CITY OF NAPLES

NORTH LAKE AND SOUTH LAKE FEASIBILITY STUDY FINAL REPORT

CITY OF NAPLES
STREETS AND STORMWATER DEPARTMENT
295 RIVERSIDE CIRCLE
NAPLES, FL 34102

PROJECT NO.: 600843
DATE: FEBRUARY 01, 2023

WSP USA
5051 S FLORIDA AVENUE SUITE 301
LAKELAND, FL 33812

T: +1 863-667-2345

WSP.COM

TABLE OF CONTENTS

1 INTRODUCTION 1

2 BACKGROUND 3

2.1 Hurricane Ian 3

2.2 Existing Data Review Summary 4

3 ECOLOGICAL EVALUATION 10

3.1 Wetlands and Surface Waters 12

3.2 Threatened and Endangered Species Survey 14

4 SEDIMENT EVALUATION 25

4.1 Sediment Engineering Evaluation 25

4.2 Sediment Flux 34

5 WATER QUALITY IMPROVEMENT TECHNOLOGIES 35

5.1 Dredging 35

5.2 Bio-augmented Aeration 37

5.3 Floating Islands 38

5.4 Littoral Shelf Modifications and Plantings 39

5.5 Exfiltration Trenches 40

5.6 Nutrient Separating Baffle Boxes and Curb Inlet Baskets 41

5.7 Rain Gardens 42

5.8 Vegetated Swales 43

5.9 Capping 44

6 ALTERNATIVES ANALYSIS 45

7 FUNDING EVALUATION 51

8 SUMMARY AND NEXT STEPS 53

BIBLIOGRAPHY 54

TABLES

TABLE 1. PLANT SPECIES OBSERVED AT NORTH LAKE AND SOUTH LAKE. 18
TABLE 2. FAUNA OBSERVED AT NORTH LAKE AND SOUTH LAKE. 18
TABLE 3. SELECT ANALYTICAL DATA FOR COMPOSITED SEDIMENT SAMPLES COLLECTED IN NOVEMBER 2022 FROM NORTH LAKE AND SOUTH LAKE WITH COMPARISON TO SOIL CRITERIA……………………………..…18
TABLE 4. SELECT ANALYTICAL DATA FOR COMPOSITED SEDIMENT SAMPLES COLLECTED IN NOVEMBER 2022 FROM NORTH LAKE AND SOUTH LAKE WITH COMPARISON TO GROUNDWATER CRITERIA……….19
TABLE 5. BMP TECHNOLOGIES – PROS VS CONS………………………………….34
TABLE 6. EXAMPLE NORTH AND SOUTH LAKE PRIMARY TECHNOLOGIES MATRIX………………………………..35

FIGURES

FIGURE 1. NORTH LAKE AND SOUTH LAKE LOCATIONS. 2
FIGURE 2. TOTAL NITROGEN CONCENTRATIONS IN NORTH LAKE, SOUTH LAKE, AND ALLIGATOR LAKE. 6
FIGURE 3. TOTAL PHOSPHORUS CONCENTRATIONS IN NORTH LAKE, SOUTH LAKE, AND ALLIGATOR LAKE. 8
FIGURE 4. NORTH LAKE AND SOUTH LAKE SURROUNDING LAND USE MAP....19
FIGURE 5. NRCS SOILS MAP FOR NORTH LAKE AND SOUTH LAKE. 20
FIGURE 6. NWI WETLAND MAP FOR NORTH LAKE AND SOUTH LAKE. 21
FIGURE 7. VEGETATION BOUNDARY LINE FOR NORTH LAKE...................................22

FIGURE 8. VEGETATION BOUNDARY LINE FOR SOUTH LAKE. 23
FIGURE 9. WILDLIFE MAP FOR NORTH LAKE AND SOUTH LAKE. 24
FIGURE 10. SEDIMENT SAMPLING AND COMPOSITE LOCATIONS. 31
FIGURE 11. SOFT SEDIMENT THICKNESS IN NORTH LAKE. 32
FIGURE 12. SOFT SEDIMENT THICKNESS IN SOUTH LAKE. 33

APPENDICES

APPENDIX A ECOLOGICAL EVALUATION DOCUMENTATION

APPENDIX B SEDIMENT CORING LABORATORY REPORTS

APPENDIX C SEDIMENT FLUX STUDY DOCUMENTATION

1 INTRODUCTION

Properly functioning stormwater lakes are important for effective management of both stormwater quality and stormwater quantity. The functioning and treatment capacity of some stormwater lakes within the City of Naples (the City) has been diminished over time as a result of sediment and pollutant loadings. The City has been conducting lake restorations at stormwater lakes throughout Naples and has recently prioritized North Lake (Lake 8) and South Lake (Lake 9) for restoration (**Figure 1**). The functions of North Lake and South Lake are to store and direct stormwater into the Gulf of Mexico to mitigate flooding and reduce peak flows during rainfall events. As such, these lakes provide valuable services to the citizens of the City of Naples, particularly the residents adjacent to North and South Lakes. Citizens desire an aesthetically pleasing lake front, without nuisance algal blooms or other objectionable conditions that may result from temporary water quality variations that are inherent to the dynamic nature of stormwater lakes.

The City implemented a Stormwater Lakes Management Plan in 2012 and identified South Lake, Lois Selfon Lake, Alligator Lake (which is downstream of North Lake and South Lake), Swan Lake, and Half Moon Lake as some of the lakes with the lowest pollutant removal efficiencies. Since 2012, the City has completed or initiated lake improvement projects to improve water quality at several of these lakes, including restoration in Spring Lake (upstream of Lois Selfon Lake) and Swan Lake. In the 2019 update to the City's Stormwater Lakes Management Plan, WSP (formally Wood Environment & Infrastructure, Inc.), identified North Lake as another high priority lake for restoration.

To support the City in its aim to restore stormwater lakes within Naples, WSP is currently developing lake restoration plans and specifications for North Lake and South Lake. WSP has conducted ecological evaluations of each lake, performed sediment depth surveys, collected sediment samples for analysis, and conducted flux analysis on lake sediment samples. This report describes the results of these surveys, potential water quality improvement technologies that may be considered for lake restorations and includes information on the current modeling effort and next steps. The report also includes context for an alternatives analysis and potential project funding opportunities.

The final feasibility analysis will include assessment of whether dredging or other means of remediation are viable such as capping, augmented aeration, or other applicable technology(s). WSP will provide a matrix analysis discussing the pollutant removal efficiencies, construction impacts, conceptual cost estimates, and other applicable factors. An Interconnected Channel and Pond Routing (ICPR) model is currently being used to simulate water-surface elevations in the North and South Lakes. The hydrologic portion of the model simulates rainfall runoff hydrographs from a variety of storm events from delineated sub-basins for each lake, while the hydraulic component routes storm hydrographs through natural and constructed stormwater features to determine flood stages and peak flows resulting from specific storm events. Two scenarios will be modelled, existing conditions and proposed conditions. The proposed conditions model will make changes to culvert sizes and stage/storage areas in each lake if additional stormwater flow capacity or stormwater retention volume is needed to accomplish project goals. Estimates of the anticipated water quality benefits will be modeled with the BMP Trains model (Version 4.3.5) developed by the University of Central Florida Stormwater Academy (Wanielista, 2020).

Figure 1. North Lake and South Lake locations.

2 BACKGROUND

North Lake is approximately 1.76 acres and South Lake is approximately 4.35 acres in size. The Combined City Clerk Report from 2010 on the ownership of City stormwater lakes describes the lake parcel ownership as “not specified on plat”, and “reserved for lake purposes”. While ownership is unknown, each property owner’s property line extends into the lakes. North Lake discharges into South Lake, which then discharges into Alligator Lake (Lake 10), which then discharges into the Gulf of Mexico via beach outfall 6.

The City has an easement around North Lake and maintains the vegetation on the north side, along 7th Avenue N, where there are no residential properties. The City also maintains two aerators in the lake associated with a previous project. This project utilized floating islands to improve water quality, but the islands were removed because of resident complaints. North Lake is surrounded by 11 residential properties. South Lake also has an easement around the lake which is maintained for drainage purposes. There are two private aerators that the City does not maintain or own. South Lake is surrounded by 25 residential properties with no access to the lake apart from a few narrow easements located at the inflow and outflow pipes.

North Lake receives some stormwater public drainage as well as runoff from the surrounding lakeshed, which consists of residences, commercial properties, and roadways. There are two inflow pipes to North Lake and one outflow pipe that discharges to South Lake. In addition to the outflow from North Lake, South Lake receives stormwater from the surrounding lakeshed, which consists of residences and roadways. There are three inflow pipes to South Lake and one outflow pipe that discharges to Alligator Lake.

The City of Naples was hit by Hurricane Ian in September 2022. In addition to the typical climatic variation that can result in fluctuations in stormwater lake water quality, hurricanes represent a larger impact on system variability as a result of more intense rainfall, longer inundation periods, storm surge, and urban flooding. Because Hurricane Ian hit during the data collection phase of this project, additional data is provided below on the hurricane’s impact on the City of Naples and potential effects of hurricanes on nearshore areas. A brief literature review, to provide additional background on the conditions within North Lake and South Lake, is also included.

2.1 HURRICANE IAN

Hurricane Ian made landfall near Cayo Costa, a barrier island west of Fort Myers and north of Naples, on September 28, 2022, as a Category 4 Atlantic Hurricane with maximum sustained winds of 150 mph. Prior to making landfall, Hurricane Ian had maximum sustained winds of 155 mph (just short of the Category 5 classification)[1]. This storm brought record-breaking storm surge and flooding to the region. Hurricane Ian has been described as producing 1-in-1,000-year rainfall with rain accumulation well over 12 inches in a 12-to-24-hour period from Port Charlotte to Orlando according to radar estimates[2].

Hurricane Ian caused water levels to rise 6.18 feet before the tidal gauge off the coast of Naples became inoperable in the afternoon of September 28[3]. Peak tide information is still being assessed, but the National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information estimates that some coastal communities may have experienced storm surge as great as 12 feet[4]. Total rainfall between September 27 and 30,

[1] NOAA National Environmental Satellite Data and Information Service, “Hurricane Ian’s Path of Destruction”, available at https://www.nesdis.noaa.gov/news/hurricane-ians-path-of-destruction (accessed 12/8/2022)
[2] Fritz, Angela and Miller, B. CNN. “Hurricane Ian’s rainfall was a 1-in-1,000 year event for the hardest-hit parts of Florida”, available at https://www.cnn.com/2022/09/29/weather/hurricane-ian-1000-year-rainfall-climate/index.html (accessed 12/8/2022)
[3] Iowa State University Environmental Mesonet, “National Weather Service Raw Text Product”, available at https://mesonet.agron.iastate.edu/wx/afos/p.php?pil=PSHMFL&e=202210141556 (accessed 12/8/2022)
[4] NOAA National Centers for Environmental Information, Monthly National Climate Report for September 2022, published online October 2022, retrieved on December 8, 2022 from https://www.ncei.noaa.gov/access/monitoring/monthly-report/national/202209/supplemental/page-5.

2022 was estimated to be a maximum of 10 inches in Naples[4]. East Naples received 6.99 inches between September 26 and 29[3].

Storm surge and flooding from hurricanes can potentially cause additional sedimentation within stormwater lakes. Storm surge can cause discrete deposits in coastal lakes, enclosed lagoons, and sinkholes. Hurricanes recorded in coastal lake sedimentation are typically observed in the sediment record as coarse-grain deposits, 0.1 to 1 cm thick, with lower amounts of organic matter interstratified in organic sediment[5]. After Hurricane Harvey landed in the Houston-Galveston region in 2017, researchers analyzed its impact on the Galveston Bay Estuarine System through the changes in its sediment. The researchers saw a significant change in the estuary's bed sediment compared to its historical data. Through quantifying the sediment's physical, chemical, and biological characteristics, they showed that natural events, such as Hurricane Harvey, can affect metal concentrations and microbial communities within the estuary[6]. In addition to sediment potentially being deposited into the lakes due to the hurricane, saltwater intrusion may have also occurred as seen in the San Bernard National Wildlife Refuge, Texas, after Hurricane Harvey[7].

2.2 EXISTING DATA REVIEW SUMMARY

WSP reviewed the following reports for data and information related to North and South Lakes and the surrounding watershed:

- City of Naples 2020-2021 Annual Surface Water and Pump Station Monitoring and Analysis Report (Wood, 2022)
- City of Naples 2019 Update to the City of Naples Stormwater Lakes Management Plan (Wood, 2019)
- City of Naples 2018 Stormwater Master Plan Update (AECOM, 2018)
- City of Naples Stormwater Quality Analysis, Pollutant Loading, and Removal Efficiencies (AMEC, 2012)

Each report was reviewed with a focus on water quality data (e.g., total suspended solids [TSS], nutrients including total phosphorus [TP] and total nitrogen [TN], and bacteria).

2.2.1 CITY OF NAPLES 2020-2021 ANNUAL SURFACE WATER MONITORING REPORT (WOOD, 2022)

Between October 2020 and September 2021, Wood conducted water quality sampling at 22 stormwater lakes and three pump stations within the City of Naples. Samples were analyzed for nutrients, chlorophyll-a (chl-a), copper (Cu), and fecal indicator bacteria. Frequent water quality monitoring is important to assess changes in water quality conditions in the lakes.

Wood (2022) found that some of the highest average concentrations of nutrients, chl-a, and fecal indicator bacteria were found in sampling locations in Half Moon Lake, North Lake, South Lake, Lantern Lake, and the Port Royal Pumping station. Statistically significant increasing trends were found for fecal coliform in both North and South Lakes.

While the stormwater lakes are not subject to the Florida Department of Environmental Protection (FDEP) regulatory water quality criteria, it can be helpful to consider in-lake water quality compared to the regulatory criteria of downstream water bodies. Water quality samples from North and South Lakes frequently contain concentrations of chl-a, TN, and TP that exceeds the criteria for the Gulf of Mexico. However, as stated in Wood (2022), "Stormwater

[5] Sabatier, P, et. al. A Review of Event Deposits in Lake Sediments. *Quarternary* 2022, 5, 34. https://doi.org/10.3390/quat5030034
[6] Kiaghadi, A., et. al. Longitudinal Patterns in Sediment Type and Quality During Daily Flow Regimes and Following Natural Hazards in an Urban Estuary. University of Houston. 2022. https://d197for5662m48.cloudfront.net/documents/publicationstatus/49854/preprint_pdf/9bed10b52e00c71dc19a7be125b50848.pdf
[7] Yao, Q, et. al. Hurricane Harvey Storm Sedimentation in the San Bernard National Wildlife Refuge, Texas: Fluvial Versus Storm Surge Deposition. *Estuaries and Coasts* 2020, 43. https://doi.org/10.1007/s12237-019-00639-6

lakes are designed to receive rainfall runoff containing nutrients and other pollutants and exceedances are expected when comparing the stormwater lakes to downstream criteria which apply to more natural waterbodies that were not designed and constructed to intercept stormwater runoff from developed lands. The comparison to downstream water quality criteria is simply a comparison tool and the downstream water quality criteria do not represent target water quality conditions in stormwater lakes. Information on stormwater lake samples with exceedances of non-applicable downstream waterbody criteria is provided to assist managers on where to conduct additional study to support water quality improvement projects."

2.2.2 CITY OF NAPLES UPDATE TO THE STORMWATER LAKES MANAGEMENT PLAN (WOOD, 2019)

The 2019 Lakes Management Plan Update (LMPU) for the City of Naples summarized the water quality and sediment data for the City's stormwater lakes, the prior management plan, and included updated lake rankings and recommendations. Based on the 2019 LMPU priority rankings, North Lake was ranked as one of the lakes that should be a high priority for restoration. In a citizen survey conducted as part of the 2019 LMPU, North Lake stakeholders reported deteriorating water quality and flooding issues.

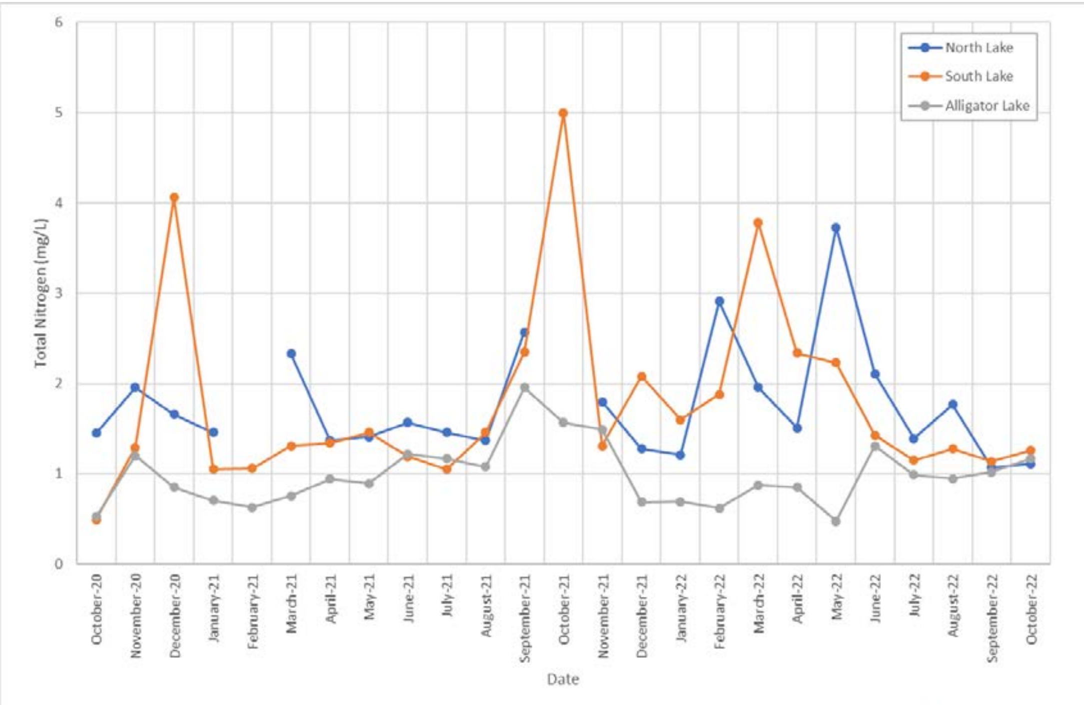
2.2.3 CITY OF NAPLES 2018 STORMWATER MASTER PLAN UPDATE (AECOM, 2018)

The 2018 update to the City of Naples Stormwater Master Plan evaluated flooding and water quality issues, described water quality and water quantity issues, and proposed stormwater improvement projects and funding opportunities for the City. North Lake and South Lake are in Basin 2, which is comprised primarily of urban land (AECOM 2018) and drains to the Gulf of Mexico. Proposed projects were not included for North Lake and South Lake. AECOM (2018) also noted that Gulf Shore Boulevard, a road within Basin 2 that experiences flooding, was to be reviewed as part of an Ocean Outfall Study.

A public survey included in this study found that the public was "…interested in improving/restoring Naples Bay and Gulf of Mexico/Naples Beaches over other water bodies," indicating potential support for restoration of North and South Lake which discharge to the Gulf of Mexico.

2.2.4 CURRENT WATER QUALITY MONITORING PROGRAM

WSP is currently collecting water quality samples monthly from the City of Naples stormwater lakes, including North Lake and South Lake. Concentrations of TN and TP since 2020 are shown in **Preliminary data** analysis incorporating data from the current water quality program (through September 2022) and previously collected data back to 2014 (as summarized in Wood, 2022) indicate increasing concentrations of ammonia-nitrogen (an inorganic component of TN) in North Lake and increasing *Enterococci* and fecal coliform in South Lake. In the downstream lake (Alligator Lake), concentrations of orthophosphate (dissolved inorganic component of TP) and *Enterococci* were significantly increasing. Statistically significant trends in nutrients were not observed in North or South Lake; TN and chl-a were decreasing in Alligator Lake. However, while trends may be statistically significant, they may not be ecologically significant. A trend slope near zero likely will not show a measurable effect within a reasonable time frame (i.e., years to decades). Therefore, decreasing trends do not necessarily indicate that additional water quality improvement projects would not be beneficial.



and

Figure 2. Total nitrogen concentrations in North Lake, South Lake, and Alligator Lake. Not displayed on the figure is the North Lake concentration from February 2021 which exceeded 40 mg/L and October 2021 of 8.5 mg/L. Nondetects displayed as the detection limit (0.05 mg/L), if applicable.

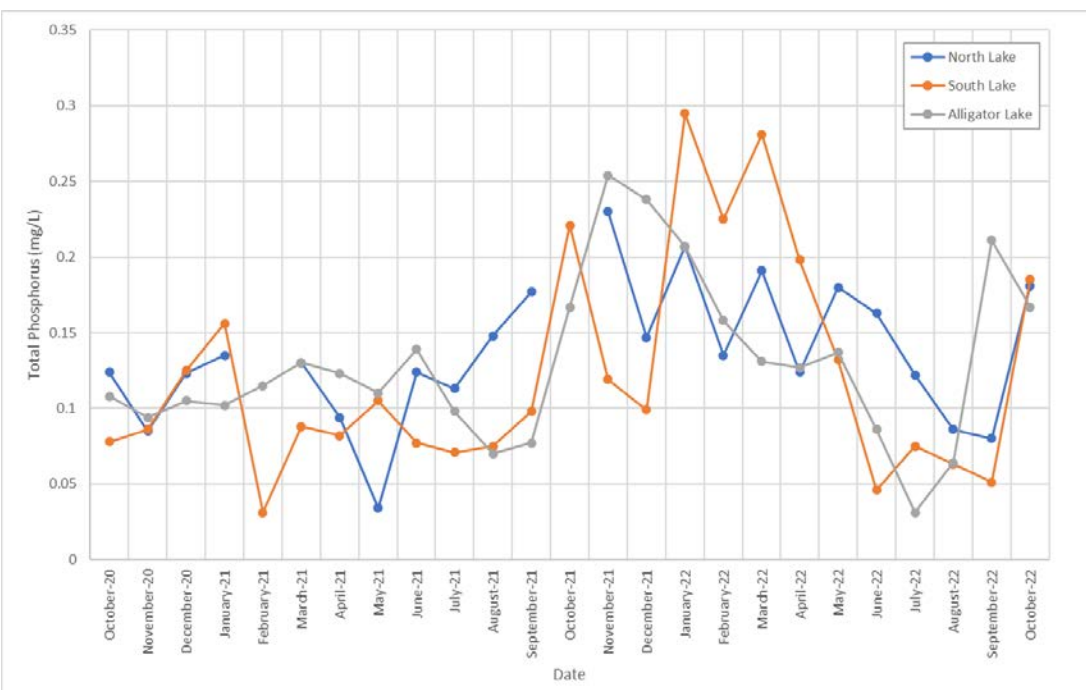


Figure 3. Preliminary data analysis incorporating data from the current water quality program (through September 2022) and previously collected data back to 2014 (as summarized in Wood, 2022) indicate increasing concentrations of ammonia-nitrogen (an inorganic component of TN) in North Lake and increasing *Enterococci* and fecal coliform

in South Lake. In the downstream lake (Alligator Lake), concentrations of orthophosphate (dissolved inorganic component of TP) and *Enterococci* were significantly increasing. Statistically significant trends in nutrients were not observed in North or South Lake; TN and chl-a were decreasing in Alligator Lake. However, while trends may be statistically significant, they may not be ecologically significant. A trend slope near zero likely will not show a measurable effect within a reasonable time frame (i.e., years to decades). Therefore, decreasing trends do not necessarily indicate that additional water quality improvement projects would not be beneficial.

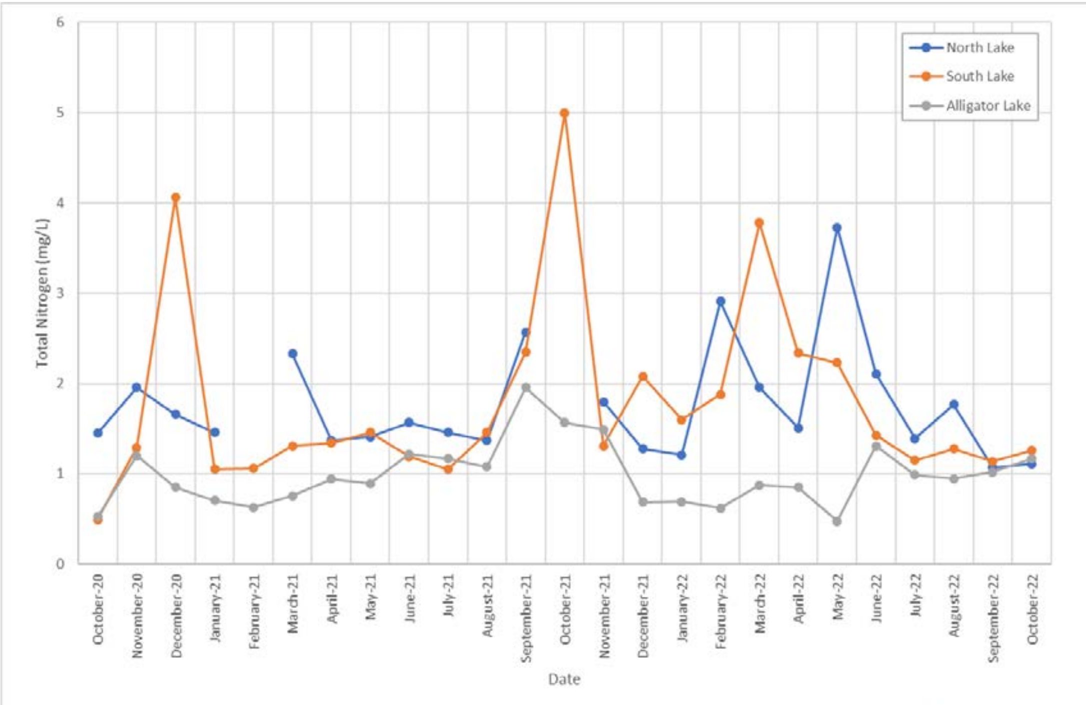


Figure 2. Total nitrogen concentrations in North Lake, South Lake, and Alligator Lake. Not displayed on the figure is the North Lake concentration from February 2021 which exceeded 40 mg/L and October 2021 of 8.5 mg/L. Nondetects displayed as the detection limit (0.05 mg/L), if applicable.

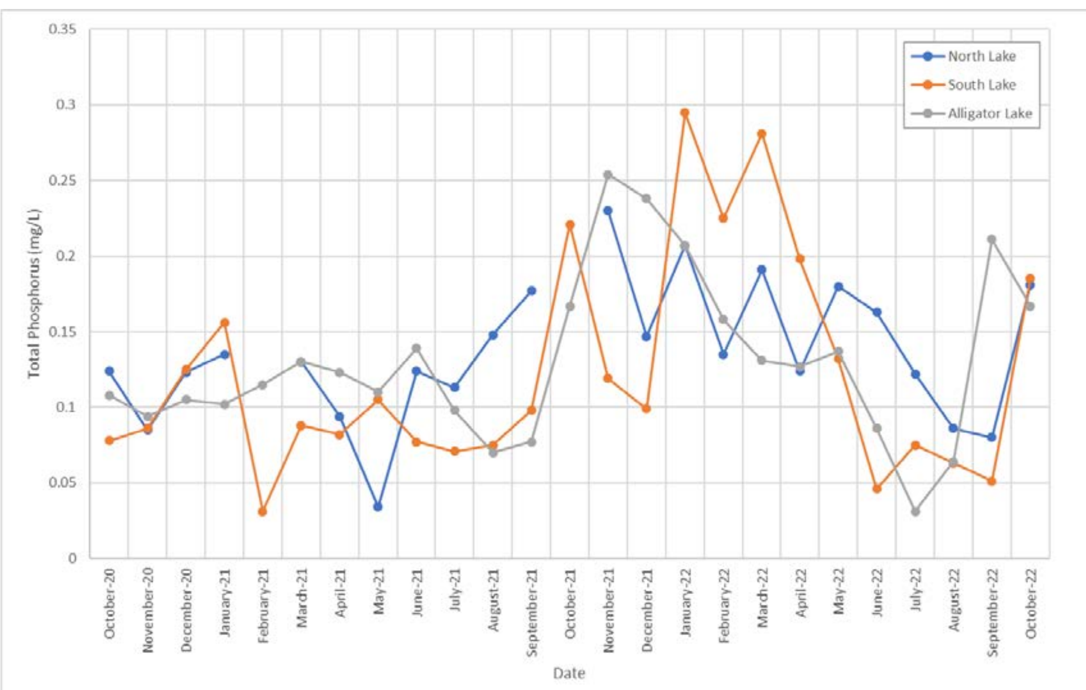


Figure 3. Total phosphorus concentrations in North Lake, South Lake, and Alligator Lake. Not displayed on the figure is the North Lake concentration from February 2021 of 3 mg/L and October 2021 of 1.7 mg/L. Nondetects displayed as the detection limit (0.008 mg/L), if applicable.

2.2.5 CONCLUSION OF DATA REVIEW

After assessing available data from North and South Lake, WSP expects that the current water quality dataset is sufficient for the North Lake and South Lake Feasibility Study. The sediment assessment conducted as part of the current project and described below, also provides valuable data, considering sediment samples have not been recently collected from North Lake and South Lake.

WSP also conducted ICPR modeling. Spatial data (in ArcGIS) on the stormwater infrastructure was provided by the City of Naples. The infrastructure dataset included the existing stormwater infrastructure (culverts, weirs, drop structures, surface ditches) relevant to the North Lake and South Lake watersheds. Review of these data were incorporated into the ICPR modeling task.

3 ECOLOGICAL EVALUATION

WSP conducted an ecological evaluation in September 2022, prior to Hurricane Ian. The lakes are artificial impoundments/reservoirs surrounded by medium density residential dwelling units according to the Florida Land Use and Cover Classification System (FLUCCS) (**Figure 4**). The Natural Resources Conservation Service (NRCS) soils map characterizes the area as surrounded by urban land at 0 to 2 percent slopes (

Figure 5). The National Wetlands Inventory (NWI) does not identify any wetlands, only surface waters, in or surrounding the project areas (

Figure 6)

3.1 WETLANDS AND SURFACE WATERS

WSP reviewed available topographic survey information, soil maps, land use maps, and NWI maps to prepare for the wetland delineation. The wetland delineation and field reconnaissance were completed September 1, 2022, by WSP scientists. The sites were delineated for wetlands using methods as described in the Delineation of the Landward Extent of Wetlands and Surface Waters [FDEP, Chapter 62.340, F.A.C]. This procedure uses a series of tests to address three characteristics of wetlands, including the presence/absence of hydrophytic vegetation, wetland hydrology, and hydric soils.

WSP conducted the field visit to characterize the delineated wetlands and surface waters. Delineation included onsite determination, marking in the field with a handheld GPS unit (sub-meter accuracy), and flagging of the aerial extent of each wetland (if any). Potential wetlands were identified along the littoral edge of the surface waters. A Uniform Mitigation Assessment Method (UMAM) was completed based on the current conditions of each lake (**Appendix A-1**).

The perimeter of each lake was assessed via kayak. No flows were observed out of the culverts at either site during the site visit. Emergent vegetation and species composition was notated. The vegetation across both sites was comprised primarily of non-native species, with some native species in concentrated areas. Prevalent species throughout both sites include alligator weed (*Alternanthera philoxeroides*) and Peruvian primrose-willow (*Ludwigia peruviana*).

North Lake was dominated by alligator weed and Peruvian primrose-willow with less than 5% desirable cover around the lake's perimeter (

Figure 7). About two-thirds of the lake was covered by duckweed (*Lemna* sp.) during the site visit. Queen palm (*Syagrus romanzoffiana)*, coconut palm (*Cocos nucifera*), and Bismarck Palm (*Bismarckia nobilis*) were identified around the perimeter of North Lake as well.

South Lake was characterized primarily by alligator weed scattered around the lake's perimeter at varying distances of 3 to 6 feet from shore (

Figure 8). Most residential yards surrounding South Lake include sod maintained to the lake's edge and had little to no emergent vegetation, with most having a slope of 60 degrees or greater at the lakes edge. The color in South Lake was a blue tint likely due to an additive. Four bubblers were active and a film on the water surface was observed at the time of the site visit. Florida royal palm (*Roystonea regia*), queen palm, coconut palm, and Sabal palm (*Sabal palmetto*) were identified around the perimeter of South Lake.

A list of all observed plant species at both sites is included in **Table 31**. Site photographs are included in **Appendix A-2**.

3.2 THREATENED AND ENDANGERED SPECIES SURVEY

The threatened and endangered (T&E) species survey was conducted in two phases consistent with the Environmental Resource Permit (ERP) application for the proposed action. The first phase was a literature search and mapping effort to identify species potentially found on the site. Available data was gathered through an online data search of the Florida Fish and Wildlife Conservation Commission (FWC), United States Fish and Wildlife Service (USFWS), Florida Natural Areas Inventory (FNAI), Florida Geographic Data Library (FGDL), and other sources. Maps of previous sightings and critical habitat of listed species were compiled. Distances from the project site to adjacent features were calculated and compared to regulatory constraints. A wildlife map was produced in GIS format and is presented in

Figure 9. Potential listed species occurrences are presented **in Appendix A-3**.

During the site visit, WSP scientists conducted a kayak-based visual survey. Records were made of any wildlife observed, listed plant species found, any evidence of wildlife utilization, and appropriate habitat for listed species.

The American wood stork core foraging area overlaps with the northeast corner of the lake (

Figure 9). No wood storks were observed within the proximity of either lake project area during the site investigation. This report can be submitted to the regulatory agencies as an exhibit noting that listed species are possibly present by not likely to be adversely affected by the proposed development. Non-listed fauna encountered at the two sites are summarized in **Table 2**. While not a complete listing of every species found, it is representative of the sites.

A listing of threatened and endangered species for Collier County, Florida, was obtained from the USFWS Information for Planning and Consultation (IPaC) website (http://ecos.fws.gov/ipac). According to the report, there are 19 species (four mammals, five birds, five reptiles/amphibians, one fish, three insects, and one flowering plant) that are known to occur or have the potential to occur within the vicinity of the project areas. There are no critical habitats listed within the project areas. A copy of the Trust Resources List is included in Appendix A3.

Additionally, WSP generated a Biodiversity Matrix from the FNAI website (http://www.fnai.org/biointro.cfm) to determine if State-listed species may be affected by the proposed project. According to the report, there are 29 species that are known to occur, or have the potential to occur within the vicinity of the project areas. This report does contain some overlap with the Federal listings from IPaC. A copy of the Biodiversity Matrix Query Results is included in Appendix A3.

Notable species listed in the FNAI Biodiversity Matrix and IPaC Trust Resources list potentially impacted at the project site are described below:

— American Alligator: The American alligator (*Alligator mississippiensis*) is federally protected by the Endangered Species Act (ESA) as a threatened species and as a state threatened species by Florida's Endangered and Threatened Species Rule. This is due to their similarity of appearance to the American crocodile (*Crocodylus acutus*), which is a federally endangered species. Alligator habitat includes permanent bodies of water such as lakes, rivers, and swamps. No alligator were observed during the kayak survey. The proposed dredging of North and South Lakes are not expected to have a permanent habitat impact. Additionally, due to the transient nature of this species, it would be expected that any alligators currently using the immediate project area would relocate to the ample available habitat of the surrounding area without disruption of their normal behavior.

Wood stork: While a small section of North Lake is within a core foraging area, no wood storks (*Mycteria americana*) were observed on site (

- **Figure 9**). This species is listed as threatened under the ESA Wood storks prefer continuously inundated wetland areas, limited to depths less than 10-12 inches. Based on these findings, we conclude that there is appropriate habitat for this species within the project area, however, the project as designed is not likely to impact this species or its habitat.

Other listed species noted in the FNAI Biodiversity Matrix and IPaC Trust Resources list were not considered to be present or potentially impacted at the project site. Transient species have the potential to be present on-site at any time. Any potential impacts on these species will be temporary and minimal.

Table 31. Plant species observed at North Lake and South Lake.

Species	Common Name	Native or Non-native	FDEP Status
North Lake			
Albizia julibrissin	Silktree; Mimosa	Non-native	FISC Category 1
Alternanthera philoxeroides	Alligator weed	Non-native	FISC Category 2
Annona glabra	Pond apple	Native	OBL
Azolla sp.	Mosquitofern		
Boehmeria cylindrica	False nettle; Bog hemp	Native	OBL
Canna sp.			
Coccoloba uvifera	Seagrape	Native	
Cupaniopsis anacardiodes	Carrotwood tree	Non-native	
Hydrocotyle umbellata	Manyflower Marshpennywort	Native	FACW
Lemna sp.	Duckweed	Native	
Ludwigia peruviana	Peruvian primrose-willow	Non-native	FISC Category 1 OBL
Najas guadalupensis	Southern waternymph	Native	
Pontederia cordata	Pickerelweed	Native	OBL
Schinus tereninthifolia	Brazilian peppertree	Non-native	FISC Category 1
Typha sp.	Cattail	Native	OBL
South Lake			
Alternanthera philoxeroides	Alligator weed	Non-native	FISC Category 2
Crinum americanum	Seven-sisters; String-lily	Native	OBL
Cyperus papyrus	Papyrus flatsedge	Non-native	OBL
Ludwigia peruviana	Peruvian primrose-willow	Non-native	FISC Category 1 OBL
Panicum repens	Torpedograss	Non-native	FISC Category 1 FACW
Pontederia cordata	Pickerelweed	Native	OBL
Schinus tereninthifolia	Brazilian peppertree	Non-native	FISC Category 1

Table 2. Fauna observed at North Lake and South Lake.

Species	Common Name	Comments
North Lake		
Cairina moschata	Muscovy duck	
Centropomus undecimalis	Snook	
Egretta thula	Snowy egret	
Gallinula chloropus	Moorhen	
Gambusia holbrooki	Mosquitofish	
South Lake		
Gallinula chloropus	Moorhen	
Butorides virescens	Little green heron	
Gambusia holbrooki	Mosquitofish	
Cyanocitta cristata	Blue jay	
Corvus sp.	Crow	
Ardea alba	Great egret	
Eudocimus albus	White Ibis	
Cairina moschata	Muscovy duck	
Mimus polyglottos	Mockingbird	
Centropomus undecimalis	Snook	Did not observe; resident informed
Megalops atlanticus	Tarpon	Did not observe; resident informed
Centrarchidae (family)	Sunfish	Did not observe; resident informed

Figure 4. North Lake and South Lake surrounding land use map.

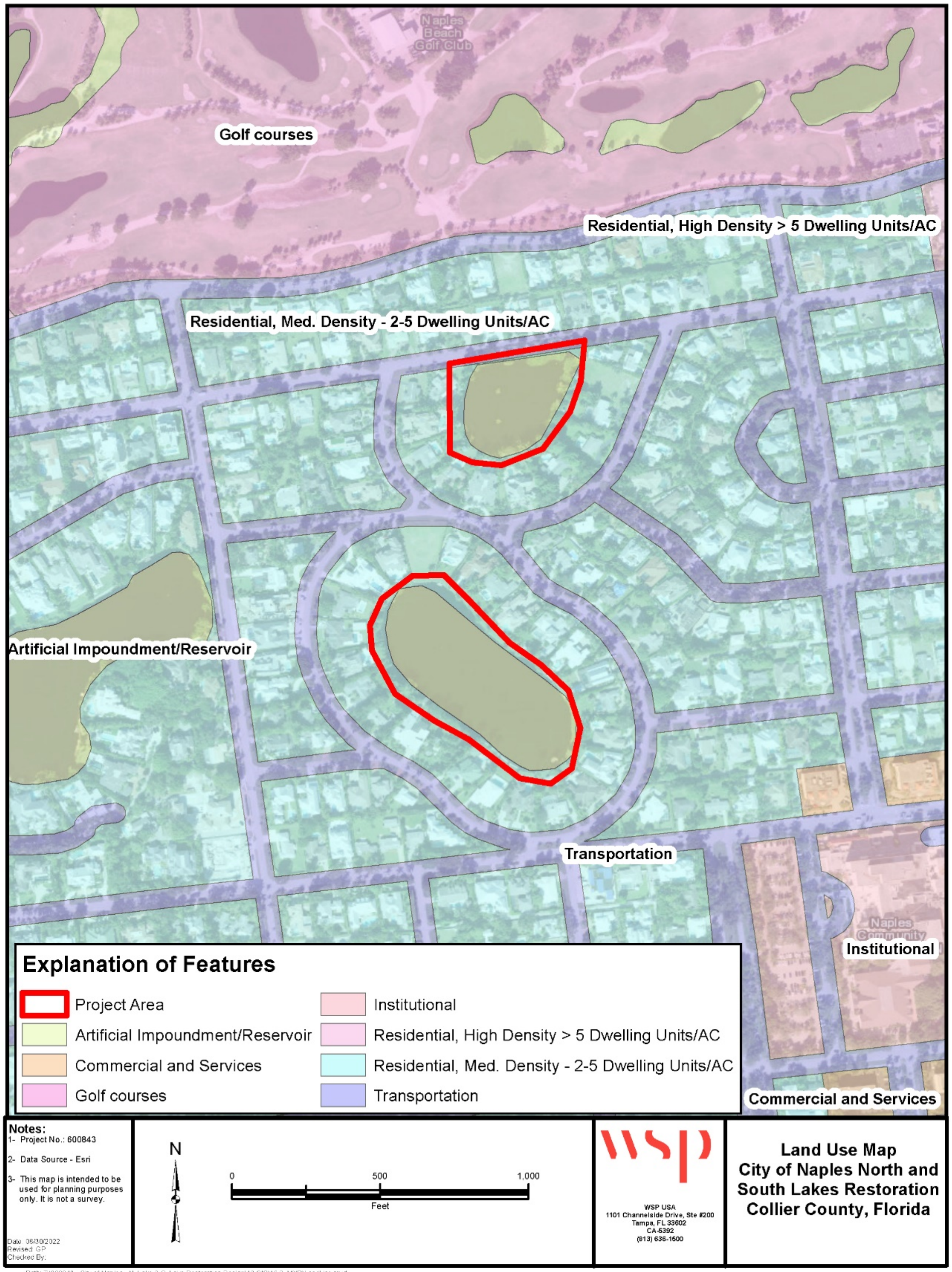


Figure 5. NRCS soils map for North Lake and South Lake.

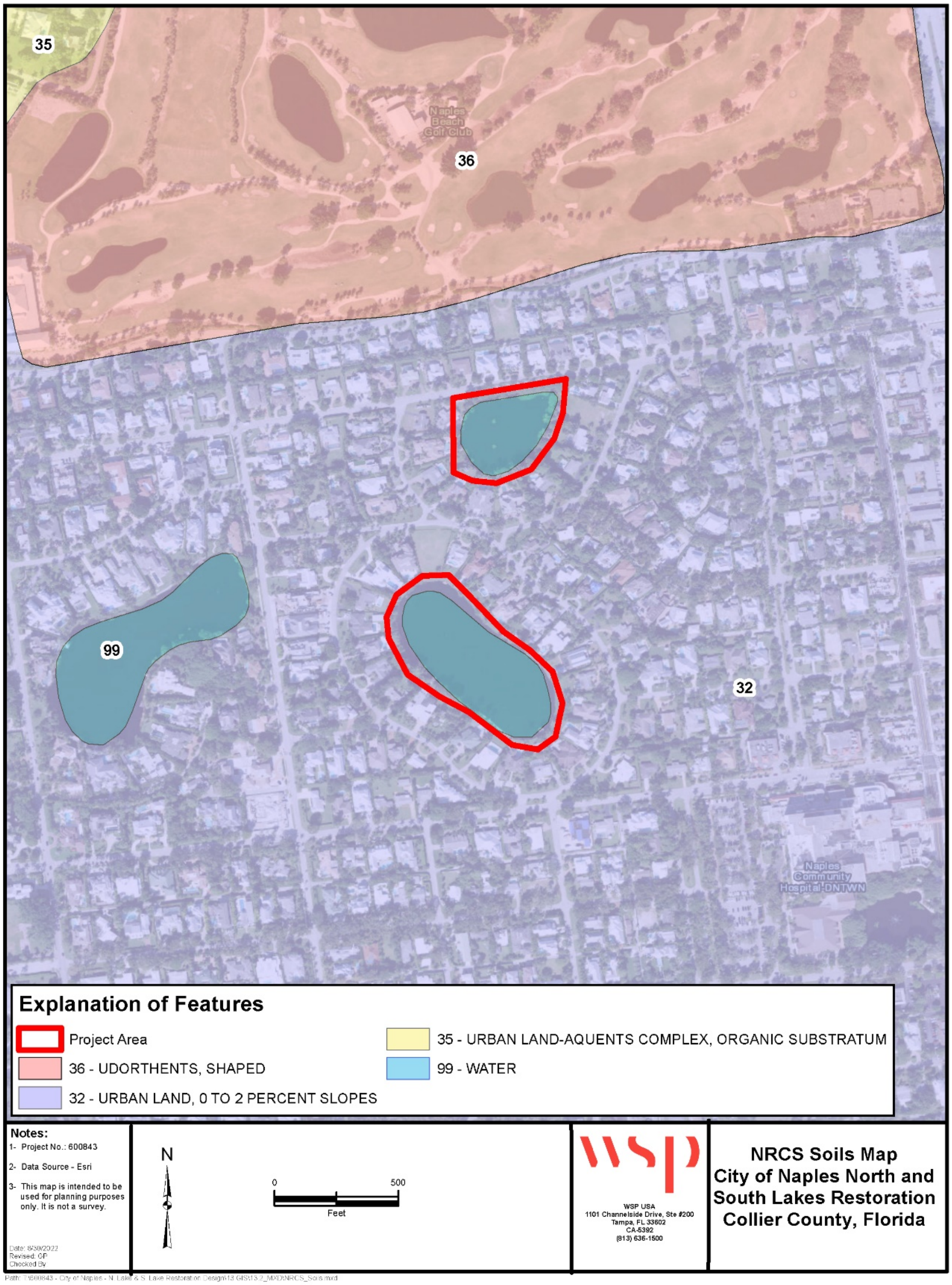


Figure 6. NWI wetland map for North Lake and South Lake.

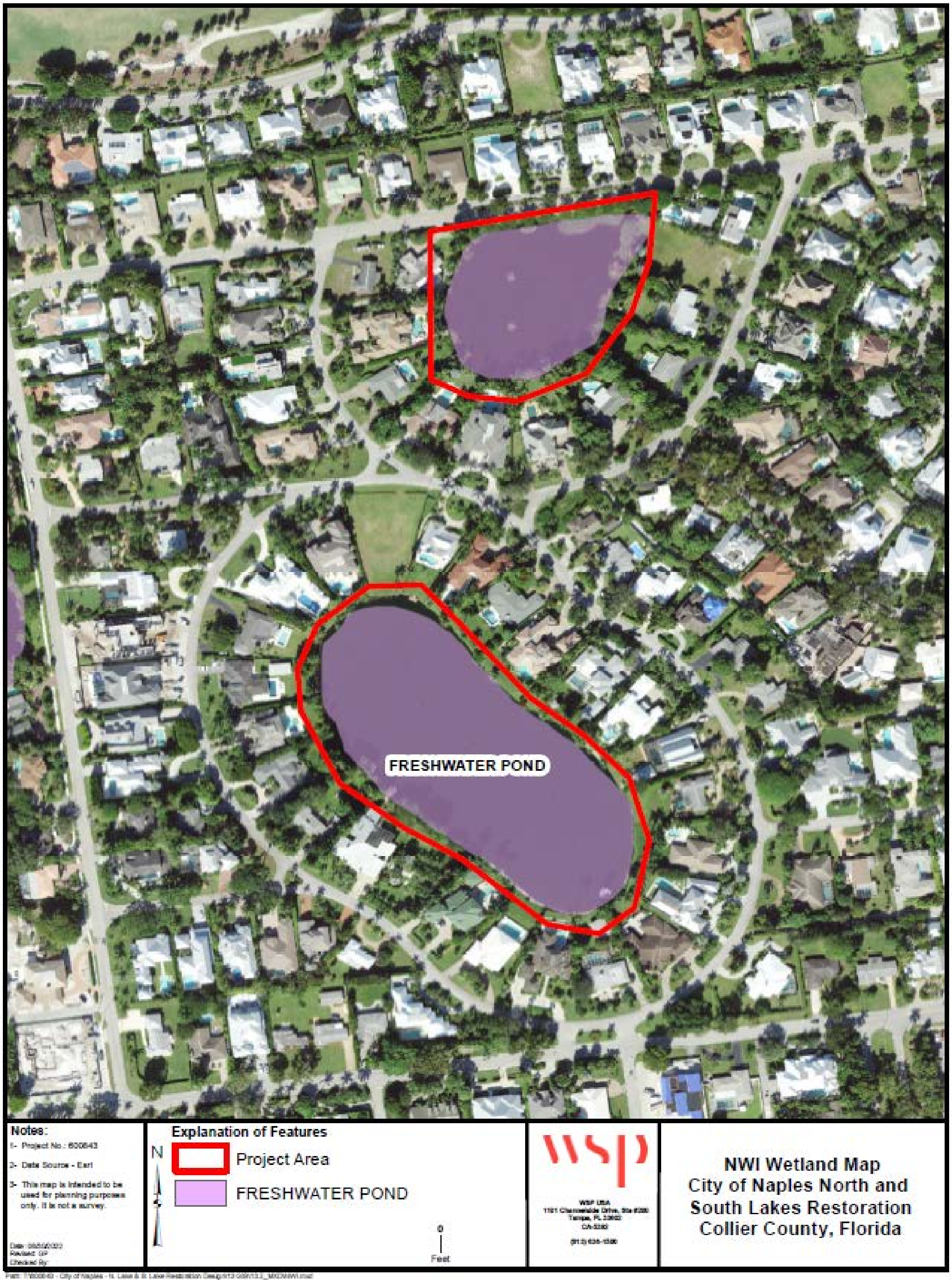


Figure 7. Vegetation boundary line for North Lake.

Figure 8. Vegetation boundary line for South Lake.

Figure 9. Wildlife map for North Lake and South Lake.

4 SEDIMENT EVALUATION

4.1 SEDIMENT ENGINEERING EVALUATION

WSP conducted engineering site visits with survey and coring to assess site conditions in North Lake and South Lake. Sediment cores were collected from each lake (**Table 4. Select analytical data for composited sediment samples collected in November 2022 from North Lake and South Lake with comparison to groundwater criteria.**

Lake	Composite Sample ID (Sample Locations used in Composite)	Total Arsenic (ug/L)	Cadmium (ug/L)	Total Chro-mium (ug/L)	Total Lead (ug/L)
North Lake (Lake 8)	LAKE 8 Comp #3 (1, 3, 7)	**110**	3.3 U	17.0 U	21.0 U
	LAKE 8 Comp # 2 (2, 4, 8)	**42 I**	3.3 U	17.0 U	21.0 U
	LAKE 8 Comp #1 (6, 5, 9)	34.0 U	3.3 U	17.0 U	21.0 U
South Lake (Lake 9)	LAKE 9 Comp #1 (1, 3, 4)	34.0 U	3.3 U	17.0 U	21.0 U
	LAKE 9 Comp #5 (15, 16, 19, 22)	**51 I**	3.3 U	17.0 U	21.0 U
	LAKE 9 Comp # 6 (17, 18, 20, 21)	**100**	3.3 U	17.0 U	21.0 U
	LAKE 9 Comp #2 (2, 5, 6)	**98 I**	3.3 U	17.0 U	21.0 U
	LAKE 9 Comp #3 (7, 9, 10, 13)	34.0 U	3.3 U	17.0 U	21.0 U
	LAKE 9 Comp #8 (11, 12, 14,)	**42 I**	3.3 U	17.0 U	21.0 U
FDEP Criteria	GCTLs	10	5	100	15
	NADCs	100	50	1000	150

Notes:

NA = Not Available

NS = Not Sampled

GCTLs = Groundwater Cleanup Target Levels specified in Table I of Chapter 62-777, F.A.C.

NADCs = Natural Attenuation Default Source Concentrations specified in Table V of Chapter 62-777, F.A.C.

Exceeds GCTL Limit

Exceeds NADC Limit

I = The reported value is between the laboratory method detection limit and the laboratory practical quantitation limit.

U = Compound was analyzed but not detected.

Figure 10) on November 14 and 15, 2022. At each sample location, intact cores were collected to the depth of the consolidated sand layer. Cores were then composited (as indicated in **Figure 10)** and each composited core sample was submitted to an analytical laboratory for physical and chemical analysis. Physical testing of each core included moisture content (ASTM D2216), percent fines (D1140), and organic matter (D2974). Chemical characterization included nitrogen and phosphorus to characterize the benefits of removal; and metals, Total Recoverable Petroleum Hydrocarbons (TRPH), and polynuclear aromatic hydrocarbons (PAHs) that may affect disposal or beneficial re-use options. A survey was conducted to assess water depth and muck thickness via sediment probing. The survey work was conducted in September (12-15 and 21-22) and October (17-18) 2022.

Analysis of the sediment core data are underway and preliminary laboratory results have been received (**Appendix B**). These results indicate exceedances of the FDEP's Soil Cleanup Target Levels (SCTLs) for arsenic, copper, benzo (a) pyrene (BAP), and the total BAP equivalent in both lakes. Arsenic concentrations also exceeded groundwater FDEP criteria (e.g., Groundwater cleanup target levels [GCTL]). Chemical suites with exceedances are included in **Table 3** and **Table 4**. Nutrient concentrations are also included in **Table 3**. Additional data is included in **Appendix B**. Results from soft sediment thickness mapping in North Lake (

Figure 11) and South Lake (

Figure 12) indicate almost 3 feet of highly organic sediment in portions of North Lake and up to 2 feet of highly organic sediment in portions of South Lake. Note: South Lake sediment elevations were collected both before and after Hurricane Ian and analysis of the survey points did not reveal evidence of differences in data between the collection dates.

The survey and sediment data will be used in future deliverables to estimate the volume of highly organic sediments for potential removal, the texture of these materials, and how it affects dredged material management/dewatering; nutrient loading which indicates the benefits of sediment removal on receiving waters; and contaminants that may affect disposal and beneficial re-use options.

Table 3. Select analytical data for composited sediment samples collected in November 2022 from North Lake and South Lake with comparison to soil criteria.

Lake	Composite Sample ID (Sample Locations used in Composite)	Metals (mg/kg)									PAHs								Nutrients (mg/kg) and Physical (%)				
		Arsenic	Cadmium	Chromium	Lead	Barium	Copper	Mercury	Selenium	Silver	Benzo (a) pyrene	Benzo (a) anthra-cene	Benzo (b) fluoran-thene	Benzo (k) fluoran-thene	Chrysene	Dibenz (a,h) anthra-cene	Indeno (1,2,3-cd) pyrene	Benzo (a) pyrene equivalent	Total Nitrogen Soil	Total Kjeldahl Nitrogen	Nitrogen, NO2 plus NO3	Phosphorus, Total (as P)	Percent Moisture (%)
North Lake (Lake 8)	LAKE 8 Comp #3 (1, 3, 7)	**16.4**	**0.17**	**5.1**	**28.9**	**1.5**	**44.3**	**0.074**	1.0 U	0.15 U	**0.23 I**	0.045 U	**0.28 I**	**0.12 I**	**0.047 I**	0.078 U	**0.16 I**	**0.32**	**1930**	**1930**	0.56 U	**106**	**55.3**
	LAKE 8 Comp # 2 (2, 4, 8)	**4.2**	**0.058 I**	**1.8**	**10.2**	**0.58 I**	**24.2**	**0.02**	0.58 U	0.086 U	0.046 U	0.025 U	0.050 U	0.050 U	0.025 U	0.043 U	0.043 U	0.051	**675**	**675**	0.38 U	**43.3 I**	**33.6**
	LAKE 8 Comp #1 (6, 5, 9)	**4.1**	**0.11**	**4.6**	**37.2**	**2.2**	**26.8**	**0.021**	**1.5**	0.083 U	**0.067 I**	**0.063 I**	**0.10 I**	0.043 U	**0.074 I**	0.037 U	**0.039 I**	**0.11**	**755**	**755**	0.35 U	**140**	**27.9**
South Lake (Lake 9)	LAKE 9 Comp #1 (1, 3, 4)	**5.2**	**0.3**	**2.6**	**2.8**	**1.3**	**114**	**0.022**	0.66 U	0.097 U	**0.31 I**	**0.15 I**	**0.43**	**0.15 I**	**0.16 I**	0.075 U	**0.18 I**	**0.43**	**983**	**983**	0.46 U	**59.4**	**45.4**
	LAKE 9 Comp #5 (15, 16, 19, 22)	**15.6**	**0.086 I**	**4**	**4.2**	**1.9**	**51.8**	**0.034**	1.1 U	0.16 U	0.11 U	0.060 U	**0.16 I**	0.12 U	0.060 U	0.10 U	0.10 U	**0.13**	**2210**	**2210**	**1.5**	**69.5 I**	**59.4**
	LAKE 9 Comp # 6 (17, 18, 20, 21)	**14.5**	**0.28**	**6.6**	**5.2**	**1.5**	**345**	**0.043**	1.0 U	0.15 U	0.093 U	0.050 U	0.10 U	0.10 U	0.050 U	0.087 U	0.086 U	0.1	**1210**	**1210**	0.69 U	**76.6 I**	**63.6**
	LAKE 9 Comp #2 (2, 5, 6)	**10.6**	**0.26**	**4.5**	**4.3**	**2.1**	**245**	**0.042**	0.90 U	0.13 U	0.090 U	0.048 U	0.097 U	0.097 U	0.048 U	0.084 U	0.083 U	0.099	**2500**	**2500**	0.56 U	**146**	**55.3**
	LAKE 9 Comp #3 (7, 9, 10, 13)	**0.49 I**	0.032 U	**0.30 I**	**0.43 I**	**0.19 I**	**3**	**0.0092 I**	0.48 U	0.070 U	**0.074 I**	**0.041 I**	**0.11 I**	0.047 U	**0.035 I**	0.041 U	**0.046 I**	**0.11**	**148**	**148**	0.32 U	33.7 U	**23.5**
	LAKE 9 Comp 8 11 12 14	**9.2**	**0.37**	**6.1**	**8.1**	**1.9**	**172**	**0.068**	1.3 U	0.19 U	0.15 U	0.081 U	0.16 U	0.16 U	0.081 U	0.14 U	0.14 U	**0.16**	**769**	**769**	0.81 U	83.6 U	**68.9**
FDEP Criteria	Leachability Based on Groundwater Criteria (mg/kg)	*	7.5	38	*	1600	NA	2.1	5.2	17	8	0.8	2.4	24	77	0.7	6.6	**	NA	NA	NA	NA	NA
	Direct Exposure Residential (mg/kg)	2.1	82	210	400	120	150	3	440	410	0.1	#	#	#	#	#	#	0.1	NA	NA	NA	NA	NA
	Direct Exposure Commercial/Industrial (mg/kg)	12	1700	470	1400	130000	89000	17	11000	8200	0.7	#	#	#	#	#	#	0.7	NA	NA	NA	NA	NA

Notes:

NA = Not Available

NS = Not Sampled

* = Leachability value may be determined using TCLP.

= Direct Exposure value not applicable except as part of the Benzo(a)pyrene equivalent.

** = Leachability value not applicable

Exceeds Leachability Based on Groundwater Criteria Limits

Exceeds Direct Exposure Residential Limits

Exceeds Direct Exposure Commercial/Industrial Limits

I = The reported value is between the laboratory method detection limit and the laboratory practical quantitation limit.

U = Compound was analyzed but not detected.

Table 4. Select analytical data for composited sediment samples collected in November 2022 from North Lake and South Lake with comparison to groundwater criteria.

Lake	Composite Sample ID (Sample Locations used in Composite)	Total Arsenic (ug/L)	Cadmium (ug/L)	Total Chro-mium (ug/L)	Total Lead (ug/L)
North Lake (Lake 8)	LAKE 8 Comp #3 (1, 3, 7)	**110**	3.3 U	17.0 U	21.0 U
	LAKE 8 Comp # 2 (2, 4, 8)	**42 I**	3.3 U	17.0 U	21.0 U
	LAKE 8 Comp #1 (6, 5, 9)	34.0 U	3.3 U	17.0 U	21.0 U
South Lake (Lake 9)	LAKE 9 Comp #1 (1, 3, 4)	34.0 U	3.3 U	17.0 U	21.0 U
	LAKE 9 Comp #5 (15, 16, 19, 22)	**51 I**	3.3 U	17.0 U	21.0 U
	LAKE 9 Comp # 6 (17, 18, 20, 21)	**100**	3.3 U	17.0 U	21.0 U
	LAKE 9 Comp #2 (2, 5, 6)	**98 I**	3.3 U	17.0 U	21.0 U
	LAKE 9 Comp #3 (7, 9, 10, 13)	34.0 U	3.3 U	17.0 U	21.0 U
	LAKE 9 Comp #8 (11, 12, 14,)	**42 I**	3.3 U	17.0 U	21.0 U
FDEP Criteria	GCTLs	10	5	100	15
	NADCs	100	50	1000	150

Notes:

NA = Not Available

NS = Not Sampled

GCTLs = Groundwater Cleanup Target Levels specified in Table I of Chapter 62-777, F.A.C.

NADCs = Natural Attenuation Default Source Concentrations specified in Table V of Chapter 62-777, F.A.C.

Exceeds GCTL Limit

Exceeds NADC Limit

I = The reported value is between the laboratory method detection limit and the laboratory practical quantitation limit.

U = Compound was analyzed but not detected.

Figure 10. Sediment sampling and composite locations.

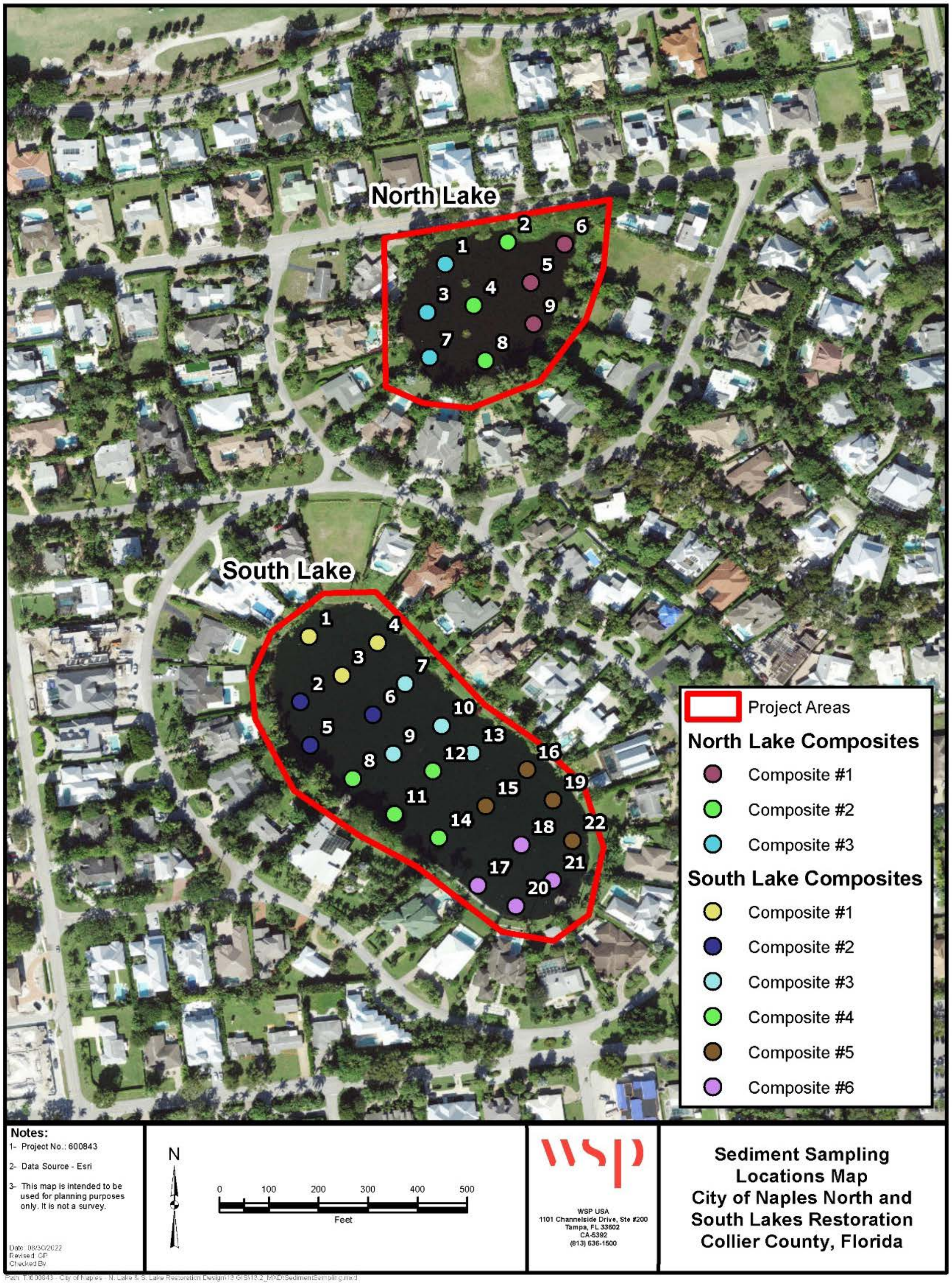


Figure 11. Soft sediment thickness in North Lake.

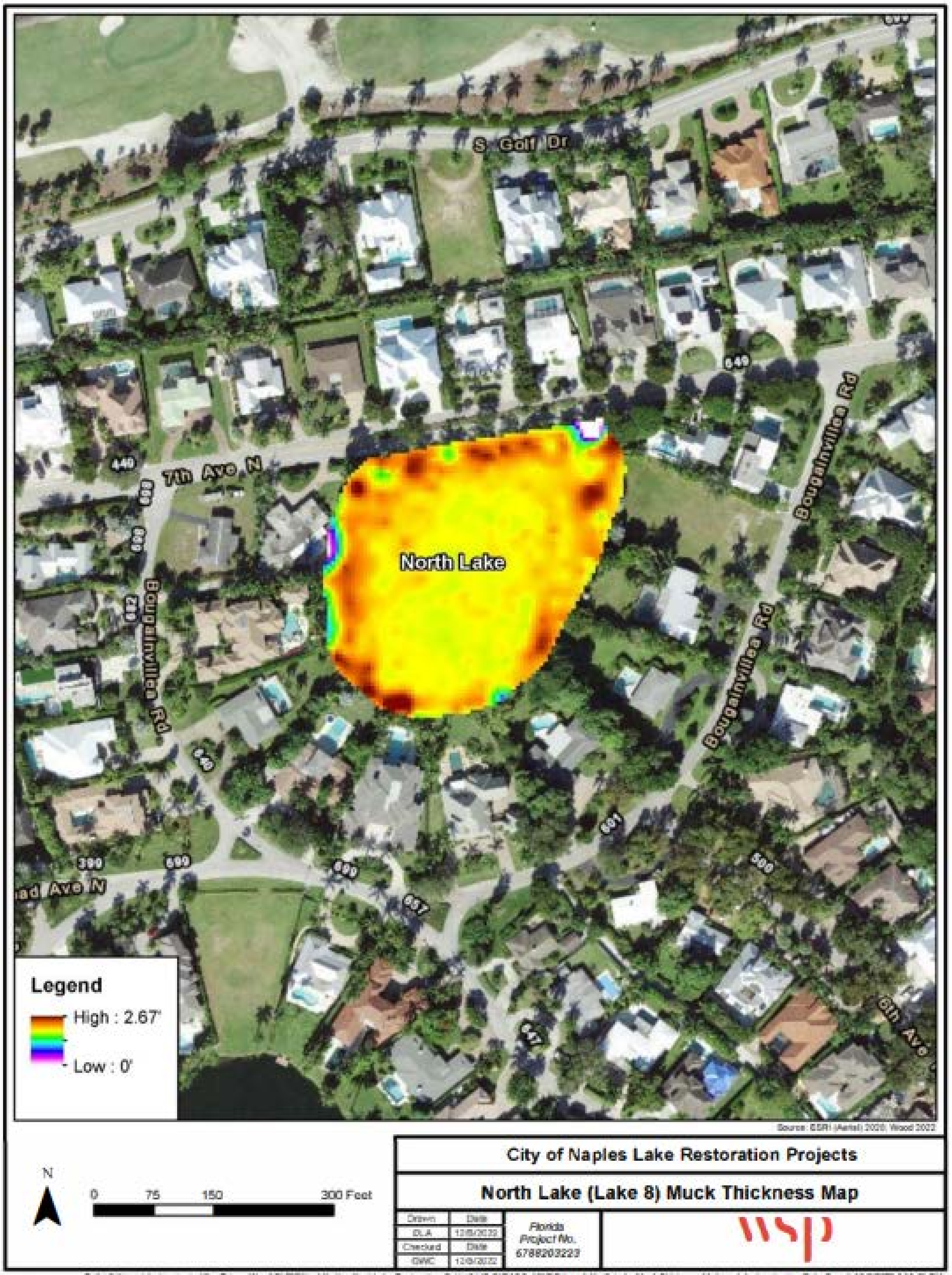
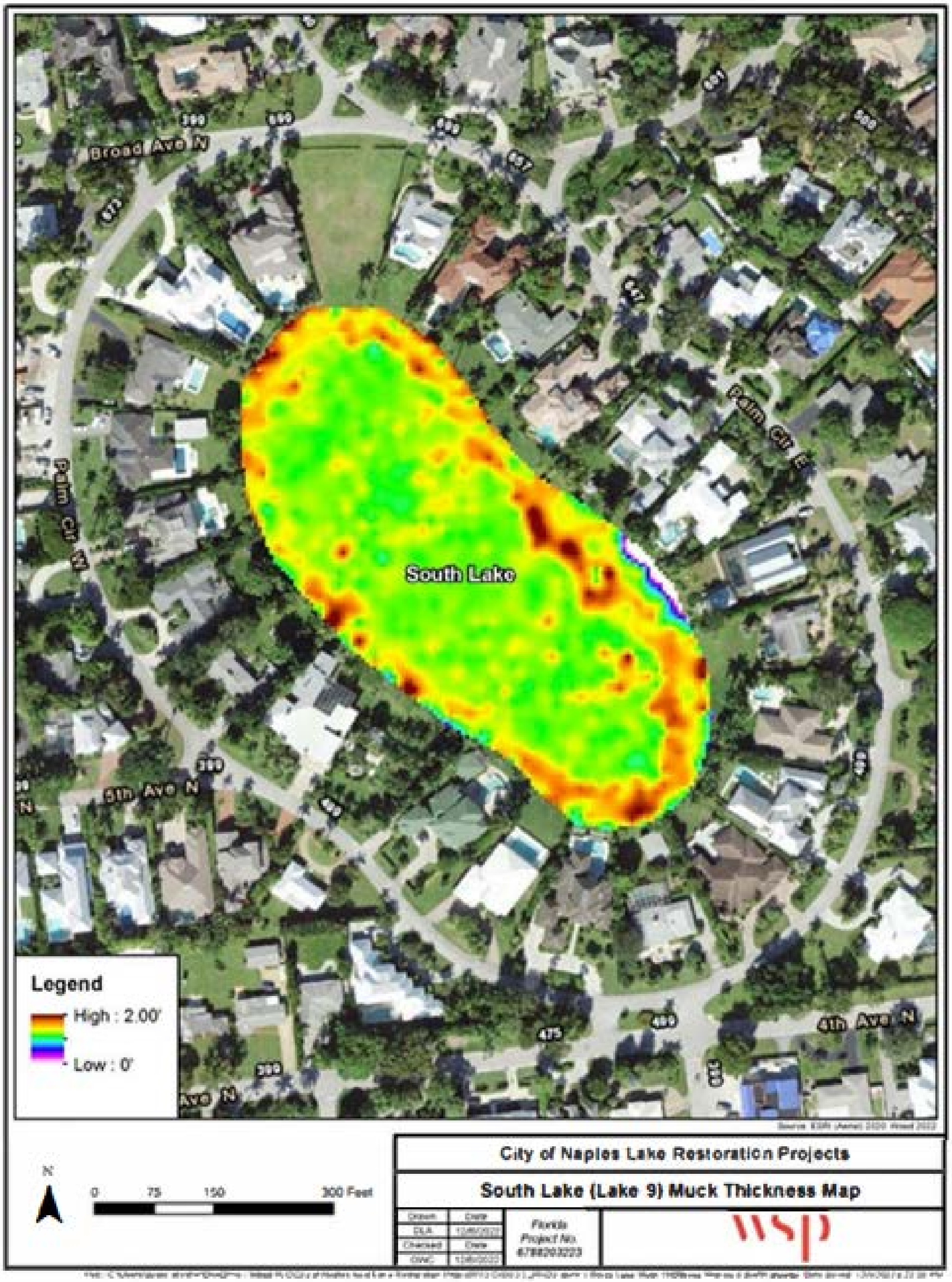


Figure 12. Soft sediment thickness in South Lake.



4.2 SEDIMENT FLUX

A pair of intact sediment cores were collected from North Lake and South Lake on September 12, 2022, in clear polycarbonate cylinders (7.3 cm diameter, 30 cm long). Sampling locations were chosen based on the amount of available sediment at locations close to inflow and outflow culverts. At the time of sampling, in-situ physicochemical data were recorded using a multiparameter sonde. Parameters included water temperature, dissolved oxygen (DO), pH, specific conductivity, salinity, and turbidity. Near-bottom ambient lake water was collected at the time of coring and filtered for use during sediment nutrient flux incubations. Sediment flux analyses were performed in the WSP USA Flux Laboratory in accordance with Standard Operating Procedure (SOP) Wood-SFLUX-002 Rev. 9. Sediment cores were prepared and incubated as two sets of two cores in a controlled environment under aerobic and anoxic conditions. The flux procedures are described briefly below, with additional details provided in **Appendix C.**

Water column samples for each core were collected at 0, 24, 48, 96, 168, and 216 hours and analyzed for TP, ammonia, and iron in a NELAC certified analytical laboratory. Sediment nutrient flux rates were estimated using the nutrient release rate (NRR) equation and the slopes were calculated from the concentration vs. time curve as described in the flux SOP. Annual internal nutrient loads were estimated at both stations and as spatial averages following the methods described by Ogdahl et al. (2014). Overall average loads were calculated from average flux rates representing the average anoxic and aerobic rates for both stations.

Average flux rates were calculated for aerobic and anoxic rates and the values were applied to the entire surface area of each pond to estimate representative values for internal loading rates. These flux rates may be further refined based on the results of the sediment engineering survey (e.g., flux rates may be applied to just those areas with highly organic sediments versus the entire lake). The internal loads calculated for the North Lake sediment core incubated under anoxic conditions were -8.84 lb/yr of TP, 57.66 lb/yr of ammonia, and 1.06 lb/yr of iron using the slope method. Using the NRR equation, internal loads were 0.00 lb/yr TP, 55.29 lb/yr ammonia, and 2.22 lb/yr iron. Under aerobic conditions, the North Lake sediment core displayed internal loads of 0.55 lb/yr TP, 45.03 lb/yr ammonia, and 1.56 lb/yr iron using the slope method. Using the NRR equation, the internal loads were 5.81 lb/yr TP, 56.24 lb/yr ammonia, and 2.98 lb/yr iron.

The internal loads calculated for the South Lake sediment core incubated under anoxic conditions were -22.60 lb/yr of TP, 159.39 lb/yr of ammonia, and 0.87 lb/yr of iron using the slope method. Using the NRR equation, internal loads were 1.65 lb/yr TP, 136.65 lb/yr ammonia, and 4.08 lb/yr iron. Under aerobic conditions, the South Lake sediment core displayed internal loads of -27.16 lb/yr TP, 16.03 lb/yr ammonia, and 1.90 lb/yr iron using the slope method. Using the NRR equation, the internal loads were 0.00 lb/yr TP, 21.20 lb/yr ammonia, and 1.96 lb/yr iron.

Sediment flux analysis showed similar TP, ammonia, and iron concentration values between North Lake and South Lake. Flux rates and loads calculated using the slope equation were on average lower and more conservative as compared to the values calculated by the NRR equation. However, both sets of equations suggest that each lake has the potential to act as a source of nitrogen while acting as a sink for phosphorus. Therefore, it is recommended that measures are taken to conduct targeted dredging and enhance ammonia uptake by biological processes.

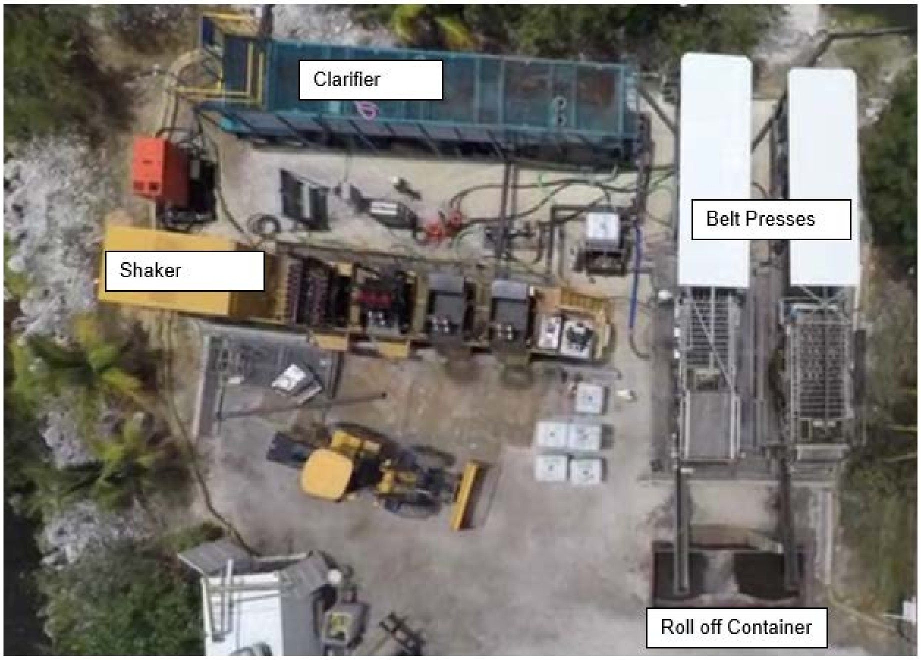
5 WATER QUALITY IMPROVEMENT TECHNOLOGIES

Best management practices (BMPs) that could improve water quality within North Lake and South Lake include dredging, bio-augmented aeration, floating islands, littoral shelf modifications, and littoral shelf plantings. There are also several in-line stormwater system improvements that can treat these contaminants upstream of entering the lake, including exfiltration trenches, curb inlet baskets, and rain gardens and/or vegetated swales at key locations within the basin. Potential water quality improvement technologies that may be beneficial to North and South lakes are described below. More targeted recommendations will be included in future deliverables.

5.1 DREDGING

There are two traditional methodologies for removal of muck sediments, mechanical and hydraulic dredging. Based on the above results for thickness and consistency, it is recommended to utilize a hydraulic dredging system as a mechanical dredging requires heavy equipment and would not be efficient in removing fine organic sediment. Mechanical dredging also requires a large footprint for dewatering since the material needs ample time to dry for hauling to a disposal area. Hydraulic dredging is a relatively low impact method of sediment removal with few effects on the surrounding environmental system. Hydraulic dredging includes a floating dredge, which essentially acts as a floating vacuum cleaner, and a temporary pipeline to transport the dredged material as a slurry to the dewatering site. The volume of the sediment slurry is greater than the in-situ volume of the sediment. The volume of dredge material can be better controlled with a hydraulic dredge than with mechanical dredging techniques. There are various types of hydraulic dredges available for sediment removal, such as the swing ladder, cutterhead, horizontal auger, plain suction, pneumatic, specialty dredge heads and diver-assisted dredge heads.

Based on past project experience, dredging has shown positive results in the improvement of water quality with Lakes, including City of Naples Lake Manor, Fleischmann Lake, Spring Lake, and East Lake. However, the technology is expensive and requires a large vacant footprint to dewater and dispose of the dredged material. The organic muck would be removed via hydraulic vacuum dredge and dewatered using either a mechanical, passive, or combination system. In mechanical dewatering, the dredged slurry is passed through a system of shakers and belt press filters to remove and dry trash and solids for disposal. In passive dewatering, the dredged slurry is passed through a system of screens and weirs to remove trash and solids and then pumped into roll off containers lined with geotextile bags to compress and dry removed material for disposal. In both systems, effluent is returned to the lake after solids are removed. In mechanical dredging, the effluent is typically passed through a clarifier tank prior to discharge into the lake.



.

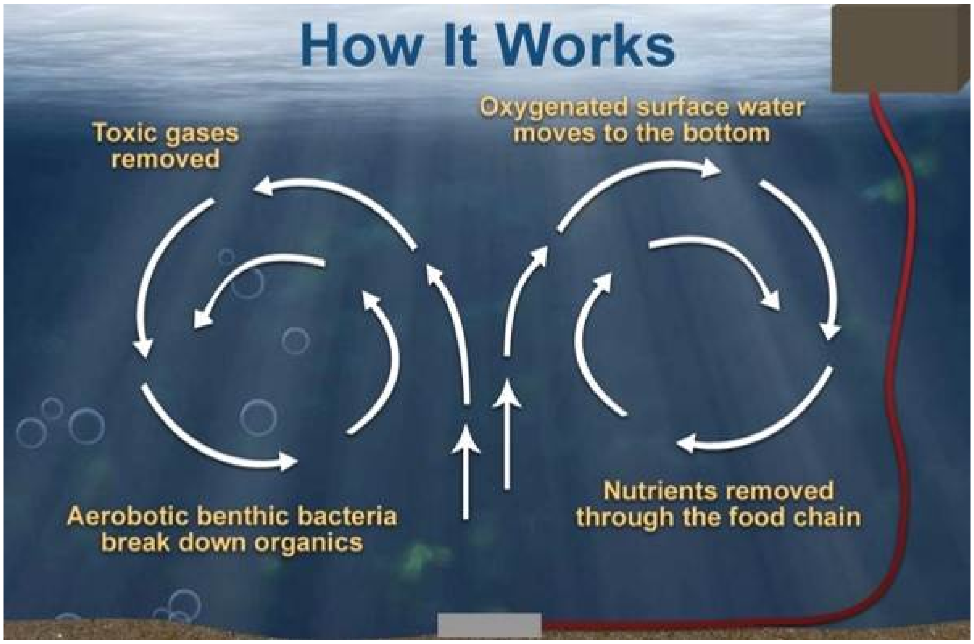
In areas with limited dewatering areas, a passive dewatering system with a series of roll off containers lined with geotextile bags and a polymer injection system may be recommended. The chemical results indicated the material exceeds the FDEP SCTLs for certain contaminants and therefore the disposal will need to be revaluated during the design process to determine if the material can be mixed and beneficial reused or sent to an approved Class I landfill for disposal. The cost of the dredging alternative will be much greater if the dredged material requires disposal in a landfill.

5.2 BIO-AUGMENTED AERATION

Stagnant water leads to accumulation of harmful and dangerous bacteria, low dissolved oxygen prohibits more beneficial aerobic bacteria from living, muck accumulates faster than the anaerobic bacteria can process it, and excess nutrients from fertilizer and run-off add to the cloudiness of the water. Aeration can correct and reverse these problems. When an aeration system is installed and turned on in a water body, a rotation of water begins that forms a doughnut pattern around the diffuser, see figure below. Water is taken into the bubble stream at the diffuser and moved toward the surface by the rising bubbles.

Introduction of aerobic bacteria will expedite this process and will cause compression of the muck as the bacteria breaks down the organic material. When the Lake bottom is anaerobic, roots and other organic material pile up without being decomposed. This leads to a large collection of organic material that remains in an undecomposed state until it is slowly broken down by anaerobic bacteria. Anaerobic decomposition is 30 to 40 times slower than aerobic decomposition, and many lakes accumulate organic material due to fertilizer runoff and other contaminates faster than this process occurs. With the introduction of oxygen at the lakebed, aerobic bacteria can take over and decompose muck faster. The bacteria that will be introduced to accomplish this are broad spectrum strains of naturally occurring bacteria with the ability to degrade most organic compounds.

Bio-augmented aeration consists of small solar powered aeration systems coupled with biological enhancements such as macro-algae. Bio-augmented aeration is completed in a modular approach, with a typical spacing of approximately 100 feet between aeration systems.



5.3 FLOATING ISLANDS

Floating islands provide nutrient uptake from the permanent pool of the wet detention pond. Floating islands generally consist of components of a typical wetland, but instead of a soil medium, the roots are anchored in an inert, floating medium and suspended within the water column. This provides the plants direct access to the soluble, bioavailable nutrients that are within the water column and targeted for removal. The floating root mass also provides an ideal substrate for periphyton growth, which works synergistically with the emergent vegetation to enhance nutrient uptake and sequestration. If designed correctly, this direct interaction between wetland root mass and water column nutrients can provide for very efficient nutrient flux and uptake and represents one of the strengths of these hydroponic systems.

Floating island nutrient removal efficiency can be variable and is highly dependent upon proper installation and maintenance. Researchers at University of Central Florida (Chang, et al., 2012) reported removal of up to 54% of TP, 32% of TN, and 48% of nitrate where the rooting media included Bold & Gold™. Researchers from New Zealand have reported about 40% removal of TSS and suspended Cu (Borne, et al. 2013), and more than 50% removal of TN and TP (White and Cousins, 2013). Researchers sometimes recommend covering 5% or less of stormwater ponds by floating islands, with coverage of less than 5% resulting in lesser pollutant removal effectiveness. Annual maintenance costs are estimated at less than 5% of construction cost. Cost information from Virginia Cooperative Extension Publication BSE-76P (Sample, et al. 2013).

However, floating islands were previously installed and subsequently removed from North Lake at the request of residents. Therefore, this technology may not be recommended for North and South Lake.

5.4 LITTORAL SHELF MODIFICATIONS AND PLANTINGS

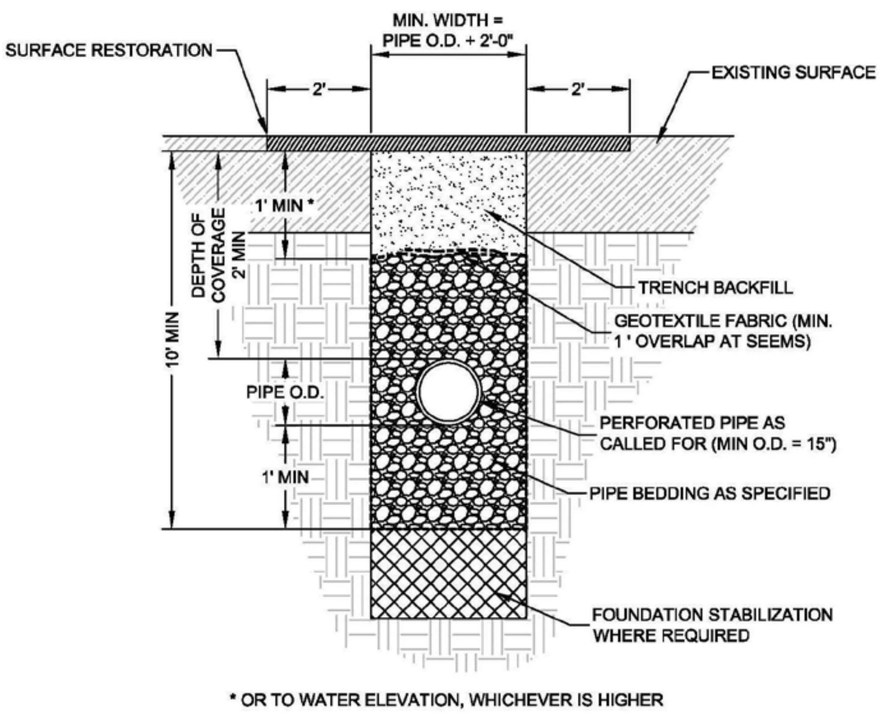
Littoral shelf plantings and modifications can limit nutrients and runoff from the adjacent lawns from entering the lake, as well as provide additional nutrient uptake within the lake from the additional littoral shelf plants that are dependent on the available nutrients within the lake targeted for removal. In addition to water quality benefit, littoral shelf modification of the overly steep areas within the banks would provide a safety upgrade for the lake to return the side slopes to a more gradual slope.

Sediment dredged from the lakes can sometimes be used to stabilize eroded shorelines within the lake, as was done on a similar project in Ocean Pines, Maryland where the dredge material from a tidal canal was dredged into geobags and used on the shoreline for stabilization. The dredge material (organic sediment/muck) was pumped directly into the geobags, which were already laid in place on the shoreline. The geobags then dewatered back into the source canal while the muck was contained in the geobags. Eight inches of stone was placed on top of the geobags and capped with articulating concrete block mat at about a 5:1 slope. Some design aspects that were considered were the time of dewatering, as the organic material would take six to nine months to dewater to 90% compaction. To combat this, they placed geotextile material on top of the geobags to run equipment over the bags during construction and provide structural stability for the bags, while still allowing water to dewater from the geobags. They also designed an anchor system to hold the bags in place and provide structural stability, which allowed them to place concrete on unconsolidated dredge material without too much shifting during construction (Gennaro 2005). However, further review of the analytical sediment data from North Lake and South Lake is needed before recommending this technology. Contaminant concentration in sediment shoreline stabilization could potentially cause lasting water quality issues from the leaching of the contaminated sediment.

Littoral shelves not only provide treatment removal efficiencies for TP and TN, they also increase habitat for birds and fishes to thrive. Although littoral shelves provide biological uptake, previous research has indicated that a vast majority of removal processes occur within the Lake rather in the littoral zone vegetation (Harper, 1985; Harper, 1988; and Harper and Herr, 1993). Installation costs for littoral shelves can range from $20,000 to $30,000 per acre.

5.5 EXFILTRATION TRENCHES

Exfiltration trenches consist of a subsurface retention system incorporating conduit such as perforated pipe surrounded by natural or artificial aggregate which would temporarily store and allow runoff to percolate into the surrounding soil. Exfiltration trenches promote more efficient infiltration of surface runoff to shallow groundwater tables by detaining stormwater and evenly distributing it throughout the base of the trench. Exfiltration trenches reduce pollutant loads primarily by way of surface runoff volume reduction, however additional reductions in suspended solids, oxygen demanding materials, heavy metals, bacteria, and some varieties of pesticides and nutrients such as phosphorus may be removed as runoff percolates through the soil. Exfiltration trenches can remove 60 to 100% of trace metals, 40 to 80% of TP and 40 to 80% of TN (SFWMD 2002). Installation costs for exfiltration trenches can range from $2.50 to $7.91 per cubic ft of treatment volume.



5.6 NUTRIENT SEPARATING BAFFLE BOXES AND CURB INLET BASKETS

Curb inlet baskets (CIB) are designed to be placed in front of a curb inlet or opening to prevent the migration of sediment into the storm drain system while allowing water to pass through. The filter allows water to temporarily pond behind the inlet which allows deposition of suspended solids. Sediment and soluble pollutants such as phosphorus and petroleum hydrocarbons are filtered from runoff water as it passes through the interior organic media. Other advantages of installing inlet filters include easy maintenance, replacement, and repair.

Nutrient separating baffle box (NSBB) is a structural BMP used for water quality treatment at the outfall of storm drains. The box primarily removes sediment and suspended solids from stormwater. The Type II boxes widely used in South Florida consist of an aluminium screen basket with a horizontal bottom at an elevation below the invert of the influent pipe but above the top of baffles. Incoming flow passes through the screen basket, which captures leaves, trash, and other large materials. In addition to capturing the large sized materials and preventing their passage into the baffle box effluent, the material captured in the screen basket is held above and out of the water column. The purported effect is to reduce or eliminate the leaching that would occur if the captured material were submerged. Since leaching of leaves would release biochemical oxygen demand, nitrogen, and phosphorus, removing leaves from the stormwater and holding the captured leaves out of the water column results in a reduction of nutrient loading to the receiving water body.

An evaluation of NSBB based on Suntree technology generally removes 90% TSS, 20% TN and 19% TP from the water being directed to the system. An evaluation of CIBs removal capacity was performed by the Orange County Lake Management Program and determined from a sample of 250 CIBs units that average annual reductions of 0.20 kilogram per year TN and 0.050 kilogram per year TP could be achieved for each CIB (Dix et al., 2011).

5.7 RAIN GARDENS

Rain gardens are shallow, constructed depressions that are planted with deep-rooted Florida-friendly plants. A rain garden slows down the rush of water from impervious surfaces, holds the water for a short period of time and allows it to naturally infiltrate into the ground. Rain gardens are usually integrated into a site's landscaping to receive runoff from hard surfaces such as a roof, a sidewalk, a driveway, or parking area. Rain gardens offer significant habitat enhancement and aesthetic value while being optimized for stormwater runoff treatment. Rain gardens are among the most effective BMP at removing pollutants from stormwater. Treatment primarily occurs in the root zone and soil media, where nutrients and dissolved pollutants are removed. Site applications of rain gardens include open spaces, parks, golf courses, commercial or industrial developments, and residential developments.

Rain gardens allow approximately 30 percent of runoff to be filtered into the ground. A properly designed rain garden can filter one inch of rainfall in four hours. Rain gardens also filter stormwater pollution, around 90 percent of Cu, lead and zinc; 50 percent of nitrogen; and 65 percent of phosphorus, which could otherwise flow into storm drains and eventually bodies of water (American Society of Landscape Architects, 2018).

5.8 VEGETATED SWALES

Treatment swales are shallow stormwater conveyance channels with vegetation covering the side slopes and bottom. Treatment occurs as runoff flows through the vegetation and infiltrates into the soil matrix. Swales can be designed as part of the stormwater conveyance system and can eliminate the need for some curbs, gutters, and storm drains. They are also well suited to treat runoff from roads and highways because of their linear nature. The treatment effectiveness is correlated to the residence time of the runoff in the swale, and therefore, flow-based swales tend to be considerably longer than other types of treatment BMPs. Site applications of vegetative swales include road shoulders and medians, parking lot islands, open spaces, and parks. Swales can reduce TP by 25%, TN by 10% and TSS by 65% (STEPL, USEPA, 2004). Grass swale installation can cost $0.60 to $1.60 per sq. ft (SFWMD, 2002)

The City of Naples Streets and Stormwater Department is an active partner in the community promoting and providing technical information on the use of treatment swales to reduce runoff volumes and pollutant concentrations into the surrounding Naples Bay and Gulf of Mexico (City of Naples, 2014).

5.9 CAPPING

Capping can be used to encase organic sediments. Capping includes using an excavator to place clean fill to effectively bury the organic-rich sediments and prevent the consumption of oxygen from the water column. Capping can decrease water depth, therefore, waterbodies that are good candidates for capping include those that have a significant amount of organics accumulated on the bottom, but not so significant that the waterbody requires the removal of organics to ensure that stable bathymetry persists. In a canal capping project recommended by WSP, canals with a soft sediment thickness greater than 0.75 feet and water depth greater than 10 feet were considered potentially suitable for capping. To develop a capping recommendation, site-specific information such as percent organic content is used to verify potentially suitable waterbodies. Also, it is recommended that during the project design phase the appropriate gradation of fill material is determined through an evaluation of sediment cores to ensure that gas does not get trapped as the material is placed on the canal bottom.

6 ALTERNATIVES ANALYSIS

As part of the final feasibility analysis, WSP will quantitatively evaluate conceptual BMPs. The below analysis (**Table 5**) provides a preliminary qualitative comparison of each potential BMP type discussed above and the potential site-specific pros and cons for implementation in stormwater lakes in developed urban/residential environments.

Table 65. BMP Technologies Pros vs. Cons.

BMP	Pros	Cons
Primary		
Dredging	Removes the contaminated sediment and provides additional storage for the Lake. Restarts the stormwater lake treatment capabilities at completion of project. No long-term operation and maintenance.	Requires a significant staging area for dewatering. Construction impacts, such as noise, traffic, and aesthetics for the surrounding property owners. Potential high cost for disposal of material based on chemical analysis.
Bio-Augmented Aeration	Low cost to install and minimal staging area restraints for equipment.	Operation impacts, such as noise, and aesthetics for the surrounding property owners. Long term operation and maintenance.
In-Lake		
Floating Islands	High efficiency at pollutant removal and low cost to install and maintain	Routine maintenance required to ensure effectiveness and reduce Lake aesthetics for the surrounding property owners.
Littoral Shelf Modifications and Plantings	High efficiency at pollutant removal and low cost to install and maintain. Provides shoreline stabilization and aesthetics for the surrounding property owners.	Routine maintenance required to ensure effectiveness. If used, geotextile bags filled with Lake sediment have a potential for leeching back into the Lake and causing continued water quality impacts.
In-catchment		
Exfiltration Trenches	High efficiency at pollutant removal and small footprint for implementation.	Routine maintenance required to ensure effectiveness. Limited impact to the watershed and Lake.
Nutrient Separating Baffle Boxes and Curb Inlet Baskets	NSBB high efficiency at pollutant removal and provides educational feature for surrounding community. CIBs small footprint and easy to install.	Routine maintenance required to ensure effectiveness. CIB provide limited impact to watershed and Lake. NSBB high cost and requires modification to stormwater drainage system.
Rain gardens	Provides aesthetics to the surrounding community.	Limited impact to the watershed and Lake. Routine maintenance required to ensure effectiveness.
Vegetated swales	High efficiency at pollutant removal and low cost to install and maintain. The City is already implementing	Limited impact to the watershed and Lake. Need land to provide sufficient storage to provide pollutant removal efficiencies.

BMP	Pros	Cons
	vegetated swales within owned right of ways.	

Further evaluation is needed on the primary technologies for effectiveness, ease to implement, ease of permitting, property owner disruption, time to achieve the restoration, and cost for implementation, and operation, and maintenance. Based on the additional analysis, recommended technologies will subject to an evaluation criterion to rank the technologies by potential for success in improving the water quality associated with the lakes in addition to implementation cost. All criteria will be scored from 0 to 5, with 0 being worse and 5 being best (**Table 6**). Rankings are under development based on continued analysis, including ICPR and BMP Trains modeling.

Table 6. North and South Lakes Potential Technologies Matrix (Preliminary)

Technology	Effectiveness (0-5)	Ease to Implement (0-5)	Permitting (0-5)	Construction Impacts (homeowner disruption) (0 to 5)	Time (0-5)	Cost (0 to 5)	Total	Rank
Primary Technologies (in-Lake)								
Dredging	5	3	5	2	4	3	22	1
Capping	3	4	4	2	4	4	21	2
Secondary Technologies (upstream)								
Curb Inlet Baskets	5	4	5	5	4	5	28	1
Rain Gardens	3	4	4	4	3	4	22	2
Exfiltration Trenches	4	3	4	3	3	4	21	3
Vegetated Swales	2	3	4	4	4	3	20	4
Nutrient Separating Baffle Boxes	5	2	4	4	2	2	19	5
Secondary Technologies (in-Lake)								
Aeration	4	4	4	4	4	4	24	1
Water Control Structure Modifications	4	3	4	3	3	3	20	2
Littoral Shelf Modifications, invasive species removal and plantings	3	2	3	3	3	4	18	3
Floating Islands	2	3	3	2	2	3	15	4
Bio-augmented Aeration	2	2	3	2	2	3	14	5

Notes:

Effectiveness: 5=most effective, 0= least effective

Ease to implement: 5=easiest to implement, 0=most difficult to implement

Permitting: 5=easiest to permit, 0=most difficult to permit

Homeowner Disruption: 5=least homeowner disruption, 0=most homeowner disruption

Time: 5=shortest duration until expected water quality improvements, 0=longest duration until expected water quality improvements

Cost: 5=least expensive, 0=most expensive

Total: sum of scores

Rank: rank based on scores, where highest score is ranked first (1) and lower scores follow.

6.1 SUMMARY

North Lake

In review of the data collection efforts and technology evaluation, North Lake restoration recommendation is shown below:

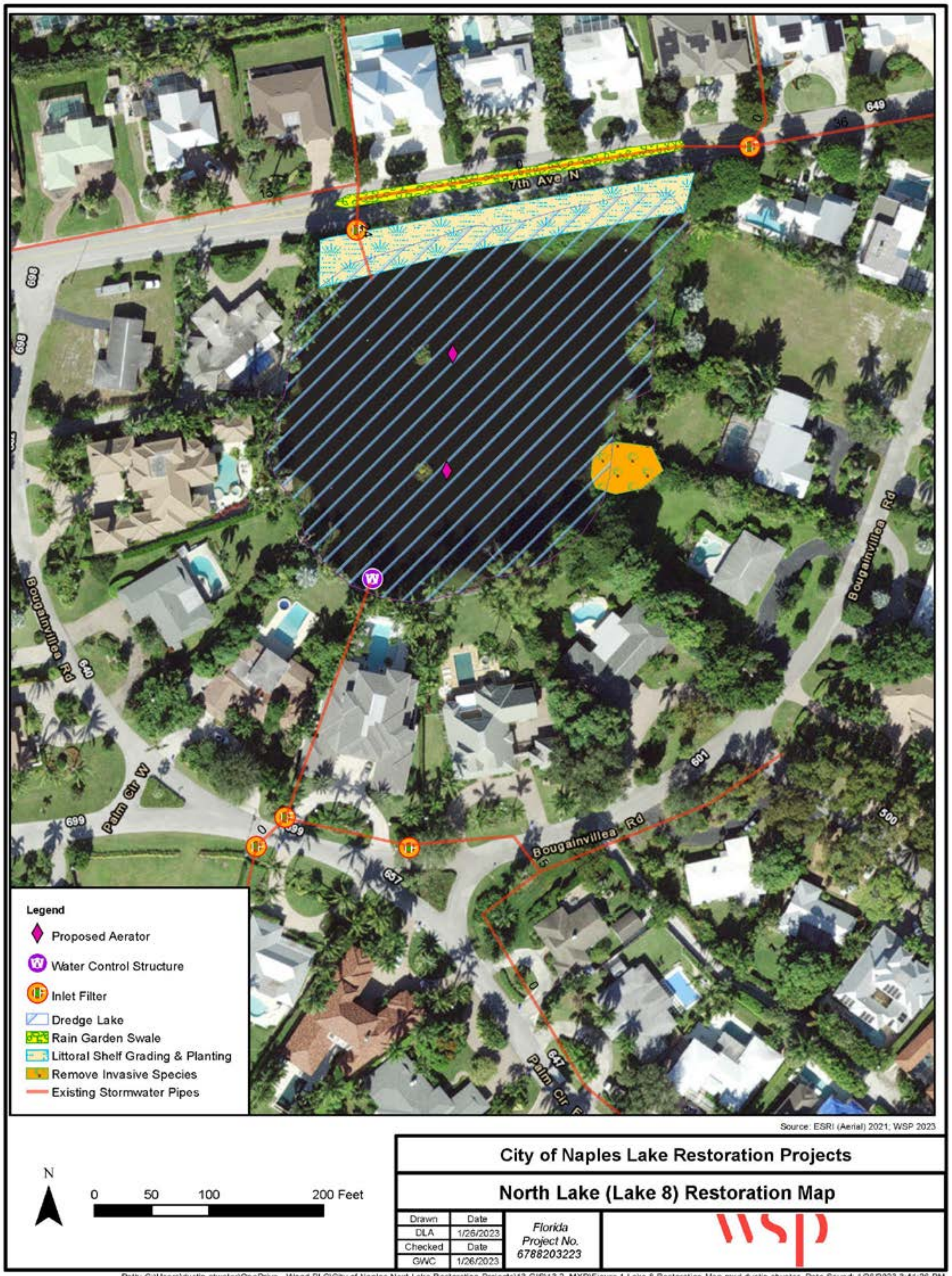
Primary – Dredging to remove unconsolidated sediments which removes contaminants and provide additional storage for stormwater treatment effectiveness.

Secondary

In-Lake - Water Control Structure Modification will provide control to the City to increase retention time during dry season and mean annual events, at the same time this structure will allow for the City to be prepared for large storm events to draw down the lake for flood protection to residents. Littoral Shelf Modifications, invasive species removal, and plantings will provide nutrient uptake effectiveness for the lake. Aeration will provide increased dissolved oxygen concentrations to reduce nutrients and provide for continuous turnover for water quality improvement.

Upstream - Curb inlets will be placed at existing filters to provide trash and sediment capture within the watershed. The rain garden, vegetated swale, and/or exfiltration trench will be evaluated within the existing median to the north of the lake to provide additional stormwater treatment prior to discharging into the lake.

Figure 13. North Lake Restoration Map.



South Lake

In review of the data collection efforts and technology evaluation, South Lake restoration recommendation is shown below:

Primary – Dredging to remove unconsolidated sediments which removes contaminants and provide additional storage for stormwater treatment effectiveness.

Secondary

In-Lake - Water Control Structure Modification will provide control to the City to increase retention time during dry season and mean annual events, at the same time this structure will allow for the City to be prepared for large storm events to draw down the lake for flood protection to residents. Invasive species removal and plantings will provide nutrient uptake effectiveness for the lake. Aeration will provide increased dissolved oxygen concentrations to reduce nutrients and provide for continuous turnover for water quality improvement.

Upstream - Curb inlets will be placed at existing filters to provide trash and sediment capture within the watershed.

Figure 14. South Lake Restoration Map

7 FUNDING EVALUATION

Obtaining sufficient project funding is one of the most challenging steps in any restoration project. The focus of this section is to accomplish the following objectives:

- Review and identify the funding opportunities,
- Evaluate the funding needed and the breakdown of cost per parcel based on private vs. public.

The City has several funding options to generate revenue to conduct restorations at North and South Lakes, with varying levels of complexity in procedures to implement. The purpose of generating revenue is a key consideration. The City may:

- Create a Special Tax District, with the support of voters in the watershed: An example of this is the East Naples Bay Special Taxing District established in 1987. Special Tax Districts are similar in function to an MSBU (Municipal Service Benefit Unit), except they require a vote of the impacted property owners. The accounting of the revenue is separate from other funds of like purpose, such as the Stormwater Utility. Providing public education and outreach is critical to assist in informing the impacted electorate of the need, purpose, structure, and impacts of a millage for improvements to the Lakes, both immediate and long-term needs. The State provides guidance on the process and the mandatory elements of the local ordinance to set up a special tax district.
- Create a Special Non-ad valorem Assessment, based on special benefit to property owners in the watershed, referred to as MSBU: Typically, an MSBU does not provide continuous revenue to support long-term operation and maintenance of the Lakes. It distributes the cost of the project to all property owners in the watershed. An assessment role is prepared, on a property-by-property basis. An interest rate is established, providing to each owner a payback period, typically up to six years, but can be up to 20 years.
- Increase Stormwater Utility fees, citywide, to include all lake management maintenance and operational programs: The City's Stormwater Fund may address the cost of project implementation and on-going maintenance by absorbing the cost within the current budget, prioritizing the project within the Capital Improvement Project and on-going maintenance programs and/or increasing current rates citywide.
- Budget capital project needs from City general fund reserves and incorporate continuing maintenance needs into on-going program priorities within the Stormwater Utility, with no rate increase attributable to the North and South Lakes capital project.
- Budget capital project needs from the Stormwater Utility reserves, adding the project to the Utility CIP and implement when enough reserves can be allocated to North and South Lakes.

Loans and grants are another funding option to consider. The Clean Water State Revolving Fund provides low-interest loans to local governments to plan, design, and build or upgrade wastewater, stormwater, and nonpoint source pollution prevention projects. The priority for these funds is heavily targeted to water supply and wastewater management capital needs, with only two stormwater projects identified as priorities in 2019, both from small and/or disadvantaged communities. After research, it was determined that receiving a loan is not a viable option.

WSP has direct experience with obtaining and managing local, state, and federal grant funding for a variety of projects including assisting the City with the Lake Manor South Florida Water Management District (SFWMD) Grant. In addition to the SFWMD grant program offered by the State of Florida, the FDEP administers a funding program, total maximum daily loads to help local governments implement BMPs designed to reduce pollutant loads to impaired waters from urban stormwater runoff.

There are six key considerations WSP uses in evaluating the funding options available.

1. Contribution from Property Owners: Will all property owners contribute revenue with shared responsibility or will the charges to fund the services only be assigned to taxable parcels?

2. Vote of Impacted Property Owners: Is a vote of the property owners within the watershed required? This adds complexity to the process and requires education and outreach to the impacted property owners to provide information on the special election.
3. Public Outreach and Education: Is public support critical to implementation of the capital project and long-term maintenance needs? Outreach must address the ultimate purpose for improving and sustaining the performance of the Lakes over time and motivate people to act.
4. Continuous Revenue Generation: To maintain the Lakes capacity and performance in water quality protection, provide routine maintenance, generate a reserve for future capital needs and dredging and upgrade systems installed, as an on-going component of stormwater operations, requires a revenue that is dedicated and continuous.
5. Capital and Maintenance Program: Is it the City's purpose to address the current conditions of the Lakes and on-going, long-term maintenance? If yes, a program budget is developed and funded annually.
6. Capital Only: Is it the City's purpose to address the current condition of the Lakes? If yes, resources in the Capital Improvement Project (CIP) budget are funded as a one-time cost.

Funding options are not equal in complexity and ease of implementation. The following table provides a comparison of attributes.

Revenue Source	All Properties Contribute	Voter Approval	Public Education	On-going Revenue	Capital and Maintenance	Capital Only
Utility Fees – No Increase*	Yes**	No	Yes	Yes	Yes	Yes
Utility Fees – Citywide	Yes**	No	Yes	Yes	Yes	Yes
Special Tax District	No	Yes	Yes***	Yes	Yes	Yes
Special Assessment District	Yes	No	Yes***	No	No	Yes
General Fund Reserves	No	No	Yes	No	No	Yes
Utility Fund Reserves	Yes	No	Yes	No	No	Yes

* Utility Fees with no increase in rates requires prioritization of the project against other needs funded by the utility and determine when to dredge the Lake based on funding.

** Vacant and undisturbed parcels are exempt from the utility fee if not served by a water meter.

*** Public education is critical during the implementation of a Special Tax District or a Special Assessment District.

If continuous revenue creation to maintain the Lakes in perpetuity is a key driver, a Special Tax District or budget from the Stormwater Utility can sustain revenue growth over decades. If a one-time capital project is the implementation approach, then all methods listed can accomplish the goal.

8 SUMMARY AND NEXT STEPS

To support the restoration of North and South Lakes, WSP conducted data collection and began an evaluation of water quality improvement technologies that may be used in the North Lake and South Lake restoration projects. Traditional methods for removal of highly organic sediments, such as mechanical dredging and hydraulic dredging are commonly used in stormwater lakes and may be recommended at North Lake and South Lake. The removal of highly organic sediments would:

- Reduce the re-release of nutrients stored within the sediments (i.e., reduce internal loading) to the water column and improve the efficiency of treatment of nutrient-rich stormwater inputs.
- Reduce the potential for dissolved oxygen depletion that can produce objectionable odors and potential fish kills.
- Increase the depth and storage capacity of the lake to improve its flood mitigation effectiveness
- Increase the residence time of water in the lake which should improve effectiveness of North Lake and South Lake in removing stormwater pollutants including TSS, TN, and TP, and improve water quality in discharges to Alligator Lake and ultimately the Gulf of Mexico.

The recommended removal methodology will be dependent on the thickness, consistency, and characteristics of the highly organic sediment material. Mechanical dredging requires heavy equipment and would not be efficient in removing fine organic sediment. Mechanical dredging also requires a large footprint for dewatering since the material needs ample time to dry for hauling to a disposal area. Hydraulic dredging is a relatively low impact method of sediment removal with few effects on the surrounding environmental system.

Other design elements for North and South Lakes and their watersheds to reduce downstream loadings of pollutants of concern and improve water quality have been reviewed for implementation. These could include littoral shelves, enclosed sediment sumps or catch basins at stormwater inlets/inflows to remove trash and debris prior to entering the infrastructure system, rain gardens in open spaces within the basin (either in public right of ways or in homeowner areas), and baffles projecting from the lake bank into the lake to increase retention time. Public involvement, including nearby residents, will also be important to the implementation and success of the North and South Lakes improvements. One of the biggest challenges for this project will be coordination with the public and designing an efficient dewatering system that can minimize disturbance to the surrounding community. Public involvement would need to include an outreach program involving agency coordination and outreach to the media, businesses, community groups, and the general public using appropriate methods and tools to solicit input and provide details on the project. The outreach program would also include mailers (flyers) directed at elected officials, agencies, property owners and tenants to announce public information meetings and provide information about the project.

BIBLIOGRAPHY

AECOM, 2018. City of Naples 2018 Stormwater Master Plan Update.

Amec. 2012. City of Naples Stormwater Quality Analysis, Pollutant Loading and Removal Efficiencies.

Amec. 2013. City of Naples Semi-Annual and Quarterly Stormwater Infrastructure Monitoring Final Report, January 2013.

Amec. 2014. City of Naples Semi-Annual and Quarterly Stormwater Infrastructure Monitoring Final Report, March 2014.

American Society of Landscape Architects, 2018. Improving Water Efficiency: Residential Rain Gardens. Website: https://www.asla.org/raingardens.aspx

Borne, K.E., E.A. Fassman, Chris C. Tanner. 2013. Floating treatment wetland retrofit to improve stormwater pond performance for suspended solids, copper and zinc. Ecological Engineering 54:173– 182.

Cardno Quarterly Stormwater Sampling Results, 2015 – 2018 (Cardno).

Chang, N.B., M.K. Islam, and M.P. Wanielista. 2012. Floating wetland mesocosm assessment of nutrient removal to reduce ecotoxicity in stormwater ponds. Int. J. Environ. Sci. Technol. 9:453–462.

City of Naples. 2012. City of Naples, Stormwater Lakes Maintenance & Restoration Plan, March 2012.

City of Naples, 2014. City of Naples, City Swales, Website: https://www.naplesgov.com/sites/default/files/Archives/Stormwater/swales%20%20_20140715134540 3680.pdf

City of Naples. 2013. Comprehensive Plan Updated 12-3-2013. Website: http://www.napleshistoricalsociety.org/pdfs/2016files/City%20of%20Naples%20Comprehensive%20Plan.pdf

Dix, N., R. Novy, B. Catanzaro. 2011. An Evaluation of Curb and Grate Inlet Baskets: Quantification of Nutrient Removal and Associated Costs in Orange County, FL. Orange County Lake Management Program. November 2011.

Florida Department of Environmental Protection (FDEP), 2005. Memorandum from Mike Sole, Director Division of Waste Management. Subject: Guidance for the Management of Street Sweepings, Catch Basin Sediments and Stormwater System Sediments. Florida Gulf Coast University (FGCU), Bathymetry and Sediment Characterization of Spring Lake, February 2013.

Florida Gulf Coast University (FGCU). 2013. Bathymetry and Sediment Characterization of Spring Lake, February 2013.

Fritz, Angela and Miller, B. CNN. September 2022. "Hurricane Ian's rainfall was a 1-in-1,000 year event for the hardest-hit parts of Florida", available at https://www.cnn.com/2022/09/29/weather/hurricane-ian-1000-year-rainfall-climate/index.html (accessed 12/8/2022)

Gennaro, Nicholas De. 2005. Beneficial Uses of Dead-End Canal Dredging in Combination with Special Use Materials for Erosion Control.

Harper, H. H. 1985. Fate of heavy metals from highway runoff in stormwater management systems (Doctoral dissertation, University of Central Florida).

Harper, H.H., 1988. Effects of stormwater management systems on groundwater quality. *Final report. Contract WM-190. Submitted to the Florida Department of Environmental Regulation, Tallahassee, FL.*

Harper, H.H., and Herr, J.L. August 1993. "Treatment Efficiency of Detention with Filtration Systems." Final Report to the St. Johns River Water Management District.

Iowa State University Environmental Mesonet, "National Weather Service Raw Text Product", available at https://mesonet.agron.iastate.edu/wx/afos/p.php?pil=PSHMFL&e=202210141556 (accessed 12/8/2022)

Kiaghadi, A., Rifai, H.S., Crum, M. and Willson, R.C., 2022. Longitudinal patterns in sediment type and quality during daily flow regimes and following natural hazards in an urban estuary: a Hurricane Harvey retrospective.

Environmental Science and Pollution Research, 29(5), pp.7514-7531.MACTEC, 2008. Spring Lake Report of Surface Water and Sediment Testing in Naples, Collier County, Florida.

NOAA National Centers for Environmental Information, Monthly National Climate Report for September 2022, published online October 2022, retrieved on December 8, 2022 from https://www.ncei.noaa.gov/access/monitoring/monthly-report/national/202209/supplemental/page-5.

NOAA National Environmental Satellite Data and Information Service, "Hurricane Ian's Path of Destruction", available at https://www.nesdis.noaa.gov/news/hurricane-ians-path-of-destruction (accessed 12/8/2022)

Ogdahl, Mary E., Alan D. Steinman, and Maggie E. Weinert. "Laboratory-determined phosphorus flux from lake sediments as a measure of internal phosphorus loading." JoVE (Journal of Visualized Experiments) 85 (2014): e51617.

Sabatier, P., Moernaut, J., Bertrand, S., Van Daele, M., Kremer, K., Chaumillon, E. and Arnaud, F., 2022. A review of event deposits in lake sediments. Quaternary, 5(3), p.34.

Sample, D.J, C-Y Wang, and L.J. Fox. 2013. Innovative Best Management Fact Sheet No. 1: Floating Treatment Wetlands. Virginia Cooperative Extension Publication BSE-76P.

SFWMD, 2002. Best Management Practices for South Florida Urban Stormwater Management Systems

US Environmental Protection Agency (USEPA). 2004. Spreadsheet Tool for the Estimation of Pollutant Load (STEPL, version 3.0).

Wanielista, M. 2020. *User Manual - BMP Trains.* University of Central Florida, Stormwater Management Academy. Orlando: University of Central Florida. Retrieved from https://stars.library.ucf.edu/bmptrains/25/

White, S.A., and M.M. Cousins. 2013. Floating treatment wetland aided remediation of nitrogen and phosphorus from simulated stormwater runoff. Ecological Engineering 61:207–215.

Yao, Q., Liu, K.B., Williams, H., Joshi, S., Bianchette, T.A., Ryu, J. and Dietz, M., 2020. Hurricane Harvey storm sedimentation in the San Bernard national wildlife refuge, Texas: Fluvial versus storm surge deposition. Estuaries and Coasts, 43(5), pp.971-983.

APPENDIX

A TITLE

APPENDIX

A-1 TITLE