Lake June Sediment Characterization and Phosphorus Inactivation Study

Final Report

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Prepared For:

Orange County
Environmental Protection Division

Prepared By:

Environmental Research & Design, Inc.
3419 Trentwood Blvd., Suite 102
Orlando, Florida 32812

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SECTION 1

INTRODUCTION

This report provides a summary of work efforts performed by Environmental Research and Design, Inc. (ERD) for the Orange County Environmental Protection Division (OCEPD) to conduct a bathymetric survey and sediment characterization study for Lake June. The primary emphasis of this study is to evaluate the significance of sediment phosphorus release and the feasibility of using alum for sediment inactivation. Lake June is a 3.57-acre urban lake located southwest of downtown Orlando and east of Clear Lake in unincorporated Orange County. A location map for Lake June is given in Figure 1-1.

Field monitoring and laboratory analyses were conducted by ERD during January 2006 to evaluate bathymetric and sediment characteristics in Lake June. Field measurements were performed for development of a water depth contour map for Lake June, along with estimated depths of unconsolidated organic sediments. A sediment monitoring program was also performed to quantify the physical and chemical characteristics of existing sediments within the lake and to evaluate the potential for internal recycling of phosphorus from sediments into the overlying water column. Physical-chemical profiles of temperature, pH, conductivity, dissolved oxygen, and redox potential were also conducted to assist in evaluating the significance of internal recycling within the lake. Laboratory jar tests were performed to evaluate lake response to various levels of alum addition.

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. The feasibility of alum inactivation of sediment phosphorus release is discussed in Section 4.

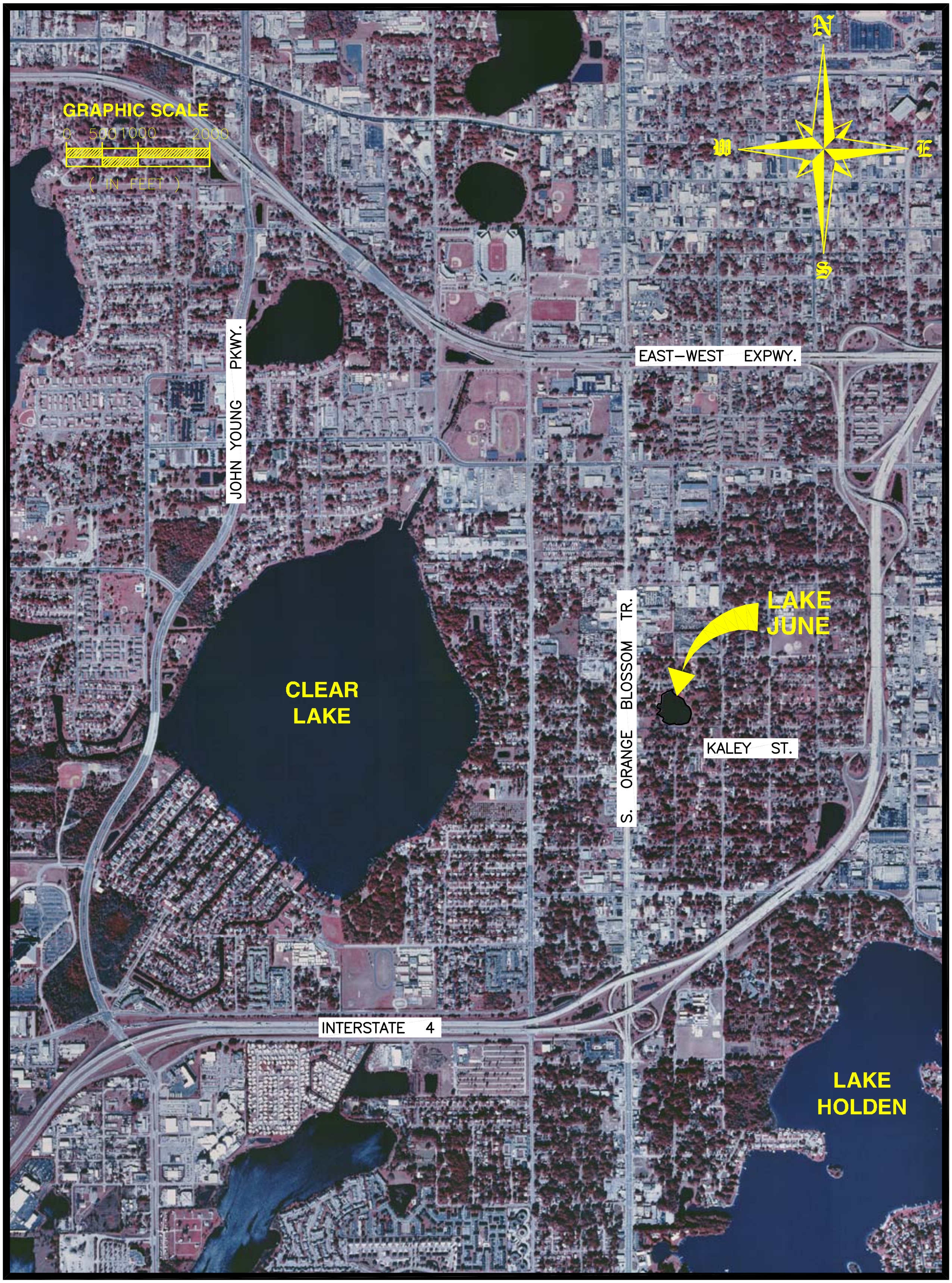

Figure 1-1. Location Map for Lake June.

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 Lake June. 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. Laboratory jar tests were conducted to evaluate water quality response to alum addition. Field and laboratory activities used to perform these assessments are described in the following sections.

2.1 Bathymetric Surveys

Bathymetric surveys were performed in Lake June on January 24, 2006 to evaluate water column depth as well as thickness of unconsolidated sediments within the lake. Bathymetric measurements of water depth and sediment thickness were conducted at 41 individual sites in Lake June. 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 is defined as the water depth at each site. After the water depth is defined at each site, a 1.5-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, measured at the water surface, is defined as the depth to the firm 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.

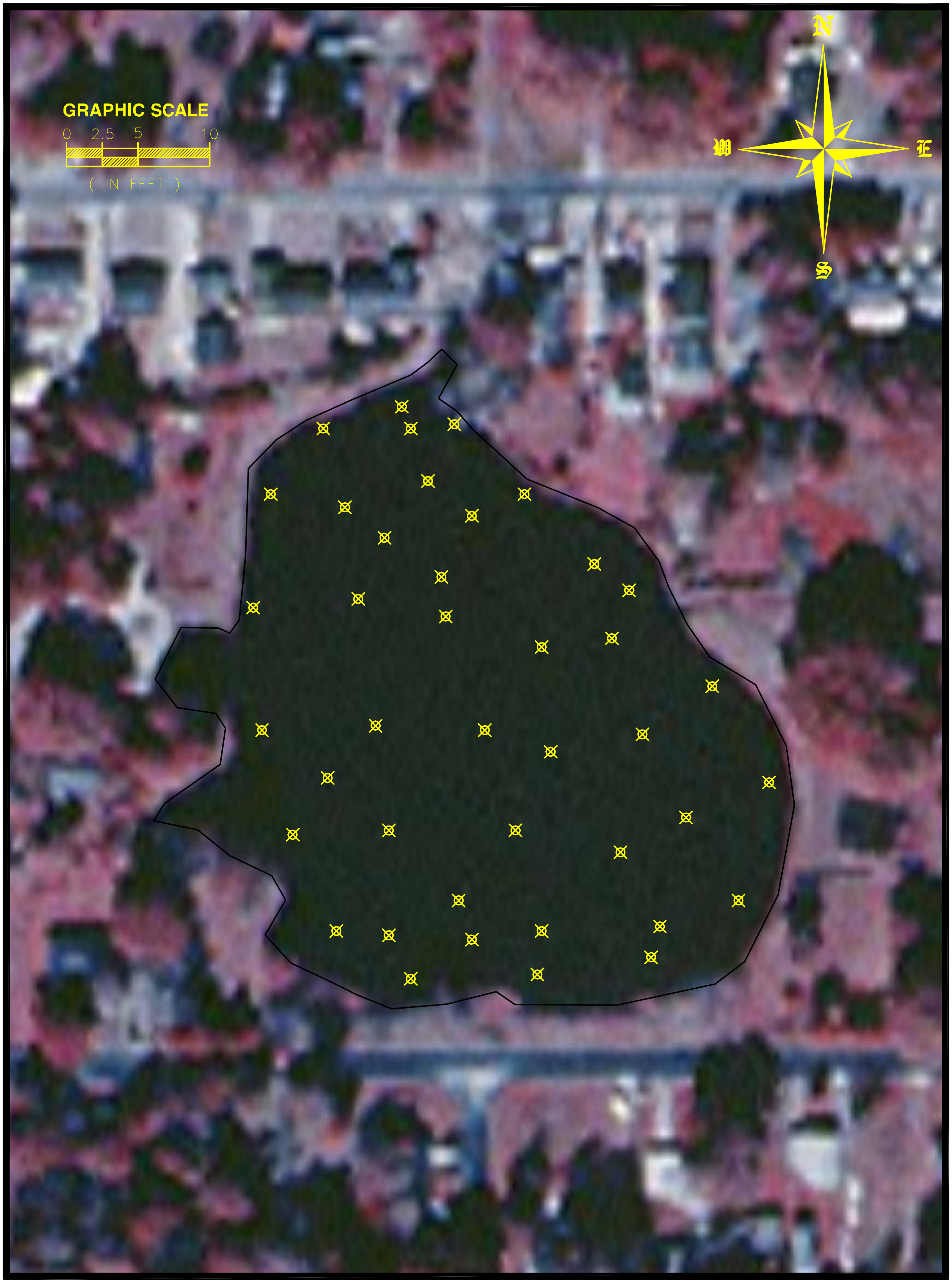

Figure 2-1. Bathymetric Data Collection Sites in Lake June.

The generated field data was converted into bathymetric maps for both water depth and unconsolidated sediment depth in Lake June using AutoDesk Land Desktop Version 2006. Estimates of water volume and unconsolidated sediment volume within the lake were generated from the bathymetric information.

2.1 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 Lake June. Sediment core samples were collected at 14 separate locations. Locations of sediment sampling sites in Lake June are illustrated on Figure 2-2. Sediment samples at the 14 sites were collected on January 24, 2006.

Sediment samples were collected at each of the 14 monitoring 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 14 monitoring sites. The polyethylene containers utilized for storage of the collected samples were filled completely so 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.

During the sediment monitoring on January 24, 2006, field measurements of pH, specific conductivity, dissolved oxygen and oxidation-reduction potential (ORP) were recorded at water depths of 0.25 m, 0.5 m and at 0.5 m intervals to the lake bottom at the center of the lake. This information is used to evaluate stratification regimes within the lake and to assist in identifying the significance of internal recycling.

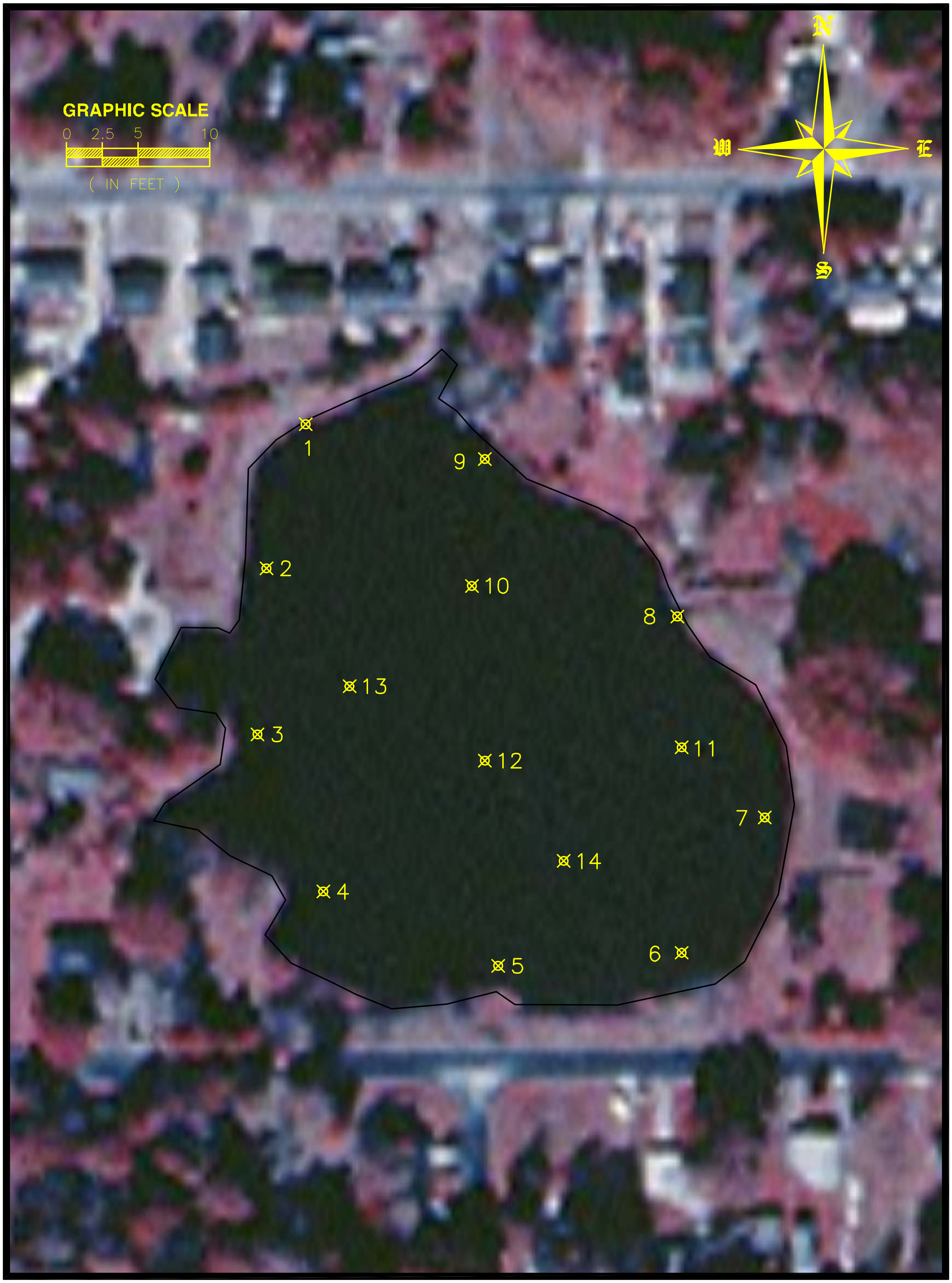

Figure 2-2. Locations of Sediment Core Collection Sites in Lake June.

2.3 Sediment Characterization and Speciation Studies

Each of the 14 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	1/ 2	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 14 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 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.

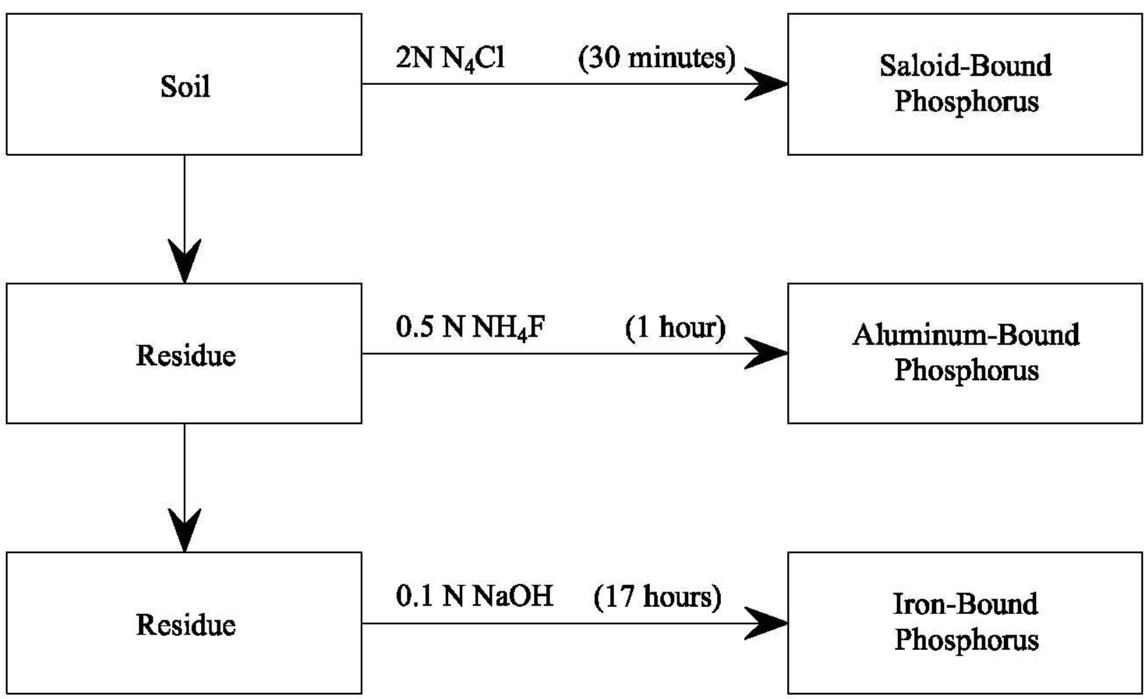

Figure 2-3. Schematic of Chang and Jackson Speciation Procedure for Evaluating Soil Phosphorus Bonding.

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.

2.4 Jar Test Procedures

A series of laboratory jar tests were conducted using alum on composite surface water samples collected from Lake June to evaluate the water quality impacts of alum coagulation at various doses on surface water from the lake. A single composite surface water sample was formed by combining equal amounts of water collected at one site in Lake June on January 24, 2006. Equal amounts of water were collected from the top, middle, and bottom portions of the water column for collection of surface water samples.

Alum-based laboratory jar tests were conducted on the composite surface water sample in individual polycarbonate containers using a sample volume of two liters for each test. Jar testing was conducted at alum doses of 5.0, 7.5, and 10.0 mg Al/liter to evaluate a wide range of potential application doses.

To begin each jar test, the appropriate amount of alum was added to a 2-liter water sample contained in a polycarbonate beaker. Following addition of the alum, the mixture was agitated for approximately 60 seconds. Measurements of pH were conducted initially in the raw sample and approximately one minute after addition of the selected alum dose. Additional measurements of pH were conducted at periods of one hour and 24 hours after addition of the alum coagulant to document changes in pH which typically occur after alum addition. In general, minimum pH levels in alum treated water typically occur within one hour after addition of the coagulant. The pH value of the treated water continues to increase steadily following addition of the alum for a period of approximately 24 hours. The alum treated samples were then allowed to settle for a period of 24 hours, simulating settling processes which would occur within the water column of the lake. At the end of the 24-hour settling period, the clear supernatant was decanted from each jar test container for subsequent laboratory analyses.

Each of the samples generated during the laboratory jar test procedures was analyzed for a wide variety of chemical constituents, including general parameters, chlorophyll-a, nutrients, and dissolved aluminum. A summary of analytical methods and detection limits for laboratory analyses conducted by ERD on each of the generated jar test samples is given in Table 2-2.

TABLE 2-2

ANALYTICAL METHODS AND DETECTION LIMITS FOR LABORATORY ANALYSES CONDUCTED ON JAR TEST SAMPLES

MEASUREMENT PARAMETER	METHOD	METHOD DETECTION LIMITS (MDLs)[1]
General Parameters		
Hydrogen Ion (pH)	EPA-83[2], Sec. 150.1	NA
Specific Conductivity	EPA-83, Sec. 120.1	0.1 μmho/cm
Alkalinity	EPA-83, Sec. 310.1	0.5 mg/l
Color	EPA-83, Sec. 110.3	1 Pt-Co Unit
Turbidity	EPA-83, Sec. 180.1	0.1 NTU
T.S.S.	EPA-83, Sec. 160.2	0.7 mg/l
Sulfate	SM-19[3] Sec. 4500-SO_4^{-2} E.	0.7 mg/l
Biological Parameters		
Chlorophyll-a	SM-19, Sec. 10200 H.3	0.08 mg/m^3
Nutrients		
Ammonia-N (NH_3-N)	EPA-83, Sec. 350.1	0.005 mg/l
Nitrate + Nitrite (NO_x-N)	EPA-83, Sec. 353.2	0.005 mg/l
Organic Nitrogen	Alkaline Persulfate Digestion[4]	0.01 mg/l
Orthophosphorus	EPA-83, Sec. 365.1	0.001 mg/l
Total Phosphorus	Alkaline Persulfate Digestion[4]	0.001 mg/l
Metals		
Diss. Aluminum	SM-19, Sec. 3500-Al E.	0.001 mg/l

1. MDLs are calculated based on the EPA method of determining detection limits.
2. Methods for Chemical Analysis of Water and Wastes, EPA 600/4-79-020, Revised March 1983.
3. Standard Methods for the Examination of Water and Wastewater, 19th Edition, 1992.
4. FDEP-approved method.

SECTION 3

RESULTS

3.1 Bathymetric Surveys

A bathymetric survey was conducted in Lake June on January 24, 2006 at 41 separate sites to generate water depth and unconsolidated sediment contours for the lake. A water depth contour map for Lake June, based upon the field monitoring program performed by ERD, is given in Figure 3-1. The maximum water depth in Lake June is approximately 10 ft in central areas of the lake.

Stage-storage relationships for Lake June are summarized in Table 3-1. At the water surface elevation present on January 24, 2006, the lake surface area is approximately 3.57 acres. The lake volume at this surface area is 20.4 ac-ft which corresponds to a mean water depth of 5.7 ft. This value is relatively shallow for a Central Florida lake.

A bathymetric contour map of the depth of unconsolidated organic sediments in Lake June is given in Figure 3-2. In general, unconsolidated organic sediments are concentrated primarily in central portions of the lake, where sediment depths exceed 7 ft.

A summary of estimated organic muck volumes in Lake June is given in Table 3-2. Approximately 52% of the lake area, consisting primarily of perimeter shoreline areas, has existing muck accumulations ranging from 0-1 ft in depth. An additional 18% of the lake area has organic muck accumulations ranging from 1-2 ft. Approximately 7% of the lake has muck depths ranging from 2-3 ft, with 5% of the lake covered by muck accumulations ranging from 3-4 ft, 10% covered by muck accumulations from 4-5 ft deep, 6% from 5-6 ft deep, and 2% of the lake with muck accumulations greater than 7 ft. Overall, Lake June contains approximately 282,264 ft^3 of unconsolidated organic sediments. The volume of unconsolidated sediment in Lake June is sufficient to cover the entire lake area to a depth of 1.82 ft.

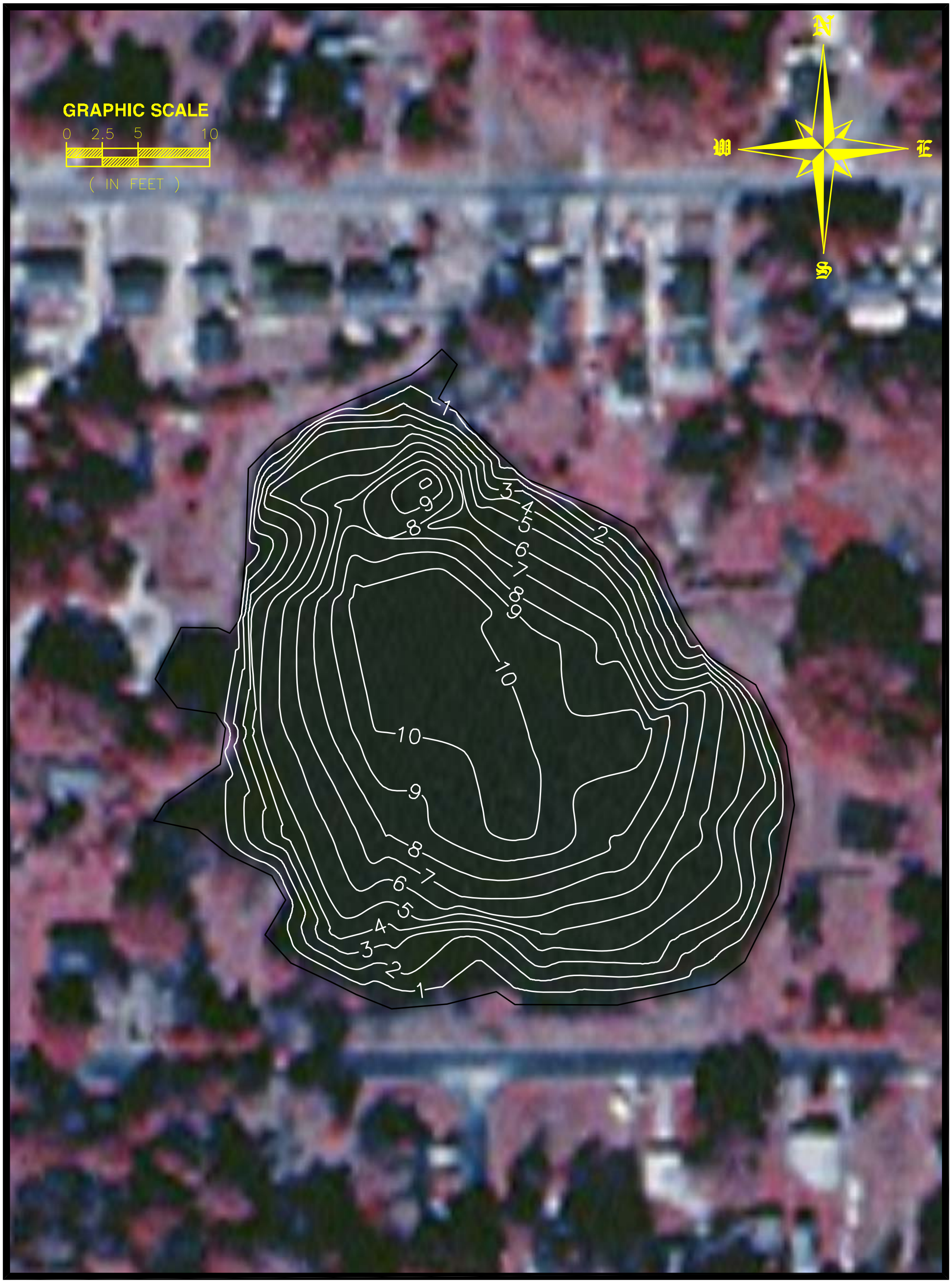

Figure 3-1. Water Depth Contours in Lake June on January 24, 2006.

Figure 3-2. Isopleths of Organic Sediment (muck) Depths in Lake June.

TABLE 3-1

STAGE-STORAGE RELATIONSHIPS FOR LAKE JUNE[1]

DEPTH (ft)	AREA (ac)	VOLUME (ac-ft)
0.0	3.57	20.4
1.0	3.21	17.1
2.0	2.93	14.0
3.0	2.67	11.2
4.0	2.42	8.65
5.0	2.10	6.39
6.0	1.75	4.46
7.0	1.45	2.86
8.0	1.16	1.55
9.0	0.79	0.58
10.0	0.37	0.00

1. Based on measurements performed on January 24, 2006

TABLE 3-2

SUMMARY OF UNCONSOLIDATED ORGANIC SEDIMENT ACCUMULATIONS IN LAKE JUNE

MUCK DEPTH (ft)	AREA IN LAKE (ac)	PERCENTAGE OF LAKE AREA	MUCK VOLUME (ft^3)
0-1	1.86	52	115,043
1-2	0.63	18	60,884
2-3	0.25	7	41,909
3-4	0.19	5	32,499
4-5	0.35	10	20,893
5-6	0.21	6	8,693
6-7	0.08	2	2,343
TOTAL:	**3.57**	**100**	**282,264**

3.2 Sediment Characteristics

3.2.1 Visual Characteristics

Visual characteristics of sediment core samples were recorded for each of the 14 sediment samples collected in Lake June during January 2006. A summary of visual characteristics of sediment core samples is given in Table 3-3. In general, shoreline areas of Lake June are characterized by sandy sediments with little or no visual accumulations of unconsolidated organic muck. The base material beneath the lake bottom consists primarily of light and dark brown fine sand.

As water depths increase within the lake, the accumulations of organic muck become deeper. Areas where deep deposits of organic muck have accumulated are characterized by a surface layer of unconsolidated organic muck, approximately 1-3 inches in thickness. 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 resuspended by wind action or boating activities which disturb the bottom. As the sediment depth increases, the organic layer becomes more consolidated with a consistency similar to pudding. These layers typically do not resuspend into the water column except during vigorous mixing action within the lake.

TABLE 3-3

VISUAL CHARACTERISTICS OF SEDIMENT CORE SAMPLES COLLECTED IN LAKE JUNE ON JANUARY 24, 2006

SITE NO.	LAYER (cm)	VISUAL APPEARANCE
1	0 - 1	Light brown fine sand
	1 - 8	Brown fine sand with organics
	8 - 11	Light brown fine sand
	11 - 17	Light brown fine sand with roots
	17 - 23	Dark brown consolidated organic muck
	23 - >38	Brown fine sand with organics
2	0 - 6	Dark brown unconsolidated organic muck
	6 - 23	Dark brown consolidated organic muck with roots
	23 - 45	Brown fine sand with organics
	45 - >58	Light brown fine sand
3	0 - 1	Dark brown unconsolidated organic muck
	1 - 4	Dark brown consolidated organic muck
	4 - 13	Dark brown consolidated organic muck with roots
	13 - 25	Brown fine sand with organics
	25 - >28	Light brown fine sand
4	0 - 6	Dark brown unconsolidated organic muck
	6 - 16	Dark brown consolidated organic muck with roots
	16 - 26	Brown fine sand with organics
	26 - >35	Light brown fine sand
5	0 - 2	Light brown fine sand
	2 - 10	Brown fine sand with organics
	10 - >30	Light brown fine sand
6	0 - 4	Dark brown unconsolidated organic muck
	4 - 22	Dark brown consolidated organic muck
	22 - >68	Light brown fine sand with roots
7	0 - 5	Dark brown unconsolidated organic muck
	5 - 26	Dark brown consolidated organic muck
	26 - >38	Brown fine sand with organics
8	0 - 0.5	Dark brown unconsolidated organic muck
	0.5 - >19	Brown fine sand with organics
9	0 - 0.5	Dark brown unconsolidated organic muck
	0.5 - >33	Light brown fine sand
10	0 - 3	Dark brown unconsolidated organic muck
	3 - 17	Dark brown consolidated organic muck
	17 - >32	Brown fine sand with organics
11	0 - 3	Dark brown unconsolidated organic muck
	3 - 22	Dark brown consolidated organic muck
	22 - 25	Dark brown consolidated organic muck with roots
	25 - >32	Brown fine sand with organics
12	0 - 0.5	Dark brown unconsolidated organic muck
	0.5 - >16	Brown fine sand with organics
13	0 - 4	Dark brown unconsolidated organic muck
	4 - 29	Dark brown consolidated organic muck
	29 - >44	Brown fine sand with organics
14	0 - 2	Dark brown unconsolidated organic muck
	2 - 33	Dark brown consolidated organic muck
	33 - >50	Brown fine sand with organics

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 14 collected sediment core samples is given in Table 3-4. In general, sediments in Lake June were found to be slightly acidic in pH, with measured sediment pH values ranging from 5.39-6.87 and an overall mean of 6.07. These values are typical of pH measurements commonly observed in hypereutrophic urban lakes.

Isopleths of pH measurements in the top 10 cm of sediment collected in Lake June are illustrated on Figure 3-3. The most elevated sediment pH values were observed in perimeter portions of Lake June in areas with little organic muck accumulation. The lowest sediment pH values were observed in central portions of the lake in areas where relatively deep organic sediment accumulations were measured.

Measurements of sediment moisture content and organic content in Lake June were found to be highly variable throughout the 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.

Isopleths of sediment moisture content in Lake June are summarized in Figure 3-4 based upon the information provided in Table 3-4. Areas of elevated moisture content are present in northeastern and southern central portions of the lake. Sediment moisture contents in access of 50-70% are often indicative of highly organic sediments, with moisture contents less than 50% reflecting either sand or mixtures of sand and muck.

TABLE 3-4

GENERAL CHARACTERISTICS OF SEDIMENT CORE SAMPLES COLLECTED IN LAKE JUNE DURING JANUARY 2006

SITE	pH	MOISTURE CONTENT (%)	ORGANIC CONTENT (%)	DENSITY (g/cm^3)	TOTAL NITROGEN ($\mu g/cm^3$)	TOTAL PHOSPHORUS ($\mu g/cm^3$)
1	6.72	33.5	2.1	1.98	4239	1215
2	5.62	64.1	6.8	1.50	11942	2089
3	6.46	56.0	5.5	1.62	12144	2507
4	6.40	71.1	9.4	1.39	10787	2241
5	6.87	28.6	1.7	2.05	4286	2617
6	6.08	89.7	33.1	1.10	11260	2703
7	5.63	88.3	31.3	1.12	14226	3415
8	6.14	36.2	3.1	1.93	10456	1892
9	6.10	28.7	1.1	2.06	5572	1069
10	5.87	66.9	13.0	1.43	16304	2551
11	5.57	83.4	21.7	1.19	12825	3638
12	5.39	35.1	2.0	1.95	8410	5230
13	6.07	90.4	31.3	1.10	10932	2673
14	6.02	90.2	34.6	1.10	10762	2053
Mean	**6.07**	**61.6**	**14.0**	**1.54**	**10296**	**2564**
Minimum	**5.39**	**28.6**	**1.1**	**1.10**	**4239**	**1069**
Maximum	**6.87**	**90.4**	**34.6**	**2.06**	**16304**	**5230**

Isopleths of sediment organic content in Lake June are illustrated on Figure 3-5 based upon the information provided in Table 3-4. In general, sediment organic content in excess of 20% is often indicative of organic muck-type sediments, with values less than 20% representing mixtures of muck and sand. Based upon this criterion, areas of concentrated organic muck are apparent in western central and southeastern portions of Lake June. This area corresponds well with the areas of elevated moisture content indicated on Figure 3-4. Measured organic sediment content within the lake ranges from 1.1-34.6%, with an overall mean of 14.0%.

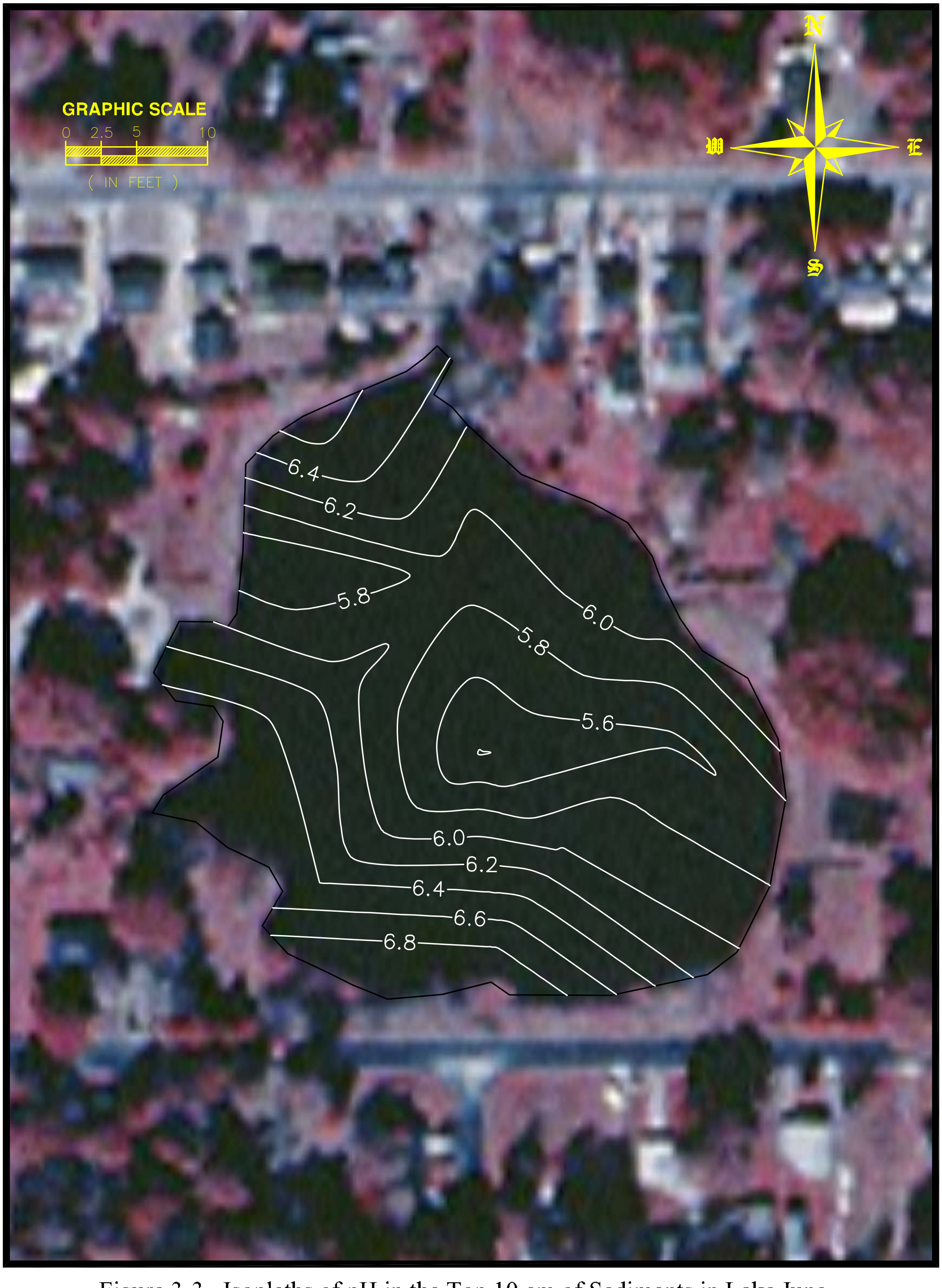

Figure 3-3. Isopleths of pH in the Top 10 cm of Sediments in Lake June.

Figure 3-4. Isopleths of Moisture Content (% dry wt.) in the Top 10 cm of Sediments in Lake June.

Figure 3-5. Isopleths of Organic Content (% dry wt.) in the Top 10 cm of Sediments in Lake June.

Values of sediment density are also useful in evaluating the general characteristics of sediments within a lake. Sediments with calculated densities between 1.0-1.5 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 Lake June range from 1.10-2.06 g/cm^3, with an overall mean of 1.54 g/cm^3. Isopleths of sediment density in Lake June, expressed in units of g/cm^3 on a wet weight basis, are illustrated on Figure 3-6. The sediment density isopleths contained in this figure are similar to the isopleths of moisture content and organic content summarized in Figures 3-4 and 3-5, respectively.

Measured concentrations of total phosphorus in Lake June sediments were found to be highly variable throughout the lake. Sediment total phosphorus concentrations range from 1069-5230 μg/cm^3, with an overall mean of 2564 μg/cm^3. 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.

Isopleths of sediment phosphorus concentrations in Lake June 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 the lake. In general, the overall total phosphorus concentrations observed in Lake June appear to be extremely elevated compared with phosphorus sediment concentrations normally observed by ERD in urban lakes.

Similar to the trends observed for sediment phosphorus concentrations, sediment nitrogen concentrations are also highly variable in Lake June. Sediment nitrogen concentrations range from 4239-16,304 μg/cm^3, with an overall mean of 10,296 μg/cm^3. The nitrogen concentrations measured in Lake June also appear to be elevated compared with values normally observed in urban lakes.

Isopleths of sediment nitrogen concentrations in Lake June are illustrated on Figure 3-8. Areas of elevated nitrogen concentrations are apparent in the north central portions of the lake. Sediment concentrations of total nitrogen appear to be more uniform throughout the lake than observed for total phosphorus, organic content, or moisture content.

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

Figure 3-7. Isopleths of Total Phosphorus (µg/cm^3 dry wt.) in the Top 10 cm of Sediments in Lake June.

Figure 3-8. Isopleths of Total Nitrogen (μg/cm^3 wet wt.) in the Top 10 cm of Sediments in Lake June.

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 phosphorus within the sediments 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 Lake June during January 2006 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 low degree of variability is apparent in saloid-bound phosphorus within the sediments of Lake June. Measured values for saloid-bound phosphorus range from 0.03-2.67 $\mu g/cm^3$, with an overall mean value of 0.71 $\mu g/cm^3$. In general, low levels of saloid-bound phosphorus are associated with sandy sediments within the lake, while more elevated levels of saloid-bound phosphorus are associated with highly organic sediments.

Isopleths of saloid-bound phosphorus in Lake June sediments are illustrated on Figure 3-9. Areas of elevated saloid-bound phosphorus are apparent in the central portions of the lake. The saloid-bound phosphorus concentrations summarized in Figure 3-9 are relatively low values compared with saloid-bound phosphorus concentrations commonly observed in urban lake systems.

Figure 3-9. Isopleths of Saloid-Bound Phosphorus (µg/cm^3 wt.) in the Top 10 cm of Sediments in Lake June.

TABLE 3-5

PHOSPHORUS SPECIATION IN SEDIMENT CORE SAMPLES COLLECTED IN LAKE JUNE DURING JANUARY 2006

SITE	SALOID-BOUND P (µg/cm^3)	Al-BOUND P (µg/cm^3)	Fe-BOUND P (µg/cm^3)	TOTAL AVAILABLE P (µg/cm^3)	PERCENT AVAILABLE P (%)
1	0.48	52.0	42.2	42.7	3.51
2	0.22	45.3	30.6	30.8	1.47
3	0.63	45.4	49.2	49.8	1.99
4	0.03	45.7	52.9	52.9	2.36
5	0.31	51.3	40.8	41.1	1.57
6	0.71	46.0	66.5	67.2	2.49
7	0.08	43.7	57.6	57.6	1.69
8	2.67	53.9	25.0	27.7	1.46
9	0.09	35.0	43.3	43.3	4.05
10	0.36	53.3	40.7	41.1	1.61
11	0.82	55.4	88.6	89.4	2.46
12	2.34	96.5	95.1	97.5	1.86
13	0.82	49.8	65.7	66.5	2.49
14	0.42	39.5	43.2	43.7	2.13
Mean	**0.71**	**50.9**	**53.0**	**53.7**	**2.22**
Minimum	**0.03**	**35.0**	**25.0**	**27.7**	**1.46**
Maximum	**2.67**	**96.5**	**95.1**	**97.5**	**4.05**

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. When anoxic conditions occur near the water-sediment interface in Lake June, large portions of the lake appear to have conditions favorable for release of iron-bound sediment phosphorus into the overlying water column. The iron-bound phosphorus concentrations summarized in Table 3-5 appear to be similar to values commonly observed in urban lake systems.

Isopleths of iron-bound phosphorus in Lake June sediments are illustrated in Figure 3-10. Areas of elevated iron-bound phosphorus associations are apparent in the central portions of the lake. Observed patterns for iron-bound phosphorus in the sediments appear to be somewhat similar to the patterns exhibited for saloid-bound phosphorus in Figure 3-9.

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 14 collected sediment core samples is given in Table 3-5. Total available sediment phosphorus concentrations range from 27.7-97.5 $\mu g/cm^3$, with an overall mean of 53.7 $\mu g/cm^3$. The mean total available phosphorus in Lake June appears to be typical of values commonly measured in urban lake systems.

Isopleths of total available phosphorus in Lake June sediments are illustrated on Figure 3-11. Similar to the trends observed with previous sediment parameters, areas of elevated total available phosphorus are apparent in the central portions of the lake. The isopleths presented in Figure 3-11 can be utilized as an application guide for future sediment inactivation activities.

Estimates of the percentage of available phosphorus within the sediments in Lake June 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 lake ranges from 1.5-4.1%, with an overall mean of 2.2%. Therefore, on an average basis, only 2% of the total sediment phosphorus within the lake is potentially available for release into the overlying water column.

Figure 3-10. Isopleths of Iron-Bound Phosphorus (µg/cm^3 dry wt.) in the Top 10 cm of Sediments in Lake June.

Figure 3-11. Isopleths of Total Available P (µg/cm^3 dry wt.) in the Top 10 cm of Sediments in Lake June.

3.4 Physical-Chemical Profiles

Physical-chemical profiles of temperature, pH, specific conductivity, dissolved oxygen, and redox potential were performed near the center of Lake June by ERD field personnel on January 24, 2006. A measurement of Secchi disk depth was also performed, with a value of 0.72 m. This value reflects extremely poor water column clarity. A complete listing of physical-chemical profiles collected during January 2006 is given in Appendix A.

A graphical comparison of vertical profiles for temperature, pH, dissolved oxygen, and specific conductivity in Lake June during January 2006 is given in Figure 3-12. Although Central Florida lakes are typically well mixed during the winter months, significant thermal stratification was observed in Lake June during the January monitoring event. A temperature difference of 2.5-3^{o}C was observed between top and bottom portions of the lake during this monitoring event.

A continuous decline in pH was observed with increasing water depth within the lake. Surface pH values were slightly alkaline, with a measured value of 7.75. A steady decrease in pH was observed with increasing water depth, decreasing to 6.78 near the bottom sediments. Rapid decreases in pH near the sediment-water interface are often associated with anoxic conditions in this portion of the lake.

Supersaturated dissolved oxygen conditions were observed in Lake June within the top 1.5 m of the lake. These supersaturated dissolved oxygen conditions are a result of the visible algal bloom which was occurring within the lake during the monitoring event. However, below this depth, dissolved oxygen concentrations were observed to decrease rapidly, reaching 0.6 mg/l near the sediment-water interface. In addition, highly reduced conditions, as indicated by redox potential values less than 200 mv, were also observed near the sediment-water interface during January 2006. These reduced conditions create an environment which maximizes the potential for release of phosphorus into the overlying water column.

Specific conductivity values in Lake June were relatively uniform within the top 3 m of the lake. However, a rapid increase in specific conductivity was observed near the sediment-

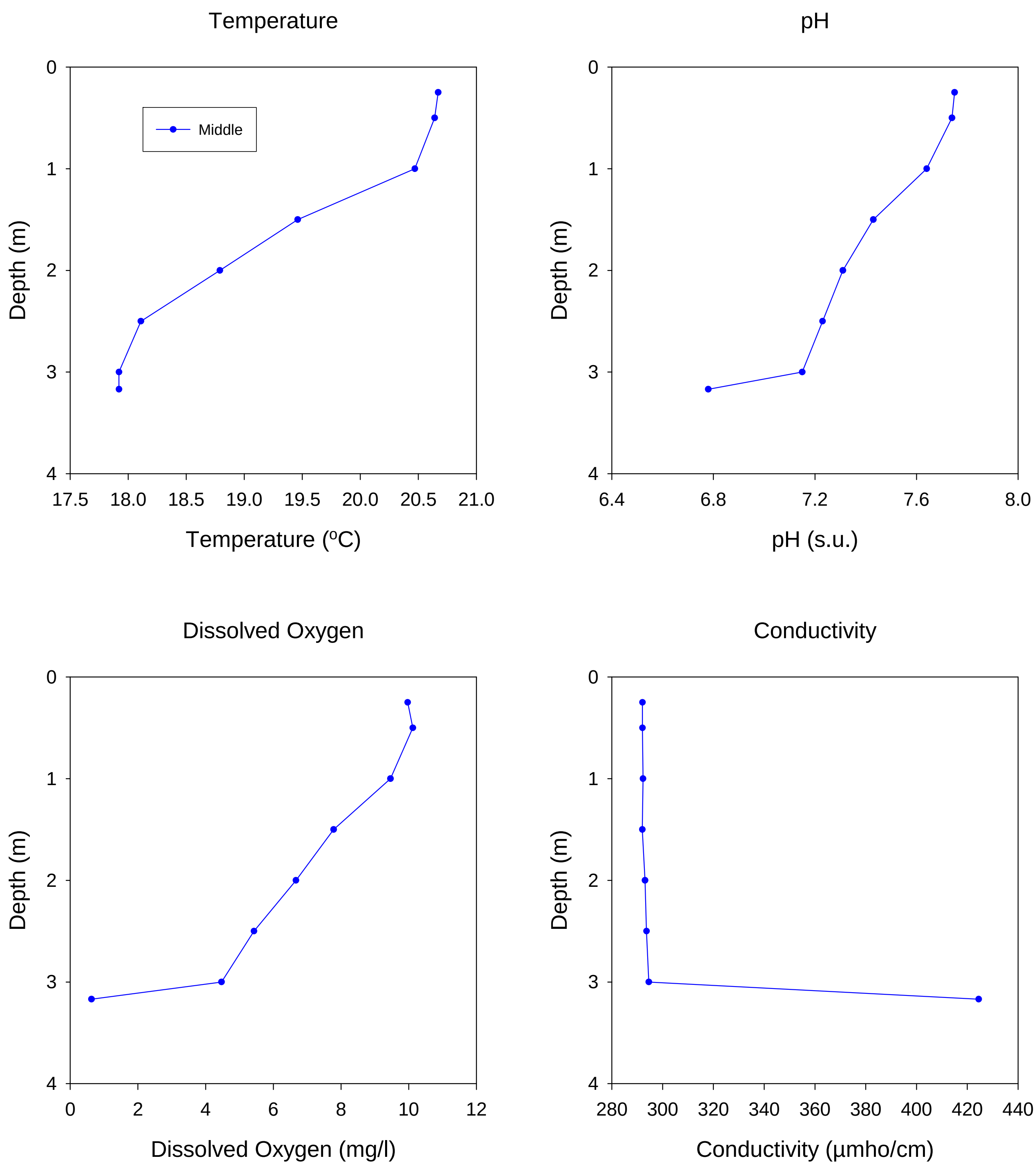

Figure 3-12. Vertical Profiles of Temperature, pH, Dissolved Oxygen, and Conductivity in Lake June During January 2006.

water interface, with a conductivity increase of approximately 44% observed near the sediment-water interface. This observed increase in conductivity is a reflection of sediment release of ions, including phosphorus near the sediment-water interface.

In summary, the vertical profiles presented in Figure 3-12 provide evidence that conditions of low dissolved oxygen are present near the sediment-water interface in Lake June even during a period when lakes typically exhibit well mixed conditions. Substantially reduced conditions were observed in this zone during January 2006, with rapid decreases in dissolved oxygen and pH and a substantial increase in specific conductivity. This information strongly suggests that internal recycling of ions is an ongoing occurrence in Lake June under existing conditions.

SECTION 4

EVALUATION OF ALUM INACTIVATION REQUIREMENTS

4.1 Significance of Internal Recycling

Based upon the sediment characterization and field monitoring performed by ERD, it appears that internal recycling of ions, including phosphorus, from anoxic bottom sediments is an ongoing occurrence within Lake June. Vertical profiles collected within the lake suggest that portions of the lake sediments exhibit anoxic conditions even during portions of the year when well oxygenated conditions are expected. In addition, increases in specific conductivity were observed in lower layers of the lake, suggesting release of ions from the sediments into the overlying water column. As a result, internal recycling appears to be a significant occurrence in Lake June, which could be reduced by a properly designed application of aluminum sulfate to the lake sediments.

4.2 Sediment Inactivation Requirements

Estimates of the mass of total available phosphorus within the top 0-10 cm layer of the sediments in Lake June were generated by graphically integrating the total available phosphorus isopleths presented on Figure 3-11. Areas contained within each isopleth contour were calculated using AutoCAD Release 12.0. The top 0-10 cm layer of the sediments in the lake 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 Lake June is given in Table 4-1. On a mass basis, the sediments of Lake June contain approximately 77 kg of available phosphorus in the top 10 cm. On a molar basis, this equates to approximately 2475 moles of available phosphorus to be inactivated as part of the sediment inactivation process.

TABLE 4-1

ESTIMATES OF AVAILABLE SEDIMENT PHOSPHORUS AND INACTIVATION REQUIREMENTS FOR LAKE JUNE

AVAILABLE P CONTOUR INTERVAL (μg/cm³)	INTERVAL MID-POINT (μg/cm³)	AREA (ac)	AVAILABLE P (kg)		INACTIVANT REQUIREMENT	
			kg	moles	moles Al[1]	gallons of alum
< 30	15	0.07	0.4	13	134	16
30-40	35	0.60	8.4	272	2,715	331
40-50	45	1.14	20.7	667	6,668	812
50-60	55	0.67	15.0	484	4,836	589
60-70	65	0.55	14.5	469	4,688	571
70-80	75	0.29	8.6	279	2,786	339
80-90	85	0.20	6.9	222	2,218	270
> 90	95	0.06	2.2	70	702	85
Total:		**3.57**	**77**	**2,475**	**24,746**	**3,013**

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

Estimated inactivation requirements were calculated for Lake June based upon a molar Al:P ratio of 10:1, as utilized by ERD in previous inactivation evaluations. 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. A 10:1 molar ratio of Al:P has been shown to be adequate to create this driving force. Based upon this ratio, inactivation of phosphorus release from sediments in Lake June will require approximately 24,746 moles of aluminum which equates to approximately 3,013 gallons of alum. Based on an average tanker volume of 4500 gallons, the required alum addition is equivalent to approximately 0.67 tanker loads.

An average water column dose of alum resulting from the sediment inactivation was calculated by dividing the alum requirement of 3,013 gallons by the overall volume of the lake (204 ac-ft). Since the alum application would occur at the surface, the overall whole-lake alum dose must be considered to evaluate potential water column impacts during the application. Application of approximately 3,013 gallons of alum to Lake June into a water column volume of approximately 20.4 ac-ft would result in an applied alum dose of 26.6 mg Al/liter.

The calculated water column alum dose of 26.6 mg Al/liter is an extremely elevated dose which will far exceed the normal buffering capacity of the lake to resist undesirable reductions in pH values during the application. An alum application of this dose to Lake June would likely reduce the water column pH level to less than 4.0. In general, water column doses of approximately 5-7.5 mg Al/liter are the maximum doses which can be safely added to a lake during a single application without supplemental buffering compounds. Although multiple applications are generally recommended by ERD to minimize overall system impacts, application of the required water column dose of 26.6 mg Al/liter would require approximately 5-7 individual applications to Lake June, spaced approximately 2-3 months apart. In some lakes, multiple applications of this magnitude may be an acceptable alternative. However, multiple applications to Lake June would add significant additional cost due to the mobilizations required to enter and exit the lake for each of the individual small applications.

It appears that the best alternative for sediment inactivation in Lake June 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 treatments performed by ERD have indicated that the simultaneous addition of 1 gallon of sodium aluminate for every 5.0 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, as indicated previously, the use of sodium aluminate can substantially reduce the amount of alum required for the inactivation project. As seen in Table 4-1, the total estimated alum volume, without the use of supplemental buffering agents, is approximately 3,013 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 2000 gallons of alum combined with 400 gallons of sodium aluminate. Of the required water column dose of 26.6 mg Al/liter, 17.5 mg/l would be supplied by alum and 9.1 mg/l supplied by sodium aluminate.

4.3 Water Quality Improvements

The results of laboratory jar tests conducted on a Lake June composite water sample collected on January 24, 2006 are summarized in Table 4-2. The initial raw water sample was approximately neutral in pH, with a measured value of 7.24. The raw water was found to be relatively well buffered with a measured alkalinity of 72.8 mg/l and a specific conductivity of 237 μmho/cm. The measured total nitrogen concentration of 1730 μg/l in the raw sample is somewhat elevated compared with nitrogen concentrations commonly observed in Central Florida lakes. Approximately 69% of the total nitrogen is comprised of organic nitrogen, with NO_x comprising approximately 31%. Similarly, total phosphorus also appears to be elevated in the raw samples, with a measured value of 102 μg/l. Organic phosphorus comprises approximately 86% of the total phosphorus measured. An elevated concentration of TSS was also observed in the sample. However, the initial chlorophyll-a concentration of 12.4 mg/m^3 appears to be moderate in value.

TABLE 4-2

RESULTS OF LABORATORY JAR TESTS PERFORMED ON A LAKE JUNE COMPOSITE WATER SAMPLE COLLECTED ON JANUARY 24, 2006

PARAMETER	UNITS	RAW	ALUM DOSE (mg Al/liter)		
			5.0	7.5	10.0
pH (raw)	s.u.	7.24	7.24	7.24	7.24
pH (1 minute)	s.u.	7.24	6.87	6.61	6.51
pH (1 hour)	s.u.	7.24	6.87	6.74	6.72
Conductivity	µmho/cm	237	233	242	255
Alkalinity	mg/l	72.8	62.8	59.4	52.2
Ammonia	µg/l	< 5	129	113	181
NO_x	µg/l	532	182	153	148
Organic N	µg/l	1195	926	929	883
Total N	µg/l	1730	1237	1195	1212
SRP (Ortho-P)	µg/l	14	< 1	< 1	< 1
Organic P	µg/l	88	20	14	9
Total P	µg/l	102	21	15	10
Turbidity	NTU	6.2	0.8	0.7	0.2
TSS	mg/l	10.5	4.8	2.8	0.6
Chlorophyll-a	mg/m^3	12.4	1.06	0.54	0.41
Diss. Al	µg/l	28	90	87	99
Sulfate	mg/l	22	44	53	72

Addition of alum to the Lake June composite water sample resulted in reductions in measured pH and alkalinity with increasing alum dose. However, at the highest tested alum dose of 10 mg Al/liter, the minimum pH value measured within the sample was 6.51.

Alum was moderately effective in reducing concentrations of total nitrogen in the treated samples. At the maximum applied alum dose of 10 mg Al/liter, the total nitrogen in the Lake June sample was reduced from 1730 µg/l to 1212 µg/l, a decrease of approximately 30%. This decrease was achieved by reductions in both concentrations of organic nitrogen and NO_x. Alum treatment was also extremely effective in reducing concentrations of total phosphorus which decreased from 102 µg/l in the raw sample to 10 µg/l at an alum dose of 10 mg Al/liter, a reduction of approximately 90%. This reduction was achieved by decreases in concentrations for both SRP and organic phosphorus. Significant decreases in turbidity, TSS, and chlorophyll-a were also observed in the treated samples.

4.4 Application Costs

A summary of estimated application costs for sediment inactivation in Lake June is given in Table 4-3. This estimate assumes an alum volume of 2000 gallons and a sodium aluminate volume of 400 gallons will be applied. Planning and mobilization costs are estimated to be approximately $750, 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 Lake June is $6580.

TABLE 4-3

ESTIMATED APPLICATION COSTS FOR SEDIMENT INACTIVATION IN LAKE JUNE

PARAMETER	AMOUNT REQUIRED	UNIT COST	TOTAL COST
1. Chemicals			
A. Alum	2000 gallons	$0.79/gallon[1]	$ 1,580
B. Sodium Aluminate	400 gallons	$4.00/gallon[1]	$ 1,600
2. Labor			
A. Planning and Mobilization	1 application	$750	$ 750
B. Chemical Application	24 man-hours	$100/hour[2]	$ 2,400
3. Lab Testing	Pre-/Post-samples	$250	$ 250
		TOTAL:	**$ 6,580**

1. Includes chemical, transportation, unloading, and taxes
2. Includes raw labor, water quality monitoring, insurance, expenses, application equipment, mileage, and rentals

4.5 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 Lake June. However, several factors can serve to reduce the effectiveness and longevity of this treatment process. First, wind action may 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. However, due to the small surface area of Lake June, 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 Lake June appears to be limited, 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. At the recommended application dose, an additional available pool of aluminum may be present within the sediments which can be used to adsorb phosphorus migrating upward as a result of groundwater seepage. The recommended repeat alum application will further reduce the impacts of groundwater seepage on phosphorus loadings to the lake. Therefore, groundwater inflow through the sediments is not anticipated to substantially reduce the longevity of a sediment inactivation process in Lake June.

4.6 Summary and Recommendations

Based upon the results presented in the previous sections, it appears that sediment recycling of phosphorus is significant in Lake June. Since Lake June appears to be predominantly a phosphorus-limited ecosystem, reduction of phosphorus released from internal recycling will result in improved water quality characteristics within the lake. Therefore, a surface alum application for inactivation of sediment phosphorus in Lake June is recommended. The application should be performed using a water column dose of 26.6 mg Al/liter which equates to approximately 2000 gallons of alum and 400 gallons of sodium aluminate. Application of this dose could be safely achieved while maintaining an equilibrium pH value in excess of 6.0.

APPENDIX A

PHYSICAL-CHEMICAL PROFILES COLLECTED IN LAKE JUNE DURING JANUARY 2006

		Date	Time	Dep25 (m)	Temp (°C)	pH (s.u.)	SpCond (µmho/cm)	DO (mg/l)	DO% (Sat)	ORP (mV)	Turb (NTU)	Secchi (m)
June	Middle	1/24/06	7:44	0.25	20.67	7.75	292	10.0	132	385	9.8	0.72
June	Middle	1/24/06	7:46	0.50	20.64	7.74	292	10.1	134	385	10.0	0.72
June	Middle	1/24/06	7:47	1.00	20.47	7.64	292	9.5	125	381	10.7	0.72
June	Middle	1/24/06	7:48	1.50	19.46	7.43	292	7.8	101	373	13.3	0.72
June	Middle	1/24/06	7:49	2.00	18.79	7.31	293	6.7	85	368	15.5	0.72
June	Middle	1/24/06	7:51	2.50	18.11	7.23	294	5.4	68	365	21.8	0.72
June	Middle	1/24/06	7:52	3.00	17.92	7.15	295	4.5	56	259	278.5	0.72
June	Middle	1/24/06	7:55	3.17	17.92	6.78	425	0.6	8	128	>1000	0.72