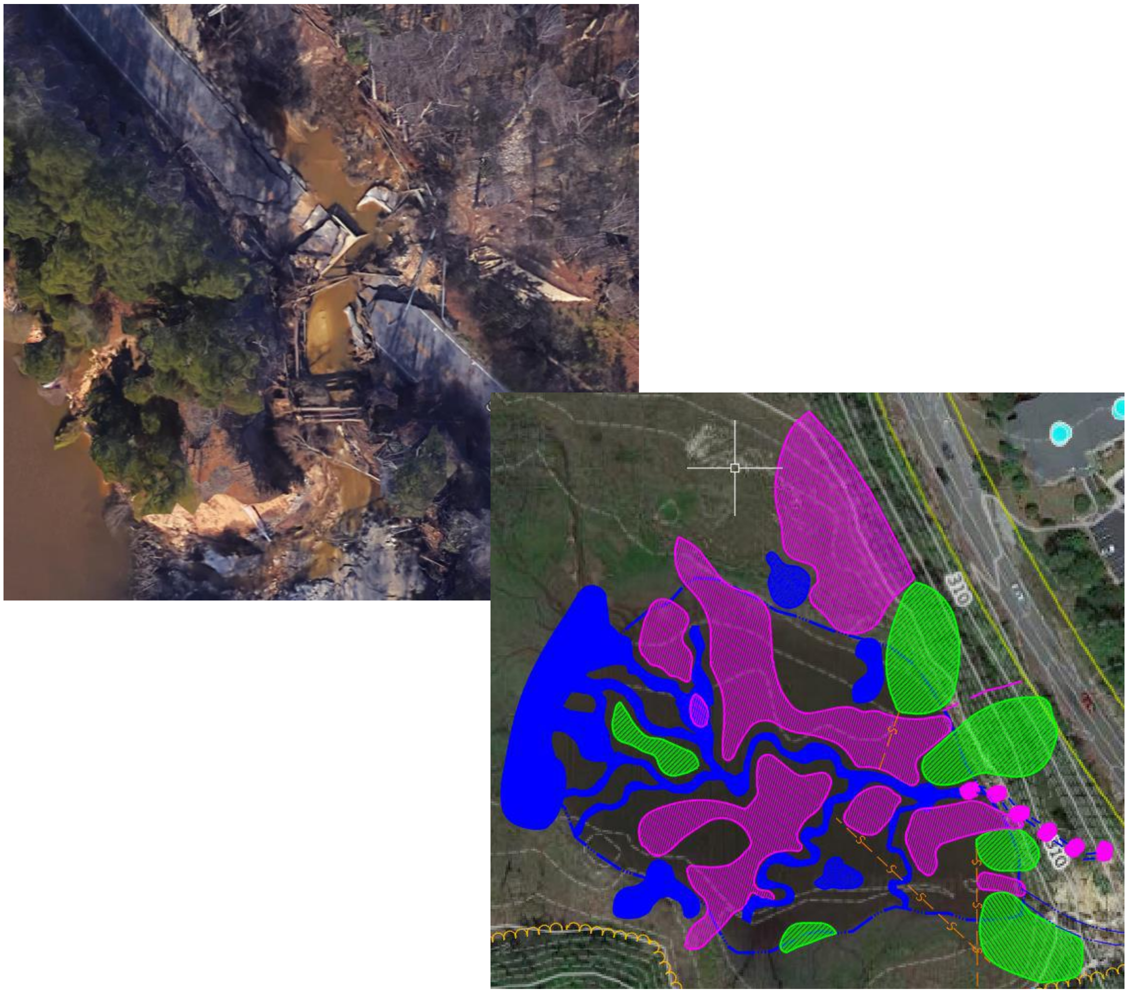
FEASIBILITY ANALYSES OF STREAM AND WETLAND RESTORATION ALTERNATIVES FOR WALDEN POND

Richland County, SC



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INTRODUCTION

Meteorological events during the period of October 1 through 5, 2015, resulted in record rainfall over large portions of South Carolina. Some areas experienced more than 20 inches of rainfall over the 5-day period with locally recorded rainfall rates of 2 inches per hour. This event occurred over developed areas in Columbia and Richland County where runoff rates are increased by impervious surface. Rainfall runoff was further amplified by high antecedent moisture conditions from previous rainfall, which reduced soil storage capacity. This historic rain event resulted in catastrophic flooding that caused nine fatalities in Richland County.

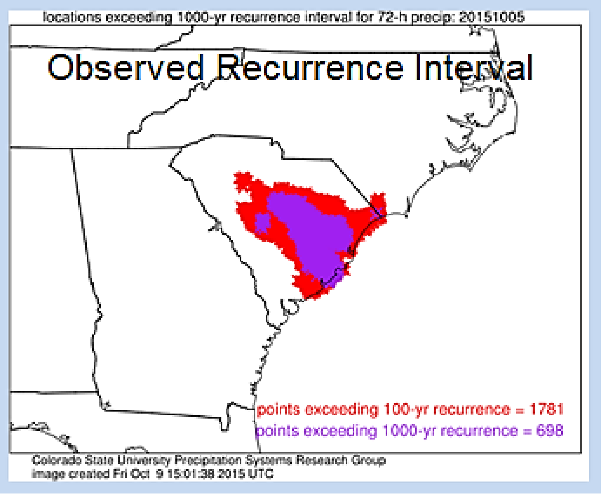

Figure 1. Hyetograph of October 2015 rain event in South Carolina (NOAA, 2016) .

Damage to private property and public infrastructure was severe. There were 36 dam failures across the state, including at Walden Pond and another dam about 0.6 miles upstream on Spears Creek. Failure of the Walden Pond dam destroyed a section of Spears Creek Church Road (S 40-53). Massive amounts of sediment were evacuated from the pond and deposited downstream of the road into the Spears Creek channel and across its floodplain.

The South Carolina Department of Transportation repaired Spears Creek Church Road and installed two new 60" diameter culverts to supplement the existing box culvert.

Repairs to the Walden Pond dam present financial challenges as well as technical issues. The dam is within common area owned by the Walden Place Property Owners Association (POA), which is made up of homeowners in the adjacent subdivision on the north side of the pond. Although the POA did receive a DHEC permit to remove the dam, the capital expenditures needed to remove or fully repair the dam present major financial challenges. Recognizing that many property owners could not reasonably be prepared to finance clean up and necessary repairs in the aftermath of such a disaster, Richland County and other government agencies have provided assistance. The dam is considered a high hazard dam by South Carolina Department of Health and Environmental Control; repairing the structure to some semblance of the pre-storm condition would be very expensive. Seeking alternatives, the County retained WK Dickson to analyze current site conditions, identify potential solutions that emphasize ecosystem restoration, and to evaluate the feasibility of selected alternatives.

The primary objective is to determine the feasibility, cost and timeline required to maintain or improve the pre-breach flood attenuation of the Walden Pond dam through alternative methods which may include, but are not limited to, stream and wetland restoration in the former pond bottom. Other objectives outlined in the Request for Proposals issued by the County in 2018, include:

- Remove current dam from South Carolina Department of Health and Environmental Control (SCDHEC) high hazard list;
- Include the unnamed upstream pond in the study;

- Create a conceptual design for stream and wetland mitigation credits associated with permanent dam removal;
- Determine water quality and habitat benefits to Spears Creek Watershed related to project implementation;
- Create a conceptual design which minimizes the need for maintenance and maximizes aesthetics and structure location/type, with a focus on future public use/access.

Figure 2. Walden Pond dam breach and road washout after October 2015 floods (Google Earth Pro).

This document describes the methods and findings of the various analyses performed to date by WK Dickson at both site and watershed scales. Two basic alternatives are presented that would restore aquatic habitats in the former pond bottom. Variations of both alternatives are considered with corresponding variations in the relative degrees of dam removal both vertically and horizontally. Both alternatives also have the potential to generate compensatory mitigation credits that could be used to offset permitted impacts to regulated streams and wetlands from other County projects or, potentially, sold to other entities.

METHODS

Historic Maps and Aerial Imagery

The site analysis consisted of a review of existing data available through Richland County Internet Mapping (https://www.richlandmaps.com) and historic aerial photographs viewable on Google Earth. Google Earth Pro provides access to images from 26 different dates ranging from January 21, 1994 through April 27, 2020, including eight images from 2015. The images are of varying quality but water level fluctuations are clearly discernable.

Historic United States Geological Survey (USGS) 7.5 Minute Series topographic maps were also analyzed. Spears Creek is mapped on the Killian Quadrangle for the years 1935 and 1937, and on the Messers Pond Quadrangle in 1953 and 1972. Spears Creek and Spears Creek Church are clearly shown on all maps. The 1937 Killian quad shows the Delks Pond upstream, but not Walden Pond. The 1953 Messers Pond quad sheet is based on aerial photographs taken in and 1952 clearly shows Walden Pond at the Spears Creek Church Road crossing, but not the Delks Pond. The 1972 Messers Pond quad is a photorevision of the 1953 map based on 1971 aerial photography; this map shows both ponds. Historic maps inform design alternatives, particularly when evaluating the potential to accurately restore a portion of the landscape to its historic form, i.e. complete dam removal.

Field Assessments and Data Collection

Ambulatory reconnaissance was conducted on multiple occasions by WK Dickson engineers and scientists. Stream channel measurements were collected in September 2018 from Spears Creek including the reach between the two breached dams. Additional data were collected in October 2020 that focused on the Walden Pond breach area and the stream between the breach and the culverts at Spears Creek Church Road. The reach of Spears Creek immediately downstream of the road has also been evaluated qualitatively. The various assessments and the data inform both the potential design alternatives and the modelling efforts.

Hydrologic and Hydraulics Analyses

Numerical simulations of rainfall-runoff processes and channel hydraulics were performed using commercial computer software. A detailed discussion of methods and findings is presented in Appendix I: Summary of Hydrologic and Hydraulic Analyses Spears Creek at Walden Pond.

Compensatory Mitigation

To determine the potential for restoration alternatives to generate stream and/or wetland mitigation credits, the Walden Pond design alternatives were evaluated based on the criteria set forth in the USACE Charleston District Compensatory Mitigation guidelines and associated credit calculation worksheets. The worksheets were completed based on converting the site from a low value open water habitat to high value buffered perennial stream and wetland habitats.

The purpose of compensatory mitigation, as established by the Clean Water Act and clarified by the 2009 Compensatory Mitigation Rule, is to compensate for unavoidable impacts to streams and/or wetlands resulting from a project. Three compensatory mitigation mechanisms have been established: mitigation banks, in-lieu fee programs, and permittee-responsible mitigation.[1] Both mitigation banking and in-lieu fee programs involve the purchase of mitigation credit from private entities or publicly managed banks that have established and restored wetland and stream in previously impacted areas.

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[1] EPA. 2020. Background about Compensatory Mitigation Requirements under CWA Section 404. https://www.epa.gov/cwa-404/background-about-compensatory-mitigation-requirements-under-cwa-section-404. Accessed November 12, 2020.

Permittee-responsible mitigation requires the project permittee to perform wetland and/or stream restoration activities to compensate for unavoidable impacts.

RESULTS AND DISCUSSION

General Watershed Characteristics

Walden Pond is an artificial palustrine open water (POW) created when an earthen dam was constructed, impounding the waters of Spears Creek, south of the Spears Creek Church Rd and Jacobs Mill Pond Rd intersection in Columbia, South Carolina (Project Location Figure). Spears Creek is a second order stream located in the Lower Wateree River 10-digit HUC (0305010404) and situated within the Sand Hills ecoregion of the Southeastern Plains. It is perennial stream as indicated by the USGS 7.5’ topographic quadrangle (USGS Topo Figure). The total drainage area of the watershed to the dam is 3.07 sq miles. (Drainage Basin Figure). The drainage basin is subject to mature residential development along with rapidly developing commercial areas, especially along Two Notch Rd and Clemson Rd at the top of the basin. The terrain is generally comprised of rolling hills with shallow valleys and incised stream due to the amount of urban development. Eighty-seven (87) percent of the watershed is developed urban land, and 33.4 percent is impervious surface. Elevations within the basin range from 310-487’ ASL (above mean sea-level), and mean basin slope is 5.26%.[2]

The Village at Sandhill is a massive retail complex that dominates the northern headwaters of the watershed. Light industrial and commercial development are rapid and active along Clemson Road and Old Clemson Road on the west side of the watershed. Older subdivisions such as Walden Place cover significant areas on the north and southwest parts of the watershed. Other significant land uses include a trailer park and golf course. Forested buffers along Spears Creek proper are generally adequate, ranging in width from 200 to 800 feet. A few areas in the northern part of the watershed have residences within 50 feet.

Current Conditions—Walden Pond

At present, the pond is mostly drained, with approximately 2.6 acres of pool remaining from what historically has been as much as 17 acres of open water (Google Earth Pro, imagery dated 1/29/2012). A fringe of unvegetated mud flat surrounds the remaining pool, varying in width from 10 to 40 feet. The width of unvegetated mud correlates with slope and elevation, with the narrower fringe being adjacent to steeper slopes and closer to higher elevations such as can be found adjacent to the remaining dam. The wider

Figure 3. Lush emergent wetland vegetation has colonized the upper 2/3 of Walden Pond. Also note recent sediment deposition in one of the characteristic braids of Spears Creek.

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[2] USGS Stream Stats. 2020. https://streamstats.usgs.gov/ss/. Accessed November 12, 2020.

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Walden Pond - Spears Creek Drainage Basin

0 700 1,400
Feet
1 inch = 1,400 feet

Figure 5. Recent beaver activity near Walden Place.

mud flats are found near the mouths of tributary streams entering the pond from the south, and these areas are also situated over the natural valley floor as seen on the historic maps. A nascent delta has formed where multiple threads of Spear Creek enter the remaining pool. The delta is comprised of coarser material than the mud flats, mostly fine and medium sized sand grains.The upstream portion of the pond has been thoroughly colonized by emergent wetland vegetation and can be classified as a Palustrine Emergent Wetland (PEM). The vegetation is a diverse array of several sedge, rush and bulrush species that provides outstanding habitat for aquatic organisms and birds. Cattails and canary grass are also common, with cattails often growing around the edges of some of the deeper remaining pools. The vegetation density is high, providing excellent water quality benefits for sediment trapping, nutrient cycling and sequestration of urban runoff pollutants through aerobic and anaerobic biogeochemical processes.

Woody species have also colonized the former lakebed. Willow and buttonbush are common, particularly near the channel braids. Loblolly pine, myrtle and sweetgum are also growing at higher elevations along the margins of the former lakebed. Recent beaver activity was noted along the slopes behind several homes in Walden Place.

The riser and outfall culvert at Walden Pond appear to be in good condition although water no longer enters the structure. Spears Creek now flows easterly through the breach at the southeast corner to the bottom of the dam, which is also near the bottom of the fill slope that supports Spears Creek Church Road. The stream turns abruptly to the north-northwest and flows in the V-shaped area between the dam and the roadway fill slope. The new 60 inch concrete culverts were installed adjacent to the pre-existing box culvert during SCDOT roadway repairs. At the new culverts, which convey flow to the east side of the road, the flow turns sharply to the right (east). As the stream is flowing parallel to the road, flow must turn 90^o to enter the culverts. Pools appear to have been excavated during the repairs to facilitate this unnatural flow path. Significant amounts of sediment and woody debris have accumulated in the pools and culvert openings, and sediment deposition in the old box culvert severely restricts hydraulic capacity.

Figure 6. New 60" RCPs at repaired crossing of Spears Creek Church Road. Note sediment deposition in older box culverts under car at right and side channel at bottom right. View is upstream from the east side of roadway.

The dam failure appears to have originated at the emergency spillway at the southeast corner of the dam. Erosion through the breach was not uniform: erosion on the upstream face of the dam ranged from 90 to 150 feet with the greater erosion higher up the embankment. At the crest, the width of the breach is about 75 feet while lower on the downstream face the breach is approximately 50 feet wide. A cross section measured through the breach is shown in Figure 8. The section was measured approximately along the line of a 6” diameter PVC pipe that was exposed and broken during the flood, but remnants of which lie nearly normal to the orientation of the dam and are visible on aerial images.

Figure 7. Southeasterly view through dam breach. Note active rilling of northern embankment and sparse vegetation along channel.

<u>Current Conditions—Spears Creek</u>

The Walden Pond dam failure is not the only forcing mechanism affecting the Spears Creek system. The failure of the Delk dam and the ensuing channel response are major factors bearing on the Walden Pond problem. In addition, any potential solutions for Walden Pond must consider potential effects to Spears Creek downstream of the roadway. Therefore, the following assessment breaks Spears Creek into five broadly defined reaches:

1) From the drained pond above Delk dam downstream to the Dominion right-of-way;
2) The forested reach from the Dominion right-of-way to the upstream end of Walden Pond;
3) Spears Creek through Walden Pond to the dam;
4) The ‘breach reach’ through the dam to the culverts at Spears Creek Church Road;
5) East of Spears Creek Church Road on property owned by DLH Preserve at Spears Creek.

Reach 1: Delk Pond to the Dominion Gas Line

Spears Creek flows northwest to southeast through the Delk property. The pond is shown on the 1937 USGS Killian Quadrangle. The 1953 Messers Pond Quadrangle does not show a pond, but maps Spears Creek along the southwest side of the natural valley and shows unforested land on the northeast side of the stream. The pond is again mapped on the 1972 quad sheet. This is significant because, in response to the failure of Delk dam, Spears Creek has eroded a channel through the former pond bottom, and that channel is located along the southwest side of the valley.

Sediment would have accumulated behind Delk dam for decades, at least since 1972, and would have filled the historic channel. Much of that sediment would have been released when the dam failed and carving a new channel would send additional sediment downstream. However, if Spears Creek has already worked its way into its historic channel, then less sediment will ultimately be sent downstream. Sediment loading is a critical driver of hydraulic geometry and must be considered in restoration design.

While the channel may be largely stable, the adjacent landscape is not. Vegetation in the formerly impounded area is very sparse. Rills and gullies are actively cutting into the valley side slopes. The channel appears to be transporting the upland sediment; no problematic in-channel storage was observed. Alder and willow are colonizing the banks, which should increase lateral stability.

Figure 8. Rills and gullies contribute high sediment loads to Spears Creek at the former Delk pond, but no in-channel deposition is evident.

Reach 2: Dominion Gas Line to Upper End of Walden Pond

Observations of Reach 2 are limited. The valley floor is forested. Some sediment from the breach was deposited on the floodplain appears to be stable.

Reach 3: Spears Creek through Walden Pond

Much of the sediment stored behind Delk dam, and from the dam itself, appears to have been transported to the upstream portion of Walden Pond. The channel slope measured from the 1937 topography was 0.0032 ft/ft (0.32%). Slope measured using the 2 foot contours of Richland County GIS is 0.002 ft/ft. Both are very low slopes that result in very low stream power and, given a relatively high sediment load, a transport-limited stream. These conditions explain the loss of competence and resultant deposition.

Braided channels typically form when the sediment supplied to a stream greatly exceeds the transport capacity of the stream, and such is the case in Walden Pond. As shown in Figure 10, Spears Creek is a braided system where it flows across the former pond bottom. A similar pattern is evident in the upper pond (not pictured) up to the tree line that delineates the upper boundary of this reach. Braided streams are highly dynamic as higher flows spread across the valley floor and work the sediments across and down valley. Due to the controlling influence of vegetation on streams in the eastern U.S., braided conditions are usually a transient response to episodic disturbance, as is the case here.

As can be observed in Figure 10, a larger channel carries much of the flow along the north side of the pond bottom. Brighter spots indicate sediment stored within this channel as (predominantly) lateral bars. This larger channel turns to the south above the remnant pool and loses all competence where local base level is encountered, producing a classic prograding delta. Observations in the field are confirmed on the aerial image: smaller channels, some of which exhibit bar storage, converge, intersect and diverge with the mainstem. It is hypothesized that this system is trending toward a single thread stream, although two or more other channels may persist as anabranches.

Other channels in the middle of the pond bed and south of the mainstem flow directly into the remnant pool. Many of these smaller channels also intertwine, but in this case the connections are no

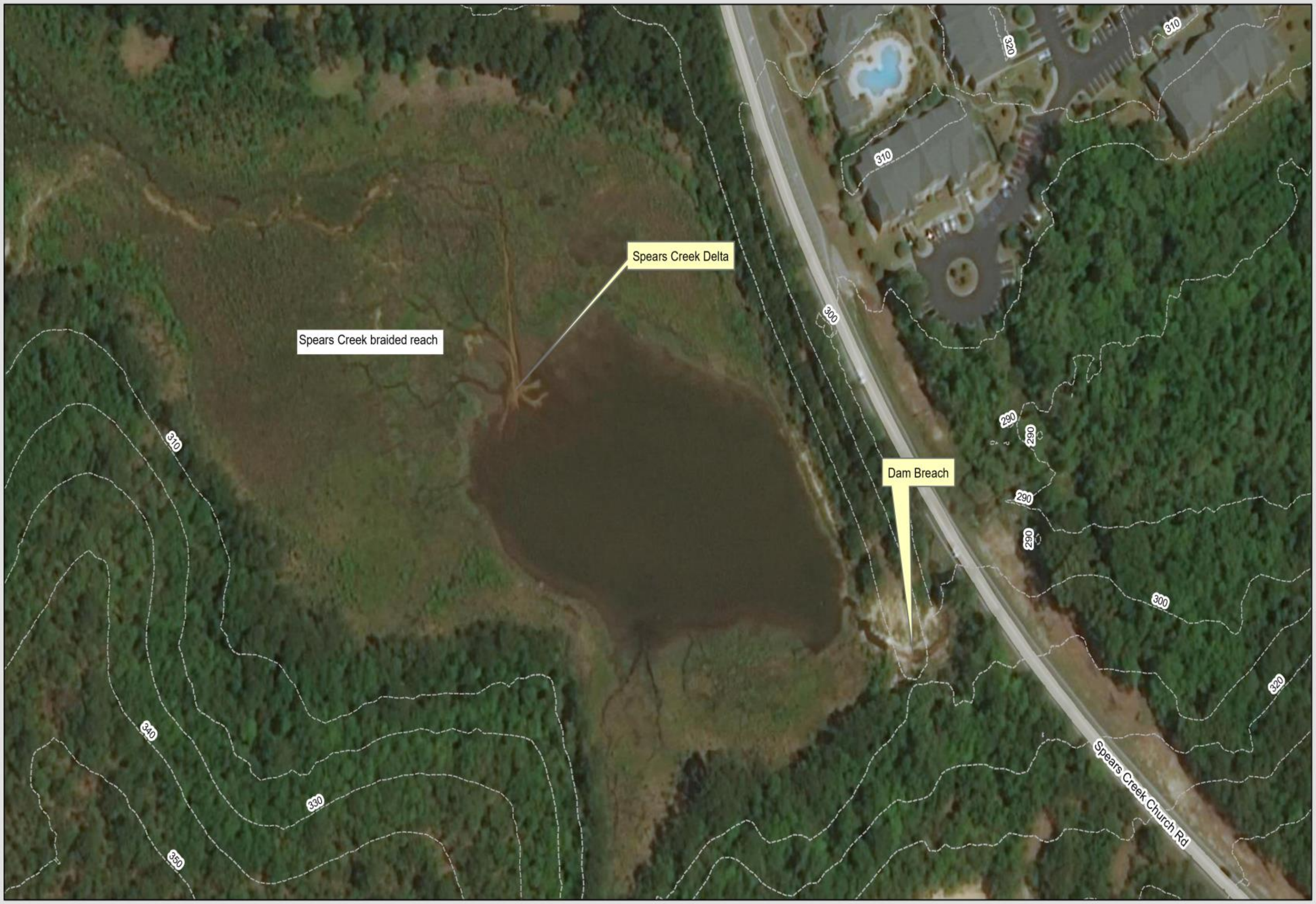

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Figure 10. Fluvial Features in Walden Pond

longer driven by high sediment loads. These channels are far enough away that morphology and process are not significantly driven by sediment load. It is surmised that these channels are vestigial and primarily collect and convey groundwater from the expansive wetland to the west.

Reach 4: 'Breach Reach' Through the Dam to Spears Creek Church Road

The new stream channel through the breach ranges from 8 to 24 feet in width, with the narrower segments corresponding to the localized steep gradients on the downstream face of the dam. The bed and bank materials of the channel are Cretaceous clays common to the region. The clay appears to be *in situ*. Two clay pits are mapped within one mile of Walden Pond on the 1972 topographic map, and the elevations indicated suggest the clay deposits probably underlie the dam. In addition, the dam material as seen at left in Figure 8 is yellowish-tan in color and contains fine sand and silt.

Through the breach, sediment transport capacity greatly exceeds sediment supply. No sediment is stored within the channel. No depositional features were observed on the relatively flat ground immediately adjacent to the channel, and vegetation in this area is extremely sparse. The overbank areas are erosional surfaces inundated by fast moving water several times per year. As will be discussed below, the hydraulic geometry of the stream is not consistent with the contributing drainage area. The stream is not in a quasi-equilibrium state and is actively adjusting the hydraulic geometry. A cross section measured through the dam breach is shown in Figure 11.

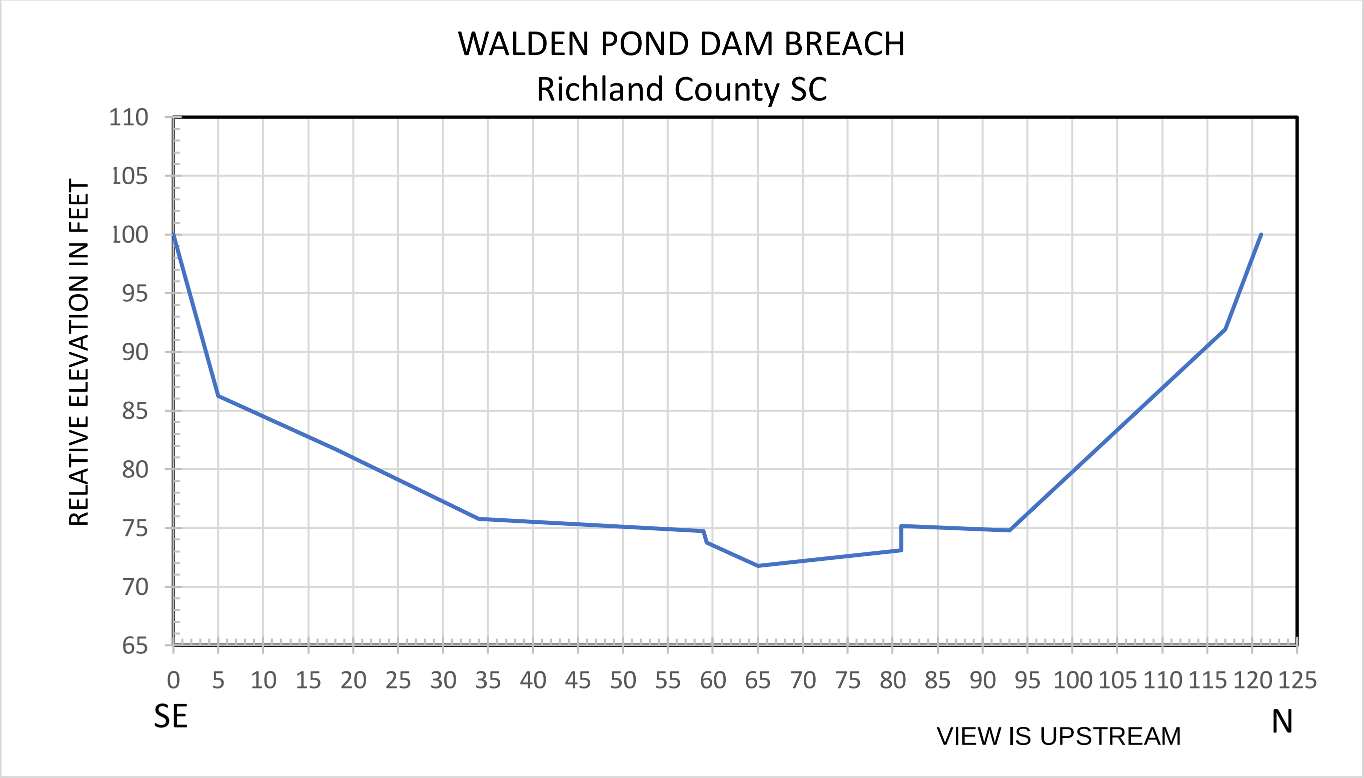


Figure 10. Cross section measured through the breach at Walden Pond dam.

The course of Spears Creek is aberrant, contained not within a natural valley but rather between remnants of the dam and a roadway built on fill. While the emergency spillway was constructed very close the where Spears Creek was mapped in 1937, the landform has been drastically altered. As described above, Spears Creek now flows easterly through the breach to the bottom of the dam, which is also near the bottom of the opposite-facing fill slope that supports Spears Creek Church

Road. The stream turns abruptly to the north-northwest and flows in the V-shaped erstwhile roadside ditch between the dam and the roadway fill slope, from there making another unnaturally abrupt turn to the east and through the culverts.

The current channel alignment directs flow at the roadway. While the channel turns to a northerly direction at the toe of the failed dam, high flows are likely to impose significant force on the road structure. In addition, the misalignment of the culverts to the channel flow has caused significant sedimentation and debris accumulation. Lacking design capacity and with nowhere else for floodwaters to go, the roadway could easily be overtopped. Overtopping could again contribute to a total failure. Therefore, a design imperative is to properly align the channel with the culverts for hydraulic efficiency and reduced erosional forces on the roadway embankments.

Figure 11. Sediment and debris blocking culvert upstream of Spears Creek Church Road .

Reach 5: East of Spears Creek Church Road

When the roadway failed (Figure 2) sediment from the breach and pond was carried downstream and deposited across the valley floor. What was previously mapped as a single thread channel is now a multi-thread system that appears to be evolving from braided to anabranched. The forested stream valley had been dominated by tall yellow poplar trees (*Leriodendron tulipifera*). Yellow poplar trees are particularly sensitive to sedimentation; many of the trees have now died.

DESIGN ANALYSIS

Several factors must be considered in the development of viable alternatives for remedial action. First are the County's objectives as listed above. Perhaps the biggest challenge is reconciling the inherent conflict between the primary objective to "maintain or improve the pre-breach flood attenuation of the Walden Pond dam" while also removing the dam from the DHEC high hazard list. Dams are very effective flood attenuators, and higher dams usually store more water. From a FEMA perspective, however, Walden Pond did not store water. The alternatives described below would rely on restored wetland complexes to increase flood attenuation above the current condition, but, the vagaries of FEMA modelling notwithstanding, the actual flood storage will be less than what the pond should have stored before the dam failed.

Some other factors to consider are related to natural geomorphic processes. The dam breaches at Delk and Walden Ponds are considered perturbations to previously stable landscapes. The perturbations have altered channel hydrology, sediment supply, sediment transport capacity and channel locations. Streams respond to disturbance by altering the hydraulic geometry to accommodate the post-disturbance sediment and hydrologic regimes. We are certain that the system will respond and naturally depart from the current conditions described above. The response will harness natural geomorphic processes (erosion and deposition) at accelerated process rates. During the course of adjustment, it is certain that:

- Stored sediment will be mobilized;

- Channels will erode, over time, to that hydraulic geometry that most efficiently transports the water and sediment delivered from upstream;
- High sediment flux will translate in waves down the system, inducing adjustments to the adjustments;
- Lacking anthropic intervention, the landscape will be active for several decades.

It should also be noted that natural landscape response will put public safety at risk and threaten a major arterial road. Thus the "do nothing alternative", consideration of which is often required, is not an advisable course of action.

Channel Hydrology

In restoration practice streams are typically sized to convey the "bankfull flow". Bankfull can be defined as the flow that fills the channel. In a natural stream system, the bankfull corresponds closely with the dominant discharge and the effective discharge, both of which require rather rigorous calculation. On average, bankfull flows occur about once per year. On the Annual Peak Duration Series the typical recurrence interval in the Eastern U.S. is about 1.5. Physical indicators of the bankfull stage can be readily identified in the field on a natural stable channel in a stable watershed. Those features, such as bankfull width and depth, result from protracted periods of consistent delivery of water and sediment to the stream. Over time, the system adjusts the hydraulic geometry to accommodate those inputs.

Bankfull discharge is not estimated for Spears Creek nor used as a design criterion for several reasons. First, the watershed remains dynamic. Spears Creek is not a stable channel in a stable watershed, so the extension of concepts deriving from bankfull flow is not appropriate . As has been described, sediment flux will be an issue for several years as materials from the Delk dam failure translate through the system. In addition, the watershed is not stable. Relatively new develop projects have altered the amounts, timing and locations of water delivery to the channel. Streams invariably respond to development by channel enlargement, the directions and timing of which can usually be predicted given the necessary data (Hammer, 1980). However, sufficient time has not yet elapsed for Spears Creek to naturally respond and the adjustment processes are complicated by the dam failures. Finally, development is ongoing. Dams and ponds aside, Spears Creek should be expected to alter the hydraulic geometry for decades after the watershed is completely built out and stabilized.

The resultant hydrologic uncertainty is addressed differently in each of the alternatives described below, but the basic inputs are the same. Designing streams for the bankfull flow has produced inconsistent results in the eastern U.S. Long experience has shown that streams in developed watersheds are subjected to flashy storm hydrology that produces a broader range of flows and flow durations that a "restored" stream must accommodate while maintaining lateral and vertical stability. In urban watersheds WK Dickson typically focuses of the range of flows bounded by the *geomorphically significant flow* and the hypothetical flow predicted from the 2-year 24-hour rainfall event on ultimate build-out conditions.

The geomorphically significant flow is the flow that commences the geomorphic work of erosion and sediment transport. For conceptual designs this flow is generally approximated as $0.66*Q_2$, where Q_2 is the 2-year peak discharge estimated from USGS regression equations under current watershed conditions. The hypothetical flow from the 2-year 24-hour rainfall event on ultimate build-out conditions is derived from standard engineering modeling software. While analyses of these discharges drive the basic channel dimensions, other large events (e.g. Q_5, Q_{10}, Q_{100}) are also considered as appropriate for regulatory compliance, culvert design, floodplain management and related engineering purposes. The table below describes discharges evaluated for restoration design purposes. Other hydrologic and hydraulic analyses are presented elsewhere in this document.

Modelled flows

Modelled Storm (6-hr)	Peak Flow (cfs)		
	Pre2015	Existing	Future
2-year	82	337	433
5-year	143	609	733
10-year	202	857	930
50-year	296	1503	1919
100-year	606	2248	2628

USGS stream flow estimates (StreamStats)

Recurrence	Urban Discharge (cfs)			Rural (cfs)
	Low Est	High Est	Value	
2 Year Peak Flood	421	1580	692	60.2
5 Year Peak Flood	647	2210	911	103
10 Year Peak Flood	1110	4270	1050	135

Because bed and bank materials are naturally *in situ*, the USGS rural regression equation best predicts the flow that will move that sediment. For Walden Pond that would indicate 0.66*60.2 is the appropriate arithmetic, which provides 39.7, or about 40 ft_3/second as the geomorphically significant flow.

Channel Hydraulics

As described in Appendix I, channel hydraulics were simulated using the SWMM Hydraulic Model. Conditions analyzed included intact dam (pre-breach), current conditions (existing breach) and the two restoration alternatives described below. Complete results are presented in the Appendix, but the salient finding is that, for both the multi-thread stream and wetland complex described as Alternative 1 and the single-thread stream restoration described as Alternative 2, velocities during modeled storm events were below 5 ft/second. Average velocities in stable natural channels at bankfull stage are typically 4 to 5.5 ft/second. Therefore, based on the analyses completed to date, both design alternatives should be expected to be physically stable.

RESTORATION ALTERNATIVES

Alternative 1: Multi-Thread Stream and Wetland Complex

As stated above, the controlling influence of vegetation on streams in the eastern U.S., generally stabilizes braided systems. Typically, in the east, the sediment supply-sediment transport imbalance that causes braiding is episodic. Braided conditions typically resolve to a single thread channel as vegetation stabilizes the banks and reduces the width-depth ratio, which improves sediment transport efficiency. In low gradient valleys like Spears Creek, the stable endpoint is often an anastomosed channel, in which multiple, highly stable channel threads are intertwined. Another potential endpoint is an anabranching system, where multiple stable threads flow downstream but intersect less frequently with other channels in the system.

Historic maps and aerial photographs document that Spears Creek should naturally be a single-thread channel. However, the natural conditions did not include an overabundance of fine sediment. The multi-thread stream and wetland complex mimics the stable response of streams throughout the Carolinas that were subjected to immense valley sedimentation as a result of antebellum agricultural practices. Many of these systems developed anastomosed channels and associated wetland forests that persisted until second -wave agriculture re-cleared the forests and channelized the streams to maximize tillable ground.

As shown in Figures 11 and 12, the conceptual design would preserve existing emergent wetland habitats and leave small pockets of open water. The existing channels upstream of the current pool would mostly be left to adjust naturally but would be constrained from excessive downcutting and concomitant increase in sediment by wood structures that would maintain the present low energy gradients. Wetland hydrology would be mostly conserved by maintaining the current marsh elevations as much as possible.

Flood conveyance is a secondary priority in favor of flood storage across the valley floor wetland system. This alternative also maximizes habitat diversity, and some colonization by woody trees and shrubs should be expected over time. However, by preserving or establishing broad variation in water depths a wide variety of vegetation will be sustainable. More construction effort would go into complex habitat types than channel revetments.

Downstream at the dam, the existing breach would be widened to accommodate a cascade/step-pool complex that would dissipate energy vertically while bringing the streambed down to the elevation of the culverts. Boulder cascades and step-pools do not naturally occur in the Coastal Plain geology; however they can be constructed here as an aesthetic amenity that also ensures robust channel stability.

In addition, marsh sills are shown on the concept plan view and in Figure 13. The sills were primarily conceived to increase flood attenuation and would be strategically located to dissipate energy from high flows. The sills would also provide stable access for construction equipment. Finally, the sills can be configured to enhance recreational opportunities. Connections between sills that might not be required for engineering or habitat purposes can be installed to improve pedestrian access. This sills can also be expanded at strategic locations for wildlife viewing or picnic spots.

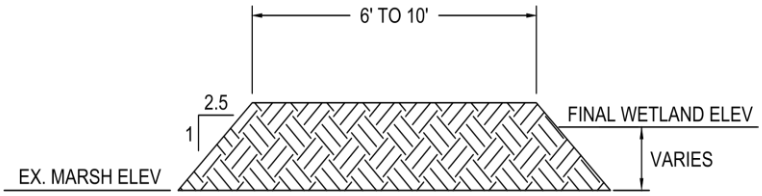
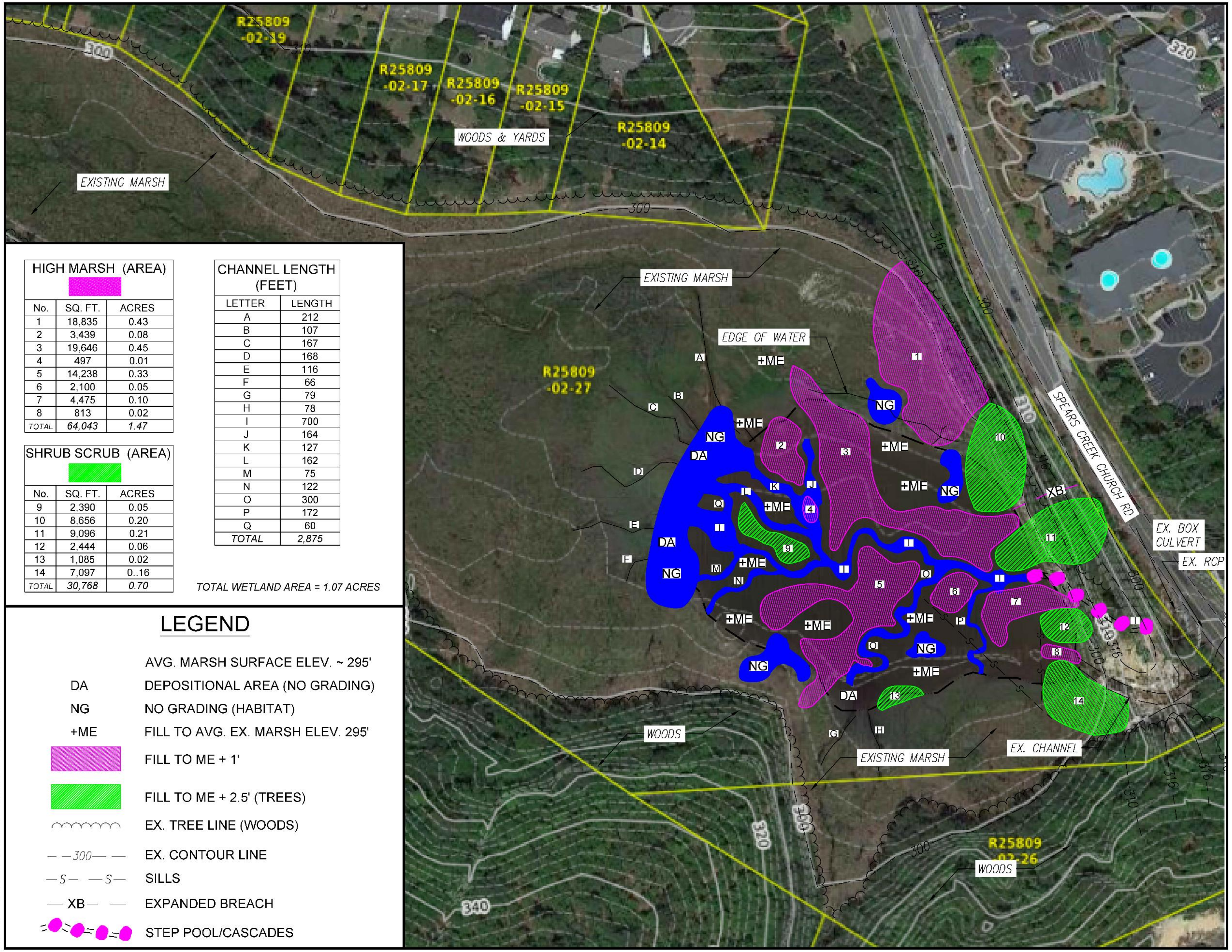


Figure 12. Marsh sill typical detail.



HIGH MARSH (AREA) ▨

No.	SQ. FT.	ACRES
1	18,835	0.43
2	3,439	0.08
3	19,646	0.45
4	497	0.01
5	14,238	0.33
6	2,100	0.05
7	4,475	0.10
8	813	0.02
TOTAL	64,043	1.47

SHRUB SCRUB (AREA) 🟩

No.	SQ. FT.	ACRES
9	2,390	0.05
10	8,656	0.20
11	9,096	0.21
12	2,444	0.06
13	1,085	0.02
14	7,097	0..16
TOTAL	30,768	0.70

CHANNEL LENGTH (FEET)

LETTER	LENGTH
A	212
B	107
C	167
D	168
E	116
F	66
G	79
H	78
I	700
J	164
K	127
L	162
M	75
N	122
O	300
P	172
Q	60
TOTAL	2,875

TOTAL WETLAND AREA = 1.07 ACRES

LEGEND

	AVG. MARSH SURFACE ELEV. ~ 295'
DA	DEPOSITIONAL AREA (NO GRADING)
NG	NO GRADING (HABITAT)
+ME	FILL TO AVG. EX. MARSH ELEV. 295'
▨	FILL TO ME + 1'
🟩	FILL TO ME + 2.5' (TREES)
⌒⌒⌒⌒⌒	EX. TREE LINE (WOODS)
— —300— —	EX. CONTOUR LINE
—S— —S—	SILLS
— XB — —	EXPANDED BREACH
●=●=●=●	STEP POOL/CASCADES

N

SCALE: 1"=60'

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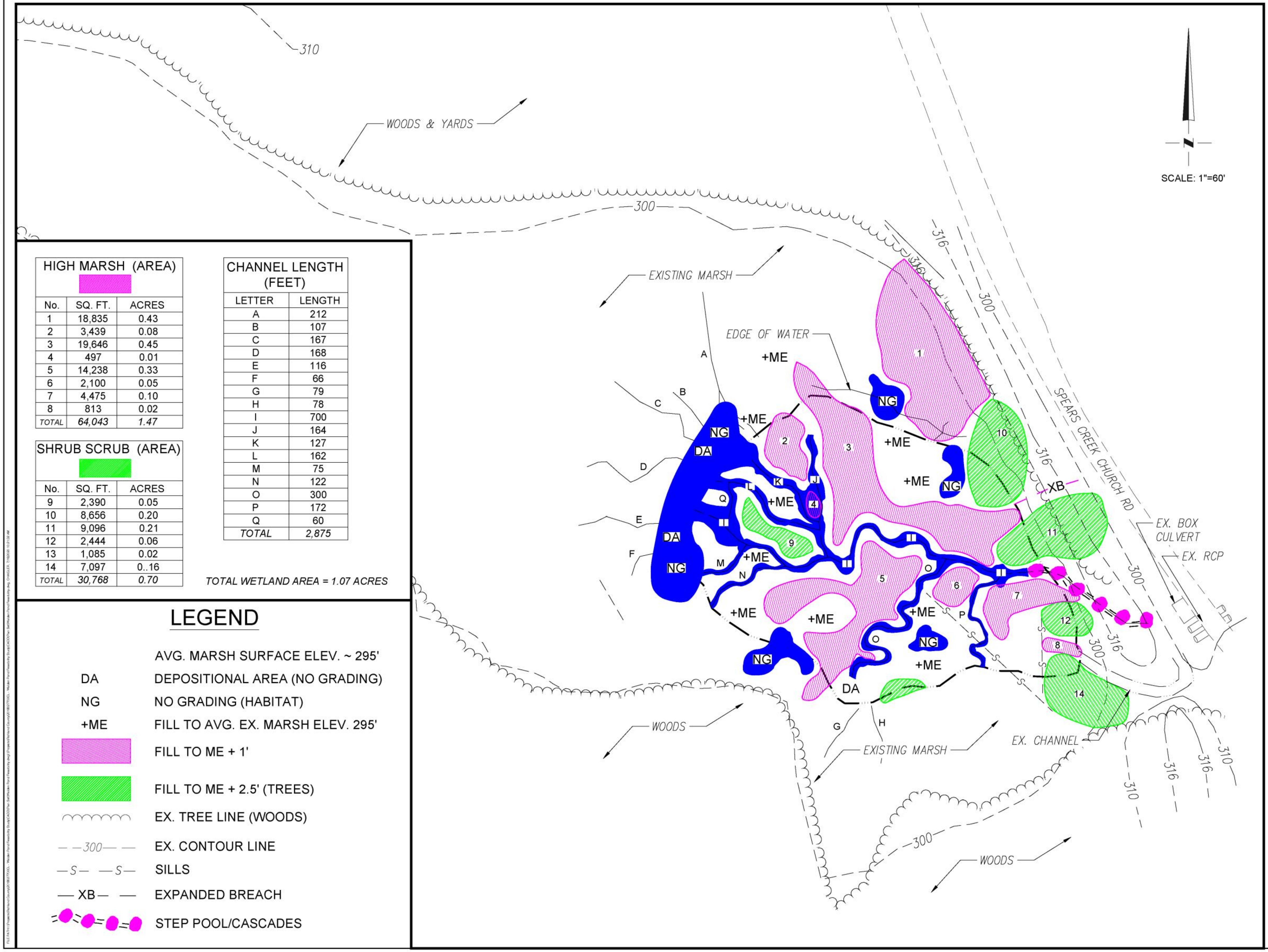
WALDEN POND CONCEPT DESIGN
Alternative 1

RICHLAND COUNTY
SOUTH CAROLINA

Figure 11. Alternative 1: multi-thread stream and wetland complex.



HIGH MARSH (AREA) 🟪		
No.	SQ. FT.	ACRES
1	18,835	0.43
2	3,439	0.08
3	19,646	0.45
4	497	0.01
5	14,238	0.33
6	2,100	0.05
7	4,475	0.10
8	813	0.02
TOTAL	*64,043*	*1.47*

SHRUB SCRUB (AREA) 🟩		
No.	SQ. FT.	ACRES
9	2,390	0.05
10	8,656	0.20
11	9,096	0.21
12	2,444	0.06
13	1,085	0.02
14	7,097	0..16
TOTAL	*30,768*	*0.70*

CHANNEL LENGTH (FEET)	
LETTER	LENGTH
A	212
B	107
C	167
D	168
E	116
F	66
G	79
H	78
I	700
J	164
K	127
L	162
M	75
N	122
O	300
P	172
Q	60
TOTAL	*2,875*

TOTAL WETLAND AREA = 1.07 ACRES

LEGEND

	AVG. MARSH SURFACE ELEV. ~ 295'
DA	DEPOSITIONAL AREA (NO GRADING)
NG	NO GRADING (HABITAT)
+ME	FILL TO AVG. EX. MARSH ELEV. 295'
🟪	FILL TO ME + 1'
🟩	FILL TO ME + 2.5' (TREES)
⌒⌒⌒⌒	EX. TREE LINE (WOODS)
— —300— —	EX. CONTOUR LINE
—S— —S—	SILLS
— XB — —	EXPANDED BREACH
●=●=●=●	STEP POOL/CASCADES

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WALDEN POND CONCEPT DESIGN
Alternative 1

RICHLAND COUNTY
SOUTH CAROLINA

Figure 12. Alternative 1: Multi-thread channel stream and wetland complex

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WALDEN POND CONCEPT DESIGN
ALTERNATIVE 2

RICHLAND COUNTY
SOUTH CAROLINA

Figure 14. Design Alternative 2: single thread channel.

Alternative 2: Single Thread Stream Restoration

As shown in Figure 14, the second alternative is a more conventional restoration of both Spears Creek and the tributary from the south to single thread meandering channels. The channel was designed to convey 575 ft^3/second. This flow is intended to provide significant in-channel sediment storage, which will reduce capacity to some degree, but reduce bank cutting in response to transient bar formation. The 2-year flows from the hydrologic analyses were the main drivers behind this design discharge. While 30% higher than the modelled discharge at build out, we anticipate the channel will self-adjust to the gradual reduction in sediment flux. In other words, the channel will be a short-term sediment sink. The design flow is also lower than the USGS regression value of 692 ft^3/second although higher than the USGS low estimate of 421 ft^3/second. The USGS regression equations are derived from thousands of data points from watershed with tremendous variation in the degree of urbanization (percent impervious surface) and landscape history, so the design value is comfortably within the range. In addition, the Spears Creek valley is generally well forested and our assessment of parcel data and topography suggests much of the forest buffer will remain intact through build-out. Finally, the vast wetlands area owned by the Walden Pond POA is not developable, and therefore can be expected to absorb the energy of high flood flows.

The cross sectional geometry is shown in Figure 15. The width:depth ratio of 10 to facilitate sediment transport through straight reaches. The meander cross section is for an oversized pool to accommodate sediment storage on the point bars. It should be expected that, over time, deposition on the point bars will be colonized with vegetation. The 36 ft design width will be reduced and the slopes of the point bars will steepen. Dune height was estimated to be approximately 0.6 ft. Dune height may become significant because most of the sediment load is expected to be sand, most of which will move along the bed in wave form. Dune height estimates should be revised with more detailed particle size data as the design process progresses.

The conceptual design presented here would expand the dam breach to allow the stream to flow directly into the culverts at Spears Creek Church Road. As presently rendered, the elevation difference between the culverts and the upstream end of the stream would be distributed evenly along the entire channel length. This is probably the most cost-effective approach for both design and construction. Alternatively, the single-thread channel can be designed to include some cascade/step-pool features close to the road.

A single thread channel design must also address the tributary entering the old pond from the south. Presently, flow from this tributary enters the remnant pool. The drainage area for the tributary is just under 20 acres. A concept design was developed to convey 35 ft^3/second. Again, the channel is oversized, in this case both to accommodate sediment and also because of recent and anticipated development over a significant portion of the drainage area. As shown in the typical cross section below, the design depth is 1.25 feet. This shallow channel should help support the continued viability of emergent wetland vegetation on its floodplain. The dune height estimate for the south tributary is 0.16 ft. but is less important for this channel because it is not expected to receive large amounts of stored sediment.

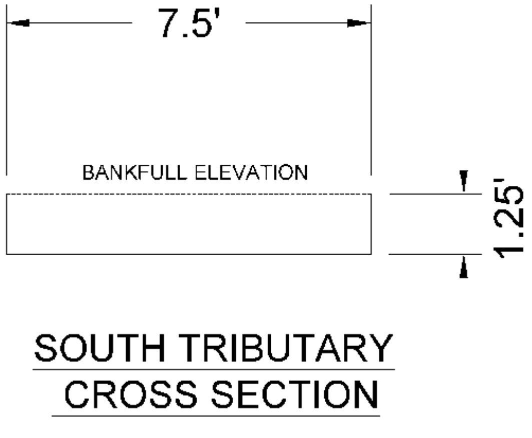


Figure 16. South tributary typical cross .section.

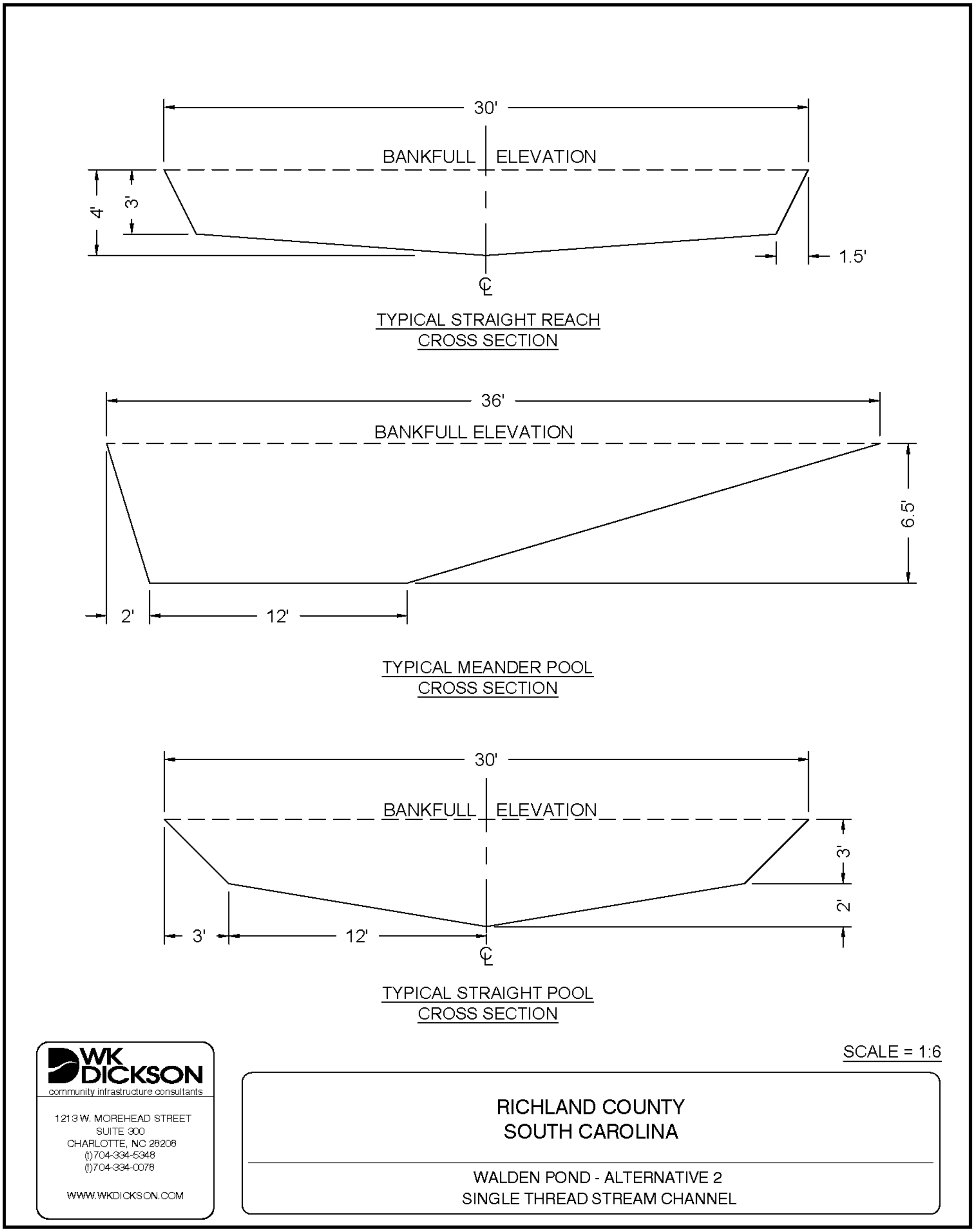


Figure 17. Spears Creek typical design sections.

COMPENSATORY MITIGATION ANALYSIS

In order to determine the feasibility of the proposed restoration to generate stream and wetland restoration credits, the Walden Pond site was assessed based on the criteria set forth in the USACE Charleston District Compensatory Mitigation guidelines and associated credit calculation worksheets. The worksheets were completed based on the conversion of the site from a low value open water habitat to high value buffered perennial stream and wetland habitat. Two alternatives were considered for this project: restoration of an anabranched system with a diverse riparian wetland complex (Alternative 1) or the restoration of the historic single thread channels for Spears Creek and the tributary immediately upstream of the failed dam (Alternative 2). Herbaceous wetland will be created as herbaceous wetland vegetation will naturally colonize in the newly drained riparian areas of the proposed channels.

Alternative 1: Multi-Thread Stream and Wetland Complex

An anabranched, multiple thread channel system, containing 2,875 lf of restored channel is proposed. Based on the results of the stream credit determination worksheet, this would result in the creation of 12,736.25 stream restoration credits. Stream credits were determined assuming this project will achieve maximum net improvement of a tertiary, 1st or 2nd order RPW located within the same 8-Digit HUC. Furthermore, a total of 2.17 acres of both herbaceous and scrub/shrub wetland will be restored in the footprint of the former open water. This a wetland restoration resulting in an in-kind, maximum net improvement within the same 8-digit HUC and would result in the creation of 9.321 wetland restoration credits. Based on rates for stream and wetland credits at mitigation banks in the Columbia area, each stream restoration credit generated would be worth approximately $200 and each wetland restoration credit would be worth approximately $20,000. This alternative would generate 12,736.25 credits worth approximately $2,547,250 and 9.321 wetland restoration credits worth $186,420. However, it should be noted that credit valuations are established by the USACE on a case-by-case basis, based upon the quality of the restoration. Results are summarized in Table 1 and the attached mitigation worksheets.

Alternative 2: Single Thread Channel

One thousand seven (1,007) linear feet of stream channel is proposed with riparian buffer consisting of forested upland and forested and herbaceous wetland extending well over 200 lf on all sides of the proposed stream channel. Stream credits were determined assuming this project will achieve maximum net improvement of a tertiary, 1st or 2nd order RPW located within the same 8-Digit HUC. 1.89-acres of riparian wetland consisting of primarily herbaceous wetland are proposed as well. This a wetland restoration resulting in an in-kind, maximum net improvement within the same 8-digit HUC. Based on the results of the restoration mitigation worksheet, we propose 4,461.01 stream restoration credits be awarded and 8.127 wetland restoration credits be awarded. Based on rates for stream and wetland credits at mitigation banks in the Columbia area, each stream restoration credit generated would be worth approximately $200 and each wetland restoration credit would be worth approximately $20,000. This alternative would generate 4,461.01 credits worth approximately $892,202 and 8.127 wetland restoration credits worth $162,540. However, it should be noted that credit valuations are established by the USACE on a case-by-case basis, based upon the quality of the restoration. Results are summarized in Table 1 and the attached mitigation worksheets.

Table 1. Summary of Mitigation Credit Results

	Alternative 1	Alternative 2
Stream Channel Restored (lf)	2,875	1,007
Wetland Area Restored (ac)	2.17	1.89
Stream Restoration Credit	12,736.25	4,461.01
Wetland Restoration Credit	9.321	8.127
Stream Credit Value ($)	2,547,250	892,202
Wetland Credit Value ($)	186,420	162,540

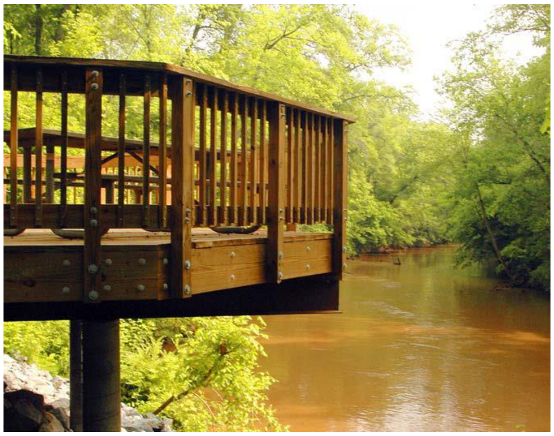
Challenges to Generating Mitigation Credits

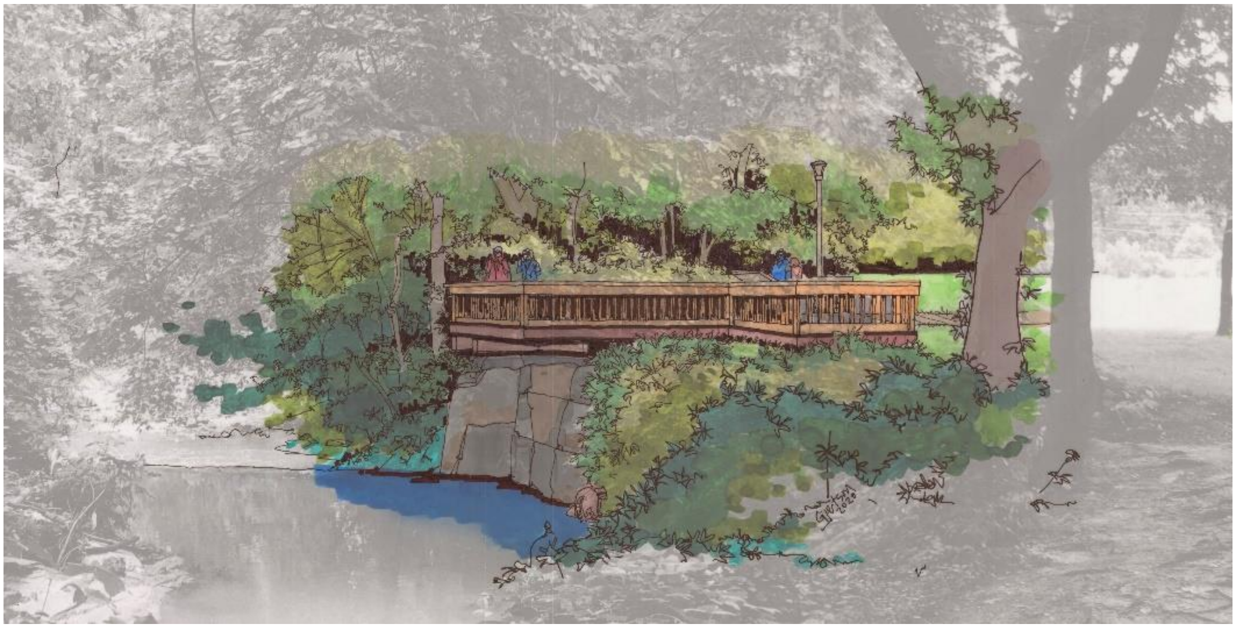
Several challenges do exist to the generation of credits with either of these proposals, and significant coordination with the USACE will be necessary to ensure that either alternative will generate the proposed credit.

- Natural colonization of wetland vegetation is expected to occur rapidly after construction of the stream channel in Alternative 2, and mitigation credit may not be awarded at standard ratios.
- There is no standard credit structure for anabranched systems as compared to single channel systems, so credit may not be given for the entire length of channel constructed in an anabranched system.
- Alternative 2 may result in the loss of wetlands upstream of the restoration area as the single thread channel could lower the water table and drain a significant area of currently existing wetland. The loss of wetland may counterbalance the creation of new wetland in this alternative, and no wetland credit would be awarded.

AMENITIES

Both of the alternatives can be augmented with features to promote public use and recreation at the restoration site. A small parcel on the south side of the dam is owned by the POA and accessible from Spears Creek Church Road to provide some parking. From this property, hiking trails can access whatever restoration may ultimately be implemented. In addition to hiking trails, most common amenities for such projects are overlooks and wildlife viewing areas. If potential amenities are identified up front, the restoration can easily be designed to facilitate future construction as funding becomes available.





CONSTRUCTABILITY

Both alternatives were developed with attention to construction issues common to aquatic resource restoration. The following common problems were identified and considered:

- Access: three access points were identified south of the pond, all of which are could easily be improved for get construction equipment to the site. Access across and through the site would typically require bog mats or geogrids. The marsh sills suggested for energy dissipation can be laid out to also improve equipment access for construction.
- Utility conflicts: as shown in Figure 18 (below) no utility conflicts are apparent based on existing data.
- Fill material: both design alternatives would require some fill material to raise the bottom of the drained pond. Preliminary estimates indicate that over 11,000 yds^3 could be harvested by complete removal of the dam.
- Vegetation success: revegetation is often a challenge for restoration projects. Emergent wetland vegetation, willows, buttonbush, and alder have rapidly colonized the pond area based on hydrology, demonstrating that an abundant seed bank exists.

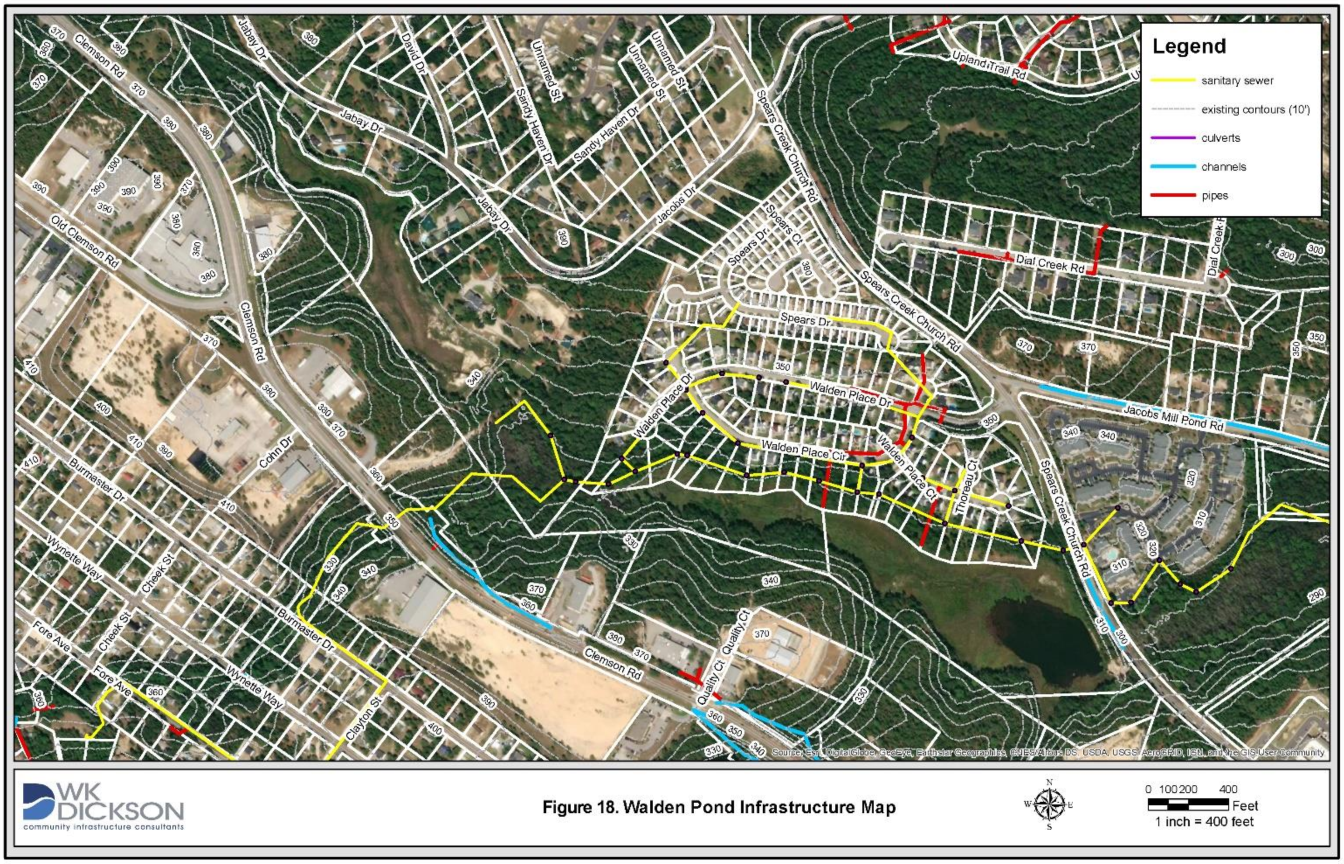


Figure 18. Walden Pond area infrastructure map.

COST ESTIMATES

Planning level costs were estimated for implementation of both options and are shown in Table 2. Costs estimated for Survey and Engineering Design assume no geotechnical borings will be needed. Note that the hydraulics analysis completed to support the described in Appendix I is sufficient to support FEMA permitting, including No Rise certification or a Conditional Letter of Map Revision. While the estimates provided below include preparation of all relevant permitting applications and supporting documents, any fees required for permitting are not included in the estimates below. Finally, it should be noted that construction prices are very dynamic. Ecosystem restoration is a specialized type of construction and experienced crews are often in high demand, which can temporarily drive up costs.

Table 2. Preliminary cost estimates for ecosystem restoration at Walden Pond.

Walden Pond Restoration Preliminary Cost Estimates

	Alternative 1		Alternative 2	
Task Description	Unit Price	Extension	Unit Price	Extension
Survey and Engineering Design	N/A	$280,000	N/A	$265,000
FEMA and USACE Permitting	LS	$52,000	LS	$52,000
Mitigation Coordination (hourly)	N/A	TBD	N/A	TBD
Conventional Stream	$220	$592,152	$325	$327,275
Stream Step-Pool/Cascade	$850	$155,890	N/A	N/A
Total Stream Construction	N/A	$748,042	N/A	$327,275
Wetland Construction	$26,800	$58,156	$26,800	$50,652
Total Stream + Wetland Construction	N/A	$1,554,240	N/A	$377,927
Construction Support Services	N/A	$32,500	N/A	$28,000
Total Cost	$1,918,740		$722,927	

FINAL CONSIDERATIONS

Two alternatives are presented that advance the County’s objectives. Each alternative has its relative strengths and weaknesses. Some additional factors that the County may wish to consider in determining its priority solution include:

- Timing: because regulatory permitting aspects of single thread channels are fairly well established and consistent, agencies are likely to process a permit application for the single thread option more efficiently that the anabranched stream and marsh complex.
- Constructability: the very large rocks needed for a cascade/step-pool channel can get expensive. They are a custom quarry product that will get a truck to its weight limit long before volumetric capacity is reached. In addition, the heavy equipment needed to handle and place such rocks will be at least one if not two classes larger than the equipment needed for other stream and wetland construction activities.
- Realigning the channel to reduce risks to Spears Creek Church Road can be accomplished as a separate project.

APPENDIX I

SUMMARY OF HYDROLOGIC AND HYDRAULIC ANALYSES
SPEARS CREEK AT WALDEN POND

May 20, 2021

WK DICKSON
community infrastructure consultants

SUMMARY OF HYDROLOGIC AND HYDRAULIC ANALYSES
SPEARS CREEK AT WALDEN POND

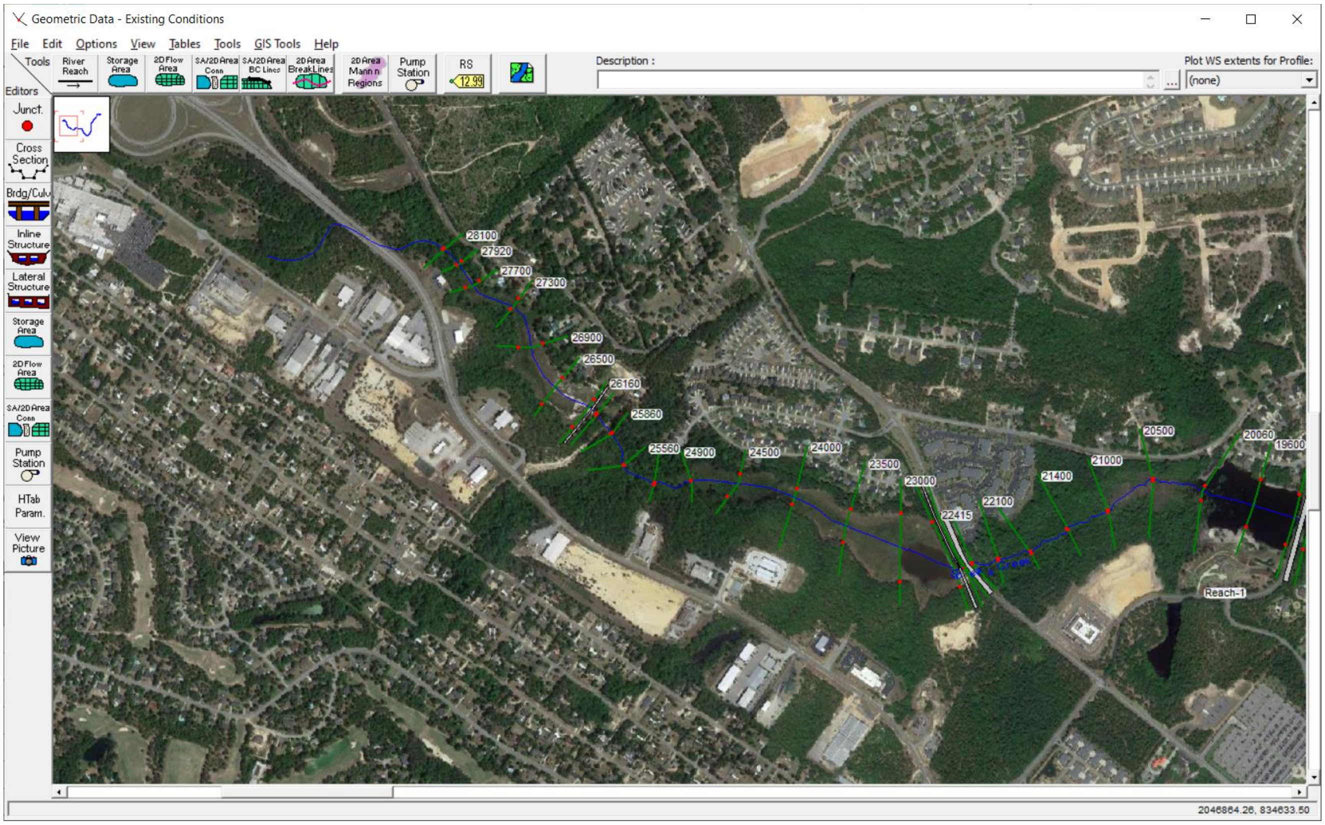
Study Area

The drainage area in this hydraulic analysis consists of the portion of Spears Creek Watershed upstream of the Spears Creek Church Road culvert, immediately downstream of the Walden Pond dam. This study incorporates the previously modeled section of Spears Creek by FEMA. The upstream sections of the watershed are maintained in the modeling in order to generate rainfall runoff and account for the travel time as the water goes through the upstream drainage systems. However, the smaller sections of the drainage network have been generalized within the model to improve simulation run times and did not significantly affect model results within the project area.

Data Gathering

The County provided WK Dickson with relevant GIS data, and additional data was collected from SCDNR, USGS and NOAA. A "Technical Data Request" was submitted to FEMA for all current effective hydrologic and hydraulic models throughout the watershed. The figure below shows the HEC-RAS data provided by FEMA that was incorporated into the modeling for this study.

To allow for further updates to the model, several field visits were conducted by WK Dickson staff to gather necessary data for hydraulic structures (dams, culverts, ponds, etc.) in and near the study area. Elevation data for these structures was estimated based off on level data and available LIDAR.

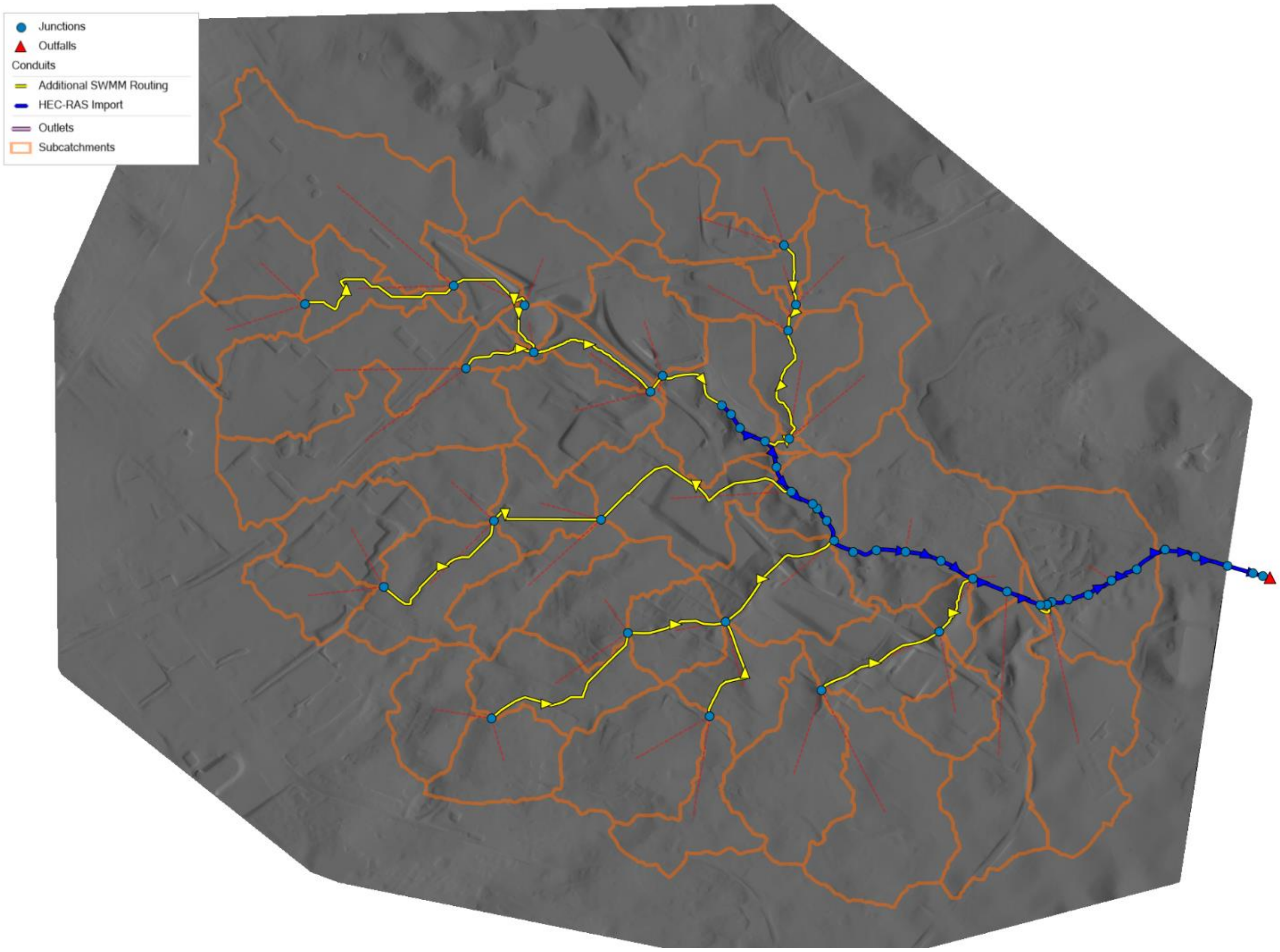


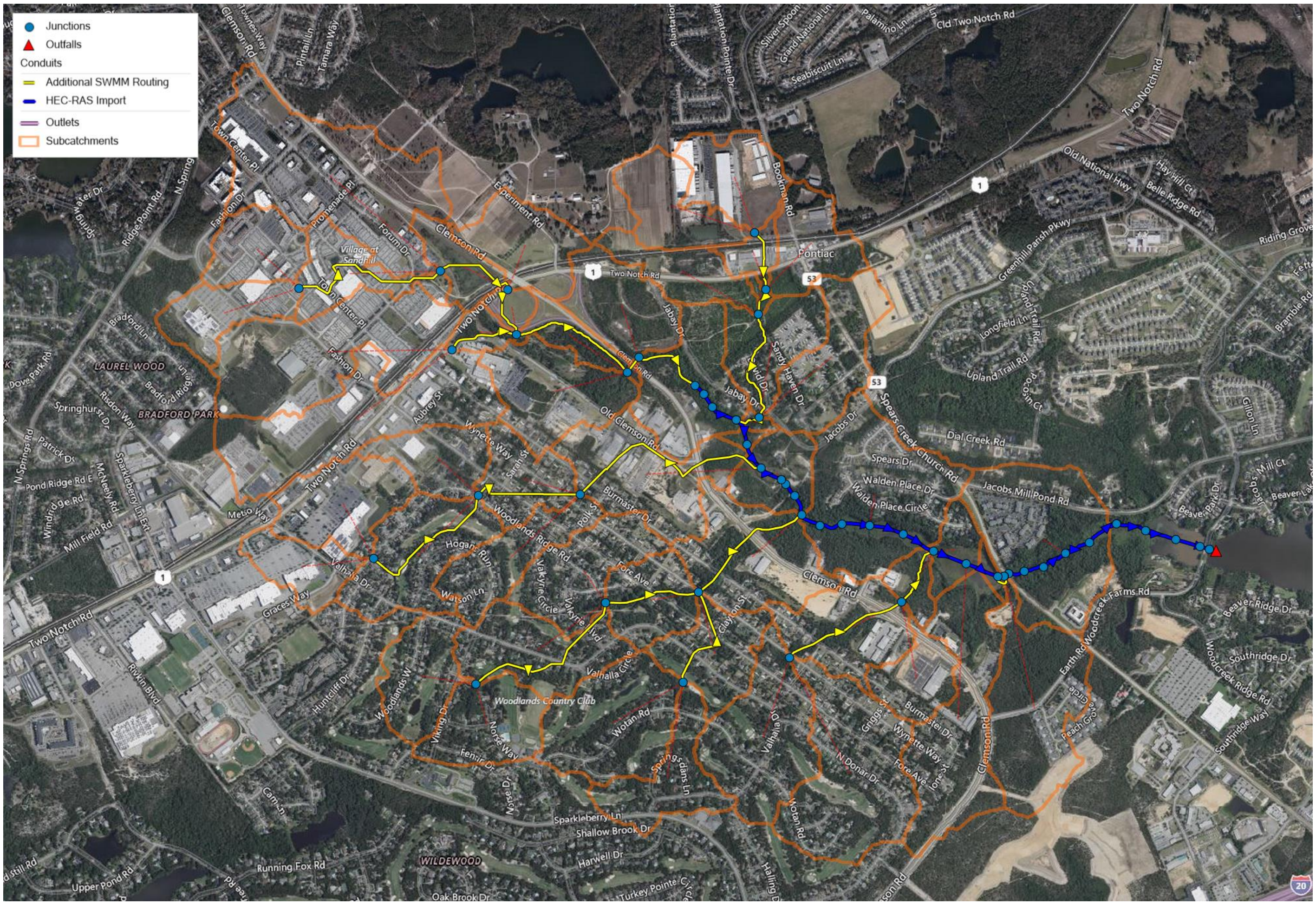
SWMM Hydrologic Model

A combined hydrologic and hydraulic model was developed using the PCSWMM modeling software by CHI. PCSWMM is a graphical user interface and enhancement of the US EPA Storm Water Management Model (SWMM). SWMM is an urban runoff simulation model that considers the complete urban rainfall/runoff, hydrograph routing cycle, including overland flow, closed system flow, and system storage. For this project, PCSWMM was used as an unsteady state dynamic model to develop the runoff hydrographs and route the runoff downstream through the drainage system until the water reaches the downstream model boundary below Spears Creek Church Road. The SWMM model provides details of the closed pipe and open channel system performance, the timing of hydrographs, and allows for scenarios to be setup and compared for the evaluation of changes made to an existing drainage system.

PCSWMM was used to develop runoff hydrographs for each subbasin. SWMM uses various subbasin hydrologic parameters such as drainage area, infiltration, and overland flow characteristics to generate runoff hydrographs for various rainfall time series data. The runoff hydrographs for each subbasin were then assigned to a node located near the downstream end of each subbasin to be routed through the drainage system.

The watershed was delineated using ESRI's ArcMap software, County planimetric layers, previous FEMA studies, the County's inventory data, and a 10 foot DEM obtained from SCDNR. The DEM, 53 subbasins for the analysis, and model connectivity are shown in the figures below.

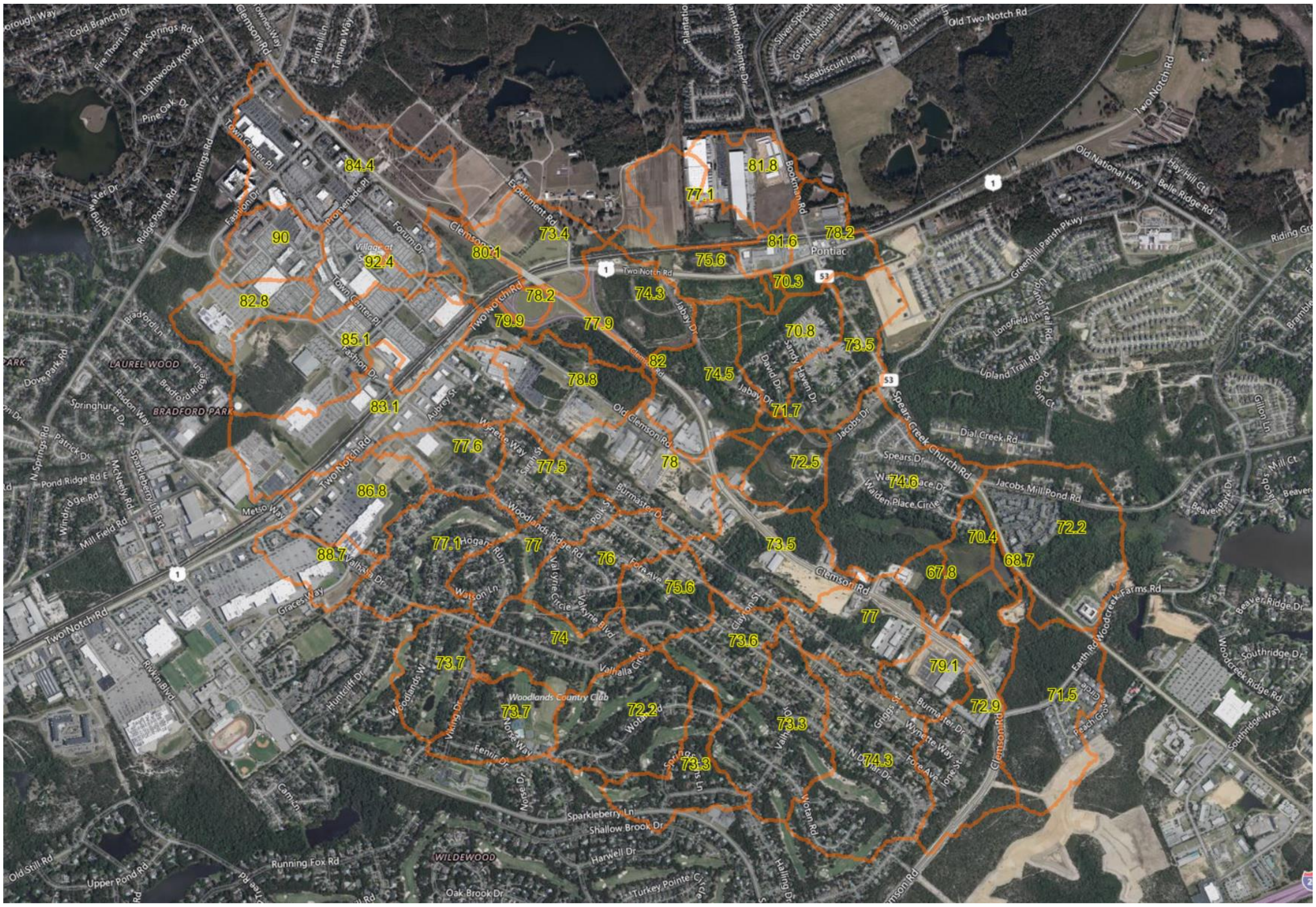




Infiltration

The NRCS runoff curve number (CN) method was used as the infiltration method to calculate the amount of rainfall that infiltrates into the ground and what amount is considered direct runoff along the ground surface. Using the NRCS unit hydrograph method, composite CN values were calculated using both the pervious and impervious areas. For the CN calculations, an existing landuse coverage was created by supplementing the 2011 National Land Cover Dataset (NLCD) with the aforementioned GIS and other data sets.

A composite CN was calculated for each subbasin by using the landuse, soils, and subbasin boundary coverages along with typical runoff CN values for the various soil and land use category combinations. The soils data used was obtained from the United States Department of Agriculture (USDA) Web Soil Survey database. USDA classifies soils into four hydrologic soil groups (HSG) to indicate the minimum rate of infiltration a soil has after prolonged wetting. The groups range from group “A” having a low runoff potential and a high infiltration rate, to group “D” having high runoff potential and very low infiltration rates.



Time of Concentration

A subbasin's flow path and/or time of concentration is needed depending on the hydrologic model method used with the SWMM model. For the NRCS unit hydrograph method, a time of concentration is used that defines the time required for a drop of water (during a 2-year runoff event) to travel from the most hydraulically remote location of a catchment to its outfall. The NRCS method calculates the time of concentration using three associated flow path components: sheet flow, shallow concentrated flow, and pipe or channelized flow. PCSWMM and the elevation DEM was used to determine the flow path location for each subbasin and derive the slope and NRCS time of concentration based on parameters for each flow path segment.

Rainfall

Rainfall data was obtained from NOAA Atlas 14 Precipitation Frequency Data Server (PFDS) available online. A 6 hour design storm duration was specified for this study, which generated the following total rainfall amounts to be used in the PCSWMM model.

Recurrence Interval	Total Rainfall
2 Year	2.62 in
5 Year	3.22 in
10 Year	3.80 in
25 Year	5.28 in
100 Year	6.02 in

SWMM Hydraulic Model

The SWMM hydraulic module uses a drainage network made up of links and nodes to represent the pipes, channels, manholes, storage areas, and control structures. The model takes the inflow hydrographs and solves the St. Venant equations, which are the full dynamic equations for gradually varied flow. Water surface elevations are computed at each node for the full range of flows encountered during a given rainfall event. The SWMM model is capable of accounting for water leaving a pipe system through surcharging inlets by either ponding the surcharge amount on the ground surface or traveling along ground surface links until it re-enters a downstream pipe system or channel link. Results from the model consist of a time series of water surface elevations, flows, and velocities at a specified time interval from the beginning to the end of a simulation.

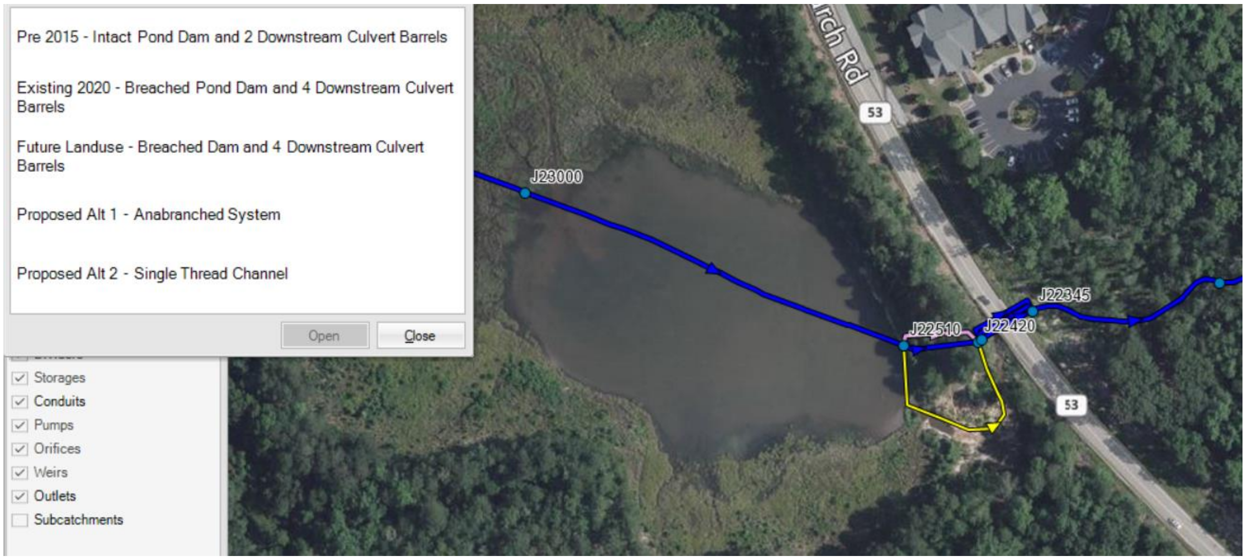
Detention structures throughout the watershed were not modeled due to limited data available on the outlet structures and the planning-level nature of the study. This had the effect of minimizing any potential attenuation of peak flows that these structures would have provided, particularly in the smaller storm events. It is recommended that consideration of these structures be given before any final design choices are selected.

Results of SWMM Modeling

Five model scenarios were constructed for this study. They include conditions before the 2015 storm that compromised the dam, existing conditions (2020), an estimate of future “built-out” landuse conditions, and two alternatives for consideration by the County which were described previously.

Results for each of these scenarios are summarized below for each storm event as well as upstream of the dam and below the roadway culvert. Note that the scale of the graphs is maintained throughout in order to allow for easier comparison.

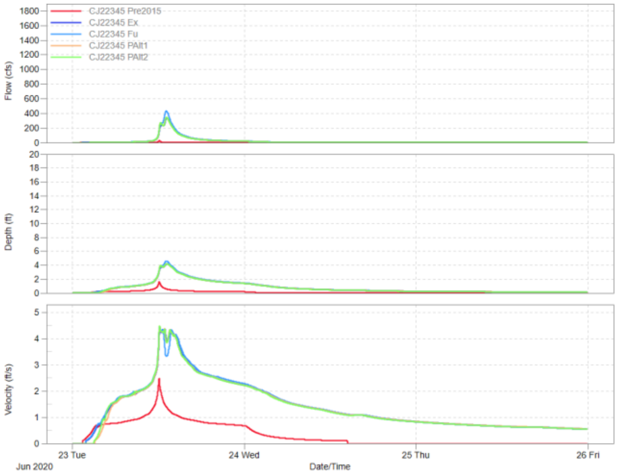
PCSWMM Summary Graphs
Flow, Depth, Velocity

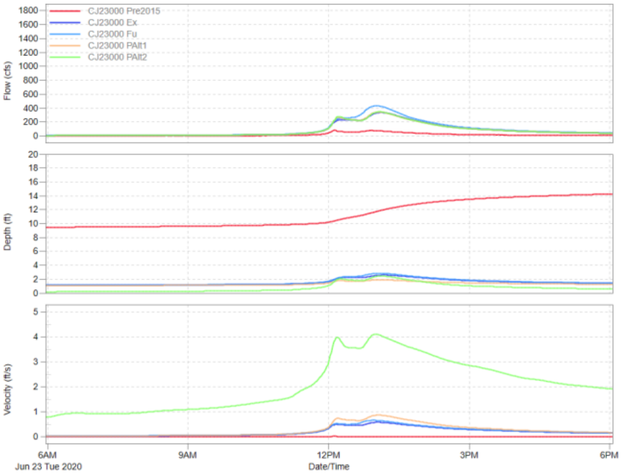


Upstream of Pond Dam

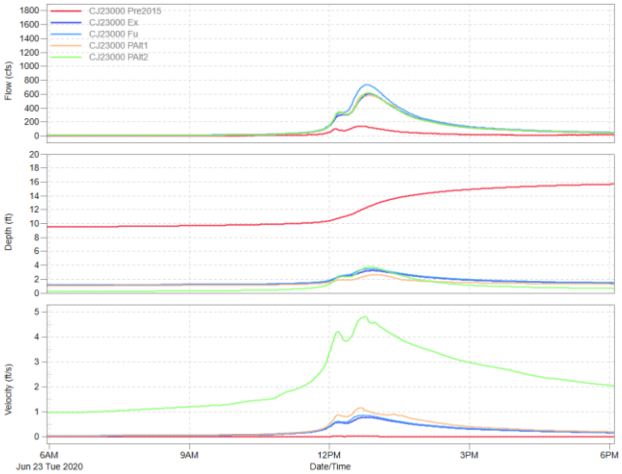
Downstream of Spears Creek Church Road

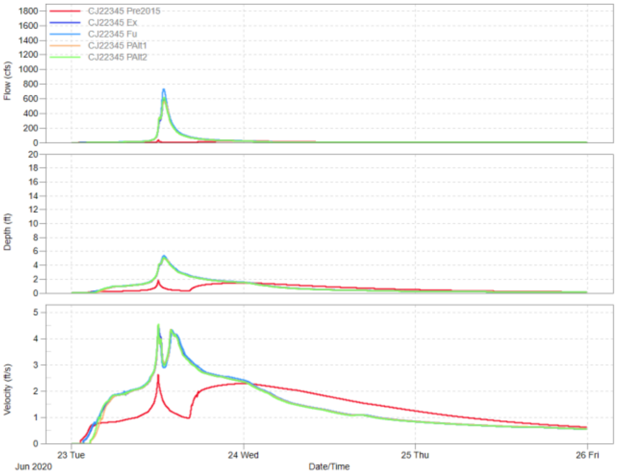
2 Year – 6 Hour



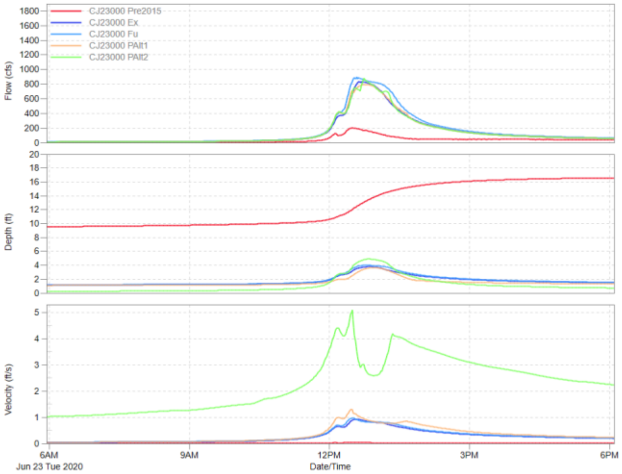


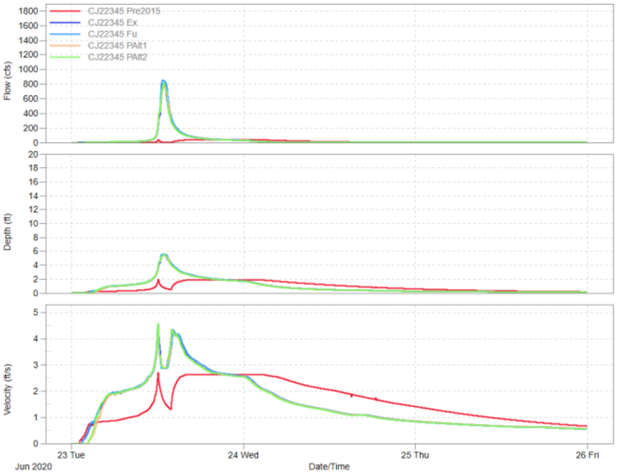
5 Year – 6 Hour





10 Year – 6 Hour

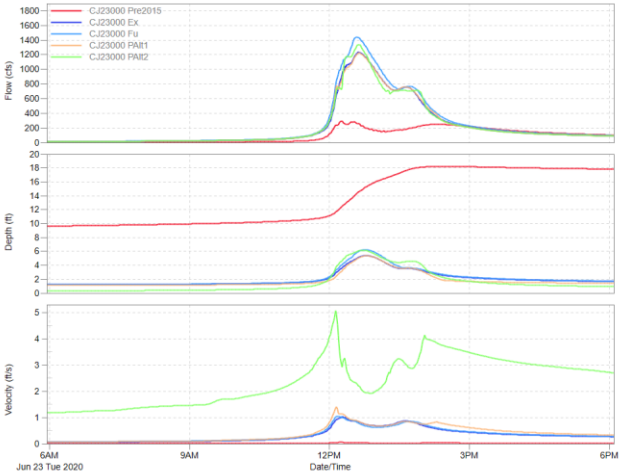


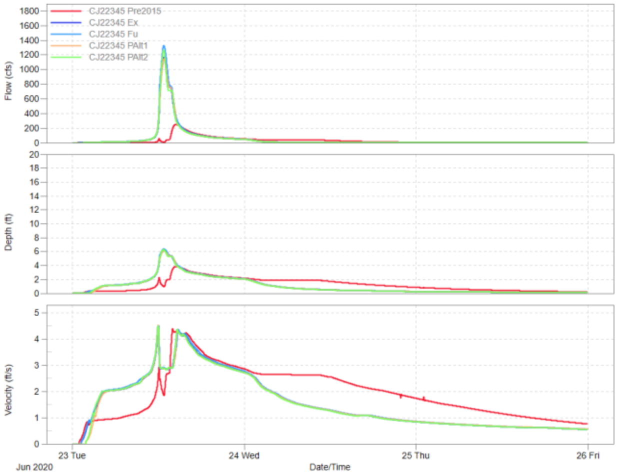


Upstream of Pond Dam

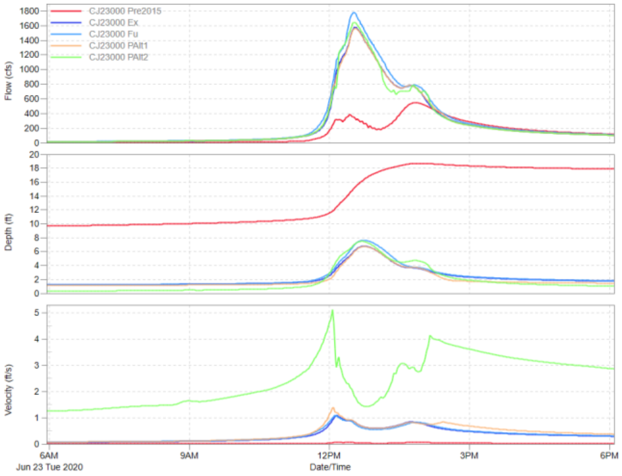
Downstream of Spears Creek Church Road

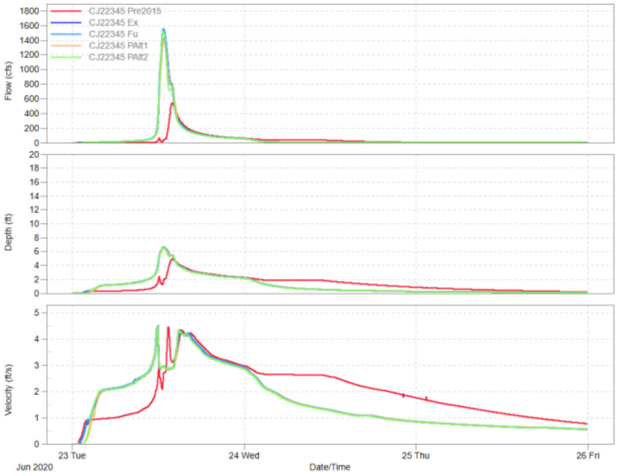
50 Year – 6 Hour





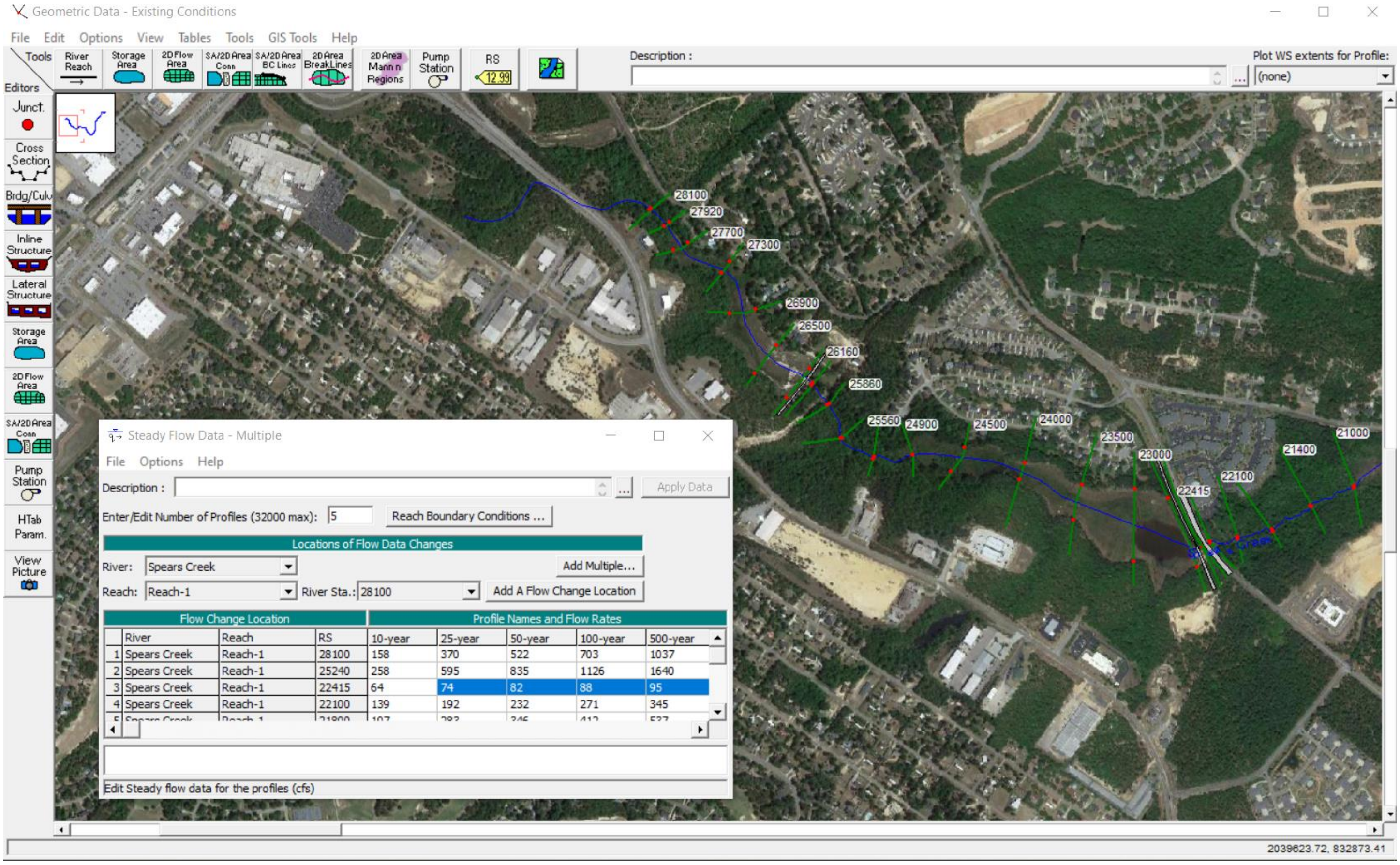
100 Year – 6 Hour





Model Validation

Unfortunately, there are no stream or flow gages in the watershed which could provide data for a conventional validation and calibration effort of the model. Because this situation is common, a validation effort is typically conducted by comparison to other available data sets. Highlighted below, FEMA's current effective HEC-RAS model has the following peak flows specified immediately upstream of the dam:



Enter/Edit Number of Profiles (32000 max): 5

River: Spears Creek

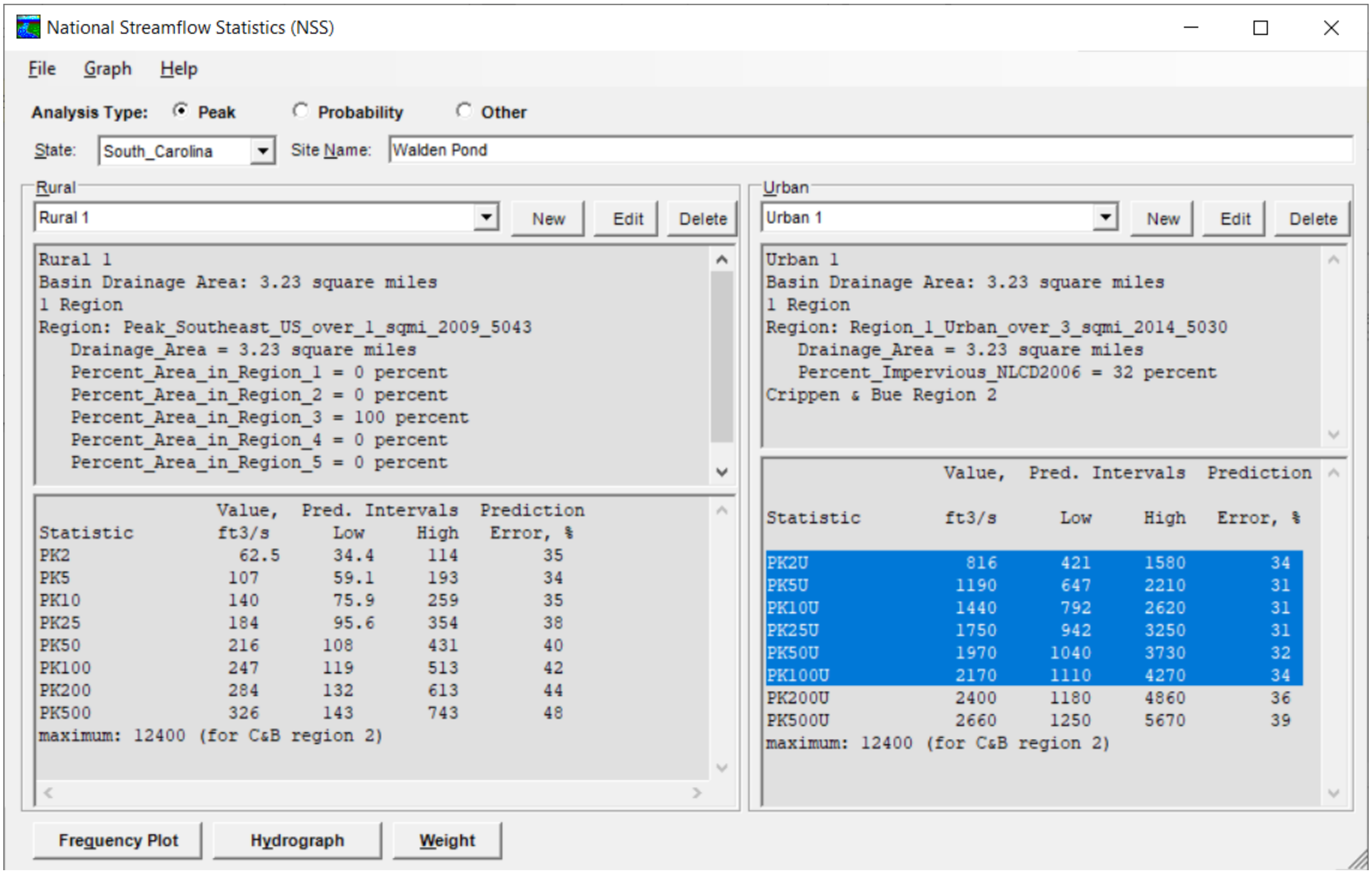
Reach: Reach-1 River Sta.: 28100

Flow Change Location				Profile Names and Flow Rates				
	River	Reach	RS	10-year	25-year	50-year	100-year	500-year
1	Spears Creek	Reach-1	28100	158	370	522	703	1037
2	Spears Creek	Reach-1	25240	258	595	835	1126	1640
3	Spears Creek	Reach-1	22415	64	74	82	88	95
4	Spears Creek	Reach-1	22100	139	192	232	271	345

Edit Steady flow data for the profiles (cfs)

Although the hydrologic model used to generate these peak flows was not available from FEMA, it is likely that such low values did not account for flow being carried by the overflow spillway or the dam proper. Rather, these peak flow numbers likely represent the flow being discharged by just the riser and outlet barrel. It is also unclear if the ponds upstream of Walden Pond (before being breached in 2015) along with their attenuation effects had been considered when determining these flows used in the HEC-RAS model.

Another opportunity for comparison is the USGS estimates of flood frequency using regression equations. The USGS National Streamflow Statistics (NSS) software application uses these equations to give a range and probability of peak flows for a variety of design storms and development intensities. Using the geographic and hydrologic characteristics of the studied watershed, NSS generates the following expected peak flows:



Analysis Type: ● Peak ○ Probability ○ Other

State: South_Carolina

Site Name: Walden Pond

Rural: Rural 1

```
Rural 1
Basin Drainage Area: 3.23 square miles
1 Region
Region: Peak_Southeast_US_over_1_sqmi_2009_5043
   Drainage_Area = 3.23 square miles
   Percent_Area_in_Region_1 = 0 percent
   Percent_Area_in_Region_2 = 0 percent
   Percent_Area_in_Region_3 = 100 percent
   Percent_Area_in_Region_4 = 0 percent
   Percent_Area_in_Region_5 = 0 percent
```

```
                 Value,  Pred. Intervals  Prediction
Statistic        ft3/s     Low    High    Error, %
PK2               62.5     34.4   114        35
PK5              107       59.1   193        34
PK10             140       75.9   259        35
PK25             184       95.6   354        38
PK50             216      108     431        40
PK100            247      119     513        42
PK200            284      132     613        44
PK500            326      143     743        48
maximum: 12400 (for C&B region 2)
```

Urban: Urban 1

```
Urban 1
Basin Drainage Area: 3.23 square miles
1 Region
Region: Region_1_Urban_over_3_sqmi_2014_5030
   Drainage_Area = 3.23 square miles
   Percent_Impervious_NLCD2006 = 32 percent
Crippen & Bue Region 2
```

```
                 Value,  Pred. Intervals  Prediction

Statistic        ft3/s      Low    High    Error, %

PK2U               816      421    1580        34
PK5U              1190      647    2210        31
PK10U             1440      792    2620        31
PK25U             1750      942    3250        31
PK50U             1970     1040    3730        32
PK100U            2170     1110    4270        34
PK200U            2400     1180    4860        36
PK500U            2660     1250    5670        39
maximum: 12400 (for C&B region 2)
```

The values from the NSS projections (using the urban regression equations) appear to be more likely that the unusually low flows in FEMA's current effective model. For example, the PCSWMM 100-yr peak flow for existing conditions in this project is 1577 cfs, which lies within the 1110-5270 cfs range predicted by NSS.