Silas Creek
Stream Restoration Project
Winston-Salem, North Carolina

North Carolina Department of Environment and Natural Resources
Wetlands Restoration Program

Prepared By:

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Executive Summary

The North Carolina Wetlands Restoration Program (WRP) proposes to restore 4,633 linear feet of stream along two reaches of Silas Creek and one reach of Buena Vista Branch in Winston-Salem, North Carolina. The reaches are located in Shaffner Park.

The existing stream channels have low sinuosity and varying levels of incision due to historic channelization. The proposed stream restoration design is based on natural channel design principles and considers drainage area, watershed land uses, floodplain land uses, urban constraints, and future development potential. The design addresses the channel dimension, pattern, and profile based on reference reach parameters and hydraulic geometry relationships. When considering design alternatives, every effort was made to create a stable meandering channel with an accessible floodplain at the bankfull elevation. Development restrictions along Silas Creek do not allow for new channel pattern to be established. The existing incised channels will be enhanced by excavating new floodplain benches at the bankfull stage and installing structures to improve bed diversity and control channel grade.

A summary of existing and design reach lengths with proposed restoration design approaches is provided in the table below.

Sub-Project	Existing Length (ft)	Restored Length (ft)	Restoration Approach
Silas Creek 1&2	3,805	3,805	Bankfull benches and in-stream structures (Priority 3 restoration)
Buena Vista Creek	828	910	Priority 2 restoration
Total	**4,633**	**4,715**	

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1 Introduction

1.1 Project Description

The North Carolina Wetlands Restoration Program (WRP) proposes to restore 4,633 linear feet of stream along two reaches of Silas Creek and one reach of Buena Vista Branch in Winston-Salem, North Carolina. The reaches are located in Shaffner Park (Figure 1.1). These streams are tributaries to Muddy Creek (USGS Hydrologic Unit 03040102) and are in the Yadkin River basin.

Table 1.1 Existing Stream Lengths and Drainage Areas.

Reach Name	Existing Length (ft)	Drainage Area (mi^2)
Silas Reach 1	1,127	5.4
Silas Reach 2	2,678	7.2
Buena Vista	828	1.4

1.2 Project Objectives

The Silas Creek stream restoration project is one component in the enhancement of the Silas Creek watershed. The overall goal is to improve the water quality, habitat, and stability within this urban watershed. As in many developed watershed, the increase of peak flow events, loss of floodplains and adjacent wetlands, and conventional engineering of streams has caused a substantial loss of the ecological value and has resulted in degraded water quality. By stabilizing channels, preserving and installing riparian buffers, enhancing habitat structure, allowing natural storage capacity for storm flows, and constructing necessary storm water treatment BMPs, the overall watershed health can be restored to Silas Creek.

The objectives of the Silas Creek stream restoration project are to enhance the Silas Creek watershed by:

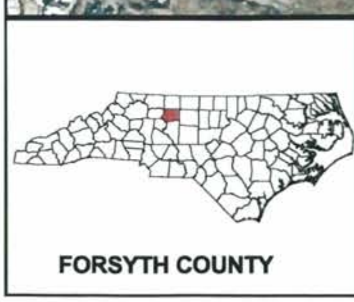
1. Restoring 4,715 LF of channel dimension, pattern, and profile to the extent possible considering the project constraints, watershed characteristics, and data from reference reaches in similar watersheds;
2. Improving floodplain functionality by matching floodplain elevation with bankfull stage therefore increasing watershed attenuation and reducing peak flows;
3. Establishment of native floodplain vegetation which will allow treatment of diffuse storm flow and nutrient uptake from vadose zone flow while help to establish part of a wildlife corridor in the watershed;
4. Improving the natural aesthetics of the stream corridor; and,

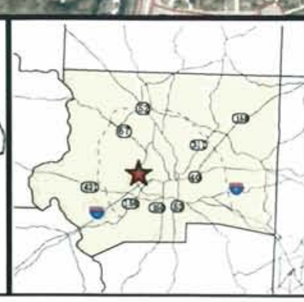
5. Improving the water quality in the Silas Creek watershed by reducing bank erosion, increasing nutrient storage and uptake, and increasing the dissolved oxygen of the system.

1.3 Watershed Characterization

The project site is located in the city of Winston-Salem in the urban Piedmont physiographic region. The topography is characterized by gently rolling hills and wide alluvial valleys with a dendritic stream pattern.

Over the last two decades, land use in the Winston-Salem area has undergone a rapid conversion from rural and open space to urban. The City of Winston-Salem Planning Department is responsible for the future growth and development of the city. Information on land use planning in Winston-Salem can be found at: http://www.cityofws.org/GIS/html/main.htm

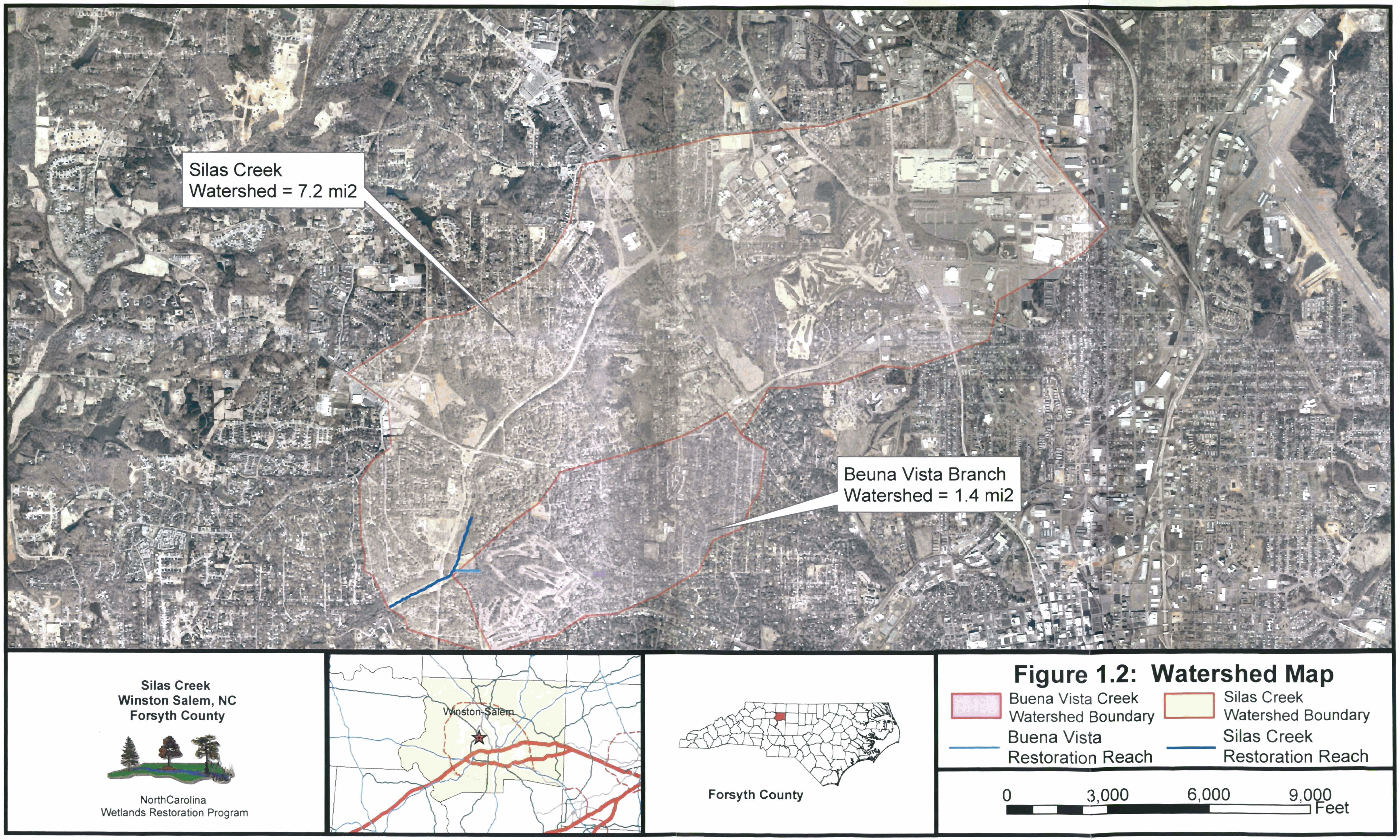




North Carolina
Wetlands Restoration Program

Figure 1.1: Project Location Map
Silas Creek Stream Restoration Project
Winston Salem, NC
Forsyth County

300 0 300 600 900 Feet


Silas Creek
Watershed = 7.2 mi2
Beuna Vista Branch
Watershed = 1.4 mi2
N
Silas Creek
Winston Salem, NC
Forsyth County
NorthCarolina
Wetlands Restoration Program
Winston-Salem
Forsyth County
Figure 1.2: Watershed Map
Buena Vista Creek
Watershed Boundary
Silas Creek
Watershed Boundary
Buena Vista
Restoration Reach
Silas Creek
Restoration Reach
0
3,000
6,000
9,000
Feet

More detailed information for each project reach is presented in the sections below. Characterizations were performed by gathering information on topography, soils, land use, and percent impervious. The percent impervious of each watershed was estimated using aerial photography and GIS analysis. Figure 1.2 shows the watershed delineations for both Silas Creek and Buena Vista Branch on aerial photography.

1.3.1 Silas Creek

The Silas Creek watershed area is approximately 7.2 square miles. Land use for the watershed is highly diversified with land uses including: residential, commercial, industrial, park, and recreational. Based on this information, the impervious land cover was determined to be approximately 39%.

Elevations within the Silas Creek watershed range from approximately 790 feet to 1,000 feet with a relative relief of 210 feet. Based on the North Carolina Soil Survey for Forsyth County (NRCS, 1976), soils at the project site are mapped primarily as Chewacla loam (Ch). The Chewacla series consists of nearly level, somewhat poorly drained soils of stream floodplains. These soils formed in recent alluvium and are frequently flooded for brief periods of time. The surface layer typically extends to a depth of 9 inches and is dark brown. The subsoil is a dark brown or light olive brown color with grayish brown to yellowish brown mottles. The Chewacla soil series is listed as hydric by the National Resource Conservation Service (1996). However, hydric conditions no longer exist within the project area due to the incision of Silas Creek and Buena Vista Branch. This incision has lowered the water table and decreased overbank flooding.

1.3.2 Buena Vista Branch

The Buena Vista Branch watershed area is approximately 1.4 square miles. The land use is composed largely of residential lots (0.25 acres) and a golf course; however approximately 10% of the watershed area was delineated as commercial and industrial. Overall, the watershed has approximately 27% impervious land cover.

Elevations within the Buena Vista Branch watershed range from approximately 800 feet to 960 feet with a relative relief of 160 feet. Similar to Silas Branch, soils at the project site are mapped as Chewacla loam (NRCS, 1976), which is described above.

2 Existing Condition Survey

The primary purposes of the existing condition survey are to determine the stability of the project stream reach and its potential for restoration, if needed. This is accomplished through a quantitative and qualitative investigation of the stream corridor, including channel dimension, pattern, and profile. This analysis provides information that is used to assess the potential for restoration. Data collected during the existing condition survey are used to determine if the stream is moving towards stability or instability and if the cause of instability is localized or system-wide. Examples of localized instability include removal of riparian vegetation and/or trampling of the stream banks by livestock or humans. System-wide instability is often caused by channel incision, which causes head-ward erosion until stopped by a knick point.

2.1 Channel Stability Assessment

Buck Engineering used a modified stream channel stability assessment methodology developed by Rosgen (2001). The Rosgen 2001 method is a field assessment of the following variables:

1. Stream Channel Condition or "State" Categories,
2. Vertical Stability – Degradation/Aggradation,
3. Lateral Stability,
4. Channel Pattern,
5. River Profile and Bed Features,
6. Channel Dimension Relations,
7. Stream Channel Scour/Deposition Potential (Sediment Competence),
8. Channel Evolution.

A description of each variable is provided below.

2.1.1 Stream Channel Condition or "State" Categories

Seven categories are included in this analysis and include: a) riparian vegetation, b) sediment depositional patterns, c) debris occurrence, d) meander patterns, e) stream size/stream order, f) flow regime, and g) altered states due to direct disturbance. These condition categories are determined from field inspection and measurement of stream channel condition characteristics.

2.1.2 Vertical Stability – Degradation/Aggradation

The bank height and entrenchment ratios are measured in the field to determine vertical stability. The bank height ratio is measured as the ratio of the lowest bank height divided by a maximum bankfull depth. Table 2.1 shows the relationship between bank height ratio and vertical stability developed by Rosgen (2001).

Table 2.1. Conversion of Bank Height Ratio (Degree of Incision) to Adjective Rankings of Stability (Rosgen, 2001).

Stability Rating	Bank Height Ratio
Stable (low risk of degradation)	1.0 – 1.05
Moderately unstable	1.06 – 1.3
Unstable (high risk of degradation)	1.3 – 1.5
Highly unstable	> 1.5

The entrenchment ratio is calculated by dividing the flood-prone width (width measured at twice the maximum bankfull depth) by the bankfull width. If the entrenchment ratio is less than 1.4 (+/- 0.2), the stream is considered entrenched (Rosgen, 1996).

2.1.3 Lateral Stability

The degree of lateral containment (confinement) and potential lateral accretion are determined in the field by measuring the meander width ratio and Bank Erosion Hazard Index (BEHI). The meander width ratio is the meander belt width divided by the bankfull channel width, and provides insight into channel adjustment processes depending on stream type and degree of confinement. BEHI ratings can be used to estimate the annual, lateral streambank erosion rate.

2.1.4 Channel Pattern

Channel pattern is assessed in the field by measuring the meander width ratio (described above), ratio of radius of curvature to bankfull width, sinuosity, and meander wavelength ratio (meander wavelength divided by bankfull width). These dimensionless ratios are compared to reference reach data for the same valley and stream type to determine where channel adjustment has occurred due to instability.

2.1.5 River Profile and Bed Features

A longitudinal profile is created by measuring elevations of the bed, water surface, bankfull, and low bank height along the reach. This profile can be used to determine changes in river slope compared to valley slope, which are sensitive to sediment transport, competence, and the balance of energy. For example, the removal of large woody debris may increase the step/pool spacing and result in excess energy and subsequent channel degradation.

2.1.6 Channel Dimension Relations

The bankfull width/depth ratio (bankfull width divided by mean bankfull depth) is measured in the field. The ratio provides an indication of departure from the reference reach and relates to channel instability. An increase in width/depth ratio indicates accelerated streambank erosion, excessive sediment deposition, stream flow changes, and alteration of channel shape (e.g., from channelization). Channel widening is also associated with an increase in width/depth ratio due to evolutionary shifts in stream type (e.g., from G4 to F4 to C4). Table 2.2 shows the relationship between the degree of width/depth ratio increases and channel stability developed by Rosgen (2001).

Table 2.2. Conversion of Width/Depth Ratios to Adjective Ranking of Stability from Stability Conditions (Rosgen, 2001).

Stability Rating	Ratio of W/D Increase
Very stable	1.0
Stable	1.0 – 1.2
Moderately unstable	1.21 – 1.4
Unstable	> 1.4

While an *increase* in width/depth ratio is associated with channel *widening*, a *decrease* in width/depth ratio is associated with channel *incision*. Hence, for incised channels, the ratio of channel width/depth ratio to reference reach width/depth ratio will be less than 1.0. The reduction in width/depth ratio indicates excess shear stress and an adjustment of the channel toward an unstable condition.

2.1.7 Stream Channel Scour/Deposition Potential (Sediment Competence)

This methodology is discussed in detail in Chapter 6 of this report.

2.1.8 Channel Evolution

A common sequence of physical adjustments has been observed in many streams following disturbance. This adjustment process is often referred to as channel evolution. Disturbance can result from channelization, increase in runoff due to build-out in the watershed, and removal of streamside vegetation, as well as other changes that negatively affect stream stability. All of these disturbances are common in the urban environment. Several models have been used to describe this process of physical adjustment for a stream. Simon's channel evolution model (1989) characterizes evolution in six steps, including 1) sinuous, pre-modified, 2) channelized, 3) degradation, 4) degradation and widening, 5) aggradation and widening, and 6) quasi equilibrium.

The channel evolution process is initiated once a stable, well-vegetated stream that has access to its floodplain is disturbed. Disturbance commonly results in an increase in stream power which causes degradation, often referred to as channel incision. Incision eventually leads to increased slopes of stream banks, and when critical bank heights are exceeded, the banks begin to fail and mass wasting of soil and rock leads to channel widening. Incision and widening continue migrating upstream, a process commonly referred to as a head-cut. Eventually the mass wasting slows and the stream begins to aggrade with a new low-flow channel forming in the sediment deposits. By the end of the evolutionary process, a stable stream with dimension, pattern, and profile similar to those of undisturbed channels forms in the deposited alluvium. The new channel is at a lower elevation than its original form with a new floodplain constructed of alluvial material and the old floodplain remains a dry terrace (FISRWG, 1998). Most urban streams are at some stage of this evolutionary process. The time required to reach a state of quasi equilibrium is highly variable and has not yet been determined.

2.2 Benchmarks and Underground Utilities

Four control benchmarks were established on site by Arcadis G&M. Their locations and coordinates are shown on the enclosed plan view. Topography, planimetric information and aerial photographs were obtained from the City of Winston-Salem in GIS format. The topographic mapping included one-foot contours. MA Engineering located all underground utilities and Arcadis G&M provided the utility mapping to overlay with the topographic and planimetric data in GIS. Buck Engineering supplemented the existing mapping with a longitudinal profile and cross sectional survey of the existing channel. Buck Engineering also collected additional topographic data in areas where intensive grading may take place (e.g. a new channel or stormwater best management practice (BMP)).

2.3 Silas Creek

Silas Creek flows through Shaffner Park within the project limits. The project is divided into two project reaches with a drainage area of 7.2 square miles at the downstream end of reach 2. The watershed was determined to be approximately 39% impervious. Reach 1 is from the point where Silas Creek enters Shaffner Park to Yorkshire Road. Reach 2 is from Yorkshire Road down to the point where Silas Creek flows out of Shaffner Park (Figure 1.1). Table 2.3 summarizes the existing condition data for Silas Creek reaches 1 & 2.

Table 2.3. Existing Condition Parameters for Silas Creek (Reaches 1 and 2 are presented by one survey dataset)

Parameters		Existing
Rosgen Stream Type		B4c*
Drainage Area (sq mi)		7.2
Reach Length (ft)		3805
Dimension	Bankfull Width (ft)	40
	Bankfull Mean Depth (ft)	3.5
	Width/Depth Ratio	11.7
	Bankfull Area (sq ft)	138
	Bankfull Max Depth (ft)	4.5
	Width of Floodprone Area (ft)	112
	Entrenchment Ratio	2.71
	Max Pool Depth (ft)	7.4
	Ratio of Max Pool Depth to Bankfull Depth	2.1
	Pool Width (ft)	35.3
	Ratio of Pool Width to Bankfull Width	0.9
	Pool to Pool Spacing (ft)	82-189
	Ratio of Pool to Pool Spacing to Bankfull Width	2.0-4.75
	Bank Height Ratio	1.3 - 1.7
Pattern	Meander Length (ft)	N/A**
	Meander Length Ratio	N/A**
	Radius of Curvature (ft)	N/A**
	Radius of Curvature Ratio	N/A**
	Meander Belt Width (ft)	40
	Meander Width Ratio	1
	Sinuosity	1.03
Profile	Valley Slope (ft/ft)	0.0029
	WS Slope (ft/ft)	0.0025
	Riffle Slope (ft/ft)	0.0028
	Ratio of Riffle Slope to WS Slope	1.12
	Pool Slope (ft/ft)	0.0005
	Ratio of Pool Slope to WS Slope	0.19

* The entrenchment ratio is high for a Bc stream type. However, given other factors such as a low sinuosity and a moderate bank height ratio, we determined that Silas Creek functioned more like a Bc / F than a C or E stream type. A more thorough discussion of stability is presented below.

** Due to the extremely low sinuosity, pattern data cannot accurately be calculated. Any data calculated would overestimate pattern.

2.3.1 Stability Assessment

As part of the stability assessment, four cross sections were surveyed at stable riffles and pools throughout both reaches. The survey data and cross sections are provided in Appendix 1. Bankfull cross sectional area averaged 138 ft^2 for the two riffles surveyed, while the pool bankfull area averaged 150 ft^2. The bankfull width/depth ratio is variable, ranging from 9.2 to 14.2 in the riffles and ranging from 7.4 to 9.5 in the pools. An increase in bankfull width/depth ratio in comparison to reference ratios is indicative of a channel that is trying to widen through streambank erosion. Lateral bars and point bars are located in areas with high bankfull width/depth ratios, evidence of channel deposition and aggradation. This type of aggradation is indicative of a stage V in Simon's channel evolution model and indicates that the stream is evolving towards greater stability. However, thousands of tons of sediment must be eroded from the streambank for the stream to reach stage VI, quasi-equilibrium.

Bank height ratios range from 1.5 to 1.7 and entrenchment ratios range from 1.7 to 6.7. These values demonstrate that the stream is highly unstable; however, the stream is not severely entrenched (no ER values below 1.4). Streambank erosion is extreme due to the high bank height ratios. There is a wide flood prone area on the left bank of Reach 1 and on the right side of Reach 2; however, this is only accessible to the stream at discharges 3.5 times the bankfull discharge or greater. Bankfull benches along the left side of the Reach 2 below Silas Creek Parkway provide a small active floodplain.

The longitudinal profile, shown in Appendix 1, varies over the project length. The overall average channel slope across both reaches is 0.25%. Reach 1 is extremely flat (slope = 0.04%) due to the backwater effect of the culvert at Yorkshire Parkway. There is very little diversity in riffle-pool sequence in Reach 1. Large scour pools below each of the culverts on the project have decreased the effective slope of Reach 2 from 0.25% to 0.18% (culverts subtracted from slope calculation). However, this slope is still significantly greater than that of Reach 1, which is reflected in the increased bed form diversity.

The modified Wolman pebble count was used to characterize the bankfull channel bottom. Transects were sampled throughout the reach and were stratified by the proportion of riffles and pools. Ten particles were sampled at ten different cross sections spread throughout each reach. The pebble count data show that the D50 is 23-mm and the D84 is 32-mm indicating that coarse gravel is the dominant bed material in the stream channel. The riffle D50 was only used for Rosgen stream classification purposes.

The riparian area within the park consists of a combination of maintained grasses and forested areas. Woody species found along the banks and surrounding riparian areas include green ash (*Fraxinus pennsylvanica*), sycamore (*Platanus occidentalis*), river birch (*Betula nigra*), sweetgum (*Liquidambar styraciflua*), tulip poplar (*Liriodendron tulipifera*), american elm (*Ulmus americana*), black walnut (*Juglans nigra*), white pine

(*Pinus strobes*), maple (*Acer spp.*), oak (*Quercus spp.)*, spicebush (*Lindera benzoin*), silky dogwood (*Cornus amomum*), elderberry (*Sambucus canadensis*), box elder (*Acer negundo),* black willow (*Salix nigra*), and tag alder (*Alnus serrulata*). These species were most prevalent in Reach 1 where a small but nearly continuous buffer exists on both sides of the stream.

The vegetative and vine layers are composed of christmas fern (*Polystichum acrostichoides*), oriental ladysthumb (*Polygonum caespitosum*), jewelweed (*Impatiens capensis*), False Stinging Nettle (*Boehmaria cylindrica*), virginia creeper (*Parthenocissus quinquefolia*), american pokeweed (*Phytolacca americana*), trumpet creeper (Campsis radicans), and poison ivy (*Toxicodendron radicans*).

2.3.2 Constraints

Constraints to achieving the highest level of stream restoration in Shaffner Park include the following:

- A walking path along the left bank and recreation fields under construction along the right bank of Reach 1 limit the potential for channel relocation and the extent of bankfull benches.
- A sanitary sewer line and recreation fields along the left bank of Reach 2 between Yorkshire Road and Silas Creek Parkway limit the potential for channel relocation and the extent of bankfull benches.
- Walking paths on both sides of Reach 2 below Silas Creek Parkway limit the potential for channel relocation and the extent of bankfull benches.
- There is a parking lot immediately adjacent to the left bank of Silas Creek and the right bank of a storm-water ditch that discharges into Silas Creek.
- The stream crosses two sanitary sewer lines and one water line along Reach 2 below Silas Creek Parkway.
- Culverts at the two major road crossings set the grade of Silas Creek, limit the potential for relocation and constrain the floodplain.
- There are a number of storm sewer outfalls located along the project.

2.4 Buena Vista Branch

The project reach of Buena Vista Branch flows through a golf course; however, it originates in a residential area. The drainage area is 1.4 square miles and was determined to be approximately 27% impervious. The summary data for this reach are shown in Table 2.4.

Table 2.4. Existing Condition Parameters for Buena Vista Branch.

Parameters		Existing
Rosgen Stream Type		E4
Drainage Area (sq mi)		1.4
Reach Length (ft)		828
Dimension	Bankfull Width (ft)	14.5
	Bankfull Mean Depth (ft)	2.11
	Width/Depth Ratio	6.86
	Bankfull Area (sq ft)	30.6
	Bankfull Max Depth (ft)	3.21
	Width of Floodprone Area (ft)	119
	Entrenchment Ratio	8.2
	Max Pool Depth (ft)	2.76
	Ratio of Max Pool Depth to Bankfull Depth	1.3
	Pool Width (ft)	15.8
	Ratio of Pool Width to Bankfull Width	1.08
	Pool to Pool Spacing (ft)	45-157
	Ratio of Pool to Pool Spacing to Bankfull Width	3.1-10.8
	Bank Height Ratio	1.8
Pattern	Meander Length (ft)	72-105
	Meander Length Ratio	5-7.2
	Radius of Curvature (ft)	25-100
	Radius of Curvature Ratio	1.7-6.9
	Meander Belt Width (ft)	15.4-23.8
	Meander Width Ratio	1.1-1.6
	Sinuosity	1.09
Profile	Valley Slope (ft/ft)	0.0111
	WS Slope (ft/ft)	0.0107
	Pool Slope (ft/ft)	0.0024
	Ratio of Pool Slope to WS Slope	0.227

2.4.1 Stream Stability Assessment

Two cross sections were surveyed along Buena Vista Branch and are shown in Appendix 1. Riffle cross sectional area was determined to be 30.6 ft^2. The width/depth ratio for the riffle surveyed was 6.9. The bank height ratio varied from approximately 1.4 to 2.3

across the site. Entrenchment ratios varied depending on the degree of incision from 1.4 up to 8.2. There are areas where the stream is incised and a bankfull bench is developing, as shown in the cross-sectional survey data. This is indicative of stage IV of the Simon stream evolution model.

The longitudinal profile shows a fair amount of diversity in bed form. However, the riffles and pools do not necessarily correspond to the tangent and bend sections, respectively. Many of the riffle sections are located at bends in the channel indicating that bank erosion is occurring, eventually resulting in increased sinuosity. The bed material is composed mostly of fine gravel, with a D50 of 5.7-mm. However, the D84 is approximately 23-mm, which is course gravel.

The right bank is primarily maintained grass through the project reach. The predominant vegetation on the left bank is consistent with the vegetation described for Silas Creek in Section 2.3.1.

Overall, Buena Vista Branch is a moderately to highly incised stream with some access to its floodplain. The Rosgen stream-type is an incised E4 with varying severity of incision and entrenchment. The channel appears to be in stage III/IV of the Simon Channel Evolution model, where downcutting is continuing with channel widening beginning to occur. The stream will continue to widen in areas lacking good vegetation and develop lateral bars (inner berm) as the channel develops a new floodplain at a lower elevation. Left unchecked, this widening and aggradation process will continue until the stream establishes a new floodplain with a sufficient belt width to create a stable dimension, pattern, and profile at a lower elevation than the existing terrace / floodprone area.

2.4.2 Constraints

Constraints to achieving the highest level of stream restoration on Buena Vista Branch include the following:

- A sewer line crossing at the upstream end of the reach prevents channel relocation in this section. The inability to relocate the channel and begin raising the bed elevation results in an overall inability to achieve a priority I restoration.
- Soccer fields along the right bank and a sewer line to the left of the channel set the beltwidth limits for the priority II restoration.
- Sewer line crossings at the downstream end prevent relocation in this area.

2.5 Threatened and Endangered Species

A search of the US Fish and Wildlife Service (USFWS) and NC Natural Heritage Program (NHP) databases, conducted on September 16, 2002, concluded that no habitat or populations of federally protected species listed for Forsyth County exist in the project area. The federally protected species for Forsyth County are listed in Table 2.5 below. A more detailed description of the characteristics and habitat requirements for the federally protected species can be found below along with conclusions regarding potential project impacts based on habitat requirements.

Table 2.5 Federally Protected Species for Forsyth County

Scientific Name	Common Name	Federal Status	State Status	Biological Conclusion
Cardamine micranthera	Small-anthered bittercress	E	E	No Effect
Clemmys muhlenbergii	Bog turtle	T (S/A)	T	No Effect
Picoides borealis	Red-cockaded woodpecker	E	E	No Effect

Notes:

- "E - Endangered" denotes a species in danger of extinction throughout all or a significant portion of its range.
- "T - Threatened" denotes a species likely to become endangered in the foreseeable future throughout all or a significant portion of its range.
- "S/A - Similarity of Appearance" denotes a species that closely resembles in appearance to an endangered or threatened species that enforcement personnel would have substantial difficulty in differentiating between the listed and unlisted species. The southern population of the bog turtle is listed as T (S/A) due to Similarity of Appearance with the northern population of the bog turtle (which is federally listed as Threatened and which does not occur in North Carolina).

***Cardamine micranthera* (Small-anthered bittercress)** **Endangered**

Plant Family: Brassicaceae
Federally Listed: September 21, 1989

Small-anthered bittercress is a slender, erect, perennial herb of the mustard family, usually with one, but occasionally with multiple, stems, either simple or branched, 8 to 16 inches (20 to 41 centimeters) tall. Leaf edges have shallow, rounded teeth. Bottom leaves are lobed, 0.4 to 0.8 inches (1 to 2 centimeters) long, and 0.2 to 0.24 inches (0.5 to 0.6 centimeters) wide. Upper leaves are alternate and usually unlobed, 0.4 to 0.6 inches (1 to 1.5 centimeters) long, and wedge-shaped, with the narrow point at the stem. Reduced leaves (bracts) occur at the base of the flowers, which have four small white petals and six stamens with small round anthers. Flowering and fruiting occur in April and May. This plant grows primarily in seeps and wet rock crevices of streambanks adjoining sandbars, floodplain depressions, and moist woods near small streams fully to partially shaded by trees and shrubs.

Small-anthered bittercress is endemic to the Dan River drainage in Stokes County. Historically, it was also known to exist in Forsyth County.

Biological Conclusion: **No Effect**

No potential habitat such as substantial streamside shading or gravel/sandbars, exists within the project area for the small-anthered bittercress. A search of the NHP database, conducted on September 16, 2002, found no occurrence of the small-anthered bittercress in the project area. It can be concluded that the project will not impact this endangered species.

***Clemmys muhlenbergii* (Bog turtle)** **Threatened (Due to Similar Appearance)**
Animal Family: Emydidae
Federally Listed: November 4, 1997

Bog turtles are small [3 to 4.5 inches (7.6 to 11.4 centimeters)] turtles with a weakly keeled carapace (upper shell) that ranges from light brown to ebony in color. The species is readily distinguished from other turtles by a large, conspicuous bright orange to yellow blotch on each side of its head. Bog turtles are semi-aquatic and are only infrequently active above their muddy habitats during specific times of year and temperature ranges. They can be found during the mating season from June to July and at other times from April to October when the humidity is high, such as after a rain event, and temperatures are in the seventies. Bog turtle habitat consists of bogs, swamps, marshy meadows, and other wet environments, specifically those that have soft muddy bottoms. The southern populations of bog turtles (in Virginia, Tennessee, North and South Carolina, and Georgia) are listed as threatened due to similar appearance (T S/A) to northern bog turtles that are listed as threatened. A Biological Conclusion is not required since T (S/A) species are not afforded full protection under the ESA. However, the protected species classification of the southern populations could be upgraded in the future.

Biological Conclusion: **No Effect**

No potential habitat for bog turtles exists in the project area. A search of the NHP database, conducted on September 16, 2002, found no occurrence of the bog turtle in the project area. It can be concluded that the project will not impact this species.

***Picoides borealis* (Red-cockaded woodpecker)** **Endangered**
Vertebrate Family: Picidae
Federally Listed: October 13, 1970

The red-cockaded woodpecker once occurred from New Jersey to southern Florida and west to eastern Texas. It occurred inland in Kentucky, Tennessee, Arkansas, Oklahoma, and Missouri. The red-cockaded woodpecker is now found only in coastal states of its historic range and inland in southeastern Oklahoma and southern Arkansas. In North Carolina, moderate populations occur in the sandhills and southern coastal plain. The few populations found in the piedmont and northern coastal plain are believed to be relics of former populations.

This woodpecker is approximately 8 inches (20 centimeters) long with a wingspan of 14 inches (36 centimeters). Plumage includes black and white horizontal stripes on its back, and its cheeks and under parts are white. Its flanks are black streaked. The cap and stripe on the throat and side of neck are black, with males having a small red spot on each side of the cap.

Eggs are laid from April through June. Maximum clutch size is seven eggs with an average of three to five. Approximately 38 days are required from egg laying to fledgling. Several more weeks pass before the young are completely independent.

Red-cockaded woodpeckers are found in open pine stands that are between 80 and 120 years old. Longleaf pine stands are most commonly utilized. Dense stands are avoided. The birds forage in pine and pine hardwood stands, with preference given to pine trees that are 10 inches (25 centimeters) or larger in diameter. The bird's diet consists of primarily insects including ants, beetles, and wood-boring insects.

Biological Conclusion: **No Effect**

No potential habitat such as pinewoods exists in the project area for the red-cockaded woodpecker. A search of the NHP database, conducted on September 16, 2002, found no occurrence of the red-cockaded woodpecker in the project vicinity. It can be concluded that the project will not impact this endangered species.

Federal Species of Concern (FSC) are not legally protected under the Endangered Species Act and are not subject to any of its provisions, including Section 7, until they are formally proposed or listed as Threatened or Endangered. Only one FSC species is listed for Forsyth County. Table 2.6 includes the FSC species listed for Forsyth County and its state classification along with comment on whether habitat is present for this species.

Table 2.6 Federal Species of Concern for Forsyth County

Scientific Name	Common Name	State Status	Available Habitat
Alasmidonta varicosa	Brook floater	T (PE)	No

Notes:

- "T - Threatened" denotes a species likely to become endangered in the foreseeable future throughout all or a significant portion of its range.
- "PE - Proposed for Endangered status" denotes a species that has been proposed to be upgraded from threatened to endangered status.

3 Bankfull Stage Verification

3.1 Bankfull Stage and Discharge

Bankfull stage and its corresponding discharge are the primary variables used to develop a natural channel design. However, the correct identification of the bankfull stage in the field can be difficult and subjective (Williams, 1978; Knighton, 1984; and Johnson and Heil, 1996). Numerous definitions exist of bankfull stage and methods for its identification in the field (Wolman and Leopold, 1957; Nixon, 1959; Schumm, 1960; Kilpatrick and Barnes, 1964; and Williams, 1978). The identification of bankfull stage in the humid Southeast is especially difficult because of dense understory vegetation and a long history of channel modification and subsequent adjustment in channel morphology. It is generally accepted that bankfull stage corresponds with the discharge that fills a channel to the elevation of the active floodplain. The bankfull discharge, known as the channel forming discharge or the effective discharge, is thought to be the flow which moves the most sediment over time. Field indicators include the back of point bars, significant breaks in slope, changes in vegetation, the highest scour line, or the top of the bank (Leopold, 1994). The most consistent bankfull indicators for streams in the Piedmont of North Carolina are the highest scour line and the back of the point bar or lateral bar. The indicator is rarely the top of the bank or the lowest scour or bar.

3.2 Bankfull Hydraulic Geometry Relationships (Regional Curves)

Hydraulic geometry relationships are often used to predict channel morphology features and their corresponding dimensions. The stream channel hydraulic geometry theory developed by Leopold and Maddock (1953) describes the interrelations between dependent variables such as width, depth, and area as functions of independent variables such as watershed area or discharge. These relationships can be developed at a single cross-section or across many stations along a reach (Merigliano, 1997). Hydraulic geometry relationships are empirically derived and can be developed for a specific river or extrapolated to a watershed in the same physiographic region with similar rainfall/runoff relationships (FISRWG, 1998).

Regional curves were first developed by Dunne and Leopold (1978) and relate bankfull channel dimensions to drainage area. A primary purpose for developing regional curves is to aid in identifying bankfull stage and dimension in un-gaged watersheds and to help estimate the bankfull dimension and discharge for natural channel designs (Rosgen, 1994). Gage station analyses throughout the United States have shown that the bankfull discharge has an average return interval of 1.5 years or 66.7% annual exceedence probability on the maximum annual series (Dunne and Leopold, 1978; Leopold, 1994).

Regional curve equations developed from the North Carolina rural and urban Piedmont study are provided by Harman et al. (1999) and Doll et al. (2002) and are shown in Table 3.1.

Table 3.1. Piedmont Rural and Urban Regional Curve Equations.

North Carolina Piedmont Rural Regional Curve Equations	
$Q_{bkf} = 89.04\ A_w^{0.72}$	R^2=0.95
$A_{bkf} = 21.43\ A_w^{0.72}$	R^2=0.91
$W_{bkf} = 13.69\ A_w^{0.38}$	R^2=0.92
$d_{bkf} = 1.57\ A_w^{0.30}$	R^2=0.88
North Carolina Piedmont Urban Regional Curve Equations	
$Q_{bkf} = 340.66\ A_w^{0.57}$	R^2=0.95
$A_{bkf} = 61.16\ A_w^{0.64}$	R^2=0.97
$W_{bkf} = 24.95\ A_w^{0.32}$	R^2=0.88
$d_{bkf} = 2.46\ A_w^{032}$	R^2=0.85

3.3 Bankfull Verification in the Silas Creek Watershed

The bankfull indicators for the Silas Creek watershed included the back of a depositional bench and an upper scour line. These indicators are consistent with other Piedmont streams that are at Stage V in Simon's Channel Evolution Model. Data for both project sites are shown on Figure 3.1. The cross sectional areas for Silas Creek and Buena Vista Branch fall between the urban and rural regional curve. Silas Creek is closer to the urban curve, which is indicative of the higher percent impervious cover (39% versus 27% for Buena Vista Branch). The average percent impervious for the urban curve is 40% with a range from 20% to 80% (Doll et al. 2002). This relationship is also similar to the Buffalo Creek watershed project in Greensboro, where the bankfull cross sectional areas fell between the two curves. This may be a unique characteristic of the Triad or could relate to the similar types of urbanization in the two watersheds (refer to the WRP Buffalo Creek Watershed: Stream Restoration Report for more information).

Bankfull discharge was determined for each reach using HEC-RAS and the field surveyed indicators of bankfull stage. The HEC-RAS bankfull discharge was cross referenced with the regional curve (Figure 3.2). Results are provided in Table 3.2 and show that the values correspond well between the HEC-RAS analysis and the regional curve.

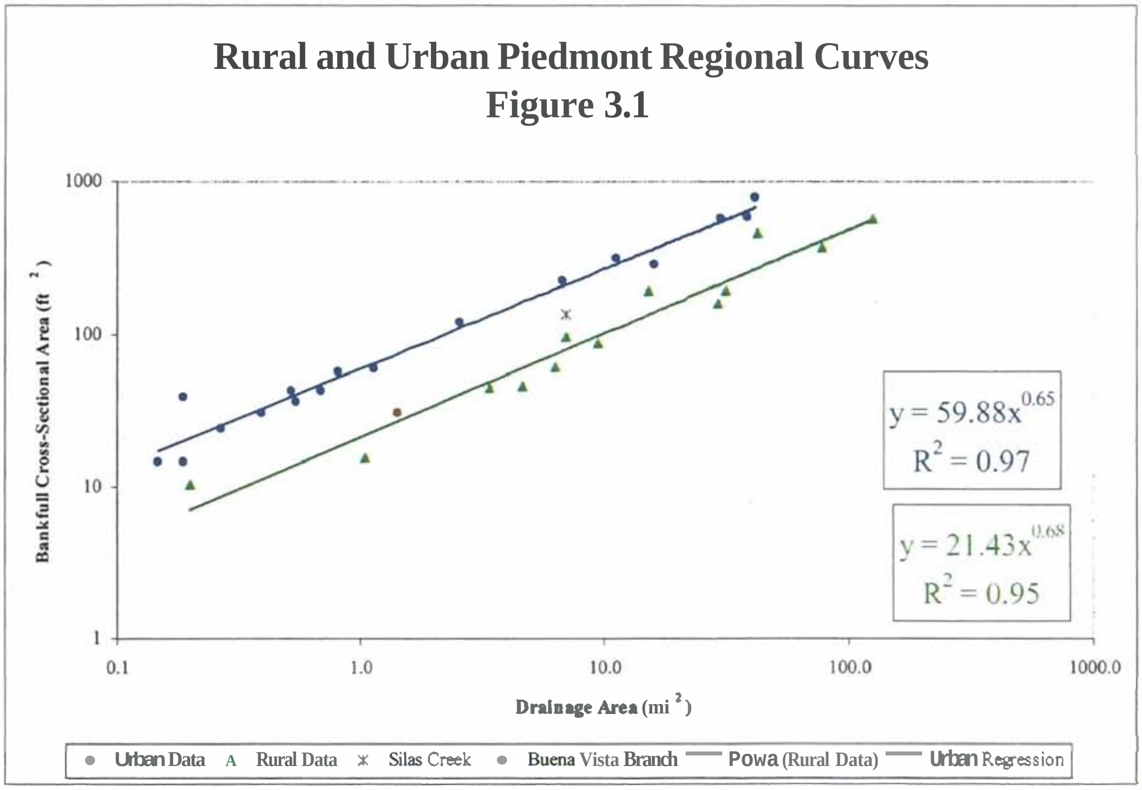


Figure 3.1. Rural and Urban Piedmont Regional Curves with Surveyed Bankfull Cross-Section Areas for Project Reaches. (Project data points were not used in determining the regression line.)

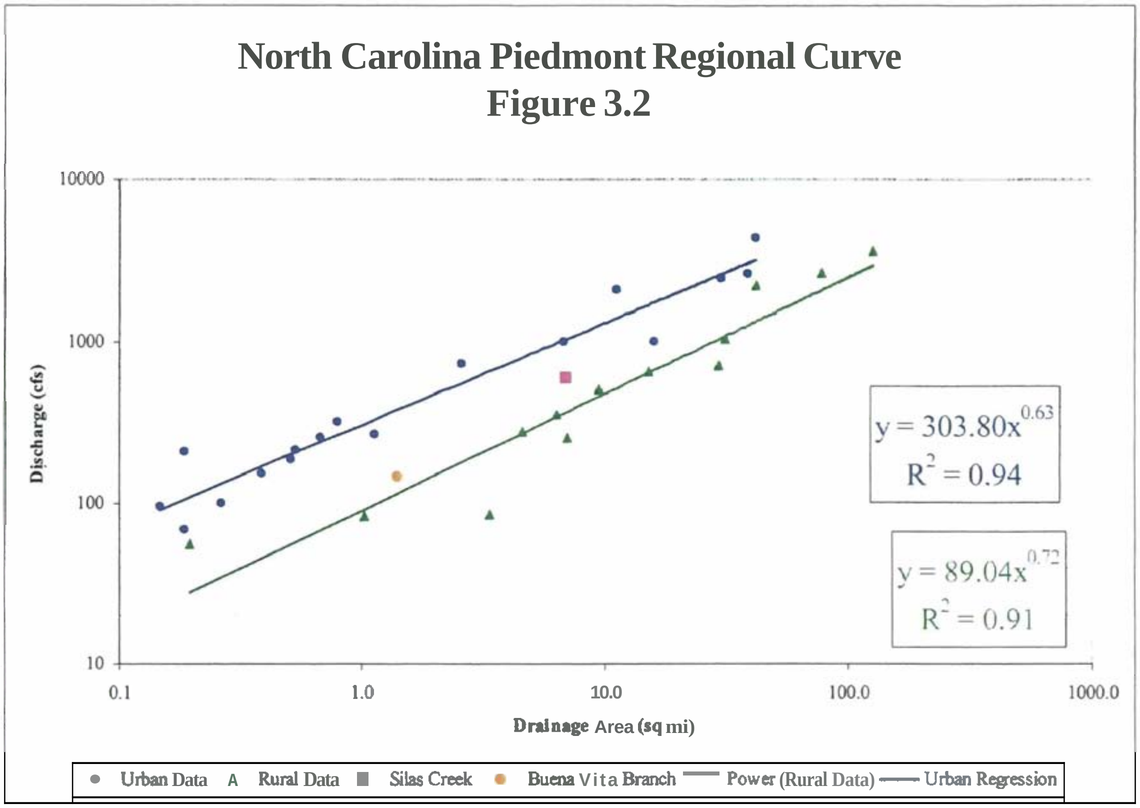


Figure 3.2 Rural and Urban Piedmont Regional Curves showing bankfull discharge versus drainage area. The bankfull discharge predicted using HEC RAS is overlaid with the regional curve for comparison.

Table 3.2. Bankfull discharge comparison of HEC-RAS and regional curve.

Reach	HEC-RAS Q (cfs)	Regional Curve Rural Q (cfs)	Regional Curve Urban Q (cfs)
Silas Reach 1	460	300	879
Silas Reach 2	600	369	1054
Buena Vista Branch	145	113	376

4 Reference Reach Analyses

The reference reach provides the basis for a natural channel design. A reference reach is a segment of river that has a stable dimension, pattern, and profile within an appropriate valley type. A reference reach is selected after the determination of the potential for restoration for the project reach and the selection of a design valley/stream type. The parameters measured at the reference reach are converted into dimensionless ratios for comparison and are used across stream reaches with varying drainage areas. Therefore, the ratios, not the actual values, become the basis for the natural channel design.

The selection of reference reach information for this project included reference reach surveys, evaluation of a reference reach database, and professional judgment based on "lessons learned" from the evaluation of past projects. Two Rosgen stream types were selected for the project and are shown in Table 4.1. These stream types were selected based on the valley type, available belt width, constraints, and channel incision.

Table 4.1. Project Design Stream Types.

Reach	**Reference Stream Type**	**Rationale**
Silas Creek (Reaches 1 & 2)	B4c	Entrenchment ratios will be increased, however the energy will be dissipated through step/pool morphology rather than pattern.
Buena Vista Branch	E4	Proper stream type for this valley.

The streams shown in Table 4.2 were taken from a reference reach database and represent stable urban Piedmont streams. The Silas Creek reference site is located approximately 1.8 miles upstream from the project site (Figure 4.1). The reach was surveyed by the NRCS in 2001. The unnamed tributary to Lake Jeanette was surveyed by North Carolina State University (Figure 4.2). Data for these streams were overlaid with the North Carolina Piedmont Regional Curves to show that they are part of the same hydro-physiographic region (see Figure 4.3); however, the Lake Jeanette reference reach is closer to the urban curve than Silas Creek. There is still a great deal of uncertainty in enlargement processes related to urbanization. Much of the uncertainty is caused by the fact that factors other than percent impervious can lead to enlargement. Other factors include the location and density of stormwater outfalls, road density, direct channel modification, and sediment supply / transport relationships (Hammer, 1973). Until the interactions amongst all of these variables are known, the degree of uncertainty will remain large. It has been observed however, that channels with well vegetated banks, low bank height ratios, moderate sinuosity, large floodplains, and grade control can support smaller bankfull channels than incised streams. As these stabilizing features will all be present in the restored reach of Buena Vista Branch, we feel that the smaller cross sectional area is justified.

In order to verify the stability of the reference reaches, site visits were made to both the Lake Jeanette tributary and the Silas Creek reference reach. A visual assessment and limited quantitative measurements were taken at Silas Creek to confirm channel stability. Considering the fact that the original survey was done in 2001 and the reach is controlled by bedrock, no further surveys were deemed necessary.

We felt that resurveying the Lake Jeanette tributary was necessary to verify the stability of this reach. The cross sections shown in Appendix 2 indicate that very little channel adjustment has taken place since the original survey in 2000. Additionally, the pattern measurements show that even the tightest bends on the reach have remained stable through time.

Table 4.2. Summary Reference Reach Data.

Parameters		Reference	Reference
Reach Name		UT to Lake Jeanette	Silas Creek
Rosgen Stream Type		E5	B4c/1
Drainage Area (sq mi)		0.2	3.3
Dimension	Bankfull Width (ft)	12.8	25.6
	Bankfull Mean Depth (ft)	1.6	1.7
	Width/Depth Ratio (ft)	8.0	15.1
	Bankfull Area (sq ft)	20.5	43.5
Pattern	Meander Length (ft)	35 - 69	130 - 245
	Meander Length Ratio	2.7 – 5.4	5.1 – 9.6
	Radius of Curvature (ft)	18 - 23	19.5 - 54
	Radius of Curvature Ratio	1.4 – 1.8	0.8 – 2.1
	Meander Belt Width (ft)	44 - 45	40 - 51
	Meander Width Ratio	3.4 – 3.5	1.6 – 2.0
	Pool Depth (ft)	3.2	4 - 5
	Pool Depth Ratio	2.0	1.4 – 1.7
	Pool Width (ft)	20.5	22.6 - 28
	Pool Width Ratio	1.6	0.9 – 1.1
	Pool Spacing (ft)	18 – 35	27.2 - 126
	Pool Spacing Ratio	1.4 – 2.7	1.1 – 4.9
	Sinuosity	1.33	1.1
Profile	Valley Slope (ft/ft)	0.0044	0.0088
	Channel Slope (ft/ft)	0.0033	0.0082
	Riffle Slope (ft/ft)	0.0066-0.011	0.020
	Riffle Slope Ratio	2.0-3.4	2.4
	Pool Slope (ft/ft)	0.002	0.0
	Pool Slope Ratio	0.64	0.0
Bed Material	D16	---	0.28
	D35	0.13	0.83
	D50	0.50	19.1
	D84	3.5	157.5
	D95	7.8	300.2

North Carolina
Wetlands Restoration Program

Figure 4.1: Reference Reach Location Map
Silas Creek
Winston Salem, NC
Forsyth County

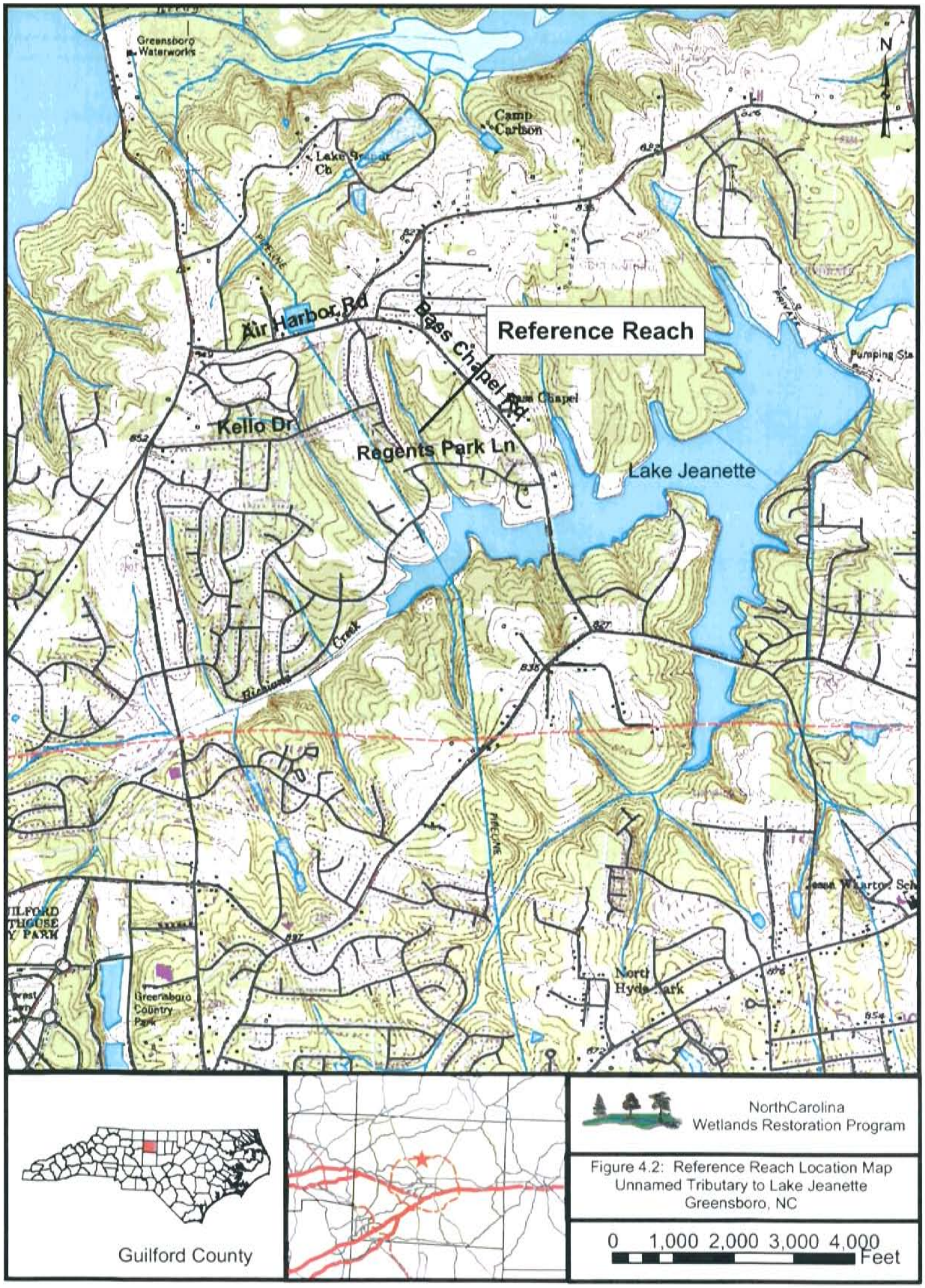


Figure 4.2: Reference Reach Location Map
Unnamed Tributary to Lake Jeanette
Greensboro, NC

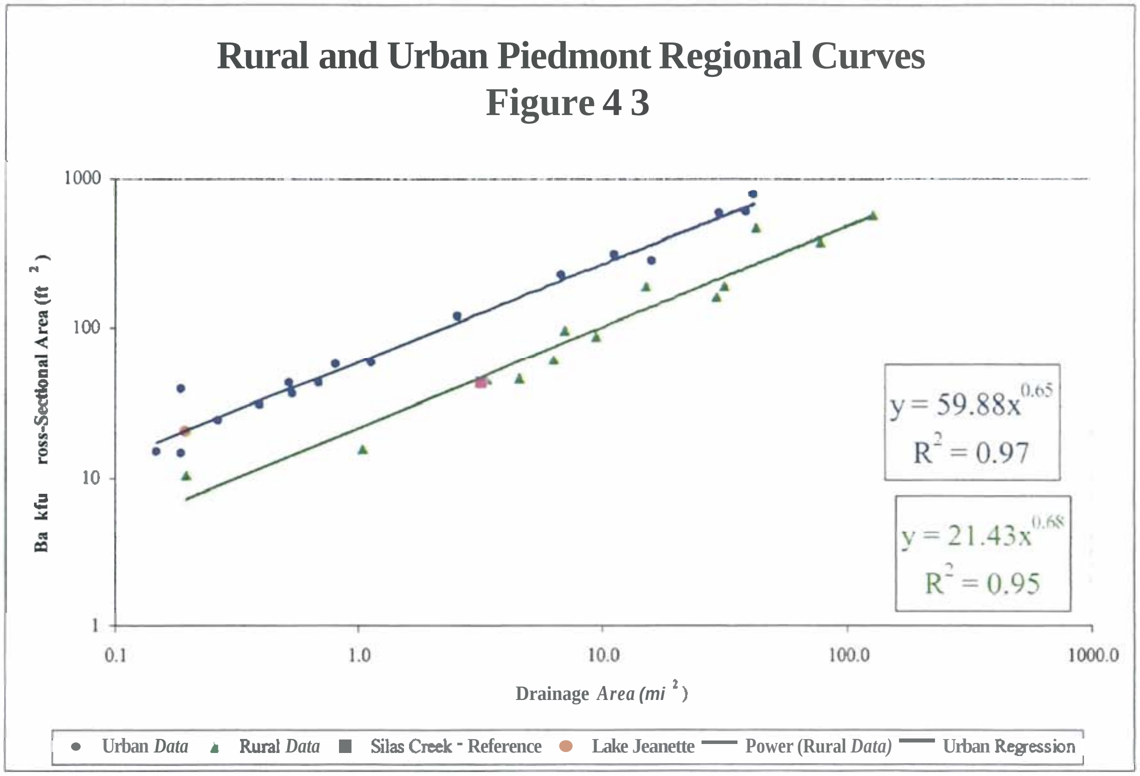


Figure **4.3.** Rural and Urban Piedmont Regional Curves with Surveyed Bankfull Cross-Section Areas for Project Reference Reaches. (Project data points were not used in determining the regression line.)

The reference reaches compare fairly well in terms of ratios; however, some stream geometry data are inappropriate for design. This is due to the fact that the reference reaches have floodplains with mature bottomland forest, while the design reaches will have a newly planted floodplain. For example, the radius of curvature ratios for the Type E reference reaches are less than 2. The design reaches should have a larger ratio because the banks will not initially have the necessary vegetation to prevent bank erosion. In addition, riffle slope ratios greater than 1.5 were used to maximize riffle habitat value.

The final design ratios are shown in Section 5 and are based on bracketing the values from the reference reaches and applying professional judgment to ensure appropriate values are used.

5 Natural Channel Design

5.1 Design Summary

For each stream reach in the Silas Creek watershed project, the proposed natural channel design is the highest level of restoration feasible given the valley type, stream type, land use and urban constraints. For the incised reaches, selection of restoration type follows Rosgen's priority restoration approaches for incised streams (Rosgen, 1997) with the overriding objective of re-establishing contact between the channel and a floodplain. For the purposes of this discussion the four Rosgen restoration approaches have been defined below in order of decreasing priority:

- <u>Priority 1</u> – Re-establish the channel on a previous floodplain (e.g., raise channel elevation); meander new channel to achieve dimension, pattern, and profile characteristic of a stable stream for the particular valley type; fill or isolate existing incised channel.
- <u>Priority 2</u> – Establish a new floodplain for the existing bankfull elevation (e.g., excavate a new floodplain); meander channel to achieve dimension, pattern, and profile characteristic of a stable stream for the particular valley type; fill or isolate existing incised channel.
- <u>Priority 3</u> – Establish a new floodplain at the existing bankfull elevation (e.g., using bankfull benches); leave existing channel in place; use in-stream structures to dissipate energy through a step/pool channel type.
- <u>Priority 4</u> – Stabilize the channel in place using in-stream structures and bioengineering to decrease streambed and streambank erosion.

5.2 Silas Creek Natural Channel Design

Refer to the plan sheets for the detailed design.

Silas Creek is constrained throughout the project area by a combination of sewer lines, walking paths, soccer fields, footbridges, and road crossings. As a result of these constraints, relocation of the Silas Creek channel is not feasible. The proposed natural channel design for Silas Creek reaches 1 & 2 is based on a combination of a Rosgen Priority 3 and Priority 4 techniques. This approach will allow for better bankfull-floodplain connectivity, encourage positive changes to occur in the channel cross-section and will create diversity in bedform.

Bankfull benches will be excavated intermittently along both sides of the channel to create a new active floodplain or increase the size of existing active floodplains. This will increase entrenchment ratios along the reach reducing near bank stresses during large flows and will allow for sediment to be stored outside of the channel. In conjunction with benching, cross vanes will be used throughout the existing channel to set and control grade as well as encourage narrowing and steepening of the riffles. Below the culverts, step-pool structures will be used to raise the bed elevation thus increasing overall channel slope which will allow for better aeration and coarsening of riffle substrate. Double wing deflectors will be constructed to narrow the low flow channel where it is over-wide as well as stabilize the existing banks by reducing near bank stress. J-hook vanes and root wads will be used to stabilize the banks on the outside of meander bends. All of these structures will be spaced so as to mimic the pool to pool spacing ratio of the Silas Creek reference reach. The spacing of these structures will allow Silas Creek to dissipate energy through this series of steps thus decreasing shear stresses and bank erosion. The streambank, bankfull bench, and terrace scarp will be seeded for temporary erosion control (see Planting Design below). The streambank and terrace scarp will be covered with erosion control matting.

A water line crosses Silas Creek at the downstream end of the project. The water line is heavily protected with riprap and is set slightly above the existing bed elevation. Buck Engineering will work with the City to relocate this water line beneath the channel bottom and remove the riprap. This will be done according to the City's engineering specifications. Removing this line from the active channel will allow for an increased slope in the lower end of Reach 2, allowing for increased diversity in bedform.

By removing the water line, raising the bed at the culvert outlets and by installing cross-vanes, wing deflectors, and j-hook vanes, Silas Creek's form will change with time. It is expected that an overall increase in water surface slope will occur and that diversity in bedform will allow for coarsening of riffles and deepening of pools thus improving habitat and aeration. The various structures will encourage the bankfull channel to narrow decreasing the width to depth ratio over time and increasing the efficiency of the channel. So, although Table 5.1 below does not show direct change in many of the design parameters, the design will set in place a change in channel dimensions and profile over time while pattern will be held constant.

Table 5.1. Natural Channel Design Parameters for Silas Creek (Reaches 1&2 are represented by the same dataset).

Parameters		Existing Reaches 1&2	Design Reaches 1&2
Rosgen Stream Type		B4c	B4c
Drainage Area (sq mi)		7.2	7.2
Reach Length (ft)		3805	3805
Dimension	Bankfull Width (ft)	40	40
	Bankfull Mean Depth (ft)	3.5	3.5
	Width/Depth Ratio (ft)	11.7	11.7
	Bankfull Area (sq ft)	138	138
	Bankfull Mean Velocity (ft/sec)	4.35	4.35
	Bankfull Discharge (cfs)	600	600
	Bankfull Max Depth (ft)	4.5	4.5
	Width of Floodprone Area (ft)	68-272	120-272

	Entrenchment Ratio	1.7-6.8	3.0-6.8
	Max Pool Depth (ft)	6.8	6.8
	Ratio of Max Pool Depth to Bankfull Depth	1.2	1.2
	Pool Width (ft)	35.25	35.25
	Ratio of Pool Width to Bankfull Width	0.9	0.9
	Pool to Pool Spacing (ft)	82-189	72 - 144
	Ratio of Pool to Pool Spacing to Bankfull Width	2-4.8	2 - 4
	Bank Height Ratio	1.6	1.0
Pattern	Meander Length (ft)	N/A*	N/A*
	Meander Length Ratio	N/A*	N/A*
	Radius of Curvature (ft)	N/A*	N/A*
	Radius of Curvature Ratio	N/A*	N/A*
	Meander Belt Width (ft)	N/A*	N/A*
	Meander Width Ratio	N/A*	N/A*
	Sinuosity	1.03	1.03
Profile	Valley Slope (ft/ft)	0.0029	0.0029
	WS Slope (ft/ft)	0.0025	0.0025
	Pool Slope (ft/ft)	0.0005	0.0005
	Ratio of pool slope to WS slope	0.19	0.19
	Riffle Slope	0.0028	0.0028
	Riffle Slope Ratio	1.12	1.12

* Due to the extremely low sinuosity, pattern data cannot accurately be calculated. Any data calculated would overestimate pattern.

Several storm-water ditches enter Silas Creek within the project area. These ditches increase the sediment load in the Creek as headcuts move up the ditches from the lower grade of Silas. The ditches will be stabilized using outlet protection structures or step/pool designs. The step/pool design has been modified from earlier designs to minimize the drop between steps (<= 0.5ft) and prevent piping. See the design drawings for more detail.

5.2.1 Planting Design

A combination of native herbaceous and woody vegetation will be established in the riparian buffer along Silas Creek. The buffer width will range between 15 and 25 feet depending on space restrictions due to park boundaries. This buffer width will be in accordance with the City of Winston-Salem's stream buffer recommendations (1999) which include a variance stating that a stream buffer shall not exceed 25% of the available land space on publicly owned property with a "cross sectional land space" less then 400 feet. In addition, areas around utilities in the buffer zone will be left free of woody vegetation to a minimum length of 10 feet and a maximum length of 30 feet.

These clearings will also act as public access areas along with a path (10-15 feet wide) leading to and from the footbridge. All access areas may need to be periodically maintained by the City of Winston-Salem (Winston-Salem 1999).

Species used for seeding and woody vegetation will depend upon availability and cost at the time of planting. Permanent seeding may include, but not be limited to, switch grass (Panicum virgatum), Virginia wild rye (Elymus virginicus), soft rush (Juncus effusus), fox sedge (Carex vulpinoidea), ironweed (Vernonia noveboracensis), joe-pye-weed (Eupatorium fistulosum), and cardinal flower (Lobelia cardinalis). Trees and shrubs that may be used include, but are not limited to, willow oak (Quercus phellos), river birch (Betula nigra), red maple (Acer rubrum), green ash (Fraxinus pennsylvanica), red chokeberry (Aronia arbutifolia), beautyberry (Callicarpa americana), witch-hazel (Hamamelis virginiana), spicebush (Lindera benzoin), and winterberry (Ilex verticillata). Species to be used for live staking include silky dogwood (Cornus amomum) and silky willow (Salix sericea). Temporary vegetation for erosion control will consist of annual rye (cool season) or millet (warm season) depending on the construction schedule.

5.2.2 Silas Creek Best Management Practice

Background

The objective of the storm-water BMP is to maximize pollutant removal considering site constraints and costs. Storm water BMPs' removal efficiency is directly related to detention time or treatment time and volume. Thus, as flows increase and volume fills, treatment decreases. Although pollutant loading increases with flow, the total annual contribution of pollutants from large (>2 inch) precipitation events is low due to their infrequent nature. In fact most of the annual pollutant load is associated with the "first flush." In the Southeast, designs are typically for the first inch of precipitation, thus treating 90% of all precipitation events and eliminating the unnecessary expense of building a large treatment facility.

The feasibility of constructing one or more best management practices (BMPs) at the tributary entering Silas Creek just downstream of Silas Creek Parkway was examined to both improve water quality and serve as a demonstration project. Due to the limited space to treat runoff from the tributary, areas adjacent to the parking lot were also examined for the potential of treating parking lot runoff.

Four potential BMPs were identified based on site space restrictions and their potential to treat water quality impacts to Silas Creek. Alternatives were also identified that represent a potential educational opportunity to demonstrate the applicability of BMPs within a maintained and landscaped area. Each alternative is described in more detail below.

Area A

This area is shown in Figure 5.1 and allows for a small detention/infiltration basin (900 ft^2) to be placed along the existing tributary to treat storm flows before entering Silas Creek. The treatment mechanisms would include particle settling, infiltration, and

Figure 5.1: Silas Creek BMP Design
Winston Salem, NC
Forsyth County

nutrient uptake by vegetation. The drainage area to this site is +/-34 acres and drains part of Silas Creek Parkway and single family residential neighborhoods. Nutrients and suspended sediment are the constituents of concern. In order to treat the first flush, the volume of this BMP would need to be approximately 30,000 cubic feet. The available volume for a BMP in this area is about 3,000 cubic feet, about a tenth of the volume needed. This area could be expanded but would involve moving the existing walking path and removal of some landscaping, an expense that would increase the potential BMP volume only slightly. This location would be a highly visible area for public education as it is located at the beginning of the walking path.

Area B

This area is shown in Figure 5.1 and allows for in channel improvements limited to channel stabilization and vegetation enhancements. Existing invasive vegetation (primarily Kudzu) would be replaced by native vegetation along the banks and the channel would be regraded to allow for the construction of a step-pool system. This alternative directly effects water quality by limiting erosion and by encouraging aeration through a series of steps pools. Energy dissipation from the step pools would also discourage erosion in Silas Creek on the opposite channel bank. This location would be highly visible for public education as it is located adjacent to the bridge crossing to the park.

Area C

This area is shown in Figure 5.1 and could be enhanced by creating a 5 foot wide filter strip along the Northern boundary of the parking lot. The filter strip would allow settling of particulates from the parking lot, catch trash, and encourage infiltration. The strip would also act as a level spreader, so concentrated runoff from the parking lot would not affect bank stability as it runs into Silas Creek. This area could be constructed in conjunction with the bank construction of Silas Creek. Vegetation would be selected to aesthetically fit within the park setting and still provide a native vegetated buffer to Silas Creek. This area is not as visible a location as Areas A and B but could still provide an educational opportunity.

Area D

This area is shown in Figure 5.1 and would be used to create a small infiltration basin (800 SF) to treat parking lot runoff before entering Silas Creek. This area could be graded to receive water from area C, allowing additional settlement, infiltration, and nutrient removal before flows enter Silas Creek. The outflow from this area could be controlled so as not to disturb the Silas Creek streambank. Area D's size is limited by the location of a large water line. This area is not a visible location for public education because it is located between the parking lot and Silas Creek Parkway.

Recommended BMP Design

Considering the site constraints, treatment potential, costs, and educational benefits, Buck Engineering recommends the improvements discussed above for areas B and C. The Area B BMP is consistent with the water quality goals of the Silas Creek restoration and also would be an aesthetic enhancement to the entrance of Shaffner Park. This is a key public viewing and awareness area. Area C is a cost effective location since it is part of the regrading efforts of Silas Creek and offers an opportunity to treat parking lot runoff before it enters Silas Creek. Area C also demonstrates how an existing parking lot can be retrofitted to improve water quality and still be an attractive amenity to a landscaped area, which is a valuable public awareness goal.

Areas A and D were rejected for cost/benefit reasons. Area A would offer an excellent opportunity but with its limited space, a significant water quality benefit could not be accomplished with construction of a BMP in this area. Area D has limited space and could only treat a limited part of the parking lot area.

5.3 Buena Vista Natural Channel Design

Refer to the plan sheets for the detailed design.

The proposed natural channel design for Buena Vista Branch is based on a combination of a Rosgen Priority 2 and Priority 3 approach. A new meandering E4 channel will be constructed from Station 11+80 to 17+81 at a lower elevation than the existing terrace. A floodplain will be excavated along both sides of the channel. Cross vanes, rock vanes and root wads will be used to stabilize the new channel and areas of the existing channel that will be left in place. The streambank, bankfull bench, and terrace scarp will be seeded for temporary erosion control (see Planting Design below). The streambank and terrace scarp will be covered with erosion control matting. The rest of Buena Vista Branch will be left at its existing location because of the presence of sewer lines, adjacent soccer fields, and pedestrian footbridge crossings.

At the downstream end of the project, Buena Vista Branch is highly incised as a result of a head-cut moving up from Silas Creek. This section will be stepped down to the bed elevation of Silas Creek using a step/pool structure. The step/pool design has been modified from earlier designs to minimize the drop between steps (<= 0.5 ft) and prevent piping. See the design drawings for more detail.

Table 5.2. Natural channel design parameters for Buena Vista Branch.

Parameters		Existing	Design
Rosgen Stream Type		E4	E4
Drainage Area (sq mi)		1.4	1.4
Reach Length (ft)		828	910
Dimension	Bankfull Width (ft)	14.5	17.6
	Bankfull Mean Depth (ft)	2.11	1.8
	Width/Depth Ratio	6.86	10
	Bankfull Area (sq ft)	30.6	32.2
	Bankfull Max Depth (ft)	3.21	2.6
	Width of Floodprone Area (ft)	20-119	60-160
	Entrenchment Ratio	1.4 - 8.2	3.4 – 9.1
	Max Pool Depth (ft)	2.76	3.4
	Ratio of Max Pool Depth to Bankfull Depth	1.3	1.9
	Pool Width (ft)	15.8	22.9
	Ratio of Pool Width to Bankfull Width	1.09	1.3
	Pool to Pool Spacing (ft)	45 - 160	60 - 100
	Ratio of Pool to Pool Spacing to Bankfull Width	3.1 - 11	3.5 - 6
	Bank Height Ratio	1.8	1.0
Pattern	Meander Length (ft)	72-105	120 - 200
	Meander Length Ratio	5-7.2	7 - 11
	Radius of Curvature (ft)	25-100	32 - 53
	Radius of Curvature Ratio	1.7-6.9	2.0 - 3.0
	Meander Belt Width (ft)	15.4-23.8	53 - 88
	Meander Width Ratio	1.1-1.6	3 - 5
	Sinuosity	1.09	1.22
Profile	Valley Slope (ft/ft)	0.0111	0.011
	WS Slope (ft/ft)	0.0107	0.009
	Pool Slope (ft/ft)	0.0025	0.0034
	Ratio of Pool Slope to WS Slope	0.23	0.38

5.3.1 Planting Design

Plantings for Buena Vista Branch will be similar to the proposed plantings for Silas Creek.

6 Sediment Transport Analysis

6.1 Background

A stable stream has the ability to move its sediment load without aggrading or degrading over long periods of time. The total volume of sediment transported through a cross section consists of bedload and suspended load fractions. Suspended load is normally composed of fine sand, silt, and clay particles transported in the water column. Bedload is generally composed of larger particles, such as course sand, gravels, and cobbles, transported by rolling, sliding, or hopping (saltating) along the bed.

The ability of the stream to transport its total sediment load is quantified through two measures: sediment transport competency and sediment transport capacity. Competency is a stream's ability to move particles of a given size and is a measurement of force, often expressed as units of lbs/ft^2. Sediment transport capacity is a stream's ability to move a quantity of sediment and is a measurement of stream power, often expressed as units of lbs/ (ft•sec). Sediment transport capacity is also calculated as a sediment transport rating curve, which provides an estimate of the quantity of total sediment load transported through a cross section per unit time. The curve is provided as a sediment transport rate in lbs/sec versus discharge or stream power.

6.1.1 Competency Analysis

Median substrate size has an important influence on the mobility of particles in streambeds. Critical dimensionless shear stress ($\tau*_{ci}$) is the measure of force required to initiate general movement of particles in a bed of a given composition. At shear stresses exceeding this critical value, essentially all grain sizes are transported at rates in proportion to their presence in the bed (Wohl, 2000). $\tau*_{ci}$ can be calculated for gravel-bed stream reaches using surface and subsurface particle samples from a stable, representative riffle in the reach (Andrews, 1983). Critical dimensionless shear stress is calculated as follows (Jessup, pers. comm., 2002):

1. Using the following equations, determine the critical dimensionless shear stress required to mobilize and transport the largest particle from the bar sample (or subpavement sample).

   a) Calculate the ratio $D_{50}/D\hat{}_{50}$
   Where: D_{50} = median diameter of the riffle bed (from 100 count in the riffle or pavement sample)
   $D\hat{}_{50}$ = median diameter of the bar sample (or subpavement)

   If the ratio $D_{50}/D\hat{}_{50}$ is between the values of 3.0 and 7.0, then calculate the critical dimensionless shear stress using Equation 1.

$$\tau^*_{ci} = 0.0834\ (D_{50}/D\hat{}_{50})^{-0.872} \qquad \textbf{(Equation 1)}$$

b) If the ratio $D_{50}/D^{\wedge}_{50}$ is not between the values of 3.0 and 7.0, then calculate the ratio of D_i/D_{50}

Where: D_i = Largest particle from the bar sample (or subpavement)
D_{50} = median diameter of the riffle bed (from 100 count in the riffle or the pavement sample)

If the ratio D_i/D_{50} is between the values of 1.3 and 3.0, then calculate the critical dimensionless shear stress using Equation 2.

$$\tau^*_{ci} = 0.0384\ (D_i/D_{50})^{-0.887} \qquad \textbf{(Equation 2)}$$

Entrainment analyses were conducted for the Silas Creek and Buena Vista reaches to ensure that the design streambed neither aggrades nor degrades during bankfull flows.

6.2 Silas Creek

Because the designs for both reaches are similar, they were grouped for the purposes of calculating sediment transport competency. The critical dimensionless shear stress for Silas Creek was calculated using bed material samples from a stable riffle. The cumulative frequency curves of the samples are shown on Figure 6.1.

Data presented in Figure 6.1 were used to determine particle sizes for the various calculations. The $D_{50}/D^{\wedge}_{50}$ ratio is 4.1, so Equation 1 is valid. Critical dimensionless shear stress was calculated using Equation 1 as $\tau^*_{ci} = 0.024$. This value of dimensionless shear stress is used in the aggradation analysis presented below.

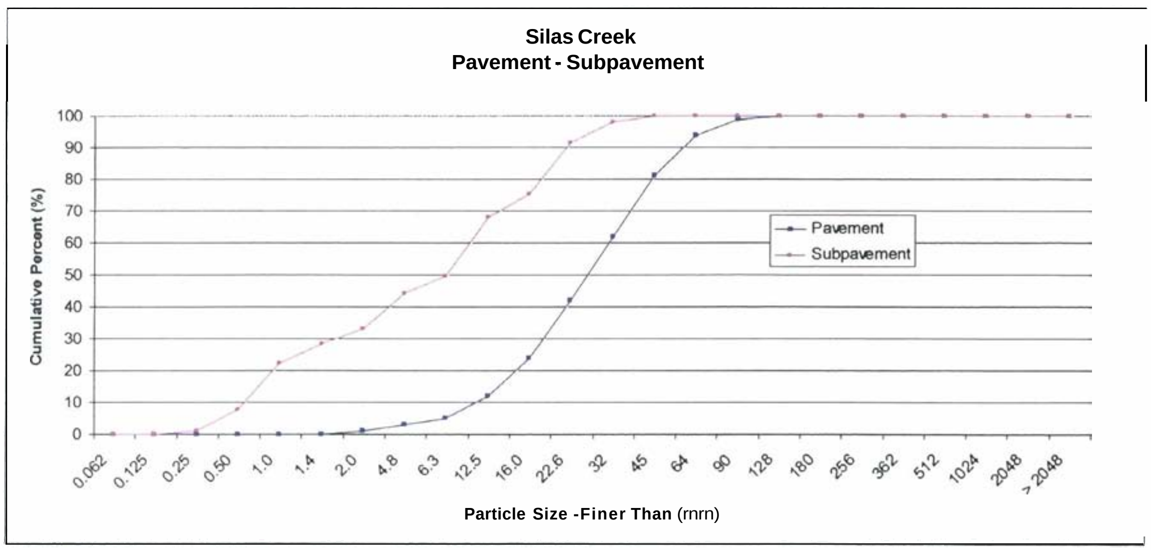


Figure 6.1. Silas Creek Pavement / Subpavement Analysis

6.2.1 Aggradation Analysis Through Critical Depth and Slope Calculation

An aggradation analysis was performed to predict whether the channel depth and slope proposed in the design will cause the stream to aggrade. The aggradation analysis is based on calculations of the required depth and slope needed to transport large sediment particles, in this case defined as the largest particle of the riffle subpavement sample. Required depth can be compared with the design mean riffle depth and required slope can be compared to the design slope to verify that the stream has sufficient competency to move large particles and thus prevent thalweg aggradation. The required depth and slope are calculated by:

$$\mathbf{d_r = \frac{1.65\tau^*_{ci}D_i}{S_e}} \qquad \textbf{(Equation 3)}$$

$$\mathbf{s_r = \frac{1.65\tau^*_{ci}D_i}{d_e}} \qquad \textbf{(Equation 4)}$$

Where:
d_r (ft) = Required bankfull mean depth
d_e (ft)= Design bankfull mean depth
1.65 = Sediment density (submerged specific weight)
= density of sediment (2.65) – density of water (1.0)
τ^*_{ci} = Critical dimensionless shear stress
D_i (ft) = Largest particle from bar sample (or subpavement)
s_r (ft/ft) = Required bankfull water surface slope
s_e (ft/ft) = Design bankfull water surface slope

Using a design slope of 0.0023 ft/ft and the largest subpavement particle diameter of 45 mm, Equation 3 indicates a required depth of 2.6 feet. The current design would create benches at the bankfull elevation but would not change the bankfull channel dimensions. Therefore the mean design bankfull riffle depth is equal to the existing mean depth along Silas Creek at 3.5 ft (Table 6.1). This is greater than the required depth and thus sufficient to transport the larger materials and prevent aggradation. Using the design depth, Equation 4 indicates a required slope of 0.0015, which is less than the design slope. Urban channels often have a design depth and slope that is greater than the required values. There are several reasons for this, including:

1. Equations 1 and 2 are empirical relationships that were developed on large rural rivers in Colorado and are very different from the project reach,
2. Since some enlargement has occurred, the increase in cross sectional area causes the mean depth to increase.

During urbanization, the grain size distribution of the bed material often decreases. Therefore, while existing depth and shear stress are increasing, the particle sizes are decreasing.

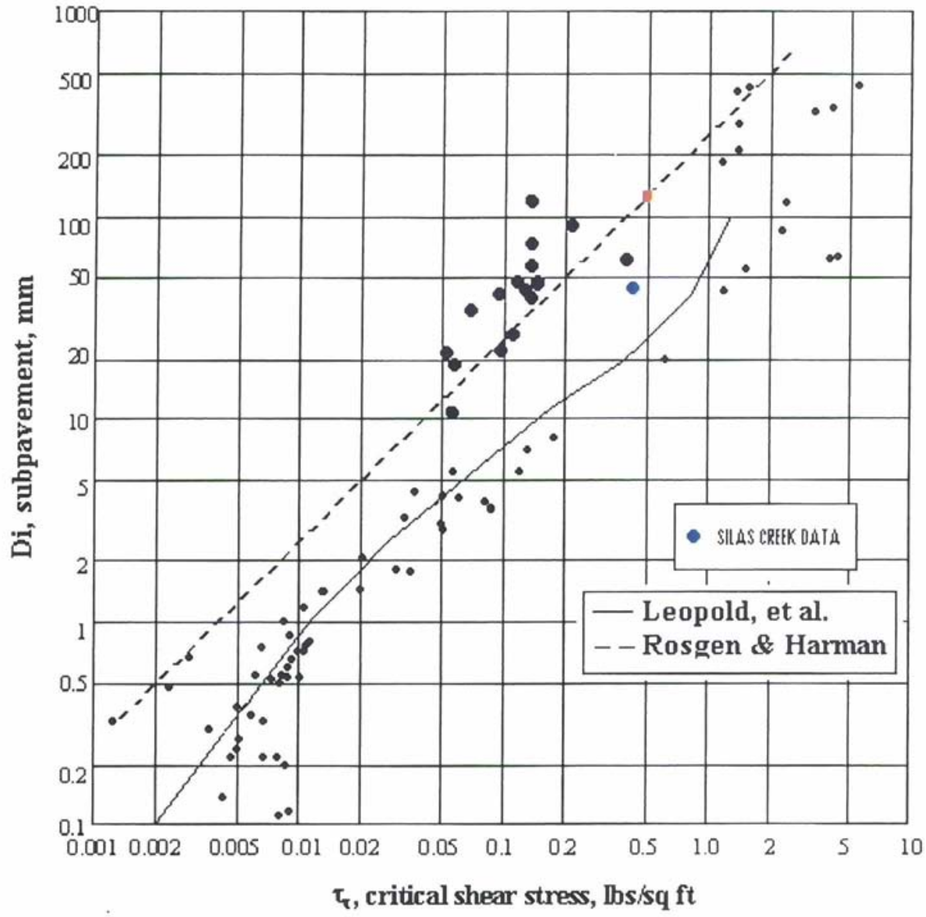
6.2.2 Competency Analysis Through Boundary Shear Stress and Shield's Curve Comparison

As a compliment to the required depth and slope calculations, we calculated boundary shear stresses for design riffle cross sections and compared these with a modified Shield's Curve to predict sediment transport competency. The shear stress placed on the sediment particles is the force that entrains and moves the particles, given by:

$$\tau = \gamma R s \qquad \textbf{(Equation 5)}$$

Where,
τ = shear stress (lb/ft^2)
γ = specific gravity of water (62.4 lb/ft^3)
R = hydraulic radius (ft)
s = average channel slope (ft/ft)

The boundary shear stress estimated for the design cross-section is 0.46 lb/ft^2. The measured D_i of the subpavement was 45 mm. As shown on the Modified Shield's Curve (Figure 6.2), this value of shear stress and D_i are just slightly below the range of values used to calculate the regression equation. The Shield's Curve analysis supports the critical depth based conclusion that the design-cross sections can move sediment competently and prevent aggradation.



(Data from: Leopold, Wolman, and Miller 1964; Rosgen, personal commun.; and *Harman, personal commun.)*

Figure 6.2. Modified Shield's Curve for Grain Diameter of Transported Particle in Relation to Critical Shear Stress.

6.2.3 Degradation Analysis

Degradation analysis was performed in order to assess whether the design cross sections would result in scour and bed downcutting. We evaluated the potential for degradation by examining the upper competency limits for design cross sections and by reviewing existing and design grade control at the site.

The calculated shear stress discussed in Section 6.2.2 can be used to describe the upper competency limits for the design channel. The estimated boundary shear stress was 0.46 lbs/ft^2. Based on the Modified Shield's Curve (Figure 6.2), shear stress in this range will move particles up to about 105 mm in size, which corresponds roughly to the largest particle size of the reach-wide pebble count sample. Preferably, this stress would correspond to the D84, but the concern for degradation is addressed through existing and design grade control. Reach wide confidence in vertical stability of the streambed comes from a review of grade control at the project site. The existing culverts and the large riprap apron at the downstream end of the project reach control the overall slope and will prevent reach-wide degradation. Rock cross vanes throughout the projects will help control grade locally.

Table 6.1. Boundary shear stresses for existing and design riffle cross sections on Silas Creek.

Shear Stress Analysis	**Existing & Design Design**
Bankfull Area (sq ft)	138
Bankfull Width, W (ft)	40
Bankfull Mean Depth, D (ft)	3.5
Wetted Perimeter	25
Hydraulic Radius, R (ft)	3.2
Slope (ft/ft)	0.0023
Bankfull Discharge, Q (ft^3/sec)	600
Flow velocity, v (ft/sec)	4.35
Boundary Shear Stress, τ (lbs/sq ft)	0.46

6.3 Buena Vista Branch

The critical dimensionless shear stress for Buena Vista Branch was calculated using bed material samples from a stable riffle. The cumulative frequency curves of the samples are shown on Figure 6.3.

Data presented in Figure 6.3 was used to determine particle sizes for the various calculations. The $D_{50}/D\hat{}_{50}$ ratio is 3.4, so Equation 1 is valid. Critical dimensionless shear stress was calculated using Equation 1 as $\tau^*_{ci} = 0.0285$. This value of dimensionless shear stress is used in the aggradation analysis presented below.

design grade control. Reach wide confidence in vertical stability of the streambed comes from a review of grade control at the project site. The existing culverts and the large riprap apron at the downstream end of the project reach control the overall slope and will prevent reach-wide degradation. Rock cross vanes throughout the projects will help control grade locally.

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Wetted Perimeter	25
Hydraulic Radius, R (ft)	3.2
Slope (ft/ft)	0.0023
Bankfull Discharge, Q (ft^3/sec)	600
Flow velocity, v (ft/sec)	4.35
Boundary Shear Stress, τ (lbs/sq ft)	0.46

6.3 Buena Vista Branch

The critical dimensionless shear stress for Buena Vista Branch was calculated using bed material samples from a stable riffle. The cumulative frequency curves of the samples are shown on Figure 6.3.

Data presented in Figure 6.3 was used to determine particle sizes for the various calculations. The D_{50}/D^$_{50}$ ratio is 3.4, so Equation 1 is valid. Critical dimensionless shear stress was calculated using Equation 1 as $\tau^*_{ci} = 0.0285$. This value of dimensionless shear stress is used in the aggradation analysis presented below.

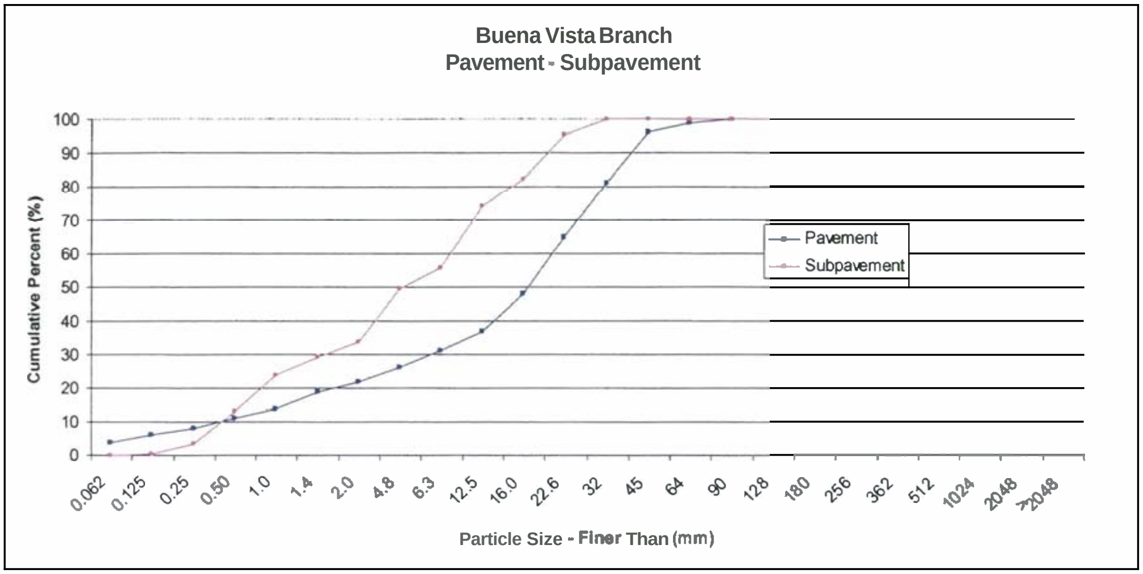


Figure 6.3. Buena Vista Branch Pavement / Subpavement Analysis.

6.3.1 Aggradation Analysis Through Critical Depth and Slope Calculation

An aggradation analysis was performed to predict whether the channel depth and slope proposed in the design will cause the stream to aggrade. The aggradation analysis is based on calculations of the required depth and slope needed to transport large sediment particles, in this case defined as the largest particle of the riffle subpavement sample. Required depth can be compared with the design mean riffle depth and required slope can be compared to the design slope to verify that the stream has sufficient competency to move large particles and thus prevent thalweg aggradation. The required depth and slope are calculated by:

$$d_r = \frac{1.65\tau^*_{ci}D_i}{S_e} \qquad \textbf{(Equation 3)}$$

$$s_r = \frac{1.65\tau^*_{ci}D_i}{d_e} \qquad \textbf{(Equation 4)}$$

Where: d, (A) = Required bankfull mean depth
d_e (ft)= Design bankfull mean depth
1.65 = Sediment density (submerged specific weight)
= density of sediment (2.65) – density of water (1.0)
τ^*_{ci} = Critical dimensionless shear stress
D_i (A) = Largest particle from bar sample (or subpavement)
s, (ft/ft) = Required bankfull water surface slope
s_e (ft/ft) = Design bankfull water surface slope

As discussed previously, urban streams often show decreased subpavement particle size distributions due to aggradation of fine sediments. This situation was evident in the first subpavement sample taken in Buena Vista Branch which resulted in extremely low critical depth and slope calculations. In order to obtain more representative samples, two different methods were utilized for analyzing the subpavement particle size distribution. One subpavement sample was taken from a point bar and compared to an additional subpavement sample from a representative riffle. The results of both methodologies are presented below.

Using a design slope of 0.0054 ft/ft and the largest subpavement (bar sample) particle diameter of 55 mm, Equation 3 indicates a required depth of 1.6 feet. Using a design slope of 0.0054 ft/ft and the largest subpavement (riffle sample) particle diameter of 36 mm, Equation 3 indicates a required depth of 1.0 feet. The mean design bankfull riffle depth along Buena Vista Branch is 1.8 ft (Table 6.2). This is greater than the required depth calculated using both samples and thus sufficient to transport the larger materials and prevent aggradation. Using the design depth and point bar subpavement sample, the slope check indicates a required slope of 0.0044. Using the design depth and riffle subpavement sample, the slope check indicates a required slope of 0.0030. Both are less than the design slope.

6.3.2 Competency Analysis Through Boundary Shear Stress and Shield's Curve Comparison

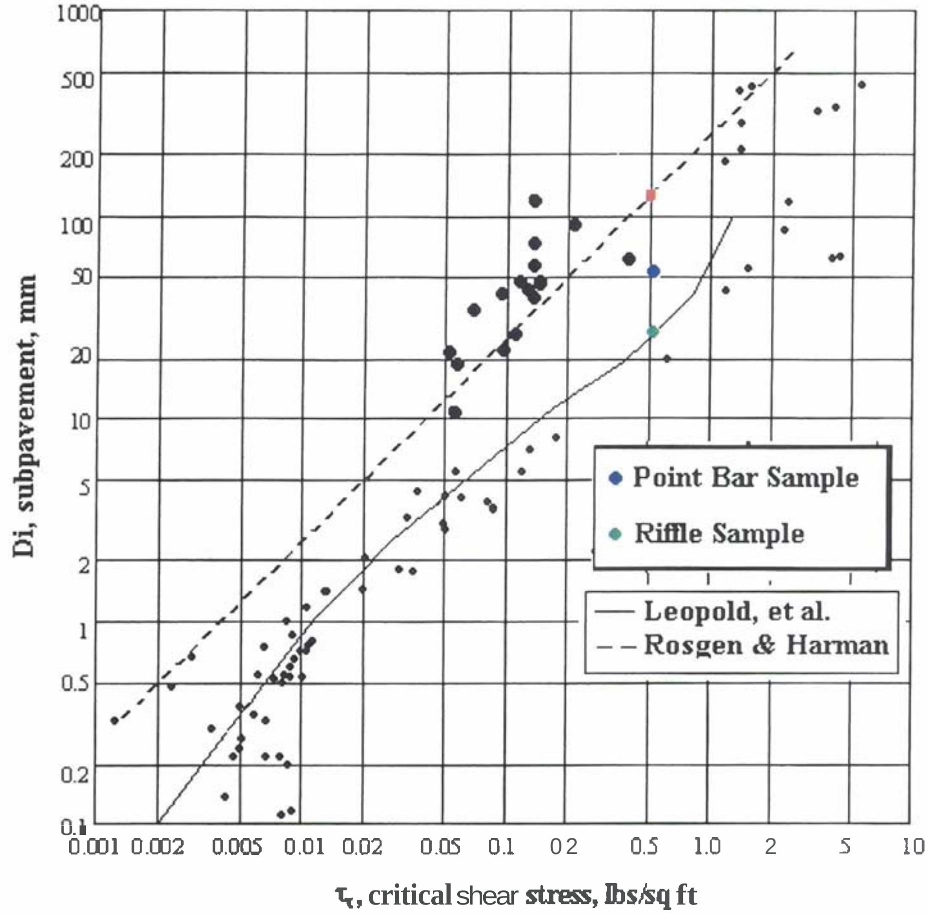
As a compliment to the required depth and slope calculations, we calculated boundary shear stresses for design riffle cross sections and compared with a modified Shield's Curve to predict sediment transport competency. The shear stress placed on the sediment particles is the force that entrains and moves the particles, given by:

$$\tau = \gamma R s \qquad \textbf{(Equation 5)}$$

Where,

τ = shear stress (lb/ft^2)
γ = specific gravity of water (62.4 lb/ft^3)
R = hydraulic radius (ft)
s = average channel slope (ft/ft)

The boundary shear stress estimated for the design cross-section on Buena Vista Branch is 0.51 lb/ft^2. The measured D_i of the subpavement was 55 mm from the bar sample and 36 mm from the riffle sample. As shown on the Modified Shield's Curve (Figure 6.4), this value of shear stress and both D_i values fall below the range of values used to calculate the regression equation. The Shield's Curve analysis supports the critical depth based conclusion that the design-cross sections can move sediment competently and prevent aggradation. The issue of potential degradation is discussed below.



(Data from: Leopold, Wolman, and Miller 1964; Rosgen, personal commun.; and Harman, personal commun.)

Figure 6.4. Modified Shield's Curve for Grain Diameter of Transported Particle in Relation to Critical Shear Stress.

6.3.3 Degradation Analysis

Degradation analysis was performed in order to assess whether the design cross sections would result in scour and bed downcutting. We evaluated the potential for degradation by examining the upper competency limits for design cross sections and by reviewing existing and design grade control at the site.

The calculated shear stress discussed in Section 6.3.2 can be used to describe the upper competency limits for the design channel. The estimated boundary shear stress was 0.51 lbs/ft^2. Based on the Modified Shield's Curve (Figure 6.4), shear stress in this range will move particles up to about 125 mm in size, which is significantly larger than any particles encountered in the reach-wide pebble count sample. Preferably, this stress would correspond to the D84, but the concern for degradation is addressed through existing and design grade control. Reach wide confidence in vertical stability of the streambed comes from a review of grade control at the project site. The existing at-grade sewer line crossings at the start and end of the project length as well as the culvert set at the existing thalweg grade control the overall slope and will prevent reach-wide degradation. Rock cross vanes throughout the project will help control grade locally.

Table 6.2 Boundary shear stresses for existing and design riffle cross sections on Buena Vista Branch (excludes priority IV restoration reach below culvert).

Shear Stress Analysis	**Existing**	**Design**
Bankfull Area (sq ft)	30.6	31.7
Bankfull Width, W (ft)	14.5	17.6
Bankfull Mean Depth, D (ft)	2.1	1.8
Wetted Perimeter	18.8	21.1
Hydraulic Radius, R (ft)	1.7	1.5
Slope (ft/ft)	0.0063	0.0054
Bankfull Discharge, Q (ft^3/sec)	145	145
Flow velocity, v (ft/sec)	4.7	4.6
Boundary Shear Stress, τ (lbs/sq ft)	0.65	0.51

7 Flooding Analyses

Silas Creek and Buena Vista Branch were located on the Federal Emergency Management Agency's (FEMA) Flood Insurance Rate Maps. Both streams are located in FEMA detailed flood study areas (designated Zone AE).

The Silas Creek existing condition stream model will be developed in HEC-RAS from a combination of available topography and the data provided from the existing FEMA generated HEC-2 model. The 10-year, 50-year, 100-year, and 500-year discharges estimated in the Flood Insurance Study produced by FEMA will be used. The proposed stream restoration condition will be compared to the existing stream condition to verify that an increase has not occurred to the 100-year floodplain elevations.

Since the existing FEMA generated HEC-2 model was not available for Buena Vista Branch, the existing and proposed models will be developed from available topography. Discharges for the 10-year, 50-year, 100-year, and 500-year storm events will be obtained from the Flood Insurance Study produced by FEMA. In order to verify that the proposed stream restoration does not adversely impact the existing floodplain elevations, a comparison will be made between the existing and proposed conditions using HEC-RAS.

A separate report will be prepared showing the results of the flood study.

8 Monitoring and Evaluation

Environmental components monitored in this project will be those that allow an evaluation of channel stability and riparian survivability. Specifically, the success of channel modification, erosion control, seeding, and woody vegetation plantings will be evaluated. This will be accomplished through the following activities for 5 years after the project is built.

8.1 Cross-sections

Permanent cross-sections (either surveyed or located using a GPS) will be established at a spacing of one per 20 bankfull-width lengths, with an effort made to include both riffles and pools. These cross-sections may be the same as ones taken to develop construction plans or they may be new. Each cross-section will be marked on both banks with permanent pins to establish the exact transect used. A common benchmark will be used for cross-sections and consistently used to facilitate easy comparison of year-to-year data. The annual cross-section survey will include points measured at all breaks in slope, including top of bank, bankfull, inner berm, edge of water, and thalweg. Calculations will be made of width/depth ratio, entrenchment ratio, and low bank height ratio. Riffle cross-sections will be classified using the Rosgen stream classification system.

Success Criteria: There should be little or no change in as-built cross-sections. If changes do take place they should be evaluated to determine if they represent a movement toward a more unstable condition (down-cutting, erosion) or are minor changes that represent an increase in stability (settling, vegetative changes, deposition along the banks, decrease in width/depth ratio and/or cross sectional area).

8.2 Pattern

Annual measurements taken for the plan view of the restoration site will include sinuosity, meander width ratio, and radius of curvature (on newly constructed meanders only for the first year of monitoring).

8.3 Materials

Annual pebble counts will be performed on all gravel-bed project reaches based on the percent of pools and riffles.

Success Criteria: Established D50 and D85 should increase in coarseness in riffles, and increase fineness in pools.

8.4 Longitudinal Profiles

A complete longitudinal profile will be completed once the first year and then every two years for a total of five years (for a total of 3 times). Measurements will include slope (average, pool, riffle) and pool-to-pool spacing. Survey points will include thalweg, water surface, inner berm, bankfull, and top of low bank. Each of these points will be taken at the head of each feature, e.g. riffle, run, pool, and glide, and the max pool depth. The survey will be tied to a permanent benchmark.

Success Criteria: The as-built longitudinal profiles should show that the bedform features are remaining stable, e.g. they are not aggrading or degrading. The pools should remain deep with flat water surface slopes and the riffles should remain steeper and shallower.

8.5 Photo Reference Sites

Photographs used to evaluate restored sites will be made with a 35-mm camera using slide film or a digital camera. There will be one photo reference site per cross-section showing both banks and the stream channel. Several of the in-stream structures (e.g., rock vanes, cross vanes, and root wads) will also be photographed. Reference sites will be photographed before construction and continued once per year for at least 5 years following construction. After construction has taken place, reference sites will be marked with wooden stakes.

Longitudinal reference photos: The stream will be photographed longitudinally beginning at the downstream end of the mitigation site and moving upstream to the end of the site. Photographs will be taken looking upstream at delineated locations. Reference photo locations will be marked and described for future reference. Points will be close enough together to get an overall view of the reach. The angle of the shot will depend on what angle provides the best view and will be noted and continued in future shots. When modifications of stream position have to be made due to obstructions or other reasons, the position will be noted along with any landmarks and the same position used in the future.

Lateral reference photos: Reference photo transects will be taken at each permanent cross-section. Photographs will be taken of both banks at each cross-section. The survey tape will be centered in the photographs of the bank. The water line will be located in the lower edge of the frame and as much of the bank as possible included in each photo. Photographers should make an effort to consistently maintain the same area in each photo over time. Photos of areas that have been treated differently should also be included; for example, two different types of erosion control material used. This will allow for future comparisons.

Success Criteria: Photographs will be used to subjectively evaluate channel aggradation or degradation, bank erosion, success of riparian vegetation, and effectiveness of erosion control measures. Longitudinal photos should indicate the absences of developing bars within the channel or an excessive increase in channel depth. Lateral photos should not indicate excessive erosion or continuing degradation of the bank over time. A series of photos over time should indicate successional maturation of riparian vegetation. Vegetative succession should include initial herbaceous growth, followed by increasing densities of woody vegetation, and then ultimately a mature overstory with herbaceous understory.

8.6 Survival Plots

Survival of planted vegetation will be evaluated using survival plots or counts. Survival of live stakes will be evaluated using enough plots or a size plot that allows evaluating at least 100 live stakes. Evaluations of live stake survival will continue for at least 5 years. When stakes do not survive a determination will be made as to the need for replacement; in general, if greater than 25% die, replacement will be done.

All rooted vegetation will be flagged and evaluated for at least 5 years to determine survival. At least 2 staked survival plots will be evaluated. Plots will be 25 ft by 100 ft and all flagged stems will be counted in those plots. Success will be defined as 320 stems per acre after 5 years. When rooted vegetation does not survive, a determination will be made as to the need for replacement; in general, if greater than 25% die, replacement will be done.

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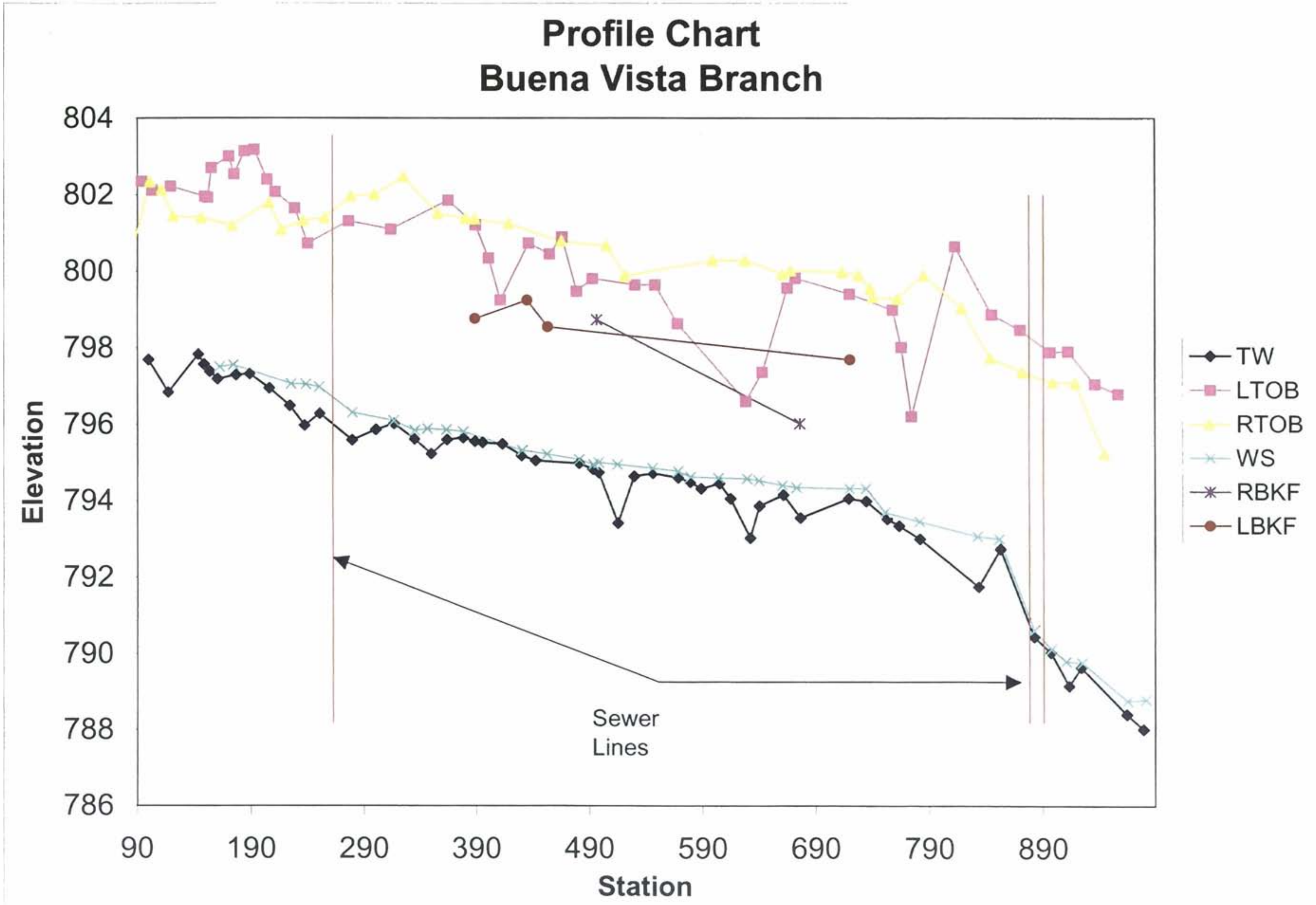
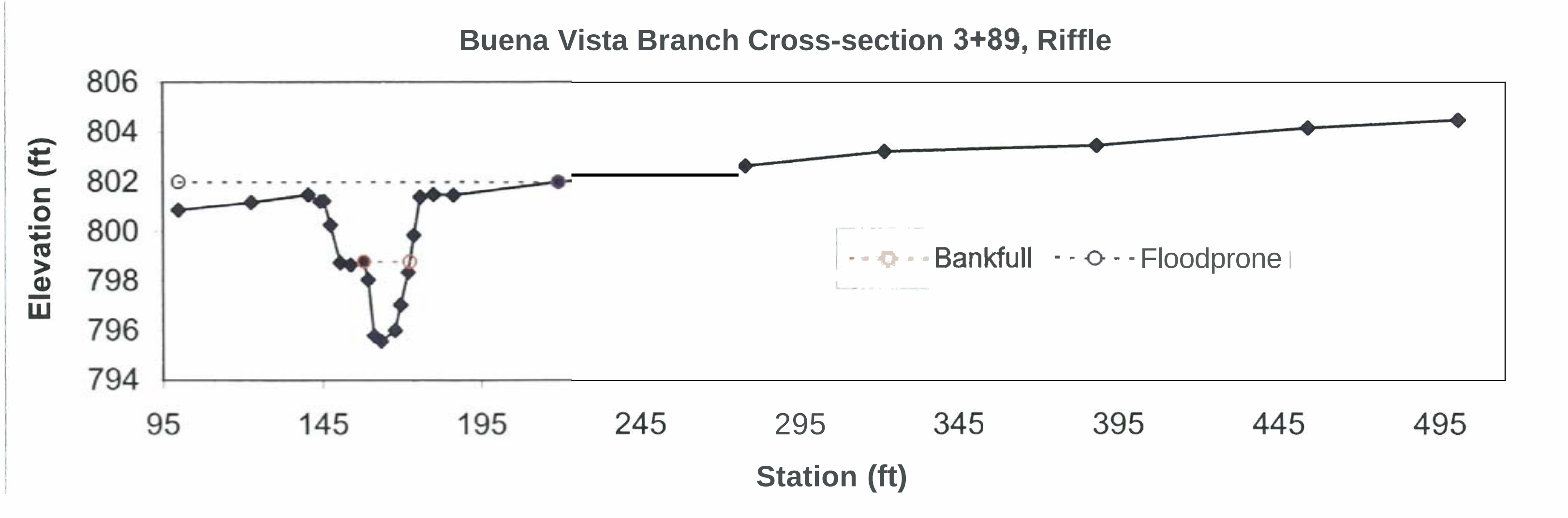
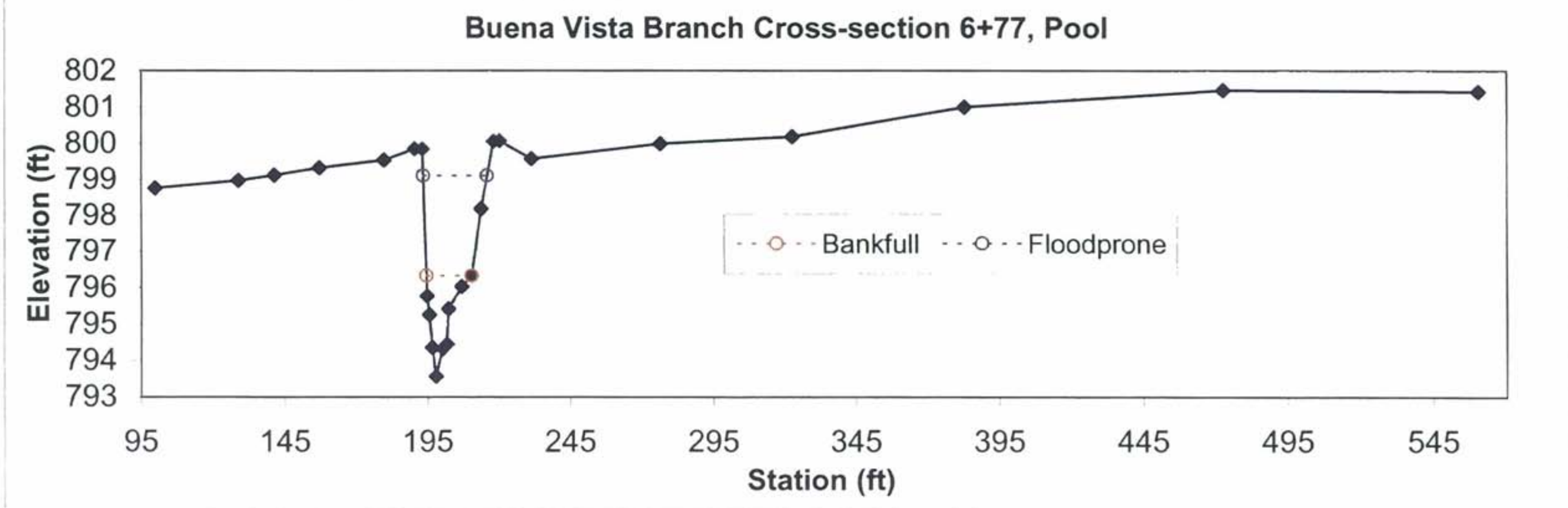
Appendix 1 Existing Condition Data

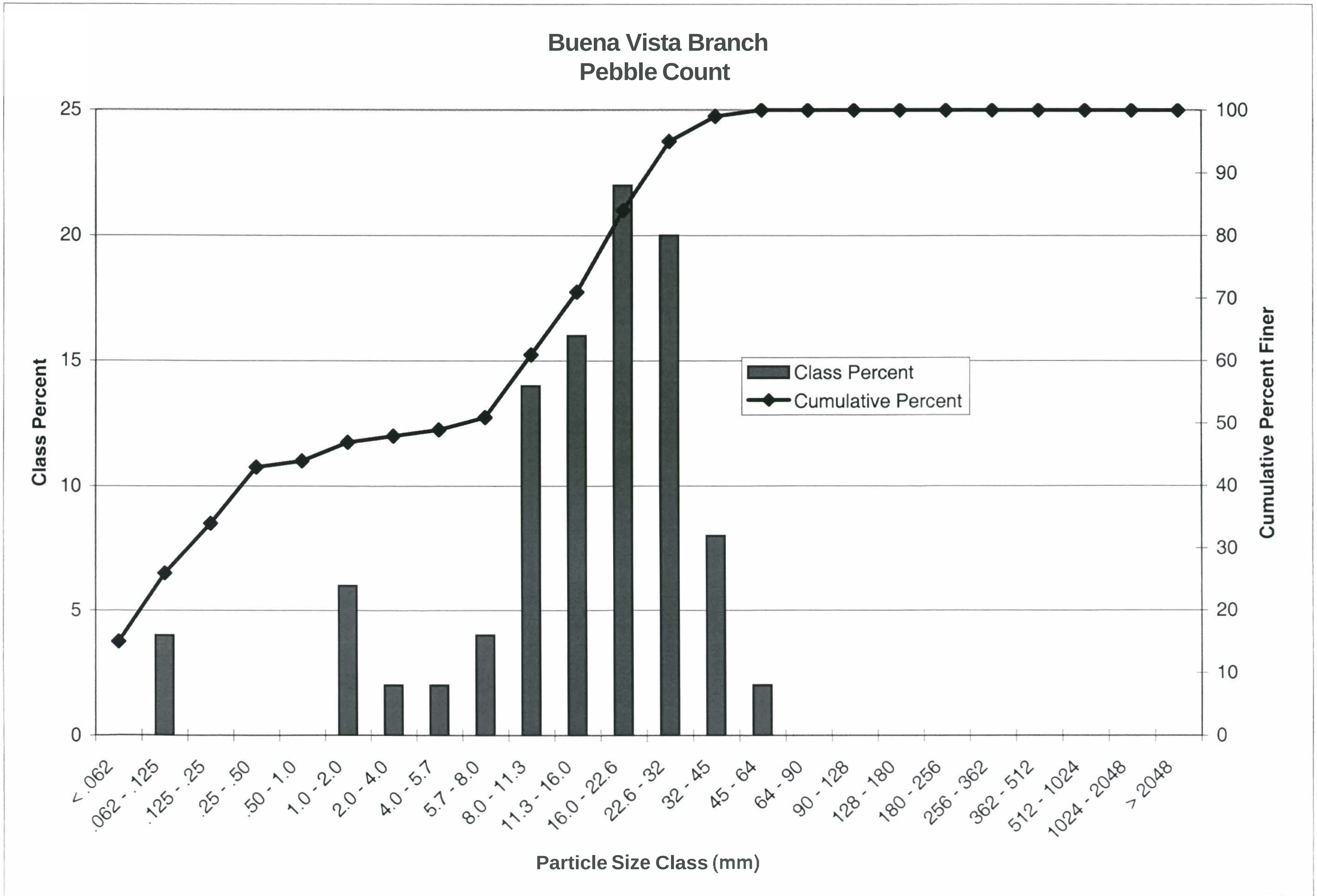

Profile Chart
Buena Vista Branch
Elevation
804
802
800
798
796
794
792
790
788
786
90
190
290
390
490
590
690
790
890
Station
Sewer
Lines
TW
LTOB
RTOB
WS
RBKF
LBKF

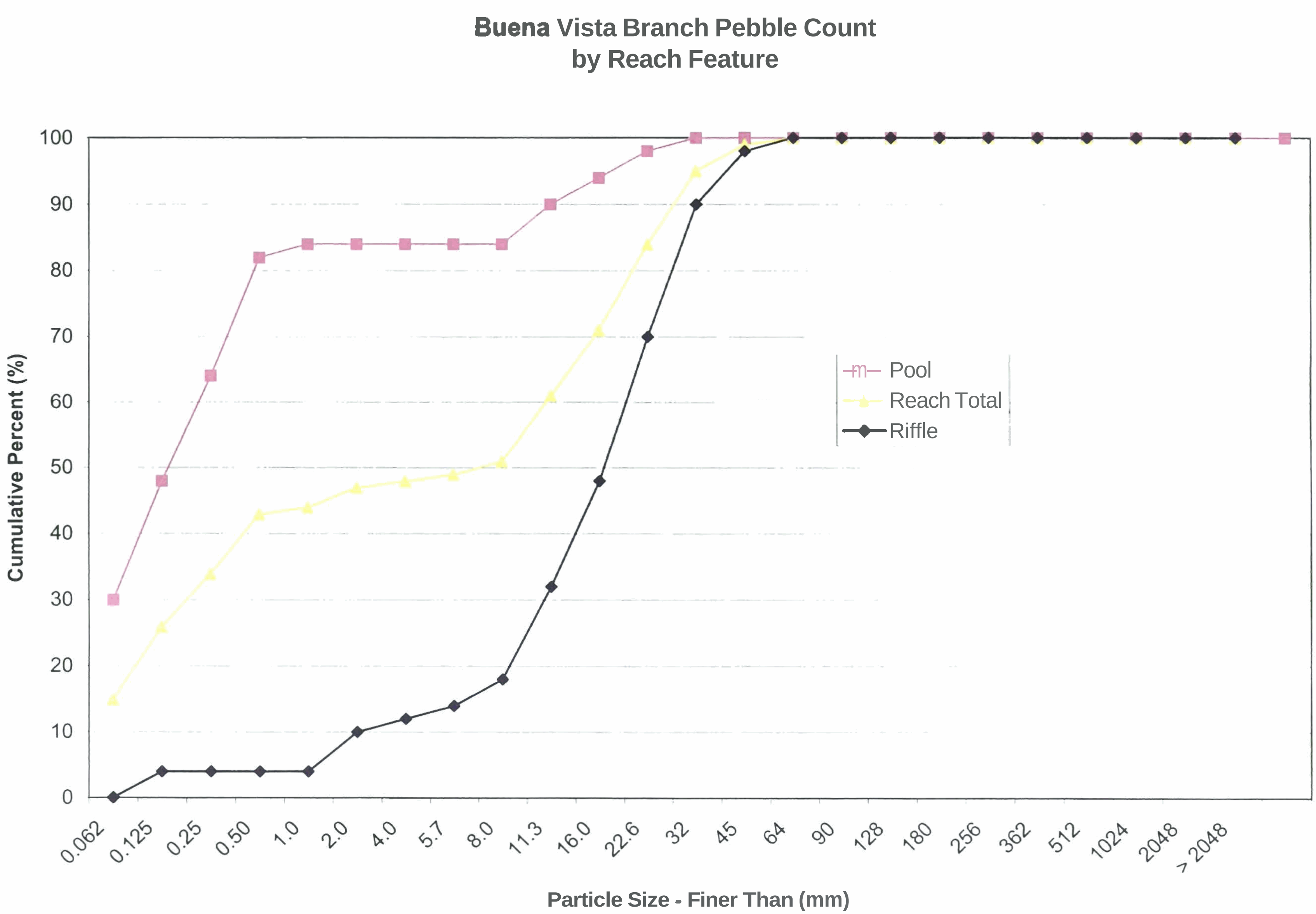
Feature	Stream Type	BKF Area	BKF Width	BKF Depth	Max BKF Depth	W/D	BH Ratio	ER	BKF Elev	TOB Elev
Riffle	E	30.6	14.5	2.11	3.21	6.86	1.8	8.2	798.77	801.22



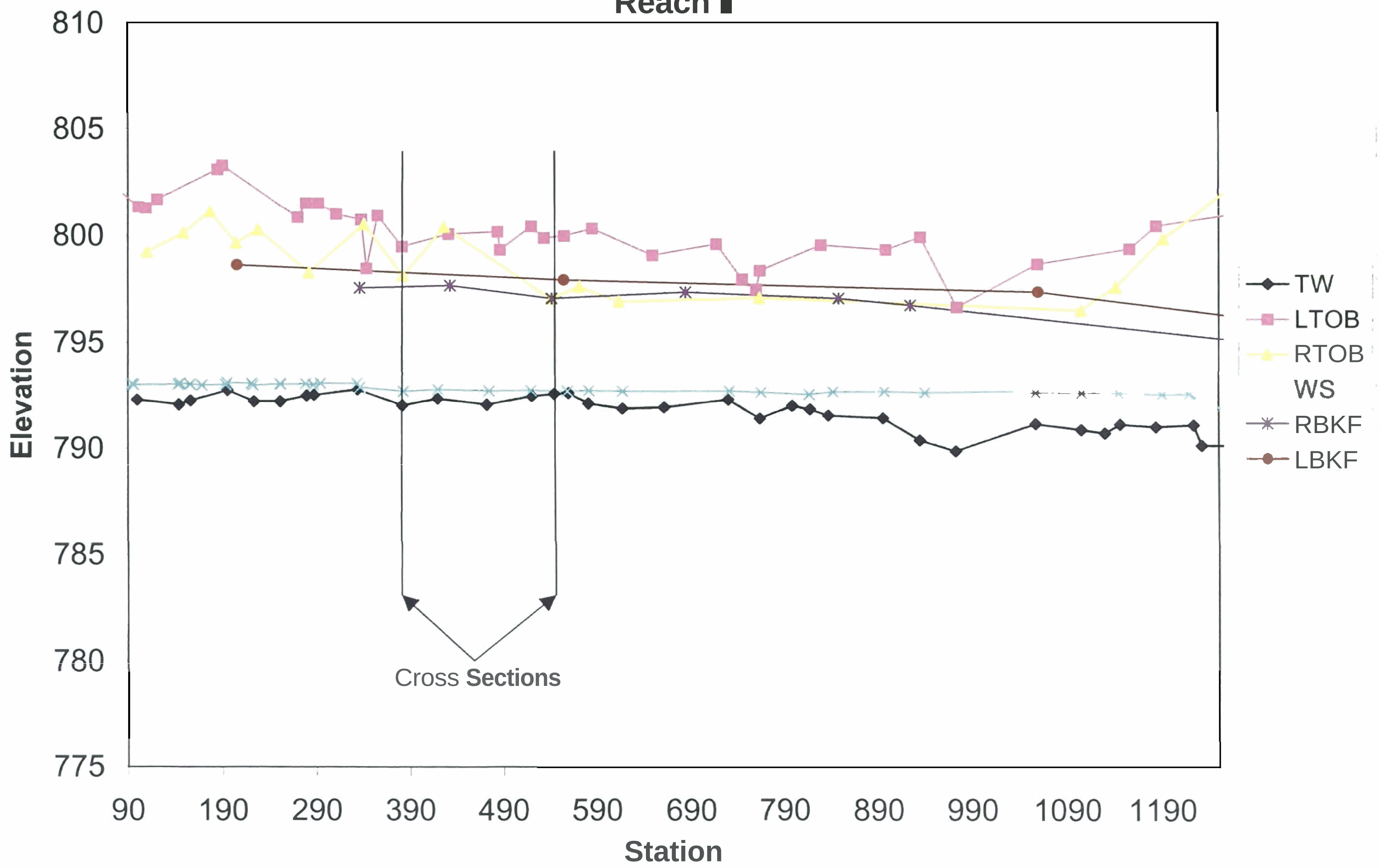
Feature	Stream Type	BKF Area	BKF Width	BKF Depth	Max BKF Depth	W/D	BH Ratio	ER	BKF Elev	TOB Elev
Pool		17.9	15.8	1.13	2.76	13.94	2.3	1.4	796.32	799.83

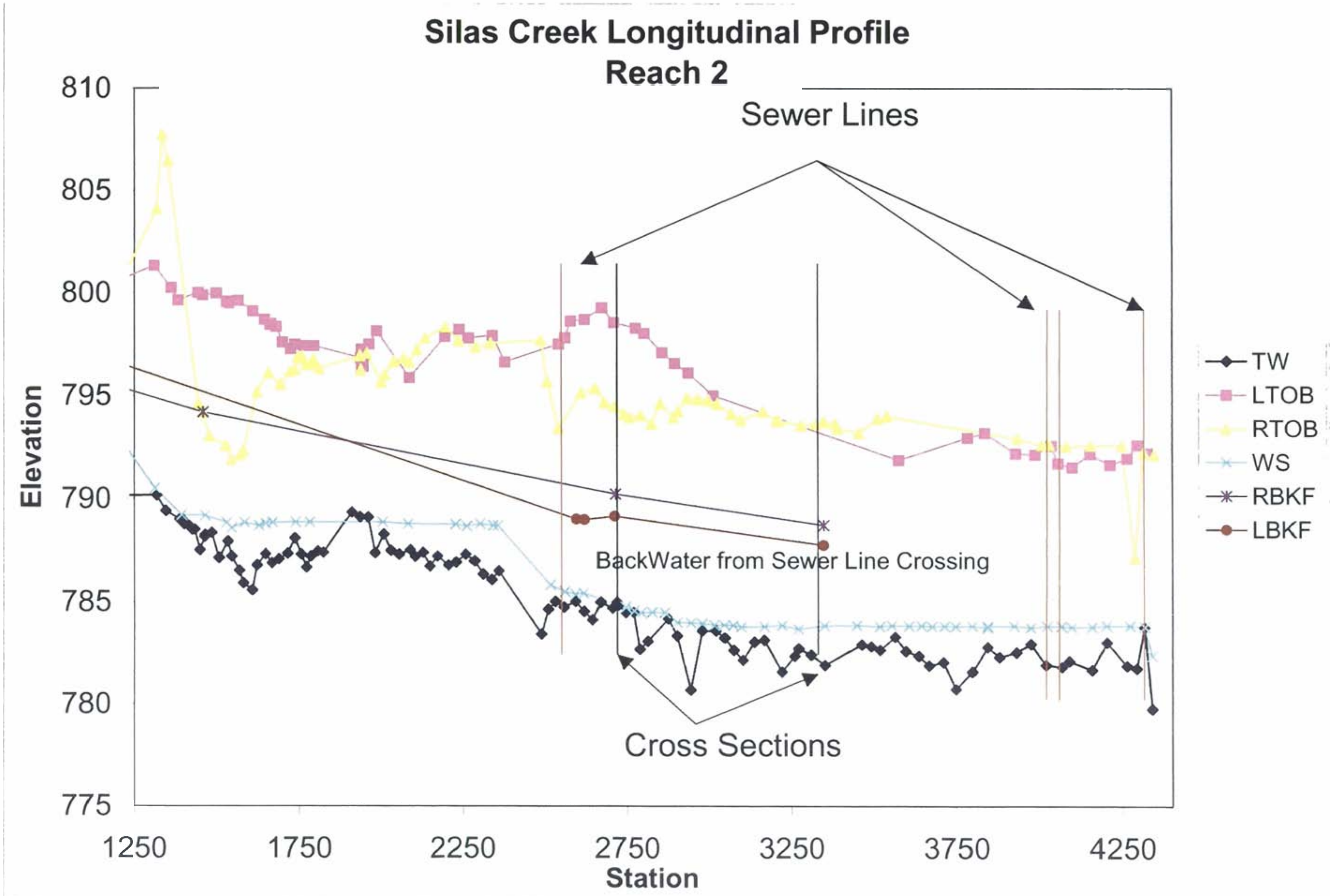



Buena Vista Branch
Pebble Count
Class Percent
Cumulative Percent Finer
25
20
15
10
5
0
100
90
80
70
60
50
40
30
20
10
0
Class Percent
Cumulative Percent
< .062
.062 - .125
.125 - .25
.25 - .50
.50 - 1.0
1.0 - 2.0
2.0 - 4.0
4.0 - 5.7
5.7 - 8.0
8.0 - 11.3
11.3 - 16.0
16.0 - 22.6
22.6 - 32
32 - 45
45 - 64
64 - 90
90 - 128
128 - 180
180 - 256
256 - 362
362 - 512
512 - 1024
1024 - 2048
> 2048
Particle Size Class (mm)


Buena Vista Branch Pebble Count
by Reach Feature
Cumulative Percent (%)
100
90
80
70
60
50
40
30
20
10
0
Pool
Reach Total
Riffle
0.062
0.125
0.25
0.50
1.0
2.0
4.0
5.7
8.0
11.3
16.0
22.6
32
45
64
90
128
180
256
362
512
1024
2048
> 2048
Particle Size - Finer Than (mm)

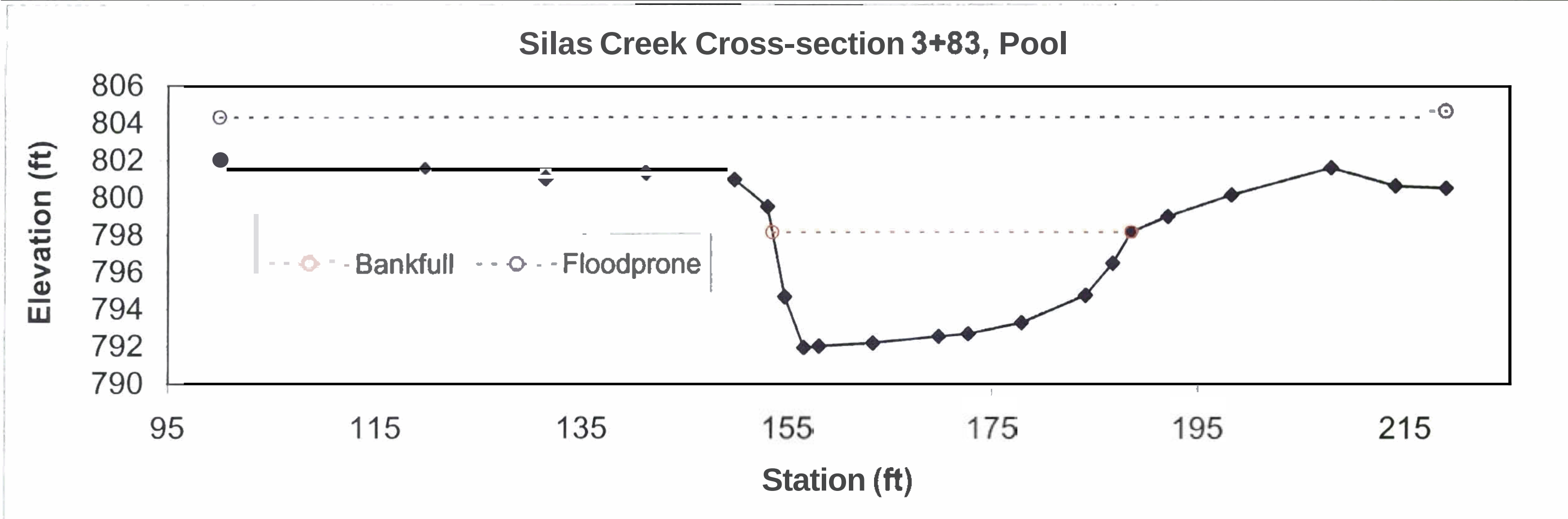
Silas Creek Longitudinal Profile
Reach [redacted]




Silas Creek Longitudinal Profile
Reach 2
Sewer Lines
BackWater from Sewer Line Crossing
Cross Sections
Elevation
810
805
800
795
790
785
780
775
1250
1750
2250
2750
3250
3750
4250
Station
TW
LTOB
RTOB
WS
RBKF
LBKF

Cross-section Data:

Feature	Stream Type	BKF Area	BKF Width	BKF Depth	Max BKF Depth	W/D	BH Ratio	ER	BKF Elev	TOB Elev
Pool		165.6	34.97	4.74	6.19	7.39	1.5	3.4	798.13	798.13



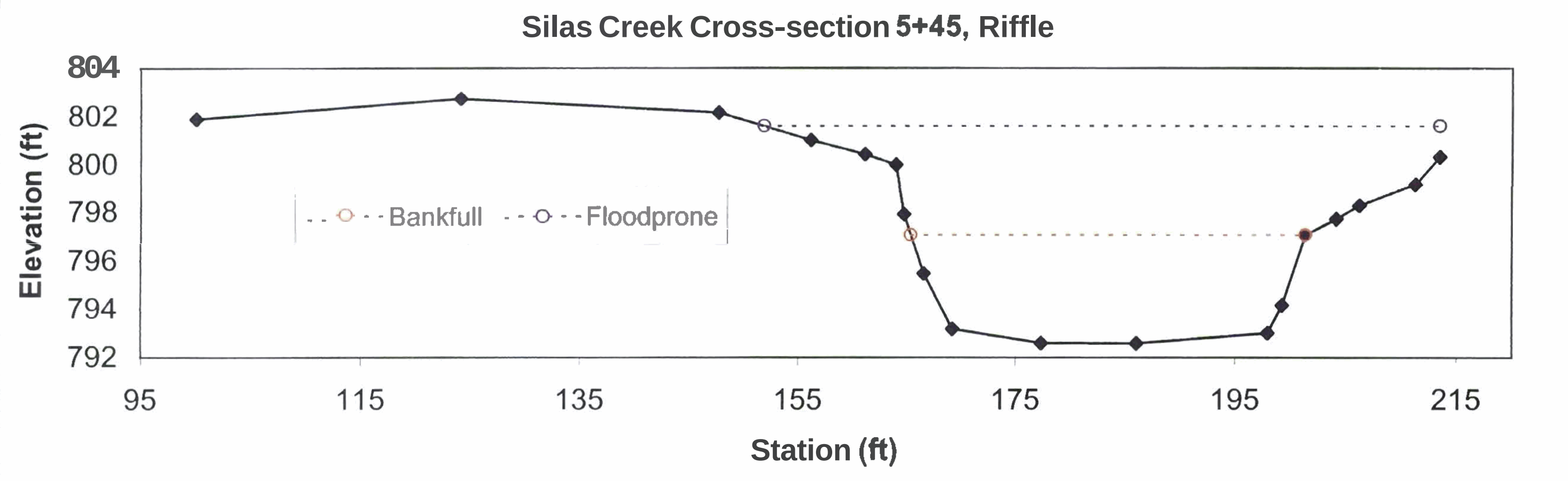
Pt #	North	East	Elevation	Note	Station
136	860231	1614196.2	802.044507	X1	100
137	860238.2	1614177.7	801.664444	X1	119.797
138	860243.2	1614167.2	801.050285	X1	131.5033
139	860247.8	1614158.5	801.309271	X1	141.2244
140	860251.3	1614150.6	800.945347	X1-LPIN	149.8322
141	860252.3	1614147.5	799.489546	X1-LTOB	153.0684
142	860252.8	1614145.9	794.67777	X1	154.7665
143	860253.3	1614144.1	791.941068	X1-LCH	156.6468
144	860253.8	1614142.7	792.022287	X1-TW	158.1014
145	860255.8	1614137.9	792.181297	X1	163.3625
146	860258.9	1614132.2	792.530727	X1	169.7945
147	860259.7	1614129.4	792.675428	X1-WS	172.648
148	860261.7	1614124.6	793.268144	X1-RCH	177.8629

Bankfull Line	
Station	Elevation
153.55	798.13
188.52	798.13

Floodprone Line	
Station	Elevation
100	804.33
218.85	804.33

Cross-section Data:

Feature	Stream Type	BKF Area	BKF Width	BKF Depth	Max BKF Depth	W/D	BH Ratio	ER	BKF Elev	TOB Elev
Riffle	Bc	140.3	36.01	3.9	4.51	9.24	1.65	1.7	797.07	797.07



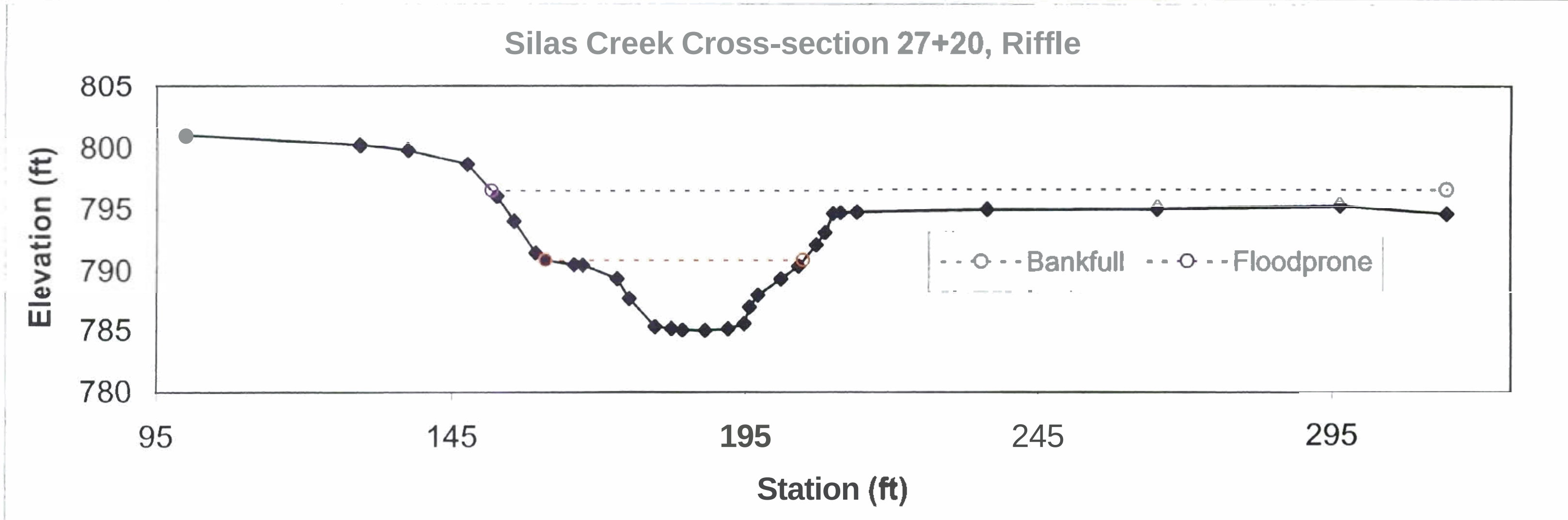
Pt #	North	East	Elevation	Note	Station
343	860089.2	1614161.5	801.860334	X2	100
344	860096	1614138.4	802.720935	X2	124.0892
345	860102.9	1614115.8	802.129558	X2	147.693
346	860105.6	1614107.8	800.998412	X2	156.1467
347	860107.4	1614103.2	800.409529	X2-LPIN	161.1282
348	860107.7	1614100.3	799.988696	X2-LTOB	163.9923
349	860107.7	1614099.5	797.933643	X2-LBKF	164.7669
350	860108.2	1614097.7	795.468325	X2	166.5777
351	860108.2	1614094.9	793.165018	X2-LCH	169.2234
352	860109.6	1614086.9	792.574641	X2	177.3514
353	860113.7	1614079	792.559018	X2-TW	186.051
354	860117.4	1614067.7	792.98818	X2-RCH	197.9695
355	860119.4	1614067	794.151725	X2	199.2869

Bankfull Line	
Station	Elevation
165.4	797.07
201.41	797.07

Floodprone
Station
151.86
213.49

Cross-section Data:

Feature	Stream Type	BKF Area	BKF Width	BKF Depth	Max BKF Depth	W/D	BH Ratio	ER	BKF Elev	TOB Elev
Riffle	C	135.7	43.91	3.09	5.72	14.21	1.7	3.7	790.71	794.54



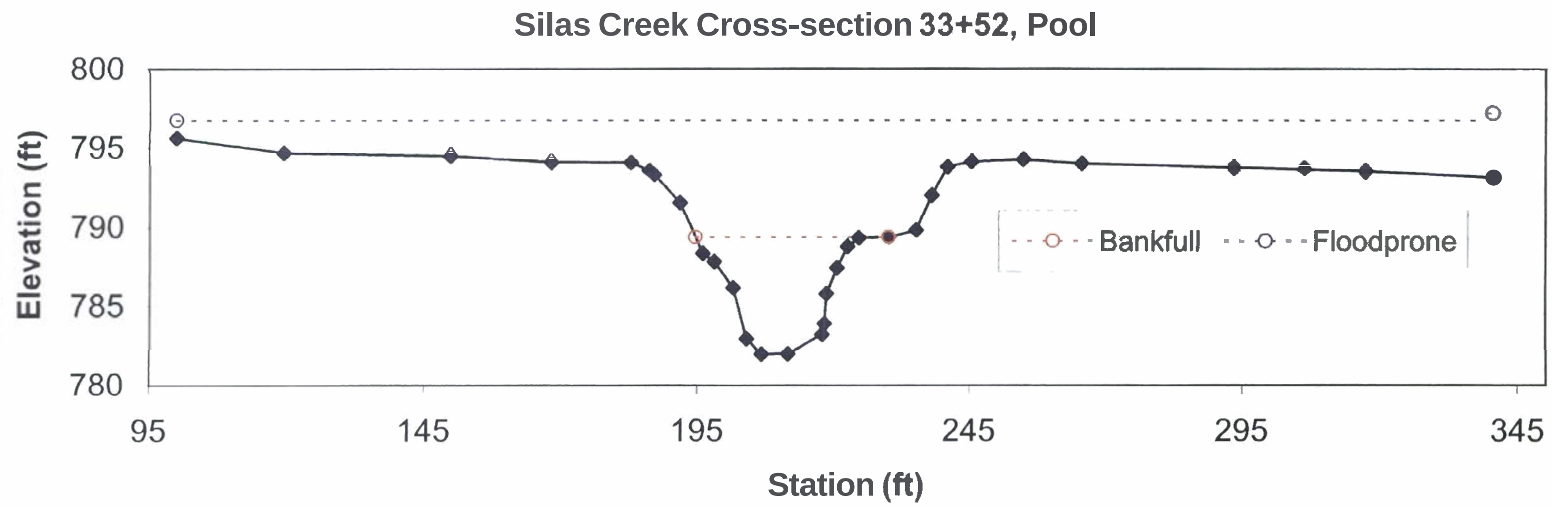
Pt #	North	East	Elevation	Note	Station
934	858463.2	1613173.9	801.040111	X3	100
935	858490.3	1613162.3	800.183251	X3	129.4853
936	858497.5	1613158.5	799.725977	X3-E-PARI	137.6076
937	858506.3	1613153.4	798.583241	X3LTOB	147.6726
938	858511	1613151.7	795.970608	X3	152.6955
939	858513.4	1613150	793.919941	X3	155.5955
940	858516.5	1613147.9	791.33506	X3	159.3383
941	858517.8	1613146.7	790.712162	X3LBKF	160.9903
942	858522.2	1613144.7	790.36631	X3LPIN	165.8313
943	858523.6	1613144.1	790.335457	X3	167.3192
944	858529.2	1613142.3	789.223972	X3	173.1975
945	858531.1	1613141.4	787.595197	X3	175.2669
946	858534.9	1613139.2	785.285909	X3	179.6644

Bankfull Line	
Station	Elevation
160.99	790.71
204.9	790.71

Floodprone Line	
Station	Elevation
151.81	796.43
314.29	796.43

Cross-section Data:

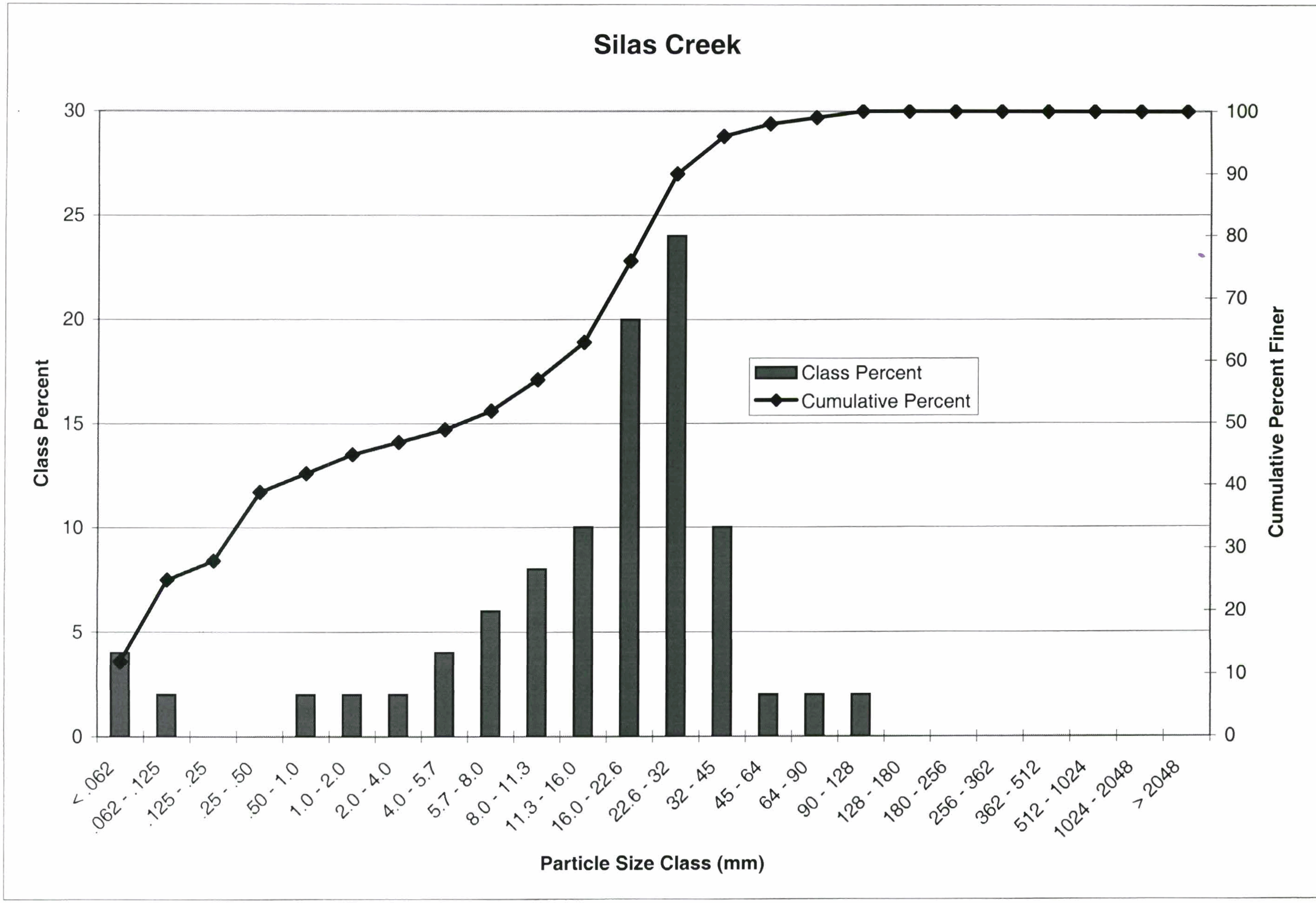
Feature	Stream Type	BKF Area	BKF Width	BKF Depth	Max BKF Depth	W/D	BH Ratio	ER	BKF Elev	TOB Elev
Pool		133.5	35.52	3.76	7.4	9.45	1.6	6.8	789.31	793.79



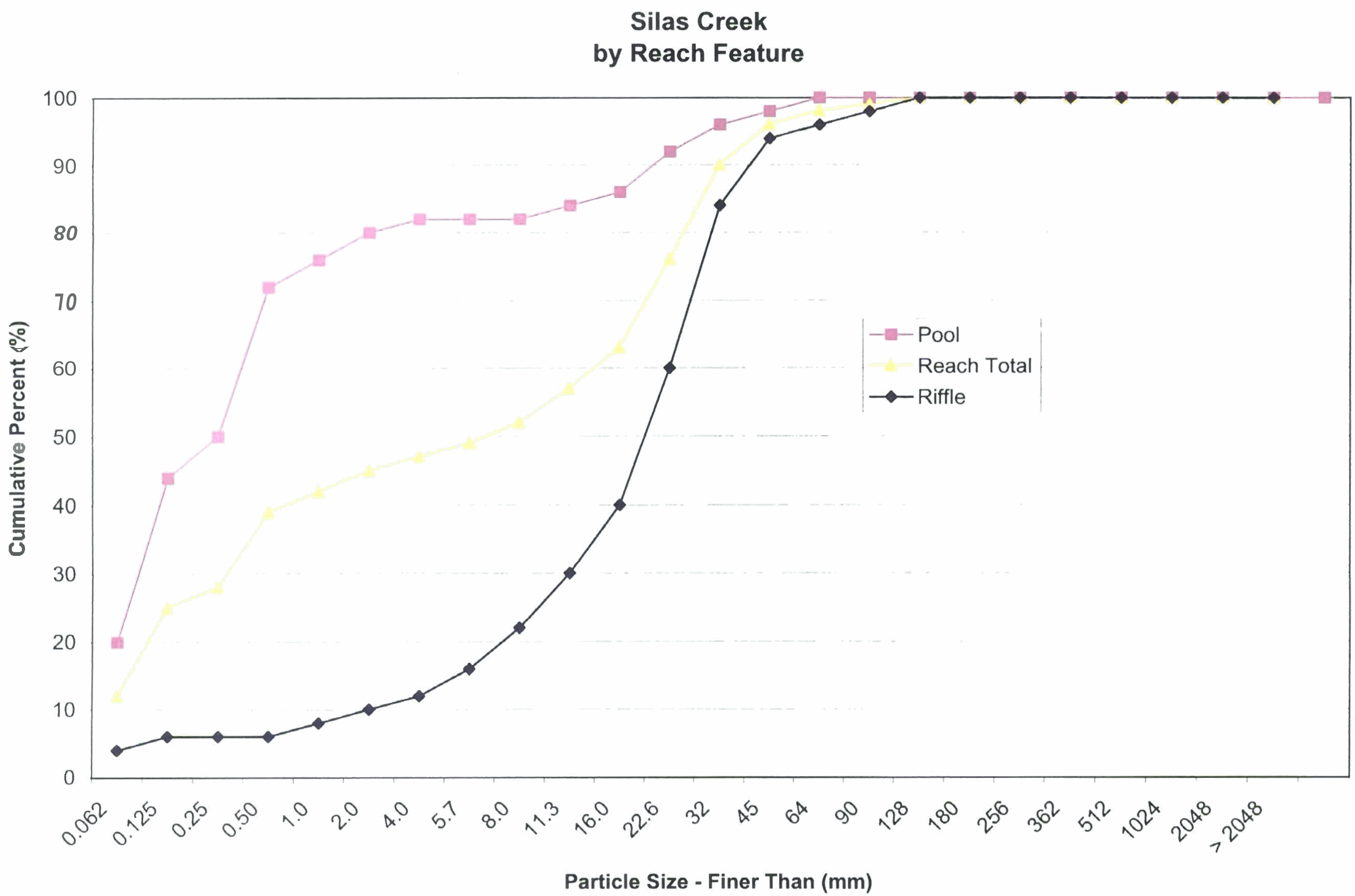
Pt #	North	East	Elevation	Note-*	Station
1142	858150.5	1612656.1	795.599641	X4	100
1143	858167.8	1612647.1	794.647036	X4	119.5067
1144	858194.1	1612631.9	794.477531	X4	149.8454
1145	858209.8	1612622.3	794.073026	X4	168.3028
1146	858222.6	1612615.4	794.046199	X4	182.8454
1147	858225.5	1612613.6	793.550594	X4LPIN	186.2695
1148	858226.4	1612613.3	793.28948	X4TOB	187.1407
1149	858230.2	1612610.5	791.503301	X4	191.8504
1150	858233.4	1612607.7	788.296105	X4LBKF	195.991
1151	858235.7	1612607.6	787.76933	X4	198.0923
1152	858238.8	1612606	786.113923	X4	201.5495
1153	858241.2	1612605.1	782.892171	X4LCH	204.0589
1154	858243.1	1612602.8	781.909578	X4TW	206.8251

Bankfull Line	
Station	Elevation,
194.68	789.31
230.2	789.31

Floodprone Line	
(Station,	Elevation
100	796.71
340.56	796.71



Silas Creek
Class Percent
Cumulative Percent
Class Percent
Cumulative Percent Finer
Particle Size Class (mm)
0
5
10
15
20
25
30
0
10
20
30
40
50
60
70
80
90
100
< .062
.062 - .125
.125 - .25
.25 - .50
.50 - 1.0
1.0 - 2.0
2.0 - 4.0
4.0 - 5.7
5.7 - 8.0
8.0 - 11.3
11.3 - 16.0
16.0 - 22.6
22.6 - 32
32 - 45
45 - 64
64 - 90
90 - 128
128 - 180
180 - 256
256 - 362
362 - 512
512 - 1024
1024 - 2048
> 2048

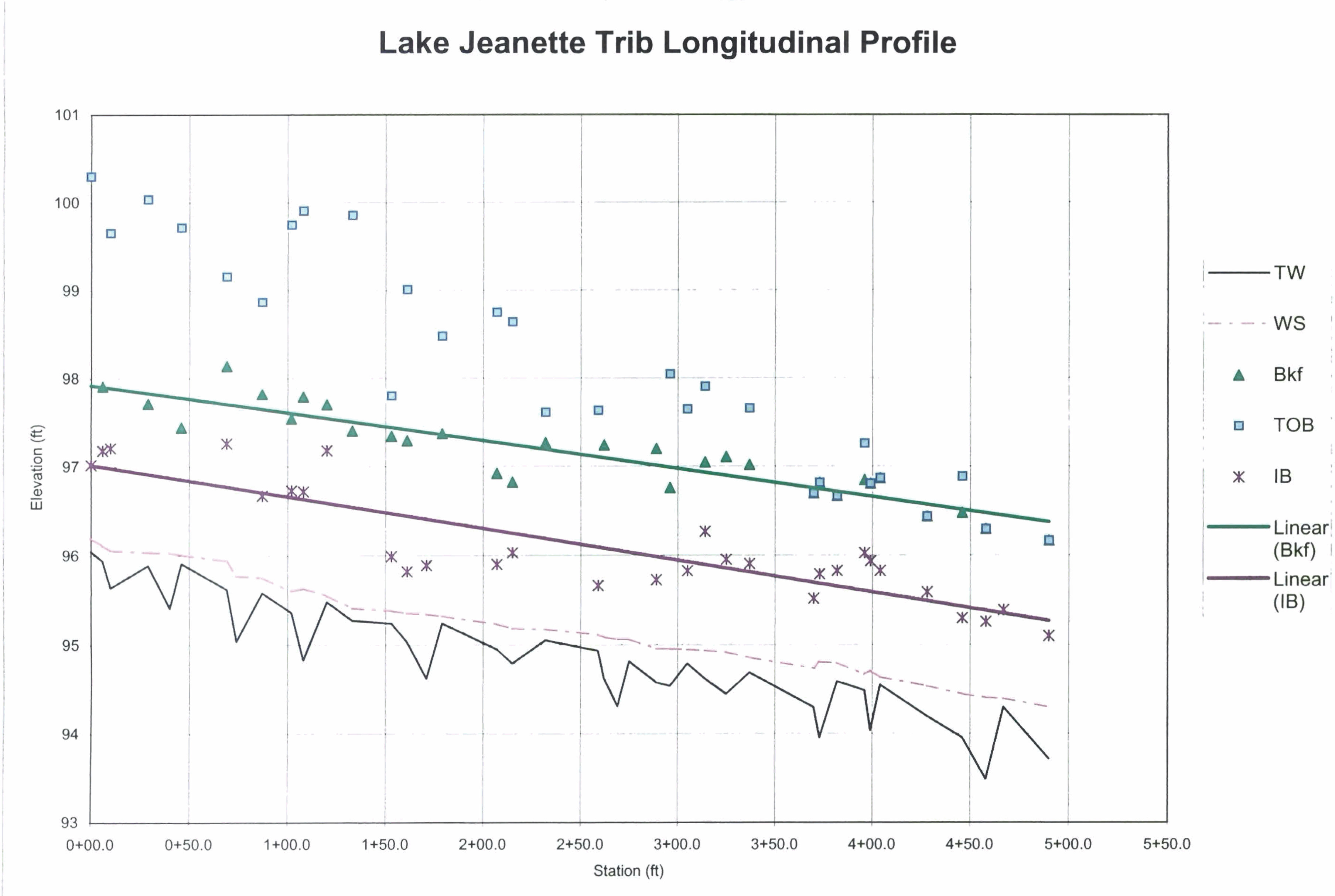


Silas Creek
by Reach Feature
Cumulative Percent (%)
100
90
80
70
60
50
40
30
20
10
0
0.062
0.125
0.25
0.50
1.0
2.0
4.0
5.7
8.0
11.3
16.0
22.6
32
45
64
90
128
180
256
362
512
1024
2048
> 2048
Particle Size - Finer Than (mm)
Pool
Reach Total
Riffle

Appendix 2 Reference Reach Data

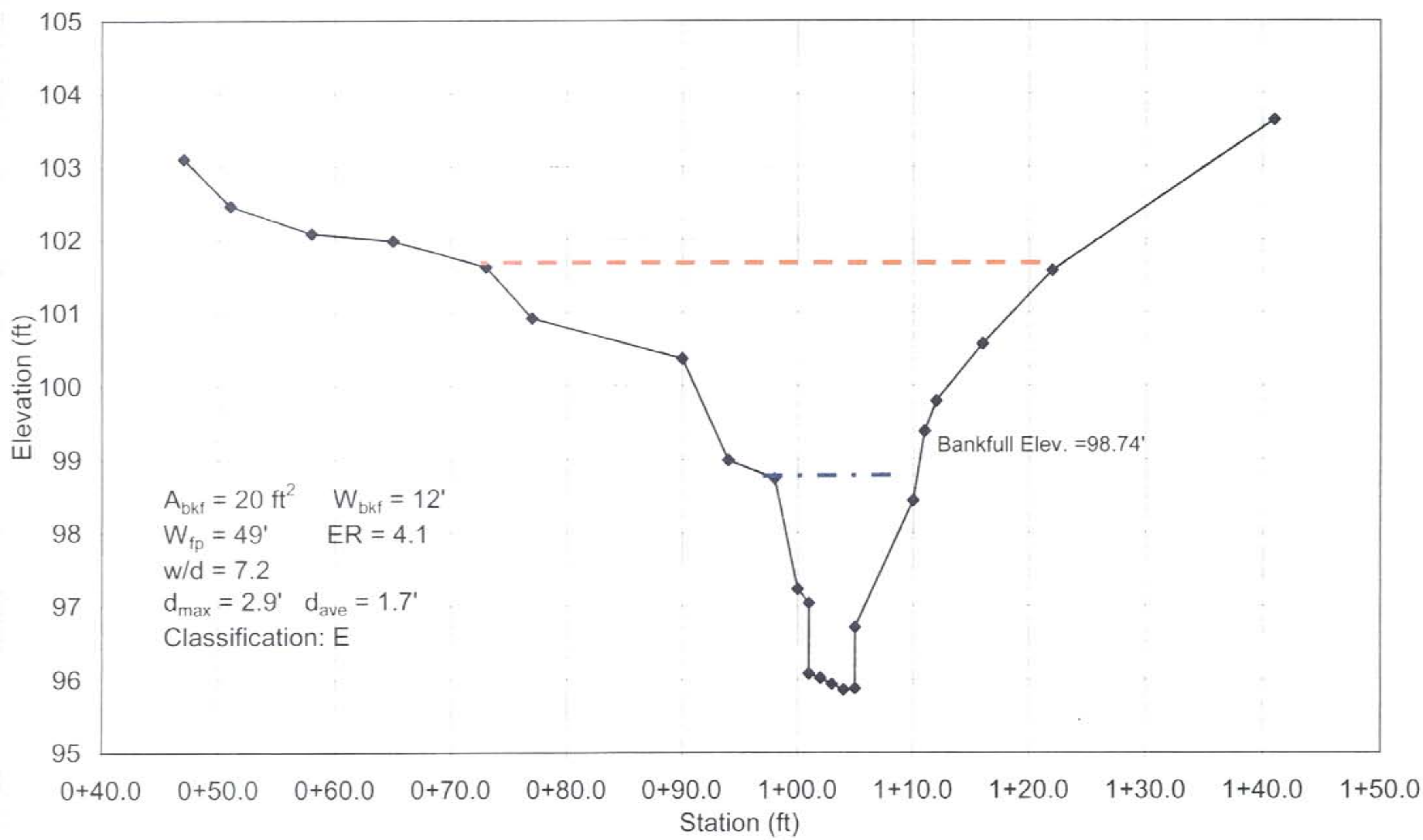
Piedmont Reference Reach Summary Table				
Stream Name	LAKE JEANETTE TRIBUTARY			
Location	GREENSBORO, NC			
Stream Type:	E			
Watershed Area:	0.15 sq. miles			
	MEAN	**MEDIAN**	**MIN**	**MAX**
Channel Dimensions				
Riffle Width/Mean Bankfull Depth (Wr/dbkf)	8.45	8.45	7.20	9.70
Max. Pool Depth/Max. Riffle Depth(dpmax/drmax):	1.28	1.28	1.28	1.28
Pool Width/Riffle Width(Wp/Wr):	1.64	1.64	1.54	1.73
Pool Area/Riffle Area(Ap/Ar):	1.38	1.38	1.33	1.43
Max. Pool Depth/Mean Bankfull Depth(dpmax/dbkf):	1.93	1.93	1.74	2.11
Lowest Bank Height/Max. Bankfull Depth(Bhlow/dmbkf):	1.15	1.15	1.10	1.20
Channel Pattern				
Meander Width Ratio(MWR=Wblt/Wbkf):	3.49	3.49	3.49	3.49
Ratio:				
Radius of Curvature/Bankfull Width(Rc/Wbkf):	0.91	0.71	0.48	1.97
Meander Wavelength/Bankfull Width(Lm/Wbkf):	3.51	3.45	1.63	5.75
Channel Profile				
Riffle Slope/ Water Surface Slope:	1.41	1.02	0.23	3.41
Pool Slope/Water Surface Slope:	1.20	0.64	0.00	8.72
Run Slope/Water Surface Slope:	1.28	1.28	1.28	1.28
Glide Slope/ Water Surface Slope:	-	-	-	-
Max. Riffle Depth/Mean Bankfull Depth:	1.52	1.51	1.38	1.67
Max.Pool Depth/Mean Bankfull Depth:	1.93	1.94	1.76	2.13
Max. Run Depth/Mean Bankfull Depth:	-	-	-	-
Max. Glide Depth/Mean Bankfull Depth:	-	-	-	-
Riffle Length/Bankfull Width:	1.43	1.18	0.44	2.75
Pool Length/Bankfull Width:	1.39	1.41	0.59	2.08
Run Length/Bankfull Width:	1.41	1.41	1.33	1.50
Glide Length/Bankfull Width:	-	-	-	-
Riffle to Riffle Spacing/Bankfull Width:	2.82	2.59	1.26	5.25
Pool to Pool Spacing/Bankfull Width:	2.94	2.67	1.92	4.92
Riffle to Pool Spacing/Bankfull Width:	1.63	1.49	0.59	3.50
Bed Material				
D84:	3.50	mm		
dmbkf:	-	mm		
dmbkf/D84:	-			
u/u* :	-			
Mannings 'n':	-			

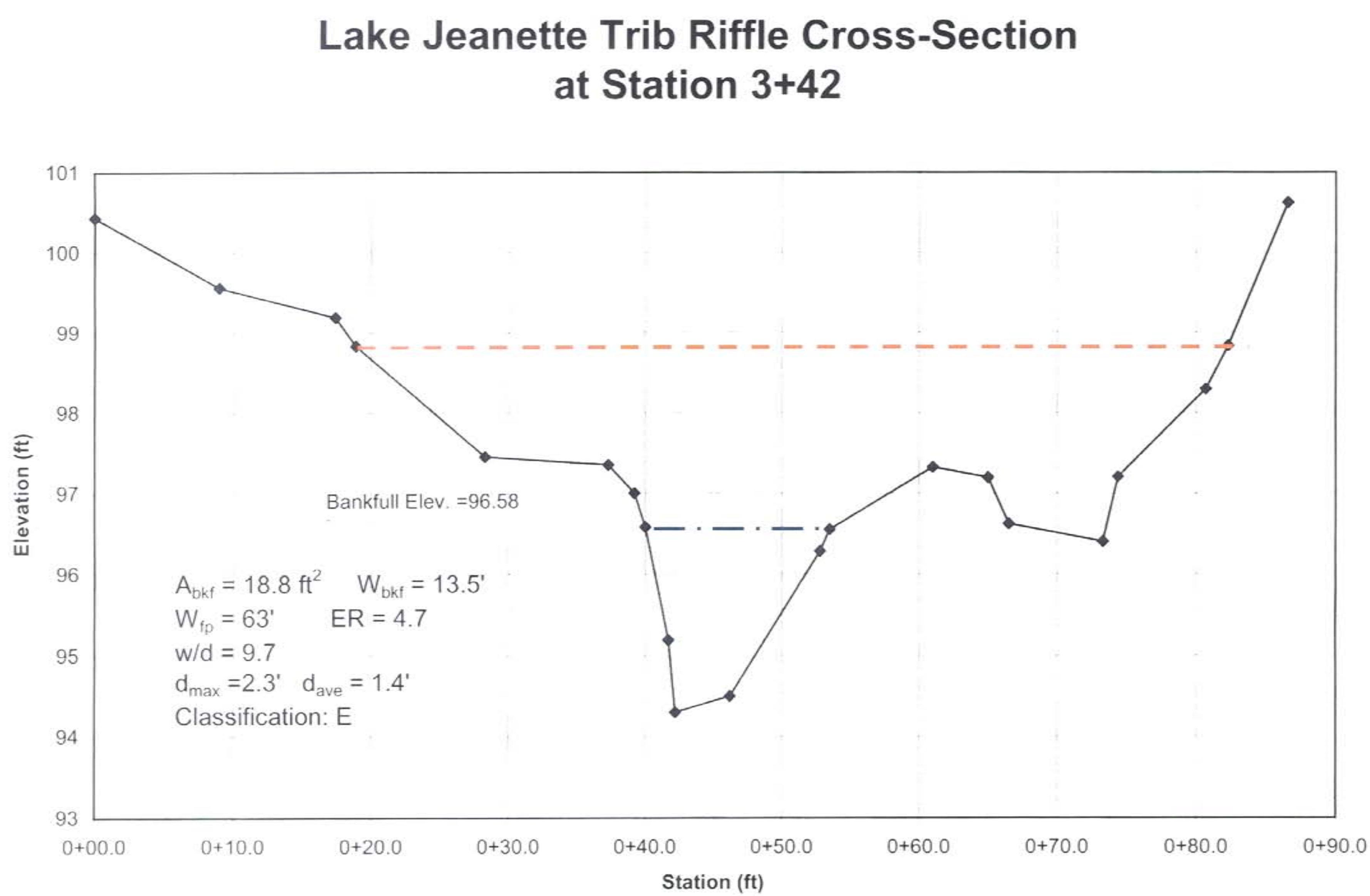
Piedmont Reference Reach Summary Table				
Stream Name	LAKE JEANETTE TRIBUTARY			
Location	GREENSBORO, NC			
Stream Type:	E			
Watershed Area:	.15 sq miles			
	MEAN	**MEDIAN**	**MIN**	**MAX**
Channel Dimensions				
Riffle Width/Mean Bankfull Depth (Wr/dbkf)	-	-	-	-
Max. Pool Depth/Max. Riffle Depth(dpmax/drmax):	1.28	1.28	1.28	1.28
Pool Width/Riffle Width(Wp/Wr):	-	-	-	-
Pool Area/Riffle Area(Ap/Ar):	-	-	-	-
Max. Pool Depth/Mean Bankfull Depth(dpmax/dbkf):	1.93	1.93	1.74	2.11
Lowest Bank Height/Max. Bankfull Depth(Bhlow/dmbkf):	0.70	0.70	0.70	0.70
Channel Pattern				
Meander Width Ratio(MWR=Wblt/Wbkf):	3.49	3.49	3.49	3.49
Ratio:				
Radius of Curvature/Bankfull Width(Rc/Wbkf):	0.91	0.71	0.48	1.97
Meander Wavelength/Bankfull Width(Lm/Wbkf):	3.51	3.45	1.63	5.75
Channel Profile				
Riffle Slope/ Water Surface Slope:	1.41	1.02	0.23	3.41
Pool Slope/Water Surface Slope:	1.20	0.64	0.00	8.72
Run Slope/Water Surface Slope:	1.28	1.28	1.28	1.28
Glide Slope/ Water Surface Slope:	-	-	-	-
Max. Riffle Depth/Mean Bankfull Depth:	1.52	1.51	1.38	1.67
Max.Pool Depth/Mean Bankfull Depth:	1.93	1.94	1.76	2.13
Max. Run Depth/Mean Bankfull Depth:	-	-	-	-
Max. Glide Depth/Mean Bankfull Depth:	-	-	-	-
Riffle Length/Bankfull Width:	1.43	1.18	0.44	2.75
Pool Length/Bankfull Width:	1.39	1.41	0.59	2.08
Run Length/Bankfull Width:	1.41	1.41	1.33	1.50
Glide Length/Bankfull Width:	-	-	-	-
Riffle to Riffle Spacing/Bankfull Width:	2.82	2.59	1.26	5.25
Pool to Pool Spacing/Bankfull Width:	2.94	2.67	1.92	4.92
Riffle to Pool Spacing/Bankfull Width:	1.63	1.49	0.59	3.50
Bed Material				
D84:	3.50	mm		
dmbkf:	-	mm		
dmbkf/D84:	-			
u/u* :	-			
Mannings 'n':	-			



Lake Jeanette Trib Longitudinal Profile
101
100
99
98
97
96
95
94
93
Elevation (ft)
0+00.0
0+50.0
1+00.0
1+50.0
2+00.0
2+50.0
3+00.0
3+50.0
4+00.0
4+50.0
5+00.0
5+50.0
Station (ft)
TW
WS
Bkf
TOB
IB
Linear (Bkf)
Linear (IB)

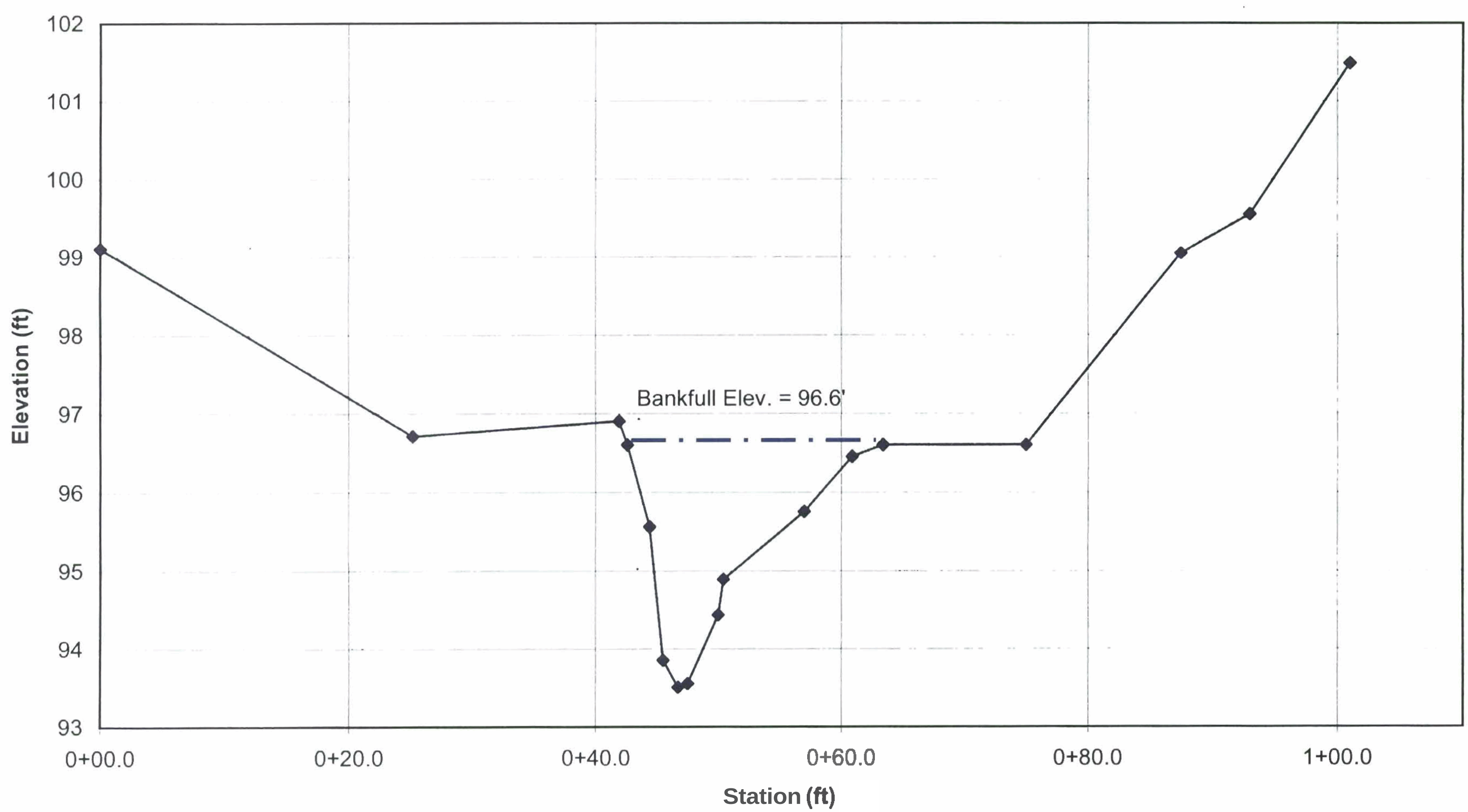
Lake Jeanette Trib Riffle Cross-Section at Station 0+18





Lake Jeanette Trib Riffle Cross-Section
at Station 3+42
Elevation (ft)
101
100
99
98
97
96
95
94
93
Bankfull Elev. =96.58
A_{bkf} = 18.8 ft^2 W_{bkf} = 13.5'
W_{fp} = 63'   ER = 4.7
w/d = 9.7
d_{max} =2.3' d_{ave} = 1.4'
Classification: E
0+00.0
0+10.0
0+20.0
0+30.0
0+40.0
0+50.0
0+60.0
0+70.0
0+80.0
0+90.0
Station (ft)

Lake Jeanette Trib Pool Cross-Section at Station 4+58



Reference Reach

Rivers

Stream:	Silas Creek
Watershed:	Upper Yadkin River
Location:	Winston-Salem, NC
Latitude:	
Longitude:	
County:	Forsyth
Date:	10/23-24/01
Observers:	Angela Jessup, Daphne Cartner, Tommy Burchette and James Murphy
Channel Type:	B4c/1
Drainage Area (sq mi):	3.3
Notes:	Suburban watershed with high percentage of forest in watershed.

Dimension

		typical	min	max
Size:	x-area bankfull	43.5	38.5	48.9
	width bankfull	25.6	23.1	28.0
	mean depth	1.7	1.5	1.9
Ratios:	Width/Depth Ratio	15.1	12.4	17.2
	Entrenchment Ratio	1.3	1.2	1.4
	Riffle Max Depth Ratio	1.6	1.4	1.7
	Pool Area Ratio	1.6	1.4	1.8
	Pool Width Ratio	1.0	0.9	1.1
	Pool Max Depth Ratio	2.6	2.4	2.9
	Bank Height Ratio	1.0		
	Run Area Ratio	1.4	1.4	1.4
	Run Width Ratio	1.0	0.9	1.1
	Run Max Depth Ratio	1.9	1.9	1.9
	Glide Area Ratio	1.1	1.1	1.2
	Glide Width Ratio	1.0	0.9	1.0
	Glide Max Depth Ratio	1.9	1.7	2.1
Hydraulics:		riffle	pool	run
	discharge rate, Q (cfs)	199.0	199.0	199.0
	velocity (ft/sec)	4.6	2.8	3.2
	shear stress @ max depth (lbs/ft sq)	1.38	2.30	1.69
	shear stress (lbs/ft sq)	0.77	1.23	1.10
	shear velocity (ft/sec)	0.63	0.80	0.75
	unit stream power (lbs/ft/sec)	3.973	3.973	3.97
	relative roughness	3.3	5.2	4.520502
	friction factor u/u*	7.3	3.6	4.3
	threshold grain size @ max depth (mm)	135.8	367.8	200.9
	threshold grain size (mm)	49	108	87

Pattern

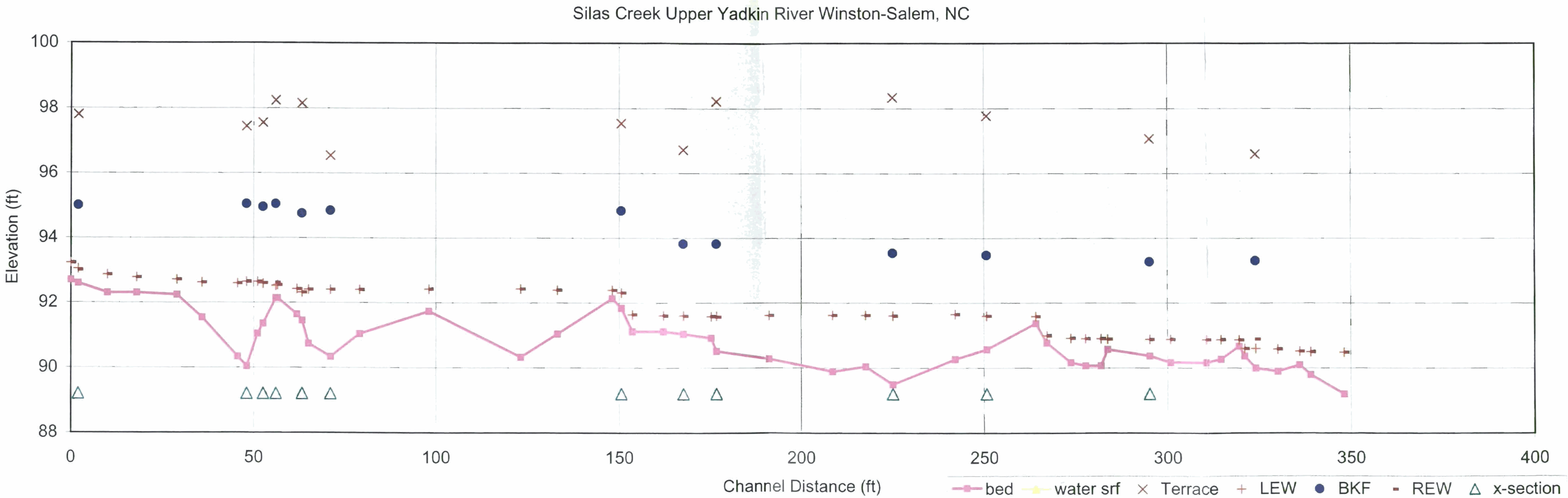
	typical	min	max
Sinuosity	1.1		
Meander Width Ratio	1.7	1.6	2.0
Amplitude Ratio	---	---	---
Meander Length Ratio	6.6	5.1	9.6
Straight Length Ratio	---	---	---
Radius Ratio	1.6	0.8	2.1
arc angle (degrees)	---	---	---

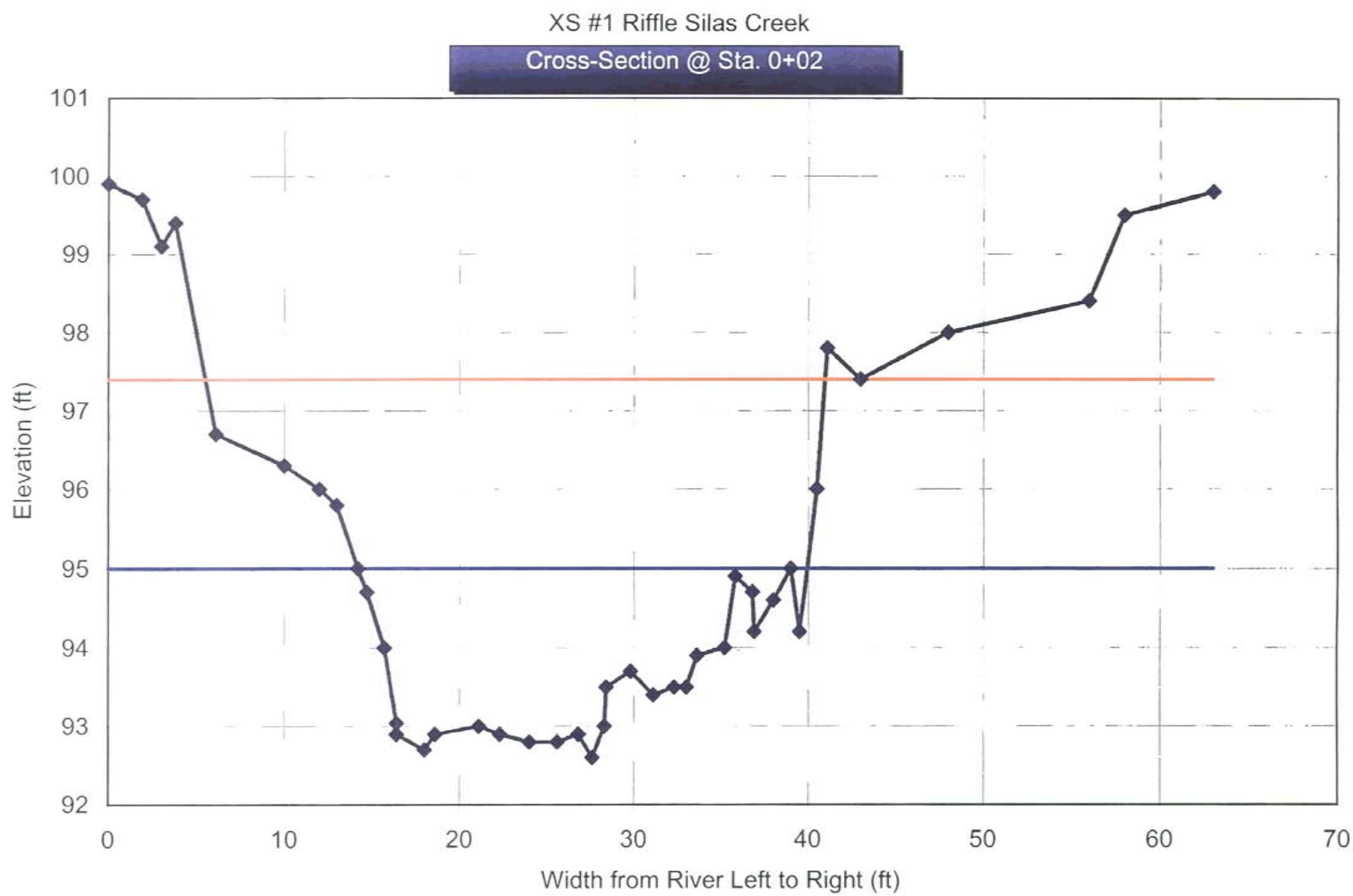
Profile

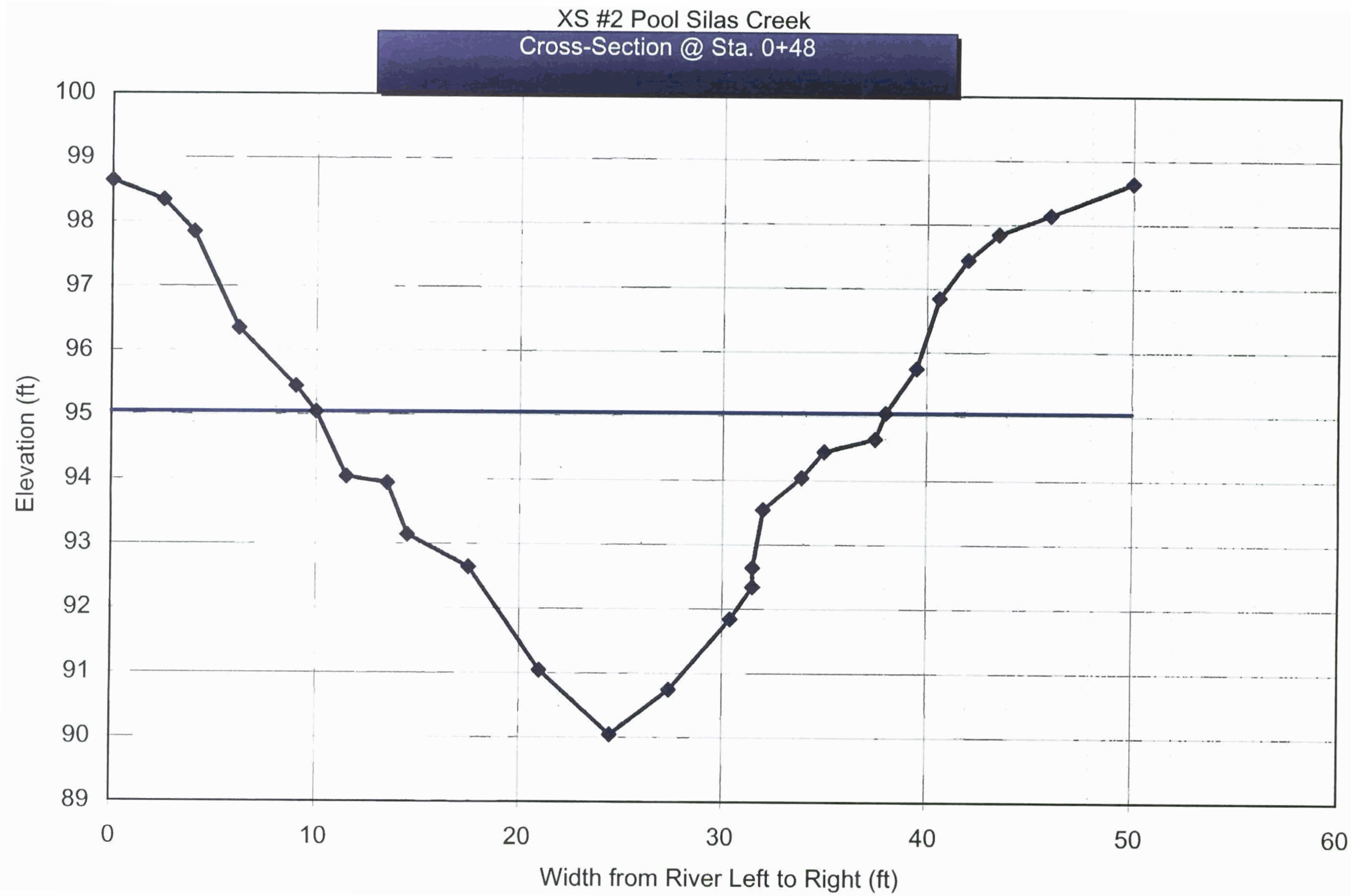
	typical	min	max
channel slope (%)	0.819	---	---
measured valley slope (%)	---	---	---
valley slope (%)	0.877		
Riffle Slope Ratio	2.4	0.1	8.6
Pool Slope Ratio	0.0	-0.2	0.1
Run Slope Ratio	0.6	0.0	1.6
Glide Slope Ratio	0.6	---	1.7
Pool Spacing Ratio	2.4	1.1	4.9

Channel Materials

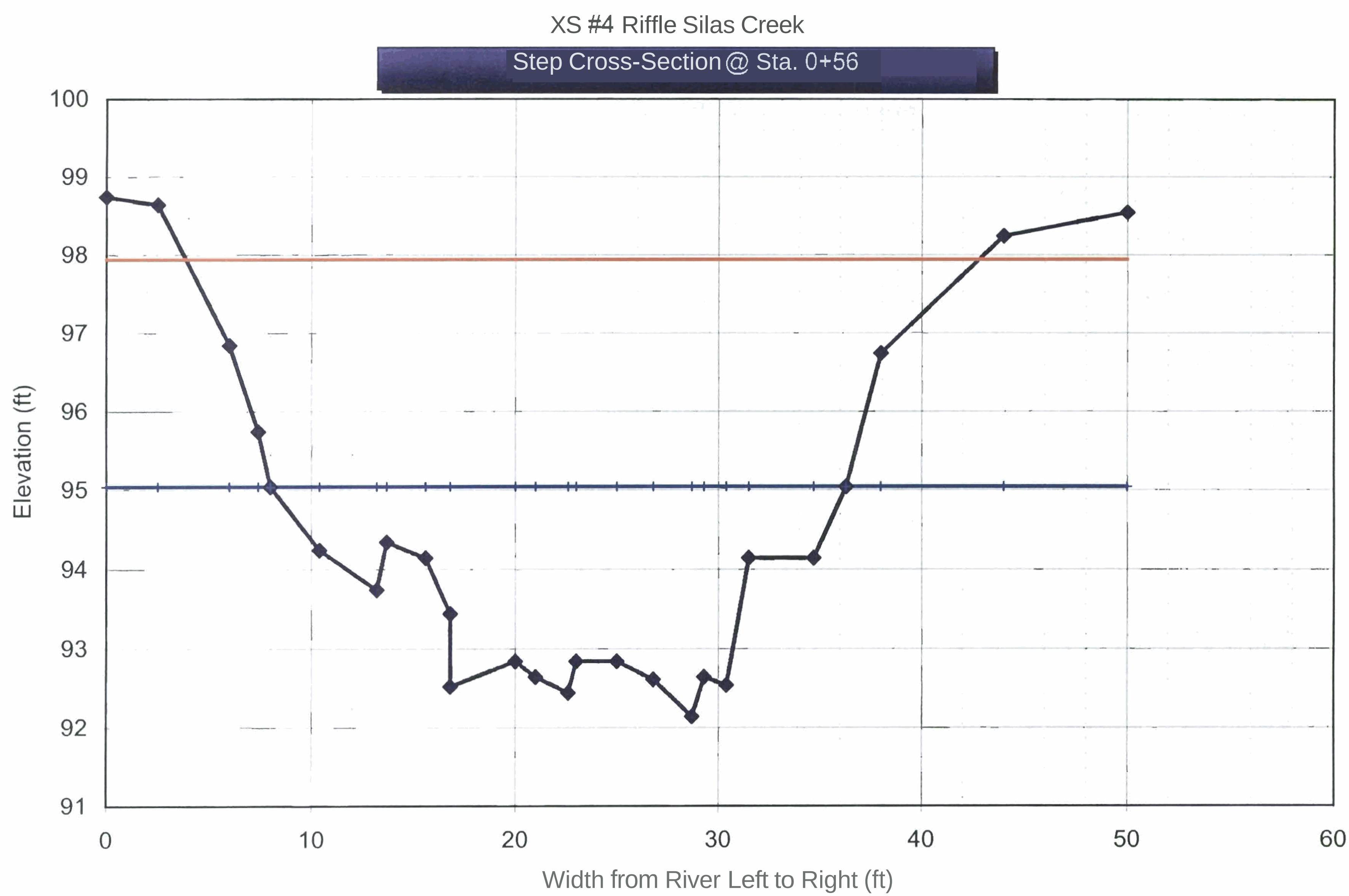
	total	riffle	pool	run	glide	bar sample
D16	0.283	0.301	0.271	0.0	0.0	1.8
D35	0.83	2.46	0.46	0	0	15
D50	19.1	26.5	7.4	0	0	32
D84	157.5	167	134	0	0	96
D95	300.2	326	237	0	0	117
Largest Bar						0
% Silt/Clay	1%	0%	3%	---	---	---
% Sand	34%	33%	36%	---	---	17%
% Gravel	25%	25%	26%	---	---	63%
% Cobble	25%	28%	22%	---	---	20%
% Boulder	7%	10%	3%	---	---	---
% Bedrock	6%	5%	9%	---	---	

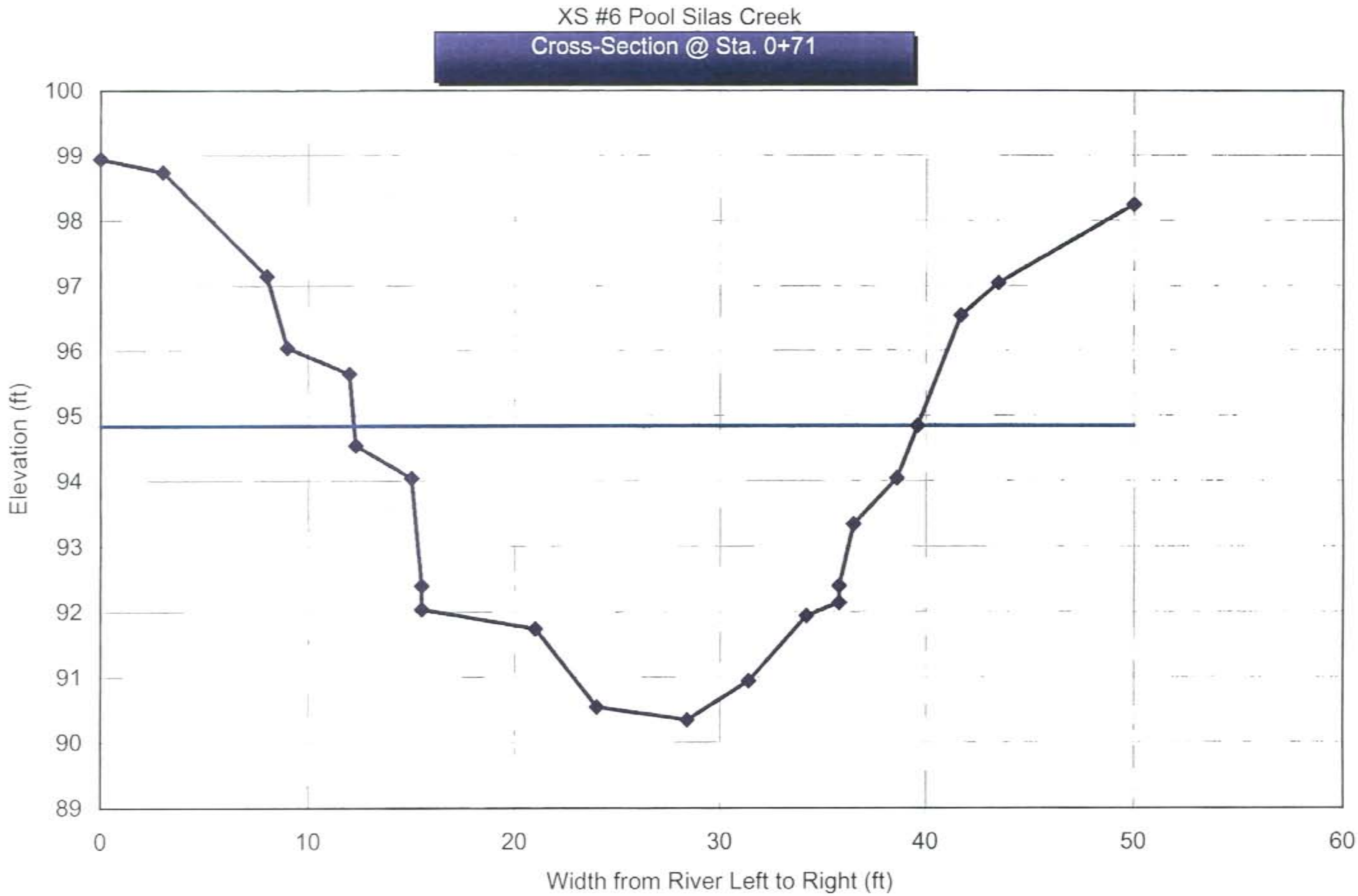

Silas Creek Upper Yadkin River Winston-Salem, NC
Elevation (ft)
100
98
96
94
92
90
88
0
50
100
150
200
250
300
350
400
Channel Distance (ft)
bed
water srf
Terrace
LEW
BKF
REW
x-section


XS #1 Riffle Silas Creek
Cross-Section @ Sta. 0+02
101
100
99
98
97
96
95
94
93
92
Elevation (ft)
0
10
20
30
40
50
60
70
Width from River Left to Right (ft)



XS #2 Pool Silas Creek
Cross-Section @ Sta. 0+48
Elevation (ft)
100
99
98
97
96
95
94
93
92
91
90
89
0
10
20
30
40
50
60
Width from River Left to Right (ft)


XS #4 Riffle Silas Creek
Step Cross-Section @ Sta. 0+56
Elevation (ft)
100
99
98
97
96
95
94
93
92
91
0
10
20
30
40
50
60
Width from River Left to Right (ft)

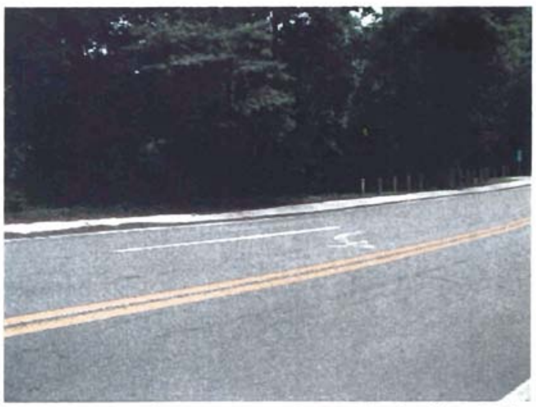

XS #6 Pool Silas Creek
Cross-Section @ Sta. 0+71
Elevation (ft)
100
99
98
97
96
95
94
93
92
91
90
89
0
10
20
30
40
50
60
Width from River Left to Right (ft)

Appendix 3 Photographic Log

Photo Log 1-Silas


A. Construction Access from Yorkshire Rd.


B. Construction Access from Yorkshire Rd.


C. Construction Access from Yorkshire Rd.


D. Construction Access from Yorkshire Rd.


E. Construction Access from Yorkshire Rd.


F. Silas Creek Parkway

Photo Log 2-Silas Reach 1

A. House on Reach 1

A. Reach 1 Upstream of Yorkshire Rd.

C. Upstream on Reach 1

D. Reach 1 at Pool Cross Section 1

E. Reach 1 at Yorkshire Rd. Culvert

F. Reach 1 at Riffle Cross Section 2


G. Greenway Upstream of Yorkshire Rd.


H. Greenway Upstream of Yorkshire Rd.


I. Greenway Upstream of Yorkshire Rd.

Photo Log 3-Silas Reach 2 Downstream of Yorkshire Road


A. Culvert Downstream of Yorkshire Rd.


B. Parking Lot at Yorkshire Rd.


C. Reach 2 Downstream of Yorkshire Rd.


D. Soccer Fields on Reach 2


E. Reach 2 Downstream of Yorkshire Rd


F. Walking Path on Reach 2

Photo Log 3-Silas Reach 2 Downstream of Yorkshire Road


G. Confluence of Silas and Buena Vista


H. Sewer Lines on Left flank of Reach 2


I. Bank Erosion on Silas Creek


J. Bank Erosion on Silas Creek


K. Bank Erosion on Silas Creek


L. Bank Erosion on Silas Creek

Photo Log 3-Silas Reach 2 Downstream of Yorkshire Road

M. Bank Erosion on Silas Creek

N. Culvert Upstream of Silas Parkway

Photo Log 4 – Silas Reach 2 Downstream of Silas Creek Parkway

A. Bench on Reach 3

B. Confluence on Reach 3

C. Existing Vegetation on Reach 3

D. Bridge at Tributary on Reach 3

E. Running Path along Reach 3

F. Cross Section 3, Riffle

Photo Log 4 – Silas Reach 2 Downstream of Silas Creek Parkway

H. Cross Section 4, Pool

I. Bank Erosion on Silas Creek

J. Bank Erosion on Silas Creek

K. Bank Erosion on Silas Creek

Photo Log 5-Buena Vista Branch


A. Footpath Crossing


B. Adjacent Soccer Fields


C. Footpath Crossing


D. Adjacent Soccer Fields


E. Culvert on Buena Vista Creek


F. Buena Vista Branch


G. Erosion on Streambanks


H. Cross Section A, Riffle


I. Sewer-line Crossing


J. Cross Section B, Pool


K. Confluence with Silas Creek


L. Cross Section B, Pool