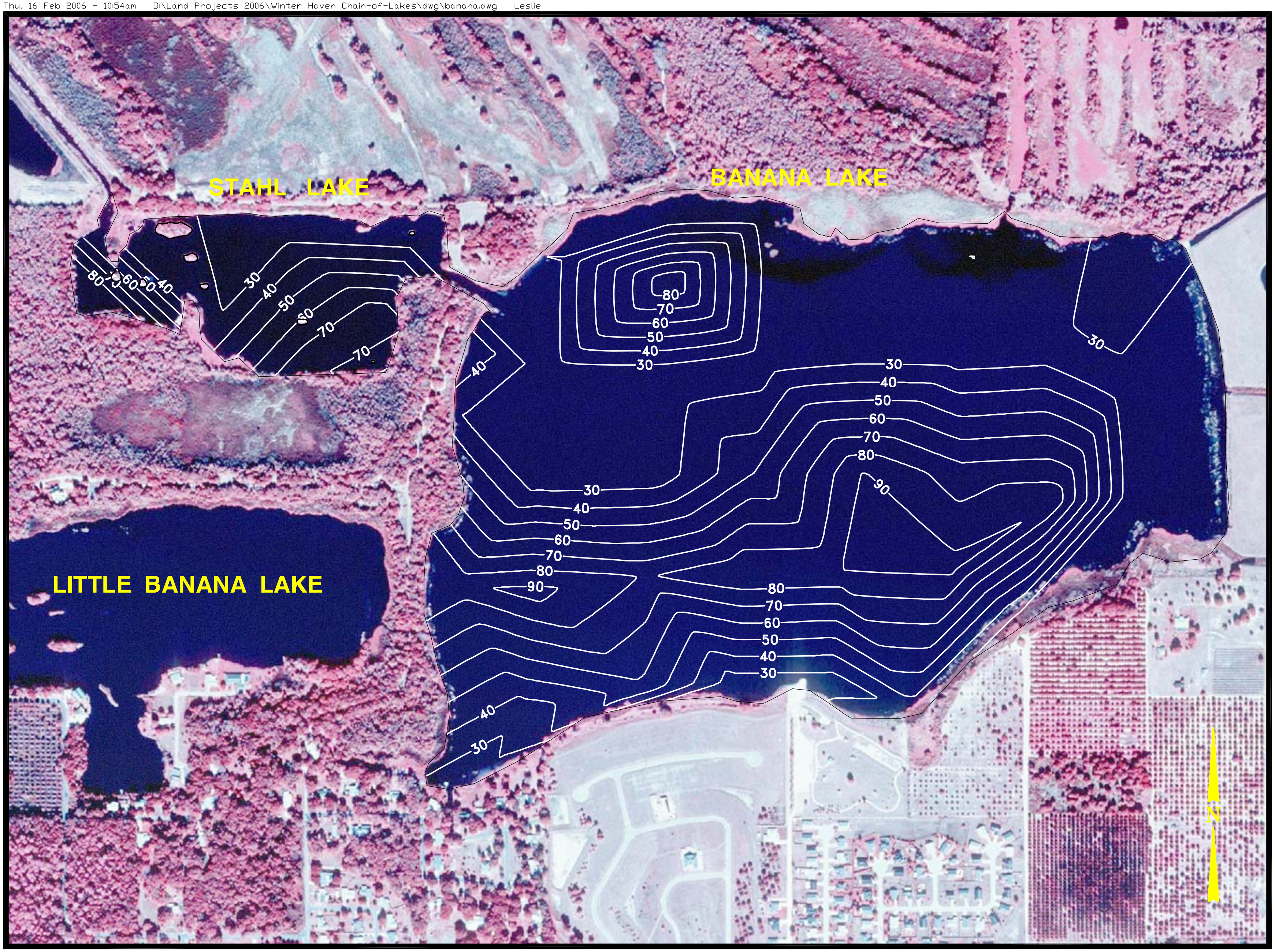

Figure 3-4. Isopleths of Sediment Moisture Content (%) in Banana Lake and Stahl Lake.

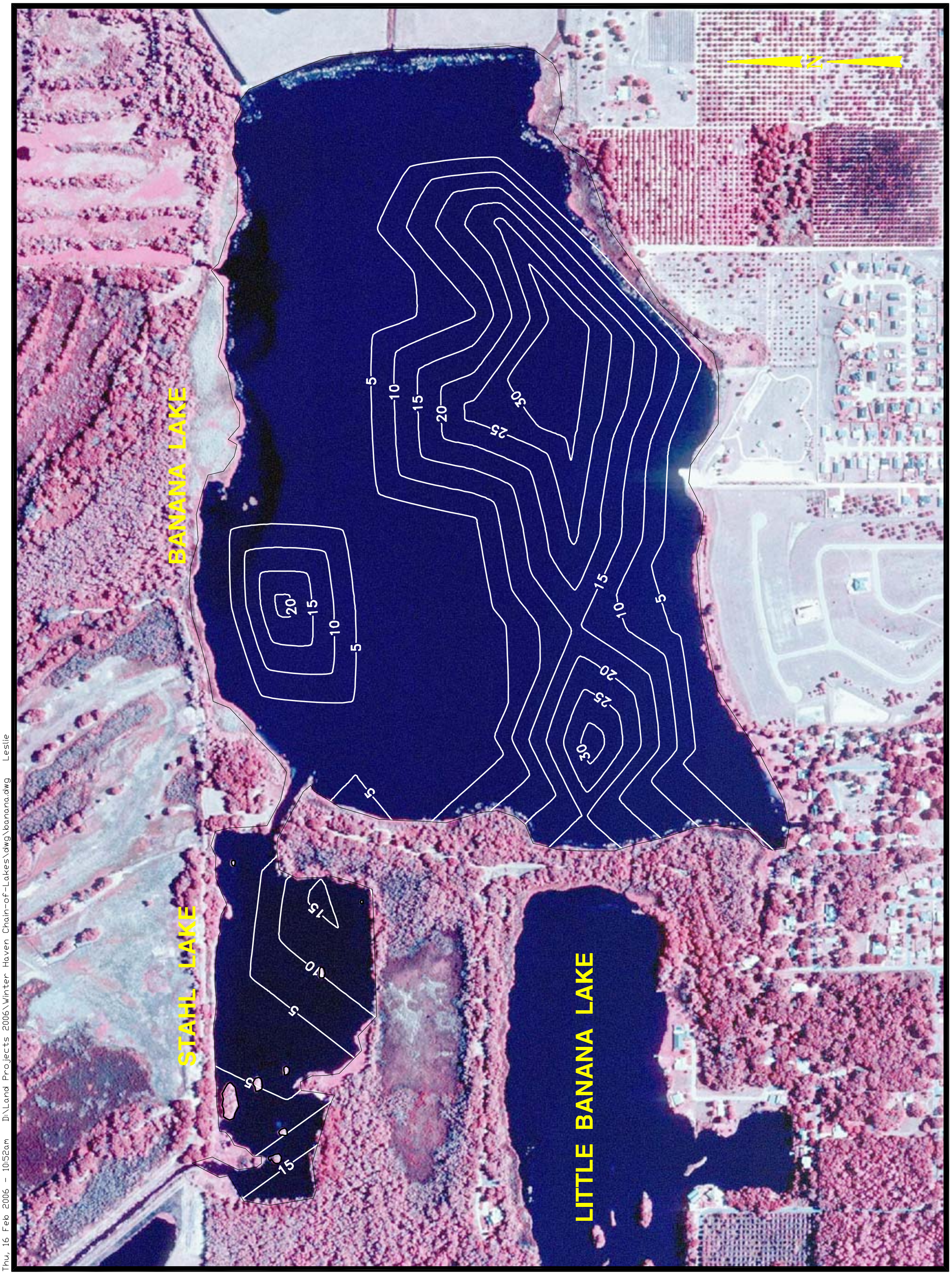

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Figure 3-5. Isopleths of Sediment Organic Content (%) in Banana Lake and Stahl Lake.

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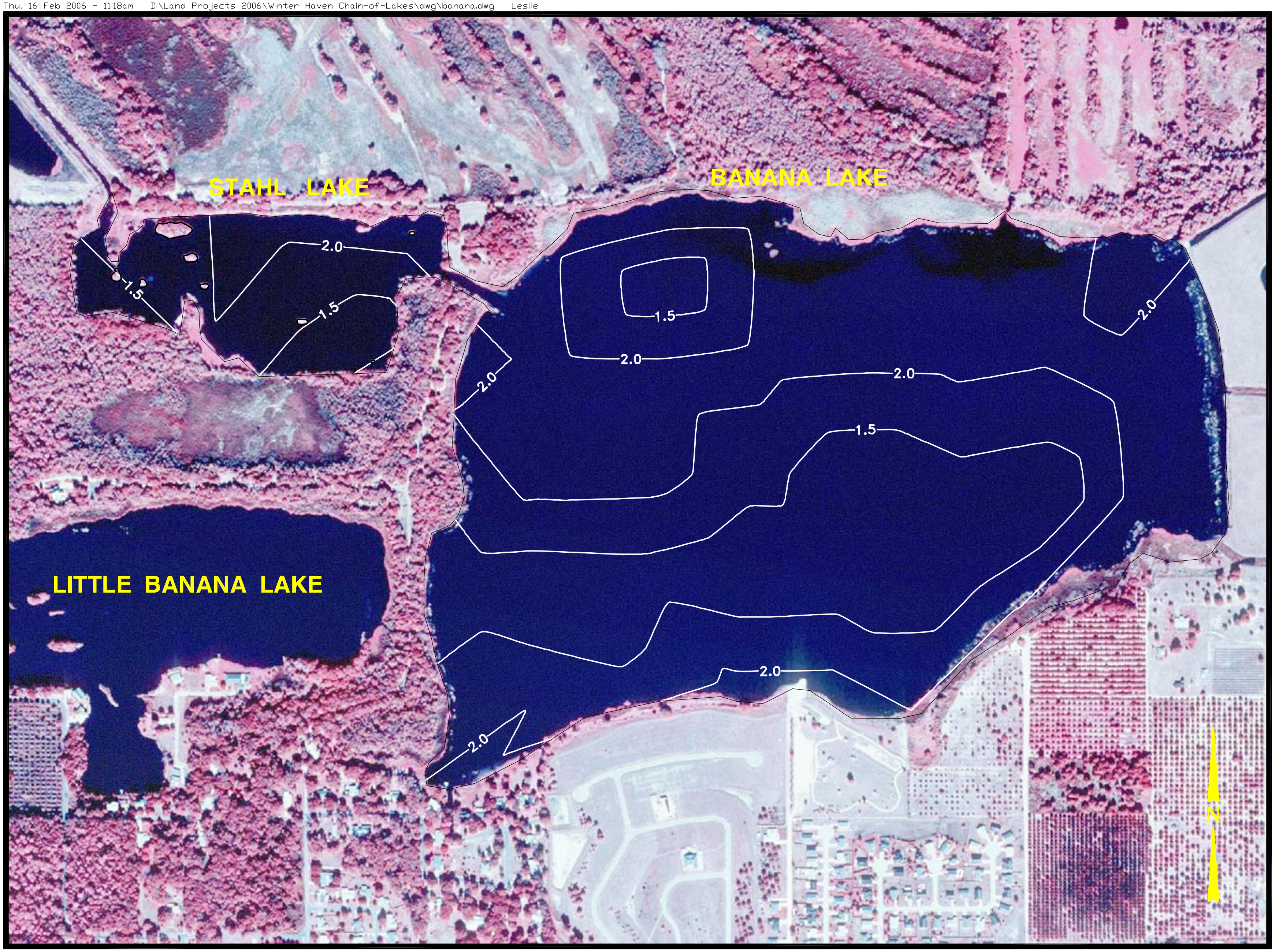

Figure 3-6. Isopleths of Sediment Density (g/cm^3 wet wt.) in Banana Lake and Stahl Lake.

concentration of 1243 μg/cm^3 in Banana Lake and 2621 μg/cm^3 in Stahl Lake. In general, sandy sediments are often characterized by low total phosphorus concentrations, while highly organic muck-type sediments are characterized by elevated total phosphorus concentrations. The mean total phosphorus concentration of 1702 μg/cm^3 measured in the two lakes is approximately 3-6 times greater than phosphorus concentrations normally measured by ERD in Central Florida lakes.

Isopleths of sediment phosphorus concentrations in Banana Lake and Stahl Lake are presented on Figure 3-7 based on information contained in Table 3-4. Areas of elevated sediment phosphorus concentrations are present in the south central portions of Banana Lake and throughout Stahl Lake. The areas of elevated total phosphorus concentrations within the lakes are very similar to the areas of elevated moisture content and organic content summarized in Figures 3-4 and 3-5, respectively.

Similar to the trends observed for sediment phosphorus concentrations, sediment nitrogen concentrations are also highly variable within the two lakes. Sediment nitrogen concentrations range from 597-5675 μg/cm^3 with an overall mean of 1862 μg/cm^3 (wet weight basis). However, in contrast to the trends observed for total phosphorus, the sediment nitrogen concentrations measured in the lakes do not appear to be elevated compared with values normally observed in urban lakes.

Isopleths of sediment nitrogen concentrations in Banana Lake and Stahl Lake are illustrated on Figure 3-8. An area of elevated nitrogen concentrations is apparent in the north central portion of both Banana Lake and Stahl Lake. Sediment concentrations of total nitrogen appear to be more uniform throughout the lakes than observed for total phosphorus, organic content, or moisture content.

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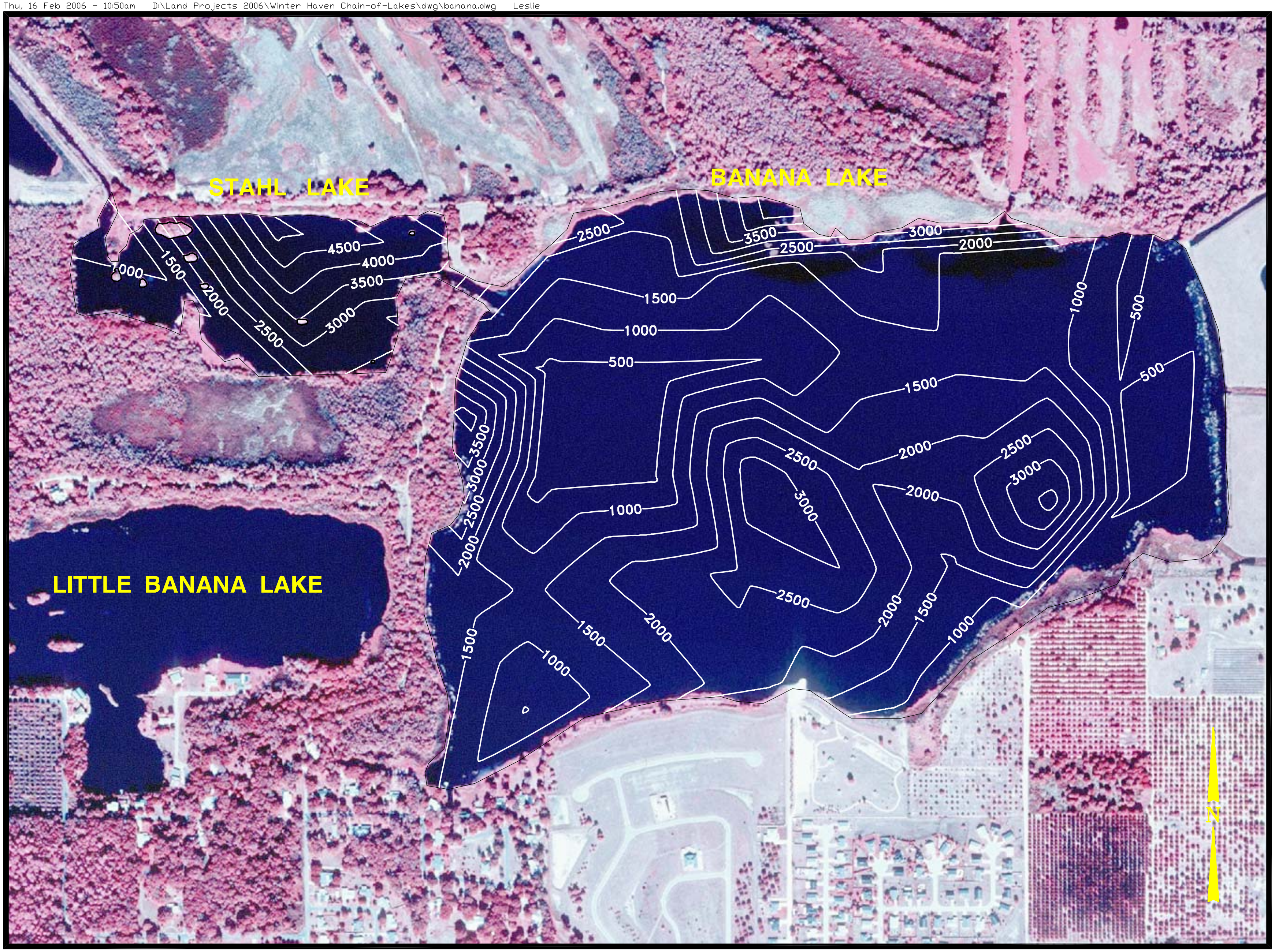

Figure 3-7. Isopleths of Sediment Phosphorus Concentrations (µg/cm^3 wet wt. basis) in Banana Lake and Stahl Lake.

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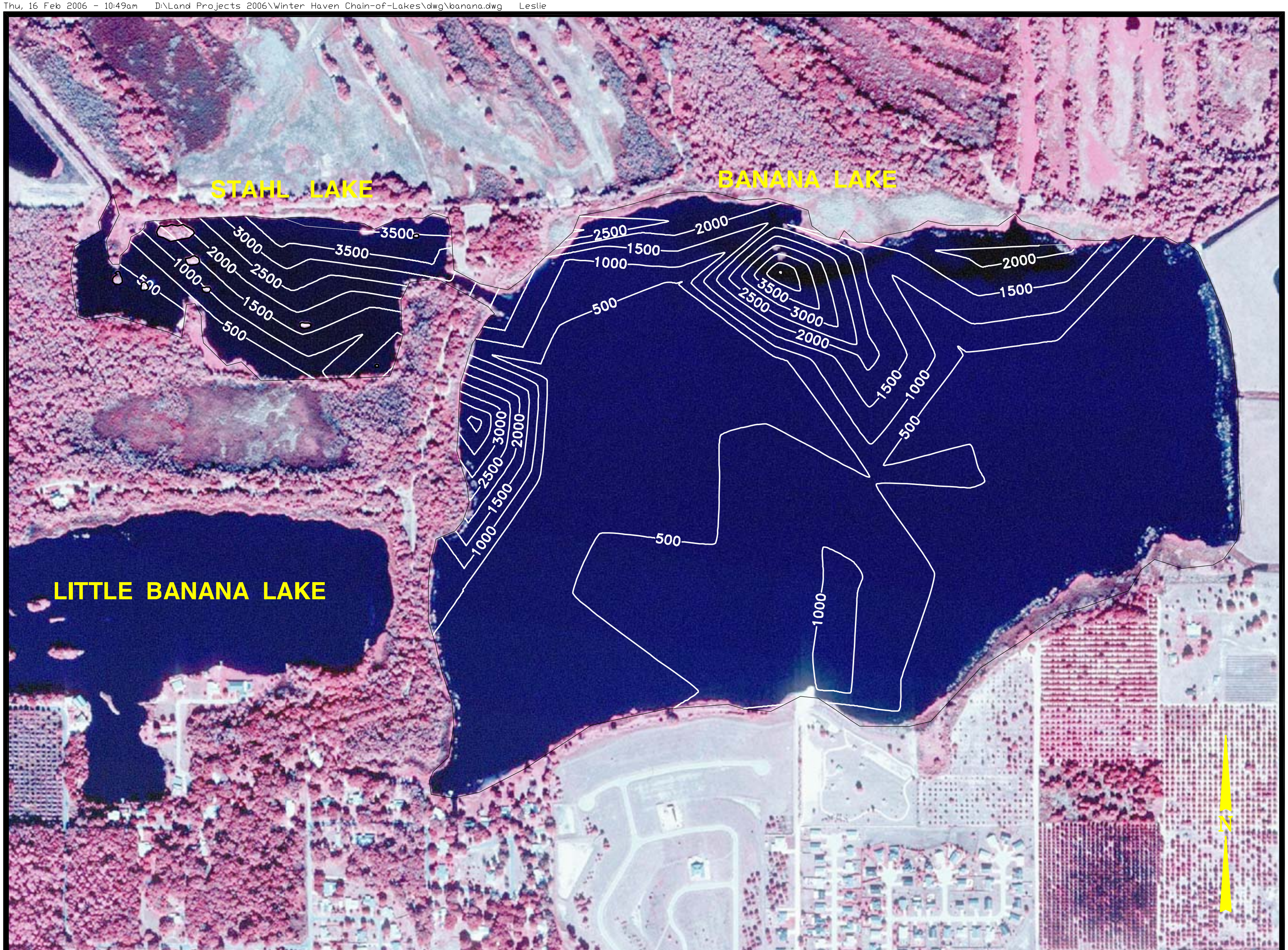

Figure 3-8. Isopleths of Sediment Nitrogen Concentrations (µg/cm^3 wet wt. basis) in Banana Lake and Stahl Lake.

3.2.3 Phosphorus Speciation

As discussed in Section 2, each of the collected sediment core samples was evaluated for phosphorus speciation based upon the Chang and Jackson Speciation Procedure. This procedure allows sediment phosphorus to be speciated with respect to bonding mechanisms within the sediments. This information is useful in evaluating the potential for release of phosphorus from the sediments under anoxic or other conditions.

A summary of phosphorus speciation in sediment core samples collected in Banana Lake and Stahl Lake during November 2005 is given in Table 3-5. Saloid-bound phosphorus represents sediment phosphorus which is either soluble or easily exchangeable and is typically considered to be readily available for release from the sediments into the overlying water column. As seen in Table 3-5, a high degree of variability is apparent in saloid-bound phosphorus within the sediments of both lakes. Measured values for saloid-bound phosphorus range from 62-1010 $\mu g/cm^3$, with an overall mean value of 384 $\mu g/cm^3$ in Banana Lake, and from 84-718 $\mu g/cm^3$ in Stahl Lake, with a mean value of 311 $\mu g/cm^3$. In general, low levels of saloid-bound phosphorus are associated with sandy sediments within the lake, while elevated levels of saloid-bound phosphorus are associated with highly organic sediments. The measured saloid-bound phosphorus concentrations in the sediments of Banana Lake and Stahl Lake are the highest saloid-bound phosphorus values ever recorded by ERD in a Central Florida lake. In fact, the minimum saloid-bound phosphorus concentration of 62 $\mu g/cm^3$ measured in Banana Lake sediments is higher than most of the maximum values previously measured by ERD in other lakes.

An isopleth map of saloid-bound phosphorus in the sediments of Banana Lake and Stahl Lake is given in Figure 3-9. The most elevated levels of saloid-bound phosphorus occur in central portions of Banana Lake and northern perimeter areas of Stahl Lake.

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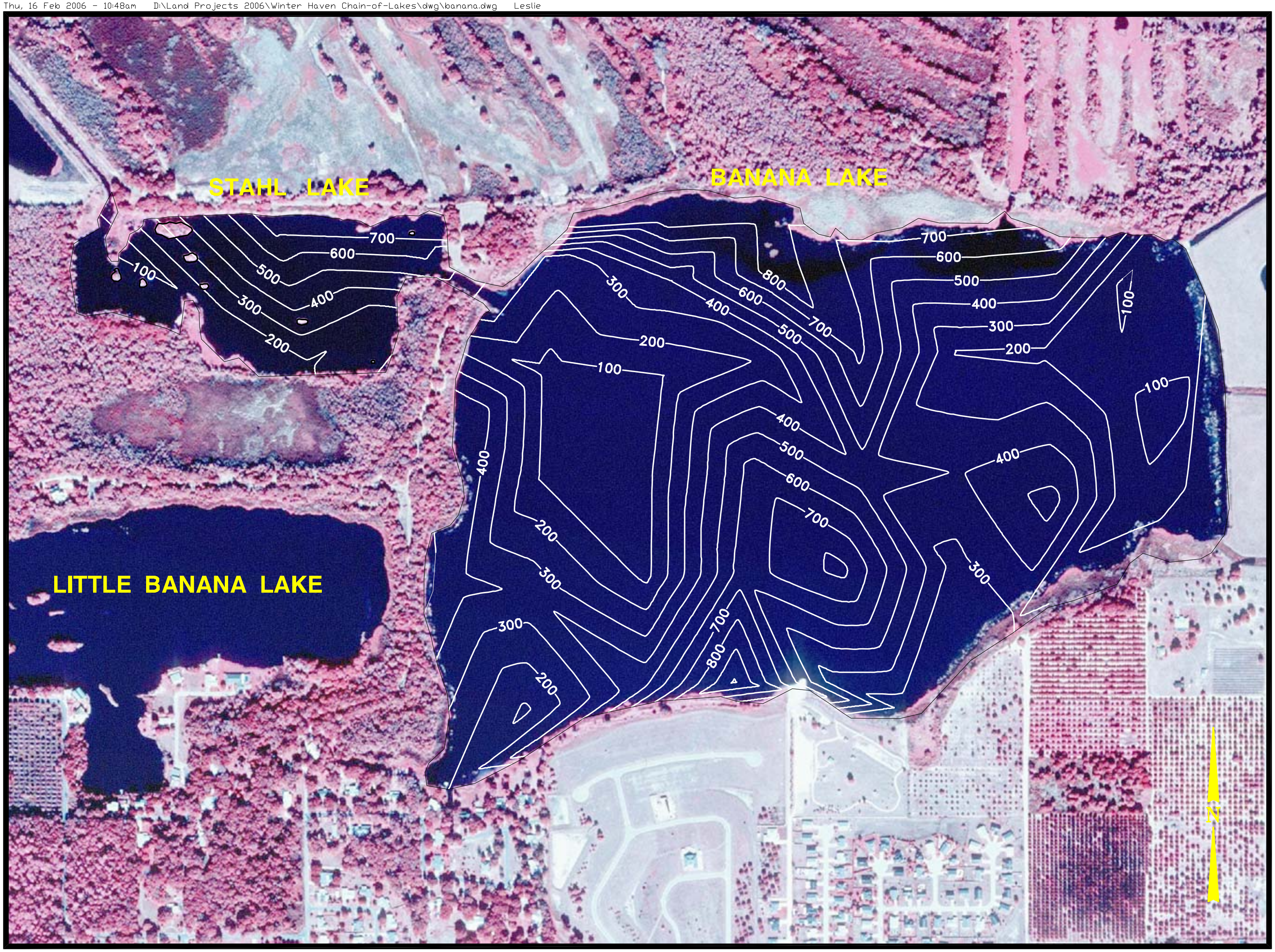

Figure 3-9. Isopleths of Saloid-Bound Phosphorus (µg/cm^3 wet wt. basis) in the Sediments of Banana Lake and Stahl Lake.

TABLE 3-5

PHOSPHORUS SPECIATION IN SEDIMENT CORE SAMPLES COLLECTED IN BANANA LAKE AND STAHL LAKE DURING NOVEMBER 2005

Banana Lake

SAMPLE SITE	SALOID-BOUND PHOSHORUS (µg/cm^3)	IRON- BOUND PHOSPHORUS (µg/cm^3)	TOTAL AVAILABLE PHOSPHORUS (µg/cm^3)	PERCENT AVAILABLE PHOSPHORUS (%)	ALUMINUM-BOUND PHOSPHORUS (µg/cm^3)
1	436	187	623	33	503
2	166	69	236	21	132
3	491	591	1082	26	2698
4	255	221	476	27	958
5	62	67	128	37	145
6	96	64	161	60	59
7	377	74	451	33	344
8	82	67	149	32	92
9	486	123	608	42	331
10	75	155	230	10	834
11	96	56	152	42	66
12	98	44	142	49	122
13	393	112	504	29	447
14	869	194	1062	50	961
15	850	81	931	20	1560
16	863	148	1010	84	4526
17	216	42	258	51	168
18	653	161	814	24	793
19	645	155	800	31	752
20	1010	104	1114	49	654
21	359	537	896	52	606
22	831	175	1006	34	1088
23	440	101	541	26	509
24	730	211	941	84	109
25	648	91	739	34	1171
26	603	191	794	66	229
27	195	159	353	27	434
28	394	122	516	22	524
29	262	64	327	23	304
30	224	76	300	35	279
31	303	134	437	60	230
32	538	87	626	17	354
33	180	95	275	22	218
34	611	119	731	50	554
35	93	166	259	59	25
36	108	55	163	32	66
37	113	23	136	30	127
38	284	88	372	53	326
39	76	82	158	56	52
40	165	97	262	37	116
Mean	**384**	**135**	**519**	**39**	**477**
Maximum	**62**	**23**	**128**	**10**	**25**
Maximum	**1010**	**537**	**1114**	**84**	**2698**

TABLE 3-5 -- CONTINUED

PHOSPHORUS SPECIATION IN SEDIMENT CORE SAMPLES COLLECTED IN BANANA LAKE AND STAHL LAKE DURING NOVEMBER 2005

Stahl Lake

SAMPLE SITE	SALOID-BOUND PHOSHORUS (μg/cm^3)	IRON- BOUND PHOSPHORUS (μg/cm^3)	TOTAL AVAILABLE PHOSPHORUS (μg/cm^3)	PERCENT AVAILABLE PHOSPHORUS (%)	ALUMINUM-BOUND PHOSPHORUS (μg/cm^3)
41	667	764	1431	33	3991
42	718	672	1389	27	3781
43	84	111	194	25	305
44	161	249	410	32	677
45	121	250	370	24	398
46	186	264	450	17	747
47	241	275	515	20	1115
Mean	**311**	**369**	**680**	**25**	**1142**
Minimum	**84**	**111**	**194**	**17**	**305**
Maximum	**718**	**764**	**1431**	**33**	**3991**

As seen in Table 3-5, a relatively high degree of variability is also apparent in iron-bound phosphorus associations in each of the two lakes, although the observed variability in measured concentrations is substantially less than that observed for saloid-bound phosphorus. In general, iron-bound phosphorus sediment associations appear to follow a pattern similar to that exhibited by saloid-bound phosphorus. Areas of the lake with relatively sandy sediments are characterized by low levels of iron-bound phosphorus, while highly organic sediment areas appear to have higher values of iron-bound phosphorus. Iron-bound phosphorus is relatively stable under oxidized conditions, but becomes unstable under a reduced environment, causing the iron-phosphorus bounds to separate, releasing the oxygen bound phosphorus directly into the water column. The iron-bound phosphorus concentrations summarized in Table 3-5 also appear to be relatively elevated compared with values commonly observed in urban lake systems.

Isopleths of iron-bound phosphorus in the sediments of Banana Lake and Stahl Lake are illustrated on Figure 3-10. Elevated levels of iron-bound phosphorus are apparent in southern central and western portions of Banana Lake, along with northeastern portions of Stahl Lake.

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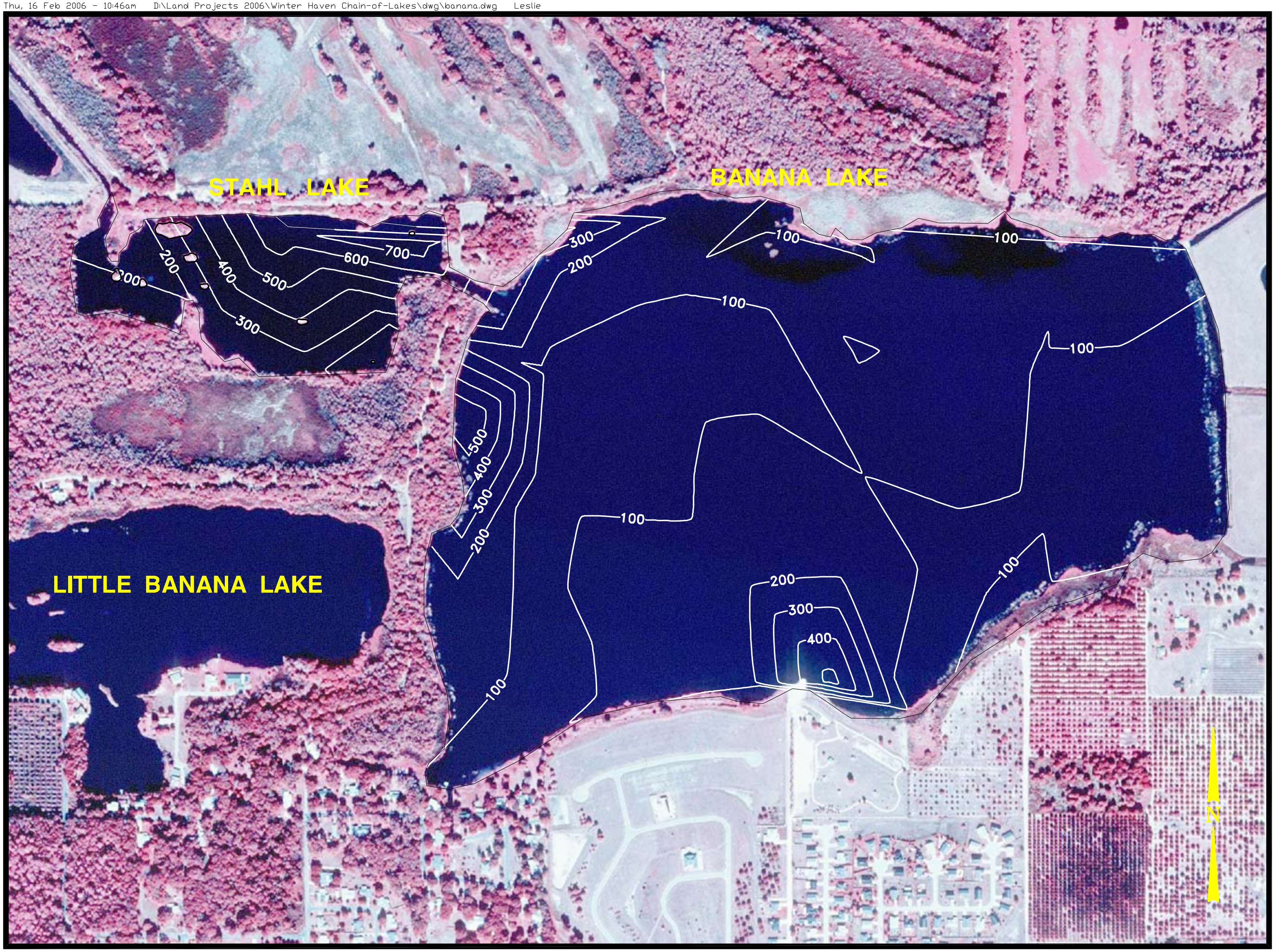

Figure 3-10. Isopleths of Iron-Bound Phosphorus ($\mu g/cm^3$) in the Sediments of Banana Lake and Stahl Lake.

Total available phosphorus represents the sum of the saloid-bound phosphorus and iron-bound phosphorus associations in each sediment core sample. Since the saloid-bound phosphorus is immediately available, and the iron-bound phosphorus is available under reduced conditions, the sum of these speciations represents the total phosphorus which is potentially available within the sediments. This information can be utilized as a guide for future sediment inactivation procedures.

A summary of total available phosphorus in each of the 47 collected sediment core samples is given in Table 3-5. Total available sediment phosphorus concentrations in Banana Lake range from 128-1114 $\mu g/cm^3$ with an overall mean of 519 $\mu g/cm^3$. In Stahl Lake, total available sediment phosphorus ranges from 194-1431 $\mu g/cm^3$, with an overall mean of 680 $\mu g/cm^3$. The mean total available phosphorus in the two lakes appears to be extremely elevated in value compared with other urban lake systems.

Isopleths of total available phosphorus in Banana Lake sediments are illustrated on Figure 3-11. The most elevated levels of total available phosphorus appear to occur in central and northwestern portions of Banana Lake along with central and northeastern portions of Stahl Lake. The isopleths presented in Figure 3-11 can be utilized as a guide for future sediment inactivation activities.

Estimates of the percentage of available phosphorus within the sediments of Banana Lake and Stahl Lake are also provided in Table 3-5. These values represent the percentage of the total sediment phosphorus concentration, summarized in Table 3-4, which is potentially available for sediment release, based upon the total available phosphorus values summarized in Table 3-5. Based upon this comparison, the percentage of available sediment phosphorus within the lakes ranges from 10-84% in Banana Lake, with an overall mean of 39%, and from 17-33% in Stahl Lake, with an overall mean of 25%. Therefore, on an average basis, approximately 25-39% of the total sediment phosphorus within the lakes is potentially available for release into the overlying water column.

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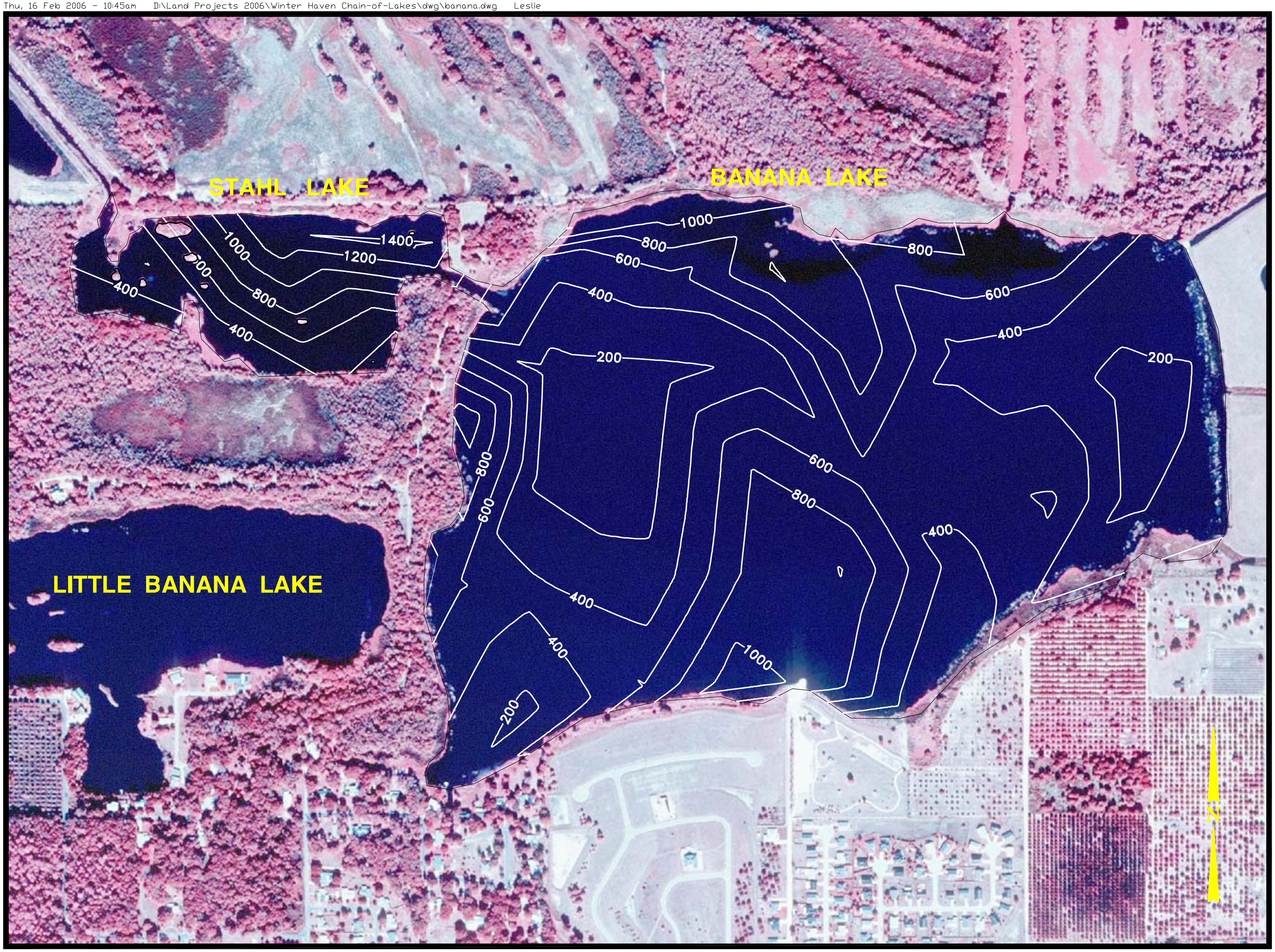

Figure 3-11. Isopleths of Total Available P ($\mu g/cm^3$) in the Sediments of Banana Lake and Stahl Lake.

Isopleths of sediment phosphorus availability, as a percentage of the total sediment phosphorus concentration, in the sediments of Banana Lake and Stahl Lake is given in Figure 3-12. In Stahl Lake, approximately 20-30% of the sediment phosphorus appears to be potentially available for sediment release throughout the lake. However, in Banana Lake, as much as 80% of the sediment phosphorus in north central portions of the lake is potentially available for release into the overlying water column.

Aluminum-bound phosphorus represents an unavailable species of phosphorus within the sediments. Phosphorus bound with aluminum is typically considered to be inert under a wide range of pH and redox conditions within the sediments. Aluminum-bound phosphorus concentrations in Banana Lake and Stahl Lake sediments are summarized in Table 3-5. Aluminum-bound phosphorus concentrations in Banana Lake range from 25-2698 $\mu g/cm^3$, with an overall mean of 477 $\mu g/cm^3$. These values appear to be elevated compared with aluminum-bound phosphorus concentrations commonly observed in urban lake systems. Isopleths of aluminum-bound phosphorus in Banana Lake and Stahl Lake sediments are given as Figure 3-13.

3.3 Impact of Sediments on Water Quality in Banana Lake and Stahl Lake

Based upon the work efforts performed by ERD, it appears that the sediments in Banana Lake and Stahl Lake contain a large pool of readily available phosphorus which can potentially be recycled from the sediments into the water column. The existing poor water quality and clarity suggest that deeper areas of the two lakes exhibit anoxic conditions throughout much of the year. As a result, conditions appear to be favorable for significant recycling of phosphorus from the sediments into the overlying water column of both lakes. However, the overall significance of this internal release of phosphorus can only be evaluated in comparison with nutrient inputs from the remaining sources which includes stormwater runoff, groundwater seepage, and bulk precipitation.

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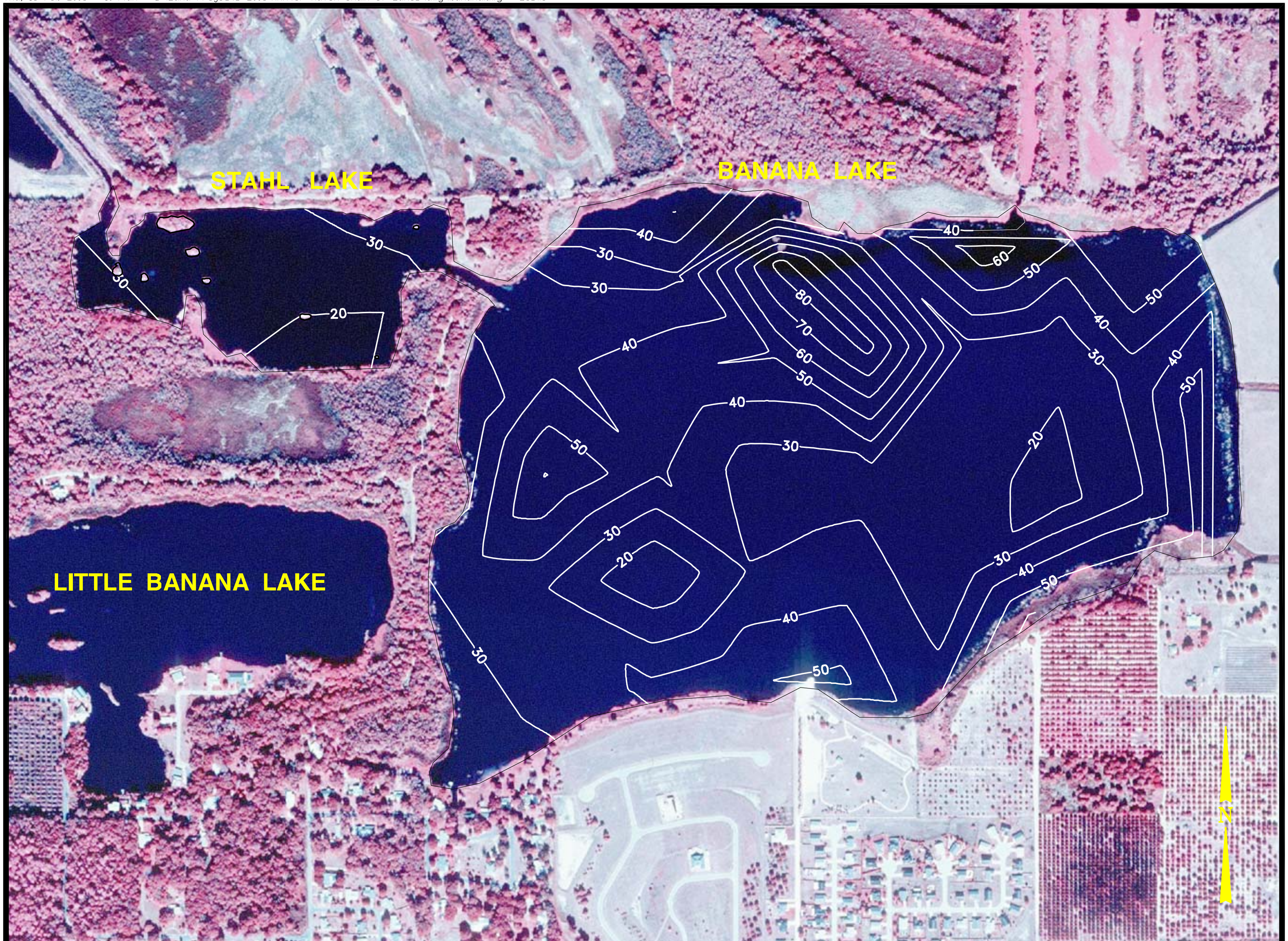

Figure 3-12. Isopleths of Sediment Phosphorus Availability (% of total sediment P) in the Sediments of Banana Lake and Stahl Lake.

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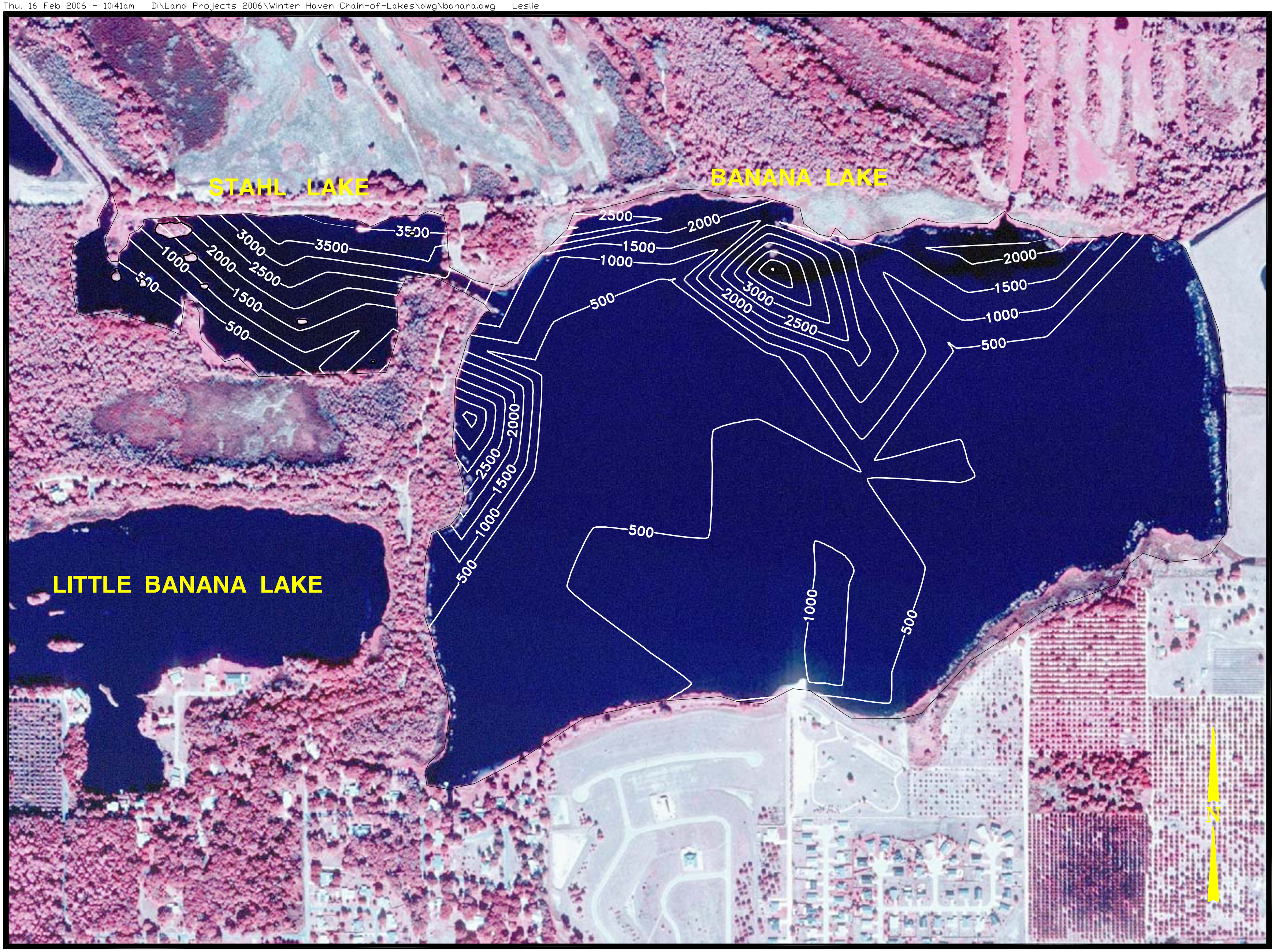

Figure 3-13. Isopleths of Aluminum-Bound Phosphorus ($\mu g/cm^3$) in the Sediments of Banana Lake and Stahl Lake.

SECTION 4

SEDIMENT INACTIVATION FEASIBILITY

4.1 Sediment Inactivation Details

4.1.1 Requirements and Costs

Sediment inactivation in Banana Lake and Stahl Lake would involve the addition of liquid aluminum sulfate at the water surface. Upon entering the water, the alum would form insoluble precipitates which would settle onto the bottom while also clarifying the existing water column within the lakes. Upon entering the sediments, the alum will combine with existing phosphorus within the sediments, primarily saloid- and iron-bound associations, forming insoluble inert precipitates which will bind the phosphorus, making it unavailable for release into the overlying water column. It is generally recognized that the top 10 cm layer of the sediments is the most active in terms of release of phosphorus under anoxic conditions. Therefore, the objective of a sediment inactivation project is to provide sufficient alum to bind the saloid- and iron-bound phosphorus associations in the top 10 cm of the sediments.

Estimates of the mass of total available phosphorus within the top 0-10 cm layer of the sediments in Banana Lake and Stahl Lake were generated by graphically integrating the total available phosphorus isopleths presented on Figure 3-11. The top 0-10 cm layer of the sediments is considered to be an active layer with respect to exchange of phosphorus between the sediments and the overlying water column. Inactivation of phosphorus within the 0-10 cm layer is typically sufficient to inactivate sediment release of phosphorus within a lake.

A summary of estimated total available phosphorus in the sediments of Banana Lake is given in Table 4-1. On a mass basis, the sediments of Banana Lake contain approximately 49,009 kg of available phosphorus in the top 10 cm. On a molar basis, this equates to approximately 1,580,938 moles of available phosphorus to be inactivated as part of the sediment inactivation process.

TABLE 4-1

ESTIMATES OF AVAILABLE SEDIMENT PHOSPHORUS IN BANANA LAKE

AVAILABLE P CONTOUR INTERVAL (µg/cm³)	INTERVAL MID-POINT (µg/cm³)	AREA (ac)	AVAILABLE P	
			kg	moles
0-200	100	22.24	900	29,033
200-400	300	74.34	9,025	291,139
400-600	500	70.13	14,190	457,752
600-800	700	37.41	10,598	341,855
800-1000	900	32.81	11,950	385,483
1000-1200	1,100	5.27	2,346	75,676
Total:		**242.2**	**49,009**	**1,580,938**

1. Based on an Al:P molar ratio of 10:1

A summary of estimated total available phosphorus in the sediments of Stahl Lake is given in Table 4-2. On a mass basis, the sediments of Stahl Lake contain approximately 9380 kg of available phosphorus in the top 10 cm. On a molar basis, this equates to approximately 302,571 moles of available phosphorus to be inactivated during the sediment inactivation process.

TABLE 4-2

ESTIMATES OF AVAILABLE SEDIMENT PHOSPHORUS IN STAHL LAKE

AVAILABLE P CONTOUR INTERVAL (µg/cm³)	INTERVAL MID-POINT (µg/cm³)	AREA (ac)	AVAILABLE P	
			kg	moles
0-200	100	0.19	7.7	248
200-400	300	6.64	806	26,000
400-600	500	8.01	1,621	52,290
600-800	700	4.19	1,187	38,290
800-1000	900	3.52	1,282	41,355
1000-1200	1,100	3.47	1,545	49,839
1200-1400	1,300	5.27	2,773	89,452
1400-1600	1,500	0.26	158	5,097
Total:		**31.6**	**9,380**	**302,571**

1. Based on an Al:P molar ratio of 10:1

Prior research involving sediment inactivation has indicated that an excess of aluminum is required within the sediments to cause phosphorus to preferentially bind with aluminum rather than other available complexing agents. Previous sediment inactivation projects performed by ERD have been performed at molar Al:P ratios of 2, 3, 5, and 10, with most recent sediment inactivation projects performed using a 10:1 ratio.

A summary of sediment inactivation requirements for Banana Lake and Stahl Lake is given in Table 4-3 based upon Al:P ratios of 2:1, 3:1, 5:1, and 10:1. At an Al:P ratio of 2:1, a total of 458,701 gallons of alum would need to be applied within Banana Lake and Stahl Lake. If the Al:P ratio is increased to 3:1, the total required alum volume increases to 688,052 gallons. Increasing the Al:P ratio to 5:1 and 10:1 will require alum volumes of 1,146,753 gallons and 2,293,506 gallons, respectively.

Estimates of chemical costs for sediment inactivation in Banana Lake and Stahl Lake are provided at the bottom of Table 4-3. The estimated chemical costs are based upon an assumed alum cost of $0.50/gallon. Chemical costs range from $229,351 at an Al:P ratio of 2:1 to $1,146,753 at an Al:P ratio of 10:1.

The relative alum volumes summarized in Table 4-3 for Banana Lake and Stahl Lake are substantially higher than previous sediment inactivation projects performed by ERD in the Central Florida area due to the extremely elevated levels of available phosphorus in the sediments of the two lakes. The required alum volume for the 2:1 ratio option is equivalent to approximately 102 tanker trucks. If this amount of alum were to be added into the two lakes during a single application, the applied water column dose would exceed 63 mg Al/liter. In general, Central Florida lakes can withstand applications of approximately 5-10 mg Al/liter without exceeding the available buffering capacity within the water and causing undesirable reductions in pH. As a result, the required alum volume for the 2:1 ratio option would need to be applied in approximately 6-10 individual separate treatments, separated by periods of approximately 2-6 months, depending on recovery of pH and alkalinity within the lakes. If higher Al:P ratios are selected, then a proportionately larger number of individual applications would be required. The mobilization costs associated with the multiple applications will substantially increase the overall application costs.

TABLE 4-3

BANANA LAKE AND STAHL LAKE INACTIVATION REQUIREMENTS

Banana Lake

AVAILABLE P CONTOUR INTERVAL ($\mu g/cm^3$)	AVAILABLE P (moles)	INACTIVANT REQUIREMENT							
		Al:P RATIO = 2:1		Al:P RATIO = 3:1		Al:P RATIO = 5:1		Al:P RATIO = 10:1	
		moles Al	gal Alum	moles Al	gal Alum	moles Al	gal Alum	moles Al	gal Alum
0-200	29,033	58,066	7,071	87,099	10,606	145,165	17,676	290,330	35,353
200-400	291,139	582,278	70,903	873,417	106,354	1,455,695	177,257	2,911,390	354,513
400-600	457,752	915,504	111,479	1,373,256	167,218	2,288,760	278,697	4,577,520	557,394
600-800	341,855	683,710	83,254	1,025,565	124,881	1,709,275	208,135	3,418,550	416,269
800-1000	385,483	770,966	93,879	1,156,449	140,818	1,927,415	234,697	3,854,830	469,394
1000-1200	75,676	151,352	18,430	227,028	27,645	378,380	46,074	756,760	92,149
Totals:	**1,580,938**	**3,161,876**	**385,015**	**4,742,814**	**577,522**	**7,904,690**	**962,536**	**15,809,380**	**1,925,073**

Stahl Lake

AVAILABLE P CONTOUR INTERVAL ($\mu g/cm^3$)	AVAILABLE P (moles)	INACTIVANT REQUIREMENT							
		Al:P RATIO = 2:1		Al:P RATIO = 3:1		Al:P RATIO = 5:1		Al:P RATIO = 10:1	
		moles Al	gal Alum	moles Al	gal Alum	moles Al	gal Alum	moles Al	gal Alum
0-200	248	496	60	744	91	1,240	151	2,480	302
200-400	26,000	52,000	6,332	78,000	9,498	130,000	15,830	260,000	31,660
400-600	52,290	104,580	12,734	156,870	19,102	261,450	31,836	522,900	63,672
600-800	38,290	76,580	9,325	114,870	13,987	191,450	23,312	382,900	46,625
800-1000	41,355	82,710	10,071	124,065	15,107	206,775	25,179	413,550	50,357
1000-1200	49,839	99,678	12,138	149,517	18,206	249,195	30,344	498,390	60,688
1200-1400	89,452	178,904	21,785	268,356	32,677	447,260	54,462	894,520	108,924
1400-1600	5,097	10,194	1,241	15,291	1,862	25,485	3,103	50,970	6,207
Totals:	**302,571**	**605,142**	**73,687**	**907,713**	**110,530**	**1,512,855**	**184,217**	**3,025,710**	**368,434**
OVERALL TOTALS:	**1,883,509**	**3,767,018**	**458,701**	**5,650,527**	**688,052**	**9,417,545**	**1,146,753**	**18,835,090**	**2,293,506**
ESTIMATED CHEMICAL COST ($):			**229,351**		**344,026**		**573,377**		**1,146,753**

It appears that the best alternative for sediment inactivation in Banana Lake and Stahl Lake is to use a buffering compound in addition to the alum to neutralize the anticipated undesirable pH impacts. Sodium aluminate, an alkaline form of alum, is commonly used in these applications as the buffering agent. Sodium aluminate provides a high level of buffering, as well as supplemental aluminum ions, which reduces the total amount of alum required during the application process. If alum and sodium aluminate are used in combination, changes in pH within the lake during the application process can be minimized.

Previous alum surface applications performed for inactivation of sediment phosphorus release by ERD have indicated that the greatest degree of improvement in surface water characteristics and the highest degree of inactivation of sediment phosphorus release are achieved through multiple applications of aluminum to the waterbody over a period of approximately 6-12 months. Each subsequent application results in additional improvements in water column quality and additional aluminum floc added to the sediments for long-term inactivation of sediment phosphorus release. The additional aluminum provided to the sediments also creates an active absorption mechanism for other phosphorus inputs into the water column as a result of groundwater seepage. Inputs of phosphorus from groundwater seepage into a lake can easily exceed inputs from internal recycling in only a few annual cycles. Multiple applications of alum provide an abundance of aluminum which can intercept groundwater inputs of phosphorus over a period of many years. As a result, multiple applications can eliminate phosphorus from the combined inputs resulting from internal recycling as well as groundwater seepage. Therefore, even though the required aluminum mass could be added through a single application if a buffering compound is used, the required aluminum additions for Banana Lake and Stahl Lake, summarized in Table 4-3, should be divided into a minimum of 2-3 separate surface treatments.

In general, the simultaneous addition of 1 gallon of sodium aluminate for every 6.5 gallons of alum is sufficient to create neutral pH conditions during the application process. One gallon of alum provides approximately 8.21 moles of available aluminum for sediment inactivation, while one gallon of sodium aluminate provides 21.46 moles of aluminum. Therefore, the use of sodium aluminate not only provides pH buffering, but it can also reduce the amount of alum required for the inactivation project. As seen in Table 4-3, the total estimated alum volume at an Al:P ratio of 2:1, without the use of supplemental buffering agents, is approximately 458,701 gallons. If sodium aluminate is used as a buffering agent, the total chemical requirements necessary to generate an equivalent total mass of available aluminum are 327,238 gallons of alum combined with 50,344 gallons of sodium aluminate. As recommended previously, this application should be divided into a minimum of two separate applications, with approximately half of the required chemical volume for alum and sodium aluminate applied during each application.

A summary of estimated application costs for sediment inactivation in Banana Lake and Stahl Lake is given in Table 4-4 based on the 2:1 Al:P ratio option. This estimate assumes an alum volume of 327,238 gallons and a sodium aluminate volume of 50,344 gallons will be applied. It is assumed that the alum is purchased directly by Polk County at contract price, with the sodium aluminate purchased by the applicator. Planning and mobilization costs are estimated to be approximately $2000 per application, which includes initial planning, mobilization of equipment to the site, demobilization at the completion of the application process, and clean-up. Estimates of man-hour requirements for the application are provided based upon experience with similar previous applications by ERD. A labor rate of $100/hour is assumed which includes labor costs, water quality monitoring, expenses, equipment rental, insurance, mileage, and application equipment fees. The estimated cost for sediment inactivation in Banana Lake and Stahl Lake is $370,618 or approximately $185,309 per application.

TABLE 4-4

ESTIMATED APPLICATION COSTS FOR SEDIMENT INACTIVATION IN BANANA LAKE AND STAHL LAKE
(Based on 2 separate treatments)

PARAMETER	AMOUNT REQUIRED/ TREATMENT	UNIT COST/ TREATMENT	COST/ TREATMENT	TOTAL COST
1. Chemicals				
A. Alum	163,619 gallons	$0.50/gallon[1]	$ 81,810	$ 163,620
B. Sodium Aluminate	25,172 gallons	$2.90/gallon	$ 72,999	$ 145,998
2. Labor				
A. Planning and Mobilization	2 applications	$2000/application	$ 2,000	$ 4,000
B. Chemical Application	280 man-hours	$100/hour[2]	$ 28,000	$ 56,000
3. Lab Testing	Pre-/Post-samples x 2 events	$500/event	$ 500	$ 1,000
		TOTAL:	**$ 185,309**	**$ 370,618**

1. Approximate Polk County contract cost
2. Includes raw labor, water quality monitoring, insurance, expenses, application equipment, mileage, and rentals

4.1.2 Longevity of Treatment

After initial application, the alum precipitate will form a visible floc layer on the surface of the sediments within the lake. This floc layer will continue to consolidate for approximately 30 days, reaching maximum consolidation at that time. Due to the unconsolidated nature of the sediments in much of the lake, it is anticipated that a large portion of the floc will migrate into the existing sediments rather than accumulate on the surface as a distinct layer. This process is beneficial since it allows the floc to sorb soluble phosphorus during migration through the surficial sediments. Any floc remaining on the surface will provide a chemical barrier for adsorption of phosphorus which may be released from the sediments.

Based on previous experiences by ERD, as well as research by others, it appears that a properly applied chemical treatment will be successful in inactivation of the available phosphorus in the sediments of Banana Lake and Stahl Lake. However, several factors can serve to reduce the effectiveness and longevity of this treatment process. First, wind action can cause the floc to become prematurely mixed into deeper sediments, reducing the opportunity for maximum phosphorus adsorption. Significant wind resuspension has been implicated in several alum applications in shallow lakes which exhibited reduced longevity. However, in the absence of wind resuspension, alum inactivation in lake sediments has resulted in long-term benefits ranging from 3 to more than 10 years. Due to the depth of Banana Lake and especially Stahl Lake, it is not anticipated that wind-induced resuspension will be a problem.

Another factor which can affect the perceived longevity and success of the application process is recycling of nutrients by macrophytes from the sediments into the water column. This recycling will bypass the inactivated sediments since phosphorus will cross the sediment-water interface using vegetation rather than through the floc layer. Although this process will not affect the inactivation of phosphorus within the sediments, it may result in increases in dissolved phosphorus concentrations which are unrelated to sediment-water column processes. However, the degree of macrophyte growth in Banana Lake and Stahl Lake appears to be limited, confined primarily to shoreline areas, and recycling of phosphorus by macrophytes does not appear to be a significant concern.

A final factor affecting the longevity of an alum treatment is significant upward migration of groundwater seepage through the bottom sediments. This seepage would almost certainly contain elevated phosphorus levels which would be adsorbed onto the aluminum floc, reducing the floc which is available for interception of sediment phosphorus release. If groundwater seepage loadings are significant, an additional available pool of aluminum will be present within the sediments. If necessary, repeat alum applications can be performed every 3-5 years to inactivate newly formed sediments and to adsorb phosphorus migrating upward as a result of groundwater seepage.

4.2 Summary and Recommendations

Based upon the field and laboratory, it appears that Banana Lake and Stahl Lake contain elevated concentrations of available phosphorus within the sediments of each lake. The concentrations of available phosphorus measured in the sediments of these two lakes are substantially greater than available sediment phosphorus concentrations measured by ERD in other lakes in the State of Florida. As a result, it appears that the sediments in Banana Lake and

Stahl Lake contain a large pool of readily available phosphorus which can potentially be recycled from the sediments into the overlying water column and is a likely contributor to ongoing conditions of poor water quality within the two lakes.

It is recommended that an aluminum-based sediment inactivation project be conducted on Banana Lake and Stahl Lake to reduce recycling of available phosphorus from the sediments. Due to the elevated available sediment phosphorus concentrations and the associated high chemical application costs, it is recommended that an initial sediment inactivation project be conducted at an Al:P ratio of 2:1. This application will involve the simultaneous addition of 327,238 gallons of alum and 50,344 gallons of sodium aluminate divided into a minimum of two separate applications. The overall estimated cost for this application is approximately $370,618 or $185,309 per application, assuming two separate applications. The resulting water quality benefits from this application should be monitored, and additional applications can be performed at a later date to increase the Al:P ratio within the sediments, if necessary.