SEDIMENT IMPACTS ON WATER QUALITY IN HARBOR ISLE LAKE

Final Report – September 2021


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SECTION 1

INTRODUCTION

1.1 Project Background

This report provides a summary of field and laboratory efforts conducted by Environmental Research & Design, Inc. (ERD) for Greenman-Pedersen, Inc. (GPI) to evaluate bathymetric characteristics, sediment chemistry, and sediment nutrient flux in Harbor Isle Lake. The work efforts discussed in this report were conducted for the City of St. Petersburg as a sub-consultant to GPI. A general location map for Harbor Isle Lake is given on Figure 1-1.

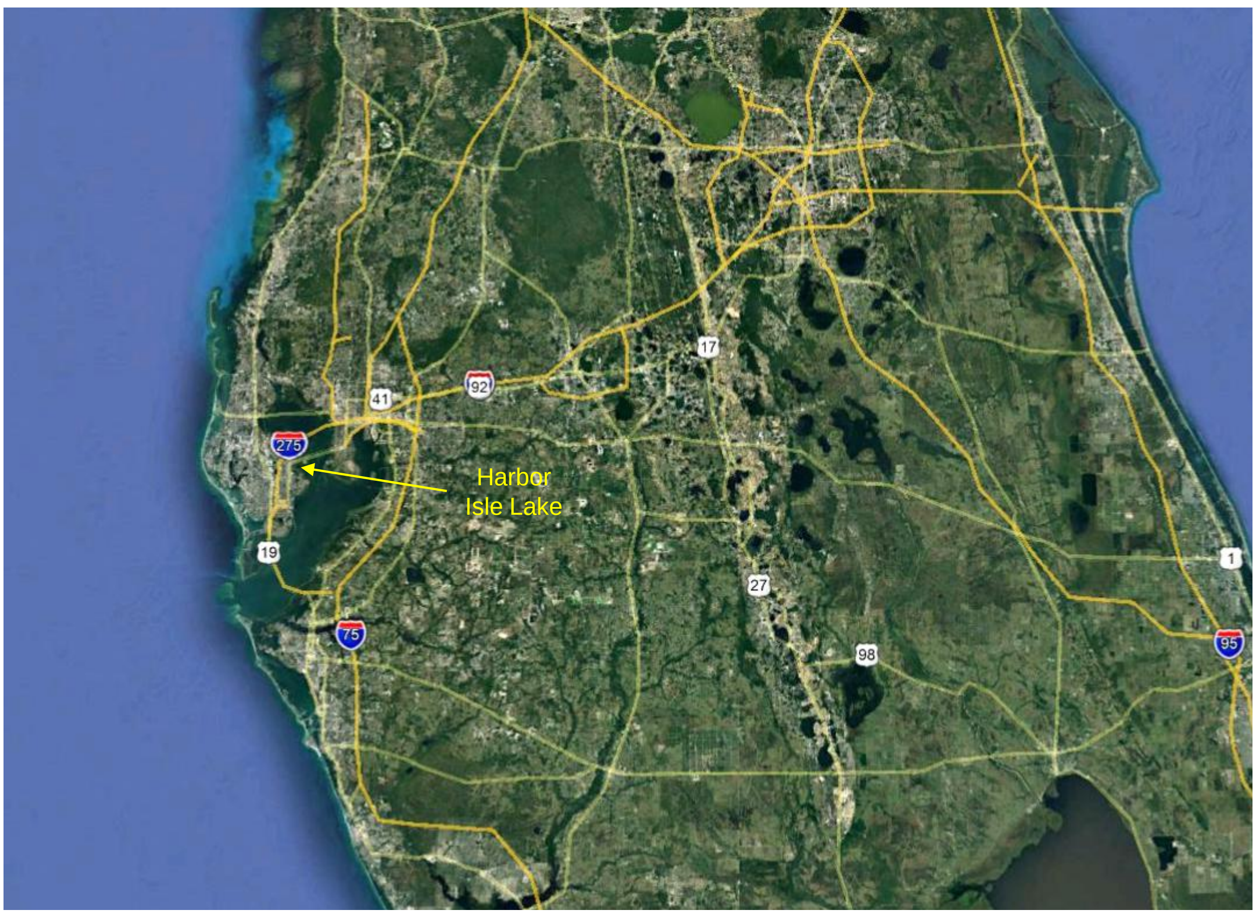


Figure 1-1. Location Map for Harbor Isle Lake.

Harbor Isle Lake is a 25.9-acre waterbody which is located in the center of the Harbor Isle development in northeast St. Petersburg and serves as a stormwater management facility for runoff generated in the Harbor Isle development. The Harbor Isle community is located southeast of the intersection of Gandy Blvd and 4^{th} St. N, south of Riviera Bay, adjacent to Old Tampa Bay. A general vicinity map for Harbor Isle Lake is given on Figure 1-2.

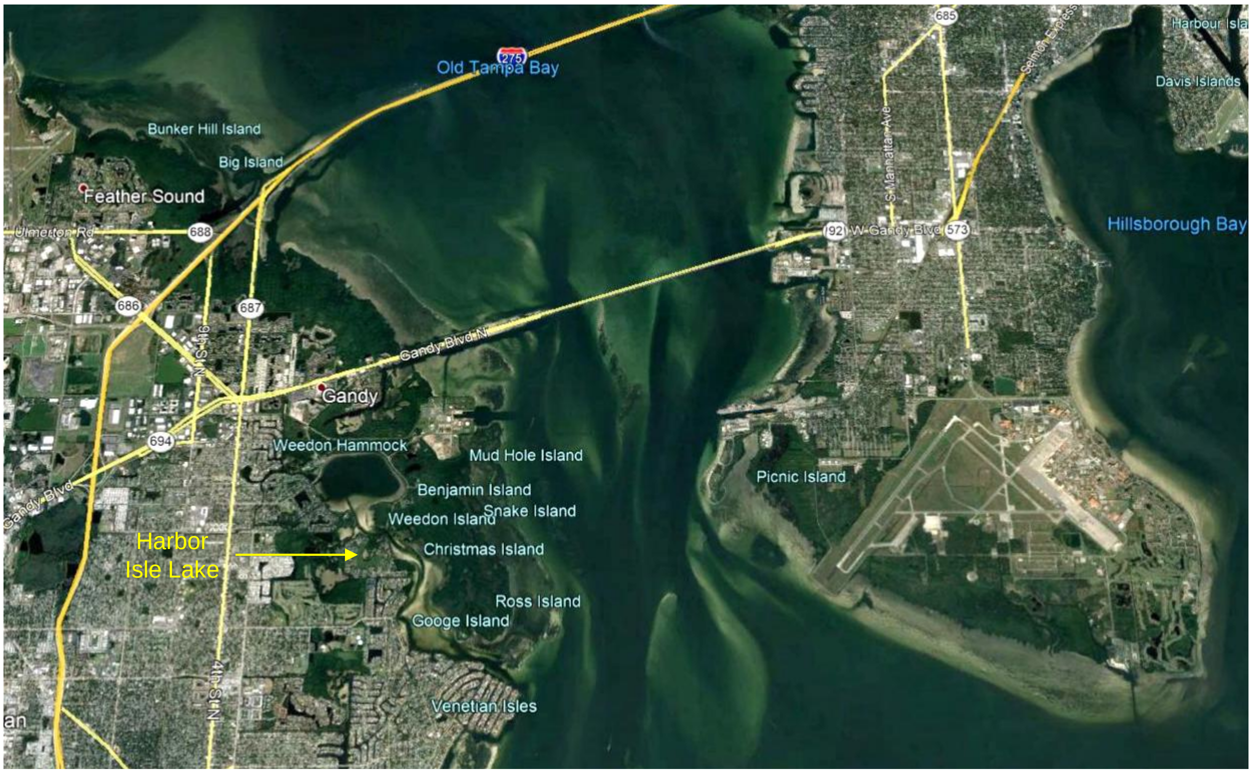


Figure 1-2. Harbor Isle Lake Vicinity Map.

The Harbor Isle community consists of 218 single-family homes, most of which are located directly on the lake. Harbor Isle Lake functions as a stormwater treatment system for the community and discharges to tide downstream from Riviera Bay. An overview of Harbor Isle Lake is given on Figure 1-3. The Harbor Isle community receives reuse irrigation from the City of St. Petersburg. An evaluation of potential impacts from the reuse irrigation was conducted by Janicki Environmental, Inc. (Janicki) during 2020, which reported reuse concentrations for total nitrogen and phosphorus in November 2018 of 24.90 mg/l for total nitrogen and 1.65 mg/l for total phosphorus, and concluded that reuse loadings to the lake were similar to or exceeded runoff loadings.

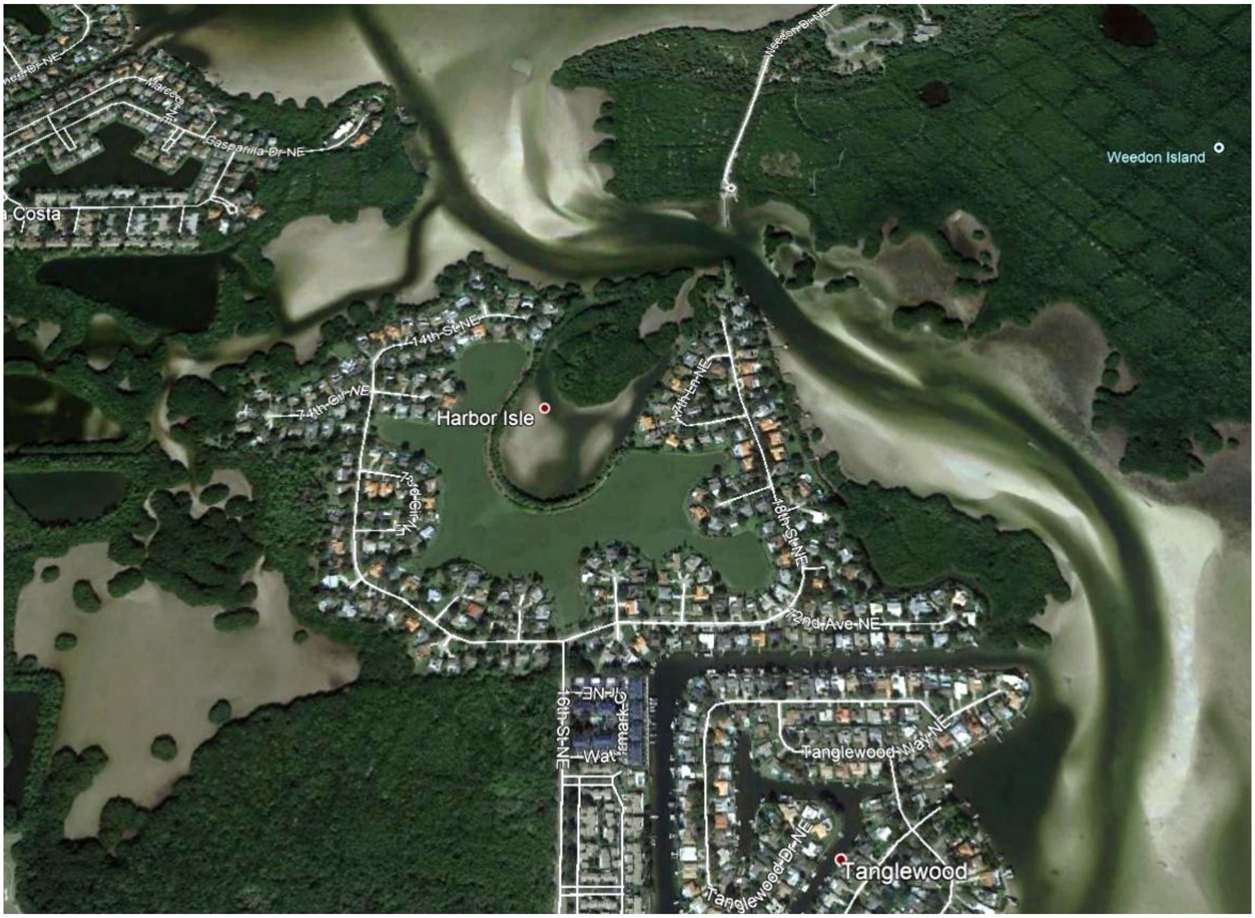


Figure 1-3. Overview of Harbor Isle Lake.

In recent years Harbor Isle Lake has experienced severe algal blooms which have concerned local residents and City personnel. Monitoring conducted by a City consultant found extremely elevated concentrations of total nitrogen, ammonia, and total phosphorus in the lake water, combined with low clarity and oxygen depletion below a depth of 10 ft at most sites. The lake is clearly hypereutrophic, although chlorophyll-a measurements were not available to calculate the corresponding Trophic State Index (TSI). The City attempted to reduce the algal blooms and improve oxygen concentrations using a nano-bubble aeration system which has had mixed results.

1.2 Current Study

The current study was undertaken to evaluate the water quality impacts from existing sediments in the lake. This was accomplished through 3 separate tasks. First, bathymetric contour maps of water and muck depth were developed to evaluate the physical characteristics of the lake and current sediment accumulations. Next, sediment core samples were collected at 10 locations in the lake to evaluate physical and chemical characteristics of existing sediments. Finally, large diameter sediment core samples were collected and incubated under aerobic and anaerobic conditions to measure sediment nutrient release as a loading source to the lake and for comparison with the runoff and reuse loading estimates contained in the Janicki report.

1.3 Report Organization

The work efforts discussed in this document have been divided into 3 separate sections for presentation of data and results. Section 1 provides an introduction to the report, a brief history of lake conditions, previous studies conducted on Harbor Isle Lake, and an overview of work efforts performed by ERD. Section 2 contains a discussion of bathymetric and sediment characteristics of the lake. A discussion of benthic nutrient release rates and annual loadings is given in Section 3. Appendices are also attached which contain raw data and other information used to support the results and conclusions provided in the report.

SECTION 2

PHYSICAL AND SEDIMENT CHARACTERISTICS OF HARBOR ISLE LAKE

2.1 Physical Characteristics

A hydrographic survey of Harbor Isle Lake was conducted by ERD on April 8, 2021 to evaluate water depth as well as thickness of unconsolidated sediments within the lake. Measurements of water depth and sediment thickness were conducted at 140 individual sites in Harbor Isle Lake. Probing locations 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 using a portable GPS device. High resolution sonar devices are currently available for conducting underwater bathymetric survey, and ERD owns several of these devices which produce detailed contour maps. However, these devices are not reliable for determining sediment thickness, especially for deeper sediment deposits. Therefore, ERD selected a manual method for the hydrographic survey which better characterizes sediment accumulations.

Water depth at each of the sites was determined by lowering a weighted 20-cm diameter Secchi disk attached to a graduated line until resistance from the sediment layer was encountered. The depth on the graduated line corresponding to the water surface was recorded in the field and is defined as the water depth at each site. After measurement of the water depth at each site, a 1.5-inch graduated aluminum pole was then lowered into the water column and forced into the sediments until a firm bottom material, typically sand or clay, was encountered. The depth corresponding to 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 at each site is defined as the depth of unconsolidated sediments.

The generated field data were converted into bathymetric maps for both water depth and unconsolidated sediment depth in Harbor Isle Lake using AutoCAD. Estimates of water volume and unconsolidated sediment volume within Harbor Isle Lake were generated using the Autodesk Land Desktop Module.

ERD did not observe a staff gauge or water level recorder in Harbor Isle Lake to use as a reference for determining the water level elevation at the time of the bathymetric survey. However, the field crew did measure the water level referenced to a seawall on the south side of the lake, next to the location used to launch the boat, and this reference point could be surveyed to determine the lake water elevation at the time of the field measurements.

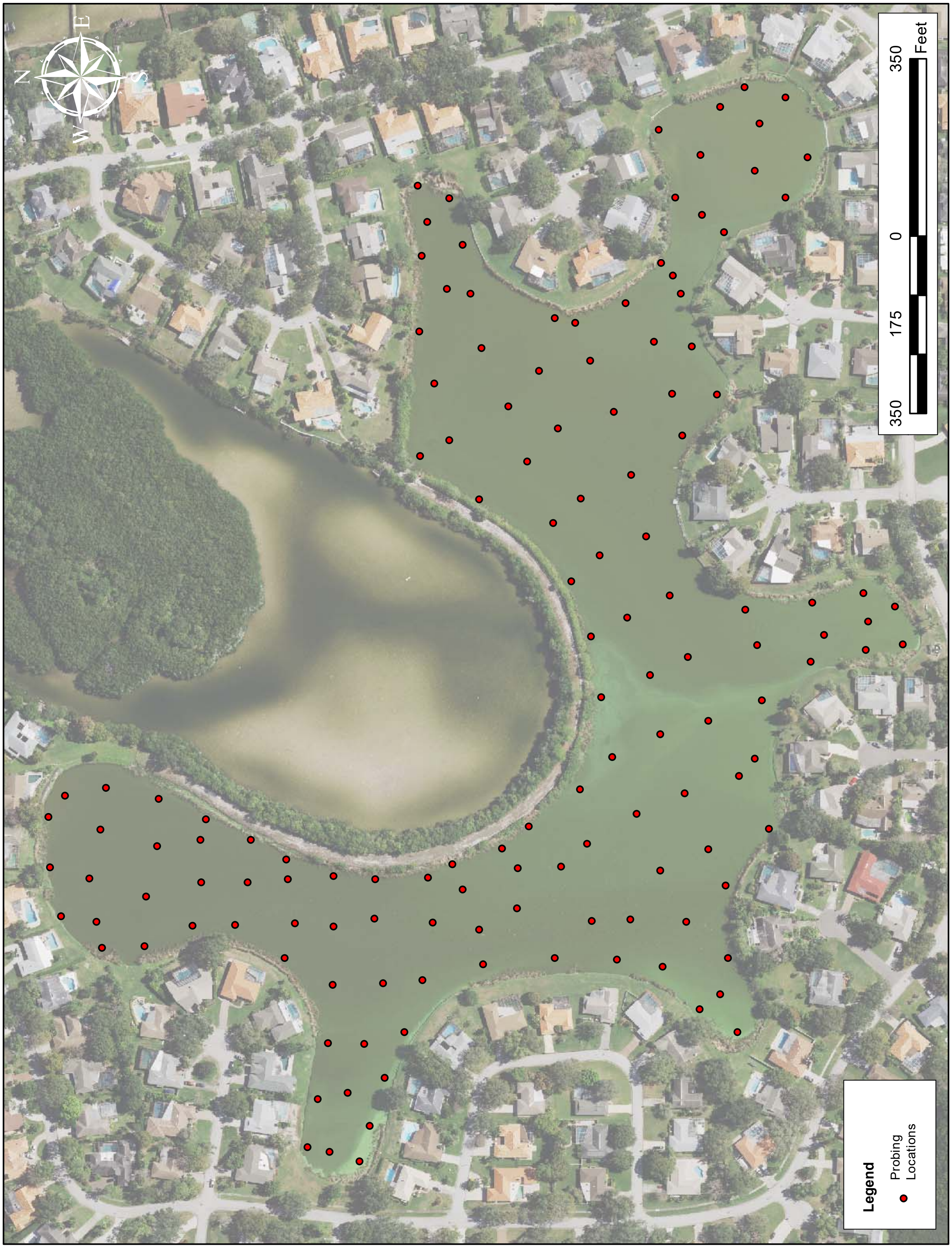


Figure 2-1. Probing Locations for Water and Muck Depth in Harbor Isle Lake (April 8, 2021).

A water depth contour map for Harbor Isle Lake, based upon the field monitoring program performed by ERD, is given in Figure 2-2. Harbor Isle Lake consists of a semi-circular shape which hugs a southwest lobe of Riviera Bay. Shoreline areas of the lake are characterized by relatively steep side slopes which extend to deep central areas with water depths ranging from 10-18 ft, although the bottom contours are somewhat irregular. The deepest areas in the lake are located in eastern and southern portions of the lake, with the most shallow areas along the west side. The uniform side slopes and flat bottom areas are characteristics of a man-made waterbody.

Depth-area-volume relationships for Harbor Isle Lake are summarized in Table 2-1 based on the bathymetric survey performed by ERD. At the water surface elevation present on April 8, 2021, the lake surface area is approximately 25.9 acres. The lake volume at this surface area is 230 ac-ft, corresponding to a mean water depth of approximately 8.9 ft. A summary of bathymetric characteristics of Harbor Isle Lake is given in Table 2-2.

TABLE 2-1

DEPTH-AREA-VOLUME RELATIONSHIPS FOR HARBOR ISLE LAKE

WATER DEPTH (ft)	AREA (acres)	CUMULATIVE VOLUME (ac-ft)
0	25.9	230
1	24.3	205
2	22.6	181
3	21.0	159
4	19.4	139
5	18.2	121
6	16.9	103
7	15.5	86.7
8	13.9	72.0
9	12.3	58.9
10	10.9	47.3
11	9.0	37.3
12	8.2	28.7
13	7.4	20.9
14	6.6	13.9
15	5.4	7.92
16	4.0	3.19
17	1.2	0.58
18	0.0	0.00

Mean Depth: 8.9 ft

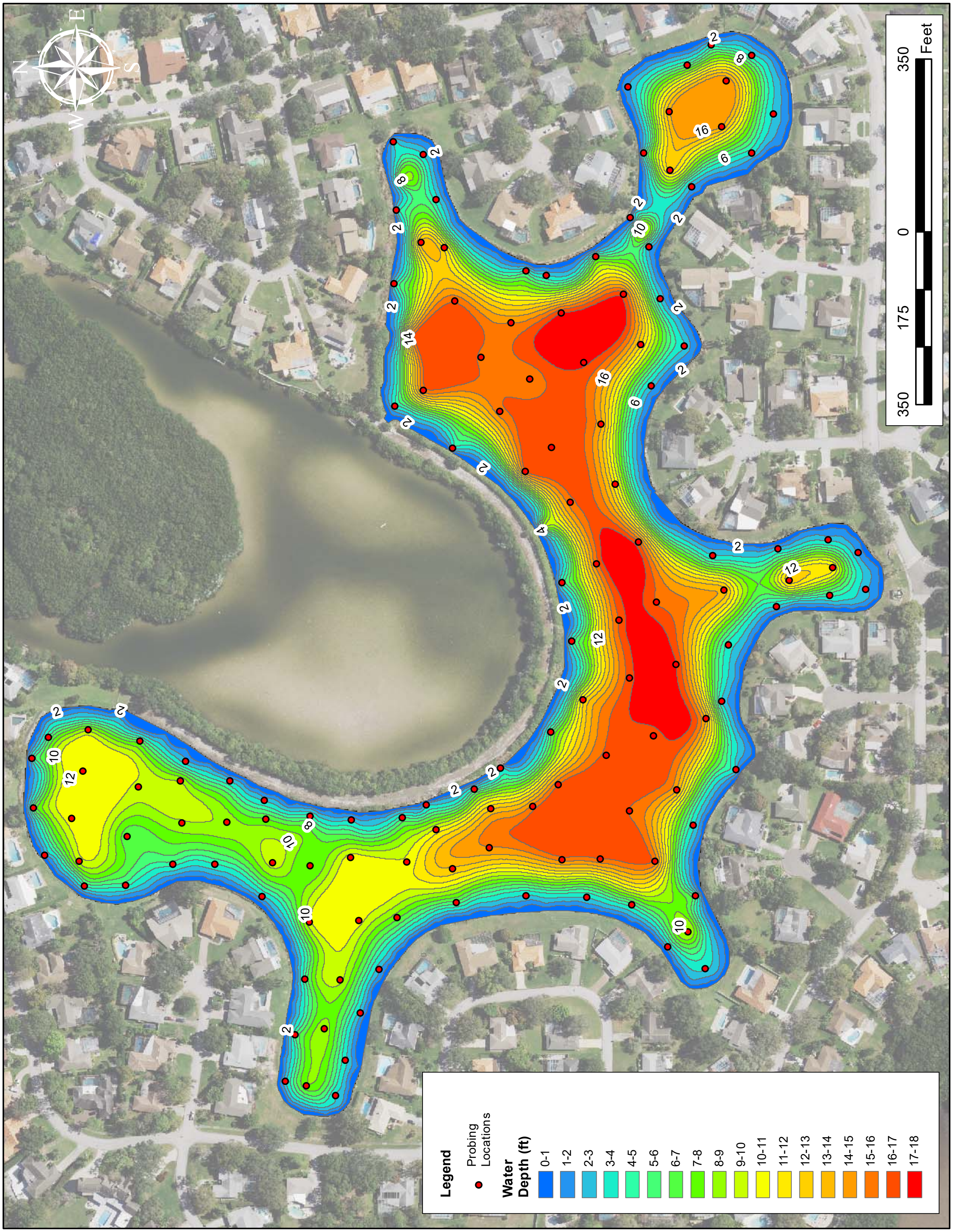


Figure 2-2. Water Depth Contours (ft below water surface) for Harbor Isle Lake on April 8, 2021.

TABLE 2-2

BATHYMETRIC CHARACTERISTICS OF HARBOR ISLE LAKE

BATHYMETRIC PARAMETER[1]	VALUE
Surface Area	25.9 acres
Total Volume	230 ac-ft
Mean Depth	8.9 ft
Maximum Depth	18 ft
Shoreline Length	9,010 ft (1.71 miles)

1. Based upon the water surface elevation present on April 8, 2021

A bathymetric contour map of the depth of unconsolidated organic sediments in Harbor Isle Lake is given in Figure 2-3. Deep pockets of organic muck, extending to depths of 10-12 ft or more, are located in the center of the eastern lobe where muck depths range from 0-10 ft, and in isolated pockets in the southwestern and western lobes where muck depths range from 0-12 ft, although the most substantial accumulations of organic muck are located in the southwestern lobe. Perimeter areas on Figure 2-3 which are colored dark blue contain muck accumulations ranging from 0-1 ft.

Estimates of area-volume relationships for organic muck accumulations in Harbor Isle Lake are given in Table 2-3. Approximately 6.9 acres (27%) of the lake area have existing muck accumulations ranging from 0-1 ft in depth, with 10% of the lake bottom covered by muck accumulations ranging from 1-2 ft in depth, and 8% ranging from 2-3 ft in depth. Overall, Harbor Isle Lake contains approximately 104 ac-ft (4,530,240 ft^3 or 167,787 yd^3) of unconsolidated organic sediments. The volume of unconsolidated sediment in Harbor Isle Lake is sufficient to cover the entire lake bottom to a depth of approximately 4.0 ft. The mean muck depth in Harbor Isle Lake is much greater than mean muck depths measured by ERD in natural lakes such as Lake Holden (1.5 ft), Lake Killarney (1.6 ft), and Lake Pickett (1.29 ft).

The organic muck measured in Harbor Isle Lake reflects deposition of biological matter onto the lake bottom following original construction, assuming that the lake was originally excavated to a firm hard bottom. If the muck volume of 104 ac-ft is added to the current lake volume of 230 ac-ft, the estimated original lake volume is approximately 334 ac-ft. Considering the current muck accumulation of 104 ac-ft, approximately 31% (104 ac-ft ÷ 334 ac-ft) of the original lake volume has become filled with organic muck.

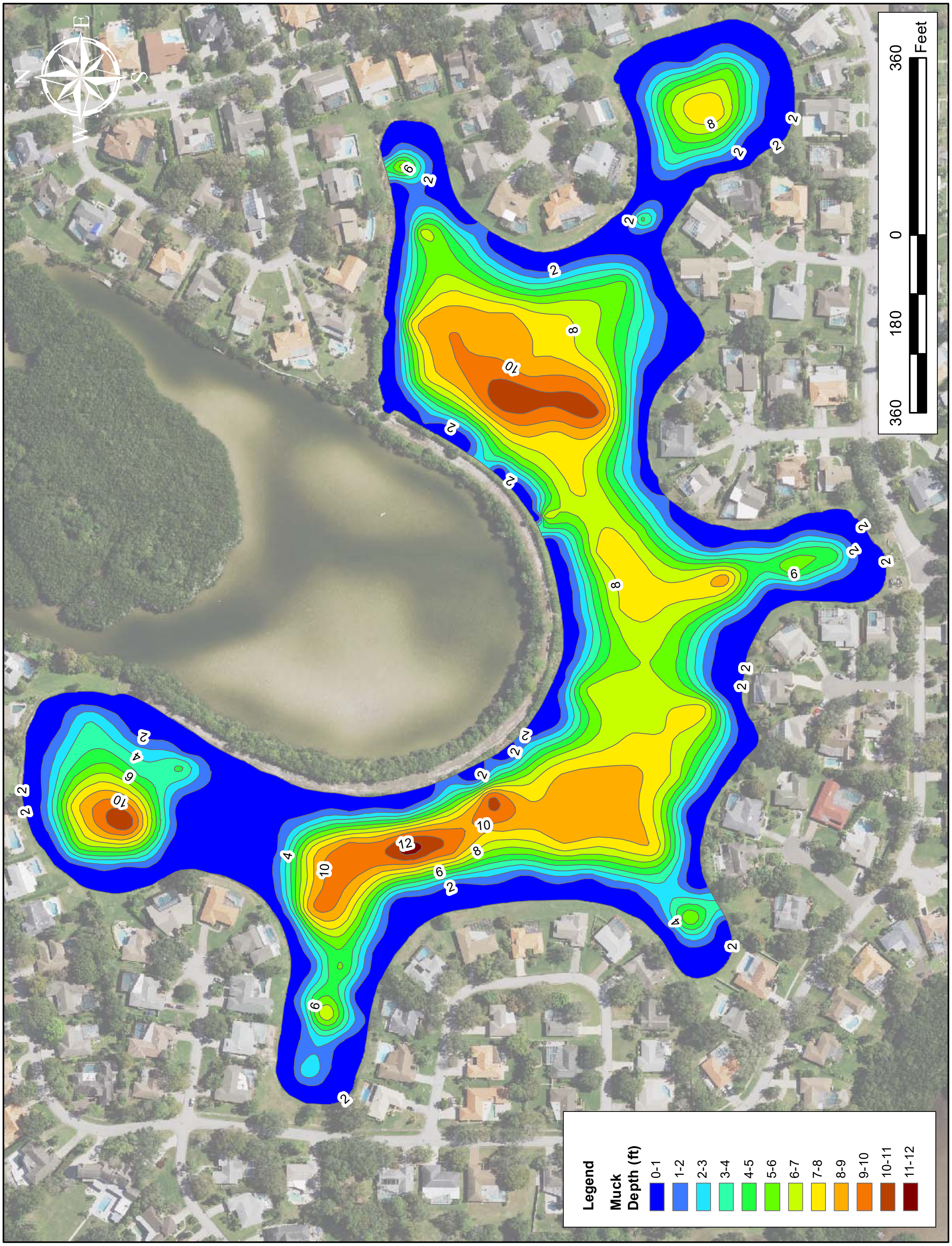


Figure 2-3. Muck Depth Contours (muck thickness) for Harbor Isle Lake on April 8, 2021.

TABLE 2-3

DEPTH-AREA-VOLUME RELATIONSHIPS FOR ORGANIC MUCK IN HARBOR ISLE LAKE

MUCK DEPTH (ft)	AREA (ft^2)	AREA (acres)	CUMULATIVE VOLUME (ac-ft)
0	1,129,484	25.9	104
1	826,719	19.0	81
2	715,903	16.4	64
3	622,628	14.3	48
4	533,407	12.2	35
5	447,280	10.3	24
6	354,836	8.1	15
7	242,556	5.6	7.7
8	142,555	3.3	3.3
9	56,653	1.3	1.0
10	16,125	0.4	0.2
11	899	0.0	0.0

Mean Depth: 4.0 ft

2.2 Sediment Characteristics

Sediment core samples were collected in Harbor Isle Lake by ERD to evaluate the characteristics of existing sediments and potential impacts on water quality within the lake. Sediment core samples were collected at 10 separate locations within the lake on April 8, 2021 by ERD personnel. Locations of sediment sampling sites in Harbor Isle Lake are illustrated on Figure 2-4. Based on the lake surface area of 25.9 acres, sediment samples were collected at a rate of one sample for every 2.6 acres of lake area.

2.2.1 Sampling Techniques

Sediment samples were collected at each of the 10 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 120-ml wide-mouth 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 10 monitoring sites. The polyethylene containers utilized for storage of the collected samples were filled completely to minimize air space in the storage container above the composite sediment sample. Each of the collected samples was stored in ice and returned to the ERD laboratory for physical and chemical characterization.

Figure 2-4. Sediment Core Sample Collection Sites in Harbor Isle Lake on April 8, 2021.

2.2.2 Sediment Characterization and Speciation Techniques

Each of the 10 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 2-4.

TABLE 2-4

ANALYTICAL METHODS FOR SEDIMENT ANALYSES

MEASUREMENT PARAMETER	SAMPLE PREPARATION	ANALYSIS REFERENCE	REFERENCE PREPARATION/ ANALYSIS*	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 10 collected sediment samples using a modified version of the Chang and Jackson Procedure developed by ERD. The modified 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.

The Chang and Jackson procedure was originally developed at the University of Wisconsin to evaluate phosphorus bonding in dried agricultural soils. However, drying of wet sediments will impact phosphorus speciation, particularly the soluble and iron-bound associations. Therefore, the basic Chang and Jackson method was adapted and modified by ERD in 1992 for wet sediments by adjusting solution concentrations and extraction timing to account for the liquid volume in the wet sediments and the reduced solids mass. This modified method has been used as the basis for all sediment inactivation projects which have been conducted in the State of Florida.

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 anaerobic 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 ERD Speciation Procedure for evaluating soil phosphorus bounding is given in Figure 2-5.

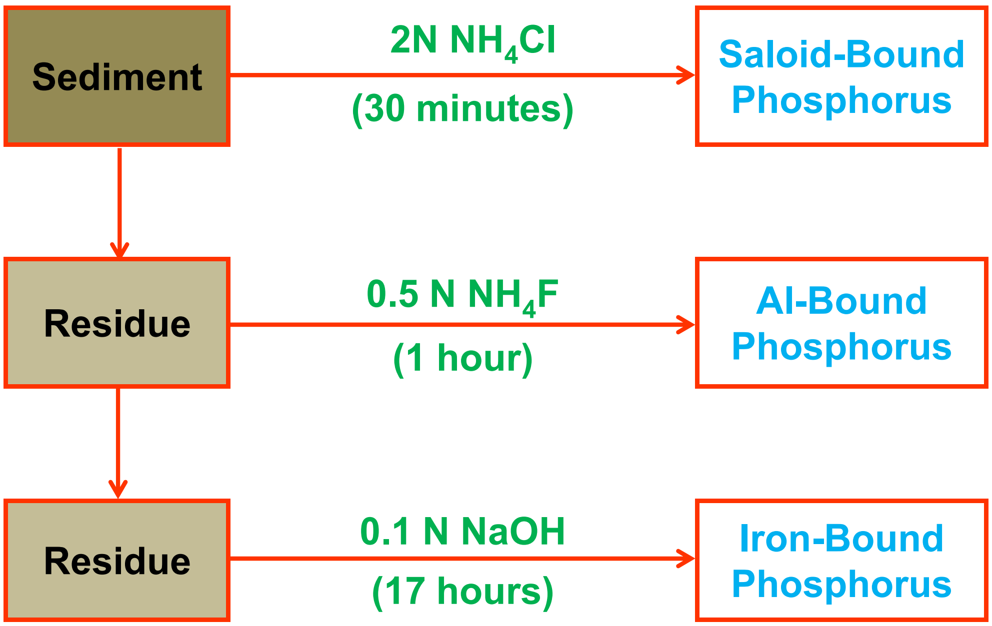


Figure 2-5. Schematic of ERD Speciation Procedure for Evaluating Soil Phosphorus Bonding.

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 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 typical sediment pH range of approximately 5.5-7.5 under a wide range of redox conditions.

Phosphorus speciation of the sediments provides information on potential water quality improvement options. Although TN/TP ratios may suggest that the lake is nitrogen-limited, highly eutrophic lakes can only be improved by controlling phosphorus, and one of the most common methods of control is sediment inactivation. Phosphorus speciation of the sediments allows estimation of chemical quantities and costs for sediment treatment options.

2.2.3 Sediment Characteristics

2.2.3.1 Visual Characteristics

Visual characteristics of sediment core samples were recorded for each of the 10 sediment samples collected in Harbor Isle Lake during April 2021. A summary of visual characteristics of sediment core samples is given in Table 2-5. In general, a thin surficial layer of unconsolidated organic muck was observed in Harbor Isle Lake at each of the monitoring sites, with measured depths ranging from 4-13 cm. This unconsolidated surficial layer is comprised primarily of fresh organic material (such as dead algal cells) and detritus which has recently accumulated onto the bottom of the lake and is easily disturbed by wind action or boating activities.

TABLE 2-5

VISUAL CHARACTERISTICS OF SEDIMENT CORE SAMPLES COLLECTED IN HARBOR ISLE LAKE ON APRIL 8, 2021

SITE NO.	LAYER (cm)	VISUAL APPEARANCE
1	0 – 4 4 - >100	Dark brown unconsolidated organic muck Dark gray consolidated organic muck and clay
2	0 – 8 8 - >89	Dark brown unconsolidated organic muck Dark gray consolidated organic muck and clay
3	0 – 4 4 - >102	Dark brown unconsolidated organic muck Dark gray consolidated organic muck and clay
4	0 – 13 13 - >99	Dark brown unconsolidated organic muck Dark gray consolidated organic muck and clay
5	0 – 8 8 - >107	Dark brown unconsolidated organic muck Dark gray consolidated organic muck and clay
6	0 – 4 4 – 105 105 - >110	Dark brown unconsolidated organic muck Dark gray consolidated organic muck and clay Dark black consolidated organic muck
7	0 – 5 5 - >73	Dark brown unconsolidated organic muck Dark gray consolidated organic muck and clay
8	0 – 5 5 - >111	Dark brown unconsolidated organic muck Dark gray consolidated organic muck and clay
9	0 – 4 4 - >88	Dark brown unconsolidated organic muck Dark gray consolidated organic muck and clay
10	0 – 6 6 - >102	Dark brown unconsolidated organic muck Dark gray consolidated organic muck and clay

At many sites with thick muck deposits, the organic muck becomes more consolidated beneath the surficial layer, with a consistency similar to pudding and an appearance that suggests large clay content. These layers reflect older organic/clay deposits which are resistant to further degradation and typically do not resuspend into the water column except during vigorous wind activity on the lake or disturbance by boat propellers. Measured depths of the consolidated organic muck/clay layer ranged from 4 cm to >111 cm. Evidence of the original lake bottom (such as sand, dense clay, or marine deposits) was not observed at any monitoring site. Photographs of sediment core samples collected at each of the 10 sites in Harbor Isle Lake are given in Appendix A.

2.2.3.2 General Sediment Characteristics

After return to the ERD Laboratory, the collected sediment core samples were evaluated for general sediment characteristics, including pH, moisture content, organic content, sediment density, total nitrogen, and total phosphorus. A summary of general characteristics measured in each of the 10 collected sediment core samples is given in Table 2-6. In general, sediments in Harbor Isle Lake were found to be near neutral in pH, with measured pH values ranging from 6.85-7.13 and an overall geometric mean of 6.96.

TABLE 2-6

GENERAL CHARACTERISTICS OF SEDIMENT CORE SAMPLES COLLECTED IN HARBOR ISLE LAKE ON APRIL 8, 2021

LAB I.D. (21-xx)	SITE	pH (s.u.)	MOISTURE CONTENT (%)	ORGANIC CONTENT (%)	WET DENSITY (g/cm^3)	TOTAL NITROGEN ($\mu g/cm^3$)	TOTAL PHOSPHORUS ($\mu g/cm^3$)
74	1	6.92	87.0	19.5	1.16	927	494
75	2	6.90	88.7	23.4	1.13	942	397
76	3	6.92	86.6	17.8	1.17	820	561
77	4	6.98	86.8	20.5	1.16	797	670
78	5	6.89	89.7	21.9	1.12	764	466
79	6	7.13	68.0	9.3	1.44	714	1,079
80	7	6.92	86.8	18.5	1.16	652	669
81	8	6.97	85.6	15.0	1.18	584	670
82	9	7.11	69.6	7.7	1.42	701	811
83	10	6.85	87.4	17.8	1.16	626	659
Minimum		6.85	68.0	7.7	1.12	584	397
Maximum		7.13	89.7	23.4	1.44	942	1,079
Geometric Mean		6.96	83.2	16.3	1.20	744	623

Isopleths of pH in the top 10 cm of sediments in Harbor Isle Lake are illustrated on Figure 2-6, based upon the information provided in Table 2-6. The majority of areas within Harbor Isle Lake are characterized by pH values ranging from approximately 6.8-7.0. In general, pH values appear to be relatively uniform throughout the sediments of Harbor Isle Lake, with pH values exceeding 7.0 in the west and southwest lobes.

Measurements of sediment moisture content and organic content in Harbor Isle Lake were found to be relatively similar throughout the lake. Many of the collected sediment samples are characterized by elevated moisture contents, suggesting that these surficial sediments are comprised primarily of organic muck. Measured sediment moisture contents in Harbor Isle Lake sediments ranged from 68.0-89.7% with an overall geometric mean of 83.2%, reflecting extremely elevated values.

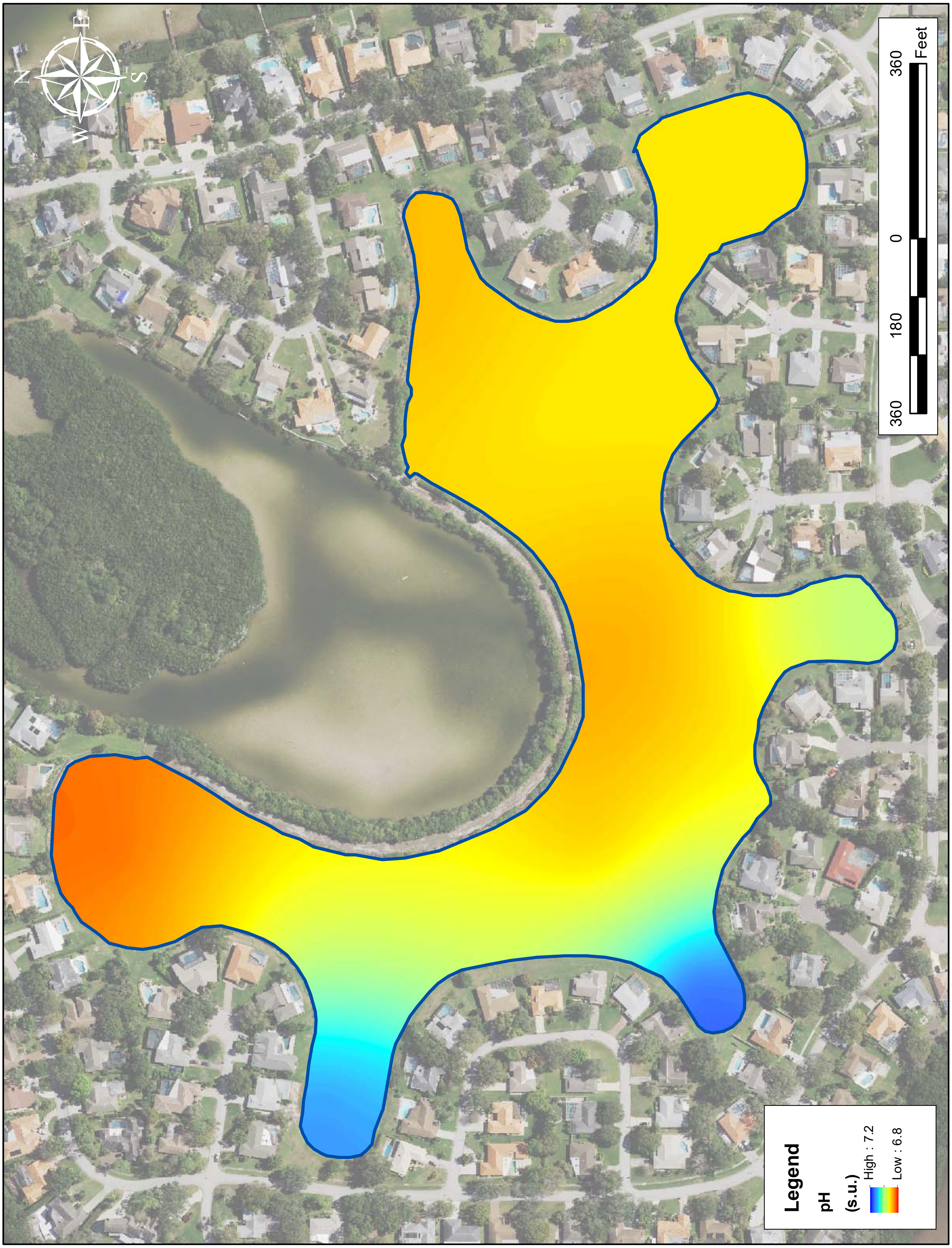


Figure 2-6. Isopleths of pH in the Top 10 cm of Sediments in Harbor Isle Lake During April 2021.

Isopleths of sediment moisture content in Harbor Isle Lake are illustrated in Figure 2-7 based upon the information provided in Table 2-6. Areas of elevated moisture content are present throughout the lake. The lowest sediment organic contents, although still reflecting elevated values, were observed in the west and southwest lobes. Sediment moisture contents in excess of 50% are often indicative of highly organic sediments, while moisture contents less than 50% reflect mixtures of sand and muck. Based on these criteria, sediments in Harbor Isle Lake consist almost exclusively of organic muck.

Isopleths of sediment organic content in Harbor Isle Lake are illustrated on Figure 2-8 based upon the information provided in Table 2-6. In general, sediment organic content values of 20% or more are indicative of organic muck type sediments, with values less than 20% representing either sand or mixtures of muck and sand. Based upon these criteria, areas of concentrated organic muck are apparent throughout most of Harbor Isle Lake. These areas of high organic content correspond relatively closely with the more significant areas of accumulated organic muck deposits illustrated on Figure 2-3. Measured sediment organic content within Harbor Isle Lake ranges from 7.7-23.4%, with an overall geometric mean of 16.3% which is much greater than organic contents measured by ERD in highly eutrophic lakes.

Measured sediment density values are also useful in evaluating the general characteristics of sediments within a lake. Sediments with calculated wet densities between 1.0 g/cm^3 and 1.25 g/cm^3 are indicative of highly organic muck type sediments, while sediment densities of approximately 2.0 or greater are indicative of sandy sediment conditions. Values between 1.25 g/cm^3 and 2.0 g/cm^3 indicate mixtures of sand muck. Measured sediment wet density values in Harbor Isle Lake range from 1.12-1.44 g/cm^3, with an overall mean of 1.20 g/cm^3. Only 2 of the 10 sites had densities exceeding 1.2 g/cm^3.

Isopleths of wet density in Harbor Isle Lake sediments are given in Figure 2-9. Areas of low density sediments are apparent throughout the lake, with slightly higher densities in the west and southwest lobes.

Measured concentrations of total phosphorus in Harbor Isle Lake sediments were found to be elevated in value and highly variable throughout the lake, ranging from 397-1,079 μg/cm^3, with an overall mean of 623 μg/cm^3 which is on the higher end of sediment phosphorus values measured by ERD in lake sediments. 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 sediment phosphorus concentration of 623 μg/cm^3 in Harbor Isle Lake is consistent with the organic muck composition of the sediments.

Isopleths of sediment phosphorus concentrations in Harbor Isle Lake are presented on Figure 2-10, based on information contained in Table 2-6. Areas of elevated sediment total phosphorus concentrations are present throughout the lake, with the highest concentrations located in the west and southwest lobes. In general, overall total phosphorus concentrations observed in Harbor Isle Lake are elevated in value compared with sediment phosphorus concentrations typically observed in urban lakes and reflect the highly productive character of the lake.

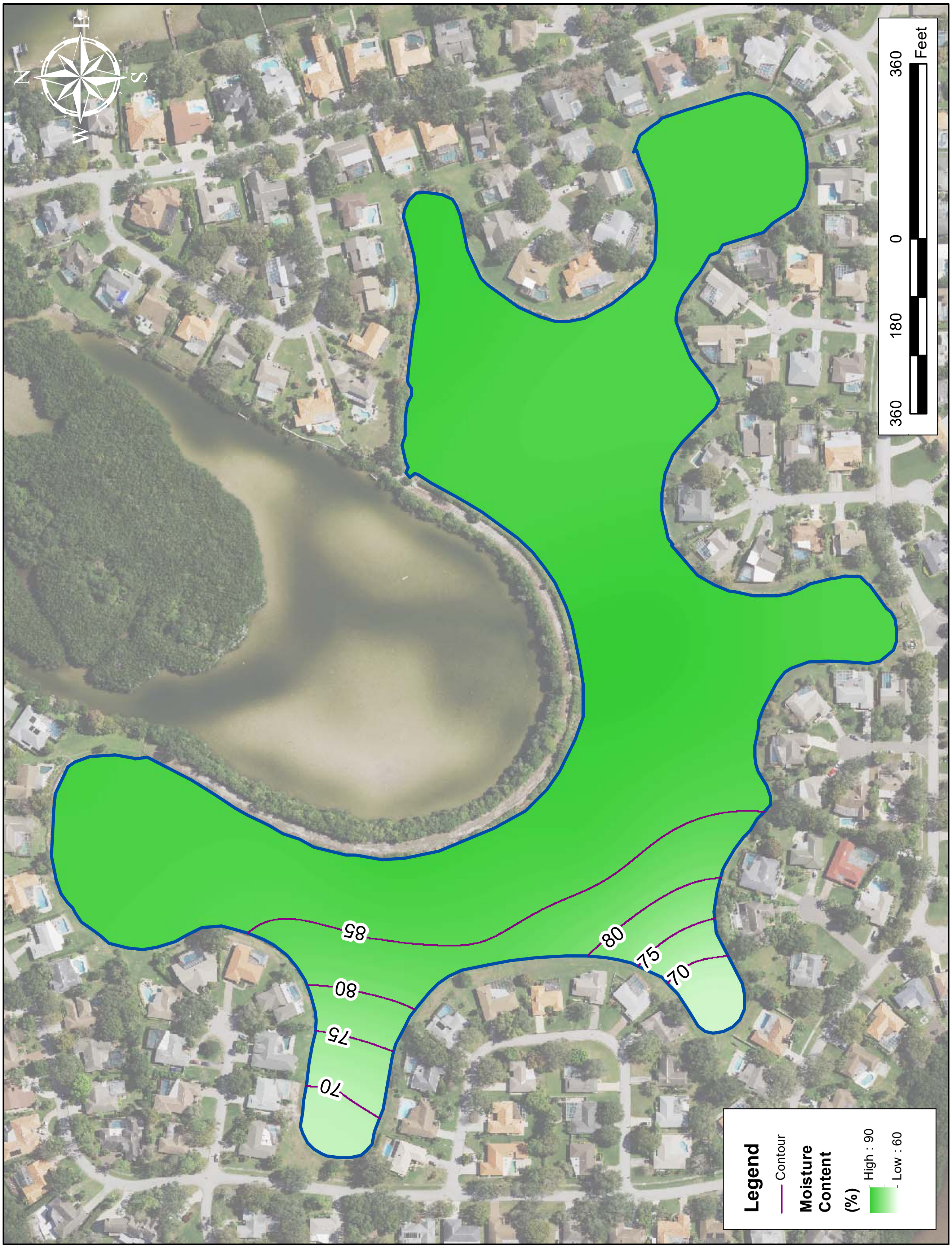


Figure 2-7. Isopleths of Moisture Content (%) in the Top 10 cm of Sediments in Harbor Isle Lake During April 2021.

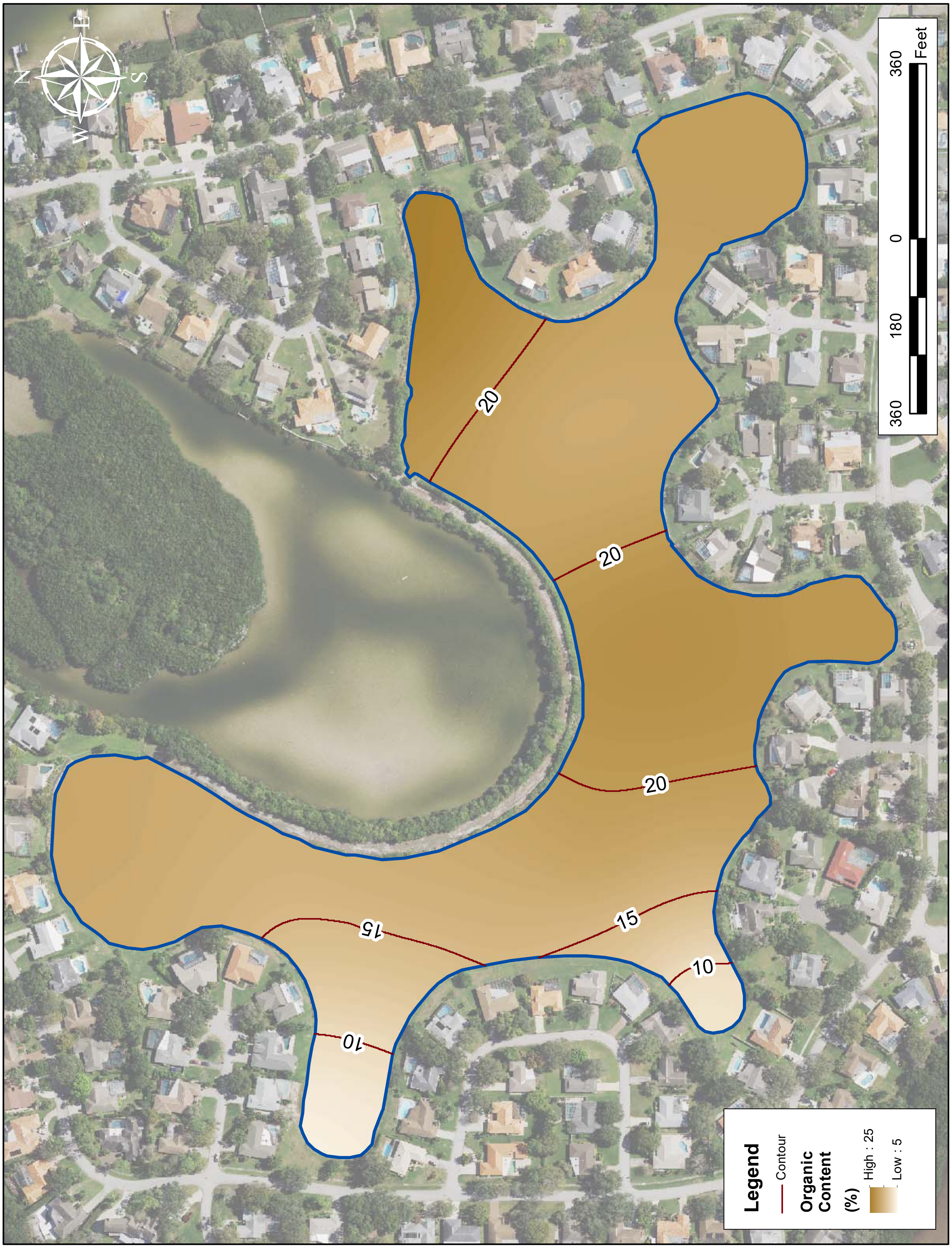


Figure 2-8. Isopleths of Organic Content (%) in the Top 10 cm of Sediments in Harbor Isle Lake During April 2021.

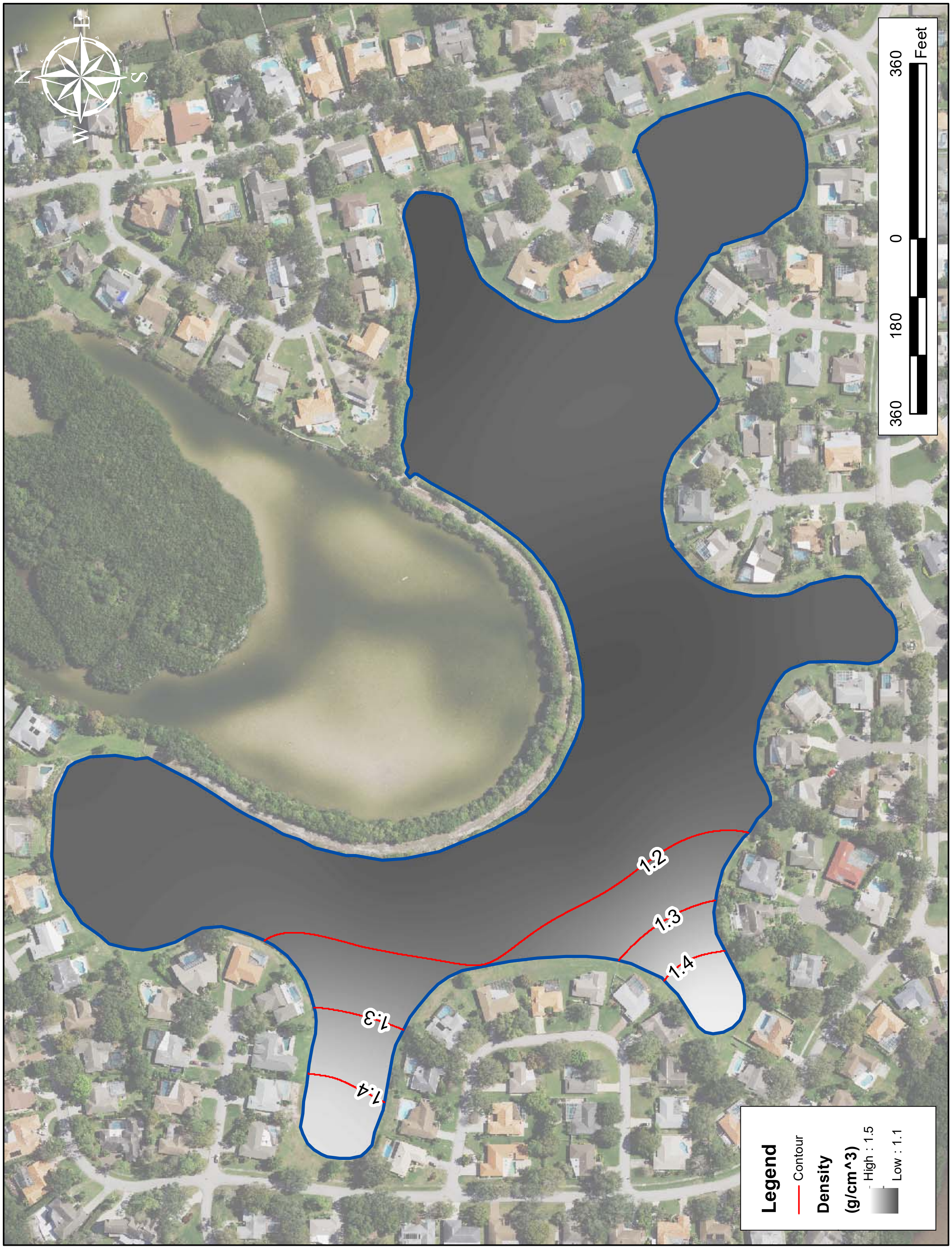


Figure 2-9. Isopleths of Wet Density (g/cm^3) in the Top 10 cm of Sediments in Harbor Isle Lake During April 2021.

Figure 2-10. Isopleths of Total Phosphorus (µg/cm^3) in the Top 10 cm of Sediments in Harbor Isle Lake During April 2021.

Unlike the trends observed for sediment phosphorus concentrations, sediment total nitrogen concentrations are moderate in value, with similar concentrations throughout Harbor Isle Lake. Measured sediment nitrogen concentrations in the lake range from 584-942 $\mu g/cm^3$, with an overall mean of 744 $\mu g/cm^3$, and appear to be on the low end of values normally observed in urban lakes. The relatively low sediment nitrogen concentrations in spite of elevated nitrogen inputs may be due to nitrogen loss through denitrification. Isopleths of sediment nitrogen concentrations in Harbor Isle Lake are illustrated on Figure 2-11. In general, nitrogen sediment concentrations exhibit a trend opposite of phosphorus, with elevated areas of sediment phosphorus corresponding to the lowest nitrogen concentrations.

2.2.3.3 Phosphorus Speciation

As discussed in Section 2.2.2, each of the collected sediment core samples was evaluated for phosphorus speciation based upon the modified Chang and Jackson speciation procedure developed by ERD. This procedure allows phosphorus within the sediments to be speciated with respect to bonding mechanisms which is useful in evaluating the stability of phosphorus in the sediments, the potential for release of phosphorus from the sediments under anaerobic or other conditions, and as a tool for estimating alum requirements for sediment inactivation.

A summary of phosphorus speciation in sediment core samples collected from Harbor Isle Lake during April 2021 is given in Table 2-7. 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 2-7, saloid-bound phosphorus concentrations appear to be fairly uniform and elevated in value throughout much of Harbor Isle Lake. Measured values for saloid-bound phosphorus range from 25.7-45.0 $\mu g/cm^3$, with an overall mean of 35.0 $\mu g/cm^3$. This value is more than an order of magnitude greater than mean saloid phosphorus concentrations commonly measured by ERD in urban lakes.

Isopleths of saloid-bound phosphorus in the top 10 cm of sediments in Harbor Isle Lake are illustrated on Figure 2-12. Elevated concentrations of saloid-bound phosphorus are present throughout the lake, with the most elevated values in the southern portion of the lake.

In general, iron-bound phosphorus associations in the sediments of Harbor Isle Lake appear to be low to elevated in value. Iron-bound phosphorus is relatively stable under oxidized conditions, but becomes unstable under a reduced environment, causing the iron-phosphorus bonds to separate, releasing the bound phosphorus directly into the water column. Iron-bound phosphorus concentrations in the sediments of Harbor Isle Lake range from 46-191 $\mu g/cm^3$, with an overall geomean of 67 $\mu g/cm^3$. Since iron-bound phosphorus can be released under anaerobic conditions, portions of Harbor Isle Lake sediments may have conditions favorable for release of iron-bound sediment phosphorus into the water column throughout much of the year.

Isopleths of iron-bound phosphorus in the top 10 cm of sediments in Harbor Isle Lake are illustrated on Figure 2-13 and are relatively uniform throughout the lake, with higher values in the southwest lobe.

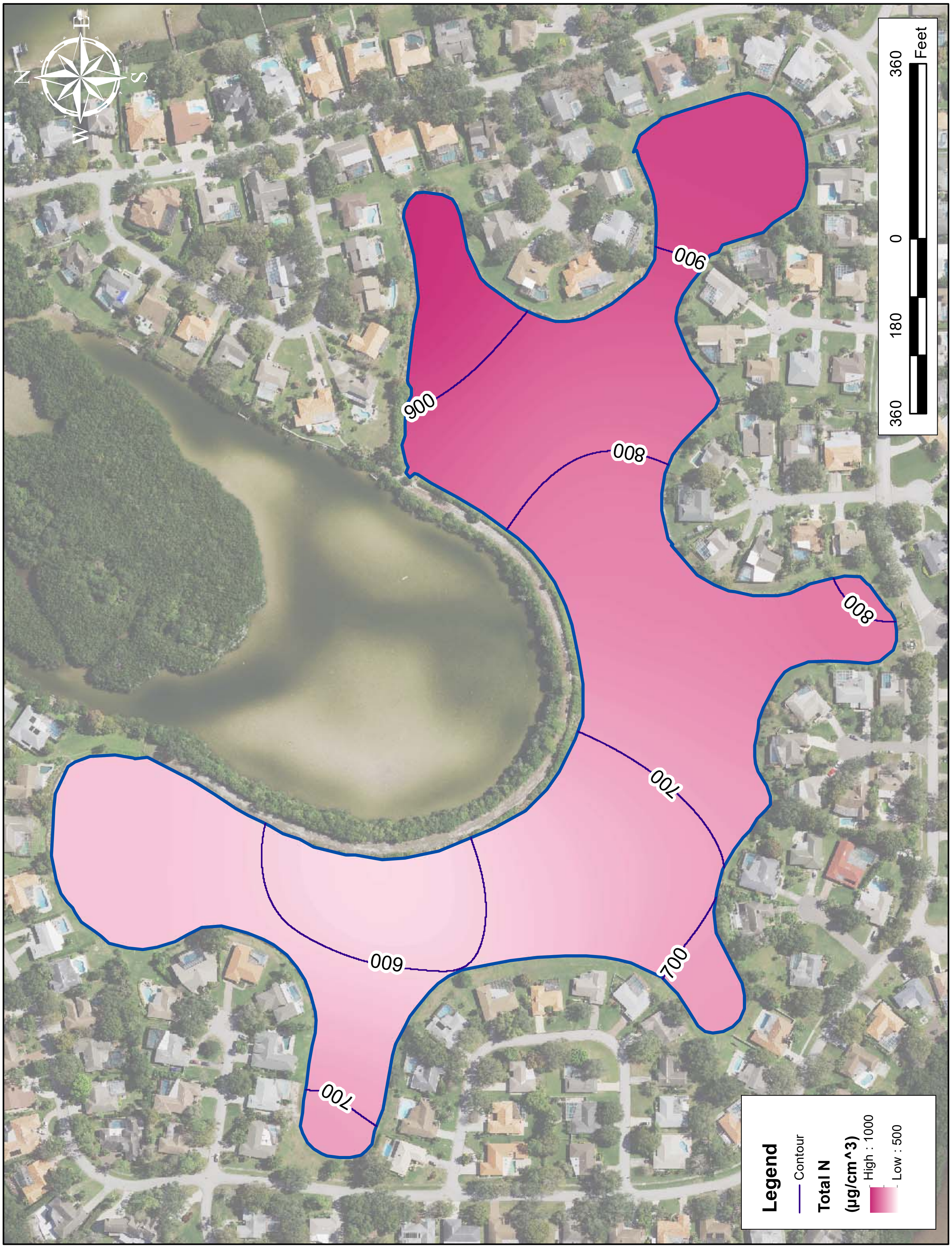


Figure 2-11. Isopleths of Total Nitrogen (µg/cm^3) in the Top 10 cm of Sediments in Harbor Isle Lake During April 2021.

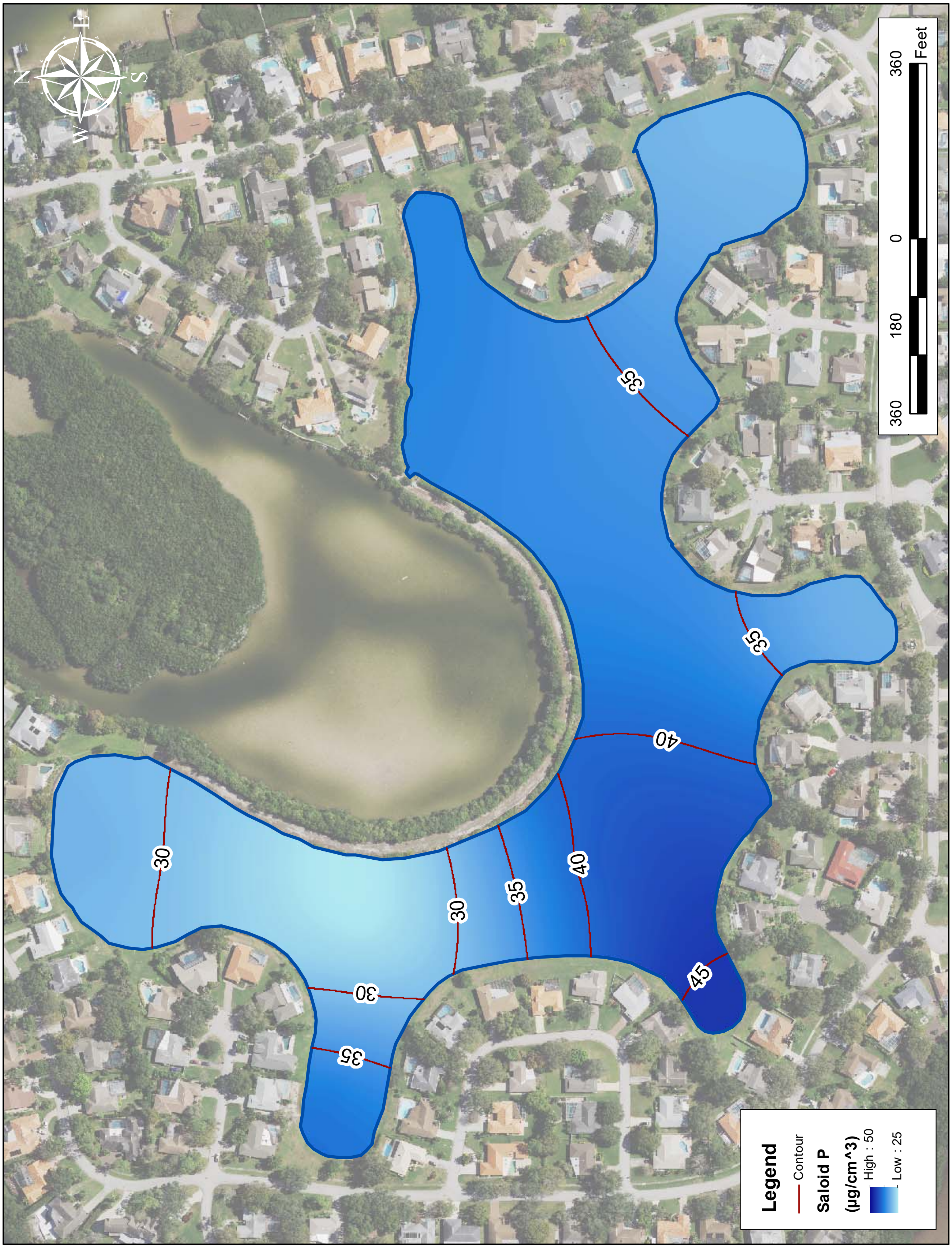


Figure 2-12. Isopleths of Saloid-Bound Phosphorus ($\mu g/cm^3$) in the Top 10 cm of Sediments in Harbor Isle Lake During April 2021.

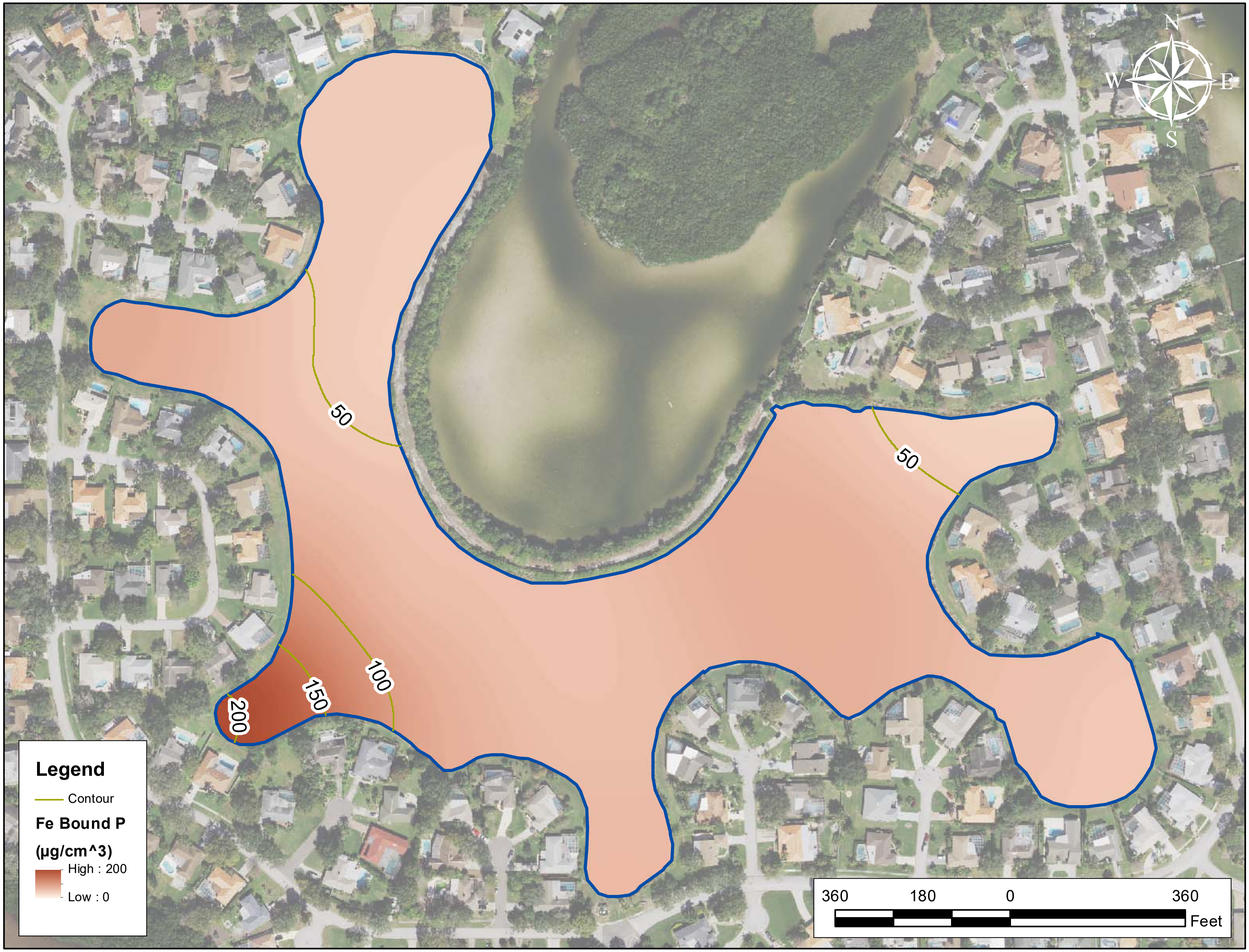


Figure 2-13. Isopleths of Iron-Bound Phosphorus (µg/cm^3) in the Top 10 cm of Sediments in Harbor Isle Lake During April 2021.

TABLE 2-7

PHOSPHORUS SPECIATION IN SEDIMENT CORE SAMPLES COLLECTED IN HARBOR ISLE LAKE DURING APRIL 2021

SITE	SALOID-BOUND P (μg/cm³ wet wt.)	IRON-BOUND P (μg/cm³ wet wt.)	TOTAL AVAILABLE P (μg/cm³ wet wt.)	ALUMINUM-BOUND P (μg/cm³ wet wt.)	PERCENT OF SEDIMENT P WHICH IS AVAILABLE (%)
1	31	53	85	128	17
2	37	47	83	113	21
3	36	80	116	202	21
4	32	66	98	169	15
5	37	60	97	135	21
6	45	191	236	383	22
7	41	69	110	269	16
8	26	49	75	251	11
9	38	82	120	283	15
10	31	46	77	263	12
Minimum	25.7	46	75	113	11
Maximum	45.0	191	236	383	22
Geometric Mean	35.0	67	103	205	17

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, and this information can be utilized as a guide for future sediment inactivation procedures.

A summary of total available phosphorus in each of the 10 collected sediment core samples is also given in Table 2-7. Total available phosphorus concentrations within the lake range from 75-236 μg/cm^3, with an overall geometric mean of 103 μg/cm^3. The mean sediment total available phosphorus in Harbor Isle Lake is much higher than the sediment available phosphorus concentrations commonly observed by ERD in urban lakes.

Isopleths of total available phosphorus in the top 10 cm of sediments in Harbor Isle Lake are illustrated on Figure 2-14. Available phosphorus concentrations are relatively uniform throughout Harbor Isle Lake, with more elevated values in the southwest lobe. The isopleths presented on Figure 2-14 can be utilized directly as a guide for future sediment inactivation activities, if desired.

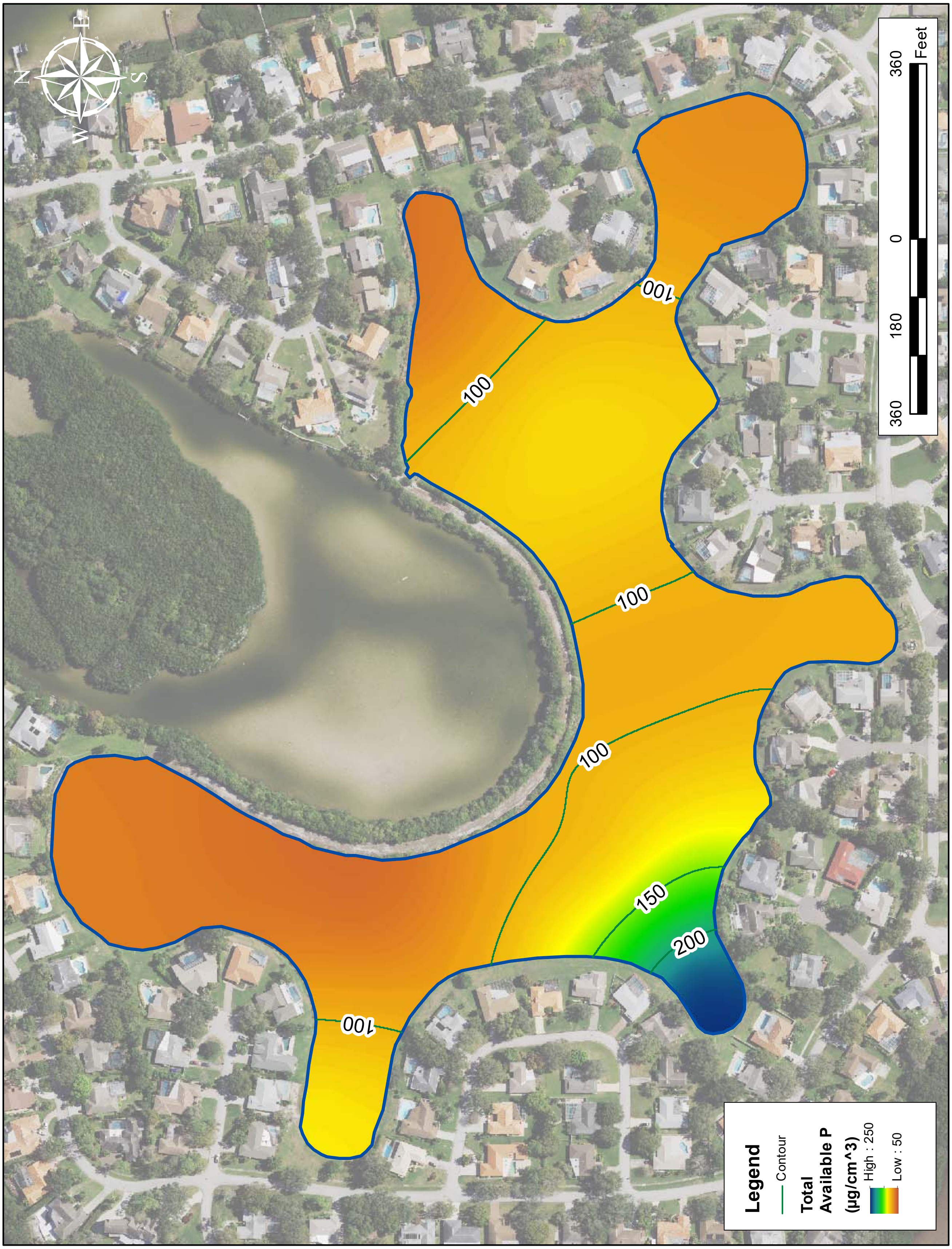


Figure 2-14. Isopleths of Total Available Phosphorus (µg/cm^3) in the Top 10 cm of Sediments in Harbor Isle Lake During April 2021.

Available sediment phosphorus is also expressed as a percentage of total phosphorus concentrations within the sediments. This value is calculated as the ratio of the total available phosphorus values listed for each site in Table 2-7 divided by the overall sediment phosphorus concentrations listed in Table 2-6. The percentage of available phosphorus within the sediments of Harbor Isle Lake ranges from approximately 11-22%, with an overall mean of 17%. This suggests that approximately 17% of the existing accumulation of phosphorus within the lake is potentially available for release into the overlying water column as a result of sediment agitation or anaerobic conditions.

Isopleths of the percentage of available sediment phosphorus in the top 10 cm of sediments in Harbor Isle Lake are illustrated on Figure 2-15. The highest percentages of available sediment phosphorus occur in northeastern portions of the lake and in the southwest lobe where the percentage of available phosphorus ranges from approximately 20-22.5%.

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 range from 113-383 $\mu g/cm^3$, with an overall mean of 205 $\mu g/cm^3$. These values appear to be much greater than aluminum-bound phosphorus concentrations commonly observed by ERD in urban lake systems and suggest that approximately 33% of the existing phosphorus within the sediments is bound in sediment associations with aluminum which are considered to be unavailable.

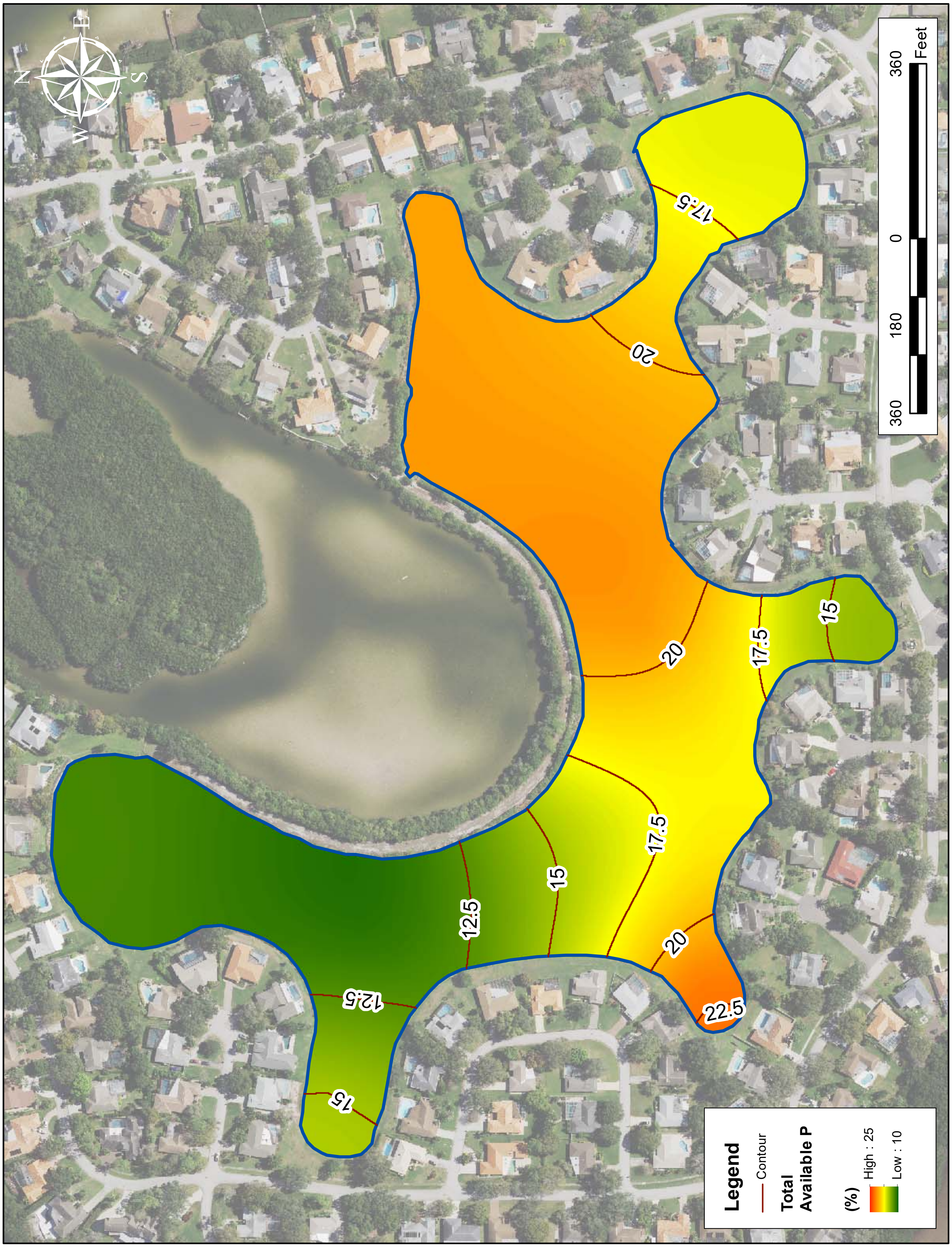


Figure 2-15. Isopleths of the Percentage of Available Sediment Phosphorus (%) in the Top 10 cm of Sediments in Harbor Isle Lake During April 2021.

SECTION 3

EVALUATION OF SEDIMENT NUTRIENT RELEASE AND MANAGEMENT OPTIONS

This section provides a summary of field and laboratory efforts conducted to measure sediment nutrient release in Harbor Isle Lake, including sediment core collection, incubation studies, lab analyses, and calculations used to quantify nutrient release throughout Harbor Isle Lake.

3.1 Introduction

Quantification of sediment phosphorus release as a result of internal recycling in lakes is difficult, and a variety of methods have been used by researchers to estimate this loading. One method which has been used in reservoirs is called the Mass Balance Method. This method is best suited to a waterbody with well defined inputs and outputs. A mass balance is then conducted on the waterbody over a one- to two-week period. An increase of phosphorus mass within the lake, after accounting for inputs and losses, would suggest that a net internal loading has occurred. However, this method appears inappropriate for use in Harbor Isle Lake since the lake is impacted by a wide variety of hydrologic and pollutant sources.

A method which has been used extensively in deep northern lakes is to measure changes in phosphorus content in the hypolimnion of a stratified lake over an extended period of anoxia. The increase in phosphorus mass within the stratified hypolimnion can then be directly correlated with sediment release rates. However, this method also appears inappropriate for use in Harbor Isle Lake due to access issues into the lake for an extended monitoring program, and uncertainty regarding the extend and duration of anaerobic conditions.

A third method of quantifying the internal loadings is through trophic state modeling. Using this approach, hydrologic and nutrient inputs are estimated from all quantifiable sources. A trophic state model is then developed to predict water column concentrations of total phosphorus. If the model underestimates phosphorus concentrations, then a missing phosphorus load may be present which can be attributed to internal recycling. However, this methodology can be highly inaccurate and is dependent upon the accuracy of the estimated loadings for other variables and the accuracy of the predictive model. In addition, nutrient availability does not necessarily limit productivity in Harbor Isle Lake and modeling may not accurately predict algal productivity.

The final method used for quantification of internal loadings is to perform sediment release experiments. In this method, large diameter sediment cores are collected from various locations within the lake and incubated in the laboratory under a variety of conditions to simulate variability in the lake throughout the year. Changes in phosphorus concentrations are measured in the overlying sediments, and this information is extrapolated to an areal release rate within the lake. This is the only method of estimating internal loadings which provides a direct measurement of phosphorus release. This method has been used by ERD in more than 60 Florida lakes in previous work efforts and was selected as the quantification method for Harbor Isle Lake.

Field and laboratory investigations were performed by ERD to quantify the mass of phosphorus released as a result of internal recycling from the sediments to the overlying water column in Harbor Isle Lake under both aerobic and anaerobic conditions. Large diameter lake sediment core samples were collected at multiple locations in the lake and incubated under anaerobic and aerobic conditions. Periodic measurements of orthophosphorus, total phosphorus, ammonia, NO_x, and total nitrogen were used to estimate sediment phosphorus release under the evaluated conditions. This information is used to provide an estimate of the significance of mass loadings of nitrogen and phosphorus from the lake sediments as part of the overall nutrient budget for the lake.

3.2 Field and Laboratory Procedures

Sediment core samples were collected at 4 locations in Harbor Isle Lake using 4-inch diameter clear acrylic core tubes. Locations used for collection of the sediment core tubes in Harbor Isle Lake are indicated on Figure 3-1. Water depths at each site are also provided for reference purposes. Sediment nutrient release varies within lakes, with higher release in deeper lake areas and lower release in shallow areas. The sample locations are intended to reflect sediment characteristics in water depths ranging from 0-5 ft (Site LC-1), 5-10 ft (Site LC-2), 10-15 ft (Site LC-3), and >15 ft (Site LC-4), and release rates at these sites are assumed to be uniform throughout the lake for each evaluated depth range.

Each of the acrylic tubes was driven into the sediments to the maximum possible depth using a 20-pound hammer weight. A 4-inch x 4-inch wooden beam was placed on top of the acrylic core tubes to evenly distribute the force of each hammer blow and to prevent direct contact between the hammer weight and the acrylic tube. The acrylic tubes were penetrated into the sediments to depths ranging from approximately 2-6 ft, depending upon the physical characteristics of the sediments at each of the selected monitoring sites or until a firm bottom material was encountered. Each of the core tubes was retrieved intact, along with the overlying water column present at each of the collection sites. Upon retrieval, a rubber cap was attached to the bottom of each core tube and secured using a stainless steel hose clamp to prevent loss of sediments and water. A 4-inch PVC cap was then placed on the top of each collected core tube, and the core tubes were transported to the ERD laboratory in a vertical position to avoid mixing of the sediment layers. Photographs of the collected large core samples are given in Figure 3-2.

Figure 3-1. Locations for Collection of Large Diameter Core Samples in Harbor Isle Lake. (Approximate water depth provided in parentheses)

Figure 3-2. Photos of Large Core Samples Collected in Harbor Isle Lake.

After return to the laboratory, the sediment depth in each of the 4 core samples was adjusted to a uniform 24-30 inches by releasing sediment as necessary from the bottom of each core tube. The collected water volume above the sediments was carefully siphoned off and replaced with a 24-inch layer of lake water collected from Harbor Isle Lake. Each of the acrylic core tubes was then cut to a uniform height of 56 inches, leaving a 6-inch air space between the water level and the top of the column. Three separate 0.25-inch diameter holes were then drilled into the PVC cap attached to the top of each core sample. A 0.25-inch diameter semi-rigid polyethylene tube was inserted through one of the holes to a depth of approximately 4-6 inches above the sediment surface, and an air stone diffuser was attached to the end of the tubing inside each core tube. This system was used to introduce selected gases into the core tubes to encourage aerobic or anaerobic conditions.

A separate piece of polyethylene tubing was inserted into the second hole in the top of each core tube, approximately 1 inch below the level of the cap, but above the water level contained in each tube. The other end of the tubing was connected to an external water trap to minimize loss of water from each column as a result of evaporation. This tubing also provided a point of exit for gases which were bubbled into each core tube to verify gas additions to each tube. The rate of gas addition was regulated at 0.2 liters per minute using a dedicated flow valve and regulator for each tube. A third 0.25-inch polyethylene tube was inserted through the top cap of the 4-inch cap and extended to approximately mid-way into the overlying water column for sample collection. The 4-inch core tubes were placed inside a 6-inch Sch. 40 PVC pipe to provide a dark controlled environment for creating either aerobic or anaerobic conditions. The 6-inch PVC chambers were attached to a frame for support. Schematics of the sediment incubation apparatus are given in Figures 3-3 and 3-4.

After initial set-up of the incubation apparatus, a stream of compressed air was introduced into each of the core tubes at a constant rate of 0.2 liter/minute through a manifold system with attachments to each of the individual air stone diffusers. This process quickly created aerobic conditions within the core tubes. This process was continued in each of the core tubes for a period of 34 days. The gas addition was used to maintain aerobic conditions in the water column and ensure that water within each of the core tubes was well mixed without disturbing the sediments, so that the nutrient mass released from the sediments could be quantified as a function of changes in concentrations within the water column of each core tube. On approximately a 1-2 day interval, 20 ml of water was withdrawn from each of the columns through the 0.25-inch polyethylene tube using a plastic laboratory syringe. Each of the collected samples was immediately filtered using a 0.45 micron syringe type membrane filter and analyzed for ammonia, NO_x, total nitrogen, orthophosphorus, and total phosphorus using the analytical methods outlined in Table 3-1.

At the conclusion of the experimentation under aerobic conditions, the compressed air source was replaced with a compressed argon source. Compressed argon was gently bubbled through each of the columns at a constant rate of 0.2 liter/minute to decrease dissolved oxygen and create anaerobic conditions within each tube. After anaerobic conditions were established, as verified by an H_2S smell in the outflow from the water trap, the argon gas addition was reduced to 1-2 hours per day, generally in association with a sampling event, to ensure completely mixed conditions within each tube prior to sample collection. In general, creation of anaerobic conditions, as indicated by measurements of redox potential (< 200 mv) within each of the columns, occurred within approximately 24-36 hours. At the onset of anaerobic conditions, sample collection was conducted at a 1-2 day interval from each of the columns using the method previously outlined for aerobic conditions.

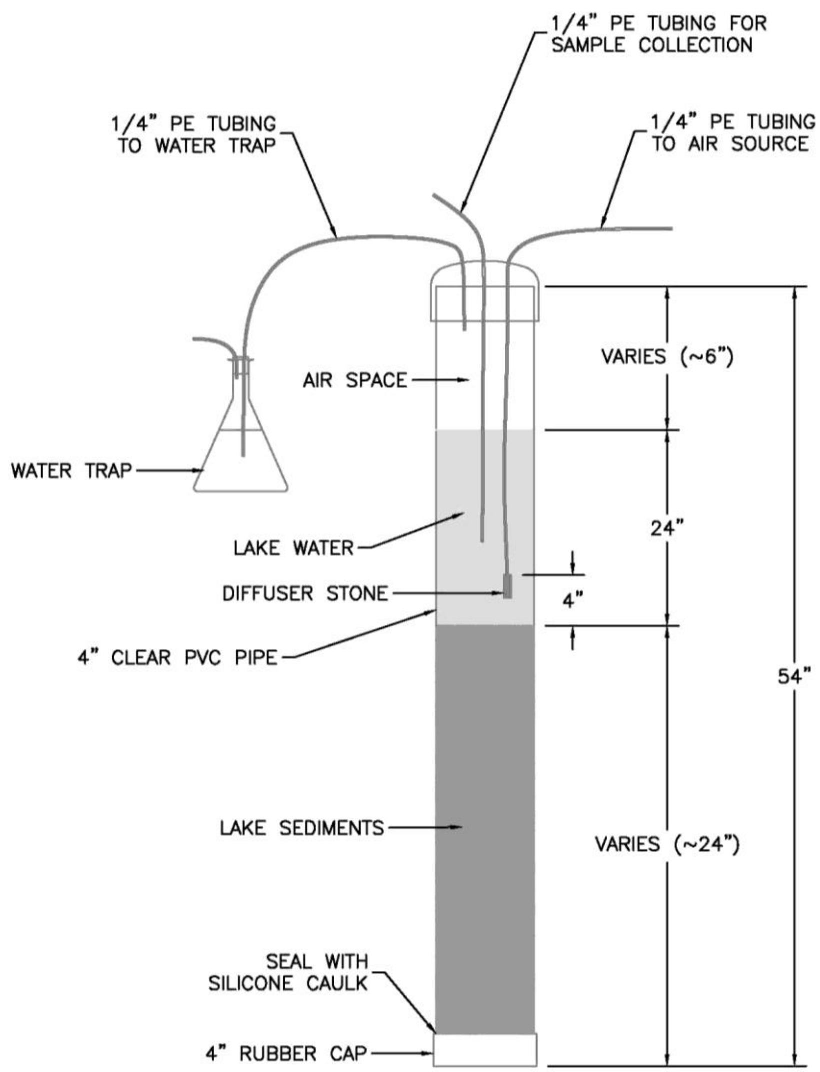


Figure 3-3. Schematic of Sediment Incubation Apparatus.

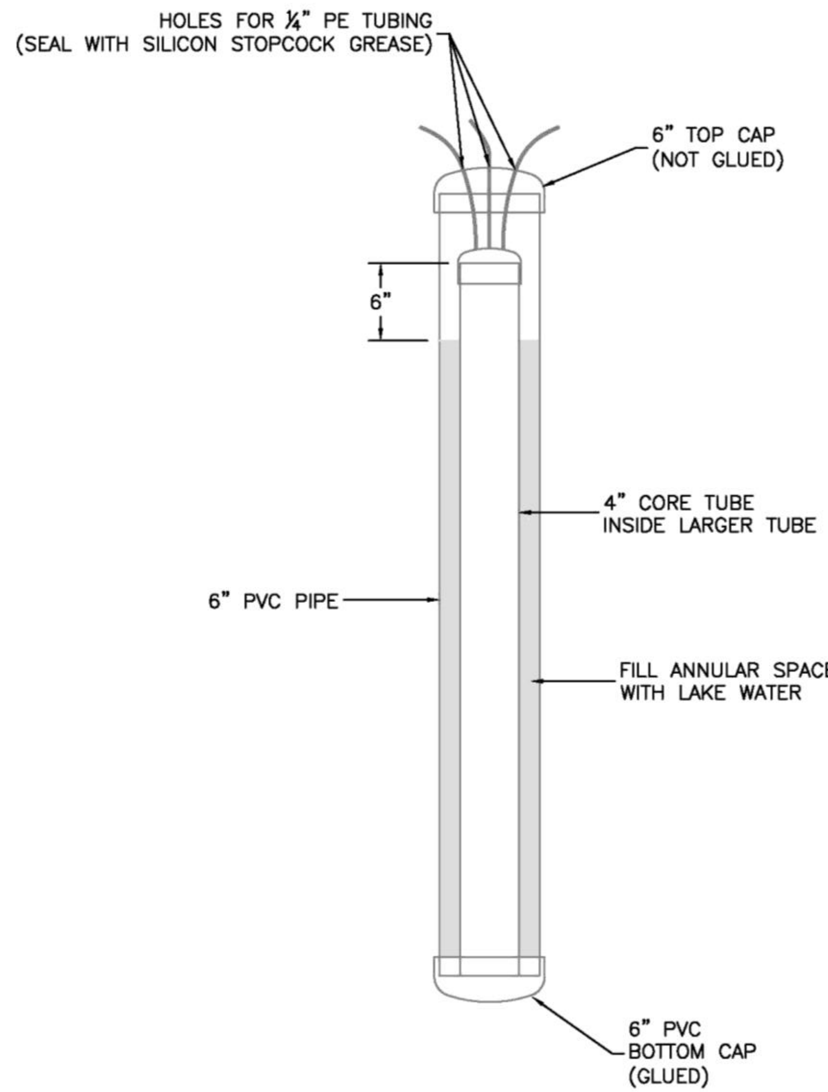


Figure 3-4. Schematic of Sediment Core Incubation System

TABLE 3-1

ANALYTICAL METHODS AND DETECTION LIMITS FOR ERD LAB ANALYSES

PARAMETER	METHOD OF ANALYSIS[1]	METHOD DETECTION LIMITS (MDL)[2]
Ammonia	SM-21, Sec. 4500-NH_3 G	0.005 mg/l
NO_x	SM-21, Sec. 4500-NO_3 F	0.002 mg/l
Total Nitrogen	SM-21, Sec. 4500-N C	0.002 mg/l
Ortho-P (SRP)	SM-21, Sec. 4500-P F	0.001 mg/l
Total Phosphorus	SM-21, Sec. 4500-P F (analysis) and Sec. 4500-P B.5	0.002 mg/l

1. Standard Methods for the Examination of Water and Wastewater, 21st Ed., 2005
2. MDLs are calculated based on the EPA method of determining detection limits

Collection of the large diameter (4-inch) sediment core samples was performed in Harbor Isle Lake on April 8, 2021. Experimentation under aerobic conditions was conducted in each core tube for a period of 34 days. Anaerobic experimentation was initiated at the end of the aerobic experiments and was also continued for a period of 34 days.

3.3 Calculation of Mass Release

A summary of the laboratory results of samples collected during the sediment release experiments is given in Appendix B-1. Changes in concentrations of phosphorus and nitrogen over time are provided for each of the isolation chamber experiments under both aerobic and anaerobic conditions. The measured concentrations of total nitrogen, SRP, and total phosphorus from each sampling date (in μg/l) are multiplied by the volume of water in each large core cylinder (liter), corrected for volume losses due to sample collection, to obtain the mass of each measured parameter in the overlying water column at the time of each monitoring event (mass in μg). The measured values reflect **net** sediment release since some of the released nutrients are likely taken up by biological processes in each tube.

The mass release rate in the incubation experiments is defined as the slope of the rising limb of the total nitrogen, SRP, and total phosphorus release plots presented in Appendix B-2. The mass of nitrogen and phosphorus in the water column of each core tube is plotted as a function of time to evaluate the rate of change in mass over time, and the best-fit regression line through the points is used to calculate the release rate in terms of μg/day. In some chambers, an initial delay in nutrient release occurred as anaerobic or aerobic conditions were established within each chamber. In these cases, the release rate is calculated using the data obtained between the start of the upward release trend and the maximum concentrations measured within a sample. In some experiments, concentrations began to decrease after reaching the maximum concentration, presumably due to biological uptake within the chamber after reaching the rate of maximum release. These data are also excluded from estimation of the release rate. Regression relationships developed for estimation of sediment phosphorus release rates in the incubation experiments under aerobic and anaerobic conditions are included in Appendix B-2.

A summary of calculated sediment nutrient release rates in Harbor Isle Lake during the isolation chamber experiments is given in Table 3-2. Release rates are provided for total nitrogen, SRP, and total phosphorus in each of the 4 isolation chamber core samples under both aerobic and anaerobic conditions. The release rates reflect the slope of the total nitrogen, SRP, and total phosphorus release rate plots provided in Appendix B-2. The calculated release rates are converted into a mass release per day by dividing by the surface area of the 4-inch diameter incubation chambers resulting in an areal mass release in terms of mg/m^2-day.

TABLE 3-2

MEASURED EXPERIMENTAL SEDIMENT RELEASE RATES IN HARBOR ISLE LAKE

CONDITION	SITE	MASS RELEASE (µg/day)			MASS RELEASE (mg/m^2-day)		
		SRP	Total P	Total N	SRP	Total P	Total N
Aerobic	LC-1	16.2	16.4	42.7	2.03	2.05	5.3
	LC-2	30.1	30.2	101	3.76	3.73	12.6
	LC-3	28.9	30.2	66.4	3.61	3.78	8.3
	LC-4	34.9	83.7	168	4.36	10.5	21.0
	Mean	**27.5**	**40.1**	**94.5**	**3.4**	**5.0**	**11.8**
Anaerobic	LC-1	8.6	25.9	119	1.08	3.24	14.9
	LC-2	20.6	22.7	205	2.58	2.84	25.6
	LC-3	25.7	26.2	327	3.21	3.28	40.9
	LC-4	16.8	17.2	731	2.10	2.15	91.4
	Mean	**17.9**	**23.0**	**346**	**2.24**	**2.88**	**43.2**

Under aerobic conditions, the mean mass release rate for SRP ranged from 2.03-4.36 mg/m^2-day in the 4 sediment isolation chambers, with total phosphorus release rates ranging from 2.05-10.5 mg/m^2-day, and total nitrogen release rates ranging from 5.3-21.0 mg/m^2-day. Overall, SRP contributed approximately 68% of the measured total phosphorus release under aerobic conditions, with the remainder contributed by organic phosphorus. Release of nitrogen from the lake sediments was comprised primarily of nitrate. The measured aerobic release rates for phosphorus in the Harbor Isle Lake sediments are similar to values normally observed in hypereutrophic lakes. Phosphorus release rates increased with increasing water depth for both SRP and total phosphorus. Nitrogen release also increased with increasing water depth, but the correlation is not as clear as observed for phosphorus.

Under anaerobic conditions, release rates for SRP and total phosphorus decreased compared with aerobic conditions, a phenomenon rarely observed in lakes. SRP release rates ranged from 1.08-3.21 mg/m^2-day and total phosphorus release rates ranged from 2.15-3.28 mg/m^2-day. Under anaerobic conditions, SRP release comprised approximately 78% of the total phosphorus release. Release rates for total nitrogen under anaerobic conditions were greater than values measured under aerobic conditions, with release rates ranging from 14.9-91.4 mg/m^2-day.

The only current source of information on vertical dissolved oxygen concentrations in Harbor Isle Lake is the very limited work conducted by Solitude. Based on a review of available Solitude data, it appears that aerobic conditions are maintained at all times in water ranging from 0-5 ft, about 50% of the time for water depths ranging from 5-10 ft, and constant anaerobic conditions at depths greater than 10 ft. This information is used to weight nutrient release rates based on the frequency of aerobic and anaerobic conditions at each site.

The measured aerobic and anaerobic release rates (summarized in Table 3-2) were weighted by the estimated frequency of occurrence of aerobic and anaerobic conditions at each of the 4 sites to obtain estimates of weighted annual nutrient release for SRP, total phosphorus, and total nitrogen within each core tube. A summary of this analysis is given on Table 3-3. Weighted release rates are provided for SRP, total phosphorus, and total nitrogen based upon the areal release rates (summarized in Table 3-2) and the assumed frequency of aerobic and anaerobic conditions. Areas contained in the 0-5 ft, 5-10 ft, 10-15 ft, and >15 ft depth intervals were obtained from the bathymetric data for Harbor Isle Lake summarized in Table 2-1. The weighted areal nutrient release rates are then multiplied by the assumed lake area over which the release rates apply to obtain estimates of overall nutrient release from the sediments into Harbor Isle Lake on an annual basis.

TABLE 3-3

CALCULATED ANNUAL SEDIMENT RELEASE OF TOTAL NITROGEN AND TOTAL PHOSPHORUS IN HARBOR ISLE LAKE

SITE	WATER DEPTH (ft)	FREQUENCY OF CONDITION (%)		WEIGHTED RELEASE (mg/m^2-day)			ASSUMED AREA (acres)	MASS PHOSPHORUS RELEASE (kg/yr)		
		Aerobic	Anaerobic	SRP	Total P	Total N		SRP	Total P	Total N
LC-1	0-5	100	0	2.0	2.1	5.3	7.8	23.3	23.6	61.5
LC-2	5-10	50	50	3.2	3.3	19.1	7.3	34.2	35.7	206
LC-3	10-15	0	100	3.2	3.3	40.9	5.4	25.6	26.1	326
LC-4	> 15	0	100	2.1	2.2	91.4	5.4	16.8	17.2	729
Geometric Mean:				**2.6**	**2.6**	**24.8**	**25.9**	**100**	**103**	**1,323**

Estimates of annual mass nutrient release from sediments in Harbor Isle Lake are provided in the final columns of Table 3-3. On an annual average basis, sediment nutrient release contributes approximately 100 kg/yr of SRP, 103 kg/yr of total phosphorus, and 1,323 kg/yr of total nitrogen to the lake.

3.4 Annual Nutrient Budgets

An estimated annual nutrient budget for Harbor Isle Lake is given in Table 3-4. The budget includes annual loadings from runoff and reuse from the 2020 Janicki report and the sediment release measured by ERD. This analysis does not include loadings from groundwater seepage or bulk precipitation, but these loading sources are generally less than 10-15% of the total nutrient budgets. Internal recycling appears to be the largest single loading source to Harbor Isle Lake, contributing 78% of the annual nitrogen and 71% of the annual phosphorus loadings to the lake. Reuse and runoff contribute variable but low proportions of annual loadings.

TABLE 3-4

ESTIMATED ANNUAL NUTRIENT BUDGETS FOR HARBOR ISLE LAKE

LOADING SOURCE	REFERENCE	MASS LOADING (kg/year)		PERCENT OF TOTAL (%)	
		Total N	Total P	Total N	Total P
Runoff	Janicki (2020)	152	27	9	19
Reuse	Janicki (2020)	221	15	13	10
Sediments	ERD (2021)	1,323	103	78	71
	TOTAL:	**1,696**	**145**	**100**	**100**

3.5 Sediment Management

The most significant source of nutrient loading to the Harbor Isle Lake is sediment nutrient release which contributes 78% of the annual nitrogen loading and 71% of the annual phosphorus loading. Although calculated nutrient ratios indicate that Harbor Isle Lake is nitrogen-limited, eutrophic waterbodies cannot be restored by controlling nitrogen since some species of cyanobacteria, common in eutrophic lakes, can assimilate atmospheric nitrogen if inorganic nitrogen becomes limiting. Therefore, eutrophic waterbodies which appear to be nitrogen-limited can only be restored by controlling phosphorus to create a phosphorus-limited condition, and nutrient management options should primarily target phosphorus.

Based upon the field monitoring and sediment incubation experiments conducted by ERD, it is apparent that the existing sediment accumulations contribute the most significant nitrogen loading to the waterways each year, and water quality within the waterways could be improved by reducing the observed internal nitrogen loadings. Freshwater systems where phosphorus is the limiting nutrient, sediment nutrient release can be easily and economically controlled using a targeted application of aluminum sulfate (commonly called alum) which binds sediment phosphorus in an insoluble form. The application of alum to sediments reduces the level of microbial activity in sediments and often indirectly reduces nitrogen release simultaneously with phosphorus. However, the chemistry of aluminum in brackish sediments becomes quite complex, and this technology has never been tested in brackish systems.

There are several basic methods which have been used in surface water management projects to mitigate impacts from internal recycling. Sediment dredging has been used in both marine and freshwater systems to remove the accumulated sediments and the source of nutrient release, although water quality improvements from dredging have been limited.

3.5.1 Sediment Dredging

Sediment dredging is a technique which reduces internal recycling by removing the existing organic muck, leaving the original parent bottom material of the waterbody. This option is designed to reduce water quality impact from the existing sediments, with added benefits of increasing water depth and water volume. A decision to remove accumulated bottom sediments generally occurs when there is sufficient evidence that the accumulated sediments are having an adverse impact on habitat, water quality, recreation, or navigation.

3.5.1.1 Dredging Methods

Sediment removal by dredging can be accomplished by either mechanical or hydraulic dredging methods. Mechanical dredging in canals can be accomplished using a shoreline-based dragline, but mechanical dredging in lakes most frequently involves either partially or completely draining the lake to expose the sediments to drying conditions. Conventional earth-moving equipment, such as bulldozers, scrapers, backhoes, and draglines, are then used to remove the dried sediments. The sediment material is stockpiled on the shore and then hauled away in dump trucks to a disposal location. This technique was used routinely by the Florida Fish and Game Commission during the 1970s and 1980s, but improvements in water quality were limited.

Given the size, the direct proximity to tidal waters, high water table, and importance of the lake for stormwater management, it is highly unlikely that even a relatively small portion of the lake could be dried enough to allow mechanical dredging to occur. Even if portions of a lake were isolated using sheetpile, continuous seepage of groundwater inflow would make adequate dewatering of these areas extremely difficult. Access to the lake for earth-moving equipment would be nearly impossible given the dense residential development and roadway systems surrounding the lake.

The most likely option for dredging in Harbor Isle Lake would be hydraulic dredging. During hydraulic dredging, a hydraulic dredge excavates and pumps material from the bottom through a temporary HDPE pipeline to an off-site location which is often several thousand feet to several miles away. The head of the dredging unit is equipped with a rotating cutter with steel blades to dislodge and homogenize the sediments, and a centrifugal pump is used to "suck up" the muck and water mixture, forming a slurry. Control of the dredging depth occurs by manipulation of the suction head in both a vertical and horizontal direction. Since water is removed along with the sediment, hydraulic dredging slurries are commonly 80-90% water. An advantage of hydraulic dredging is that it is generally faster than mechanical dredging, does not require dewatering, and creates less turbidity in the dredged waterbody. Hydraulic dredging is also often the most cost-effective method for large dredging projects. As a result, this analysis will assume that the proposed dredging is accomplished in Harbor Isle Lake using a hydraulic dredge.

3.5.1.2 <u>Containment Area Requirements</u>

The dredged sediment material would be pumped to a disposal area where the sediments would be allowed to dewater and dry out over time, and the clarified water may or may not be returned to the place of origin, depending on the location of the containment pond. The disposal area must be sufficient in size to hold not only the dredged sediments, but also the large volume of pumped sediment/water slurry that occurs during the actual dredging process. When sediments are formed into a slurry by the dredge, the volume of the sediments tends to increase temporarily which is referred to as the "bulking factor". This additional volume must also be considered when designing the disposal basin. Bulking factors ranging from 1.2-1.5 are typical, with a mid-range factor of 1.35 assumed for Harbor Isle Lake.

A summary of dredging design assumptions and containment area requirements for Harbor Isle Lake sediments is given on Table 3-5. Based on the information provided in Table 2-3, this analysis assumes that a sediment volume of approximately 104 ac-ft would be removed during the dredging process, equivalent to approximately 167,787 yd^3. Assuming a bulking factor of 1.35, the total volume of sediment/water slurry which must be contained within the containment area is 251,680 yd^3 assuming that all portions of the lake were dredged at the same time.

Containment areas are commonly constructed on relatively flat ground, with a berm around the perimeter to contain the dredged slurry. To minimize stability issues associated with the containment berm, the depth of the dredged slurry is frequently limited to approximately 3-4 ft. An additional freeboard of approximately 1 ft would also be incorporated into the design to provide an average berm height of approximately 5 ft with a maximum slurry depth of 4 ft. Based upon these criteria, the required containment area for hydraulic dredging of Harbor Isle Lake sediments would be approximately 35 acres. Assuming an additional 20% area for roadways and access to various portions of the containment area, the total required site area would be approximately 42 acres. The containment site would ideally be located close to the waterbody being dredged, although remote locations can also be utilized at an increased unit cost. Assuming 0.50-acre lots, the containment area is equivalent to approximately 84 residential lots.

TABLE 3-5

SUMMARY OF DREDGING DESIGN ASSUMPTIONS AND CONTAINMENT AREA REQUIREMENTS FOR HARBOR ISLE LAKE

PARAMETER	UNITS	VALUE
Existing Sediment Volume	ac-ft ft^3 yd^3	104 4,530,240 167,787
Assumed Bulking Factor	--	1.35
Containment Area Volume	ac-ft ft^3 yd^3	140 6,098,400 225,867
Assumed Containment Area Depth, with 1 ft Freeboard	ft	5
Required Containment Area (4-ft slurry depth)	acres	35
Disposal Site Area with 20% Buffer	acres	42

3.5.1.3 Dredging Costs

Costs for hydraulic dredging typically range from approximately \$15-40/yd^3 which includes the actual dredging, pumping of the dredged slurry to the containment area, construction of containment area berms, construction of a return water discharge from the containment area, expenses for treatment of the dredged slurry to meet discharge requirements, and in some cases, post-dredging restoration of the containment site. The variability in cost is a function of accessibility, length of slurry pipeline required, and the composition and dewatering characteristics of the sediment material. Pumping the sediment slurry long distances to remote disposal sites often requires booster pumping systems which add substantially to the project cost.

No significant vacant parcels currently exist in the Harbor Isle Lake drainage basin which could accommodate the proposed containment area, so an off-island parcel would need to be obtained. Land costs for these parcels are assumed to be approximately $100,000/acre, although costs could be substantially higher or may not be available at all. For purposes of estimating dredging costs, an assumed dredging cost of \$40/yd^3 is used.

A summary of estimated costs for hydraulic dredging of Harbor Isle Lake sediments is given in Table 3-6 and includes costs for dredging, land costs for the disposal area, and engineering design and testing. The estimated dredging cost for removal of 167,787 yd^3 of material from Harbor Isle Lake is conservatively estimated at approximately $6,711,480. This value does not include any cost associated with land purchase which may be required for the containment area. Assuming that land purchase is required, the estimated cost for 42 acres of vacant off-island land at a cost of $100,000/acre is $4,200,000. An additional $200,000 is included for engineering, design and testing during the dredging feasibility analysis phase, and dredging oversight. The estimated total project cost with land purchase is approximately $11,111,480. However, a portion of the total cost may be recovered by restoring and selling the land required for the disposal area when dredging is completed.

TABLE 3-6

ESTIMATED COSTS FOR HYDRAULIC DREDGING OF HARBOR ISLE LAKE SEDIMENTS

PARAMETER	UNITS	VALUE
Sediment Volume	yd^3	167,787
Assumed Dredging Cost	$\$/yd^3$	40
Dredging Cost	$	6,711,480
Assumed Land Costs (42 acres)	$	4,200,000
Engineering/Design	$	200,000
TOTAL COST:	**$**	**11,111,480**

It is unlikely that dredging of Harbor Isle Lake sediments would completely eliminate internal recycling for several reasons. First, previous evaluations of dredging projects have indicated that dredging is rarely 100% effective in removing sediments, and isolated pockets of sediments will remain which redistribute over the bottom of the waterway, contributing a continued internal loading. Second, the parent material which is exposed as a result of the dredging may also have a limited nitrogen release in spite of sediment removal. In addition, sediment removal would not impact nutrient loadings entering Harbor Isle Lake from groundwater seepage, and this unquantified input may be sufficient to maintain eutrophic conditions in spite of sediment removal. Finally, water quality improvements from previous dredging projects have been highly variable.

3.6 Sediment Inactivation

3.6.1 Introduction

Sediment inactivation is a lake restoration technique which is designed to reduce sediment phosphorus release by combining available phosphorus in the sediments with a metal salt to form an insoluble inert precipitate, rendering the sediment phosphorus unavailable for release into the overlying water column. Although salts of aluminum, calcium, and iron have all been used for sediment inactivation in previous projects, aluminum salts are the clear compounds of choice for this application. Inactivation of sediment phosphorus using aluminum is often a substantially less expensive option for reducing sediment phosphorus release since removal of the existing sediments is not required.

Sediment phosphorus inactivation is most often performed using aluminum sulfate, commonly called alum, which is applied at the surface in a liquid form using a boat or barge. Upon entering the water column, the alum forms an insoluble precipitate of aluminum hydroxide which attracts phosphorus, bacteria, algae, and suspended solids within the water column, settling these constituents into the bottom sediments. After reaching the bottom sediments, the residual aluminum binds tightly with phosphorus within the sediments (primarily saloid-bound and iron-bound associations), forming an inert precipitate which will not be re-released under any conceivable condition of pH or redox potential which could occur in a natural lake system.

It is generally recognized that the top 10 cm layer of the sediments is the most active in terms of release of phosphorus under anaerobic conditions, although the active layer may extend to 15 cm in highly fluid sediments. 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. More than 50 whole-lake sediment inactivation projects have been conducted within the State of Florida, with the first large-scale application conducted during 1992 on Lake Conine in Polk County. To our knowledge, sediment inactivation has never been conducted to control sediment nutrient release in a brackish system, and almost all previous projects have been conducted in lakes with salinity of 1.9 ppt or less, compared with recent salinity measurements in Harbor Isle Lake ranging from 5.5-6.09 ppt. There is no doubt that sediment inactivation would reduce internal nutrient recycling in Harbor Isle Lake. However, the increased salinity will cause co-precipitation of aluminum with a variety of compounds in addition to phosphorus, and the impacts of this process on the dose determination, effectiveness, and longevity of sediment inactivation in brackish water. It is likely that sediment inactivation in brackish water will require a higher aluminum dose, and the calculations of chemical requirements conducted in this section are based on assumptions which enhance aluminum dose calculations.

Due to differences in electronegativities, phosphorus preferentially attaches to iron and several other metals in sediments before aluminum. The concept behind inactivating sediment phosphorus using aluminum is based upon increasing aluminum concentrations within the sediments to the point where phosphorus would preferentially bind with aluminum rather than in a redox sensitive form with iron. The addition of aluminum to the sediments uses Le Chatelier's Principle which states that an increase in reactants (in this case aluminum) will drive the chemical reaction to increase the concentration of the products (aluminum-bound phosphorus). Once phosphorus is bound to aluminum, it is essentially removed from biological availability.

Previous sediment inactivation work conducted by ERD as well as other researchers has indicated that a molar Al:P ratio of 10:1 is typically sufficient to provide a driving force to allow aluminum to preferentially absorb phosphorus in freshwater sediments over iron. If the average available sediment phosphorus concentration is <50 $\mu g/cm^3$, the molar Al:P ratio is typically increased to 15:1, or 20:1 for available sediment phosphorus concentrations substantially less than 50 $\mu g/m^3$, to provide a sufficient driving force. As indicated in Table 2-7, the geomean total available phosphorus concentration in Harbor Isle Lake is 103 μg/l which is in the range where an Al:P ratio of 10:1 is used. However, this ratio is increased to 15:1 for Harbor Isle Lake to compensate for co-precipitation processes.

Estimates of chemical requirements for sediment inactivation projects are typically based upon the mass of total available phosphorus within the top 0-10 cm layer of the sediments. For sediment inactivation purposes, available phosphorus is defined as the sum of the saloid-bound phosphorus, defined as soluble + easily exchangeable, and iron-bound phosphorus associations. Phosphorus bound to iron in the sediments is stable under aerobic conditions, but solubilizes under anaerobic conditions and is subject to re-release from the sediments into the overlying water column.

Additional aluminum can be added to the sediments to create 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. Carefully planned applications of alum can provide an abundance of aluminum which can intercept groundwater inputs of phosphorus, regardless of source, over a period of many years. As a result, alum applications can be used to eliminate phosphorus from the combined inputs from internal recycling as well as groundwater seepage.

Although sediment inactivation is a common tool in freshwater lakes, this process has never been conducted on a large scale in a waterbody with a salinity greater than 1 ppt. Aluminum will still bond to phosphorus at higher salinities, but a number of competing precipitates will also form, and the impacts to dosing requirements and longevity are not known. A discussion of chemical requirements and costs for alum sediment inactivation is given in following sections, and conservative assumptions have been used to increase the applied dose to compensate for competing precipitates. However, sediment inactivation in Harbor Isle Lake should be viewed as an experimental effort.

3.6.2 Chemical Requirements and Costs

Estimates of the mass of total available phosphorus within the top 0-10 cm layer of the sediments in Harbor Isle Lake were generated by graphically integrating the isopleth map of total available phosphorus in the lake sediments (provided in Figure 2-14). An overview of contour areas of total available phosphorus in Harbor Isle Lake sediments is given on Figure 3-5. Total available phosphorus contours on this map range from 50-250 μg P/cm^3. The top 0-10 cm layer of the sediments is considered to be the most active layer with respect to exchange of phosphorus between the sediments and the overlying water column, and 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 Harbor Isle Lake and alum requirements for sediment inactivation is given in Table 3-7 based on the assumed Al:P ratio of 15:1. On a mass basis, the sediments of Harbor Isle Lake contain approximately 1,067 kg of available phosphorus in the top 10 cm which equates to approximately 34,406 moles of phosphorus to be inactivated as part of the sediment inactivation process. Using an Al:P ratio of 15:1, sediment inactivation in Harbor Isle Lake would require approximately 62,730 gallons of alum, equivalent to 13.9 tanker loads containing 4,300 gallons each.

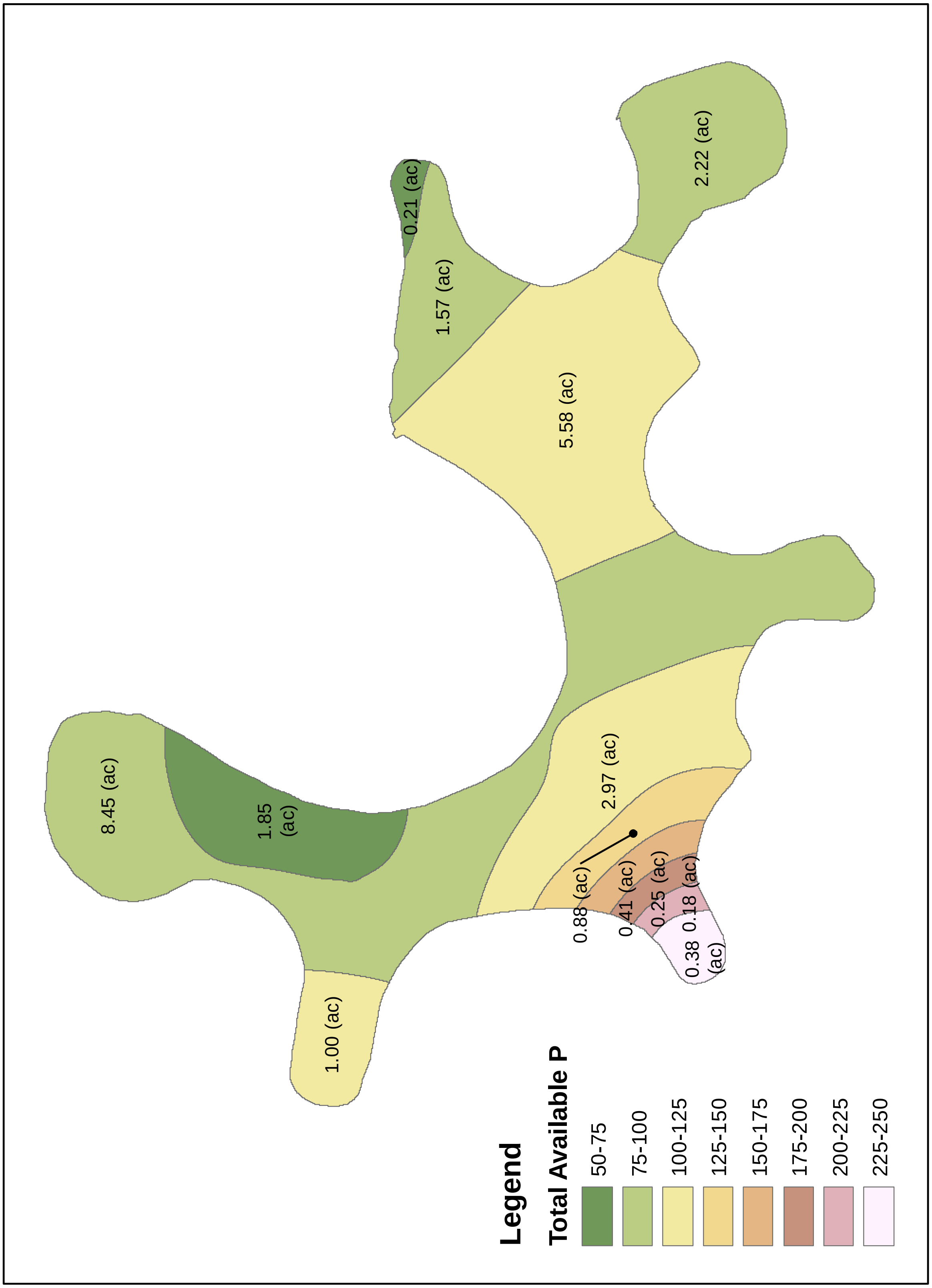


Figure 3-5. Isopleth Areas of Total Available Phosphorus in Harbor Isle Lake Sediments.

TABLE 3-7

HARBOR ISLE LAKE SEDIMENT INACTIVATION REQUIREMENTS

AVAILABLE P CONTOUR INTERVAL (µg/cm^3)	CONTOUR INTERVAL MID-POINT (µg/cm^3)	CONTOUR AREA (acres)	AVAILABLE PHOSPHORUS		ALUM REQUIREMENTS (Al:P Ratio = 15:1)	
			kg	moles	moles Al	gallons alum
50-75	62.5	2.06	52.1	1,682	25,224	3,066
75-100	87.5	12.22	432.9	13,966	209,483	25,462
100-125	113	9.54	434.6	14,018	210,267	25,558
125-150	138	0.88	49.0	1,580	23,706	2,881
150-175	163	0.41	27.0	870	13,053	1,587
175-200	188	0.25	19.0	612	9,184	1,116
200-225	213	0.18	15.5	500	7,494	911
225-250	238	0.38	36.5	1,179	17,681	2,149
Overall Totals:		25.9	1,067	34,406	516,092	62,730

Areal Aluminum Dose: 132.8 Al/m^2
Water Column Aluminum Dose: 49.0 mg Al/liter

Phosphorus loadings to lakes also originate from groundwater seeping into the sides and bottom of the lake. This inflow, referred to as groundwater seepage, is commonly measured by ERD during surface water evaluations. Based on seepage measurements in over 40 lakes, phosphorus influx has ranged from 0.02-0.25 g P/m^2-yr. A conservative value of 0.18 g P/m^2-yr (500 µg/m^2-day) is assumed for Harbor Isle Lake.

A summary of alum requirements for control of phosphorus loading from groundwater seepage entering Harbor Isle Lake is given in Table 3-8. Based on the assumed phosphorus influx rate of 0.18 g P /m^2-day, phosphorus loading from groundwater seepage over the assumed lake area of 25.9 acres is estimated to be approximately 19.1 kg/yr. For purposes of estimating chemical requirements, this analysis assumes that control of phosphorus in groundwater seepage is desired for a period of approximately 15 years. Therefore, the total mass of phosphorus from groundwater seepage which must be inactivated over the 15-year period is approximately 287 kg which equates to approximately 9,260 moles of total phosphorus. Assuming an Al:P ratio of 15:1 for adequate phosphorus adsorption of groundwater inflows, control of 9,260 moles of total phosphorus will require approximately 138,907 moles of aluminum which equates to an alum volume of 16,914 gallons.

The proposed alum treatment to Harbor Isle Lake would add sufficient alum to control both internal recycling and intercept phosphorus loadings from groundwater seepage. Assuming that approximately 62,730 gallons of alum are needed for sediment inactivation and 16,914 gallons of alum are needed for interception of groundwater seepage, the total amount of alum to be added to Harbor Isle Lake would be 79,645 gallons, equivalent to 17.7 tankers.

TABLE 3-8

ALUM REQUIREMENTS FOR CONTROL OF PHOSPHORUS LOADING FROM GROUNDWATER SEEPAGE TO HARBOR ISLE LAKE

PARAMETER		UNITS	VALUE
Estimated Phosphorus Mass to be Controlled	Seepage Phosphorus Loading	g/m^2-yr	0.18
	Annual Phosphorus Loading from Seepage	kg/yr	19.1
	Desired Length of Control	years	15
	Total Phosphorus Mass to be Inactivated	kg	287
	Moles of Phosphorus to be Inactivated	moles	9,260
Alum Requirements	Inactivation Al:P Ratio	--	15
	Moles of Aluminum Required	moles	138,907
	Alum Required	gallons	16,914
	Number of Tankers @4300 gallons/tanker	--	3.9

Based on the assumed lake volume of 230 ac-ft, the amount of alum for internal recycling and control of seepage inflows equates to a whole-lake alum dose of approximately 67.2 mg Al/liter which far exceeds the available buffering capacity in the lake to withstand reductions in water column pH if the entire alum volume was added at one time. Harbor Isle Lake is a well buffered waterbody with alkalinity values typically in excess of 150 mg/l, so pH control during alum addition is not a concern, provided that the alum application is divided into a series of smaller treatments.

Multiple smaller applications of alum rather than a single event also have water quality benefits and improves the effectiveness of phosphorus sequestration. 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 spaced at intervals of approximately 4-12 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. Conducting multiple treatments also allows alkalinity to be restored naturally between treatments, reducing the need for supplemental buffering compounds, although this is not a concern for Harbor Isle Lake. It is recommended that the required alum volume be divided into 4 separate applications, with approximately one-fourth of the required alum volume applied during each application.

A summary of proposed alum requirements to control internal recycling and groundwater seepage in Harbor Isle Lake is given in Table 3-9. Supplemental lime additions for pH control will not be required due to the high alkalinity in the lake. Each treatment would be applied using a boat or barge to spread the chemicals over the lake surface based on the available phosphorus isopleth map given in Figure 2-14. The total recommended alum volume for treatment of internal recycling and seepage inflows is 79,645 gallons, equivalent to 17.7 tankers. Since 4 applications are proposed, each application will use 4.4 tankers each, with a total alum volume of 19,911 gallons per application. However, the cost of a partial tanker of alum is only slightly less than a full tanker, so the number of tankers per application is increased to 5, with a total alum volume of 21,500 gallons per application.

TABLE 3-9

RECOMMENDED ALUM ADDITION REQUIREMENTS OF SEDIMENT PHOSPHORUS RELEASE AND GROUNDWATER SEEPAGE ENTERING HARBOR ISLE LAKE

PARAMETER		UNITS	VALUE
Alum Requirements per Treatment	Number of Treatments	--	4
	Alum Required per Treatment	gallons tankers	21,500 5
	Water Column Dose per Treatment	mg Al/liter	16.8
Overall Chemical Requirements	Alum to be Applied	gallons tankers	86,000 20
	Applied Water Column Dose	mg Al/liter	67.2
	Applied Areal Dose	g Al/m^2	182

A summary of estimated application costs for sediment inactivation and control of groundwater seepage in Harbor Isle Lake is given in Table 3-10. This estimate assumes an alum volume of 86,000 gallons (20 tankers) will be applied overall, with 21,500 gallons (5 tankers) applied during each of the 4 treatments. It is assumed that the alum is purchased directly by the City at the current contract price of $0.62/gallon. Planning and mobilization costs are estimated to be approximately $5,000 per application, which includes initial planning, mobilization of equipment to the site, demobilization at the completion of the application process, and clean-up. An application rate of $1,750 per tanker (partial or full) is assumed which includes labor costs, daily water quality monitoring during the application, expenses, equipment rental, insurance, mileage, and application equipment fees.

TABLE 3-10

ESTIMATED APPLICATION COSTS FOR SEDIMENT INACTIVATION AND CONTROL OF GROUNDWATER SEEPAGE IN HARBOR ISLE LAKE (Based on a total of 4 applications)

PARAMETER		QUANTITY/ TREATMENT	UNITS	UNIT COST ($)	COST PER TREATMENT ($)	TOTAL COST ($)
Chemical Costs	Alum	21,500	gallons	0.62[1]	13,330	53,320
	Lime	0	gallons	5.00	0	0
Labor Costs	Planning and Mobilization	1	each	5,000	5,000	20,000
	Chemical Application	5	each	1,750	8,750	35,000
Monitoring/ Lab Testing	Field Monitoring (pre/post)	1	each	1,000	1,000	4,000
	Lab Analyses (pre/post)	8	samples	200	1,600	6,400
				TOTAL:	**$ 29,680**	**$ 118,720**

1. Assumed contract cost
2. Estimated volume; actual volume may vary
3. Includes chemical cost plus application

Chemical Costs:	**$ 53,320**
Application and Testing:	**$ 65,400**
Total Cost:	**$ 118,720**

The estimated cost for sediment inactivation and control of groundwater seepage in Harbor Isle Lake is $118,720 or approximately $29,680 per application, including all labor and chemical costs. Of the project cost, approximately 45% is for alum, with 55% for application and testing. Since the treatment will be a multi-year process, the treatment costs can be distributed over multiple fiscal cycles.

3.6.3 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 30-90 days, reaching maximum consolidation during 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.

At least 50 previous sediment inactivation projects have been conducted by ERD on freshwater lakes in the State of Florida since 1992. Approximately half of these waterbodies have sufficient pre- and post-water quality data to evaluate the effectiveness of the alum sediment inactivation process. Based on these data, it appears that a properly planned and executed alum treatment project for a typical lake would maintain a continuous level of effectiveness for a minimum of approximately 10-12 years or more. However, the longevity and effectiveness of an application to brackish water is not known.

3.7 Sediment Capping

3.7.1 Introduction

Nutrient loadings from the sediments to the water column in Harbor Isle Lake originate from both groundwater seepage (not quantified as part of this study) and direct sediment nutrient release. Sediment capping is a process where an artificial barrier is inserted between the sediments and water column to reduce the transport of nutrients and other pollutants entering the water column from the sediments. The cap consists of multiple layers of media which are determined based on the nutrient or pollutant of concern. Ions moving upward through the media are removed by the specific mechanisms provided in the media, such as adsorption or microbial processing. Currently, sediment caps are used primarily for toxic or hazardous pollutants, although a limited number of experimental projects have been conducted for nutrient removal. Some consider alum sediment inactivation as a capping technique, but the floc becomes incorporated into the sediments rather than forming a distinct surface layer.

A general schematic of a typical sediment cap is given in Figure 3-6. A typical cap would include an initial "mixing" or "sacrificial" layer which provides an initial barrier at the water-sediment interface as some of the media and sediment become mixed during placement due to differences in specific gravity and physical properties. The next layer is the chemical and/or biological media which is specific for the parameter of concern. The height and characteristics of the layer are determined in a series of bench and field scale experiments. Activated carbon is a common constituent in layers designed to remove organics. If erosion is a concern, an erosion protection layer may be installed to prevent disturbance of the chemical/biological isolation layer. A layer of natural sediment material is placed on top to provide a habitat zone for aquatic plants and benthos. Sediment capping is less effective in shallow lakes where wind or boating activities can extend wave energy to the water-sediment interface.

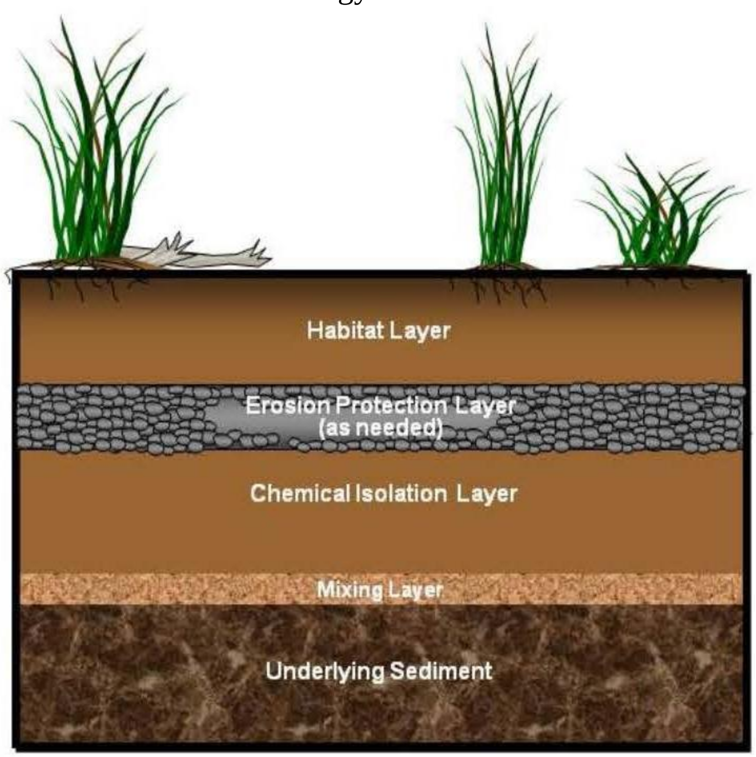


Figure 3-6.

General Schematic of Sediment Cap.

3.7.2 Application

Distribution of the capping materials can be achieved using several different methods, all of which require large equipment and significant staging areas adjacent to the water, which is not generally available at Harbor Isle Lake. The mixing and isolation layers are solid materials such as soils, sands, or clays. Typical distribution methods include: (1) direct placement with a mechanical clamshell bucket, (2) surface release from a barge, hopper, conveyor belt, or broadcast spreader, (3) spreading using hydraulic pipeline with multiple discharge points, (4) spraying from a barge, and (5) submerged diffuser. Most of these application methods will result in an initially turbid water column until full settling has occurred.

3.7.3 Effectiveness

Available literature indicates that sediment capping can be extremely effective in reducing nutrient concentrations entering lakes from the sediments. Alvarado, et al. (2020) tested a dolomite and zeolite mixture to reduce nitrogen and phosphorus inflows. When the dolomite was placed above the zeolite, removal efficiencies in excess of 95% were achieved for ammonia, SRP, and total phosphorus, but the efficiencies were reduced by half when the placement order was reversed. Determination of the optimum capping materials must be determined through a series of bench and field scale experiments before a design can be implemented.

3.7.4 Applicability

Although sediment capping is an interesting concept, it does not appear to be a likely candidate for Harbor Isle Lake for several reasons. First, lake access and available set-up areas are very limited and may exclude this option altogether. Second, bench scale and field testing must be performed to determine the optimum capping material, which adds substantial cost. Finally, the cost of this process, including initial testing, materials, engineering, and application, cannot be estimated at this time, but it is almost certain that the cost would be prohibitive for this project.

APPENDICES

APPENDIX A

PHOTOGRAPHS OF SEDIMENT CORE SAMPLES COLLECTED IN HARBOR ISLE LAKE DURING APRIL 2021

Harbor Isle Lake Sediment Photos

Sites 1 - 2

Site 1

Site 2

Harbor Isle Lake Sediment Photos

Sites 3 - 4

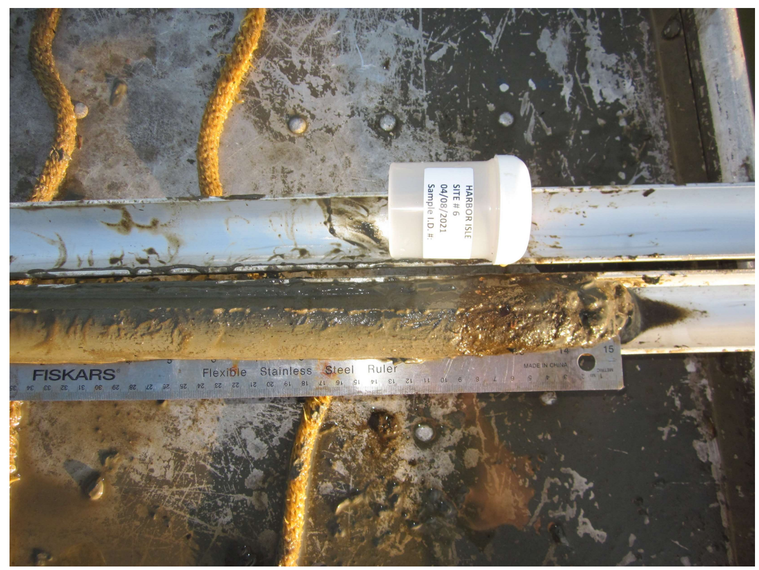
Site 3

Site 4

Harbor Isle Lake Sediment Photos

Sites 5 - 6

Site 5



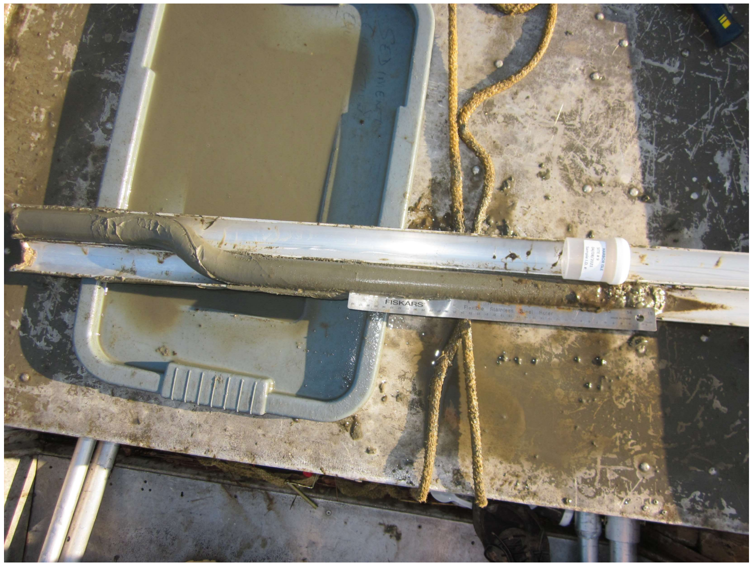
Site 6

Harbor Isle Lake Sediment Photos
Sites 7 - 8

Site 7

Site 8

Harbor Isle Lake Sediment Photos
Sites 9 - 10



Site 9

Site 10

APPENDIX B

RESULTS OF SEDIMENT PHOSPHORUS RELEASE EXPERIMENTS CONDUCTED ON HARBOR ISLE LAKE CORE SAMPLES

B-1 Laboratory Analyses

B-2 Regression Relationships of Sediment Nutrient Release

B-1 Laboratory Analyses

Results of Sediment Benthic Nutrient Release Rate Studies at Harbor Isle Lake Sites

Lab ID (21-xxx)	Site	Redox Condition	Date Collected	Time (days)	NH3 (µg/L)	NO_x (µg/L)	Organic N (µg/L)	Total N (µg/L)	SRP (µg/L)	Organic P (µg/L)	Total P (µg/L)	Volume (L)	Total N (µg)	SRP (µg)	Total P (µg)
	Starting water level (inches):			24.00			Ending water level (inches):				20.25				
713	LC-1	Aerobic	5/13/21	0	147	5	957	1,109	5	25	30	4.84	5,368	24	145
724	LC-1		5/17/21	4	139	9	1,155	1,303	7	23	30	4.75	6,191	33	143
758	LC-1		5/20/21	7	79	139	1,195	1,413	16	10	26	4.68	6,620	75	122
763	LC-1		5/21/21	8	64	207	1,190	1,461	17	19	36	4.66	6,812	79	168
774	LC-1		5/24/21	11	40	378	1,004	1,422	26	19	45	4.60	6,535	119	207
799	LC-1		5/26/21	13	24	492	1,009	1,525	37	16	53	4.55	6,941	168	241
836	LC-1		5/28/21	15	12	544	1,060	1,616	44	17	61	4.51	7,283	198	275
857	LC-1		6/1/21	19	12	612	1,097	1,721	59	9	68	4.42	7,603	261	300
876	LC-1		6/2/21	20	10	621	1,135	1,766	64	10	74	4.40	7,763	281	325
889	LC-1		6/4/21	22	8	647	1,131	1,786	75	12	87	4.35	7,771	326	379
902	LC-1		6/7/21	25	7	706	1,058	1,771	88	12	100	4.28	7,588	377	428
906	LC-1		6/9/21	27	6	715	1,001	1,722	93	8	101	4.24	7,301	394	428
914	LC-1		6/11/21	29	3	769	1,013	1,785	110	15	125	4.20	7,489	461	524
918	LC-1		6/14/21	32	3	780	1,039	1,822	121	14	135	4.13	7,523	500	557
941	LC-1		6/16/21	34	3	836	1,026	1,865	125	14	139	4.08	7,617	511	568
	Starting water level (inches):			24.00			Ending water level (inches):				20.00				
715	LC-2	Aerobic	5/13/21	0	326	0	814	1,140	6	25	31	4.84	5,518	29	150
725	LC-2		5/17/21	4	285	18	1,184	1,487	15	18	33	4.75	7,057	71	157
759	LC-2		5/20/21	7	277	190	1,112	1,579	34	20	54	4.67	7,381	159	252
764	LC-2		5/21/21	8	133	292	1,204	1,629	37	28	65	4.65	7,576	172	302
775	LC-2		5/24/21	11	77	553	1,215	1,845	52	30	82	4.58	8,449	238	376
800	LC-2		5/26/21	13	75	713	1,110	1,898	73	24	97	4.53	8,602	331	440
837	LC-2		5/28/21	15	68	743	1,090	1,901	79	30	109	4.48	8,525	354	489
858	LC-2		6/1/21	19	68	766	1,074	1,908	108	26	134	4.39	8,376	474	588
877	LC-2		6/2/21	20	59	785	1,172	2,016	116	24	140	4.37	8,802	506	611
890	LC-2		6/4/21	22	58	776	1,203	2,037	149	20	169	4.32	8,797	643	730
903	LC-2		6/7/21	25	58	956	1,030	2,044	161	22	183	4.25	8,682	684	777
907	LC-2		6/9/21	27	40	917	1,032	1,989	191	21	212	4.20	8,354	802	890
915	LC-2		6/11/21	29	36	865	1,102	2,003	213	16	229	4.15	8,317	884	951
919	LC-2		6/14/21	32	24	861	1,154	2,039	227	15	242	4.08	8,322	926	988
942	LC-2		6/16/21	34	5	943	1,168	2,116	237	17	254	4.03	8,536	956	1,025

Results of Sediment Benthic Nutrient Release Rate Studies at Harbor Isle Lake Sites

Lab ID (21-xxx)	Site	Redox Condition	Date Collected	Time (days)	NH3 (µg/L)	NO_X (µg/L)	Organic N (µg/L)	Total N (µg/L)	SRP (µg/L)	Organic P (µg/L)	Total P (µg/L)	Volume (L)	Total N (µg)	SRP (µg)	Total P (µg)
	Starting water level (inches):			24.00		Ending water level (inches):					22.00				
716	LC-3		5/13/21	0	580	0	606	1,186	6	26	32	4.84	5,741	29	155
727	LC-3		5/17/21	4	515	32	1,484	2,031	11	24	35	4.79	9,735	53	168
760	LC-3		5/20/21	7	473	175	1,402	2,050	21	24	45	4.76	9,753	100	214
765	LC-3		5/21/21	8	76	343	1,638	2,057	23	21	44	4.75	9,762	109	209
776	LC-3		5/24/21	11	67	397	1,559	2,023	24	20	44	4.71	9,528	113	207
801	LC-3		5/26/21	13	56	446	1,543	2,045	26	21	47	4.69	9,584	122	220
838	LC-3		5/28/21	15	23	656	1,442	2,121	28	23	51	4.66	9,889	131	238
859	LC-3	Aerobic	6/1/21	19	16	668	1,499	2,183	44	12	56	4.62	10,075	203	258
878	LC-3		6/2/21	20	14	694	1,527	2,235	58	13	71	4.60	10,288	267	327
891	LC-3		6/4/21	22	12	697	1,541	2,250	79	19	98	4.58	10,304	362	449
904	LC-3		6/7/21	25	9	710	1,586	2,305	106	15	121	4.54	10,474	482	550
908	LC-3		6/9/21	27	8	751	1,614	2,373	123	14	137	4.52	10,726	556	619
916	LC-3		6/11/21	29	8	800	1,489	2,297	90	12	102	4.50	10,328	405	459
920	LC-3		6/14/21	32	6	945	1,318	2,269	85	12	97	4.46	10,122	379	433
943	LC-3		6/16/21	34	3	1,002	1,514	2,519	54	15	69	4.44	11,177	240	306
	Starting water level (inches):			24.00		Ending water level (inches):					18.75				
717	LC-4		5/13/21	0	417	2	991	1,410	6	27	33	4.84	6,825	29	160
728	LC-4		5/17/21	4	456	33	971	1,460	27	22	49	4.72	6,885	127	231
762	LC-4		5/20/21	7	432	268	1,067	1,767	41	18	59	4.62	8,168	190	273
766	LC-4		5/21/21	8	241	514	1,071	1,826	54	14	68	4.59	8,384	248	312
777	LC-4		5/24/21	11	35	677	1,109	1,821	54	16	70	4.50	8,191	243	315
802	LC-4		5/26/21	13	21	688	1,127	1,836	69	15	84	4.44	8,144	306	373
839	LC-4		5/28/21	15	12	716	1,140	1,868	73	18	91	4.37	8,170	319	398
860	LC-4	Aerobic	6/1/21	19	3	724	1,195	1,922	99	14	113	4.25	8,166	421	480
879	LC-4		6/2/21	20	3	729	1,206	1,938	127	14	141	4.22	8,174	536	595
892	LC-4		6/4/21	22	3	751	1,342	2,096	141	18	159	4.16	8,710	586	661
905	LC-4		6/7/21	25	3	883	1,270	2,156	179	16	195	4.06	8,758	727	792
909	LC-4		6/9/21	27	3	1,095	1,286	2,384	203	13	216	4.00	9,535	812	864
917	LC-4		6/11/21	29	3	1,222	1,237	2,462	167	16	183	3.94	9,694	658	721
921	LC-4		6/14/21	32	3	1,317	1,307	2,627	141	16	157	3.84	10,098	542	604
944	LC-4		6/16/21	34	3	1,375	1,208	2,586	133	19	152	3.78	9,779	503	575

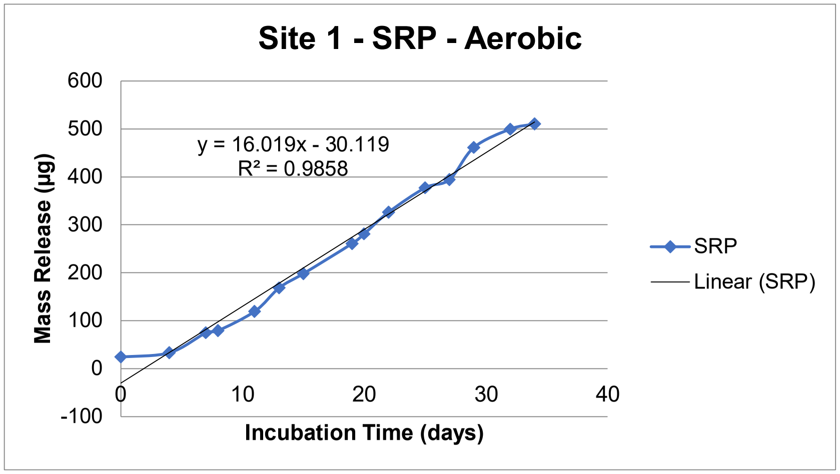
Results of Sediment Benthic Nutrient Release Rate Studies at Harbor Isle Lake Sites

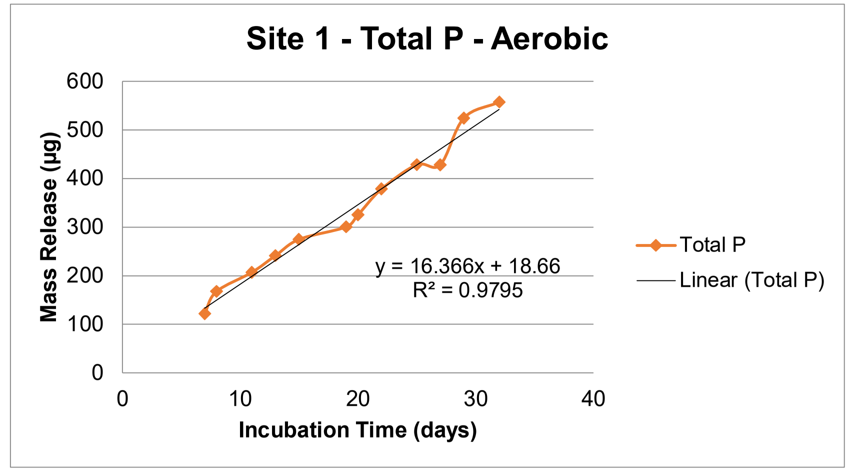
Lab ID (21-xxx)	Site	Redox Condition	Date Collected	Time (days)	NH3 (µg/L)	NO_X (µg/L)	Organic N (µg/L)	Total N (µg/L)	SRP (µg/L)	Organic P (µg/L)	Total P (µg/L)	Volume (L)	Total N (µg)	SRP (µg)	Total P (µg)
	Starting water level (inches):			24.00			Ending water level (inches):				22.25				
945	LC-1	Anoxic	6/16/21	0	8	29	1,217	1,254	7	29	36	4.84	6,070	34	174
949	LC-1		6/17/21	1	40	16	1,223	1,279	17	26	43	4.83	6,178	82	208
1005	LC-1		6/21/21	5	203	10	1,163	1,376	64	22	86	4.79	6,589	306	412
1070	LC-1		6/24/21	8	308	9	1,063	1,380	84	32	116	4.76	6,565	400	552
1078	LC-1		6/25/21	9	340	2	1,186	1,528	117	30	147	4.75	7,254	555	698
1082	LC-1		6/28/21	12	415	2	1,162	1,579	121	29	150	4.72	7,447	571	707
1094	LC-1		6/30/21	14	433	2	1,187	1,622	122	36	158	4.70	7,616	573	742
1102	LC-1		7/2/21	16	508	2	1,117	1,627	130	34	164	4.67	7,605	608	767
1111	LC-1		7/6/21	20	720	2	1,167	1,889	138	35	173	4.63	8,752	639	801
1124	LC-1		7/7/21	21	650	2	1,068	1,720	142	39	181	4.62	7,951	656	837
1137	LC-1		7/9/21	23	704	2	1,078	1,784	145	54	199	4.60	8,210	667	916
1141	LC-1		7/12/21	26	812	2	1,192	2,006	154	55	209	4.57	9,169	704	955
1161	LC-1		7/14/21	28	871	2	1,257	2,130	152	71	223	4.55	9,691	692	1,015
1217	LC-1		7/16/21	30	946	2	1,243	2,191	158	83	241	4.53	9,923	716	1,092
1222	LC-1		7/20/21	34	1,102	2	1,078	2,182	163	78	241	4.49	9,792	731	1,082
	Starting water level (inches):			24.00			Ending water level (inches):				21.50				
946	LC-2	Anoxic	6/16/21	0	11	72	1,190	1,273	6	37	43	4.84	6,162	29	208
950	LC-2		6/17/21	1	64	31	1,250	1,345	53	28	81	4.83	6,491	256	391
1006	LC-2		6/21/21	5	434	18	1,220	1,672	86	46	132	4.77	7,969	410	629
1071	LC-2		6/24/21	8	614	10	1,112	1,736	128	44	172	4.72	8,197	604	812
1079	LC-2		6/25/21	9	697	10	1,139	1,846	133	43	176	4.71	8,689	626	828
1083	LC-2		6/28/21	12	729	2	1,179	1,910	140	40	180	4.66	8,906	653	839
1095	LC-2		6/30/21	14	893	2	1,228	2,123	144	49	193	4.63	9,836	667	894
1103	LC-2		7/2/21	16	1,100	2	1,153	2,255	152	54	206	4.60	10,380	700	948
1112	LC-2		7/6/21	20	1,150	2	1,176	2,328	155	57	212	4.54	10,578	704	963
1125	LC-2		7/7/21	21	1,224	2	1,156	2,382	158	59	217	4.53	10,788	716	983
1138	LC-2		7/9/21	23	1,237	2	1,133	2,372	159	66	225	4.50	10,673	715	1,012
1142	LC-2		7/12/21	26	1,449	2	1,196	2,647	158	69	227	4.45	11,792	704	1,011
1162	LC-2		7/14/21	28	1,596	2	1,106	2,704	164	91	255	4.43	11,966	726	1,128
1218	LC-2		7/16/21	30	1,810	2	1,144	2,956	167	127	294	4.40	12,994	734	1,292
1223	LC-2		7/20/21	34	2,054	2	1,094	3,150	169	115	284	4.34	13,659	733	1,232

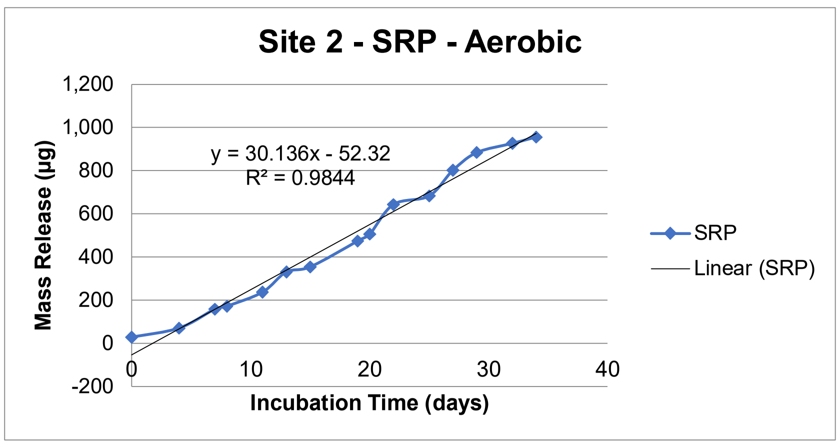
Results of Sediment Benthic Nutrient Release Rate Studies at Harbor Isle Lake Sites

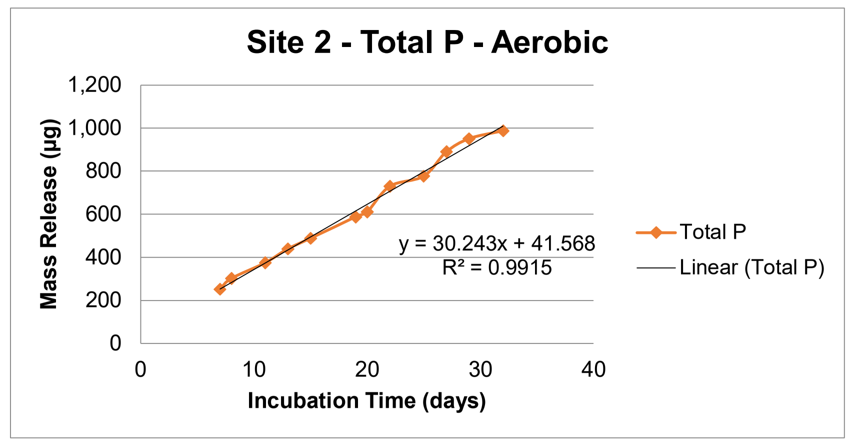
Lab ID (21-xxx)	Site	Redox Condition	Date Collected	Time (days)	NH3 (µg/L)	NO_x (µg/L)	Organic N (µg/L)	Total N (µg/L)	SRP (µg/L)	Organic P (µg/L)	Total P (µg/L)	Volume (L)	Total N (µg)	SRP (µg)	Total P (µg)
	Starting water level (inches):			24.00			Ending water level (inches):				22.25				
947	LC-3		6/16/21	0	12	18	1,292	1,322	5	39	44	4.84	6,399	24	213
951	LC-3		6/17/21	1	140	9	1,218	1,367	45	34	79	4.83	6,603	217	382
1007	LC-3		6/21/21	5	593	6	1,113	1,712	94	25	119	4.79	8,198	450	570
1072	LC-3		6/24/21	8	871	2	1,275	2,148	146	23	169	4.76	10,219	695	804
1080	LC-3		6/25/21	9	950	2	1,433	2,385	144	29	173	4.75	11,322	684	821
1084	LC-3		6/28/21	12	1,025	2	1,452	2,479	150	40	190	4.72	11,691	707	896
1096	LC-3		6/30/21	14	1,180	2	1,385	2,567	153	40	193	4.70	12,053	718	906
1104	LC-3	Anoxic	7/2/21	16	1,430	2	1,305	2,737	148	51	199	4.67	12,794	692	930
1113	LC-3		7/6/21	20	1,478	2	1,360	2,840	147	53	200	4.63	13,158	681	927
1126	LC-3		7/7/21	21	1,726	2	1,328	3,056	150	52	202	4.62	14,127	693	934
1139	LC-3		7/9/21	23	1,879	2	1,313	3,194	153	59	212	4.60	14,698	704	976
1143	LC-3		7/12/21	26	1,905	2	1,447	3,354	159	76	235	4.57	15,330	727	1,074
1163	LC-3		7/14/21	28	2,087	2	1,446	3,535	163	92	255	4.55	16,084	742	1,160
1219	LC-3		7/16/21	30	2,177	2	1,434	3,613	165	99	264	4.53	16,364	747	1,196
1224	LC-3		7/20/21	34	2,259	2	1,289	3,550	166	108	274	4.49	15,931	745	1,230
	Starting water level (inches):			24.00			Ending water level (inches):				22.50				
948	LC-4		6/16/21	0	7	127	1,189	1,323	7	36	43	4.84	6,404	34	208
952	LC-4		6/17/21	1	70	125	1,138	1,333	19	28	47	4.83	6,441	92	227
1008	LC-4		6/21/21	5	139	97	1,133	1,369	49	35	84	4.80	6,566	235	403
1073	LC-4		6/24/21	8	147	79	1,015	1,241	57	35	92	4.77	5,919	272	439
1081	LC-4		6/25/21	9	150	75	1,222	1,447	63	32	95	4.76	6,888	300	452
1085	LC-4		6/28/21	12	157	66	1,102	1,325	64	36	100	4.73	6,272	303	473
1097	LC-4		6/30/21	14	192	50	1,120	1,362	65	39	104	4.72	6,423	307	490
1105	LC-4	Anoxic	7/2/21	16	194	23	1,088	1,305	71	40	111	4.70	6,131	334	521
1114	LC-4		7/6/21	20	212	13	1,101	1,326	85	42	127	4.66	6,183	396	592
1127	LC-4		7/7/21	21	259	0	1,115	1,374	95	42	137	4.65	6,394	442	638
1140	LC-4		7/9/21	23	467	0	1,087	1,554	104	42	146	4.64	7,204	482	677
1144	LC-4		7/12/21	26	1,299	0	1,288	2,587	120	39	159	4.61	11,924	553	733
1164	LC-4		7/14/21	28	1,676	0	1,376	3,052	128	31	159	4.59	14,013	588	730
1220	LC-4		7/16/21	30	1,892	0	1,290	3,182	134	32	166	4.57	14,553	613	759
1225	LC-4		7/20/21	34	1,963	0	1,142	3,105	141	40	181	4.54	14,091	640	821

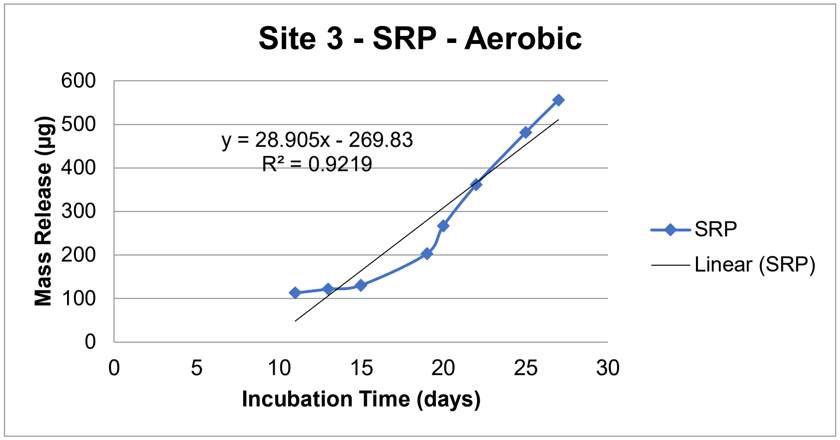
B-2 Regression Relationships of Sediment Nutrient Release

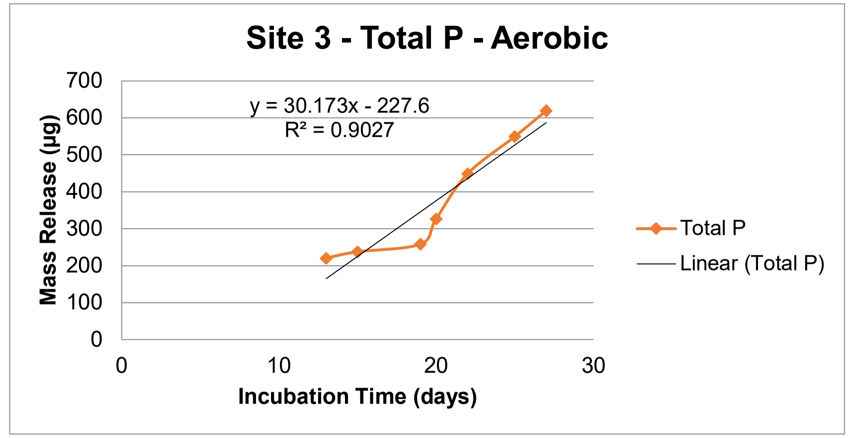

Site 1 - SRP - Aerobic
Mass Release (µg)
Incubation Time (days)
y = 16.019x - 30.119
R² = 0.9858
SRP
Linear (SRP)

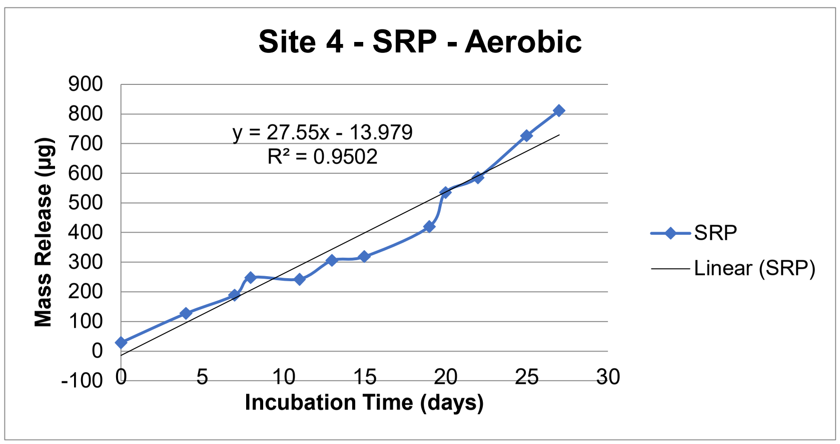

Site 1 - Total P - Aerobic
Mass Release (µg)
Incubation Time (days)
y = 16.366x + 18.66
R² = 0.9795
Total P
Linear (Total P)

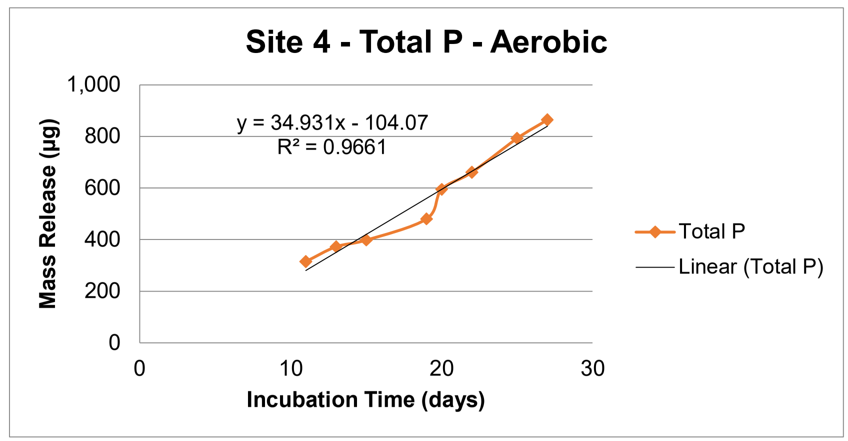

Site 2 - SRP - Aerobic
Mass Release (µg)
Incubation Time (days)
y = 30.136x - 52.32
R² = 0.9844
SRP
Linear (SRP)

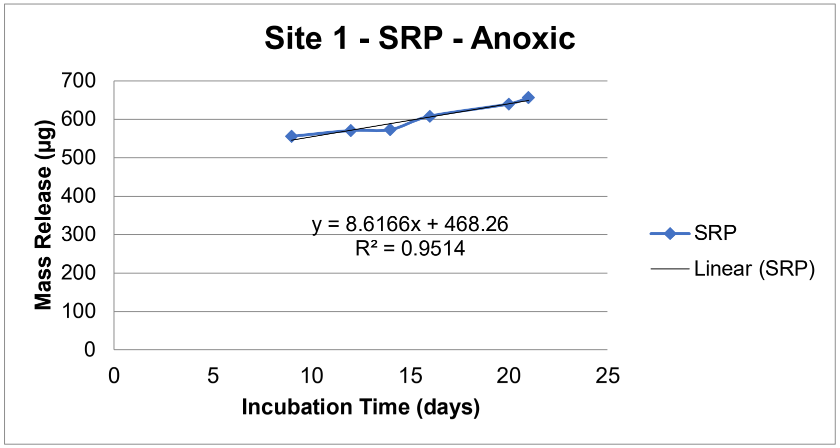

Site 2 - Total P - Aerobic
Mass Release (µg)
Incubation Time (days)
y = 30.243x + 41.568
R² = 0.9915
Total P
Linear (Total P)


Site 3 - SRP - Aerobic
y = 28.905x - 269.83
R² = 0.9219
Mass Release (µg)
Incubation Time (days)
SRP
Linear (SRP)

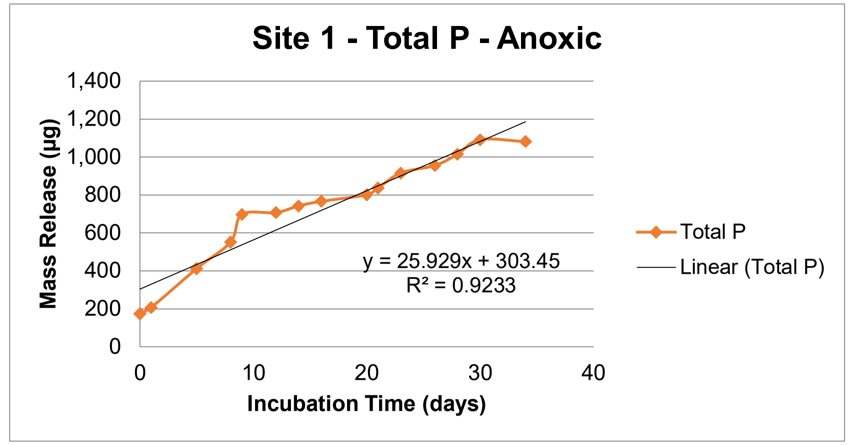

Site 3 - Total P - Aerobic
y = 30.173x - 227.6
R² = 0.9027
Mass Release (µg)
Incubation Time (days)
Total P
Linear (Total P)


Site 4 - SRP - Aerobic
y = 27.55x - 13.979
R² = 0.9502
Mass Release (µg)
Incubation Time (days)
SRP
Linear (SRP)

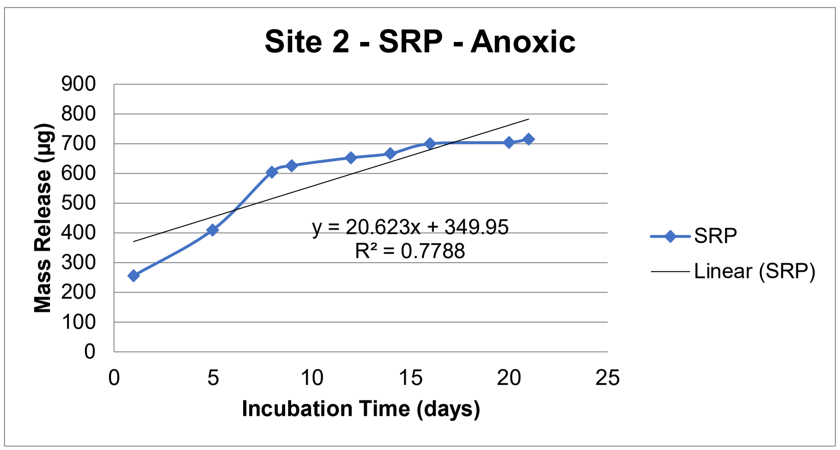

Site 4 - Total P - Aerobic
y = 34.931x - 104.07
R² = 0.9661
Mass Release (µg)
Incubation Time (days)
Total P
Linear (Total P)



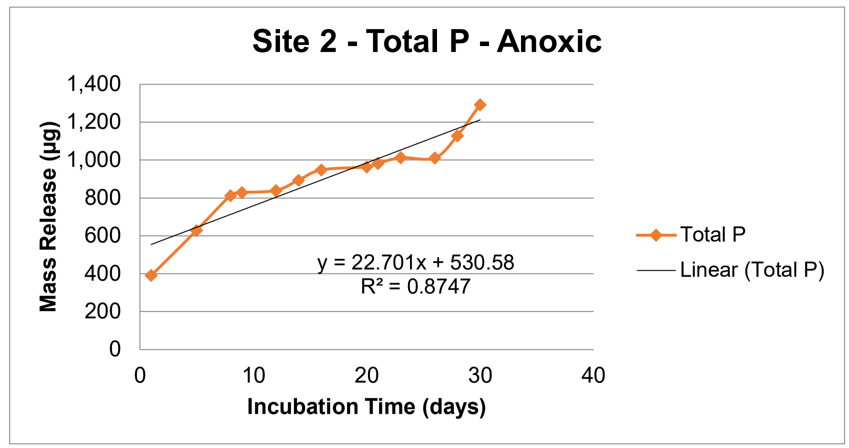
Site 1 - SRP - Anoxic
y = 8.6166x + 468.26
R² = 0.9514
Mass Release (µg)
Incubation Time (days)
SRP
Linear (SRP)



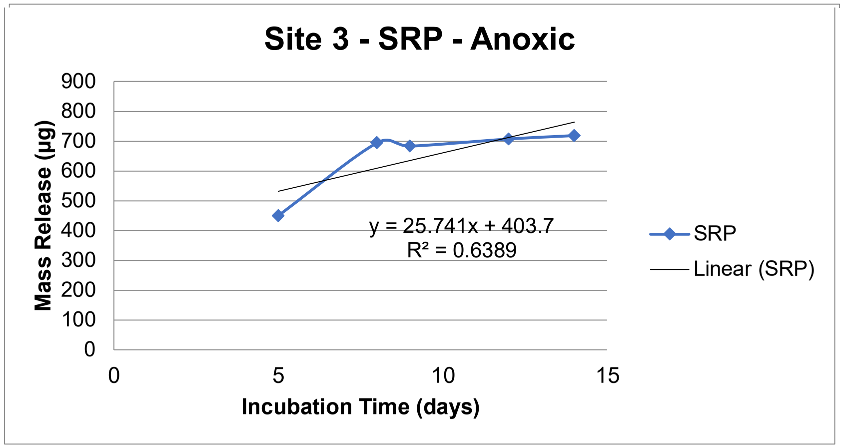
Site 1 - Total P - Anoxic
y = 25.929x + 303.45
R² = 0.9233
Mass Release (µg)
Incubation Time (days)
Total P
Linear (Total P)

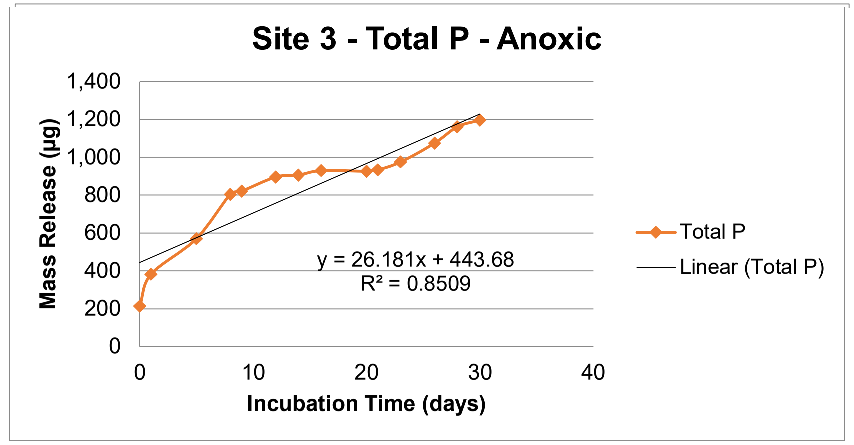


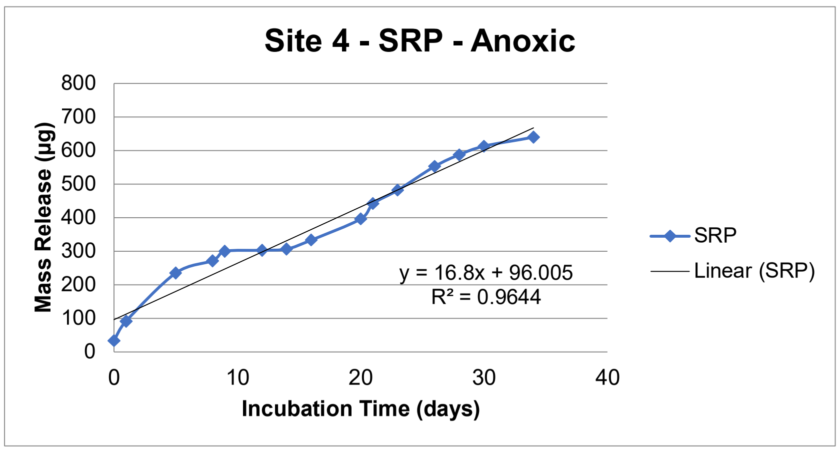
Site 2 - SRP - Anoxic
y = 20.623x + 349.95
R² = 0.7788
Mass Release (µg)
Incubation Time (days)
SRP
Linear (SRP)

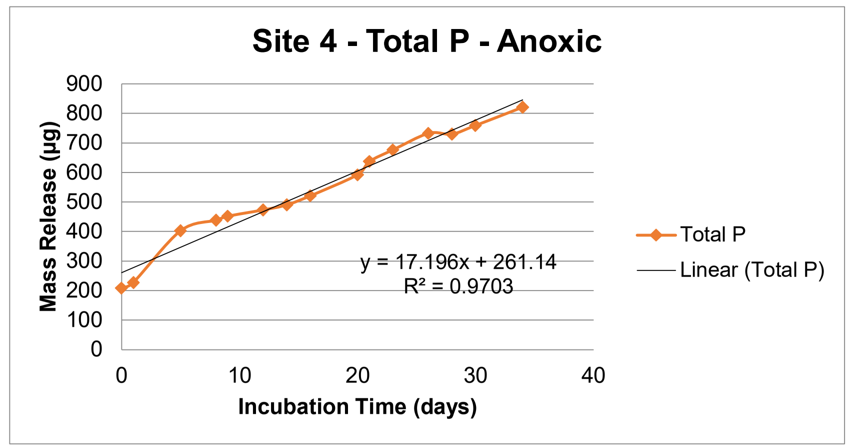


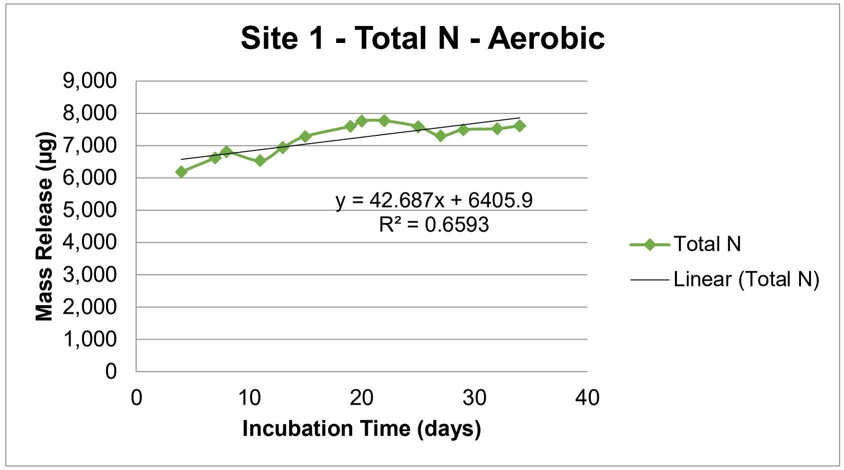
Site 2 - Total P - Anoxic
y = 22.701x + 530.58
R² = 0.8747
Mass Release (µg)
Incubation Time (days)
Total P
Linear (Total P)

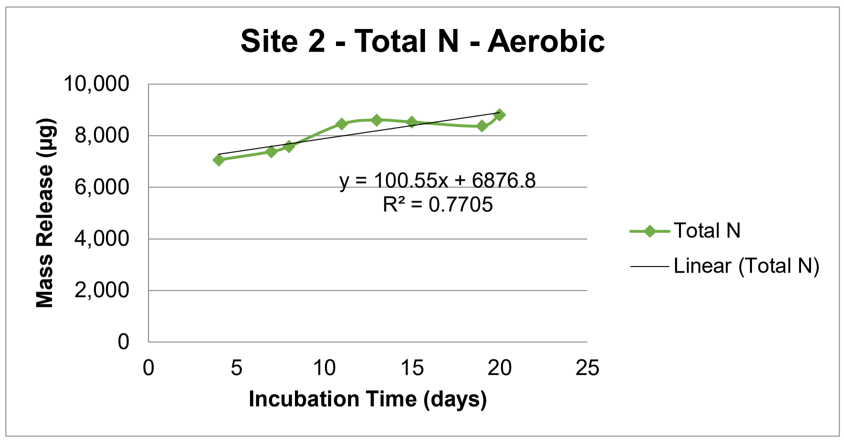

Site 3 - SRP - Anoxic
Mass Release (µg)
Incubation Time (days)
y = 25.741x + 403.7
R² = 0.6389
SRP
Linear (SRP)

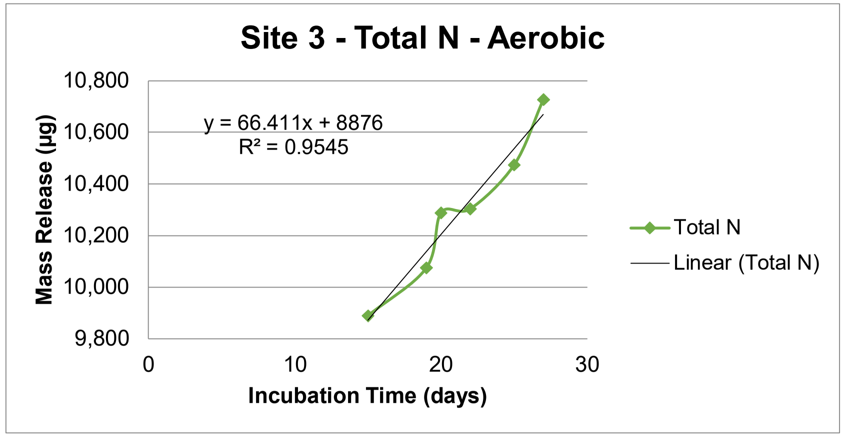

Site 3 - Total P - Anoxic
Mass Release (µg)
Incubation Time (days)
y = 26.181x + 443.68
R² = 0.8509
Total P
Linear (Total P)

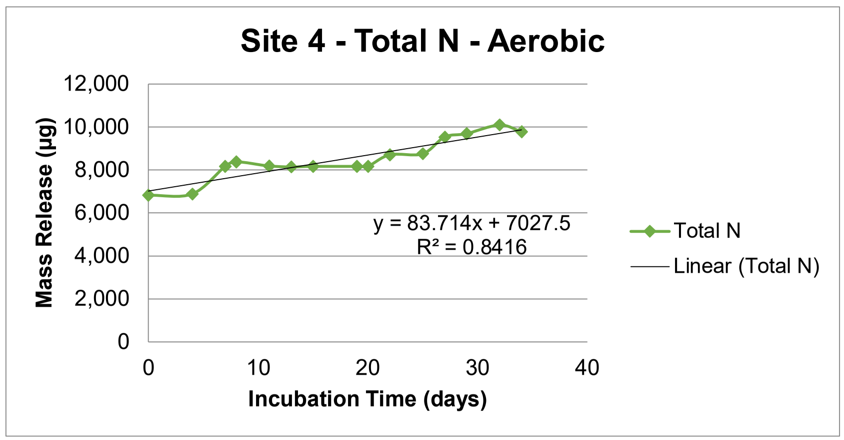

Site 4 - SRP - Anoxic
Mass Release (µg)
Incubation Time (days)
y = 16.8x + 96.005
R² = 0.9644
SRP
Linear (SRP)

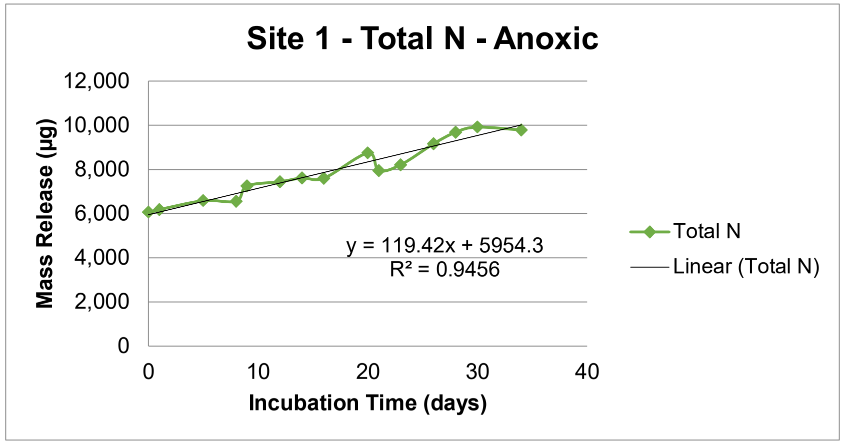

Site 4 - Total P - Anoxic
Mass Release (µg)
Incubation Time (days)
y = 17.196x + 261.14
R² = 0.9703
Total P
Linear (Total P)

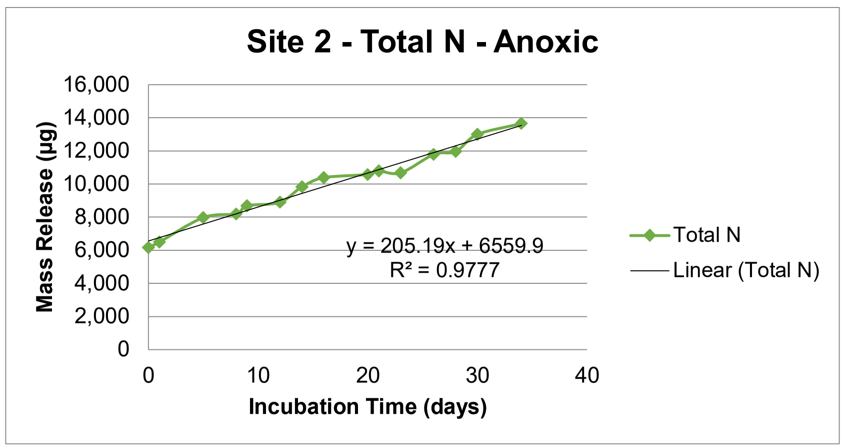

Site 1 - Total N - Aerobic
Mass Release (µg)
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
0
10
20
30
40
Incubation Time (days)
y = 42.687x + 6405.9
R² = 0.6593
Total N
Linear (Total N)

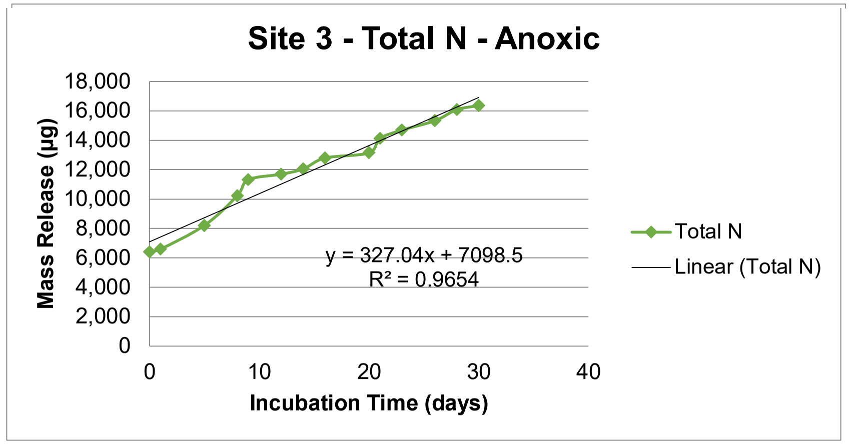

Site 2 - Total N - Aerobic
Mass Release (µg)
10,000
8,000
6,000
4,000
2,000
0
0
5
10
15
20
25
Incubation Time (days)
y = 100.55x + 6876.8
R² = 0.7705
Total N
Linear (Total N)

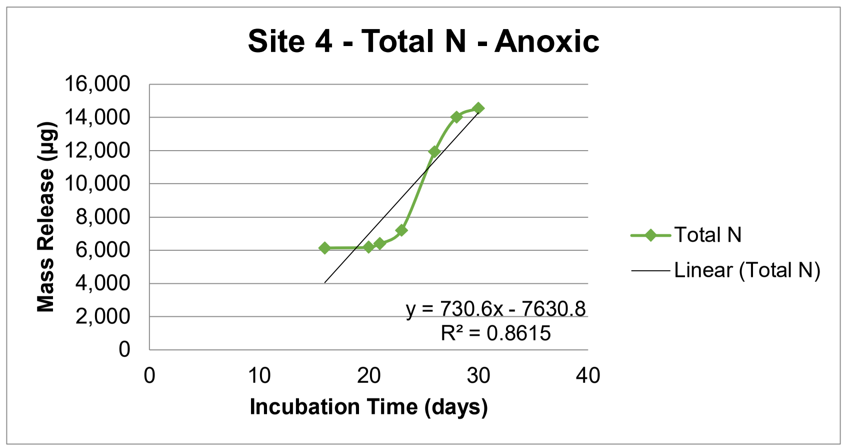

Site 3 - Total N - Aerobic
Mass Release (µg)
10,800
10,600
10,400
10,200
10,000
9,800
0
10
20
30
Incubation Time (days)
y = 66.411x + 8876
R² = 0.9545
Total N
Linear (Total N)


Site 4 - Total N - Aerobic
Mass Release (µg)
12,000
10,000
8,000
6,000
4,000
2,000
0
0
10
20
30
40
Incubation Time (days)
y = 83.714x + 7027.5
R² = 0.8416
Total N
Linear (Total N)


Site 1 - Total N - Anoxic
Mass Release (µg)
12,000
10,000
8,000
6,000
4,000
2,000
0
0
10
20
30
40
Incubation Time (days)
y = 119.42x + 5954.3
R² = 0.9456
Total N
Linear (Total N)


Site 2 - Total N - Anoxic
Mass Release (µg)
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0
10
20
30
40
Incubation Time (days)
y = 205.19x + 6559.9
R² = 0.9777
Total N
Linear (Total N)


Site 3 - Total N - Anoxic
Mass Release (µg)
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0
10
20
30
40
Incubation Time (days)
y = 327.04x + 7098.5
R² = 0.9654
Total N
Linear (Total N)


Site 4 - Total N - Anoxic
Mass Release (µg)
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0
10
20
30
40
Incubation Time (days)
y = 730.6x - 7630.8
R² = 0.8615
Total N
Linear (Total N)