# *Stream Restoration Plan*

## Third Fork Creek in Forest Hills Park
## Durham, North Carolina

N.C. Wetlands Restoration Program
NCDENR

**February 2003**

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# EXECUTIVE SUMMARY

The North Carolina Wetlands Restoration Program (WRP) intends to restore a degraded section of Third Fork Creek located within Forest Hills Park in Durham, North Carolina. The project reach is approximately 2,900 linear feet. It is located in the headwaters of the Third Fork Creek watershed (US Geological Survey 14-digit Hydrologic Unit Code 03030002060120) within the New Hope Creek Sub-basin of the Upper Cape Fear River (NC Division of Water Quality Sub-basin 03-06-05).

The project site is an urban park dominated by open space, with structures and facilities located in close proximity to the stream. The surrounding area is highly urbanized, with residential and commercial development and secondary roads comprising the majority of the land use. The project reach is incised with active bed degradation and channel widening characterized by severe bank erosion.

The goals and objectives of the Third Fork Creek Stream Restoration Project are to:

- Restore stable channel morphology that is capable of moving the flows and sediment provided by its watershed;
- Reduce sediment-related water quality impacts resulting from lateral bank erosion and bed degradation;
- Improve aquatic habitat diversity through the reestablishment of riffle-pool bed variability and the use of in-stream structures;
- Restore vegetative riparian buffers utilizing native plant species; and,
- Improve natural aesthetics in an urban park setting.

The proposed stream dimension, pattern, and profile will be based on the detailed morphological criteria and hydraulic geometry relationships developed from a reference reach – a stable portion of North Prong Creek, a second order urban stream also located in Durham. The reference reach is located in the same hydrophysiographic province and a similar watershed position as the project stream. The reference also has similar land use, valley slope, and sediment distribution as the project site.

The restoration design is based on a Priority Level 2 approach that will reestablish approximately 3,025 linear feet of meandering, bankfull channel and a new floodplain at the stream's existing level to provide stable flow maintenance and sediment transport. The design bankfull stage will equal the new floodplain elevation. The design stream profile will restore stable bed morphology including appropriate riffle-pool sequencing. Cross-Vane and J-Hook Vane (J-Vane) instream structures have been integrated in the design to provide grade control, assist in stabilizing the banks and reduce the burden of energy dissipation on the channel geometry. Coir fiber matting will be used to provide temporary stabilization on the newly graded streambanks. The confluence of a tributary within the project reach will be incorporated and stabilized with a grade control structure to match the proposed grade of the restored main channel. Excavated materials from the design channel will be used to backfill the abandoned portions of the existing channel.

Native woody and herbaceous species will be used to establish fifty (50) foot wide riparian buffers on both sides of the restored reach. Park utilization space requirements dictate that the riparian buffers consist of a thirty (30) foot wide fully forested buffer adjacent to the stream bordered by a twenty (20) foot wide strip of managed native grasses. Live staking with appropriate native species will also be used along the streambanks to provide natural stabilization.

Monitoring shall consist of the collection and analysis of stream stability and riparian/stream bank vegetation survivability data to assist in the evaluation of the project in meeting established restoration objectives. Specifically, the success of channel modification, erosion control and re-vegetation parameters will be assessed using measurements of stream dimension, pattern, and profile, site photographs, and vegetation sampling.

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# 1.0 INTRODUCTION

## 1.1 Project Description

The North Carolina Wetlands Restoration Program (WRP) intends to restore a degraded section of Third Fork Creek located within Forest Hills Park in Durham, North Carolina. This Plan presents detailed information regarding the existing site and watershed conditions, the morphological design criteria developed from a selected reference reach, and the project design parameters based upon natural channel restoration methodologies.

## 1.2 Project Goals and Objectives

The goals and objectives of the Third Fork Creek Stream Restoration Project are to:

- Restore stable channel morphology that is capable of moving the flows and sediment provided by its watershed;
- Reduce sediment-related water quality impacts resulting from lateral bank erosion and bed degradation;
- Improve aquatic habitat diversity through the reestablishment of riffle-pool bed variability and the use of in-stream structures;
- Restore vegetative riparian buffers utilizing native plant species; and,
- Improve natural aesthetics in an urban park setting.

# 2.0 PROJECT SITE LOCATION

## 2.1 General Description

Third Fork Creek is located within the City of Durham, North Carolina (Durham County) (Figure 1: Vicinity Map). Third Fork Creek is a second-order stream that flows in a southerly direction joining New Hope Creek, which eventually drains into the B. Everett Jordan Reservoir (Jordan Lake), a major area water supply and recreational resource.

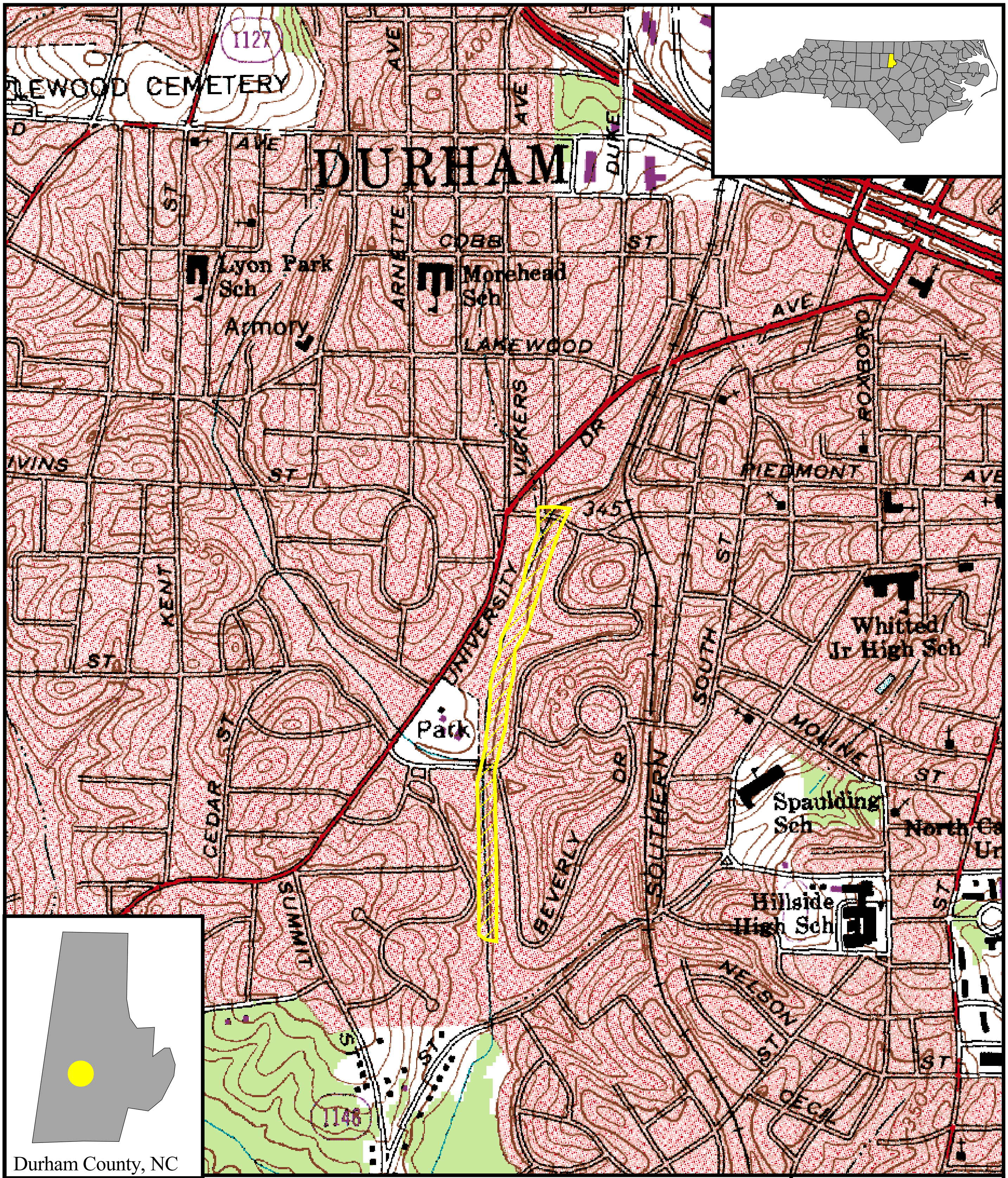
The entire restoration site is contained within Forest Hills Park on property owned by the City of Durham. The project reach totals approximately 2,900 linear feet and extends in a north-south orientation from East Forest Hills Boulevard (near the intersection with University Drive) downstream to the Park property boundary, located upstream of South Roxboro Street (Figure 2: Location Map).

## 2.2 USGS and NCDWQ River Basin Designations

The project reach is located in the headwaters of the Third Fork Creek watershed (US Geological Survey 14-digit Hydrologic Unit Code 03030002060120) within the New Hope Creek Sub-basin of the Upper Cape Fear River (NC Division of Water Quality Sub-basin 03-06-05).

## 2.3 NCDWQ Surface Water Classification

The NCDWQ assigns surface waters a classification in order to help protect, maintain, and preserve water quality. The section of Third Fork Creek containing the project reach (NCDWQ Stream Index Number 16-41-1-12-(1)) is designated as a Class C water body (NCDENR, 2002). Class C is a baseline water quality classification, intended to protect water resources for fishing, wildlife, fish and aquatic life propagation and survival, agriculture, and secondary recreation. There are no restrictions associated with Class C waters regarding watershed development or types of discharges. However, the subject section of Third Fork Creek




# Figure 1. Vicinity Map

Project Reach

N

700 0 700 Feet

*Source: USGS 7.5' Southwest Durham Topographic Quadrangle*

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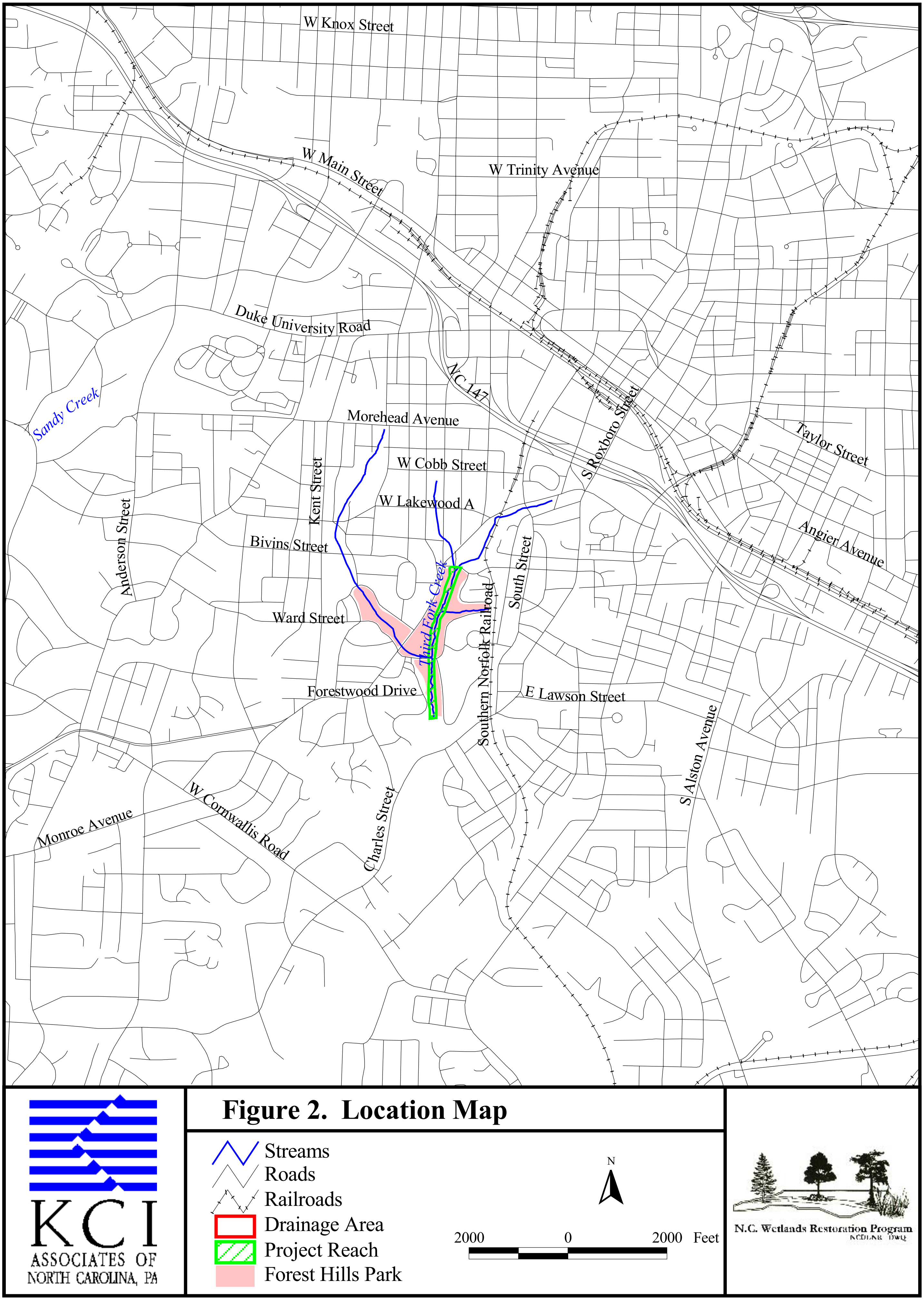


**Figure 2. Location Map**

also carries the supplemental classification as Nutrient Sensitive Waters (NSW), which requires limitations on nutrient inputs. Third Fork Creek has a designated use support rating of NR (Not Rated) due to inappropriate or incomplete data.

Further, the NCDWQ includes this section of Third Fork Creek as an impaired stream on the North Carolina Draft 2002 Impaired Waters List (303(d) list). This section of Third Fork Creek is assigned a Low Priority within Category 6 (biologically impaired waters). Results from future pollution/pollutant monitoring may place Category 6 waters within either Category 4c (waters impaired by pollution, not by a pollutant, and therefore don't require TMDLs) or Category 5 (waters impaired by a pollutant, for which TMDLs are required).

# 3.0 WATERSHED CHARACTERIZATION

## 3.1 General Description

The project site is located in an urban setting within the Piedmont Physiographic Province. Topography is characterized by gently rolling hills with elevations in the contributing drainage area ranging from 410 feet above mean sea level (AMSL) to 290 feet AMSL with a relative relief of 120 feet. The historic dendritic drainage patterns of the watershed have been substantially replaced by curb and gutter stormwater drainage systems. Likewise, the normally broad alluvial valleys have been narrowed due to the encroachment of residential and commercial development and associated transportation systems.

## 3.2 Drainage Area

The total drainage area for the project reach is 1.76 $mi^2$ (Figure 3: Watershed). The contributing area at the upstream project limits is 0.8 $mi^2$. Two intermittent tributaries add an additional 0.12 and 0.56 $mi^2$, respectively, of drainage area to the project reach. Prior to reaching the downstream limits, an additional 0.28 $mi^2$ of area drains to the project reach.

## 3.3 Land Use and Development Potential

An Anderson Level I (Modified) classification indicates that the contributing watershed is dominated by urban-high (56%), urban-low (29%), and forest (10%) land use/land cover; with the remaining 5% divided between open space/park, scrub/shrub, and water (Figure 4: Land Use/Land Cover). Approximately 44% of the watershed is impervious. Historical trends and current observations indicate that the watershed is fully developed and the potential for further build-out is low.

## 3.4 Significant Cultural and Natural Resources

### 3.4.1 Historical Resources

A review of available records at the North Carolina Department of Cultural Resources – State Historic Preservation Office (SHPO) indicates that the project site lies within the proposed Forest Hills Historic District (Figure 5: Proposed Forest Hills Historic District). During initial coordination, SHPO Environmental Review Coordinator Ms. Renee Gledhill-Early stipulated that a review of the Project Restoration Plan would be necessary in order for SHPO to provide a final effect determination.

### 3.4.2 Archaeological Resources

A review of available records at and initial coordination with the State Office of Archaeology indicates that no archaeological sites are recorded within the project vicinity and no archeology survey is recommended.

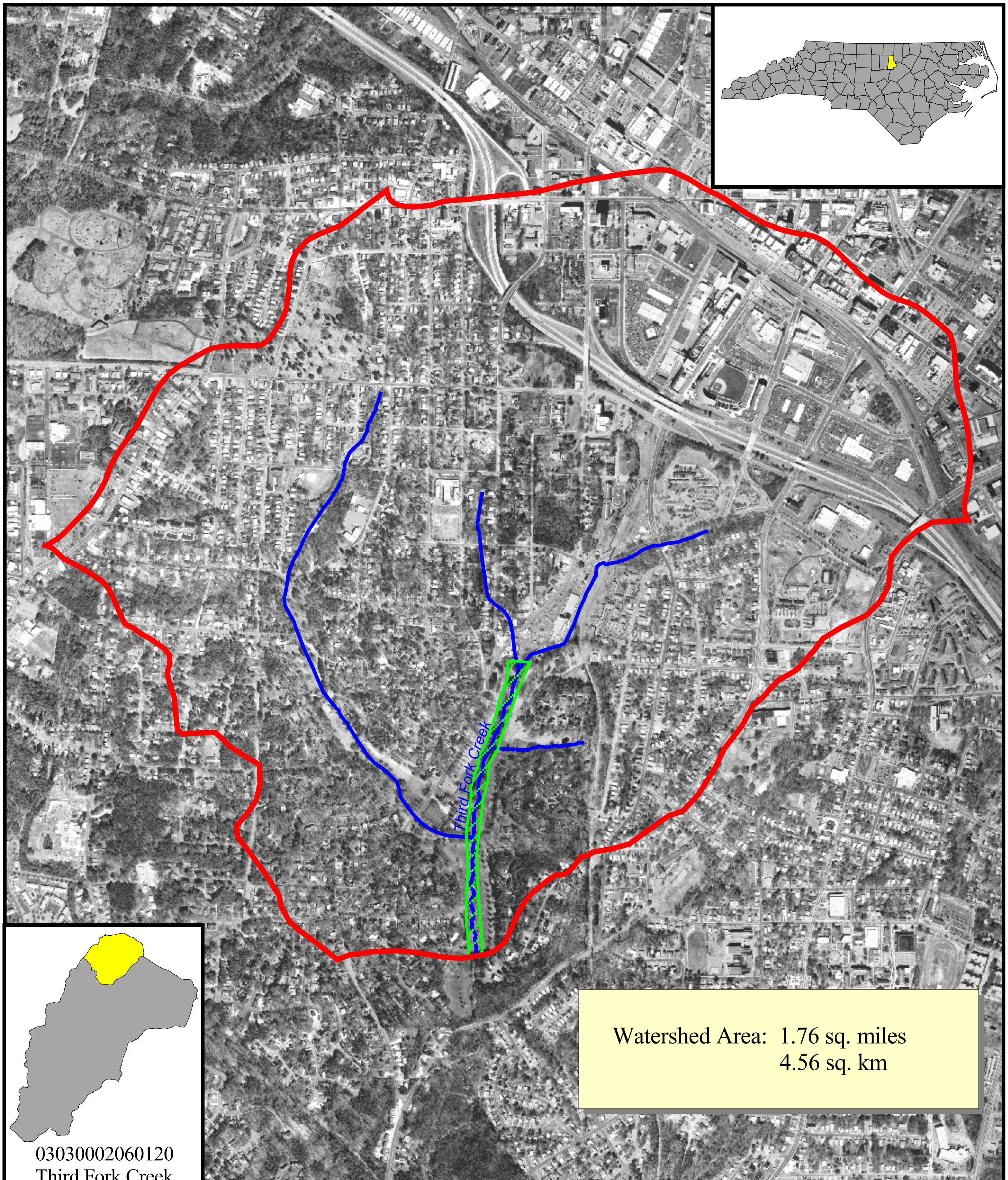


**Figure 3. Watershed Boundary**

Streams
Drainage Area
Project Reach

N

2000 0 2000 Feet

*Source: 1999 Digital Orthophotographs, Durham County*

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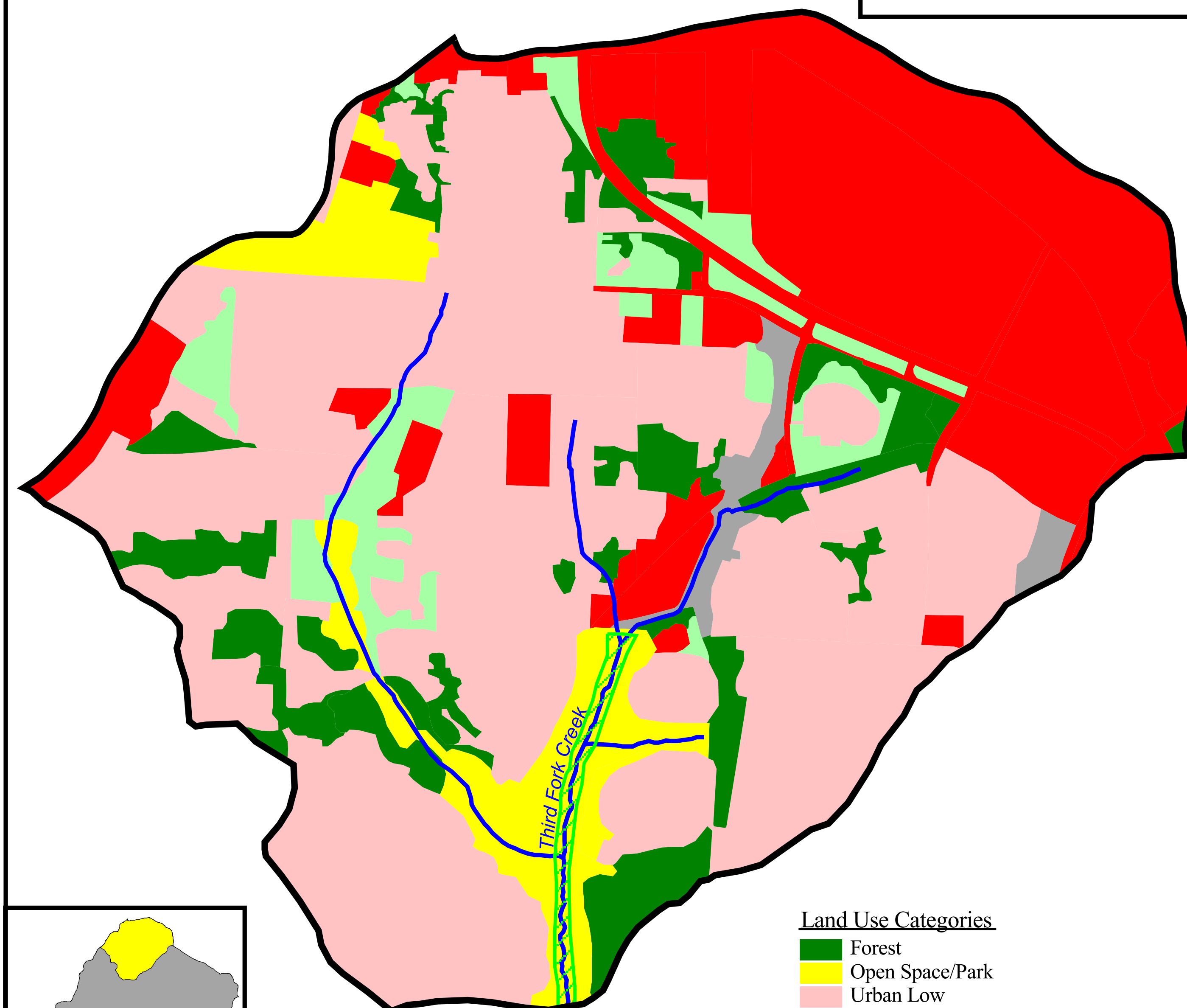


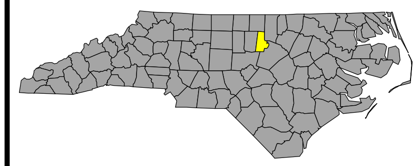

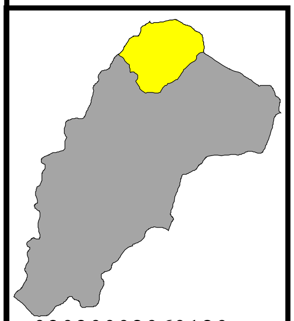


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**Figure 4. 1999 Land Use/Land Cover**

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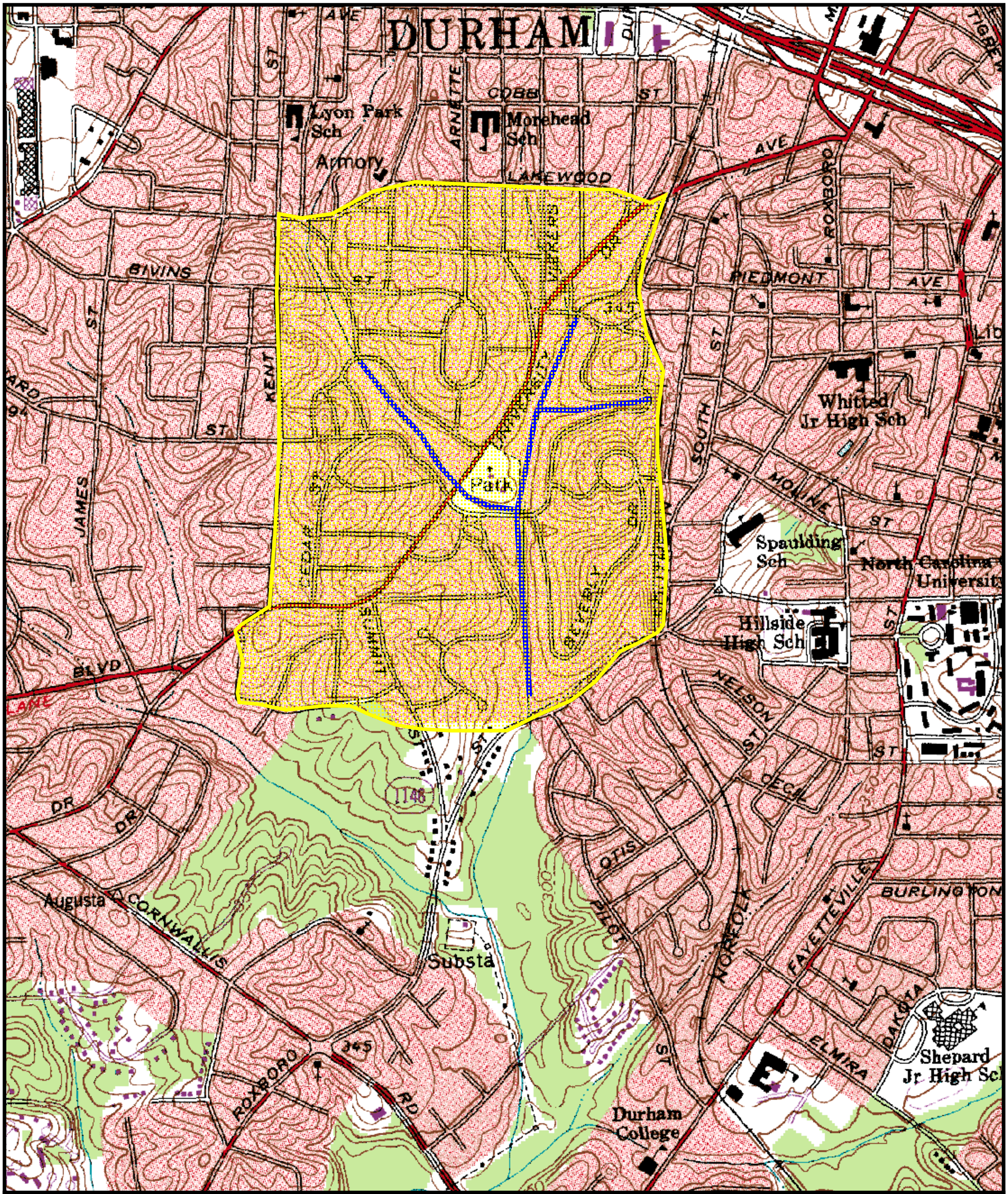


## Figure 5. Proposed Historic District

Proposed Historic District Location
Stream Reach

N

500 0 500 1000 Feet

Source: USGS 7.5' Southwest Durham Topographic Quadrangle

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#### 3.4.3 Rare/Threatened/Endangered Species and Critical Habitats

A review of available North Carolina Natural Heritage Program (NHP) databases was conducted online to identify all known occurrences by both USGS Quadrangle and by County. The physical file review at the NHP office followed and documented known occurrences within the project vicinity. The database reviews indicated that in June 1996 the Cooper's Hawk (*Accipiter cooperii*) was twice observed in Forest Hills Park. Cooper's Hawk is listed as a State Species of Special Concern. During coordination following the database review, NHP Review Coordinator Mr. Harry LeGrand stated that the Cooper's Hawk has been moved to the watch list and that no further review of the proposed restoration project would be required.

## 4.0 PROJECT SITE EXISTING CONDITIONS SURVEY

### 4.1 General Site Description

The project site is an urban park surrounded by residential properties and secondary roads (Figure 6: Site Aerial). The majority of the project site is dominated by open space of mowed grass, with limited large woody vegetation confined solely to areas immediately along the existing streams and roads. Various park structures and facilities, including a large picnic shelter, playground, pool, and park/police administrative building, are located near the project midpoint. Two pedestrian bridges span the project reach.

The project reach consists of 2,900 linear feet of stream beginning at East Forest Hills Boulevard in the north and flowing south to near the subject property boundary. The project reach was subdivided into two sections due to the controlling influence of a culverted road crossing (East Forest Hills Boulevard) and the confluence of a tributary that significantly increases the contributing drainage area. The tributary joins the project reach via the culvert that is part of the second East Forest Hills Boulevard road crossing located midway through the project. The floodplain of Third Fork Creek within the project site varies in width from approximately 100 feet to greater than 400 feet. Photographs of representative site conditions are provided in Appendix A.

### 4.2 Geology and Soils

The project site is located in the Chatham Group, Sanford-Durham Sub-basin of the Triassic Basin. In the project vicinity, this geologic formation is characterized by medium to very coarse-grained, arkosic sandstone.

According to the Soil Survey of Durham County (NRCS, 1971), predominant soil types found within the project watershed include White Store sandy loam, White Store-Urban land complex, Mayodan sandy loam, Mayodan-Urban land complex, Cartecay and Chewacla soils, Congaree and Urban land (Figure 7: Soil Map).

Soils at the project site are mapped as Congaree silt loam (Cp). These well-drained soils generally occur in narrow bands on nearly level slopes (0-2%) parallel to streams where channels are deep enough to provide good drainage. They were formed in fine loamy material washed from soils on uplands. Congaree soils are frequently flooded for very brief periods, have moderate permeability, and low shrink-swell potential. The seasonal high water table can be as shallow as 2.5 feet. In a typical profile, the surface layer is silt loam approximately 9 inches thick with underlying material to a depth of 52 inches that is friable silt loam stratified with thin lenses of fine sandy loam. Below this, to a depth of about 65 inches is silty clay loam. Congaree soils are classified in the B hydrologic soil group.

If destabilized, the low cohesive strength of these soils makes them highly vulnerable to active erosional processes such as slab and rotational failure due to basal cleanout, especially in the absence of adequate streambank vegetation.

# Figure 6. Site Aerial

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Trees
Roads
Topography
Sanitary Sewer
Storm Drain
Bridges and Walls
Pipe Outfall
Manhole

N

*Source: 1999 Digital Orthophotographs, Durham County*

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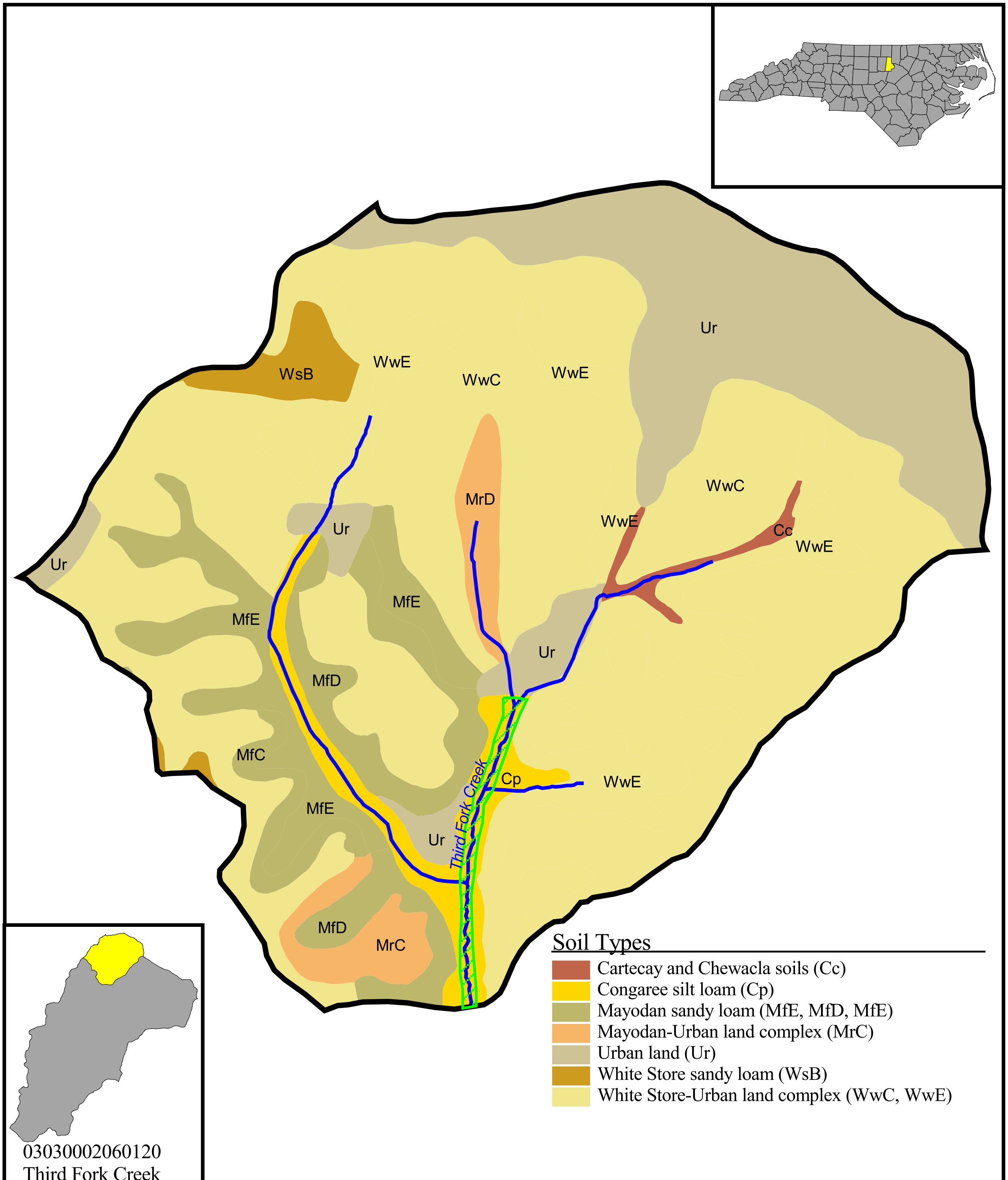


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**Figure 7. Soils**



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## 4.3 Existing Riparian Buffer and Natural Communities

The project site is an urban park dominated by mowed grass fields with minimal large woody vegetation. No natural communities meeting categories established within the "Classification of the Natural Communities of North Carolina" (Schafale and Weakley, 1990) exist within the project area. However, large individual trees exist immediately adjacent to streams and roads. These individual trees were recognized as significant and documented in order to facilitate their incorporation into the proposed restoration design.

## 4.4 Existing Stream Characteristics

### *4.4.1 Morphological Description*

A Rosgen Level II assessment was conducted in July and August 2002 to gather existing stream dimension, pattern, and profile data (i.e., width, depth, cross-sectional area, slope, radius of curvature, belt width, meander length), develop morphological parameters (i.e., W/D ratio, entrenchment ratio, radius of curvature to bankfull width ratio, sinuosity), and determine the potential for restoration. The project reach is subdivided into two sections due to the controlling influence of a culverted road crossing and the confluence of a tributary that significantly increases the contributing drainage area. Data developed from this assessment are summarized below and detailed data records are presented in Appendix A.

**Table 1. Existing Channel Morphology by Sub-Reach.**

| ***Parameter*** | **Upper Reach** | **Lower Reach** |
|---|---|---|
| Drainage Area ($mi^2$) | 0.8 - 1.1 | 1.76 |
| Bankfull Width (ft) | 21.8 - 26.8 | 29.5 |
| Mean Bankfull Depth (ft) | 1.7 - 2.6 | 2.4 |
| Width / Depth Ratio | 8.3 - 15.9 | 12.2 |
| Bankfull Area ($ft^2$) | 45.1 - 57.2 | 71.4 |
| Entrenchment Ratio | 1.1 - 18.3 | 6.8 |
| Bank Height Ratio | 1.55 - 2.57 | 1.27 |
| Local W. S. Slope (ft/ft) (%) | 0.25 | 0.20 |
| Sinuosity (K) | 1.03 | 1.01 |
| Discharge (cfs) | 268 | 322 |
| $D_{50}$ (mm) | 0.31 | 0.41 |
| Rosgen Stream Type | F5, G5, E5 | C5 |

Additionally, sections of the two tributaries within the project area were assessed and characterized in order to facilitate discharge estimation and stable confluence design.

### *4.4.2 Channel Evolution Stage*

Stream instability in an urban environment is often a result of direct and indirect human-induced disturbances such as channelization, riparian and bank vegetation removal, floodplain encroachment, stream crossing installation, and watershed development. Conceptual channel evolution models are used to describe the sequential changes a stream undergoes after disturbance and predict its most probable stable endpoint (stream type). The Simon Channel Evolution Model (Simon, 1989) was utilized to evaluate the project stream's current stage of adjustment and assist in developing an appropriate restoration approach.

Based upon measurements and observations recorded during the field investigation, sections of the project reach are in varying stages of evolution toward a stable state. The upstream section of the project reach, between two East Forest Hills Boulevard road crossings (Sta. 10+00 to 30+00), is in Stage IV/V where degradation/incision has largely ended. Active bank erosion in outside meander bends is evident as the stream continues to widen in an effort to establish necessary belt width. Evidence of aggradation (Stage V) is also observable in areas through the deposition of alternating bars and the redevelopment of a meandering planform.

The downstream section (Sta. 30+00 to 40+25) extending from the midpoint East Forest Hills Boulevard road crossing, including the culverted confluence of Tributary 2, to the project endpoint is primarily in Stage V where aggradation is predominant. However, bank erosion can be observed where the stream continues to establish necessary belt-width. Limited portions of this section have reached Stage VI – Restabilization, as evidenced by the development of a new floodplain (bankfull) bench with establishing woody vegetation.

Without intervention, it is likely that the evolutionary process will continue until the stream establishes the belt width, cross-sectional area and floodplain necessary to maintain a stable dimension, pattern and profile. However, this will only occur over time while the stream and site continue to experience degraded conditions including continued erosion, water quality and habitat impairment, and the loss of valuable trees.

*4.4.3 Stability Assessment*

The current “stream state or condition” (Rosgen, 1996) was further analyzed using Rosgen Level III methodologies to assess stability through an examination of such parameters such as channel dimension ($W/D_{site}$ compared with $W/D_{reference}$), vertical stability (Bank Height Ratio), lateral stability (Bank Erosion Hazard Index (BEHI)), and sediment supply/transport.

In the upper portion of the project reach (Sta. 10+00 to 30+00), comparisons of the existing width-to-depth ratio values to the reference reach width-to-depth ratio values vary greatly (0.67 – 1.27). Additionally, bank height ratios in this section ranged from 1.55 to 2.71. Bank Erosion Hazard Index (BEHI) scores ranged from 32 to 34 indicating a high potential for continued bank erosion and channel widening in the upper project reach. Sediment supply is high from severely eroding banks. Collectively, these factors indicate both vertical and lateral instability through channel incision and widening, respectively, in this portion of the project reach.

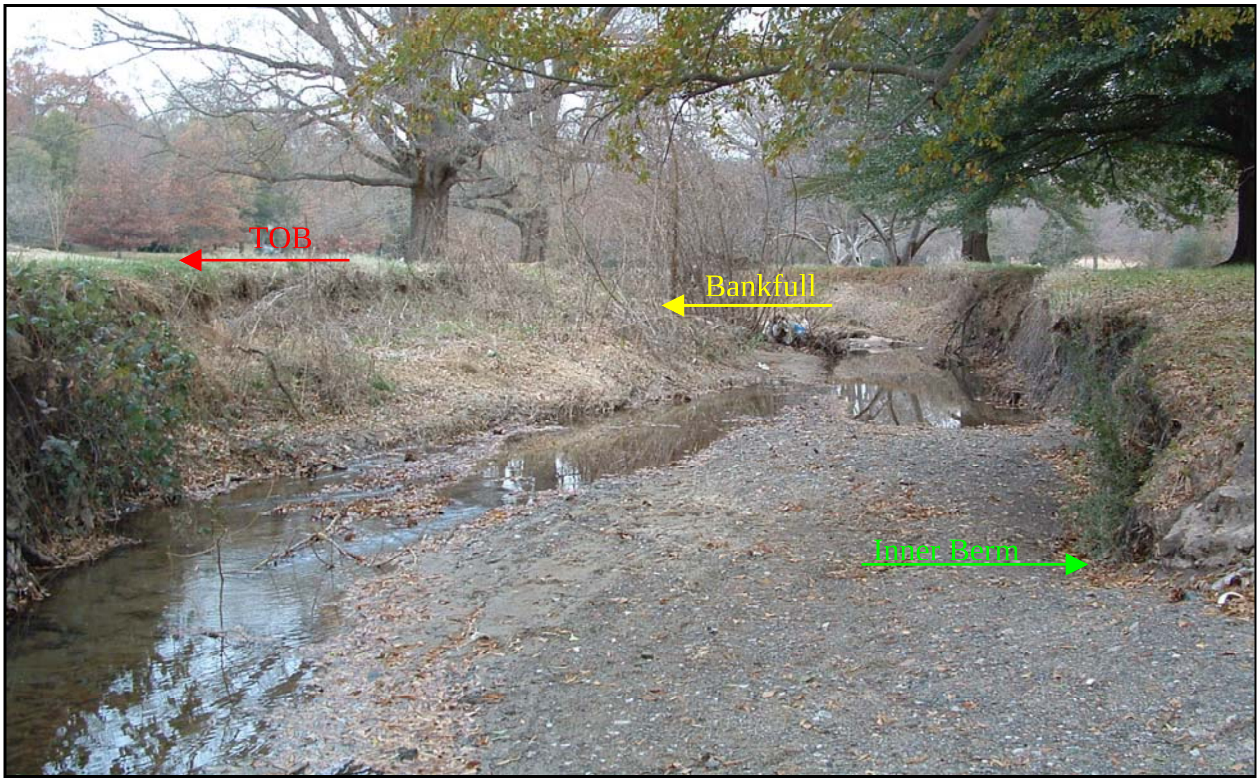
Conversely, stability assessments suggest that the channel the lower portion of the project reach (Sta. 30+00 to 40+25) has progressed farther towards reestablishing a stable form. Width-to-depth ratio comparisons produce values ranging from 0.79 to 0.95, as well as bank height ratios ranging from 0.87 to 1.24, indicate that no significant down cutting is occurring. The channel continues to widen in an effort to establish sufficient cross-sectional area. BEHI scores for the section range from 28 and 30, indicating moderate potential for continued bank erosion, as compared to high values in the upper reach. Overall bank erosion is less frequent in this section, primarily limited to outside meander bends. The formation of new floodplain benches shows that the channel is beginning to recover.

*4.4.4 Bankfull Verification*

The accepted methodology for natural channel design is based on the ability to select the appropriate bankfull discharge and generate the corresponding bankfull hydraulic geometry from a stable reference reach. Thus, the determination of bankfull stage is the most critical component of the natural channel design process.

Observable bankfull stage indicators in North Carolina include the incipient point of flooding (top of bank), upper breaks in bank slope, the back of the highest depositional feature (i.e. point bars and benches), and the highest scour line. At the project reach, the most consistent field indicator of bankfull stage proved to be the highest depositional feature – the back edge of the stable benches. Photographs of typical bankfull indicators and related morphological features at the project site are provided below (Figure 8: Bankfull Indicators).

**Figure 8. Representative Bankfull Indicator Photos**




Typical bankfull indicators in upstream section.


Typical bankfull indicators in downstream project area.

The identification of bankfull stage can be problematic, especially in a degraded urban system. Therefore, verification measures must be taken to ensure the accurate identification of the bankfull stage. The field indicated bankfull stage was verified using a combination of tools and data, including: HEC-RAS, Regional hydraulic geometry relationships (regional curves), Log Pearson Type III Flood Frequency analysis of gauged urban streams in the Piedmont (7 sites with 10+ years of record), and project site surface water level data recorded over a three-month period using two pressure transducer/data logger gauges.

Stream stage data (water levels) documented for the two gauges were correlated to an estimated discharge using a rating curve generated for the corresponding cross-sections. These flows were subsequently compared to HEC-RAS outputs and cross-referenced with hydraulic geometry regional curve data and corresponding equations developed for urban streams in the Piedmont of North Carolina (Doll et al, 2002). The bankfull discharges and cross-sectional areas for the project reach were consistent with both the discharge and cross-sectional area regressed power function lines from the regional curve; plotting within the 95% confidence limits (Figures 9A-B: Regional Curves).

The verification procedures indicate that the bankfull discharges and cross-sectional areas identified in the field are valid and that in Third Fork Creek the flood frequency curve has clearly shifted left with bankfull discharge occurring on a more frequent basis than that typically experienced in less developed watersheds.

### 4.5 Constraints

The following are documented constraints that were considered in the development of the restoration strategy for Third Fork Creek within Forest Hills Park:

- FEMA Detailed Flood Study Area.
- Stakeholder mandate to preserve large trees along existing stream corridor.
- Park infrastructure and space utilization requirements constraining channel adjustment/relocation in specified areas.
- Presence of a subsurface sanitary sewer line that runs parallel and adjacent to the west bank of project reach for its entire length.
- Sanitary sewer line crossings, including one at Sta. 28+20 that will need to be modified in order to accommodate proposed design profile.
- Two culverted road crossings for East Forest Hills Boulevard that control profile and planform adjustments.
- Two existing pedestrian bridge crossings: one which remains and one which will be removed and replaced over the proposed stream.

## 5.0 REFERENCE REACH ANALYSIS

A reference reach is a channel with a stable dimension, pattern, and profile within a particular valley morphology. The reference reach is used to develop dimensionless morphological ratios (based on bankfull stage) that can be extrapolated to disturbed/unstable streams to restore a stream of the same type and disposition as the reference stream (Rosgen, 1998).

A stable section of North Prong Creek, a second order urban stream located in Durham that flows south into Northeast Creek, was selected as the reference reach for the project (Figure 10: Reference Reach Location). Approximately 400 linear feet (20 bankfull widths) of North Prong Creek were surveyed in October 2002. The selection of this reach was based on its location in the same hydrophysiographic province, similar watershed position and land use, and similar sediment regime as the project site. Likewise, the valley slope (0.23% compared to 0.30%) and sediment distribution ($d_{50}$ of 0.2 mm compared to 0.4 mm) of the reference site are very similar to that of the project site.

**Figure 9a. NC Urban Piedmont Regional Curve (Discharge)**

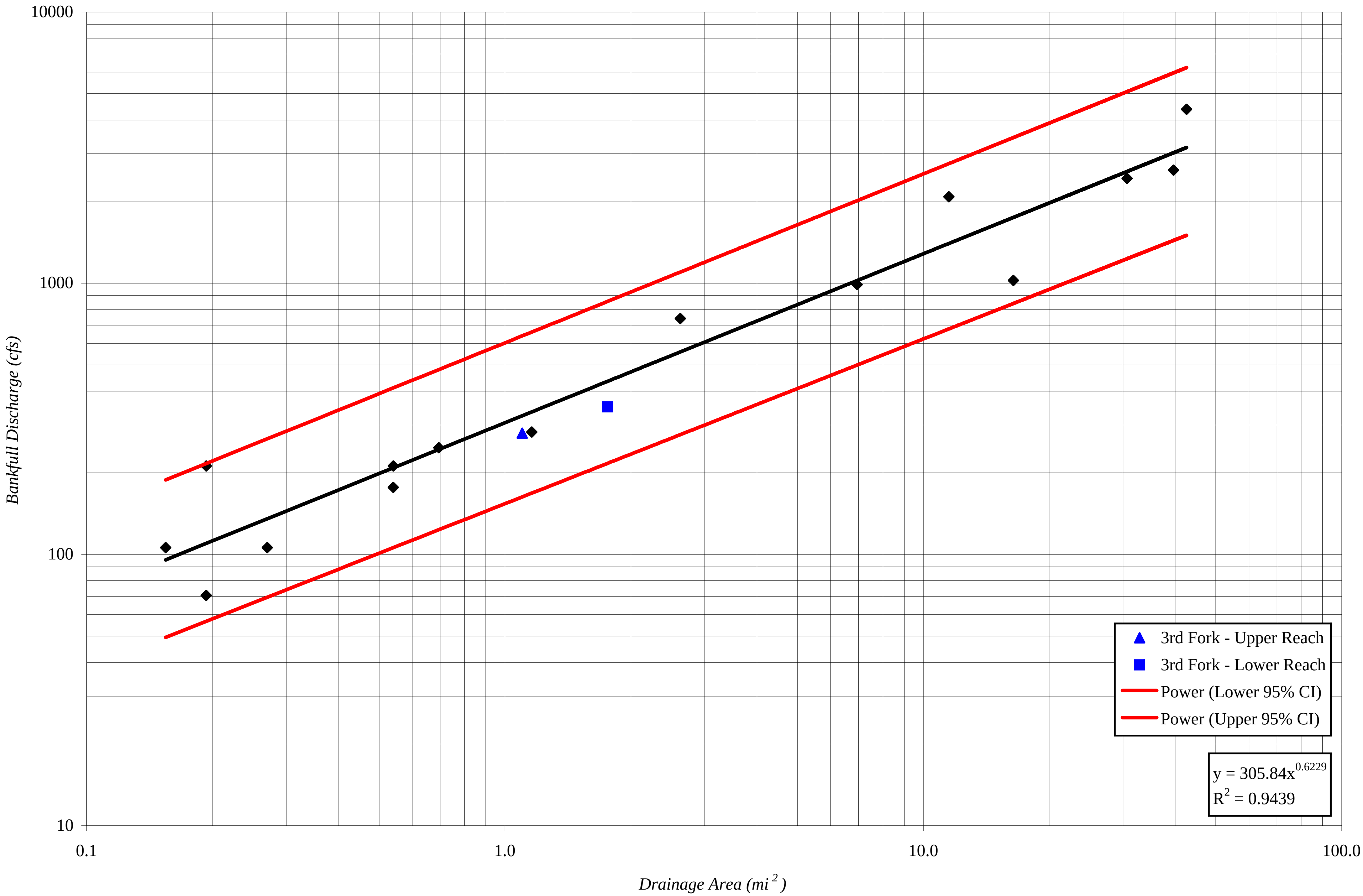
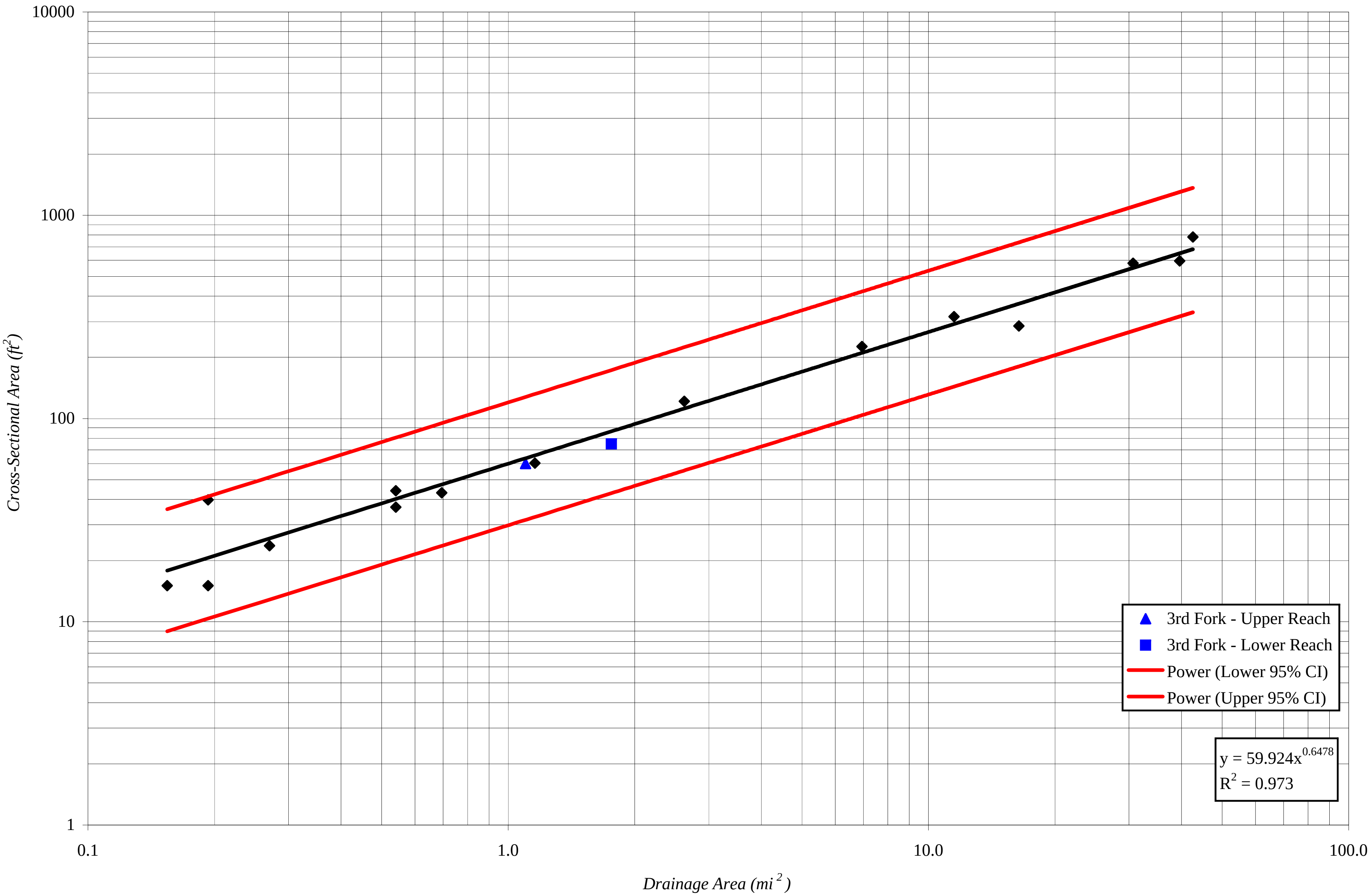


**Figure 9b.  NC Urban Piedmont Regional Curve (Cross-Sectional Area)**



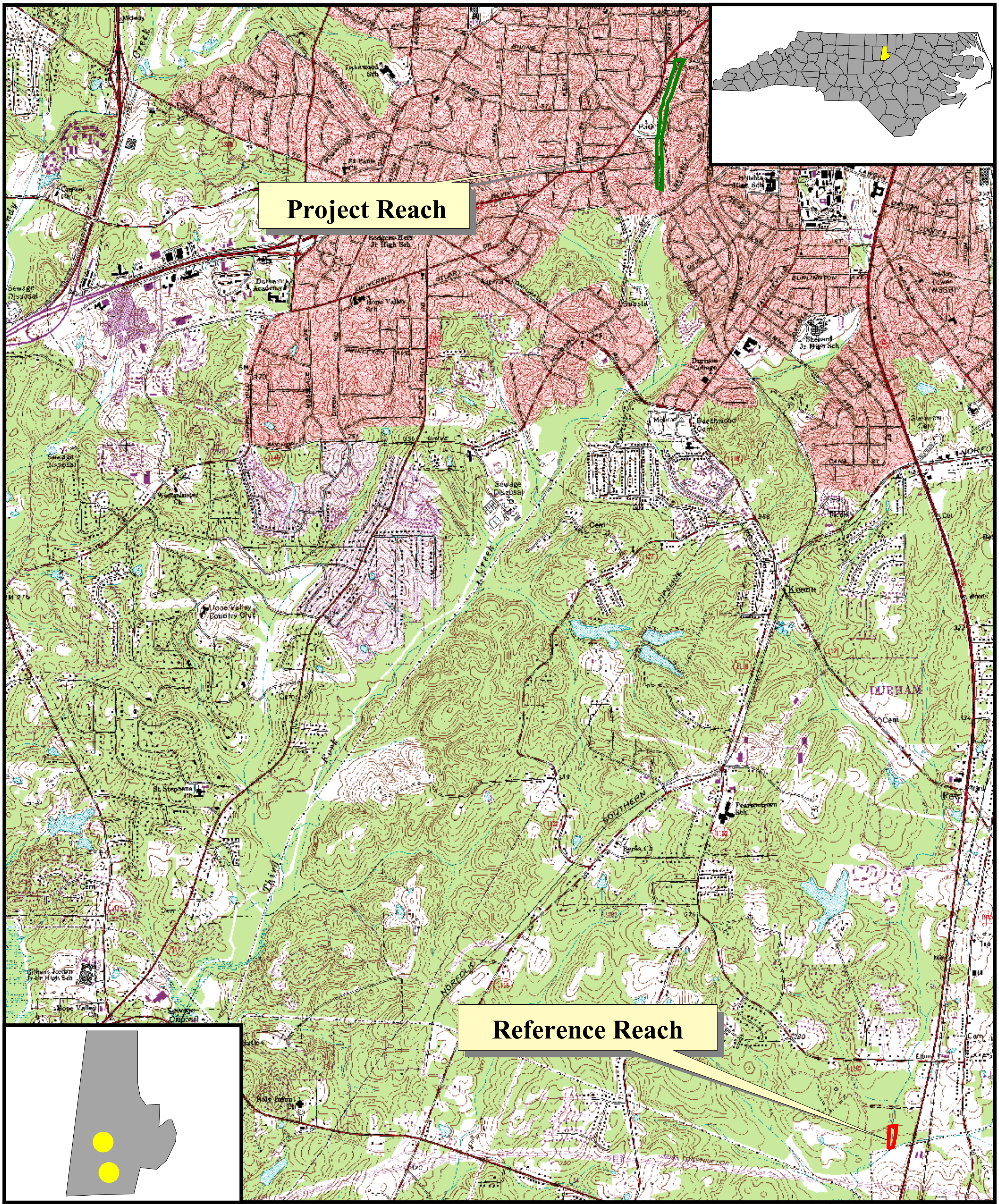



**Figure 10. Reference Reach Location Map**

Source: USGS 7.5' Southwest Durham Topographic Quadrangle

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To verify the acceptability of the reference site, a field visit with Steve Mitchell (NCDWQ, Raleigh Regional Office) was conducted. In a letter dated February 6, 2003, Mr. Mitchell confirmed that the surveyed reach would be an appropriate reference for the Third Fork Creek Restoration Design (Appendix B).

The North Prong Creek reference reach was classified as a narrow width/depth ratio C5 stream type. Collected morphological data as well as representative photographs of the reference site are provided in Appendix B. The measured morphological variables and dimensionless hydraulic geometry relationships developed to facilitate the restoration design are provided below in Section 6.1: Restoration Design - Stream.

## 6.0 RESTORATION DESIGN

### 6.1 Stream

The restoration design of Third Fork Creek is based on a Priority Level 2 approach, as described in "A Geomorphological Approach to Restoration of Incised Rivers", (Rosgen, 1997). For clarity and convenience, definitions of the four restoration priorities are provided in Table 2.

The design proposes constructing 3,025 linear feet of meandering channel. The restoration will establish a bankfull channel with a new floodplain at its existing level and the dimension necessary to provide stable flow maintenance and sediment transport. The design bankfull stage will equal the floodplain elevation in the new channel (bank height ratio = 1.0). The proposed stream dimension, pattern, and profile will be based on the detailed morphological criteria and hydraulic geometry relationships developed from the reference stream, see Table 3. The establishment of a stable bedform (i.e., riffle-pool sequence, pool spacing) will be addressed in the profiling of the design channel. Refer to Figures 11A-B and 12A-D for the proposed channel dimension, pattern and profile.

In-stream structures will be incorporated to reduce the burden of energy dissipation on the channel geometry. Cross-Vanes and J-Hook Vanes (J-Vanes) (Figure 13: Instream Structures) will be used to stabilize the restored channel. These structures are designed to reduce bank erosion and the influence of secondary circulation in the near-bank region of stream bends. The structures further promote efficient sediment transport and produce/enhance in-stream habitat. Cross-vanes will serve as grade control in the restored channel. Coir fiber matting will be used to provide temporary stabilization on the newly graded streambanks. The confluence of a tributary with the restored stream will be stabilized with grade control structures and step sequences where necessary to match the proposed grade of the restored main channel. Excavated materials from the design channel will be used to backfill the abandoned channel sections. The existing pedestrian bridge located at Sta. 24+90 will be removed and replaced over the restored stream.

### 6.2 Riparian Buffers

Native woody and herbaceous species will be used to establish fifty (50) foot wide riparian buffers on both sides of the restored reach. Park utilization space requirements dictate that the riparian buffers consist of a thirty (30) foot wide fully forested buffer adjacent to the stream bordered by a twenty (20) foot wide strip of managed native grasses. In addition, ten (10) to thirty (30) foot wide portions of the buffer areas adjacent to existing utilities are required to be left free of woody vegetation.

Four hundred thirty-six (436) trees per acre (based on an average 10' x 10' spacing) will be planted to achieve a mature survivability of three hundred twenty (320) trees per acre in the riparian zone (DENR, 2001). To provide structural diversity, native shrubs will also be incorporated in the buffers at a 4' x 4' spacing sufficient to provide for 2,700 shrubs per acre. Plant placement and groupings will be randomized during installation in order to develop a more naturalized appearance in the buffer. Woody vegetation planting will be conducted during dormancy.

**Table 2. Priority Levels of Incised River Restoration.**

| Description | Methods | Advantages | Disadvantages |
|---|---|---|---|
| **Priority 1**<br>Convert G and/or F stream types to C or E at previous elevation with floodplain. | Re-establish channel on previous floodplain using relic channel or construction of new bankfull discharge channel. Design new channel for dimension, pattern, and profile characteristic of stable form. Fill in existing incised channel or with discontinuous oxbow lakes level with new floodplain elevation. | Re-establishment of floodplain and stable channel:<br>1) reduces bank height and streambank erosion,<br>2) reduces land loss,<br>3) raises water table,<br>4) decreases sediment,<br>5) improves aquatic and terrestrial habitats,<br>6) improves land productivity, and<br>7) improves aesthetics. | 1) Floodplain re-establishment could cause flood damage to urban, agricultural, and industrial development.<br>2) Downstream end of project could require grade control from new to previous channel to prevent head-cutting. |
| **Priority 2**<br>Convert F and/or G stream types to C or E. Re-establishment of floodplain at existing level or higher, but not at original level. | If belt width provides for the minimum meander width ratio for C or E stream types, construct channel in bed of existing channel, convert existing bed to new floodplain. If belt width is too narrow, excavate streambank walls. End-haul material or place in streambed to raise bed elevation and create new floodplain in the deposition. | 1) Decreases bank height and streambank erosion,<br>2) Allows for riparian vegetation to help stabilize banks,<br>3) Establishes floodplain to help take stress off of channel during flood,<br>4) Improves aquatic habitat,<br>5) Prevents wide-scale flooding of original land surface,<br>6) Reduces sediment,<br>7) Downstream grade transition for grade control is easier. | 1) Does not raise water table back to previous elevation.<br>2) Shear stress and velocity higher during flood due to narrower floodplain.<br>3) Upper banks need to be sloped and stabilized to reduce erosion during flood. |
| **Priority 3**<br>Convert to a new stream type without an active floodplain, but containing a floodprone area. Convert G to B stream type, or F to Bc. | Excavation of channel to change stream type involves establishing proper dimension, pattern, and profile. To convert a G to B stream involves an increase in width/depth and entrenchment ratio, shaping upper slopes and stabilizing both bed and banks. A conversion from F to Bc stream type involves a decrease in width/depth ratio and an increase in entrenchment ratio. | 1) Reduces the amount of land needed to return the river to a stable form.<br>2) Developments next to river need not be relocated due to flooding potential.<br>3) Decreases flood stage for same magnitude flood.<br>4) Improves aquatic habitat. | 1) High cost of materials for bed and streambank stabilization.<br>2) Does not create the diversity of aquatic habitat.<br>3) Does not raise water table to previous levels. |
| **Priority 4**<br>Stabilize channel in place. | A long list of stabilization materials and methods have been used to decrease streambed and streambank erosion, including concrete, gabions, boulders, and bioengineering methods. | 1) Excavation volumes are reduced.<br>2) Land needed for restoration is minimal. | 1) High cost for stabilization.<br>2) High risk due to excessive shear stress and velocity.<br>3) Limited aquatic habitat depending on nature of stabilization methods used. |

*Source: Rosgen, 1997, "A Geomorphological Approach to Restoration of Incised Rivers".*

**Table 3. Morphological Design Criteria**

| *Parameters* | | Reference Reach | Upper Reach* | | Lower Reach* | |
|---|---|---|---|---|---|---|
| | | | Existing | Design | Existing | Design |
| Rosgen Stream Type | | C5 | F5, G5, E5 | C5 | C5 | C5 |
| Drainage Area (mi$^2$) | | 3.04* | 0.8 - 1.1 | 0.8 - 1.1 | 1.76 | 1.76 |
| Reach Length (ft) | | 407 | 1890 | 2083 | 900 | 925 |
| *Dimension* | Bankfull Width (ft) | 17.8 | 21.8 - 26.8 | 27 | 29.5 | 30.0 |
| | Mean Bankfull Depth (ft) | 1.5 | 1.7 - 2.6 | 2.2 | 2.4 | 2.5 |
| | Width/Depth Ratio | 12.1 | 8.3 - 15.9 | 12.1 | 12.2 | 12.0 |
| | Bankfull Area (ft$^2$) | 26.2 | 45.1 - 57.2 | 60 | 71.4 | 75 |
| | Max Bankfull Depth | 3.0 | 2.5 - 4.0 | 4.0 | 4.0 | 4.25 |
| | Width of Floodprone Area (ft) | 600 + | 29.2 - 400 | 62 - 400 | 200 | 200 |
| | Entrenchment Ratio | 33.7 | 1.1 - 18.3 | 2.3 - 14.8 | 6.8 | 6.7 |
| | Max. Pool Depth (ft) | 3.3 - 4.0 | 4.7 | 4.8 - 6.0 | 5.8 | 5.5 - 6.75 |
| | Ratio: Max. Pool Depth / Mean Bkf Depth | 2.2 - 2.7 | 1.81 - 2.76 | 2.2 - 2.7 | 2.42 | 2.2 - 2.7 |
| | Pool Width (ft) | 26.1 | 17.4 | 38 | 28.9 | 43 |
| | Ratio: Pool Width / Bankfull Width | 1.5 | 0.65 - 0.80 | 1.41 | 0.98 | 1.43 |
| | Pool Cross-Sectional Area (ft$^2$) | 30.9 | 58.7 | 84 | 84.4 | 105 |
| | Ratio: Pool Area / Bankfull Area | 1.2 | 1.03 - 1.30 | 1.4 | 1.18 | 1.4 |
| | Bankfull Mean Velocity (u) (ft/s) | 3.1 | 4.7 | 4.7 | 4.5 | 4.7 |
| | Bankfull Discharge (Q) (cfs) | 83* | 268 | 280 | 322 | 350 |
| *Pattern* | Meander Length (ft) | 94 - 143 | * | 160 - 190 | * | 180 - 210 |
| | Ratio: Meander Length / Bankfull Width | 5.3 - 8.0 | * | 6.0 - 7.0 | * | 6.0 - 7.0 |
| | Radius of Curvature (ft) | 37 - 40 | * | 60 - 75 | * | 60 - 80 |
| | Ratio: Radius Curvature / Bankfull Width | 2.1 - 2.3 | * | 2.2 - 2.8 | * | 2.2 - 2.7 |
| | Meander Belt Width (ft) | 158 | * | 120 | * | 90 |
| | Meander Width Ratio (MWR) | 8.9 | * | 4.4 | * | 3.0 |
| | Sinuosity (K) | 1.28 | 1.03 | 1.13 | 1.01 | 1.10 |
| *Profile* | Valley Slope (ft/ft) (%) | 0.23 | 0.30 | 0.30 | 0.30 | 0.30 |
| | Water Surface Slope (ft/ft) (%) | 0.24 | 0.25 | 0.25 | 0.20 | 0.20 |
| | Riffle Slope (ft/ft) (%) | 0.2 - 2.1 | 0.24 - 0.57 | 0.25 - 0.29 | 0.25 | 0.25 |
| | Ratio: Riffle Slope / WS Slope | 0.8 - 8.8 | 0.89 - 2.1 | 1.07 | 1.08 | 1.25 |
| | Pool Slope (ft/ft) (%) | 0.0 - 0.05 | 0.05 | 0.0 - 0.05 | 0.04 | 0.0 - 0.05 |
| | Ratio: Pool Slope / WS Slope | 0.0 - 0.2 | 0.19 | 0.0 | 0.17 | 0.0 |
| | Pool to Pool Spacing (ft) | 40 - 85.5 | * | 60 - 125 | * | 70 - 140 |
| | Ratio: Pool Spacing / Bankfull Width | 2.2 - 4.7 | * | 2.3 - 4.7 | * | 2.3 - 4.7 |
| | Pool Length (ft) | 8 - 30 | * | 27 - 40 | * | 30 - 45 |
| | Ratio: Pool Length / Bankfull Width | 0.4 - 1.6 | * | 1.0 - 1.5 | * | 1.0 - 1.5 |
| | Low Bank Height (ft) | 3.0 | 6.2 - 6.43 | 4.0 | 5.1 | 4.25 |
| | Ratio: Low Bank Height / Max. Bkf Depth | 1.0 | 1.55 - 2.57 | 1.0 | 1.27 | 1.0 |
| Channel Materials (D50) (mm) | | 0.20 | 0.31 - 0.38 | 0.31 - 0.38 | 0.41 | 0.41 |

*Note:*

- *The project reach is subdivided into two sections due to the controlling influence of a culverted road crossing (East Forest Hills Blvd.) and the confluence of a tributary that increases the contributing drainage area.*
- *The discharge contributed to the reference site by its delineated drainage area is reduced due to impoundment and altered drainage patterns in the watershed.*
- *Existing channel pattern and bed morphological features have been altered due to extensive site disturbance.*
- *The design belt width and sinuosity are less than those indicated by the reference due to project site (Park) space utilization requirements that laterally constrain stream planform adjustments.*

Figure 11a. Typical Cross-sections (Sta. 10+00 to 31+00)

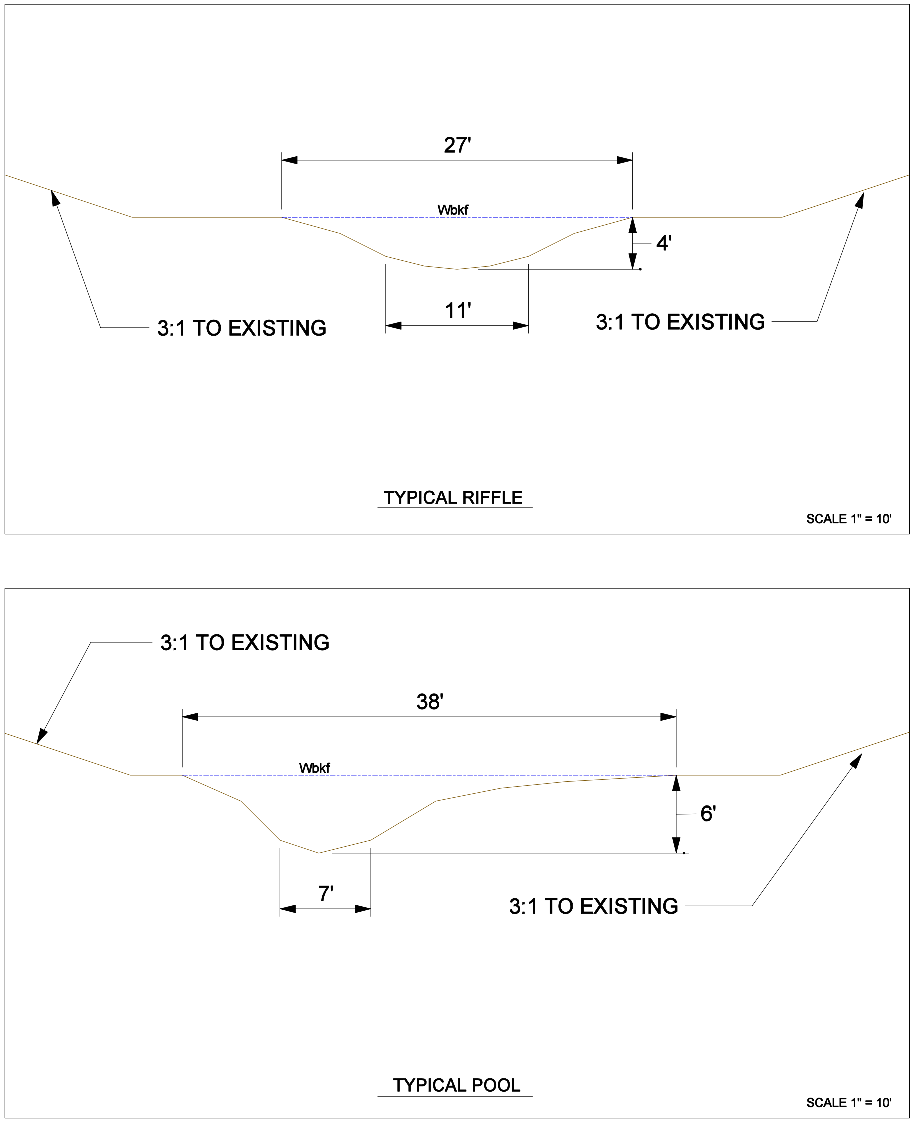
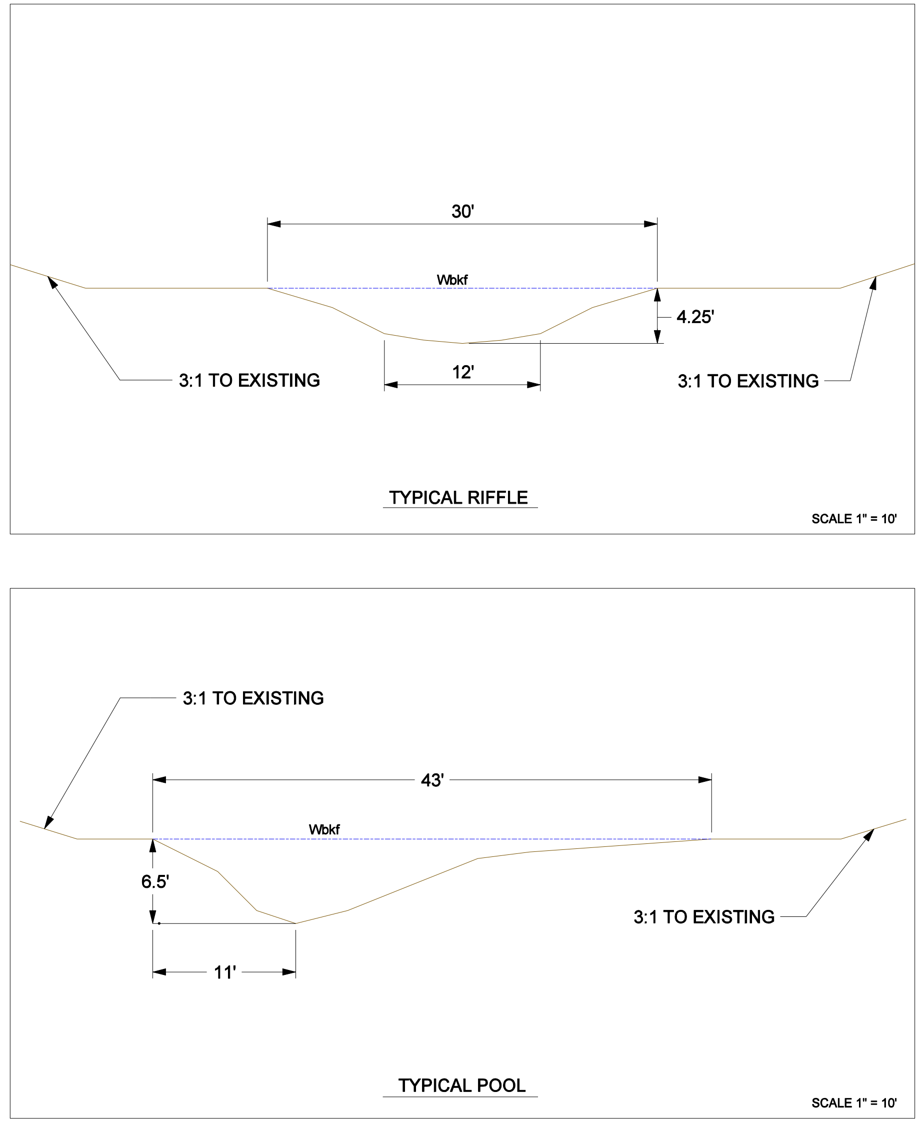
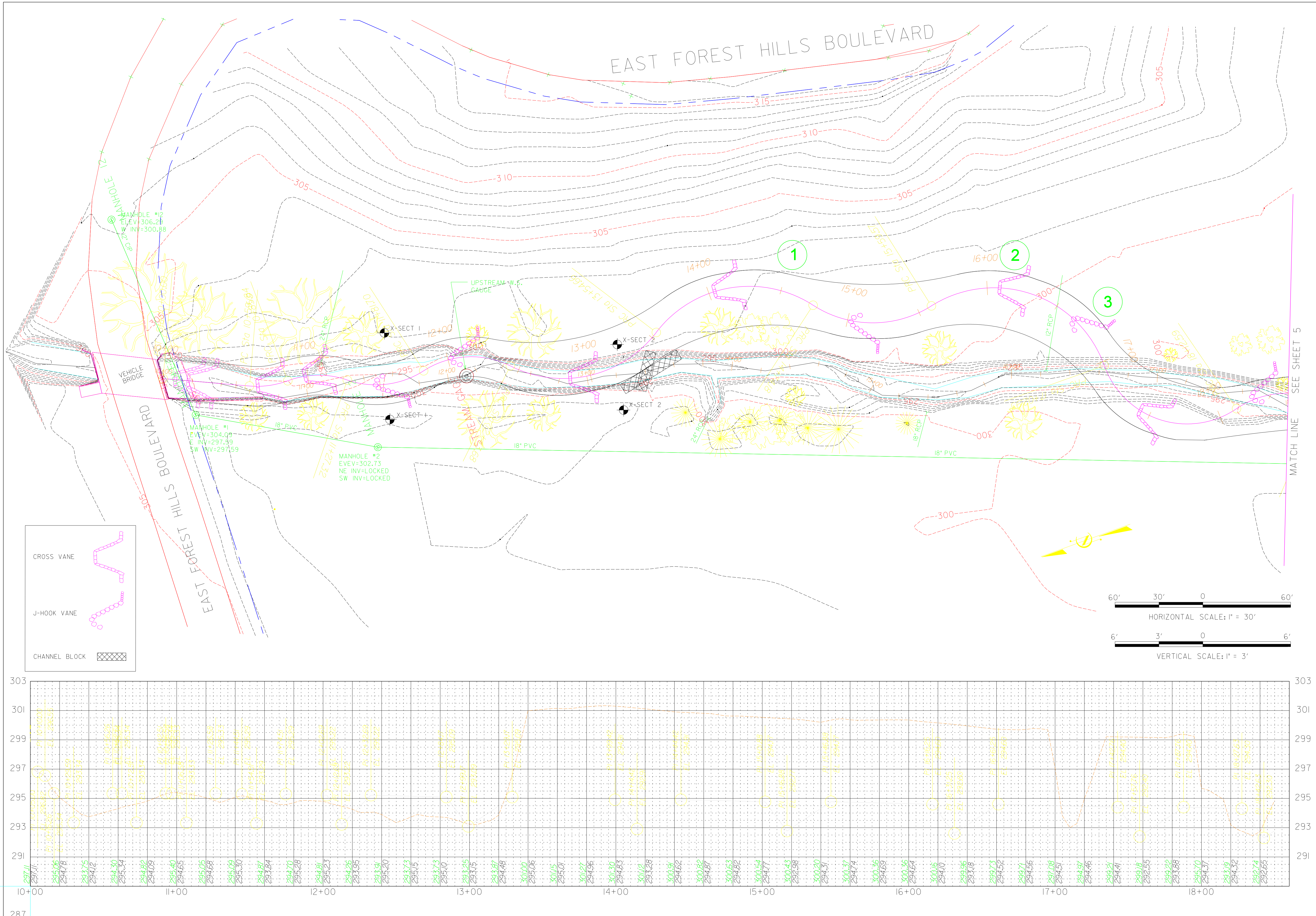



Figure 11b. Typical Cross-sections (Sta. 31+00 to 40+25)




...\Third Fork_Fig 11 Typ Sections 3/3/2005 2:53:05 PM




| SYM. | DESCRIPTION | DATE | APPROVED |
|---|---|---|---|
| A | ISSUED FOR PERMITS ONLY | 04-01-03 | |
| B | ISSUED FOR SCO REVIEW | 11-03-03 | |
| C | ISSUED FOR SCO FINAL REVISION | 02-17-04 | |

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N.C. Wetlands Restoration Program

KCI ASSOCIATES OF NC

ENGINEERS • PLANNERS • SCIENTISTS

4601 SIX FORKS ROAD
RALEIGH, NORTH CAROLINA 27609

# THIRD FORK CREEK STREAM RESTORATION PROJECT

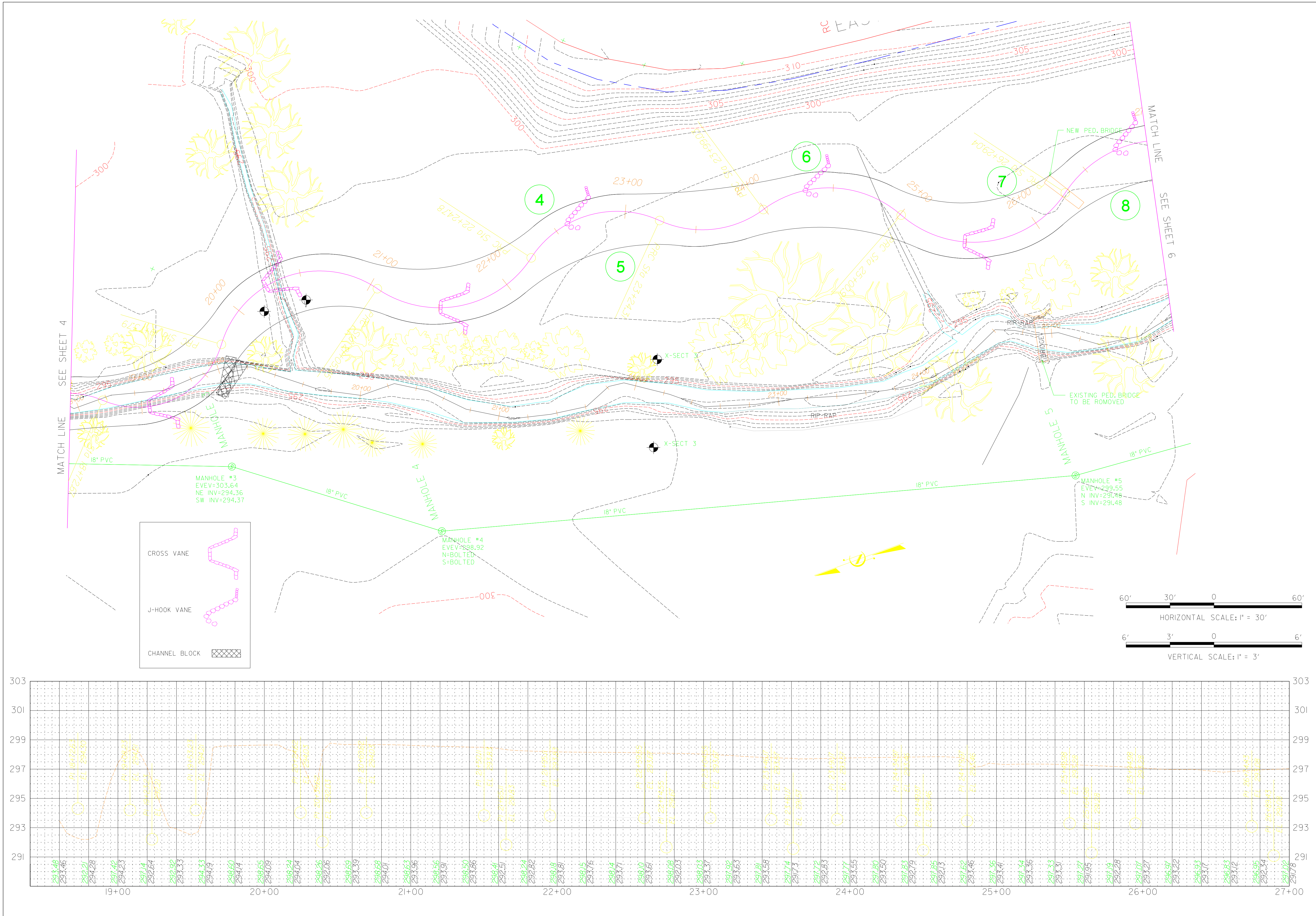
FOREST HILLS PARK, DURHAM, NORTH CAROLINA

STA. 10+00.00 TO STA. 18+50.00

DATE: FEBRUARY, 2004
SCALE: GRAPHIC

SHEET OF 20

FIG. 12-A




| SYM. | DESCRIPTION | DATE | APPROVED |
|---|---|---|---|
| A | ISSUED FOR PERMITS ONLY | 04-01-03 | |
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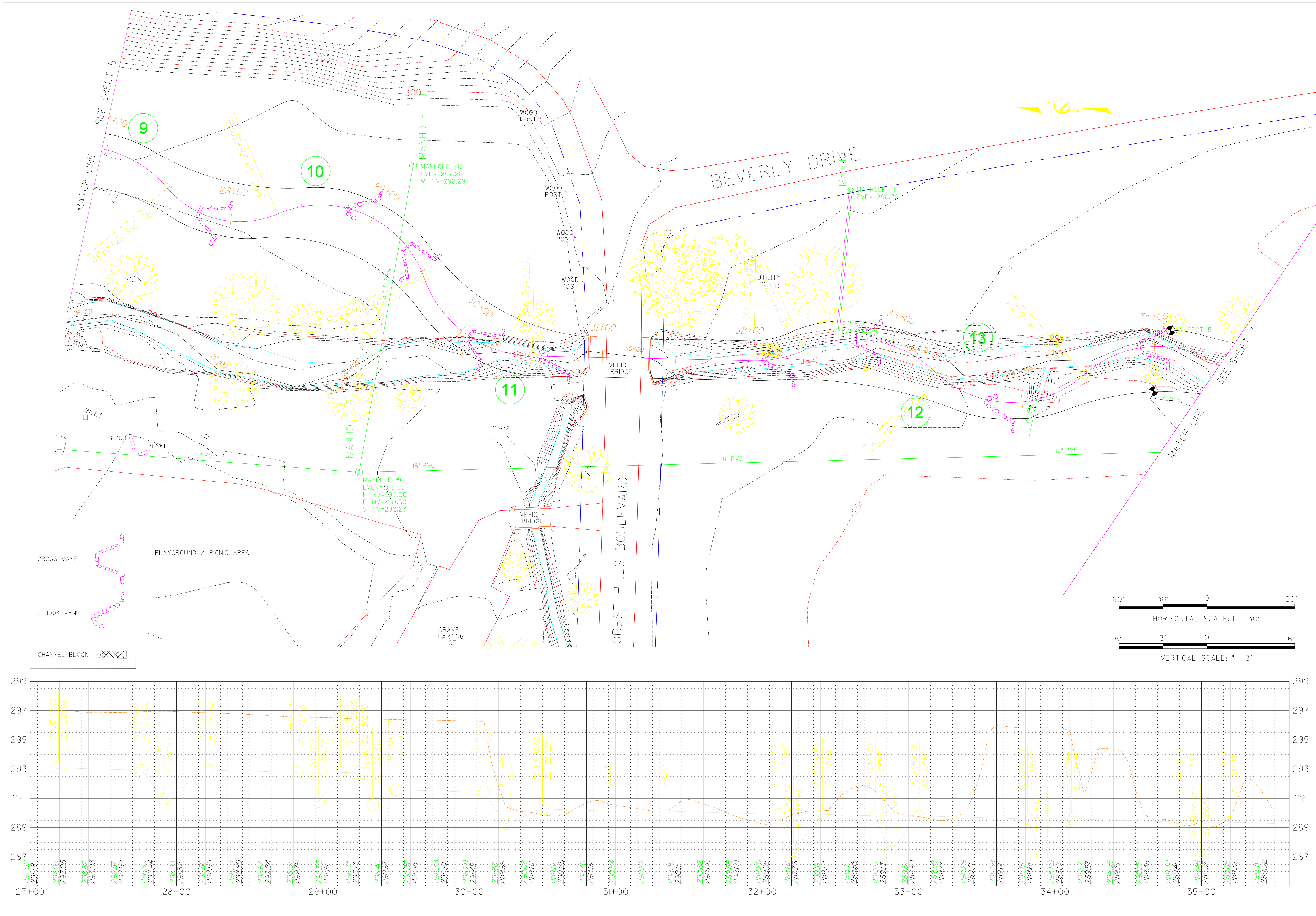
# THIRD FORK CREEK STREAM RESTORATION PROJECT
## FOREST HILLS PARK, DURHAM, NORTH CAROLINA

STA. 18+50.00 TO STA. 27+00.00

DATE: FEBRUARY, 2004
SCALE: GRAPHIC

SHEET OF 20

FIG. 12-B




| SYM. | DESCRIPTION | DATE | APPROVED |
|---|---|---|---|
| A | ISSUED FOR PERMITS ONLY | 04-01-03 | |
| B | ISSUED FOR SCO REVIEW | 11-03-03 | |
| C | ISSUED FOR SCO FINAL REVISION | 02-17-04 | |

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# THIRD FORK CREEK STREAM RESTORATION PROJECT

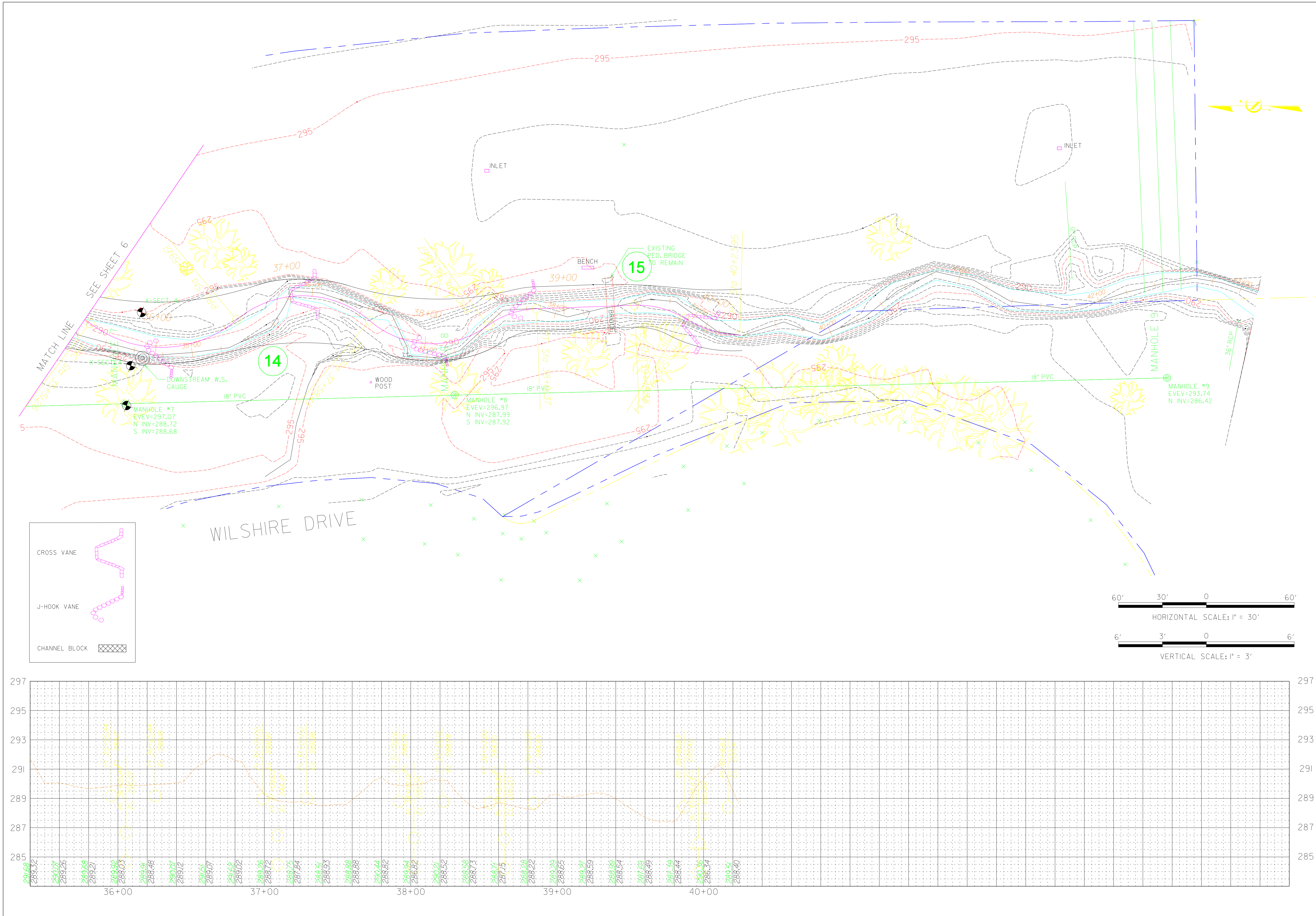
FOREST HILLS PARK, DURHAM, NORTH CAROLINA

STA. 27+00.00 TO STA. 35+50.00

DATE: FEBRUARY, 2004
SCALE: GRAPHIC

SHEET OF 20

FIG. 12-C




| SYM. | DESCRIPTION | DATE | APPROVED |
|---|---|---|---|
| A | ISSUED FOR PERMITS ONLY | 04-01-03 | |
| B | ISSUED FOR SCO REVIEW | 11-03-03 | |
| C | ISSUED FOR SCO FINAL REVISION | 02-17-04 | |

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# THIRD FORK CREEK STREAM RESTORATION PROJECT

FOREST HILLS PARK, DURHAM, NORTH CAROLINA

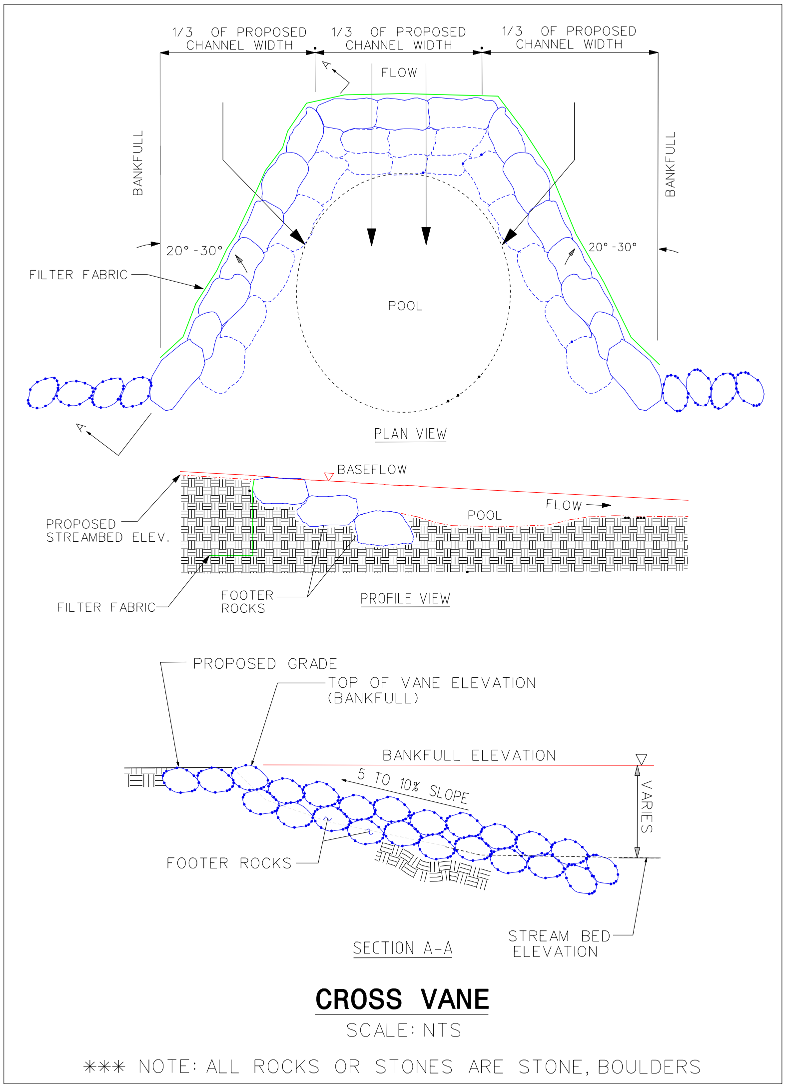
STA. 35+50.00 TO STA. 40+23.95

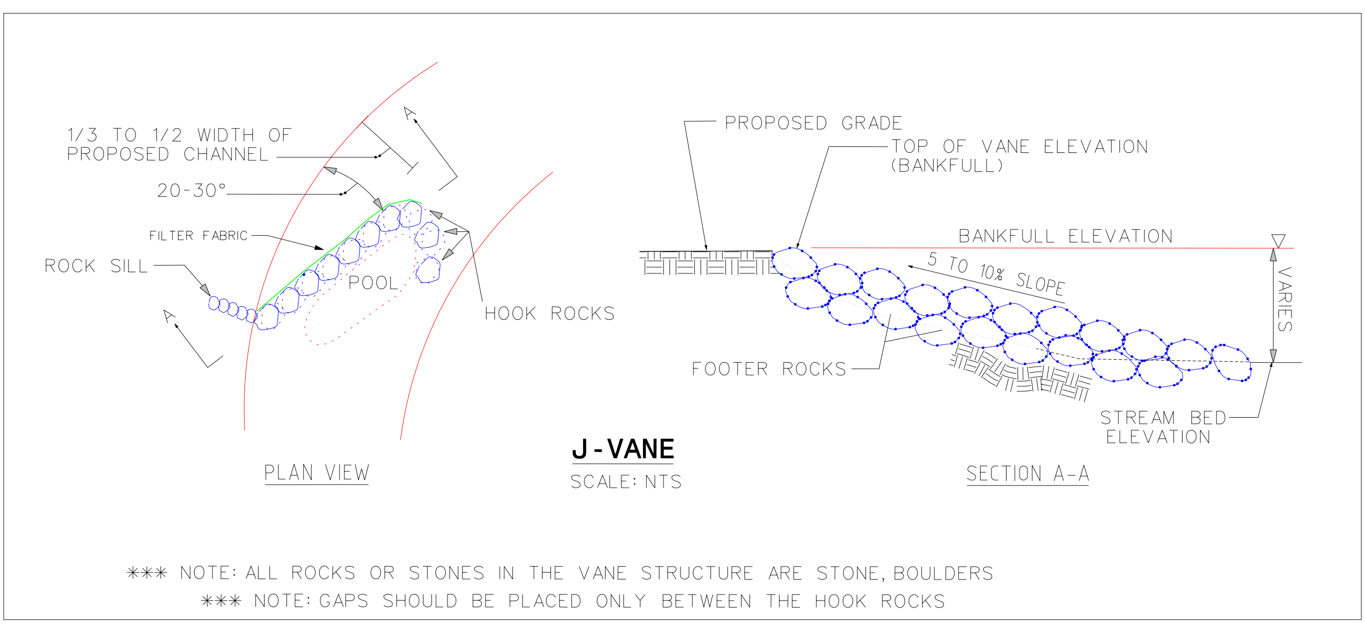
DATE: FEBRUARY, 2004
SCALE: GRAPHIC

SHEET OF 20

FIG. 12-D

# Figure 13. Typical In-Stream Structures



Tree and shrub species to be planted may consist of the following:

| Trees | Shrubs |
|---|---|
| American sycamore (*Platanus occidentalis*) | Spicebush (*Lindera benzoin*) |
| Tulip poplar (*Liriodendron tulipifera*) | Witch hazel (*Hamamelis virginiana*) |
| Green ash (*Fraxinus pennsylvanica*) | Alder (*Alnus serrulata*) |
| River birch (*Betula nigra*) | Fetterbush (*Leucothoe racemosa*) |
| Cherrybark oak (*Quercus pagoda*) | Wax myrtle (*Myrica cerifera*) |
| Willow oak (*Quercus phellos*) | Strawberry bush (*Euonymus americanus*) |
| Water oak (*Quercus nigra*) | American beautyberry (*Callicarpa americana*) |

Herbaceous vegetation within the buffer shall consist of a native grass mix that may include: big bluestem (*Andropogon gerardii*), purple love grass (*Eragrostis spectabilis*), deertongue (*Panicum clandestinum*), gama grass (*Tripsacum dactyloides*), orchardgrass (*Dactylis glomerata*), river oats (*Chasmanthium latifolium*), and Virginia wildrye (*Elymus virginicus*). Rye grain (*Secale cereale*) or brown top millet (*Pennisetum glaucum*) will be used for temporary stabilization, depending upon the construction schedule.

On the restored stream banks, live stakes will be used in conjunction with the native herbaceous seed mix to provide natural stabilization. Appropriate species identified for live staking include elderberry (*Sambucus canadensis*), silky willow (*Salix sericea*), silky dogwood (*Cornus amomum*), and black willow (*Salix nigra*).

## 7.0 SEDIMENT TRANSPORT ANALYSIS

A stable channel is able to move the sediment supplied by its watershed without aggrading or degrading. This ability is evaluated through two parameters: competency and capacity. Competency is the channel's ability to move particles of a certain size, expressed as units of $lbs/ft^2$. Capacity is the channel's ability to move a specific volume of sediment (sediment discharge). Sediment discharge is the amount of sediment moving through a cross section over a specified period of time, expressed as units of lbs/sec.

### 7.1 Competency

The initiation of particle movement (entrainment) is the first stage in sediment transport and shear stress (tractive force) is the parameter most commonly used to approximate the particle size that can be entrained.

The composition of the project reach streambed is predominantly sand ($d_{50}$= 0.3 - 0.4 mm). In many cases, the shear stress (> 0.01 $lbs/ft^2$) in a channel, at the bankfull stage, is considerably higher than that required to move even the largest sand particle (2.0 mm). Thus, competency is not usually the primary consideration related to sediment transport in sand-bed streams because nearly if not all of the sediment (bed material) moves at bankfull.

To validate this theory-based explanation, shear stress was calculated for the design riffle cross-sections in both the upper and lower project reaches using the equation:

$$\tau = \gamma R s$$

Where:
$\tau$ = shear stress ($lbs/ft^2$)
$\gamma$ = specific gravity of water (62.4 $lbs/ft^3$)
R = hydraulic radius (ft)
s = average water slope (ft/ft)

The shear stress values estimated for the upper and lower design riffle cross-sections are 0.38 and 0.37 $lbs/ft^2$, respectively. Comparison to a modified Shield's Curve indicates that particles approximately 20-22 mm in diameter can be mobilized by these shear stresses. This supports the conclusion that the design cross-sections will competently move sediment and prevent aggradation.

The calculated shear stress values were further utilized to evaluate whether the design would result in bed degradation. The estimated shear stress of 0.38 will move particles up to 22 mm in size, which compares favorably to the project reach cumulative pebble count $D_{84}$ of 20.6 mm. In addition, the design incorporates cross vane grade control structures, further increasing confidence that the design stream will maintain vertical stability.

## 7.2 Capacity

A sediment transport capacity analysis was conducted to determine whether the project design channel would transport the same volume of sediment, at bankfull, as the existing stabilizing sections in both the upper and lower project reaches. A spreadsheet model (calculator) was developed based upon the Ackers and White Equations (1973) and used in conjunction with field data to predict sediment discharge (lbs/s) for various discharge rates (flows). This model incorporated three separate components that influence sediment transport: particle size ($D_{gr}$ based on the $D_{50}$ channel material), particle mobility ($F_{gr}$ based on shear stress and immersed sediment weight), and a transport parameter ($G_{gr}$ based on stream power).

The sediment transport calculator produced total sediment load transport estimates of 33.5 and 38.6 lbs/s at bankfull in the existing upper and lower sections, respectively. The calculator estimated total load transport rates of 50.8 and 46.9 lbs/s at the bankfull stage in the design sections. This comparison indicates that the restored channel will have sufficient sediment transport capacity to accommodate the total sediment load to the project reach. In addition, the restoration of an accessible floodplain exhibited a significant change (flattened) in the sediment discharge curve above bankfull in the restored reaches compared with discharges above bankfull in the existing degraded reaches. Floods confined within the existing incised channel have resulted in excess stream power and subsequent erosion and degradation. Supporting sediment transport calculations and rating curves are provided in Appendix C.

# 8.0 FLOODING ANALYSIS

Third Fork Creek in Forest Hills Park is located in a Federal Emergency Management Agency (FEMA) Detailed Flood Study Zone. As such, any modifications to the stream that would result in the increase of the 100-year flood elevation would require a Conditional Letter of Map Revision. It is the intent of the restoration design to maintain the 100-year flood elevation at the current level following restoration.

An existing conditions HEC-RAS (River Analysis System) model was developed to establish an existing conditions hydrologic/hydraulic parameters "baseline" that proposed post-restoration conditions can be compared against. Following approval of the restoration design, the existing conditions model will be finalized to reflect proposed changes to the channel and floodplain.

# 9.0 MONITORING AND EVALUATION

Monitoring shall consist of the collection and analysis of stream stability and riparian/stream bank vegetation survivability data to support the evaluation of the project in meeting established restoration objectives. Specifically, project success will be assessed utilizing measurements of stream dimension, pattern, and profile, site photographs, and vegetation sampling.

### 9.1 Duration

The first scheduled monitoring will be conducted at the end of the first full growing following project completion. Monitoring shall subsequently be conducted annually for a total period of five (5) years.

### 9.2 Reporting

Monitoring reports will be prepared and submitted after all monitoring tasks for each monitoring event are completed. Each report will provide the new monitoring data and compare the new data against previous findings. Data tables, cross sections, profiles, photographs and other graphics will be included in the report as necessary. Each report will include a discussion of any significant deviations from the as-built survey and previous annual measurements, as well as evaluations as to whether the changes indicate a stabilizing or de-stabilizing condition.

### 9.3 Stream Stability

The purpose of monitoring is to evaluate the stability of the restored stream. Following the procedures established in the USDA Forest Service Manual, *Stream Channel Reference Sites* (Harrelson, et.al, 1994) and the methodologies utilized in the Rosgen stream assessment and classification system (Rosgen, 1994 and 1996), data collected will consist of detailed dimension and pattern measurements, a longitudinal profile, and bed materials sampling. Width/depth ratio, entrenchment ratio, low bank height ratio, sinuosity, meander width ratio, radius of curvature (on newly constructed meanders during 1$^{st}$ year monitoring only), pool-to-pool spacing as well as the average, riffle and pool water slopes will be calculated from the collected data. Pebble count data will be plotted by size distribution in order to assess the D50 and D84 size class.

#### *9.3.1 Dimension*

Four permanent cross-sections, two riffle and two pool, will be established and used to evaluate stream dimension. At least one riffle and one pool cross-section will be located within the area also surveyed as part of the longitudinal profile. Permanent monuments will be established by either conventional survey or GPS. The cross-section surveys shall provide a detailed measurement of the stream and banks, to include points on the adjacent floodplain, at the top of bank, bankfull, at all breaks in slope, the edge of water, and thalweg. Subsequently, width/depth ratios, entrenchment ratios and bank height ratios will be calculated for each cross-section.

Cross-section measurements should show little change from the as-built cross-sections. If changes do occur, they will be evaluated to determine whether they are minor adjustments associated with settling and increased stability or whether they indicate movement toward an unstable condition.

#### *9.3.2 Pattern*

Measurements associated with the restored channel pattern will include belt width, meander length, and radius of curvature (on newly constructed meanders only for the first year). Subsequently, sinuosity, meander width ratio and radius of curvature and meander length/bankfull width ratios will be calculated.

#### *9.3.3 Profile*

A longitudinal profile of a representative reach of the restored channel will be surveyed. The profile will extend a minimum of 20 bankfull widths. Measurements will include slopes (average, pool, riffle), as well as calculations of pool-to-pool spacing. Annual measurements should indicate stable bedform features with little change from the as-built survey. The pools should maintain their depth with lower water surface slopes, while the riffles should remain shallower and steeper.

#### *9.3.4 Bed Materials*

Pebble counts will be conducted at each riffle cross-section, as well as across the overall study reach (based upon percentage of riffles and pools) for the purpose of classification and to evaluate sediment transport.

### 9.4 Photograph Reference Points

Photograph reference points (PRP's) will be established to assist in characterizing the site and to allow qualitative evaluation of the site conditions. The location of each photo point will be permanently marked in the field and the bearing/orientation documented to allow for repeated use.

#### *9.4.1 Cross-section Photograph Reference Points*

Four (4) photographs will be taken at each permanent cross section, as follows: 1) from the left bank permanent monument/pin showing the right bank, 2) from the right bank permanent monument/pin showing the left bank, 3) from downstream of the cross-section looking upstream, and 4) from upstream of the cross-section looking downstream. The survey tape will be centered in each photograph and the water line will be located near the lower edge. Effort will be made to consistently show the same area in each photograph.

#### *9.4.2 Longitudinal Photograph Reference Points*

Ten (10) permanent points will be established longitudinally throughout the project site to allow further photo-documentation of the restored stream channel condition.

#### *9.4.3 Additional Photograph Locations*

Additional PRP's will be located, as needed, to document the condition of specific in-stream structures such as J-vanes and cross vanes, as well as infrastructure associated with the stream such as utility and road crossings.

### 9.5 Bank and Riparian Vegetation Monitoring

The success of the bank and riparian buffer plantings will be evaluated using ten (10) fifty by fifty foot (50' x 50') vegetative sampling plots. The corners of each monitoring plot will be permanently marked in the field. The monitoring will consist of a physical inventory within each plot and a subsequent statistical analysis in order to determine the following: 1) composition and number of surviving species, 2) differentiation between planted individuals and volunteers, and 3) total number of stems per acre. Additionally, photographs will be taken from the center of each monitoring plot, starting due north to create a 360-degree view of the sample site.

Riparian vegetation must meet a minimum survival success rate of 320 stems/acre after five years. If monitoring indicates that the specified survival rate is not being met, appropriate corrective actions will be developed, to include invasive species control, the removal of dead/dying plants and replanting.

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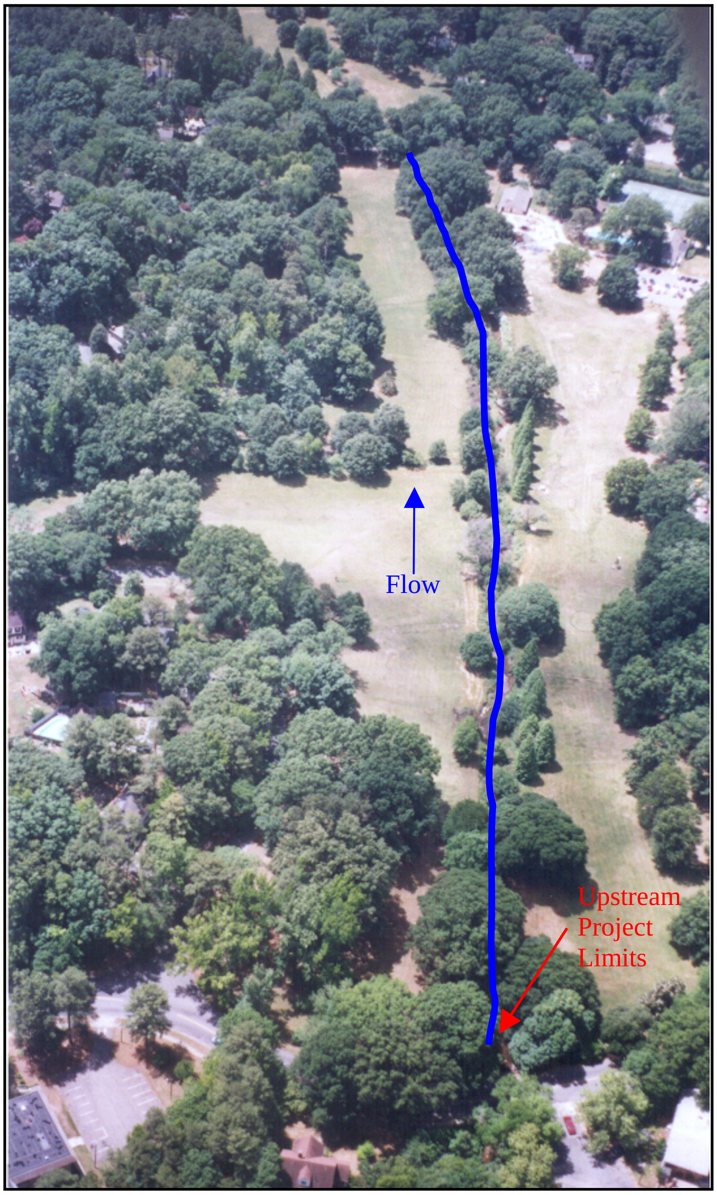
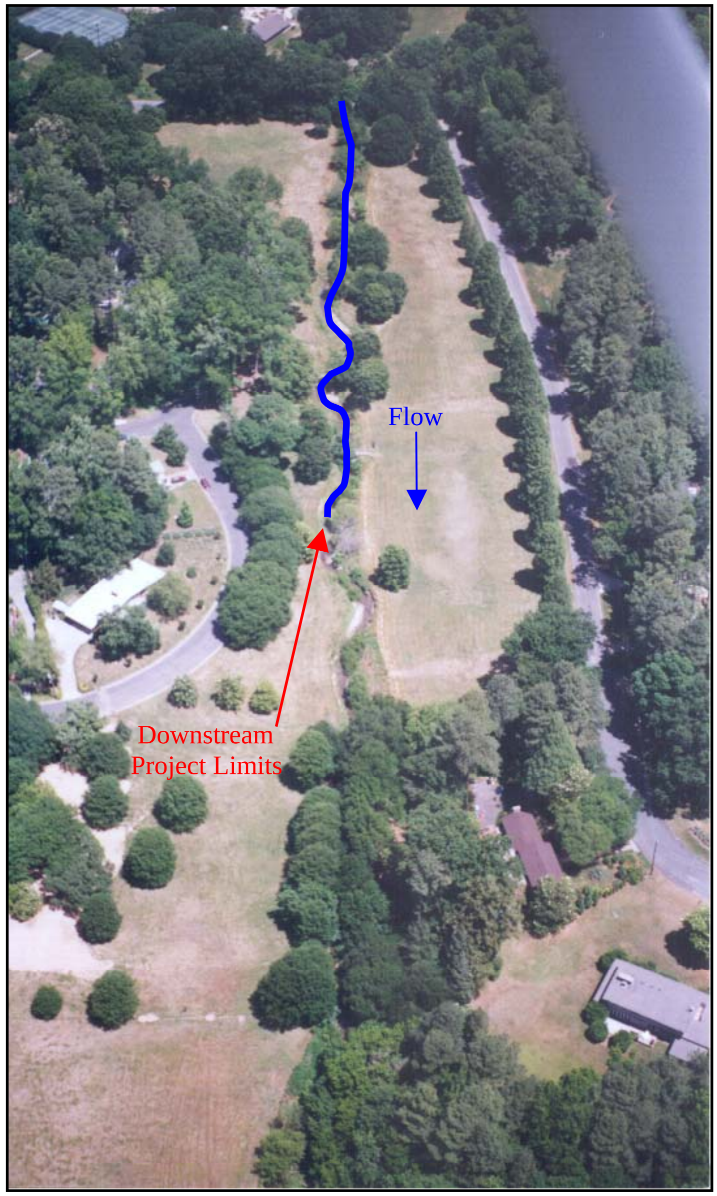
# Appendix A

## Project Site Existing Conditions Data

***Third Fork Creek – Representative Site Photos***




Aerial view of upstream project area, looking south.




Aerial view of downstream project area, looking north.

## *Third Fork Creek – Representative Site Photos*

Upstream Project limits. (East Forest Hills Drive culvert/pipe, looking upstream.)

Severely eroded streambank. (Right bank at Sta. 11+50.)

*Third Fork Creek – Representative Site Photos*

Incised stream section in upstream project area. (Near Sta. 13+00, looking downstream.)

Typical degraded stream section in upstream project area. (Near Sta. 15+40, looking downstream.)

*Third Fork Creek – Representative Site Photos*

Tributary 1. (At confluence with main channel, Sta. 19+50, looking upstream.)

Park open space east of existing stream through which design channel would be located.

***Third Fork Creek – Representative Site Photos***

Typical section with eroding banks and developing lateral bars.  (Sta. 23+00, looking downstream.)

Existing concrete pedestrian bridge, to be removed.  (Sta. 24+90, looking downstream.)

# *Third Fork Creek – Representative Site Photos*

Large trees, playground/picnic area adjacent to stream.  (Near Sta. 26+00, looking downstream.)

Second East Forest Hill Drive stream crossing box culverts.  (Sta. 30+00, looking downstream.)

## *Third Fork Creek – Representative Site Photos*

Degraded section downstream of E. Forest Hills Dr. crossing. (Sta. 30+50, looking downstream.)

Typical degraded section in downstream project area. (Sta. 34+00, looking downstream.)

## *Third Fork Creek – Representative Site Photos*

Existing steel/wood pedestrian bridge, to remain. (Sta. 38+40, looking downstream.)

Typical degraded section in downstream project area. (Near Sta. 40+25, looking downstream.)

*Third Fork Creek Stream Restoration Project*

**Existing Conditions**

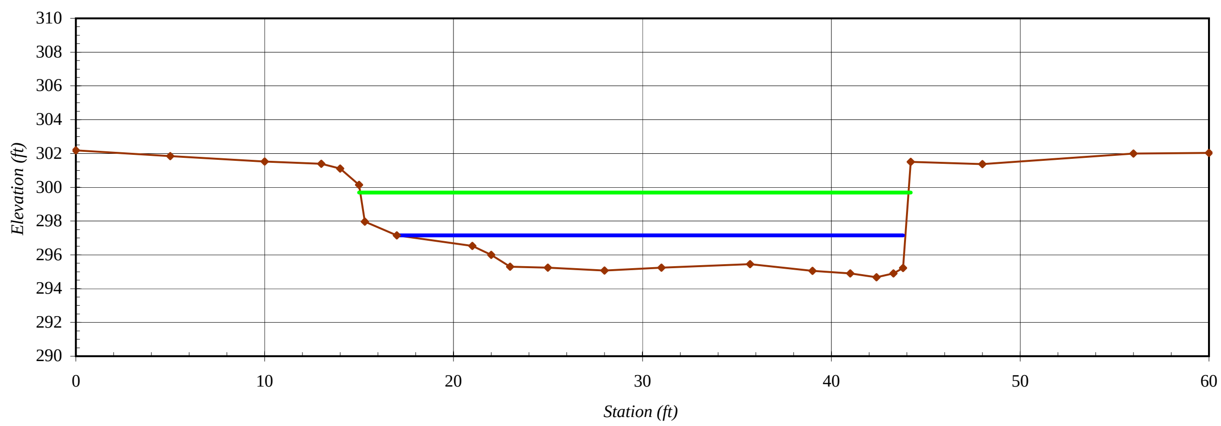
| | |
|---|---|
| **River Basin:** | Cape Fear, |
| **Watershed:** | Third Fork Creek, |
| **XS ID** | X-Sec 1 (Sta. 11+55), Riffle |
| **Drainage Area ($mi^2$):** | 0.80 |
| **Date:** | 7/8/2002 |
| **Field Crew:** | D. Redgate, K. Nimmer, B. Greco |

| Station | Rod Ht. | Elevation |
|---|---|---|
| 0.0 | 6.14 | 302.18 |
| 5.0 | 6.48 | 301.84 |
| 10.0 | 6.80 | 301.52 |
| 13.0 | 6.92 | 301.40 |
| 14.0 | 7.22 | 301.10 |
| 15.0 | 8.18 | 300.14 |
| 15.3 | 10.35 | 297.97 |
| 17.0 | 11.16 | 297.16 |
| 21.0 | 11.79 | 296.53 |
| 22.0 | 12.33 | 295.99 |
| 23.0 | 13.03 | 295.29 |
| 25.0 | 13.08 | 295.24 |
| 28.0 | 13.24 | 295.08 |
| 31.0 | 13.07 | 295.25 |
| 35.7 | 12.87 | 295.45 |
| 39.0 | 13.26 | 295.06 |
| 41.0 | 13.42 | 294.90 |
| 42.4 | 13.64 | 294.68 |
| 43.3 | 13.41 | 294.91 |
| 43.8 | 13.09 | 295.23 |
| 44.2 | 6.81 | 301.51 |
| 48.0 | 6.94 | 301.38 |
| 56.0 | 6.32 | 302.00 |
| 60.0 | 6.28 | 302.04 |

| Summary Data | |
|---|---|
| **Bankfull Width (ft):** | 26.8 |
| **Mean Bankfull Depth (ft):** | 1.7 |
| **Width / Depth Ratio:** | 15.9 |
| **Bankfull Area ($ft^2$):** | 26.8 |
| **Entrenchment Ratio:** | 1.1 |
| **Max. Depth Bankfull (ft):** | 2.5 |
| **Bank Height Ratio:** | 2.6 |
| **Local WS Slope (ft/ft) (%):** | 0.57 |
| **Discharge (cfs):** | 252.0 |
| **$D_{50}$ (mm):** | 2.97 |
| **Rosgen Stream Type:** | F4 |

View looking upstream

**Cape Fear, Third Fork Creek, X-Sec 1 (Sta. 11+55), Riffle**

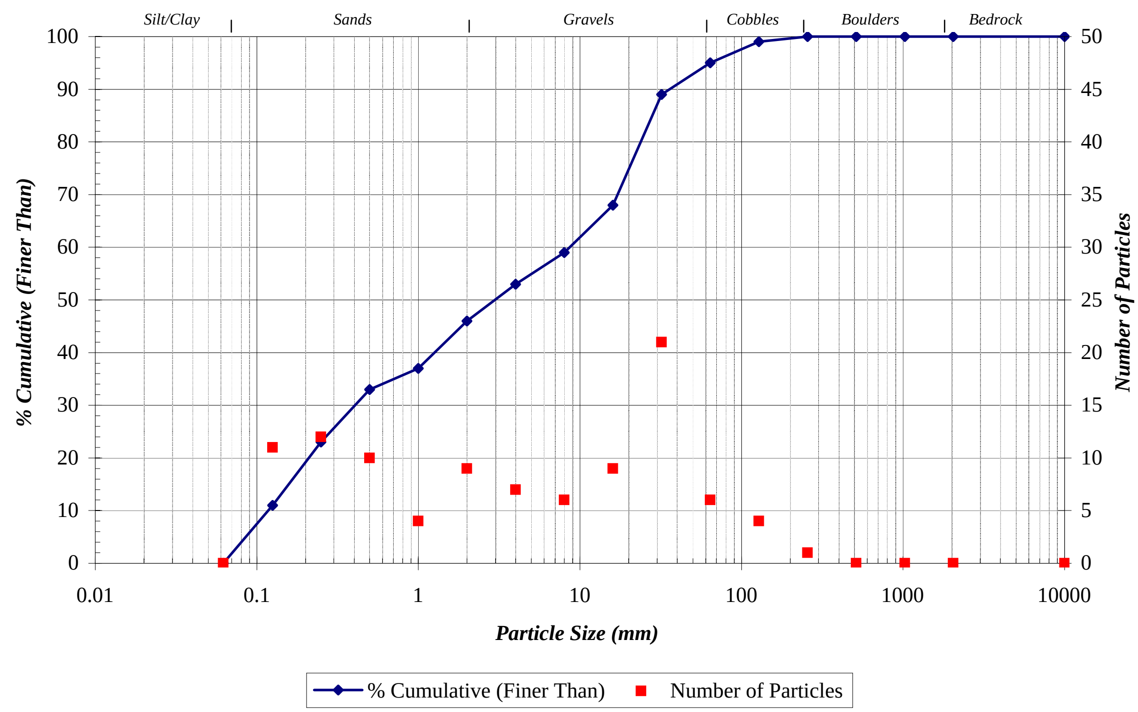


***Third Fork Creek Stream Restoration Project***

**Existing Conditions**

| | |
|---|---|
| **Stream:** | Third Fork Creek |
| **Location:** | Cross-section 1 (Sta. 11+55) |
| **Date:** | |

| **Particle** | | **Size Range (mm)** | **Total #** | **Item %** | **% Cum.** |
|---|---|---|---|---|---|
| S/C | Silt/Clay | 0 < 0.062 | 0 | 0 | 0 |
| Sand | Very Fine Sand | 0.062 < 0.125 | 11 | 11 | 11 |
| | Fine Sand | 0.125 < 0.25 | 12 | 12 | 23 |
| | Medium Sand | 0.25 < 0.50 | 10 | 10 | 33 |
| | Coarse Sand | 0.50 < 1.0 | 4 | 4 | 37 |
| | Very Coarse Sand | 1 < 2 | 9 | 9 | 46 |
| Gravel | Very Fine Gravel | 2 < 4 | 7 | 7 | 53 |
| | Fine Gravel | 4 < 8 | 6 | 6 | 59 |
| | Medium Gravel | 8 < 16 | 9 | 9 | 68 |
| | Coarse Gravel | 16 < 32 | 21 | 21 | 89 |
| | Very Coarse Gravel | 32 < 64 | 6 | 6 | 95 |
| Cbl | Small Cobble | 64 < 128 | 4 | 4 | 99 |
| | Large Cobble | 128 < 256 | 1 | 1 | 100 |
| Bldr | Small Boulder | 256 < 512 | 0 | 0 | 100 |
| | Medium Boulder | 512 < 1024 | 0 | 0 | 100 |
| | Large Boulder | 1024 < 2048 | 0 | 0 | 100 |
| Bdrk | Bedrock | Bedrock | 0 | 0 | 100 |
| | | ***Totals:*** | 100 | 100 | 100 |




| **Size percent less than (mm)** | | | | |
|---|---|---|---|---|
| D16 | D35 | D50 | D84 | D95 |
| 0.167 | 0.71 | 2.97 | 26.5 | 45 |

| **Percent by substrate type (%)** | | | | | |
|---|---|---|---|---|---|
| Silt/Clay | Sand | Gravel | Cobble | Boulder | Bedrock |
| 0 | 46 | 49 | 5 | 0 | 0 |

# Bank Erodibility Hazard Rating Guide

**Stream**: Third Fork Creek **Reach:** XS1, Right Bank **Date:** 7/10/02 **Crew:** BG, KN

| Bank Erosion Potential | Bank Height (ft): 6.72<br>Bankfull Height (ft): 2.48 | | Bank Height/ Bankfull Ht | | Root Depth/ Bank Height | | Root Density % | | Bank Angle (Degrees) | | Surface Protection% | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | VERY LOW | Value Range | 1.0 | 1.1 | 1.0 | 0.9 | 80 | 100 | 0.0 | 20.0 | 80 | 100 |
| | | Index Range | 1.0 | 1.9 | 1.0 | 1.9 | 1.0 | 1.9 | 1.0 | 1.9 | 1.0 | 1.9 |
| | | **Choice** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** |
| | LOW | Value Range | 1.11 | 1.19 | 0.5 | 0.89 | 55 | 79 | 21.0 | 60.0 | 55 | 79 |
| | | Index Range | 2.0 | 3.9 | 2.0 | 3.9 | 2.0 | 3.9 | 2.0 | 3.9 | 2.0 | 3.9 |
| | | **Choice** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** |
| | MODERATE | Value Range | 1.2 | 1.5 | 0.3 | 0.49 | 30 | 54 | 61.0 | 80.0 | 30 | 54 |
| | | Index Range | 4.0 | 5.9 | 4.0 | 5.9 | 4.0 | 5.9 | 4.0 | 5.9 | 4.0 | 5.9 |
| | | **Choice** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** |
| | HIGH | Value Range | 1.6 | 2.0 | 0.15 | 0.29 | 15 | 29 | 81.0 | 90.0 | 15 | 29 |
| | | Index Range | 6.0 | 7.9 | 6.0 | 7.9 | 6.0 | 7.9 | 6.0 | 7.9 | 6.0 | 7.9 |
| | | **Choice** | **V:** | **I:** | **V: 0.18** | **I: 6.4** | **V: 20.0** | **I: 6.7** | **V:** | **I:** | **V: 20.0** | **I: 6.7** |
| | VERY HIGH | Value Range | 2.1 | 2.8 | 0.05 | 0.14 | 5 | 14 | 91.0 | 119.0 | 10 | 14 |
| | | Index Range | 8.0 | 9.0 | 8.0 | 9.0 | 8.0 | 9.0 | 8.0 | 9.0 | 8.0 | 9.0 |
| | | **Choice** | **V: 2.7** | **I: 8.9** | **V:** | **I:** | **V:** | **I:** | **V: 97.0** | **I: 8.2** | **V:** | **I:** |
| | EXTREME | Value Range | >2.8 | | <0.05 | | <5 | | >119 | | <10 | |
| | | Index Range | 10 | | 10 | | 10 | | 10 | | 10 | |
| | | **Choice** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** |
| | V = value, I = index | | | | | | **SUB-TOTAL (Sum one index from each column)** | | | | | 36.8 |

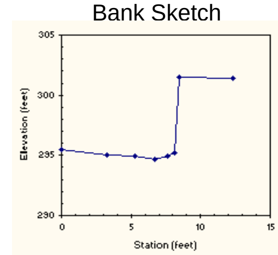
**Bank Material Description:**

Fine silty loam with significant sand component (in lenses and as deposition)

**Bank Materials**

- **Bedrock** (Bedrock banks have very low bank erosion potential)
- **Boulders** (Banks composed of boulders have low bank erosion potential)
- **Cobble** (Subtract 10 points. If sand/gravel matrix greater than 50% of bank material, then do not adjust)
- **Gravel** (Add 5-10 points depending percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt Clay** (+ 0: no adjustment)

Bank Sketch




**BANK MATERIAL ADJUSTMENT** 10

**Stratification Comments:**

No stratification

**Stratification**

Add 5-10 points depending on position of unstable layers in relation to bankfull stage

**STRATIFICATION ADJUSTMENT** 0

| VERY LOW | LOW | MODERATE | HIGH | VERY HIGH | EXTREME |
|---|---|---|---|---|---|
| 5-9.9 | 10-19.9 | 20-29.9 | 30-39.9 | 40-45.9 | 46-50 |

**Bank location description (check one)**

Straight Reach X Outside of Bend

**GRAND TOTAL** 46.8

**BEHI RATING** EXTREME

*Third Fork Creek Stream Restoration Project*

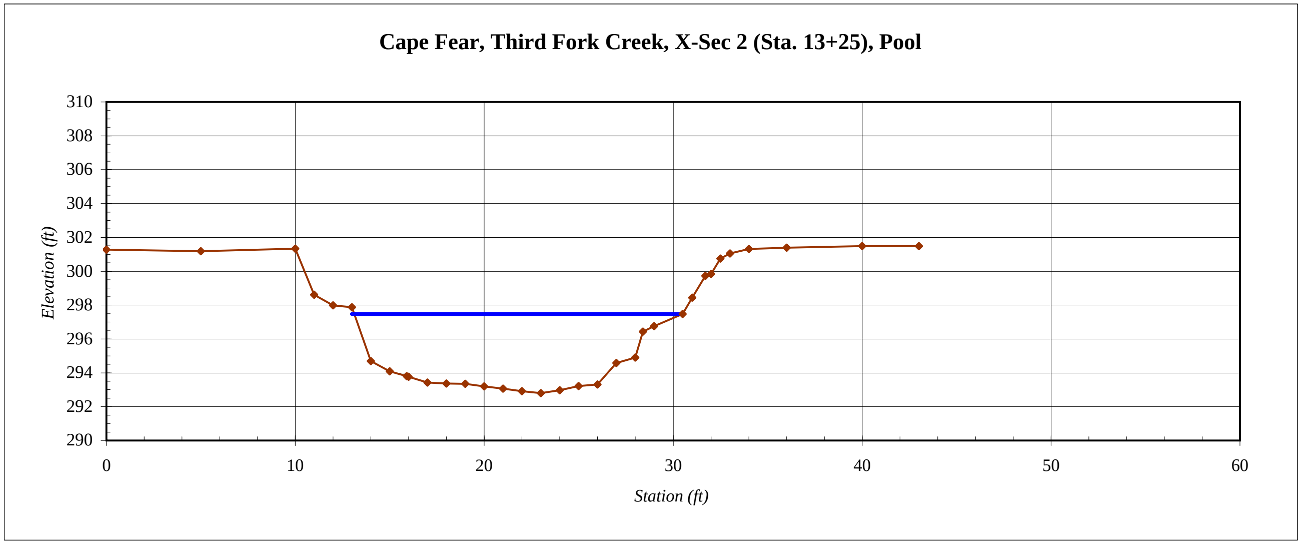
**Existing Conditions**

| | |
|---|---|
| **River Basin:** | Cape Fear, |
| **Watershed:** | Third Fork Creek, |
| **XS ID** | X-Sec 2 (Sta. 13+25), Pool |
| **Drainage Area ($mi^2$):** | 0.80 |
| **Date:** | 7/8/2002 |
| **Field Crew:** | D. Redgate, K. Nimmer, B. Greco |

View looking downstream

| Station | Rod Ht. | Elevation |
|---|---|---|
| 0.0 | 7.05 | 301.27 |
| 5.0 | 7.14 | 301.18 |
| 10.0 | 6.99 | 301.33 |
| 11.0 | 9.72 | 298.60 |
| 12.0 | 10.34 | 297.98 |
| 13.0 | 10.45 | 297.87 |
| 14.0 | 13.62 | 294.70 |
| 15.0 | 14.23 | 294.09 |
| 15.9 | 14.52 | 293.80 |
| 16.0 | 14.55 | 293.77 |
| 17.0 | 14.90 | 293.42 |
| 18.0 | 14.95 | 293.37 |
| 19.0 | 14.98 | 293.34 |
| 20.0 | 15.13 | 293.19 |
| 21.0 | 15.26 | 293.06 |
| 22.0 | 15.40 | 292.92 |
| 23.0 | 15.52 | 292.80 |
| 24.0 | 15.34 | 292.98 |
| 25.0 | 15.11 | 293.21 |
| 26.0 | 15.00 | 293.32 |
| 27.0 | 13.75 | 294.57 |
| 28.0 | 13.41 | 294.91 |
| 28.4 | 11.88 | 296.44 |
| 29.0 | 11.56 | 296.76 |
| 30.5 | 10.85 | 297.47 |
| 31.0 | 9.88 | 298.44 |
| 31.7 | 8.60 | 299.72 |
| 32.0 | 8.49 | 299.83 |
| 32.5 | 7.57 | 300.75 |
| 33.0 | 7.27 | 301.05 |
| 34.0 | 7.00 | 301.32 |
| 36.0 | 6.92 | 301.40 |
| 40.0 | 6.84 | 301.48 |
| 43.0 | 6.83 | 301.49 |
| 45.0 | 6.85 | 301.47 |

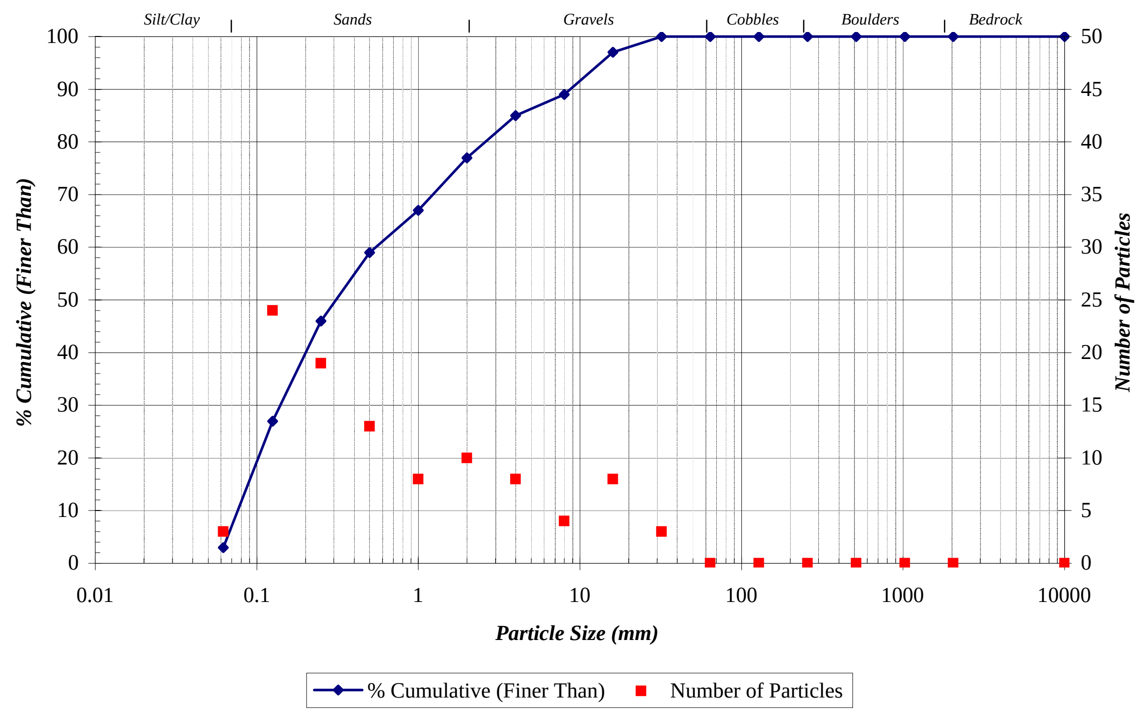
| Summary Data | |
|---|---|
| **Bankfull Width (ft):** | 17.4 |
| **Mean Bankfull Depth (ft):** | 3.4 |
| **Width / Depth Ratio:** | - |
| **Bankfull Area ($ft^2$):** | 58.7 |
| **Entrenchment Ratio:** | - |
| **Max. Depth Bankfull (ft):** | 4.7 |
| **Bank Height Ratio:** | 1.81 |
| **Local WS Slope (ft/ft) (%):** | 0.05 |
| **Discharge (cfs):** | - |
| **$D_{50}$ (mm):** | 0.31 |
| **Rosgen Stream Type:** | G5 |



*Third Fork Creek Stream Restoration Project*
**Existing Conditions**

| | |
|---|---|
| **Stream:** | Third Fork Creek |
| **Location:** | Cross-section 2 (Sta. 13+25) |
| **Date:** | |

| Particle | | Size Range (mm) | Total # | Item % | % Cum. |
|---|---|---|---|---|---|
| S/C | Silt/Clay | 0 < 0.062 | 3 | 3 | 3 |
| Sand | Very Fine Sand | 0.062 < 0.125 | 24 | 24 | 27 |
| | Fine Sand | 0.125 < 0.25 | 19 | 19 | 46 |
| | Medium Sand | 0.25 < 0.50 | 13 | 13 | 59 |
| | Coarse Sand | 0.50 < 1.0 | 8 | 8 | 67 |
| | Very Coarse Sand | 1 < 2 | 10 | 10 | 77 |
| Gravel | Very Fine Gravel | 2 < 4 | 8 | 8 | 85 |
| | Fine Gravel | 4 < 8 | 4 | 4 | 89 |
| | Medium Gravel | 8 < 16 | 8 | 8 | 97 |
| | Coarse Gravel | 16 < 32 | 3 | 3 | 100 |
| | Very Coarse Gravel | 32 < 64 | 0 | 0 | 100 |
| Cbl | Small Cobble | 64 < 128 | 0 | 0 | 100 |
| | Large Cobble | 128 < 256 | 0 | 0 | 100 |
| Bldr | Small Boulder | 256 < 512 | 0 | 0 | 100 |
| | Medium Boulder | 512 < 1024 | 0 | 0 | 100 |
| | Large Boulder | 1024 < 2048 | 0 | 0 | 100 |
| Bdrk | Bedrock | Bedrock | 0 | 0 | 100 |
| | | ***Totals:*** | 100 | 100 | 100 |




| Size percent less than (mm) | | | | |
|---|---|---|---|---|
| D16 | D35 | D50 | D84 | D95 |
| 0.091 | 0.17 | 0.31 | 3.7 | 11 |

| Percent by substrate type (%) | | | | | |
|---|---|---|---|---|---|
| Silt/Clay | Sand | Gravel | Cobble | Boulder | Bedrock |
| 3 | 74 | 23 | 0 | 0 | 0 |

# Bank Erodibility Hazard Rating Guide

**Stream**: Third Fork Creek **Reach:** XS2, Right Bank **Date:** 7/10/02 **Crew:** BG, KN

**Bank Erosion Potential**

| Bank Height (ft): | 8.60 | Bank Height/ Bankfull Ht | | Root Depth/ Bank Height | | Root Density % | | Bank Angle (Degrees) | | Surface Protection% | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bankfull Height (ft): | 5.80 | | | | | | | | | | |
| VERY LOW | Value Range | 1.0 | 1.1 | 1.0 | 0.9 | 80 | 100 | 0.0 | 20.0 | 80 | 100 |
| | Index Range | 1.0 | 1.9 | 1.0 | 1.9 | 1.0 | 1.9 | 1.0 | 1.9 | 1.0 | 1.9 |
| | **Choice** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** |
| LOW | Value Range | 1.11 | 1.19 | 0.5 | 0.89 | 55 | 79 | 21.0 | 60.0 | 55 | 79 |
| | Index Range | 2.0 | 3.9 | 2.0 | 3.9 | 2.0 | 3.9 | 2.0 | 3.9 | 2.0 | 3.9 |
| | **Choice** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** |
| MODERATE | Value Range | 1.2 | 1.5 | 0.3 | 0.49 | 30 | 54 | 61.0 | 80.0 | 30 | 54 |
| | Index Range | 4.0 | 5.9 | 4.0 | 5.9 | 4.0 | 5.9 | 4.0 | 5.9 | 4.0 | 5.9 |
| | **Choice** | **V: 1.5** | **I: 5.9** | **V:** | **I:** | **V: 50.0** | **I: 5.6** | **V: 80.0** | **I: 5.9** | **V: 50.0** | **I: 5.6** |
| HIGH | Value Range | 1.6 | 2.0 | 0.15 | 0.29 | 15 | 29 | 81.0 | 90.0 | 15 | 29 |
| | Index Range | 6.0 | 7.9 | 6.0 | 7.9 | 6.0 | 7.9 | 6.0 | 7.9 | 6.0 | 7.9 |
| | **Choice** | **V:** | **I:** | **V: 0.29** | **I: 7.9** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** |
| VERY HIGH | Value Range | 2.1 | 2.8 | 0.05 | 0.14 | 5 | 14 | 91.0 | 119.0 | 10 | 14 |
| | Index Range | 8.0 | 9.0 | 8.0 | 9.0 | 8.0 | 9.0 | 8.0 | 9.0 | 8.0 | 9.0 |
| | **Choice** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** |
| EXTREME | Value Range | >2.8 | | <0.05 | | <5 | | >119 | | <10 | |
| | Index Range | 10 | | 10 | | 10 | | 10 | | 10 | |
| | **Choice** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** |
| V = value, I = index | | **SUB-TOTAL (Sum one index from each column)** | | | | | | | | 30.9 | |

**Bank Material Description:**

Fine silty/sandy loam

**Bank Materials**

**Bedrock** (Bedrock banks have very low bank erosion potential)

**Boulders** (Banks composed of boulders have low bank erosion potential)

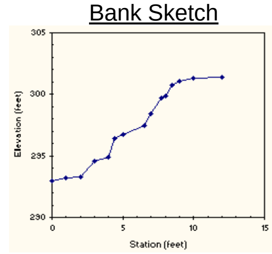
**Cobble** (Subtract 10 points. If sand/gravel matrix greater than 50% of bank material, then do not adjust)

**Gravel** (Add 5-10 points depending percentage of bank material that is composed of sand)

**Sand** (Add 10 points)

**Silt Clay** (+ 0: no adjustment)

Bank Sketch




**BANK MATERIAL ADJUSTMENT** 10

**Stratification Comments:**

No stratification

**Stratification**

Add 5-10 points depending on position of unstable layers in relation to bankfull stage

**STRATIFICATION ADJUSTMENT** 0

| VERY LOW | LOW | MODERATE | HIGH | VERY HIGH | EXTREME |
|---|---|---|---|---|---|
| 5-9.9 | 10-19.9 | 20-29.9 | 30-39.9 | 40-45.9 | 46-50 |

**Bank location description (check one)**

Straight Reach X Outside of Bend

**GRAND TOTAL** 40.9

**BEHI RATING** VERY HIGH

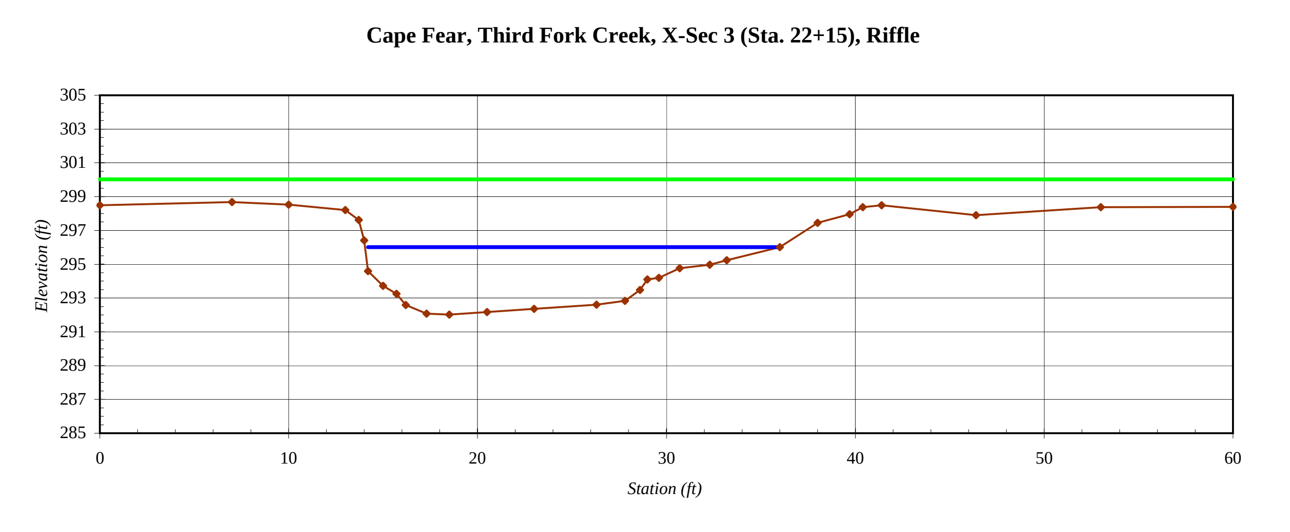
*Third Fork Creek Stream Restoration Project*
**Existing Conditions**

| | |
|---|---|
| **River Basin:** | Cape Fear, |
| **Watershed:** | Third Fork Creek, |
| **XS ID** | X-Sec 3 (Sta. 22+15), Riffle |
| **Drainage Area ($mi^2$):** | 1.10 |
| **Date:** | 7/8/2002 |
| **Field Crew:** | D. Redgate, K. Nimmer, B. Greco |

| Station | Rod Ht. | Elevation |
|---|---|---|
| 0.0 | 4.75 | 298.50 |
| 7.0 | 4.57 | 298.68 |
| 10.0 | 4.72 | 298.53 |
| 13.0 | 5.05 | 298.20 |
| 13.7 | 5.62 | 297.63 |
| 14.0 | 6.84 | 296.41 |
| 14.2 | 8.66 | 294.59 |
| 15.0 | 9.52 | 293.73 |
| 15.7 | 10.00 | 293.25 |
| 16.2 | 10.66 | 292.59 |
| 17.3 | 11.18 | 292.07 |
| 18.5 | 11.23 | 292.02 |
| 20.5 | 11.08 | 292.17 |
| 23.0 | 10.89 | 292.36 |
| 26.3 | 10.64 | 292.61 |
| 27.8 | 10.42 | 292.83 |
| 28.6 | 9.78 | 293.47 |
| 29.0 | 9.15 | 294.10 |
| 29.6 | 9.05 | 294.20 |
| 30.7 | 8.48 | 294.77 |
| 32.3 | 8.27 | 294.98 |
| 33.2 | 8.01 | 295.24 |
| 36.0 | 7.23 | 296.02 |
| 38.0 | 5.80 | 297.45 |
| 39.7 | 5.29 | 297.96 |
| 40.4 | 4.87 | 298.38 |
| 41.4 | 4.75 | 298.50 |
| 46.4 | 5.35 | 297.90 |
| 53.0 | 4.88 | 298.37 |
| 60.0 | 4.85 | 298.40 |

| Summary Data | |
|---|---|
| **Bankfull Width (ft):** | 21.8 |
| **Mean Bankfull Depth (ft):** | 2.6 |
| **Width / Depth Ratio:** | 8.3 |
| **Bankfull Area ($ft^2$):** | 57.2 |
| **Entrenchment Ratio:** | 18.3 |
| **Max. Depth Bankfull (ft):** | 4.0 |
| **Bank Height Ratio:** | 1.55 |
| **Local WS Slope (ft/ft) (%):** | 0.24 |
| **Discharge (cfs):** | 267.9 |
| **$D_{50}$ (mm):** | 0.38 |
| **Rosgen Stream Type:** | E5 |

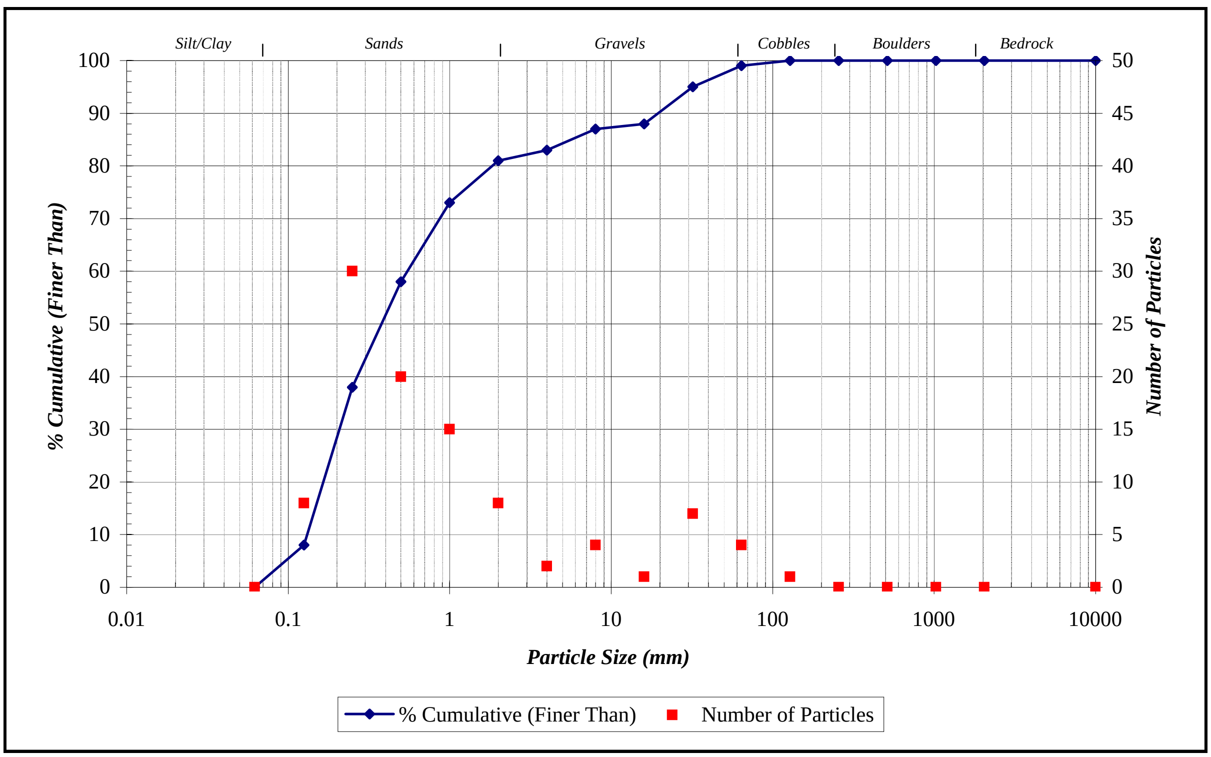
View looking upstream



*Third Fork Creek Stream Restoration Project*
**Existing Conditions**

| | |
|---|---|
| **Stream:** | Third Fork Creek |
| **Location:** | Cross-section 3 (Sta. 22+15) |
| **Date:** | |

| Particle | | Size Range (mm) | Total # | Item % | % Cum. |
|---|---|---|---|---|---|
| S/C | Silt/Clay | 0 < 0.062 | 0 | 0 | 0 |
| Sand | Very Fine Sand | 0.062 < 0.125 | 8 | 8 | 8 |
| | Fine Sand | 0.125 < 0.25 | 30 | 30 | 38 |
| | Medium Sand | 0.25 < 0.50 | 20 | 20 | 58 |
| | Coarse Sand | 0.50 < 1.0 | 15 | 15 | 73 |
| | Very Coarse Sand | 1 < 2 | 8 | 8 | 81 |
| Gravel | Very Fine Gravel | 2 < 4 | 2 | 2 | 83 |
| | Fine Gravel | 4 < 8 | 4 | 4 | 87 |
| | Medium Gravel | 8 < 16 | 1 | 1 | 88 |
| | Coarse Gravel | 16 < 32 | 7 | 7 | 95 |
| | Very Coarse Gravel | 32 < 64 | 4 | 4 | 99 |
| Cbl | Small Cobble | 64 < 128 | 1 | 1 | 100 |
| | Large Cobble | 128 < 256 | 0 | 0 | 100 |
| Bldr | Small Boulder | 256 < 512 | 0 | 0 | 100 |
| | Medium Boulder | 512 < 1024 | 0 | 0 | 100 |
| | Large Boulder | 1024 < 2048 | 0 | 0 | 100 |
| Bdrk | Bedrock | Bedrock | 0 | 0 | 100 |
| | | ***Totals:*** | 100 | 100 | 100 |




| Size percent less than (mm) | | | | |
|---|---|---|---|---|
| D16 | D35 | D50 | D84 | D95 |
| 0.15 | 0.23 | 0.38 | 6 | 32 |

| Percent by substrate type (%) | | | | | |
|---|---|---|---|---|---|
| Silt/Clay | Sand | Gravel | Cobble | Boulder | Bedrock |
| 0 | 81 | 18 | 1 | 0 | 0 |

# Bank Erodibility Hazard Rating Guide

**Stream**: Third Fork Creek **Reach:** XS3, Left Bank **Date:** 7/10/02 **Crew:** BG, KN

**Bank Erosion Potential**

| Bank Height (ft): 6.66<br>Bankfull Height (ft): 4.00 | | Bank Height/ Bankfull Ht | | Root Depth/ Bank Height | | Root Density % | | Bank Angle (Degrees) | | Surface Protection% | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **VERY LOW** | Value Range | 1.0 | 1.1 | 1.0 | 0.9 | 80 | 100 | 0.0 | 20.0 | 80 | 100 |
| | Index Range | 1.0 | 1.9 | 1.0 | 1.9 | 1.0 | 1.9 | 1.0 | 1.9 | 1.0 | 1.9 |
| | **Choice** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** |
| **LOW** | Value Range | 1.11 | 1.19 | 0.5 | 0.89 | 55 | 79 | 21.0 | 60.0 | 55 | 79 |
| | Index Range | 2.0 | 3.9 | 2.0 | 3.9 | 2.0 | 3.9 | 2.0 | 3.9 | 2.0 | 3.9 |
| | **Choice** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** |
| **MODERATE** | Value Range | 1.2 | 1.5 | 0.3 | 0.49 | 30 | 54 | 61.0 | 80.0 | 30 | 54 |
| | Index Range | 4.0 | 5.9 | 4.0 | 5.9 | 4.0 | 5.9 | 4.0 | 5.9 | 4.0 | 5.9 |
| | **Choice** | **V:** | **I:** | **V: 0.45** | **I: 5.5** | **V: 54.0** | **I: 5.9** | **V:** | **I:** | **V: 30.0** | **I: 4.0** |
| **HIGH** | Value Range | 1.6 | 2.0 | 0.15 | 0.29 | 15 | 29 | 81.0 | 90.0 | 15 | 29 |
| | Index Range | 6.0 | 7.9 | 6.0 | 7.9 | 6.0 | 7.9 | 6.0 | 7.9 | 6.0 | 7.9 |
| | **Choice** | **V: 1.7** | **I: 6.5** | **V:** | **I:** | **V:** | **I:** | **V: 90.0** | **I: 7.9** | **V:** | **I:** |
| **VERY HIGH** | Value Range | 2.1 | 2.8 | 0.05 | 0.14 | 5 | 14 | 91.0 | 119.0 | 10 | 14 |
| | Index Range | 8.0 | 9.0 | 8.0 | 9.0 | 8.0 | 9.0 | 8.0 | 9.0 | 8.0 | 9.0 |
| | **Choice** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** |
| **EXTREME** | Value Range | >2.8 | | <0.05 | | <5 | | >119 | | <10 | |
| | Index Range | 10 | | 10 | | 10 | | 10 | | 10 | |
| | **Choice** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** | **V:** | **I:** |
| V = value, I = index | | | | | | | **SUB-TOTAL (Sum one index from each column)** | | | | 29.8 |

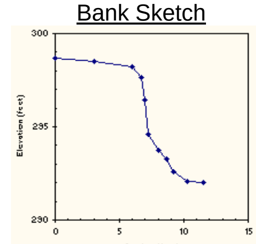
**Bank Material Description:**

Fine silty/sandy loam

**Bank Materials**

- **Bedrock** (Bedrock banks have very low bank erosion potential)
- **Boulders** (Banks composed of boulders have low bank erosion potential)
- **Cobble** (Subtract 10 points. If sand/gravel matrix greater than 50% of bank material, then do not adjust)
- **Gravel** (Add 5-10 points depending percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt Clay** (+ 0: no adjustment)

Bank Sketch




**BANK MATERIAL ADJUSTMENT** 10

**Stratification Comments:**

No Stratification

**Stratification**

Add 5-10 points depending on position of unstable layers in relation to bankfull stage

**STRATIFICATION ADJUSTMENT** 0

| VERY LOW | LOW | MODERATE | HIGH | VERY HIGH | EXTREME |
|---|---|---|---|---|---|
| 5-9.9 | 10-19.9 | 20-29.9 | 30-39.9 | 40-45.9 | 46-50 |

**Bank location description (check one)**

Straight Reach X Outside of Bend

**GRAND TOTAL** 39.8

**BEHI RATING** HIGH

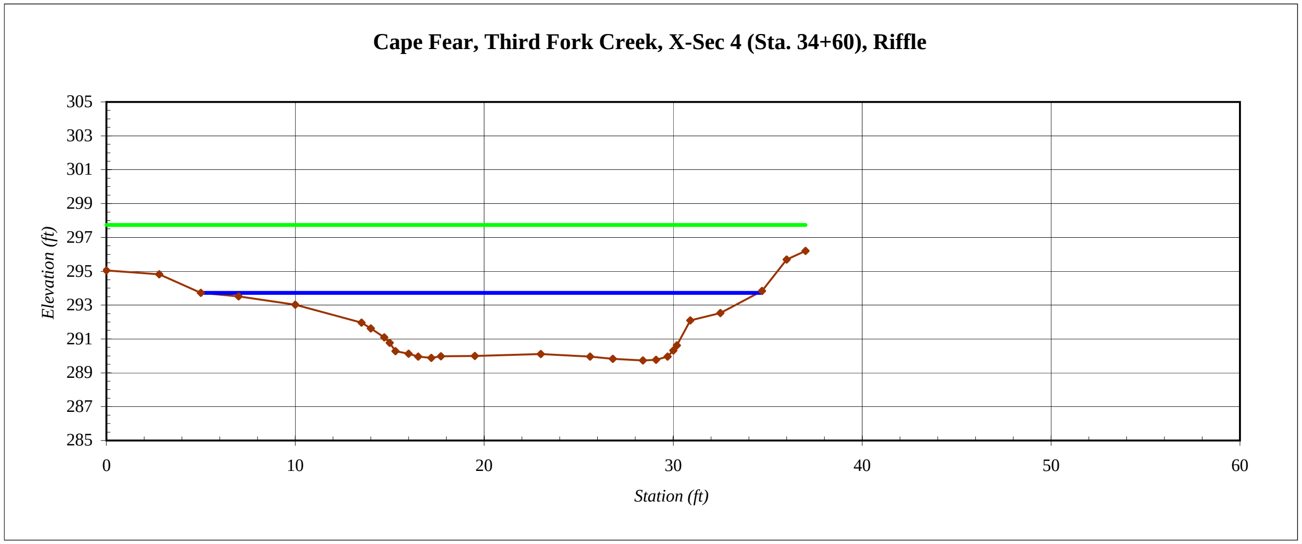
*Third Fork Creek Stream Restoration Project*
**Existing Conditions**

| | |
|---|---|
| **River Basin:** | Cape Fear, |
| **Watershed:** | Third Fork Creek, |
| **XS ID** | X-Sec 4 (Sta. 34+60), Riffle |
| **Drainage Area ($mi^2$):** | 1.76 |
| **Date:** | 7/8/2002 |
| **Field Crew:** | D. Redgate, K. Nimmer, B. Greco |

| Station | Rod Ht. | Elevation |
|---|---|---|
| 0.0 | 5.53 | 295.04 |
| 2.8 | 5.75 | 294.82 |
| 5.0 | 6.84 | 293.73 |
| 7.0 | 7.06 | 293.51 |
| 10.0 | 7.54 | 293.03 |
| 13.5 | 8.61 | 291.96 |
| 14.0 | 8.94 | 291.63 |
| 14.7 | 9.47 | 291.10 |
| 15.0 | 9.79 | 290.78 |
| 15.3 | 10.29 | 290.28 |
| 16.0 | 10.45 | 290.12 |
| 16.5 | 10.61 | 289.96 |
| 17.2 | 10.68 | 289.89 |
| 17.7 | 10.59 | 289.98 |
| 19.5 | 10.57 | 290.00 |
| 23.0 | 10.47 | 290.10 |
| 25.6 | 10.61 | 289.96 |
| 26.8 | 10.75 | 289.82 |
| 28.4 | 10.84 | 289.73 |
| 29.1 | 10.80 | 289.77 |
| 29.7 | 10.61 | 289.96 |
| 30.0 | 10.25 | 290.32 |
| 30.2 | 9.95 | 290.62 |
| 30.9 | 8.48 | 292.09 |
| 32.5 | 8.04 | 292.53 |
| 34.7 | 6.74 | 293.83 |
| 36.0 | 4.87 | 295.70 |
| 37.0 | 4.36 | 296.21 |

| Summary Data | |
|---|---|
| **Bankfull Width (ft):** | 29.5 |
| **Mean Bankfull Depth (ft):** | 2.4 |
| **Width / Depth Ratio:** | 12.2 |
| **Bankfull Area ($ft^2$):** | 71.4 |
| **Entrenchment Ratio:** | 6.8 |
| **Max. Depth Bankfull (ft):** | 4.0 |
| **Bank Height Ratio:** | 1.27 |
| **Local WS Slope (ft/ft) (%):** | 0.25 |
| **Discharge (cfs):** | 322.0 |
| **$D_{50}$ (mm):** | 0.44 |
| **Rosgen Stream Type:** | C5 |

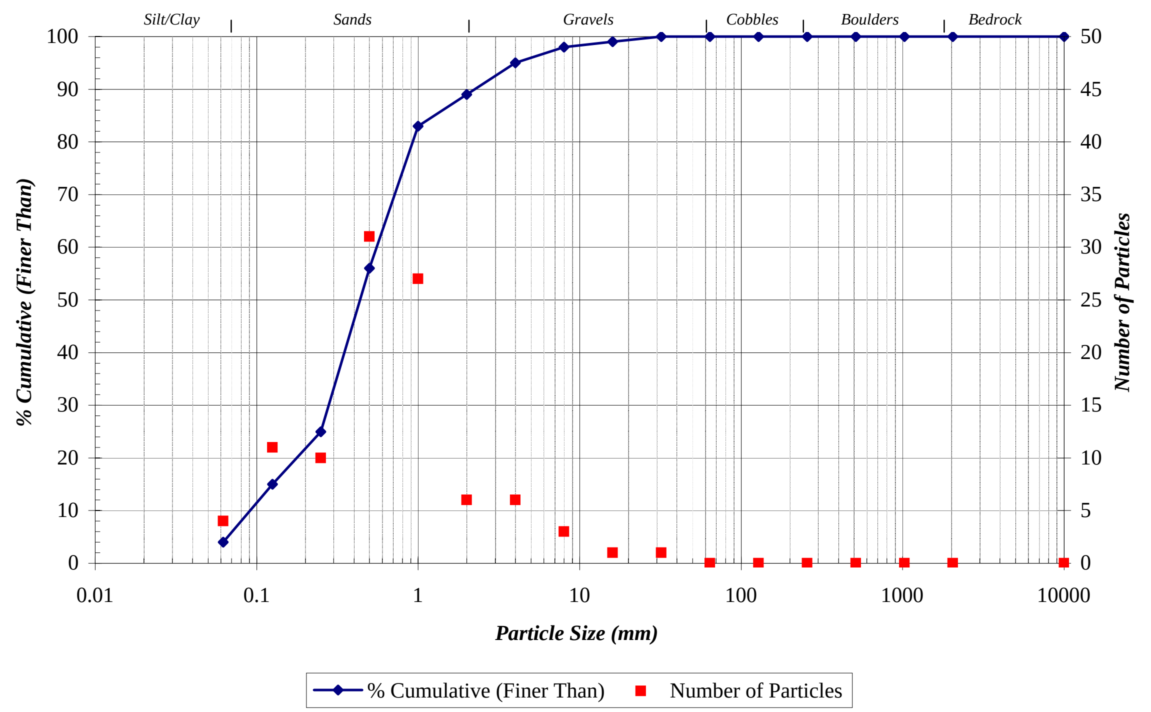
View looking downstream



*Third Fork Creek Stream Restoration Project*
**Existing Conditions**

| | |
|---|---|
| **Stream:** | Third Fork Creek |
| **Location:** | Cross-section 4 (Sta. 34+60) |
| **Date:** | |

| Particle | | Size Range (mm) | Total # | Item % | % Cum. |
|---|---|---|---|---|---|
| S/C | Silt/Clay | 0 < 0.062 | 4 | 4 | 4 |
| Sand | Very Fine Sand | 0.062 < 0.125 | 11 | 11 | 15 |
| | Fine Sand | 0.125 < 0.25 | 10 | 10 | 25 |
| | Medium Sand | 0.25 < 0.50 | 31 | 31 | 56 |
| | Coarse Sand | 0.50 < 1.0 | 27 | 27 | 83 |
| | Very Coarse Sand | 1 < 2 | 6 | 6 | 89 |
| Gravel | Very Fine Gravel | 2 < 4 | 6 | 6 | 95 |
| | Fine Gravel | 4 < 8 | 3 | 3 | 98 |
| | Medium Gravel | 8 < 16 | 1 | 1 | 99 |
| | Coarse Gravel | 16 < 32 | 1 | 1 | 100 |
| | Very Coarse Gravel | 32 < 64 | 0 | 0 | 100 |
| Cbl | Small Cobble | 64 < 128 | 0 | 0 | 100 |
| | Large Cobble | 128 < 256 | 0 | 0 | 100 |
| Bldr | Small Boulder | 256 < 512 | 0 | 0 | 100 |
| | Medium Boulder | 512 < 1024 | 0 | 0 | 100 |
| | Large Boulder | 1024 < 2048 | 0 | 0 | 100 |
| Bdrk | Bedrock | Bedrock | 0 | 0 | 100 |
| | | ***Totals:*** | 100 | 100 | 100 |




| Size percent less than (mm) | | | | |
|---|---|---|---|---|
| D16 | D35 | D50 | D84 | D95 |
| 0.134 | 0.31 | 0.44 | 1.1 | 4 |

| Percent by substrate type (%) | | | | | |
|---|---|---|---|---|---|
| Silt/Clay | Sand | Gravel | Cobble | Boulder | Bedrock |
| 4 | 85 | 11 | 0 | 0 | 0 |

# Bank Erodibility Hazard Rating Guide

**Stream**: Third Fork Creek **Reach:** XS4, Right Bank **Date:** 11/19/02 **Crew:** BG

| Bank Erosion Potential | Bank Height (ft): 5.50<br>Bankfull Height (ft): 4.10 | | Bank Height/ Bankfull Ht | | Root Depth/ Bank Height | | Root Density % | | Bank Angle (Degrees) | | Surface Protection% | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | VERY LOW | Value Range | 1.0 | 1.1 | 1.0 | 0.9 | 80 | 100 | 0.0 | 20.0 | 80 | 100 |
| | | Index Range | 1.0 | 1.9 | 1.0 | 1.9 | 1.0 | 1.9 | 1.0 | 1.9 | 1.0 | 1.9 |
| | | Choice | V: | I: | V: | I: | V: | I: | V: | I: | V: | I: |
| | LOW | Value Range | 1.11 | 1.19 | 0.5 | 0.89 | 55 | 79 | 21.0 | 60.0 | 55 | 79 |
| | | Index Range | 2.0 | 3.9 | 2.0 | 3.9 | 2.0 | 3.9 | 2.0 | 3.9 | 2.0 | 3.9 |
| | | Choice | V: | I: | V: | I: | V: 55.0 | I: 2.0 | V: 45.0 | I: 3.2 | V: 65.0 | I: 2.8 |
| | MODERATE | Value Range | 1.2 | 1.5 | 0.3 | 0.49 | 30 | 54 | 61.0 | 80.0 | 30 | 54 |
| | | Index Range | 4.0 | 5.9 | 4.0 | 5.9 | 4.0 | 5.9 | 4.0 | 5.9 | 4.0 | 5.9 |
| | | Choice | V: 1.3 | I: 4.6 | V: 0.37 | I: 4.7 | V: | I: | V: | I: | V: | I: |
| | HIGH | Value Range | 1.6 | 2.0 | 0.15 | 0.29 | 15 | 29 | 81.0 | 90.0 | 15 | 29 |
| | | Index Range | 6.0 | 7.9 | 6.0 | 7.9 | 6.0 | 7.9 | 6.0 | 7.9 | 6.0 | 7.9 |
| | | Choice | V: | I: | V: | I: | V: | I: | V: | I: | V: | I: |
| | VERY HIGH | Value Range | 2.1 | 2.8 | 0.05 | 0.14 | 5 | 14 | 91.0 | 119.0 | 10 | 14 |
| | | Index Range | 8.0 | 9.0 | 8.0 | 9.0 | 8.0 | 9.0 | 8.0 | 9.0 | 8.0 | 9.0 |
| | | Choice | V: | I: | V: | I: | V: | I: | V: | I: | V: | I: |
| | EXTREME | Value Range | >2.8 | | <0.05 | | <5 | | >119 | | <10 | |
| | | Index Range | 10 | | 10 | | 10 | | 10 | | 10 | |
| | | Choice | V: | I: | V: | I: | V: | I: | V: | I: | V: | I: |
| | V = value, I = index | | | | | | SUB-TOTAL (Sum one index from each column) | | | | | 17.3 |

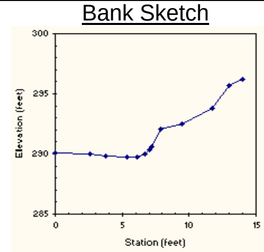
**Bank Material Description:**

Fine silty/sandy loam

**Bank Materials**

**Bedrock** (Bedrock banks have very low bank erosion potential)
**Boulders** (Banks composed of boulders have low bank erosion potential)
**Cobble** (Subtract 10 points. If sand/gravel matrix greater than 50% of bank material, then do not adjust)
**Gravel** (Add 5-10 points depending percentage of bank material that is composed of sand)
**Sand** (Add 10 points)
**Silt Clay** (+ 0: no adjustment)

Bank Sketch




**BANK MATERIAL ADJUSTMENT** 8

**Stratification Comments:**

No Stratification

**Stratification**

Add 5-10 points depending on position of unstable layers in relation to bankfull stage

**STRATIFICATION ADJUSTMENT** 0

| VERY LOW | LOW | MODERATE | HIGH | VERY HIGH | EXTREME |
|---|---|---|---|---|---|
| 5-9.9 | 10-19.9 | 20-29.9 | 30-39.9 | 40-45.9 | 46-50 |

**Bank location description (check one)**

Straight Reach [X] Outside of Bend [ ]

**GRAND TOTAL** 25.3

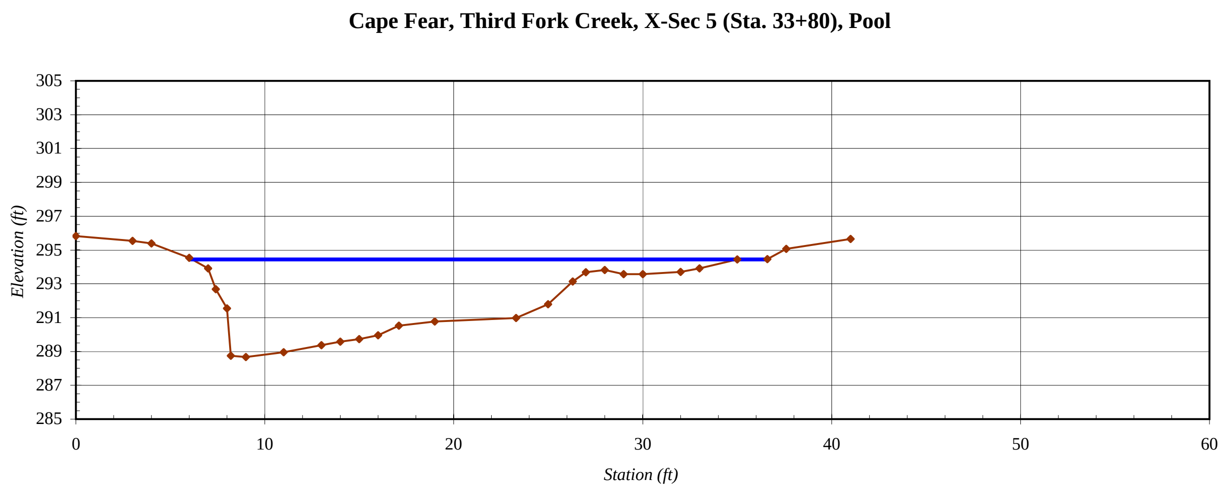
**BEHI RATING** MODERATE

| | |
|---|---|
| **River Basin:** | Cape Fear, |
| **Watershed:** | Third Fork Creek, |
| **XS ID** | X-Sec 5 (Sta. 33+80), Pool |
| **Drainage Area ($mi^2$):** | 1.76 |
| **Date:** | 7/8/2002 |
| **Field Crew:** | D. Redgate, K. Nimmer, B. Greco |

View looking downstream

| Station | Rod Ht. | Elevation |
|---|---|---|
| 0.0 | 4.37 | 295.83 |
| 3.0 | 4.67 | 295.53 |
| 4.0 | 4.82 | 295.38 |
| 6.0 | 5.67 | 294.53 |
| 7.0 | 6.29 | 293.91 |
| 7.4 | 7.52 | 292.68 |
| 8.0 | 8.65 | 291.55 |
| 8.2 | 11.46 | 288.74 |
| 9.0 | 11.53 | 288.67 |
| 11.0 | 11.25 | 288.95 |
| 13.0 | 10.82 | 289.38 |
| 14.0 | 10.62 | 289.58 |
| 15.0 | 10.47 | 289.73 |
| 16.0 | 10.24 | 289.96 |
| 17.1 | 9.68 | 290.52 |
| 19.0 | 9.42 | 290.78 |
| 23.3 | 9.22 | 290.98 |
| 25.0 | 8.41 | 291.79 |
| 26.3 | 7.07 | 293.13 |
| 27.0 | 6.51 | 293.69 |
| 28.0 | 6.38 | 293.82 |
| 29.0 | 6.62 | 293.58 |
| 30.0 | 6.63 | 293.57 |
| 32.0 | 6.50 | 293.70 |
| 33.0 | 6.29 | 293.91 |
| 35.0 | 5.76 | 294.44 |
| 36.6 | 5.73 | 294.47 |
| 37.6 | 5.13 | 295.07 |
| 41.0 | 4.54 | 295.66 |

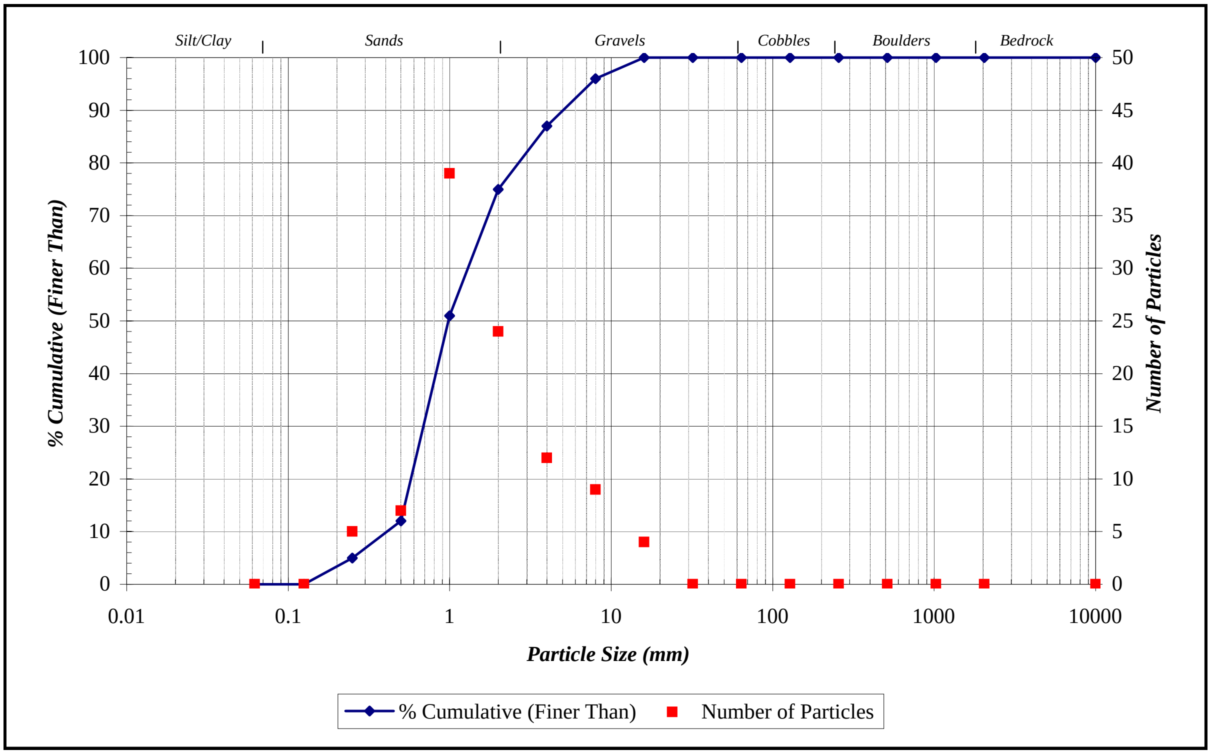
| Summary Data | |
|---|---|
| **Bankfull Width (ft):** | 28.9 |
| **Mean Bankfull Depth (ft):** | 2.9 |
| **Width / Depth Ratio:** | - |
| **Bankfull Area ($ft^2$):** | 84.4 |
| **Entrenchment Ratio:** | - |
| **Max. Depth Bankfull (ft):** | 5.8 |
| **Bank Height Ratio:** | - |
| **Local WS Slope (ft/ft) (%):** | 0.04 |
| **Discharge (cfs):** | - |
| **$D_{50}$ (mm):** | 0.98 |
| **Rosgen Stream Type:** | C5 |



*Third Fork Creek Stream Restoration Project*
**Existing Conditions**

| | |
|---|---|
| **Stream:** | Third Fork Creek |
| **Location:** | Cross-section 5 (Sta. 33+80) |
| **Date:** | |

| Particle | | Size Range (mm) | Total # | Item % | % Cum. |
|---|---|---|---|---|---|
| S/C | Silt/Clay | 0 < 0.062 | 0 | 0 | 0 |
| Sand | Very Fine Sand | 0.062 < 0.125 | 0 | 0 | 0 |
| | Fine Sand | 0.125 < 0.25 | 5 | 5 | 5 |
| | Medium Sand | 0.25 < 0.50 | 7 | 7 | 12 |
| | Coarse Sand | 0.50 < 1.0 | 39 | 39 | 51 |
| | Very Coarse Sand | 1 < 2 | 24 | 24 | 75 |
| Gravel | Very Fine Gravel | 2 < 4 | 12 | 12 | 87 |
| | Fine Gravel | 4 < 8 | 9 | 9 | 96 |
| | Medium Gravel | 8 < 16 | 4 | 4 | 100 |
| | Coarse Gravel | 16 < 32 | 0 | 0 | 100 |
| | Very Coarse Gravel | 32 < 64 | 0 | 0 | 100 |
| Cbl | Small Cobble | 64 < 128 | 0 | 0 | 100 |
| | Large Cobble | 128 < 256 | 0 | 0 | 100 |
| Bldr | Small Boulder | 256 < 512 | 0 | 0 | 100 |
| | Medium Boulder | 512 < 1024 | 0 | 0 | 100 |
| | Large Boulder | 1024 < 2048 | 0 | 0 | 100 |
| Bdrk | Bedrock | Bedrock | 0 | 0 | 100 |
| | | ***Totals:*** | 100 | 100 | 100 |




| **Size percent less than (mm)** | | | | |
|---|---|---|---|---|
| D16 | D35 | D50 | D84 | D95 |
| 0.54 | 0.75 | 0.98 | 3.4 | 7.6 |

| **Percent by substrate type (%)** | | | | | |
|---|---|---|---|---|---|
| Silt/Clay | Sand | Gravel | Cobble | Boulder | Bedrock |
| 0 | 75 | 25 | 0 | 0 | 0 |

# Bank Erodibility Hazard Rating Guide

**Stream**: Third Fork Creek **Reach:** XS5, Left Bank **Date:** 11/19/02 **Crew:** BG

| Bank Erosion Potential | Bank Height (ft): 7.16 / Bankfull Height (ft): 5.77 | Bank Height/ Bankfull Ht | | Root Depth/ Bank Height | | Root Density % | | Bank Angle (Degrees) | | Surface Protection% | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| VERY LOW | Value Range | 1.0 | 1.1 | 1.0 | 0.9 | 80 | 100 | 0.0 | 20.0 | 80 | 100 |
| | Index Range | 1.0 | 1.9 | 1.0 | 1.9 | 1.0 | 1.9 | 1.0 | 1.9 | 1.0 | 1.9 |
| | Choice | V: | I: | V: 1.0 | I: 1.0 | V: 80.0 | I: 1.0 | V: | I: | V: | I: |
| LOW | Value Range | 1.11 | 1.19 | 0.5 | 0.89 | 55 | 79 | 21.0 | 60.0 | 55 | 79 |
| | Index Range | 2.0 | 3.9 | 2.0 | 3.9 | 2.0 | 3.9 | 2.0 | 3.9 | 2.0 | 3.9 |
| | Choice | V: | I: | V: | I: | V: | I: | V: | I: | V: | I: |
| MODERATE | Value Range | 1.2 | 1.5 | 0.3 | 0.49 | 30 | 54 | 61.0 | 80.0 | 30 | 54 |
| | Index Range | 4.0 | 5.9 | 4.0 | 5.9 | 4.0 | 5.9 | 4.0 | 5.9 | 4.0 | 5.9 |
| | Choice | V: 1.2 | I: 4.0 | V: | I: | V: | I: | V: | I: | V: 50.0 | I: 5.6 |
| HIGH | Value Range | 1.6 | 2.0 | 0.15 | 0.29 | 15 | 29 | 81.0 | 90.0 | 15 | 29 |
| | Index Range | 6.0 | 7.9 | 6.0 | 7.9 | 6.0 | 7.9 | 6.0 | 7.9 | 6.0 | 7.9 |
| | Choice | V: | I: | V: | I: | V: | I: | V: 85.0 | I: 6.8 | V: | I: |
| VERY HIGH | Value Range | 2.1 | 2.8 | 0.05 | 0.14 | 5 | 14 | 91.0 | 119.0 | 10 | 14 |
| | Index Range | 8.0 | 9.0 | 8.0 | 9.0 | 8.0 | 9.0 | 8.0 | 9.0 | 8.0 | 9.0 |
| | Choice | V: | I: | V: | I: | V: | I: | V: | I: | V: | I: |
| EXTREME | Value Range | >2.8 | | <0.05 | | <5 | | >119 | | <10 | |
| | Index Range | 10 | | 10 | | 10 | | 10 | | 10 | |
| | Choice | V: | I: | V: | I: | V: | I: | V: | I: | V: | I: |

V = value, I = index

**SUB-TOTAL (Sum one index from each column)** 18.4

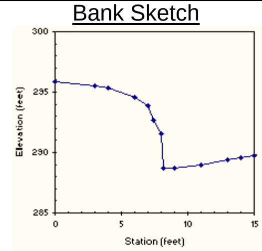
**Bank Material Description:**

Fine silty/sandy loam

**Bank Materials**

- **Bedrock** (Bedrock banks have very low bank erosion potential)
- **Boulders** (Banks composed of boulders have low bank erosion potential)
- **Cobble** (Subtract 10 points. If sand/gravel matrix greater than 50% of bank material, then do not adjust)
- **Gravel** (Add 5-10 points depending percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt Clay** (+ 0: no adjustment)

Bank Sketch




**BANK MATERIAL ADJUSTMENT** 8

**Stratification Comments:**

No Stratification

**Stratification**

Add 5-10 points depending on position of unstable layers in relation to bankfull stage

**STRATIFICATION ADJUSTMENT** 0

| VERY LOW | LOW | MODERATE | HIGH | VERY HIGH | EXTREME |
|---|---|---|---|---|---|
| 5-9.9 | 10-19.9 | 20-29.9 | 30-39.9 | 40-45.9 | 46-50 |

**Bank location description (check one)**

Straight Reach X Outside of Bend

**GRAND TOTAL** 26.4

**BEHI RATING** MODERATE

# Appendix B

## Reference Reach Data

Michael F. Easley, Governor
William G. Ross Jr., Secretary
North Carolina Department of Environment and Natural Resources

Alan W. Klimek, P.E. Director
Division of Water Quality

February 6, 2003

Cherri Smith
NCDENR/DWQ
Wetland Restoration Program
1619 Mail Service Center
Raleigh, N.C. 27699-1619

Subject: Third Fork Creek/Forest Hills Park
Stream, and Buffer
Reference and Restoration Reaches
Cape Fear River Basin
Durham County

Dear Ms. Smith:

This letter is being sent to you in response to your request for written verification relative to the suitability of the subject reaches. As per our site visit, conducted November 7, 2002, the reference reach appears to be a relatively stable channel and suitable for use in developing a restoration design. North Prong Creek appears to duplicate the land usage and is similar in sediment size and distribution, water shed position, and valley slope.

The proposed stream restoration plan for the impacted reach located on the Third Fork Creek within Forest Hills Park must meet the minimum criteria for acceptance. Please be reminded that when conducting morphological evaluations and measurements, the length of the reference reach must be at least two (2) full meander wavelengths, approximately five to six riffle pools, or twenty bankfull channel widths.

If you should have any questions, please do not hesitate to contact me. at (919)-571-4700.

Sincerely,

Steve Mitchell
Environmental Scientist

Cc: CO/Todd St. John
RRO

RECEIVED

FEB 14 2003

NC WETLANDS
RESTORATION

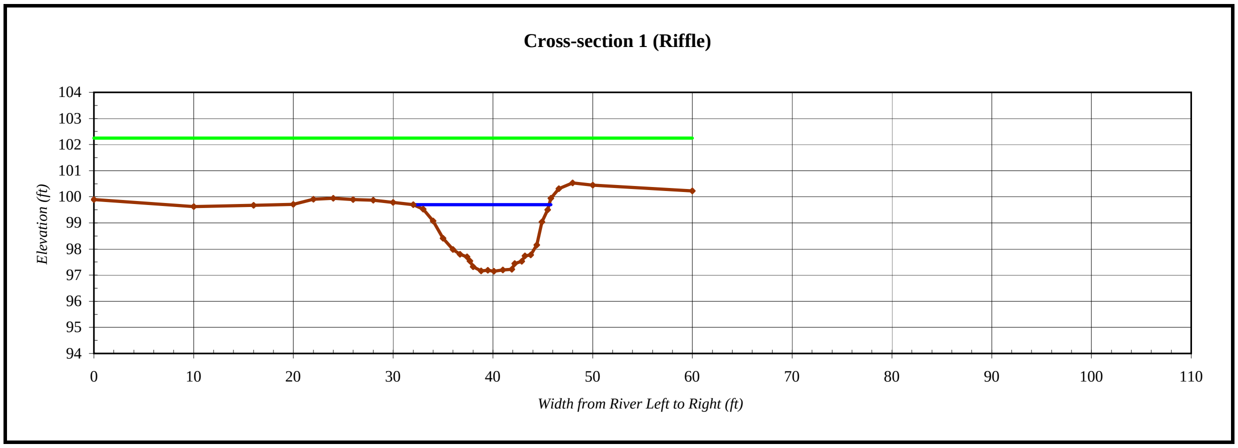
*Third Fork Creek Stream Restoration Project*

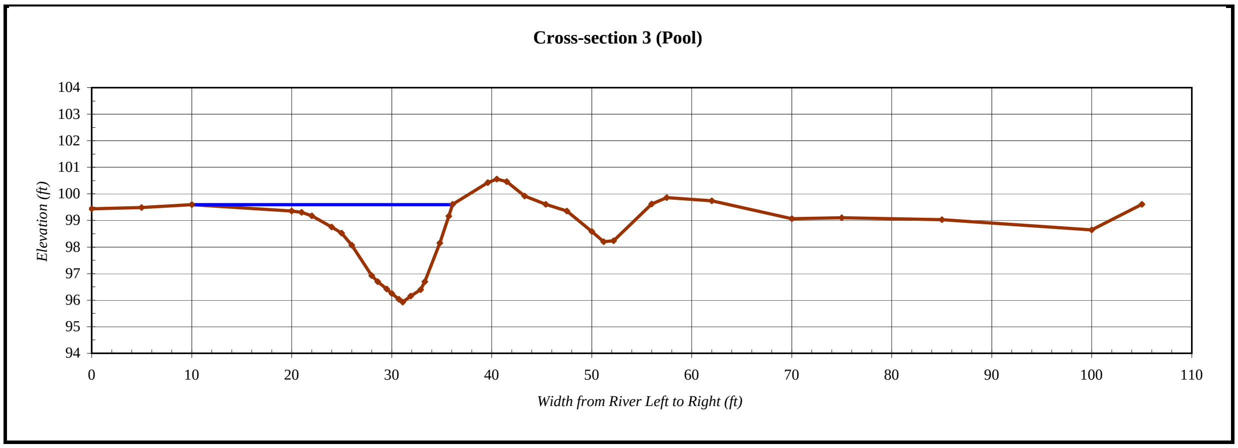
**North Prong Creek Reference Reach Data and Dimensionless Ratios**

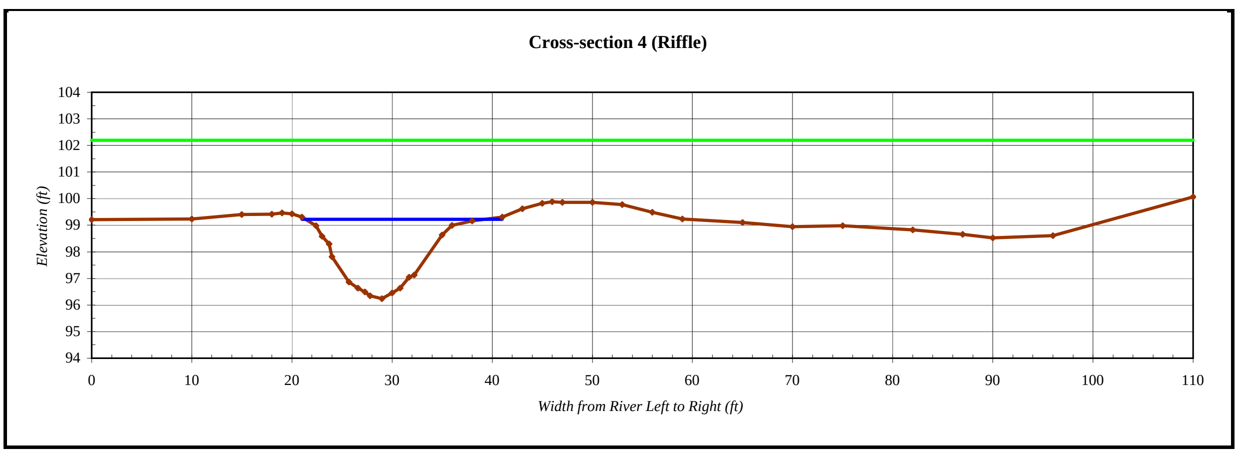
| Parameters | | Reference Reach |
|---|---|---|
| Rosgen Stream Type | | C5 |
| Drainage Area ($mi^2$) | | 3.04* |
| Reach Length (ft) | | 407 |
| *Dimension* | Bankfull Width (ft) | 17.8 |
| | Mean Bankfull Depth (ft) | 1.5 |
| | Width/Depth Ratio | 12.1 |
| | Bankfull Area ($ft^2$) | 26.2 |
| | Max Bankfull Depth | 3.0 |
| | Width of Floodprone Area (ft) | 600+ |
| | Entrenchment Ratio | 33.7 |
| | Max. Pool Depth (ft) | 3.34 - 4.00 |
| | Ratio: Max. Pool Depth / Mean Bankfull Depth | 2.2 - 2.7 |
| | Pool Width (ft) | 26.1 |
| | Ratio: Pool Width / Bankfull Width | 1.5 |
| | Pool Cross-Sectional Area ($ft^2$) | 30.9 |
| | Ratio: Pool Area / Bankfull Area | 1.2 |
| | Bankfull Mean Velocity (u) (ft/s) | 3.1 |
| | Bankfull Discharge (Q) (cfs) | 83* |
| *Pattern* | Meander Length (ft) | 94 - 143 |
| | Ratio: Meander Length / Bankfull Width | 5.3 - 8.0 |
| | Radius of Curvature (ft) | 37 - 40 |
| | Ratio: Radius Curvature / Bankfull Width | 2.1 - 2.3 |
| | Meander Belt Width (ft) | 158 |
| | Meander Width Ratio (MWR) | 8.9 |
| | Sinuosity (K) | 1.28 |
| *Profile* | Valley Slope (ft/ft) (%) | 0.23 |
| | Water Surface Slope (ft/ft) (%) | 0.24 |
| | Riffle Slope (ft/ft) (%) | 0.2 - 2.1 |
| | Ratio: Riffle Slope / WS Slope | 0.8 - 8.8 |
| | Pool Slope (ft/ft) (%) | 0.0 - 0.05 |
| | Ratio: Pool Slope / WS Slope | 0.0 - 0.2 |
| | Pool to Pool Spacing (ft) | 40 - 85.5 |
| | Ratio: Pool Spacing / Bankfull Width | 2.2 - 4.7 |
| | Pool Length (ft) | 8 - 30 |
| | Ratio: Pool Length / Bankfull Width | 0.4 - 1.6 |
| | Low Bank Height (ft) | 3.0 |
| | Ratio: Low Bank Height / Max. Bkf Depth | 1.0 |
| Channel Materials (D50) (mm) | | 0.20 |

*Note: The discharge contributed to the reference site by its delineated drainage area is reduced due to impoundment and altered drainage patterns in the watershed.*

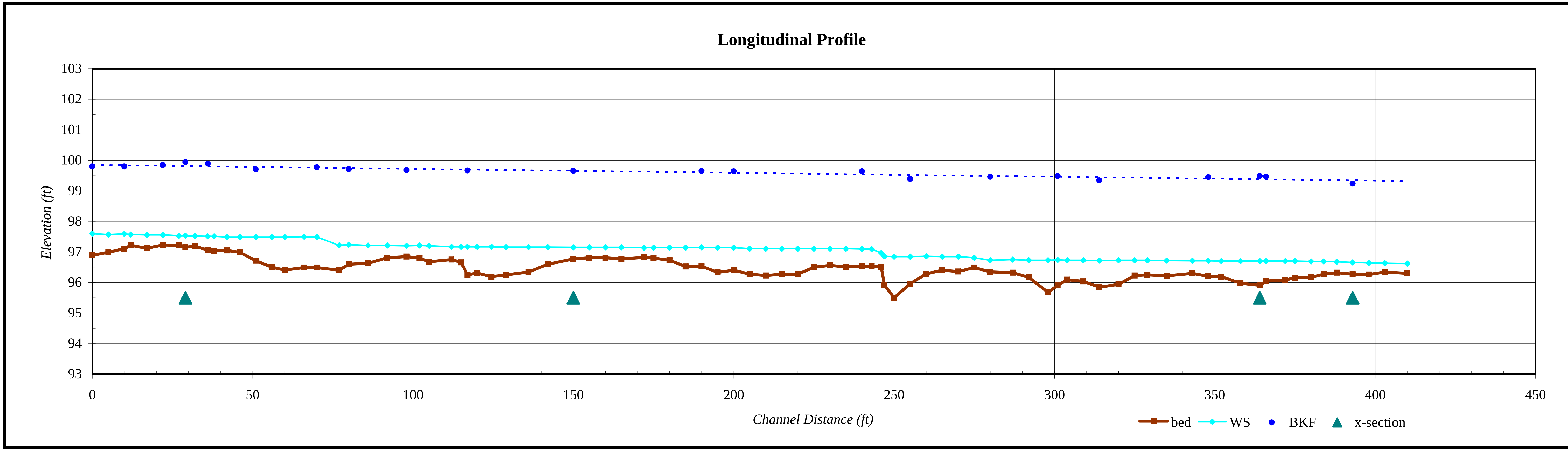
*Third Fork Creek Stream Restoration Project*
**North Prong Creek Reference Reach Data - Longitudinal Profile**



# *Third Fork Creek Stream Restoration Project*
## North Prong Creek Reference Reach Data - Longitudinal Profile



*Third Fork Creek Stream Restoration Project*

**North Prong Creek Reference Reach Data - Bed Materials**

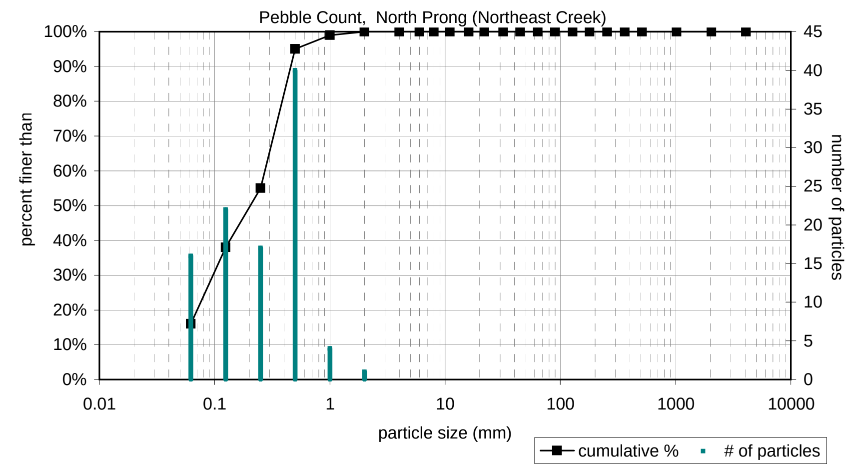
**Pebble Count of Channel Reach**

Pebble Count,
North Prong (Northeast Creek)

Durham, NC

Note: **Composite**

| Material | Size Range (mm) | | Count | |
|---|---|---|---|---|
| silt/clay | 0 | 0.062 | **16** | 16% |
| very fine sand | 0.062 | 0.13 | **22** | 38% |
| fine sand | 0.13 | 0.25 | **17** | 55% |
| medium sand | 0.25 | 0.5 | **40** | 95% |
| coarse sand | 0.5 | 1 | **4** | 99% |
| very coarse sand | 1 | 2 | **1** | 100% |
| very fine gravel | 2 | 4 | | 100% |
| fine gravel | 4 | 6 | | 100% |
| fine gravel | 6 | 8 | | 100% |
| medium gravel | 8 | 11 | | 100% |
| medium gravel | 11 | 16 | | 100% |
| coarse gravel | 16 | 22 | | 100% |
| coarse gravel | 22 | 32 | | 100% |
| very coarse gravel | 32 | 45 | | 100% |
| very coarse gravel | 45 | 64 | | 100% |
| small cobble | 64 | 90 | | 100% |
| medium cobble | 90 | 128 | | 100% |
| large cobble | 128 | 180 | | 100% |
| very large cobble | 180 | 256 | | 100% |
| small boulder | 256 | 362 | | 100% |
| small boulder | 362 | 512 | | 100% |
| medium boulder | 512 | 1024 | | 100% |
| large boulder | 1024 | 2048 | | 100% |
| very large boulder | 2048 | 4096 | | 100% |
| | | total particle count: | 100 | |
| bedrock | | | | |
| clay hardpan | | | | |
| detritus/wood | | | | |
| artificial | | | | |
| | | total count: | 100 | |




| | size percent less than (mm) | | | | | | particle size distribution | | |
|---|---|---|---|---|---|---|---|---|---|
| based on sediment particles only | D16 | D35 | D50 | D65 | D84 | D95 | gradation | geo mean | std dev |
| | 0.062 | 0.11 | 0.2 | 0.3 | 0.4 | 0.5 | 2.7 | 0.2 | 2.6 |

| | percent by substrate type | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| based on total count | silt/clay | sand | gravel | cobble | boulder | bedrock | hardpan | wood/det | artificial |
| | 16% | 84% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |

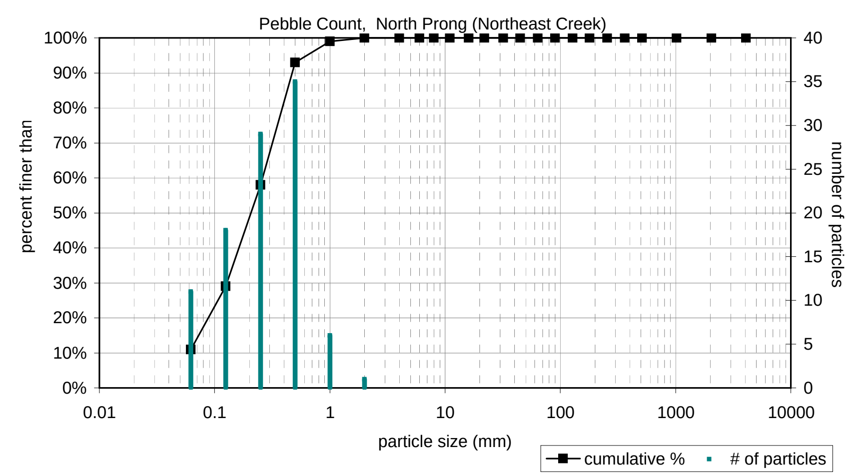
**Pebble Count of Channel Reach**

Pebble Count,
North Prong (Northeast Creek)

Durham, NC

Note: **Representative Riffle (XS-4)**

| Material | Size Range (mm) | | Count | |
|---|---|---|---|---|
| silt/clay | 0 | 0.062 | **11** | 11% |
| very fine sand | 0.062 | 0.13 | **18** | 29% |
| fine sand | 0.13 | 0.25 | **29** | 58% |
| medium sand | 0.25 | 0.5 | **35** | 93% |
| coarse sand | 0.5 | 1 | **6** | 99% |
| very coarse sand | 1 | 2 | **1** | 100% |
| very fine gravel | 2 | 4 | | 100% |
| fine gravel | 4 | 6 | | 100% |
| fine gravel | 6 | 8 | | 100% |
| medium gravel | 8 | 11 | | 100% |
| medium gravel | 11 | 16 | | 100% |
| coarse gravel | 16 | 22 | | 100% |
| coarse gravel | 22 | 32 | | 100% |
| very coarse gravel | 32 | 45 | | 100% |
| very coarse gravel | 45 | 64 | | 100% |
| small cobble | 64 | 90 | | 100% |
| medium cobble | 90 | 128 | | 100% |
| large cobble | 128 | 180 | | 100% |
| very large cobble | 180 | 256 | | 100% |
| small boulder | 256 | 362 | | 100% |
| small boulder | 362 | 512 | | 100% |
| medium boulder | 512 | 1024 | | 100% |
| large boulder | 1024 | 2048 | | 100% |
| very large boulder | 2048 | 4096 | | 100% |
| | | total particle count: | 100 | |
| bedrock | | | | |
| clay hardpan | | | | |
| detritus/wood | | | | |
| artificial | | | | |
| | | total count: | 100 | |

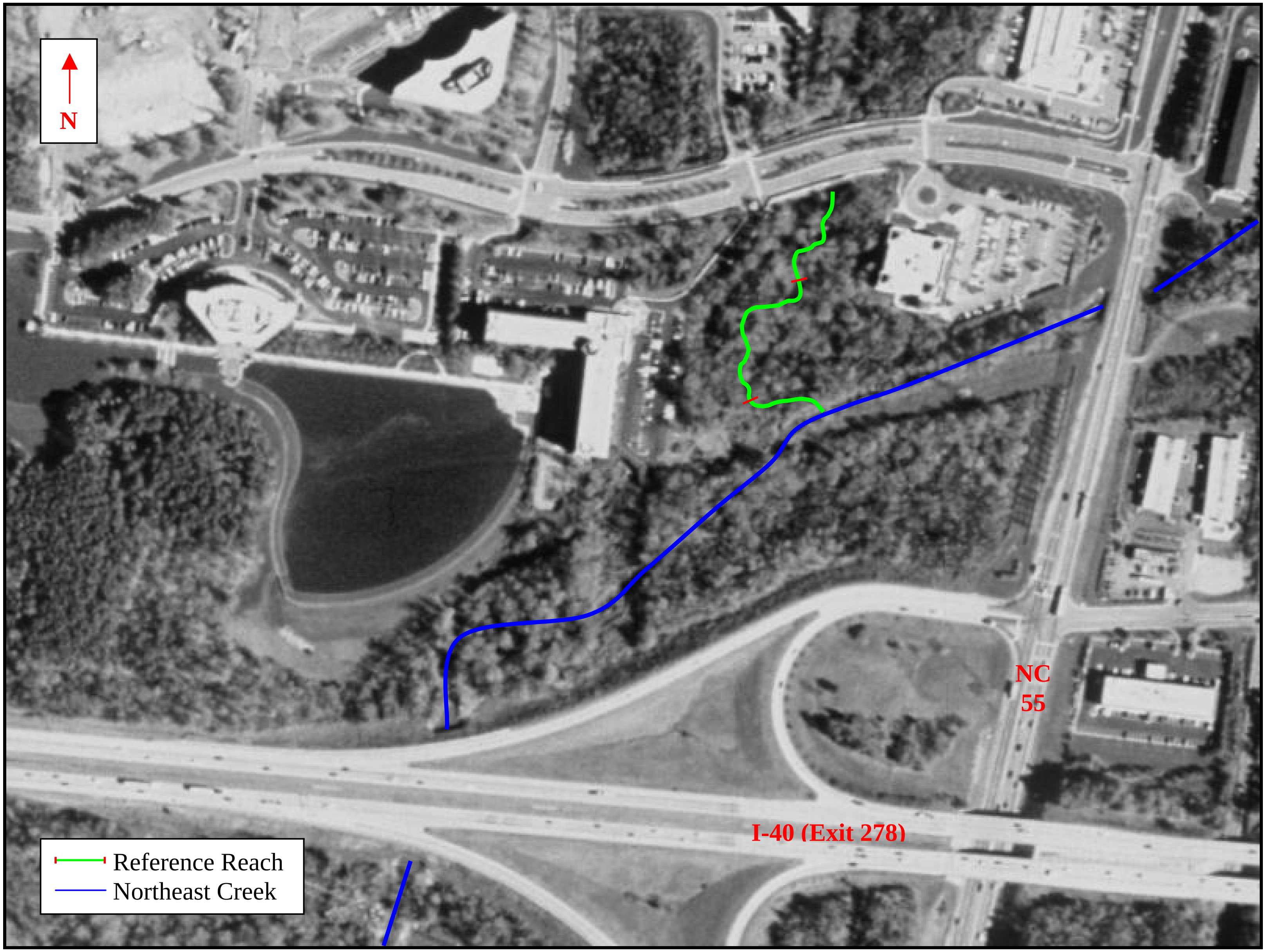



| | size percent less than (mm) | | | | | | particle size distribution | | |
|---|---|---|---|---|---|---|---|---|---|
| based on sediment particles only | D16 | D35 | D50 | D65 | D84 | D95 | gradation | geo mean | std dev |
| | 0.075 | 0.14 | 0.2 | 0.3 | 0.4 | 0.6 | 2.4 | 0.2 | 2.4 |

| | percent by substrate type | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| based on total count | silt/clay | sand | gravel | cobble | boulder | bedrock | hardpan | wood/det | artificial |
| | 11% | 89% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |

*Third Fork Creek Stream Restoration Project*

**North Prong Creek Reference Reach, Durham, North Carolina**



*Third Fork Creek Stream Restoration Project*
**North Prong Creek Reference Reach: Photo Log**


Typical section at upstream limits of surveyed reach.


Typical pool section.


Typical riffle section.


Typical pool section.


Typical riffle section.


Typical section at downstream limits of surveyed reach.

# Appendix C

## Sediment Transport Data

*Third Fork Creek Stream Restoration Project*
**Sediment Transport – Critical Shear Stress Calculations**

**Upper Section - Design**

Critical Shear Stress:

$\tau = \gamma R S$

$\tau = (62.4)(2.12)(0.0029) = 0.384 \text{ lbs/ft}^2$

*The particle mobility based on Shield's Curve is approximately 21-22 millimeters (mm).

**Lower Section - Design**

Critical Shear Stress:

$\tau = \gamma R S$

$\tau = (62.4)(2.37)(0.0025) = 0.370 \text{ lbs/ft}^2$

*The particle mobility based on Shield's Curve is approximately 20 millimeters (mm).

*Third Fork Creek Stream Restoration Project*

**Sediment Transport Calculator - Total Load (lbs/sec)**

**Existing Conditions - Upper Section**

**Step 1:**

| | |
|---|---|
| **g** | 9.81 |
| **R** | 0.6952728 |
| **$S_o$** | 0.0024 |
| **$u_*$** | 0.1279 |

| | |
|---|---|
| **Q** | 7.34 |
| **A** | 5.32 |
| **P** | 7.66 |
| **W** | 6.69 |
| **$d_{mean}$** | 0.80 |
| **$D_{50}$ (m)** | 0.00038 |

**Step 2:**

| | |
|---|---|
| **$r_s$** | 2650 |
| **r** | 1000 |
| **n** | 1.1E-06 |
| **$D_{gr}$** | 9.02 |

| | |
|---|---|
| **n** | 0.4651 |
| **m** | 2.427 |
| **$A_{gr}$** | 0.2166 |
| **C** | 0.020 |

$D_{gr}$ (dimensionless particle size number)

Expresses the relationship between immersed weight of sediment grains and viscous forces.

**Step 3:**

| | |
|---|---|
| **$F_{gr}$** | 1.0524 |
| **$G_{gr}$** | 0.5425 |
| **$q_s$** | 0.0009 |
| **$Q_s$** | 0.0057 |

$F_{gr}$ (particle mobility number) - Function of shear stress/immersed weight of grains.

$G_{gr}$ (sediment transport parameter) - Based on stream power.

$q_s$ Sediment discharge per unit channel width ($m^3$/m s)

$Q_s$ Sediment discharge ($m^3$/s)

| | |
|---|---|
| **SEDIMENT TRANSPORT - TOTAL LOAD (lbs/s)** | 33.5 |
| **DISCHARGE - IMPERIAL CONVERSION ($ft^3$/s)** | 259 |

*Based on Ackers and White Formula (Ackers, 1993)*

*Third Fork Creek Stream Restoration Project*
**Sediment Transport Calculator - Total Load (lbs/sec)**

**Design - Upper Section**

**Step 1:**

| | |
|---|---|
| **g** | 9.81 |
| **R** | 0.6454793 |
| **$S_o$** | 0.0029 |
| **$u_*$** | 0.1355 |

| | |
|---|---|
| **Q** | 8.03 |
| **A** | 5.58 |
| **P** | 8.65 |
| **W** | 8.23 |
| **$d_{mean}$** | 0.68 |
| **$D_{50}$ (m)** | 0.00038 |

**Step 2:**

| | |
|---|---|
| **$r_s$** | 2650 |
| **r** | 1000 |
| **n** | 1.1E-06 |
| **$D_{gr}$** | 9.02 |

| | |
|---|---|
| **n** | 0.4651 |
| **m** | 2.427 |
| **$A_{gr}$** | 0.2166 |
| **C** | 0.020 |

$D_{gr}$ (dimensionless particle size number)
Expresses the relationship between immersed weight of sediment grains and viscous forces.

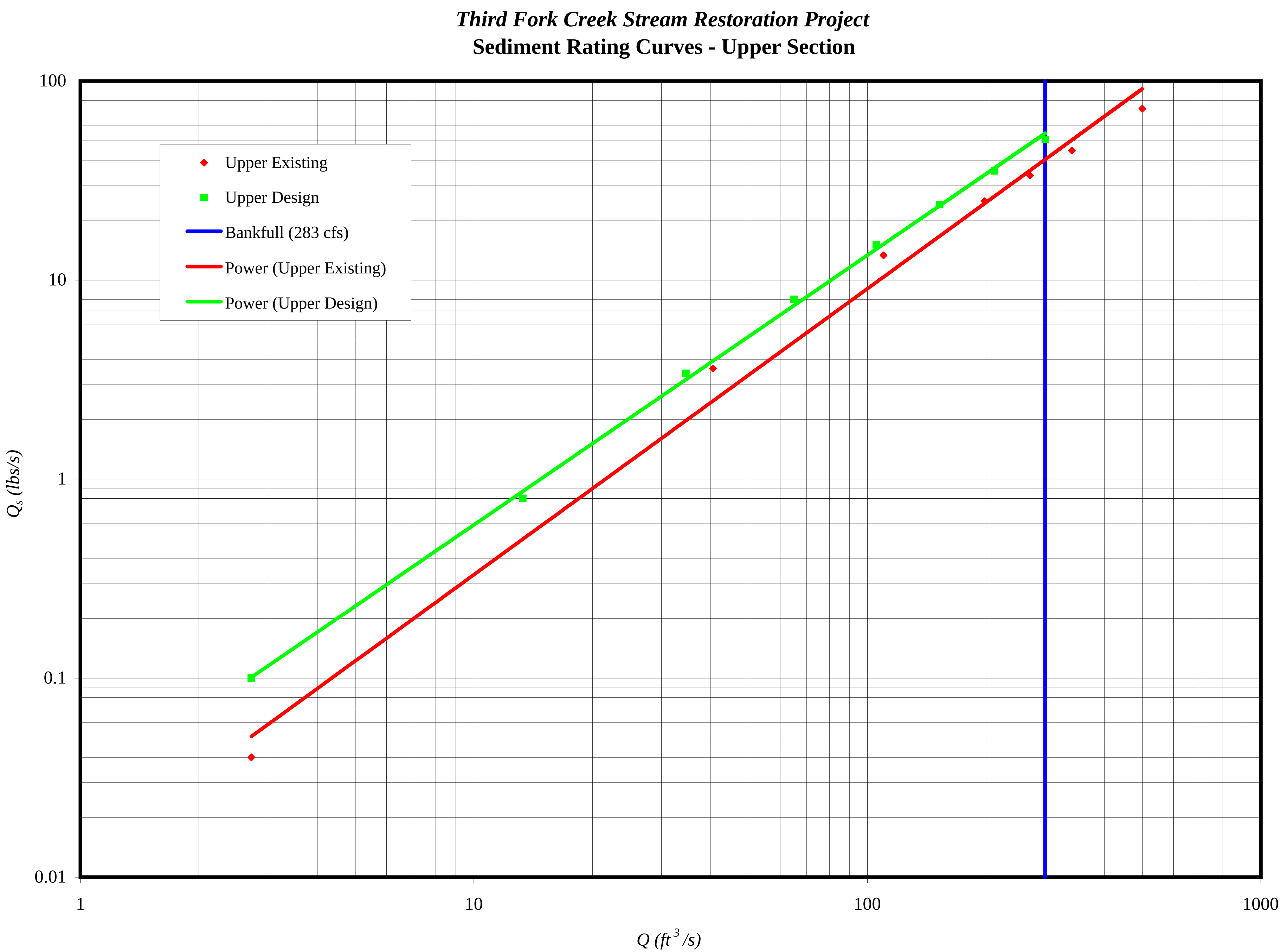
**Step 3:**

| | |
|---|---|
| **$F_{gr}$** | 1.1152 |
| **$G_{gr}$** | 0.6468 |
| **$q_s$** | 0.0011 |
| **$Q_s$** | 0.0087 |

$F_{gr}$ (particle mobility number) - Function of shear stress/immersed weight of grains.
$G_{gr}$ (sediment transport parameter) - Based on stream power.
$q_s$ Sediment discharge per unit channel width ($m^3$/m s)
$Q_s$ Sediment discharge ($m^3$/s)

| | |
|---|---|
| **SEDIMENT TRANSPORT - TOTAL LOAD (lbs/s)** | 50.8 |
| **DISCHARGE - IMPERIAL CONVERSION ($ft^3$/s)** | 283 |

*Based on Ackers and White Formula (Ackers, 1993)*


*Third Fork Creek Stream Restoration Project*
**Sediment Rating Curves - Upper Section**
100
10
1
0.1
0.01
$Q_s$ (lbs/s)
Upper Existing
Upper Design
Bankfull (283 cfs)
Power (Upper Existing)
Power (Upper Design)
1
10
100
1000
$Q$ ($ft^3$/s)

*Third Fork Creek Stream Restoration Project*

**Sediment Transport Calculator - Total Load (lbs/sec)**

**Existing Conditions - Lower Section**

**Step 1:**

| | |
|---|---|
| **g** | 9.81 |
| **R** | 0.6762891 |
| **$S_o$** | 0.0025 |
| **u*** | 0.1288 |

| | |
|---|---|
| **Q** | 9.12 |
| **A** | 6.63 |
| **P** | 9.81 |
| **W** | 8.90 |
| **$d_{mean}$** | 0.75 |
| **$D_{50}$ (m)** | 0.00044 |

**Step 2:**

| | |
|---|---|
| **$r_s$** | 2650 |
| **r** | 1000 |
| **n** | 1.1E-06 |
| **$D_{gr}$** | 10.44 |

| | |
|---|---|
| **n** | 0.4294 |
| **m** | 2.324 |
| **$A_{gr}$** | 0.2112 |
| **C** | 0.023 |

$D_{gr}$ (dimensionless particle size number)

Expresses the relationship between immersed weight of sediment grains and viscous forces.

**Step 3:**

| | |
|---|---|
| **$F_{gr}$** | 0.9633 |
| **$G_{gr}$** | 0.4439 |
| **$q_s$** | 0.0007 |
| **$Q_s$** | 0.0066 |

$F_{gr}$ (particle mobility number) - Function of shear stress/immersed weight of grains.

$G_{gr}$ (sediment transport parameter) - Based on stream power.

$q_s$ Sediment discharge per unit channel width ($m^3$/m s)

$Q_s$ Sediment discharge ($m^3$/s)

| | |
|---|---|
| **SEDIMENT TRANSPORT - TOTAL LOAD (lbs/s)** | 38.6 |
| **DISCHARGE - IMPERIAL CONVERSION ($ft^3$/s)** | 322 |

*Based on Ackers and White Formula (Ackers, 1993)*

*Third Fork Creek Stream Restoration Project*

**Sediment Transport Calculator - Total Load (lbs/sec)**

## Design - Lower Section

**Step 1:**

| | |
|---|---|
| **g** | 9.81 |
| **R** | 0.7230498 |
| **$S_o$** | 0.0025 |
| **$u_*$** | 0.1332 |

| | |
|---|---|
| **Q** | 10.00 |
| **A** | 6.94 |
| **P** | 9.60 |
| **W** | 9.14 |
| **$d_{mean}$** | 0.76 |
| **$D_{50}$ (m)** | 0.00044 |

**Step 2:**

| | |
|---|---|
| **$r_s$** | 2650 |
| **r** | 1000 |
| **n** | 1.1E-06 |
| **$D_{gr}$** | 10.44 |

| | |
|---|---|
| **n** | 0.4294 |
| **m** | 2.324 |
| **$A_{gr}$** | 0.2112 |
| **C** | 0.023 |

$D_{gr}$ (dimensionless particle size number)

Expresses the relationship between immersed weight of sediment grains and viscous forces.

**Step 3:**

| | |
|---|---|
| **$F_{gr}$** | 1.0021 |
| **$G_{gr}$** | 0.4990 |
| **$q_s$** | 0.0009 |
| **$Q_s$** | 0.0080 |

$F_{gr}$ (particle mobility number) - Function of shear stress/immersed weight of grains.

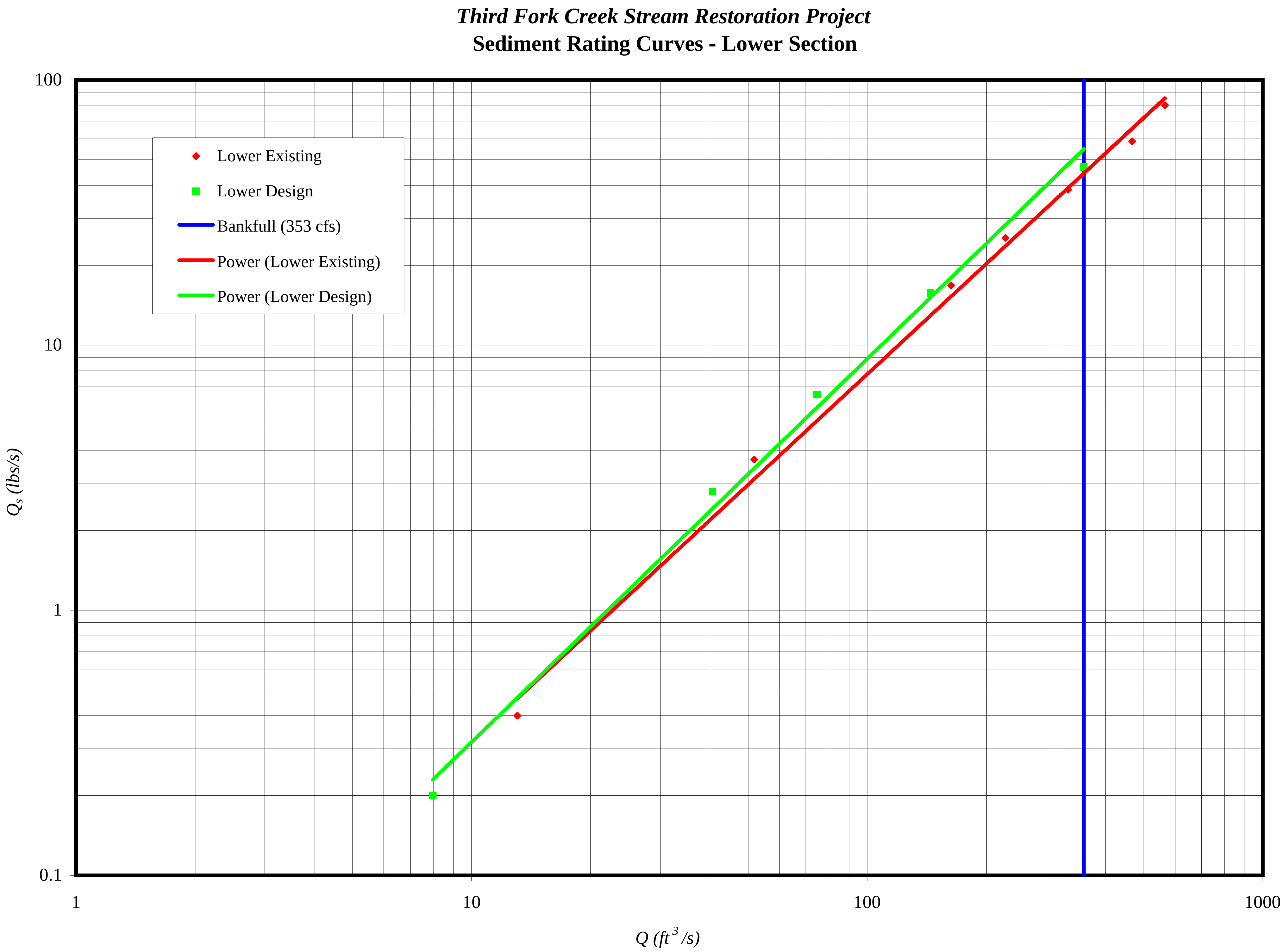
$G_{gr}$ (sediment transport parameter) - Based on stream power.

$q_s$ Sediment discharge per unit channel width ($m^3$/m s)

$Q_s$ Sediment discharge ($m^3$/s)

| | |
|---|---|
| **SEDIMENT TRANSPORT - TOTAL LOAD (lbs/s)** | 46.9 |
| **DISCHARGE - IMPERIAL CONVERSION ($ft^3$/s)** | 353 |

*Based on Ackers and White Formula (Ackers, 1993)*


Third Fork Creek Stream Restoration Project
Sediment Rating Curves - Lower Section
100
10
1
0.1
1
10
100
1000
Lower Existing
Lower Design
Bankfull (353 cfs)
Power (Lower Existing)
Power (Lower Design)
Qs (lbs/s)
Q (ft3/s)