Upper Durant Lake Retrofit Alternatives Analysis

Final Report

Prepared for:

City of Raleigh

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Prepared by:

Barbara Doll[1,2], PhD, PE
Extension Assistant Professor & Extension Specialist

Jonathan Page[2], PE
Extension Associate

Daniel Line[2], PE
Extension Specialist

Jack Kurki-Fox[2], PhD
Research Associate

[1]NC Sea Grant
[2]NC State Dept. Bio & Ag Engineering

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Executive Summary

Upper Durant Lake is one of two lakes within the City of Raleigh's 237-acre Durant Nature Preserve in North Raleigh. In 2013, an engineering firm contracted by the City deemed the dams and spillways of both lakes to be structurally and hydraulically deficient. In 2019, the City completed construction of modifications to the Lower Lake, including its dam, spillway, and downstream channel, removing its deficiencies. Modifications to the Upper Lake to address its deficiencies have not yet been undertaken. The Upper Lake also has been negatively impacted by large amounts of sedimentation due to development in the watershed and, as a result, has reduced ability to treat stormwater by trapping sediment, support programmed or casual recreational use opportunities, and provide habitat value for fish and wildlife.

The City recognizes that the best use of the area of the Upper Lake potentially could be as a water body other than an open-water lake. In 2017, the City initiated a study for considering alternatives for the area of the Upper Lake. For this study, the City contracted with NC State University's Department of Biological and Agricultural Engineering (NCSU BAE) and NC Sea Grant to assess the Upper Lake, its watershed, and its environs and to develop and evaluate conceptual alternatives for potentially retrofitting the area of this lake, including possibly retaining its existing condition as an open-water lake.

The assessment revealed that the 1.14-square-mile watershed of the Upper Lake had undergone significant development between 1992 and 2001. Very little new development has occurred since 2001, and the watershed is now essentially fully developed. Probably as a result of soil erosion during development construction, as well as during construction of I-540 in the watershed, sediment has accumulated in the Upper Lake and in the stream valley upstream of the lake. Although sediment continues to accumulate in the lake, its source since 2001 probably is largely from erosion of streambanks resulting from higher rates of stormwater runoff caused by an increase in impervious surface area in the watershed. Based on surveys conducted as part of this assessment, an estimated 12,500 cubic yards of sediment had accumulated in the lake as of March 2018.

Analysis of water samples collected from the lake indicate that, to a limited extent, pollutants are removed from water as it flows through the lake. Concentrations of nitrate nitrogen, phosphorous, and solids (sediment) are reduced across the lake, and concentrations of ammonium nitrogen are increased across the lake. Analysis of sediment samples collected from the lake indicate that lake sediments contain some contaminants commonly associated with urban stormwater runoff, such as metals and organic compounds. Sediment contaminant concentrations are low, and lake sediments could be reused as part of a retrofit project for the lake or, if they were removed from the site, they would not need to be managed as hazardous waste. Suitability of the sediments for reuse would need to be evaluated by a geotechnical engineer in support of the lake retrofit design.

Based on the assessment of the Upper Lake and its environs, four alternatives for the future use of the area of the lake were developed:

- Lake As Is – Repair and/or replace the lake's spillways and associated infrastructure.
- Stormwater Wetland – Convert the area of the lake to a constructed wetland with primary focus on improving water quality.

- Habitat Wetland – Convert the area of the lake to a constructed wetland with primary focus on wildlife habitat enhancement.
- Stream Restoration – Breach or remove the existing dam and construct a stream channel and riparian floodplain system along the present lake bed.

These alternatives are described and designed on a conceptual level, and their implementation costs estimated as probable cost ranges. The alternatives have been compared and ranked using multi-criteria decision analysis (MCDA) applying evaluation factors identified by the City. The Habitat Wetland alternative ranked as the most favorable, followed by the Stormwater Wetland and Stream Restoration alternatives. The Lake As Is alternative ranked as least favorable by the MCDA.

All the identified alternatives are subject to North Carolina and Federal regulations. The dam is subject to the Dam Safety Act, existing wetlands and stream features are jurisdictional waters under the Clean Water Act, and surface waters are subject to the Neuse River Buffer Rules. None of these regulations would prevent implementation of any of the alternatives. Before construction of any alternative, permits would be required from the North Carolina Department of Environmental Quality and the U.S. Army Corps of Engineers.

As described in this study report, the City has several viable options for modifying the Upper Lake to improve the function of the area of the lake and remove its deficiencies. The City may use the descriptions, conceptual designs, and evaluations in this report to inform scoping of possible supplemental evaluations and to support decisions regarding the best future use of the area of the Upper Lake and associated expenditures.

1 Introduction

Upper Durant Lake, constructed in 1947, is a 6-acre lake located within the City of Raleigh's 237-acre Durant Nature Preserve in North Raleigh. The lake's watershed, covering 1.14 square miles, is largely residential land and is bisected by I-540 (see Figure 1). Water discharges from Upper Durant Lake through a concrete apron and flume spillway over an earthen dam and into a 100-foot-long channel that flows into the 12-acre Lower Durant Lake, which discharges to a stream channel that flows into Perry Creek about 2 miles downstream. These lakes, their tributaries, and Perry Creek are designated as Nutrient Sensitive Waters by the NC Department of Environmental Quality (NC DEQ). Lower Durant Lake also is classified as "B-waters" because of its potential for use for recreational swimming and other organized recreational activities. In addition, Perry Creek formerly was listed on North Carolina's 303(d) list of impaired waters and currently is designated as a Total Maximum Daily Load (TMDL) stream.

In 2013, an engineering firm contracted by the City deemed the dams and spillways of both lakes to be structurally and hydraulically deficient (Schnabel Engineering, 2013), and the City has recognized that these lakes need to be modified to address their deficiencies. The Lower Lake has long served as a valuable recreation area for programmed and casual uses (e.g., canoeing, fishing, wildlife observation, hiking, and nature education) for the preserve. In 2019, the City completed construction of modifications to the Lower Lake, including its dam, spillway, and downstream channel, removing its deficiencies.

Modifications to the Upper Lake to address its hydraulic and structural deficiencies have not yet been undertaken. In addition, the Upper Lake has been negatively impacted by large amounts of sedimentation due to development in the watershed and, as a result, has reduced ability to treat stormwater by trapping sediment, support programmed or casual recreational use opportunities, and provide habitat value for fish and wildlife. The City recognizes that the best use of the area of the Upper Lake, both programmatic and ecologic, potentially could be as a water body other than an open-water lake and, in 2017, initiated a study for considering alternatives for the area of the Upper Lake. For this study, the City contracted with NC State University's Department of Biological and Agricultural Engineering (NCSU BAE) and NC Sea Grant to assess the Upper Lake, its watershed, and its environs and to develop and evaluate conceptual alternatives for potentially retrofitting the area of this lake, including retaining its existing condition as an open-water lake. Based on this evaluation, four alternatives have been developed, compared, and ranked using multi-criteria decision analysis (MCDA) applying evaluation factors identified by the City. The City may use the information and evaluations in this report to inform scoping of possible supplemental evaluations and to support decisions regarding the best future use of the area of the Upper Lake and expenditures needed to address its identified deficiencies.

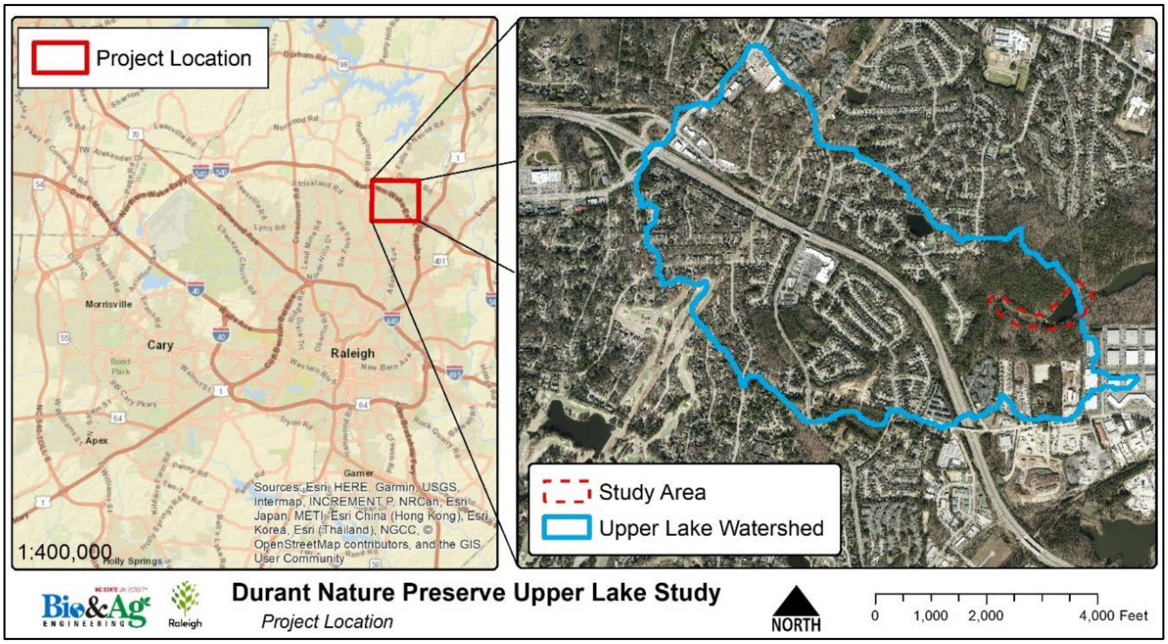

Figure 1. Upper Durant Lake project location.

2 Project Objectives and Scope

Given the current reduced capacity of the Upper Durant Lake due to decades of sedimentation, a failing outlet structure and the structurally compromised spillway, the City of Raleigh contracted with NC Sea Grant and NCSU BAE to evaluate alternatives for long-term management and use of the Upper Durant Lake. The purpose of this project was to identify opportunities for repairing and modifying the existing lake to improve water quality protection, flood control, habitat and recreational and educational opportunities. The project scope included:

- Investigate and document the historical and existing condition of the Upper Durant Lake and the morphologic features immediately upstream.
- Determine the volume and quality (metals or other contaminant concentrations) of the sediment accumulated in the lake.
- Evaluate the water quality improvement performance of the Upper Durant Lake
- Develop a hydrologic model for the Upper Durant Lake watershed and evaluate the flood control performance of the lake.
- Produce conceptual designs for alternatives to retrofit the Upper Durant Lake to improve ecosystem services and rank the retrofit alternatives using MCDA. The specific objectives of the design process included:
    - Protect downstream waterways by improving water quality treatment through enhancing physical and biological processes.
    - Increase diversity of habitats for aquatic flora and fauna.
    - Increase recreation and educational opportunities in the nature preserve.
    - Minimize project cost and disturbance to the adjacent nature preserve and existing upstream wetlands and riparian forest areas.

3 Methods

3.1 Site investigation

The historical and existing conditions of the Upper Durant Lake and the morphologic features immediately upstream were inventoried and assessed. Historical aerial photos from 1993, 1998, 2002, 2013, 2017 and 2018 were obtained from the U.S. Geological Survey and the NC Center for Geographic Information and Analysis. National Land Cover Database (NLCD) land use and impervious cover datasets from 1992 to 2016 were obtained from the Multi-Resolution Land Characteristics Consortium. These datasets were examined to characterize and describe land history and land use. The changes in land use were evaluated by comparing the percentage change in land cover indices (percent developed, percent impervious, percent forest) over time, and the changes were explained using the aerial imagery. In addition, the infrastructure surrounding the lake was inventoried using the City of Raleigh's Geographic Information Systems (GIS) data for public utilities.

To document the current site conditions, a detailed site survey was completed by a professional surveyor in March 2018. Surface water features were mapped in March 2018 by a contractor specialized in jurisdictional determinations to determine if the water and wetland features on site are regulated by the US Army Corps of Engineers (USACE) under the authority of the Clean Water Act, and which types of permits would be needed for potential site retrofits. The field delineations of surface water features at the site were submitted to the NC DEQ Division of Water Resources (DWR) and the USACE for approval (see Appendix E).

3.2 Sediment Sampling

Lake bed sediment sampling and laboratory analyses were completed by a contractor specialized in environmental sampling. Samples were collected at three locations in the lake as shown in Figure 2. The samples were collected in August 2018 using a stainless steel trap box retriever. The samples were analyzed for semi-volatiles (EPA Method 8270), 8 Resource Conservation and Recovery Act (RCRA) metals (EPA Methods 6010, 6020, 200.7, 200.8, 7470, 7471 and 245.1), Toxicity Characteristic Leaching Procedure (TCLP) 8 RCRA metals (EPA SW-846 Methods), and polychlorinated biphenyls (PCBs) (EPA Method 8082B) at Con Test Labs in East Longmeadow, MA. In addition, to obtain an estimate of the volume of sediment accumulated in the lake, ground penetrating radar (GPR) was used to measure the depth to the top of the accumulated sediment and the depth to the in-situ lake bed. The volume of sediment was estimated as the difference between the two measured depths.

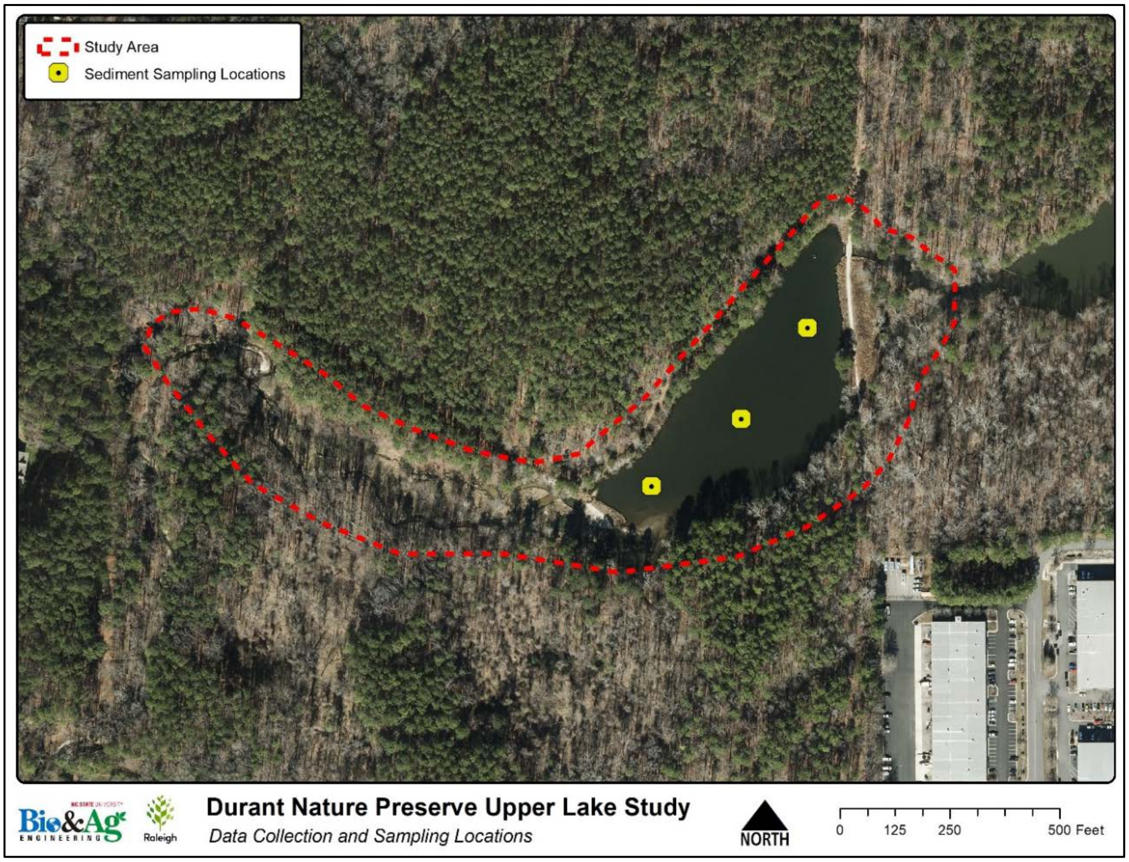

Figure 2. Sediment quality sampling locations.

3.3 Water Quality and Hydrology Monitoring

Water quality and streamflow were monitored at the inlet (DUR-up) and outlet (DUR-dn) of the Upper Durant Lake from February 2018 to March 2019 (see Figure 3 and Figure 4). Automatic samplers (ISCO 6712) equipped with level probe water level recorders were installed at each location. A tipping bucket rain gauge was used to record rainfall at DUR-dn because this station was far enough away from the tree canopy to record reasonably accurate rainfall measurements. In addition, temperature recording sensors were maintained at both inflow (DUR-up) and outflow (DUR-dn) stations. The sensors were mounted so that they were continuously underwater and were not exposed to direct sunlight. The sensors recorded measurements every 20 minutes. Air temperature data was obtained from the North Carolina State Climate Office website for the Lake Wheeler site (Station ID: LAKE).

Water level was monitored continuously (every 10 minutes) at both locations. At the inlet location (DUR-up), thirteen manual flow measurements were made at various water levels (0.57 to 1.70-ft) using a current meter to develop a water level-discharge rating curve, which was input into the automatic sampler to convert water level to discharge. Measurement of discharge at DUR-dn station was facilitated by manual measurements and computed discharge using an equations for a chute spillway. However, water level measurements at the outlet were problematic during monitoring due mainly to woody debris collecting on the lip of the spillway, which erroneously raised the level/stage of the water, resulting in an over-prediction of discharge. Water level measurements were corrected as necessary by removing the debris and recording the associated drop in water level; the measured drop was then used to adjust the water level measurements for that monitoring period. When substantial debris was encountered causing high uncertainty in outflow discharge, the outflow was set equal to the inflow. This assumption is reasonable given the lack of storage capacity in the lake and the drainage area between the DUR-up and DUR-dn stations is relatively small compared to the drainage area of DUR-up.

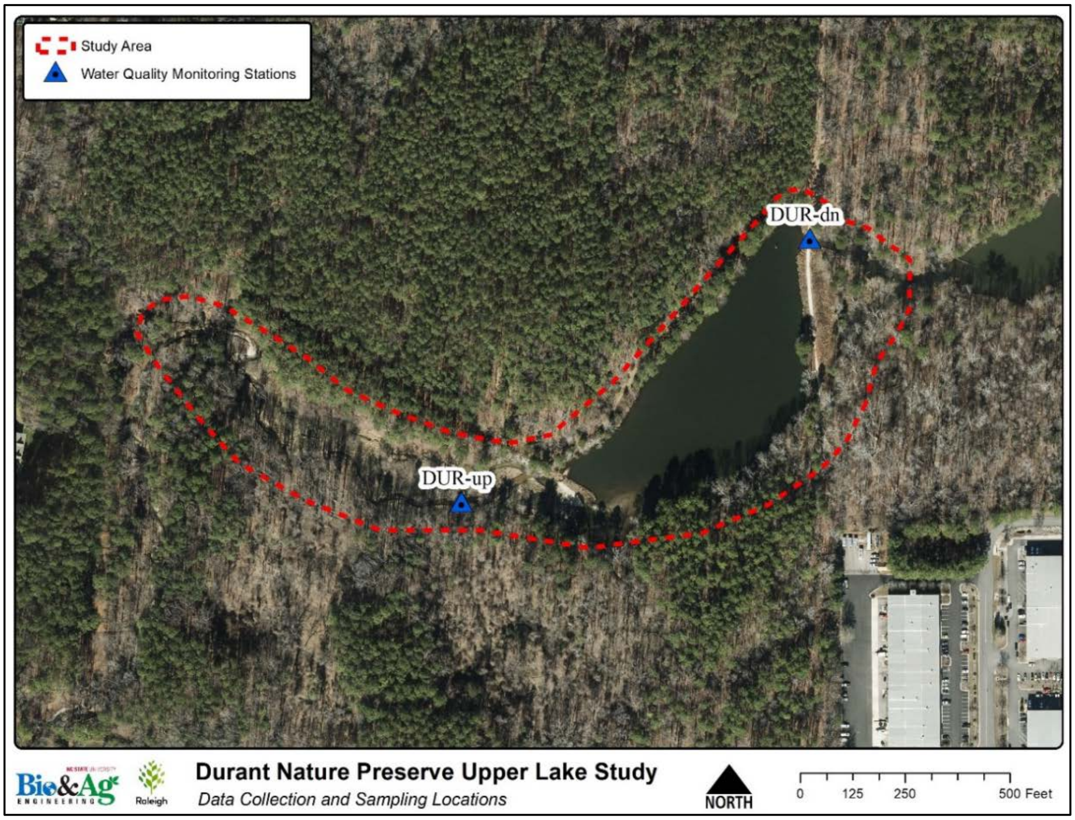

Figure 3. Water quality and flow monitoring locations.

Figure 4. Upstream (DUR-up) (left) and downstream (DUR-dn) (right) flow and water quality monitoring stations.

The computed discharge measurements were used to collect flow-proportional samples at each monitoring station. Sample collection and preservation methods followed recommendations from US EPA (1982). Odd numbered sample bottles (each sampler had 24 bottles) were pre-acidified (using H_2SO_4) to prevent nutrient transformation prior to collection and analysis. Samples were analyzed for total Kjeldahl nitrogen (TKN), ammonia nitrogen (NH_3-N), nitrate+nitrite nitrogen (NO_x-N) and total phosphorus (TP) at the NC State Department of Biological and Agricultural Engineering's Environmental Analysis Lab (BAE EAL) using standard methods. Total nitrogen (TN) was calculated from the results as the sum of TKN and NO_x-N. Composite samples from even-numbered sample bottles (non-acidified) were analyzed for TSS at the BAE EAL using standard methods. Overall, 27 composite samples were collected at the upstream station and 25 at the downstream station throughout the monitoring period. Inflow and outflow constituent loads were calculated from the discharge and concentration results for each sampling period. Inflow and outflow loads were compared using boxplots and paired T-tests.

3.4 Macroinvertebrate Sampling

Benthic insects were collected from two locations in the Durant Nature Preserve watershed in April and October of 2018 using the NC DEQ Division of Water Resources (DWR) "Qual 4" collection protocol by a contractor specialized in macroinvertebrate sampling. The 'upstream' monitoring site was located approximately 300 feet above the Upper Durant Lake and the 'downstream' site was located approximately 150 feet below the Lower Durant Lake dam and above the confluence with the receiving stream (see Figure 5).

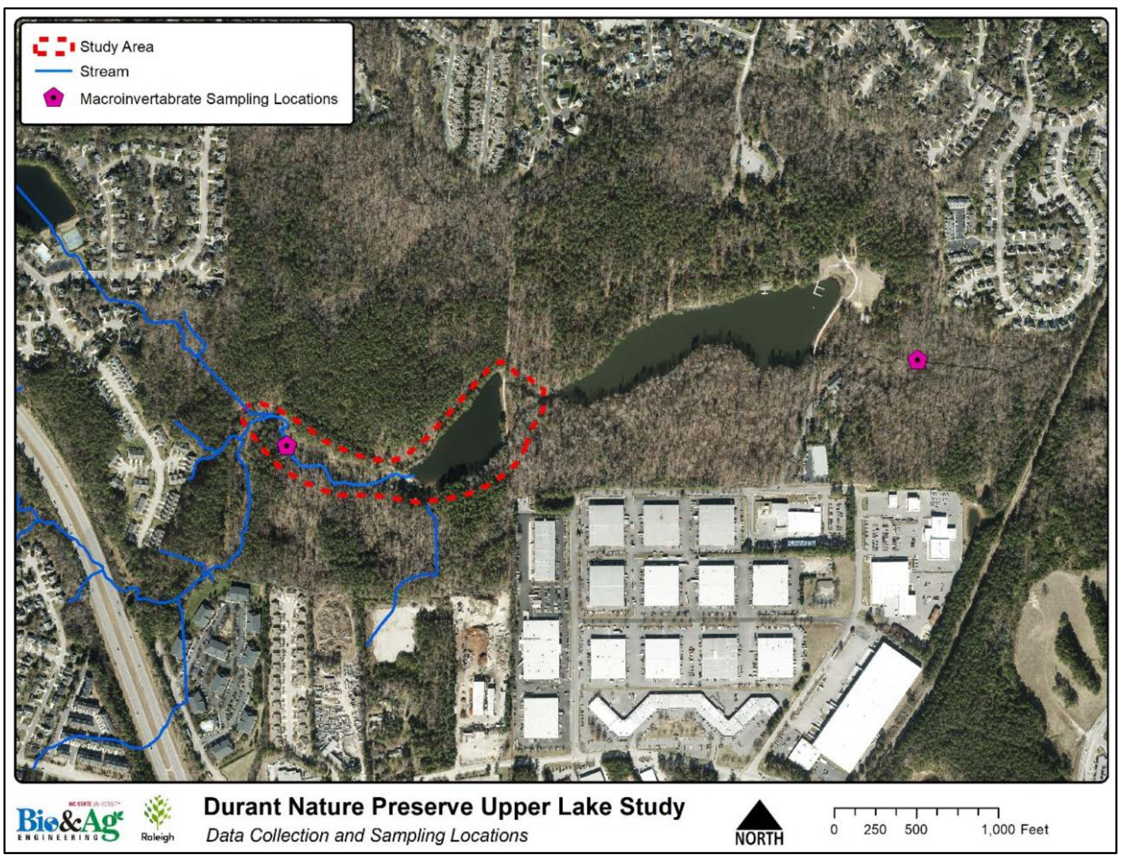

Figure 5. Macroinvertebrate sampling locations.

The "Qual-4" method is intended for sites having a drainage are of less than three square miles. The "Qual-4" method specifies a kick net sample from a riffle habitat, a sweep net sample from a stream bank and a leaf pack sample. In addition, a visual inspection of the collection site was also conducted to look for more cryptic organisms. Organisms were picked roughly in proportion to their abundance, but no attempt was made to remove all organisms. If an organism can be reliably identified as a single taxon in the field, then no more than 10 individuals need to be collected. Organisms are classified as *Abundant* if 10 or more specimens are collected, *Common* if 3-9 specimens are collected and *Rare* if 1-2 specimens are collected. Samples were processed in the field and taken to the contractor's lab in Asheville, NC for identification and summary.

The macroinvertebrate data was analyzed by calculating the overall species richness (number of species) and the EPT species richness (species from the genera *Ephemeroptera*, *Plecoptera* and *Trichoptera)*, as these are good indicators of water quality and a direct measure of benthic biological diversity. However, for small streams (<3.0 square miles), the NC DEQ DWR uses the NC Biotic Index values (see Table 1). Additional metrics computed include the total number of EPT taxa and EPT abundance and total taxa richness.

Table 1. Bioclassification using small stream criteria for Piedmont streams.

Bioclassification	NC Biotic Index
Excellent	< 4.31
Good	4.31 – 5.18
Good/Fair	5.19 – 5.85
Fair	5.86 – 6.91
Poor	>6.91

3.5 Hydrologic Modeling

A Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) hydrologic model (USACE, 2017) was developed for the watershed to predict runoff volume and peak discharge for different design storms to use during the design of the site retrofits. HEC-HMS is a widely used process-based, lumped parameter hydrologic model developed by the USACE. Model inputs include drainage area (see Figure 6), Soil Conservation Service (SCS) curve number, percent imperviousness, and lag time for each model sub-basin, and stream cross section, slope and length. In addition, a storage-discharge relationship (outflow for spillway) was developed and entered into the HEC-HMS model for the Upper Durant Lake. Hourly rainfall collected on-site was used for model calibration. The HEC-HMS model was calibrated to a 1.0-inch storm that occurred in March of 2018. The discharge hydrograph generated by the model was compared to the observed record of discharge. The model was calibrated by adjusting input parameters (SCS curve number and lag time) until the simulated discharge hydrograph closely matched the observed hydrograph. Next, rainfall depths for various return period design storms (e.g. 50-yr, 24-hr), ranging from 1 to 100 years were input into the model and the design storm hydrographs were computed for use in the design process.

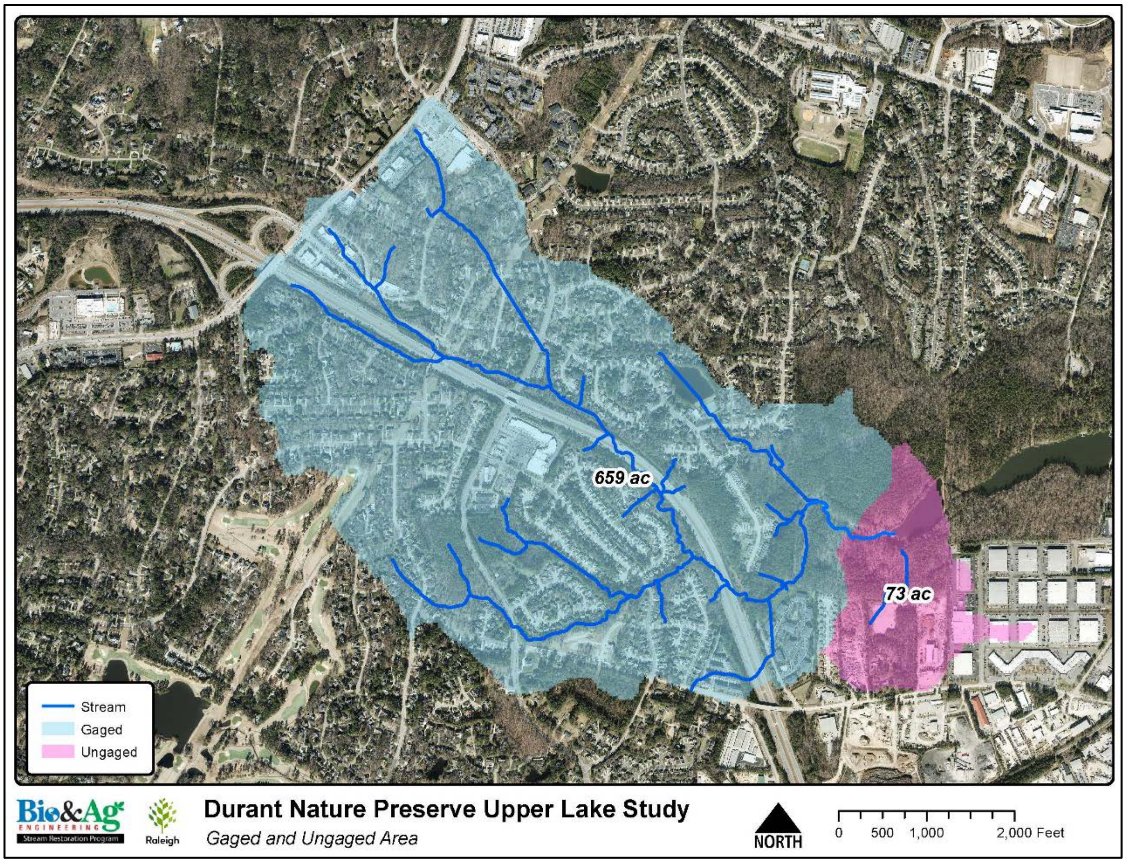

Figure 6. Watershed area for Upper Durant Lake used in the hydrologic model.

3.6 Retrofit Alternatives

Concept level designs for four alternatives for retrofitting the Upper Durant Lake site were developed using AutoCAD Civil 3D. The concept designs include hydraulic analysis, plan sheets and cost estimates. The retrofit alternatives include:

1. **Lake As Is**: Repair/replace existing structures and lower normal pool elevation to increase storage.
2. **Stormwater Wetland**: Wetland system for water quality benefit.
3. **Habitat Wetland**: Wetland system for enhanced habitat function.
4. **Stream Restoration**: Breach dam and restore natural stream and floodplain system.

The retrofit alternatives were compared using multi-criteria decision analysis (MCDA). MCDA is valuable tool to help decision makers objectively prioritize complex alternatives. The first step of the MCDA process is to select a number of decision criteria variables that are important for evaluating the alternatives (e.g. water quality benefit, flood control). The next step is to rate the alternatives corresponding to how well they satisfy each of decision criteria variables. Then weighting factors are assigned to each of the decision criteria variables based on their importance as assessed by the decision makers. Finally, a score is calculated for each alternative as the sum of the weighted rating for each of decision criteria. Environmental permitting requirements for implementing each retrofit alternative were also investigated and documented.

4 Results and Discussion

4.1 Site Investigation

The Upper Durant Lake watershed covers an area of 1.14 square miles (Figure 7). The watershed is 83% developed and 23% of the area is impervious. The primary land use in the watershed is residential with some industrial and commercial areas. The Durant Nature Preserve is one of the few undeveloped areas in the watershed. The watershed is bisected by I-540 and several other secondary roads traverse the watershed. However, the only significant infrastructure immediately adjacent to the Upper Durant Lake, aside from the spillway and riser structure, is a sewer line that runs along the northern edge of the lake (see Figure 8). Therefore, there are few potential infrastructure conflicts to avoid when considering retrofits for the Upper Durant Lake.

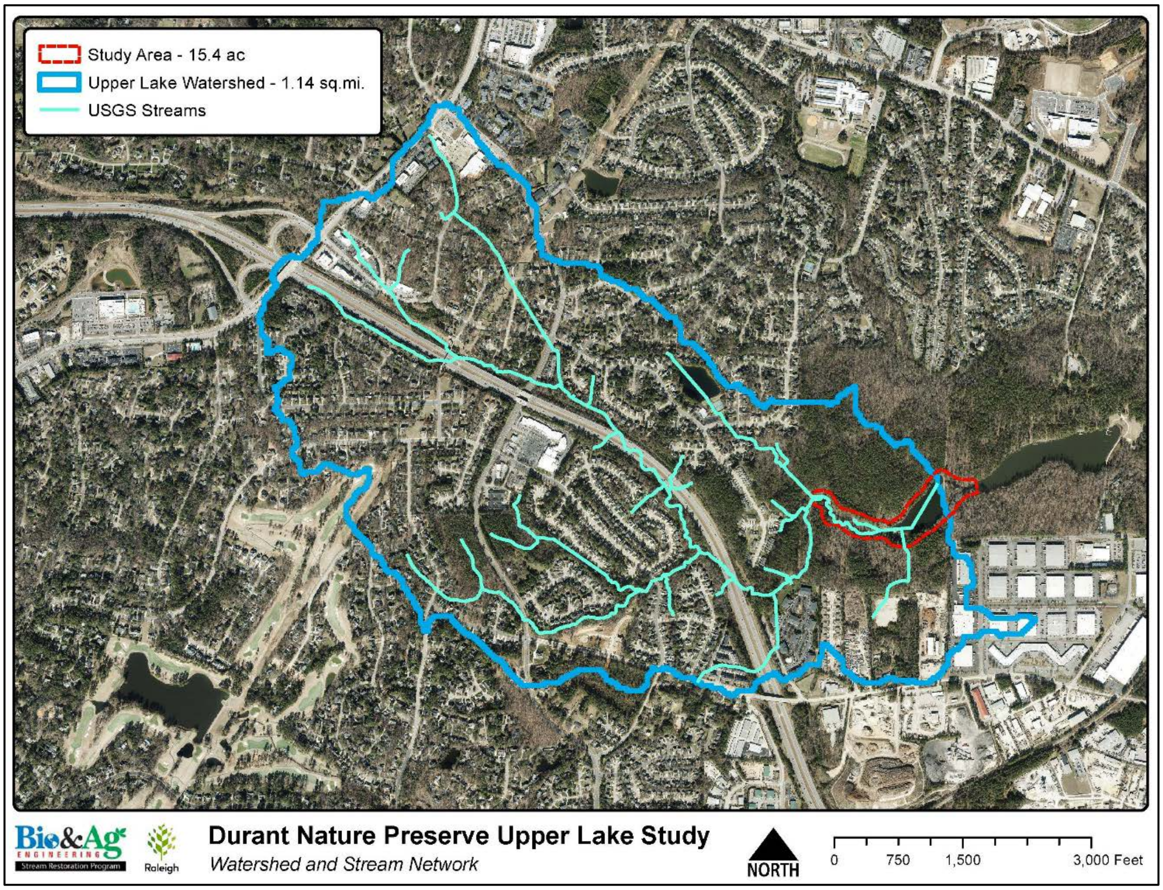

Figure 7. Watershed and stream network draining to Upper Durant Lake.

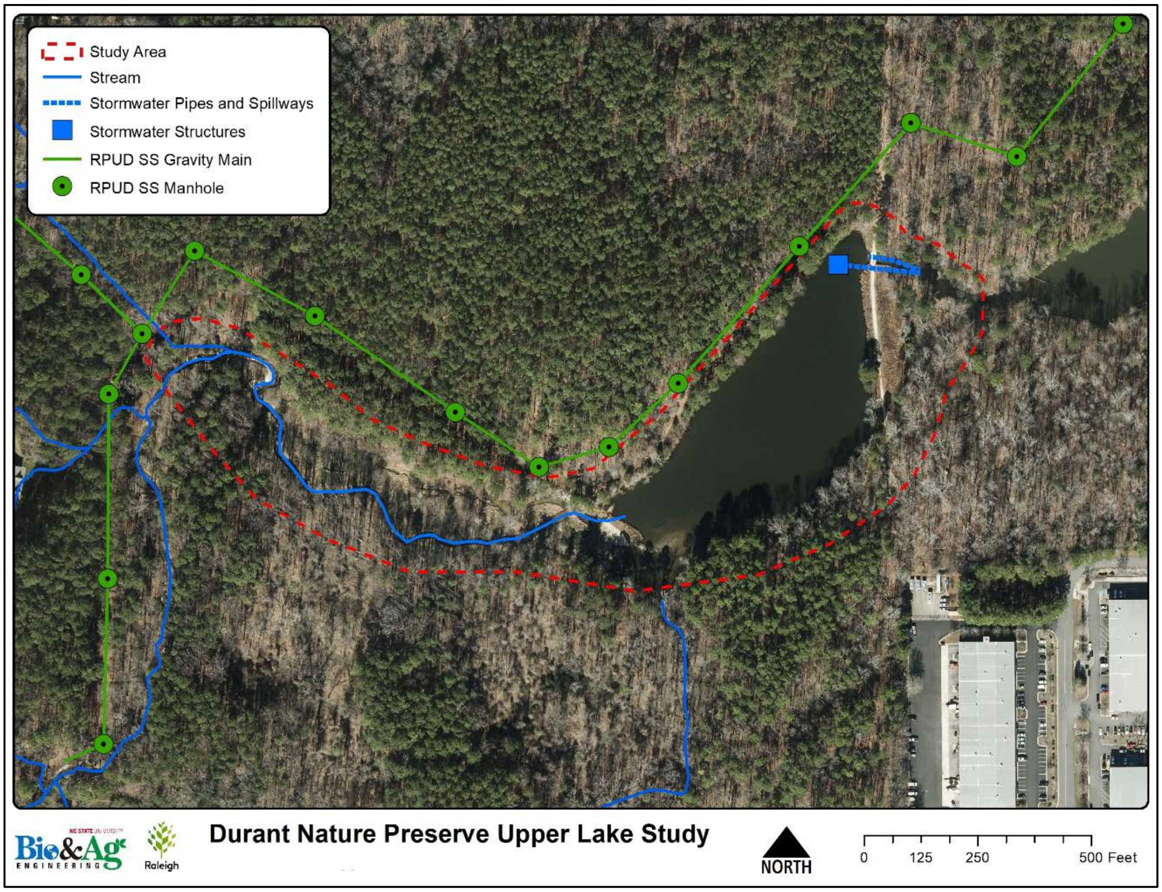

Figure 8. Infrastructure adjacent to the Upper Durant Lake study area.

The City and their engineering consultant conducted a site assessment in 2013 and determined that the riser structure in the Upper Durant Lake is not functional and the spillway is in need of repairs. The lack of a functional outlet control structure eliminated the temporary storage of stormwater in the lake as normal pool is currently at the elevation of the spillway crest. Further investigation by NCSU BAE revealed that the outlet structure barrel daylights directly underneath the spillway. Given the age of the dam (the State's dam inventory database indicates the dam was constructed in 1947), the corrugated metal pipe outlet is likely deteriorated, if not collapsed. The 28-ft wide concrete spillway is cracked in several places, the bottom end of the spillway is undermined and the downstream channel is severely eroded at the spillway outfall (Figure 9).

Figure 9. (A) lake outlet showing non-functioning riser and normal pool at spillway crest elevation, (B) downstream view of spillway showing erosion, failing rip rap repairs and undermining of spillway structure, (C) downstream end of spillway showing cracked concrete and location of outlet barrel for riser structure and (D) spillway viewed from bridge showing cracked and repaired concrete.

4.1.1 Past Land Uses

Historical aerial imagery of the Upper Durant Lake watershed from 1993 to 2017 is shown in Figures 10 through 13. A summary of the land cover changes from 1992 to 2016 is included in Table 2. The aerial imagery showed that a majority of the recent development in the watershed (residential development and construction of Interstate 540) occurred between 1992 and 2002. There were only minimal changes between 2002 and 2017, including several small residential developments and two commercial developments in the upper watershed. These development trends were captured by the change in land cover as the developed area increased from 35% to 81% between 1992 and 2001. The forested area decreased from 56% to 16% over the same period. From 2001 to 2011 there was little change in developed area (81% to 82%); impervious area increased slightly from 19% to 22%. From 2011 to 2016 there was no change in the percentage of developed area in the watershed (see Table 2).

This data suggests that a majority of the sediment load from construction runoff likely occurred prior to 2001. Sediment load since that time is likely the result of increased erosion of stream banks resulting from changes to hydrology of the watershed caused by development. Based on the current level of development, zoning within the watershed (see Figure 14) and the protected status of the forested areas in Durant Nature Preserve, there is limited potential for further development in the watershed.

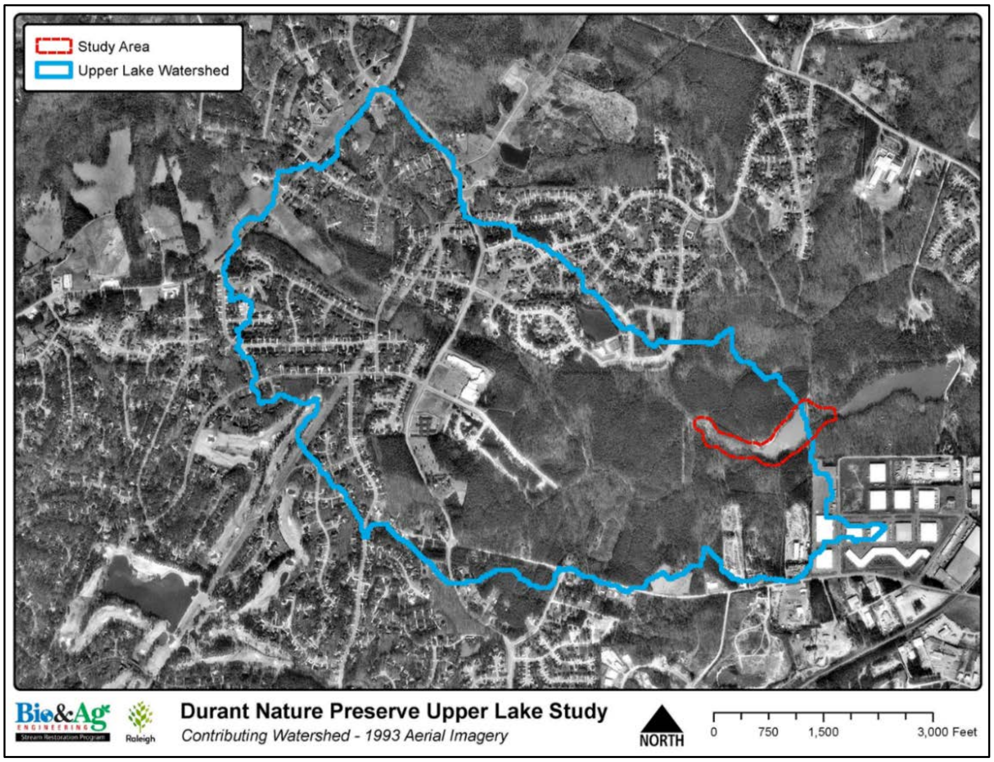

Figure 10. 1993 Aerial imagery for the Upper Durant Lake watershed.

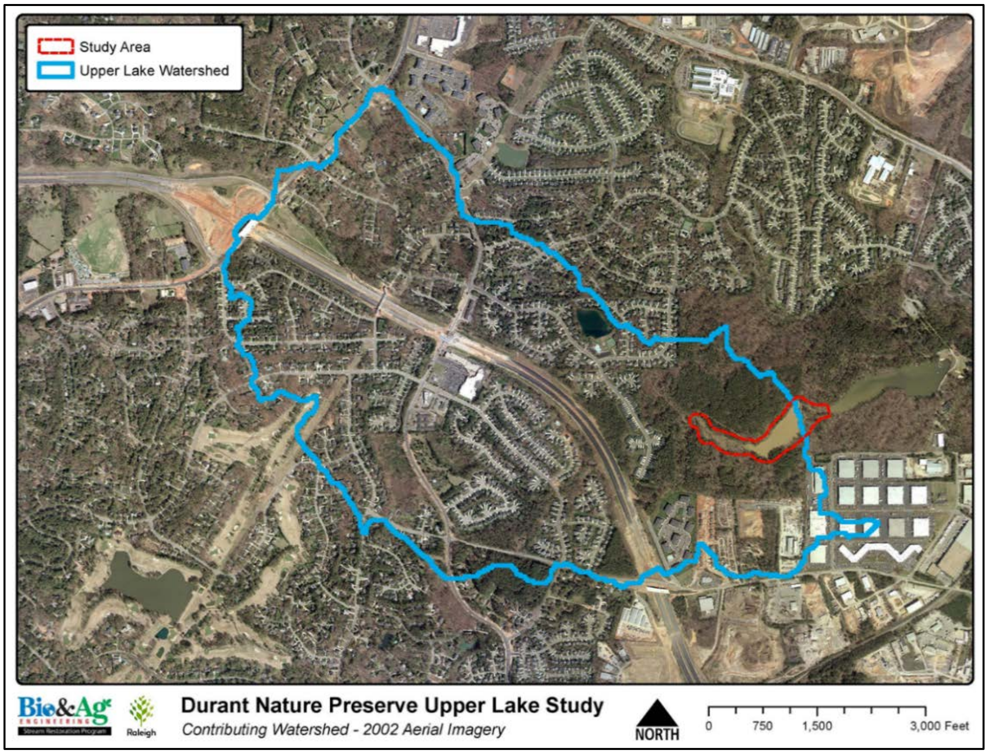

Figure 11. 2002 Aerial imagery for the Upper Durant Lake watershed.

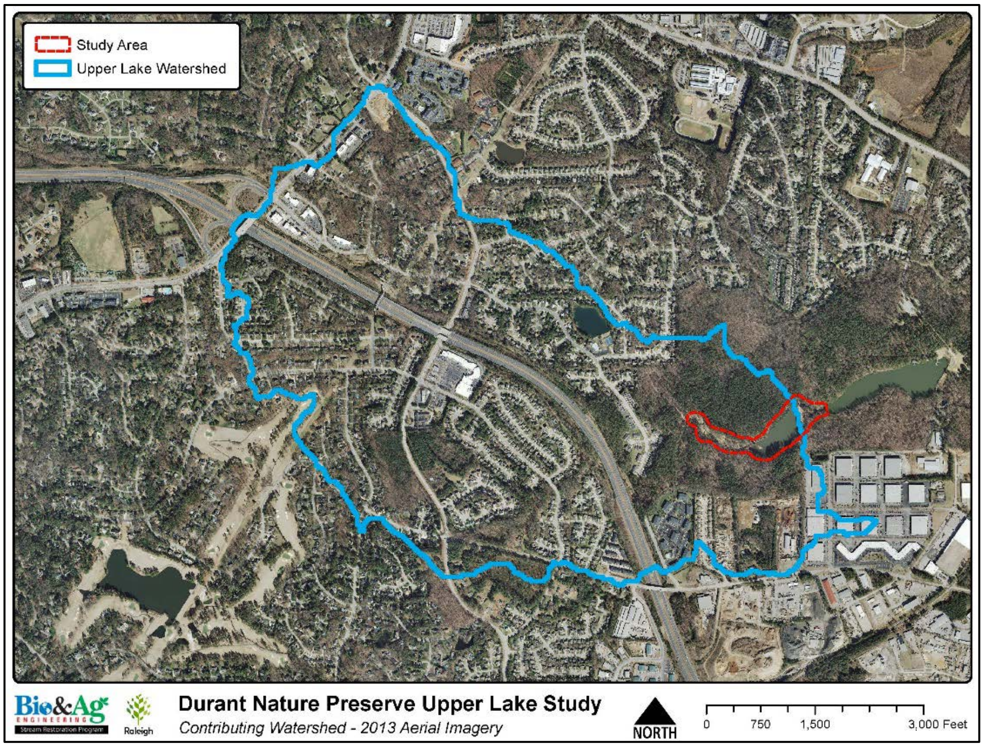

Figure 12. 2013 Aerial imagery for the Upper Durant Lake watershed.

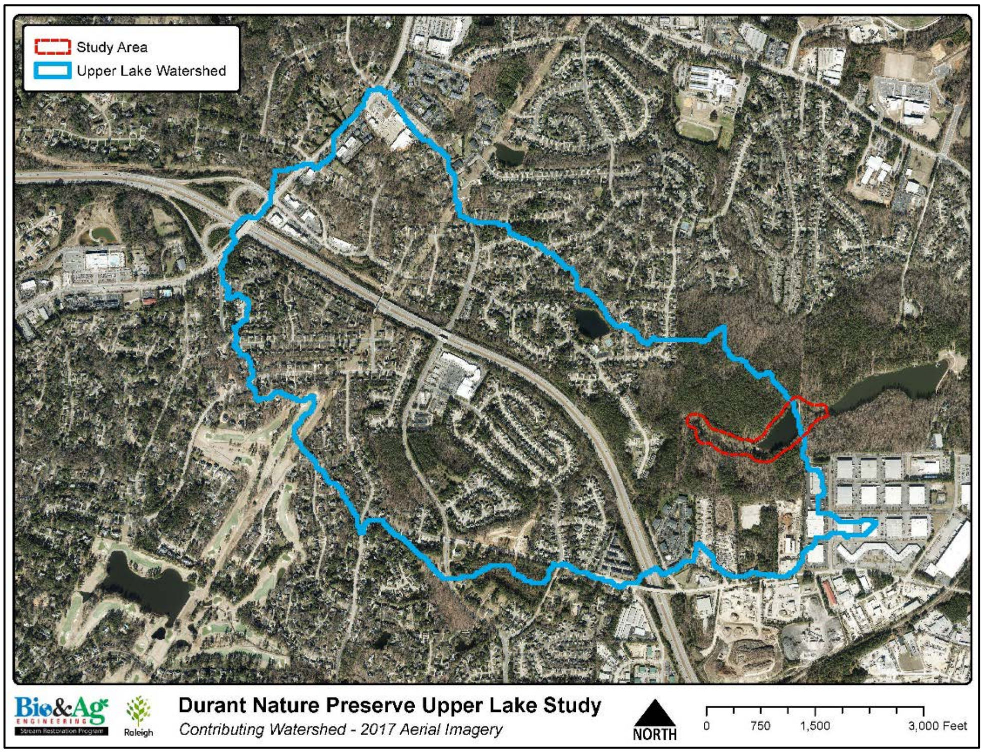

Figure 13. 2017 Aerial imagery for the Upper Durant Lake watershed.

Table 2. Land use changes in the Upper Durant Lake watershed from 1992 to 2016.

Year	Percent Developed (%)	Percent Impervious (%)	Percent Forest (%)
1992	35	NA	56
2001	81	19	16
2011	82	22	15
2016	82	22	14

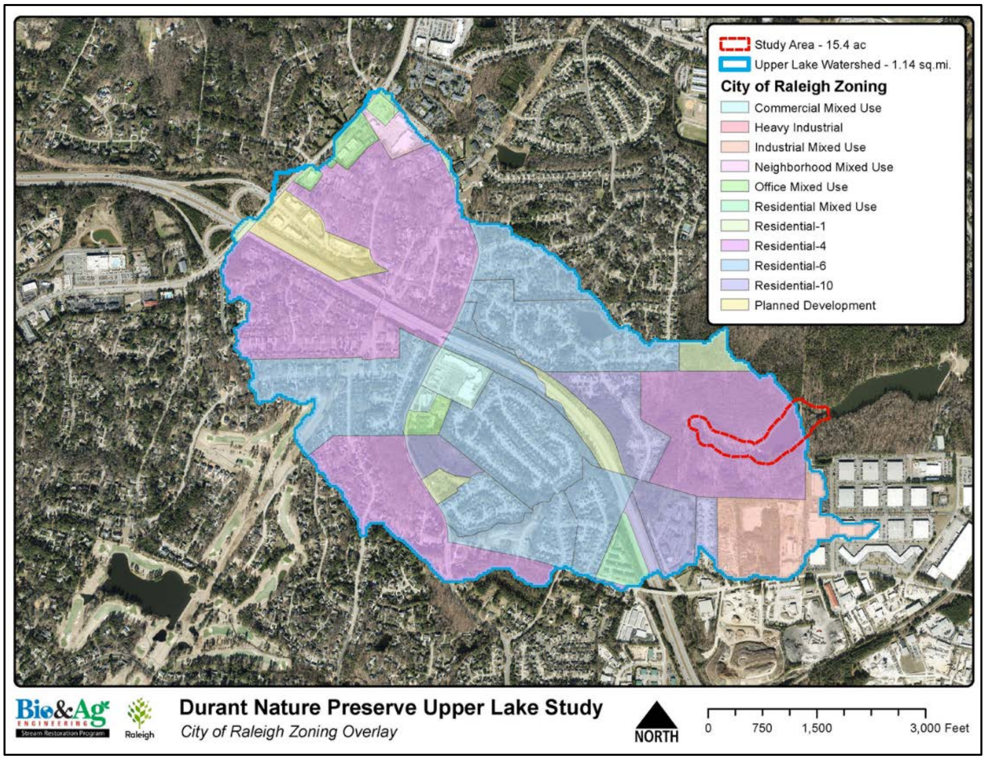

Figure 14. City of Raleigh 2018 zoning in the Upper Durant Lake watershed.

The historical aerial imagery of the Upper Durant Lake project area is shown in Figure 15. The photos of the lake indicated minimal change in lake area from 1993 to 2002. However, the photo from 2013 indicates accumulation of sediment extending into the lake at the inlet. The sediment accumulation at the inlet had increased further in the 2018 photo. The observed changes in sediment accumulation in the lake appear to have occurred after the large increase in developed area (35% to 81%) and decrease in forest area (56% to 16%) that occurred from 1992 to 2001 in the Upper Durant Lake watershed. The recent tropical storms/depressions (Matthew, Florence and Michael) likely also resulted in substantial erosion of stream banks in the watershed and associated sediment delivery to the lake.

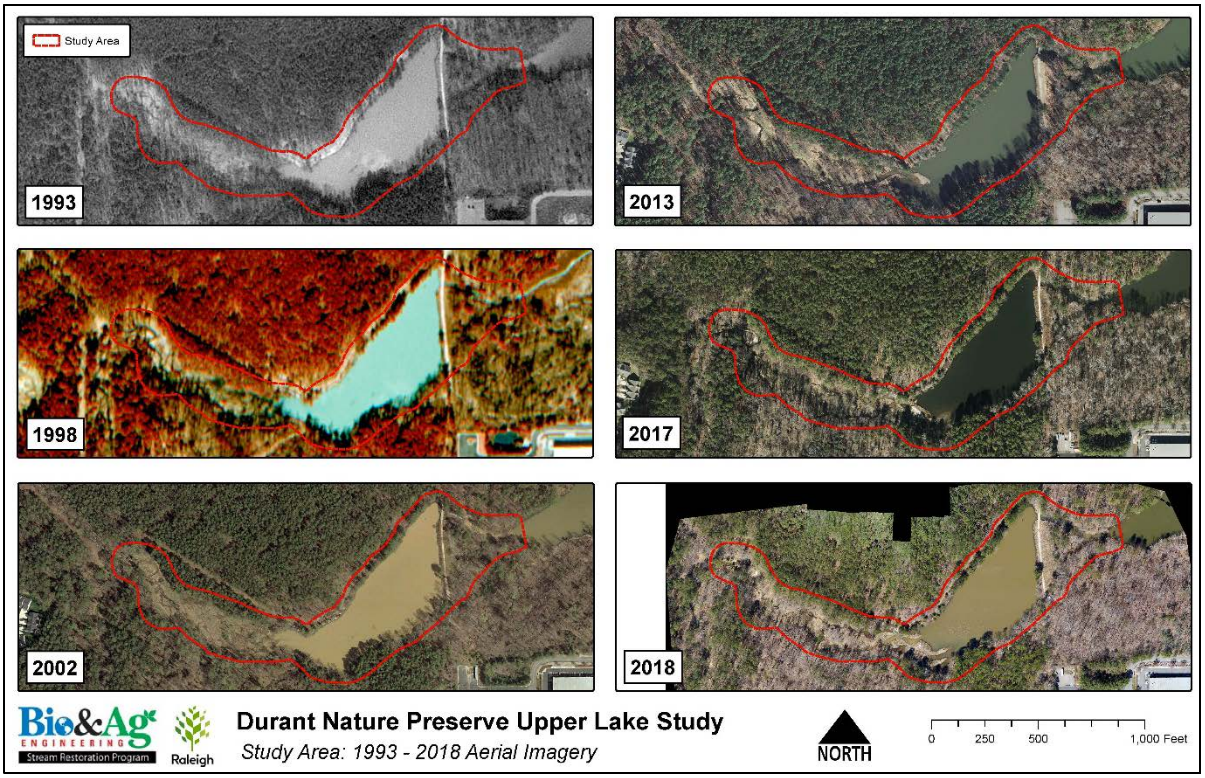

Figure 15. Aerial imagery of the Upper Durant Lake from 1993 to 2018.

4.1.2 Jurisdictional Features

There are several jurisdictional features (regulated under the Clean Water Act) located in the project area (Figure 16). The jurisdictional wetland and stream features include the following (also see contractors report in Appendix E):

- A perennial stream that enters the Upper Lake from the west.
- A stream that enters the Upper Lake from the south. It is likely intermittent.
- A stream that enters the Lower Lake from the south. It is likely intermittent.
- Wetlands adjacent to the upper end of the Lower Lake.
- Wetlands adjacent to the Upper Lake at the northern corner of the dam.
- Wetlands adjacent to the upper end of the Upper Lake and the perennial stream that flows into the upper lake).
- A possibly isolated small wetland pocket in the flood plain adjacent to the sanitary sewer line in the western end of the study area.

The wetlands onsite were identified as Headwater Forest Wetlands, Fringe Wetlands or Bottomland Hardwood Forest wetland types. These wetland types are common throughout the Piedmont ecoregion of North Carolina and are found mainly along headwater streams and along pond or lake fringes like the ones at Durant Nature Preserve. In addition to Clean Water Act Jurisdiction, the streams and lake are subject to the Neuse River Basin Buffer Rules. The contractor’s jurisdictional determinations were accepted by the USACE and NC DEQ DWR. As a result of the presence of these features, permits would be required from NC DEQ DWR and USACE for the implementation of a retrofit to the Upper Durant Lake.

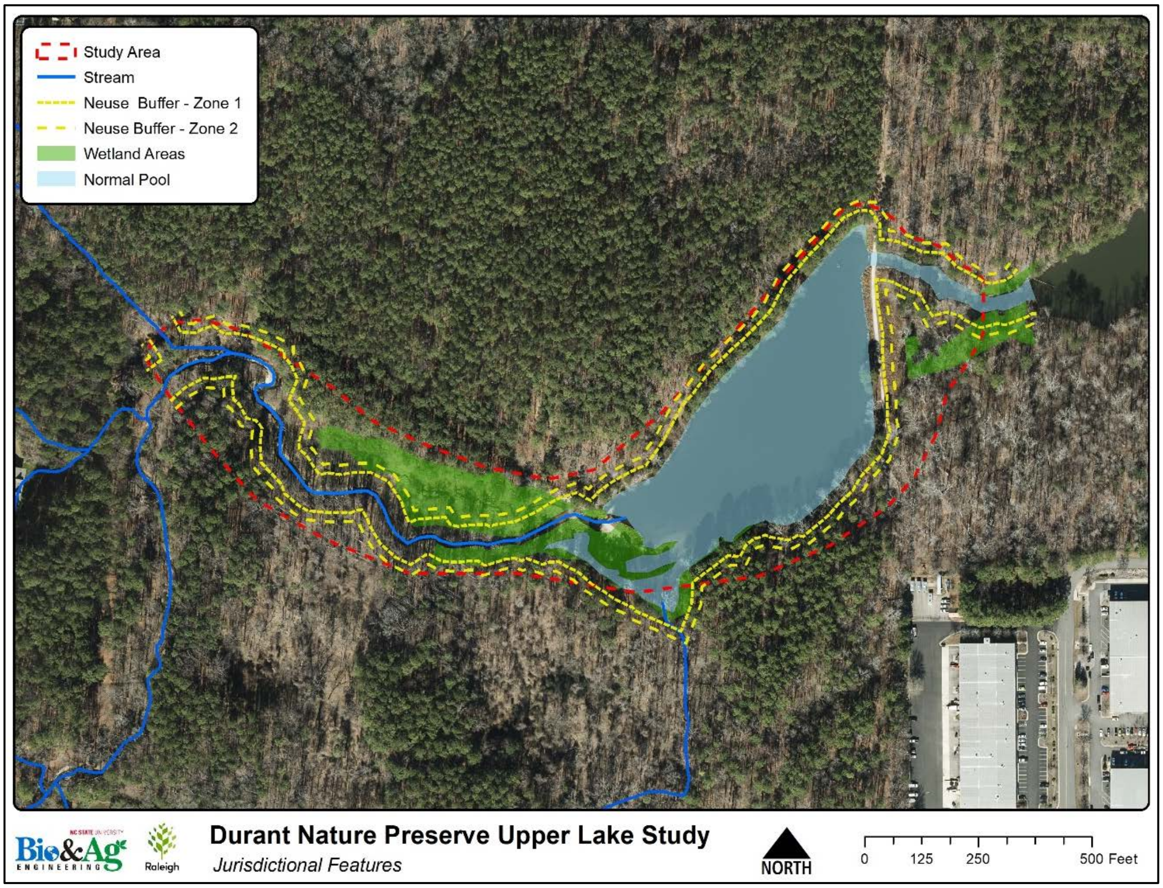

Figure 16. Jurisdictional surface water features at the Upper Durant Lake.

4.2 Sediment Quality

RCRA metals and semi-volatile organic compounds were detected in low concentrations in the lake sediments. Polychlorinated biphenyls (PCBs) were not detected in any of the samples. The sample results for the 8 RCRA metals were compared to the NC DEQ Preliminary Soil Remediation Goals (PSRG), which are based on Regional Soil Screening Levels from the U.S. EPA (NC DEQ, 2018) (see Table 3). Chromium and arsenic were the only RCRA metals that were detected above the NC DEQ PSRGs. Chromium concentrations were well above all the PSRGs, while arsenic concentrations only slightly exceeded the goals for residential and industrial/commercial soils. However, both chromium and arsenic concentrations fell in the range of typical background levels for the eastern U.S. (0-10 ppm for arsenic and 0-70 ppm for chromium (U.S. EPA, 2005, 2008)). In addition, the fractions of chromium and arsenic that were leachable (TCLP metals- bioavailable or mobile in the environment) were below the limit of detection. In fact, the leachable fractions of all metals sampled were below the detection limit, with the exception of barium (very low level) in one sample (see Table 3). Therefore, while RCRA metals were present in the sediments, they were not in the form that would cause detrimental impacts to biota or threaten downstream waters or the underlying groundwater.

Table 3. Sediment analysis sample results for RCRA metals.

Metal	8 RCRA Metals (ppm)	TCLP 8 RCRA Metals (Leachable Fraction) (ppm)	NC DEQ PSRG* (ppm)		
			Residential Health	Industrial/ Commercial Health	Protection of Groundwater
Arsenic (As)	1.3 - 3.8	ND	0.68	3.0	5.8
Mercury (Hg)	<0.1	ND	2.3	9.7	1.0
Barium (Ba)	100-140	ND-0.81	3100	47000	580
Cadmium (Cd)	<0.1	ND	7.5	110	3.0
Chromium (Cr)	31-44	ND	0.31	6.5	3.8
Lead (Pb)	19-29	ND	-	-	270
Selenium (Se)	0.2-0.6	ND	78	1200	2.1
Silver (Ag)	<0.1	ND	78	1200	3.4

* NC DEQ Preliminary Soil Remediation Goals based on USEPA Regional Screening Tables (NC DEQ, 2018).
Note: ND = Below limit of detection

The results for semi-volatile organic compounds are included in Table 4. Benzo(a)pyrene and Benzo(a)anthracene were the only semi-volatiles that were detected above the NC DEQ PRSG level for groundwater (NC DEQ, 2018). There were no sample results above the Residential or Industrial/Commercial PRSGs. While groundwater contamination is not a concern at the Upper Durant Lake site or specific part of this study, these thresholds are used for regulatory screening purposes and need to evaluated at all sites. Benzo(a)pyrene does not readily leach to groundwater as it is relatively insoluble in water (U.S. EPA, 2007). In addition, typical background concentrations of up to 1.3 ppm have been reported (ATSDR, 1995). One sample had a Benzo(a)anthracene concentration of 0.38 ppm, slightly above the 0.35 ppm PRSG. However, this is an estimated result as it is below the reporting limit of 0.55 ppm, but above the limit of detection. Benzo(a)anthracene also binds strongly to sediment and thus is unlikely to pose a risk at levels only marginally higher than the PRSGs.

Overall, the lake sediments have no detectable TCLP (mobile, bioavailable) RCRA metals, low levels of semi-volatile organic compounds and no detected PCBs. Therefore, the sediment is not considered hazardous waste and could be disposed of in a landfill or reused on site. However, the sample analysis results above the NC PSRG standards may need to be reported to the N.C. Department of Waste Management when the sediment is disturbed or removed during construction. Overall, the sediment sample results do not constrain potential site retrofits.

Table 4. Semi-volatile organic compounds content in the lake sediment.

Constituent*	Result (ppm)	NC DEQ PSRG** (ppm)		
		Residential Health	Industrial/Commercial Health	Protection of Groundwater
Benzo(a)pyrene	0.19-0.57	0.11	2.1	0.12
Benzo(b)fluoranthene	0.38-0.98	1.1	21	1.2
Benzo(a)anthracene	ND-0.38	1.1	21	0.35
Benzo(g,h,i)perylene	ND-0.44	-	-	15,600
Benzo(k)fluoranthene	ND-0.34	11	21	12
Chrysene	0.23-0.73	110	2100	36
Fluoranthene	0.42-1.2	480	6000	670
Pyrene	0.34-0.99	360	4500	440
Phenanthrene	ND-0.39	-	-	134
Indeno(1,2,3-cd)pyrene	ND-0.46	1.1	21	3.9

*Only results with detectable concentration (above detection limit) are shown.
**NC DEQ Preliminary Soil Remediation Goals based on USEPA Regional Screening Tables (NC DEQ, 2018).
Note: ND = Below the limit of detection

4.3 Sediment Quantity

Analysis of the ground penetrating radar data revealed that there is about 11,000 to 12,500 cubic yards of sediment accumulated in the lake bottom (Figure 17). This equates to about 22% of the lake volume. However, most of the sediment was located in the deepest part of the lake and does not contribute substantially to the decreased flood control capacity of the lake. In addition, this volume of sediment could reasonably be removed from the site, if necessary for a potential site retrofit. However, the calculated volume did not include the sediment accumulated along the stream entering the lake or near the inlet of the lake.

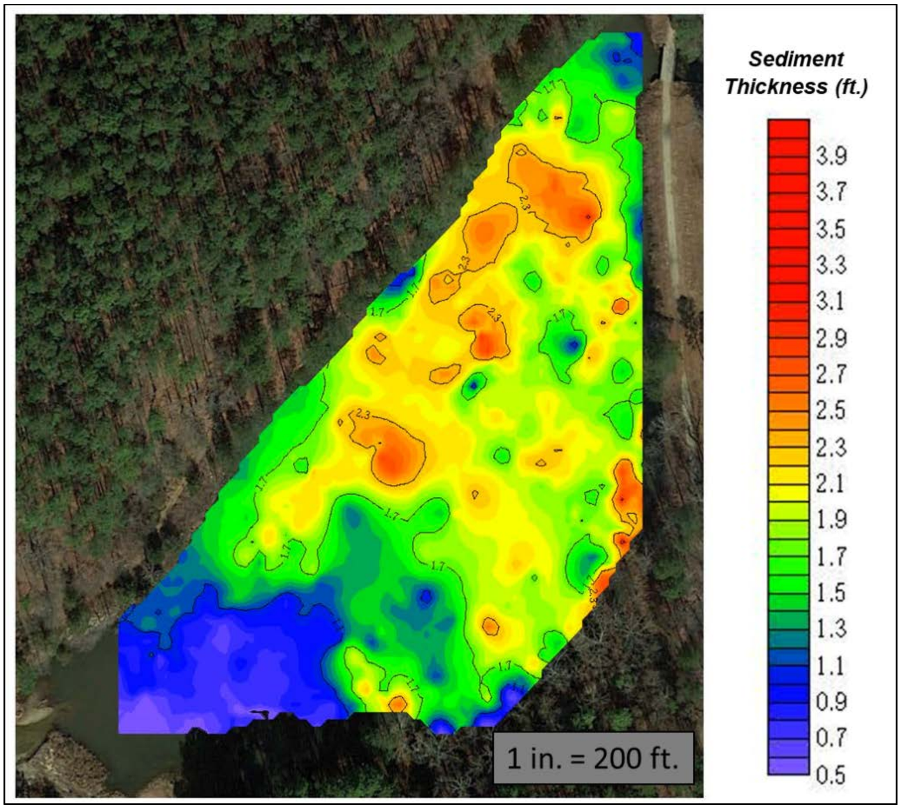

Figure 17. Sediment thickness map generated from ground penetrating radar (GPR) data.

4.4 Water Quality

4.4.1 Nutrient Concentrations

Boxplot summaries of water sample concentration data (27 samples upstream and 25 downstream) are shown in Figures 18 and 19. Median concentrations of TKN decreased slightly from upstream (DUR-up) to downstream (DUR-dn), whereas NH_3-N increased from upstream to downstream. Median concentrations of NOx-N, TP and TSS also decreased from upstream to downstream. The slight increase in NH_3-N concentrations may be attributed to a combination of waterfowl waste and/or nitrogen deposition in rainfall. The reduction in NOx-N can likely be attributed to denitrification in the lake, while the reduction in TP concentrations was likely associated with the reduction in TSS concentrations (Figure 19) as TP is commonly attached to sediment.

The mean outflow concentrations from the lake were compared to the effluent mean concentrations (EMCs) as given for engineered stormwater control measures (SCMs) in the NC Stormwater Design Manual (Table 5). TN concentrations discharged from the Upper Lake were slightly higher than the EMCs for wet detention basins and stormwater wetlands, while TP concentrations were slightly lower than the EMCs from these SCMs. This indicates that, while the discharge concentrations are comparable to conventional SCMs, there may be potential for some improvement, specifically for nitrogen treatment.

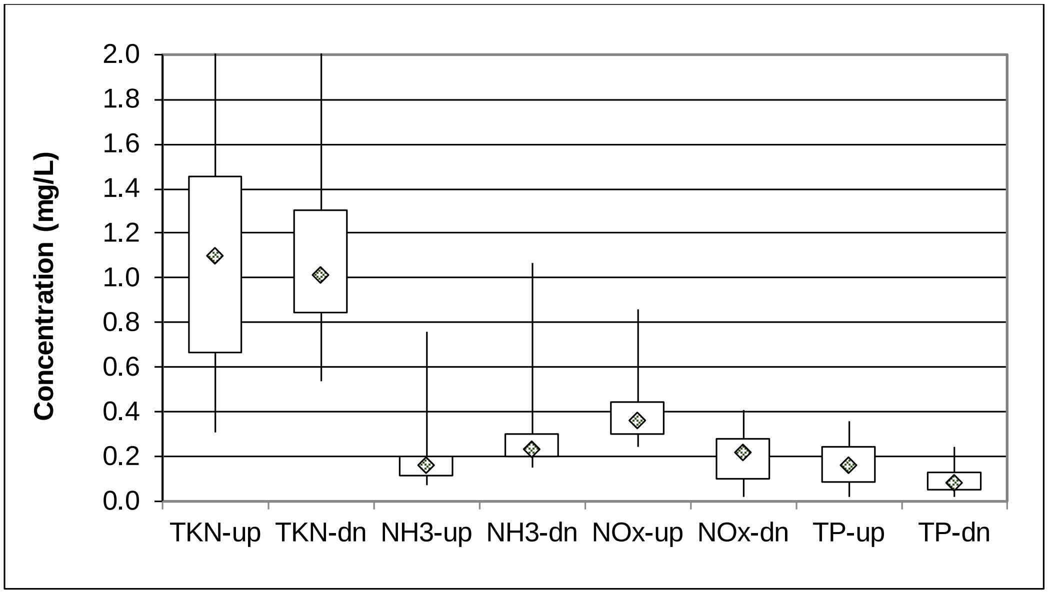

Figure 18. Boxplots of N and P in water samples.

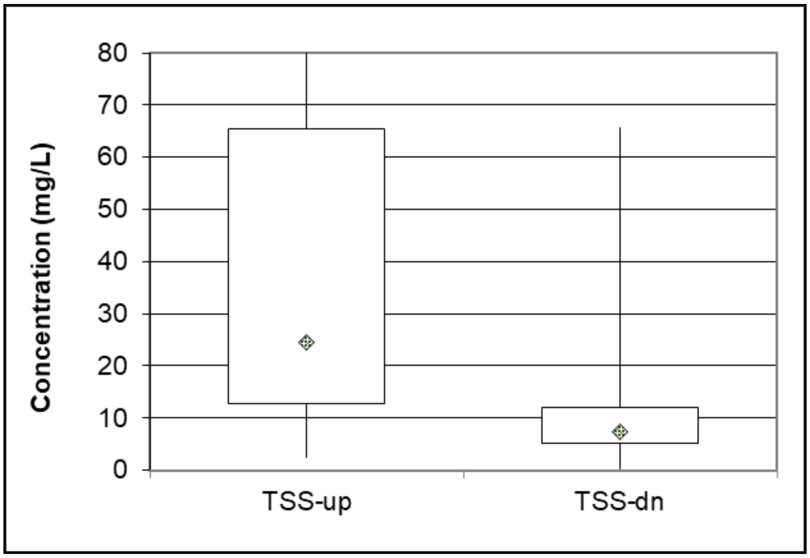

Figure 19. Boxplots of TSS in water samples.

Table 5. Effluent mean concentrations (EMCs) per NC Stormwater Design Manual.

Stormwater Control Measure (SCM)	TN (mg/L)	TP (mg/L)
Upper Durant Lake	1.41	0.09
Wet Detention Basin	1.22	0.15
Constructed Stormwater Wetland	1.12	0.18
Bioretention Cell	0.58	0.12

4.4.2 Nutrient Loading

To more accurately assess the effect of the Upper Durant Lake, constituent loads were computed from the concentration and discharge data as shown in Table 6. Rainfall for the monitoring periods (column 2) varied considerably resulting in differences between outflow and inflow as shown in column 3. This was because the drainage area to the DUR-dn monitoring station (at the spillway of the Upper Durant Lake) is about 70 acres greater than the drainage area to DUR-up, including more than 4 acres of open water. Other than the water surface itself, the area between the stations is mostly wooded, so the ground has to be saturated or the rainfall intense to produce significant runoff from this area. Hence, when there was little rainfall (<0.25 inches) such as for the periods starting on 2/22/18 and 4/26/18, there was minimal increase in flow from upstream (DUR-up) to downstream (DUR-dn).

The difference between TKN load into and out of the lake varied considerably for the monitoring periods with no discernable trend. Overall there was a net export of 171 lbs. of TKN from the lake indicating that the lake was not effective at reducing TKN in inflow. Further, a paired t-test on inflow and outflow loads showed no significant difference (α=0.05). Similarly, the difference between inflow and outflow NH_3-N load varied for each monitoring period and overall there was a net export of 262 lbs. of NH_3-N. Also, like TKN, a paired t-test showed that outflow was not significantly different from inflow. The definitive reason for the net export TKN and NH_3-N load from the lake was not known; however, since the differences in rates of inflow and outflow were not statistically significant, it cannot be concluded that the lake was not substantially exporting TKN and NH_3-N.

Inflow loads for NOx-N, TP and TSS were generally greater than the outflow loads for the monitoring periods with only a few minor exceptions. This resulted in 516, 170 and 80,782 lbs less NOx-N, TP and TSS loads in outflow compared to inflow. In addition, paired t-tests showed that outflow loads were significantly less than inflow loads. Thus, the data show that the lake was effective at reducing loads of NOx-N, TP and TSS. The reason for the reduction in NOx-N loads was likely denitrification, while the reduction in TP and TSS loads was likely the result of sediment settling out in the lake.

Table 6. Rainfall, discharge and loads for Upper Durant Lake.

Date	Rain (in)	Inflow-Outflow	Inflow-Outflow Loads				
		Discharge (Mgal)	TKN (lb)	NH_3-N (lb)	NOx-N (lb)	TP (lb)	TSS (lb)
2/22/2018 - 2/26/2018	0.03	-0.01	-7.3	-2.9	0.2	0.4	18
2/26/2018 - 3/6/2018	0.69	-0.08	-16.8	-2.2	6.0	4.0	399
3/6/2018 - 3/20/2018	2.44	-0.54	-44.3	-10.8	13.7	0.2	789
3/20/2018 - 4/5/2018	1.16	-0.36	133.2	1.3	1.3	7.9	11144
4/5/2018 - 4/11/2018	1.1	-0.06	13.9	-4.4	2.2	1.3	655
4/11/2018 - 4/26/2018	2.53	-0.34	-96.6	-22.9	10.4	1.1	2097
4/26/2018 - 5/14/2018	0.25	-0.02	-1.8	-10.8	6.0	-1.8	-134
5/14/2018 - 5/24/2018	1.84	-0.52	11.0	-7.1	9.7	2.4	2070
5/24/2018 - 6/7/2018	1.43	-0.61	-5.3	-7.3	11.9	2.6	1188
6/7/2018 - 6/21/2018	1.14	-0.36	13.9	-8.6	8.4	1.3	1900
6/21/2018 - 7/26/2018	5.76	-2.34	74.7	-51.6	25.6	6.6	7652
7/26/2018 - 8/9/2018	2.94	-4.47	13.9	-61.5	15.0	26.2	4665
8/9/2018 - 8/23/2018	4.03	-6.92	-43.4	-45.2	10.1	22.3	7736
8/23/2018 - 9/4/2018	0.69	-0.99	-16.8	4.0	6.0	0.7	1640
9/4/2018 - 9/18/2018	5.7	-7.16	4.9	-87.3	82.0	32.8	4899
9/18/2018 - 10/10/2018	0.16	-0.96	-6.4	-2.6	-0.2	0.2	626
10/10/2018 - 10/23/2018	0.09	-0.01	-4.2	-0.9	4.6	0.9	104
10/23/2018 - 11/9/2018	2.18	-3.52	-8.8	-35.1	35.5	10.4	5562
11/9/2018 - 11/29/2018	2.22	-0.26	19.2	-5.1	19.0	19.0	761
11/29/2018 - 12/13/2018	5.52	-9.09	-13.0	179.5	153.9	7.1	16204
12/13/2018 - 1/2/2019	1.12	-0.78	-43.7	-11.7	11.7	3.1	1858
1/2/2019 - 1/17/2019	1.04	-1.68	29.8	-16.5	-0.4	-1.1	3715
1/17/2019 - 2/4/2019	1.41	-0.19	-22.3	-13.4	17.4	3.3	996
2/4/2019 - 2/18/2019	1.12	-0.12	-77.2	-14.3	18.5	0.0	187
2/18/2019 - 3/4/2019	1.17	-1.57	-29.1	-15.7	13.7	-1.3	1038
Total	**51.8**	**-44.1**	**-157**	**-262**	**516**	**170**	**80782**

In order to assess whether lake retrofits would affect water quality of downstream waters, it is helpful to compare current pollutant export to other areas in the Neuse River Basin or neighboring basins. The discharges and pollutant loads for the monitoring periods in Table 6 were summed and divided by the drainage area and duration to obtain export rates as shown in Table 7. Export rates for TKN, NOx-N, TP and TSS were less for DUR-dn compared to DUR-up because the 70.4 acres between the stations (mostly wooded) contributed disproportionately less of these constituents' load compared to the drainage area to DUR-up. Export for NH_3-N was greater for DUR-dn compared to DUR-up because the area between contributed disproportionately greater NH_3-N, possibly due to waterfowl waste and atmospheric deposition, than the area to DUR-up. The TN and TP export rates at DUR-dn were greater than the target rates for TN (2.2 lb/ac/yr) and TP (0.33 lb/ac/yr) for the Falls Lake watershed. However, export rates for nitrogen species, phosphorus and suspended sediment were less than those from a new residential area in the Upper Neuse River Basin as reported by Line et al. (2002) and shown in Table 7. Export rates for TKN, NOx-N, TN, TP and TSS from DUR-dn were even less than those for the wooded area reported by Line et al. (2002); however, nitrogen and phosphorus export rates were greater than those from a new low impact development (LID) residential area in central NC (Line and White, 2016). The TSS export from DUR-dn was much less than the wooded or new LID areas mostly because of the effectiveness of the pond at reducing TSS loads. Thus, the pollutant export rates for the existing watershed with the Upper Lake are not particularly high, but are not as low as the Falls Lake targets for TN and TP or an LID residential development.

Table 7. Annual rainfall, discharge and export rates.

Station	Monitoring Period (months)	Rain (in/yr)	Discharge (in/yr)	Export Rate (lb/ac/yr)					
				TKN	NH_3-N	NOx-N	TN	TP	TSS
Dur-up	13	51.9	19	5.6	1.3	2.4	8.0	0.91	211
Dur-dn	13	51.9	19.9	5.3	1.6	1.3	6.7	0.54	59.4
New residential[1]	15	37.7	21.5	23.2	2.7	3.6	26.8	2.6	434
Wooded[1]	15	45.9	14.7	8.7	0.34	4.0	12.8	1.1	1105
New LID[2]	42	33.9	8.1	3.1	0.53	0.93	4.0	0.41	179

[1] Export rates for residential areas in the Upper Neuse River Basin from Line et al. (2002).
[2] From Line and White (2016) for a NC residential LID development.

4.4.3 Temperature

Average weekly temperature observations and weekly rainfall are shown in Table 8. There was a range of rainfall and inflow for the weeks with no significant correlation between the rainfall or discharge and the difference between inflow and outflow temperatures. There was a 1.7 to 12.4 degree F increase in temperature from the inflow of the lake (DUR-up) to the outflow (DUR-dn) during each week from March to November, but for the other months, the difference was much less. Figure 20 shows that when the weekly air temperature drops below the water temperature, the increase in water temperature from DUR-up to DUR-dn becomes small or negative. In fact, there was a relatively good correlation (Figure 21) between the air temperature and the difference in water temperature between DUR-dn and DUR-up. This was expected given the relatively high surface area to depth ratio of the lake. The lake's surface provides an air-to-water interface favorable for heat transfer relative to the total volume of water in the lake. Outlet water temperatures above 77 degrees F are of concern due to potential negative impacts to downstream aquatic organisms (LEI, 2011). Further, peak temperatures in summer approach the state standard of 89.6 degrees F for Class B waters (NCAC, 2019).

Table 8. Rainfall, inflow and temperatures for the Upper Durant Lake.

Week*	Rainfall (in)	Inflow (Mgal)	Air Temp. (ºF)	Dur-up Temp. (ºF)	Dur-dn Temp. (ºF)	Difference Temp. (ºF)
3/6/18	1.30	6.45	41.4	46.3	50.4	4.1
3/13/18	1.16	2.86	49.7	49.9	51.6	1.7
3/20/18	1.33	12.93	42.0	47.8	52.1	4.3
3/27/18	0.03	1.97	61.4	55.9	60.2	4.3
4/3/18	1.10	4.99	51.6	55.0	60.8	5.9
4/10/18	1.61	10.65	59.7	58.7	64.2	5.6
4/17/18	0.67	5.14	58.5	57.4	65.1	7.7
4/24/18	0.39	5.15	61.9	59.8	67.1	7.3
5/1/18	0.00	1.37	69.2	65.1	75.2	10.0
5/8/18	0.12	1.19	75.5	68.6	80.4	11.8
5/15/18	1.32	4.76	73.8	71.1	79.4	8.3
5/22/18	1.58	4.44	75.3	71.8	80.9	9.1
5/29/18	0.24	2.49	76.1	72.2	82.6	10.5
6/5/18	0.98	2.18	74.9	71.5	83.9	12.4
6/12/18	0.00	0.69	80.5	73.3	85.2	11.8
6/19/18	0.31	0.94	80.9	76.9	89.1	12.2
6/26/18	0.43	0.97	82.5	75.6	87.1	11.5
7/3/18	2.39	5.27	76.5	75.0	86.0	11.0
7/10/18	0.79	1.78	79.4	74.0	85.0	11.0
7/17/18	1.25	1.96	76.8	74.0	84.6	10.7
7/24/18	1.85	4.04	77.6	75.3	84.9	9.5
7/31/18	1.58	8.50	78.1	76.0	83.7	7.7
8/7/18	2.34	7.50	77.8	76.5	86.2	9.7
8/14/18	1.87	4.27	78.7	75.3	85.0	9.6
8/21/18	0.24	2.15	75.4	72.2	82.7	10.5
8/28/18	0.69	1.49	80.0	75.9	86.7	10.8
9/4/18	0.36	0.77	78.3	75.2	85.6	10.4
9/11/18	5.34	27.25	77.1	75.0	80.0	5.0
9/18/18	0.00	1.25	74.5	72.6	80.4	7.7
9/25/18	0.16	1.20	72.8	70.9	79.0	8.1
10/2/18	0.01	1.16	75.5	71.4	80.2	8.8
10/9/18	2.11	16.76	67.2	67.7	74.8	7.1
10/16/18	0.15	7.15	58.2	59.9	68.3	8.4
10/23/18	1.27	9.82	51.3	54.0	59.6	5.6
10/30/18	0.95	5.21	58.2	57.4	61.0	3.5
11/6/18	3.65	12.16	53.0	55.7	59.7	4.0
11/13/18	0.80	26.59	46.4	51.9	51.7	-0.3
11/20/18	1.07	7.96	44.2	49.6	50.3	0.7
11/27/18	0.00	5.44	49.8	50.5	50.9	0.4
12/4/18	0.83	12.47	39.2	45.5	46.6	1.1
12/11/18	1.33	15.55	45.1	47.6	45.6	-2.0
12/18/18	0.65	8.00	47.9	49.9	49.7	-0.2
12/25/18	0.84	10.98	49.9	50.6	50.6	0.0
1/1/19	0.62	9.79	53.1	53.5	53.9	0.4
1/8/19	0.79	9.47	39.6	48.9	50.4	1.6
1/15/19	0.50	6.78	40.3	44.3	45.1	0.7
1/22/19	0.47	6.44	41.6	43.2	45.8	2.6
1/29/19	0.15	2.97	42.5	42.5	44.9	2.5
2/5/19	0.16	2.48	53.2	50.9	54.1	3.2
2/12/19	1.01	5.74	47.9	48.4	50.0	1.6

Week*	Rainfall (in)	Inflow (Mgal)	Air Temp. (ºF)	Dur-up Temp. (ºF)	Dur-dn Temp. (ºF)	Difference Temp. (ºF)
2/19/19	2.33	23.19	44.5	47.4	47.9	0.5
2/26/19	1.75	20.03	46.6	49.5	50.6	1.1
3/5/19	0.10	5.29	45.0	48.3	49.4	1.1
3/12/19	0.12	3.58	53.3	52.4	57.9	5.5
3/19/19	0.99	5.32	50.3	50.7	55.6	4.9
Mean	**0.98**	**6.79**	**61.1**	**60.7**	**66.5**	**5.9**

*The date corresponds to the start of week the measurements were averaged over.

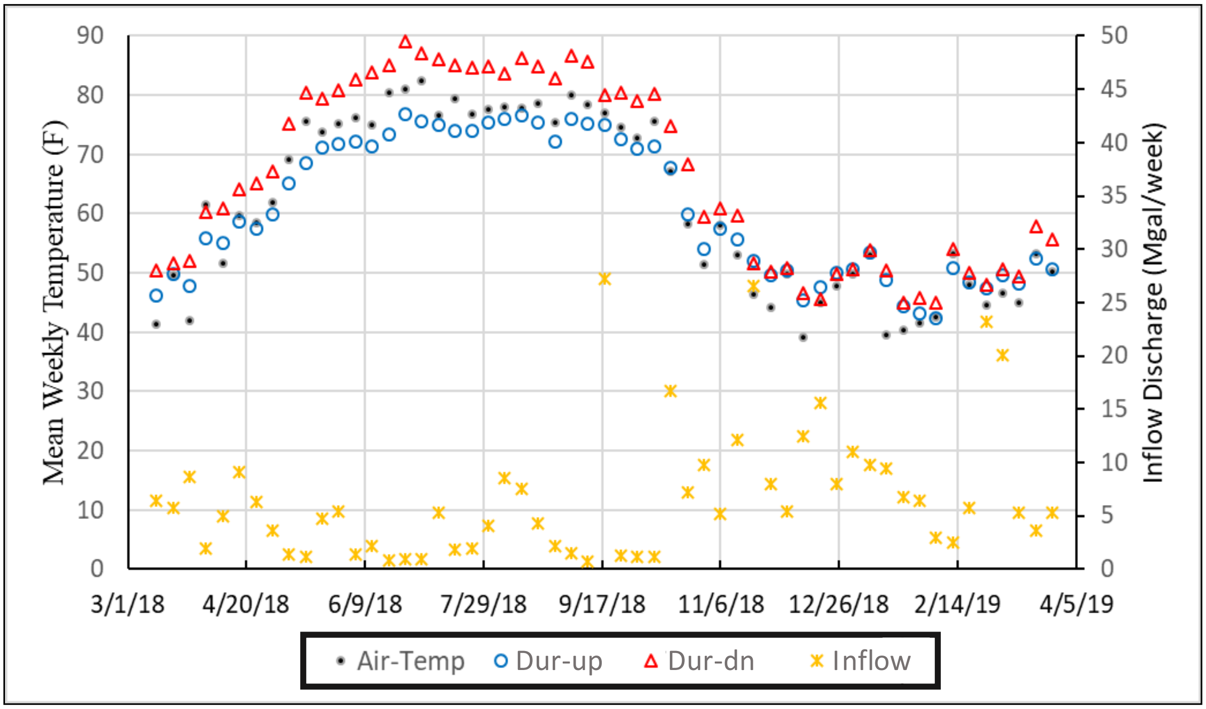

Figure 20. Mean weekly water and air temperature and discharge.

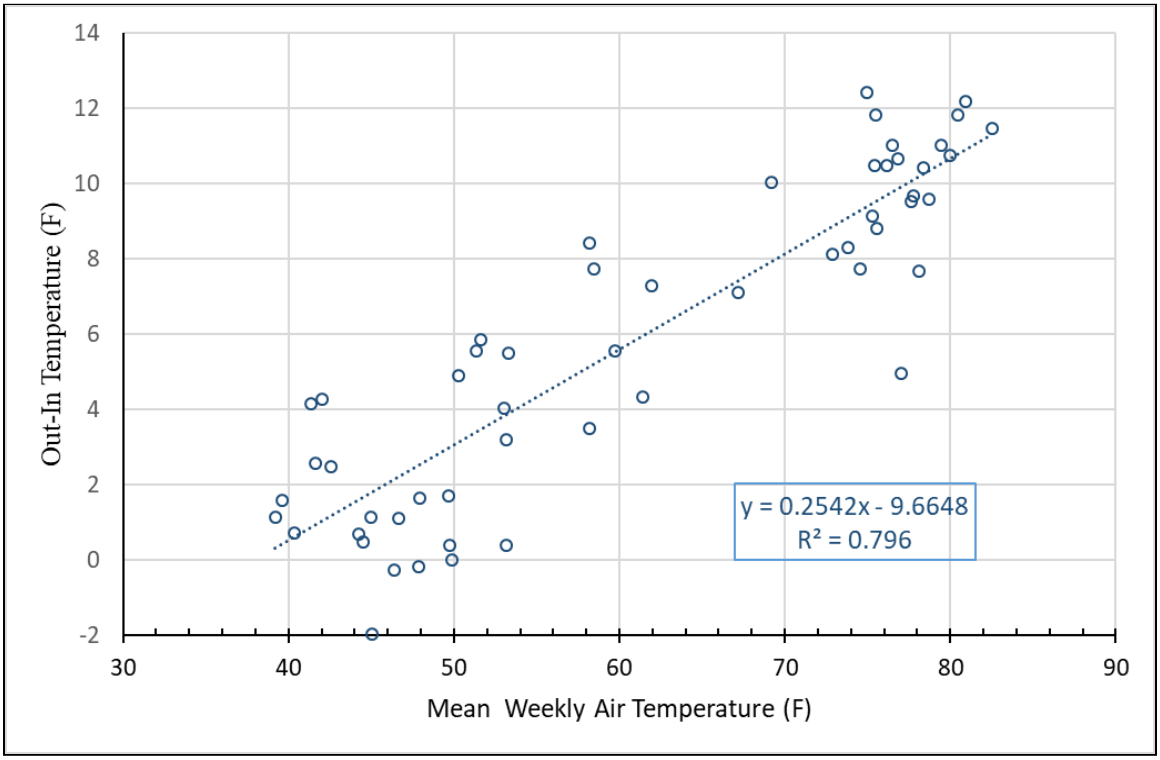

Figure 21. Difference in water temperature between DUR-dn and DUR-up versus air temperature.

4.4.4 Bacteria

Enterococci levels in grab samples collected by Wake County personnel are shown in Figure 22. About 10% (62 of 612 samples) of individual grab samples had enterococci levels greater than 70 mpn/100 ml, and 29 of 667 samples had E. coli levels greater than 235 mpn/100 ml. These are the criterion which are often used to determine if waterbodies are suitable for primary contact recreation. Further, 12 times from 2007 to 2018 five consecutive samples had a geometric mean concentration of Enterococci greater than 33 mpn/100ml, which was above a Wake County standard for primary contact recreation; however, nine of these times occurred in 2014. Thus, while there are some concerns with bacteria in the lake, bacteria concentrations neither appear to be increasing in the recent past, nor do they prohibit the lake's use for primary contact recreation over extended periods of time.

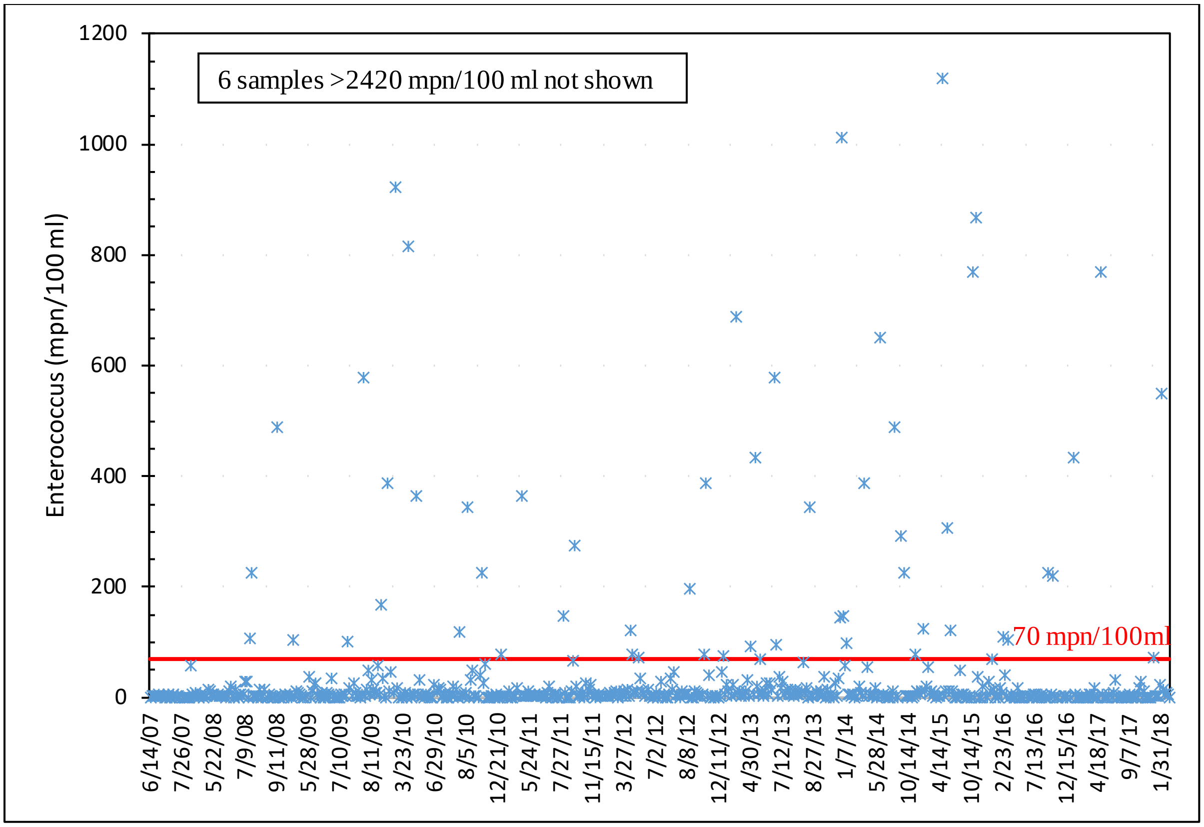

Figure 22. Enterococci concentrations in grab samples (62 of 612 samples >70 mpn/100ml).

4.5 Macroinvertebrate Sampling

A summary of the taxa collected from the two sites is included in Table 9. The April 2018 sampling showed very low taxa richness and EPT abundance values and very high biotic index values at both locations resulting in Poor bioclassifications. The upstream monitoring location was within a stable riparian zone with mature vegetation, but had an extremely sandy substrate and very little stable substrate. Sediment from upstream sources, including construction of the I-540 beltline and/or housing, are likely contributors. The extremely low abundance at this location suggests that sedimentation has impaired habitat and that the downstream reservoirs and the lack of tributary refugia have created a barrier to recolonization. Prior to the October 2018 investigation, stream flows in the Raleigh area were extremely high following hurricanes Florence and Michael, and scour of unstable sandy substrates was likely. However, taxa richness at the upstream location was higher in October 2018 (following extremely high flows) than the spring survey in April 2018. Many taxa were collected at this site in October 2018 and not in April 2018. EPT taxa include *Labiobaetis propinquus*, *Cheumatopsyche* spp. and *Chimarra* spp. This observation may be somewhat due to seasonality, but suggests that if sources of sediment are curtailed in the watershed, there may be refugia that could supply sources of insect recolonization. The increase in number of EPT taxa resulted in a slightly lower biotic index and a Fair bioclassification. Total taxa richness increased at the downstream monitoring location in April 2018, however, fauna was dominated by tolerant species.

In October 2018, many fewer total taxa and the dominance of *Glyptotendipes* spp. (a very tolerant Chironomidae) resulted in a Poor bioclassification at the downstream monitoring location. These data were collected following a drawdown of the Lower Lake and spillway maintenance. The stream at this location is extremely incised and the substrate is dominated by hard-packed clay and/or bedrock, so there was limited habitat available.

Table 9. Summary of benthic macroinvertebrate data.

Taxonomic Group	Upstream		Downstream	
	April, 2018	Oct, 2018	April, 2018	Oct, 2018
Ephemeroptera	1	2	0	0
Trichoptera	1	3	1	1
Diptera; Misc.	0	0	1	0
Diptera; Chironomidae	3	5	9	4
Odonata	2	2	2	0
Oligochaeta	2	2	0	0
Crustacea	0	0	2	1
Mollusca	0	1	1	1
Other taxa	0	0	1	2
--				
Total Taxa Richness	9	15	17	9
EPT Taxa Richness	2	5	1	1
EPT Abundance	4	27	1	3
Biotic Index	**7.16**	**6.06**	**8.09**	**7.09**
Bioclass using small stream criteria	**Poor**	**Fair**	**Poor**	**Poor**

4.6 Hydrologic Modeling

The calibrated HEC-HMS hydrologic model was run for several different design storm scenarios. The predicted storms flows were routed through the lake and the outflow was predicted using Hydraflow an extension of AutoCAD Civil3D. The predicted inflow, outflow and maximum water surface elevation (WSE) of the lake for various design storms are shown in Table 10.

The results of the hydraulic analysis of the current lake and spillway configuration indicated that the dam could overtop during the 100-yr storm event. The low point elevation for the top of the dam embankment is 271.0-ft, and the modeled maximum water surface of the lake during the 100-yr event was 270.9-ft (Table 10). Also, the dam could be overtopped during the 50-yr event (270.5-ft) if wave action resulting from wind is considered.

The existing lake also provides minimal flood control benefit. The peak outflow was only reduced by about 5% compared to the inflow across most of the storm events. This was due to the lack of storage capacity (normal pool was at the spillway crest elevation).

Table 10. Watershed model results for existing conditions.

Rainfall event	Rainfall (in)	Runoff Volume to the Upper Lake (ac-ft)	Peak Inflow to the Upper Lake (cfs)	Peak Outflow from the Upper Lake (cfs)	Max Water Surface Elevation (ft)
1“, 24-hr	1.00	19	40	34	267.2
1-yr, 24-hr	2.80	89	170	163	268.2
2-yr, 24-hr	3.60	132	252	237	268.7
5-yr, 24-hr	4.75	195	369	352	269.3
10-yr, 24-hr	5.60	244	470	444	269.7
25-yr, 24-hr	6.50	299	575	545	270.1
50-yr, 24-hr	7.20	343	660	625	270.5
100-yr, 24-hr	8.10	400	772	733	270.9

4.7 Lake Retrofit Alternatives

The development of each alternative for retrofitting the Upper Durant Lake is discussed below. Detailed plan sheets, cost estimates and calculations for each retrofit alternative are included in the appendices.

4.7.1 Lake As Is

4.7.1.1 Design Goals and Technical Approach

The Lake As Is retrofit alternative maintains the site as a lake. The goals of this retrofit alternative were to increase storage capacity and route the 100-yr design storm with adequate freeboard (2-ft). This retrofit alternative includes upgrading the spillway and outlet riser structure to improve the flood control function of the lake. Calculations indicate that, in addition to replacing the outlet structure, the spillway size must also be increased to route the 100-yr event with adequate freeboard. To increase the hydraulic capacity of the spillway without substantially increasing the spillway footprint, a labyrinth weir is assumed for the spillway entrance. This would allow for a 58-ft effective weir crest length, with only a 35-ft wide spillway (Figure 23). The addition of a proposed riser structure would allow for lowering the normal pool elevation (NPE) 1.5-ft. This would provide 7.5 ac-ft. of temporary storage (Table 11). Lowering the water level would require the removal of about 2000 cubic yards of sediment at the lake inlet to maintain the capacity of the lake with a lower water level. The Lake As Is retrofit alternative includes several key features:

- New spillway with labyrinth weir to route 100-yr storm with adequate freeboard,
- Energy dissipater at the end of the spillway to reduce downstream erosion,
- New concrete riser structure and 24-in RCP barrel to control NPE and provide the option to drain the lake for maintenance,
- Removal of sediment at the lake’s inlet,
- Removal of woody vegetation and trees on dam embankment, and
- Installation of grade control structures on tributaries to prevent stream erosion.

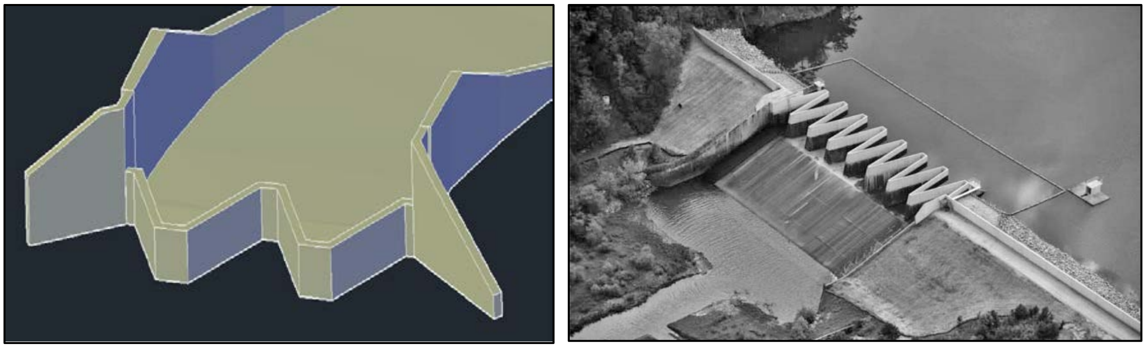

Figure 23. 3D rendering of spillway with labyrinth weir (left) and large-scale example of labyrinth weir and spillway from Crookston and Tullis (2013) (right).

Table 11. Existing and proposed lake parameters.

Parameter	Existing	Proposed
Spillway Width (ft)	28	35
Weir Crest Length (ft)	28	58
Normal Pool Elevation (ft)	266.65	265.00
Riser Structure Weir Invert (ft)	-	265.00
Spillway Crest Elevation (ft)	266.65	266.50
Temporary Storage (ac-ft)	0.0	7.5
Lake Volume at Normal Pool (ac-ft)	27.5	20.0

4.7.1.2 Hydraulic Analysis

The comparison between the existing and proposed hydraulic routing results for the lake is shown in Table 12. The longer weir crest provided by the labyrinth weir configuration results in lower WSE for all events and adequate freeboard during extreme events (2-ft). However, this modification also results in greater outflow at lower WSE and a slight increase in peak outflow compared to the existing conditions. Therefore, even with the lower NPE, the Lake As Is retrofit alternative would provide no additional flood control benefit (peak outflow increased compared to the existing conditions). This is due to the large storm volume and relatively small area of the lake (see Table 10). For example, the predicted volume of the 1-yr storm is 89 ac-ft. and the volume of the entire lake drained is only 27 ac-ft. In addition, the Lake As Is retrofit alternative could only retain about 40% of the 1-in storm. Therefore, based on the size of the watershed and the resulting storm volume, there is limited opportunity to provide any additional flood control benefit, regardless of the retrofit alternative implemented.

Table 12. Hydraulic routing results for Lake As Is retrofit alternative.

Event	Rainfall (in)	Peak Inflow to Lake (cfs)	Existing Peak Outflow from lake (cfs)	Proposed Peak Outflow from Lake (cfs)	Existing Max WSE (ft)	Proposed Max WSE (ft)
1-in	1.00	40	35	25	267.2	266.5
1-yr, 24 hr	2.80	176	163	170	268.2	267.3
2-yr, 24 hr	3.60	252	237	247	268.7	267.6
5-yr, 24 hr	4.75	373	352	368	269.3	268.0
10-yr, 24 hr	5.60	469	444	461	269.7	268.3
25-yr, 24 hr	6.50	575	545	566	270.1	268.6
50-yr, 24 hr	7.20	660	625	651	270.5	268.8
100-yr, 24 hr	8.10	772	733	761	270.9	269.0

Note: The low point on the top of the existing dam is 271.0-ft.
WSE: Water surface elevation.

4.7.1.3 Water Quality and Other Impacts

The proposed Lake As Is retrofit alternative would likely continue to provide the same moderate water quality benefits as the existing lake configuration, serving as a sink for nitrate-N, TP and TSS. There is potential for marginal improvement in nutrient removal due to longer retention time for small storm events, although this is uncertain given the already low influent nutrient levels. This retrofit alternative would not add significant educational or recreational values at the park, given these benefits are already provided by the Lower Durant Lake.

4.7.2 Stormwater Wetland

4.7.2.1 Design Goals and Technical Approach

The goals of this retrofit alternative are to convert the lake to a wetland to increase water quality function, ecosystem diversity and educational potential, and to route the 100-yr storm event. Because of the relatively steep slope of the existing lake bed (1.5%), a wetland could not be easily implemented by simply lowering the water level of the lake to create shallow, inundated conditions. Instead a "terraced" wetland cell approach is assumed. This design allows the cells to follow the slope of the existing lake bed and limit excess excavation or fill. The wetland cells would be separated by berms tied into either side of the valley. Concrete labyrinth weirs in the berms would control WSE in the cells, allowing the water surface to drop 2-ft over each weir. Temporary ponding would be controlled by adjustable inset weirs or orifices in the larger concrete overflow weir (see Figure 24).

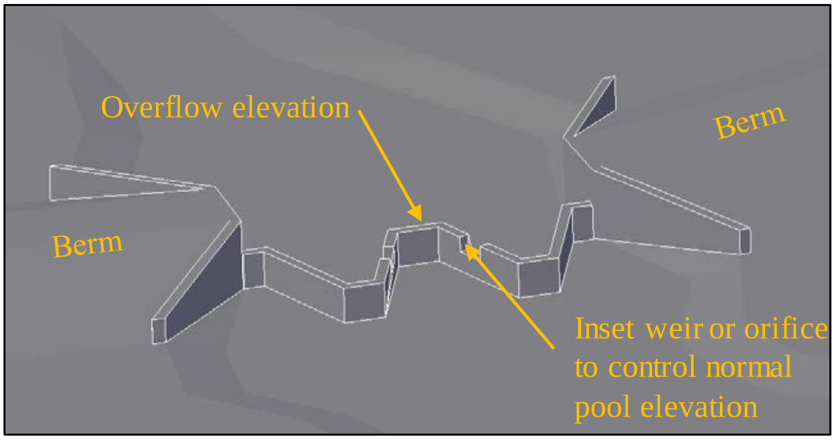

Figure 24. 3D rendering of concrete weir for water surface elevation control in wetland cell berms (top) and labyrinth weir at the Jack Smith Creek Stormwater Wetland in New Bern, NC (bottom) (photo from estormwater.com) .

This retrofit alternative also requires the removal of the existing spillway and the construction of a lower elevation, higher capacity structure. Overall, the water surface would drop 6-ft from an energy dissipation/sediment capture pool at the inlet to the outlet spillway weir across three wetland cells. The new spillway would then make up the additional 10-ft of drop to the Lower Durant Lake NPE. To reduce downstream erosion, an energy dissipation structure was proposed at the end of the spillway

The top of dam elevation would be lowered several feet and the excavated soil used for the construction of the wetland berms (Figures 25 and 26 and Table 13). The cut (amount of material excavated from high areas) and fill (amount of material added to low areas) were close to balanced for this retrofit alternative, with the removal of approximately 2,000 cubic yards of sediment required. However, this assumes the lake sediment could be used as fill for the wetland cells. Further geotechnical investigation during the design process may determine the need for additional imported fill or removal of sediment. If the sediment cannot be reused onsite, this would necessitate the removal of approximately 11,000 cubic yards of sediment and the import of about 9,000 cubic yards of suitable soil.

Similar to more conventional stormwater wetlands, the wetland cells for this design would incorporate areas of shallow water, deep pools and temporary inundations zones to allow a diversity of vegetation, promote biogeochemical processes to improve water quality by creating anaerobic and aerobic soil zones and provide habitat diversity (see Figure 26). The cells were sized for 6-in of water in the shallow water areas and up to 3 to 4-ft or more in the deep pools. The weirs are sized to create a temporary ponding depth of 18-in in each wetland cell. This retrofit alternative would create about 3.5 acres of wetland.

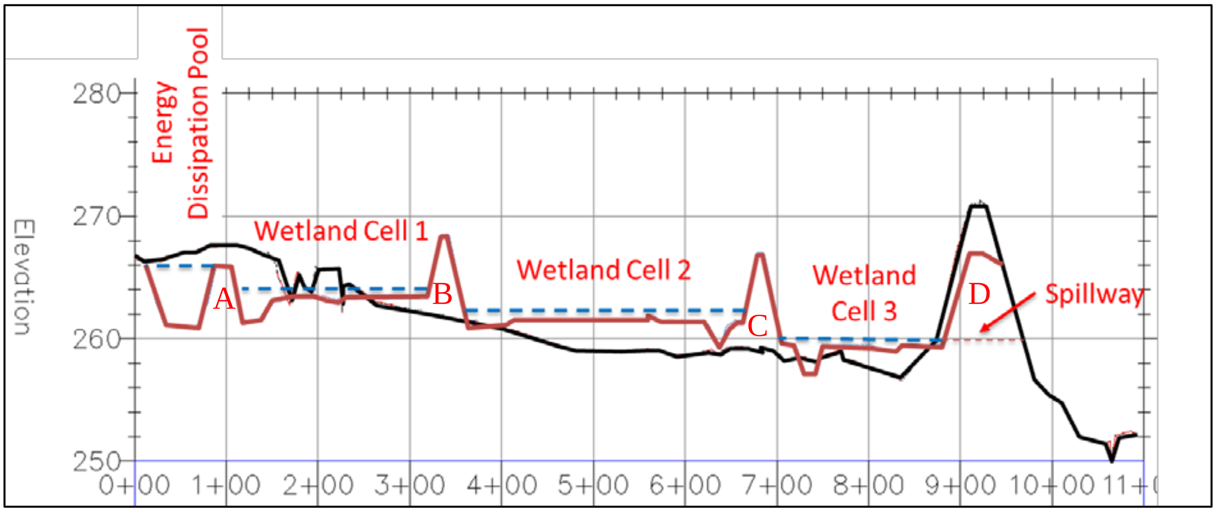

Figure 25. Proposed profile view of the Stormwater Wetland retrofit alternative. The black line represents the existing ground elevation and the red line is the proposed profile.

Table 13. Proposed berm and weir elevations for the Stormwater Wetland concept design.

Berm	Top of Berm (ft)	Overflow Weir (ft)	Normal Pool Control Weir or Orifice (ft)
A	267.0	267.0	266.0
B	268.5	265.5	264.0
C	267.0	263.5	262.0
D	267.0	261.5	260.0

Figure 26. Plan view schematic of proposed topography features for the Stormwater Wetland retrofit alternative. See Appendix A for more details.

4.7.2.2 Hydraulic Analysis

The spillway is designed for 2-ft of freeboard at the dam during the 100-yr event. The berms separating the wetland cells are sized for much less freeboard and could potentially overtop during extreme events. However, this would not be critical given the downstream dam and spillway. This retrofit alternative would provide no flood control benefit relative to existing conditions (Table 14).

Table 14. Routing results for the Stormwater Wetland retrofit alternative.

Event	Rainfall (in)	Peak Inflow to Wetland (cfs)	Peak Outflow from Wetland (cfs)	Max WSE Cell 1 (ft)	Max WSE Cell 2 (ft)	Max WSE Cell 3 (ft)
1-in, 24-hr	1.00	40	34	265.9	263.9	262.0
1-yr, 24-hr	2.80	176	*	266.5	264.5	262.8
2-yr, 24-hr	3.60	252	*	266.8	264.8	263.1
5-yr, 24-hr	4.75	373	*	267.2	265.1	263.6
10-yr, 24-hr	5.60	469	*	267.4	265.4	264.0
25-yr, 24-hr	6.50	575	*	267.9	265.7	264.3
50-yr, 24-hr	7.20	660	*	268.0	266.0	264.6
100-yr, 24-hr	8.10	772	*	268.3	266.4	264.9

*Negligible change relative to the peak inflow.
WSE: Water surface elevation

4.7.2.3 Water Quality and Other Impacts

The Stormwater Wetland retrofit alternative would likely provide water quality improvement due to the introduction of wetland features (e.g. aerobic and anaerobic soil zones, deep and shallow water zones and increased vegetation), which would enhance biogeochemical treatment processes and plant uptake. However, the relative performance compared to the existing lake may not be substantial due to low influent nutrient concentrations. Wetlands reduce nutrient concentration through a number of biological and physical processes, but the primary process wetlands perform is the removal of nitrate through denitrification, or the biological transformation of dissolved nitrate to nitrogen gas. However, the measured median influent concentration to the lake are 0.4 mg/L and the effluent is just above 0.2 mg/L. The wetland could potentially reduce the median outflow nitrate concentration to less than 0.1 mg/L. The reduction in TSS and TP would likely be similar to the performance of the lake as a result of sedimentation. There is also potential to reduce ammonium levels though plant uptake and possible coupled nitrification-denitrification. However, given the fairly low concentrations in the influent, the relative improvement in downstream water quality may be limited.

The Stormwater Wetland alterative would provide opportunities for the public to learn about wetland ecosystems and stormwater management. The design includes a proposed boardwalk/overlook for the public to observe the various landscape features and wildlife and signage could be incorporated to enhance educational potential.

4.7.3 Habitat Wetland

4.7.3.1 Design Goals and Technical Approach

The goals of this retrofit alternative are to convert the lake to a wetland to provide habitat function, ecosystem diversity, educational values, water quality benefit and route the 100-yr storm event. A design approach similar to the Stormwater Wetland retrofit alterative was used for this design. This retrofit alternative includes an energy dissipation pool at the inlet and terraced cells to transition from the influent stream to the outlet spillway elevation. This design integrates 4-ft of elevation drop from the influent stream to the outlet spillway and then 12-ft of elevation drop from the new spillway crest to the elevation of the Lower Lake (Figure 27 and

Table 15). An energy dissipation structure at the spillway outlet is also included. Additional habitat features would be created by including a more contiguous wetland area separated into two cells rather than three, combined with a lower temporary ponding depth during small storm events (6-in vs. 18-in). Varied topographic features including deep pools, shallow water and temporary ponding areas are included to provide habitat potential and enhance water quality benefits (Figure 28). This retrofit alternative also would result in minimal excess excavated material, assuming the accumulated sediment in the lake could be reused on-site for fill in the wetland cells. If the sediment cannot be reused onsite, this would require the removal of approximately 11,000 cubic yards of sediment and the import of about 10,000 cubic yards of suitable soil. This retrofit alternative would result in the creation of 4 acres of wetland.

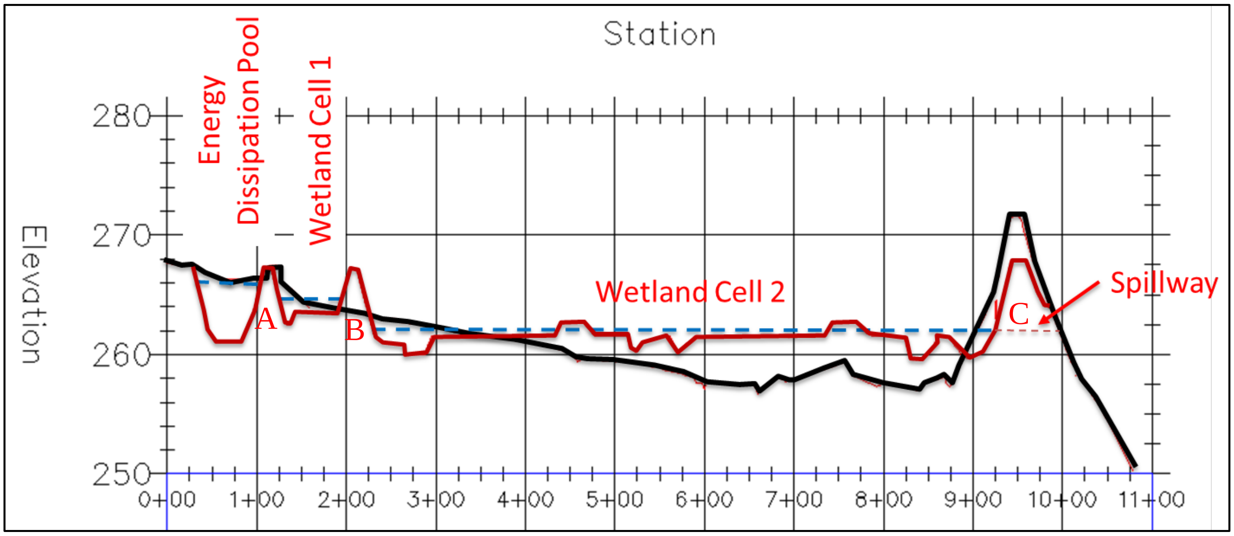

Figure 27. Proposed profile view of the Habitat Wetland retrofit alternative. The black line represents the existing ground elevation and the red line is the proposed profile.

Table 15. Proposed berm and weir elevations for the Habitat Wetland concept design.

Berm	Top of Berm (ft)	Overflow Weir (ft)	Normal Pool Control Weir or Orifice (ft)
A	267.0	267.0	266.0
B	267.0	264.5	264.0
C	267.0	262.5	262.0

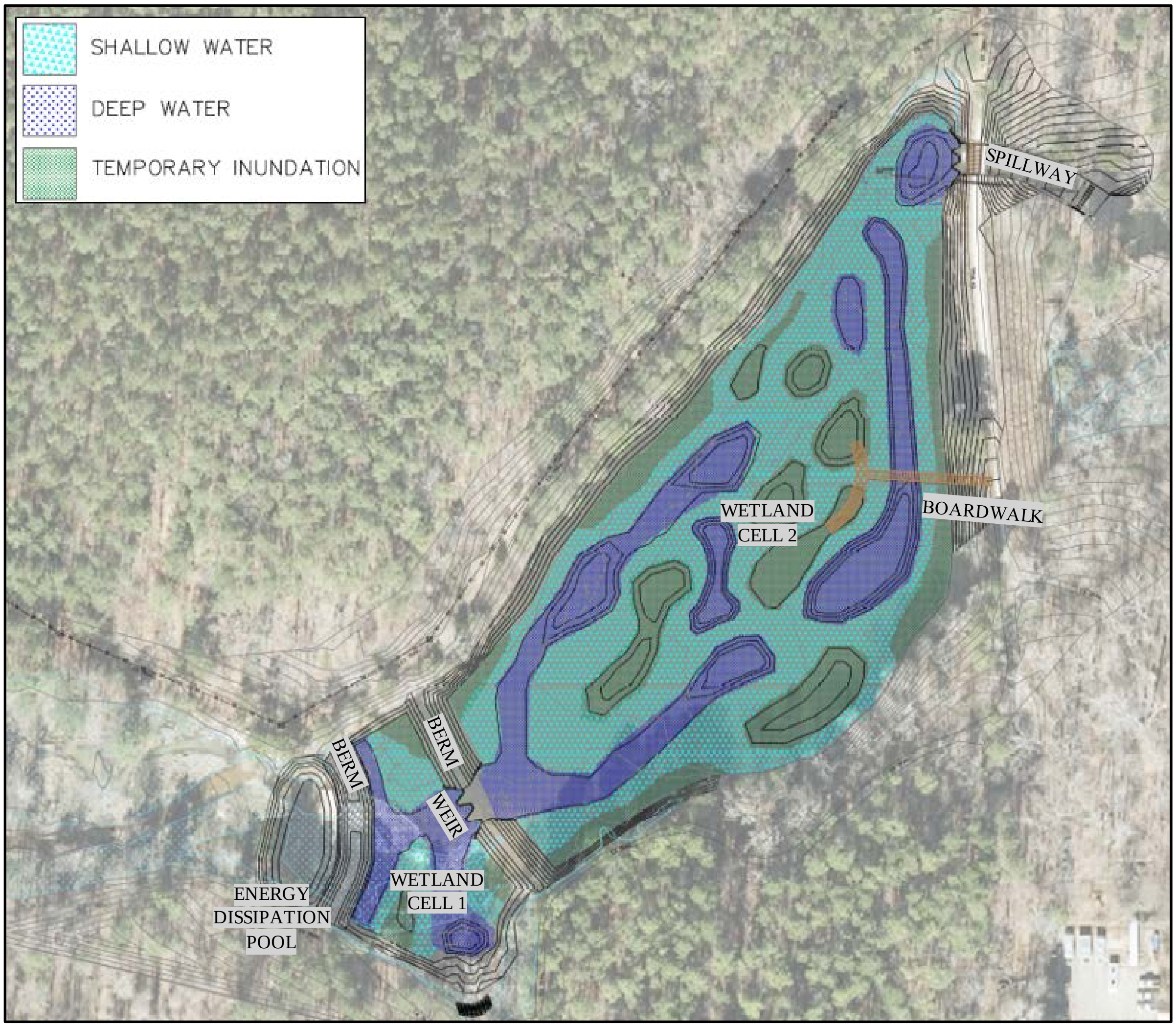

Figure 28. Plan view schematic of proposed topography features for the Habitat Wetland retrofit alternative. See Appendix A for more detailed plan.

4.7.3.2 Hydraulic Analysis and Water Quality Impacts

The Habitat Wetland retrofit alternative would provide no additional flood control benefit beyond that of the existing lake (Table 16). Also, due to the lower ponding level than the Stormwater Wetland retrofit alternative (thus lower retention time) the water quality treatment potential, specifically for biological treatment processes, would likely be slightly lower during small storms. However, treatment potential would be similar for baseflow conditions. Additional water quality benefits would primarily result from the removal of nitrate and ammonium, but again would be limited by low the influent concentrations.

Table 16. Routing results for the Habitat Wetland retrofit alternative.

Event	Rainfall (in)	Peak Inflow to Wetland (cfs)	Peak Outflow from Wetland (cfs)	Max WSE** Cell 1 (ft)	Max WSE** Cell 2 (ft)
1-in	1.00	40.2	*	264.4	263.0
1-yr, 24-hr	2.80	176	*	265.0	263.8
2-yr, 24-hr	3.60	252	*	265.2	264.1
5-yr, 24-hr	4.75	373	*	265.7	264.6
10-yr, 24-hr	5.60	469	*	266.0	264.9
25-yr, 24-hr	6.50	575	*	266.4	265.3
50-yr, 24-hr	7.20	660	*	266.7	265.6
100-yr, 24-hr	8.10	772	*	267.0	265.9

*Negligible change relative to peak inflow.
WSE: Water surface elevation

4.7.4 Stream Restoration

4.7.4.1 Design Goals and Technical Approach

The goals of the Stream Restoration retrofit alternative are to remove the dam and restore a stream channel and floodplain system in the lake bed to increase ecosystem diversity and enhance habitat function. This retrofit alternative is the most earthwork intensive retrofit alternative as it required the removal of the dam and the accumulated sediment on the lake bottom to construct the stream channel in the more stable, in-situ lake bed soil. The excavated soil would need to be hauled offsite for disposal. The earthwork volume could be reduced if only partial removal of the dam were considered. The design also includes floodplain wetlands for increased habitat function. It is assumed that the small tributary entering the site from the south would be routed through the floodplain wetland before entering the main channel (Figure 29). To maintain the trail system, a boardwalk and walking bridge could be included to replace of the existing trail that traverses the top of the dam.

A conservative approach was used in the sizing of the stream channel with a relatively low sinuosity of 1.15 and high radius of curvature to bankfull width ratio (R_c/W_{bkf}) to minimize shear stress at meander bends. A high entrenchment ratio (6-10) was used for the concept design to ensure adequate floodplain conveyance during extreme events. The proposed stream slope (1.5%) matches the existing lake bed when possible to avoid adding to the volume of soil removed from the site (Figure 30). However, the 1.5% slope produces a fairly high shear stress (1.1 lb/ft^2), which creates a higher risk for streambed erosion and associated instability of the in-stream boulder grade control structures, if not constructed properly. The design targets used are summarized in Table 18. Overall, 1250-ft of channel, 4 acres of floodplain and 0.5 acres of floodplain wetlands are included in this alterative.

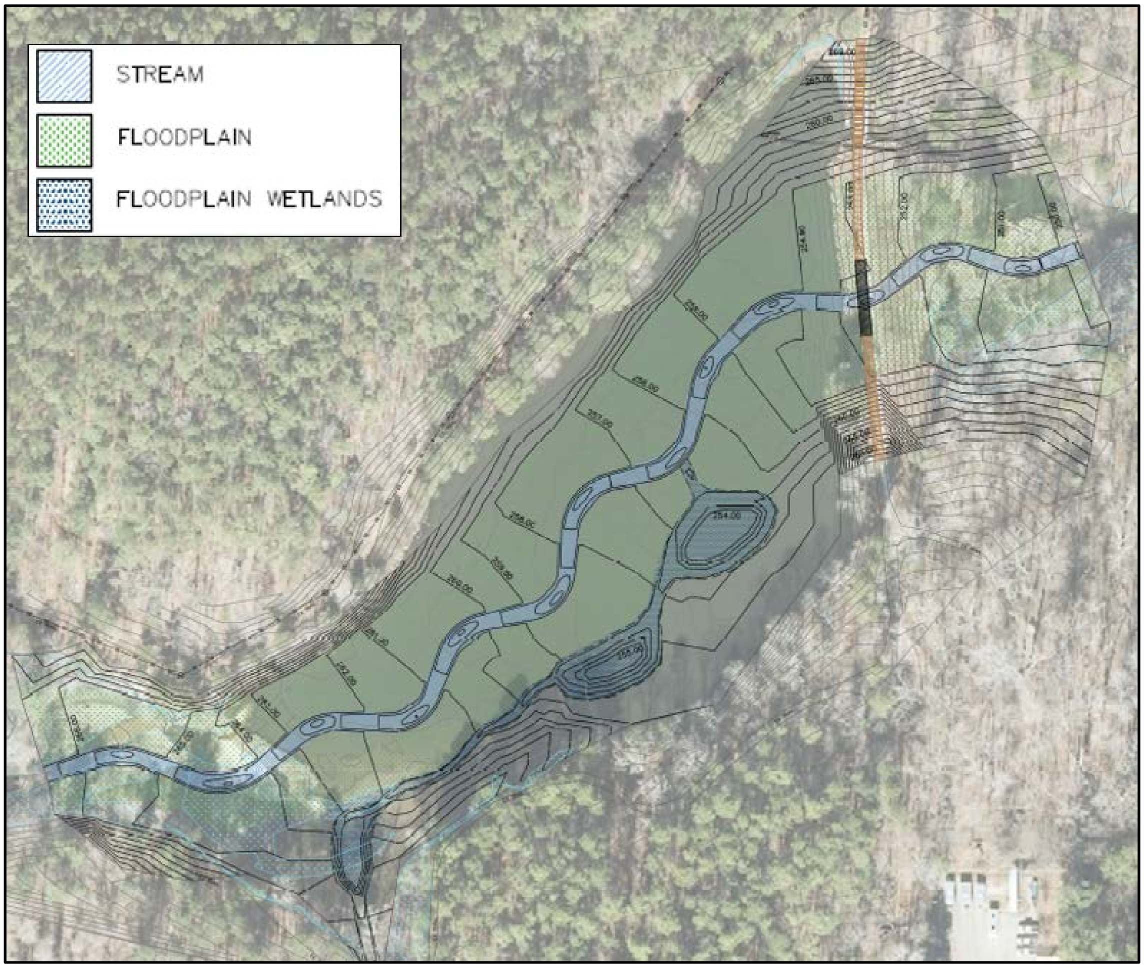

Figure 29. Plan view schematic of proposed topography features for the Stream Restoration retrofit alternative. See Appendix A for more details.

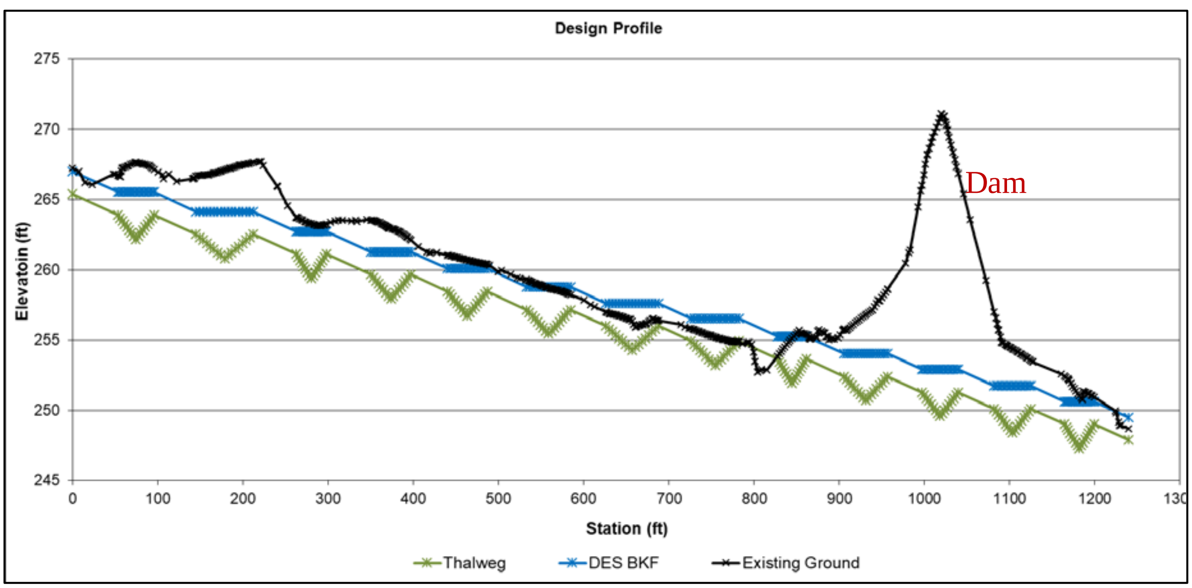

Figure 30. Stream Restoration retrofit alternative design profile.

Table 17. Parameters used for Stream Restoration retrofit alternative.

Parameter	Value
Stream type (Rosgen)	C
Drainage area, DA (sq mi)	1.14
Stream length, SL (ft)	1250
Water surface slope, S (ft/ft)	0.015
Sinuosity, K = (ft/ft)	1.15
Entrenchment ratio, ER [W_{fpa}/W_{bkf}]	6-10
Mannings bankfull discharge, Q_{bkf} (cfs)	140
Bankfull Shear Stress, t (lb/ft$^{2)}$	1.1
Riffle cross-section area, A_{bkf} (sq ft)	25
Width-to-depth ratio, [W_{bkf}/d_{bkf}]	14
Mean riffle depth, d_{bkf} (ft)	1.3
Radius of curvature ratio [R_c/W_{bkf}]	2.5-4

4.7.4.2 Hydraulic Analysis and Water Quality Impacts

The design bankfull discharge of 140 cfs is less than the 1-yr discharge of about 170 cfs calculated using the U.S. Geological Survey's regional regression equations. Therefore, there should be overbank flow in the floodplain more than once per year and likely more frequently given the watershed characteristics, which indicates appropriate channel size and good channel-floodplain connection.

The Stream Restoration retrofit alternative presents the greatest risk to the Lower Durant Lake. Currently the Upper Durant Lake dissipates the energy of the upstream flow. If the lake was drained and the stream restored, there would be potential for the accumulated sediments to be mobilized and transported to the Lower Durant Lake. This is a serious concern given the coarse-grained nature of the sediment accumulated in the floodplain above the Upper Durant Lake.

The Stream Restoration retrofit alternative would likely result in decreased downstream water quality compared to the existing conditions, specifically for TP and TSS. Nitrate removal would likely also decrease. Streams can reduce nitrate though denitrification in the hyporheic zone, however this would likely be limited in this project given the construction on the low permeability lake bed. However, ammonium export may decrease as the stream would likely not be a source of ammonium to the extent that the lake is currently.

4.8 Cost Estimates

Cost estimates were developed for each of the four retrofit alternatives on a unit cost basis. Due to the uncertainty regarding geotechnical conditions at the site, a range of costs is presented for each of the retrofit alternatives. The low and high cost estimates are based on the assumptions described in Table 18.

Table 18. Basis for cost estimate ranges.

Retrofit Alternative	Low Estimate	High Estimate
Lake As Is	The dam embankment will not need to be replaced.	The dam embankment will need to be removed and reconstructed using imported soil.
Stormwater Wetland	The sediment in the lake can be reused as fill in the wetland cells.	The sediment in the lake cannot be reused for fill in the wetland cells. The sediment will be removed and soil will be imported.
Habitat Wetland	The sediment in the lake can be reused as fill in the wetland cells.	The sediment in the lake cannot be reused for fill in the wetland cells. The sediment will be removed and soil will be imported.
Stream Restoration	Partial breach of the dam for the stream and floodplain.	Complete removal of the dam.

The estimated unit costs were obtained from the City of Raleigh, previous NCSU BAE projects, the project costs for the Lower Durant Lake and other lake projects in Raleigh, and other public sources including the U.S Bureau of Reclamation and the Charlotte Regional Transportation Planning Organization. All the concept level cost estimates include 5% mobilization, 15% contingency and 20% engineering, surveying and permitting fees. The summary of the cost estimates is included in Table 19. Detailed cost estimates are included in Appendix B. The Lake As Is retrofit alternative is projected to potentially be the most costly of the retrofit alternatives ($2.0 million to $3.6 million). The high-end estimate cost is due to the substantial volume of soil that would need to be removed and imported if the dam requires replacement. The two wetland retrofit alternatives are similar in cost. The Stormwater Wetland retrofit alternative is estimated at between $2.3 million to $2.9 million, while the Habitat Wetland retrofit alternative is estimated to cost $2.1 million to $2.8 million. These estimates are largely driven by the reinforced concrete spillway and weir structures, the earthwork and planting costs. The low-end estimates for the wetlands are based on the assumption that the sediment accumulated in the lake could be used for fill in the wetland cells. If this is not possible, the cost will likely be closer to the high-end estimate. The Stream Restoration retrofit alternative cost will likely be comparable to that of the wetland alternatives at $2.3 million to $2.8 million. The high-end estimate is based on complete dam removal. To reduce the cost of the Stream Restoration retrofit alternative, partial dam removal could also be considered.

Table 19. Cost estimate summary for the retrofit alternatives.

Item	LAKE AS IS		STORMWATER WETLAND		HABITAT WETLAND		STREAM RESTORATION	
	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH
SITE WORK	$ 205,000	$ 205,000	$ 210,000	$ 210,000	$ 210,000	$ 210,000	$ 125,000	$ 125,000
DEMOLITION	$ 91,000	$ 91,000	$ 91,000	$ 91,000	$ 91,000	$ 91,000	$ 91,000	$ 91,000
EARTHWORK	$ 212,500	$ 962,500	$ 287,500	$ 467,500	$ 270,000	$ 466,000	$ 945,000	$ 1,214,500
REINFORCED CONCRETE STRUCTURES	$ 715,000	$ 715,000	$ 600,000	$ 600,000	$ 510,000	$ 510,000	$ -	$ -
BRIDGES AND TRAILS	$ 89,400	$ 89,400	$ 158,900	$ 158,900	$ 147,300	$ 147,300	$ 132,000	$ 171,000
STRUCTURES AND STONE	$ 20,350	$ 18,700	$ 47,300	$ 47,300	$ 41,800	$ 41,800	$ 138,300	$ 128,300
PLANTING AND SOIL PREP	$ 10,000	$ 10,000	$ 218,120	$ 218,120	$ 237,220	$ 237,220	$ 213,600	$ 213,600
SUBTOTAL (rounded)	**$ 1,431,000**	**$2,554,000**	**$ 1,638,000**	**$ 2,043,000**	**$ 1,532,000**	**$1,978,000**	**$ 1,670,000**	**$ 1,968,000**
Mobilization (5%)	$ 71,550	$ 127,700	$ 81,900	$ 102,150	$ 76,600	$ 98,900	$ 83,500	$ 98,400
Contingency (15%)	$ 214,650	$ 383,100	$ 245,700	$ 306,450	$ 229,800	$ 296,700	$ 250,500	$ 295,200
Engineering, Surveying, and Permitting Fees (20%)	$ 286,200	$ 510,800	$ 327,600	$ 408,600	$ 306,400	$ 395,600	$ 334,000	$ 393,600
TOTAL (rounded)	**$ 2,000,000**	**$3,580,000**	**$ 2,290,000**	**$ 2,860,000**	**$ 2,140,000**	**$2,770,000**	**$ 2,340,000**	**$ 2,760,000**

4.9 Multi-Criteria Decision Analysis

The MCDA results are shown in Table 20. The MCDA decision criteria variables were selected by the City. For each of the variables identified, relative performance ratings were assigned to each of the retrofit alternatives based on best professional judgement. The weighting factors for each of the decision criteria variables were developed based on the input from the City. Higher weighting factors represent more important variables. For example, the ‘Risk to Downstream Lake’ variable is assigned a high weighting factor because maintaining the long-term functioning of the Lower Lake is very important to the City. In contrast, the ‘Flood Control’ variable is assigned a low weighting factor because all of the retrofit alternatives provide minimal flood control benefits, and thus it is not a critical project outcome. Overall, the Habitat Wetland retrofit alternative is the most favorable retrofit alternative, followed by the Stormwater Wetland retrofit alternative and then the Stream Restoration retrofit alternative. The Lake As Is retrofit alternative is ranked lowest as it is potentially the costliest retrofit alternative and does not substantially enhance or add to the ecosystems services currently provided by the lake. This ranking should not be viewed as definitive, but rather as a tool to aid the decision making process.

Table 20. MCDA Summary.

MCDA Decision Criteria Variables	Water Quality	Flood Control	Habitat Enhancement	Educational/ Interpretive Opportunities	Risk to Downstream Lake	Project Implementation Time	Initial Capital Cost	Yearly Ongoing Cost		
	MCDA Rating (1-4)*									
Weighting Factor (1-4)	**3**	**1**	**3**	**3**	**4**	**1**	**3**	**2**	**MCDA Score*** **	**MCDA Rank********
Habitat Wetland	3	1	3	4	4	1	2	1	**56**	**1**
Stormwater Wetland	4	1	2	3	4	1	2	1	**53**	**2**
Stream Restoration	1	1	3	4	1	2	2	3	**43**	**3**
Lake As Is	2	1	1	1	4	3	1	2	**39**	**4**

*MCDA rating represent a relative rating of the retrofit alternatives. Ratings range from 1 (less favorable) to 4 (more favorable).
**Weighting factors represent the importance of the decision criteria variables to the City. Higher values represent more important variables.
***Represents weighted score for each retrofit alternative.
****MCDA rank represents the final ranking of the retrofit alternative based on the MCDA score (1 represents the most favorable and 4 the least favorable).

4.9.1.1 MCDA Variable Descriptions

Descriptions of the decision criteria variables (e.g., Water Quality, Flood Control, Habitat Enhancement) used in the MCDA process and the rationale behind the relative scores for each retrofit alternative are included below.

- **Water Quality:** Refers to the potential for the retrofit alternative to improve downstream water quality through biological and physical treatment processes.
  - The Stream Restoration retrofit alternative could potentially negatively impact downstream water quality relative to the existing conditions. This is a result of the potential mobilization and transport of sediment and bound TP to the downstream lake and the short retention time, which could limit biological treatment processes. The Lake As Is retrofit alternative would likely continue to provide the same water quality benefits as the existing lake by reducing sediment, TP and nitrate. There could be a slight improvement in treatment for small events (<1") as a result of increased retention time. The Habitat Wetland retrofit alternative would provide many of same water quality benefits as the lake by providing deep pools and an energy dissipation pool for sediment removal. However, nitrogen treatment during baseflow would likely increase due to more contact with the anaerobic soils and increased plant uptake. The Stormwater Wetland retrofit alternative would have these same benefits as the Habitat Wetland retrofit

alternative but additional temporary ponding would increase retention time for small events and likely result in greater nutrient removal. All four retrofit alternatives would have limited water quality benefit during storms in excess of one inch. It should be noted that the nutrient concentrations of the influent entering the Upper Lake are relatively low, so the potential to substantially improve downstream water quality is limited.

- **Flood Control:** Refers to the potential for the retrofit alternative to provide peak flow attenuation.
    - All four of the retrofit alternatives would result in negligible reduction in peak discharge. All the retrofit alternatives would increase peak outflow 2-5% compared to the existing conditions. The Stream Restoration retrofit alternative would have the least impact on peak flow mitigation. The Lake As Is retrofit alternative would only reduce peak flow by 1-3%. The wetland retrofit alternatives would have negligible peak flow attenuation. Overall, peak flow reduction is not a viable outcome for any of the retrofit alternatives, given the large storm runoff volumes and the relatively small storage capacity provided by of all the designs.
- **Habitat Enhancement:** Refers to the increase in habitat function for important species of flora and fauna.
    - The Lake As Is retrofit alternative would have limited habitat value beyond what already exists at the site. Depending on the target species, the stream restoration and Habitat Wetland retrofit alternative would offer substantial habitat improvement. The pools, shallow water and higher terrain provided by the Habitat Wetland retrofit alternative would result in substantial vegetation diversity and the different types of ecosystems could result in increased diversity of animal species. The new fauna attracted to the site would likely be different species of birds and amphibians. The Stream Restoration retrofit alternative could eventually provide additional forested floodplain habitat, wetland habitat and riffle and pool features. The Stormwater Wetland retrofit alternative habitat benefits might be slightly less than the other wetland retrofit alternative due to the non-contiguous nature of the wetland cells because of the additional berm and the greater water level fluctuations.
- **Educational/Interpretive Opportunities:** Refers to the potential for citizens to learn about and interact with different ecosystems created by the retrofit alternative.
    - The Lake As Is retrofit alternative would provide limited educational opportunities beyond what already exists on-site as the Lower Lake provides ample recreational resources for the public. The Stream Restoration retrofit alternative would provide educational opportunities on the importance of various stream habitats (i.e. riffles, pools, floodplain and wetland pools), the importance of floodplain connectivity and watershed processes. This retrofit alternative would

also provide for additional space for potential hiking trails in the floodplain. The wetland retrofit alternatives would provide the opportunity to engage citizens regarding different habitat features in wetlands, the water quality treatment potential and other important ecosystem services that wetlands provide.

- **Risk to Downstream Lake:** Refers to potential risk to the function of the downstream lake caused by sedimentation.
  - The Lake As Is retrofit alternative and the wetland retrofit alternatives pose minimal risk to the downstream lake as they all provide for sediment capture. The Stream Restoration retrofit alternative presents the greatest risk to the downstream lake due to the possible mobilization of sediment from the area above the Upper Lake and the potentially unstable lake bed.
- **Project Implementation Time:** Time required for design, permitting and construction process.
  - The permitting requirements for the four retrofit alternatives would be similar so the time required for project implementation would be controlled by design and construction. The two wetland retrofit alternatives would require the most design work including structural and geotechnical investigations and designs. The wetlands would also require significant earthwork and grading. The stream restoration construction process would not require any structural design or concrete work. The major task for the construction of the Stream Restoration retrofit alternative would be the large volume of earthwork required.
- **Initial Capital Cost:** Cost of design, permitting and construction.
  - See the cost estimate section. The relative rating of the retrofit alternatives was based on the high-end estimates as a conservative approach. The Lake As Is was the most costly of the retrofit alternative. This was the result of the possibility of having to remove and replace the dam. The costs of the other three retrofit alternatives were comparable.
- **Ongoing Yearly Cost:** Estimated yearly costs of maintaining the function of the retrofit alternative.
  - The wetland retrofit alternatives would likely require the highest yearly maintenance expenditures. This would include maintenance of the berms, potentially removing accumulated sediment, vegetation maintenance, maintenance of the boardwalks and repair and clearing of the concrete structures. The Lake As Is retrofit alternative maintenance requirements would include maintenance of vegetation on the dam embankment and maintenance of the concrete structures. These maintenance costs would increase over time as the project ages. There is some uncertainty associated with the maintenance for the stream restoration retrofit alternative. There could be some maintenance associated with boardwalks. However, once the vegetation is established there would be minimal routine maintenance required for the floodplain or wetlands.

- These yearly values are based on approximate estimates of routine maintenance activities (Table 21). Actual costs will depend on the level of maintenance the City commits to at the site. In addition, yearly costs will increase for major storms. It is strongly recommended that the City examine the maintenance costs for their existing stormwater and park facilities before making decisions regarding budget allocations for this project.

Table 21. Estimated yearly maintenance costs.

Retrofit Alternative	Days per year	Yearly Ongoing Cost ($/yr)**
Lake As Is	6	$8,000
Stormwater Wetland	12	$14,500
Habitat Wetland	12	$14,500
Stream Restoration*	2	$2,000

*This assumes minimal sediment mobilization or major storms during vegetation establishment.

**Assumptions for estimates of routine maintenance cost:

- Inspecting concrete structures, berm maintenance (mowing, removal of woody vegetation, repair of erosion) and other preventative maintenance.
- These costs are based on an assumed 3-man crew at a rate of $100/per hour, plus the cost of equipment (estimated at $200/day) and yearly average cost of materials for repairs (estimated as $1000).
- Sediment removal was estimated at 30 CY/year (based on the observed TSS removal in the lake) at a cost of $50/CY.
- Sediment removal or other maintenance in response to large storm events is not included in this cost.

4.10 Permitting Investigation

4.10.1 Dam Safety Regulations

The Upper Durant Lake dam (referred to as Camp Durant Lake Dam #1 in the State's dam inventory database) is governed by the Dam Safety Law of 1967 and is considered a low hazard level dam. Thus, a permit from NC DEQ Department of Energy, Mineral and Land Resources (DEMLR) would be required to modify, repair or remove the dam. The permit process requires a set of construction drawing, construction specifications and an engineer's design report. The permit costs include a $200 minimum fee plus an additional processing fee based on the cost of project construction.

However, the dam dimensions and storage capacity listed in NC DEQ DEMLR's database appears to be inaccurate based on the survey data (see Table 22). The storage capacity at normal pool is overestimated by a factor of ten and the maximum storage capacity is overestimated by a factor of five. The maximum discharge from the dam is well below the maximum spillway discharge at full capacity. A request for a new jurisdictional determination could be submitted to NC DEQ DEMLR based on the surveyed data. However, a dam breach analysis would likely need to be included. It is unclear if a new determination based on the survey data would change the jurisdictional status of the dam.

Table 22. Comparison of Upper Durant Lake dam parameters.

Parameter	NC DEQ DEMLR Database	Calculated from Survey Data
Normal Pool capacity (Ac-ft)	264	27
Max Impoundment Capacity (Ac-ft)	320	61
Max Discharge (cfs)*	95	770
Normal Freeboard (ft)	4.0	4.4
Structural Height (ft)	18	23
Hydraulic Height (ft)	14	14

*Assumed to refer to discharge at max impoundment capacity

4.10.2 Clean Water Act Regulations

All retrofit alternatives would require Clean Water Act Section 404 and Section 401 permits. The Section 404 permit from the USACE would be needed as the proposed retrofits would disturb the existing fringe wetlands and include regrading and placing fill in the jurisdictional lake. There would also be temporary impacts related to construction activities that would need to be authorized by a Section 404 permit.

In addition, a Section 401 permit would be required. Typically, if the USACE determines that a 404 Permit is required, then a 401 permit is also required. 401 permits are issued by the NC DEQ DWR. This permit ensures that Waters of the State are not degraded or State Water Quality Standards are not violated by the proposed project.

4.10.3 Neuse Buffer Rules

The streams and lakes in the nature preserve are subject to the Neuse River Riparian Buffer Rules (15A NCAC 02B .0233 (8)(b)), therefore a Buffer Authorization would be required. This permit is issued through the NC DEQ DWR.

4.10.4 Erosion and Sediment Control

Prior to construction, an erosion and sediment control permit will need to be obtained from NC DEQ DEMLR. This permit requires the submission and approval of an erosion and sediment control plan and a required permit fee.

4.10.5 Summary of Permit Requirements

The permit requirements for each of the retrofit alternatives are included in Table 23. These requirements should be confirmed prior to design and construction to check for possible changes.

Table 23. Summary of permit requirements for each retrofit alternative.

Retrofit alternative	Dam Safety Permit	Section 404 and 401 Permits	Neuse River Buffer Authorization	Erosion and Sediment Control Permit
Lake As Is	X	X	-	X
Stormwater Wetland	X	X	X	X
Habitat Wetland	X	X	X	X
Stream Restoration	X	X	X	X

5 Conclusion

5.1 Site Investigation

The site investigation revealed the Upper Durant Lake watershed experienced significant development in the 1990s; however, aside from a few small residential and commercial developments, little has changed in the watershed since 2001 and there is limited potential for further development as most of the undeveloped area is located in the Durant Nature Preserve. The sediment accumulated in the Upper Lake and in the valley above the lake was likely the result of the rapid in development in the watershed and construction of I-540 in the 1990s. However, the current sediment supply is likely the result of ongoing streambank erosion in the watershed.

5.2 Lake Sediment

Lake bed sampling showed the sediment accumulated in the lake is not considered hazardous waste and could be hauled offsite and disposed of in a landfill or used for fill during construction of the proposed site retrofits. This would need to be further investigated by a geotechnical engineer during the design process. About 12,500 cubic yards of sediment have accumulated in the lake as of March 2018.

5.3 Water Quality

Water quality sampling revealed that the lake provides moderate water quality benefits to downstream waters. The Upper Lake acts as a sink for nitrate-N, TP and TSS, but also exports ammonium-N to the downstream lake. Overall, the median effluent concentrations for TP and TN were similar to the effluent mean concentration for wet detentions basins from NC DEQ's Stormwater Design Manual. In addition, the influent stream provides limited macroinvertebrate habitat as the NC bioclassification for small streams was Poor to Fair, likely due to sedimentation.

5.4 Retrofit Alternatives: Designs, Cost Estimates and MCDA

Concept level designs were developed for four lake retrofit alternatives including: repairing or replacing the existing infrastructure of the lake (Lake As Is retrofit alternative), a wetland design targeting water quality improvement (Stormwater Wetland retrofit alternative), a wetland design for increased habitat function (Habitat Wetland retrofit alternative) and the removal of the dam and construction of a stream channel in the lake bed (Stream Restoration retrofit alternative). Cost estimate ranges (low and high) were developed for each retrofit alternative based on the uncertain geotechnical conditions at the site. The Lake As Is retrofit alternative has the greatest cost range (approximately to \$2.0 million to \$3.6 million), the wetland retrofit alternatives are similar in cost (approximately $2.2 million to $2.9 million) and the Stream Restoration is comparable to the wetland alternatives (approximately $2.3 million to $2.8 million). The retrofit alternatives were ranked using MCDA based on several important factors identified by the City of Raleigh. The Habitat Wetland is identified as the most favorable retrofit alternative, followed by the Stormwater Wetland and Stream Restoration retrofit alternatives. The Lake As Is retrofit alternative is the least favorable according to this analysis due to the potentially high cost and because this retrofit alternative would not substantially add to or enhance the ecosystems services currently provided by the lake.

5.5 Environmental Permitting

The Upper Durant Lake dam is subject to the Dam Safety Act regulations, the wetland and stream features are jurisdictional under the Clean Water Act and the surface waters are subject to the Neuse Buffer Rules. However, these regulations would not prevent implementation of any of the retrofit alternatives, but permits would be required from NC DEQ DWR, USACE and NC DEQ DEMLR.

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7 Appendices

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7.1 Appendix A. Concept Design Plan Sheets

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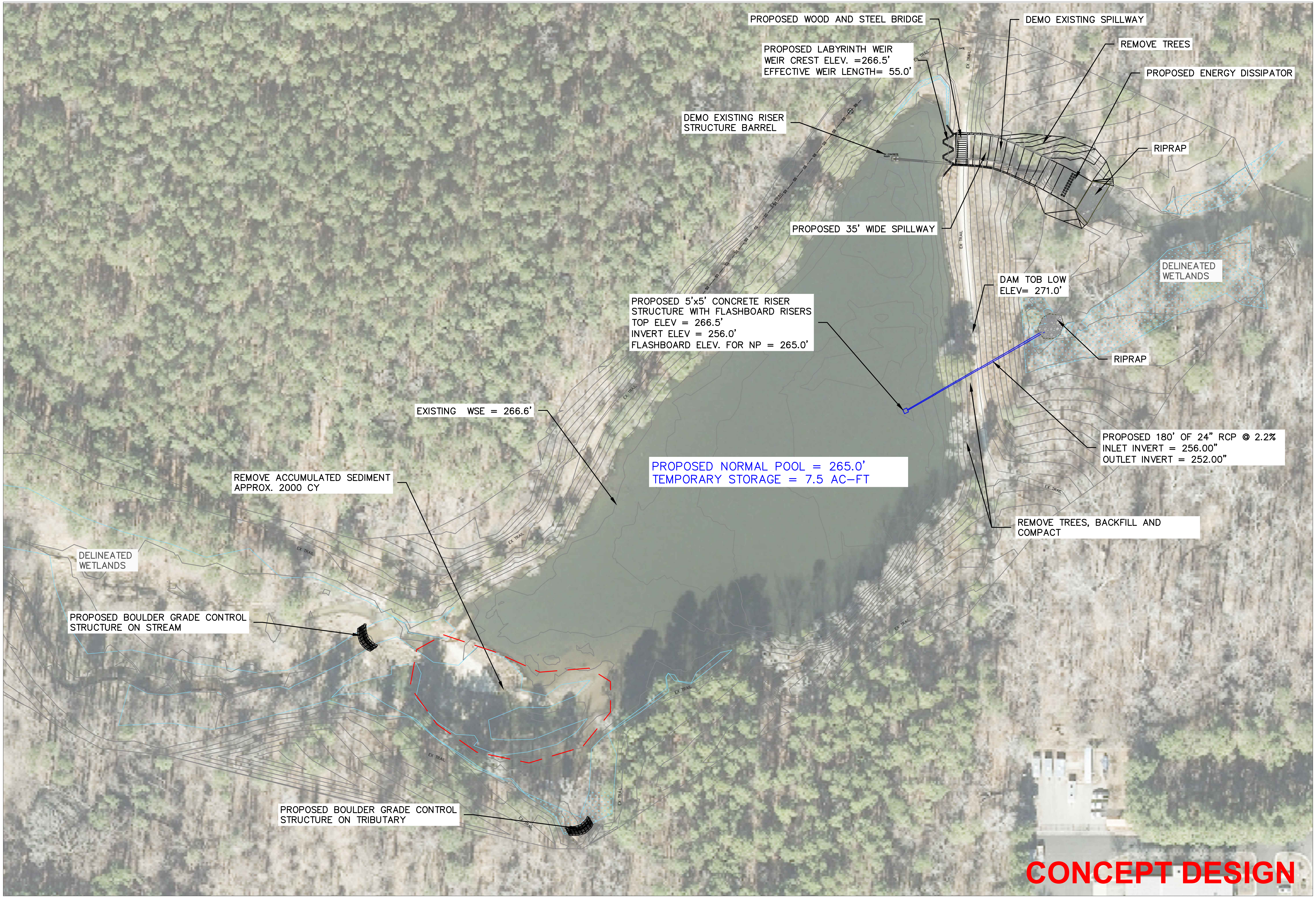


UPPER DURANT LAKE RETROFIT ALTERNATIVES ANALYSIS

LAKE AS IS

Sea Grant North Carolina

NC COOPERATIVE EXTENSION

cleanwater MANAGEMENT TRUST FUND

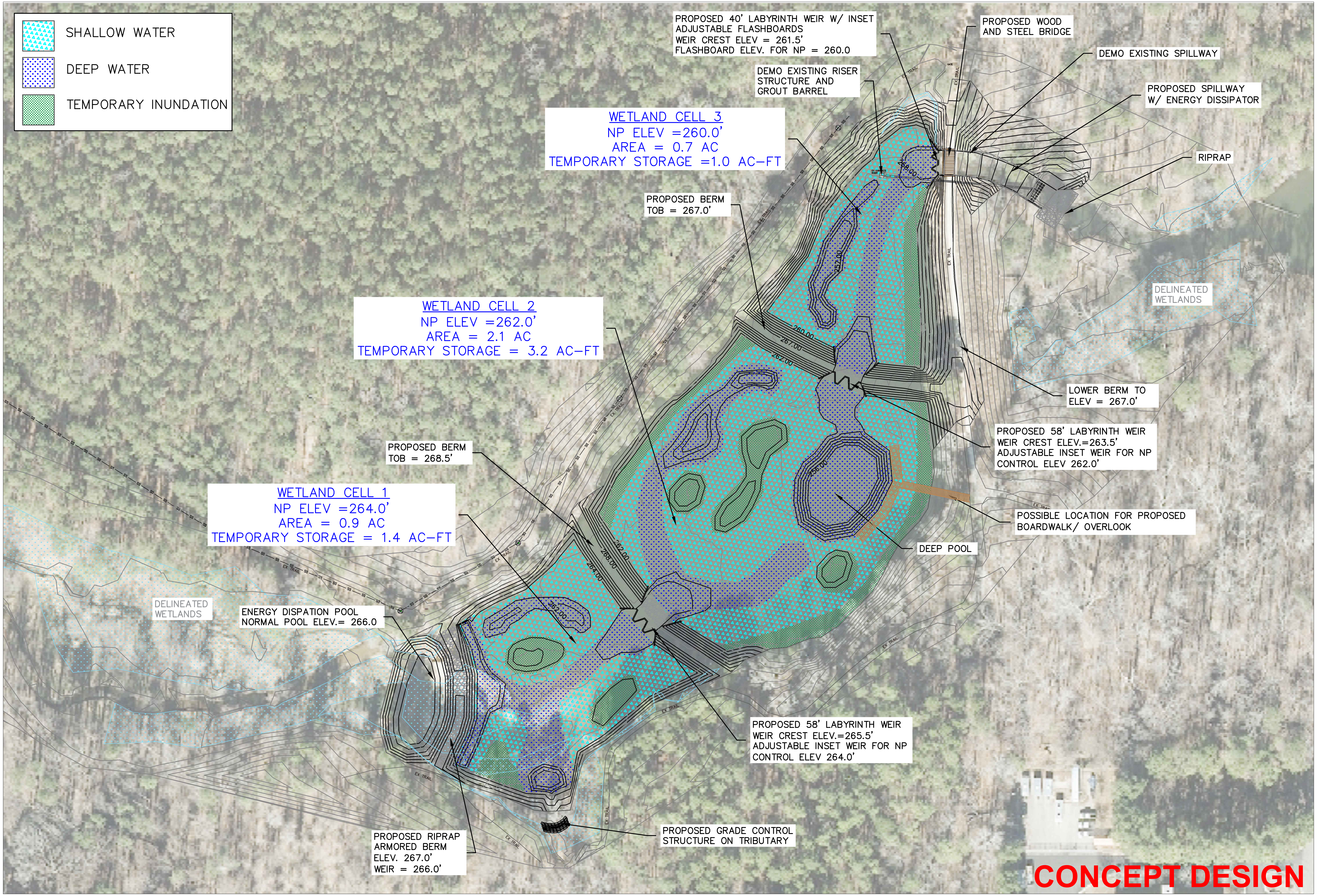
CONCEPT DESIGN

NC STATE UNIVERSITY Bio&Ag ENGINEERING

DRAWN : JKF
DESIGN : JKF, JLP, BAD
ORIGINAL : MAY 14, 2019
REVISION : JUNE 28, 2019

PROJECT NAME : UPPER DURANT LAKE
SCALE : 1" = 100'
DATE : JUNE 28, 2019

PROJECT # 572114
PHASE #



UPPER DURANT LAKE RETROFIT ALTERNATIVES ANALYSIS

STORMWATER WETLAND

Sea Grant North Carolina

NC COOPERATIVE EXTENSION

cleanwater MANAGEMENT TRUST FUND

CONCEPT DESIGN

NC STATE UNIVERSITY Bio&Ag ENGINEERING

DRAWN : JKF
DESIGN : JKF, JLP, BAD
ORIGINAL : MAY 14, 2019
REVISION : JUNE 28, 2019

PROJECT NAME : UPPER DURANT LAKE
SCALE : 1" = 100'
DATE : JUNE 28, 2019

PROJECT # 572114
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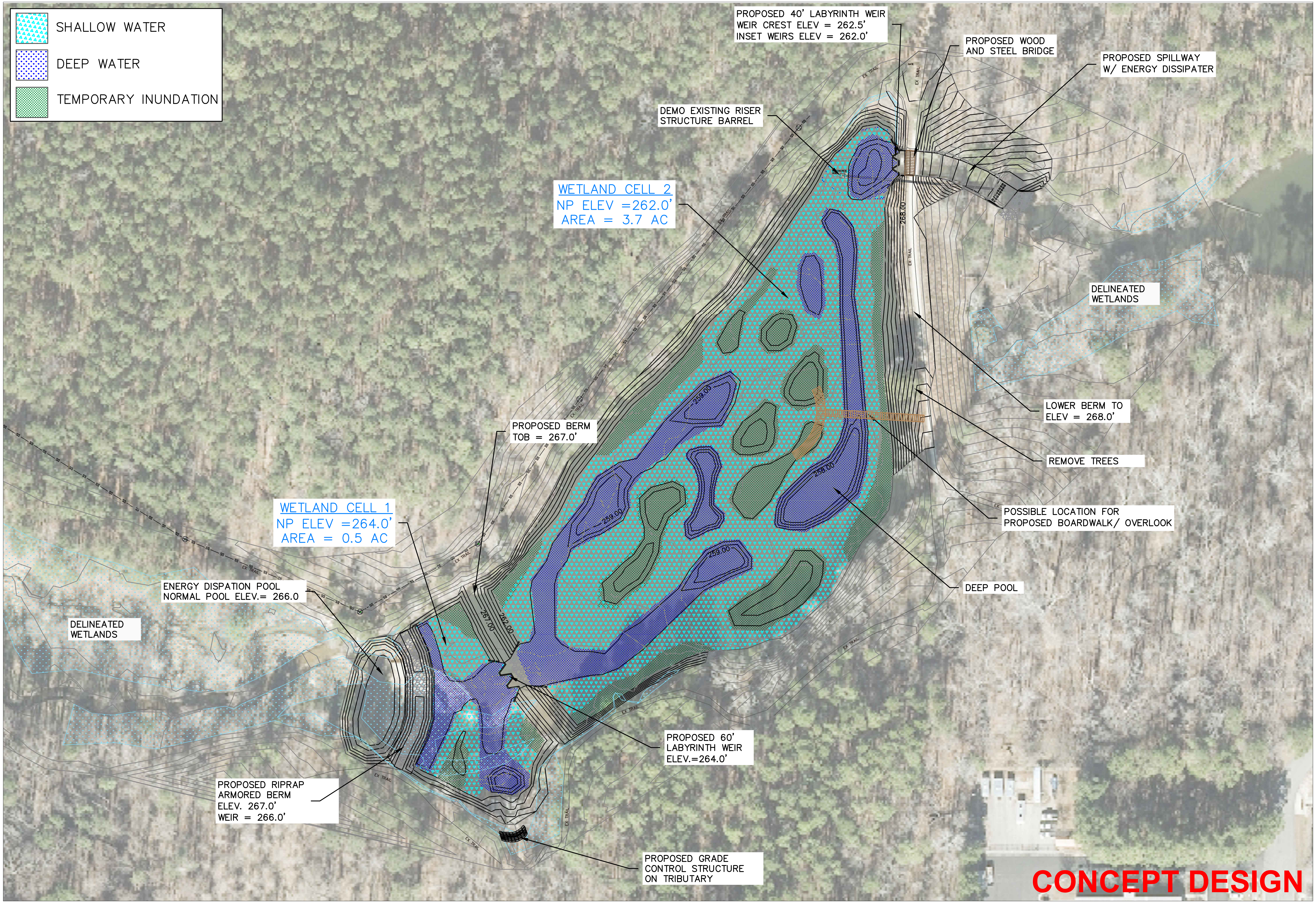

UPPER DURANT LAKE RETROFIT ALTERNATIVES ANALYSIS

HABITAT WETLAND

CONCEPT DESIGN

DRAWN : JKF
DESIGN : JKF, JLP, BAD
ORIGINAL : MAY 14, 2019
REVISION : JUNE 28, 2019

PROJECT NAME : UPPER DURANT LAKE
SCALE : 1" = 100'
DATE : JUNE 28, 2019

PROJECT # 572114
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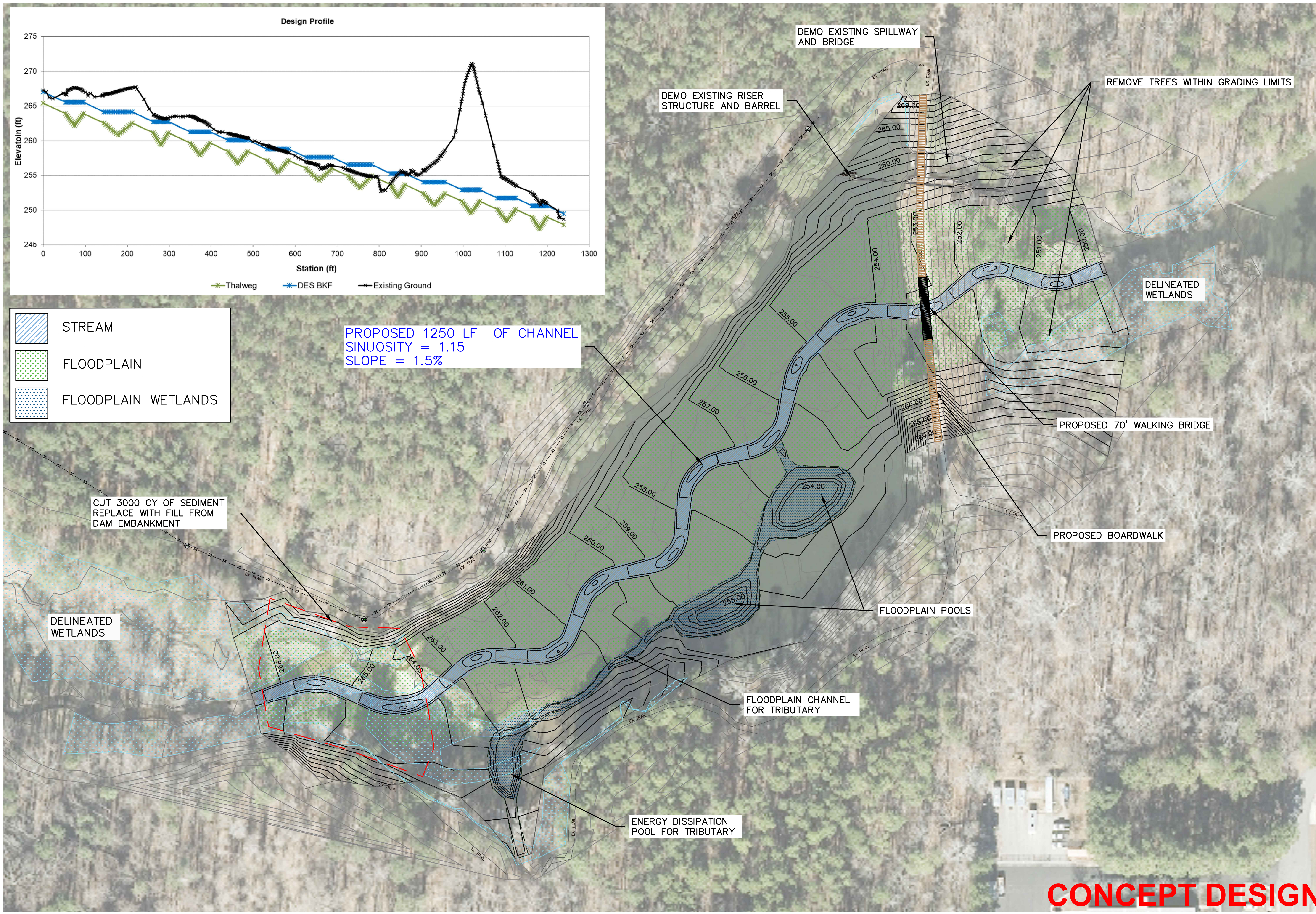

UPPER DURANT LAKE RETROFIT ALTERNATIVES ANALYSIS

STREAM RESTORATION

CONCEPT DESIGN

NC STATE UNIVERSITY Bio&Ag ENGINEERING

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DESIGN : JKF, JLP, BAD	SCALE : 1" = 100'
ORIGINAL : MAY 14, 2019	DATE : JUNE 28, 2019
REVISION : JUNE 28, 2019	

PROJECT # 572114

PHASE # ____

7.2 Appendix B. Detailed Cost Estimates

UPPER DURANT LAKE RETROFIT ALTERNATIVES COST ESTIMATE

Item	Units	Estimated Unit Cost	LAKE AS IS				STORMWATER WETLAND				HABITAT WETLAND				STREAM RESTORATION			
			Low Estimate		High Estimate		Low Estimate		High Estimate		Low Estimate		High Estimate		Low Estimate		High Estimate	
			Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost	Quantity	Cost
SITE WORK																		
Erosion Control	LS	$ 40,000	1	$ 40,000	1	$ 40,000	1	$ 40,000	1	$ 40,000	1	$ 40,000	1	$ 40,000	1	$ 30,000	1	$ 30,000
Control of Water	LS	-	1	$ 150,000	1	$ 150,000	1	$ 150,000	1	$ 150,000	1	$ 150,000	1	$ 150,000	1	$ 60,000	1	$ 60,000
Clearing and Grubbing	LS	-	1	$ 15,000	1	$ 15,000	1	$ 20,000	1	$ 20,000	1	$ 20,000	1	$ 20,000	1	$ 35,000	1	$ 35,000
Temporary Facilities	LS	$ 25,000	1	$ 25,000	1	$ 25,000	1	$ 25,000	1	$ 25,000	1	$ 25,000	1	$ 25,000	1	$ 25,000	1	$ 25,000
DEMOLITION																		
Demo Spillway	CY	$ 300	220	$ 66,000	220	$ 66,000	220	$ 66,000	220	$ 66,000	220	$ 66,000	220	$ 66,000	220	$ 66,000	220	$ 66,000
Demo Riser Structure	LS	$ 15,000	1	$ 15,000	1	$ 15,000	1	$ 15,000	1	$ 15,000	1	$ 15,000	1	$ 15,000	1	$ 15,000	1	$ 15,000
Remove Barrel	LS	$ 10,000	1	$ 10,000	1	$ 10,000	1	$ 10,000	1	$ 10,000	1	$ 10,000	1	$ 10,000	1	$ 10,000	1	$ 10,000
EARTHWORK																		
Excavation and Grading	CY	$ 15	5000	$ 75,000	20000	$ 300,000	13500	$ 202,500	13500	$ 202,500	14400	$ 216,000	14400	$ 216,000	27000	$ 405,000	34700	$ 520,500
Embankment Earthwork	CY	$ 15	2500	$ 37,500	17500	$ 262,500	3000	$ 45,000	3000	$ 45,000	2000	$ 30,000	2000	$ 30,000	0	$ -	0	$ -
Soil Removal and Disposal	CY	$ 20	5000	$ 100,000	20000	$ 400,000	2000	$ 40,000	11000	$ 220,000	1200	$ 24,000	11000	$ 220,000	27000	$ 540,000	34700	$ 694,000
Imported Fill	CY	$ 25	2500	$ 62,500	17500	$ 437,500	0	$ -	9000	$ 225,000	0	$ -	10000	$ 250,000	0	$ -	0	$ -
REINFORCED CONCRETE STRUCTURES																		
Construct Reinforced Concrete Spillway	CY	$ 1,200	550	$ 660,000	550	$ 660,000	350	$ 420,000	350	$ 420,000	350	$ 420,000	350	$ 420,000	0	$ -	0	$ -
Construct Reinforced Concrete Weir Structures	CY	$ 1,200	0	$ -	0	$ -	150	$ 180,000	150	$ 180,000	75	$ 90,000	75	$ 90,000	0	$ -	0	$ -
Construct Riser and Barrel	LS	$ 55,000	1	$ 55,000	1	$ 55,000	0	$ -	0	$ -	0	$ -	0	$ -	0	$ -	0	$ -
BRIDGES AND TRAILS																		
Main Spillway Bridge	LF	$ 1,800	38	$ 68,400	38	$ 68,400	30	$ 54,000	30	$ 54,000	30	$ 54,000	30	$ 54,000	0	$ -	0	$ -
Pedestrian Bridges	LF	$ 1,200	0	$ -	0	$ -	0	$ -	0	$ -	0	$ -	0	$ -	60	$ 72,000	60	$ 72,000
Boardwalk	LF	$ 300	0	$ -	0	$ -	240	$ 72,000	240	$ 72,000	220	$ 66,000	220	$ 66,000	200	$ 60,000	330	$ 99,000
Fencing around Weir Structures and Spillway	LF	$ 70	300	$ 21,000	300	$ 21,000	470	$ 32,900	470	$ 32,900	390	$ 27,300	390	$ 27,300	0	$ -	0	$ -
STRUCTURES AND STONE																		
Stone for Riffles	SY	$ 60	0	$ -	0	$ -	0	$ -	0	$ -	0	$ -	0	$ -	1250	$ 75,000	1250	$ 75,000
Riprap	CY	$ 110	125	$ 13,750	110	$ 12,100	400	$ 44,000	400	$ 44,000	350	$ 38,500	350	$ 38,500	0	$ -	0	$ -
Boulder Grade Control	TON	$ 150	44	$ 6,600	44	$ 6,600	22	$ 3,300	22	$ 3,300	22	$ 3,300	22	$ 3,300	22	$ 3,300	22	$ 3,300
Stream Structures	LS	$ 50,000	0	$ -	0	$ -	0	$ -	0	$ -	0	$ -	0	$ -	1	$ 60,000	1	$ 50,000
PLANTING																		
Coir Matting	SY	$ 7	0	$ -	0	$ -	0	$ -	0	$ -	0		0	$ -	4500	$ 31,500	4500	$ 31,500
Temporary Seeding, Soil Prep	Acre	$ 10,000	0.5	$ 5,000	0.5	$ 5,000	0.5	$ 5,000	0.5	$ 5,000	0.5	$ 5,000	0.5	$ 5,000	4	$ 40,000	4	$ 40,000
Top Soil (4")	CY	$ 25	0	$ -	0	$ -	2100	$ 52,500	2100	$ 52,500	2200	$ 55,000	2200	$ 55,000	2700	$ 67,500	2700	$ 67,500
Permanent Seeding	Acre	$ 10,000	0.5	$ 5,000	0.5	$ 5,000	1.2	$ 12,000	1.2	$ 12,000	0.9	$ 9,000	0.9	$ 9,000	4	$ 40,000	4	$ 40,000
Live stakes (3' spacing)	Acre	$ 15,000	0	$ -	0	$ -	0.5	$ 7,500	0.5	$ 7,500	0.5	$ 7,500	0.5	$ 7,500	1	$ 15,000	1	$ 15,000
Wetland Plugs (18" spacing)	Acre	$ 39,200	0	$ -	0	$ -	3.6	$ 141,120	3.6	$ 141,120	4.1	$ 160,720	4.1	$ 160,720	0.5	$ 19,600	0.5	$ 19,600
SUBTOTAL (rounded)				**$ 1,431,000**		**$ 2,554,000**		**$ 1,638,000**		**$ 2,043,000**		**$ 1,532,000**		**$ 1,978,000**		**$ 1,670,000**		**$ 1,968,000**
Mobilization (5%)	LS	5%		$ 71,550		$ 127,700		$ 81,900		$ 102,150		$ 76,600		$ 98,900		$ 83,500		$ 98,400
Contingency (15%)	LS	15%		$ 214,650		$ 383,100		$ 245,700		$ 306,450		$ 229,800		$ 296,700		$ 250,500		$ 295,200
Engineering, Surveying, and Permitting Fees (20%)	LS	20%		$ 286,200		$ 510,800		$ 327,600		$ 408,600		$ 306,400		$ 395,600		$ 334,000		$ 393,600
TOTAL (rounded)			**LOW:**	**$ 2,000,000**	**HIGH:**	**$ 3,580,000**	**LOW:**	**$ 2,290,000**	**HIGH:**	**$ 2,860,000**	**LOW:**	**$ 2,140,000**	**HIGH:**	**$ 2,770,000**	**LOW:**	**$ 2,340,000**	**HIGH:**	**$ 2,760,000**

7.3 Appendix C: Design Calculations

Existing Conditions

Existing Spillway: 28' width, Weir crest at 266.65'. Bridge over spillway low chord elevation at 271.0

Constaint: Low elevation of the top of dam is 270.05'

National Engineering Handbook equation for a Chute Spillway

Discharge-Head Relationship for a Straight Inlet. The discharge-head relationship of a straight inlet is given by the weir formula

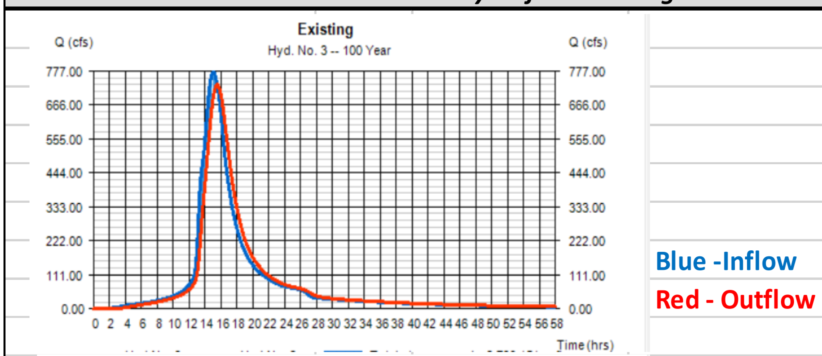
$$Q = 3.1\ W \left[H + \frac{v_a^2}{2g}\right]^{3/2} = 3.1\ W\ H_e^{3/2} \qquad 2.4$$

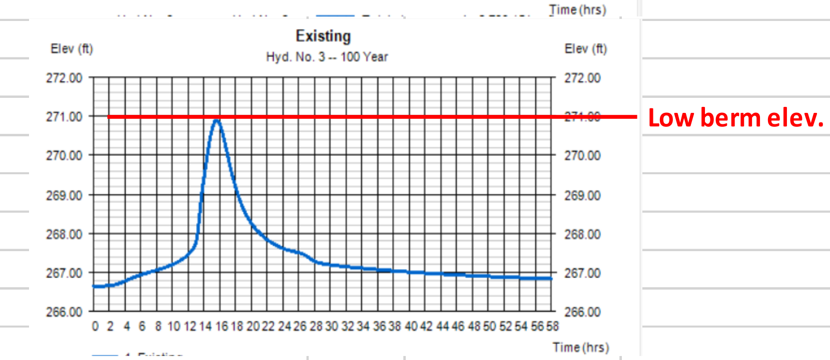
where Q = discharge of inlet in cfs
W = width of chute or inlet in ft

Routing results for exisitng conditions

Rainfall Event	Rainfall (in)	HEC-HMS model Storm Volume (Ac-ft)	HEC-HMS model Peak Q_{in} (cfs)	Peak Q_{out} (cfs)	Max WSE (ft)
1", 24 hr	1	19	40	34	267.2
1-yr, 24 hr	2.8	89	170	163	268.2
2-yr, 24 hr	3.6	132	252	237	268.7
5-yr, 24 hr	4.75	195	369	352	269.3
10-yr, 24 hr	5.6	244	470	444	269.7
25-yr, 24 hr	6.5	299	575	545	270.1
50-yr, 24 hr	7.2	343	660	625	270.5
100-yr, 24 hr	8.1	400	772	733	270.9

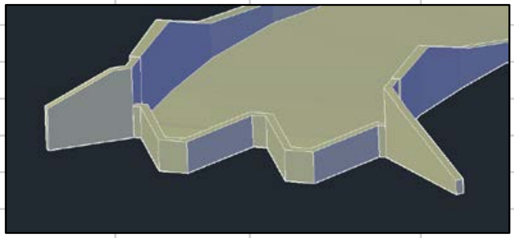
Hydraflow Routing Results



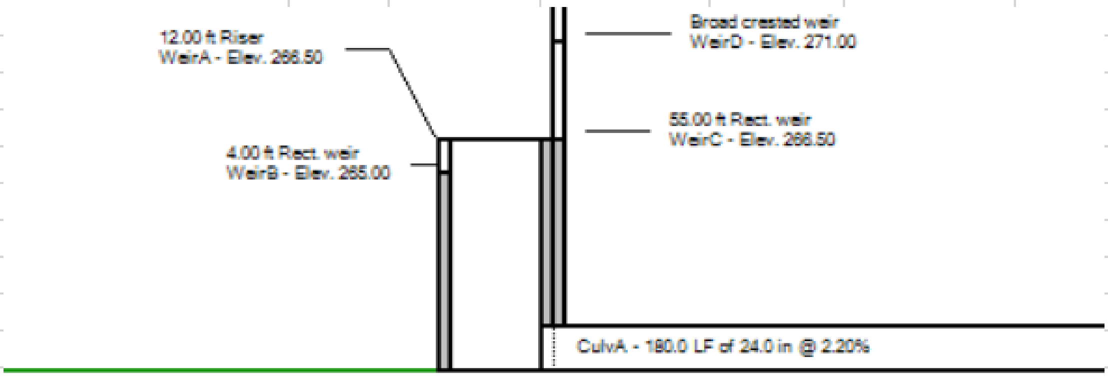


Lake As Is

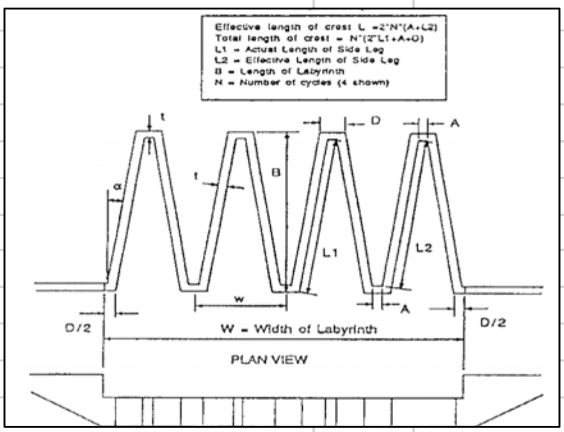
Proposed Spillway:		
Width	58'	
Weir Crest Length	58'	
Weir Crest Elevation	266.5'	
Proposed Riser: 5x5 concrete riser, 24" barrel		
NP Weir Elevation	265.0'	
Overflow Elevation	266.5'	



Civil3d Hydraflow Schematic



Spillway Design



$$Q = \frac{2}{3} C_d L \sqrt{2g} H_t^{3/2}$$

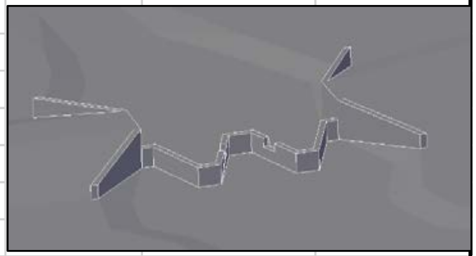
Tullis, J. P., Amanian, N., & Waldron, D. (1995). Design of labyrinth spillways. *Journal of hydraulic engineering*, *121* (3), 247-255.

Routing results for Lake As Is alternative

Event	Rainfall (in)	Peak Qin (cfs)	Existing Qout (cfs)	Proposed Qout (cfs)	Existing Max WSE (ft)	Proposed Max WSE (ft)
1", 24 hr	1	40	35	25	267.2	266.5
1-yr, 24 hr	2.8	176	163	170	268.2	267.3
2-yr, 24 hr	3.6	252	237	247	268.7	267.6
5-yr, 24 hr	4.75	373	352	368	269.3	268.0
10-yr, 24 hr	5.6	469	444	461	269.7	268.3
25-yr, 24 hr	6.5	575	545	566	270.1	268.6
50-yr, 24 hr	7.2	660	625	651	270.5	268.8
100-yr, 24 hr	8.1	772	733	761	270.9	269.0

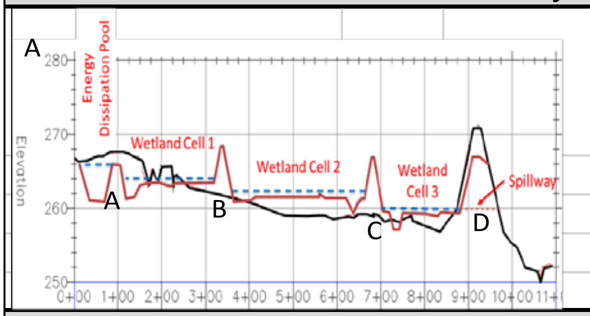
Stormwater Wetland

Proposed Spillway:	
Width	28'
Weir Crest Length	50'
NP Weir Crest Elev.	260.0'
Overflow Weir Crest Elev.	261.5'
Proposed Wetland Cell Weirs:	
Width	35'
Weir Crest Length	58'
NP Weir Crest Elev.	Varies (see table below)
Overflow Weir Crest Elev.	Varies (see table below)



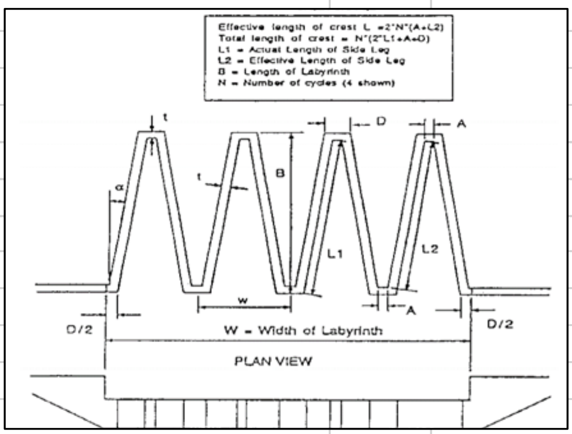
Wetland cell outlet weir

Profile Schematic



Berm	Top of Berm (ft)	Overflow Weir (ft)	Normal Pool Control Weir or Orifice (ft)
A	267.0	267.0	266.0
B	268.5	265.5	264.0
C	267.0	263.5	262.0
D	267.0	261.5	260.0

Spillway and Weir Design



$$Q = \frac{2}{3} C_d L \sqrt{2g} H_t^{3/2}$$

Tullis, J. P., Amanian, N., & Waldron, D. (1995). Design of labyrinth spillways. *Journal of hydraulic engineering*, *121* (3), 247-255.

$$Q_s = Q_f\left[1-\left(\frac{H_b}{H_a}\right)^n\right]^{0.385}$$

Q_s = submerged flow rate
Q_f = free-flow rate at Ha
H_a = depth at the point of measurement
H_b = depth downstream (relative to crest elevation)
n = discharge exponent (1.5 for rectangular weirs, 2.5 for v-notch weirs)

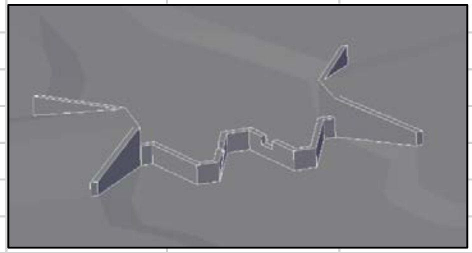
Submerged Weir Discharge Studies, Engineering News Record, 194

Routing results for Wetland - Stormwater alternative

Event	Rainfall (in)	Peak Qin (cfs)	Peak Qout (cfs)	Max WSE Cell 1 (ft)	Max WSE Cell 2 (ft)	Max WSE Cell 3 (ft)
1", 24 hr	1	40	34	265.9	263.9	262
1-yr, 24 hr	2.8	176	-	266.5	264.5	262.8
2-yr, 24 hr	3.6	252	-	266.8	264.8	263.1
5-yr, 24 hr	4.75	373	-	267.15	265.1	263.6
10-yr, 24 hr	5.6	469	-	267.4	265.4	263.95
25-yr, 24 hr	6.5	575	-	267.9	265.7	264.3
50-yr, 24 hr	7.2	660	-	268	266	264.55
100-yr, 24 hr	8.1	772	-	268.3	266.35	264.9

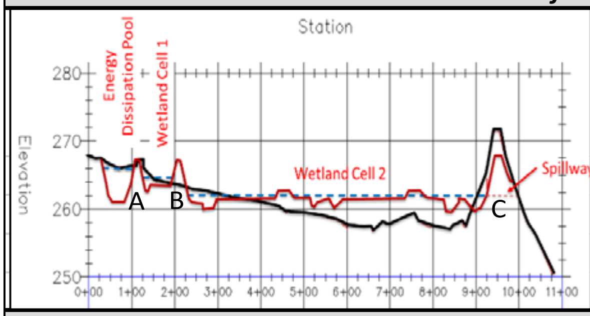
Habitat Wetland

Proposed Spillway:		
	Width	28'
	Weir Crest Length	50'
	NP Weir Crest Elev.	262.0'
	Overflow Weir Crest Elev.	262.5'
Proposed Cell 1 Outlet Weir:		
	Width	35'
	Weir Crest Length	58'
	NP Weir Crest Elev.	264.5'
	Overflow Weir Crest Elev.	264.0'



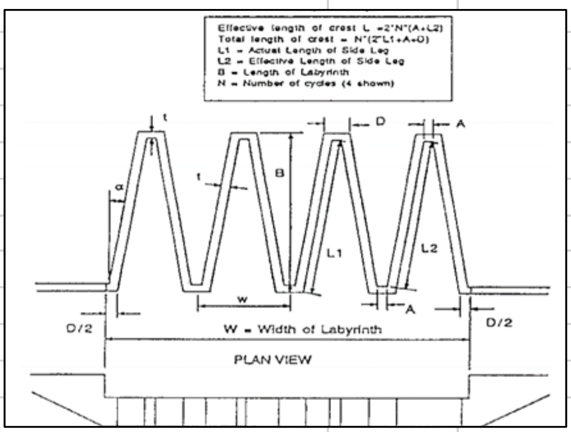
Wetland cell outlet weir

Profile Schematic



Berm	Top of Berm (ft)	Overflow Weir (ft)	Normal Pool Control Weir or Orifice (ft)
A	267.0	267.0	266.0
B	267.0	264.5	264.0
C	267.0	262.5	262.0

Spillway and Weir Design



$$Q = \frac{2}{3} C_d L \sqrt{2g} H_t^{3/2}$$

Tullis, J. P., Amanian, N., & Waldron, D. (1995). Design of labyrinth spillw ays. *Journal of hydraulic engineering*, *121* (3), 247-255.

$$Q_s = Q_f\left[1-\left(\frac{H_b}{H_a}\right)^n\right]^{0.385}$$

Q_s = submerged flow rate
Q_f = free-flow rate at Ha
H_a = depth at the point of measurement
H_b = depth downstream (relative to crest elevation)
n = discharge exponent (1.5 for rectangular weirs, 2.5 for v-notch weirs)

Submerged Weir Discharge Studies, Engineering New s Record, 194

Routing results for Wetland - Habitat alternative

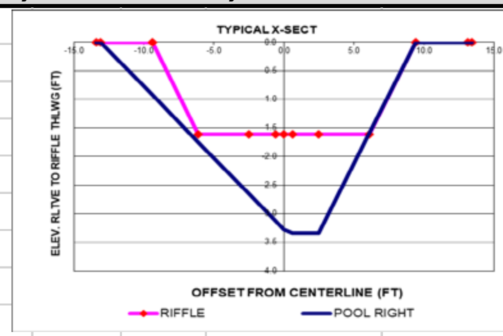
Event	Rainfall (in)	Peak Q_{in} (cfs)	Max WSE Cell 1 (ft)	Max WSE Cell 2 (ft)	Peak Qout
1", 24-hr	1	40.2	264.4	263	*
1-yr, 24-hr	2.8	176	265	263.8	*
2-yr, 24-hr	3.6	252	265.2	264.1	*
5-yr, 24-hr	4.75	373	265.7	264.6	*
10-yr, 24-hr	5.6	469	266	264.9	*
25-yr, 24-hr	6.5	575	266.4	265.3	*
50-yr, 24-hr	7.2	660	266.7	265.6	*
100-yr, 24-hr	8.1	772	267	265.9	*

Stream Restoration

Stream Name:	DNP
Stream type (Rosgen)	C
Design slope, S (ft/ft)	0.015
Stream length, SL (ft)	1250
Sinuosity, K = (ft/ft)	1.15
Entrenchment Ratio	6-10

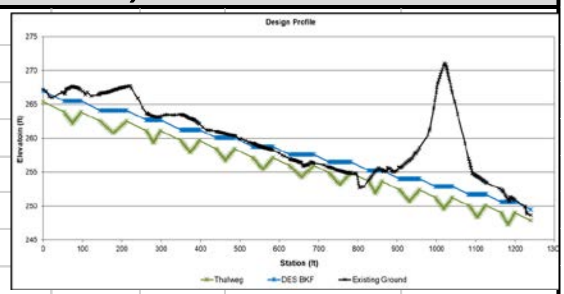
Cross-Section Dimension and Hydraulic Summary

Riffle cross-section area, A_{bkf} (sq ft)	25.0
Width-to-depth ratio, $[W_{bkf}/d_{bkf}]$	14.0
Riffle width, W_{bkf} (ft)	18.7
Mean riffle depth, d_{bkf} (ft)	1.3
Mannings bankfull discharge, Q_{bkf} (cfs)	140
Bankfull velocity, V_{bkf} (ft/s)	5.6
Bankfull shear stress, t (lb/ft^2)	1.1
Shields - diameter mobilized (min) (mr	86
Shields - diameter mobilized (max) (m	163

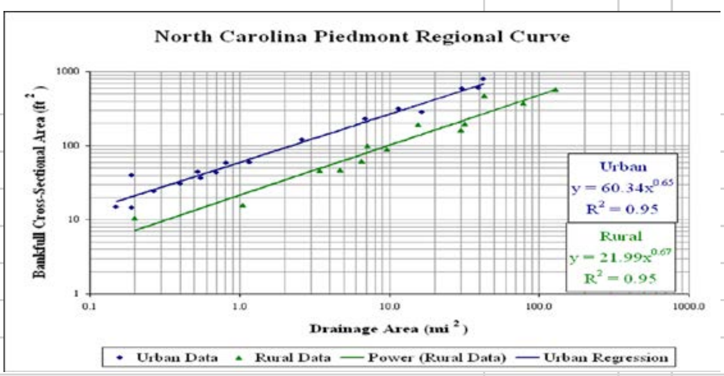


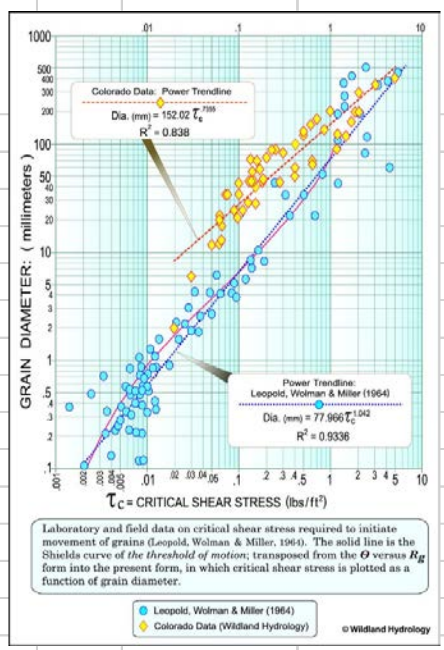
Pattern and Profile Summary

Radius of curvature ratio $[Rc/W_{bkf}]$	2.5-4
Pool length ratio $[L_p/W_{bkf}]$	2-4
Riffle length ratio, $[L_{rif}/W_{bkf}]$	2-3
Riffle Slope (ft/ft)	0.028



Design Sources





7.4 Appendix D: Site Survey

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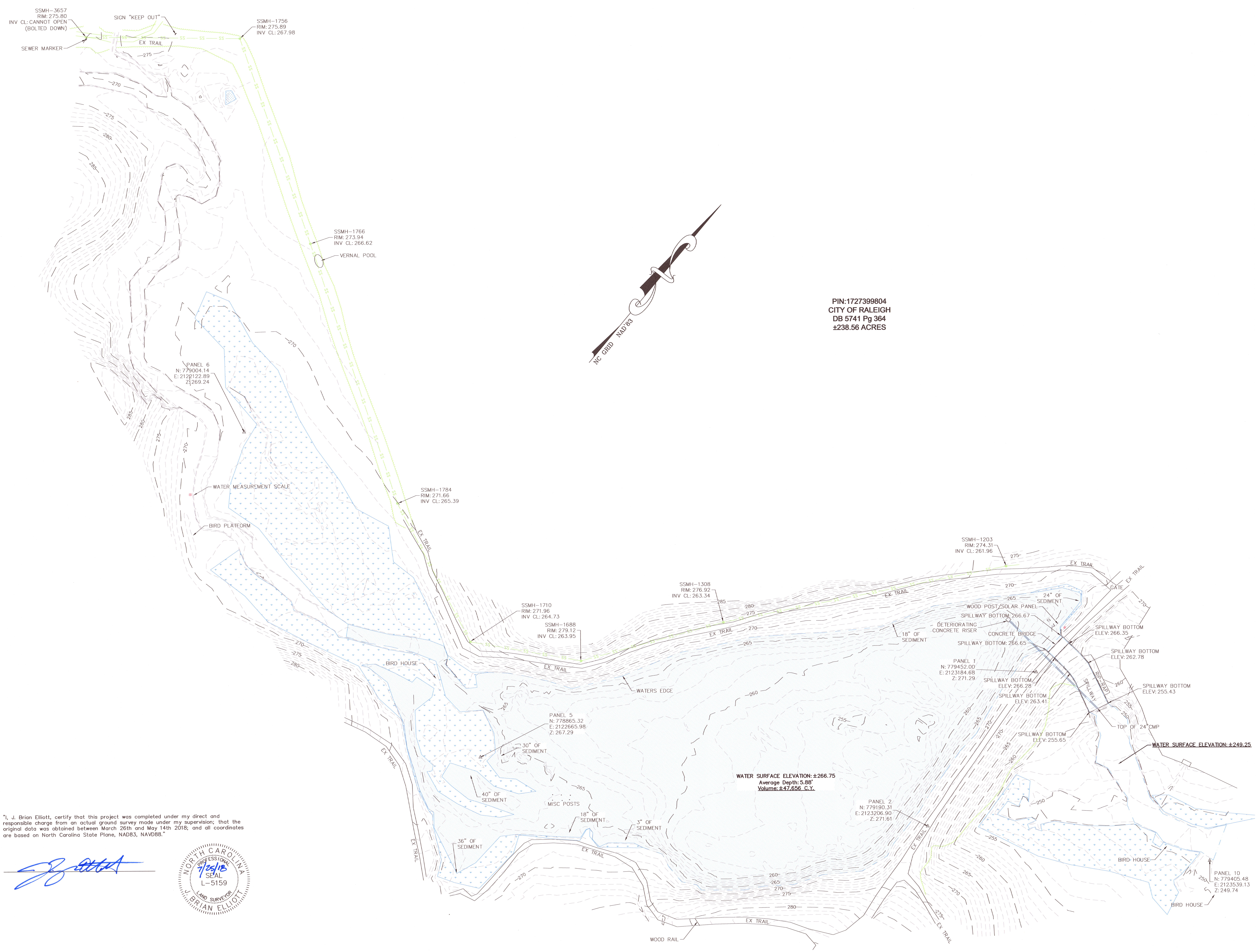

"I, J. Brian Elliott, certify that this project was completed under my direct and responsible charge from an actual ground survey made under my supervision; that the original data was obtained between March 26th and May 14th 2018; and all coordinates are based on North Carolina State Plane, NAD83, NAVD88."

NORTH CAROLINA PROFESSIONAL SEAL L-5159 LAND SURVEYOR J. BRIAN ELLIOTT 7/25/18

General Notes:
1. Deed Reference – DB 5741 Pg 364
2. Tax Parcel ID – 1727399804
3. Current Owner – CITY OF RALEIGH
4. The North Carolina Grid Coordinates shown on this map were derived by real-time kinematic GPS observations using Trimble R8 Receivers and processed using North Carolina Geodetic Survey Virtual Reference System.

Point Legend:

Symbol	Abbr	Description
	SSMH	Sanitary Sewer Manhole
		Sign

Line Legend:

Symbol	Description
	Fence Line
	Lake Edge
	Wetland
	Sanitary Sewer Line
	Existing Path
	Wetland Area

Topographic Survey of Durant Nature Preserve

8305 Camp Durant Road
City of Raleigh
Wake County
North Carolina

prepared for:
North Carolina State University

No.	Revision	By	Date
1			
2			
3			
4			

LDSI SURVEYING GIS SUE ENGINEERING
201 West 29th Street
Charlotte, NC 28206
Phone: (704) 337-8329
Fax: (704) 308-3153
License No.: C-1925
www.ldsi-inc.com

Graphic Scale 60 30 0 60
Text Scale: 1"=60'

Date: 07/03/2018	Plot Date: 07/25/2018
Project Number: 4518023	
Drawn By: JBE	
Reviewed By:	Sheet 1 of 1
Sealed By: JBE	

7.5 Appendix E: Jurisdictional Determinations

S&EC

Soil & Environmental Consultants, PA

8412 Falls of Neuse Road, Suite 104, Raleigh, NC 27615 • Phone: (919) 846-5900 • Fax: (919) 846-9467
sandec.com

DETAILED WETLAND DELINEATION & STREAM EVALUATION FOR PART OF THE DURANT NATURE PARK SITE

On **APRIL 10TH, 2018**, S&EC personnel completed a detailed wetland delineation and stream evaluation on the part of the Durant Nature Park that you requested that we evaluate (±15.4 acres). The site is located at 8305 Camp Durant Rd., Raleigh, NC. Figure 1 and Figure 2 show the location of the site on a USGS topographic quadrangle and NRCS County Soil Survey, respectively.

EXECUTIVE SUMMARY

We have determined that wetlands, ponds and streams generally account for the jurisdictional waters observed on the site. The attached wetland sketch map depicts the approximate locations of streams and wetlands identified during our evaluation. Please refer to the sketch map and the results and recommendations section below for more detailed information.

SCOPE OF WORK

The detailed wetland delineation consisted of traversing the property to examine soils, vegetation, and hydrology across the site in search of areas that meet the criteria for jurisdictional wetlands as described by the procedures set forth in the Corps of Engineers Wetlands Delineation Manual (January 1987 – Final Report). Areas on the site with positive indicators of hydric soils, evidence of wetland hydrology, and presence of hydrophytic vegetation were flagged with sequentially numbered, pink S&EC logo flagging. Proof of wetland hydrology would be the existence of hydric soils with oxidized root channels in the upper 12 inches of the soil profile, water borne deposits, drift lines, scour marks, drainage patterns, regional indicators of soil saturation, etc. Surface waters such as intermittent and perennial stream channels, ponds, and lakes, which are also subject to regulation by the US Army Corps of Engineers (USACE) as waters of the US, were also identified. These surface waters may also be referred to as jurisdictional waters to indicate that they are within the jurisdiction of the USACE. It is important to note that wetlands are also classified as waters of the US and regulated by the USACE under authority of the Clean Water Act (33 USC 1344).

RESULTS & RECOMMENDATIONS

The results of the detailed wetland delineation and stream evaluation are discussed below.

Wetlands and Jurisdictional Waters:

We have determined that jurisdictional waters (i.e., streams and wetlands) exist on the site. Please refer to the attached "Wetland Sketch Map" for specific flag numbers and approximate locations.
A number of jurisdictional wetlands and streams were observed during the site evaluation; the approximate locations of each are illustrated on the attached wetland sketch map. Wetlands and streams identified on-site are described below:

- A perennial stream that enters the Upper pond from the west.
- A stream that enters the upper pond from the south. It is likely intermittent.
- A stream that enters the lower pond from the south. It is likely intermittent.
- Wetlands adjacent to the upper end of the lower pond (Flags 1 thru 15)
- Wetlands adjacent to the upper pond at the northern corner of the dam (Flags 16 thru 20)
- Wetlands adjacent to the upper end of the upper pond and the perennial stream that flows into the upper pond)Flags 21 thru 72)
- A possibly isolated small wetland pocket in the flood plain adjacent to the sewer line in the western end of the study area (Flags A, B, C & 36)

Surface waters on this site flow into an unnamed tributary of Perry Creek in the Neuse River Basin, which has been classified in "Classification and NC DWQ Standards Applicable to Surface Waters and Wetlands of North Carolina" as B: NSW**.**

The wetlands onsite were identified as being a Headwater Forest Wetlands, Fringe Wetlands or Bottomland Hardwood Forest wetland types as outlined in the publication [1]"A Field Guide to North Carolina Wetlands." These wetland types are common throughout the piedmont region of North Carolina and are found mainly along headwater streams and along pond margins like the ones onsite. An Upland and Wetlands data form completed for the project as required by the USACE are attached.

Neuse River Buffers:

The surfaces waters potentially subject to the Neuse River Riparian Buffers include **the perennial stream entering the upper pond, the upper pond, the lower pond and two small streams that enter the ponds from the south.** One other stream is shown entering the lower pond from the north from the north, and another small stream is shown intersecting the perennial stream from the north on Wake County Soil Survey maps. S&EC does not believe that these two areas meet the requirements to be considered a buffered stream. A site meeting with a representative from the NCDWR has been requested to confirm our buffer determinations. S&EC will advise you of the time and date of the meeting when we are notified.

The riparian buffer is measured from the top of bank, landward on each side of the stream or from the normal pool elevation of the ponds.

All S&EC flags comprising the wetland and jurisdictional waters delineation, the normal pool elevation of the ponds and the top of bank of each side of each stream should be surveyed and a Wetland Delineation Map generated for use in site planning and USACE approval and

[1]" A Field Guide To North Carolina Wetlands"; Department of Environment, Health and Natural Resources, January 1996.

permitting. The entire length of each stream and the normal pool of the ponds was not flagged, but will need to be survey located for the Wetland Delineation Map**.** Stream features may be located either along the centerline (with channel widths noted at each survey point) or at the top-of-bank. The Wetland Delineation Map should prepared using the standards described in the attached SAW Survey Standards_10_6_2016.pdf. S&EC delineation flag numbers should be shown on the wetland survey.

Regulations

A general list of regulations that apply to jurisdictional wetlands and waters present on the site are discussed below. Please be aware that other local, state, and federal regulations not included in this list may also apply. S&EC personnel are available to discuss these regulations as they apply to your project.

Neuse River Buffer Rules:

The Neuse River Basin: Nutrient Sensitive Waters Management Strategy: Protection and Maintenance of Riparian Areas with Existing Forest Vegetation (15A NCAC 2B.0233) rules apply 50-foot wide riparian buffers directly adjacent to surface waters in the Neuse River Basin (intermittent streams, perennial streams, lakes, ponds, and estuaries), excluding wetlands. The rule defines surface waters as features approximately shown on either the most recent version of the soil survey map prepared by the Natural Resource Conservation Service (NRCS) of the US Department of Agriculture (USDA) or the 7.5-minute quadrangle topographic maps prepared by the US Geologic Survey (USGS). Surface waters that appear on these maps are not subject only if an on-site determination by the NC Division of Water Resources / Water Quality Programs (DWR/WQP) shows that they fall into one of the following categories:

1) Ditches and manmade conveyances other than modified natural streams;
2) Manmade ponds and lakes that are located outside natural drainage ways; or
3) Ephemeral (stormwater) streams.

Isolated Wetland Rules:

The isolated wetland rules are administered by the DWR/WQP and apply only to features that do not possess a jurisdictional connection, as determined by the USACE. The rules state that discharges to isolated, man-made ponds or isolated ditches except for those wetlands or waters constructed for compensatory mitigation or for onsite stormwater management do not require a permit. However surpassing the following thresholds will require written notification and approval by the DWR/WQP. These thresholds include impacts to isolated streams greater than or equal to 150 cumulative linear feet of stream taken from its centerline, impacts to isolated wetlands equal to or greater than 1 acre east of I-95 or 1/2 acre west of I-95, and/or greater than or equal 1/3 acre in the mountains.

Wetland Permitting:

The current Nationwide Permits were issued by the USACE on March 18, 2017. The USACE Wilmington District issued revised Regional Conditions for the 2017 Nationwide Permits. We recommend you forward a conceptual site plan to our office for review by one of our permitting specialist, who can best advise you of the specific permitting needs as you progress through the planning process.

Generally, wetland impact permits are issued on a per-project basis as determined by the USACE. The USACE has determined that impacts on parcels sub-divided from larger tracts are sometimes considered to be cumulative to existing impacts for the large tract. If this is the case, then thresholds for notification may not apply to your project and impacts to streams/wetlands must be considered in light of existing permits.

Limitations

Our evaluations, conclusions, and recommendations are based on project and site information available to us at the time of this report and may require modification if there are any changes in the project or site conditions, or if additional data about the project or site becomes available in the future. These findings are not intended or recommended to be suitable for reuse on extensions of the project or on any other project. Reuse on extensions of this project or on any other project shall be done only after written verification or adaptation by SOIL & ENVIRONMENTAL CONSULTANTS, PA, for the specific purpose intended.

Conclusion

The wetland and stream delineation for this portion of the Durant Nature Park Property was completed by S&EC on April 10th, 2018. This site contains jurisdictional streams, ponds and wetland areas that that may require preconstruction authorization for impacts, depending on the size and nature of the impact (i.e. road construction, lot fill, stormwater pond construction, etc.). USACE and DWR/WQP verification of our site assessment has been requested. Following verification meetings with regulatory agencies, the next step in the stream and wetland identification and permitting process is to obtain a field survey of our delineation for formal approval by the USACE. Upon completing the survey, these site constraints may then be integrated into planning for property development.

7.6 Appendix F: Benthic Macroinvertebrate Report

BENTHIC INSECT SUMMARY

DURANT NATURE PARK

Penrose Environmental

November, 2018

Background. Penrose Environmental has been contracted by the North Carolina State University to help with the baseline determination of water quality conditions in Durant Nature Park. Our scope of work includes the collection and evaluation of benthic macroinvertebrate populations from two monitoring locations in the watershed.

Methods and metrics. The watershed within Durant Nature Park is a very small (approximately 2 square miles) which suggests the use of a modification of the full-scale collection protocol developed by the Division of Water Resources. This collection protocol is defined in the DWR Standard Operating Procedure (DWR 2016) and termed a "Qual 4". The "Qual-4" requires a kick net sample from a riffle habitat, a sweep net sample from a stream bank and a leaf pack sample. In addition a visual inspection of the collection site is also conducted to look for more cryptic organisms. Organisms are picked roughly in proportion to their abundance, but no attempt is made to remove all organisms. If an organism can be reliably identified as a single taxon in the field, then no more than 10 individuals need to be collected. Organisms are classified as Abundant if 10 or more specimens are collected, Common if 3-9 specimens are collected, and Rare if 1-2 specimens are collected. Samples are processed in the field and taken back to the Penrose Environmental lab in Asheville for identification and summary.

The simplest method of data analysis is the tabulation of species richness (number of species), and species richness is the most direct measure of biological diversity. The association of good water quality with high species (or taxa) richness has been thoroughly documented. Increasing levels of pollution gradually eliminate the more sensitive species, leading to lower and lower species richness. EPT (Ephemeroptera, Plecoptera and Trichoptera) is the primary metric used to evaluate small streams. However, the NC Division of Water Resources recommends the use of small stream classification criteria if the watershed is less than 3.0 square miles in size and relies exclusively on the calculated NCBI values. These criteria for Piedmont streams are summarized in Table 1. The drainage area of the Durant Nature Park is approximately 2 square miles. Additional metrics include the total number of EPT taxa and EPT abundance and total taxa richness. Data were

Table 1. Bioclassification using small stream criteria for Piedmont streams.

Bioclass	NC Biotic Index
Excellent	< 4.31
Good	4.31 – 5.18
Good/Fair	5.19 – 5.85
Fair	5.86 – 6.91
Poor	>6.91

collected during surveys in April and October in 2018 and classification protocols comply with the small stream classification criteria of DWR.

Station Locations. Benthic insects were collected from two locations in the Durant Nature Park watershed using the DWR Qual 4 collection protocol. The 'upstream' monitoring site is located approximately 100 meters above the upstream reservoir and above the footprint of the reservoir and the 'downstream' site was located approximately 50 meters below the lower dam, but above the confluence with the receiving stream. Initially a third site was proposed between the two reservoirs, but flow was very restricted within this reach and inappropriate for lotic insects. Spillway maintenance was occurring during the October survey and water had been recently released from the lower reservoir. Flow through the reservoir was baseline only (see attached photograph).

Results and Discussion. A summary of the taxa collected from the two sites are listed in Table 2 and all organisms found at both sites during both surveys are listed in Appendix 1 of this report. Prior to the October investigation flows in the Raleigh area were extremely high following hurricanes Florence and Michael and scour of unstable sandy substrates was likely. However, taxa richness at the upstream location was higher in October (following extremely high flows) than the spring survey in April. Many taxa were collected at this site in October and not in April: EPT taxa include *Labiobaetis propinquus*, *Cheumatopsyche* spp., and *Chimarra* spp. This observation may be somewhat due to seasonality, but suggests that if sources of sediment are curtailed in the watershed that there may be refugia that could supply sources of insect recolonization. The increase in number of EPT taxa resulted in a slightly lower biotic index and a Fair bioclassification.

Many fewer total taxa and the dominance of *Glyptotendipes* spp. (a very tolerant Chironomidae) resulted in a Poor bioclassification at the downstream monitoring location. These data were collected following a recent drawdown of the lower reservoir and spillway maintenance. The stream at this location is extremely incised and the substrate dominated by hardpacked clay (see attached photograph). It's very likely that the release of anoxic sediments following reservoir drawdown resulted in Poor water quality conditions at this location.

Table 2. Summary of Benthic Macroinvertebrate Data. Durant Nature Park. April and October, 2018				
	upstream		downstream	
Collection Date	April, 2018	Oct, 2018	April, 2018	Oct, 2018
Taxonomic Group				
Ephemeroptera	1	2	0	0
Trichoptera	1	3	1	1
Diptera; Misc.	0	0	1	0
Diptera; Chironomidae	3	5	9	4
Odonata	2	2	2	0
Oligochaeta	2	2	0	0
Crustacea	0	0	2	1
Mollusca	0	1	1	1
Other taxa	0	0	1	2
Total Taxa Richness	9	15	17	9
EPT Taxa Richness	2	5	1	1
EPT Abundance	4	27	1	3
Biotic Index	7.16	6.06	8.09	7.09
Bioclass using small stream criteria	Poor	Fair	Poor	Poor

Reference

North Carolina Division of Water Resources. Standard Operating Procedures for the Collection and Analysis of Benthic Maroinvertebrates. North Carolina Department of Environmental Quality. February, 2016