APPENDIX 2: MILL RACE TRIBUTARY PROJECT MATERIALS

Aerial photo of the tributary to Mill Race (Mill Race is to the left)

At the bottom of Mil Race trib, the banks of an OWASA easement crossing are caving in

Bank erosion is cutting into the OWASA easement along the length of the stream

The “mystery outfall” – we have no idea what it’s connected to

Lots of sediment is accumulating in the lower reaches

There’s a 15ft deep gully back in here!

There’s another deep gully hidden back in here

All along the OWASA easement the streambanks are caving in

More high, eroding streambanks

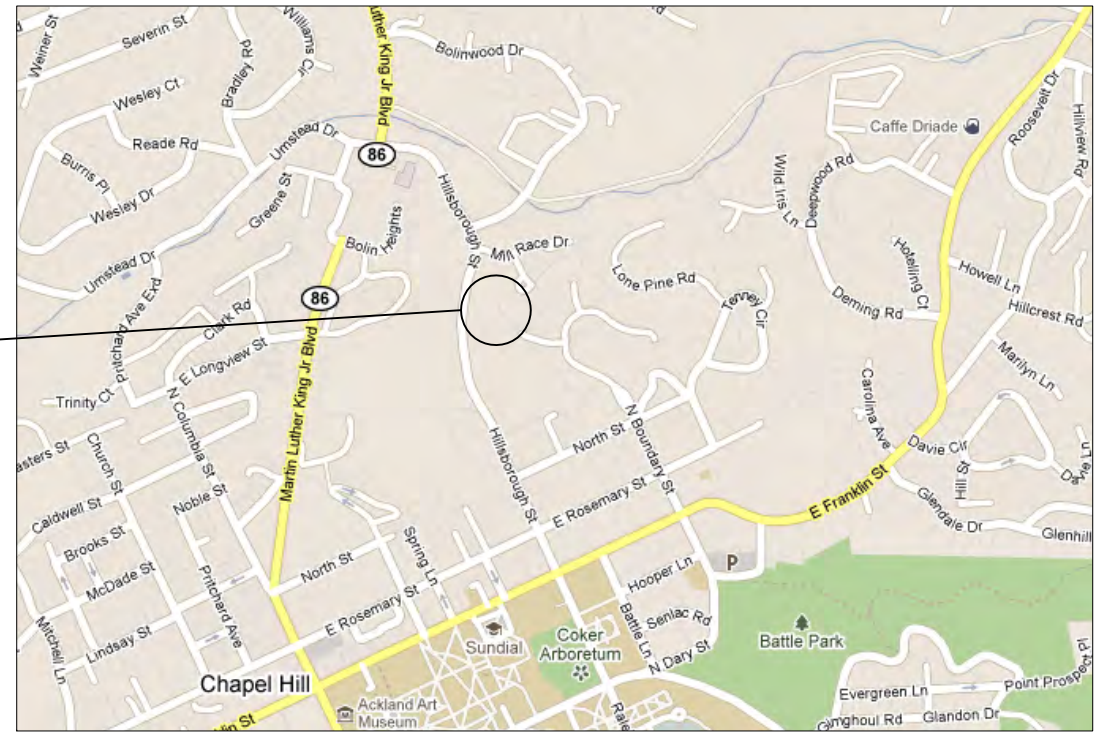
Incipient gullies forming

Kudzu is tanking down the riparian forest

There’s a third huge gully hiding under this kudzu field

MILL RACE STREAM ENHANCEMENT AND EROSION CONTROL PROJECT CHAPEL HILL, NC

SITE



PREPARED FOR:
TOWN OF CHAPEL HILL, NC

SHEET INDEX

1. TITLE
2. SITE OVERVIEW
3. SITE OVERVIEW W/ AERIAL
4. REACH 1A
5 REACH 1B
6. REACH 1C
7. REACH 1D
8. REACH 2A
9. REACH 2B

CONCEPTUAL PLAN: NOT FOR CONSTRUCTION

NO	REVISIONS	DRN	CHK	DATE
1	CONCEPTUAL DESIGN	ZP	GJ	06/30/11

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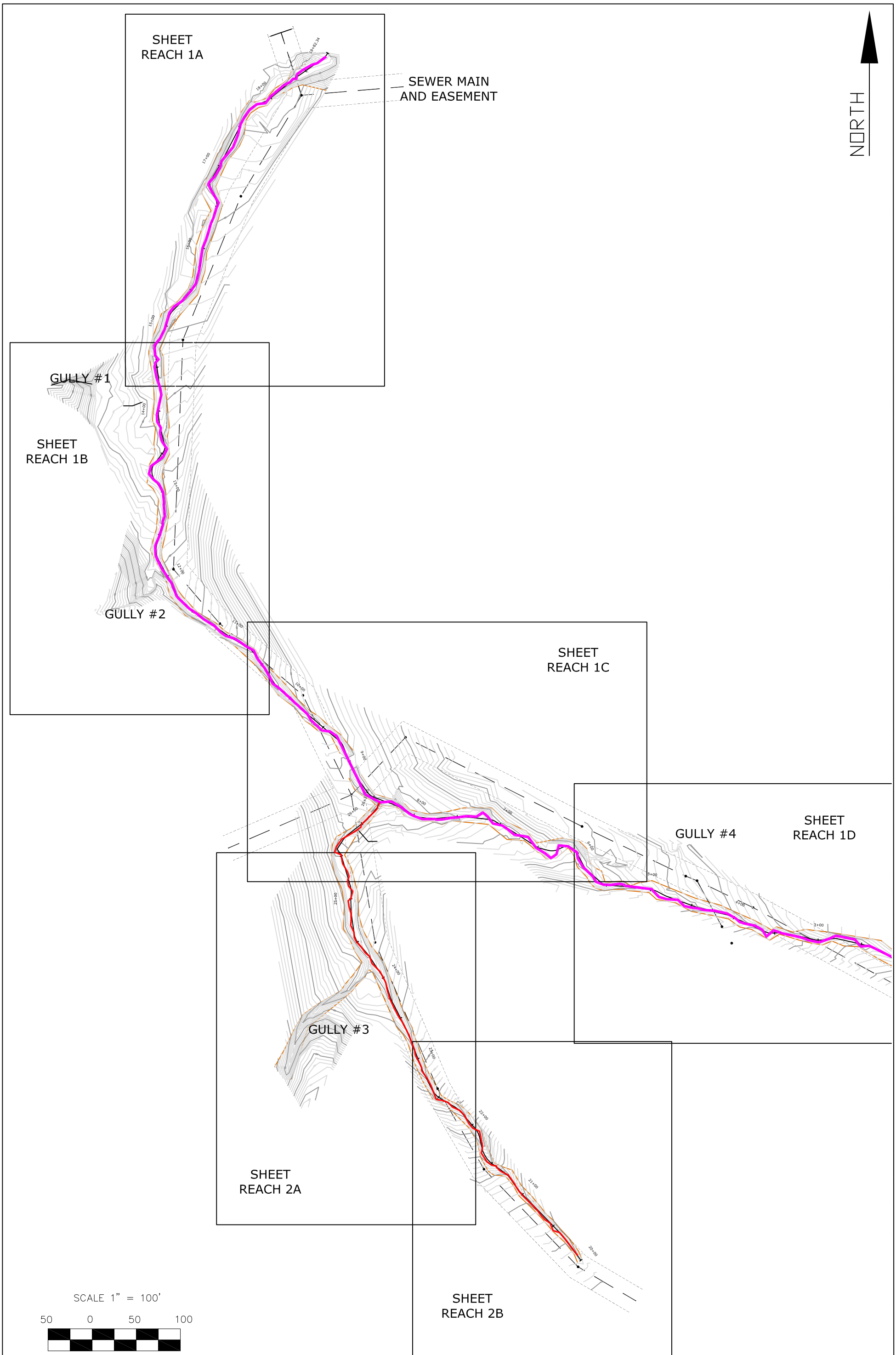
Raleigh, NC 27695

MILL RACE STREAM ENHANCEMENT AND EROSION CONTROL PROJECT CHAPEL HILL, NC

TITLE SHEET

DATE 06/30/2011
PROJECT NO.
FILENAME FILE.DWG
SHEET NO. PL – 1
DRAWING NO.



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SHEET NO.	PL – 1
FILENAME	FILE.DWG
PROJECT NO.	
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MILL RACE STREAM ENHANCEMENT
AND EROSION CONTROL PROJECT
CHAPEL HILL, NC

CONCEPTUAL PLAN
SITE OVERVIEW

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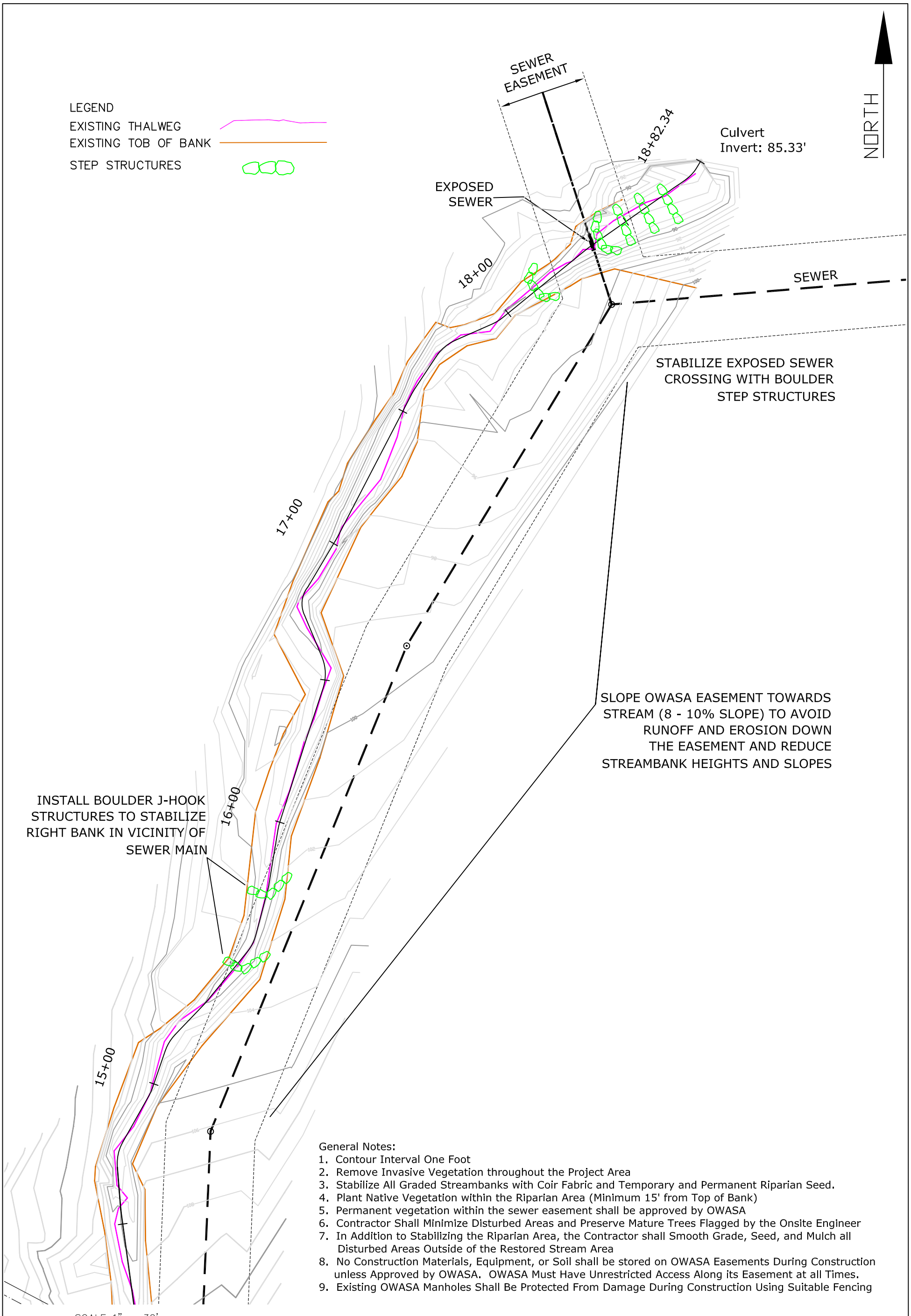

General Notes:

1. Contour Interval One Foot
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9. Existing OWASA Manholes Shall Be Protected From Damage During Construction Using Suitable Fencing

DRAWING NO.			
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MILL RACE STREAM ENHANCEMENT AND EROSION CONTROL PROJECT
CHAPEL HILL, NC

CONCEPTUAL PLAN SHEET
REACH 1A

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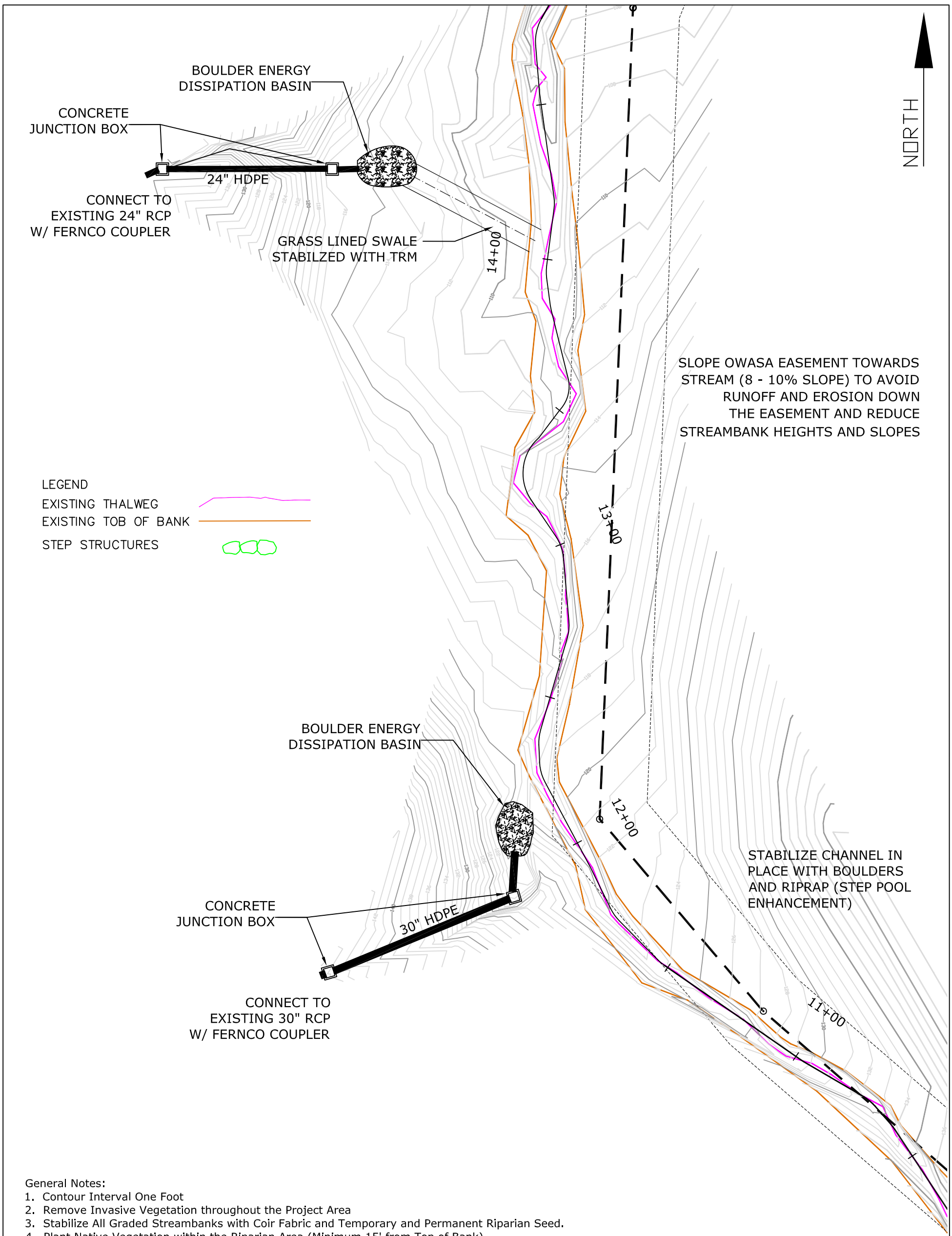

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SCALE 1" = 30'

15 0 15 30

DRAWING NO.	SHEET NO. PL – 1	FILENAME FILE.DWG	PROJECT NO.	DATE 06/30/2011	MILL RACE STREAM ENHANCEMENT AND EROSION CONTROL PROJECT CHAPEL HILL, NC CONCEPTUAL PLAN SHEET REACH 1B

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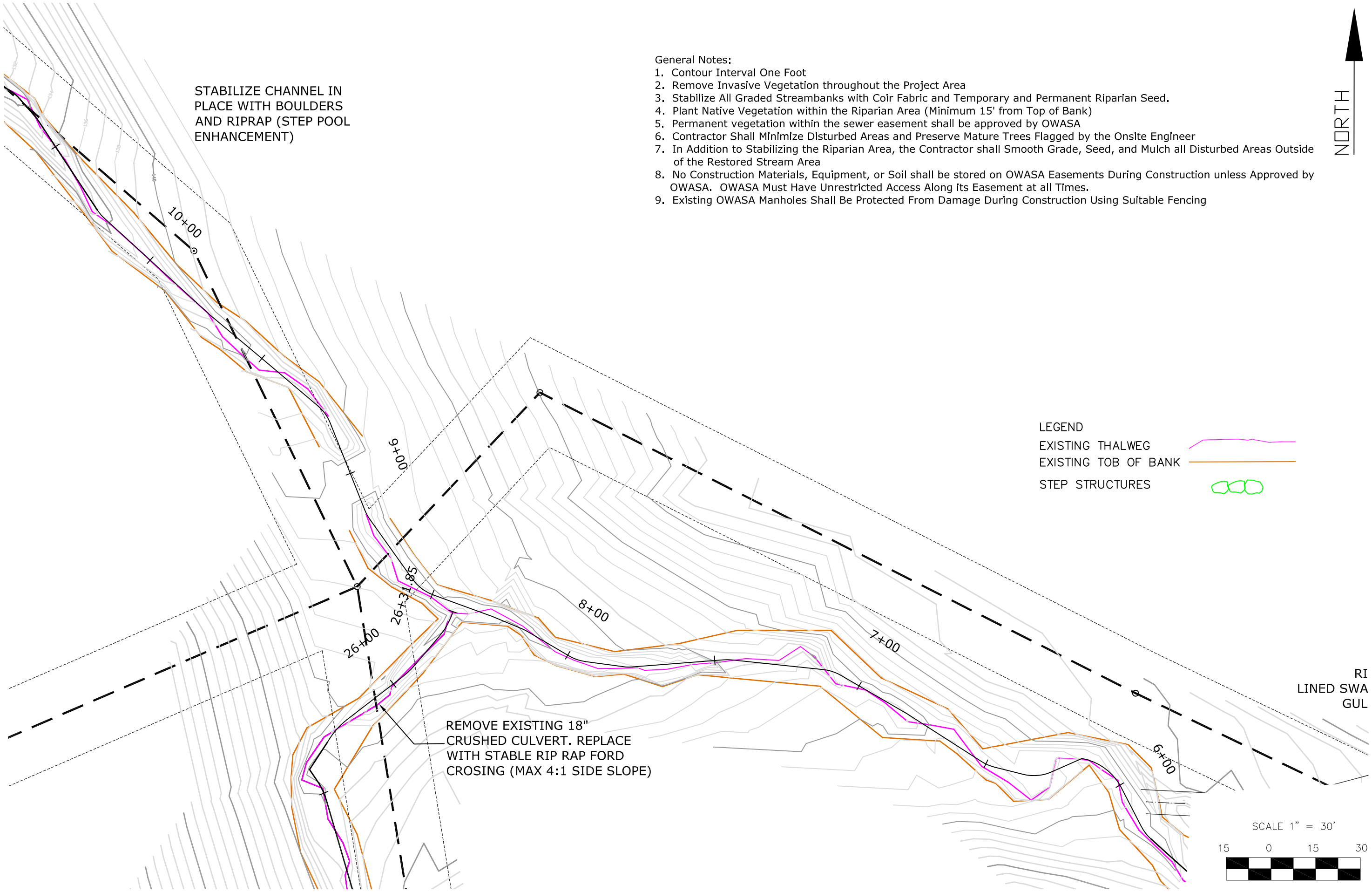
NORTH



NO	REVISIONS	DRN	CHK	DATE
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MILL RACE STREAM ENHANCEMENT AND EROSION CONTROL PROJECT
CHAPEL HILL, NC

CONCEPTUAL PLAN SHEET
REACH 1C

DATE	06/30/2011
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SHEET NO.	PL – 1
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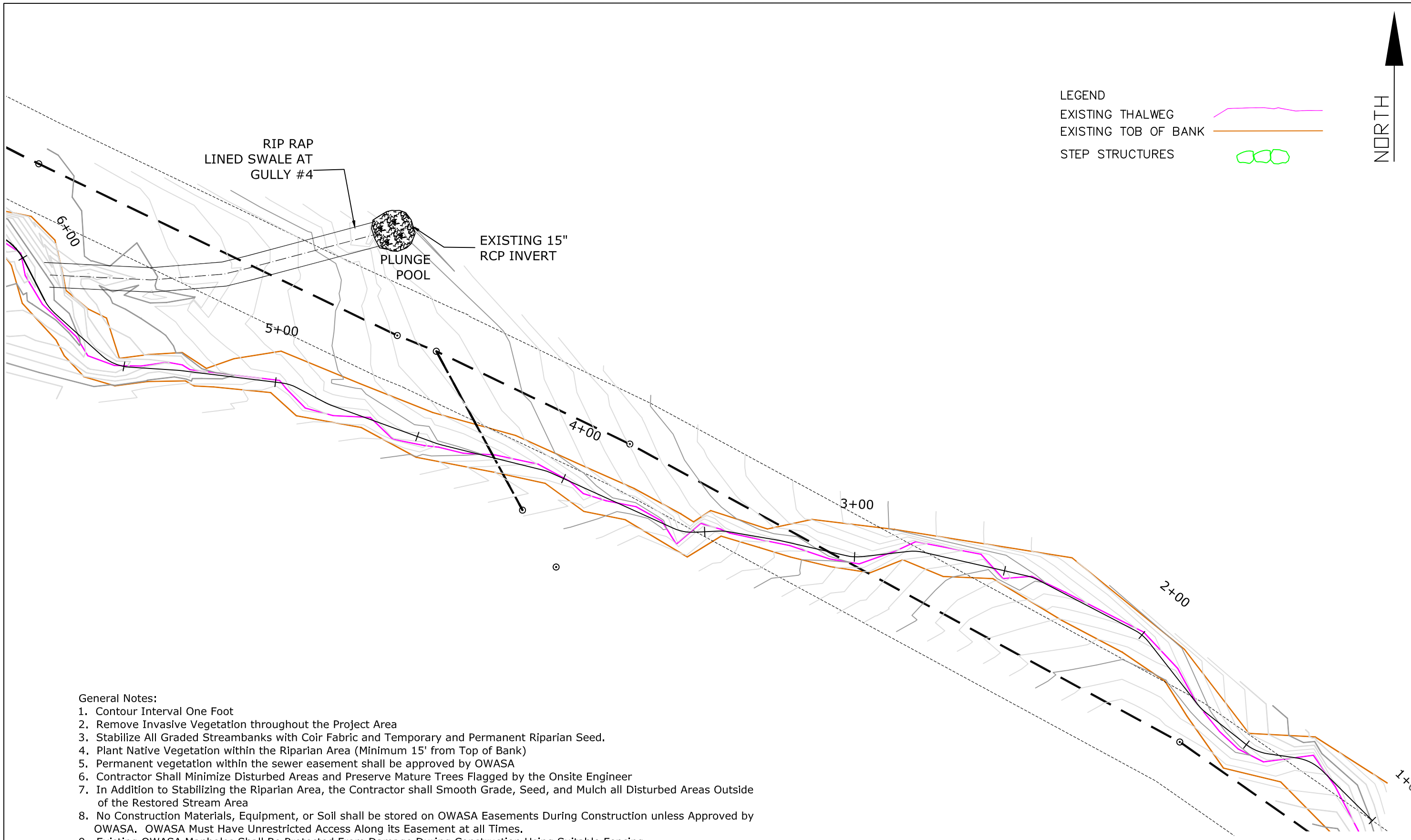

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15 0 15 30

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MILL RACE STREAM ENHANCEMENT
AND EROSION CONTROL PROJECT
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CONCEPTUAL PLAN SHEET
REACH 1D

DATE	06/30/2011
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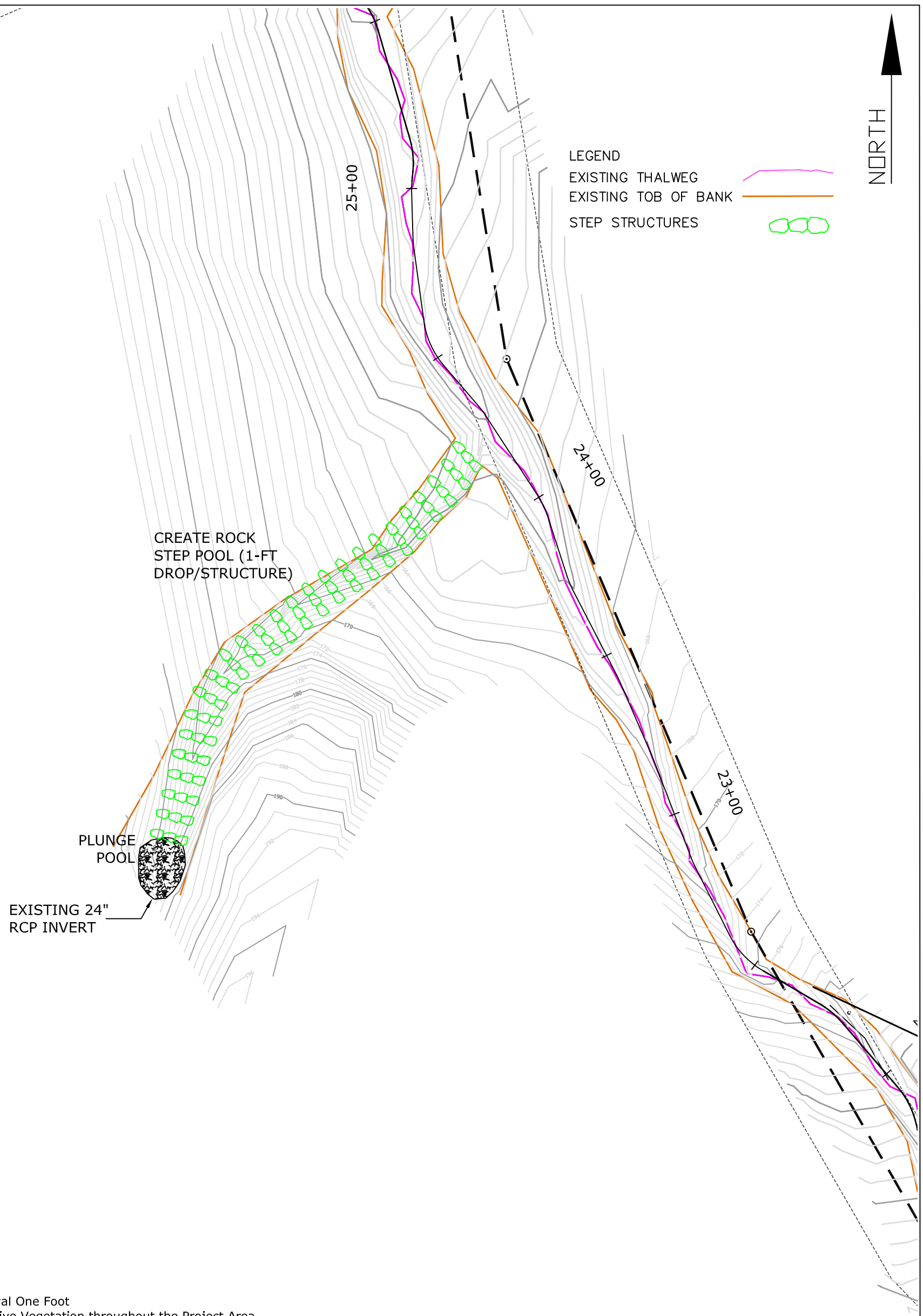
FILENAME	FILE.DWG
SHEET NO.	PL – 1
DRAWING NO.	



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SCALE 1" = 30'

15 0 15 30

DRAWING NO.

SHEET NO. PL – 1

FILENAME FILE.DWG

PROJECT NO.

DATE 06/30/2011

MILL RACE STREAM ENHANCEMENT
AND EROSION CONTROL PROJECT
CHAPEL HILL, NC

CONCEPTUAL PLAN SHEET
REACH 2A

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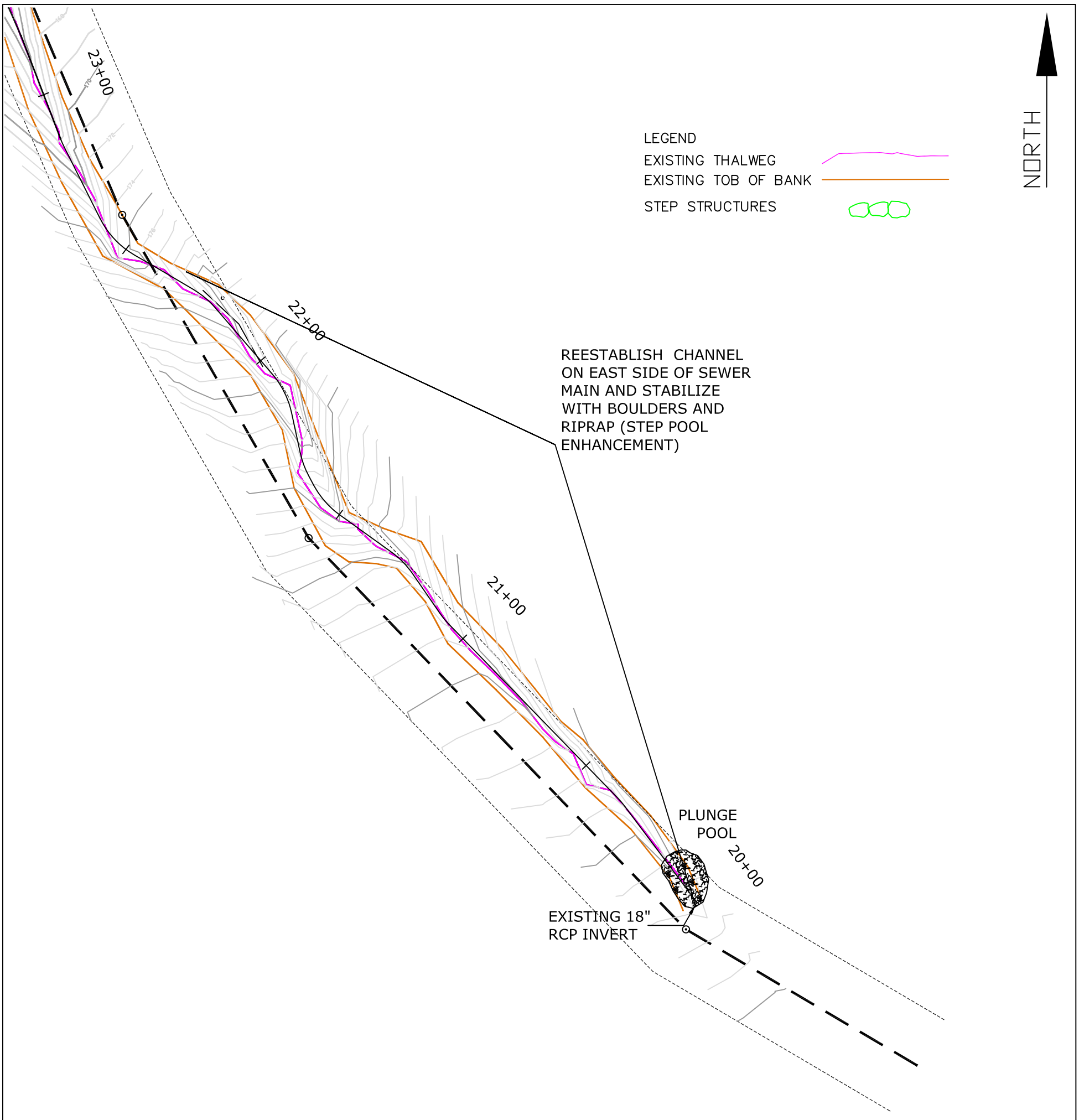

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15 0 15 30

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MILL RACE STREAM ENHANCEMENT AND EROSION CONTROL PROJECT
CHAPEL HILL, NC

CONCEPTUAL PLAN SHEET
REACH 2B

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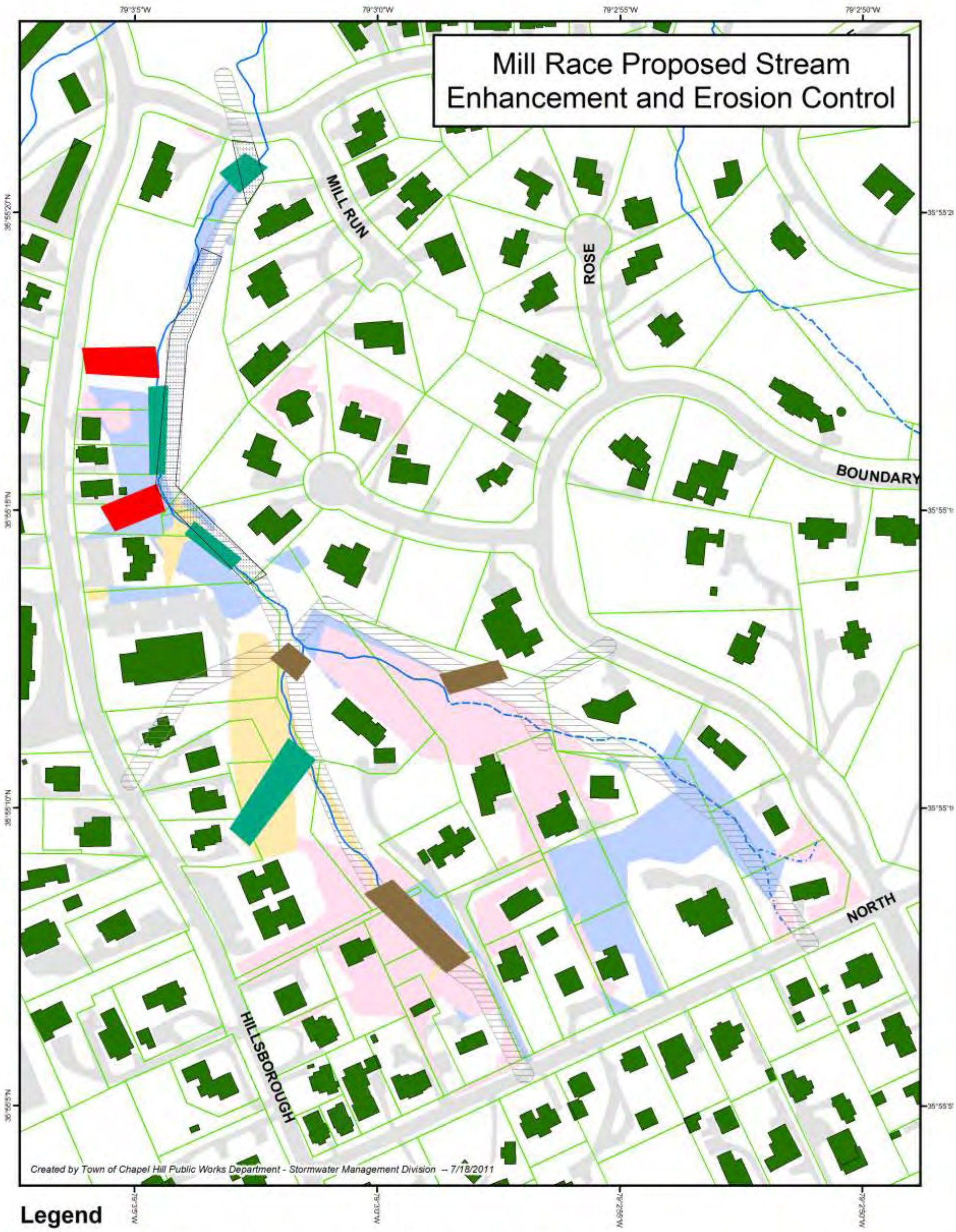
1	CONCEPTUAL DESIGN	ZP	GJ	06/30/11

Mill Race Proposed Stream Enhancement and Erosion Control



Legend

- Ephemeral Stream
- Intermittent Stream
- Perennial Stream
- Buildings
- Parcel Boundaries
- Streets and Driveways
- Pipes and Baffle Box
- Invasive Plants - Property Owner Guidance
- Invasive Plants - Cut and Paint
- Invasive Plants - Foliar Treatment
- OWASA Easement
- Grading in OWASA Easement
- Easement Stabilization
- Step-Pools

N W E S

0 150 300 600 Feet

Bolin Creek Watershed Restoration Project

Location: Mill Race Run, Chapel Hill

Project Description: Federal and State funding will pay for design, construction, materials, and native plants to stabilize the stream. This is one of two restoration projects underway in Chapel Hill to improve water quality in the Jordan Lake Watershed.

Estimated Completion: Spring 2012

EROSION is undermining sewer lines, stressing the lines and risking leaks.

In the site below, a series of in-stream “step-pools” and bank shaping is planned to reduce erosional stresses on the banks.

SEDIMENT smothers stream habitats and impairs water quality here and downstream in Bolin Creek. Sediment comes from erosion of sand sidewalks, OWASA easements, storm drain outfalls, and the stream channel itself.

INVASIVE PLANTS outcompete native trees and understory. Native plants and forest are critical to streams to reduce water temperature. Fallen tree leaves and microorganisms that colonize them form the basis of the stream food chain.

Replacement of invasive species with native trees, bushes, and undergrowth will provide slope stabilization and privacy for homeowners, while also providing shade

SEVERE GULLIES have formed below storm drain outfalls. Tons of sediment wash into streams and trees uproot as a result.

Repair includes extending storm drains down very steep slopes, installing energy-dissipating structures, and stabilizing banks of smaller gullies with step-pool structures.

APPENDIX 3: STORMWATER ALTERNATIVES ANALYSIS FOR TANYARD BRANCH

CHAPTER 5: INCREASING STREAM GEOMORPHIC STABILITY USING LOW-IMPACT DEVELOPMENT PRACTICES AND/OR WET PONDS IN A HEAVILY URBANIZED WATERSHED IN CHAPEL HILL, NORTH CAROLINA

This study used previously established unit critical discharges, annual allowable erosional hours and annual allowable volume of eroded bedload standards, to evaluate 2 types of stormwater control measures (SCMs): low-impact development (LID) practices and a large detention SCM (wet pond). Nine initial scenarios modeled in PCSWMM incorporated different combinations of wet ponds, green roofs, rainwater harvesting systems, permeable pavement, and rain gardens, to determine the best scenario for reducing stream erosion potential within a highly urbanized watershed in Chapel Hill, North Carolina and throughout Piedmont North Carolina. The best-case scenario to reduce annual erosional hours and eroded bedload within the stream consisted of an aggressive utilization of LID practices in combination with an undersized wet pond. While this scenario did not meet the annual erosional hour standard for rural reference streams, 0.33 h/ha/yr, it did reduce erosional hours and eroded bedload sediment by factors of 2.4 and 2.5 respectively, improving the existing condition. An alternative wet pond outlet, use of 2 drawdown orifices, was explored to determine if current wet pond design practices could be improved to include stream stability. The new configuration provided a modest improvement to erosional hours, factor of 1.3, while increasing volume of eroded bedload by a factor of 1.2 when compared to the “normal” wet pond. However, adding widespread LID practices to the alternative outlet design reduced erosional hours and bedload transport by factors of 1.8 and 1.2 respectively when compared to the “normal” wet pond. The failure to meet the erosional standards in all scenarios demonstrated the difficulty of requiring such urbanized watersheds (60% impervious) to meet such strict stream metrics.

5.1 Introduction

The negative effects of urbanization and increased imperviousness within watersheds have been explored and well documented (Leopold, 1968; Hammer, 1972; Leopold, 1973; Graf, 1977). As the percentage of impervious surfaces increases, less precipitation infiltrates through the soil to recharge the groundwater. Instead, rain flows over the impervious cover, increasing stormwater flow rates and volumes entering streams, leading to erosion and degradation in water quality (Hollis, 1975; Doyle et al., 2000; Bledsoe and Watson, 2001). An increase as small as 10% impervious surface can potentially cause stream geomorphic instability (Booth and Reinelt, 1993; Scheuler, 1995; Booth and Jackson, 1997).

To mitigate negative impacts of urban development, some state and local governments require post-construction hydrology to be restored to the pre-constructed state using stormwater control measures (SCMs). SCMs are designed to reduce peak flow rates, reduce stormwater runoff volumes, and/or improve water quality by providing additional storage for runoff. The North Carolina Department of Environment and Natural Resources (NCDENR), for example, requires post-urbanized peak flow rates not to surpass the pre-development peak flow rate for the 2-year and/or 10-year, 24-hour event in Piedmont North Carolina. SCMs are also required to capture runoff from the first inch of precipitation for water quality purposes (NCDENR, 2007a).

There are two general types of SCMs being designed in developing watersheds: (1) large structural SCMs such as wet ponds and stormwater wetlands, and (2) small, decentralized low-impact development (LID) practices such as green roofs, bioretention, rainwater harvesting, permeable pavement, and rain gardens. The larger SCMs require large plots of land and are placed in one location within the watershed (often near the outlet, discharging into streams). They are designed to temporarily store and slowly release surface runoff (USEPA, 2006). If placed along perennial streams, an alternative analysis using LID practices must be conducted to comply with 401/404 certification of the Clean Water Act (USEPA, 2002). Decentralized LID practices individually require less land and are placed in multiple locations (rooftops, yards, and underground) distributed throughout the watershed. They are designed to treat, infiltrate, and release surface runoff at the source. LID practices are commonly used in highly urbanized watersheds where space is limited and expensive (USEPA, 2010).

Recently, research has shown that while large structural SCMs are reducing peak flow rates and to some extent stormwater volumes (Lenhart and Hunt, 2011; EPA, 1999), they are not

reducing the frequency and duration of erosional events in streams. Every particle of sediment has a certain critical shear stress that, when exceeded, incipient motion, or erosion, of the particle will occur (Bledsoe, 2002). Urbanization causes site-specific critical shear stresses to be exceeded more frequently due to increase in peak flow rates and stormwater volumes. The result is uncontrolled erosion and geomorphic instability within stream channels (Robinson, 1976; Rhoads, 1991; May, 1998; Pizzuto et.al, 2000; Niezgoda and Johnson, 2005; Julien and Torres, 2006). Since larger SCMs capture and slowly release runoff, if the controlled sub-bankfull release rate exceeds the critical shear stress of the sediment, SCMs can extend the duration of erosional events beyond that of uncontrolled discharges *without an* SCM. Therefore, some SCMs are hurting geomorphic stability within streams by causing sub-bankfull erosive flows to remain within the channel longer (Bledsoe and Watson, 2001; Roesner et al., 2001; Bledsoe, 2002; Nehrke and Roesner, 2004; Navratil et al., 2006; Rohrer and Roesner, 2006; Pomeroy et al., 2008). These studies emphasize the importance of controlling sub-bankfull flows by altering discharge design standards to include stream stability.

Analyses conducted by Nehrke and Roesner (2004), Rohrer and Roesner (2006), and Pomeroy et al. (2008) demonstrated the need to incorporate: 1) volume controls to capture and control release 90% of all runoff producing events, 2) control the peak flow rate of the 1-year 24-hour storm event, and 3) a maximum unit discharge release rate, to limit the amount of erosion occurring within receiving streams. Tillinghast et al. (2011) used rural reference streams located in Piedmont North Carolina to establish a power regression relationship between sediment size (d_{65} (mm)) and unit critical discharge (Equation 5.1), an annual erosional hour standard (Equation 5.2), and annual volume of eroded bedload standard (Equation 5.3), to determine benchmarks to stabilize degrading streams of urbanized watersheds.

$$Q_c = 0.0035(d_{65})^{1.5048} \tag{5.1}$$

Where
Q_c = unit critical discharge (L/s/ha)
d_{65} = reach-wide d_{65} (mm) from pebble count

$$\text{Log (AAEH)} = -1.26\text{Log}(d_{65}) + 1.21 \tag{5.2}$$

Where
AAEH = allowable annual erosional hours (h/ha/yr)

d_{65} = reach-wide d_{65} (mm) from pebble count

$$\text{Log (AV)} = -0.64(Q_c) - 1.52 \tag{5.3}$$

Where
AV = allowable annual volume of eroded bedload sediment (m^3/m/ha/yr)
Q_c = unit critical discharge (L/s/ha)

The purpose of this study was to: 1) apply Equations 5.1, 5.2, and 5.3 developed by Tillinghast et al. (2011) and PCSWMM, to assess stability of a highly disturbed stream in Chapel Hill, NC using LID practices and a wet pond.

5.2 Site Description and Methods

5.2.1 Site Description

Tanyard Branch, an approximately 68 ha (168 acre) sub-watershed located in Chapel Hill, North Carolina (Figure 5.1), receives 1210 mm (48 in.) of rain annually. Loamy soils and sandy loam with moderate slopes ranging from 1.5 to 3.5% comprise the watershed (NRCS, 2011). Tanyard Branch is approximately 60% impervious and discharges from two 1.2 meter (4 feet) diameter concrete pipes into the receiving stream. No SCMs are present in this older urban watershed. Due to the excessive volumes and high flow rates of the stormwater runoff, the headwaters of Tanyard Branch are extremely unstable and experiencing substantial amounts of scour and erosion (Figure 5.2).

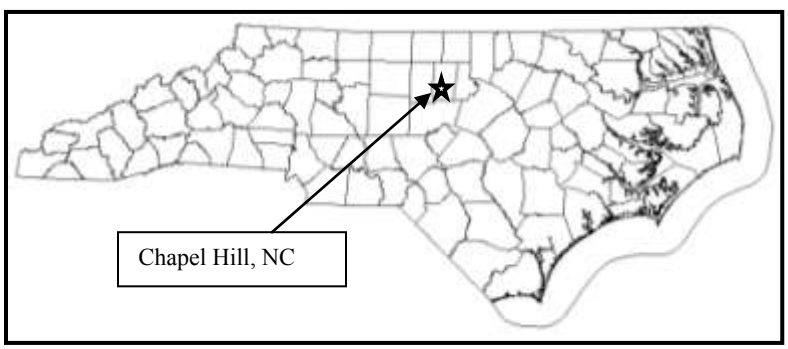


Figure 5.1: Location of Chapel Hill, NC (NCDOT, 2010)

Figure 5.2: Erosion and Incision of Tanyard Branch Banks

For this study, Tanyard Branch was split into 3 different land uses: residential, UNC campus, and downtown to generate multiple SCM treatment alternatives (Figure 5.3). The residential section of Tanyard Branch, approximately 24 ha (59 acres) and 44% impervious, consisting of single- and multi-family homes. The UNC campus portion of Tanyard Branch, approximately 12 ha (29 acres), consisted of campus buildings, parking lots, sidewalks, and houses. It was 46% impervious. The downtown section included a hotel, restaurants, commercial areas, parking lots, sidewalks, and roads. It was 32 ha (71 acres) and 77% impervious.

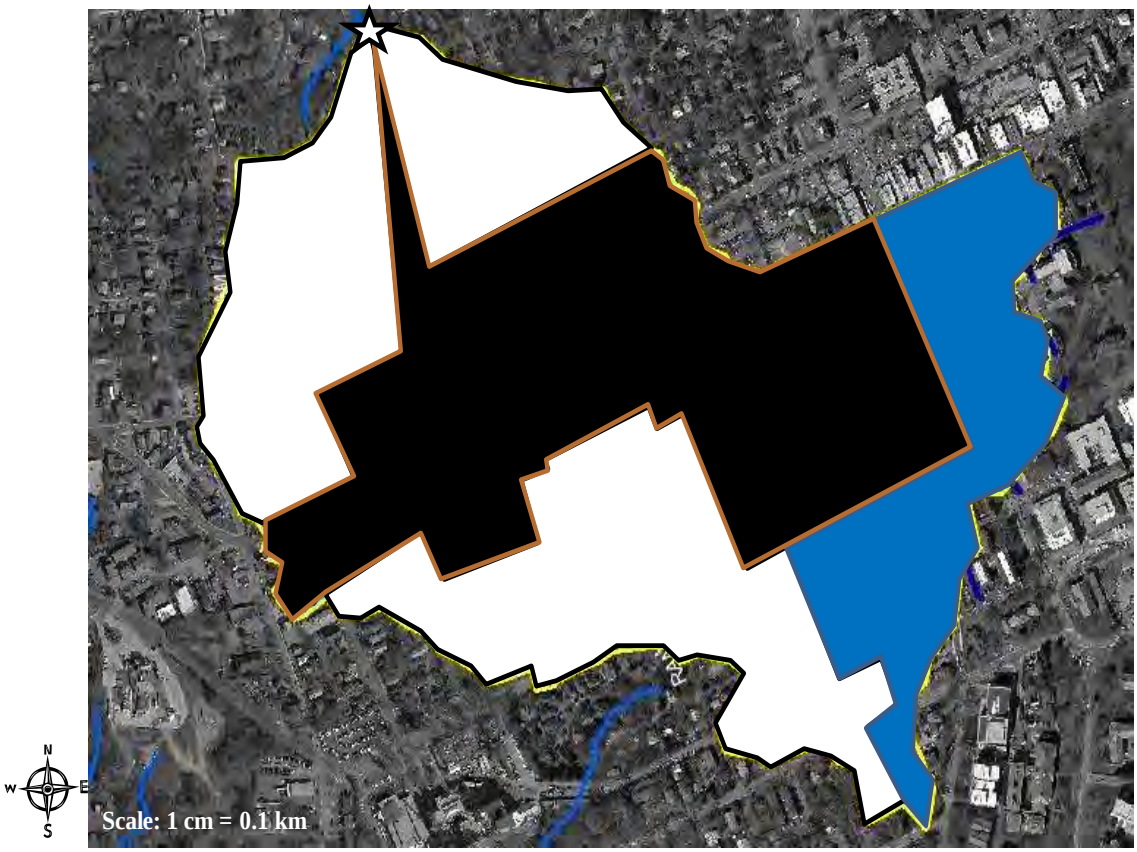


Figure 5.3: Location of Land Uses (Residential (White), Downtown (black), and UNC Campus (gray)) and Outfall (Star) of Tanyard Branch Used to Model 9 Scenarios in PCSWMM

5.2.2 Reach-Wide Pebble Counts and Tape-Down Cross-Sections

To determine the unit critical discharge of sediment found within Tanyard Branch, a Wolman reach-wide pebble count was conducted in a stable location within the stream (Leopold et. al, 1964). The measurer selected 100 pebbles by looking away from the bed of the channel and randomly putting their finger on the bed. Whichever particle was first touched, the length of the intermediate axis was recorded. A cumulative frequency plot of the particle size distribution was used to calculate the d_{65} (mm) of the sediment. The d_{65} was then the input to Equation 5.1 and 5.2 (Tillinghast et al., 2011), to determine the unit critical discharge and annual allowable erosional hours. The unit critical discharge calculated using Equation 5.1 was then the input to Equation 5.3 to calculate the annual allowable volume of eroded bedload the watershed treated by SCMs should not collectively exceed.

Three riffle tape-down cross-sections were conducted to determine the extent of incision within the stream (Harrelson et al., 1994). All three cross-sections were taken clear of culverts or pipes to prevent backwater effects. From the top of banks, a tape measure was placed perpendicular to flow at the height of the top of bank and the depth of the stream channel was

measured in 0.3 m (1 ft) increments. The bankfull width, maximum depth, bankfull area, entrenchment ratio, width-to-depth ratio, and bank height ratio (BHR) were calculated and compared to urban regional curves for Piedmont NC to determine the magnitude of channel incision (Doll et al., 2002).

5.2.3 Modeling Tanyard Branch Scenarios in Stormwater Management Model (PCSWMM)

Soil properties, land use characteristics, and slopes of Tanyard Branch were acquired via ArcGIS 9.3. This information was used as inputs for PCSWMM, a dynamic rainfall-runoff modeling program that uses non-linear reservoir routing to determine flow rates and pollutant loads in urbanized watersheds (CHI, 2009). PCSWMM, along with information from ArcGIS 9.3, were used to model 9 scenarios (Table 5.1).

Table 5.1: Description of 9 Scenarios Modeled in PCSWMM

Scenario	Areas Treated	Description
1	None	Existing condition
2	Entire watershed (68 ha) with additional 1.2 ha[1]	Undersized wet pond at outlet
3	Entire watershed (68 ha) with additional 2.4 ha[1] (Figure 6)	Full-size wet pond at outlet
4	Residential area only (24 ha)	41 cisterns and 56 rain gardens
5	Residential area + under-sized wet pond (25.2 ha)	48 cisterns, 63 rain gardens, under-sized wet pond from scenario 2
6	Residential + UNC campus (36 ha)	41 cisterns, 56 rain gardens, 4 green roofs (0.49 ha), and 7 permeable pavements (2.45 ha)
7	Residential + UNC campus + under-sized wet pond (37.2 ha)	48 cisterns, 63 rain gardens, 4 green roofs (0.49 ha), 7 permeable pavements (2.45 ha), and under-sized wet pond from scenario 2
8	Residential + UNC campus + downtown (68 ha)	41 cisterns, 56 rain gardens, 10 green roofs (1.01 ha), and 13 permeable pavements (6.5 ha)
9	Residential + UNC campus + downtown + under-sized wet pond (69.2 ha)	48 cisterns, 63 rain gardens, 10 green roofs (1.01 ha), 13 permeable pavements (6.5 ha), and under-sized wet pond from scenario 2

[1] Additional 1.2 and 2.4 ha added to drainage area due to partial construction of wet pond extending beyond initial drainage area.

PCSWMM uses a five-step aproach to model stormwater runoff: 1) continuous rainfall data or design storm precipitation is processed by SWMM Rain for use in SWMM Runoff, 2) SWMM Runoff uses topography, sub-catchment, land use characteristics, and precipitation to generate surface runoff, 3) SWMM Extran creates stage-discharge relationships from the surface runoff to be used in SWMM Transport, 4) SWMM Transport routes either continous or event-based flows through the sub-catchments to the outlet, where 5) SWMM Statistics Block performs necessary statistics (Rossman, 2009; Pomeroy et al., 2008).

5.2.3.1 Scenario 1: Existing Conditions Model

The existing condition scenario was modeled without LID practices or an in-line SCM. It represented the base model from which all other scenarios were built.

To determine the accuracy of the base model, field data were used for calibration. The monitoring equipment was installed at the end of a 3.7 meter (12.1 ft.) square, concrete culvert approximately 142 meters (465 ft) from the Tanyard Branch outfall. The automatic rain gage (Figure 5.4a) recorded the time of each bucket tip, equaling 0.25 mm (0.010 inches) of rainfall per tip. The ISCO 4230 (Figure 5.4b and 5.4c) used a bubbler to measure the level of flow within the culvert (ISCO, 1994). Manning's equation (Equation 5.3) was used to convert the depths to flowrates.

$$Q = \frac{1}{n} * A * R^{\frac{2}{3}} * S^{\frac{1}{2}} \tag{5.3}$$

Where:
Q = flowrate (m^3/s)
n = Manning's roughness coefficient (0.011)
A = cross-sectional area (m^2)
R = hydraulic radius (m)
S = slope of culvert (0.0004)

(a) (b) (c)

Figure 5.4: a) ISCO 674 Automatic Rain Gage b) ISCO 4230 Bubbler Flow Meter c) Bubbler Used to Measure Level

Eleven rainfall and flow rate storms were monitored from 10/14/2010 to 12/13/2010 to calibrate the model for Tanyard Branch. Scenarios were compared among each other without changing input parameters; therefore, exact calibration was not necessary, however, the calibration was used to verify the shape and peak flow rates of the modeled outflow hydrographs. Since the location of the monitoring equipment was 142 m away from the outfall, the additional contributing land area (2.4 ha) was also modeled (Figure 5.5). Once the model was calibrated,

the land area was removed for scenarios 1, 4, 6, and 8, half remained (1.2 ha) for scenarios 2, 5, 7, and 9, and fully remained for scenario 3.

Figure 5.5: Location of Added Drainage Area for Required Size Wet Pond

An 11-year continuous precipitation dataset from 1/1/1999 to 12/31/2009 from Chapel Hill-Williams Airport and daily potential evapotranspiration rates supplied by the North Carolina State Climate Office were used in all scenarios (NCSCO, 2003). The aiport was approximately 3.22 kilometers (2 miles) from the outfall.

5.2.3.2 Scenario 2-9: Modeling LID Practices and Wet Ponds of Tanyard Branch

The North Carolina BMP Manual (2007), BMP Modeling Concepts and Simulation (2006), along with multiple journal articles and factsheets developed by North Carolina State University were used to design the LID practices and wet ponds for scenarios 2-9 of Tanyard Branch (Table 5.2).

Table 5.2: Design of Multiple LID Practices and Wet Ponds Used In Tanyard Branch for Scenarios 2-9 and Modeled in PCSWMM

SCM	Design	References for Design

Under-Sized Wet Pond	• Drainage area: 69.2 ha
	• 3 Inlet stormwater pipes
	• Surface area: 0.29 ha
	• Vertical walls
	• Max. storage depth: 1.5 m
	• Storage volume: 4,441 m^3
	• Outlet structure:
	  o Draw-down orifice at stream elevation: 10.16 cm diameter
	  o 4 Rectangular weirs 1.5 m above orifice: 1.83 m by 0.457 m (one on each side of riser structure)
	  o Rectangular overflow weir : 1.83 m by 1.83 m
	  o Emergency Spillway (convey 10-yr, 24-hr storm): 9.14 m
	• Outflow through 1.83 diameter pipe to 3.66 m concrete culvert
	• Water quality volume released in 3.8 days
		NC DENR BMP Manual (2007)

Full-Sized Wet Pond	• Drainage area: 70.4 ha
	• 3 Inlet stormwater pipes
	• Surface area: 0.7 ha
	• Vertical Walls
	• Max. storage depth: 1.5 m
	• Storage volume: 10,553 m^3
	• Outlet structure
	  o Draw-down orifice at stream elevation: 20.32 cm diameter
	  o 4 Rectangular weirs 1.5 m above orifice: 1.52 m by 0.457 m
	  o Rectangular overflow weir: 1.52 m by 1.52 m
	  o Emergency Spillway (convey 50-yr, 24-hr storm) 6.1 m
	• Outflow through 1.83 diameter pipe to 3.66 m concrete culvert
	• Water quality volume released in 3.9 days
		NC DENR BMP Manual (2007)

Rain Garden	• Drainage area: 0.085 ha • Drainage area imperviousness: 27% • Drainage area slope: 0.5% • Depth: 15 cm • Surface area: 13 m^2 • Vertical Walls • Potential evapotranspiration factor: 1 • Infiltration parameters: Sandy loam or loam • 0.37 m diameter overflow pipe for larger storms	NC DENR BMP Manual (2007) Hunt and White, 2001 Huber et al., 2006
Cistern	• Template model from Geosyntec • Roof area: 91m^2 • 3785 liter cistern • Irrigation pump	Huber et al., 2006 Jones and Hunt, 2010

Table 5.2 (continued)

	• Car washing pump (1 hr at 757 liters per hr per month during April to Sept.) • Depth of rainfall on soil less than 3.81 cm, irrigation pump turned on; when depth of rainfall on soil greater than 5.08 cm, irrigation pump turned off.	Hunt and Spzir, 2006

Green Roof	• Roof : 100% impervious sub-catchment
	• Soil media storage device:
	  o Depth: 10 cm
	  o Porosity: 40%
	  o Evapotranspiration factor: 1
	  o Overflow pipe for larger storms
	  o Outlet to drainage layer storage
	• Drainage layer storage device:
	  o 4.06 cm depression pockets
	  o Storage capacity: 9.8L/m^2
		NC DENR BMP Manual (2007)
		
		Hathaway et al., 2008

Permeable Pavement	• 100% impervious sub-catchment
	• Initial abstraction: 0.03 cm
	• Permeable pavement storage device:
	  o Depth: 15 cm
	  o Hydraulic conductivity: 16 cm/hr
	  o Overflow pipe for larger storms
	  o Outlet to 57 stone gravel storage
	• 57 stone gravel storage device:
	  o Depth: 30.48 cm
	  o Hydraulic conductivity: 25 cm/sec
	  o Evapotranspiration factor: 0.25
	  o Porosity: 37%
	  o Internal water storage depth: 50.8 cm
	  o Outlet for infiltration
	  o Pipe for overflow back into conveyance system
		NC DENR BMP Manual (2007)
		
		Huber et al., 2006
		
		Bean et al., 2007
		
		NCSU BAE, 2008
		
		Das, 2006
		
		Brown and Hunt, 2009

5.3 Results and Discussion

5.3.1 Classifying Geomorphic Instability of Tanyard Branch

Rosgen's classification of natural streams and Piedmont NC hydraulic relationships for urban reference streams were used in conjunction with tape-down cross-sections to determine the current state of geomorphic instability within Tanyard Branch (Rosgen, 2006; Doll et al., 2002) (Table 5.3).

Table 5.3: Comparing Urban Reference Streams to Tanyard Branch Stream Characteristics to Determine Degradation and Incision (Doll et al., 2002)

	Urban Reference Stream	Tanyard Branch	Percent Difference Between Urban Stream Characteristic and Measured at Tanyard Branch
Bankfull Cross-Sectional Area (m^2)	2.19	8.1	-270
Bankfull Discharge (cms)	3.49	18.15	-420
Width (m)	4.61	7.62	-65
Depth (m)	0.46	1.28	-178

Due to urbanization and uncontrolled stormwater runoff, Tanyard Branch was incised and wider than stable, urban reference streams. The bankfull discharge was 420% greater, the bankfull width was 65% greater, and the bankfull depth was 178% greater than an urban reference stream with equivalent drainage area, demonstrating the high geomorphic instability for the curent state of Tanyard Branch.

Per the Rosgen classification of natural streams, Tanyard Branch does not neatly fall into one category, but mainly contains characteristics of a G4 stream (Table 5.4). A G4 stream is highly disturbed and typically classified as an "entrenched gully" with extreme sensitivity to disturbances, very poor recovery potential, very high sediment supply, and very high streambank erosion potential (Rosgen, 2006). The bank height ratio is a field measurement used to classify the extent of erosion within stream channels. Tanyard Branch had a BHR of 2.26, or 126% greater than the optimal stream restoration design goal of 1.

Table 5.4: Stream Characteristics of Tanyard Branch Calculated from Tape-Down Cross-Section

Stream Characteristic	Value
Entrenchment Ratio	1
Width-Depth Ratio	9.1
Bank Height Ratio	2.26
Sinuousity	1.2
d_{50} (mm)	14
Slope	0.013

5.3.2 Modeling Scenarios of Tanyard Branch in PCSWMM

The 9 scenarios involving LID practices and wet ponds were modeled in PCSWMM to determine the best combination of SCMs to meet the annual allowable erosional hour and volume of eroded bedload standards (Table 5.5) (Tillinghast et al., 2011). The unit critical discharges and annual allowable erosional hours were calculated using Equation 5.1, Equation 5.2, and a d_{65} of 21.2 mm. The unit critical discharges for all scenarios was 0.369 L/s/ha. An annual allowable erosional duration of 0.33 h/ha/yr was calculated as the threshold of natural erosion within stable streams (Equation 5.2) . The unit critical discharge, 0.369 L/s/ha, was then used to determine the allowable annual volume of eroded bedload of 0.02 m^3/m/ha/yr (Equation 5.3) (Tillinghast et al., 2011).

Table 5.5: Summary of Annual Erosional Hours, Annual Eroded Bedload, and Percent Volume Reduction Calculated from Modeling 9 Scenarios of Tanyard Branch in PCSWMM

Scenario	Average Annual Erosional Hours (hr/ha/yr)	Average Annual Eroded Bedload (m^3/m/ha/yr)	% Volume Reduction (Normalized by Drainage Area)
1) Existing Condition	8.33	0.15	0
2) Under-Sized Wet Pond	5.05	0.11	0
3) Full Sized Wet Pond	19.56	0.06	0
4) Residential	4.66	0.13	30
5) Residential+Under-Sized Wet Pond	4.66	0.08	30
6) UNC Campus	4.59	0.12	34
7) UNC Campus+Under-Sized Wet Pond	3.74	0.07	34
8) Downtown	4.44	0.10	41
9) Downtown+Under-Sized Wet Pond	3.53	0.06	41
Stability Thresholds	***0.33***	***0.02***	

All scenarios exceeded both the annual allowable erosional hour and allowable volume of eroded bedload standards (Tillinghast et al., 2011). The best scenarios to restrict volume of eroded bedload were both scenarios 3 and 9. In scenario 3, the full sized wet pond reduced peak

flow rates entering the stream due to the availability of storage for the stormwater runoff. In scenario 9, the LID practices reduced stormwater runoff volume through infiltration by 41%, and the under-sized wet pond reduced the flow rates before entering the stream. The full-sized pond reduced estimated volume of eroded bedload by a factor of 2.5, while a wet pond 42% of the storage capacity reduced volume of eroded bedload by a factor of 1.4 illustrating the importance of designing stormwater wet ponds with the correct storage volume.

The best scenario using the erosional hours metric was the Downtown+Under-Sized Wet Pond (reduced by factor of 2.4). The LID practices captured and infiltrated stormwater runoff at the location where the precipitation fell; therefore, reducing the volume annually traveling through stormwater conveyance system by 41%. The smaller runoff volumes led to a reduction in time that flow rates exceeded the unit critical discharge even though the wet pond was undersized (42% of required storage volume), indicating the importance of LID practices in a highly urbanized watershed. The under-sized wet pond had fewer expected erosional hours than a full sized wet pond due to more stormwater runoff leaving quickly through the overflow weir instead of the drawdown orifice, also indicated by the higher eroded bedload estimatation (incorporates magnitude of exceedance). The downtown + under-sized wet pond, scenario 9, still did not meet the annual erosional hour standard of 0.33 h/ha/yr, but clearly a combination of LID practices and a wet pond had the maximum reductions in annual erosional hours within the stream.

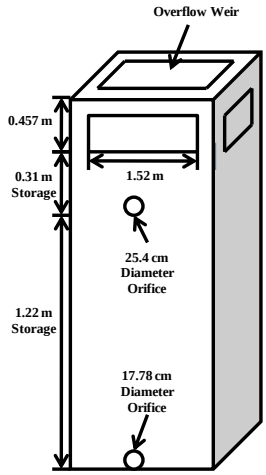
The infiltration of stormwater runoff from LID practices provde an additional benefit within urbanized watersheds: contribution of runoff to increase groundwater baseflow to the stream. This will help protect the stream within Tanyard Branch from drying up during periods of increased temperatures, evapotranspiration rates, and reduced precipitation.

The analysis conducted within Tanyard Branch does not determine the standard that is more indicative of geomorphic instability within streams. While the full sized wet pond had the highest reduction in estimated eroded bedload, a factor 2.5, it increased erosional hours by a factor of 2.4. This is due to the stored stormwater volume being slowly released at erosive flows. Since eroded bedload calculations incorporate both duration and magnitude of exceedance, the outlet structure of the full sized wet pond was explored to determine if an alternative outlet configuratation could reduce erosional hours and better protect stability of streams.

5.3.3 Altering Outlet Configuration of Wet Pond to Better Meet Erosional Standards

When the discharge from the pond orifice exceeds the critical discharge of the sediment, wet ponds extend the time of erosive flows leaving the system (full sized wet pond from Table 5.5). For this reason, an outlet structure with 2 orifices *specifically designed* to discharge outflow at rates less than the critical discharge of the sediment was modeled (Figure 5.6). This is not the current design convention used in North Carolina and most states (NCDENR, 2007a). The wet ponds used in the prior analysis were solely designed to meet current design requirement (for water quality) and therefore did not reflect this subtle change in outlet configuration. This new configuration released stored runoff volume in 4.2 days. By implementing this change to scenario 3 (only full sized wet pond), the average annual erosional hours noticeably decreased from 19.56 to 15.4 h/ha/yr and the volume of eroded bedload modestly increased from 0.06 to 0.07 m^3/m/ha/yr. The cause for volume of eroded bedload increase was the top 0.31 m of stored volume leaving the system at higher flow rates through the 25.4 cm orifice. The key to limiting allowable annual erosional hours through the new outlet configuration was to maximize the portion of stored water quality volume discharging through the smaller drawdown orifice (17.78 cm diameter) but still being released within 2-5 days time limit (NCDENR, 2007a).

The alternative wet pond outlet configuration was then applied to a full-sized wet pond (instead of under-sized) of scenario 9, to see if the annual erosional hour standard could be further reduced. The annual erosional hours decreased to 10.60 h/ha/yr and estimated volume of eroded bedload was 0.05 m^3/m/ha/yr. The erosional hours were reduced compared to the full sized wet pond with the alternative outlet configuration; however, the erosional hours still increased from the existing condition (from 8.33 to 10.60 h/ha/yr). The calculated eroded bedload was below any of the previous 9 scenarios conducted illustrating that the alternative outlet configuration has the potential to improve current wet pond design standards in regards to stream stability. While this optionstill did not meet the annual allowable volume of eroded bedload goal (by a factor of 2.5), this scenario did decrease estimated volume of eroded bedload by a factor of nearly 3 (0.15 to 0.05 m^3/m/ha/yr).



Description	Dimensions
Draw-Down Orifice at Stream Elevation	17.78 cm Diameter
Draw-Down Orifice 1.22 m above Stream Elevation Orifice	25.4 cm Diameter
4 Rectangular Weirs	1.52 m by 0.457 m
Overflow Weir	1.52 m by 1.52 m

Figure 5.6: Alternate Outlet Structure with 2 Draw-Down Orifices to Reduce Calculated Erosional Hours with the Full-Sized Wet Pond

The modeling of 9 initial scenarios in Tanyard Branch illustrated the importance of using LID practices in conjunction with a detention on SCM in highly urbanized watersheds to improve stream stability. The LID practices infiltrated and maximized storage of rainfall runoff, while the wet pond controlled the flow rate entering the stream, reducing erosional hours and volume of eroded bedload. Since calculation of eroded bedload incorporates both magnitude and duration of erosive flows, an alternative outlet structure designed to reduce flow rates even further than currently designed, was explored. The alternative outlet configuration, an additional draw-down orifice on the full-sized wet pond, reduced annual volume of eroded sediment by a factor of 2.1. When applied with LID practices, the volume of eroded bedload was reduced by a factor of 3, while the erosional hours increased by a factor of 1.3. This demonstrated that wet pond outlet structures can be altered from their current designs to increase stability within streams and reduce potential erosion; however, the annual erosional hour standard, 0.33 h/ha/yr, was not met, indicating the difficulty of requiring a 60% impervious watershed to meet robust stream erosion metrics.

5.4 Conclusion & Summary

Urbanization alters the geomorphic stability within streams through increased peak flow rates and stormwater runoff volumes. Tanyard Branch was classified as an “entrenched gully”, G4 stream, according to cross-sectional measurements and guidelines from Rosgen classification of natural streams (Rosgen, 2006). Due to the large runoff volumes and high peak flow rates, Tanyard Branch became incised and unstable. The bankfull flow rate was 420% greater, the

bankfull depth was 178% greater, and the bankfull width was 65% greater than stable, urban reference streams with equivalent drainage areas in Piedmont North Carolina. A large detention SCM (wet pond) and/or multiple LID practices (green roof, rain garden, cistern, and permeable concrete) were modeled in PCSWMM to determine their effectiveness in increasing stream stability and reducing in-stream erosion potential by meeting allowable annual erosional hour and volume of eroded bedload standards of rural reference streams (Tillinghast et al., 2011). From this study, it can be concluded that:

1. LID practices in conjunction with an under-sized wet pond maximized storage and infiltration within the watershed and had the largest reduction in modeled volume of eroded bedload and annual erosional hours.
2. By altering the outlet structure to include a second drawdown orifice, wet ponds can increase stream stability compared to their current design standards.
3. A highly impervious watershed, 60%, was incapable of meeting such strict stream erosion metrics using LID practices and wet ponds.

The analyses conducted in this study were extremely site specific depending on soil, topography, and land uses of Tanyard Branch. In this study, LID practices alone were not sufficient to reach a geomorphic stable stream in Tanyard Branch. An under-sized wet pond along with green roofs, permeable pavement, rainwater harvesting systems, and rain gardens were incapable of meeting the rural reference stream standards developed by Tillinghast et al. (2011), indicating the difficulty in requiring a 60% impervious watershed to meet such robust stream metrics. This scenario reduced both, volume of eroded bedload and erosional hours by factors of 2.5 and 2.4, respectively. This demonstrated that LID practices in conjunction with wet ponds provided the greatest reduction in erosion potential and increase in stream geomorphic stability.

Improvements to the outlet structure of wet ponds were explored to determine if alterations could better reduce erosional hours and volume of eroded bedload. When the new outlet configuration, and additional drawdown orifice, was compared to the current design requirements of wet ponds, the altered outlet structure reduced erosional hours by a factor of 1.3 and increased eroded bedload by a factor of 1.2. When LID practices were modeled in addition to 2 draw-down orifices in a full-sized wet pond, the LID practices did provide a substantial improvement. The LID practices plus the new configuration reduced erosional hours and

volume of eroded bedload even further (factors of 1.2 and 1.8 respectively when compared to a full sized wet pond without altered outlet structure). Similar applications of the altered wet pond outlet structure should be conducted before definitive conclusions can be made.

CHAPTER 6: COST-BENEFIT ANALYSIS OF TANYARD BRANCH

6.1 Introduction

As watersheds become urbanized, infiltration and recharge of groundwater decrease. Instead, stormwater runoff enters receiving surface waters at higher flow rates and volumes, impacting the geormorphic processes of streams. To mitigate the affect of urbanization on streams, most regulating authorities require post-constructed hyrdology to be returned to a pre-constructed state through the use of stormwater control measures (SCMs) for peak flow attenuation. Other design considerations include water quality volumes and reduction in stormwater runoff volumes (NCDENR, 2007a). There are two general types of SCMs being designed in developing watersheds: (1) large structural SCMs such as wet ponds and stormwater wetlands, and (2) small, decentralized low-impact development (LID) practices such as green roofs, bioretention, rainwater harvesting, permeable pavement, and rain gardens. The larger SCMs require large plots of land and are placed in one location within the watershed (often near the outlet, discharging into streams). They are designed to temporarily store and slowly release surface runoff (USEPA, 2006). Decentralized LID practices individually require less land and are placed in multiple locations (rooftops, yards, and underground) distributed throughout the watershed. They are designed to treat, infiltrate, and release surface runoff at the source. LID practices are commonly used in highly urbanized watersheds where space is limited and expensive (USEPA, 2010).

Recently, research has shown that while large structural SCMs are reducing peak flow rates and to some extent stormwater volumes (Lenhart and Hunt, 2011; EPA, 1999), they are not reducing the frequency and duration of erosional events in streams. Every particle of sediment has a certain critical shear stress that, when exceeded, incipient motion, or erosion, of the particle will occur (Bledsoe, 2002). Urbanization causes site-specific critical shear stresses to be exceeded more frequently due to increase in peak flow rates and stormwater volumes. The result is uncontrolled erosion and geomorphic instability within stream channels (Robinson, 1976; Rhoads, 1991; May, 1998; Pizzuto et.al, 2000; Niezgoda and Johnson, 2005; Julien and Torres, 2006). Since larger SCMs capture and slowly release runoff, if the controlled sub-bankfull release rate exceeds the critical shear stress of the sediment, SCMs can extend the duration of

erosional events beyond that of uncontrolled discharges *without an* SCM. Therefore, some SCMs are hurting geomorphic stability within streams by causing sub-bankfull erosive flows to remain within the channel longer (Bledsoe and Watson, 2001; Roesner et al., 2001; Bledsoe, 2002; Nehrke and Roesner, 2004; Navratil et al., 2006; Rohrer and Roesner, 2006; Pomeroy et al., 2008). These studies emphasize the importance of controlling sub-bankfull flows by altering discharge design standards to include stream stability.

Nine scenarios of Tanyard Branch (Table 6.1), consisting of combinations of green roofs, permeable pavement, wet ponds, rain gardens, and rainwater harvesting systems, were modeled in PCSWMM (a hydraulic-hydrologic modeling program for urbanized areas) to determine the best scenario to reduce erosion potential and to meet previously established stream stability thresholds (Chapter 4 and 5). The conducted cost-benefit analysis can aid the Town of Chapel Hill in determining the economic feasibilty of implementing the 9 scenarios in lieu of the benefits each scenario provided.

Table 6.1: SCMs and Drainage Areas Treated of 9 Scenarios Modeled of Tanyard Branch in PCSWMM

Scenario	Areas Treated	Description
1	None	Existing condition
2	Entire watershed (68 ha) with additional 1.2 ha	Undersized wet pond at outlet
3	Entire watershed (68 ha) with additional 2.4 ha (Figure 6)	Full-size wet pond at outlet
4	Residential area only (24 ha)	41 cisterns and 56 rain gardens
5	Residential area + under-sized wet pond (25.2 ha)	48 cisterns, 63 rain gardens, under-sized wet pond from scenario 2
6	Residential + UNC campus (36 ha)	41 cisterns, 56 rain gardens, 4 green roofs (0.49 ha), and 7 permeable pavements (2.45 ha)
7	Residential + UNC campus + under-sized wet pond (37.2 ha)	48 cisterns, 63 rain gardens, 4 green roofs (0.49 ha), 7 permeable pavements (2.45 ha), and under-sized wet pond from scenario 2
8	Residential + UNC campus + downtown (68 ha)	41 cisterns, 56 rain gardens, 10 green roofs (1.01 ha), and 13 permeable pavements (6.5 ha)
9	Residential + UNC campus + downtown + under-sized wet pond (69.2 ha)	48 cisterns, 63 rain gardens, 10 green roofs (1.01 ha), 13 permeable pavements (6.5 ha), and under-sized wet pond from scenario 2

6.2 Procedure

For the cost-benefit analysis, the capital costs of the SCMs from each scenario were computed based upon prices from previous projects within North Carolina. For constructing permeable pavements, rain gardens, and green roofs, an average value per square meter was used to determine the overall capital cost of the specific SCM (Table 6.2). For the cisterns, a local vendor, Rainwater Solutions, was contacted and an approximate cost of the residential rainwater

harvesting system; $1,500.00, was used. To determine the cost of the 2 wet ponds, prices were taken from the RSMEANS Building Construction Cost Data (Waier, 2006), as well as construction costs of previous local projects. Land acquisition and sewer line re-construction costs were based upon real estate estimates and information provided by Patricia D'Arconte, Town of Chapel Hill, and Orange Water and Sewer Authority (OWASA). The annual maintanence costs were calculated from Determining Inspection and Maintanence Costs for Structual BMPs in North Carolina (Hunt and Lord, 2007).

The benefits of the scenarios were determined based upon increased gemorphic stability (decrease in erosion) and decreased risk of flooding provided by PCSWMM (CHI, 2009), nutrient removal (NCDENR and NCState, 2011), and ecological enhancement (Costanza et al., 1997). The nutrient removal program, Jordan Lake Stormwater Load Accounting Tool (JLSLAT), models nitrogen and phosphrous loads and concentrations associated with specific land uses and the reductions attributed to specific SCMs. Each SCM (rain garden, cistern, permeable pavement, and green roof) and contributing drainage area were modeled individually and then applied to the entire watershed to determine the overall percent removal because JLSLAT is intended to model small sub-catchcments. This program was suited for very basic calculations given limited data of the watershed and therefore the reductions calculated should not be considered exact, but a crude estimate. This program estimated nitrogen and phosphorous removals to make relative comparisons among the scenarios. The data output by JLSLAT should not be considered exact. All benefits were not given a monetary value, but were instead compared to determine improvement upon the existing condition.

Table 6.2: Cost Per m^2 of LID Practices Used In Tanyard Branch

LID Practice	General Cost Per m^2 LID Practice Constructed	Reference
Permeable Pavement	$110	Hathaway and Hunt (2007)
Rain Garden	$35	Hathaway and Hunt (2007)
Green Roof	$135	Personal Correspondence (Ed Snodgrass) (01/2011)

6.3 Results

The costs and benefits of each scenario were calculated to determine the economic feasibility of implementing the LID practices and wet ponds vis-á-vis the benefits they provided (Tables 6.3). The costs consisted of: capital cost and installation, annual maintenance, land

purchase, sewer line removal and/or re-location, stream restoration, and stream compensatory mitigation. A price of $1150.00 per linear meter of stream was used for necessary stream restoration (vegetation, decrease bankfull depth/width, increase sinuosity, addition of riffles/pools, etc.) and to compensate for any length of stream that was taken for a wet pond (NC EEP, 2010). The maintenance costs were estimated based upon an average inflation rate, 2.46%, and a 30-year life span (USBLS, 2011).

The least expensive project was the existing scenario because no alteration to the watershed was made. The only cost consisted of restoring the stream (increase sinuosity, return back to respective bankfull depth and cross-sectional area based upon regional curves, vegetation along banks, etc); however, simply restoring the stream would be an immediate solution to stream erosion without addressing the factors (i.e. the developed watershed) causing the erosion. The stream would need to be maintained annually. The most expensive scenario was scenario 9 (the downtown + residential + UNC Campus LID retrofit, with an under-sized wet pond) due to construction of 6.5 ha of permeable pavement in downtown Chapel Hill.

Table 6.3: Estimated Costs of Implementing Wet Ponds and LID Practices of the 9 Scenarios Modeled of Tanyard Branch in PCSWMM (2010 Dollars)

Scenario	Total Capital Cost	Maintenance
1) Existing	179,000	447,800
2) Under-Sized Wet Pond	510,000	346,800
3) Required Wet Pond	1,840,000	114,200
4) Residential	265,000	1,756,100
5) Residential+ Under-Sized Wet Pond	610,000	2,282,900
6) Residential + UNC Campus	3,600,000	1,940,500
7) Residential + UNC Campus+Under-Sized Wet Pond	4,080,000	2,502,500
8) Residential + UNC + Downtown	13,800,000	2,063,500
9) Residential + UNC + Downtown+Under-Sized Wet Pond	14,300,000	2,634,200

The benefits consisted of 1) phosphorous and nitrogen reduction, 2) increased ecological habitat and water regulated services, 3) number of expectant flooding events, 4) the elimination

of some annual excavation of sediment within the stream that would have been due to erosion, and 5) risk of sewer line being exposed within 30 years (Tables 6.4-6.7).

To determine the benefit of restoring ecological functions within Tanyard Branch, the cost which people are willing to pay for equal services was explored. For example, if a river provided an additional $100.00 in fishing production, local fishermen should be willing to pay up to $100.00 to ensure the fish were able to survive. A study conducted by Costanza et al. (1997) determined that humans were willing to pay $8,498 per ha per year to ensure rivers and lakes provided the appropriate ecosystem services (water regulation, water supply, waste treatment, food production, and recreational functions). Based upon meeting the established erosional standards, each scenario was ranked from 1 (best) to 9 (worst) (Table 6.4 and Table 6.5) (Tillinghast et al., 2011). Scenario 9 best met both erosional standards, therefore is predicted to protect ecosystem services the best.

Table 6.4: Summary of Annual Erosional Hours, Annual Eroded Bedload, and Percent Volume Reduction Calculated from Modeling 9 Scenarios of Tanyard Branch in PCSWMM

Scenario	Average Annual Erosional Hours (hr/ha/yr)	Average Annual Eroded Bedload (m^3/m/ha/yr)	% Volume Reduction (Normalized by Drainage Area)
1) Existing Condition	8.33	0.15	0
2) Under-Sized Wet Pond	5.05	0.11	0
3) Full Sized Wet Pond	19.56	0.06	0
4) Residential	4.66	0.13	30
5) Residential+Under-Sized Wet Pond	4.66	0.08	30
6) UNC Campus	4.59	0.12	34
7) UNC Campus+Under-Sized Wet Pond	3.74	0.07	34
8) Downtown	4.44	0.10	41
9) Downtown+Under-Sized Wet Pond	3.53	0.06	41
Stability Thresholds	***0.33***	***0.02***	

Table 6.5: Subjective Ranking of Ecological Services, Reduction in Excavation of Sediment, and Protection of Existing Sewer Line Benefits of Implementing Wet Ponds and LID Practices in Tanyard Branch Based upon Meeting Erosional Standards

Scenario	Ecological Services[1]	Cost Needed to Excavate Eroded Sediment to Maintain Restored Stream[2]	Sewer Line Exposure (In 30 Years?)
1) Existing	9	9	Yes
2) Under-Sized Wet Pond	6	6	No
3) Required Wet Pond	2	2	Removed
4) Residential	8	8	No
5) Residential+ Under-Sized Wet Pond	4	4	No
6) Residential + UNC Campus	7	7	No
7) Residential + UNC Campus+Under-Sized Wet Pond	3	3	No
8) Residential + UNC + Downtown	5	5	No
9) Residential + UNC + Downtown+Under-Sized Wet Pond	1	1	No

[1]Ecological services were ranked from 1-9, 1 indicating stream and watershed provided best environment for ecological functions and 9 being the worst.
[2]Excavation of sediment were ranked from 1-9, 1 indicating smallest amount of transported sediment (but enough so stream not eroding itself) within the stream and 9 being the most.

Similar to ecological services, the erosion rate of Tanyard Branch's banks was ranked from 1 (best) to 9 (worst) based on incipient erosion analysis and meeting the annual erosional hour and volume of eroded bedload standards (Table 6.4 and Table 6.5). The decrease in predicted erosional hours and volume of eroded bedload, less erosion within the stream was expected, increasing geomorphic stability and decreasing eroding sediment. Less predicted eroded sediment meant less annual excavation was needed with the stream to maintain the restored bankfull depth, width, and cross-section. It was assumed that all scenarios provided enough suspended sediment to the channel to keep the stream from eroding itself. This assumption was applicable for Tanyard Branch because the main affect of erosion was incision due to high flow rates. Banks of Tanyard Branch remained stable. The higher the predicted annual erosional hour and volume of eroded sediment, the increase in incision, erosion, and instability with the stream, impacting nearby utility lines. The ability to meet the erosional standards affected whether a nearby sewer line would be exposed within 30 years (currently 0.91 meter below the stream). The only scenario expected to expose the sewer line was the existing condition. The sewer line would be removed to construct the full-sized wet pond. Due to the decrease in runoff volumes, the sewer line would not be expected to be exposed when LID practices were implemented. Due to the decrease in flow rates leaving the under-sized wet pond,

the sewer line was not expected to be exposed with the 30 years. Scenario 9 best met erosional standards, therefore is predicted to also provide the greatest stream stability and reduce annual excavation of eroded sediment and exposure of a nearby sewer line.

The reduction in nutrient loading was determined using JLSLAT (NCDENR and NCState, 2011). Officials in Chapel Hill are required to reduce nitrogen and phosphorous loads in Tanyard Branch to comply with the Jordan Lake Rules (NCDENR, 2007b). The Upper New Hope Creek portion of Jordan Lake (location of Chapel Hill) is required to have its total maximum daily load of nitrogen and phosphorous reduced by 35% and 5%, respectively (NCDENR, 2007b). For this reason alone, while the Existing scenario is the least expensive, it is not allowed. The only scenario complying with reduction goals was the required sized wet pond (Table 6.6). The full-sized wet pond allowed for enough contact time for the runoff to stay within the pond before being released. This allowed for sedimentation to occur, reducing nitrogen and phosphorous. Nitrogen was further removed through possible denitrification sites at the bottom of the pond. Nitrogen and phosphorous was not reduced substantially with the addition of green roofs and permeable pavement. Green roofs typically leach nitrogen and phosphorous due to the compost within the soil media (Hathaway et al., 2008). Due to aerobic conditions within permeable pavement, ammonia is nitrified to nitrate and not significantly reducing the amount of nitrogen in runoff when compared to untreated asphalt (Collins et al., 2010). The NC Ecosystem Enhancement Program (NC EEP) requires all entities to pay $20.59 per pound nitrogen and $142.02 per pound phosphorous exceeding the required limit (NC EEP, 2011).

Table 6.6: Reduction in Annual Nitrogen and Phosphorous Loads from Constructing LID Practices and/or Wet Ponds in Tanyard Branch (Potential Cost Paid by Town of Chapel Hill Due to Nitrogen and Phosphorous Exceedances in ())

Scenario	% Reduction Nitrogen	% Reduction Phosphorous
Existing	0 ($14,200)	0 ($2,100)
Under-Sized Wet Pond	11 ($9,700)	14
Required Wet Pond	39	52
Residential	4 ($12,500)	5
UNC Campus	4 ($12,500)	5
Downtown	4 ($12,500)	5
Residential+ Under-Sized Wet Pond	15 ($8,100)	19
UNC Campus+Under-Sized Wet Pond	15 ($8,100)	19
Downtown+Under-Sized Wet Pond	15 ($8,100)	19

The benefit of reduced flooding of nearby residential property was determined based upon the largest storm the SCMs (under-sized and full-sized wet ponds) and a restored stream could safely convey without over-topping the banks (Table 6.7). The depth of the restored stream, 0.46 m, was calculated from urban reference streams regime curves (Doll et al., 2002). The largest storm a restored Tanyard Branch without SCMs could safely convey was between the 1-year and 2-year, 24-hour event. This is consistent with the definition of bankfull, flow on the brink of overtopping banks and usually has a recurrent interval of 1.3- to 1.4-years (Doll et al., 2002, Navratil et al., 2006). The under-sized and required-size wet pond provided less risk to adjacent properties by safely conveying larger storms, 5- and 25-year, 24-hour storms, respectively.

Table 6.7: Risk of Flooding Residential Properties for Given Design Storm Events if the Exisiting Scenario, Under-Sized Wet Pond, or Full-Sized Wet Pond was Chosen to be Implemented in Tanyard Branch

Storm Event	As-Is Restored Channel	Under-Sized Wet Pond	Required Sized Wet Pond
100-year, 24-hour	Yes	Yes	Yes
50-year, 24-hour	Yes	Yes	Yes
25-year, 24-hour	Yes	Yes	No
10-year, 24-hour	Yes	Yes	No
5-year, 24-hour	Yes	No	No
2-year, 24-hour	Yes	No	No
1-year, 24-hour	No	No	No

This study demonstrated that while LID practices are commonly used in highly urbanized watersheds to reduce total available land dedicated to SCMs, the incremental cost of LID practices greatly surpassed those of wet ponds. When LID practices were used in conjunction with wet ponds, the greatest reduction in modeled erosional hours and volume of eroded bedload

were predicted (Table 6.4). But, the cost of the project increased by about $10 million. However, when LID practices were combined with the wet pond: 1) costs for future excavation of eroded sediment in the stream were reduced, 2) the need to replace a current sewer line crossing the stream was eliminated, 3) nitrogen and phosphorous compensations were less, and 4) the amount of compensation to nearby residents for property damage due to flooding was cut.

The residential scenario was the least costly of all retrofit options; however, it also provided the least benefit of stream geomorphic stability ($53,000/ha). Scenario 9 (LID in residential, UNC, downtown, and under-sized wet pond), provided the lowest risk of flooding and the highest potential for appropriate ecosystem services, reduction in nitrogen and phosphorous, and least amount of necessary excavation for eroded sediment, but had a cost of $14 million ($200,000/ha). Scenario 7, LID practices in residential and UNC campus with an under-sized wet pond, appears to be the optimal solution because it predicted the highest stability in terms of erosional processes while being cost effective ($60,000/ha).

6.4 Conclusion

Per this cost-benefit analysis, as higher geomorphic stability within a stream is achieved, so, too, do the costs of the project increase. Of 9 retrofit scenarios, scenario 9 (residential + UNC + downtown + under-sized wet pond) would mitigate the disturbances from the heavily impervious watershed the best at an estimated cost of $14 million ($200,000/ha), while scenario 7 (residential + UNC + under-sized wet pond) provided comparable stream stability at 29% of the cost.

Both the wet ponds, under-sized and full sized, decreased volume of eroded bedload; however, increased erosional hours from the existing scenario. When used solely, the under-sized wet pond provided minimal mitigation for 1) eroded sediment and 2) nitrogen and phosphorous reduction, negatively impacting ecological services when compared to the other scenarios. While the full sized wet pond had the highest reduction of estimated nitrogen and phosphorous, it also had the highest number of erosional hours, about 2.3 times larger than the existing condition. However, being such a large (68 ha) impervious (60%) watershed, LID practices alone did not provide sufficient benefits (4% and 5% reduction of nitrogen and phosphorous, respectively, and minimal ecological services) for their total appropriate capital costs. To obtain the most benefits in terms of the cost of the project, LID practices are needed with detention SCMs; however alternative methods to reduce nitrogen would be needed

regardless of scenario chosen (unless full sized wet pond) to meet current Jordan Lake introduction and phosphorous reduction goals.

D. 8 Plan View of Under-Sized Wet Pond

Figure D.7: Plan View of Under-Sized Wet Pond Designed for Outlet in Tanyard Branch

D.9 Plan View of Full Sized Wet Pond

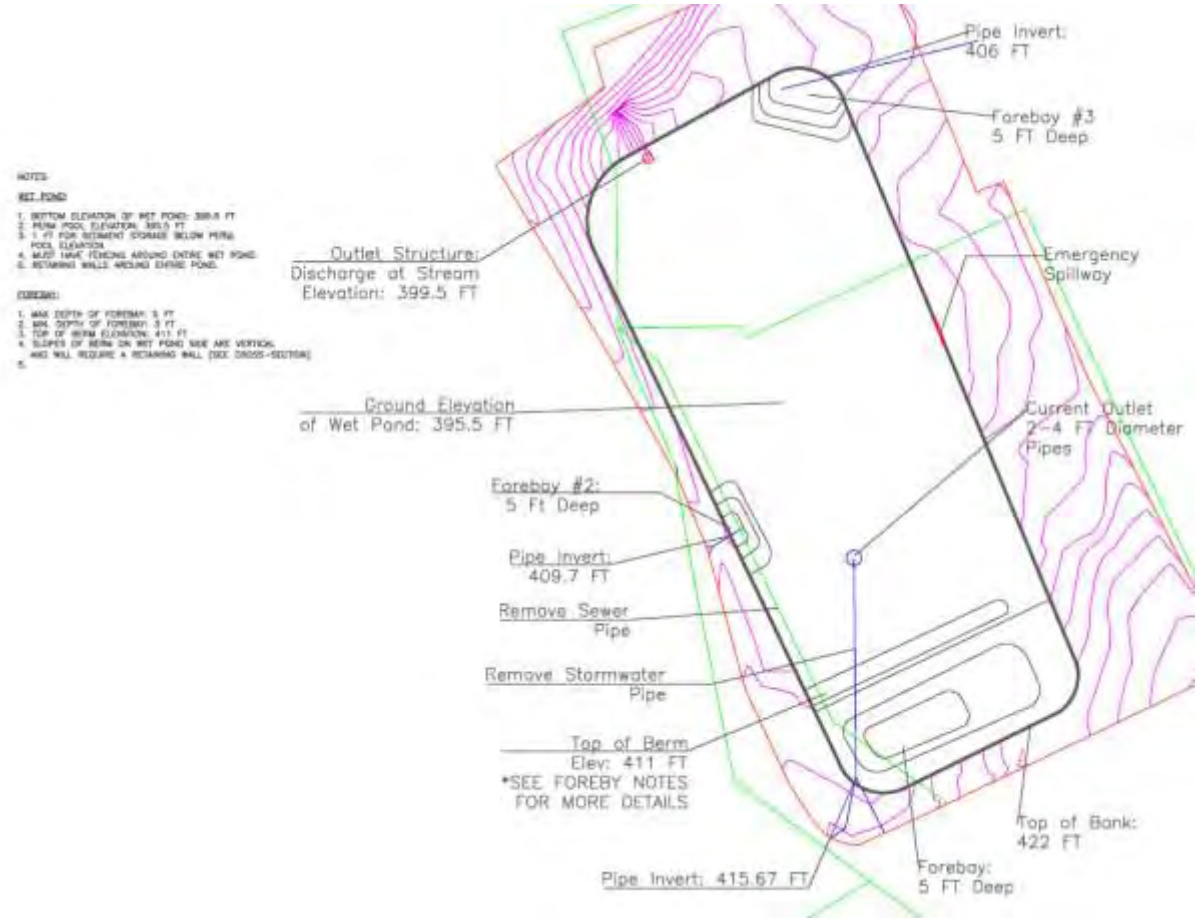


Figure D.8: Plan View of Full Sized Wet Pond Designed for Outlet in Tanyard Branch

D.10 Cross-Section of Under-Sized and Full Sized Wet Pond

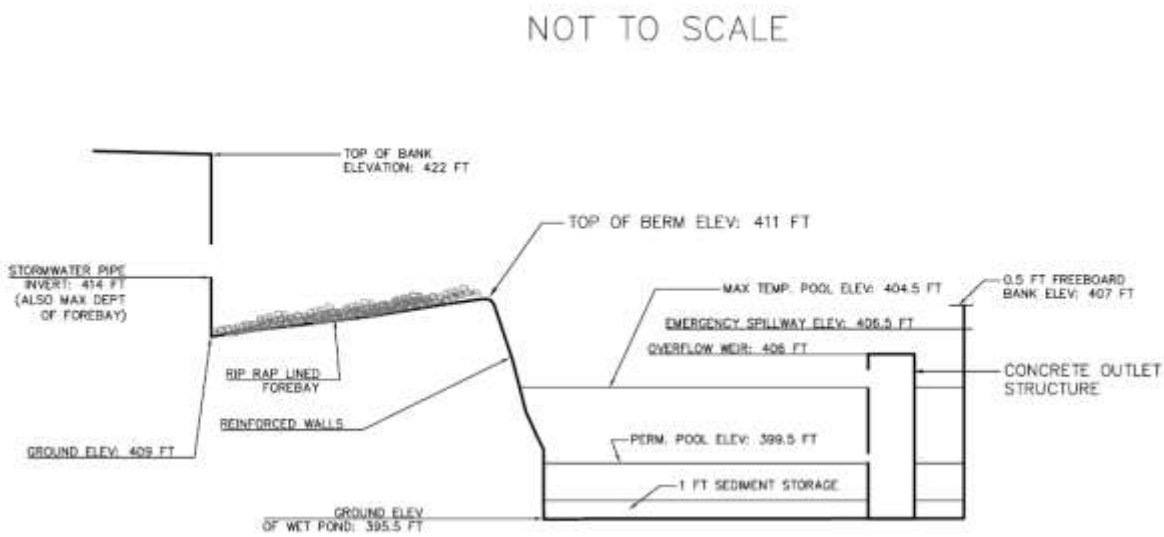


Figure D.9: Cross-Section of Full Sized and Under-Sized Wet Pond and Outlet Structure Designed for Outlet in Tanyard Branch

D.11 Added Drainage Area for Under-Sized Wet Pond

Figure D.10: Added Drainage Area (1.21 ha) Due to Construction of Under-Sized Wet Pond at Outlet of Tanyard Branch

D.12 Necessary Land for Full-Sized Wet Pond (Outlined in White)

Figure D.11: Necessary Land (1.05 ha) for Required Size Wet Pond Designed for the Outlet of Tanyard Branch

D.13 Sewer Line Removal for Full Sized Wet Pond

Figure D.12: Necessary Removal of Sewer Lines (Green Lines Crossed out by White Lines) and Re-location of Sewer Lines (Yellow Lines) for Required Size Wet Pond at Outlet of Tanyard Branch

APPENDIX E: COST-BENEFIT ANALYSIS

E.1 Wet Pond Costs

Under-Sized Wet Pond

Table E.1: Estimated Capital Cost for Under-Sized Wet Pond Designed for Tanyard Branch

Under-Sized Wet Pond Costs				
Description	Price		Estimated Days	Total
Excavator	2.37	per cubic yard		50071
Loading onto Trucks	0.15			1640
Dump Truck	10.35	per 20 cubic yards		10933
Mobilization and De-mobilization	305			305
Rip-Rap/Retaining Wall	172	per day	5	860
Fine Grading	1.23	per square yard	31363	38576
Removal Storm Pipes				140000
Plants				20000
Outlet Structure				2800
			TOTAL	**265186**

Full-Sized Wet Pond

Table E.2: Estimated Capital Cost for Full-Sized Wet Pond Designed for Tanyard Branch

Full-Sized Wet Pond Costs				
Description	Price		Estimated Days	Total
Excavator	2.37	per cubic yard		155256
Loading onto Trucks	0.15			5085
Dump Truck	10.35	per 20 cubic yards		33901
Mobilization and De-mobilization	305	per day	41	305
Rip-Rap/Retaining Wall	172	per day	10	1720
Fine Grading	1.23	per square yard		139305
Removal Storm Pipes				277500
Plants				34000
Outlet Structure				3350
			TOTAL	**650422**

E.2 Cost Analysis

Table E.3: Total Estimated Cost of 9 Scenarios of LID Practices and/or Wet Ponds Modeled in Tanyard Branch in PCSWMM

Scenario	Construction/ Installation Cost	Annual Maintenance	Land Acquisition	Sewer Removal/ Relocation	Stream Restoration	Stream Compensatory Mitigation	Total Cost
Existing	0	10240	0	NA	179200	0	**179200**
Under-Sized Wet Pond	190000	7860	0	140000	92750	86450	**509200**
Required Wet Pond	489000	2560	886664	277500	0	179200	**1832364**
Residential	92860	39200	0	0	179200	0	**272060**
UNC Campus	3362936	44200	0	0	179200	0	**3542136**
Downtown	13560664	46200	0	0	179200	0	**13739864**
Residential+ Under-Sized Wet Pond	293780	51960	0	140000	92750	86450	**612980**
UNC Campus+Under-Sized Wet Pond	3753856	56960	0	140000	92750	86450	**4073056**
Downtown+Under-Sized Wet Pond	13951584	58960	0	140000	92750	86450	**14270784**

E.3 Nutrient Removal of LID Practices

Residential Rain Garden

Physiographic/Geologic Region:	Piedmont
Soil Hydrologic Group	B
Precipitation location:	Carrboro

Total Development Area (ft²):	
Development Name:	
Model Prepared By:	

COLUMN 1 -- NON-RESIDENTIAL LAND USES

	TN EMC (mg/L)	TP EMC (mg/L)	Pre-Development (ft²)	Post-Development
COMMERCIAL				
Parking lot	1.44	0.16		
Roof	1.08	0.15		
Open/Landscaped	2.24	0.44		
INDUSTRIAL				
Parking lot	1.44	0.39		
Roof	1.08	0.15		
Open/Landscaped	2.24	0.44		
TRANSPORTATION				
High Density (interstate, main)	3.67	0.43		
Low Density (secondary, feeder)	1.4	0.52		
Rural	1.14	0.47		
Sidewalk	1.4	1.16		
PERVIOUS				
Managed pervious	3.06	0.59		
Unmanaged (pasture)	3.61	1.56		
Forest	1.47	0.25		
JURISDICTIONAL LANDS*				
Natural wetland	--	--		
Riparian buffer	--	--		
Open water	--	--		
LAND TAKEN UP BY BMPs	1.08	0.15		7,840

*Jurisdictional land uses are not included in nutrient/flow calculations.

Total post-development land use areas do not sum to equal entered development size!!!

COLUMN 2 -- RESIDENTIAL LAND USES

	Custom Lot Size (ac)	Age (yrs)	TN EMC (mg/L)	TP EMC (mg/L)	Pre-Development	Post-Development (ft²)
PART A						
¾-ac lots	--		--	--		
½-ac lots	--		--	--		
⅓-ac lots	--		--	--		
1-ac lots	--		--	--		
2-ac lots	--		--	--		
Multi-family	--		--	--		
Townhomes	--		--	--		
Custom Lot Size	0.15	Before 1995	2.0283	0.429	520,128	512,288
PART B						
Roadway		--	1.4	0.52		
Driveway		1.0	1.44	0.39		
Parking lot		--	1.44	0.39		
Roof		--	1.08	0.15		
Sidewalk/Patio		--	1.4	1.16		
Lawn		--	2.24	0.44		
Managed pervious		--	3.06	0.59		
Forest		--	1.47	0.25		
Natural wetland*		--	--	--		
Riparian buffer*		--	--	--		
Open water*		--	--	--		
LAND TAKEN UP BY BMPs		--	1.08	0.15		

LAND USE AREA CHECK	
Total Development Area Entered (ft²):	0
Total Pre-Development Calculated Area (ft²):	520,128
Total Post-Development Calculated Area (ft²):	520,128

Figure E.1: Input Parameters for Residential Rain Garden in Jordan Lake Stormwater Load Accounting Tool (NCSU, 2011)

REGION:	Piedmont
TOTAL DEVELOPMENT AREA (ft²):	520,128

	Pre-Development Conditions	Post-Development Conditions	Post-Development w/ BMPs
Percent Impervious (%)	28.5%	29.6%	1.5%
Annual Runoff Volume (c.f.)	615,805	635,304	413,932
Total Nitrogen EMC (mg/L)	2.03	1.99	1.15
Total Nitrogen Loading (lb/ac/yr)	6.53	6.60	2.49
Total Phosphorus EMC (mg/L)	0.43	0.42	0.17
Total Phosphorus Loading (lb/ac/yr)	1.39	1.39	0.36

Percent Difference Between:

	Pre-Dev. & Post-Dev. without BMPs	Pre-Development & Post-Development with	Post-Dev without BMPs & Post-Dev with BMPs
Percent Impervious (%)	1%	-27%	-28%
Annual Runoff Volume (c.f.)	3%	-33%	-35%
Total Nitrogen EMC (mg/L)	-2%	-43%	-42%
Total Nitrogen Loading (lb/ac/yr)	1%	-62%	-62%
Total Phosphorus EMC (mg/L)	-3%	-61%	-60%
Total Phosphorus Loading (lb/ac/yr)	0%	-74%	-74%

*Negative percent difference values indicate a decrease in runoff volume, pollutant concentration or pollutant loading. Positive values indicate an increase.

Figure E.2: Summary of Nitrogen and Phosphorous Removal of Residential Rain Garden (NCSU, 2011)

Residential Cistern

Physiographic/Geologic Region:	Piedmont
Soil Hydrologic Group	B
Precipitation location:	Carrboro

Total Development Area (ft²):	
Development Name:	
Model Prepared By:	

COLUMN 1 -- NON-RESIDENTIAL LAND USES

	TN EMC (mg/L)	TP EMC (mg/L)	Pre-Development (ft²)	Post-Development
COMMERCIAL				
Parking lot	1.44	0.16		
Roof	1.08	0.15		
Open/Landscaped	2.24	0.44		
INDUSTRIAL				
Parking lot	1.44	0.39		
Roof	1.08	0.15		
Open/Landscaped	2.24	0.44		
TRANSPORTATION				
High Density (interstate, main)	3.67	0.43		
Low Density (secondary, feeder)	1.4	0.52		
Rural	1.14	0.47		
Sidewalk	1.4	1.16		
PERVIOUS				
Managed pervious	3.06	0.59		
Unmanaged (pasture)	3.61	1.56		
Forest	1.47	0.25		
JURISDICTIONAL LANDS*				
Natural wetland	--	--		
Riparian buffer	--	--		
Open water	--	--		
LAND TAKEN UP BY BMPs	1.08	0.15		

*Jurisdictional land uses are not included in nutrient/flow calculations.

Total post-development land use areas do not sum to equal entered development size!!!

COLUMN 2 -- RESIDENTIAL LAND USES

	Custom Lot Size (ac)	Age (yrs)	TN EMC (mg/L)	TP EMC (mg/L)	Pre-Development	Post-Development (ft²)
PART A						
¾-ac lots	--		--	--		
¼-ac lots	--		--	--		
½-ac lots	--		--	--		
1-ac lots	--		--	--		
2-ac lots	--		--	--		
Multi-family	--		--	--		
Townhomes	--		--	--		
Custom Lot Size	0.15	Before 1995	2.0283	0.429	35,711	35,711
PART B						
Roadway		--	1.4	0.52		
Driveway		1.0	1.44	0.39		
Parking lot		--	1.44	0.39		
Roof		--	1.08	0.15		
Sidewalk/Patio		--	1.4	1.16		
Lawn		--	2.24	0.44		
Managed pervious		--	3.06	0.59		
Forest		--	1.47	0.25		
Natural wetland*		--	--	--		
Riparian buffer*		--	--	--		
Open water*		--	--	--		
LAND TAKEN UP BY BMPs		--	1.08	0.15		

LAND USE AREA CHECK	
Total Development Area Entered (ft²):	0
Total Pre-Development Calculated Area (ft²):	35,711
Total Post-Development Calculated Area (ft²):	35,711

Figure E.3: Input Parameters for Residential Cistern in Jordan Lake Stormwater Load Accounting Tool (NCSU, 2011)

REGION:	Piedmont
TOTAL DEVELOPMENT AREA (ft²):	35,711

	Pre-Development Conditions	Post-Development Conditions	Post-Development w/ BMPs
Percent Impervious (%)	28.5%	28.5%	0.0%
Annual Runoff Volume (c.f.)	42,280	42,280	38,052
Total Nitrogen EMC (mg/L)	2.03	2.03	2.03
Total Nitrogen Loading (lb/ac/yr)	6.53	6.53	5.88
Total Phosphorus EMC (mg/L)	0.43	0.43	0.43
Total Phosphorus Loading (lb/ac/yr)	1.38	1.38	1.24

Percent Difference Between:

	Pre-Dev. & Post-Dev. without BMPs	Pre-Development & Post-Development with	Post-Dev without BMPs & Post-Dev with BMPs
Percent Impervious (%)	0%	-28%	-28%
Annual Runoff Volume (c.f.)	0%	-10%	-10%
Total Nitrogen EMC (mg/L)	0%	0%	0%
Total Nitrogen Loading (lb/ac/yr)	0%	-10%	-10%
Total Phosphorus EMC (mg/L)	0%	0%	0%
Total Phosphorus Loading (lb/ac/yr)	0%	-10%	-10%

*Negative percent difference values indicate a decrease in runoff volume, pollutant concentration or pollutant loading. Positive values indicate an increase.

Figure E.4: Summary of Nitrogen and Phosphorous Removal of Residential Cistern (NCSU, 2011)

UNC Campus Scenario Permeable Pavement

Physiographic/Geologic Region:	Piedmont
Soil Hydrologic Group:	B
Precipitation location:	Carrboro

Total Development Area (ft²):	
Development Name:	
Model Prepared By:	

COLUMN 1 -- NON-RESIDENTIAL LAND USES

	TN EMC (mg/L)	TP EMC (mg/L)	Pre-Development (ft²)	Post-Development
COMMERCIAL				
Parking lot	1.44	0.16	263,538	263,538
Roof	1.08	0.15		
Open/Landscaped	2.24	0.44		
INDUSTRIAL				
Parking lot	1.44	0.39		
Roof	1.08	0.15		
Open/Landscaped	2.24	0.44		
TRANSPORTATION				
High Density (interstate, main)	3.67	0.43		
Low Density (secondary, feeder)	1.4	0.52		
Rural	1.14	0.47		
Sidewalk	1.4	1.16		
PERVIOUS				
Managed pervious	3.06	0.59		
Unmanaged (pasture)	3.61	1.56		
Forest	1.47	0.25		
JURISDICTIONAL LANDS*				
Natural wetland	--	--		
Riparian buffer	--	--		
Open water	--	--		
LAND TAKEN UP BY BMPs	1.08	0.15		

*Jurisdictional land uses are not included in nutrient/flow calculations.

Total post-development land use areas do not sum to equal entered development size!!!

COLUMN 2 -- RESIDENTIAL LAND USES

	Custom Lot Size (ac)	Age (yrs)	TN EMC (mg/L)	TP EMC (mg/L)	Pre-Development	Post-Development (ft²)
PART A						
⅓-ac lots	--		--	--		
¼-ac lots	--		--	--		
½-ac lots	--		--	--		
1-ac lots	--		--	--		
2-ac lots	--		--	--		
Multi-family	--		--	--		
Townhomes	--		--	--		
Custom Lot Size	0.15	Before 1995	2.0283	0.429		
PART B						
Roadway		--	1.4	0.52		
Driveway		1.0	1.44	0.39		
Parking lot		--	1.44	0.39		
Roof		--	1.08	0.15		
Sidewalk/Patio		--	1.4	1.16		
Lawn		--	2.24	0.44		
Managed pervious		--	3.06	0.59		
Forest		--	1.47	0.25		
Natural wetland*		--	--	--		
Riparian buffer*		--	--	--		
Open water*		--	--	--		
LAND TAKEN UP BY BMPs		--	1.08	0.15		

LAND USE AREA CHECK	
Total Development Area Entered (ft²):	0
Total Pre-Development Calculated Area (ft²):	263,538
Total Post-Development Calculated Area (ft²):	263,538

Figure E.5: Input Parameters for Permeable Pavement of UNC Campus Scenario in Jordan Lake Stormwater Load Accounting Tool (NCSU, 2011)

REGION:	Piedmont
TOTAL DEVELOPMENT AREA (ft²):	263,538

	Pre-Development Conditions	Post-Development Conditions	Post-Development w/ BMPs
Percent Impervious (%)	100.0%	100.0%	100.0%
Annual Runoff Volume (c.f.)	967,437	967,437	967,437
Total Nitrogen EMC (mg/L)	1.44	1.44	1.44
Total Nitrogen Loading (lb/ac/yr)	14.38	14.38	14.34
Total Phosphorus EMC (mg/L)	0.16	0.16	0.16
Total Phosphorus Loading (lb/ac/yr)	1.60	1.60	1.59

Percent Difference Between:

	Pre-Dev. & Post-Dev. without BMPs	Pre-Development & Post-Development with	Post-Dev without BMPs & Post-Dev with BMPs
Percent Impervious (%)	0%	0%	0%
Annual Runoff Volume (c.f.)	0%	0%	0%
Total Nitrogen EMC (mg/L)	0%	0%	0%
Total Nitrogen Loading (lb/ac/yr)	0%	0%	0%
Total Phosphorus EMC (mg/L)	0%	0%	0%
Total Phosphorus Loading (lb/ac/yr)	0%	0%	0%

*Negative percent difference values indicate a decrease in runoff volume, pollutant concentration or pollutant loading. Positive values indicate an increase.

Figure E.6: Summary of Nitrogen and Phosphorous Removal of UNC Campus Permeable Pavement (NCSU, 2011)

UNC Campus Scenario Green Roof

Physiographic/Geologic Region:	Piedmont
Soil Hydrologic Group	B
Precipitation location:	Carrboro

Total Development Area (ft²):	
Development Name:	
Model Prepared By:	

COLUMN 1 -- NON-RESIDENTIAL LAND USES

	TN EMC (mg/L)	TP EMC (mg/L)	Pre-Development (ft²)	Post-Development (ft²)
COMMERCIAL				
Parking lot	1.44	0.39		
Roof	1.08	0.15	52,743	52,743
Open/Landscaped	2.24	0.44		
INDUSTRIAL				
Parking lot	1.44	0.39		
Roof	1.08	0.15		
Open/Landscaped	2.24	0.44		
TRANSPORTATION				
High Density (interstate, main)	3.67	0.43		
Low Density (secondary, feeder)	1.4	0.52		
Rural	1.14	0.47		
Sidewalk	1.4	1.16		
PERVIOUS				
Managed pervious	3.06	0.59		
Unmanaged (pasture)	3.61	1.56		
Forest	1.47	0.25		
JURISDICTIONAL LANDS*				
Natural wetland	--	--		
Riparian buffer	--	--		
Open water	--	--		
LAND TAKEN UP BY BMPs	1.08	0.15		

*Jurisdictional land areas are not included in nutrient/flow calculations.

Total post-development land use areas do not sum to equal entered development size!!!

COLUMN 2 -- RESIDENTIAL LAND USES

	Custom Lot Size (ac)	Age (yrs)	TN EMC (mg/L)	TP EMC (mg/L)	Pre-Development (ft²)	Post-Development (ft²)
PART A						
¾-ac lots	--		--	--		
½-ac lots	--		--	--		
¼-ac lots	--		--	--		
1-ac lots	--		--	--		
2-ac lots	--		--	--		
Multi-family	--		--	--		
Townhomes	--		--	--		
Custom Lot Size	0.15	Before 1995	2.0283	0.429		
PART B						
Roadway	--		1.4	0.52		
Driveway	1.0		1.44	0.39		
Parking lot	--		1.44	0.39		
Roof	--		1.08	0.15		
Sidewalk/Patio	--		1.4	1.16		
Lawn	--		2.24	0.44		
Managed pervious	--		3.06	0.59		
Forest	--		1.47	0.25		
Natural wetland*	--		--	--		
Riparian buffer*	--		--	--		
Open water*	--		--	--		
LAND TAKEN UP BY BMPs	--		1.08	0.15		

LAND USE AREA CHECK

Total Development Area Entered (ft²):	0
Total Pre-Development Calculated Area (ft²):	52,743
Total Post-Development Calculated Area (ft²):	52,743

Figure E.7: Input Parameters for Green Roof of UNC Campus Scenario in Jordan Lake Stormwater Load Accounting Tool (NCSU, 2011)

REGION:	Piedmont
TOTAL DEVELOPMENT AREA (ft²):	52,743

	Pre-Development Conditions	Post-Development Conditions	Post-Development w/ BMPs
Percent Impervious (%)	100.0%	100.0%	100.0%
Annual Runoff Volume (c.f.)	193,617	193,617	96,809
Total Nitrogen EMC (mg/L)	1.08	1.08	1.08
Total Nitrogen Loading (lb/ac/yr)	10.75	10.75	5.38
Total Phosphorus EMC (mg/L)	0.15	0.15	0.15
Total Phosphorus Loading (lb/ac/yr)	1.50	1.50	0.75

Percent Difference Between:

	Pre-Dev. & Post-Dev. without BMPs	Pre-Development & Post-Development with	Post-Dev without BMPs & Post-Dev with BMPs
Percent Impervious (%)	0%	0%	0%
Annual Runoff Volume (c.f.)	0%	-50%	-50%
Total Nitrogen EMC (mg/L)	0%	0%	0%
Total Nitrogen Loading (lb/ac/yr)	0%	-50%	-50%
Total Phosphorus EMC (mg/L)	0%	0%	0%
Total Phosphorus Loading (lb/ac/yr)	0%	-50%	-50%

*Negative percent difference values indicate a decrease in runoff volume, pollutant concentration or pollutant loading. Positive values indicate an increase.

Figure E.8: Summary of Nitrogen and Phosphorous Removal of UNC Campus Green Roof (NCSU, 2011)

Downtown Scenario Permeable Pavement

Physiographic/Geologic Region:	Piedmont
Soil Hydrologic Group:	B
Precipitation location:	Carrboro

Total Development Area (ft²):	
Development Name:	
Model Prepared By:	

COLUMN 1 -- NON-RESIDENTIAL LAND USES

	TN EMC (mg/L)	TP EMC (mg/L)	Pre-Development (ft²)	Post-Development
COMMERCIAL				
Parking lot	1.44	0.16	699,476	699,476
Roof	1.08	0.15		
Open/Landscaped	2.24	0.44		
INDUSTRIAL				
Parking lot	1.44	0.39		
Roof	1.08	0.15		
Open/Landscaped	2.24	0.44		
TRANSPORTATION				
High Density (interstate, main)	3.67	0.43		
Low Density (secondary, feeder)	1.4	0.52		
Rural	1.14	0.47		
Sidewalk	1.4	1.16		
PERVIOUS				
Managed pervious	3.06	0.59		
Unmanaged (pasture)	3.61	1.56		
Forest	1.47	0.25		
JURISDICTIONAL LANDS*				
Natural wetland	--	--		
Riparian buffer	--	--		
Open water	--	--		
LAND TAKEN UP BY BMPs	1.08	0.15		

*Jurisdictional land uses are not included in nutrient/flow calculations.

Total post-development land use areas do not sum to equal entered development size!!!

COLUMN 2 -- RESIDENTIAL LAND USES

	Custom Lot Size (ac)	Age (yrs)	TN EMC (mg/L)	TP EMC (mg/L)	Pre-Development	Post-Development (ft²)
PART A						
¼-ac lots	--		--	--		
½-ac lots	--		--	--		
¾-ac lots	--		--	--		
1-ac lots	--		--	--		
2-ac lots	--		--	--		
Multi-family	--		--	--		
Townhomes	--		--	--		
Custom Lot Size	0.15	Before 1995	2.0283	0.429		
PART B						
Roadway		--	1.4	0.52		
Driveway		1.0	1.44	0.39		
Parking lot		--	1.44	0.39		
Roof		--	1.08	0.15		
Sidewalk/Patio		--	1.4	1.16		
Lawn		--	2.24	0.44		
Managed pervious		--	3.06	0.59		
Forest		--	1.47	0.25		
Natural wetland*		--	--	--		
Riparian buffer*		--	--	--		
Open water*		--	--	--		
LAND TAKEN UP BY BMPs		--	1.08	0.15		

LAND USE AREA CHECK	
Total Development Area Entered (ft²):	0
Total Pre-Development Calculated Area (ft²):	699,476
Total Post-Development Calculated Area (ft²):	699,476

Figure E.9: Input Parameters for Permeable Pavement of Downtown Scenario in Jordan Lake Stormwater Load Accounting Tool (NCSU, 2011)

REGION:	Piedmont
TOTAL DEVELOPMENT AREA (ft²):	699,476

	Pre-Development Conditions	Post-Development Conditions	Post-Development w/ BMPs
Percent Impervious (%)	100.0%	100.0%	100.0%
Annual Runoff Volume (c.f.)	2,567,747	2,567,747	2,567,747
Total Nitrogen EMC (mg/L)	1.44	1.44	1.44
Total Nitrogen Loading (lb/ac/yr)	14.38	14.38	14.34
Total Phosphorus EMC (mg/L)	0.16	0.16	0.16
Total Phosphorus Loading (lb/ac/yr)	1.60	1.60	1.58

Percent Difference Between:

	Pre-Dev. & Post-Dev. without BMPs	Pre-Development & Post-Development with	Post-Dev without BMPs & Post-Dev with BMPs
Percent Impervious (%)	0%	0%	0%
Annual Runoff Volume (c.f.)	0%	0%	0%
Total Nitrogen EMC (mg/L)	0%	0%	0%
Total Nitrogen Loading (lb/ac/yr)	0%	0%	0%
Total Phosphorus EMC (mg/L)	0%	0%	0%
Total Phosphorus Loading (lb/ac/yr)	0%	0%	0%

*Negative percent difference values indicate a decrease in runoff volume, pollutant concentration or pollutant loading. Positive values indicate an increase.

Figure E.10: Summary of Nitrogen and Phosphorous Removal of Downtown Permeable Pavement (NCSU, 2011)

Downtown Scenario Green Roof

Physiographic/Geologic Region:	Piedmont
Soil Hydrologic Group	B
Precipitation location:	Carrboro

Total Development Area (ft²):	
Development Name:	
Model Prepared By:	

COLUMN 1 -- NON-RESIDENTIAL LAND USES

	TN EMC (mg/L)	TP EMC (mg/L)	Pre-Development (ft²)	Post-Development
COMMERCIAL				
Parking lot	1.44	0.16		
Roof	1.08	0.15	539,272	539,272
Open/Landscaped	2.24	0.44		
INDUSTRIAL				
Parking lot	1.44	0.39		
Roof	1.08	0.15		
Open/Landscaped	2.24	0.44		
TRANSPORTATION				
High Density (interstate, main)	3.67	0.43		
Low Density (secondary, feeder)	1.4	0.52		
Rural	1.14	0.47		
Sidewalk	1.4	1.16		
PERVIOUS				
Managed pervious	3.06	0.59		
Unmanaged (pasture)	3.61	1.56		
Forest	1.47	0.25		
JURISDICTIONAL LANDS*				
Natural wetland	--	--		
Riparian buffer	--	--		
Open water	--	--		
LAND TAKEN UP BY BMPs	1.08	0.15		

*Jurisdictional land uses are not included in nutrient/flow calculations.

Total post-development land use areas do not sum to equal entered development size!!!

COLUMN 2 -- RESIDENTIAL LAND USES

	Custom Lot Size (ac)	Age (yrs)	TN EMC (mg/L)	TP EMC (mg/L)	Pre-Development	Post-Development (ft²)
PART A						
⅛-ac lots	--		--	--		
¼-ac lots	--		--	--		
½-ac lots	--		--	--		
1-ac lots	--		--	--		
2-ac lots	--		--	--		
Multi-family	--		--	--		
Townhomes	--		--	--		
Custom Lot Size	0.15	Before 1995	2.0283	0.429		
PART B						
Roadway		--	1.4	0.52		
Driveway		1.0	1.44	0.39		
Parking lot		--	1.44	0.39		
Roof		--	1.08	0.15		
Sidewalk/Patio		--	1.4	1.16		
Lawn		--	2.24	0.44		
Managed pervious		--	3.06	0.59		
Forest		--	1.47	0.25		
Natural wetland*		--	--	--		
Riparian buffer*		--	--	--		
Open water*		--	--	--		
LAND TAKEN UP BY BMPs		--	1.08	0.15		

LAND USE AREA CHECK	
Total Development Area Entered (ft²):	0
Total Pre-Development Calculated Area (ft²):	539,272
Total Post-Development Calculated Area (ft²):	539,272

Figure E.11: Input Parameters for Green Roof of Downtown Scenario in Jordan Lake Stormwater Load Accounting Tool (NCSU, 2011)

REGION:	Piedmont
TOTAL DEVELOPMENT AREA (ft²):	539,272

	Pre-Development Conditions	Post-Development Conditions	Post-Development w/ BMPs
Percent Impervious (%)	100.0%	100.0%	100.0%
Annual Runoff Volume (c.f.)	1,979,645	1,979,645	989,823
Total Nitrogen EMC (mg/L)	1.08	1.08	1.08
Total Nitrogen Loading (lb/ac/yr)	10.78	10.78	5.38
Total Phosphorus EMC (mg/L)	0.15	0.15	0.15
Total Phosphorus Loading (lb/ac/yr)	1.50	1.50	0.75

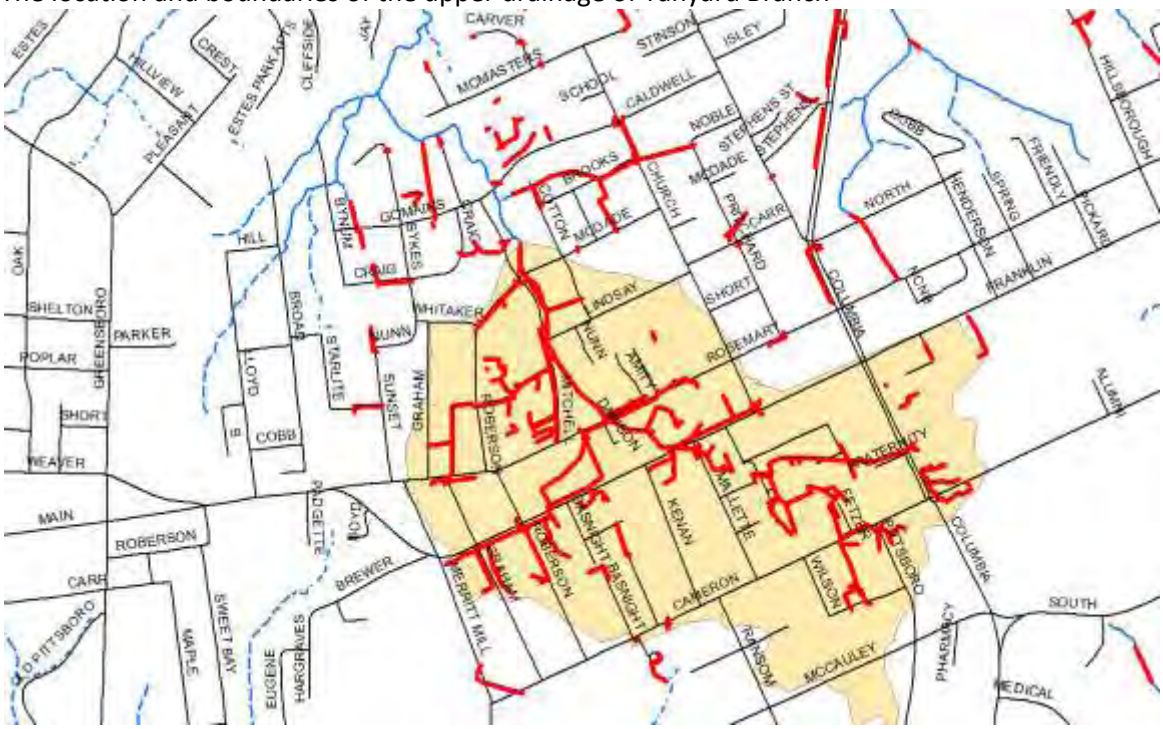
Percent Difference Between:

	Pre-Dev. & Post-Dev. without BMPs	Pre-Development & Post-Development with	Post-Dev without BMPs & Post-Dev with BMPs
Percent Impervious (%)	0%	0%	0%
Annual Runoff Volume (c.f.)	0%	-50%	-50%
Total Nitrogen EMC (mg/L)	0%	0%	0%
Total Nitrogen Loading (lb/ac/yr)	0%	-50%	-50%
Total Phosphorus EMC (mg/L)	0%	0%	0%
Total Phosphorus Loading (lb/ac/yr)	0%	-50%	-50%

*Negative percent difference values indicate a decrease in runoff volume, pollutant concentration or pollutant loading. Positive values indicate an increase.

Figure E.12: Summary of Nitrogen and Phosphorous Removal of Downtown Green Roof (NCSU, 2011)

The location and boundaries of the upper drainage of Tanyard Branch



The convoluted and dense stormdrain network is in red

The location of the proposed basin would be at the black triangle

The “double-barrel shotgun” outfall where it all daylights and erosion starts

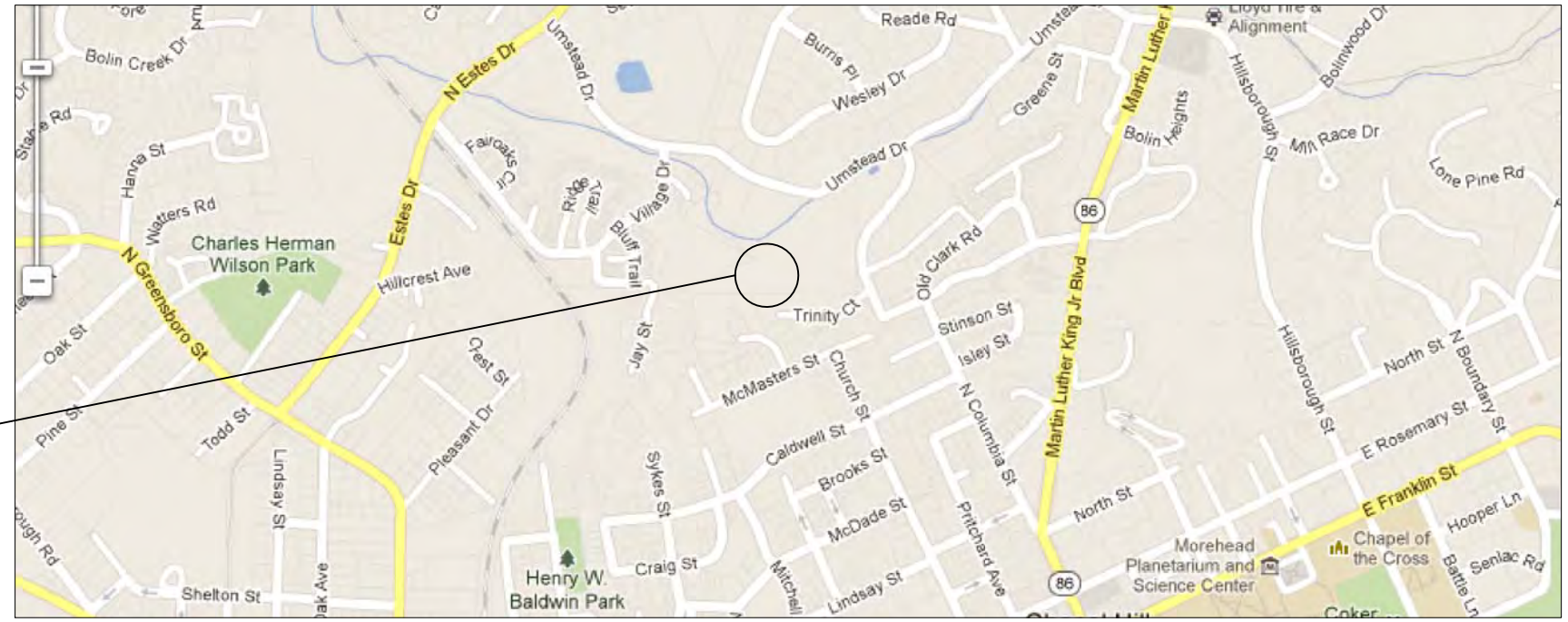
Erosion of the banks downstream

More downstream bank erosion

APPENDIX 4: TRINITY COURT STREAM RESTORATION PROJECT MATERIALS

Trinity Court
Stream Stabilization
Chapel Hill, NC
Orange County

SITE



Prepared for:
Town of Chapel Hill
Stormwater Management Division
208 N. Columbia Street
Chapel Hill, NC 27514

Prepared by:
North Carolina State University
Dept. of Biological and Agricultural Engineering
3100 Faucette Dr.
Raleigh, NC 27695

CHSWD Contact:
Patricia D'Arconte -
Project Manager
919-969-7202

NCSU Contact:
Zan Price - Design/Construction
828-712-9194

Sheet Index

Sheet 1: Cover & Sheet Index
Sheet 2: Existing Conditions - Plan View
Sheet 3: Design Plan View
Sheet 4: Design - Longitudinal Profile
Sheet 5: Design - Cross-sections
Sheet 6: Construction Details
Sheet 7: Construction Details

NO	REVISIONS	DRN	CHK	DATE
1	INITIAL DESIGN	ZP	GJ	01/16/12

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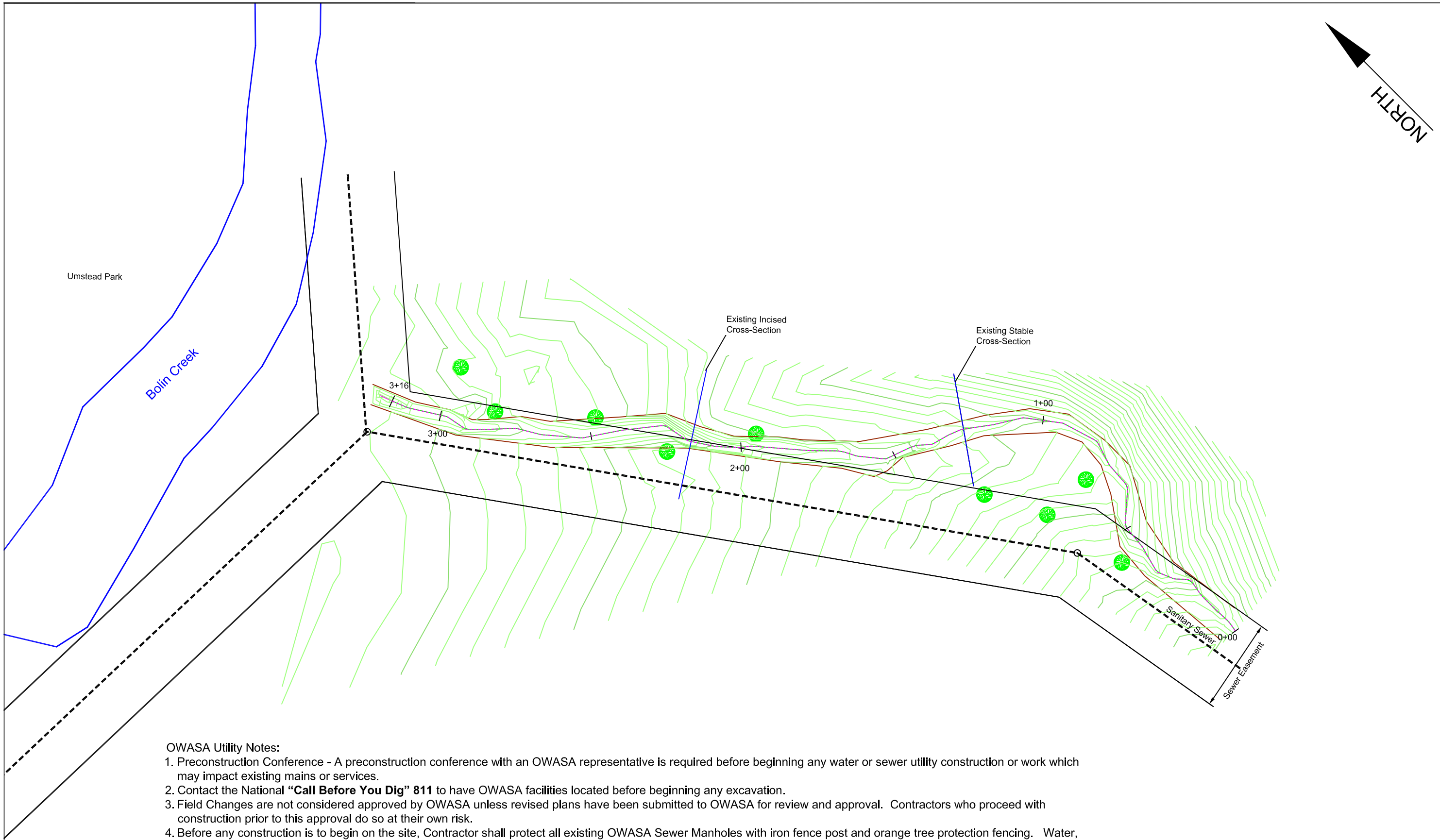
TRINITY COURT STREAM STABILIZATION
CHAPEL HILL, NC

COVER AND SHEET INDEX

DATE 1/16/12
PROJECT NO.
FILENAME FILE.DWG
SHEET NO. PL – 1
DRAWING NO.



OWASA Utility Notes:

1. Preconstruction Conference - A preconstruction conference with an OWASA representative is required before beginning any water or sewer utility construction or work which may impact existing mains or services.
2. Contact the National **"Call Before You Dig" 811** to have OWASA facilities located before beginning any excavation.
3. Field Changes are not considered approved by OWASA unless revised plans have been submitted to OWASA for review and approval. Contractors who proceed with construction prior to this approval do so at their own risk.
4. Before any construction is to begin on the site, Contractor shall protect all existing OWASA Sewer Manholes with iron fence post and orange tree protection fencing. Water, stone, dirt, or any other debris shall not be allowed to enter the OWASA Sanitary Sewer System during flushing operations or at any other time. Construction taking place in the vicinity of any existing OWASA sewer lines or manholes shall not cause any inflow of surface water or debris to enter the OWASA Sanitary Sewer System. Existing OWASA manholes located in construction sites are to be kept clear and accessible to OWASA personnel at all times. The Owner and/or Contractor shall be responsible for any damages incurred to the OWASA Sanitary Sewer System and any fines imposed by the State of North Carolina Division Of Water Quality due to sewer spills or overflows.
5. Existing water and/or sewer lines encountered during construction must be supported in a manner acceptable to the OWASA Construction Inspector. The OWASA Construction Inspector under the direction of the OWASA Engineering Manager may require existing pipes to be replaced with new ductile iron pipe.

SCALE 1" = 30'

15 0 15 30

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EXISTING CONDITIONS PLAN VIEW

DATE 1/16/12
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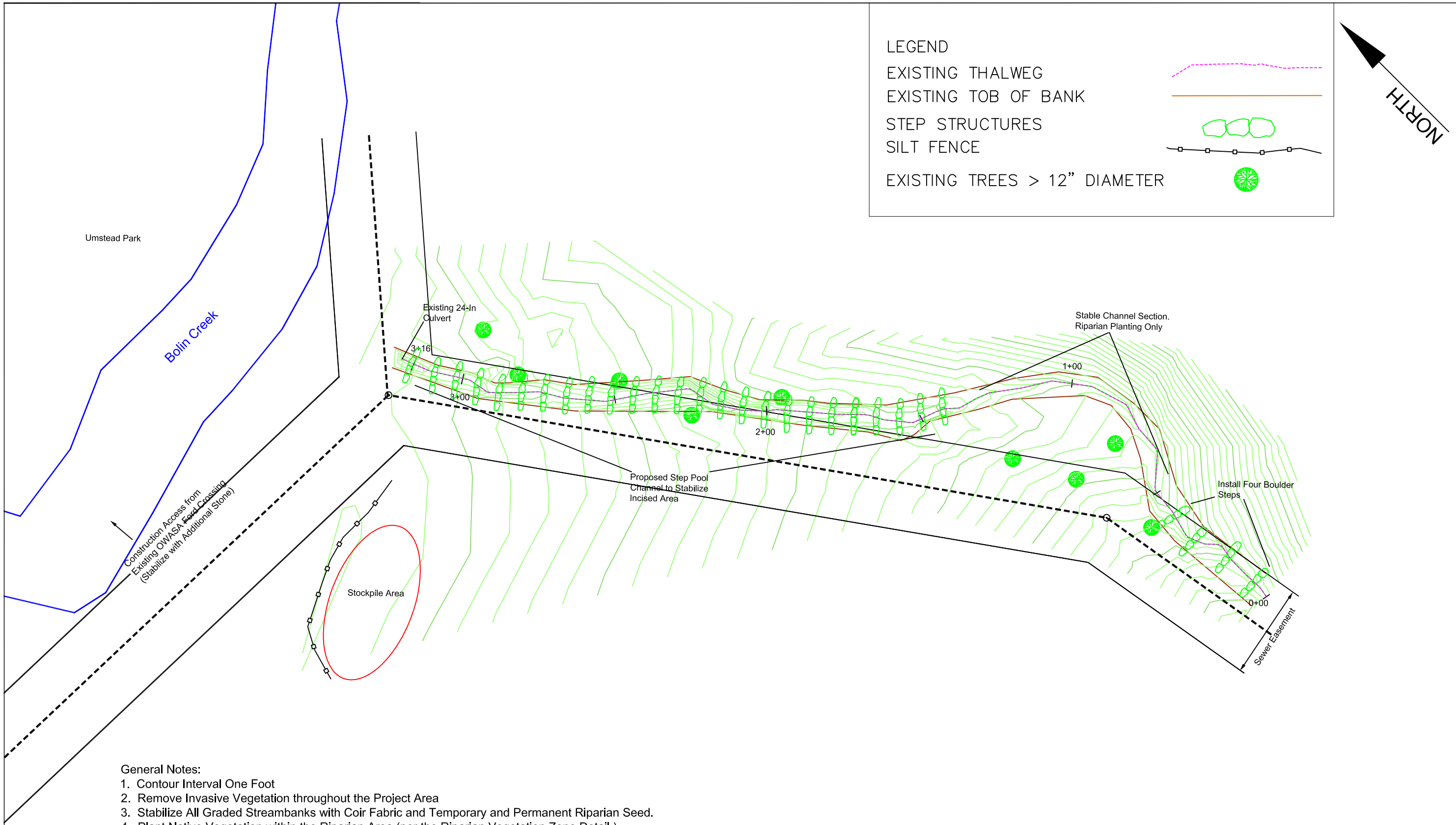
SHEET NO. 2
DRAWING NO.



General Notes:

1. Contour Interval One Foot
2. Remove Invasive Vegetation throughout the Project Area
3. Stabilize All Graded Streambanks with Coir Fabric and Temporary and Permanent Riparian Seed.
4. Plant Native Vegetation within the Riparian Area (per the Riparian Vegetation Zone Detail)
5. Permanent vegetation within the sewer easement shall be approved by OWASA
6. Proposed Step Locations Can Be Modified in the Field by the Onsite Engineer.
7. Contractor Shall Minimize Disturbed Areas and Preserve Mature Trees Flagged by the Onsite Engineer
8. In Addition to Stabilizing the Riparian Area, the Contractor shall Smooth Grade, Seed, and Mulch all Disturbed Areas Outside of the Restored Stream Area
9. No Construction Materials, Equipment, or Soil shall be stored on OWASA Easements During Construction unless Approved by OWASA. OWASA Must have Unrestricted Access Along the Easement at all Times.
10. Existing OWASA Manholes Shall be Protected From Damage During Construction Using Suitable Fencing.

SCALE 1" = 30'

15 0 15 30

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CHAPEL HILL, NC

DESIGN PLAN SHEET

DATE	1/16/12
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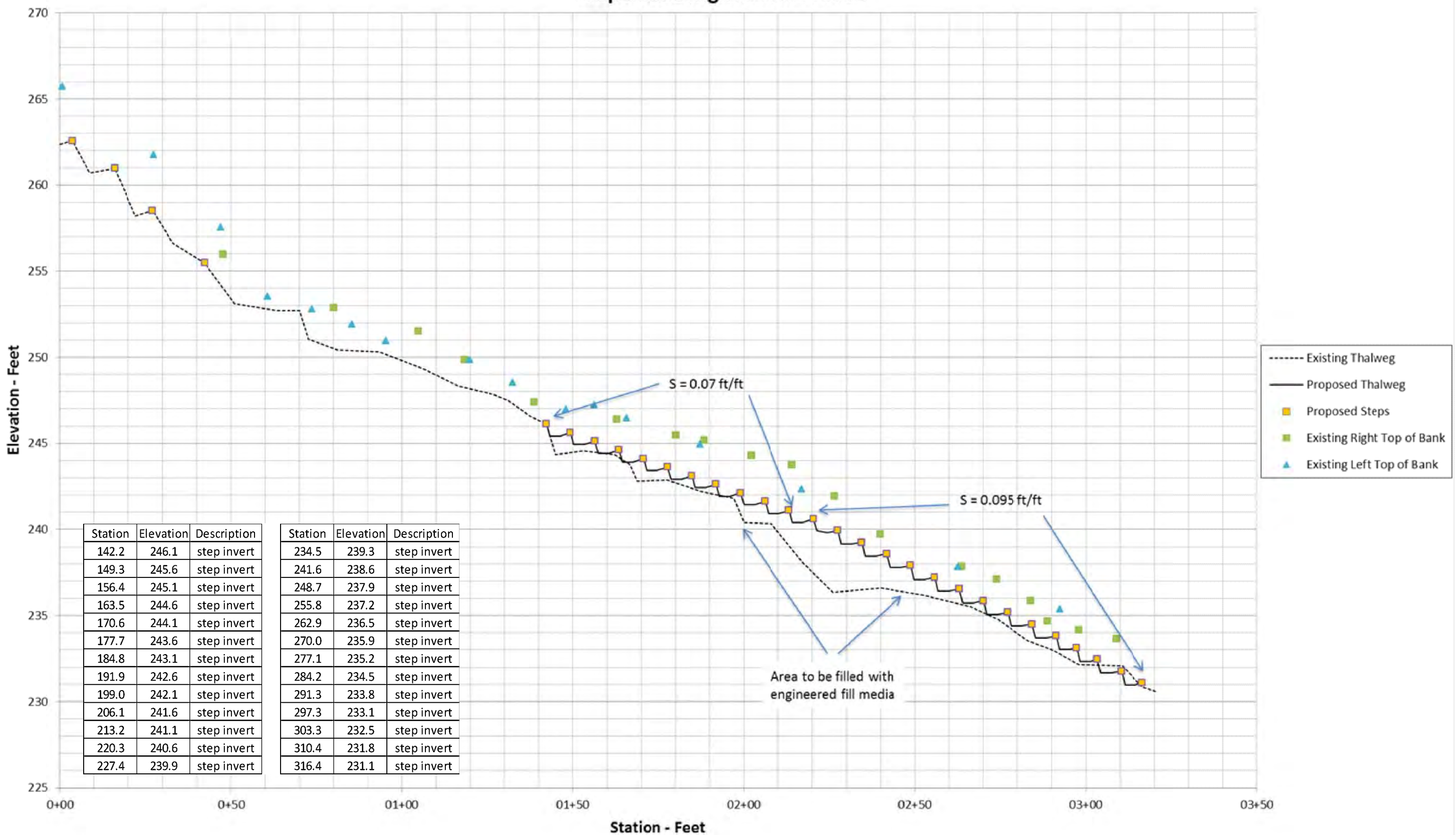
SHEET NO.	3
DRAWING NO.	

Proposed Longitudinal Profile



Station	Elevation	Description
142.2	246.1	step invert
149.3	245.6	step invert
156.4	245.1	step invert
163.5	244.6	step invert
170.6	244.1	step invert
177.7	243.6	step invert
184.8	243.1	step invert
191.9	242.6	step invert
199.0	242.1	step invert
206.1	241.6	step invert
213.2	241.1	step invert
220.3	240.6	step invert
227.4	239.9	step invert

Station	Elevation	Description
234.5	239.3	step invert
241.6	238.6	step invert
248.7	237.9	step invert
255.8	237.2	step invert
262.9	236.5	step invert
270.0	235.9	step invert
277.1	235.2	step invert
284.2	234.5	step invert
291.3	233.8	step invert
297.3	233.1	step invert
303.3	232.5	step invert
310.4	231.8	step invert
316.4	231.1	step invert

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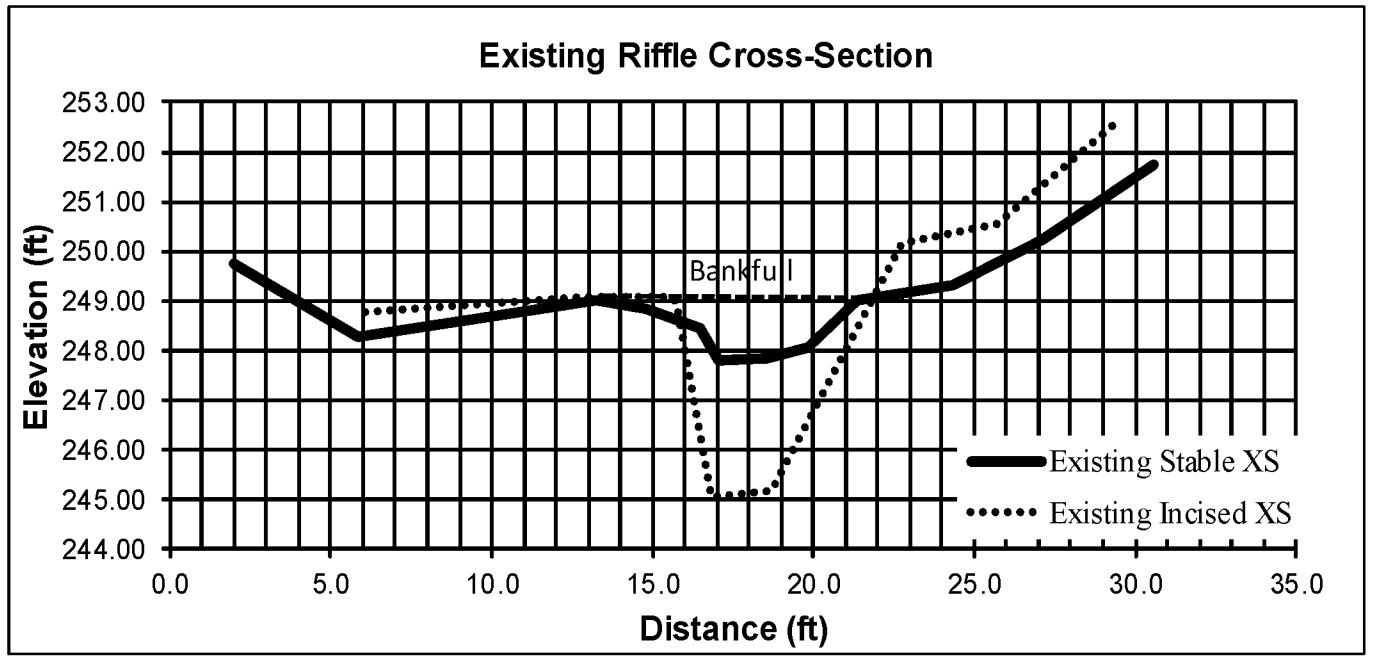
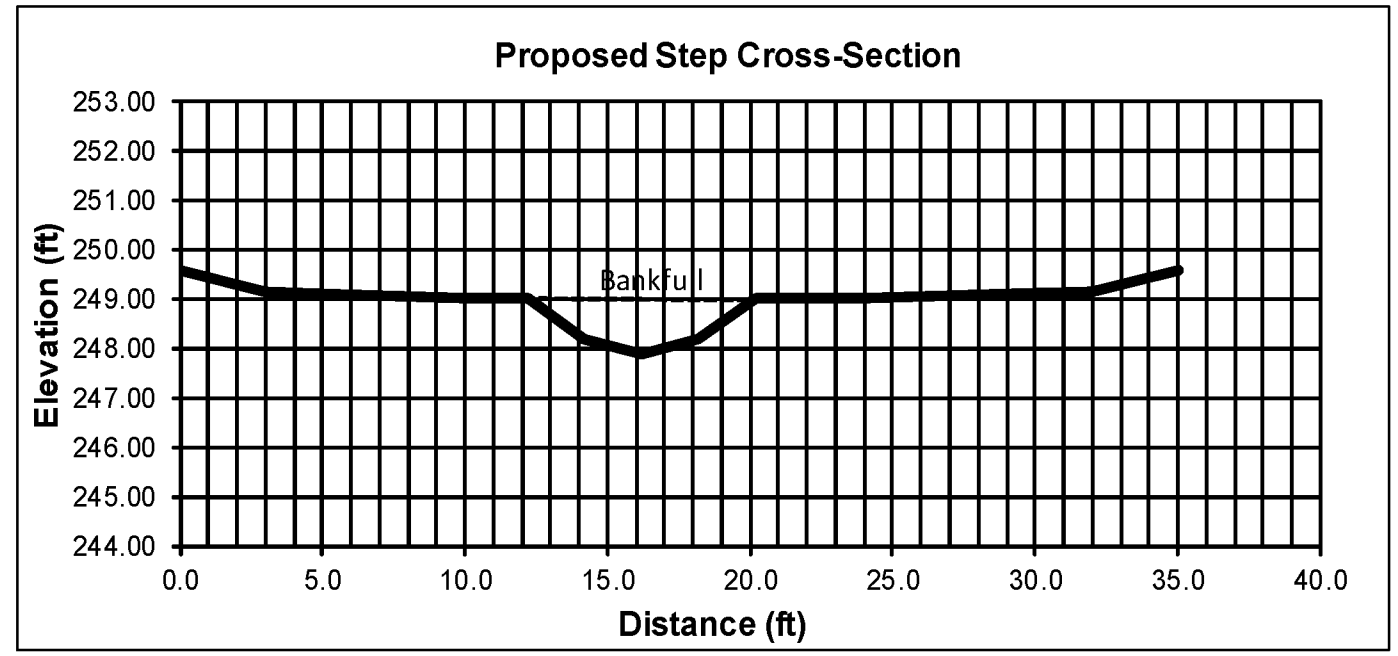
DRAWING NO.

Trinity Court - Existing and Proposed Cross Section





Existing Condtions	Stable XS	Incised XS
Width flood-prone area, Wfpa (ft)	22	10.0
Bankfull Mannings n (estimate)	0.04	0.04
Average water surface slope, S (ft/ft)	0.089	0.089
Bankfull elevation (ft)	249	249
Riffle width, Wbkf (ft)	8.0	6.1
Entrenchment ratio, ER [Wfpa/Wbkf]	2.7	1.6
Riffle cross-section area, Abkf (sq ft)	5.0	15.4
Mean riffle depth, dbkf (ft)	0.6	2.5
Width-to-depth ratio, [Wbkf/dbkf]	12.9	2.4
Max riffle depth, dmbkf (ft)	1.2	4.0
Max riffle depth ratio, [dmbkf/dbkf]	1.9	1.6
Bankfull wetted perimeter, WP (ft)	9.3	11.1
Bankfull hydraulic radius, R (ft)	0.5	1.4
Mannings bankfull discharge, Qbkf (cfs)	36.9	211.5
Mannings bkf velocity, ubkf = Q/A (ft/s)	7.4	13.8
Bankfull shear stress, t (lb/ft2)	3.0	7.7

Proposed Condtions		
Width flood-prone area, Wfpa (ft)	35	(Flood prone width will vary depending on site conditions)
Bankfull Mannings n (estimate)	0.04	
Average water surface slope, S (ft/ft)	0.08	
Bankfull elevation (ft)	249	
Riffle width, Wbkf (ft)	8	
Entrenchment ratio, ER [Wfpa/Wbkf]	4.4	
Riffle cross-section area, Abkf (sq ft)	5.4	
Mean riffle depth, dbkf (ft)	0.7	
Width-to-depth ratio, [Wbkf/dbkf]	11.9	
Max riffle depth, dmbkf (ft)	1.1	
Max riffle depth ratio, [dmbkf/dbkf]	1.6	
Bankfull wetted perimeter, WP (ft)	9.4	
Bankfull hydraulic radius, R (ft)	0.6	
Mannings bankfull discharge, Qbkf (cfs)	39.4	
Mannings bkf velocity, ubkf = Q/A (ft/s)	7.3	
Bankfull shear stress, t (lb/ft2)	2.9	

Regional Curve Analysis

Site Drainage Area: 0.02 sq mi	XS Area (sq ft)	Discharge (cfs)	Bankfull Width (ft)	Mean Depth (ft)
NC Piedmont Urban	**4.7**	**26.1**	**6.7**	**0.7**
NC Piedmont Rural	1.6	5.7	3.5	0.5

Source: http://www.bae.ncsu.edu/programs/extension/wqg/srp/reg_curve_graph.html

Note: Existing regional curves do not have data points as low as 0.02 sq miles. This is an order of magnitude lower than the smallest drainage area on the published curves for the NC Piedmont. Therefore, it is not advised to use regional curve data for this site. A stable cross-section within the project reach was used to calculate the proposed cross-section dimensions.

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TRINITY COURT STREAM STABILIZATION
CHAPEL HILL, NC

DESIGN– CROSS SECTIONS

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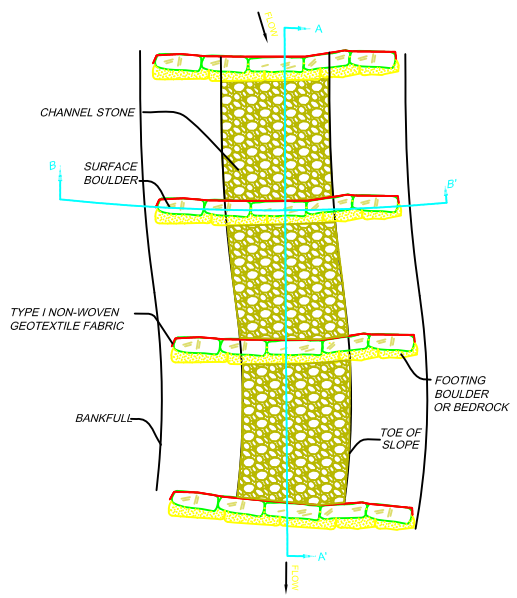
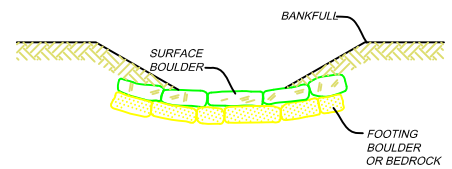
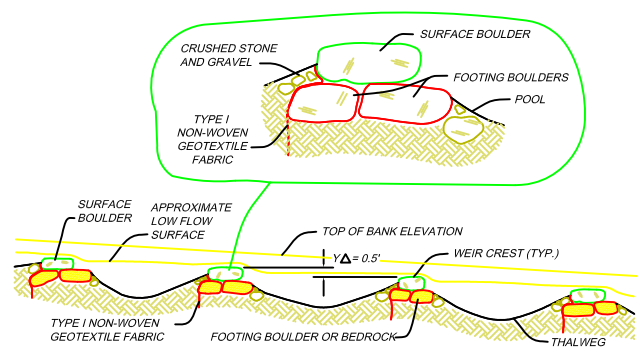
SHEET NO. 5
DRAWING NO.



STEP POOL PLAN VIEW



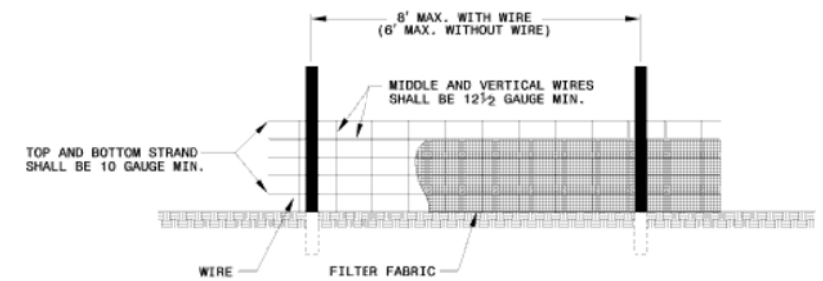
STEP POOL WEIR - SECTION B-B'
NOT TO SCALE



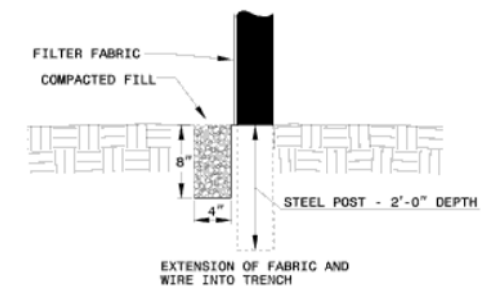
STEP POOL PROFILE - A-A'
NOT TO SCALE

STEP POOL CHANNEL
NTS

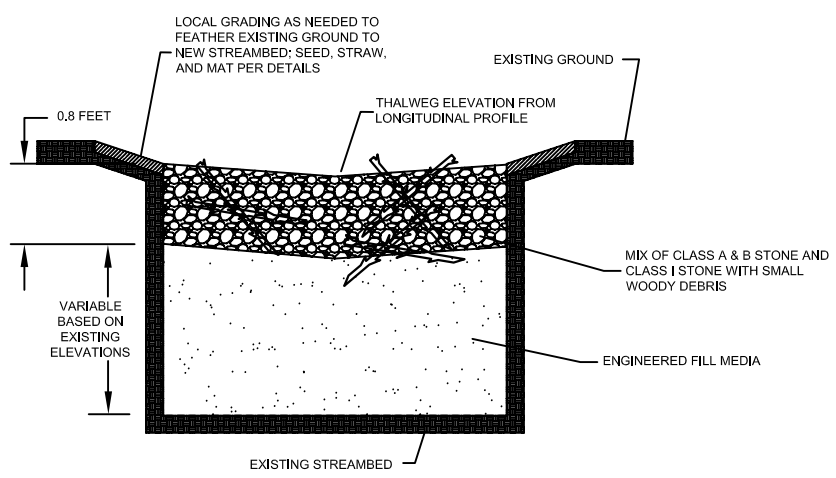
SILT FENCE DETAIL



NOTES
USE WIRE A MINIMUM OF 32" IN WIDTH AND WITH A MINIMUM OF 6 LINE WIRES WITH 12" STAY SPACING.
USE FILTER FABRIC A MINIMUM OF 36" IN WIDTH AND FASTEN ADEQUATELY TO THE WIRE AS DIRECTED BY THE ENGINEER.
PROVIDE 5'-0" STEEL POST OF THE SELF-FASTENER ANGLE STEEL TYPE. ANGLE STEEL TYPE.

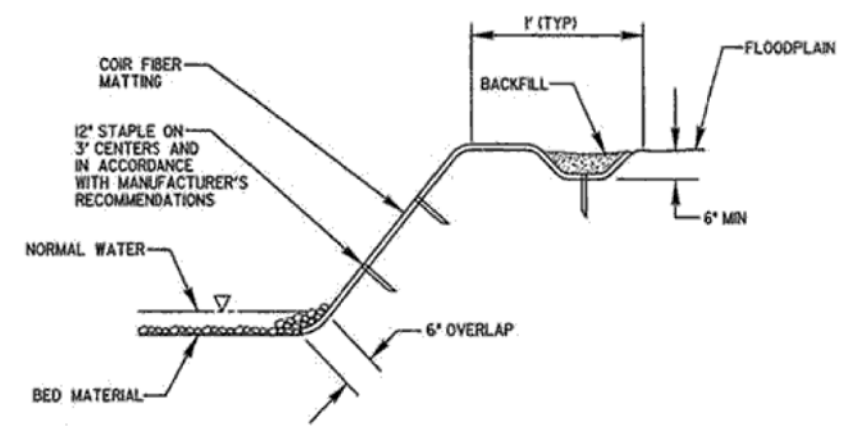


TYPICAL CROSS-SECTION TO RAISE CHANNEL BED



NOTES:
1. ENGINEERED FILL MEDIA SHALL CONSIST OF 80% SAND AND 20% FINE WOOD CHIPS, BY VOLUME..
2. SAND SHALL BE COARSE WASHED SAND, RIVER SAND, OR SIMILAR MATERIAL APPROVED BY ENGINEER.
3. SAND SHALL NOT ORIGINATE FROM A LOCATION LIKELY TO RESULT IN CONTAMINATION BY EXCESS NUTRIENTS, PETROLEUM PRODUCTS, OR OTHER CHEMICALS. SOIL TESTING AND/OR DOCUMENTATION OF ORIGINATION MAY BE REQUESTED AT THE DISCRETION OF THE ENGINEER.
4. MATERIAL AND SIZE OF FINE WOOD CHIPS TO BE APPROVED BY ENGINEER PRIOR TO PLACEMENT, AND MAY INCLUDE PINE BARK FINES.
5. FILL MEDIA SHALL BE WELL-MIXED PRIOR TO PLACEMENT IN STREAM.
6. SMALL WOODY DEBRIS SHALL BE DERIVED FROM ONSITE MATERIAL WITH DIAMETER <4".
8. SMALL WOODY DEBRIS SHALL NOT PROTRUDE ABOVE FINISHED STREAMBED BY >6".
9. NATIVE ON SITE BED MATERIAL CAN BE USED IF APPROVED BY ENGINEER PRIOR TO PLACEMENT
10. ALL DISTURBED STREAMBANKS SHALL BE REGRADED TO A 2:1 SLOPE OR FLATTER, UNLESS SUCH GRADING WOULD ADVERSELY AFFECT EXISTING STREAMSIDE VEGETATION.
11. SEE PROPOSED CROSS SECTION SHEET FOR CROSS SECTION DIMENSIONS.

MATTING DETAIL



COIR FIBER MATTING SECTION
NOT TO SCALE

NOTES:
1. All exposed stream banks shall be matted from toe of slope to top of bank.
2. Banks shall be matted the same day as final graded.
3. Wood stakes shall be used in place of wire staples.
4. 2-foot oak stakes shall be used at the toe and upstream edge of matting.
5. Use medium weight (700g/m^2) woven coir matting
6. No plastic netting shall be used on this project.

1	INITIAL DESIGN	ZP	GJ	01/16/12
NO	REVISIONS	DRN	CHK	DATE

NC STATE UNIVERSITY

BIOLOGICAL & AGRICULTURAL ENGINEERING
Weaver Labs Campus Box 7625
North Carolina State University
Raleigh, NC 27695

TRINITY COURT STREAM STABILIZATION
CHAPEL HILL, NC

DETAIL SHEET 1

DATE	1/16/12
PROJECT NO.	
FILENAME	FILE.DWG
SHEET NO.	6
DRAWING NO.	

SEEDING AND MULCHING NOTES

NOTES:
1. ALL DISTURBED AREAS SHALL BE SEEDED AND MULCHED AS PER NCDENR DLR LAND QUALITY REQUIREMENTS.
2. ALL DISTURBED AREAS SHALL BE PLANTED OR OTHERWISE PROVIDE PERMANENT GROUND COVER SUFFICIENT TO RESTRAIN EROSION WITH 15 WORKING DAYS OR 60 CALENDAR DAYS, WHICHEVER PERIOD IS SHORTER, FOLLOWING COMPLETION OF CONSTRUCTION.
3. ALL DISTURBED AREAS SHALL BE STABILIZED WITH VEGETATION OR OTHERWISE PROVIDED WITH GROUND COVER SUFFICIENT TO RESTRAIN EROSION WITHIN 21 CALENDAR DAYS OF COMPLETION OF ANY PHASE OF GRADING.
4. MULCH SHOULD BE APPLIED AT THE RATE OF 1 to 2 TONS PER ACRE AND TACKED WITH HYDRAULICALLY APPLIED MULCH WHEN INSTALLED.
5. TEMPORARY AND PERMANENT SEED SHALL BE APPLIED TOGETHER.
6. IRRIGATION MAY BE REQUIRED AT THE DESCRETION OF THE ENGINEER.
7. THE CONTRACTOR IS RESPONSIBLE TO FOLLOWING ALL RULES OF THE NCDENR DLR LAND QUALITY SECTION AS OUTLINED IN THE EROSION AND SEDIMENT CONTROL PLANNING AND DESIGN MANUAL.
8. ALL EROSION CONTROL DEVICES SHALL BE INSPECTED AT THE BEGINNING AND END OF EACH WORK DAY. THE CONTRACTOR AND DESIGNER SHALL CONDUCT THE INSPECTION JOINTLY.

TEMPORARY AND PERMANENT SEEDING SPECIFICATION

NON RIPARIAN AREAS

TEMPORARY AND PERMANENT SEED MIX

Rye Grain (Dec-Feb)	60 lbs/ ac
Red Clover *Trifolium pratense*	10 lbs / acre
Creeping Red Fescue *Festuca rubra*	20 lbs / acre

SOURCE: NC DIVISION OF WILDLIFE RESOURCES: SEED MIXES FOR REVEGETATING DISTURBED SITES

RIPARIAN AREAS

TEMPORARY SEED MIX

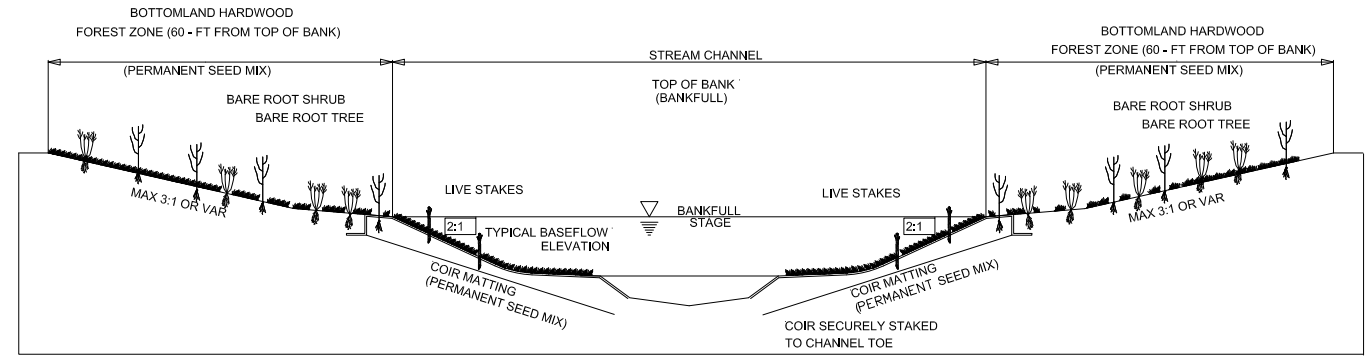
Rye Grain	30lbs/ acre
Wheet	30 lbs / acre

RIPARIAN AREAS
PERMANENT SEED MIX

AT LEAST 4 SPECIES FROM THE LIST BELOW, INCLUDING ONE SPECIES FROM EACH TYPE (WARM SEASON, COOL SEASON, WETLAND) AT A RATE OF 12-15 LBS/ACRE

Common Name	Type
Switchgrass	Warm Season
Indiangrass	Warm Season
Deertongue	Warm Season
Big Bluestem	Warm Season
Little Bluestem	Warm Season
Sweet Woodreed	Warm Season
Indian Woodoats	Cold Season
Viriginia Wildrye	Cold Season
Eastern Bottle-Brush Grass	Cold Season
Soft Rush	Wetland
Shallow Sedge	Wetland
Fox Sedge	Wetland

RIPARIAN VEGETATION ZONE DETAIL (OUTSIDE OF THE OWASA EASEMENT)
SCALE: NTS



BOTTOMLAND FOREST ZONE PLANTING
Plant Spacing: 8 ft
Bare Root Species List:

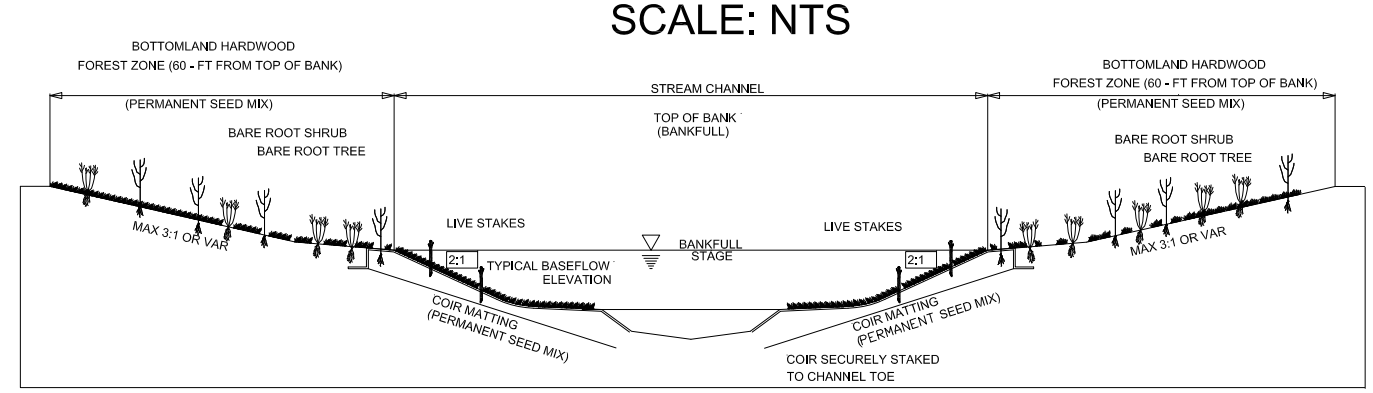
Cornus amomum (silky dogwood)
Physocarpus opulifolius (ninebark)
Sambucus Canadensis (American elderberry)
Hamamelis virginiana (witchhazel)
Lindera benzoin (spicebush)
Fraxinus pennsylvanica (green ash)
Betula nigra (river birch)
Aesculus sylvatica (painted buckeye) - transplants from on site

STREAM CHANNEL BANK ZONE PLANTING
Plant Spacing: 3 ft

Polystichum acrostichoides (christmas fern)

Live Stake Species List (potential for winter 2012/2013):
Cornus amomum (silky dogwood)
Physocarpus opulifolius (ninebark)

RIPARIAN VEGETATION ZONE DETAIL (WITHIN THE OF THE OWASA EASEMENT)
SCALE: NTS



NOTE: No trees or shrubs shall be planted within the main travel-way of the easement (approx 15-ft wide over the sewer main), only planted/replanted to the limit of where trees/shrubs are currently growing.

BOTTOMLAND FOREST ZONE PLANTING
Plant Spacing: 8 ft
Bare Root Species List:

Cornus amomum (silky dogwood)
Physocarpus opulifolius (ninebark)
Sambucus Canadensis (American elderberry)
Hamamelis virginiana (witchhazel)
Lindera benzoin (spicebush)
Aesculus sylvatica (painted buckeye) - transplants from on site

STREAM CHANNEL BANK ZONE PLANTING
Plant Spacing: 3 ft

Polystichum acrostichoides (christmas fern)

NO	REVISIONS	DRN	CHK	DATE
1	INITIAL DESIGN	ZP	GJ	01/16/12

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TRINITY COURT STREAM STABILIZATION
CHAPEL HILL, NC

DETAIL SHEET 2

DATE 1/16/12
PROJECT NO.
FILENAME FILE.DWG
SHEET NO. 7
DRAWING NO.

The stream at Trinity Court, showing the steep, eroded banks

More bank erosion, and one of three old bridges that were removed

A series of step-pools was installed

Close up of the large blocks arranged for the “step” in the step-pool structure

The area behind each step-pool is filled in with sand and wood chips over fabric, covered by heavier gravel and rocks

Looking down the 10% grade after the rocks are laid

Coir matting is laid for erosion control, the OWASA easement has new gravel to protect it from heavy foot and vehicle traffic, and flags are set out for plants

Further downstream after the ferns are planted

One of 100 Christmas ferns planted for bank erosion control

The bottom end of the reach near the confluence with Bolin Creek

A step-pool after grass has started growing

One of the witch-hazels planted along the stream

Bolin Creek Watershed Restoration Project
Trinity Court—Chapel Hill's Umstead Park

▲ (Before) **SEVERE CHANNEL EROSION** created large cuts in the streambed and bank, which would only get worse without stabilization. Sediment washed into Bolin Creek.

Location: South side of Chapel Hill's Umstead Park, between Trinity Court Public Housing and Bolin Creek

Project Description: Federal and State grant funding paid for restoration design, construction, materials, and plants in the 300' project to repair and stabilize an intermittent tributary to Bolin Creek.

Partner: NC State University Stream Restoration Program

Date of Completion: April 2012

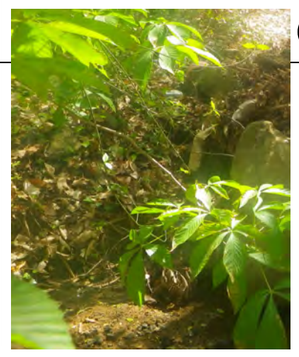
▲(After) **BANK RESHAPING AND STABILIZATION** angles the banks to allow floodwater to flow out of the channel and spread out, reducing water's destructive energy during high flows. This prevents further erosion of the banks. This bank has been reshaped, covered with fiber matting, and planted with shrubs and ferns.

▲ A finished "step" with "pools" above and below.

(After) **ROCK STEP-POOLS** absorb the energy of high flows and reduce erosion on the streambed and banks. Step-pools are comprised of large rock "steps" with small rock and gravel "pools" between them. Above are shown two of several steps installed along the stream's length. ►

▼In addition, the sewer easement was graded to drain more runoff into the floodplain area on its other side. A wider gravel path allows easy access for both the utility and park visitors.

NATIVE SHRUBS AND FERNS were planted to stabilize the streambank along the OWASA easement. To prevent sewage line leaks and breaks, OWASA prohibits trees and large shrubs to grow in their easements. This project used smaller shrubs and ferns to create a shallow network of roots to help stabilize stream banks and prevent erosion. Existing buckeye trees were rescued during construction and transplanted.



TRASH CLEANUPS beautified the area and prevented litter and household garbage from entering Bolin Creek. Anti-litter education will continue.