Restoration Plan

Smith and Austin Creeks Stream ~~Mitigation~~ Plan & Design Wake Forest, North Carolina

North Carolina Department of Environment and Natural Resources
Wetlands Restoration Program

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Stream Mitigation Plan & Design
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Executive Summary

The North Carolina Wetlands Restoration Program (WRP) proposes to restore over 11,200 ft of Smith and Austin Creeks in Wake Forest, North Carolina, for the purpose of obtaining stream mitigation credit. The project reaches are tributaries to the Neuse River.

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 principals and considers differences in drainage area, adjacent land uses, upstream impoundments, 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 bankfull stage located at the existing floodplain elevation. Where valley or development restrictions 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 features and control channel grade.

The downstream reach of Smith Creek below its confluence with Austin Creek is moderately stable with mature riparian vegetation along most of its length; therefore a stabilization approach is proposed. The project will include creation of approximately 700 ft of additional channel length. A summary of existing and design reach lengths with proposed restoration design approaches is provided in the table below.

Reach	Existing Length (ft)	Restored Length (ft)	Restoration Approach
SR1	1,928	2,042	Change dimension, pattern, and profile. Priority 2 restoration of incised channel.
SR2	2,317	2,546	Change dimension, pattern, and profile.
SR3	735	735	Stabilize eroding streambanks.
AR1	2,831	2,831	Change dimension and profile. Priority 3 restoration of incised channel.
AR2	392	392	Change dimension and profile. Priority 3 restoration of incised channel.
AR3	2,323	2,682	Change dimension, pattern, and profile.
Total	**10,526**	**11,228**	

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1 Introduction

1.1 Project Description

The NC Wetlands Restoration Program (WRP) proposes to restore over 11,200 ft of Smith and Austin Creeks for the purpose of obtaining stream mitigation credit. The project streams are located near the town of Wake Forest in Wake County, North Carolina (Figure 1.1). These streams are tributaries to the Neuse River (USGS HU # 03020201). The overall drainage area for the project watershed is 12.5 square miles.

The project is divided into six reaches based on stream classification, reach drainage area, construction sequence, and confluence with tributaries (Figures 1.2 and 1.3). The project reach lengths and their respective drainage areas are listed in Table 1.1.

Table 1.1 Project Reaches with Existing Lengths and Drainage Areas.

Reach Name and Location	**Existing Length (ft)**	**Drainage Area (mi^2)**
SR1 – Smith Creek from Property Boundary to Ford Crossing	1,928	3.3
SR2 – Smith Creek from Ford Crossing to Confluence with Austin Creek	2,317	3.6
SR3 – Smith Creek from Confluence to Forestville Road	735	12.5
AR1 – Austin Creek from Property Boundary to Box Culverts	2,831	8.4
AR2 – Austin Creek from Box Culverts to Bedrock Knickpoint	392	8.5
AR3 – Austin Creek from Bedrock Knickpoint to Confluence with Smith Creek	2,323	8.8
Total	**10,526**	

1.2 Project Objectives

The objectives of the Smith and Austin Creeks stream restoration project are to:

1. Restore unstable stream channels to natural stable forms by modifying dimension, pattern, and profile based on reference reach parameters;
2. Improve floodplain functionality by matching bankfull stage with floodplain elevation;
3. Establish native floodplain vegetation through a forested riparian buffer;
4. Improve the natural aesthetics of the stream corridor; and
5. Obtain mitigation credits for other unavoidable impacts to streams within the same Hydrologic Unit Code (HUC).

1.3 Watershed Characterization

The project site is located in the eastern portion of the Piedmont Physiographic Region. The topography is characterized by gently rolling hills with a dendritic drainage pattern and wide alluvial valleys. Elevations range from approximately 190 feet to 470 feet with a relative relief of 280 feet. The underlying geology consists of foliated granitic rocks. The site is on the edge of the Raleigh Geologic Belt, which is characterized as gneiss, schist, and amphibole. The granites were formed during the Middle Paleozoic to Late Paleozoic periods.

Soils in the upper watershed are predominantly from the Cecil unit. These consist of sandy loams with variable slopes. In upland areas, the surface soils are grayish-brown to yellowish brown to a depth of 6-10 inches. The subsoil is red, firm clay extending 30-40 inches.

In the restoration project area, the soils are primarily Chewacla and Louisburg units. Chewacla soils are typically located in areas with a seasonally high water table and are formed in alluvial deposits of fine loamy material. The surface layer is brown to dark grayish-brown sandy loam 4 to 12 inches thick. Beneath this layer, soil ranges from brown to grayish brown and extends to 72 inches thick. The Louisburg series consist of sloping excessively drained soils of the Piedmont uplands. These soils have formed under forest in material that has weathered from rocks. The surface layer is grayish-brown to yellowish-brown 4-6 inches thick. The subsurface layer is yellowish-brown and extends from 4-24 inches thick.

Land use in the watershed is changing from primarily forested/agricultural to residential as several new developments are under construction or planned. The Northeast Wake County Land Use Plan (Wake County Planning Department, 2000) provides a detailed assessment of current and planned development of parks, businesses and residences. The Land Use Plan is available at:

http://web.co.wake.nc.us/planning/LandUse/Land Use Plan/Text/newalup.pdf

Located within the project drainage area are several existing and planned residential developments, park/recreation facilities, greenways, commercial sites, three natural heritage sites, an existing school, and a segment of the proposed Highway 98 By-Pass. The project drainage area is part of both the Rolesville and Wake Forest Urban Service Areas, with future development consisting of cluster and other subdivisions up to two or three dwellings per acre when municipal water and sewer become available. The land use plan map is available at:

http://web.co.wake.nc.us/planning/landuse/Land%20Use%20Plan/maps/NeWALUPlucmap01b.pdf

There is one large impoundment, the Wake Forest Reservoir, located on Austin Creek and one small reservoir on Smith Creek. In addition, there are numerous small farm ponds spread throughout the watershed. Field investigations and data analyses indicate that these impoundments are affecting the watershed's hydrologic response to urbanization by reducing bankfull peak discharges. This is evident in the relatively small measured bankfull cross-section areas discussed later in this report.

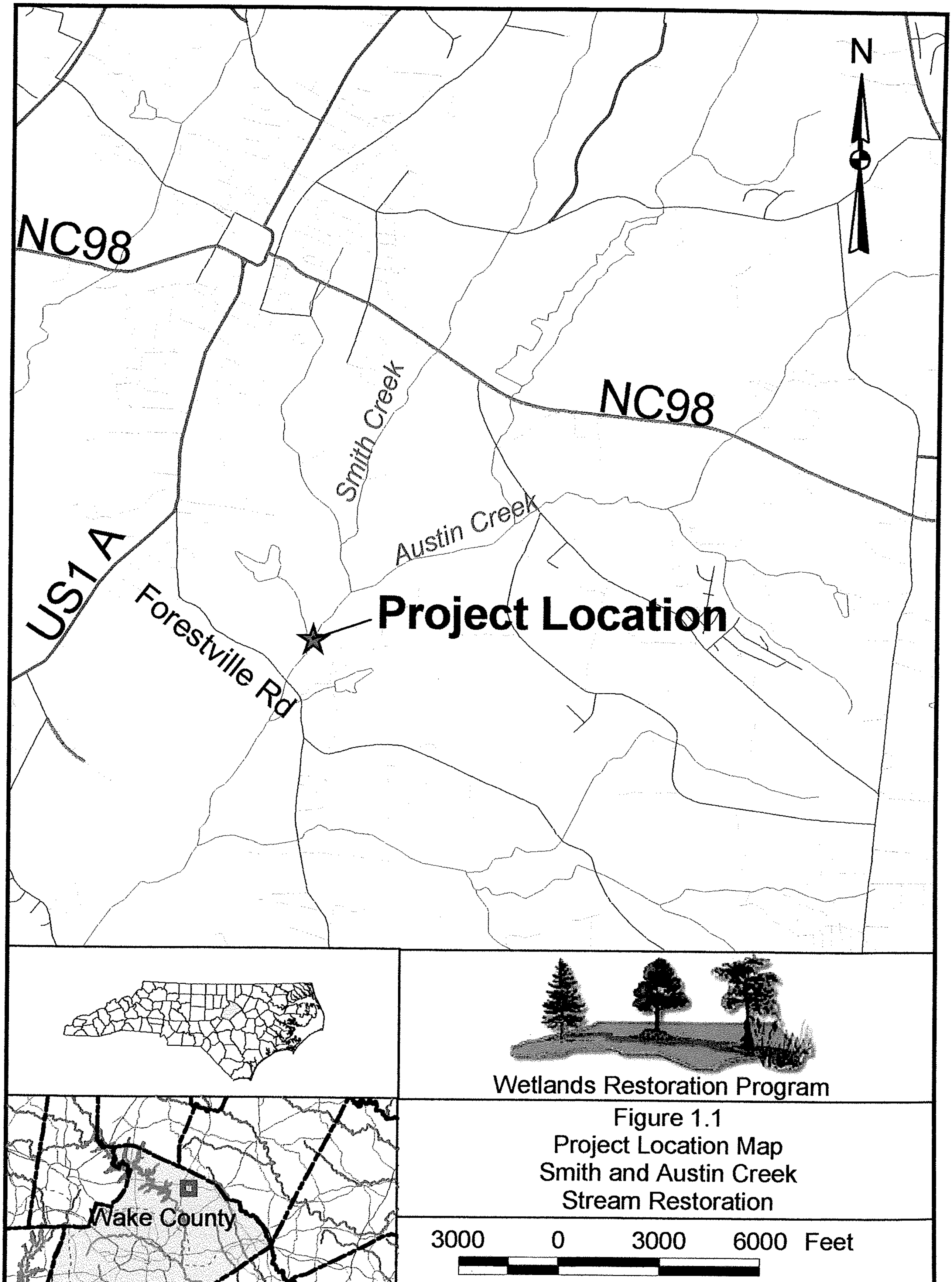
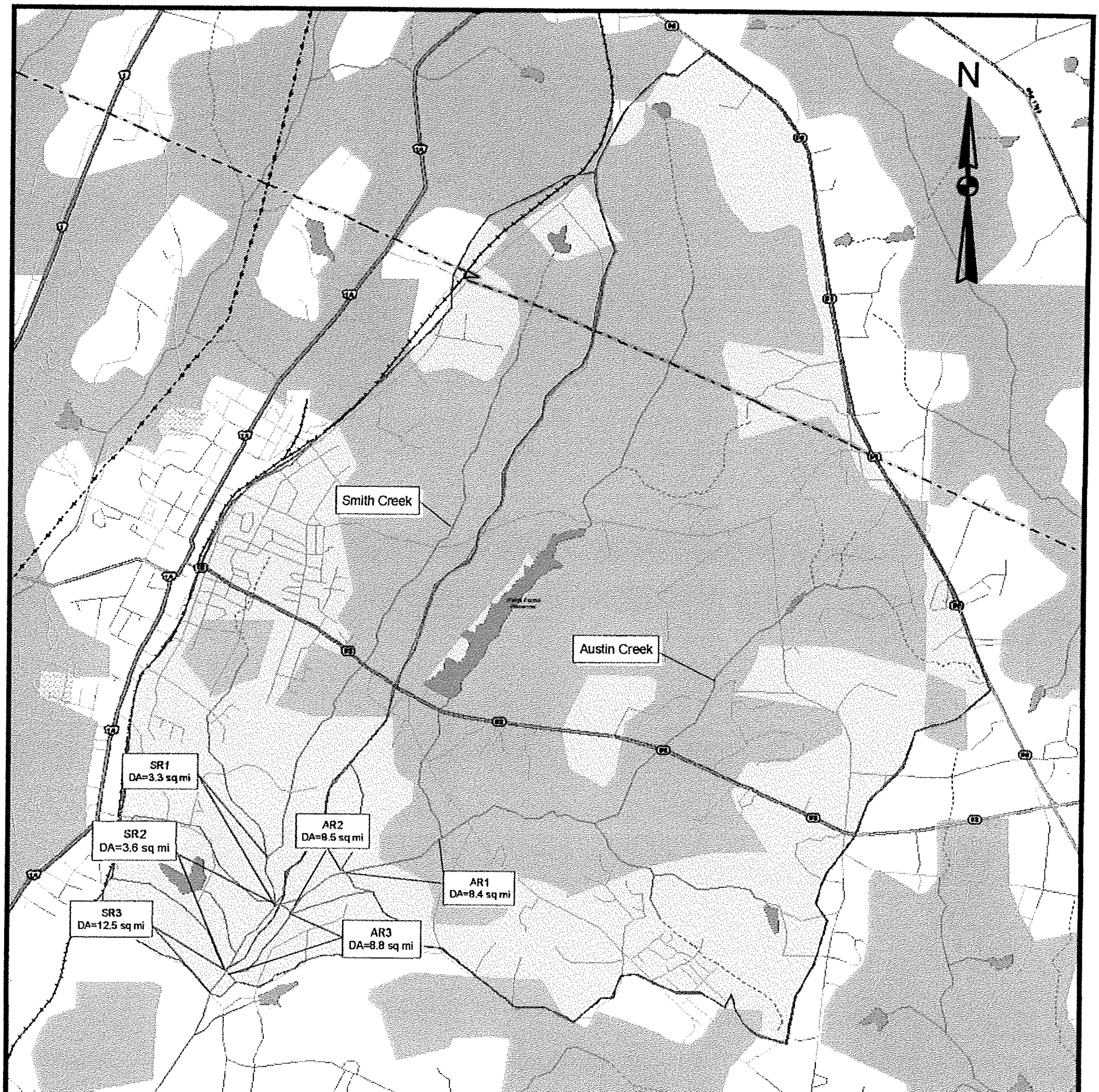
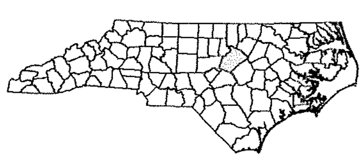


Figure 1.1
Project Location Map
Smith and Austin Creek
Stream Restoration





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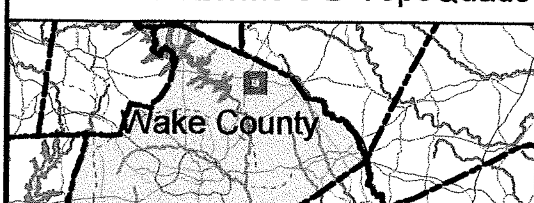
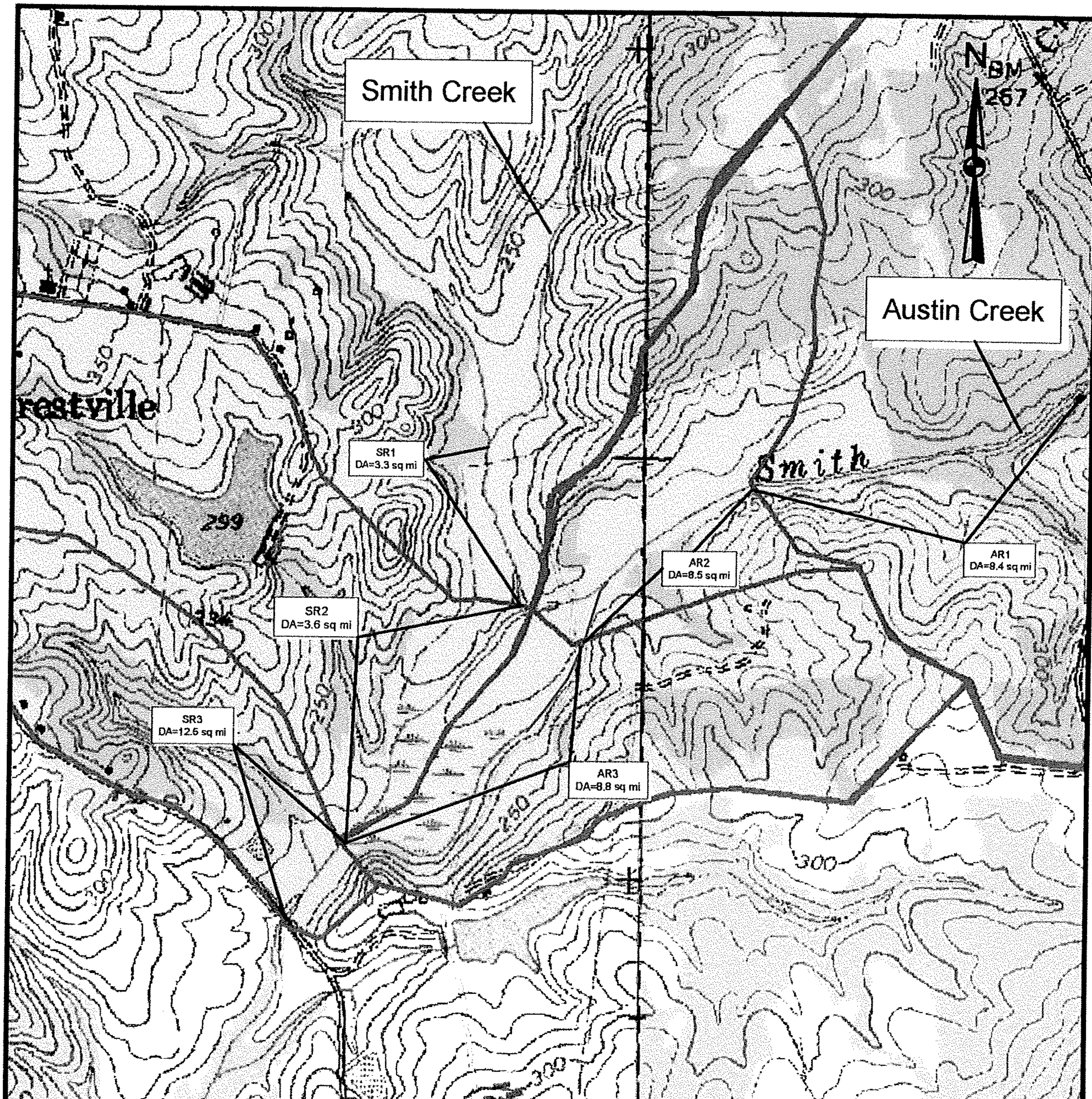
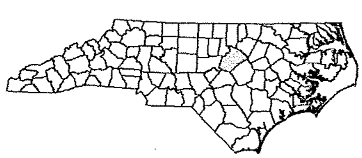


Wetlands Restoration Program

Figure 1.2
Watershed Map
Smith and Austin Creek
Stream Restoration

3000 0 3000 6000 Feet





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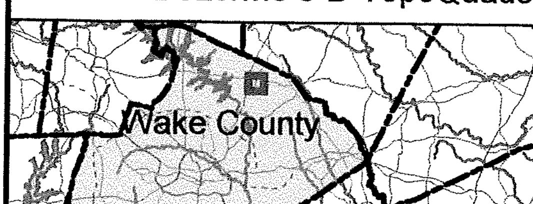

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Figure 1.3
Project Reach Map
Smith and Austin Creek
Stream Restoration

2000 0 2000 4000 Feet

2 Existing Condition Survey

2.1 Summary Information for Existing Project Reaches

Historic agricultural land uses dramatically altered Smith and Austin Creeks on the project site. Past channelization resulted in the current low-sinuosity stream channels that are incised in many sections. Streambanks and bed features are unstable throughout the project site due to high shear stress and poor riparian vegetation. The location of the confluence of the two streams has changed as evidenced by old USGS topographic and USDA soil survey maps showing Austin Creek flowing into Smith Creek approximately 2,500 ft upstream of the current confluence (Figure 2.1). A large flood in the early 1990s caused an avulsion to occur and re-routed Austin Creek to its current downstream confluence with Smith Creek. A previous landowner completed the avulsion by excavating the current Austin Creek channel at the edge of the valley (Figure 2.1).

Currently, the land area between Smith and Austin Creeks immediately upstream of their confluence is being developed for a public park. The land uses further upstream on the project site include a golf course and residential development. Figure 2.2 shows locations of the project reaches and the proposed land uses. For all six reaches, a conservation easement of 50 to 100 ft from streambank has been secured with no development planned within the stream corridor.

Existing condition data are summarized for each stream reach in Table 2.1. Additional existing condition data are included in Appendix 1. Sections 2.2 through 2.7 include narrative descriptions of existing conditions for each project reach. Figures 2.2 through 2.6 show the locations of the existing stream reaches and the locations of photographs shown in Appendix 4.

2.2 Reach SR1

Reach SR1 extends 1,928 ft along Smith Creek from the upstream property boundary at longitudinal station 0+00 to the ford crossing at station 19+28 (Figures 2.2 and 2.3). The Rosgen stream classification transitions from G5c upstream near station 0+00 to E5/C5 moving downstream past station 7+76 (Rosgen, 1994). Bank height ratios range from approximately 1.0 to 1.9. Because of channel incision, the floodplain is only accessible during extreme flood events. Many sections of this reach have active streambank erosion and poor bed stability. The reach is in Stage IV of the Simon Channel Evolution Model. The fluvial processes associated with Stage IV include aggradation, development of a meandering thalweg, initial deposition of alternate bars, and reworking of failed material on the lower banks. The dominant hillslope processes include slab, rotational, and pop-out failures, and low angle slides of previous failures. All of the fluvial processes were observed in this reach. Hillslope processes were also observed and include mass wasting and lateral retreat of the streambanks.

Table 2.1 Existing Condition Parameters for Smith and Austin Creeks.

	Parameter	Reach SR1	Reach SR2	Reach SR3	Reach AR1	Reach AR2	Reach AR3
	Rosgen Stream Type	G/E/C	C	E	F/G	E	C
	Drainage Area (mi^2)	3.3	3.6	12.5	8.4	8.5	8.8
	Reach Length (ft)	1,928	2,317	735	2,831	392	2,323
Dimension	Bankfull Area (ft^2)	37-48	38-47	90-130	58-90	50-60	70-78
	Bankfull Width (ft)	16-26	33-51	22-25	24-39	17-21	32-35
	Width/Depth Ratio (ft)	7-15	25-67	4-6	10-21	6-8	14-18
	Bankfull Mean Depth (ft)	1.7-2.6	0.8-1.3	4.5-5.5	1.7-2.5	2.6-3.0	2.0-2.4
	Bank Height Ratios	1.0-1.9	1.0	1.2-1.5	1.5-3.2	1.1-1.3	1.0
Pattern	Meander Length (ft)	85-160	>200	N/A	N/A	N/A	N/A
	Radius of Curvature (ft)	27-40	N/A	N/A	N/A	N/A	N/A
	Meander Belt Width (ft)	60-70	50-70	N/A	N/A	N/A	N/A
	Sinuosity	1.3	1.1	1.0	1.1	1.0	1.0
Profile	Valley Slope (ft/ft)	0.0050	0.0050	0.0050	0.0039	0.0039	0.0039
	Channel Slope (ft/ft)	0.0040	0.0045	0.0050	0.0036	0.0039	0.0038

Sandy riffles and runs dominate the streambed in Reach SR1. Pools are created by adjustments in channel pattern and scour around large woody debris (LWD). The streambed material consists of predominantly sand-sized particles.

Vegetation consists of a mix of native and exotic species along the upstream section of this reach from the property line to the edge of the tree line. Mature trees are scattered along the stream banks and floodplain including sycamore (*Platanus occidentalis*), green ash (*Fraxinus pennsylvanica*), river birch (*Betula nigra*), and red maple (*Acer rubrum*). Additional trees within the floodplain include sweetgum (*Liquidambar styraciflua*), hawthorn (*Crataegus* spp.), loblolly pine (*Pinus taeda*), black cherry (*Prunus serotina*), tulip poplar (*Liriodendron tulipifera*) and red cedar (*Juniperus virginiana*). Dispersed throughout the reach are several exotic species of shrubs and herbaceous plants including Chinese privet (*Ligustrum sinense*), multi-floral rose (*Rosa multiflora*), Japanese honeysuckle (*Lonicera japonica*), and microstegium (*Microstegium virmineum*) along with other species including blackberry (*Rubus* spp.), greenbrier (*Smilax* spp.), poison ivy (*Toxicodendron radicans*), fescue (*Festuca* spp.), aster (*Aster* spp.), and broomsedge (*Andropogon virginicus*).

From the tree line to the ford crossing the floodplain is open on both sides of the stream, supporting no mature trees. The dominant vegetation types are shrubby and herbaceous including blackberry, multi-floral rose, elderberry (*Sambucus canadensis*), pokeweed (*Phytolacca americana*), Chinese privet, goldenrod (*Solidago* spp.), dog-fennel (*Eupatorium capillifolium*), microstegium, broomsedge, and fescue.

2.3 Reach SR2

Reach SR2 extends 2,317 ft along Smith Creek from the ford crossing at longitudinal station 19+28 to the confluence of Smith and Austin Creeks at station 42+45 (Figures 2.2 and 2.4). The Rosgen stream classification is C5 with bank height ratios of approximately 1.0. The right streambank is adjacent to a terrace; however, the left streambank is connected to an active floodplain. In several places, there are multiple channels resulting from past channelization. The extremely high bankfull width/depth ratios up to 67 are much higher than stable C streams observed in the Piedmont of North Carolina.

Sandy riffles and runs dominate the streambed. Pools are created by adjustments in channel pattern and scour around large woody debris (LWD). The streambed material consists of predominantly sand-sized particles.

The floodplain adjacent to the left bank of this reach is a marsh consisting of soft rush (*Juncus effusus*), panic grasses (*Panicum* spp.), seed-box (*Ludwigia alternifolia*), asters, cocklebur (*Xanthium strumarium*), black willow saplings (*Salix nigra*), and river birch saplings. A narrow woody buffer consisting of sycamore, river birch, green ash and hawthorn exist along the right bank of this reach. The dominant vegetation in the understory and herbaceous layers along the right bank include boxelder (*Acer negundo*), Chinese privet, giant cane (*Arundinaria gigantea*) blackberry, greenbrier, multi-floral rose, Japanese honeysuckle, poison ivy (*Toxicodendron radicans*), panic grasses, and fescue.

2.4 Reach SR3

Reach SR3 extends 735 ft along Smith Creek from the confluence with Austin Creek at longitudinal station 42+45 to the bridge at Forestville Road at station 49+80 (Figures 2.2 and 2.6). The Rosgen stream classification is E5 with bank height ratios ranging from 1.2 to 1.5. This reach is channelized with very low sinuosity (approximately 1.0) but remains moderately stable because of mature woody vegetation along the streambanks.

Bed materials are primarily sands. The lower half of the reach is one long shallow run, which is formed from backwater created by a steep rip rapped riffle upstream of the bridge at the sewer line crossing. Streambanks for the reach appear to be stable, with few areas of active erosion. The floodplain along both banks of this reach is similar to the right bank above the confluence. However the riparian buffer is completely denuded near the bridge.

2.5 Reach AR1

Reach AR1 extends 2,831 ft along Austin Creek from the upstream property boundary at longitudinal station 0+00 to the entrance of the concrete box culverts under the New Forestville Road extension at station 28+31 (Figures 2.2 and 2.5). The 150-ft section of stream flowing through the box culverts is not included in this reach. The Rosgen stream classification is F5/G5 with bank height ratios ranging from 1.5 to 3.2. The channel is currently in Stages III and IV of the Simon Channel Evolution Model. Bank erosion is prevalent throughout the reach, especially along the denuded right bank. The left streambank is high; however, large woody vegetation provides bank stability for most of the reach. In areas devoid of trees, there is bank erosion along the left bank.

Near the downstream end of Reach AR1, the stream flows under a sewer pipe and a newly constructed golf cart bridge before flowing through four large box culverts. The box culverts are not positioned parallel with the flow, and the channel is overly wide. This has caused sediment deposition to occur along the left streambank and culvert.

The floodplain adjacent to the right bank has been completely cleared due to construction activities. The dominant vegetation along the right bank is primarily herbaceous including fescue, microstegium, soft rush, dog-fennel, goldenrod, and giant cane. Sycamore and river birch saplings are scattered along the right bank. The left bank and floodplain is stabilized by woody vegetation including red maple, river birch, sycamore, green ash, and black cherry. The understory layer consists of hornbeam, tag-alder, giant cane, Chinese privet, blackberry, multi-floral rose, greenbrier, microstegium, and Japanese honeysuckle. The left bank along the section just upstream of the footbridge is dominated mostly by giant cane.

2.6 Reach AR2

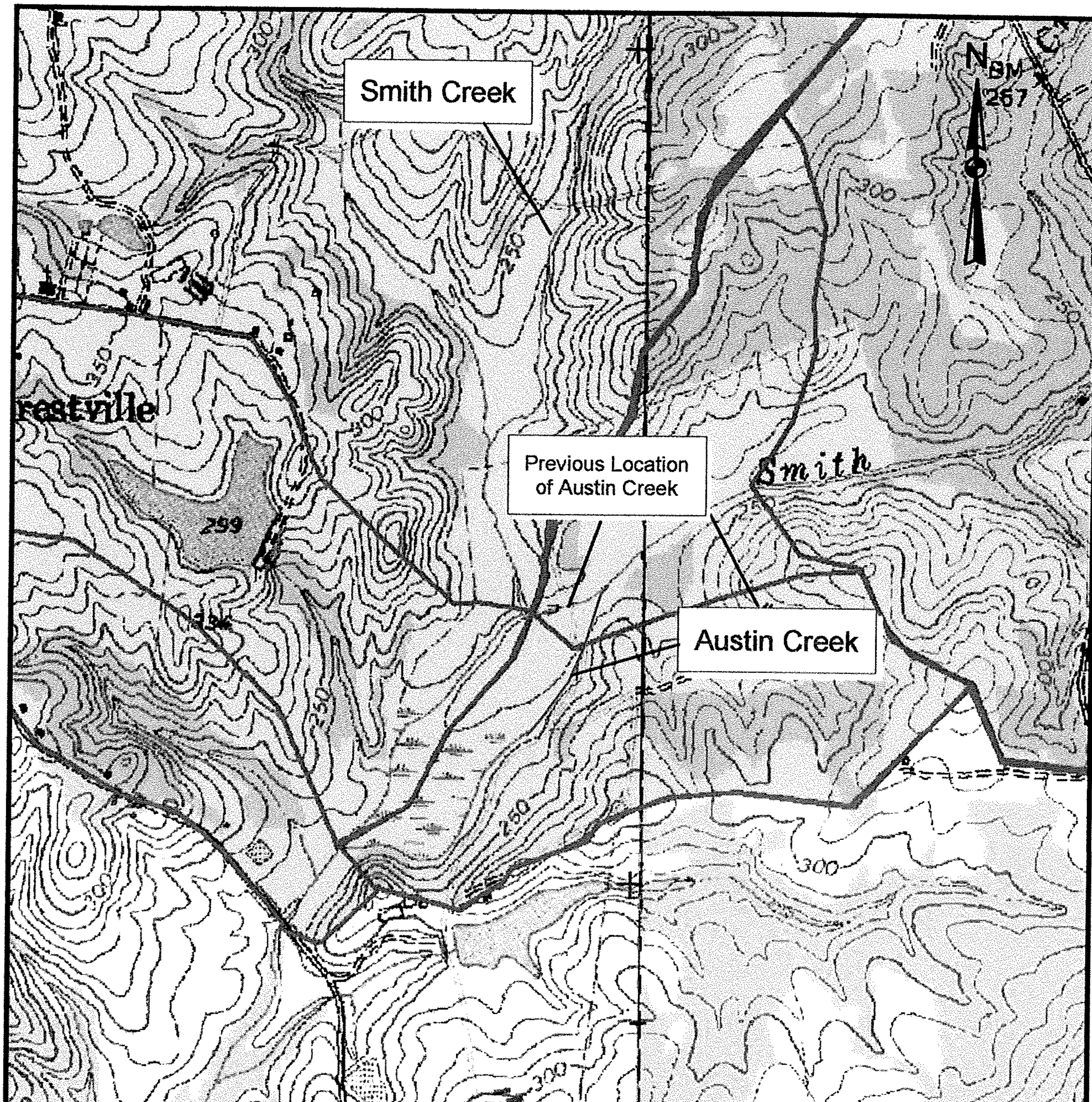
Reach AR2 extends 392 ft along Austin Creek from the box culvert outflow below New Forestville Road at longitudinal station 29+81 to the bedrock knickpoint at station 33+73 (Figures 2.2 and 2.4). The 150-ft section of stream flowing through the box culverts is not included in this reach. The Rosgen stream classification is an incised E5 channel with bank height ratios ranging from 1.1 to 1.3. Grade control is provided by a culvert crossing, several bedrock outcrops, and Smith Creek downstream. Reaches AR2 and AR3 were created after a large flood in the early 1990s caused an avulsion to occur and re-routed Austin Creek. A previous landowner completed the avulsion by excavating a channel at the edge of the valley (Figure 2.1). Overall, Reach AR2 is moderately stable but lacks bedform diversity and channel pattern.

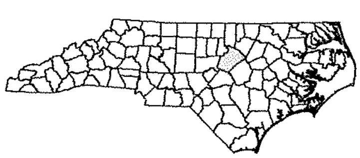
The existing vegetation community of left bank/floodplain of this reach is similar to the left bank/floodplain of Reach AR1. The right bank floodplain has been cleared by construction activities. The remaining vegetation includes soft rush, cocklebur, panic grass, dog-fennel, and black willow saplings.

2.7 Reach AR3

Reach AR3 extends 2,323 ft along Austin Creek from the bedrock knickpoint at longitudinal station 33+73 to the confluence of Austin and Smith Creeks at station 56+96 (Figures 2.2 and 2.4). The Rosgen stream classification is C5 with a bank height ratio of approximately 1.0. Reach AR3 is moderately stable but lacks bedform diversity and channel pattern.

The existing vegetation community is dominated by soft rush, cocklebur, panic grass, and dog-fennel. The left bank becomes terraced again for the last approximately 200 feet and is vegetated with a woody buffer similar to the left bank described in Reaches AR1 and AR2.





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Source: DeLorme 3-D TopoQuads

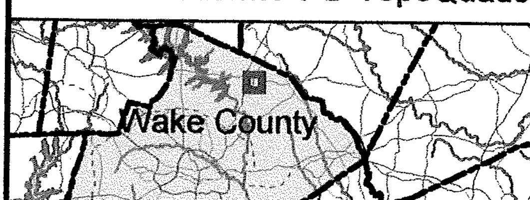

Figure 2.1
Previous Location of Austin Creek
Smith and Austin Creek
Stream Restoration

2000 0 2000 4000 Feet

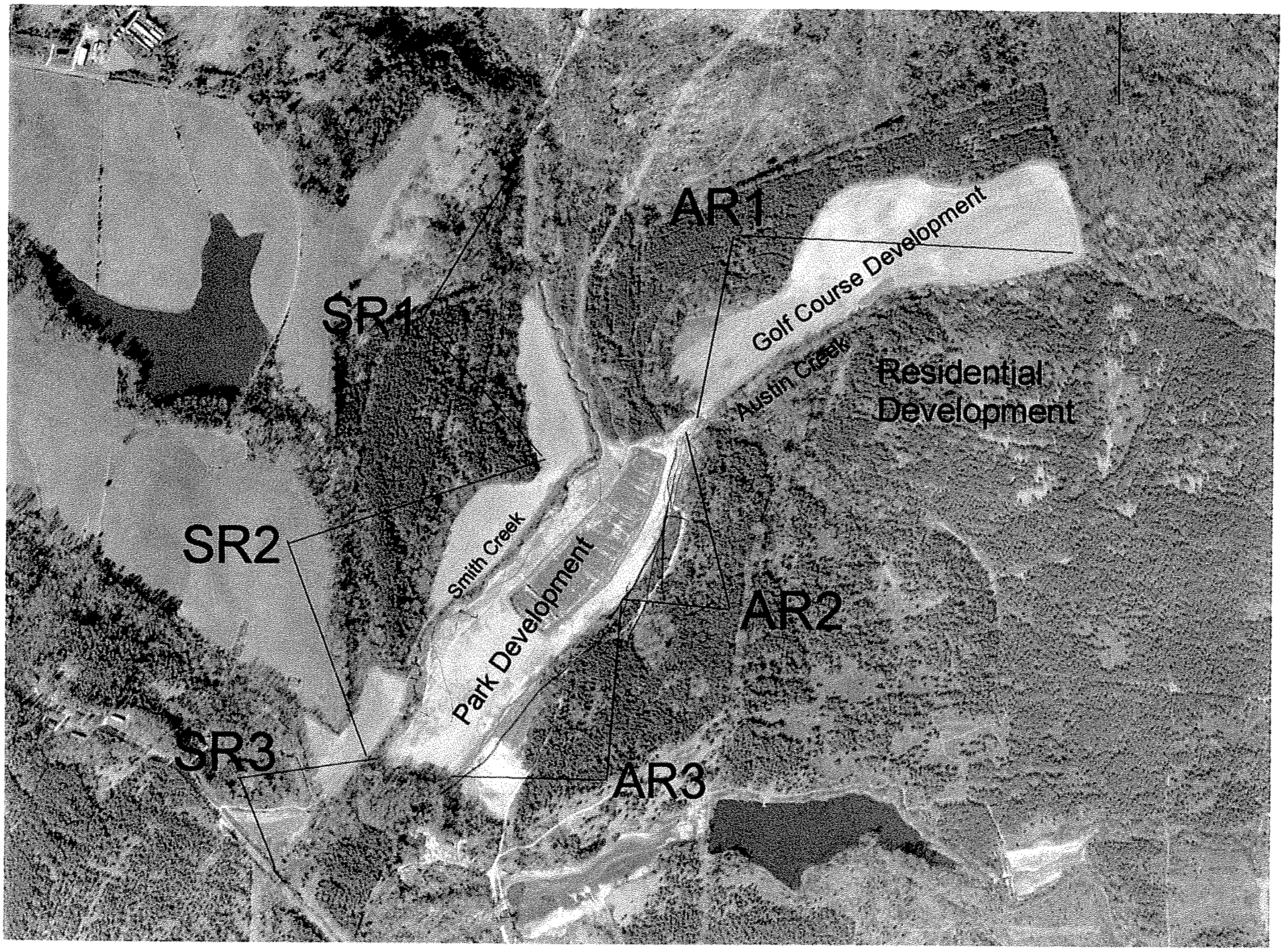

Figure 2.2 Smith and Austin Creeks Existing Condition Plan View

0 1000 Feet

Source: Wake County Government

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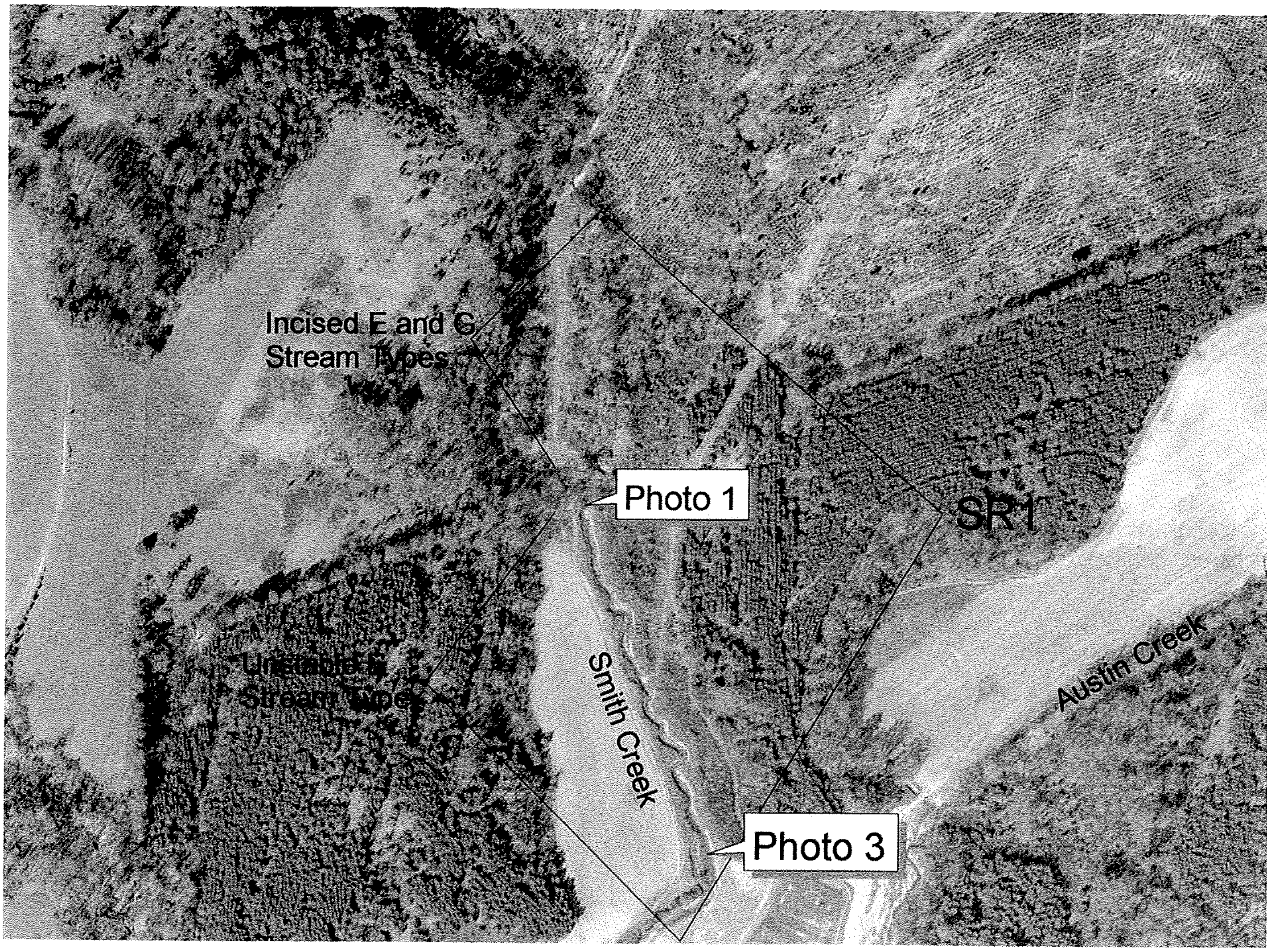

Figure 2.3 Smith Reach 1 (SR1) Existing Condition

0 600 Feet

Source: Wake County Government

N

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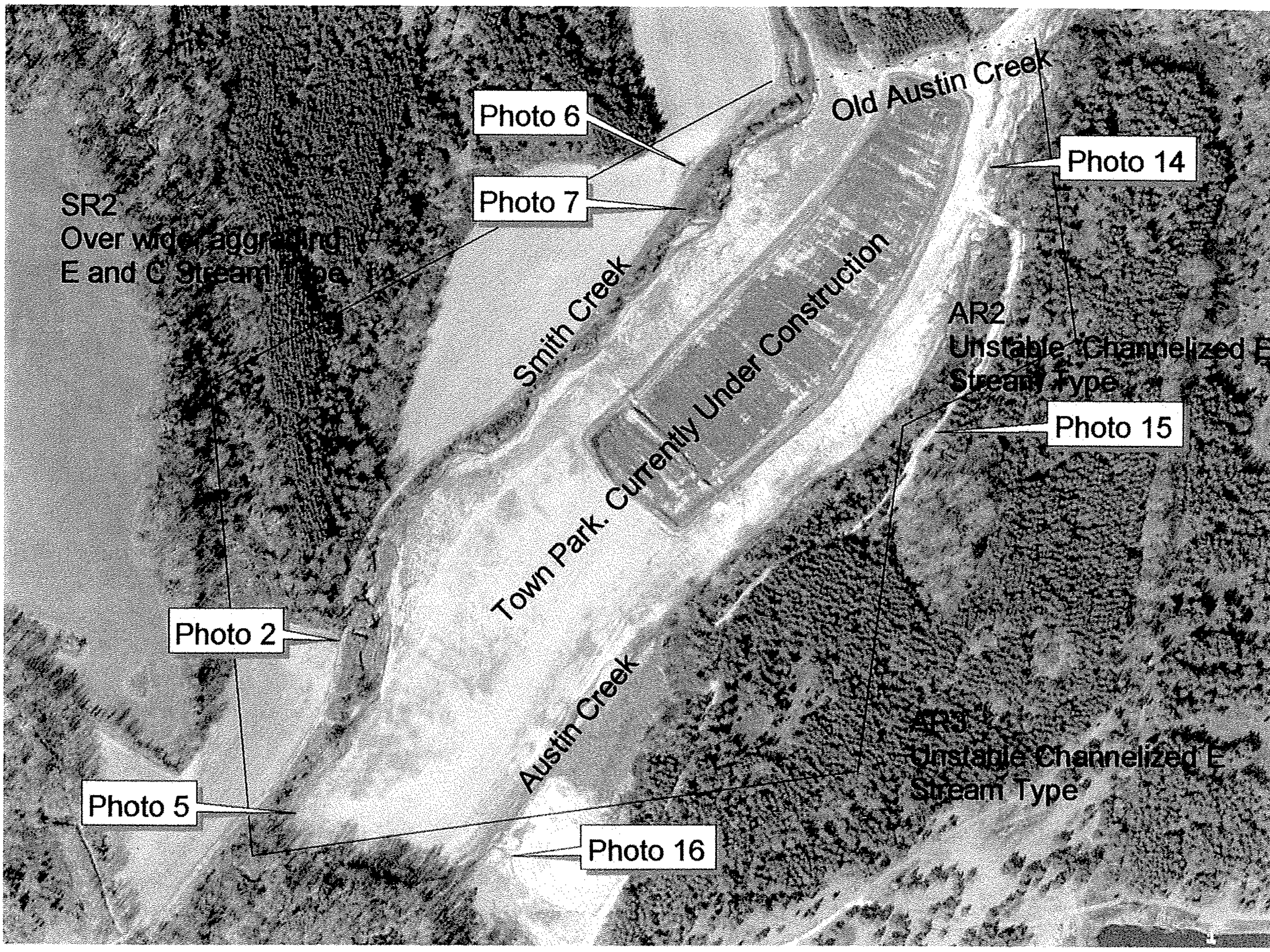

Figure 2.4 Smith Reach 2 (SR2), Austin Reach 2 (AR2), and Austin Reach 3 (AR3) Existing Condition

0 600 Feet

Source: Wake County Government

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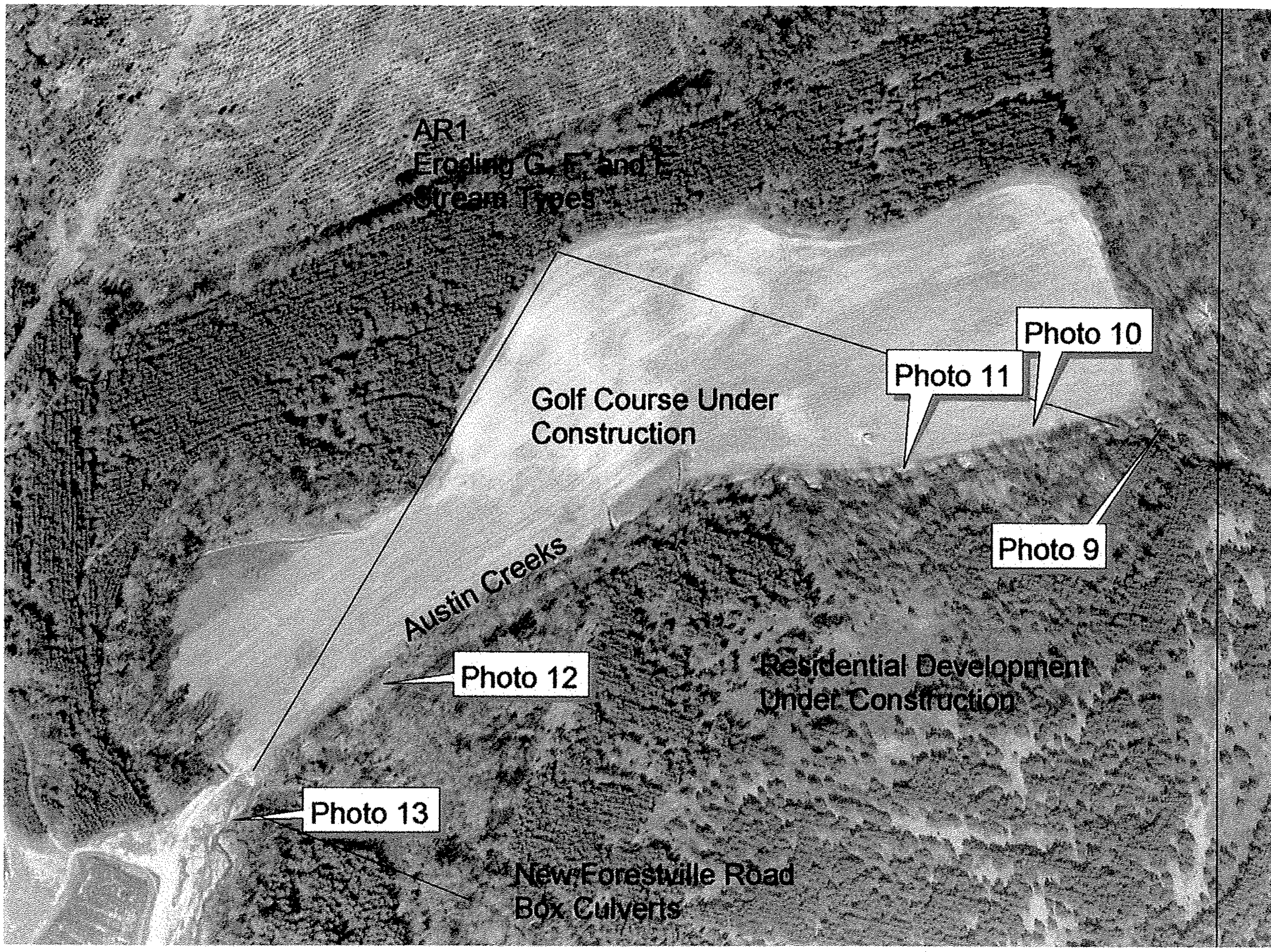

Figure 2.5 Austin Reach 1 (AR1) Existing Condition

0 600 Feet

Source: Wake County Government

N

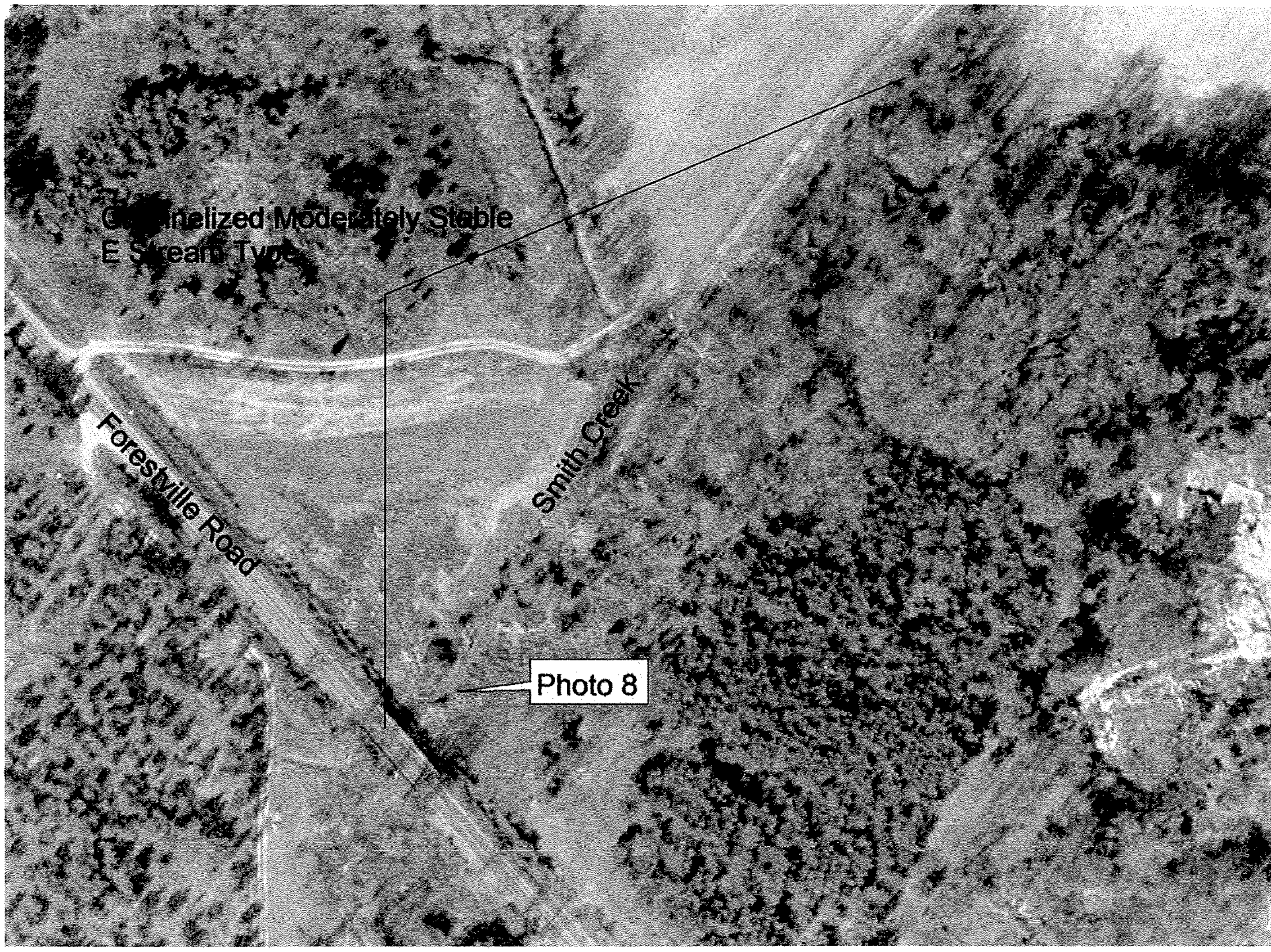

Figure 2.6 Smith Reach 3 (SR3) Existing Condition

N

0 200 Feet

Source: Wake County Government

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3 Bankfull Stage Verification

The bankfull indicators for Smith Creek and Austin Creek included the back of a depositional bench, a scour line, and in a few cases, the top of the streambank. These indicators are consistent with other Piedmont streams that are at a Stage IV/V in Simon's Channel Evolution Model. Data for Smith and Austin Creeks are shown on Figure 3.1. The project points match well with other data on the rural Piedmont regional curve, indicating that bankfull was correctly identified. All of the points for Austin Creek are below the regression line. This is likely caused by the upstream Wake Forest water supply reservoir.

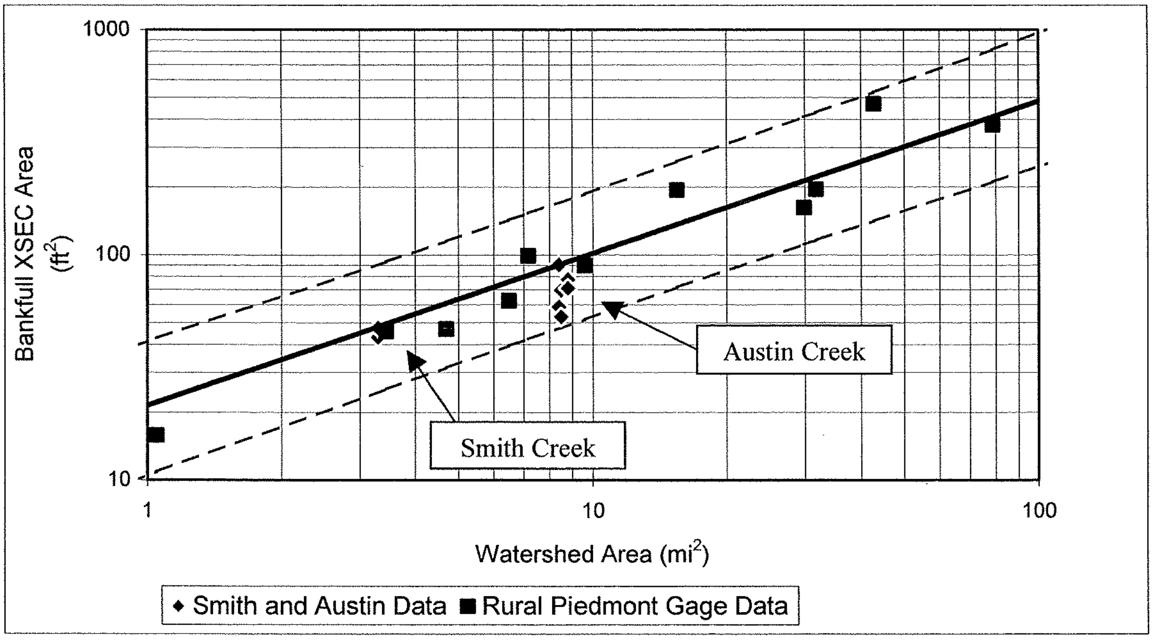


Figure 3.1 Rural Piedmont Regional Curve with surveyed bankfull cross-section areas for Smith and Austin Creeks. Data points for Smith and Austin Creeks were not used in determining the regression line.

4 Reference Reach Analyses

Reference reaches are stable streams used to determine the functional potential of a stream channel to be restored. Reference reach surveys are conducted to quantify the dimension, pattern, and profile of the stable reference reach. These data are then used in the design for the degraded stream that is to be restored.

Sals Branch was used as the reference reach for Smith and Austin Creeks. Sals Branch is located in Umstead State Park in Wake County, North Carolina and has a similar valley morphology and drainage area characteristics. In addition to the reference reach data, lessons learned from monitoring restored reaches are included in the selection of the final ratios. The reference reach data and ratios are presented with the design tables in Appendix 2.

5 Natural Channel Design

5.1 Design Summary

The stream restoration design for Smith and Austin Creeks is based on natural channel design principals. The design takes into account differences in drainage area, adjacent land uses, upstream impoundments, and future development potential. Overall, the natural channel design addresses the dimension, pattern, and profile for both Smith and Austin Creeks (Figure 5.1). The design approach for each of the six project reaches is described in Sections 5.2 through 5.7. The design parameters and cross-sections (existing and design) are provided in Appendix 2. Typical drawings of instream structures are shown in Appendix 3.

5.2 Considerations for Future Development

Land use in the watershed is changing from primarily forested/agricultural to residential as several new developments are under construction or planned. The Northeast Wake County Land Use Plan (Wake County Planning Department, 2000) provides a detailed assessment of current and planned development of parks, businesses and residences (Section 1.3). The project drainage area is part of both the Rolesville and Wake Forest Urban Service Areas, with future development consisting of cluster and other subdivisions up to two or three dwellings per acre when municipal water and sewer become available.

Several research studies have shown that for urbanizing watersheds, bankfull cross-section area increases with increasing impervious cover (Doll et al., 2000; Dunne and Leopold, 1978; Leopold et al., 1992; Leopold, 1994). An important component to this analysis is the degree of incision. Incised channels carry more water and thus are more prone to enlarging. There is evidence to support, however, that non-channelized urban streams with bank height ratios near 1.0 have bankfull cross-section areas closer to those in rural streams.

Currently, the bankfull cross-section areas of both Smith and Austin Creeks correlate closely with the rural Piedmont regional curve (Figure 3.1). If the urban Piedmont curve were used to design the new channel dimension, bankfull cross-section area would have to be increased by 300%. The urban Piedmont curve represents streams that have much higher impervious coverage than the projected increases for Smith and Austin Creeks. In addition, the design proposed for both Smith and Austin maximizes the width of the floodplain, thus keeping flood flows on the floodplain rather than in the channel. Therefore, the final design includes a moderate increase (20%) in the bankfull cross-section area to account for upstream urbanization and design uncertainty without creating an overly large channel.

5.3 Reach SR1

The proposed natural channel design for Reach SR1 of Smith Creek is based on a Priority 2 restoration approach. A new floodplain will be created at a lower elevation by excavating a stable bankfull bench of varying width. The resulting bank height ratio will be 1.0. The upstream section from station 0+00 to 7+76 will be converted from a G5c channel to an E5 channel in its existing location. Bedform will be improved through the use of instream structures. The downstream section from station 7+76 to 19+28 is currently an eroding incised E5 channel. In addition to changes in dimension and profile, the meander geometry will be improved through this section to provide a more stable plan form. Root wads will be used to stabilize the streambanks, improve bedform diversity, and improve aquatic habitats. Instream structures will be used to provide grade control, protect streambanks, and enhance bedform.

5.4 Reach SR2

The proposed natural channel design for Reach SR2 of Smith Creek is based on a Priority 1 restoration approach. The existing straight channel will be replaced by a new meandering channel with bankfull stage at the existing floodplain elevation. A stable meandering channel will be cut in the existing well-vegetated floodplain. Woody transplants and sod mats will be used to stabilize the streambanks along the new channel. Instream structures such as root wads and rock vanes will be used to stabilized the streambanks and improve bedform diversity.

5.5 Reach SR3

Reach SR3 of Smith Creek downstream of the confluence of Smith and Austin Creeks is moderately stable and has a well-vegetated riparian buffer. No changes in dimension, pattern, or profile are proposed for this reach. However, there are short eroding sections which will be stabilized with root wads.

5.6 Reach AR1

The proposed natural channel design for Reach AR1 of Austin Creek is based on a Priority 3 restoration approach. Stream restoration will be confined to within the 50-ft conservation easement on both sides of the existing stream channel. Since the left streambank is moderately stable with mature vegetation providing shade to the stream, a bankfull bench will not be constructed on the left bank except for several short sections devoid of woody vegetation. On the right streambank, a 45-ft wide bankfull bench will be excavated along the right streambank and vegetated. The streambank, bankfull bench and terrace scarp will be seeded with millet and covered with C 125 BN erosion control matting. Permanent seeding will take place during the winter.

Instream structures, including root wads, log vanes, and rock vanes will be used to repair eroding streambanks and improve the channel profile (bedforms). Cross vanes will be installed upstream and downstream of the golf cart bridge to prevent near bank scour at the bridge. Cross vanes will also be constructed upstream of the box culverts to decrease the width of the low flow channel.

5.7 Reach AR2

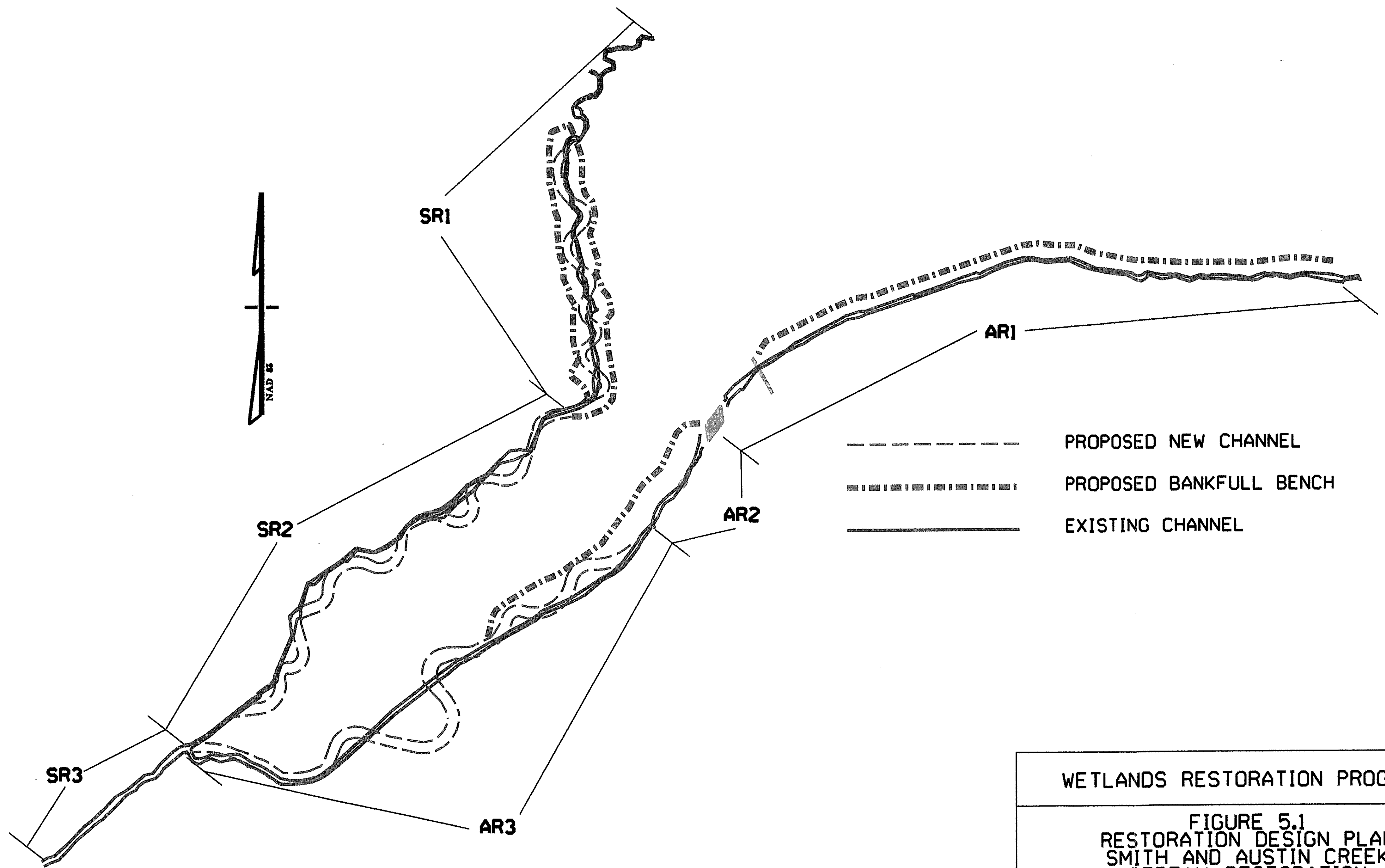
The proposed natural channel design for Reach AR2 of Austin Creek is based on a Priority 3 restoration approach similar to Reach AR1. The section immediately downstream of the New Forestville Road box culverts is overly wide. In addition, the box culverts are angled such that stream velocity vectors are pointed at the right streambank. A rock vane will be used to redirect the velocity vectors away from the streambank. A rock cross vane will be constructed downstream of the rock vane to prevent further widening of the channel. A rock cross vane and root wads will be used to build a plunge pool on the downstream side of the culvert at the gravel road crossing near station 31+00. The Town of Wake Forest has requested that the culvert crossing remain after restoration. Additional instream structures will be installed to improve the channel profile by improving bedform diversity. A 95-ft bankfull bench will be installed along the right streambank.

5.8 Reach AR3

The proposed natural channel design for Reach AR3 of Austin Creek is based on a Priority 1 restoration approach. The existing straight channel will be replaced by a new meandering channel with bankfull stage at the existing floodplain elevation. A stable meandering channel will be cut in the existing well-vegetated floodplain. Woody transplants and sod mats will be used to stabilize the streambanks along the new channel. Instream structures such as root wads and rock vanes will be used to stabilized the streambanks and improve bedform diversity.

5.9 Planting Design

The planting design is being provided by Soil and Environmental Consultants, Inc. of Raleigh, North Carolina and is not a part of this report. A copy of the report can be obtained from the NC Wetlands Restoration Program.



WETLANDS RESTORATION PROGRAM

FIGURE 5.1
RESTORATION DESIGN PLAN
SMITH AND AUSTIN CREEK
STREAM RESTORATION

500 0 FT 500 1000 FT

6 Sediment Transport Analysis

A stable stream has the capacity to move its sediment load without aggrading or degrading over time. The total load of sediment can be divided into bedload and suspended load. Suspended load is normally composed of fine sand, silt and clay particles transported in the water column. Bedload is transported by rolling, sliding, or hopping (saltating) along the bed.

The movement of sediment particles depends on the energy of the stream and their physical properties. Grain size has a direct influence on the mobility of a given particle. Critical dimensionless shear stress (τ^*_{ci}) is a measure of the force required to move a given size particle resting on the channel bed. It can be calculated for a gravel-bed stream using a surface and subsurface particle sample from a representative riffle in the reach.

$$\tau *_{ci} = 0.0834\left(\frac{d_i}{\hat{d}_{50}}\right)^{-0.872} \qquad \text{[Equation 6.1]}$$

Where,

τ^*_{ci} = critical dimensionless shear stress
d_i = median particle size of riffle bed surface (mm)
$\hat{d}_{50}$ = median particle size of subsurface sample (mm)

Critical dimensionless shear stress can then be used in the following equation to predict the minimum water depth required to move the d84 of the pavement sample. The water depth is calculated by:

$$Dcr = \frac{1.65\tau *_{ci} d84_{sub}}{s} \qquad \text{[Equation 6.2]}$$

Where,

Dcr = water depth (ft)
τ^*_{ci} = critical dimensionless shear stress
$d84_{sub}$ = d84 of subpavement sample (ft)
s = average channel slope (ft/ft)

Critical dimensionless shear stress was calculated separately for Smith and Austin Creeks using a pavement/subpavement sample. Representative riffles were selected in each stream and sampled using the following techniques.

1. A bottomless bucket was placed on the riffle and slightly submerged to block flowing water.
2. The surface layer of the bed was sampled by removing the smallest to largest particle on the bed surface. All surface samples were collected.
3. A subsurface sample was collected to a depth of 1 to 2 times the mean diameter of the largest particle sampled from the surface sample.

4. The two samples were sieved and the percent cumulative distribution was plotted on a log-normal scale. The pavement subpavement distributions for Smith and Austin Creeks are shown in Figures 6.1 and 6.2, respectively.

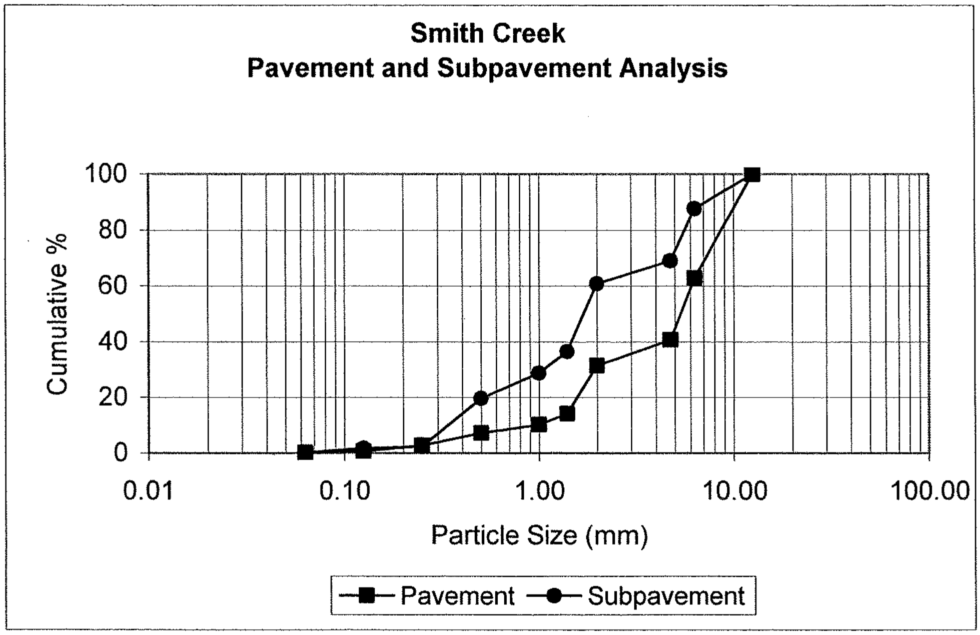


Figure 6.1 Substrate Analysis for Smith Creek.

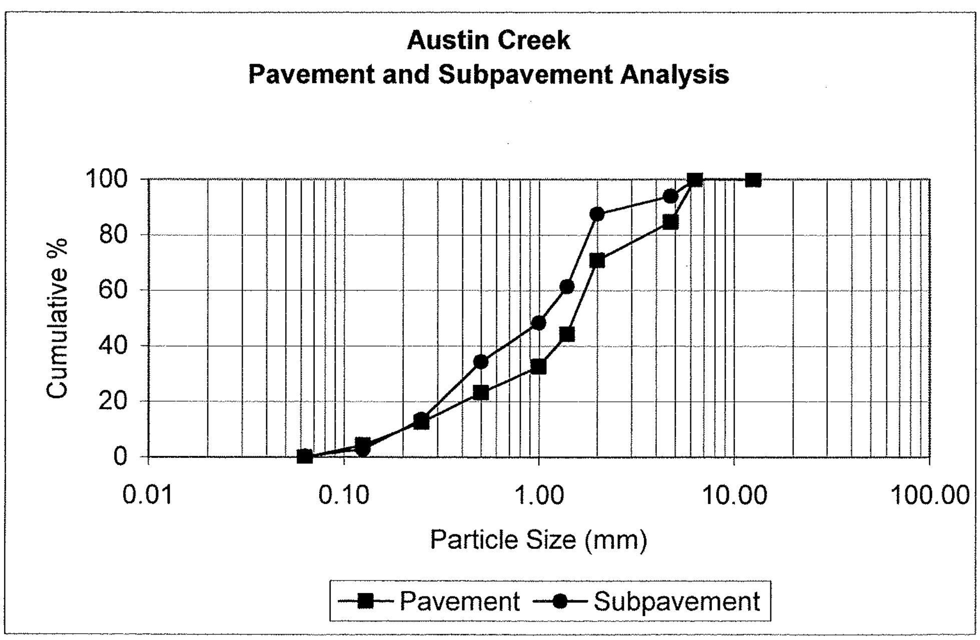


Figure 6.2 Substrate Analysis for Austin Creek.

To find the depth of water necessary to move the d84 of the pavement sample or the largest particle on the bar, Equation 6.2 was used. The results for Smith and Austin Creeks are shown in Tables 6.1 and 6.2, respectively. Based on this analysis, the design channel is competent to move large particles and should not agrade.

Table 6.1 Critical and Boundary Shear Stress Calculations for Smith Creek.

Shear Stress Analysis	Existing	Design
Bankfull Xsec Area, Abkf (sq ft)	43	60
Bankfull Width, Wbkf (ft)	18	28
Bankfull Mean Depth, Dbkf (ft)	2.4	2.1
Wetted Perimeter, WP=W+2D (ft)	22.8	32.3
Hydraulic Radius, R (ft)	1.9	1.9
Schan (ft/ft)	0.0039	0.0038
Boundary Shear Stress, τ (lb/sq ft)	0.46	0.44
d84 (mm)	22	22
d50 rif bed (mm)	5.5	5.5
d50 (mm)	1.7	1.7
τci	0.0300	0.0300
d bar large (mm)	12	12
d bar large (ft)	0.04	0.04
Dcrit (ft)	0.5	0.5

Table 6.2 Critical and Boundary Shear Stress Calculations for Austin Creek.

Shear Stress Analysis	Existing	Design
Bankfull Xsec Area, Abkf (sq ft)	70	110
Bankfull Width, Wbkf (ft)	30	38
Bankfull Mean Depth, Dbkf (ft)	2.3	2.9
Wetted Perimeter, WP=W+2D (ft)	34.7	43.8
Hydraulic Radius, R (ft)	2.0	2.5
Schan (ft/ft)	0.0034	0.0033
Boundary Shear Stress, τ (lb/sq ft)	0.43	0.52
d84 (mm)	14	14
d50 rif bed (mm)	1.8	1.8
d50 (mm)	1	1
τci	0.0500	0.0500
d bar large (mm)	12	12
d bar large (ft)	0.04	0.04
Dcrit (ft)	1.0	1.0

As a check, boundary shear stresses were calculated for design cross-sections and compared with Shields Curve. The shear stress placed on the sediment particles is the force that entrains and moves the particles, given by:

$$\tau = \gamma R s \qquad \text{[Equation 6.3]}$$

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)

Boundary shear stresses were calculated for the design cross-sections using Equation 6.3. From Shields diagram (Figure 6.3), these shear stresses values would be able to move particle sizes from 20 to 30 mm for Smith and Austin Creeks, respectively. These numbers are significantly higher than the largest particles sampled, which were 12 mm. Therefore, grade control structures will be required to ensure that the bed does not degrade. Bedrock knickpoints, cross vanes, and existing culverts will be used to provide grade control.

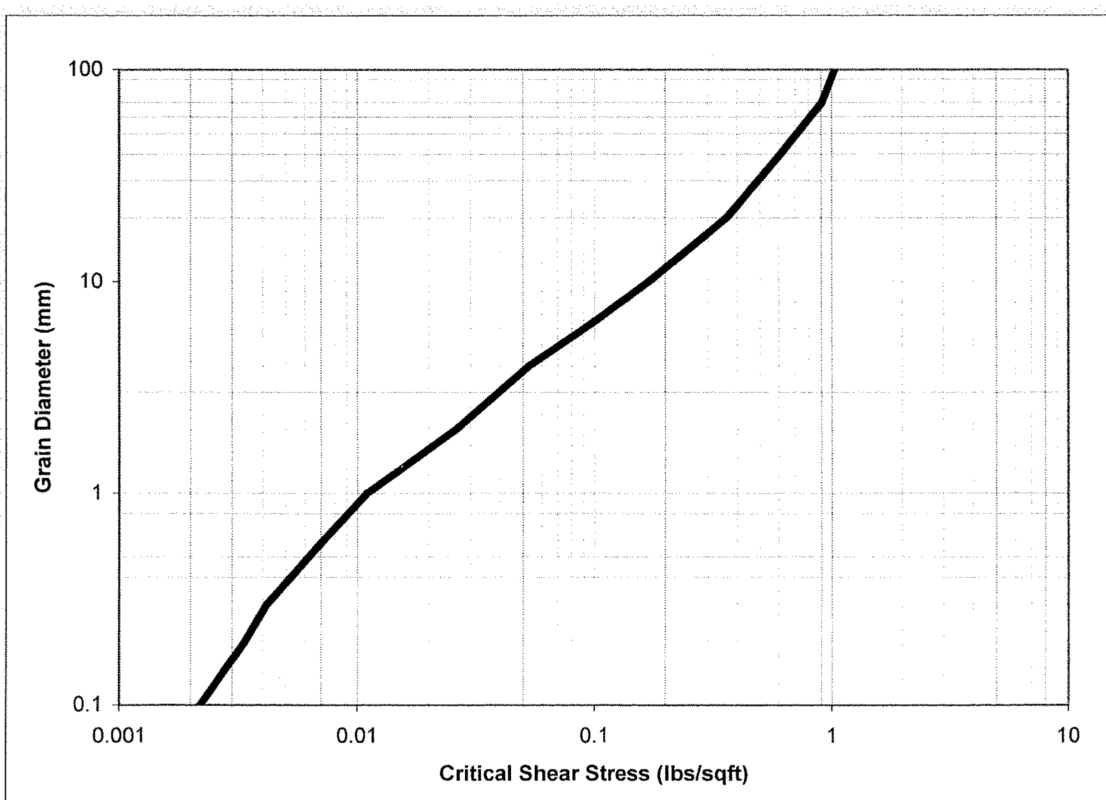


Figure 6.3 Shield's Curve for Grain Diameter of Transported Particle in Relation to Critical Shear Stress.

7 Flooding Analyses

Once the final design is approved, a hydraulic model analyses will be conducted to assure that there will be no increase in flooding as a result of the proposed design. HEC-RAS simulations will be run to determine the existing 100-year flood stage. Design cross-sections will then be input into HEC-RAS to determine if any increase in flood stage will result from the proposed design. If flood stage will be increased, the proposed stream design will be altered such that the 100-year flood stage will not be increased. HEC-RAS model simulations will be conducted upon approval of the restoration design by the permitting agencies.

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 will be established at a minimum of one riffle and one pool per reach, for a total of 12. 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. 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).

8.2 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 thalweg, water surface, inner berm, bankfull, and top of low bank. Each of these measurements 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.

8.3 Bank Erosion Estimates

Permanent bank erosion pins and bank profiles will be made at each permanent cross-section. A bank toe pin will be installed close to the observed bank. The bank profile toe pin will be tied to a station in the longitudinal profile. Measurements will be made once per year at the same time the cross-section is measured. A bank erodibility hazard index (BEHI) score will also be made. An estimate of near-bank shear stress will be made by measuring the water surface slope along the observed bank length, as well as for the entire feature length, following the thalweg.

Success Criteria: The BEHI score should be low by the second year of restoration. Bank erosion measurements should be less than 0.1 ft/year.

8.4 Photo Reference Sites

Photographs used to evaluate restored sites will be made with a 35-mm camera using slide film or a digital camera. Reference sites will be photographed before construction and continued for at least 5 years following construction. Reference photos will be taken once a year. 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.

8.5 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.

8.6 Benthic Macroinvertebrate Monitoring

Benthic macroinvertebrate monitoring will be conducted by the NC Division of Water Quality.

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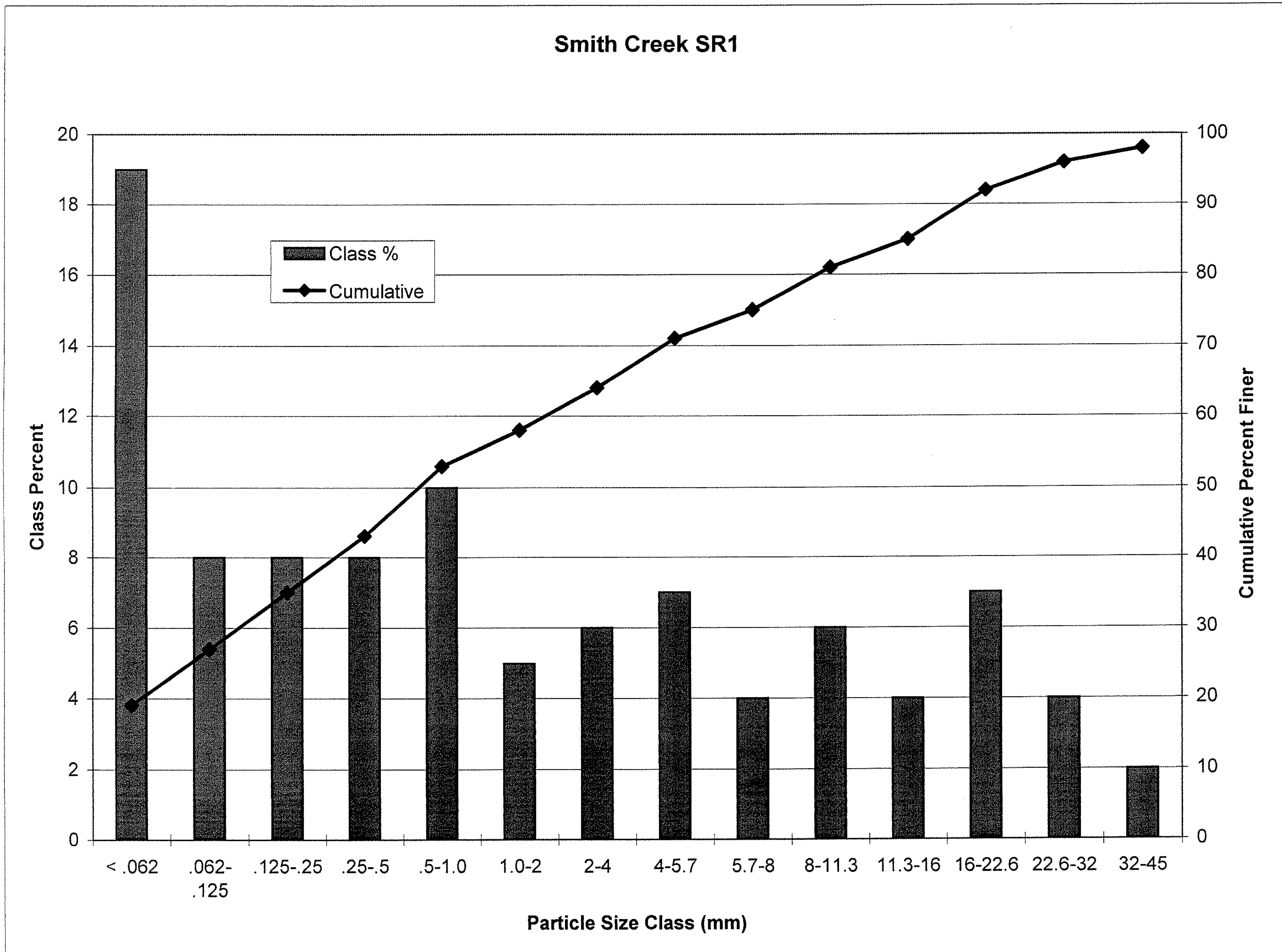
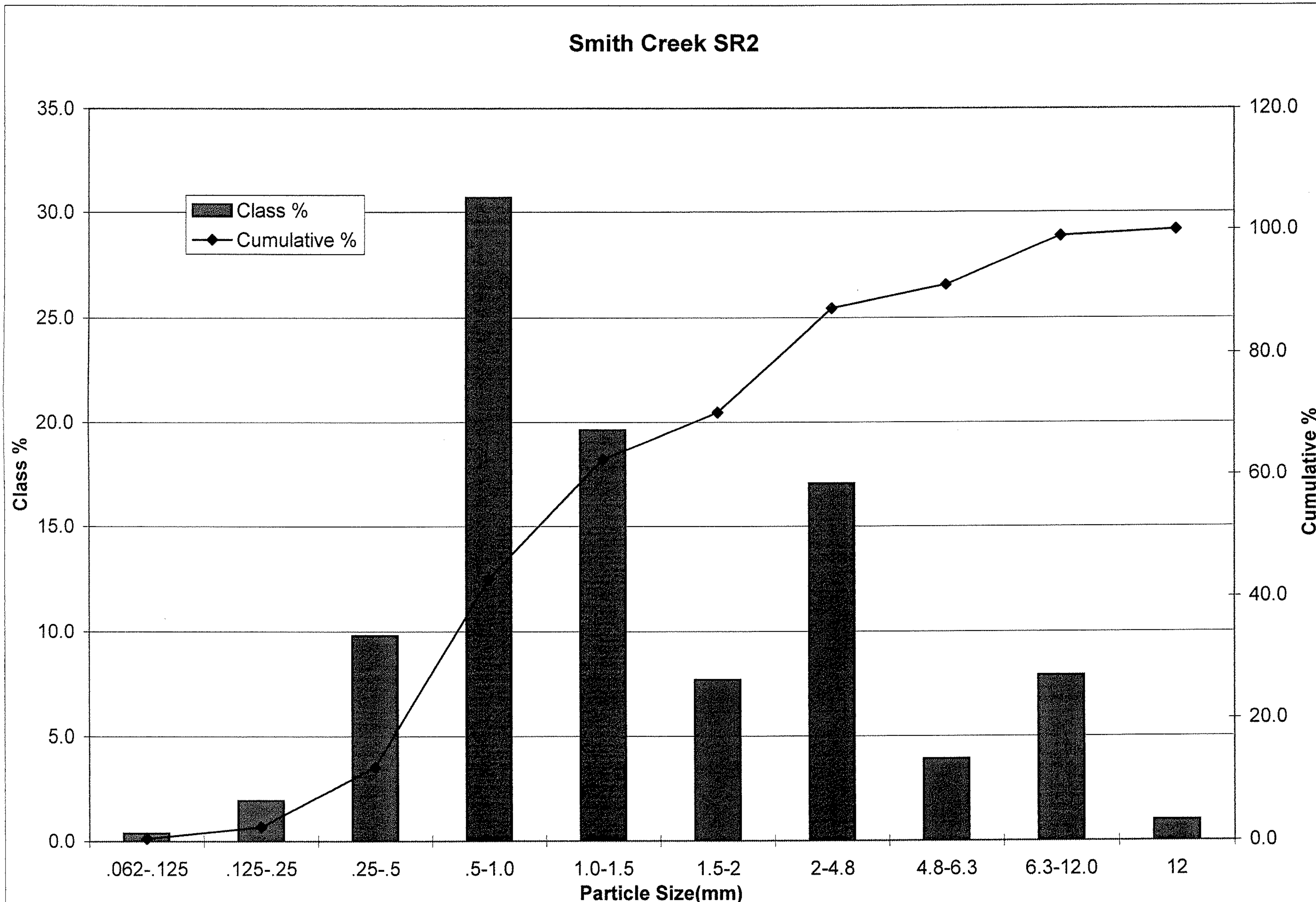
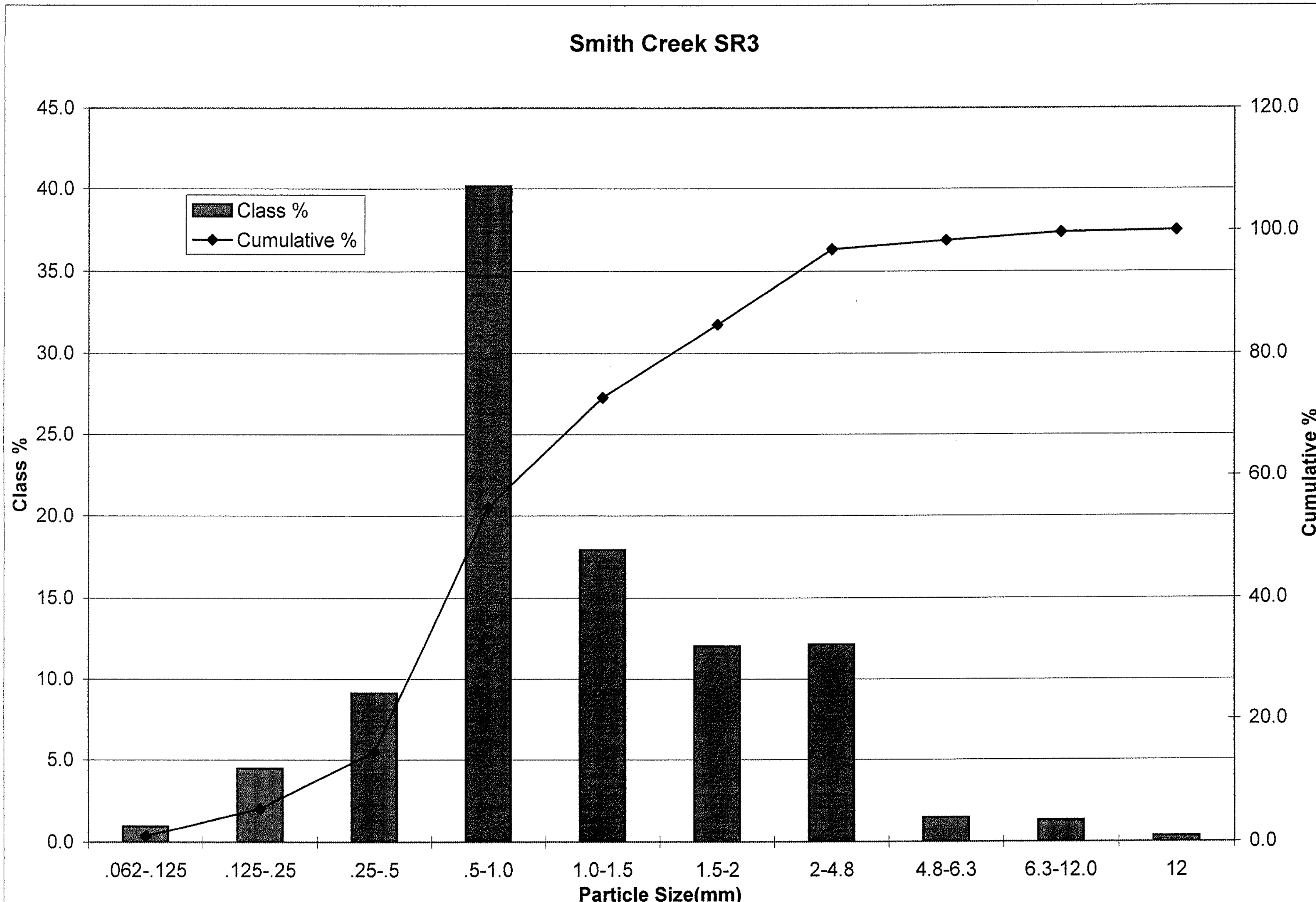
Appendix 1 Existing Condition Data

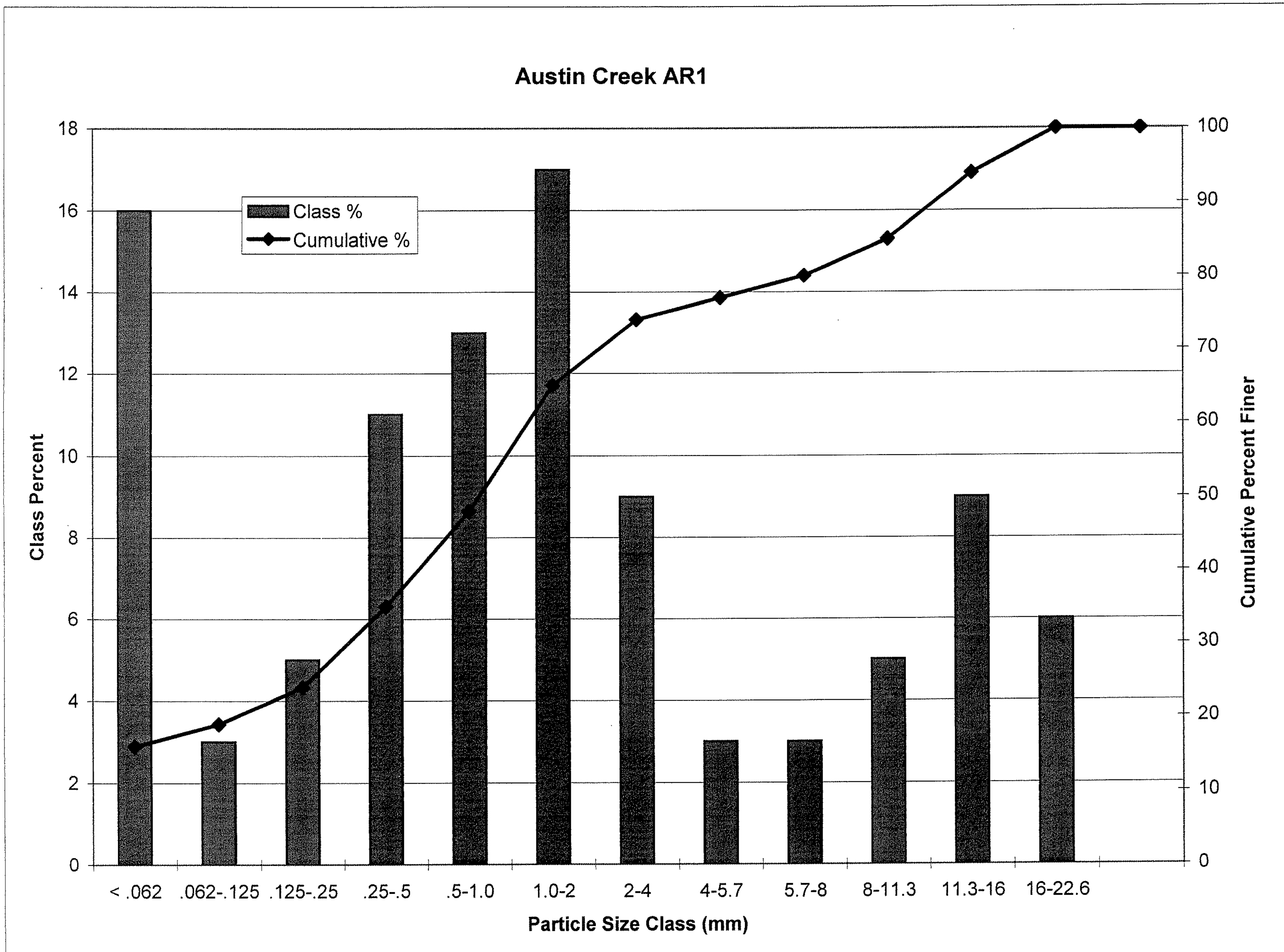

Smith Creek SR1
Class %
Cumulative
Class Percent
Cumulative Percent Finer
Particle Size Class (mm)
0
2
4
6
8
10
12
14
16
18
20
0
10
20
30
40
50
60
70
80
90
100
< .062
.062-.125
.125-.25
.25-.5
.5-1.0
1.0-2
2-4
4-5.7
5.7-8
8-11.3
11.3-16
16-22.6
22.6-32
32-45

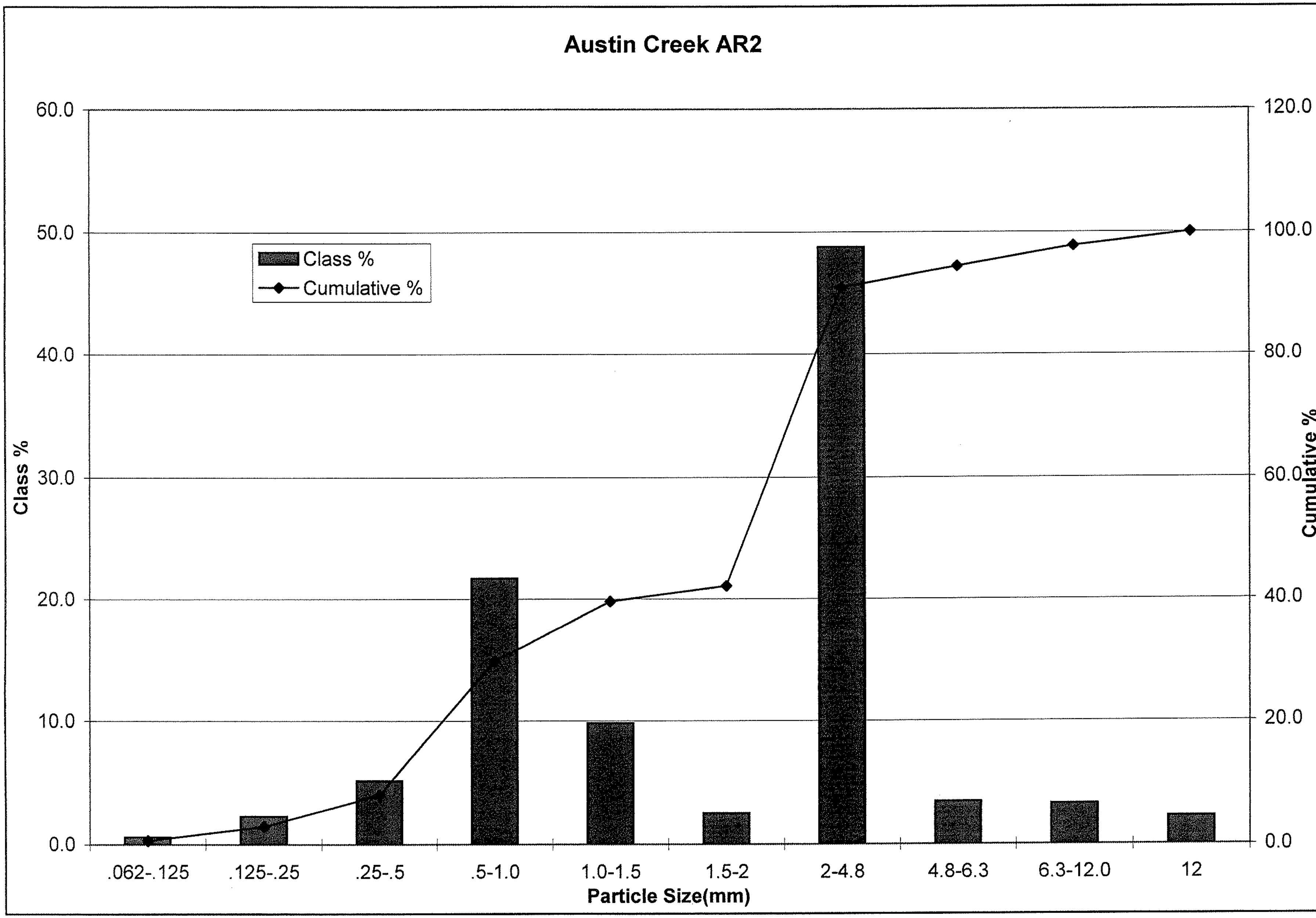


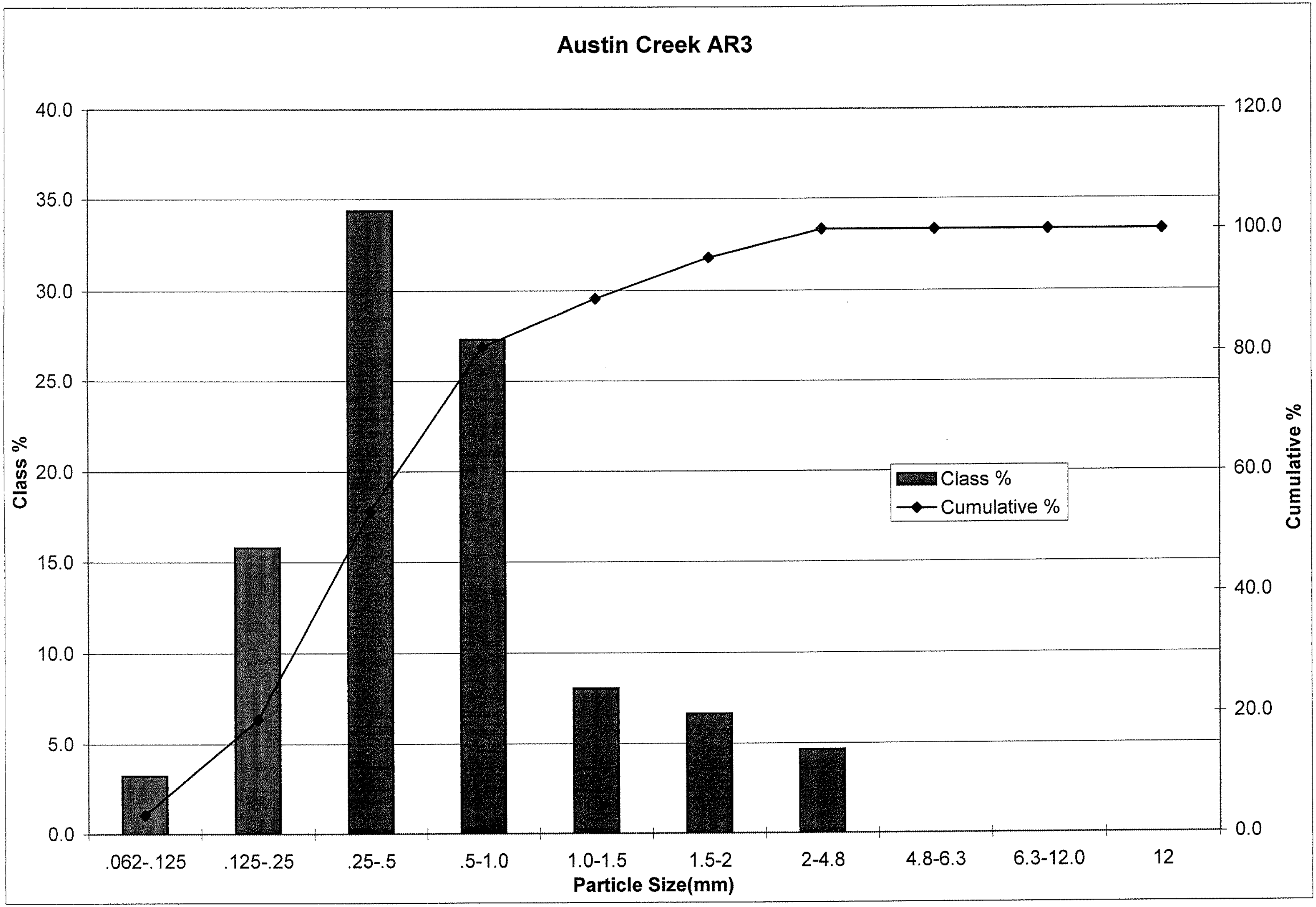
Smith Creek SR2
Class %
Cumulative %
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
.062-.125
.125-.25
.25-.5
.5-1.0
1.0-1.5
1.5-2
2-4.8
4.8-6.3
6.3-12.0
12
Particle Size(mm)



Smith Creek SR3
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Class %
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Cumulative %
Class %
Cumulative %
.062-.125
.125-.25
.25-.5
.5-1.0
1.0-1.5
1.5-2
2-4.8
4.8-6.3
6.3-12.0
12
Particle Size(mm)


Austin Creek AR1
Class %
Cumulative %
Class Percent
0
2
4
6
8
10
12
14
16
18
Cumulative Percent Finer
0
10
20
30
40
50
60
70
80
90
100
< .062
.062-.125
.125-.25
.25-.5
.5-1.0
1.0-2
2-4
4-5.7
5.7-8
8-11.3
11.3-16
16-22.6
Particle Size Class (mm)


Austin Creek AR2
Class %
Cumulative %
60.0
50.0
40.0
30.0
20.0
10.0
0.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
.062-.125
.125-.25
.25-.5
.5-1.0
1.0-1.5
1.5-2
2-4.8
4.8-6.3
6.3-12.0
12
Particle Size(mm)



Austin Creek AR3
Class %
Cumulative %
Particle Size(mm)
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
.062-.125
.125-.25
.25-.5
.5-1.0
1.0-1.5
1.5-2
2-4.8
4.8-6.3
6.3-12.0
12

Appendix 2 Design Parameters

Design Dimension, Pattern and Profile for Smith Creek

** Indicates No Data Available*

Parameter	Design	Design	Design	Reference
Reach Name	SR1	SR2	SR3	Sals Branch
Stream Type	C5	C5		E4
Drainage Area (sq mi)	3.3	3.6	Streambank Stabilization Only	0.2
Bankfull Xsec Area, Abkf (sq ft)	60.0	60.0		10.4
Bankfull Width, Wbkf (ft)	28.0	28.0		8.7
Bankfull W/D	13.0	13.0		7.3
Bankfull Mean Depth, Dbkf (ft)	2.2	2.2		1.2
Min Meander Length, Lm (ft)	224	224		38
Max Meander Length, Lm (ft)	280	280		45
Min Meander Len Ratio, Lm/Wbkf	8.0	8.0		4.4
Max Meander Len Ratio, Lm/Wbkf	10.0	10.0		5.2
Min Radius of Curvature, Rc (ft)	42	42		13.1
Max Radius of Curvature, Rc (ft)	84	84		29.6
Min Rc Ratio, Rc/Wbkf	1.5	1.5		1.5
Max Rc Ratio, Rc/Wbkf	3.0	3.0		3.4
Min Belt Width, Wblt (ft)	78	78		10
Max Belt Width, Wblt (ft)	140	140		16
Min MW Ratio, Wblt/Wbkf (ft)	2.8	2.8		1.1
Max MW Ratio, Wblt/Wbkf (ft)	5.0	5.0		1.8
Sinuosity, K	1.3	1.3		1.3
Valley Slope, Sval (ft/ft)	0.0050	0.0050		---
Channel Slope, Schan=Sval/K (ft/ft)	0.0038	0.0038		0.011
Pool Slope, Spool (ft/ft)	0.0004	0.0004		0.004

** Indicates No Data Available*

Parameter	Design	Design	Design	Reference
Pool Slope Ratio, Spool/Schan	0.10	0.10		0.36
Min Pool Depth, Dpool (ft)	4.4	4.4		1.5
Max Pool Depth, Dpool (ft)	6.6	6.6		3.1
Min Pool Depth Ratio, Dpool/Dbkf	2.0	2.0		1.3
Max Pool Depth Ratio, Dpool/Dbkf	3.0	3.0		2.6
Min Pool Width, Wpool (ft)	30.8	30.8		10
Max Pool Width, Wpool (ft)	42.0	42.0		24
Min Pool Wid Ratio, Wpool/Wbkf	1.1	1.1		1.1
Max Pool Wid Ratio, Wpool/Wbkf	1.5	1.5		2.8
Min Length Pool Spacing, Lps (ft)	112	112		34.8
Max Length Pool Spacing, Lps (ft)	196	196		51.1
Min Pool Spacing Ratio, Lps/Wbkf	4.0	4.0		4.0
Max Pool Spacing Ratio, Lps/Wbkf	7.0	7.0		7.0

Design Dimension, Pattern and Profile for Austin Creek

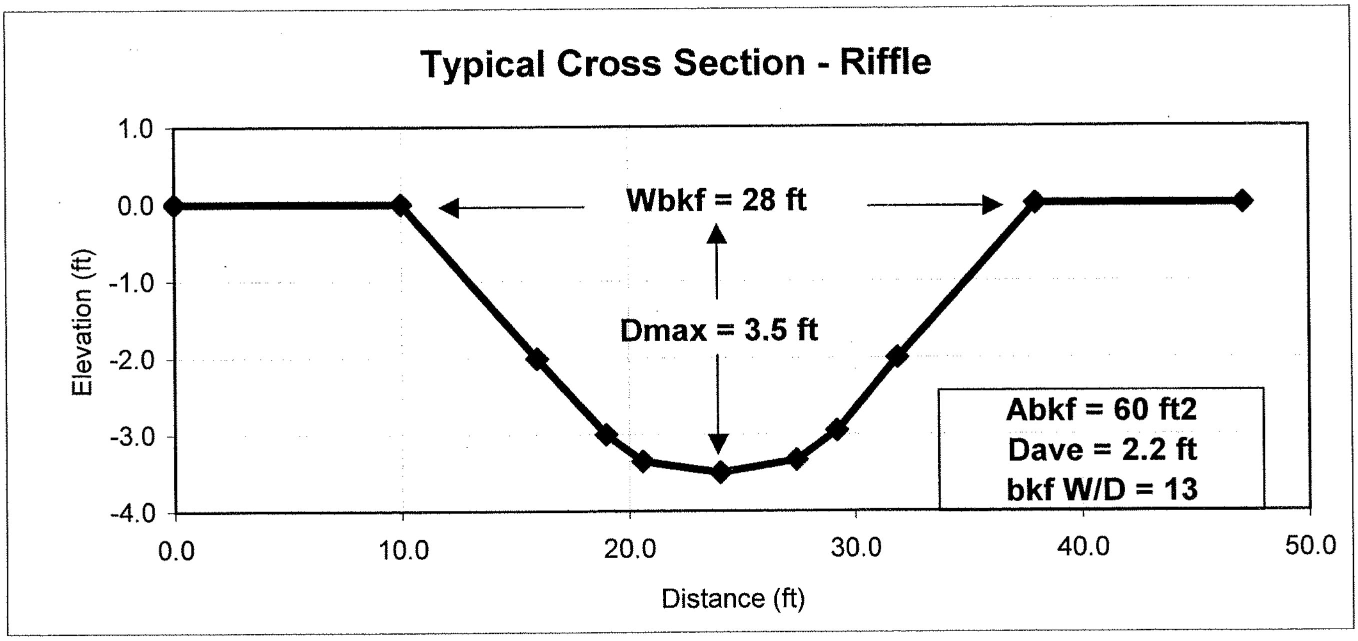
** Indicates No Data Available*

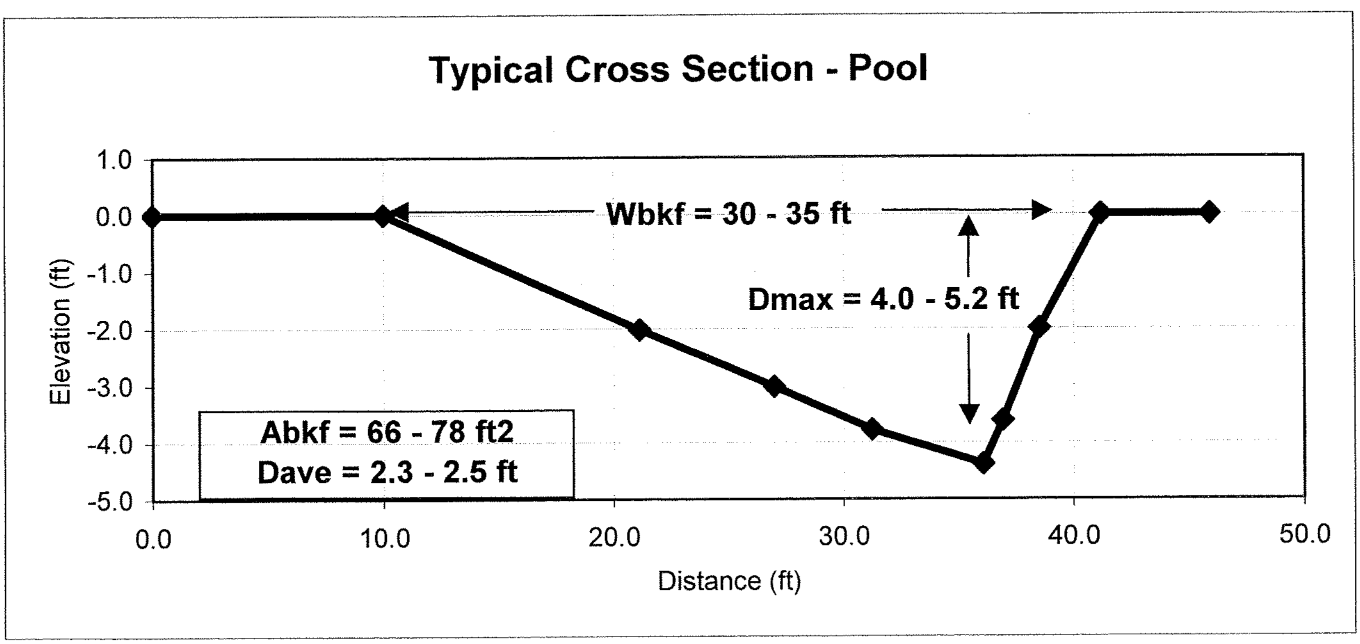
Parameter	Design	Design	Design	Reference
Reach Name	**AR1**	**AR2**	**AR3**	**Sals Branch**
Stream Type	B5c	B5c	C5	E4
Drainage Area (sq mi)	8.4	8.5	8.8	0.2
Bankfull Xsec Area, Abkf (sq ft)	110.0	110.0	110.0	10.4
Bankfull Width, Wbkf (ft)	38.0	38.0	38.0	8.7
Bankfull W/D	13.0	13.0	13.0	7.3
Bankfull Mean Depth, Dbkf (ft)	3.0	3.0	3.0	1.2
Min Meander Length, Lm (ft)	N/A	N/A	304	38
Max Meander Length, Lm (ft)	N/A	N/A	380	45
Min Meander Len Ratio, Lm/Wbkf	N/A	N/A	8.0	4.4
Max Meander Len Ratio, Lm/Wbkf	N/A	N/A	10.0	5.2
Min Radius of Curvature, Rc (ft)	N/A	N/A	57	13
Max Radius of Curvature, Rc (ft)	N/A	N/A	114	30
Min Rc Ratio, Rc/Wbkf	N/A	N/A	1.5	1.5
Max Rc Ratio, Rc/Wbkf	N/A	N/A	3.0	3.4
Min Belt Width, Wblt (ft)	N/A	N/A	106	10
Max Belt Width, Wblt (ft)	N/A	N/A	190	16
Min MW Ratio, Wblt/Wbkf (ft)	N/A	N/A	2.8	1.1
Max MW Ratio, Wblt/Wbkf (ft)	N/A	N/A	5.0	1.8
Sinuosity, K	1.1	1.1	1.2	1.3
Valley Slope, Sval (ft/ft)	0.0039	0.0039	0.0039	---
Channel Slope, Schan=Sval/K (ft/ft)	0.0035	0.0035	0.0033	0.0110
Pool Slope, Spool (ft/ft)	0.0004	0.0004	0.0003	0.0040

** Indicates No Data Available*

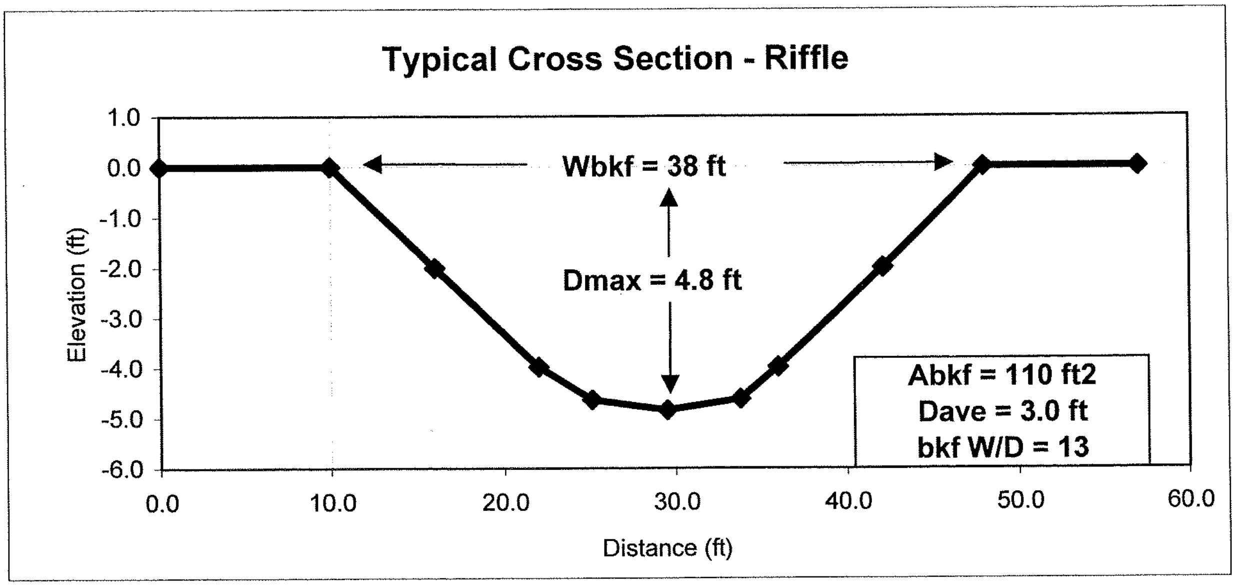
Parameter	Design	Design	Design	Reference
Pool Slope Ratio, Spool/Schan	0.10	0.10	0.10	0.36
Min Pool Depth, Dpool (ft)	5.1	5.1	5.1	1.5
Max Pool Depth, Dpool (ft)	7.5	7.5	7.5	3.1
Min Pool Depth Ratio, Dpool/Dbkf	1.7	1.7	1.7	1.3
Max Pool Depth Ratio, Dpool/Dbkf	2.5	2.5	2.5	2.6
Min Pool Width, Wpool (ft)	41.8	41.8	41.8	10.0
Max Pool Width, Wpool (ft)	57.0	57.0	57.0	24.0
Min Pool Wid Ratio, Wpool/Wbkf	1.1	1.1	1.1	1.1
Max Pool Wid Ratio, Wpool/Wbkf	1.5	1.5	1.5	2.8
Min Length Pool Spacing, Lps (ft)	N/A	N/A	152	35
Max Length Pool Spacing, Lps (ft)	N/A	N/A	266	51
Min Pool Spacing Ratio, Lps/Wbkf	N/A	N/A	4.0	4.0

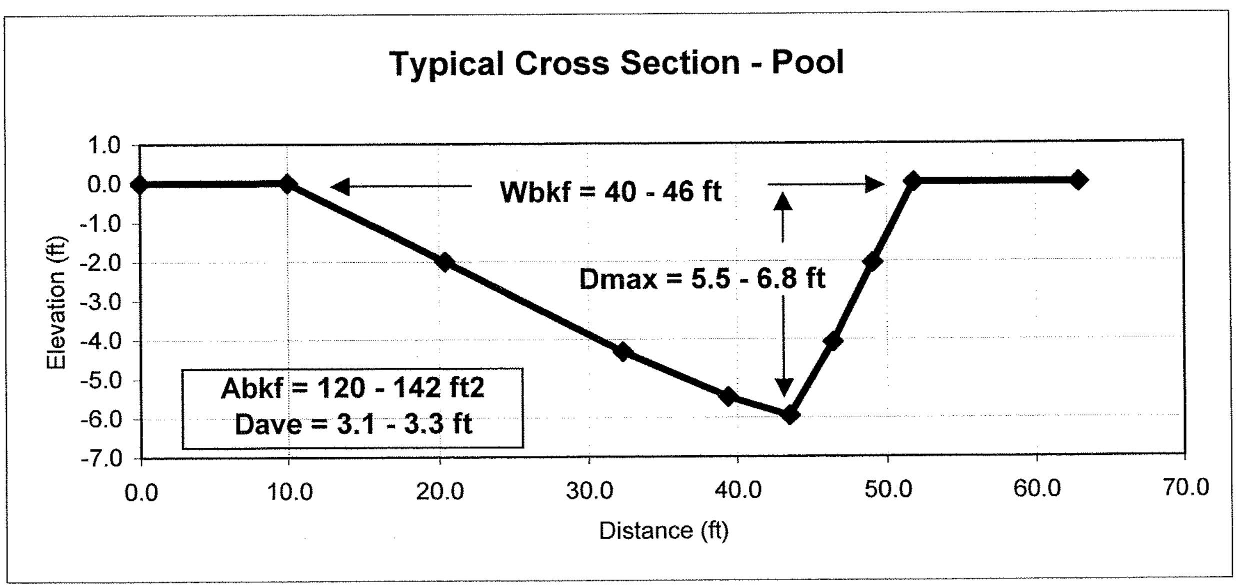
TYPICAL RIFFLE AND POOL CROSS SECTIONS FOR STREAM REACHES SR1 AND SR2



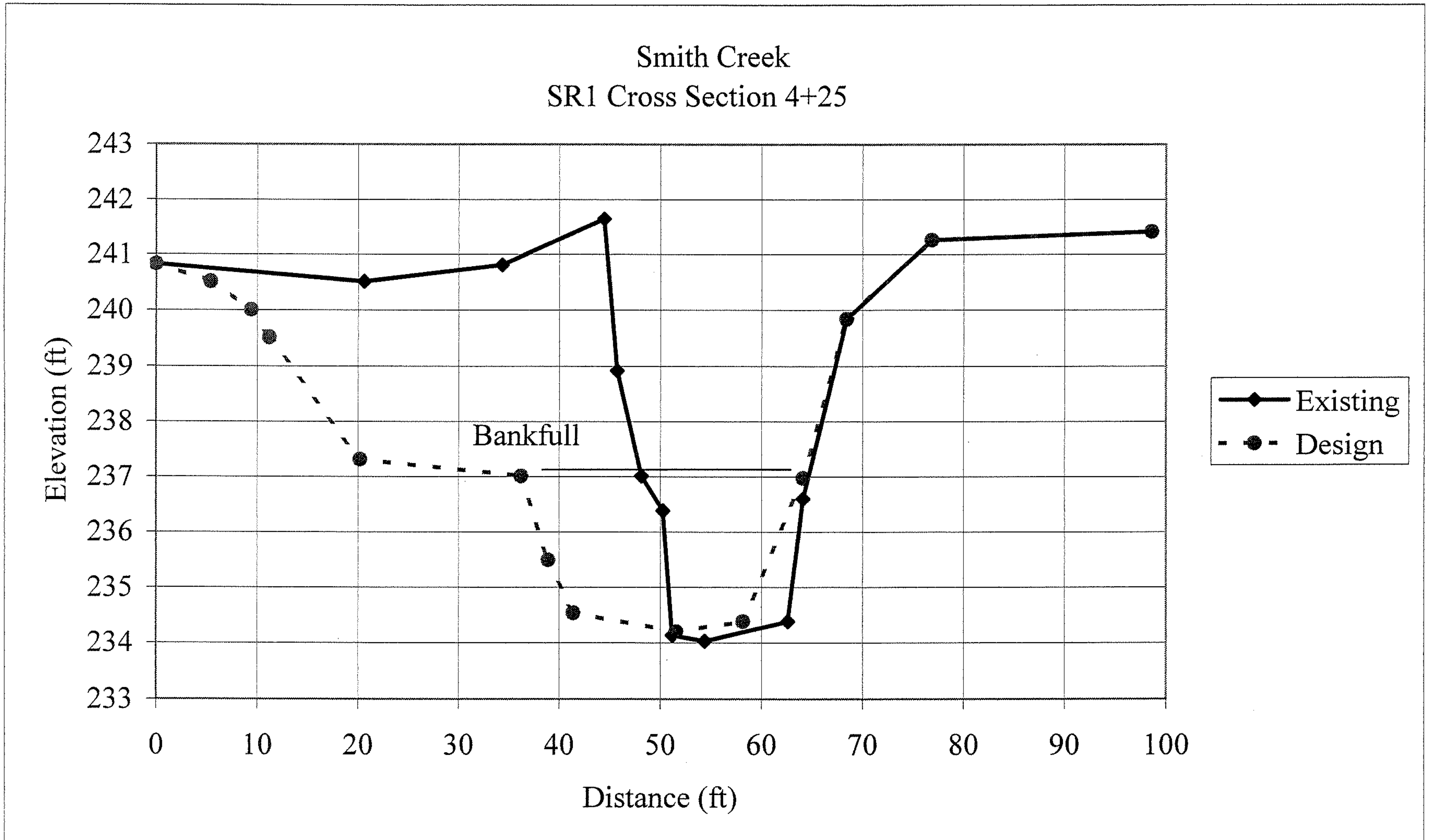


TYPICAL RIFFLE AND POOL CROSS SECTIONS FOR STREAM REACHES AR1, AR2, AND AR3

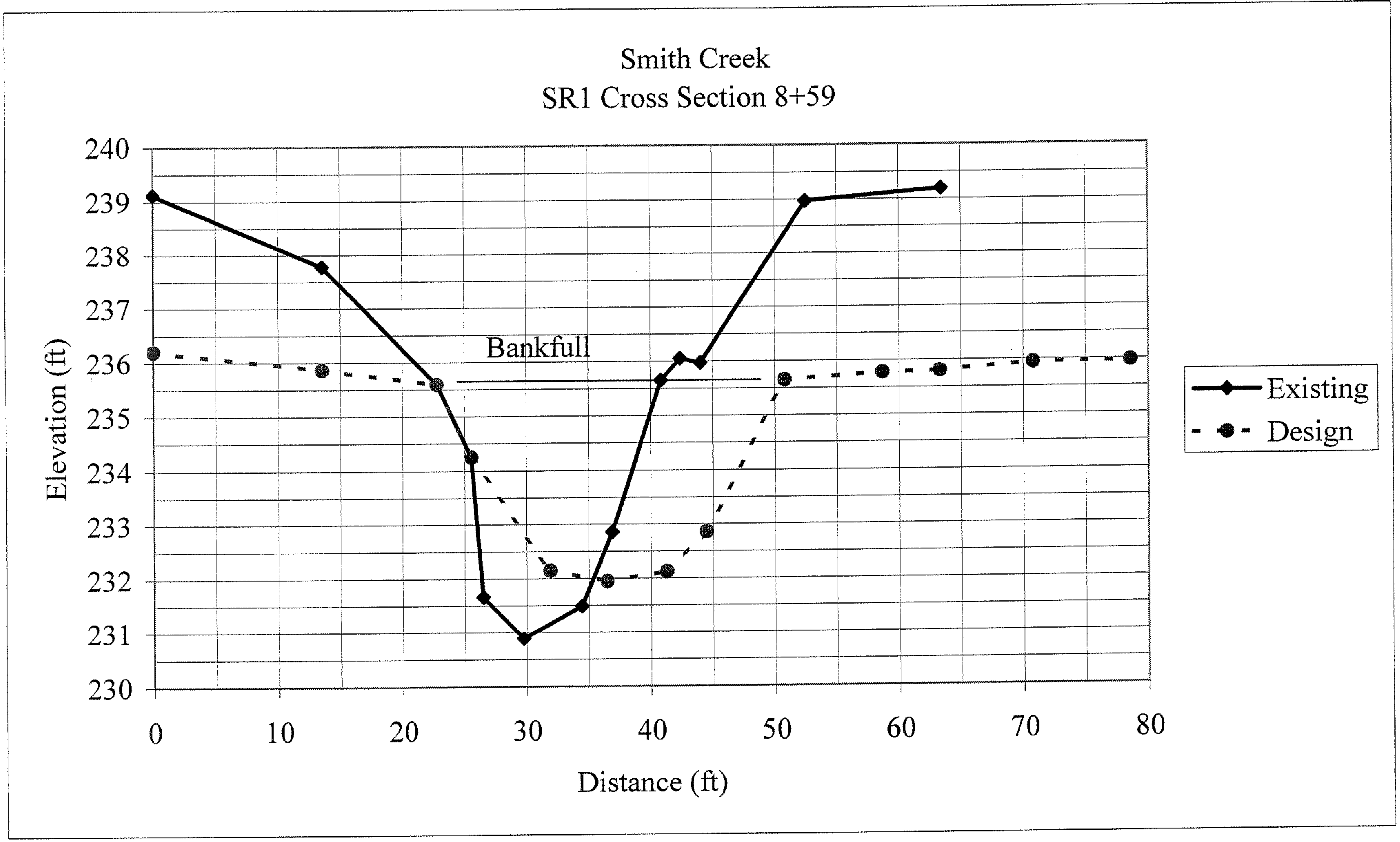




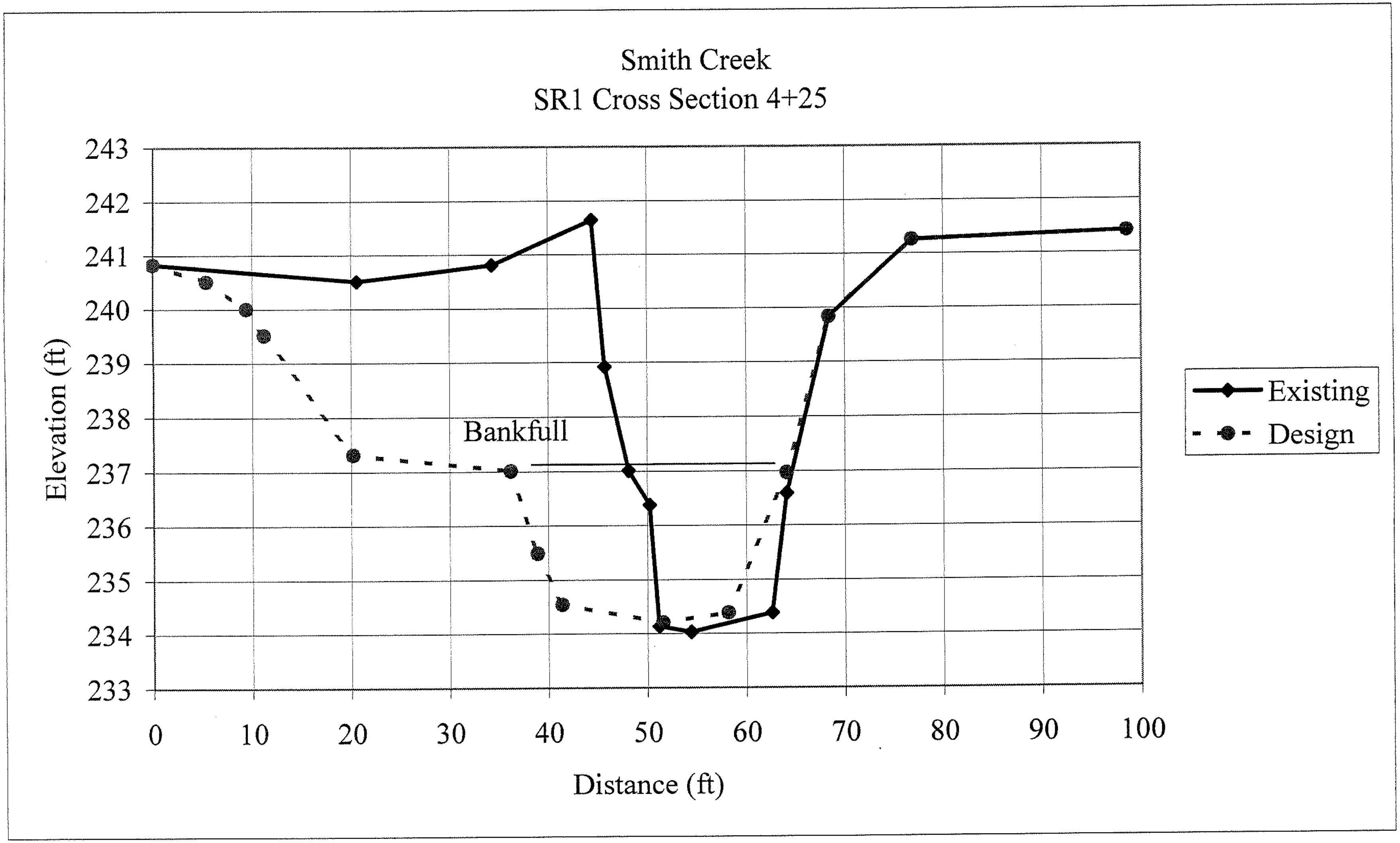
4+25	Feature	Type	Wfpa	LBKF	RBKF	ELbkf	Wbkf	Dbkf	W/D	Abkf	Dmax	ER	BHR
Existing	Riffle	G5c	37.2	48.1	64.1	237.01	16.0	2.3	6.9	37.1	3.0	2.3	1.9
Design	Riffle	C5	70	36.2	64.1	237.01	27.9	2.1	13.0	59.8	2.8	2.5	1.0



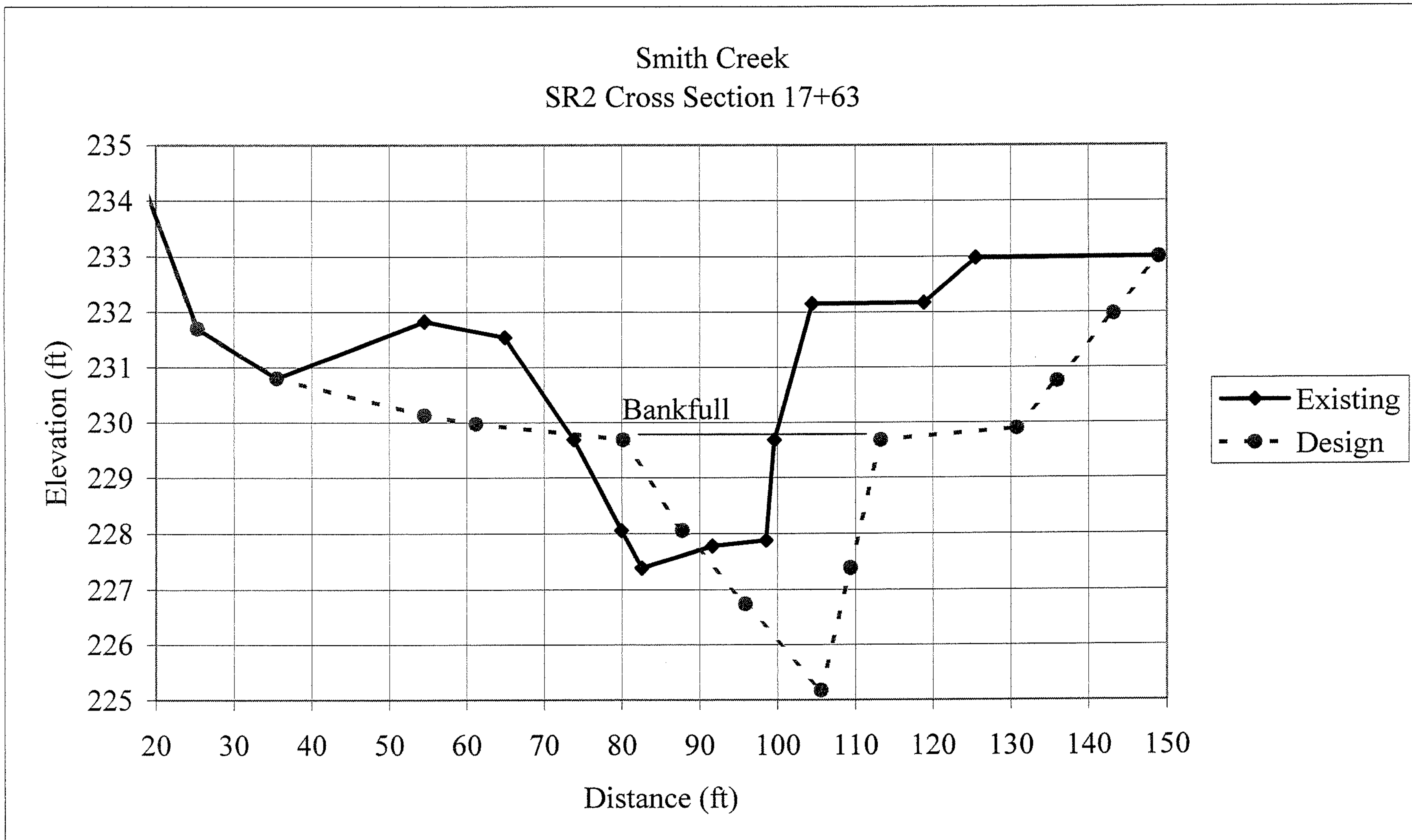
8+59	Feature	Type	Wfpa	LBKF	RBKF	ELbkf	Wbkf	Dbkf	W/D	Abkf	Dmax	ER	BHR
Existing	Riffle	E5	200	22.8	40.9	235.59	18.1	2.6	6.9	47.5	4.7	11.1	1.5
Design	Riffle	E5	200	22.8	50.8	235.59	28.0	2.2	13.0	60.4	3.7	7.1	1.0



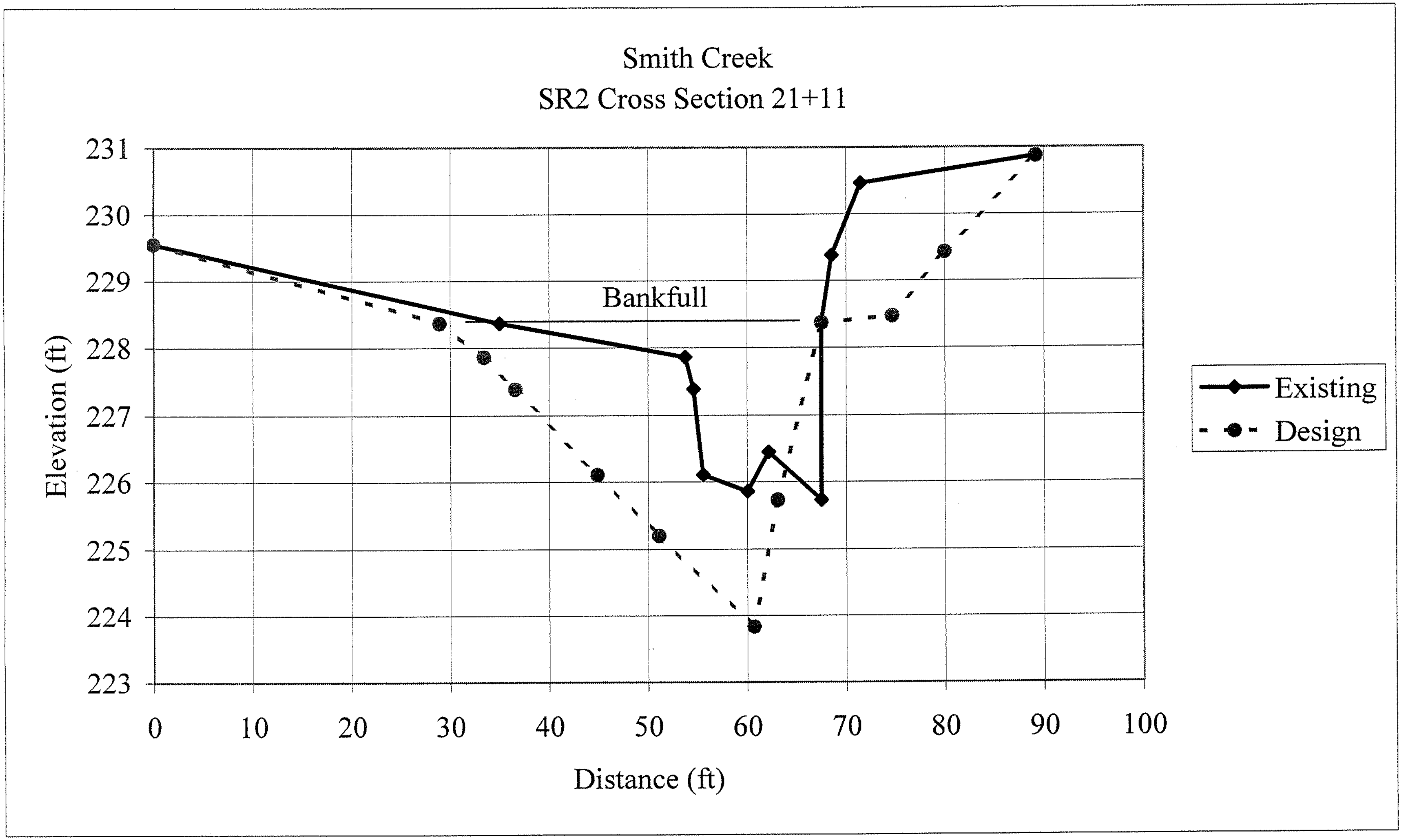
4+25	Feature	Type	Wfpa	LBKF	RBKF	ELbkf	Wbkf	Dbkf	W/D	Abkf	Dmax	ER	BHR
Existing	Riffle	G5c	37.2	48.1	64.1	237.01	16.0	2.3	6.9	37.1	3.0	2.3	1.9
Design	Riffle	C5	70	36.2	64.1	237.01	27.9	2.1	13.0	59.8	2.8	2.5	1.0



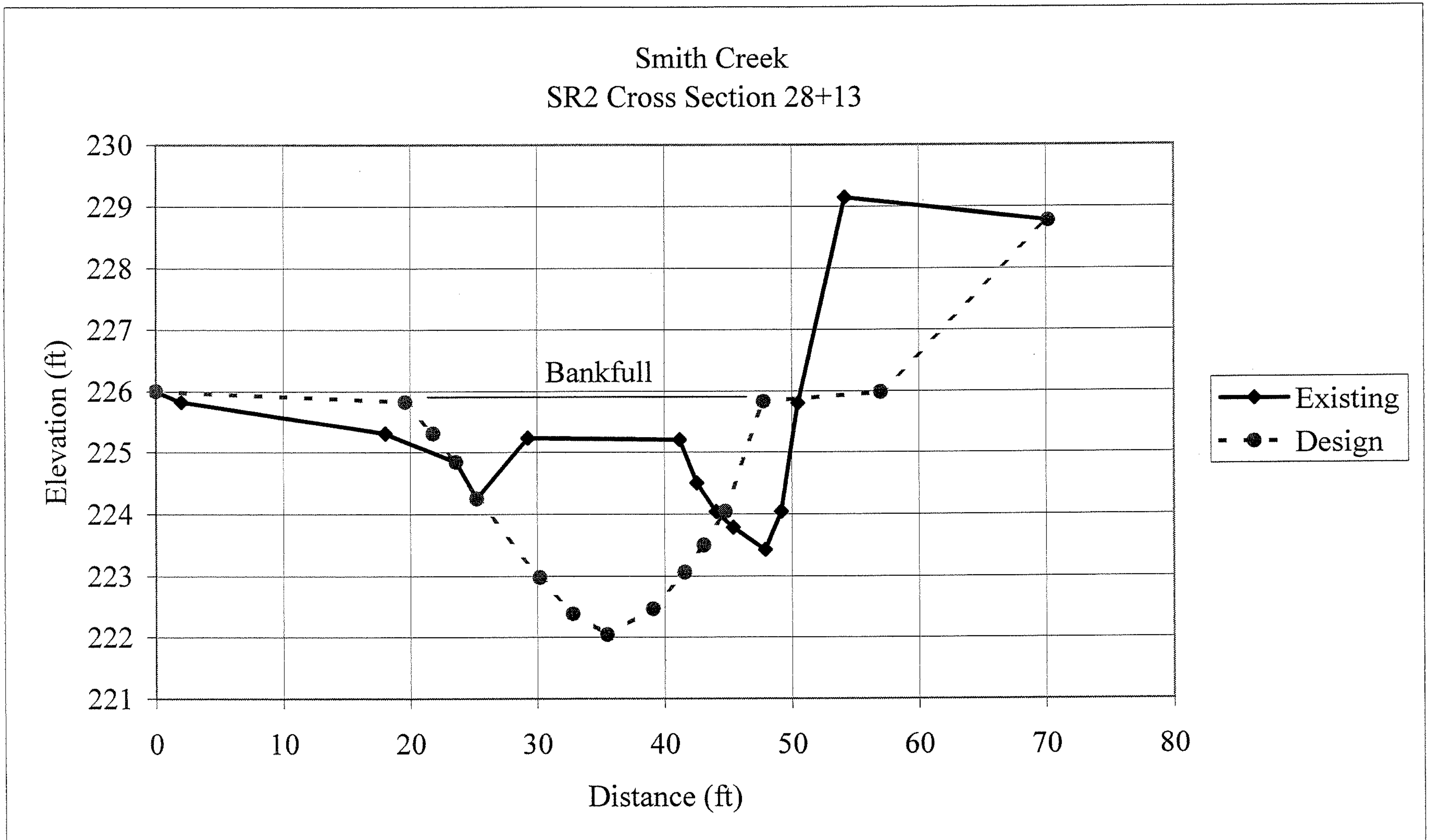
17+63	Feature	Type	Wfpa	LBKF	RBKF	ELbkf	Wbkf	Dbkf	W/D	Abkf	Dmax	ER	BHR
Existing	Riffle	C5	300	73.9	99.6	229.68	25.8	1.7	15.4	43.0	2.3	11.6	1.8
Design	Pool	C5	300	80.2	113.3	229.68	33.1	2.4	14.0	78.3	4.5	9.1	1.0



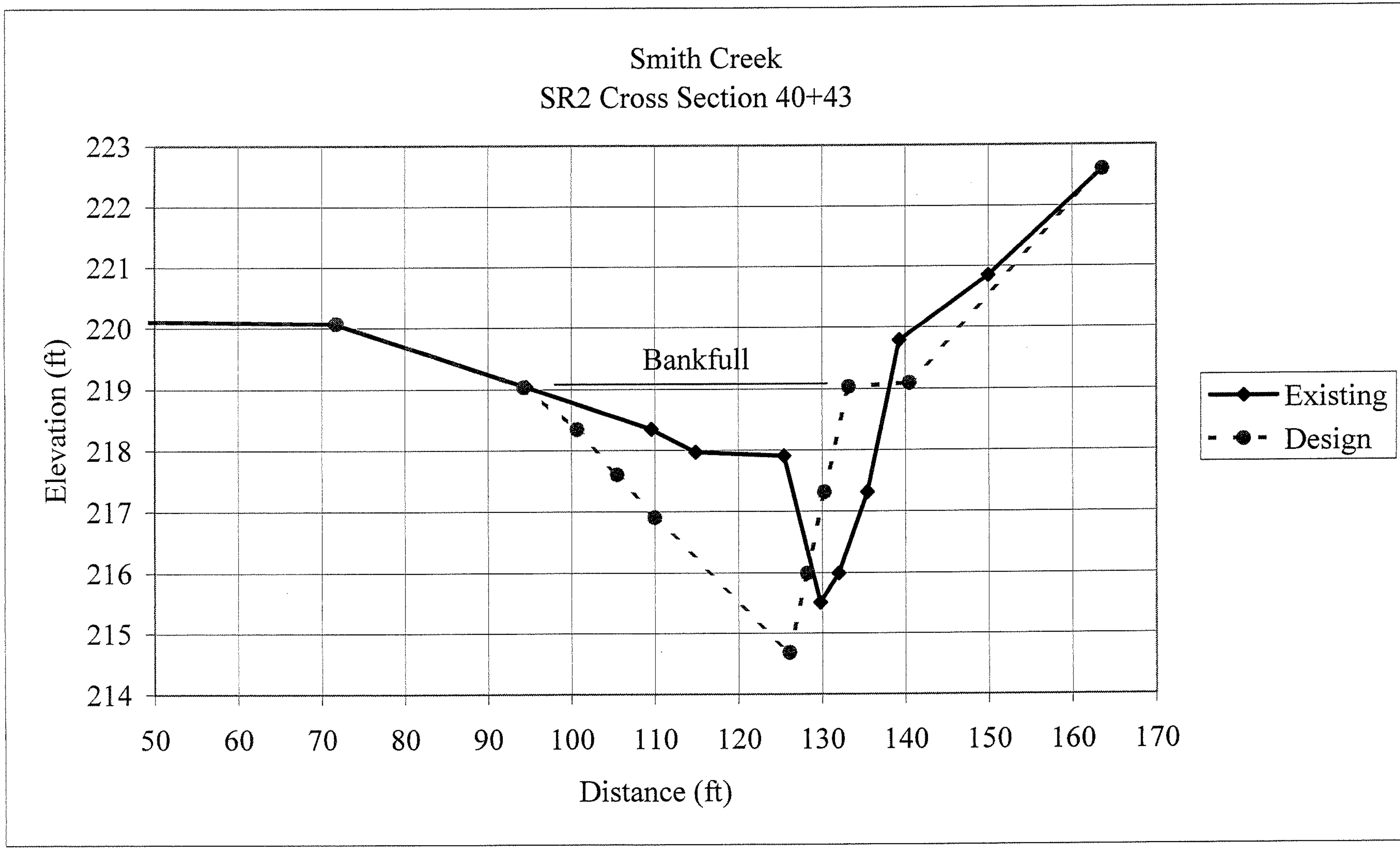
21+11	Feature	Type	Wfpa	LBKF	RBKF	ELbkf	Wbkf	Dbkf	W/D	Abkf	Dmax	ER	BHR
Existing	Riffle	C5	300	35.0	67.5	228.36	32.5	1.3	24.5	43.2	2.6	9.2	1.0
Design	Pool	C5	300	28.9	67.5	228.36	38.6	2.1	18.5	80.5	4.5	7.8	1.0



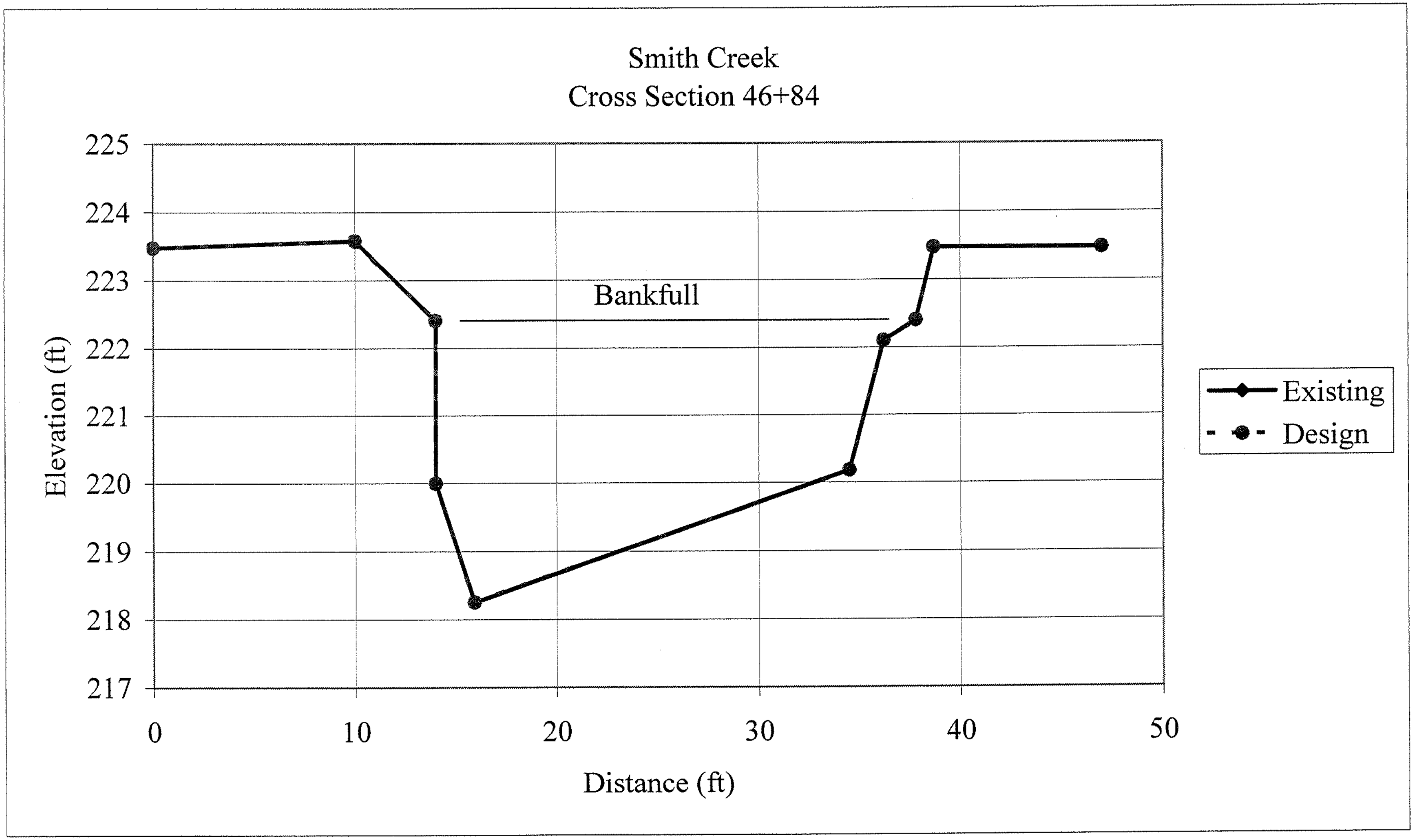
28+13	Feature	Type	Wfpa	LBKF	RBKF	ELbkf	Wbkf	Dbkf	W/D	Abkf	Dmax	ER	BHR
Existing	Riffle	C5	300	2.0	50.5	225.82	48.5	0.8	59.4	39.6	2.4	6.2	1.0
Design	Riffle	C5	300	19.6	47.8	225.82	28.2	2.2	13.1	60.7	3.8	10.6	1.0



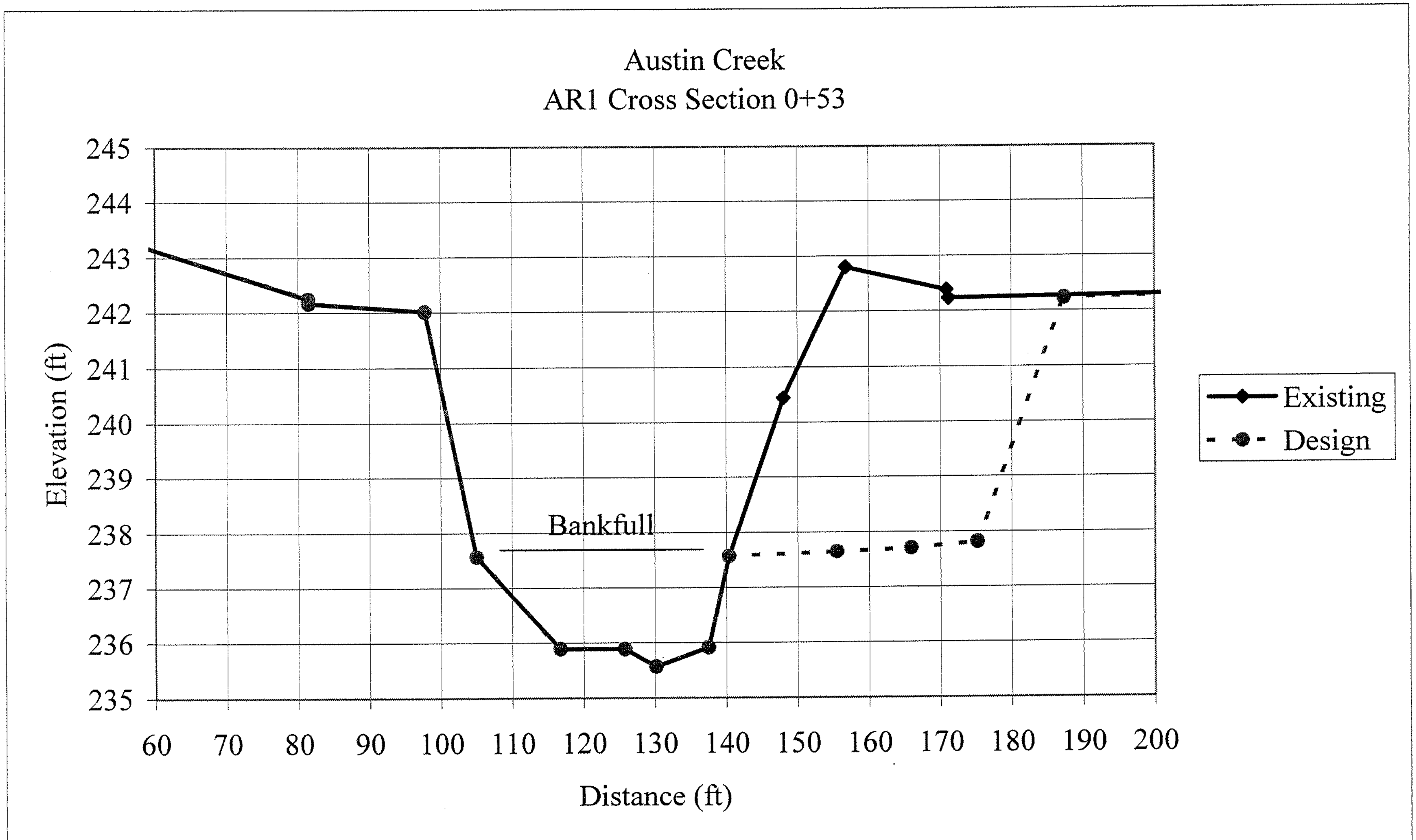
40+43	Feature	Type	Wfpa	LBKF	RBKF	ELbkf	Wbkf	Dbkf	W/D	Abkf	Dmax	ER	BHR
Existing	Pool	C5	164	94.6	139.3	219.04	44.7	1.1	42.3	47.2	3.5	3.7	1.0
Design	Pool	C5	164	94.3	133.2	219.03	38.9	2.1	18.3	82.7	4.3	4.2	1.0



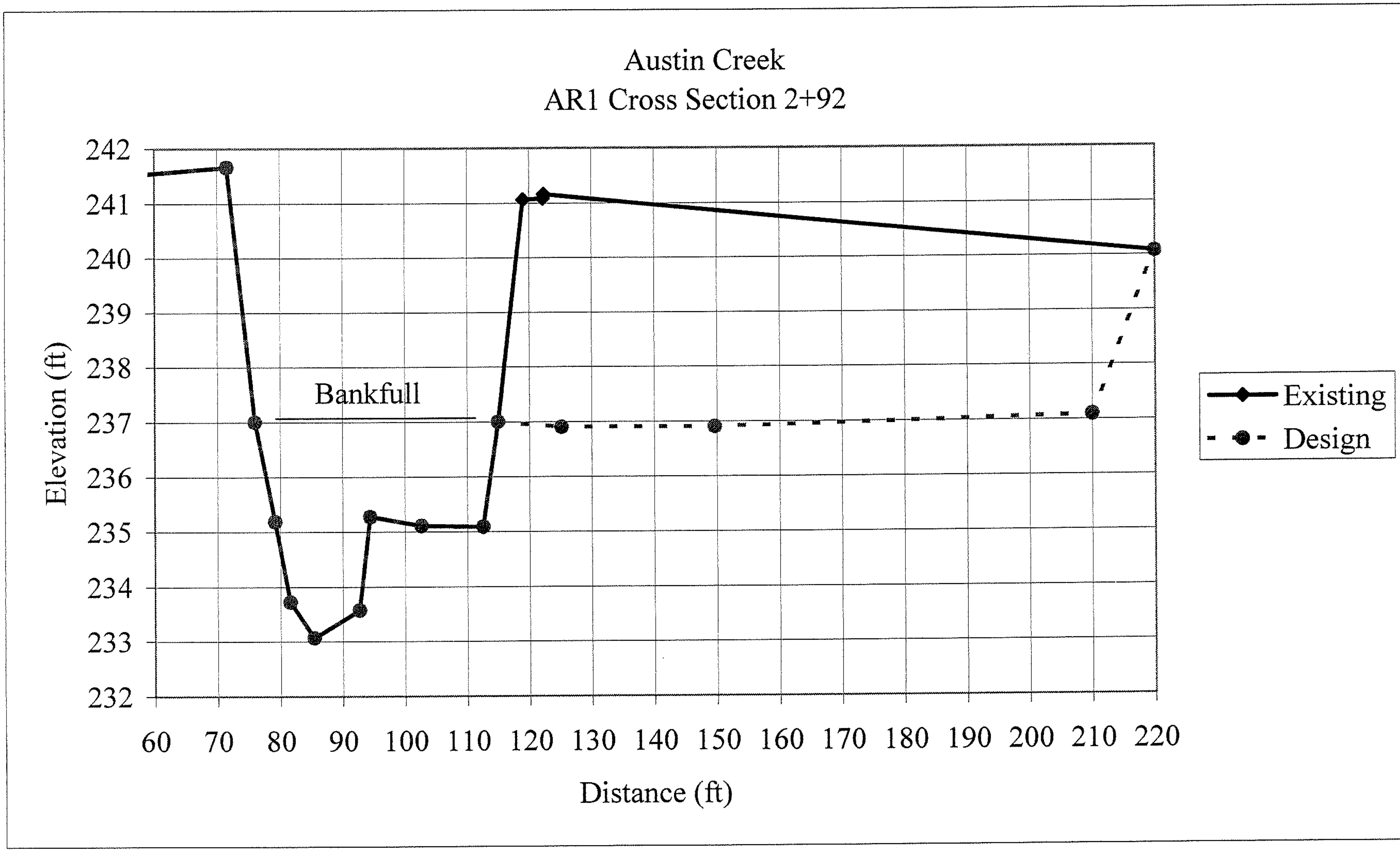
46+84	Feature	Type	Wfpa	LBKF	RBKF	ELbkf	Wbkf	Dbkf	W/D	Abkf	Dmax	ER	BHR
Existing	Riffle	E5	90	14.0	37.8	222.40	23.8	5.0	4.8	117.9	4.2	3.8	1.0
Design	Riffle	E5	90	14.0	37.8	222.40	23.8	5.0	4.8	117.9	4.2	3.8	1.0



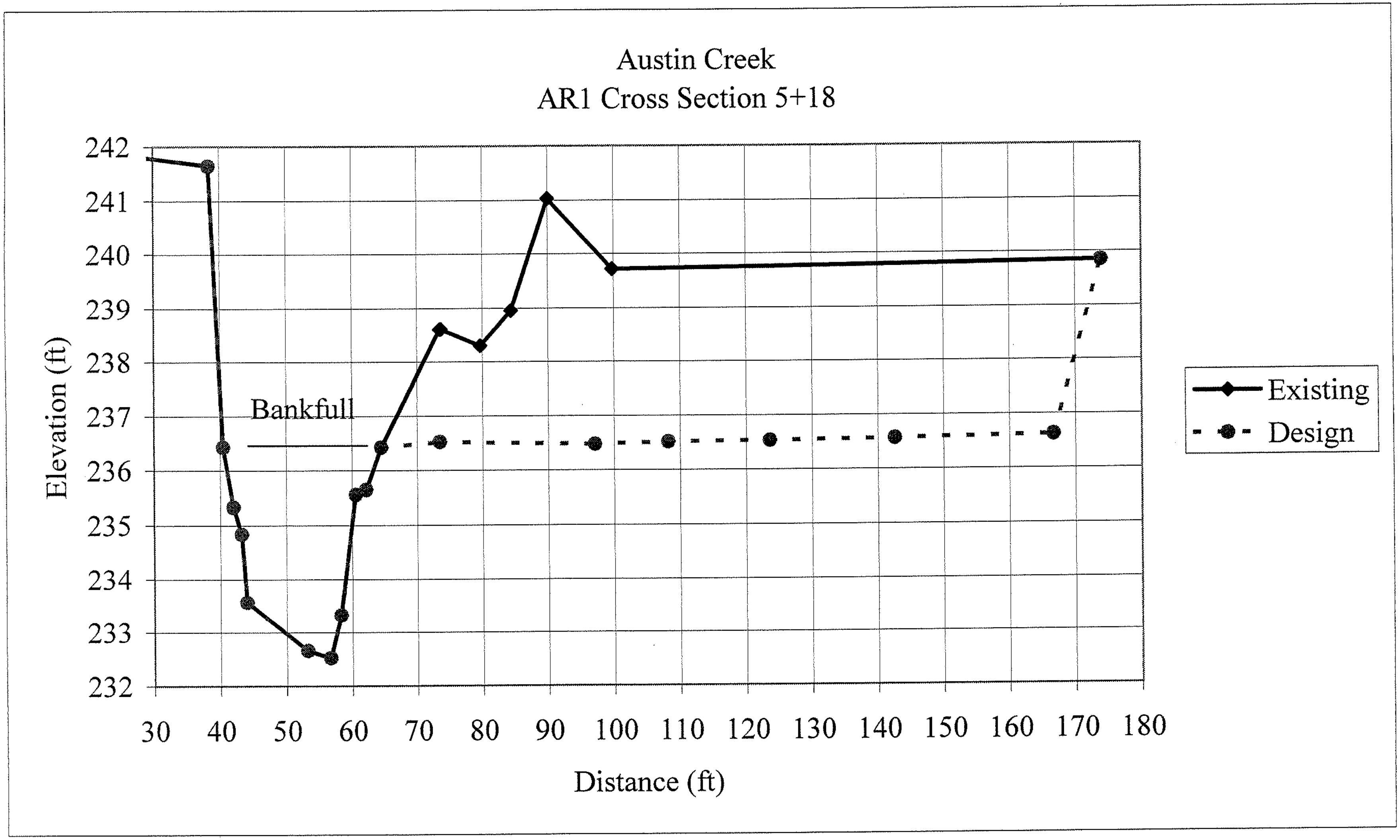
0+53	Feature	Type	Wfpa	LBKF	RBKF	ELbkf	Wbkf	Dbkf	W/D	Abkf	Dmax	ER	BHR
Existing	Riffle	F5	45	105.0	140.4	237.56	35.4	1.7	21.4	58.6	2.0	1.3	3.2
Design	Riffle	C5	74	105.0	140.4	237.56	35.4	1.7	21.4	58.6	2.0	2.1	1.0



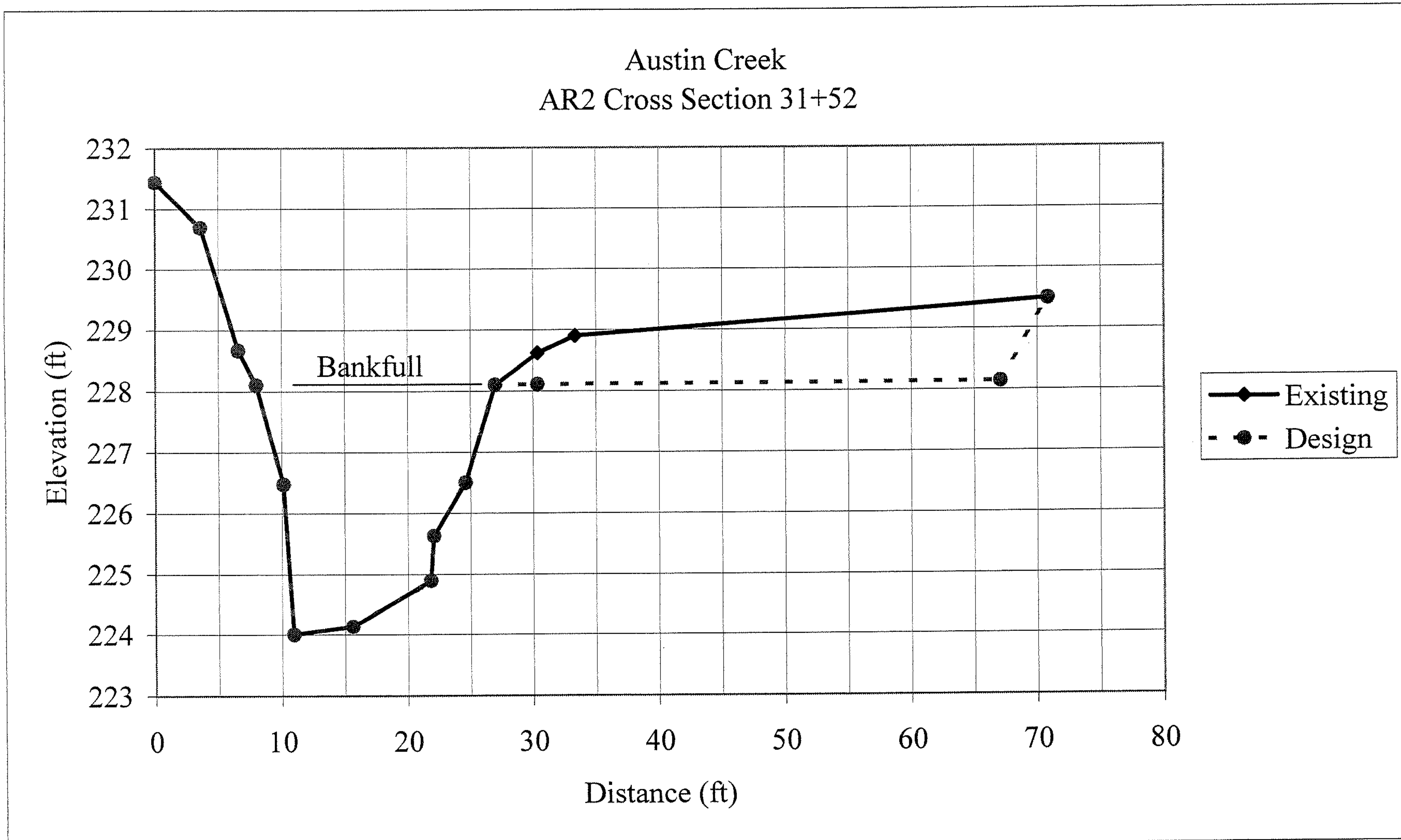
2+92	Feature	Type	Wfpa	LBKF	RBKF	ELbkf	Wbkf	Dbkf	W/D	Abkf	Dmax	ER	BHR
Existing	Pool	F5	43	76.0	115.0	237.00	39.0	2.3	16.9	90.1	3.9	1.1	2.0
Design	Pool	C5	129	76.0	115.0	237.00	39.0	2.4	16.3	93.1	3.9	3.3	1.0



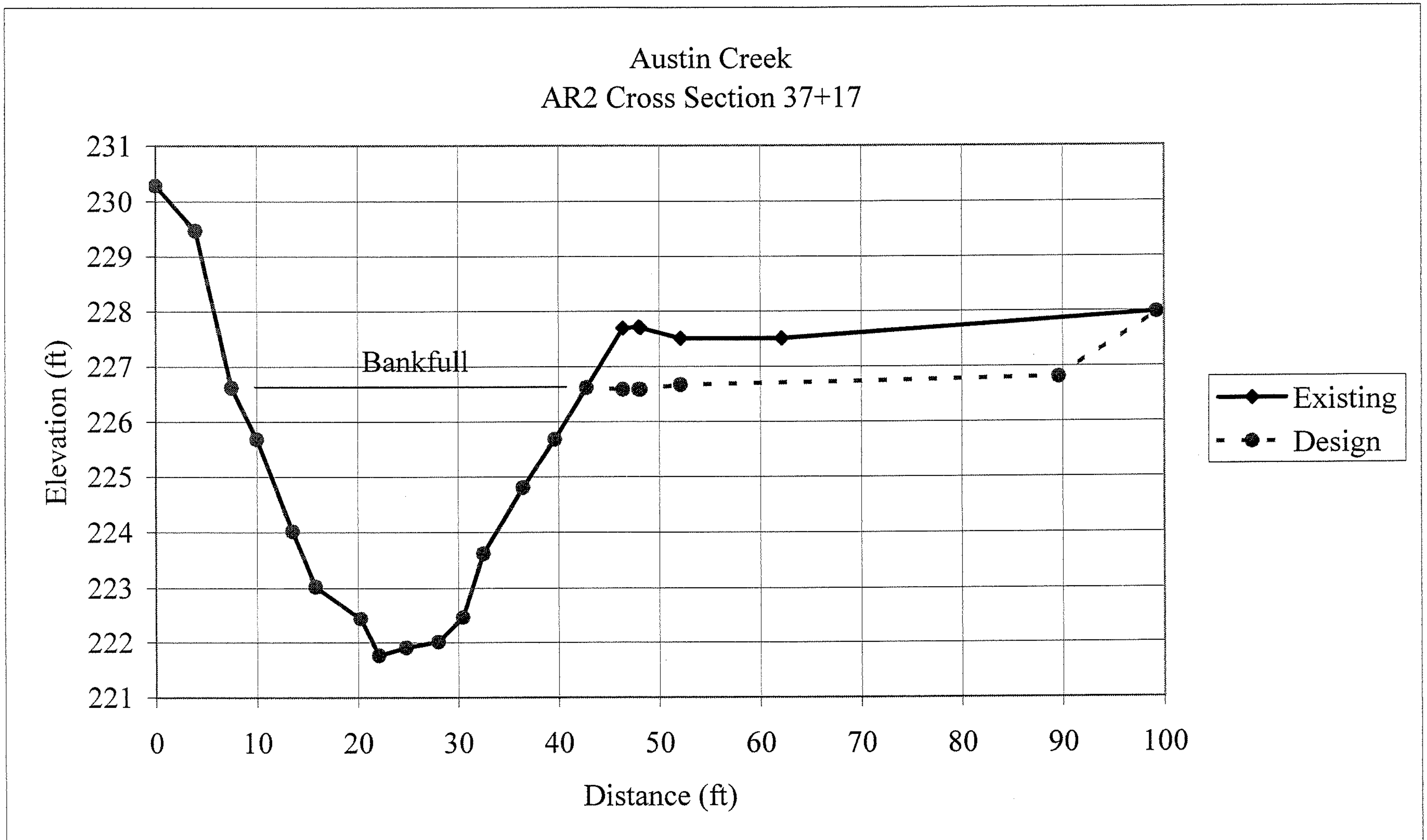
5+18	Feature	Type	Wfpa	LBKF	RBKF	ELbkf	Wbkf	Dbkf	W/D	Abkf	Dmax	ER	BHR
Existing	Riffle	G5c	49	40.5	64.5	236.42	24.0	2.5	9.6	60.4	3.9	2.0	1.5
Design	Riffle	C5	127	40.5	64.5	236.42	24.0	2.6	9.3	61.9	3.9	5.3	1.0



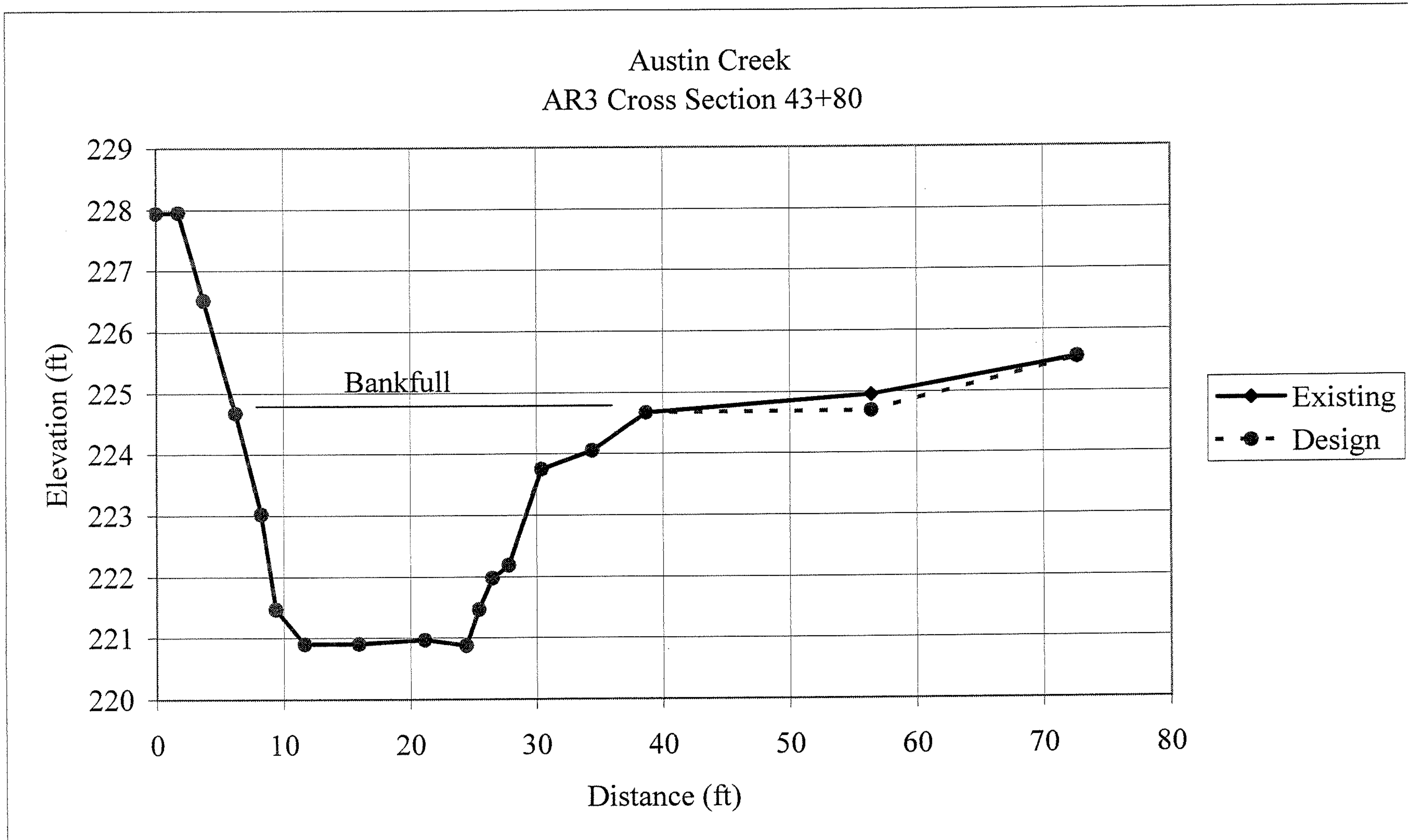
31+52	Feature	Type	Wfpa	LBKF	RBKF	ELbkf	Wbkf	Dbkf	W/D	Abkf	Dmax	ER	BHR
Existing	Riffle	E5	200	8.0	27.0	228.10	19.0	2.8	6.8	53.0	4.1	10.5	1.1
Design	Riffle	E5	200	8.0	27.0	228.10	19.0	2.8	6.8	53.0	4.1	10.5	1.0



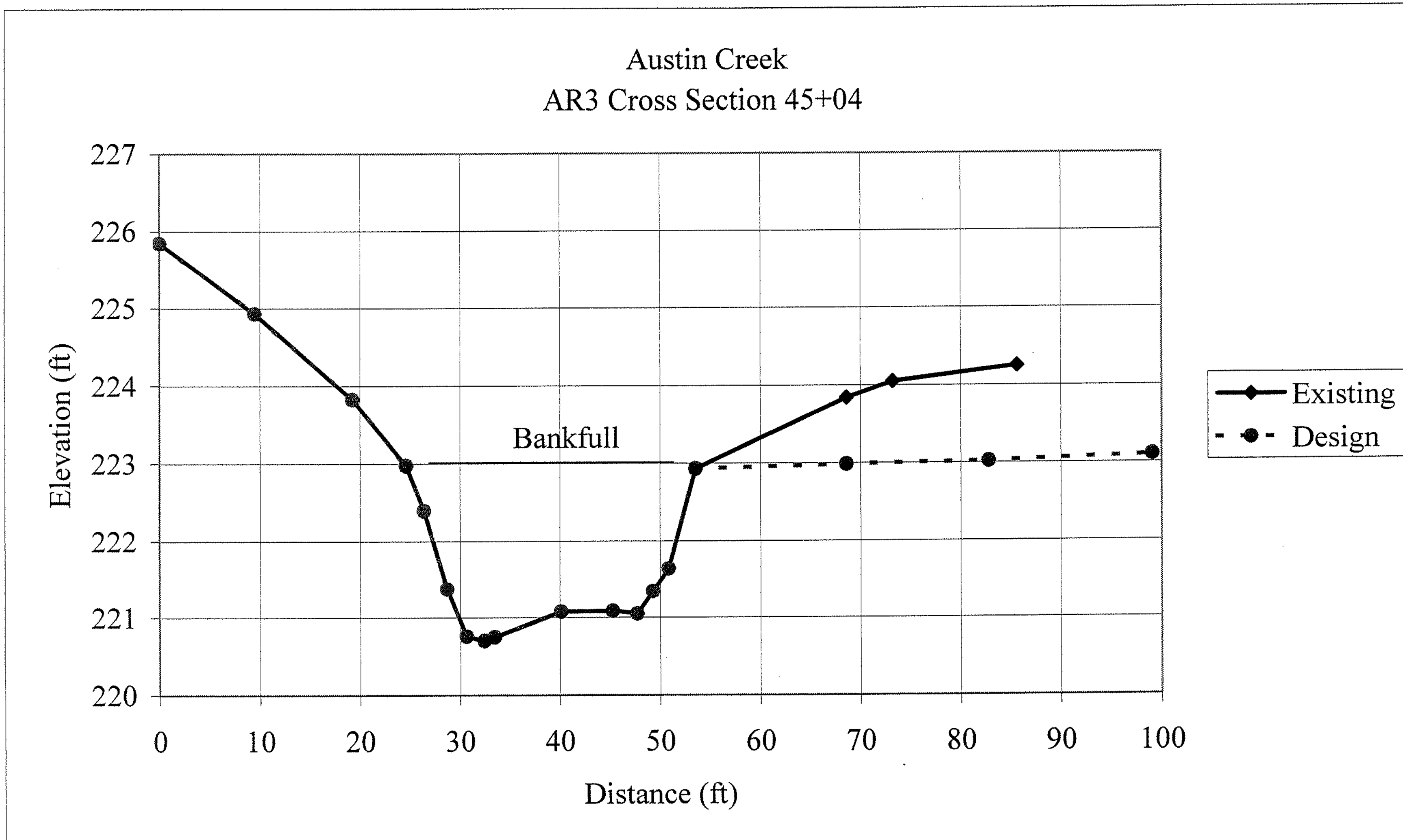
37+17	Feature	Type	Wfpa	LBKF	RBKF	ELbkf	Wbkf	Dbkf	W/D	Abkf	Dmax	ER	BHR
Existing	Riffle	C5	150	7.5	42.8	226.61	35.3	2.0	17.9	69.5	4.9	4.3	1.0
Design	Riffle	C5	150	7.5	42.8	226.61	35.3	2.0	17.9	69.6	4.9	4.3	1.0



43+80	Feature	Type	Wfpa	LBKF	RBKF	ELbkf	Wbkf	Dbkf	W/D	Abkf	Dmax	ER	BHR
Existing	Riffle	C5	150	6.2	38.7	224.67	32.4	2.4	13.6	77.6	3.8	4.6	1.0
Design	Riffle	C5	150	6.2	38.7	224.67	32.4	2.4	13.6	77.6	3.8	4.6	1.0

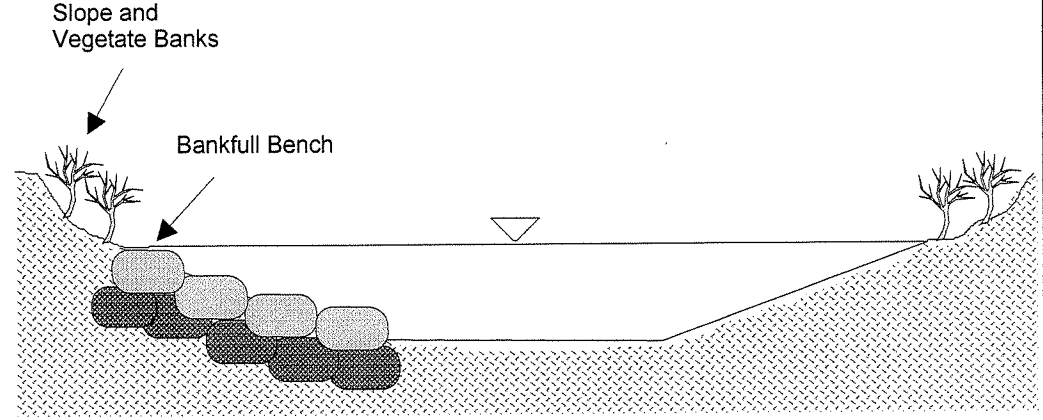


45+04	Feature	Type	Wfpa	LBKF	RBKF	ELbkf	Wbkf	Dbkf	W/D	Abkf	Dmax	ER	BHR
Existing	Riffle	C5	150	19.3	53.6	223.83	34.3	2.1	16.6	70.9	3.1	4.4	1.0
Design	Riffle	C5	150	19.3	53.6	223.83	34.3	2.1	16.6	70.9	3.1	4.4	1.0

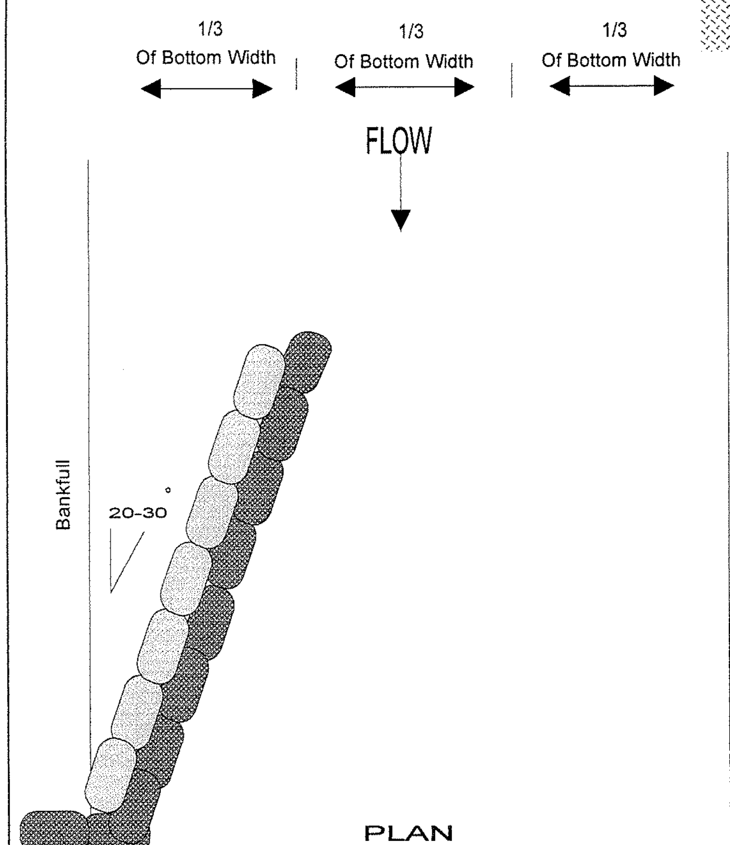


Appendix 3 Structure Drawings

Note:
-There should be no gaps between the rocks in the vane.



CROSS-SECTION



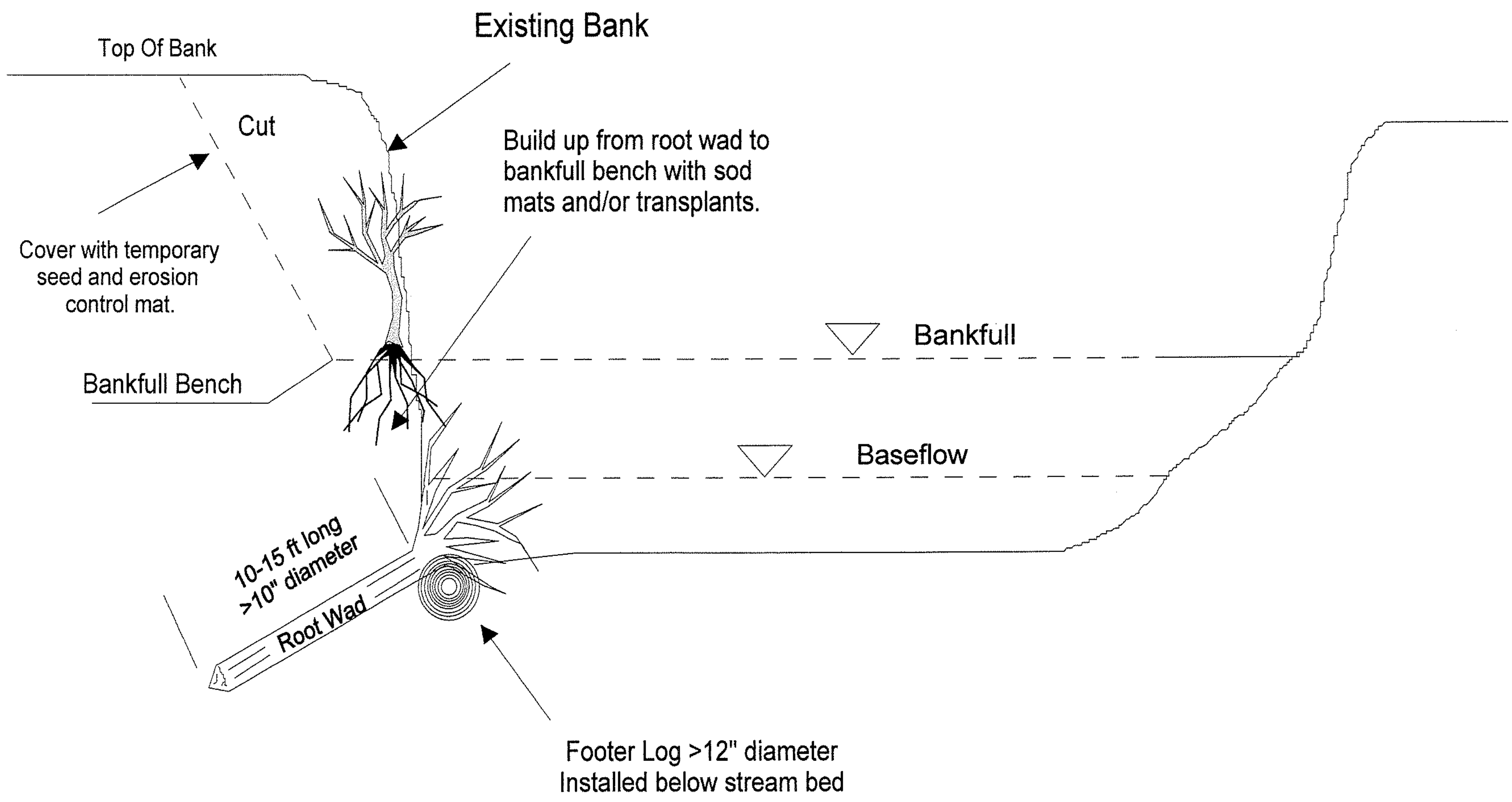
PLAN

Typical Rock Vane Design

Rock (approx. 6'x4'x3')

Footer Rock (approx. 6'x4'x3')

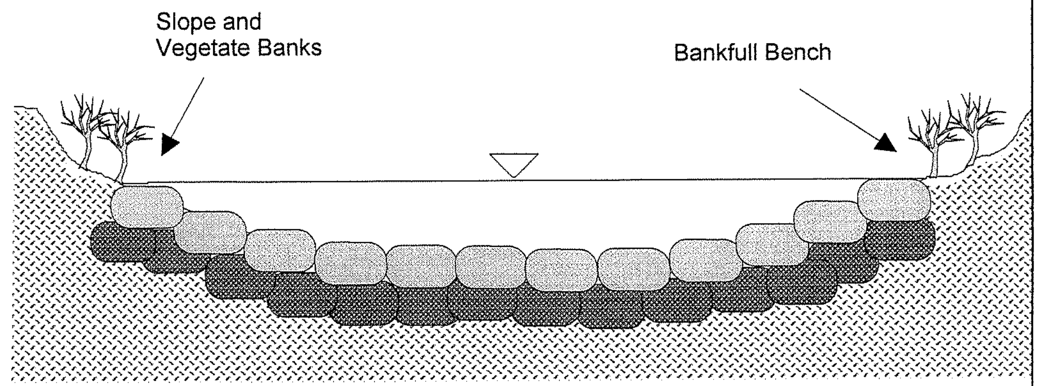
BUCK ENGINEERING



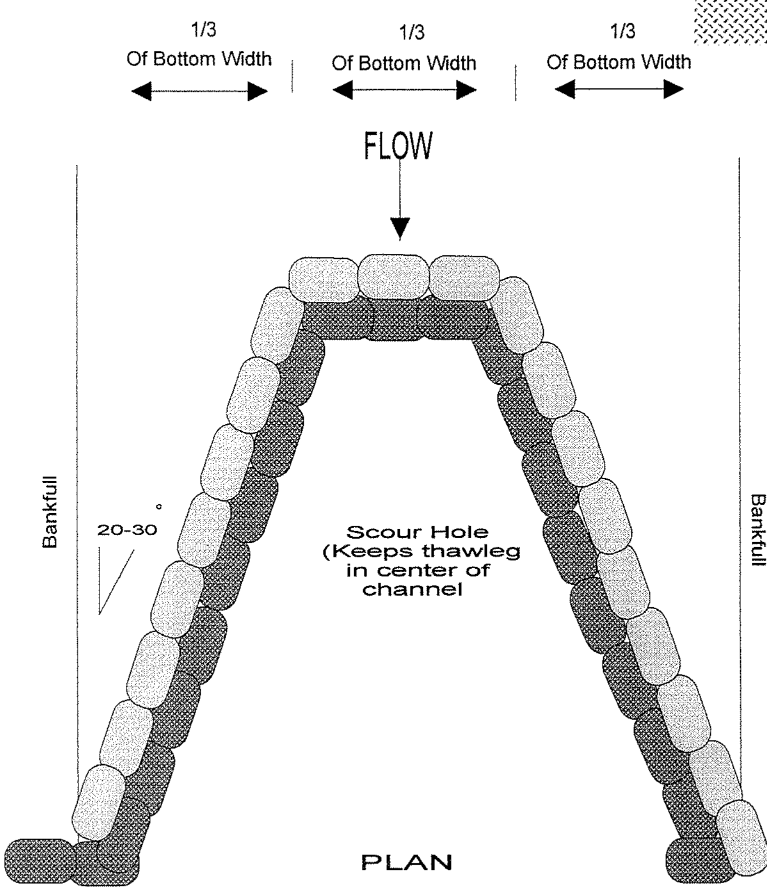
Typical Root Wad Cross Section

BUCK ENGINEERING

Note:
-There should be no gaps between the rocks in the cross vane.



CROSS-SECTION



PLAN

Typical Cross Vane Design

Rock
(approx. 6'x4'x3')

Footer Rock
(approx. 6'x4'x3')

BUCK ENGINEERING

Appendix 4 Photograph Log

Smith and Austin Creeks Photo Log

Photo 1 – Eroding bank along SR1

Photo 2 – Over wide section of SR2

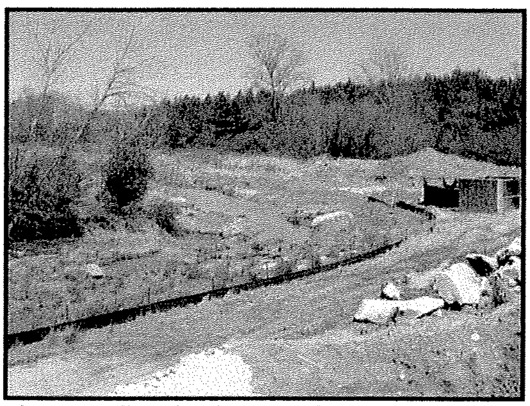


Photo 3 – Crossing between SR1 and SR2
Looking upstream

Photo 4 – Crossing b/w SR1 and 2 during high flow
Looking downstream

Photo 5 – Confluence of Smith and Austin
During high flow (SR2 and AR3)

Photo 6 – Smith Reach 2 (SR2) after flood

Photo 7 – Mid channel bar on Smith SR2

Photo 8 – Smith SR3 from Forrestville Road
During high flow

Photo 9 – Austin Creek upstream of project
Looking downstream

Photo 10 Austin Creek (AR1) near beginning
of project. Looking downstream

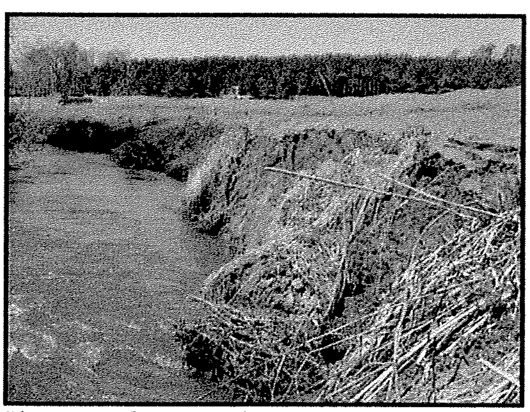


Photo 11 – Streambank erosion along AR1

Photo 12 – Upstream of golf cart crossing
AR1 and golf course under construction

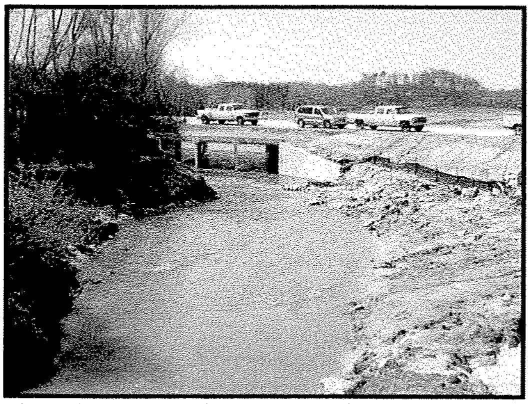


Photo 13 – Box culverts separating AR1 and AR2


Photo 14 – AR2 downstream of box culverts

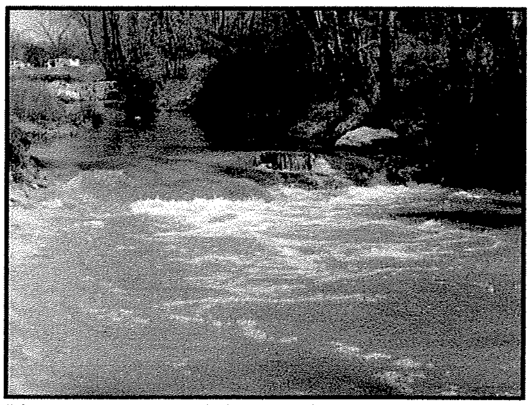


Photo 15 – Bedrock knickpoint between AR2 And AR3


Photo 16 – Austin stream reach AR3 looking downstream