PROCTOR CREEK DRAFT FEASIBILITY REPORT

APPENDIX A - ENGINEERING

September 2017

US Army Corps
of Engineers
Mobile District

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1. Introduction

The U.S. Army Corps of Engineers (USACE), Mobile District, in partnership with the City of Atlanta (the non-federal sponsor), is conducting a general investigation study to evaluate the feasibility of restoring Proctor Creek in Atlanta, Georgia. The specific focus of the study is to identify restoration actions to enhance the aquatic ecosystem of the Proctor Creek watershed. A team comprised of engineering technical experts from the Mobile and Savannah Districts were charged with (1) characterizing the existing and future (with- and without-project) hydraulic, hydrologic, and geologic conditions of the study area, (2) supporting the development of the ecological models (as documented in McKay et. al 2017a and McKay et. al 2017b) used to evaluate the effects/benefits of potential restoration actions, (3) producing concept- and feasibility-level designs for the various restoration alternatives considered, and (4) generating feasibility level cost estimates for all potential restoration actions for use in the plan formulation process. Details of the engineering efforts to satisfy items (1) – (3) are discussed below in this appendix. The efforts to support item (4) are discussed in a separate Cost Engineering Appendix.

2. Study Area

Proctor Creek is an approximately 9-mile long stream located in Atlanta, Georgia. It is fed by two major tributaries (Terrell Creek and Grove Park Creek) along with several other minor perennial features. The headwaters of the watershed include a majority of the downtown metropolitan area and, consequently, the stream suffers from severe ecological degradation. Common drivers and stressors in the watershed include combined sewer overflows, extremely high impervious surface coverage (> 30% on average), and other industrial and residential sources of pollution (Horowitz et al. 2008, McKay et al. 2017b, Peters 2009, Wright et al. 2012). High rates of poverty, crime, property abandonment, illegal dumping, and interior flooding are also common within the study area (EPA 2015, McKay et al. 2017b).

2.1. Watershed Characteristics

2.1.1. Drainage Area Description

The Proctor Creek watershed, as seen in figure 1, is located in the Chattahoochee River Basin in the City of Atlanta, Georgia. The Chattahoochee River Basin is part of the larger Apalachicola-Chattahoochee-Flint Rivers Basin (ACF Basin), which flows south to the Gulf of Mexico and also drains portions of Alabama and Florida. Proctor Creek is located in western Atlanta and drains an area of approximately 16 square miles between downtown Atlanta and the Chattahoochee River. The drainage area encompasses portions of heavily developed downtown Atlanta, industrial areas, and residential neighborhoods.

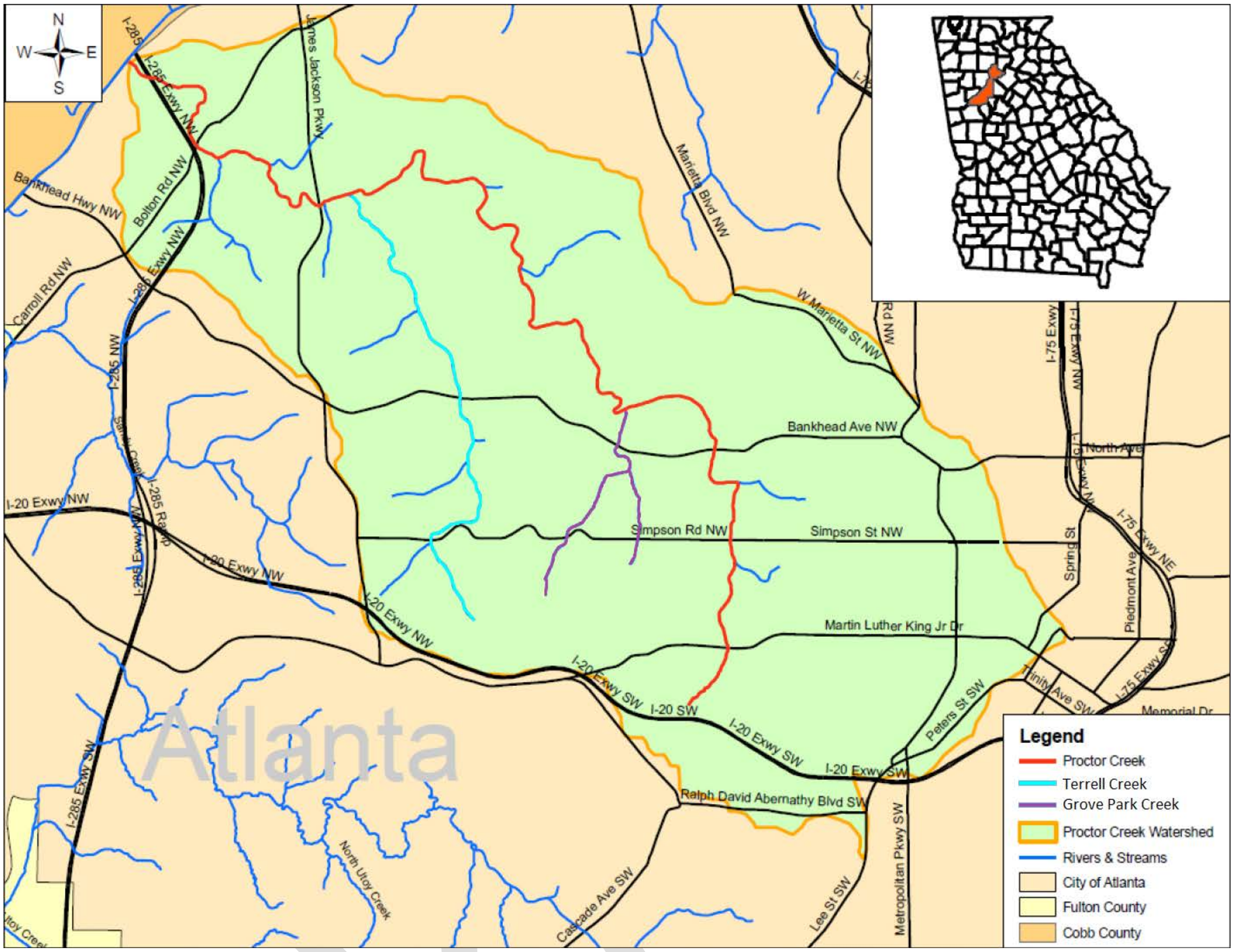

Figure 1: Proctor Creek Location Map

The Proctor Creek main stem consists of approximately 9 stream miles. The National Hydrography Dataset shows 20.2 total stream miles, when including tributaries. There are two tributaries to Proctor Creek that were large enough to be considered for restoration opportunities in this study. The Terrell Creek tributary (identified by FEMA as Center Hill Tributary) encompasses approximately 5.1 stream miles with a drainage basin of 3 square miles. Terrell Creek flows into Proctor Creek at Proctor Creek stream mile 2.3, as measured upstream from the confluence with the Chattahoochee River. The Grove Park Tributary (as named by the project team) encompasses approximately 2.2 stream miles with a drainage basin of 1.4 square miles. Grove Park Tributary flows into Proctor Creek at Proctor Creek stream mile 5.9.

2.1.2. Land Use

The headwaters of Proctor Creek begin in highly urbanized downtown Atlanta, with the creek flowing generally westward. Land use varies across the watershed with low density residential (35.1 percent) and industrial (22.8 percent) being the most prevalent land uses. Other significant land use classifications include roads/right-of-away at 13.5 percent and institutional/office at 12.5 percent of the watershed. The average imperviousness for the basin is estimated to be 35 percent, from the 2011 NLCD landcover dataset. A map showing the distribution of landcover/landuse within the Proctor Creek watershed is shown in Figure 2.

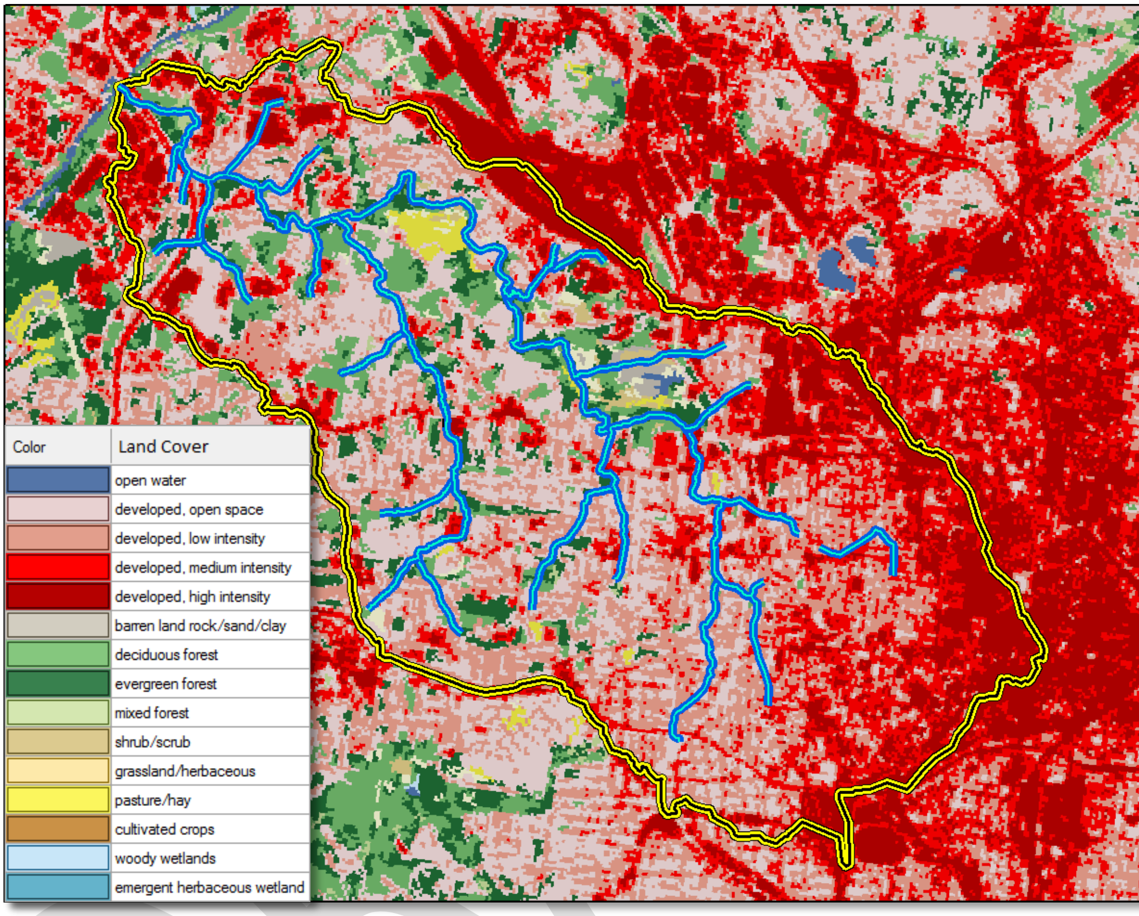

Figure 2: Land Cover Map.

2.1.3. Alluvium and Soils

The study area is located in what is known as the upper Piedmont physiographic province. This area is in what can be considered the foothills of the Appalachian Mountains. The Piedmont is a region of moderate-to-high-grade metamorphic rocks, such as schists, amphibolites, gneisses, and migmatites, and igneous rocks like granite. Topographically, the Piedmont mostly consists of rolling hills. Piedmont soils are commonly a red color for which Georgia is famous. Those soils consist of kaolinite and halloysite (1:1 aluminosilicate clay minerals) and of iron oxides. They result from the intense weathering of feldspar-rich igneous and metamorphic rocks. This intense weathering dissolves or alters nearly all minerals and leaves behind a residue of aluminum-bearing clays and iron-bearing iron oxides because of the low solubilities of aluminum and iron at earth-surface conditions. Those iron oxides give the red color to the clay-rich soil.

2.1.4. Geology

2.1.4.1. Regional Geology

The Proctor Creek Project area geographically lies in northwest Atlanta. The geomorphic province is the southern portion of the Piedmont physiographic province—an area underlain by highly deformed crystalline rocks. In Georgia, the Piedmont is located between the Valley and Ridge and Blue Ridge provinces to the north and the Coastal Plain to the south (fig. 3). Atkins and Higgins (1980), McConnell and Abrams (1984), and Higgins and others (1984, 1988, 1998) have described the geology of the Piedmont. Higgins and others (1988) proposed one of the more widely accepted structural geologic interpretations for the area. They suggested that the movement of massive stacks of thrust sheets during the Middle Ordovician through Carboniferous time essentially formed much of the deformation and metamorphism in the Atlanta region. The injection of igneous intrusions in the thrust sheets has occurred at various times during thrusting. There was further metamorphism as well as folding and faulting of the thrust stacks, resulting in a complex distribution of lithologies.

Geologic units comprise several major thrust sheets, including portions of the Bill Arp, Clairmont, Sandy Springs, and Zebulon thrust sheets (Higgins and others, 1988). Massive granite gneiss underlies the northern part of the county. This formation name is Lithonia Gneiss, the type locality being at Lithonia, Georgia, just west of Rockdale County in eastern DeKalb County. The grouping of the Lithonia Gneiss is with the Silurian-Devonian igneous intrusions (Higgins and others, 1988), which regional thrusting has deformed and metamorphosed.

Proctor Creek lies in the southern Piedmont geologic province. Regionally the Southern Piedmont "covers the area between the Brevard fault zone and the coastal plain overlap". (McConnell and Abrams 1984)
The term southern Piedmont consists of rocks southeast of the Brevard fault zone. There are significant post-metamorphic granite intrusives in the southern Piedmont.

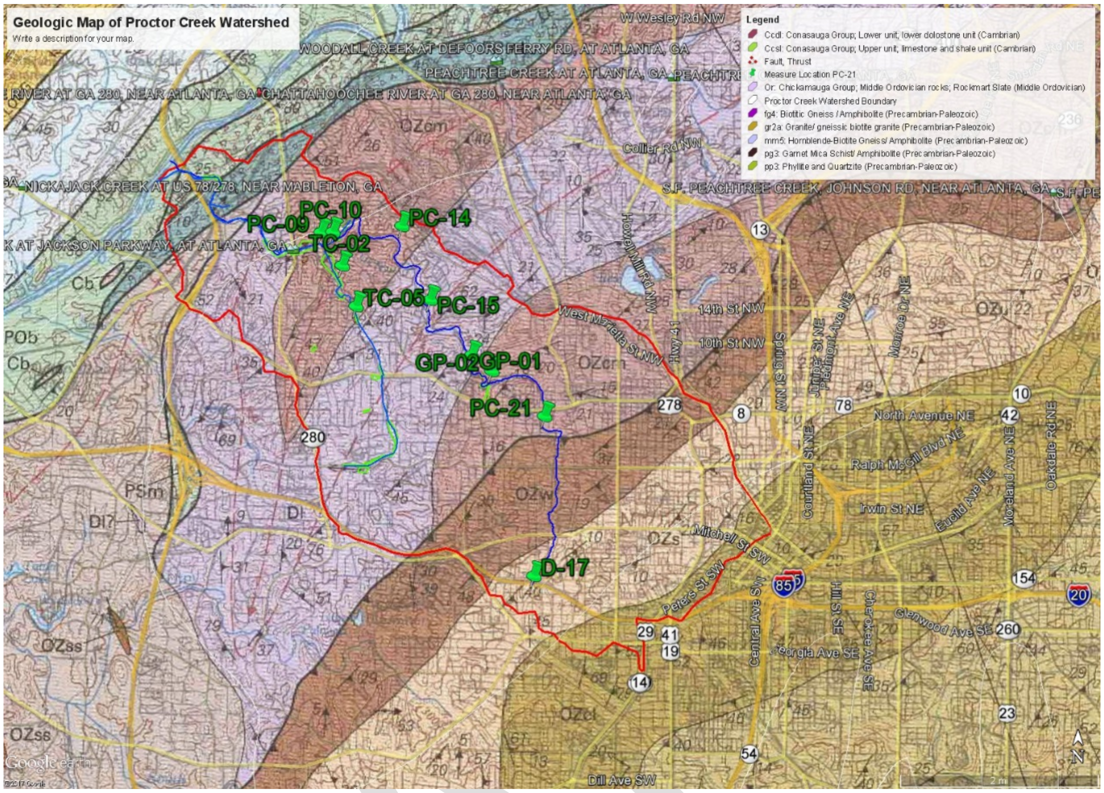

Figure 3: The Piedmont physiographic province.

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2.1.4.2. Regional Stratigraphy

2.1.4.2.1. Brevard Fault Zone

“The Brevard fault zone is a distinct linear zone of ductile shearing that is traceable from the Coastal Plain onlap in Alabama, northeastward through Georgia, South Carolina and most of North Carolina (Hatcher, 1971b, 1978a; Hurst 1973). Interpretations regarding the nature of movement and extent of displacement along the Brevard fault zone are varied. The Brevard Fault Zone separates the northern Piedmont from the southern Piedmont. In the greater Atlanta Region, The Brevard fault zone boundary is on the southeast rocks of the Atlanta Group and separates rocks on the northwest that are part of the Sandy Springs Group. The boundaries of the Brevard fault zone is by the presence the Chattahoochee River valley that is fault controlled.

2.1.4.2.2. Stratigraphy of Southern Piedmont

The formations that compose the Atlanta Group are the Camp Creek Formation, a massive granite gneiss; the Intrenchment Creek Quartzite, the Big Cotton Indian Formation, an intercalcated biotite –plagioclase gneiss; the Clarkston Formation, a silmanite schist; the Stonewall Formation, a fine grained biotite schist; the Wahoo Creek Formation, a plagioclase gneiss; the Senoia Formation, a garnet biotite muscovite schist; the Clairmont Formation, a biotite-plagioclase gneiss; the Promised Land Formation, a massive biotite granite gneiss; the Wolf Creek Formation, an amphibolite schist; the Inman Yard Formation, a biotite gneiss; the Norcross Gneiss, the Snellville Formation, that contains two members the lower is a garnet-biotite schist, the upper member termed the Lanier Mountain Quartzite; the Sandy Springs Group, similar in sequence to the Atlanta Group; Unnamed or Unassigned Units that are an assemblage of meta-ultramafic rocks; the Soapstone Ridge Complex, a actinolite-chlorite-talc schist; the Lithonia Gneiss, the Palmetto Granite, a coarse grained granite,, the Ben Hill Granite, the Panola Granite, the Stone Mountain granite, Ductilely sheared rocks that lie in the Brevard zone, and the Diabase Dikes.

2.1.4.3. Regional Structural Geology

The Southern Piedmont structural boundary on the southeast is the Pine Mountain-Towauga thrust fault. The throw of the thrust is to the northwest. The Southern Piedmont northwest boundary is the Brevard fault zone, which thrusts to the southeast.

2.1.5. Groundwater

The ground water in the area is shallow groundwater that lies on top of the shallow bedrock. The top of the bedrock is typically about 17 to 27- feet below ground surface in Marietta, GA which about 5 miles northeast of Proctor Creek.

Groundwater is not a major source of potable water in the Atlanta area. Major production sources for deep groundwater is typically fracture flow with fracture occurrences from 77 to 545-feet below ground surface. (Addison, 2003)

2.1.6. Hydrology/Runoff Characteristics

2.1.6.1. Temperature

The average daily low and high temperatures in the study area range from the mid-30s to the low 50s (in °F) in the winter months and the low 70s to the high 80s in the summer months (source: http://www.usclimatedata.com/climate/atlanta/georgia/united-states/usga0028).

2.1.6.2. Rainfall

Synthetic rainfall data for the study area, per National Oceanic Administration (NOAA) Atlas 14, is shown in Table 1. Rainfall depths (in inches) range from 0.398 inches for the 1-year, 5-minute storm to 9.52 inches for the 500-year, 24-hour storm.

Table 1: NOAA Atlas 14 Rainfall for Proctor Creek Watershed

	Return Interval Rainfall (inches)								
Duration	1	2	5	10	25	50	100	200	500
5-min	0.398 (0.314-0.500)	0.458 (0.361-0.575)	0.56 (0.439-0.704)	0.648 (0.506-0.817)	0.774 (0.588-1.00)	0.875 (0.650-1.14)	0.979 (0.706-1.29)	1.09 (0.756-1.46)	1.24 (0.831-1.69)
10-min	0.583 (0.459-0.732)	0.671 (0.528-0.842)	0.82 (0.643-1.03)	0.949 (0.740-1.20)	1.13 (0.861-1.46)	1.28 (0.952-1.67)	1.43 (1.03-1.90)	1.59 (1.11-2.14)	1.81 (1.22-2.48)
15-min	0.711 (0.560-0.892)	0.819 (0.644-1.03)	1 (0.785-1.26)	1.16 (0.903-1.46)	1.38 (1.05-1.79)	1.56 (1.16-2.03)	1.75 (1.26-2.31)	1.94 (1.35-2.61)	2.21 (1.48-3.02)
30-min	1.02 (0.806-1.28)	1.18 (0.926-1.48)	1.44 (1.13-1.81)	1.66 (1.30-2.09)	1.98 (1.51-2.56)	2.24 (1.66-2.91)	2.5 (1.81-3.31)	2.78 (1.93-3.74)	3.16 (2.12-4.33)
60-min	1.32 (1.04-1.66)	1.52 (1.19-1.90)	1.85 (1.45-2.32)	2.14 (1.67-2.69)	2.56 (1.95-3.31)	2.9 (2.16-3.78)	3.26 (2.35-4.31)	3.64 (2.53-4.90)	4.16 (2.80-5.71)
2-hr	1.62 (1.29-2.01)	1.85 (1.48-2.30)	2.26 (1.79-2.80)	2.61 (2.06-3.25)	3.13 (2.42-4.02)	3.56 (2.69-4.59)	4.01 (2.94-5.26)	4.49 (3.17-5.99)	5.16 (3.52-7.00)
3-hr	1.82 (1.46-2.24)	2.06 (1.66-2.54)	2.5 (2.00-3.08)	2.89 (2.30-3.57)	3.47 (2.70-4.43)	3.95 (3.01-5.07)	4.46 (3.30-5.82)	5.02 (3.57-6.65)	5.79 (3.99-7.81)
6-hr	2.23 (1.81-2.71)	2.5 (2.03-3.04)	2.99 (2.42-3.65)	3.44 (2.77-4.20)	4.11 (3.25-5.19)	4.68 (3.62-5.95)	5.29 (3.97-6.83)	5.95 (4.30-7.81)	6.89 (4.81-9.20)
12-hr	2.76 (2.27-3.32)	3.07 (2.53-3.69)	3.63 (2.98-4.37)	4.13 (3.37-4.99)	4.9 (3.93-6.11)	5.54 (4.34-6.96)	6.23 (4.74-7.95)	6.98 (5.12-9.06)	8.05 (5.71-10.6)
24-hr	3.31 (2.76-3.93)	3.72 (3.10-4.42)	4.44 (3.69-5.28)	5.07 (4.19-6.05)	5.98 (4.84-7.34)	6.73 (5.33-8.32)	7.52 (5.79-9.45)	8.36 (6.21-10.7)	9.52 (6.84-12.4)

2.1.6.3. Impact of Development on Runoff Volumes and Peak Flows

The Proctor Creek watershed is contained entirely within the city limits of Atlanta, with much of the headwaters in the highly urbanized downtown area. Urban development and increased impervious area in the watershed lead to increased runoff volumes compared to pre-development conditions as more rainfall is converted directly to runoff. In addition to increased runoff volumes, the timing of rainfall runoff is also impacted by development. Runoff is delivered to streams much more quickly through stormwater pipes and impervious areas, resulting in “flashy” or “spikey” hydrographs that quickly rise and fall with each storm event. The result is more frequent and higher “flood” events. A typical “flashy” hydrograph from the USGS gage on Proctor Creek is shown in Figure 4. Stormwater management measures such as detention ponds mitigate the impacts of development, but these features are severely lacking in Proctor Creek.

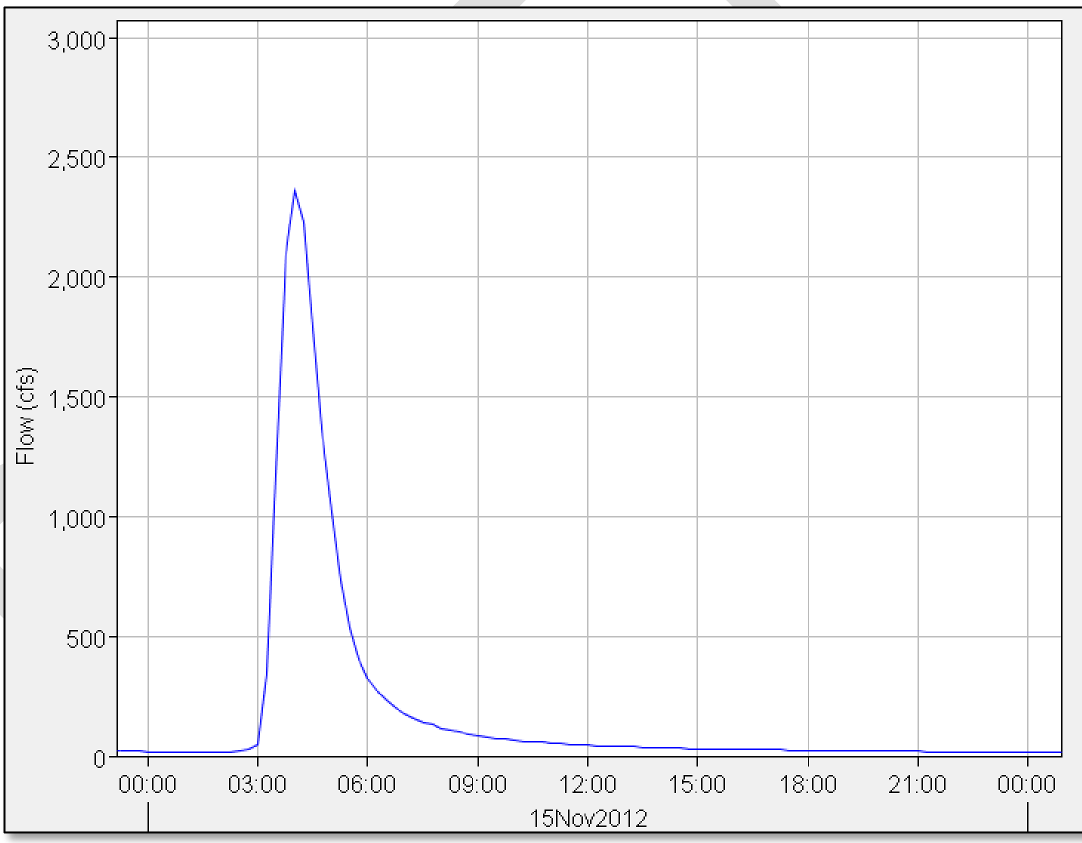


Figure 4: Typical Proctor Creek Hydrograph.

2.1.7. Stream Hydraulics and Morphology

Decades of development in metro-Atlanta has caused a flashy rainfall-runoff flow regime, with an increased channel forming discharge and more frequently occurring high-flow events. The channel-forming discharge, typically around the 1-year to 2-year return interval flow, plays the largest role in determining a stream’s morphology; its planform, cross section shape, and profile. For a highly urbanized stream like Proctor Creek, changes in the stream's morphology follows a well-studied evolutionary pattern of downcutting, and mass wasting. Because the Proctor Creek watershed has been urbanized for decades, the stream has more-or-less reached a new equilibrium in its morphology. In many locations the stream is incised, widened, and embedded with excessive sediment.

The riparian buffer along Proctor Creek varies along its length, ranging from pristine old growth hardwoods, to parks maintained by the city, to a total lack of vegetative buffer as residential and commercial areas butt up immediately adjacent to the stream bank. In numerous locations the vegetative buffer is almost completely covered by kudzu.

3. Formulation of Alternatives

3.1. Problems and Opportunities

The USACE project delivery team (PDT), through coordination with the non-federal sponsor and other interested stakeholders, identified numerous ecosystem related (and other) problems and restoration opportunities within the Proctor Creek watershed. These were elicited during the planning charrette and stakeholder coordination meetings, and were further investigated and refined through on-site field assessments. The specific problems and opportunities identified through these efforts are discussed in the following sections.

3.1.1. Problem Identification

Proctor Creek is a highly urbanized watershed that has been developed over many decades. Problems that were identified include the following:

- There is accelerated bank erosion and failure in the Proctor Creek watershed.
- Proctor Creek is not a swimmable or fishable stream. Residents cannot partake in these activities due to a lack of access as well as stream contaminants.
- The stream is currently on the 303d list for fecal coliform.
- Periodic combined sewer overflows create public and ecological health risks.
- There is flooding in various parts of the Proctor Creek watershed.
- Due to the land use practices of the last 200 years, the physical characteristics of the stream have drastically changed (morphology, lined channel, piping, etc.).
- Recreational opportunities and access in and around Proctor Creek are limited.
- Dumping of old household items and garbage is a problem in the watershed.
- There is riparian zone encroachment (degradation/removal).
- There are invasive plant species throughout the watershed.
- Lack of aquatic habitat diversity in the watershed.
- Lack of aquatic habitat along various stretches of Proctor Creek.

3.1.2. Opportunities

Opportunities identified during the planning charrette and through additional stakeholder coordination to address the problems listed above are as follows:

- Restore the aquatic ecosystem
- Reconnect the residents with the stream
- Improve recreational access and experience
- Use Proctor Creek as a living, learning laboratory
- Develop an integrated framework for effective coordination and communication of stakeholders in developing a watershed master-plan.
- Include stakeholders in the decision making and formulation process, not just during the review period.

3.2. Study Goals, Objectives, and Constraints

The National or Federal objective of water and related land resources planning is to contribute to National Economic Restoration (NER) consistent with protecting the nation's environment, pursuant to national environmental statutes, applicable executive orders, and other Federal planning requirements. This objective is the project goal for this effort, and the specific study objectives and constraints, as determined by the PDT in coordination with the non-federal sponsor, are outlined below.

3.2.1. Specific Objectives

The specific objectives of this study, as shown below, were developed to address the problems identified in Section 3.1.1.

- Improve in-channel conditions suitable for a diversity of aquatic organisms
- Improve riparian conditions supportive of a diverse aquatic and riparian community
- Restore flow regimes to best attainable conditions achievable in altered urban environments
- Promote an interconnected system resilient to foreseen and unforeseen disturbances
- Reconnect residents to aquatic and historic landscapes
- Make the creek a living laboratory for learning about local waters
- Maintain or decrease existing levels of flood risk
- Reduce health risks to neighboring communities

3.2.2. Constraints

The formulation and evaluation of alternatives to address study objectives can be limited by planning and/or design constraints. Constraints are statements of effects that the alternative plans should avoid to prevent undesirable changes between without and with-project future conditions. Constraints for this study include the following:

- Avoid Hazardous, Toxic and Radioactive Waste (HTRW) sites

- Maintain (or decrease) existing levels of flood risk
- Avoid impacts to existing structures and infrastructure whenever practical
- Avoid impacts to cultural and historic resources
- Avoid adverse social and economic impacts on community residents

3.3. Design Criteria

Criteria used for the design of restoration measures was developed by the PDT based on the specific study objectives and constraints. A listing of the criteria organized by restoration objective is shown below.

- Objective: Improve in-channel conditions suitable for a diversity of aquatic organisms
  - Criteria:
    - Restore channel geomorphic conditions to less disturbed conditions
    - Reduce sediment loading from stream bed and banks
    - Increase in-stream habitat for a diverse assemblage of local fauna
- Objective: Improve riparian conditions supportive of a diverse aquatic and riparian community
  - Criteria:
    - Restore natural sources of organic carbon (i.e., energy) within the system
    - Increase nutrient uptake within the basin
    - Improve temperature regimes
    - Increase riparian habitat to support native biodiversity
- Objective: Restore flow regimes to best attainable conditions achievable in altered urban environments
  - Criteria:
    - Decrease peak flows induced by high levels of impervious areas
    - Increase baseflows through increased watershed infiltration and shallow groundwater
    - Decrease flashiness of the “peaky” urban hydrograph
    - Minimize the difference between altered and unaltered hydrographs
- Objective: Promote an interconnected system resilient to foreseen and unforeseen disturbances
  - Criteria:
    - Increase connectivity of movement corridors for aquatic and riparian species
    - Increase the capacity to absorb natural and anthropogenic disturbance
- Objective: Reconnect residents to aquatic and historic landscapes
  - Criteria:
    - Increase recreational access
- Objective: Make the creek a living laboratory for learning about local waters
  - Criteria:

        - Provide educational opportunities for both residents and tourists
- Objective: Maintain or decrease existing levels of flood risk
    - Criteria:
        - Ensure the future with-project water surface elevations are no greater than the future without-project conditions for all selected alternatives.
- Objective: Reduce health risks to neighboring communities
    - Criteria:
        - Reduce exposure to contaminated water
        - Decrease mosquito breeding areas to reduce vector borne disease transmission

3.4. Restoration Measures Considered

A suite of restoration measures were considered in this study to help satisfy the objectives and design criteria. These measures were utilized during the development of alternative designs and applied throughout the study area based on location-specific problems and restoration objectives. The measures, organized by the objective type they would support (i.e., in-stream, riparian, connectivity, and hydrology), are discussed below.

3.4.1. In-stream Measures

3.4.1.1. Engineered Log Jam (ELJ)

Log jams are meant to compensate for a lack of woody habitat in degraded streams and are composed of logs, with or without rootwads, stacked in a criss-cross arrangement and anchored into the streambank. Log jams serve multiple purposes in stream restoration, including: flow diversion, bank protection, sediment retention, and providing aquatic and riparian habitat. An example configuration of a log jam structure is presented in Figure 5 below.

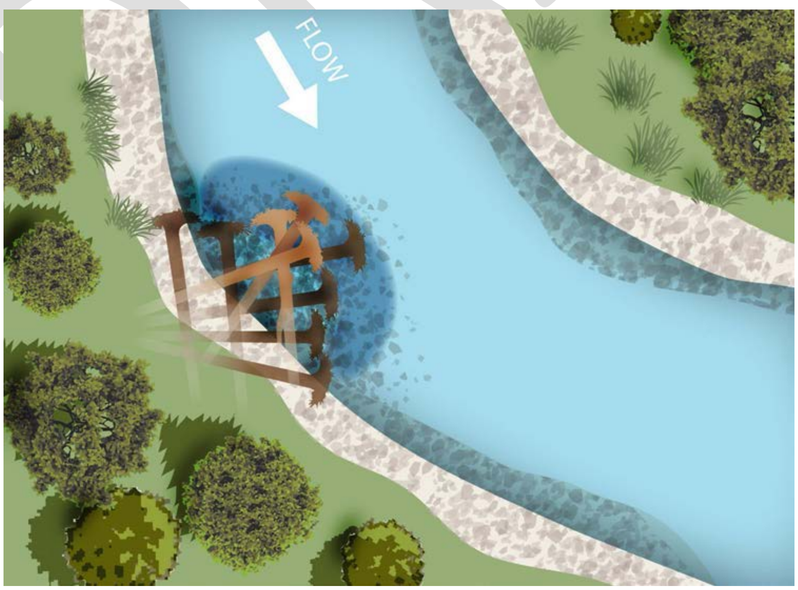


Figure 5: Engineered Log Jam (Knutson and Fealko 2014)

3.4.1.2. Log Grade Control

Grade control within a stream channel can be accomplished through the use of logs and other natural features. Single logs or bundles of logs are used to limit bed erosion by placing them perpendicular to the direction of flow, or concave if used to divert flow away from the bank. The end of logs are secured to the bank by anchoring to trees or rocks, or buried within in the streambank. These features may also provide pool habitat upstream of the log structure. See Figure 6 below.

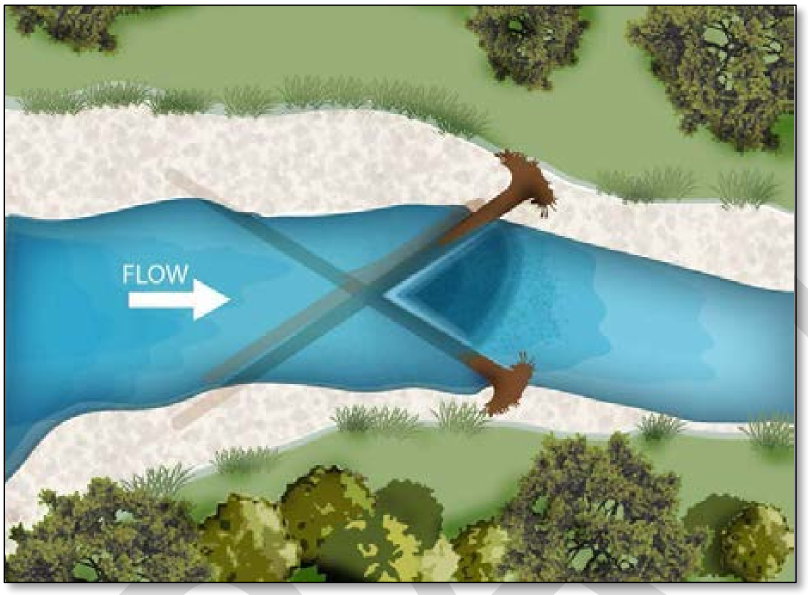


Figure 6: Large Wood Grade Control Structure (Knutson and Fealko 2014)

3.4.1.3. Log Revetment

Revetments consist of a series of logs placed parallel to the direction of flow, anchored to the streambank. Revetments provide energy dissipation, bank protection, and aquatic and riparian habitat. Logs are anchored to the toe of the streambank and to one another to stabilize the structure. An example of this approach is shown in Figure 7.

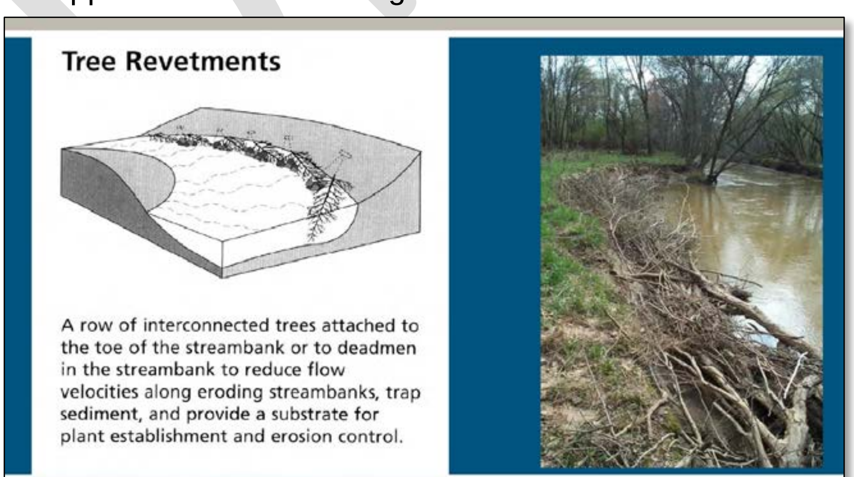


Figure 7: Longitudinal Log Revetment

3.4.1.4. Rootwads

Root wads are made by taking tree trunks with the root mass still attached and placing it in the bank with the roots sticking into the stream. They provide energy dissipation, bank protection, and habitat. Rootwads are often used in conjunction with other measures to increase the habitat benefit. An example of rootwad placement is shown Figure 8 below.

Figure 8:Rootwad Placement (Haring).

3.4.1.5. Bank shaping

Bank shaping involves excavating and filling a raw, eroded streambank to the minimum side slope which is stable for the soil materials, moisture conditions, and loading conditions of the site. Bank shaping also includes placing topsoil and other materials needed for sustaining plant growth. Vegetating includes the selection and planting of appropriate plant materials. Bank shaping and vegetating is one of the least intensive approaches to restoration of the streambank and is often a preparatory step for other bank stabilization techniques. Figure 9 illustrates this method.

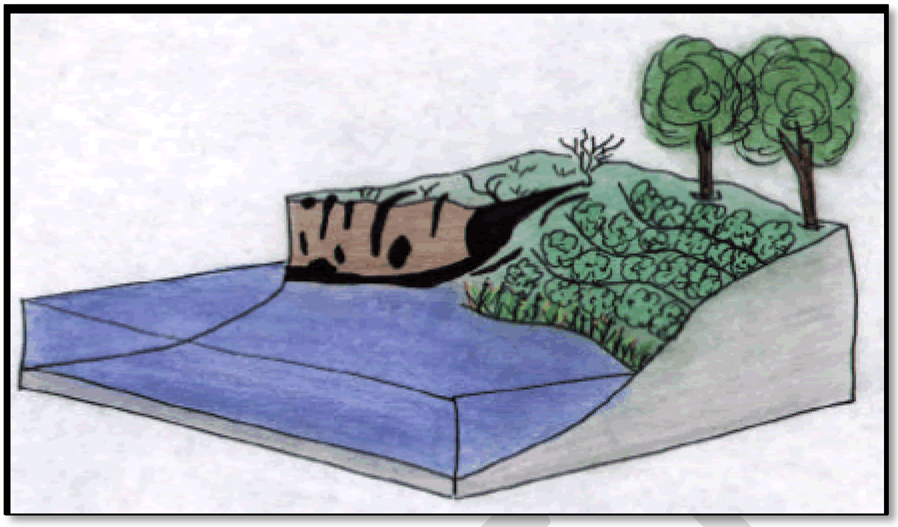


Figure 9: Bank Shaping (Stream Corridor Restoration Handbook)

3.4.1.6. Bar Cut/ Creation

In-channel bars provide habitat and shape local hydraulic impacts. Channel realignment through moving or shaping existing bars with earth moving equipment provides for improved channel morphology and habitat availability. An example of a created piedmont stream bar is shown in Figure 10 below.

Figure 10: Typical Piedmont Bar (Merritts, 2011)

3.4.1.7. Stream Barbs

Barbs are structures that are placed within the stream and angled upstream, and are designed to redirect flow within the channel. As flow passes over the structure, it accelerates and discharges perpendicular to the crest of the structure. Performance of the structures vary with the water stage; during low flows the structure may totally deflect flow rather than redirect it. During high flows the effect of the structure becomes insignificant. Stream barbs are typically constructed with stone, though brush and woody structures may be included for some applications. Stream barbs are often constructed in bends to direct the flow away from the outside streambank. Stream barbs differ from bendway weirs in that they have a sloped crest, a tighter upstream angle, and wider spacing (Haring). A typical stream barb is shown in Figure 11.

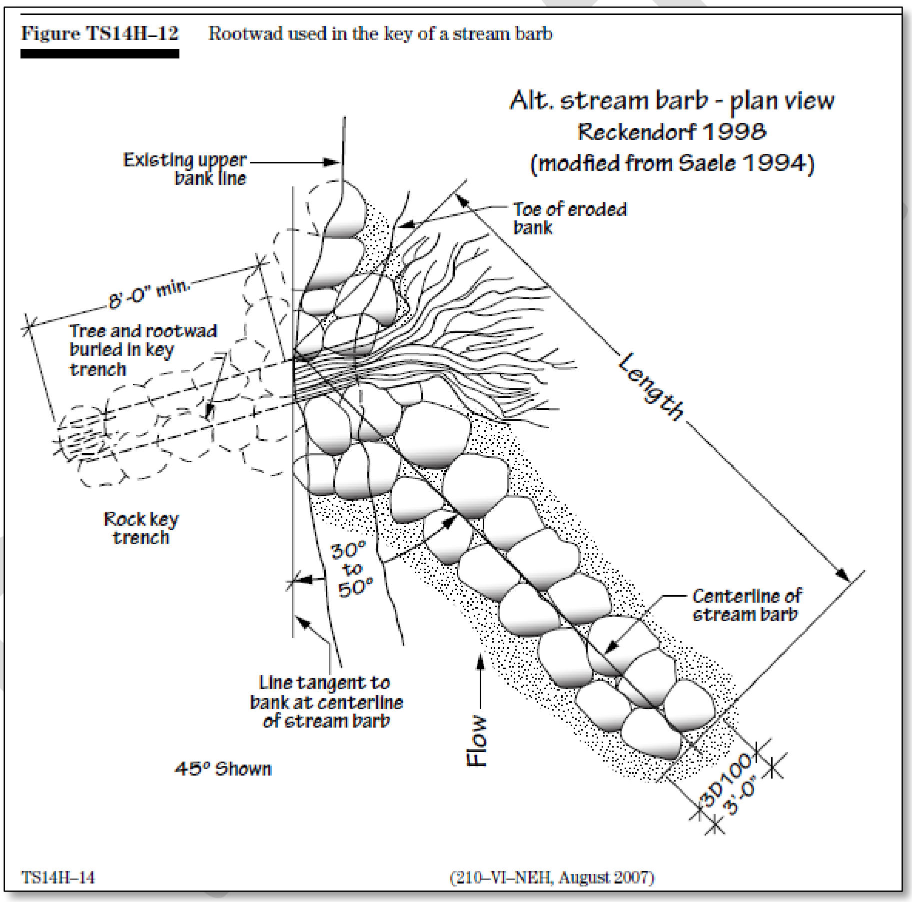


Figure 11: Stream Barb (National Engineering Handbook, TS-14)

3.4.1.8. Bendway Weirs

Bendway Weirs are structures that are placed within the stream and angled upstream, and are designed to redirect flow within the channel. As flow passes over the structure, it accelerates and discharges perpendicular to the crest of the structure. Performance of the structures vary with the water stage; during low flows the structure may totally deflect flow rather than redirect it.

During high flows the effect of the structure becomes insignificant. Bendway wiers are typically constructed with stone. Bendway weirs are usually constructed in bends to direct the flow away from the outside streambank, but can be used in other location to move the flow away from a streambank. Bendway weirs differ from Stream barbs in that they have a flat crest, a wider upstream angle, and a closer spacing (Haring). A typical Bendway weir is shown in Figure 12.

Figure 12:Bendway Weirs. (Haring)

3.4.1.9. Training Dikes

Training dikes are used to deflect the stream flow away from the protected streambank and into the center of the stream. They are generally constructed in groups, and over time they move the streambed away from the protected streambank by keeping the thalweg toward the center of the channel and precipitating deposition in the slack water between the dikes. Riprap is the most common construction material for training dikes. Training Dikes are most commonly used in large rivers to assist with navigation, however their application can be scalable to small streams and rivers as well. Construction of training dikes on a navigable river is shown in Figure 13.

Figure 13: Construction of Training Dikes.

3.4.1.10. Cross Vanes

Cross vanes are rock structures, generally in a U-shape, placed across the width of a channel. These structures provide grade control by locking the channel invert in place and provide pool habitat. The U-shape of the rock structure also acts to redirect flow toward the center of the channel as water flows over the structure perpendicular to the crest. This flow redirection provides some benefit to bank stabilization immediately downstream of the structure. A typical example of a cross vane structure is shown in Figure 14 below.

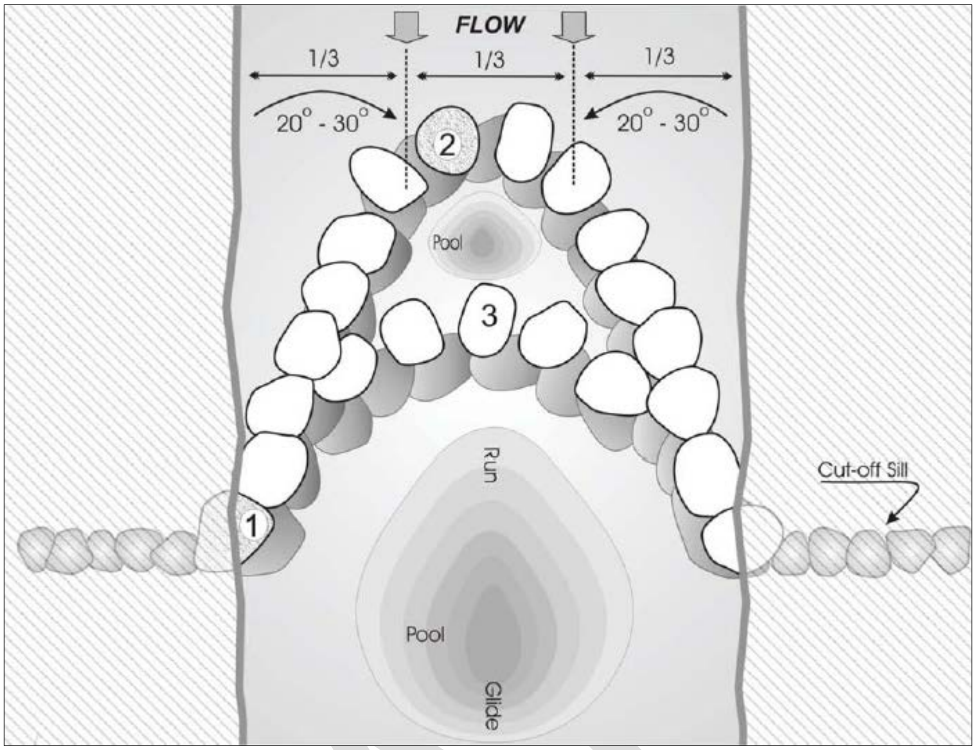


Figure 14: Cross Vane Structure with Step (Rosgen, 2006)

3.4.1.11. J-Hooks

A J-Hook is an upstream directed, gently sloping structure composed of natural materials. The structure can include a combination of boulders, logs and root wads and is located on the outside of stream bends. The structure is designed to reduce bank erosion by reducing velocity, shear stress, and stream power near the bank. The vane portion of the structure occupies 1/3 of the bankfull width of the channel, while the "hook" occupies the center 1/3. A plan view of a typical J-hook is shown in Figure 15. While the bank protection benefits of a J-hook are similar to those of a stream barb, the J-hook provides more in stream habitat benefits. This is done by the "hook" portion of the structure, which concentrates the flow and creates a small downstream scour pool. The determination of whether to use a J-hook or a stream barb depends on the geometry and stream flow of the location.

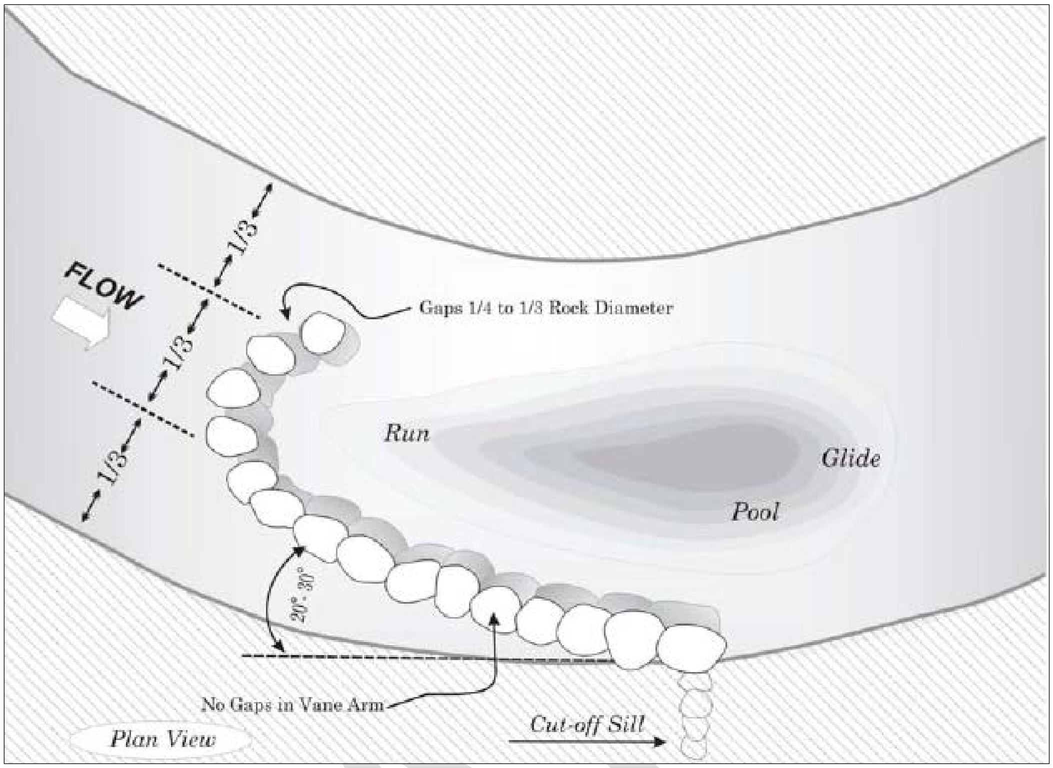


Figure 15: J-Hook Configuration (Rosgen, 2006)

3.4.1.12. Stone Toe Protection

Longitudinal peak stone toe (LPST) involves the placement of a windrow of stone in a peak ridge along the toe of an eroding bank. LPST is particularly applicable where the upper bank is fairly stable, and the erosion is due to mass wasting from the toe of the bank. This technique protects the toe, while allowing the upper bank to stabilize on its own and depends on the rapid establishment of vegetation landward from the stone.

A LPST is often enhanced with the inclusion of woody debris and stone spurs along the length. These encourage deposition along the toe, create edge habitat, and move the higher velocity flow away from the bank. An example section of stone toe protection is shown in Figure 16 below.

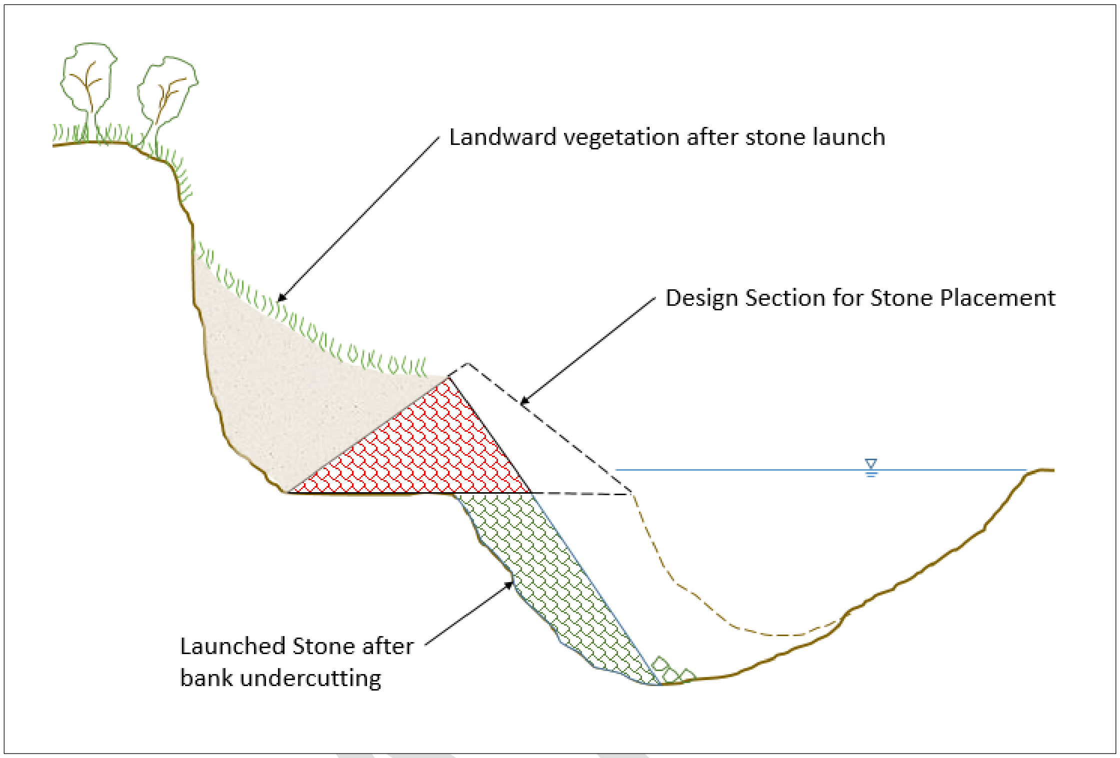


Figure 16: Stone Toe Protection

3.4.1.13. Riprap Lining

Riprap lining can be used to protect channels and dissipate energy from high velocities exiting culverts.

3.4.1.14. Other – Concrete piers @ PC08

Two large concrete structures, likely abandoned bridge piers, are located within the channel near reach PC-08. These structures will be relocated and angled upstream to deflect flow away from the stream bank and provide an anchor point for any bank shaping that occurs within the reach. A photo of these structures is presented in Figure 17 below.

Figure 17: In-situ concrete piers near PC-08

3.4.2. Riparian Measures

3.4.2.1. Invasive Plant Species Control

Invasive plant species such as kudzu and privet are common throughout the study area. These species crowd out native species that provide habitat in overbank areas and riparian buffers. These species also impact the local flow regime by changing flow characteristics (e.g. roughness values) and may increase bank erosion. Removal of these species in the selected reaches will be accomplished through manual removal of plant and root systems (e.g. disking) and by application of herbicides where necessary. Best practices for invasive removal include multi-year programs for removal and native vegetation re-establishment.

3.4.2.2. Plantings

Vegetated reinforced slope stabilization combines rock, geosynthetics, and native vegetation plantings to stabilize steep and eroding slopes. Quick growing vegetation provides root structures to stabilize the bank. Typical features include live stake plantings, often willow or dogwood on the stream bank during spring and fall which grow quickly to establish woody vegetation.

3.4.2.3. Wetland Creation

Several locations in the Proctor Creek watershed allow for the creation of off-channel wetlands in overbank areas near the stream channel. These wetland areas are created through excavation of the overbank areas, vegetation planting, and diversion of occasional high flows from the stream through the wetland itself. Wetlands provide potential benefits in water-quality improvement, flood attenuation, aesthetics, and recreational opportunities. An example of a created wetland under construction, with designated flow path and vegetation plantings, is presented in Figure 18 below.

Figure 18: Created Wetland under Construction (Wikimedia Commons)

3.4.3. Connectivity Improvement Measures

3.4.3.1. Culvert Removal and Channelization

Portions of the Proctor Creek tributaries currently flow through long sections of culvert. Culverted reaches do not provide suitable instream habitat, and disconnect in-stream species from the riparian zone and floodplain. In order to address these concerns certain portions of the streams may be “daylighted”, by removing the culverts and restoring the channel to a more natural morphology. The open channel will need to have the same or better conveyance capabilities as the existing culvert so as to not increase flood risk.

3.4.3.2. Fish Passage Ramp

Several hard points (e.g. grade control structures, low head weirs, etc.) are present along main-stem Proctor that act as impediments to fish and other species that depend on stream connectivity for access to suitable habitat. Construction of a fish passage ramp at these structures would allow for the movement of fish and other aquatic species throughout the study reach. Construction generally involves placement of rock, or other natural material, with a gradual upstream slope to the crest of the impediment to allow movement of species upstream. A conceptual layout of a fish-passage structure is presented in Figure 19 below.

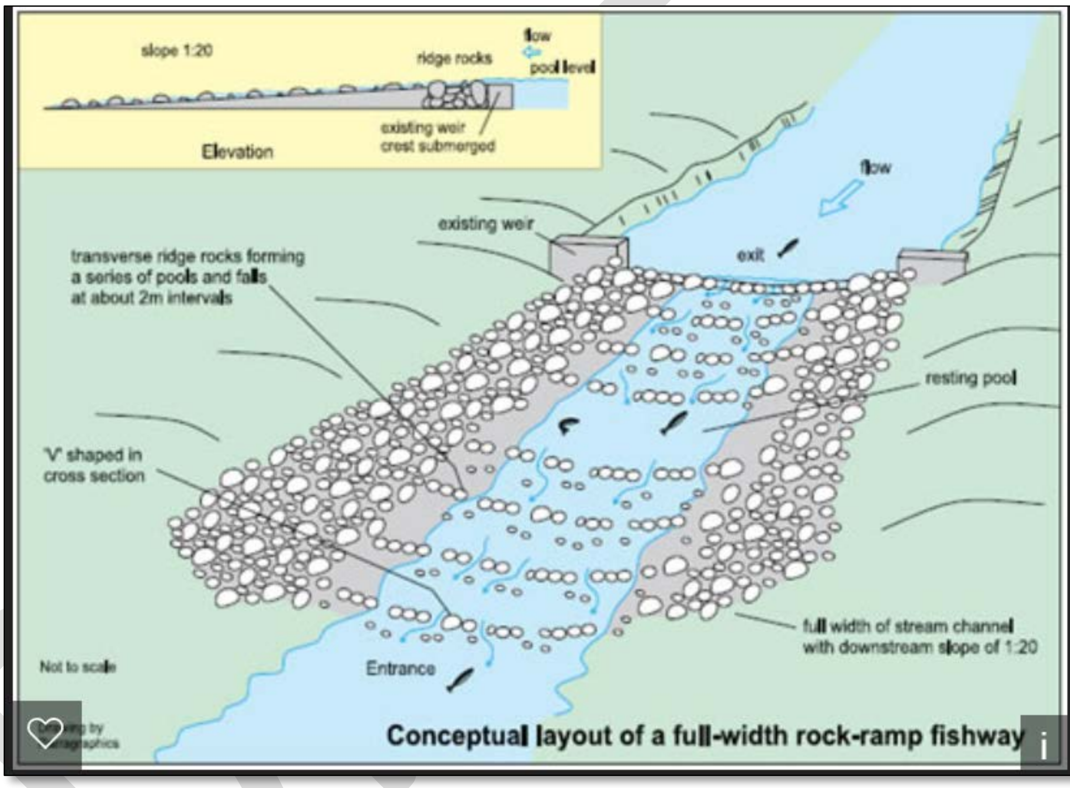


Figure 19: Conceptual Fish Ramp Passage Structure

3.4.4. Hydrologic Improvement Measures

3.4.4.1. Detention Ponds

Detention ponds can be used as a measure to help restore the aquatic ecosystem of urban streams by helping to decrease the flashiness of the hydrograph caused by the high percentage impervious area. This attenuation of the hydrograph can assist in the restoration of natural flow regimes, which tends to have a stabilizing effect on a stream system.

3.4.4.2. Outlet Structure Retrofit

Development and impervious surfaces within the Proctor Creek watershed have caused much of the ecosystem impairment discussed previously.

Impervious area results in flashy rainfall-runoff, increased flows, and higher channel velocities. Stormwater management infrastructure is a common approach used to help mitigate post-development hydrology regimes. The retrofit of existing stormwater infrastructure allows for improved hydrology by reducing peak flows and releasing water over a longer period of time. The outlet works of existing detention and retention ponds can be modified to retain flows from smaller events that have a large impact on channel morphology downstream. Typical features of this type may include replacement of outlet works structures with a modified riser pipe, as pictured in Figure 20 below, or a cast-in-place concrete structure.

Figure 20: Outlet Structure Retrofit

3.5. Identification of Reaches for the Initial Array of Alternatives

The initial identification of potential restoration locations, referred to as Phase I hereafter, occurred in February 2016. Project delivery team (PDT) members walked all of main stem Proctor Creek, Terrell Creek, and Grove Park tributaries. Team members included engineers, ecologists, and biologists. Onsite investigation allowed for PDT members to use expert judgement in identifying the problems and opportunities throughout the watershed on a reach by reach level.

The Phase I investigation resulted in the identification and subdivision of reaches along Proctor Creek, Terrell Creek, and Grove Park Tributary. Potential detention pond sites were also identified during the Phase I investigation. Photographs, field notes, site surveys, and variables associated with the PCEM Phase I ecosystem model were taken in the field and used in a rapid screening assessment as described in the Phase I Screening Report. The Phase I screening reduced the number of reaches and detention ponds that were being assessed for the tentatively selected plan. See the reaches and detention features in Figure 21 that remained after the initial screening. A more detailed analysis of those sites that were identified for restoration potential was completed in Phase II. Refer to the PCEM Phase 1 documentation and Plan Formulation appendix for additional discussion of the screening of restoration reaches and possible alternatives.

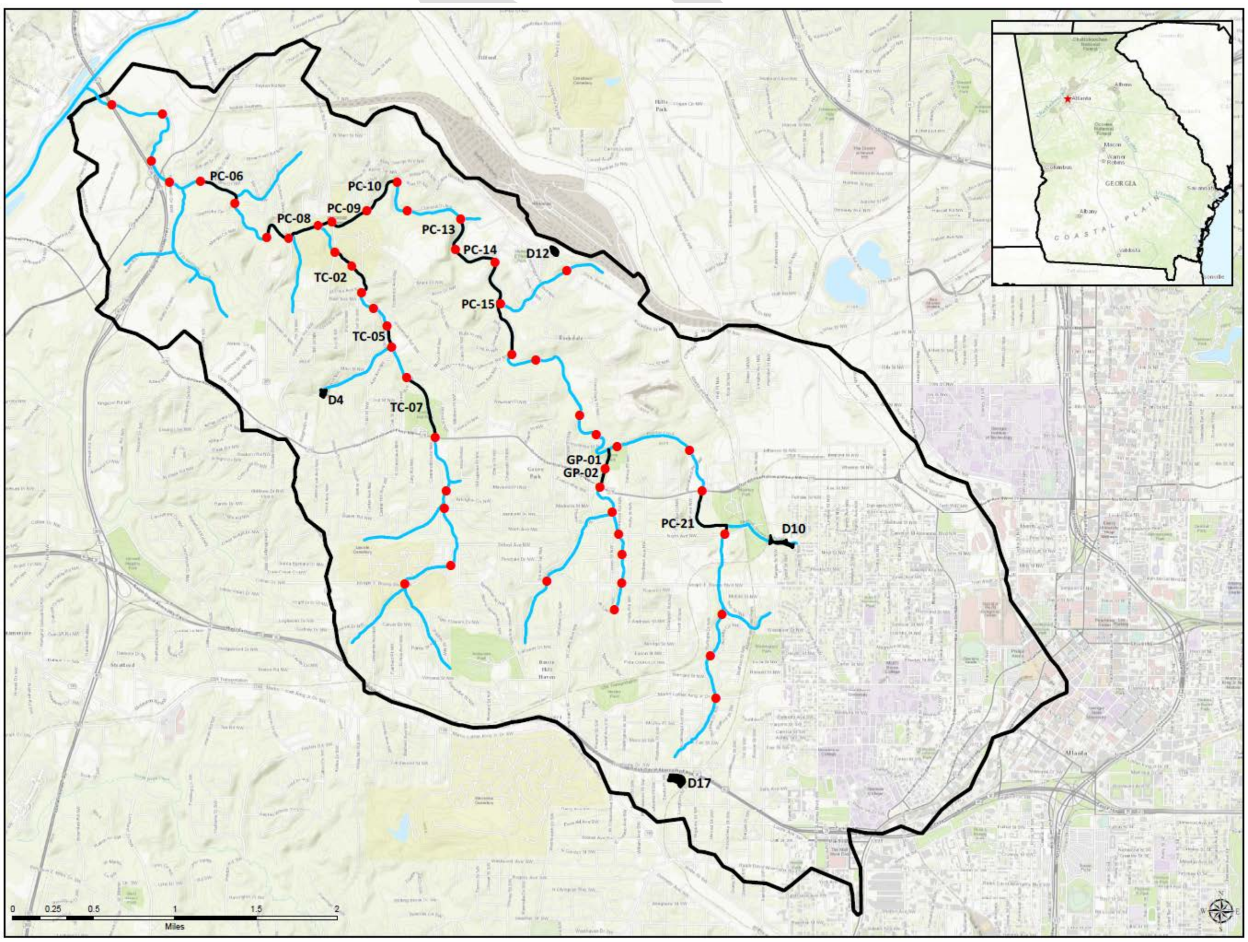


Figure 21: Reaches and Detention Ponds after Initial Screening

3.6. Description of Reaches Considered for the Focused Array of Alternatives

The Phase II site investigations occurred in June 2016. The reduced array of reaches and detention pond sites allowed the PDT to identify and define more detailed measures for ecosystem restoration. The PDT identified measures that would be used within each reach during numerous streamwalks and team meetings in the field. Conditions within each reach dictated the measures selected for use within that reach, based on best professional judgment. For example, a reach likely to experience head-cutting in the future would likely benefit from a grade control structure such as a cross-vane. Further information regarding feature evaluation, and the reach conditions can be found in the Phase II Screening Report. The conceptual designs are used to assess the costs and impacts that measures will have on the stream reaches. Concept designs can be found in the Proctor Creek Ecosystem Restoration Engineering Appendix Attachment 1.

3.6.1. PC-08

PC-08 encompasses the reach of Proctor Creek just upstream and just downstream of James Jackson Parkway. Refer to Plates PC-08, C-1 through C-7, in Attachment 1 for locations and conceptual drawings of the proposed features for PC-08. PC-08 is further subdivided into three sub-reaches: PC-08-1, PC-08-2, and PC08-3. PC-08-1 and PC-08-2 are discussed in more detail below; no work is planned for PC-08-03 which is located upstream of the confluence with Terrell Creek.

3.6.1.1. PC-08-1

Section PC08-1 extends from approximately 400 feet downstream of a historic pet cemetery to James Jackson Parkway. The following describes the measures included in this section.

Log Revetment

From STA 2+00 to 3+00 the downstream left bank (LB) will be protected by a log revetment. Anywhere from 20-30 large logs, depending on sizing, will be needed to armor the LB.

Invasive Plant Species Control

Approximately 6.7 acres of invasive plant control is estimated on the right bank (RB). Invasive plants include kudzu and privet.

Bar Cut and Creation

Approximately 1600 cubic yards (cy) of bar material area will be moved within the reach to create and/or facilitate bar creation along the LB in order to protect the pet cemetery and narrow the base and low flow channel. The existing bar material located at STA 3+00 to 6+60 will be moved to both RB and LB in order to create low floodplains. The bars at STA 12+00 and 14+00 are proposed to be moved to the LB for low floodplain creation that will enhance the banks of the pet cemetery.

Cross Vanes

Six cross vanes are designed to reduce flow stresses on both the LB and RB. Cross vanes will also create scour holes that are beneficial for fish. Cross vanes will be placed at STA 1+80, 3+80, 7+40, 10+25, 12+80, and 14+75. Cross vanes will require rectangular stones in the channel and riprap for key-ins.

Plantings

Approximately 1 acre of plantings is estimated. Plantings will occur on low floodplain areas that are existing and on those that will be created with the movement of bar material.

Other

Two concrete pier structures that are presently sitting as debris in the creek at STA 5+80 will be moved approximately 40 feet to either side of the creek. The structures will need to be placed in an orientation that will facilitate the formation of a LB and RB bar just downstream.

3.6.1.2. PC-08-2

PC-08-2 is located from just upstream of James Jackson Pkwy to the confluence of Terrell Creek tributary. This section includes a large,open field on the right bank and a wooded area on the left bank near Terrell Creek. The following describes the measures included in this section.

Bank shaping

Approximately 960 feet of the LB will be reshaped to create a low floodplain bench for floodwaters to access. The proposed section, shown in Figure 22 below, extends from STA 18+40 to 28+00. The proposed low floodplain bench would rise 3 feet on a slope of approximately 1V:10H slope to elevation 768.5 feet. The slope would then rise on a 1V:3H slope until a tie-in with existing ground is reached. Plantings would be required on the new slope.

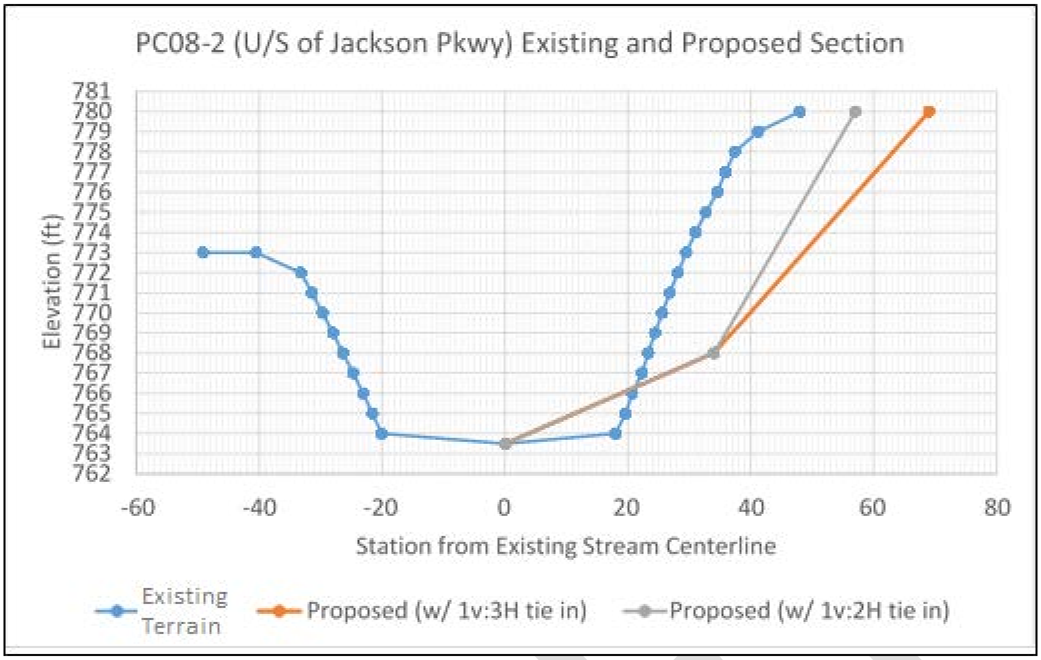


Figure 22: Proposed Bank Shaping Cross Section

Training Dikes

In order to keep the low floodplain in place approximately 19 rock training dikes at a 50 foot spacing will be included along the right bank. The training dikes will be designed to slope up with the proposed low floodplain and will need to be keyed in to the 1V:2H slope.

Cross Vane

A single cross vane is proposed for the downstream end of Terrell Creek. The cross vane will realign Terrell Creek flows to the channel center, reduce bank stress and assist with grade control.

Plantings

Approximately 1.4 acres of land is expected to be disturbed as a result of the bank shaping. This area will need to be planted.

Invasive Plant Species Control

Approximately 6.6 acres along the right bank and 0.6 acres along the left bank will require invasive plant control for privet and kudzu in this reach.

3.6.1.3. PC-08 Geology and Geotechnical Information

Since this reach will undergo restoration improvements that will be in the form of grade control and invasive control, there is the anticipation of minor excavation and reshaping of stream banks. The site did not require any additional investigation at the time of the field survey with no hand augers advanced at this site. Paleozoic age undifferentiated biotite gneiss underlies Site PC-08. The site soil cover is with very weathered in place igneous and metamorphic rock termed sapprolite. Sapprolite is a weathering product of rock in very humid environments that appears to look like rock but can be excavated like soil. The depth of the sapprolite soil may vary from two-feet to some tens of feet. The soil is typically a silty sand to a clayey sand. The clay content depends on the Potassium Feldspar concentration.

3.6.2. PC-09 and PC-10

PC-09 and PC-10 are described as one reach since PC-09 has only one measure proposed for it. The PC-09 and PC-10 reaches extend from Hollywood Road to a location on Proctor Creek adjacent to the intersection of Ajax Dr. and Addison Pl NW. The overbank area for most of the length of the length of the reach is forested. However, there are stretches with poor riparian cover and encroaching neighborhoods. There is a sewer line that crosses the creek and creates a fish passage barrier during low flows.

Fish Passage Ramp

A fish passage ramp similar to the one pictured in Figure 17 will be included at STA 0+50 to provide fish passage over the sewer crossing at this location.

Rock Stream Barbs

Riprap is proposed for use as stream barbs off of the RB. The purpose of the weirs is to reduce erosion along the RB and to encourage sedimentation for a small low floodplain between the weirs. The proposed weirs are 30 feet apart and six weirs are proposed from station 4+80 to 6+40. Riprap barbs will be placed in areas that are not likely to achieve long term stabilization through vegetation.

Log Stream Barbs

At the inside bend of the upstream end of PC10 near STA 18+00 there is an opportunity to turn an island into a LB point bar. Log stream barbs are proposed to encourage sedimentation along the LB. Natural vegetation is expected to take hold if the sedimentation occurs. It is estimated that there are three locations along the LB where barbs and/or log jams are needed. Log barbs will be placed in areas that are likely to achieve long term stabilization through vegetation.

Stone Toe Protection

150 feet of LPST is proposed for protecting the RB in the bend near STA 8+00. The stone toe is expected to be about 3 feet high with 1V:1.5H side slopes.

Log Revetment

Approximately 100 feet of log revetment is proposed on the RB near STA 16+00.

Invasive Plant Species Control

Large portions of the RB will be treated for invasive plant species. Kudzu is the primary invasive plant in this area. Total treated area is estimated to be 3.6 acres.

Plantings

Approximately 3.6 acres on the RB will be planted to improve the riparian condition. Hardwoods will be planted at higher elevations, while willows and wet tolerant species will be planted at lower elevations.

3.6.2.1. PC-09 and PC-10 Geology and Geotechnical Information

Since Reaches PC-09 and PC-10 will only undergo fish passage improvements, invasive plant control, and riparian plantings, the initial geotechnical investigation did not perform any sampling of the soil or rock. Based on regional studies, the soil underlying PC-09 and PC-10 is the Paleozoic porphyritic granite. Overlying the granite is residual sapprolite soil. The soil consists of silty sand and slightly clayey sand. The estimated depth of the sapprolite is two to ten feet.

3.6.3. PC-13

This reach runs adjacent to the Gun Club area and the West Highlands subdivision. The reach maintains a narrow riparian corridor due to encroachment from the Gun Club area and the subdivision. Improved plantings, invasive plant control, bank protection, and the addition of woody debris for habitat are some of the potential measures for this reach.

Rock Stream Barbs and Rootwads

A riprap and rootwad combination is proposed for use as stream barbs off of the LB from STA 5+20 to 7+00. The purpose of the stream barbs is to reduce erosion along the LB and improve habitat. Rootwads are proposed under the key-ins. The rootwads will add woody debris for habitat and also increase roughness along the outer bank for improved erosion control.

Engineered Log Jam (ELJ)

At the upstream end of the project area at approximate STA 8+40 there is a RB bar forming with a high flow chute cutting around the bar on the right bank toe. Woody debris jams will be used to further cut off this chute and encourage bar formation, vegetation, and woody debris habitat.

Invasive Plant Species Control

Large portions of the LB will be treated for invasive plant species. Invasive plants in this area primarily include kudzu and privet. The total treated area is estimated to be 1.8 acres.

Plantings
Approximately 1.8 acres on the LB will be planted to improve the riparian condition. Hardwoods will be planted at the higher elevations, while willows and wet tolerant species will be planted at lower elevations.

3.6.3.1. PC-13 Geology and Geotechnical Information
A geotechnical investigation of this site was unnecessary because the proposed restoration measures only include improved plantings, invasive plant species control, bank protection, and the addition of woody debris. Underlying PC-13 is the (gr1b) Paleozoic porphyritic granite. Overlying the granite is residual sapprolite soil. The soil consists of silty sand and slightly clayey sand. The estimated depth of the sapprolite is two to ten feet.

3.6.4. PC-14
The PC-14 reach extends from the upper limit of reach PC-13 to the crossing with Sandford Dr./Kerry Cir NW. The reach runs adjacent to the West Highlands subdivision on the RB and LB.

J-hook Vanes
J-hook vanes are proposed at the creek bend at STA 14+00 to 15+00. The structures would be constructed with rock; root wads and/or logs can be added for improved habitat. The structures would be tied into the LB in order to reduce outer bend erosion and direct flow to the channel center.

Rock Stream Barbs
Riprap is proposed for use at stream barbs off of the RB from STA 15+80 to 17+40. The purpose of the barbs is to reduce erosion along the RB. Rootwads are proposed under the key-ins. The rootwads will add woody debris for habitat and also increase roughness along the outer bank for improved erosion control. Four barbs are proposed with spacing of approximately 50 feet between barbs.

Engineered Log Jam (ELJ)
At STA 14+00 there is a RB bar forming with a high flow chute cutting around the bar on the RB toe. Woody debris jams are being proposed to further cut off this chute and encourage bar formation, vegetation recruitment, and woody debris habitat.

Log Revetment
Tree revetment is proposed to prevent toe and bank erosion from STA 15+00 to 16+40 on the outside of a bend on the RB. Wood revetments can provide habitat and reduce erosion on the bank.

3.6.4.1. PC-14 Geology and Geotechnical Information
No soil sampling occurred in this reach because the restoration measures will only consist of J-Hook vanes and rock stream barbs. Underlying PC-14 is the (gr1b) Paleozoic porphyritic granite. Overlying the granite is residual

sapprolite soil. The soil consists of silty sand and slightly clayey sand. The estimated depth of the sapprolite is two to ten feet.

3.6.5. PC-15

The PC15 reach extends from the crossing of Sandford Dr./Kerry Cir NW to Johnson Rd. The reach runs adjacent to the West Highlands subdivision on the RB and LB at the downstream end of the reach. A hike/bike trail runs along the RB.

J-hook Vanes

Three J-hook vanes are proposed in the creek between STA 4+00 and 8+00. The structures would be constructed with rock. Root wads and/or logs can be added for improved habitat. The structures would tie into the LB in order to reduce outer bend erosion and direct flow to the channel center.

Stream Barbs

Riprap and logs are being used to construct stream barbs throughout this reach. They will be located off of the LB and RB from STA 3+00 to 11+00, off of the LB from STA 23+50 to 30+40, and two barbs are located on the LB at STA 33+30 and 33+80. The purpose of the barbs is to reduce erosion along the banks, encourage sedimentation along the toe, and narrow the channel. The barbs will be spaced approximately 50 feet apart from each other.

Engineered Log Jam (ELJ)

At STA 21+00 there is a LB bar forming. ELJs are being placed at STA 21+20 and 21+50 to encourage bar formation further upstream of the existing bar and to decrease LB erosion. ELJs will encourage sediment deposition for the bar, encourage vegetation, and add in stream habitat. Four ELJs are also proposed between STA 31+20 and 32+00 on the RB. These ELJs will encourage bar formation that will tie into an existing RB bar downstream.

Cross Vanes

Cross vanes are proposed at STA 2+40, 23+20, 27+00, 31+00, and 34+40. Cross vanes are used for reducing shear stress along both banks, encouraging sedimentation along the banks, creating habitat through scour in the stream centerline, and for grade control. Cross vanes will be made of stone with key-ins made of rip rap.

Longitudinal Peaked Stone Toe (LPST)

LPST is proposed in areas where a hard structure is needed to prevent further toe erosion and channel widening. LPST will be located at two locations; from STA 23+00 to 25+40 on the RB and from STA 31+00 to 33+00 along the LB.

Log Revetment

A tree revetment will be used to prevent toe and bank erosion from STA 27+00 to 29+00 on the outside of a bend on the RB. Woody revetments can provide habitat while also reducing erosion.

Bar Cut / Creation

At STA 14+00 there is a bar forming on the LB. Bar material will be moved to the RB in order to improve the flow alignment prior to entering the downstream bend in the creek. At STA 32+60 to STA 34+41 bar material on the RB will be moved to the LB in order to realign the creek as it exits the bridge crossing and enters a downstream bend.

Root Wads

Approximately 5-10 root wads will be placed at STA 22+20 and approximately 15-25 are proposed from STA 15+00 to 15+80. Root wads will deflect flow off of an outer bend and reduce bank erosion, while also creating habitat.

Bank Shaping

Bank shaping of the LB is proposed from STA 22+20 to 31+00. The purpose of the bank shaping is to create a low LB floodplain so more frequent flow events can access the floodplain. The low floodplain will extend out to the approximate midpoint of the current channel and will therefore reduce the stream width by half at the baseflow elevation. Material from the existing bank would be used to shape the new bank and low floodplain. Plantings will occur on the newly shaped slopes.

Wetland

A wetland is proposed for the left overbank area adjacent to the bank shaping. The proposed wetland would be excavated down to elevation 800 feet; elevation 804 feet to 805 feet is the predominant existing condition elevation. A pilot channel is proposed to run through the wetland in order to allow stream flow to enter and exit the wetland. The channel would be approximately 5 feet wide with mild slopes tying in to the wetland. The slopes would be mild at approx. 0.5% in order to prevent erosion. A small log dam staging up an inundated area 18-24 inches could be placed in the wetland in order to create a frequently inundated area. Rip rap is proposed at the outlet and inlet in order to reduce erosion. A concrete diversion will likely be needed at the inlet of the channel where flow is diverted from the main creek.

Plantings

Approximately 2.7 acres of plantings are proposed in the wetland area and in support of the bank shaping.

Invasive Plant Species Removal

Invasive plant species will be removed from an approximately 2.1 acre area at the proposed wetland site.

Sewer Line Demolition

There is an old sewer line identified in the streamwalk that could be removed upon verification with the city of Atlanta. The line is located at STA 14+70.

3.6.5.1. PC-15 Geology and Geotechnical Information

The Lithonia Gneiss underlies Reach PC-15. The gneiss appears as deeply weathered in the area of PC-15. The borings in the stream channel reveal sand and organic deposits. The team advanced two borings along the western stream bank to a maximum depth of 5 feet. The soils encountered consist of silty sand. The proposed restoration measures for PC-15 include stability of stream banks, channel depth improvements of depth to width ratio, provision of woody debris habitat, floodplain enhancement, creation of wetland areas, improvement of riparian vegetation, and invasive plant species removal. The silty sand is easily excavated.

3.6.6. PC-21

The PC-21 reach extends from just upstream of Donald Lee Hollowell Pkwy to North Avenue NW, encompassing the colloquially known “Mosquito Hole”.

Cross Vane

A single cross vane is proposed at STA 4+60 to provide grade control and to redirect flows back to the channel center to help prevent erosion along the LB.

Longitudinal Peaked Stone Toe (LPST)

LPST will be placed from STA 2+60 to 4+40 where severe bank erosion is occurring along the LB. This will help stabilize the bank and prevent future erosion and channel migration.

Additional LPST will be placed at STA 19+00 to 20+00, in a bend in the Mosquito Hole area. Toe protection placed at this location will help armor the bank from high velocities entering this portion of the reach from the channelized portion just upstream.

Stream Barbs

Riprap and logs are will be used as stream barbs throughout this reach. Rock barbs with embedded rootwads will be located along the LB from STA 10+00 to 15+00, approximately every 100 feet. Log barbs will be placed along the RB from STA 4+75 to 5+75 and STA 16+00 to 17+75: approximately every 25 feet. The purpose of the barbs is to reduce erosion along the banks, encourage sedimentation along the toe, and narrow the channel.

Rootwads

Approximately 10-20 root wads will be placed at STA 12+20 to 14+40. Root wads will deflect flow off of an outer bend, reduce bank erosion, and create habitat.

Bank shaping and Training Dikes

Approximately 350 feet of the RB will be reshaped to provide a more stable slope along the streambank to reduce erosive forces. Plantings will be required on the new slope. In order to keep the bank shaping in place approximately 12 rock training weirs at a 25 feet spacing will be included along the RB. The training weirs will be designed to slope up with the proposed bank and will need to be keyed in to the 1V:2H slope.

Wetland

A wetland is proposed for the RB overbank area in what is sometimes referred to as Proctor Creek Park. The proposed wetland would be excavated several feet below existing grade with a pilot channel through the wetland in order to allow stream flow to enter and exit the wetland. The channel would be approximately 5 feet wide with mild slopes tying in to the wetland. The slopes would be mild at approx. 0.5% in order to prevent erosion. A small log dam staging up an inundated area 18-24 inches could be placed in the wetland in order to create a frequently inundated area. Rip rap is proposed at the outlet and inlet in order to reduce erosion. A concrete diversion will likely be needed at the inlet of the channel where flow is diverted from the main creek.

Plantings and Invasive Plant Species Control

Nearly all of the proposed wetland area is covered with kudzu which will need to be removed and replaced with native plantings; approximately five acres of wetland grasses, willows, and other suitable native plantings are needed and seven acres of invasive removal needed. An additional ¼ acre of plantings are needed along the LB from STA 0+00 to 3+00.

3.6.6.1. PC-21 Geology and Geotechnical Information

The proposed restoration measures include streambank restoration, channel depth improvements, woody debris habitat, floodplain enhancement, improvement of riparian vegetation, wetland areas, and invasive plant species removal. The team advanced three hand auger borings to a maximum depth of 5-feet. PC-21-1 revealed man-made fill (silty sand). PC21-2 revealed 5 feet of man-made fill with a trace of 1 inch asphalt pieces. PC-21-3 revealed 5 feet of manmade fill (silty sand) with some amounts of construction debris. The team observed some large concrete and asphalt chunks in the area. The site could encounter difficult excavation conditions because of the construction debris.

3.6.7. TC-02

The TC-02 reach of Terrell Creek is bounded by the crossings with Hollywood Rd. at the upstream and downstream end, in the vicinity of St. Paul Avenue. The majority of the work will be in an area adjacent to a cemetery, with opportunities for streambank stabilization and wetland creation.

Wetland

The wetland area will cover approximately 1.25 acres, with a small amount of excavation below existing grade. There will be 4 small log and earthen-structures within the wetland area used to pond up water and create small pools in the diversion channel. Ponding depths should not exceed more than 18 to 2 inches. Earthen benches will be created for wildlife and plants.

Diversion

A diversion at approximate STA 15+90 will be created to divert stream flow from Terrell Creek to an offline wetland area. A concrete or rock diversion weir will be set at an elevation such that base flow continues in the creek downstream, but some of the flow is diverted to the wetland during higher flow events.

Diversion Channel

A small channel with a 3 foot bottom width will divert flow to the wetland. The area will be confined between the existing stream and a utility line. Channel slopes will be mild so as to reduce erosion potential. Side slopes of the channel should be no greater than 1V:3H. The channel will return to the creek at approximate STA 7+00 after flowing through the wetland area. Rip rap erosion protection will be provided where the diversion channel returns flow to the creek.

Longitudinal Peaked Stone Toe (LPST)

Three locations were identified for bank stabilization. There is approximately 120 feet of LPST on the RB in the upstream-most section of the reach at STA 16+80 to 18+00 and 220 feet of LPST on the LB from STA 10+20 to 12+40. There is also a 70 foot section along the RB from STA 9+50 to 10+20 where locked logs or some other bioengineered revetment will be placed.

Invasive Plant Removal

Approximately 3.9 acres will be treated for invasive plant removal. Invasive plants in this area include kudzu and privet.

Plantings

Approximately 3.9 acres will be planted. Plant types will depend on the location, elevation, and access to water. Willow and sycamore trees are likely plant options as there are successful examples present. Marsh/wetland vegetation will be planted as well. Hardwood trees can be planted at higher elevations.

3.6.7.1. TC-02 Geology and Geotechnical Information

Proposed restoration measures include possible diversion channels, creation of wetlands, bank stabilization, removal of invasive plant species, and plantings. The reach is underlain by Clairmont Formation a bluish gray porphyritic gneiss. The weathered portion of the underlying rock is generally silty sand to depth of 5-feet. Boring TC-02-02 encountered an elastic silt for the full 5 foot depth of the boring. The five foot depth of soil should allow construction of the proposed remedial measures. Proposed restoration measures include possible diversion channels, creation of wetlands, bank stabilization, removal of invasive plant species, and plantings.

3.6.8. TC-05

The TC-05 reach extends from approximately the intersection of Brooks Ave and Lotus Ave to a location approximately 800 feet downstream. Much of the adjacent overbank area is forested with an abandoned apartment building in the right overbank area. There is a concrete encased sewer crossing at the upstream end of the project that is a barrier to fish passage.

Fish Passage Ramp

A fish passage ramp similar to the one pictured in Figure 13 is proposed, so fish and other creatures can move up and over the sewer crossing at base flows.

Bar Cut and Creation

The rocky bar forming on the RB will be moved to the LB from STA 4+00 to 6+00. This will allow for a channel to be designed at appropriate dimensions and will align the downstream end of the fish passage ramp. Approximately 190 c.y. of material will be moved.

Training Dikes / Bendway Weirs

Wood logs are proposed for use as training weirs on the left bank for 200 feet downstream of the fish passage ramp. The purpose of the weirs is to hold the proposed LB bar in place and to encourage further bar formation on the LB. The weirs will also keep the channel towards the RB and will assist in maintaining an appropriate bankfull width-depth ratio. The weirs will be 25 feet apart with a total of 7 weirs from STA 4+40 to 5+90.

Cross Vane

Two rock cross vanes will be placed at STA 3+40 and 4+30. The purpose of the cross vanes is to anchor the stream alignment and thalweg, reduce flow pressure on the banks, and to act as a grade control.

Stone Toe Protection with Rootwads

Two, hard outer bends are proposed to be protected with stone toe and root wads at STA 1+20 and 2+20. Approximately 90 feet of stone toe is proposed for the upstream bend and approximately 100 feet is proposed for the downstream bend. The stone toe is expected to be about 3 feet high with 1v:1.5H side slopes. A total of 10-15 root wads are estimated to be needed for the two bends combined.

Invasive Plant Species Control

Both the LB and the RB will be treated for invasive plant species. Invasive plants include English ivy and privet. Total treated area is estimated to be 1.7 acres on the RB and 1.4 acres on the LB.

Plantings

Approximately 1.4 acres on the LB will be planted to improve the riparian condition.

Wetland

A wetland is proposed on the LB of the reach. The wetland area would be approximately 0.65 acres with a depth ranging from 1 to 3 feet. The pilot channel through the wetland would run at an approximate 0.5% slope and would have a 3 foot bottom width with no greater than 1v:3h side slopes. Two small check-dam structures will be placed across the diversion channel to create pools within the wetland as water ponds up behind the structures. Plantings will be included in the wetland area. A diversion channel will be created in order to divert stream flow from Terrell Creek to the offline wetland area in the left overbank. A concrete or rock diversion weir will be set at an elevation such that base flow continues downstream in the creek, but some of the flow is diverted to the wetland during higher flow events. It will be located at approximate STA 7+80 along the unnamed tributary to Terrell Creek, upstream of the fish passage ramp.

3.6.8.1. TC-05 Geology and Geotechnical Information

The Lithonia Gneiss underlies TC-05 The team hand augered two borings at this site. Hand auger boring TC-05-1 encountered dense excavatable gravel. TC-05-2 encountered 5-feet of silty sand (Sapprolite) the maximum depth of penetration.

3.6.9. GP-01

The GP-01 reach extends from the confluence of Valley Park Branch (VPB) with Proctor Creek to the Grove Park driveway culvert. The reach runs adjacent to Grove Park, with a community garden off of the LB and tennis courts and ball fields off of the RB. There is minimal room for overbank improvement on the RB, and the community garden encroaches on some locations of the riparian buffer on the LF. The potential measures in GP-01 include stabilizing streambanks, improving the channel depth/width ratio to move sediment, improving fish passage, and improving riparian vegetation.

Cross Vanes

There are two existing, log K-dams located in the reach. The K-dams appear to be effective at providing grade control along the reach. One of the K-dams, the downstream-most dam at approximate STA 2+40, appears to be a fish barrier during low flows. This K-dam will be replaced with a cross vane which will provide grade control and allow fish passage during low flows. The proposed cross vane would be made with logs instead of rock.
A rock cross vane is proposed for the downstream end of GP-01 near the confluence with Proctor Creek. The purposed of the cross vane is to prevent head cutting from migrating upstream from Proctor Creek. The cross vane will also create a scour pool for habitat and reduce erosion on the toe and banks. The vane would be located at approximate STA 0+70.

Stream Barbs

Log stream barbs are proposed for both the LB and the RB downstream of the proposed log cross vane. The stream barbs would be spaced approximately every 50 feet along both banks from STA 1+00 to 5+40. The purpose of the barbs is to reduce erosion along the banks, encourage sedimentation along the toe, and to narrow the channel. The proposed design calls for a pair of barbs on each side of the tributary.

Root Wads

Approximately 3-6 root wads are proposed for the downstream end of the reach near the confluence with Proctor Creek. The purpose of the root wads is to reduce erosion on the outside bend of the Grove Park Tributary just before it enters Proctor Creek. Root wads will also create habitat. It is estimated that all root wad materials should be available from downed trees in the vicinity of the project site. The root wads will be located at approximate STA 0+50.

Plantings

Plantings are proposed at the confluence of Proctor Creek and VPB as well as along the banks of VPB through the GP-01 reach. A mix of hardwoods and flood tolerant species will be needed.

3.6.9.1. GP-01 Geology and Geotechnical Information

The Crider Gneiss underlies Reach GP-01. Crider Gneiss, which is a massive and slabby medium to coarse muscovite-quartz-plagioclase gneiss, generally weathers to a light tan to dark yellow soil with stones of gneiss. The soil has residual boulders of gneiss where the unit is deeply weathered.

3.6.10. GP-02

The GP-02 reach extends along Valley Park Branch (VPB) from the Grove Park driveway culvert upstream to the crossing with Donald Lee Hollowell Pkwy. The reach runs through Grove Park, and the majority of the stream is currently piped through two 10x5-foot box culverts. There is a grass field above the culverts that the community uses for sports and other recreational activities. The primary measure in GP-02 is daylighting the portion of VPB that is in the culvert. A proposed open channel concept will allow fish passage up VPB. Stabilization measures such as log vanes, cross vanes, j-hooks, and plantings are proposed in order to create a stable, healthy stream reach.

Culvert Removal and Channelization

A proposed channel concept was designed to replace the culvert section of the reach with an open channel. The open channel will need to have the same or better conveyance capabilities as the existing culvert so as to not increase flood risk. The channel is proposed to bend to the east side of the field so that open space will remain to the west for the community. The slope of the channel profile is estimated to be approximately 0.6%; excavation and material haul off will be required. The channel will tie into the existing culvert infrastructure at the Donald Lee Hollowell Pkwy and at the Grove Park driveway. The tie in at the Grove Park driveway will involve the construction of a headwall at the upstream end of the crossing. A typical cross section for the proposed channel are presented Figure 23, with sections from the upstream and downstream reaches also shown.

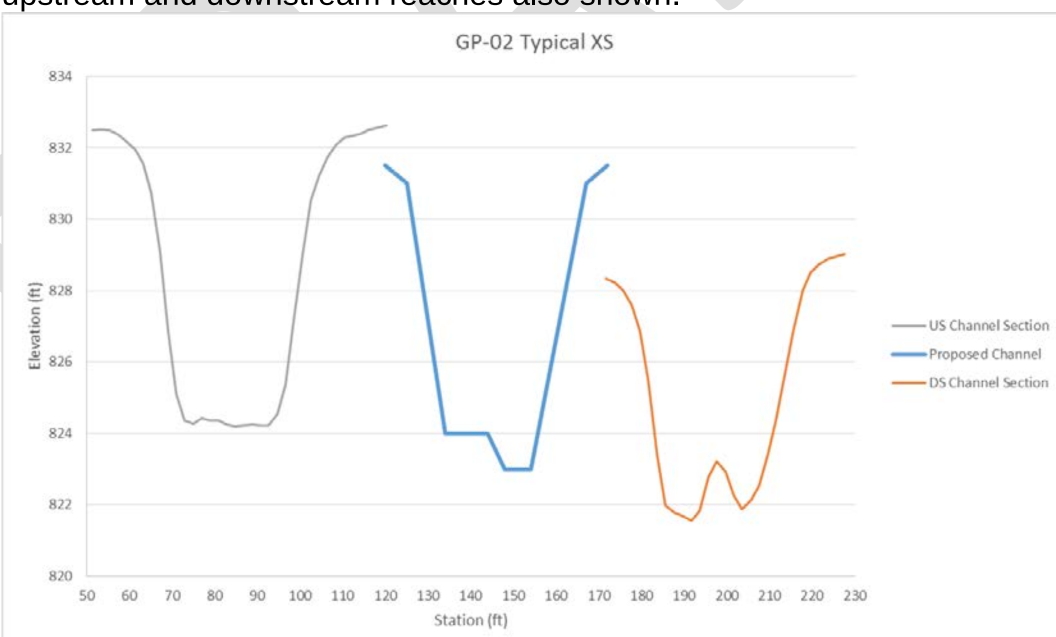


Figure 23: GP-02 Proposed Cross Section, with US and DS sections

The GP-02 proposed typical section shown above was estimated along the reach. Four proposed cross sections were input into the hydraulic model to represent the proposed channel. The slope of the proposed channel was estimated to need to be approximately 0.58%. This value was estimated with the LiDAR data of existing conditions. The culvert under the Grove Park driveway will remain, and this was included in the proposed model. The two upstream-most and downstream-most existing conditions cross sections shown were assumed to remain the same in the proposed condition. Manning's n values for the proposed channel are 0.35, 0.7., and 0.03 for the stream channel, side slopes and grass field overbank respectively.

Culvert Demolition

Portions of the existing culvert will have to be demolished and hauled off. Since the proposed channel will bend to the east much of the culvert can remain intact underground. The remaining culvert can be plugged or left in place as an overflow path for high flows. Approximately 125 feet of the culvert will be demolished and removed at the DS end of the reach. At the upstream end of the reach approximately 100 feet of concrete lined channel will need to be removed.

Cross Vane

Three cross vanes are proposed in the new open channel. The upstream most and downstream most cross vanes will be constructed of rock. They are located at STA 6+90 and 12+00. The third cross vane at STA 9+70 will be constructed of logs. The purpose of the vanes is to create scour holes for habitat, reduce bank erosion, and prevent head cutting.

Stream Barbs

Log stream barbs are proposed for both the LB and the RB along the reach. The stream barbs would be spaced approximately every 50 feet along both banks from STA 7+90 to 11+40. The purpose of the barbs is to reduce erosion along the banks, encourage sedimentation along the toe, stabilize the banks, and to maintain channel design width. The proposed design calls for a pair of barbs on each side of the tributary.

J-hook Vanes

Two J-hook vanes are proposed in the new channel at STA 7+50 to 8+60. The structures would be constructed of rock with rootwads and/or logs added for improved habitat. The structures would tie into the RB in order to reduce outer bend erosion and direct flow to the channel center.

Rip rap Lining

Rip rap lining for erosion control and energy dissipation are proposed for the 25 foot section of the reach directly downstream of Donald Lee Hollowell Pkwy. The channel and banks will require measures to prevent erosion and reduce velocities exiting the upstream culvert but also allow for fish passage. Velocities in that area are anticipated to be approximately 7.3-11 ft/s for 2% and 1% annual percent chance storm events respectively. Velocities this high require erosion protection.

Plantings

Plantings will be placed along the banks of the newly constructed channel. A planting buffer of 10 feet is proposed on either side of the channel from where the channel ties into existing ground and the top of the banks. Flood tolerant species at the lower elevations and hardwoods at the higher elevations will be used. Approximately 0.8 acres of planting will be needed.

3.6.10.1. GP-02 Geology and Geotechnical Considerations

The Crider Gneiss underlies Reach GP-01. Crider Gneiss, which is a massive and slabby medium to coarse muscovite-quartz-plagioclase gneiss, generally weathers to a light tan to dark yellow soil with stones of gneiss. The soil has residual boulders of gneiss where the unit is deeply weathered.

3.6.11. D-17

The initial concept for the outlet structure retrofit at D-17 includes placing a cast-in-place box, connected with and upstream of the box culverts passing under I-20. The box will have a 24 inch base flow culvert that will limit flows to a 60 inch RCP and cause water to begin ponding upstream in Pond D-17. The riser pipe will allow for an increase in flow capacity for large storm events once the ponding reaches elevation 865 feet.

3.6.11.1. D-17 Geology and Geotechnical Information

The boundaries of the detention area on the North is Interstate 20, on the east by Langhorn Street SW, on the south by residential property, and on the west by Enota Pl SW. The detention area is underlain by a dense rock layer. Refusal to hand auger drilling occurred at all of the borings from depths as shallow as 2 feet to a maximum depth of 3 feet below ground surface. The overlying soil is primarily sapprolite a residual soil of decomposed igneous and metamorphic rocks. The three hand borings excavated on the site encountered light yellow brown sand. The 3-hand borings were able to penetrate to a depth. 2.0 feet to 3.1- feet below the ground surface to hand auger refusal. The rock in this area is considered massive and any proposed excavation will require heavy excavation equipment.

3.7. Hydraulic Model for Alternative Evaluation

An existing condition, steady flow hydraulic model was modified to include the proposed projects for each alternative. The with-project condition model was created in order to check the feasibility of the open channel modifications. The model includes estimates for the proposed cross sections as well as connections to upstream and downstream existing conditions cross sections. The model allows the team to check the capacity of the reach, estimated velocities in the reach, and estimated water surface elevations (WSELs). Flow inputs used for the with-project condition are the same as those for the existing conditions model, as it is assumed that the watershed is fully developed and not likely to see an increase in flows due to increased impervious area. See Section 5.4 for additional discussion regarding climate change and anticipated hydrologic conditions over the 50-yr project planning horizon.

3.8. Tentatively Selected Plan

All measures discussed in section 3.6 are currently included in the Tentatively Selected Plan (TSP). Refer to the main report or plan formulation appendix for additional discussion of the TSP.

3.9. Climate Change

Climate change was not considered in the engineering analyses prior to TSP, due to extreme variability in forecasts in the region (< +0.5 to > +4 ^{0}C minimum and maximum temperature anomalies and < –10 to > +25 percent change in precipitation) based on statistically downscaled General Circulation Model projections for the Chattahoochee watershed in year 2090 (Lafontaine et al. 2015, McKay et al. 2017b). Consequently, the future with- and without-project hydrologic conditions were assumed to be the same. As such, the existing condition was also assumed to persist for the duration of the 50-year planning horizon. In later stages of the feasibility study (i.e. post TSP milestone), alternative futures with- and without-project will be tested with scenario analyses of alternative land uses, climate conditions, and actions by others (McKay et al. 2017b).

3.10. Erosion and Sedimentation Assessment

The effects of urban stream restoration on sediment transport is an incredibly complex subject due to multiple sources (upland, bed, and bank), interacting projects (e.g., PC-13 could affect PC-08), massive data requirements (topography, lithology, and sediment size), and uncertainty in underlying processes in urban environments. Because of these challenges, sediment processes remain a key issue on the risk register, and a subject of much discussion among the team. Currently, a three-pronged approach, as outlined below, is proposed for addressing sediment, post identification and verification of the TSP (i.e., post TSP milestone).

- Monitoring and Adaptive Management (M&AM) plan: Regardless of analytic findings (described below), this subject will appear as a primary component of the M&AM plan. While sediment transport is not explicitly a goal of these projects, these processes could threaten the success of the effort.

- Tiered Analysis: To avoid cost and schedule problems, an initial qualitative sediment analysis is proposed prior to conducting a quantitative analysis (e.g., via sediment functionality of HEC-RAS or SIAM). The qualitative analysis will address reach-by-reach assessments of the effects of restoration actions on: source control (e.g., eroding banks, large in-channel deposits), sediment movement and continuity (as altered by shear stress and stream power), effects on downstream reaches (restoration and non-restoration), known bedrock grade controls (numerous throughout the basin), and known upland sources (e.g., construction in a sub-basin). These analyses will be compiled at a PDT meeting following the TSP milestone and informed by local knowledge of the stream from prior field trips, the existing HEC-RAS model, and ongoing analyses by the Environmental Protection Agency (EPA) of sediment quality. A more quantitative approach will be explored only if restoration actions have a high potential for inducing large-scale sediment problems.

- Partner Cooperation: Sediment management and processes are central to the success of a variety of projects being explored through the Urban Waters Federal Partnership (UWFP). The PDT will review the findings of the qualitative analysis with the broader working group as a means of quality control. This subject may also become a key topic for a sub-group of interested parties working under this UWFP umbrella (e.g., EPA's ongoing study, U.S. Geological Survey, City of Atlanta, etc.).

4. Hydrologic Modeling Approach

Investigations into available hydrologic modeling for the Proctor Creek watershed resulted in the acquisition of a previously developed HEC-HMS model of the basin. The model was created in 2009 in support of the 2011 Fulton County Hydrology Report and FEMA mapping efforts for Flood Insurance Study (FIS) purposes; the HEC-HMS model was provided to USACE by Atkins Global. While the Fulton County Hydrology Report describes in general the methods and data used for the modeling efforts, discussion focusing specifically on Proctor Creek was not available. Review of the model determined that, with some modifications, it is of sufficient quality to use for the Proctor Creek feasibility study.

4.1. Existing Conditions

The FEMA HEC-HMS model of the Proctor Creek watershed uses the SCS Curve Number method to compute losses, the SCS Unit Hydrograph transformation method, and the Muskingum-Cunge routing method. Several validation events were simulated with the FEMA HEC-HMS model to determine the model's level of accuracy prior to any model modification. Simulation results indicated that modifications to the model were needed, which are discussed in the following sections.

4.1.1. Basin delineation

The existing conditions model used for this study, based off of the FEMA FIS model, divides Proctor Creek into 31 subbasin elements, averaging ½ square mile in size. A combined sewer overflow (CSO) diversion included in the FEMA model was removed from the existing conditions model as the diversion did not produce reasonable model results. Additional information regarding the operation and properties of the CSO was unavailable, and therefore excluded from the model. A schematic of the basin model used in HEC-HMS is presented in Figure 24 below.

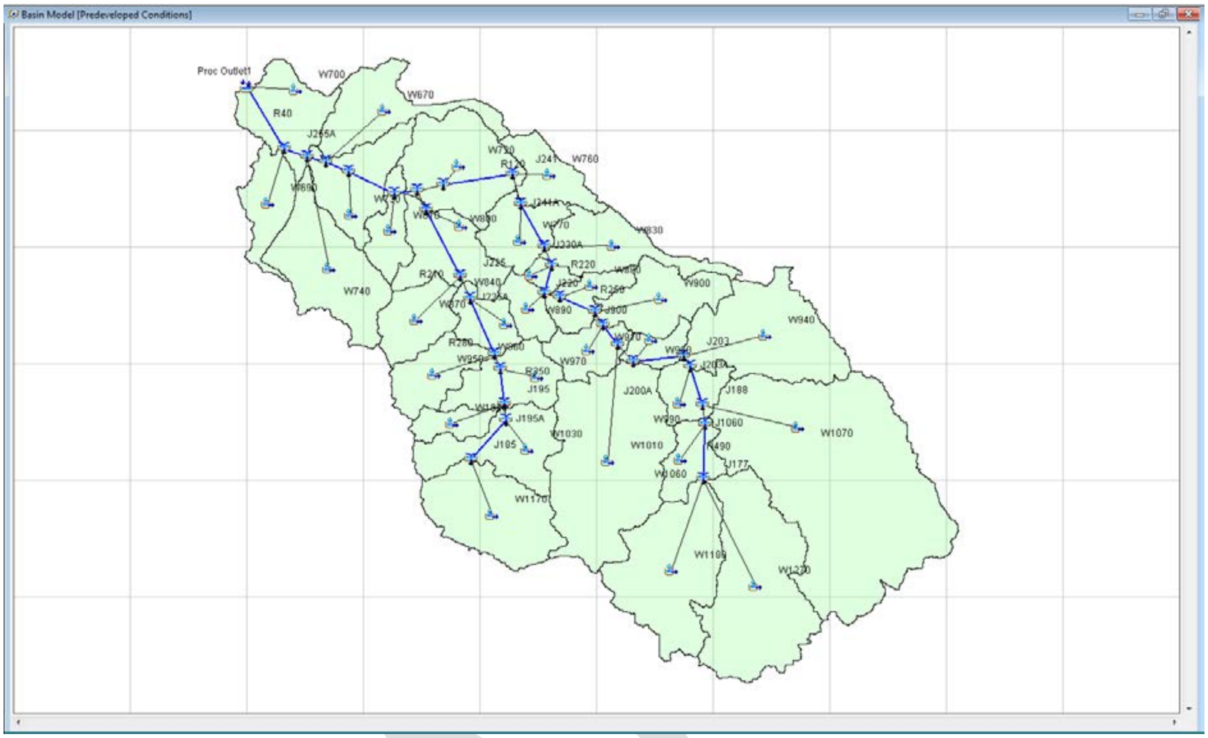


Figure 24: HEC-HMS Basin Model Schematic

4.1.2. Infiltration/Runoff Computations

The SCS Curve Number Method and SCS Unit Hydrograph method were used to compute excess rainfall and runoff values. The curve numbers in the model were updated using GIS analysis of hydrologic soil group types and land use classifications. Additionally, curve-numbers were increased by 4% over the GIS computed values to better match observed runoff volumes. The percent impervious parameter was not used in the SCS Curve Number Loss method; instead, impervious area as it pertains to landuse and runoff was included in the calibrated composite curve number for each subbasin.

Initial abstraction in the basin model was set to 0.1 to reflect significant urbanization within the watershed. Lag times in the model were also adjusted from those found in the FEMA model, with final lag time values generally less than those used in the FEMA model; especially for the larger headwater subbasins. The Curve Number and lag times used in the model are presented in Table 2 below.

Table 2: HEC-HMS Subbasin Parameters

Subbasin	Lag Time (min)	Curve Number
W1070	24	82
W1270	26	87
W1180	23	90
W1060	29	81
W990	16	86
W940	16	90
W960	31	70
W1010	51	78
W910	30	77
W900	24	81
W880	40	74
W890	23	71
W840	17	74
W830	37	85
W770	42	68
W760	26	91
W720	67	70
W1170	21	75
W1030	38	78
W1020	31	77
W970	40	81
W950	40	77
W860	37	77
W800	52	68
W810	24	70
W730	42	72
W670	39	85
W740	41	79
W870	13	71
W690	29	82
W700	30	82

4.1.3. Simulated Rainfall Events – 24-hour Synthetic Storms

NOAA Atlas 14 data were used to update the meteorlogic model from the TP-40 values used in the FEMA FIS model. 24-hour rainfall depths, as shown in table 3 below, were used with an SCS Type 2 distribution for the 2-year through 500-year return interval.

Table 3: Atlas 14 24-hour Rainfall Depths

Return Interval	24-hour Rainfall Depth (in)
1-year	3.31
2-year	3.72
5-year	4.43
10-year	5.06
25-year	5.98
50-year	6.73
100-year	7.52
500-year	9.53

4.1.4. Model Calibration

Several historic events were used to calibrate/validate the updated model prior to simulation of synthetic rainfall events. The goal of calibration was to match simulated runoff volumes with observed streamflow volumes, and to produce Nash-Sutcliffe values (magnitude of residual variance compared to measured data variance) close to 1. Historic precipitation data for the calibration events were obtained from USGS precipitation gages (or NWS precipitation grid, if available) within the study area and converted to a format compatible with the existing model configuration (e.g. Standard Hydrologic Grid).

The first event, occurring between 7 April and 8 April 2014 resulted in an observed peak flow of 3,800 cfs at USGS 02336526. An optimization trial was developed for the April event, whereby lag times for each sub basin were adjusted to achieve a best-fit (minimization of objective function) hydrograph. Optimization was carried out with univariate gradient optimization method and a peak-weighted Root Mean Square (RMS) error objective function, for each subbasin. An iterative workflow approach was used to optimize each sub-basin by adjusting the SCS unit hydrograph - lag time parameter, while working from the upper portion of the basin to the lower portion.

Figure 25 below provides the April 2014 simulation output and the observed flow hydrograph at USGS 02336526 near James Jackson Pkwy. As can be seen in the figure the hydrograph timing is nearly identical to the observed, volume is conserved, but the simulated peak flow is approximately 12% less than that of the observed data.

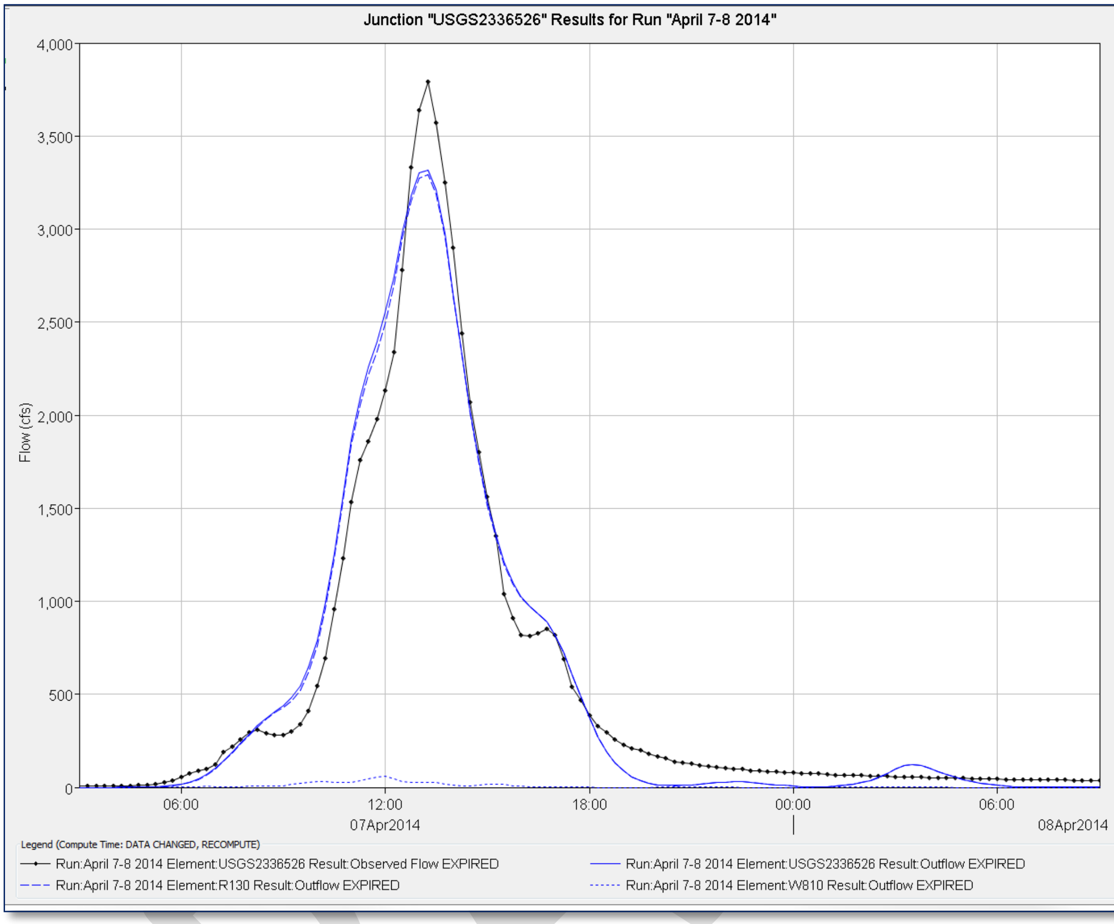


Figure 25: Simulation and observed hydrographs for junction USGS 02336526, pre-calibration

Two validation events were used to check model parameters for accuracy, November 2015 and August 2014. Table 4 provides a summary of peak flows, nash-sutcliffe values, volumes, and percent difference values for the various events. The November 2015 event is a double-peak event and values for both peaks are presented in Table 4.

Table 4: Calibration and Validation Model Results

April 7-8, 2014		
Result	**Observed**	**Simulated**
Peak flow (cfs)	3790	3206
Volume (ac-ft)	1339	1341
Nash-Sutcliffe	0.958	
Percent Difference (flow)	-15%	
Percent Difference (volume)	0	
August 8-9, 2014		
Result	**Observed**	**Simulated**
Peak flow (cfs)	1090	1441
Volume (ac-ft)	231	336
Nash-Sutcliffe	-0.046	
Percent Difference (flow)	32%	
Percent Difference (Volume)	45%	
November 8-9. 2015		
Result	**Observed**	**Simulated**
Peak flow (cfs)	1750/1160	1383/1201
Volume (ac-ft)	551/283	405/260
Nash-Sutcliffe	0.900/0.892	
Percent Difference (flow)	-21%/4%	
Percent Difference (Volume)	-26%/-8%	

Peak flow values and runoff volumes are over-predicted for the 2014 event, and under-predicted for the 2015 event. Uncertainty associated with the available precipitation data is the most likely source of major differences between observed and simulated model results. Additional efforts to refine the model did not result in significantly better results than those presented in the table above. The model parameters arrived upon through the calibration effort discussed previously were adopted for use in the final calibrated model used to simulate the synthetic storm events.

4.1.5. Results

Model simulation runs were created for the 1-year, 2-year, and 5-year synthetic rainfall values in the calibrated basin model discussed above. The results of these simulations represent the existing conditions runoff-response for Proctor Creek watershed. The maximum flow values for all basin elements, for each of these simulations, is presented in table 5 below.

Table 5: HMS Existing Conditions Peak Flow Results

HMS Element	Peak Flow Event (cfs) 1-year	2-year	5-year
J1060	2193.2	2567.9	3220.2
J177	2050.8	2399.6	3002.2
J185	495.6	599.1	787.3
J188	4148.3	4868	6171.3
J195	815	977.6	1278.3
J195A	734.3	880.7	1152.2
J200	4389.4	5221.7	6631
J200A	3798.6	4510.8	5703.3
J203	3771.9	4482.5	5669.4
J203A	3486.5	4153.7	5265.9
J206	1117.7	1356	1741.6
J206A	968.2	1176.4	1507.6
J215	4336	5098	6450.3
J220	4540.5	5320.8	6736.1
J225	1228.1	1482	1917.5
J225A	1181.9	1425.9	1842
J230	4227.7	5030.4	6362.9
J230A	4397.9	5211.1	6614.8
J238	5835.6	6922.7	8957.2
J238A	4608.7	5465.6	6992.5
J238B	1336.6	1609.7	2093.6
J241	4450	5285.4	6721.9
J241A	4391.2	5218	6639.7
J246	5235	6342.8	8393
J255A	5007.1	6069	8031.3
J258	5193.4	6279.8	8299.5
J263	5502.2	6636	8571
J880	4509.8	5283.8	6687.7
J900	4464.7	5250.2	6643.9
R120	4438.7	5258.8	6706
R130	5715.2	6811.6	8822.3
R140	5440.1	6554.5	8464.8
R180	4326.5	5139.4	6535.6
R210	1215.7	1462.3	1895.2
R220	4218.9	5021	6349.5
R250	4432.3	5200.1	6565.3
R280	1101.6	1329.7	1717.2
R300	3753.9	4456.6	5631.6
R320	4252.5	4998.2	6321.2
R350	768.3	938.2	1207
R370	3416.4	4072.1	5164.2
R40	4537.3	5397.6	6895.8
R470	467.2	559.7	733.9
R490	2027.1	2369.7	2964.7
R60	4981.1	6037	7988.7
R70	5144.6	6227.4	8233.4
R90	5122.5	6190	8177.1
USGS2336526	5737.3	6838.1	8859.8
W1010	590.8	710.9	927.7
W1020	90.8	109.4	143.1
W1030	269.1	323.9	422.8
W1060	167.6	200.4	259
W1070	2073.9	2473.3	3184.8
W1170	495.6	599.1	787.3
W1270	1063.6	1249.4	1574.6
W670	312.5	369.8	471.1
W690	215.2	256.7	330.6
W700	319.5	380.6	489.7
W720	189.5	231.2	308.1
W730	188.5	229.4	304.4
W740	377.5	453.2	589.3
W760	291.2	337.5	417.6
W770	121.7	149	199.7
W800	146	178.8	239.7
W810	128.6	157.1	209.7
W830	295.2	349.2	444.5
W840	52.9	64.1	84.5
W860	119	143.4	187.7
W880	100.9	122.3	161.3
W890	99.5	121.3	161.4
W900	344	411.2	531.4
W910	151.4	182.4	238.4
W940	1114.4	1294.7	1607
W950	162.2	195.5	255.7
W960	65.1	79.4	105.8
W970	217.8	260.2	335.9
W990	266.4	313.5	396.1

4.2. Future Without-Project Conditions

The Proctor Creek watershed is heavily developed and future landuse changes are unlikely to significantly impact the system's hydrology. It was assumed for the purposes of this project that future-without project conditions are the same as existing-conditions.

4.3. Future With-Project Conditions

The with-project condition, in terms of hydrology for Proctor Creek, includes the impacts of modification to the outlet structure at Pond D-17 so that attenuation of storm flow for events of the 5-yr magnitude are maximized compared to existing conditions. Aside from the impacts of Pond D-17 the HEC-HMS model for the with-project condition is identical to the existing conditions model. A detailed description of the proposed work at D-17 can be found in section 3.6.10.1.

To account for changes to the hydrology as a result of D-17, the HMS subbasin element in which D-17 is located, W-1180, was split to separate out D-17's contributing drainage area. A stage-discharge relationship for the retrofitted D-17 outlet structure was also included for the new D-17 model element (discussed in section 4.3.1 below). A schematic of the updated basin model as implemented in HEC-HMS is shown in Figure 26, with the relevant changes to the D-17 drainage area highlighted in red.

New times of concentration and curve numbers were calculated for the newly subdivided basins in order to compute runoff using the SCS runoff curve number methodology. Curve numbers were calculated using SSURGO landuse data and soil map data in ArcMap. Times of concentration were calculated using TR-55 methodology. The variables for each flow regime were estimated using LiDAR contours and aerial imagery in ArcMap. Times of concentration of 22 minutes and 39 minutes were calculated for Pond D-17 and W1180D17 subbasins, respectively. Curve numbers of 72.4 and 72.5 were calculated for the Pond D-17 and W-1180D17 subbasins, respectively. These values were incorporated into the with-project conditions model.

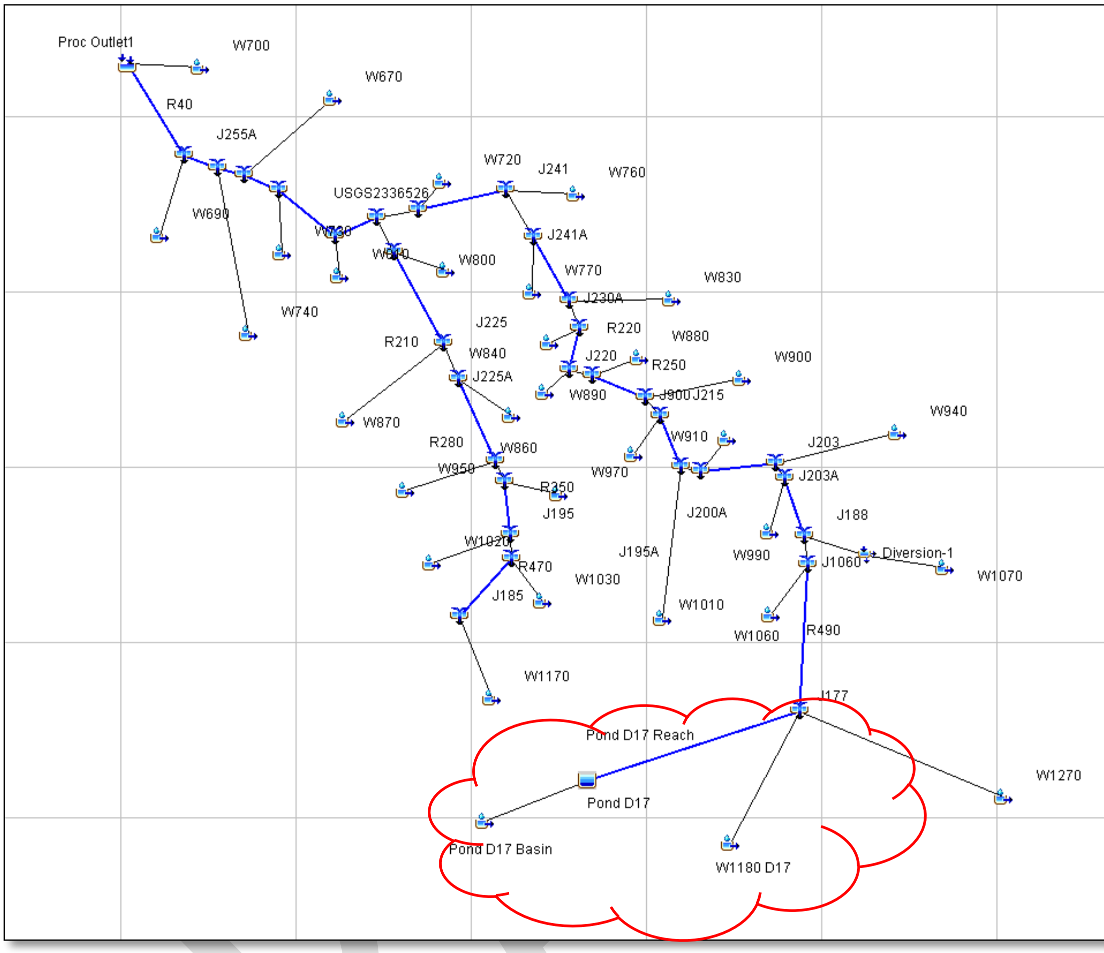


Figure 26: Pond D-17 HEC-HMS Schematic

4.3.1. Pond D-17 Impacts on Hydrology

Bentley Pondpack was used to create a simple basin representing the D-17 drainage area to evaluate the impacts of an outlet structure retrofit. Pondpack is designed for modeling small basins and detention ponds. Within Pondpack the SCS Curve Number method variables were input to calculate the storm runoff hydrograph. Type II SCS storms for the 24 hour - 1yr, 2yr, 5yr, 10yr, 25yr, 50yr, 100yr and 500yr events were analyzed, for the existing site conditions as well as for the proposed site conditions, with Atlas 14 precipitation depths used for each respective event. The existing conditions and future conditions hydrology upstream of D-17 are assumed to be the same.

Pond D-17 was given an elevation-storage function and a storage-discharge function to control flow into and out of the reservoir. The elevation-storage function was calculated in ArcMap using LiDAR DEM. The storage-discharge function was developed using PondPacks built-in routines for various outlet and culvert characteristics. The proposed outlet structure retrofit, a riser pipe at elevation 865, was built into the model and the associated elevation-discharge function copied to the HEC-HMS with-project conditions model.

Hydrologic results from Pondpack and HEC-HMS were compared to ensure that the software programs were producing similar results and that no significant errors should be expected due to software differences. The Pondpack defaults to a computational time step of 3 minutes, while the HEC-HMS model uses a 5 minute time step. The difference in results for the 1-year through 5-year events are very small with the HEC-HMS calculated outflows within within 1 cfs of the Pondpack model results.

4.3.2. Model Results

The outlet structure retrofit at D-17 results in a decrease in peak flows immediately downstream of the site for the one through five year return interval events, as summarized in Table 6 below. The hydrographs for the 2-year event, both existing and with project conditions, is shown in Figure 27.

Table 6: Peak Flows for With-Project Conditions Immediately Downstream of D-17

	Peak Flow (cfs)	
Event	**Existing**	**With D17 Retrofit**
1-year	277.6	174.0
2-year	321.3	185.9
5-year	390.4	199.7

The impacts of reduced discharges from D-17 are mitigated as the hydrograph travels downstream through the Proctor Creek system. Additionally, the relative magnitude of the flow reduction along the main stem of the system is reduced as additional runoff from tributary subbasins joins the main stem of Proctor Creek. For example the next major junction downstream of the D-17 site, junction element J-188, has a with-project peak flow of 4,746 cfs for the 2-year event compared to 4,868 cfs for existing conditions; only a 2% decrease. This phenomenon is observed for all nodes downstream of D-17 as the flow hydrographs are attenuated and routed through the system.

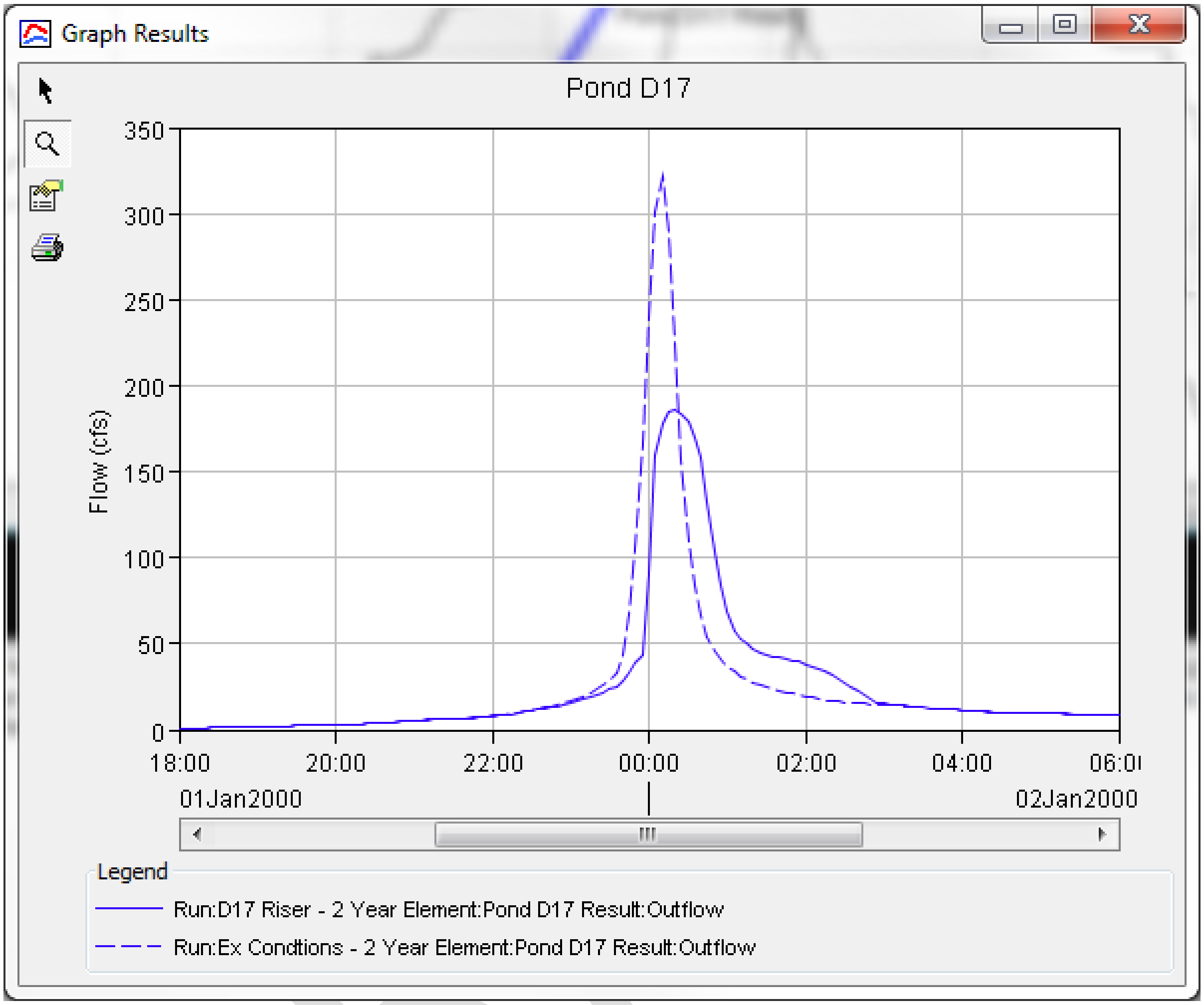


Figure 27: 2-year Hydrograph Comparison

5. Hydraulic Modeling Approach

5.1. Existing Conditions

In April 2016 the effective hydraulic model for Proctor Creek and its tributaries was obtained from the FEMA Engineering Library. The model reflects conditions within the basin at the time of publication, revised in September 2013, and was used as the “existing conditions” model for this analysis.

5.1.1. Model Layout

The model obtained from FEMA contains cross sections for both Proctor Creek and its major tributary, Terrell Creek (also referred to as Center Hill Creek). Cross section data consists of field-collected survey data and 2006 LiDAR data of Fulton County. Cross section station numbers are measured in feet from the confluence of Proctor Creek and the Chattahoochee River. The schematic of the HEC-RAS model used to represent Existing Conditions is presented in Figure 28 below.

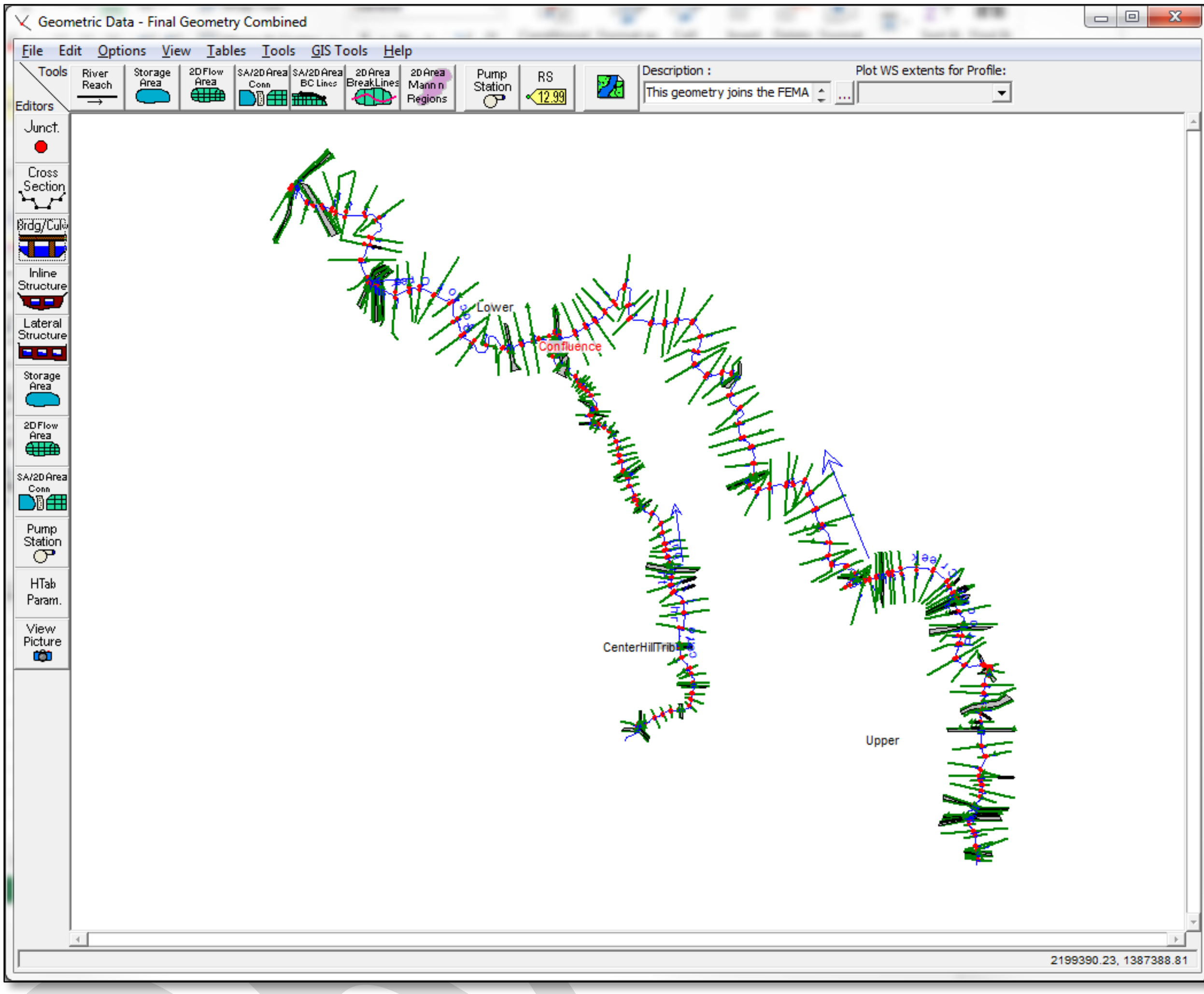


Figure 28: Existing Conditions Hydraulic Model Schematic

5.1.2. Manning's N values

Manning's roughness values used in the FEMA model range from 0.025 to 0.065 in the channel and 0.06 to 0.11 in the overbank areas. N values were chosen by investigating available landuse data, aerial photography, engineering judgment and field observation, according to the Fulton County Hydraulics Report from Georgia DNR.

5.1.3. Bridges

All bridges and culverts for detail study streams were field surveyed to obtain elevation data and structural geometry. Twenty-three bridges and culverts are included in the model along the main-stem of Proctor Creek, and twelve are included along the Terrell Creek tributary. The geometric data of the bridges included in the model appear to be quite detailed, with bridge pier and deck information obtained from field surveys and supplemented with elevations extracted from LiDAR data as needed. A mix of energy, momentum, and pressure/weir modeling approaches were used to compute water surface elevations for the various bridges.

5.1.4. Combined Sewer Overflow (CSO)

There is no discussion of the Proctor Creek CSO in either the FIS or the Hydraulics Report obtained from Atkins. However, there is a plan and flow file in the HEC-RAS model obtained from the FEMA Engineering Library that are named “CSO”. The flow values therein match those reported at the locations within Proctor Creek reported in the FIS. It is assumed for this study that the flow file labeled “CSO” represents flows used in the FIS; these flow values will be used in hydraulic analysis for this effort.

5.1.5. Boundary Conditions

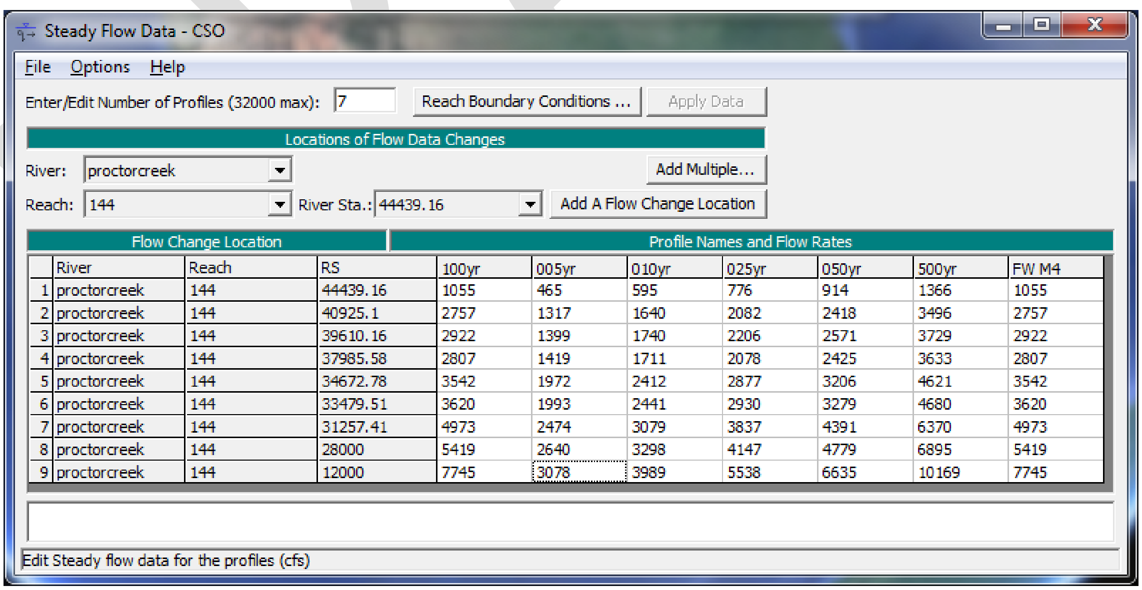
A normal depth slope of 0.0033 was used for all simulations in the FEMA provided model; this was also used for the existing conditions model for this study.

5.1.6. Flow Regime

A subcritical flow regime (in steady flow simulation mode) was used for all simulations in the FEMA hydraulics model: for the 5 through 500-year return interval events.

5.1.7. Flow Data

Flow values used in the steady flow simulations for existing conditions are presented in Figure 29 below.



	River	Reach	RS	100yr	005yr	010yr	025yr	050yr	500yr	FW M4
1	proctorcreek	144	44439.16	1055	465	595	776	914	1366	1055
2	proctorcreek	144	40925.1	2757	1317	1640	2082	2418	3496	2757
3	proctorcreek	144	39610.16	2922	1399	1740	2206	2571	3729	2922
4	proctorcreek	144	37985.58	2807	1419	1711	2078	2425	3633	2807
5	proctorcreek	144	34672.78	3542	1972	2412	2877	3206	4621	3542
6	proctorcreek	144	33479.51	3620	1993	2441	2930	3279	4680	3620
7	proctorcreek	144	31257.41	4973	2474	3079	3837	4391	6370	4973
8	proctorcreek	144	28000	5419	2640	3298	4147	4779	6895	5419
9	proctorcreek	144	12000	7745	3078	3989	5538	6635	10169	7745

Figure 29: Steady Flow Values from the Existing Conditions Model

5.2. Future Without-Project Conditions

The Proctor Creek watershed is heavily developed and future landuse changes are unlikely to significantly impact the system's hydrology or in-stream channel configuration. It was assumed for the purposes of this project that future-without project conditions are the same as existing-conditions.

5.3. Future With-Project Conditions

5.3.1. Model Adjustments

The existing conditions HEC-RAS model was modified to reflect changes to the system geometry as a result of proposed project implementation. These changes, while minor, are presented below.

5.3.1.1. Manning's N values

Manning's n values remain largely unchanged from the existing conditions model. Most in-channel and over-bank work will have a more significant impact to the channel geometric configuration rather than roughness factors. In instances where proposed work would have an impact on the underlying roughness values, for example riparian plantings, the n value was adjusted to reflect with-project conditions.

5.3.1.2. Conveyance Area Changes

The size and scale of most proposed measures in the tentatively selected plan are not easily represented with the relatively coarse HEC-RAS model used for this study. Features such as stream barbs and rootwads are relatively small, on the order of tens of feet, compared to the average cross section spacing of 300 ft throughout the study reach. These small features were not included in the model as they would be difficult to represent and their impacts on hydraulic computations would be limited to local impacts only. Larger features such as long linear bank shaping were included in the modified model geometry.

5.3.1.3. Results

The HEC-RAS model results will be provided upon completion of the analysis.

6. Cost Estimates

The cost engineer, with support from the PDT, generated parametric cost estimates for each restoration reach discussed in Sections 3.4 and 3.5. These estimates were used during the alternative formulation and evaluation process to identify the initial and focused array of alternatives and ultimately identify the TSP. The total project cost summary (TPCS) of the TSP, broken down by restoration reach, is shown in Table 7 below. Details of the cost estimating approach, along with the estimates for all costs considered during the alternative screening process, are provided in the Cost Appendix.

Table 7: Total Project Cost Summary for the TSP

Total Project Cost, in $K						
Reach	**Construction**	**Lands**	**PED***	**CM****	**Contingency**	**Total**
PC-08-1	306	82	143	30	163	709
PC-08-2	348	73	147	36	177	765
PC-09	155	1	119	15	78	365
PC-10	378	26	150	37	176	760
PC-13	187	36	128	20	100	472
PC-14	137	21	117	13	73	364
PC-15	592	47	189	60	254	1,134
PC-21	664	66	191	65	357	1,270
TC-02	365	23	148	37	178	735
TC-05	217	22	130	22	115	496
GP-01	239	5	132	23	113	512
GP-02	433	3	161	43	163	802
D-17	147	20	117	15	92	371
Total	**4,168**	**424**	**1,873**	**416**	**2,039**	**8,756**

Note: Not all of the rows and columns add up to the totals due to rounding in the TPCS worksheets.
*PED = Preconstruction Engineering and Design
**CM = Construction Management

7. Recommendations for Future Analysis of the Final Plan

Due to the expedited nature of the SMART planning process, several efforts were streamlined prior to the TSP milestone and others were either postponed to after the TSP milestone or until Preconstruction Engineering and Design (PED). A discussion of the scope and timing of these items and the associated risks with delaying these efforts is provided below.

7.1. Surveys

To date, no site-specific topographic survey data has been collected as part of this study to support the engineering analyses and development of the alternative designs. All elevation data shown on the concept design drawings and utilized for the hydrologic and hydraulic analyses came from a combination of previously collected data sets provided by the City of Atlanta and FEMA (i.e., from the FEMA HEC-RAS model). Bathymetric and channel data used in the HEC-RAS model to support this study were those found in the existing FEMA model. No bathymetric survey data were obtained as part of the study to update the existing HEC-RAS model.

Approximately $70,000 is included in the study budget to collect site-specific survey information post Agency Decision Milestone (ADM), if deemed necessary by the engineering team, to support completion of the final feasibility level analysis and design of the recommended plan.

The study risk associated with delaying surveys until after the ADM is low. The elevation data used for the concept designs, as shown in Attachment 1, was recently collected (i.e., 2015) via Light Detection and Ranging (LiDAR) technology and the design team was able to field verify many of the topographic features within the stream corridor during two site visits (June 2016 and November 2016). Therefore, the team is confident, at this time, in the location and quantities of the recommended restoration measures, given the age and resolution of the LiDAR data set.

7.2. Geotechnical Investigations

A preliminary geotechnical investigation was conducted in November 2016 (i.e., hand auger borings at locations where possible excavation could occur) to determine if rock excavation would be required for some of the alternatives under consideration for the TSP. This information was useful in better understanding the subsurface conditions and validating the cost assumptions for excavation of the potential detention pond and wetland features.

Approximately $100,000 is budgeted to conduct a more thorough geotechnical investigation post ADM, if deemed necessary by the engineering team, to verify the subsurface conditions of the restoration reaches included in the recommended plan.

The study risk associated with delaying the more comprehensive geotechnical investigation to post ADM is documented as high in the risk register, given the fact that the limited preliminary investigation could not completely delineate the presence/absence of rock throughout the extent of all potential excavation areas due to the natural irregularities in the geology of the study area. However, the PDT's confidence and certainty in the ability to construct the potential wetland and detention pond features without encountering substantial rock was increased due to the findings of the preliminary geotechnical investigation (i.e., no rock was found at any of the excavation sites that would prevent implementation of the measures included in the TSP). That confidence will be further increased after completion of the additional geotechnical analysis, ultimately resulting in a moderate to low risk moving into PED.

7.3. Climate Change and Resiliency Assessment

As discussed in Section 3.9, climate change and resiliency were not considered in identifying the TSP. However, the PDT plans to conduct scenario analyses post ADM to evaluate various alternative futures with- and without-project to test the sensitivity and resiliency of the recommended plan to changes in land uses, climate conditions, and possible actions by others. This approach was presented to and supported by the vertical USACE team during In-Progress Review meetings between the Alternatives Milestone and TSP milestone. The study risk associated with this approach is considered to be low and is consistent with the intent of SMART planning. To date climate change has only been considered very qualitatively. The climate change analysis that will be completed prior to final report approval will be conducted in accordance with ECB 2016-25 and ETL 1100-2-3.

7.4. Erosion and Sedimentation Assessment

The PDT will assess sediment transport processes, and possible changes due to implementation of the recommended plan, post ADM in accordance with the three-pronged approach outlined in Section 5.5. The final recommended plan will be refined, as necessary, to ensure minimal negative effect on areas outside of and/or adjacent to restoration reaches. The study risk associated with following this approach is considered to be low and in-line with the streamlined intent of SMART planning (i.e., increase the level and detail of analysis on a smaller subset of possible actions as the study progresses). The PDT does not expect the results of this assessment to impact or jeopardize selection of the recommended plan.

7.5. Hazardous, Toxic, Radioactive Waste (HTRW) Assessment

The PDT is currently coordinating with the EPA to identify all of the potentially contaminated sites within the study area. Once this information is obtained, it will be cross-referenced with the locations where work would be required to implement the recommended plan, and HTRW assessments will be conducted post ADM, as necessary, to fill data gaps. The current risk associated with following this approach is considered moderate, per the study risk register.

7.6. Refinement of Feasibility Level Designs

Concept level designs were developed for each alternative within the Focused Array. These designs were refined to an adequate level of detail to confidently identify and quantify the features needed, and the costs associated with those features, to meet the restoration objectives within each reach (see Section 3.6 for descriptions of the measures considered/recommended). These concept level designs will be further refined into “feasibility level designs” post ADM. The PDT will utilize the updated topographic surveys, geotechnical information, climate change and resiliency assessment, and the erosion and sedimentation assessment, along with any other details realized post TSP, to better define the limits and quantities of the restoration measures for the recommended plan. The risk associated with following this tiered design approach is considered to be low and in-line with the expectations of the streamlined SMART planning process.

7.7. Development of Operations and Maintenance (O&M) Measures for the Recommended Plan

O&M measures and their associated annual costs were identified for all alternatives in the Focused Array, utilizing feedback from the range of experts on the PDT. These costs and O&M assumptions are discussed further in the Cost Appendix and they will be refined, as necessary, post ADM during development of the final feasibility level design of the recommended plan. The risk associated with following this refinement approach is low and in-line with the expectations of the streamlined SMART planning process.

8. Summary and Conclusions

The engineering team was charged with supporting the development and evaluation of ecosystem restoration alternatives for Proctor Creek in Atlanta, Georgia. Proctor Creek is an approximately 9-mile long stream fed by two major tributaries (Terrell Creek and Grove Park Creek) along with several other minor perennial features. The headwaters of the watershed include a majority of the downtown metropolitan area and, consequently, the stream suffers from severe ecological degradation.

Specific tasks completed by the engineering team, as documented in this appendix, include (1) characterization of the existing and future (with- and without-project) hydraulic, hydrologic, and geologic conditions of the study area, (2) support of the development of the ecological models (as documented in McKay et. al 2017a and McKay et. al 2017b) used to evaluate the effects/benefits of potential restoration actions, (3) production of concept- and feasibility-level designs for the various restoration alternatives considered, and (4) generation of feasibility level cost estimates for all potential restoration actions for use in the plan formulation process.

To identify the existing and future (with- and without-project) hydrologic and hydraulic conditions of the study area, the team used the latest HEC-HMS and HEC-RAS models developed by FEMA for the Flood Inundation Study (FIS) encompassing the Proctor Creek watershed. These models were evaluated and updated, as necessary, to represent the current conditions within the watershed and possible future with-project conditions due to the implementation of the TSP. Since the Proctor Creek watershed is heavily developed and future land use changes are unlikely to significantly impact the system's hydrology, the future-without project conditions were assumed to be the same as existing-conditions. In addition, due to extreme variability in forecasts in the region based on statistically downscaled General Circulation Model projections for the Chattahoochee watershed in year 2090 (Lafontaine et al. 2015, McKay et al. 2017b), climate change was not considered in the analyses either. However, the PDT plans to conduct scenario analyses post ADM to evaluate various alternative futures with- and without-project to test the sensitivity and resiliency of the recommended plan to changes in land uses, climate conditions, and possible actions by others. A detailed discussion of the scope and results of the hydrologic and hydraulic assessments is included in Sections 4 and 5.

The engineering team was also involved in the development of the two ecological models (known as PCEM Phase 1 and PCEM Phase 2 and documented in McKay et. al 2017a and McKay et. al 2017b respectively). Hydraulic engineers and geologists participated in three site visits (February 2016, June 2016, and November 2016) throughout the study to assess the existing conditions of the creek, highlight problems and opportunities for restoration within the watershed, and identify site-specific restoration measures that could be implemented to address the ecosystem related problems within the study area. The team also assisted in the scoring of the reaches with respect to their current and possible future (due to the implementation of an alternative) instream, riparian, connectivity, and hydrologic functions. The support provided by the engineering team to the development of the ecological models and plan formulation/evaluation process is provided in Section 3.

Finally, the team produced concept level designs and cost estimates for all reaches included in the Focused Array of alternatives. A suite of in-stream, riparian, connectivity, and hydrologic restoration measures were proposed throughout the study area to address location-specific problems and restoration objectives. Ultimately, this information was used to support the identification of the TSP, which consists of all 12 reaches considered in the Focused Array. Details of concept level designs, including all measures considered, are provided in Section 3.6 and Attachment 1. The total project cost of the TSP, as documented in the total project cost summary (TPCS) shown in Section 6, is $8,756,000.

Additional efforts such as site-specific surveys, a geotechnical investigation, a climate change and resiliency assessment, an erosion and sedimentation assessment, and an HTRW assessment will be conducted post ADM to refine the concept level design into a feasibility level design for the recommended plan. This streamlined/tiered analysis approach is consistent with the intent of SMART planning and should result in an efficient use of resources while maintaining an acceptable level of risk. A discussion of the scope of the additional assessment items and the associated risks with the timing of the efforts is provided in Section 7.

9. References

Addison, A.D., Characterization of a Crystalline-Bedrock aquifer using Borehole Geophysics, Marrietta, Cobb County Georgia, *Proceedings of the 2003 Georgia Water Resources Conference*, held April 23–24, 2003, at the University of Georgia. Kathryn J. Hatcher, editor, Institute of Ecology, The University of Georgia, Athens, Georgia.

Environmental Protection Agency (EPA). 2015. Proctor Creek's Boone Boulevard Green Street Project Health Impact Assessment (HIA). Office of Research and Development and Region 4, U.S. Environmental Protection Agency, Atlanta, Georgia.

University of Georgia, Georgia Department of Geology http://www.gly.uga.edu/railsback/GAGeology.html#DISC, 2015(HTML)

Horowitz A.J., Elrick K.A., and Smith J.J. 2008. Monitoring urban impacts on suspended sediment, trace element, and nutrient fluxes within the City of Atlanta, Georgia, USA: Program design, methodological considerations, and initial results. Hydrological Processes, 22, 1473-1496.

Haring, Chris. Advanced Stream Bank Erosion and Protection Prospect Class Presentations, Engineer Research and Development Center, 2016 Streambank Protection Class.

Higgins, M.W., Crawford, T.J., Atkins, R.L., and Crawford, R.F. 2003. Geologic Map of the Atlanta 30' X 60' quadrangle, Georgia, U.S. Geological Survey, Geologic Investigations Series Map I-2602

Knutson a Fealko 2014 Large Woody Material – Risk Based Design Guidelines

Lafontaine J.H., Hay L.E., Viger R.J., Regan R.S., and Markstrom S.L. 2015. Effects of climate and land cover on hydrology in the Southeastern U.S.: Potential impacts on watershed planning. Journal of the American Water Resources Association, 51 (5), 1235-1261.

McConnell, K.I. and Abrams, C. E., 1984, Geology of the Greater Atlanta Region, Georgia Geologic Survey, Bulletin 96, Environmental Protection Division, Department of Natural Resources.

McKay K.S., Pruitt B.A., Zettle B.A., Hallberg N., Hughes C., Annaert A., LaDart M., and McDonald J. 2017a. Proctor Creek Ecological Model (PCEM): Phase 1 Site Screening. ERDC TR-XX-DRAFT. U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi.

McKay K.S., Pruitt B.A., Zettle B.A., Hallberg N., Moody V., Annaert A., LaDart M., Hayden M., and McDonald J. 2017b. Proctor Creek Ecological Model (PCEM): Phase 2

Benefits Analysis. ERDC TR-XX-DRAFT. U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi.

Merritts, Dorothy, et al. "Anthropocene streams and base-level controls from historic dams in the unglaciated mid-Atlantic region, USA." *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences* 369.1938 (2011): 976-1009.

Peters N.E. 2009. Effects of urbanization on stream water quality in the city of Atlanta, Georgia, USA. Hydrological Processes, 23, 2860-2878.

Rosgen, David L. "CROSS-VANE, W-WEIR, and J-HOOK VANE Structures (Updated 2006)." Their Description, Design and Application for Stream Stabilization and River Restoration. Pagosa Springs, CO (2006).

Wright D.B., Smith J.A., Villarini G., and Baeck M.L. 2012. Hydroclimatology of flash flooding in Atlanta. Water Resources Research, 48, doi: 10.1029/2011WR011371.