Appendix E

USFWS Project Designs for Upstream Section

Little Beaver Kill Creek Stream Restoration, Livingston Manor, New York: Project Assessment and 30% Design Report

CBFO-S15-07

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LITTLE BEAVER KILL CREEK STREAM RESTORATION, LIVINGSTON, NEW YORK: PROJECT ASSESSMENT AND 30 % DESIGN REPORT

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I. INTRODUCTION

The U.S. Corps of Engineers, Philadelphia District (COE) and the U.S. Fish and Wildlife Service (Service) - Chesapeake Bay Field Office are involved in a collaborative effort to restore in-stream habitat and re-establish brook trout in approximately 6,500 linear feet of Little Beaver Kill, located in Livingston Manor, New York. The COE completed a feasibility study in 2013 that identified several water resource problems that include flooding, fish habitat impairment, sediment management, as well as loss of floodplain and riparian buffer habitat. Based on these problems, the focus of this project is to reduce the occurrence of frequent flooding damages within the community of Livingston Manor, NY and improve aquatic habitat conditions and functions for trout populations in the watersheds of the Little Beaver Kill Creek. The focus of the Service is to address the improvement to trout aquatic habitat conditions. Specifically the Service will conducted a limited function-based stream assessment and develop 30 percent complete designs. This report documents the findings of the function-based assessment, and design development process.

II. WATERSHED AND REACH ASSESSMENT

This section presents a brief summary of the methods used by the Service to conduct a limited assessment on the watershed (**Figure 1)** and a limited function-based stream assessment.

A. WATERSHED ASSESSMENT

The COE previously conducted a detailed watershed assessment as part of the feasibility study, therefore, the Service focused on the watershed sediment supply. The Service identified potential sources and amounts of sediment supply based on watershed land uses and stream stability. The majority of the watershed is forested with some limited agriculture and residential and commercial development. As a result, most stream reaches are stable and produce a low sediment supply. Where there is some instability, typically there is either a natural or a man-made feature downstream that traps a significant portion of the sediment supply.

Where a source of sediment supply starts to appear is approximately three miles upstream of the project area where the main stem Beaver Kill crosses Route 17 at the Fox Mountain Road intersection. From this point, downstream to the project area there is moderate to high stream bank erosion on the main stem Beaver Kill and numerous locations of sediment deposition in the form of lateral, mid channel and point bars. Approximately one and one half mile upstream of the project area (south of Route 178 before it intersects with Route 17) is an area where the valley floor widens and is a natural sediment depositional area. While this area does not trap 100 percent of the sediment supply, it does reduce the amount of sediment being transported to the project area.

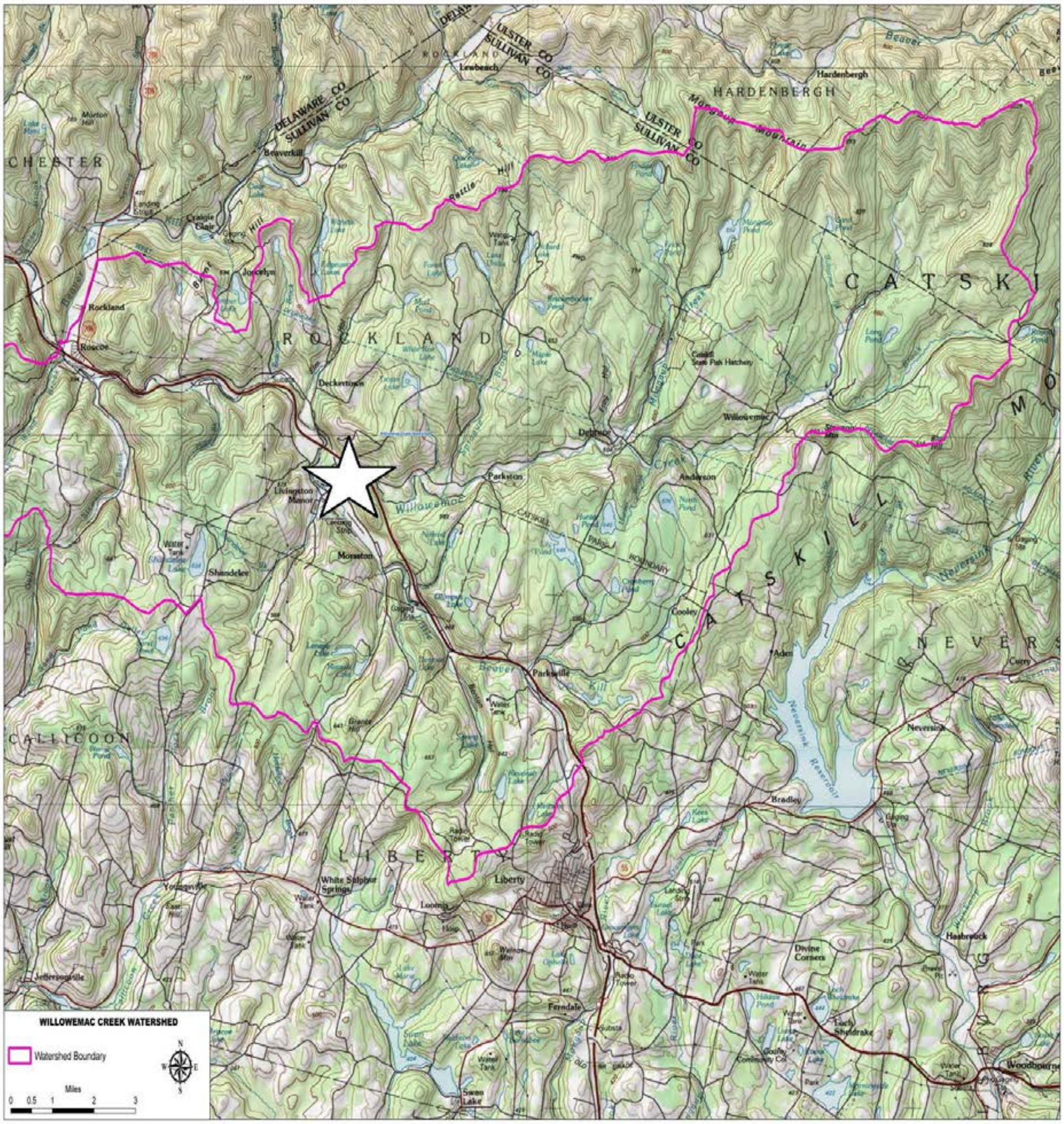

Figure 1. Project Area Map – Livingston Manor, NY located at "star"

A second source of sediment supply was identified one half mile upstream of the project area near the intersection of Route 178 and Route 146. The source is associated with an unnamed tributary that enters the Beaver Kill from the west. At this confluence is a large depositional fan that indicates this unnamed tributary has a potential high sediment supply.

Based on the watershed assessment and the deposition that has occurred over the past four decades throughout the project area (supported by recent cross section and longitudinal profile overlays shown in Appendix A), the Service has concluded that there is a moderate sediment supply reaching the project area. However, the Service recommends that a sediment yield curve be developed before final designs are developed to ensure that the sediment supply is adequately addressed to meet project goals and objectives. Specifically, to ensure aggradation does not occur within the town limits and affect potential flood levels.

B. PROJECT REACH FUNCTION-BASED ASSESSMENT

The Service conducted a limited function-based assessment of Little Beaver Kill. This function-based assessment approach is outlined in the Stream Functions Pyramid Framework (SFPF) (Harman et. al, 2012). The SFPF focuses on the hierarchical relationship of stream functions to determine the overall functional condition of a stream reach. It includes measurement methods, performance standards and goal setting criteria for function-based stream restoration. The framework outlines five critical categories that evaluate stream functions (**Figure 2**).

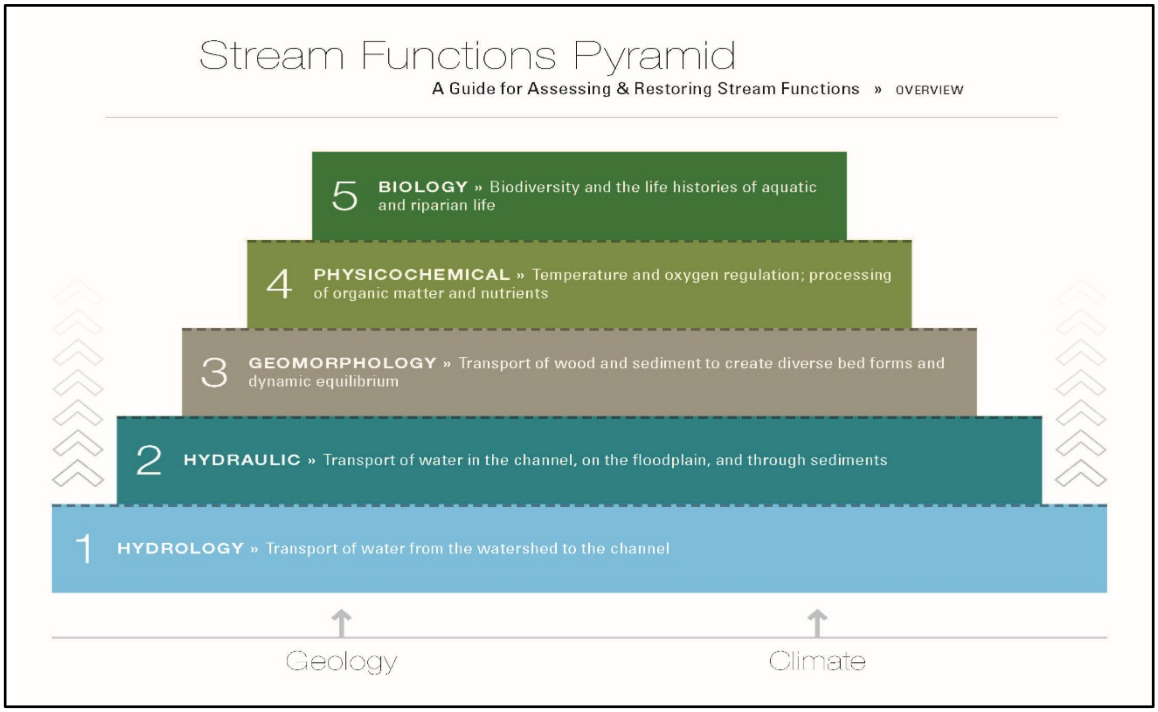

Figure 2. Stream Functions Pyramid (Harman et al., 2012)

The Service's limited assessment focused on Pyramid Levels 2 – Hydraulics and 3 – Geomorphology. Levels 1 – Hydrology, Level 4 – Physicochemical and Level 5 – Biology will be assessed by the COE. The Service evaluated only the critical assessment parameters that supported the project goals and objectives. Table 1 shows the critical parameters and measurement methods used to evaluate the parameters. An overall reach rating was based on an accumulation of ratings at two different levels. First, each pyramid level is rated based on the individual measurement method and assessment parameter ratings (**Table 1, Column Pre-Restoration Condition – Overall by Level**). Second, the overall reach rating is based on the individual pyramid level ratings (**Table 2, Column Pre-Restoration Condition – Overall Reach**).

Little Beaver Kill - Function-based Assessment Existing Conditions						
Level and Category	**Parameter**	**Measurement Method**	**Pre-Restoration Condition**			
			Value	**Rating**	**Overall by Level**	**Overall Reach**
1 - Hydrology	Runoff	Flashiness				
		Concentrated Flow				
2 - Hydraulics	Floodplain Connectivity	Bank Height Ratio				
		Entrenchment Ratio				
	Floodplain Complexity	FWS Rapid Assessment				
3 - Geomorphology	Bedform Diversity	Pool-to-pool Spacing				
		Pool Depth Variability				
		Depositional Pattern				
	Lateral Stability	Lateral Erosion Rate -Percent Eroding banks				
		Meander Width Ratio (C and E Stream Types)				
		Meander Pattern				

Table 1. Function-based Assessment Parameters and Measurement Methods

The Service identified six stream reaches with different, distinct function-based conditions within the project area (Figure 3). A brief description of the function-based conditions for each reach is described below.

Figure 3. Existing Project Reaches

1. Reach 1

Little Beaver Kill Reach 1- Function-based Assessment Existing Conditions							
Level and Category	**Parameter**	**Measurement Method**	**Pre-Restoration Condition**				
			Value	**Rating**	**Overall by Level**	**Overall Reach**	
1 - Hydrology	Runoff	Flashiness	Non-flashy	F	**F**	**FAR**	
		Concentrated Flow	No concentrated flow	F			
2 - Hydraulics	Floodplain Connectivity	Bank Height Ratio	1	F	**F**		
		Entrenchment Ratio	10	F			
	Floodplain Complexity	FWS Rapid Assessment	N/A	F			
3 - Geomorphology	Bedform Diversity	Pool-to-pool Spacing	NA*	N/A	**FAR**		
		Pool Depth Variability	1.7	F			
		Depositional Pattern	B1	F			
	Lateral Stability	Lateral Erosion Rate -Percent Eroding banks	48.7	NF			
		Meander Width Ratio (C and E Stream Types)	6.6	F			
		Meander Pattern	M1	F			
* Reach too short and only had one pool							

Table 2. Little Beaver Kill Reach 1 – Function-based Assessment Existing Conditions

The Service determined that the overall function-based condition of Little Beaver Kill Reach 1 is Functioning-at-Risk and is trending towards stability (Table 2). The reach is well connected to its floodplain. The floodplain is broad and complex. There is storage for flood flows and areas to retain flood flows as they recede. Bedform diversity is slightly lacking but this is more a result of the short reach length. Lateral bank erosion is the primary issue with the reach. Nearly half of the banks are actively eroding. This is most likely a result of the poor riparian vegetation and not channel alignment issues. The majority of banks and floodplain in the reach are recently formed and therefore do not have dense, mature vegetation. The recent deposition is because a majority of the reach was a former in-line pond that has aggraded. The pond was actually a gravel borrow pit used to construct Route 17 several decades ago. The pit was originally adjacent to Little Beaver Kill Creek but during a large storm event many years ago, the stream moved into the pit and has remained there since.

The ability of the reach to evolve back to some level of quasi-equilibrium is unlikely to occur anytime in the near future without intervention. The current geomorphic functions are still undergoing adjustments but trending towards stability. A new floodplain and channel alignment has formed but riparian vegetation needs to mature before the lateral erosion rate slows down. However, this evolutionary process could still take several years, possibly even decades to complete and during this time could adversely affect downstream resources.

2. Reach 2

Little Beaver Kill Reach 2- Function-based Assessment Existing Conditions						
Level and Category	Parameter	Measurement Method	Pre-Restoration Condition			
			Value	Rating	Overall by Level	Overall Reach
1 - Hydrology	Runoff	Flashiness	Non-flashy	F	F	FAR
		Concentrated Flow	No concentrated flow	F		
2 - Hydraulics	Floodplain Connectivity	Bank Height Ratio	1	F	FAR	
		Entrenchment Ratio	7.4	F		
	Floodplain Complexity	FWS Rapid Assessment	N/A	FAR		
3 - Geomorphology	Bedform Diversity	Pool-to-pool Spacing	5.6	F	FAR	
		Pool Depth Variability	1.8	F		
		Depositional Pattern	B4	FAR		
	Lateral Stability	Lateral Erosion Rate -Percent Eroding banks	37.3	FAR		
		Meander Width Ratio (C and E Stream Types)	6.6	F		
		Meander Pattern	M1	F		

Table 3. Little Beaver Kill Reach 2 – Function-based Assessment Existing Conditions

The Service determined that the overall function-based condition of Little Beaver Kill Reach 2 is Functioning-at-Risk and is trending towards stability (Table 3). The reach is well connected to its floodplain. The floodplain is broad and complex. There is storage for flood flows and areas to retain flood flows as they recede. There is good bedform diversity and pools and riffles are well represented. Lateral bank erosion is the primary issue with the reach. Nearly half of the banks are actively eroding. This is most likely a result of the poor riparian vegetation, unstable channel alignment and excessive sediment deposition. The majority of banks and floodplain in the reach are recently formed. Therefore, they do not have dense, mature vegetation and the channel is still adjusting to a stable form. The recent deposition is because the entire reach is in the former in-line pond described above in Reach 1.

The ability of the reach to evolve back to some level of quasi-equilibrium is unlikely to occur anytime in the near future without intervention. The current geomorphic functions are still undergoing adjustments but trending towards stability. A new floodplain formed but the channel alignment still needs to adjust to a more stable form and the riparian vegetation still needs to mature before the lateral erosion rate can slow down. However, this evolutionary process could still take several years, possibly even decades to complete and during this time could adversely affect downstream resources.

3. Reach 3

Little Beaver Kill Reach 3- Function-based Assessment Existing Conditions						
Level and Category	Parameter	Measurement Method	Pre-Restoration Condition			
			Value	Rating	Overall by Level	Overall Reach
1 - Hydrology	Runoff	Flashiness	Non-flashy	F	F	NF
		Concentrated Flow	No concentrated flow	F		
2 - Hydraulics	Floodplain Connectivity	Bank Height Ratio	1	F	FAR	
		Entrenchment Ratio	7.5	F		
	Floodplain Complexity	FWS Rapid Assessment	N/A	FAR		
3 - Geomorphology	Bedform Diversity	Pool-to-pool Spacing	Only one pool	NF	NF	
		Pool Depth Variability	2.3	F		
		Depositional Pattern	B7	NF		
	Lateral Stability	Lateral Erosion Rate -Percent Eroding banks	77	NF		
		Meander Width Ratio (C and E Stream Types)	Straightened	NF		
		Meander Pattern	Straightened	NF		

Table 4. Little Beaver Kill Reach 3 – Function-based Assessment Existing Conditions

The Service determined that the overall function-based condition of Little Beaver Kill Reach 3 is Not Functioning (NF) and beginning to trend towards stability (Table 4). This entire reach is located within the second gravel pit mined for the Rt 17 road construction, which is immediately downstream of other gravel mine pit mentioned above. This reach is considered NF because the level of aggradation is far less than the upstream gravel mine pit and the stream is essentially a broad, shallow stream with one pool. Additionally, over three quarters of the banks are actively eroding from poorly established riparian vegetation.

The ability of the reach to evolve back to some level of quasi-equilibrium is unlikely to occur anytime in the near future without intervention. The current geomorphic functions are still undergoing significant adjustments, but starting to trend towards stability. A new floodplain needs to form first. Then the channel alignment and bottom can begin to form into a stable condition. Throughout this process, the riparian vegetation will need to establish in order to provide lateral stability. However, this evolutionary process could still take several years, possibly even decades to complete and during this time could adversely affect downstream resources.

4. Reach 4

<table>
<tr><th colspan="7">Little Beaver Kill Reach 4- Function-based Assessment Existing Conditions</th></tr>
<tr><th rowspan="2">Level and Category</th><th rowspan="2">Parameter</th><th rowspan="2">Measurement Method</th><th colspan="4">Pre-Restoration Condition</th></tr>
<tr><th>Value</th><th>Rating</th><th>Overall by Level</th><th>Overall Reach</th></tr>
<tr><td rowspan="2">1 - Hydrology</td><td rowspan="2">Runoff</td><td>Flashiness</td><td>Non-flashy</td><td>F</td><td rowspan="2">F</td><td rowspan="11">NF</td></tr>
<tr><td>Concentrated Flow</td><td>No concentrated flow</td><td>F</td></tr>
<tr><td rowspan="3">2 - Hydraulics</td><td rowspan="2">Floodplain Connectivity</td><td>Bank Height Ratio</td><td>1.5</td><td>NF</td><td rowspan="3">NF</td></tr>
<tr><td>Entrenchment Ratio</td><td>6.3</td><td>F</td></tr>
<tr><td>Floodplain Complexity</td><td>FWS Rapid Assessment</td><td>N/A</td><td>FAR</td></tr>
<tr><td rowspan="6">3 - Geomorphology</td><td rowspan="3">Bedform Diversity</td><td>Pool-to-pool Spacing</td><td>9.3</td><td>NF</td><td rowspan="6">FAR</td></tr>
<tr><td>Pool Depth Variability</td><td>2.4</td><td>F</td></tr>
<tr><td>Depositional Pattern</td><td>B5</td><td>NF</td></tr>
<tr><td rowspan="3">Lateral Stability</td><td>Lateral Erosion Rate -Percent Eroding banks</td><td>68.8</td><td>NF</td></tr>
<tr><td>Meander Width Ratio (C and E Stream Types)</td><td>5.50</td><td>F</td></tr>
<tr><td>Meander Pattern</td><td>M3</td><td>F</td></tr>
</table>

Table 5. Little Beaver Kill Reach 4 – Function-based Assessment Existing Conditions

The Service determined that the overall function-based condition of Little Beaver Kill Reach 4 is Not Functioning but starting to trend towards stability (Table 5). The reach is disconnected from its floodplain except during large flood events. However, the floodplain is broad and complex and has areas to store and retain flood flows but does have some concentrated flow paths. Sediment supply and deposition is a significant contributor to the instability issues occurring within this reach. Bedform diversity is poor. While the pools and riffles are well defined, the total percentage of pools to riffles is low and the riffles are being smothered by the excessive sediment deposition. Lateral bank erosion is occurring on over half of the banks. This is because of the deposition and poorly established riparian vegetation. The excessive deposition redirects stream flows to the banks and increases bank shear stresses.

The ability of the reach to evolve back to some level of quasi-equilibrium is unlikely to occur anytime in the near future without intervention. The current geomorphic functions are still undergoing adjustments but trending towards stability. A new floodplain is forming but the channel alignment still needs to adjust to a more stable form and the riparian vegetation still needs to mature before the lateral erosion rate can slow down and sediment can be transported. However, this evolutionary process could still take several years, possibly even decades to complete and during this time could adversely affect downstream resources.

5. Reach 5

Little Beaver Kill Reach 5 - Function-based Assessment Existing Conditions						
Level and Category	Parameter	Measurement Method	Pre-Restoration Condition			
			Value	Rating	Overall by Level	Overall Reach
1 - Hydrology	Runoff	Flashiness	Non-flashy	F	F	NF
		Concentrated Flow	No concentrated flow	F		
2 - Hydraulics	Floodplain Connectivity	Bank Height Ratio	> 2	NF	NF	
		Entrenchment Ratio	7.2	F		
	Floodplain Complexity	FWS Rapid Assessment	N/A	FAR		
3 - Geomorphology	Bedform Diversity	Pool-to-pool Spacing Ratio	8.9	NF	NF	
		Pool Depth Ratio Variability	2	F		
		Depositional Pattern	B2	F		
	Lateral Stability	Lateral Erosion Rate -Percent Eroding banks	55.4	NF		
		Meander Width Ratio (C and E Stream Types)	Straightened	NF		
		Meander Pattern	Straightened	NF		

Table 6. Little Beaver Kill Reach 5 – Function-based Assessment Existing Conditions

The Service determined that the overall function-based condition of Little Beaver Kill Reach 5 is Not Functioning but starting to trend towards stability (Table 6). This reach has been highly altered numerous times in the past in an attempt to alleviate flood levels, which is a significant contributor to the instability issues occurring within this reach. It has been straightened, widened and deepened. It is now disconnected from its floodplain, except during large flood events.

Additionally, the floodplain has been encroached upon from infrastructure and buildings. The bedform diversity is poor. Pools and riffles are moderately defined and the total percentage of pools to riffles is low. Pools are shallow and riffles are being smothered by sediment deposition. Lateral bank erosion is occurring on over half of the banks. This is primarily because of the channel straightening and poorly established riparian vegetation.

The ability of the reach to evolve back to some level of quasi-equilibrium is unlikely to occur anytime in the near future without intervention. The greatest factor influencing self-recovery is the low energy of this reach. The reach is extremely flat and has a high width/depth ratio. A stream with low energy requires a long time to adjust because it is less efficient in transporting sediment and scouring, which is critical for creating sinuosity and bedform diversity. The reach is trending towards stability, however, because of the low stream energy and limited floodplain area, this evolutionary process could still take several years, possibly even decades to complete and during this time could adversely affect downstream resources.

6. <u>Reach 6</u>

Little Beaver Kill Reach 6 - Function-based Assessment Existing Conditions						
Level and Category	**Parameter**	**Measurement Method**	**Pre-Restoration Condition**			
			Value	**Rating**	**Overall by Level**	**Overall Reach**
1 - Hydrology	Runoff	Flashiness	Non-flashy	F	**FAR**	**FAR**
		Concentrated Flow	Some concentrated flow	FAR		
2 - Hydraulics	Floodplain Connectivity	Bank Height Ratio	no XS [1]	F	**FAR**	
		Entrenchment Ratio	1.4 [2]	FAR		
	Floodplain Complexity	FWS Rapid Assessment	N/A	FAR		
3 - Geomorphology	Bedform Diversity	Pool-to-pool Spacing Ratio	8.3	NF	**FAR**	
		Pool Depth Ratio Variability	1.9	F		
		Depositional Pattern	B4	FAR		
	Lateral Stability	Lateral Erosion Rate -Percent Eroding banks	12.2	F		
		Meander Width Ratio (C and E Stream Types)	Straightened	NF		
		Meander Pattern	Straightened	NF		
1 - No riffe, short reach- BHR based on observation						
2 -No riffe, short reach- used average dmax to find ER and ER rating was based on stream potential of C4						

Table 7. Little Beaver Kill Reach 6 – Function-based Assessment Existing Conditions

The Service determined that the overall function-based condition of Little Beaver Kill Reach 6 is Functioning-at-Risk and is trending towards stability (Table 7). This reach, like Reach 5, has been highly altered numerous times in the past in an attempt to alleviate flood levels, which is a significant contributor to the stability issues occurring within this reach. It has been straightened, widened and deepened. Additionally, it confluences with the Willowomec River and is influenced by its backwater during storm events. It is connected to its floodplain, however, there is limited floodplain area because it has been encroached upon from infrastructure and buildings. Even though it has been straightened in the past, the bedform diversity has evolved into well-defined pools and riffles. However, the ratio of pools to riffles is low. Lateral bank erosion is low because of well-established riparian vegetation.

The ability of the reach to evolve back to some level of quasi-equilibrium is unlikely to occur anytime in the near future without intervention. The greatest factor influencing self-recovery is the low energy of this reach since it is in the backwater of the Willowomec River. The reach is trending towards stability, however, because of the low stream energy and limited floodplain area, this evolutionary process could still take several years, possibly even decades to complete and during this time could adversely affect downstream resources.

7. Overall Project Summary

Little Beaver Kill Creek - Function-based Assessment Summary				
Reach	**Reach Length (ft)**	**Rosgen Stream Type**	**Channel Evolution**	**Reach Level Function-based Rating**
1	402	C4	Stable C4 (localized lateral erosion)	FAR
2	1270	D4	D4 -> C4	NF
3	1110	NA- backwater area from relic in line pond		NF
4	1291	F4	F4 high W/D -> high W/D C4	NF
5	1100	F4	F4 -> high W/D F4	NF
6	1070	B4c	B4c	FAR

Table 8. Little Beaver Kill Overall – Function-based Assessment Existing Conditions

The Service determined that the overall function-based condition of the Little Tuscarora Creek project area is ***Not Functioning*** but is trending towards stability (Table 8). While some areas of the project area are ***Functioning-at-Risk***, the majority if the project area is ***Not Functioning***.

The Hydrology level, Level 1, is currently ***functioning*** mostly because current land uses within the watershed (i.e., mostly forested) have not significantly influenced the amount and rate of flood flows reaching the project area, resulting in a non-flashy flow regime. A non-flashy flow regime will produce lower stream shear stresses and improve ground water recharge. Lower stream shear stresses will reduce lateral and vertical degradation. Improved ground water recharge will better maintain stream base flows during the drier times of the year and support aquatic species.

The Hydraulics level, Level 2, is overall currently ***Not Functioning*** mostly due to high bank height ratio, which shows that the stream is not well connected to the floodplain for the majority if the project area. When a stream becomes disconnected from the floodplain, stream energy increases because flow depths increase while channel widths do not (Leopold et al., 1992). Increased stream energy increases stream shear stresses and promotes vertical and lateral stream degradation, which adversely affects riparian vegetation, bedform diversity, turbidity, and macroinvertebrate and fish communities.

The Geomorphology level, Level 3, is overall currently ***Functioning-at-Risk*** mostly due to limited bed form diversity, absence of riparian vegetation and moderate to high levels of stream bank erosion. As stated above in Level 2 – Hydraulics, geomorphic processes are functioning at risk because of increased stream energies associated with a disconnected floodplain. Limited geomorphic functions adversely affect macroinvertebrate and fish communities due to the loss of available quality habitat structure.

8. Channel Evolution

The ability of the proposed project area to evolve back to some level of quasi-equilibrium is unlikely to occur anytime in the near future without intervention. The current geomorphic functions are still undergoing significant adjustments. As stated above, past incision resulted in the stream becoming disconnected from the floodplain. Now that the stream is disconnected from the floodplain, it will actively erode stream banks to build a new floodplain at a lower level than the original floodplain. Based on the current meander width ratio, the stream has the required beltwidth needed for lateral stability but the bedform diversity, specifically pool- to-pool spacing, is still lacking. This will cause down-valley lateral stream bank erosion until the proper bedform diversity is achieved. Only then can the riparian vegetation can start to recover and provide the shading and woody material needed to support brook trout and other functions. However, this evolutionary process could take decades to complete and will prevent brook trout from repopulating the proposed project area and adversely impact downstream resources.

III. DESIGN PROCESS

This section presents the restoration potential, project constraints, design objectives, design alternatives analysis, design criteria, and monitoring strategies involved in the Little Beaver Kill Creek Stream Restoration.

A. RESTORATION POTENTIAL

Restoration potential is the highest level of restoration or functional lift that can be achieved given the site constraints and health of the watershed (Harman et al., 2012). Using watershed conditions, function-based assessment results, and constraints and stressors, the Service was able to determine the highest level of restoration that could be achieved at the Little Beaver Kill Creek restoration site. Based on these factors, the Service determined that pyramid Levels 2 - Hydraulics and 3 – Geomorphology can be restored to fully functional (Table 9). Restoration of levels 2 and 3 functions are typically the easiest to achieve since they involve direct, physical manipulation of stream channel dimension, pattern, and profile. Stream channel parameters such as beltwidth, bank heights, wave lengths, facet feature lengths, slopes and depths can be constructed to specifications considered functioning upon completion of construction.

There is also a potential for lift in Levels 4 – Physicochemical and 5 – Biology, however documenting the actual lift is the responsibility of the COE. Even though this is the responsibility of the COE, the Service wants to note that levels 4 and 5 functions cannot be constructed and rely on the functionality of lower level functions and watershed health. Therefore, it takes time for levels 4 and 5 functions to respond to changes in lower level functions and watershed health. Research has shown that it can take up to 10 to 15 years to see biological lift (Orzetti, 2010). For example, riparian vegetation needs to mature in order to provide shade to reduce stream temperature and to provide detritus for aquatic species. Then aquatic species need to migrate in to the newly created habitat to repopulate the stream. While there is potential for water quality and biological lift, it is uncertain at this time what the lift could be because assessment of water quality and biological functions were not included as a project goal in the Service's SOW. The COE was responsible for those measurements.

Lastly, there are a few reach-level constraints, which will influence design objectives more than restoration potential. They include a vehicular bridge crossing at the farthest downstream portion of the proposed project area and floodplain encroachment by structures also within assessment project areas 5 and 6.

Little Beaver Kill - Restoration Potential				
Level and Category	**Assessment Parameter**	**Reach**	**Existing Condition**	**Potential Potential**
1 - Hydrology	Runoff	1	F	F
		2	F	F
		3	F	F
		4	F	F
		5	F	F
		6	F	F
2 - Hydraulics	Floodplain Connectivity	1	F	F
		2	F	F
		3	F	F
		4	NF	F
		5	NF	F
		6	FAR	F
	Floodplain Complexity	1	F	F
		2	FAR	F
		3	FAR	F
		4	FAR	F
		5	FAR	F
		6	FAR	F
3 - Geomorphology	Bedform Diversity	1	F	F
		2	FAR	F
		3	NF	F
		4	NF	F
		5	NF	F
		6	FAR	F
	Lateral Stability	1	FAR	F
		2	FAR	F
		3	NF	F
		4	FAR	F
		5	NF	F
		6	FAR	F

Table 9. Little Beaver Kill – Restoration Potential

B. DESIGN OBJECTIVES

Design objectives are based on project goals and project area restoration potential. The design objectives reflect the project goals but state specifically how the project will be completed. Thus, design objectives are quantifiable and measureable. The goals of the study are to reduce the occurrence of frequent flooding damages within the community of Livingston Manor, NY and improve trout habitat conditions in the Little Beaverkill Creek. The Service developed, in coordination with the COE, design objectives to address the trout habitat improvement project goal, while considering the effects of any proposed design on flood elevations. The COE focused on reducing flood levels by proposing changes to the stream downstream of the Main Street bridge to the confluence, and wetland restoration in the floodplain area. Restoration design objectives are shown in Table 10.

Table 10. Little Beaverkill Creek – Design Objectives. *The underlined words under the objectives are parameters or measurement methods from the* ***Stream Functions Pyramid Framework*** *(Harman, et al. 2012.)*

Level and Category	Parameters	Design Objectives
Level 2 - Hydraulics	Floodplain Connectivity	1. Achieve a Bank Height Ratio = 1 2. Increase floodplain complexity by eliminating concentrated flows, creating wetlands and providing areas to trap and store flood flows.
Level 3 - Geomorphology	Lateral Stability, In-stream Habitat (i.e., diversity and quality), Riparian Buffer	1. Reduce stream bank erosion rates to match reference erosion rates (<u>bank migration / lateral stability</u>) 2. Increase Bedform Diversity – Create 60:40 pool / riffle ratio 3. Match species diversity and composition of reference condition and make buffer width 35 ft wider than required meander width ratio. 4. Transport the sediment supply delivered to the project area without channel aggradation or degradation. 5. Transport the sediment supply being delivered to the project area without excessive degradation or aggradation.
Level 4 - Physicochemical	Water Quality	1. Water Temperature – Reduce water temperatures to a range suitable to trout for year round use within 5 yrs.

Table 10. Goals and Objectives

C. DESIGN ALTERNATIVES ANALYSIS

The purpose of design alternatives analysis is to select the best restoration design approach that meets the project goals, design objectives, and the restoration potential of the site. It focuses on how a specific design approach could influence stream functions (i.e., highest functional lift), impacts to existing functions, costs, and risk.

1. Potential Design Alternatives

There are a variety of design approaches available to restore stream functions of highly degraded stream systems. Design approaches generally address two typical types of stream conditions: 1) low stream energy and low sediment supply and 2) moderate to high stream energy and a sediment supply. Stream energy and sediment supply significantly influence the size and shape of a stream channel. A stream with low energy and a low sediment supply is considered a low risk project because shear stresses are low and limited sediment needs to be transported. Low shear stresses mean less stress on the streambed and banks. Design approaches used for this stream condition generally involve a base flow channel with low banks so that even the smallest storm events inundate the floodplain.

A stream with moderate to high energy and a sediment supply requires a more involved design approach. Stream energy must be accurately calculated in order to manage shear stresses so that lateral and vertical degradation does not occur. Furthermore, the sediment supply being delivered to the stream must be transported and cannot aggrade and smoother the stream bed. If a particular design approach cannot transport sediment, it could be bad or good. If the sediment deposition occurs at a rate that vegetation cannot establish and hold the sediment in place, it prohibits bank stability. This means that the stream channel and floodplain are in a constant state of flux, adversely affecting water quality and biology. If the sediment deposition occurs at a rate that vegetation can establish and hold the sediment in place, it allows rooted vegetation to establish. However, over time the sediment deposition will eventually form a stream channel that can transport sediment. Design approaches used for this stream condition generally involve a bankfull flow (or channel forming discharge flow) channel shaped to transport the sediment supply.

The watershed and reach-level assessments identified that there is a sediment supply being delivered to the project area. Therefore, the Service focused on the design approaches that could transport sediment and those are Natural Channel Design and Analytical Design.

2. <u>Analytical Design Approach</u>

The Analytical Design approach is a subset of the broader Alluvial Channel Design Methodology described in Chapter 9 of the United States Department of Agriculture, Natural Resources Conservation Service, National Engineering Handbook (NEH) 654 (NRCS, 2007). The theory supporting the Analytical Approach is that channel dimensions can be calculated from physically based equations including continuity, hydraulic resistance, and sediment transport. These equations require that a design discharge and inflowing sediment concentration be estimated. The design discharge may include the bankfull discharge, effective discharge, or other user-defined discharge. Bank material characteristics and estimates of the bed material composition are also required. The primary result is a channel stability curve that predicts riffle depth and average channel slope for a range of channel widths. It does not explicitly prescribe methods for laying out the channel planform and profile. Typically, empirical approaches are sometimes used based on local reference reaches or relationships in Copeland and McComas (2001). A better approach is to use design criteria from reference reaches with similar valley slopes, bed material, and stream type as the project reach (Hey, 2006).

This approach, if implemented, will result in functional uplift to floodplain connectivity, riparian vegetation and water temperature. However, since it does not explicitly prescribe methods for laying out the channel planform and profile, undesired stream channel adjustments could occur over time that would adversely affect geomorphic stability, water quality and biology. Specially, bedform and lateral adjustments can occur. Bedform features such as facet lengths, slopes and depths and planform features such as sinuosity significantly influence dissipation of stream energy. If these stream parameters are not designed correctly they will adjust, causing functional impacts. As facet features adjust, habitat for aquatic species can be scoured out in some locations and smothered with excessive sediment in other areas. Water quality can become turbid from excessive sediment associated with the scouring, and riparian vegetation can be lost because of lateral stream channel migration. Since these potential impacts could occur, this approach is considered a moderate to high risk project. Therefore, the Service eliminated the Analytical Design Approach as a feasible design approach.

3. Natural Channel Design Approach

The Natural Channel Design (NCD) Approach is based on measured morphological relations associated with bankfull flow, geomorphic valley type, and geomorphic stream type (NRCS 2007). This design approach involves a combination of hydraulic geometry, analytical calculation, regionalized validated relationships, and a series of precise reference reach measurements. This design process involves designing channel dimension, pattern, and profile based on reference reach data first and then using analytical calculations, same as the analytical design approach, to validate vertical and lateral stability and sediment transport.

This approach, if implemented, will result in functional uplift through level 5 – biology. Assessment parameters in level 2 - hydraulics and level 3 – geomorphology will be fully functional while assessment parameters in level 4 – physicochemical and level – 5 biology will remain functioning-at-risk but have functional uplift. As was stated in the restoration potential section, restoration of levels 2 and 3 functions are typically the easiest to achieve since they involve direct, physical manipulation of stream channel dimension, pattern, and profile. While not a design objective, functional uplift for levels 4 and 5 can occur. The expected level 4 uplift will be associated with water temperature reductions. Currently the proposed project area lacks adequate riparian vegetation to provide shading. One of the design objectives is to restore the riparian vegetation and research has shown that providing shade to the stream could reduce water temperatures by 1.9^{o} Celsius (Fink 2008). The expected level 5 uplift will be associated with improvements to macroinvertebrate and fish communities through the increase of available in-stream habitat. The increase of available in-stream habitat is a result of improved bedform diversity functions associated with level 2 proposed restoration objectives.

Implementation of the Natural Channel Design approach typically involves channel realignment and extensive grading. This type of activity could adversely affect existing riparian vegetation. However, since the existing riparian vegetation was rated as ***Functioning-at-Risk***, any potential realignment or grading will not adversely affect the existing riparian vegetation. Additionally, some temporary effects may occur during construction. These effects are typical of stream restoration projects regardless of which design approach is implemented and generally include displacement of aquatic species and increases in turbidity. To reduce these potential impacts, the Service recommends a construction sequence where all new channel construction will occur first and then be reconnected to the existing channel.

The Natural Channel Design approach meets project goals and design objectives; addresses sediment transport needs; provides the greatest functional uplift and produces the least impacts to existing functions; and is based on reference conditions, thus considered low risk. Therefore, the Service selected Natural Channel Design as the design approach for the proposed project area.

D. DESIGN DEVELOPMENT

As stated above, the Natural Channel Design approach was the preferred alternative. NCD uses form and process to develop stream restoration designs. Form is the structural features of a stream and includes channel dimensions, pattern, and profile. It is based on reference stream conditions that are the same stream type, valley type, vegetation type, and bed material. Process is the analytical assessment of a design. Hydraulic and sediment calculations are conducted to determine the potential stability of the design. Adjustments are made to the design based on the results of the analytical assessment and then the design is re-assessed. This iterative process continues until the analytical assessment shows that the design will be self-maintaining and that the channel dimensions, pattern, and profile match reference conditions

In this section, the Service documents how the NCD process was applied to the project area. It contains design criteria, proposed plan, in-stream structures, hydrologic and hydraulic assessment, sediment transport assessment, and proposed vegetation.

1. Design Criteria

Design criteria was compiled by standardizing existing channel plan, profile, and dimension of reference stream reaches. Additionally, the Service identified two reference riffles upstream of the project area that were used to develop the riffle dimension design criteria. Refer to Appendix B for a complete list of the design criteria.

2. Proposed Design

The Service used the Natural Channel Design (NCD) approach to develop the stream restoration designs. The Rosgen Stream types designed include Rosgen C4 and B4c (Appendix F). The C4 is located from station 15+00 to 58+87 (the farthest upstream station of the project area). The B4c is located from station 0+00 (Main Street bridge) to 15+00. A C4 stream type is the stream type that would naturally form in the existing valley type (Rosgen valley type VIII – alluvial) in which Little Beaverkill flows. Therefore, a majority of the proposed project area consists of a C4 stream type. However, as the creek approaches the downtown portion of Livingston Manor, the floodplain is confined by buildings and infrastructure. As a result, a B4c stream type was designed because it requires less floodplain area to dissipate stream energy.

3. In-Stream Structures

Rock and log structures are in-stream structures, made of natural materials, used to divert erosive stream flows away from stream banks and maintain streambed elevations. The most typical rock and log structures used in stream restoration are cross-vanes, j-hooks and toe wood. The rock and log structures provide streambed and bank stability, and allow the streambed to naturally armor and the riparian vegetation to establish.

The Service has determined that cross-vanes are only required at utility crossings to maintain grade and the rest of the project area will utilize toe wood and wood j-hook structures to promote stability and increase aquatic habitat. The locations of these structures were determined by matching the naturally occurring pool-to-pool spacing and strategically placing them in areas that would exhibit higher shear stress values during high flow events.

a. Cross-Vane

The cross-vane (**Figure 4**) will establish grade control, reduce bank erosion, create a stable width/depth ratio, and maintain channel capacity while also maintaining sediment transport capacity and sediment competence. The cross-vane also provides the proper natural conditions of secondary circulation patterns commensurate with channel pattern, but with high velocity gradients and boundary stress shifted from the near-bank region. The cross-vane also provides stream habitat improvement through: 1) increasing bank cover as a result of the differential raise of the water surface in the bank region; 2) creating holding and refuge cover during both high and low flow periods in deep pools; 3) developing feeding lanes in flow separation zones (the interface between fast and slow water) due to the strong down welling and upwelling forces in the center of the channel; and 4) creating spawning habitat in the tail-out or glide portion of pools (Rosgen, D.L.). While the figure below shows a structure consisting of large boulders, the Cross-Vane can be constructed using other materials such as logs and rootwads.

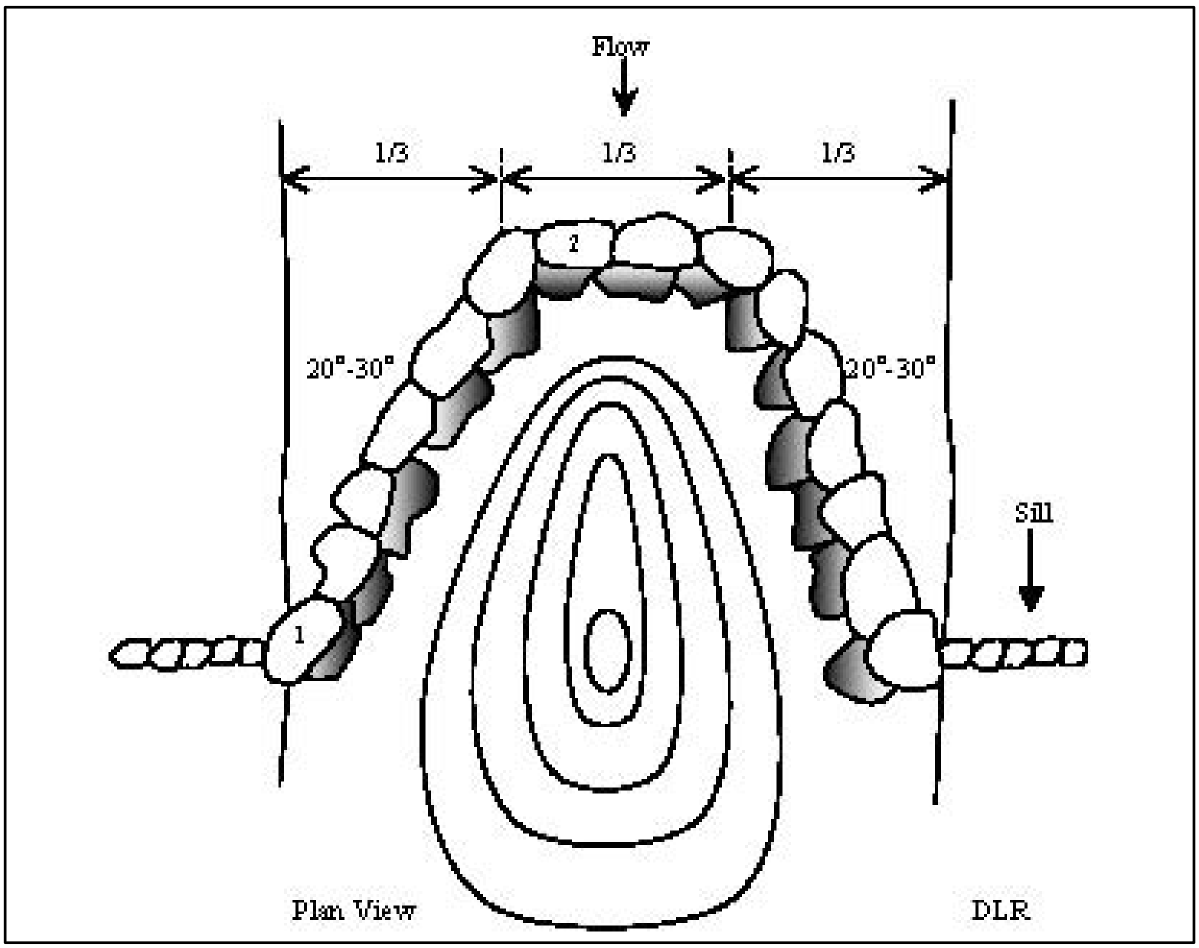

Figure 4. Cross-Vane in Plan View

b. J-Hook

The J-hook vane is an upstream directed, gently sloping structure composed of natural materials. The structure can include a combination of boulders, logs and root wads (Figures 6-7) and is located on the outside of stream bends where strong down welling and upwelling currents, high boundary stress, and high velocity gradients generate high stress in the near-bank region. The structure is designed to reduce bank erosion by reducing near-bank slope, velocity, velocity gradient, stream power and shear stress. Redirection of the secondary cells from the near-bank region does not cause erosion due to back-eddy re-circulation. The vane portion of the structure occupies 1/3 of the bankfull width of the channel, while the "hook" occupies the center 1/3 as shown in **Figure 5** (Rosgen, D.L.).

Maximum velocity, shear stress, stream power and velocity gradients are decreased in the near-bank region and increased in the center of the channel. Sediment transport competence and capacity can be maintained as a result of the increased shear stress and stream power in the center of the channel. Backwater is created only in the near-bank region, reducing active bank erosion (Rosgen D. L.). While the figure below shows a structure consisting of large boulders, the J-hook vane can be constructed using other materials such as logs and root wads.

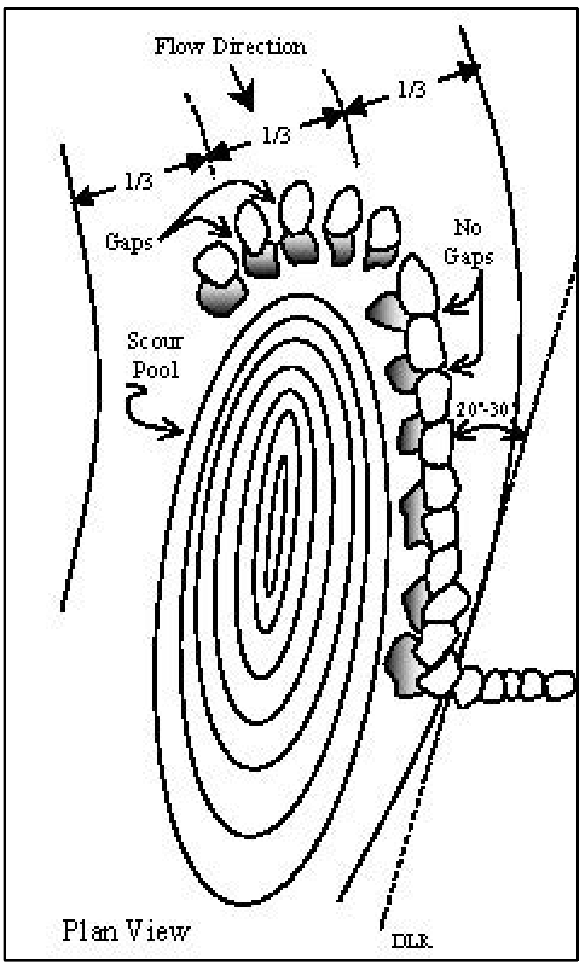

Figure 5. J-Hook Vane in Plan View

c. Toe Wood

The toe wood structure (**Figure 6**) incorporates native woody material into a submerged undercut bank to replicate natural stream banks. Toe wood is positioned on the lower 1/3 to 1/2 of bank height to ensure it is submerged year round to prevent wood deterioration. Cuttings with sod and live staking or woody transplants cover the toe wood and are installed up to the bankfull stage. Not only does toe wood act as an area of increased roughness which promotes reduction in shear stresses to the outside of the meander, it also serves as a haven for benthic macroinvertebrates and fish communities.

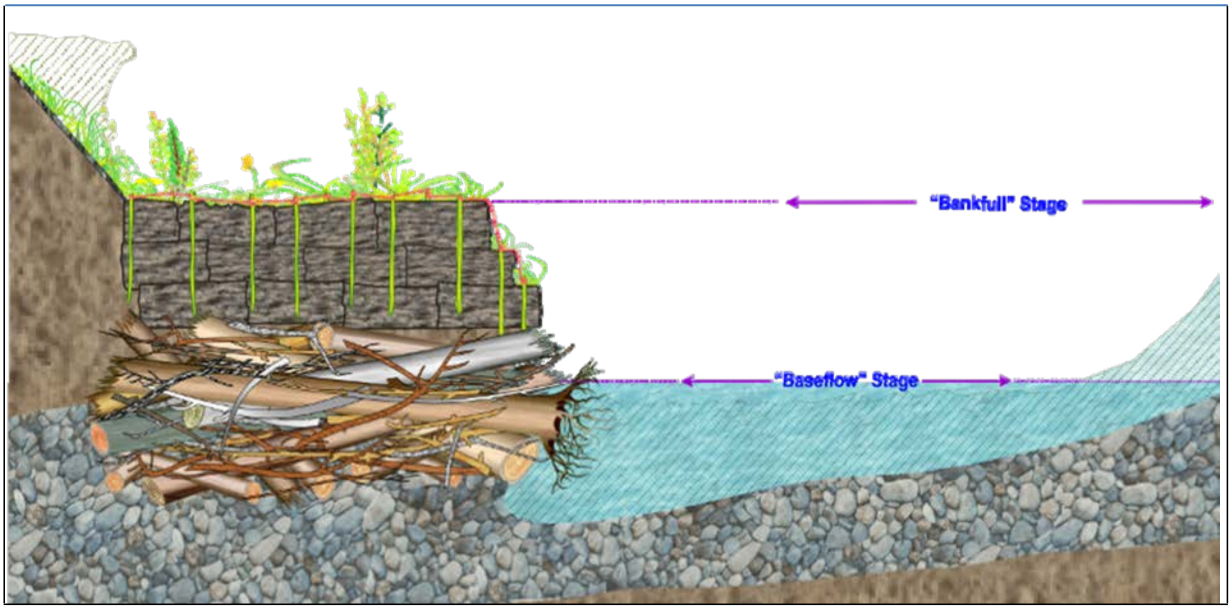

Figure 6. Toe Wood Cross Section View

4. Hydrologic and Hydraulic Analysis

Since this is only a 30 percent concept design, the Service only conducted limited Hydraulic (H&H) Analyses and the Hydrologic analysis was completed by the COE. The Service focused on validating bankfull flow and channel characteristics, and properly sizing the stream channel to transport the sediment supply.

Evaluating the hydraulics of a stream system is an important component to any assessment because it gives a better understanding of how water and sediment are transported through the channel and its associated floodplain. Since the design methodology used for this project is NCD, bankfull validation is required before conducting the hydraulic analysis.

a. Bankfull Validation

Bankfull discharge characterizes the range of discharges that is effective in shaping and maintaining a stream. Over time, geomorphic processes adjust the stream capacity and shape to accommodate the bankfull discharge within the stream. Bankfull discharge is strongly correlated to many important stream morphological features (e.g., bankfull width, drainage area, etc.) and is the critical parameter used by the Service in assessing Little Beaver Kill. Bankfull discharge is also used in natural channel design procedures as a scale factor to convert morphological parameters from a stable reach of one size to a disturbed reach of another size. The Service used *Regional Relationships* as well as *Resistance Relationships* to determine the bankfull discharge and channel dimension at Little Beaver Kill.

i. Geomorphic Indicators

During the Little Beaver Kill assessment, the Service identified bankfull stage using geomorphic indicators formed by the stream as described by McCandless and Everett (2002). **Figure 7** depicts significant geomorphic indicators typically found in the Mid-Atlantic. Based on these indicators, the Service identified a consistent geomorphic feature at Little Beaver Kill and recorded the information on the geomorphic maps (Appendix B). This geomorphic indicator was typically a significant slope break or back of bench found throughout the project area. The Service then measured the water surface to bankfull geomorphic elevation distance with a range of 2.3 to 2.7 feet consistently through the project area. Riffle cross sections were surveyed to calculate channel dimensions (i.e., width, depth, and area) associated with this geomorphic indicator. The riffle cross dimensions were then compared to the Catskills, New York regional curve (Miller et al, 2003). Details of this comparison are described below in section III.D.5.ii. – Resistance Relationships.

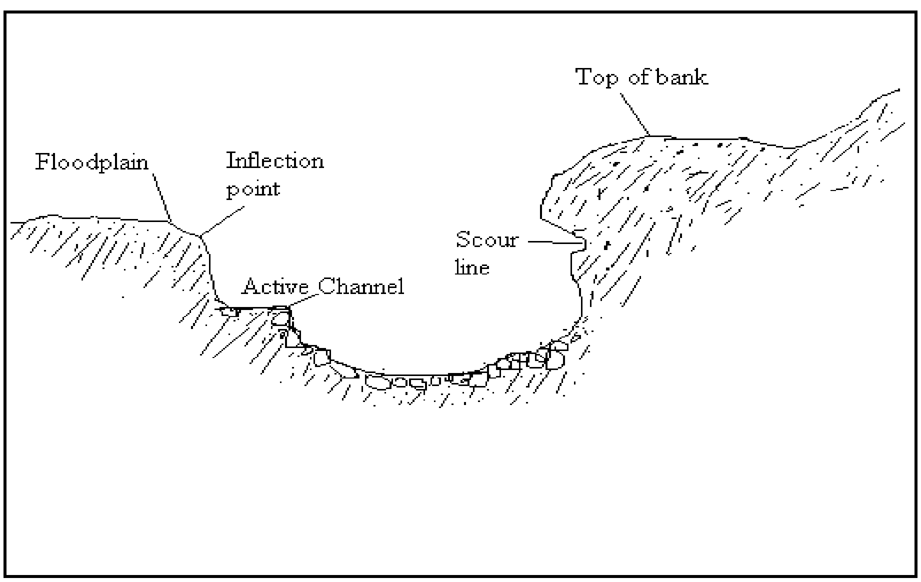

Figure 7. Typical Bankfull Indicators (McCandless and Everett 2002)

ii. Resistance Relationships

There are several methods to estimate bankfull discharge and velocity using resistance relationships. These methods typically make use of the cross sectional area, flow depth, representative particle size of channel substrate, channel slope and a determined roughness coefficient, or "friction factor". The Service used the Roughness Coefficient equation to determine discharge. This equation, $u = 1.49 * R^{2/3} * S^{1/2}/n$, uses the hydraulic radius of the representative cross section, the channel slope and a known Manning's *n* (based on friction factor/relative roughness) to determine velocity and discharge values. The Service surveyed two reference riffles upstream of that project area and three riffles located through the project area to calculate bankfull discharge and channel dimensions. Table 11 shows the results of the resistance analysis. Detailed information can be found on the *Computation of velocity and bankfull discharge* worksheets in Appendix D.

Surveyed Cross Section	Channel Dimensions			Mannings "n"	Velocity (ft/sec)	Discharge (cfs)
	Mean Depth (ft)	Width (ft)	Area (sqft)			
Reference XS 1	2.88	54	156	N/A	N/A	N/A
Reference XS 2	2.85	49	139	N/A	N/A	N/A
Project XS 1	2.47	62	153	0.03	4.81	736
Project XS 2	1.52	104	158	0.03	3.50	553
Project XS 3	2.47	59	145	0.03	4.75	688
Regional Curve Bankfull Data (NYDEP Region 4a)	2.57	58	144	N/A	5.72	823
Proposed Riffle Design	2.70	55	150	0.03	5.20	780

Table 11. Bankfull Validation

iii. Regional Relationships

The regional curve estimates channel discharge based on a linear regression equation derived from gaged sites across the same physiographic region with similar characteristics. Using only the drainage area, the Service was able to derive the estimated channel width, depth, cross sectional area and discharge using the Catskills, New York regional curve (Miller et al, 2003) (Table 11). This information was then compared to the field measured riffle cross section to validate bankfull dimension and discharge.

iv. Bankfull Validation

Based on the bankfull analysis, the Service determined that the bankfull or channel forming flow for Little Beaver Kill ranges between 553 and 736 cfs. This discharge range generally corresponds well with the regional curve. Reach 2 is somewhat low because of the channel characteristics associated with this reach. Reach 2 is a braided system with a high width/depth ratio that typically results in lower discharge calculations. More importantly though, is how closely the surveyed cross section channel dimensions correspond with the regional curve. Estimating discharge has a higher range of error due to the sensitivity of the factors used in calculating discharge. Measurement of cross section area is more precise and a better indicator for validating bankfull.

5. Sediment Analysis

Since this project is resulting in only a 30 percent complete design, the Service conducted a limited sediment analysis. The Service calculated sediment competency and estimated sediment capacity based on observations.

i. Sediment Competency

The Service conducted a sediment competency analysis at two locations within the project area and one location approximately 1000 feet upstream of the project area to determine shear stress and required channel depths and slopes (at bankfull stage) to move the largest particle size collected as part of the bar samples (Appendix E). Table 13 shows the results of the riffle pebble counts and bar samples surveyed for each area. Table 14 shows the existing and predicted shear stresses, and existing and required water surface slopes and mean depths.

Initial competency findings for the Little Beaver Kill resulted in three different conditions (Table 13). Project cross section 1 (located upstream of the project area) calculations showed that the reach had the required depth and slope to initiate movement of its largest particle size. Project cross section 2 (located in project assessment reach 2) calculations showed that the reach did not have the required depth and slope to initiate movement of its largest particle size and therefore is aggrading. This was further supported by field observed depositional patterns with significant bar formations, including mid-channel, lateral, and point bars. Project cross section 3 (located in project assessment reach 4) calculations showed that the reach had depths greater required to initiate movement of its largest particle size and therefore is degrading.

The objective of sediment transportation for the project is to design Little Beaver Kill Creek with the competency to entrain the largest measured particle sizes found in the bar samples. The bar sample, riffle pebble count, and water surface slope from project cross section 1 were used to calculate required depth and slope for the proposed riffle channel dimension because its location is the farthest upstream (outside of the influence of the first pond) and best represents the sediment supply being delivered to the project area. Furthermore, the predicted particle size that can be moved within this location (using Rosgen's power trend line on Shields critical shear stress relationship) is 106 mm which is just slightly smaller than the largest particle size (125 mm) collected in the bar sample. This ensures the channel will not degrade or aggrade over time.

The entrainment calculations (Table 14) show that the proposed riffle channel dimensions are similar to the required dimensions. This level of entrainment calculations is adequate for a 30% design, but a further detailed analysis is needed to verify competency for the 100% final design.

ii. Sediment Capacity

As stated above, the Service only estimated sediment capacity based on observations. The results of the observations were described earlier in the report under section II.A. Watershed Assessment. The findings showed that the project area has a moderate sediment supply. Furthermore, the Service recommended that a sediment yield curve be developed before final designs are developed to ensure that the sediment supply is adequately addressed to meet project goals and objectives. Specifically, to ensure aggradation does not occur within the town limits and effect potential flood levels.

Surveyed Cross Section	Riffle Pebble Count					Bar Sample					
	D15	D35	D50	D84	D100	D15	D35	D50	D84	D100	Largest Particle
Proj XS 1 - Bar Sample 1	11.3	26.36	45	180	2048	4.02	15.77	37.78	93.92	125	125
Proj XS 2 - Bar Sample 2	18.64	32.39	42.71	76.48	128	4.88	24.73	41.94	84.17	105	105
Proj XS 3 - Bar Sample 3	12.24	20.74	30.29	51.24	128	0	0	17.94	52.42	68	68

Table 12. Pebble and Bar Sample Data

Surveyed Cross Section	Dimensionaless Shear Stress (*t**)	*Existing Bankfull Shear Stress (t)*	*Predicted Bankfull Shear Stress (t)*	Existing Mean Depth (ft)	Required Mean Depth (ft)	Existing Slope (ft/ft)	Required Slope (ft/ft)
Proj XS 1 - Bar Sample 1	0.016	0.709	0.766	2.47	2.28	0.0046	0.00425
Proj XS 2 - Bar Sample 2	0.017	0.73	0.605	1.52	1.28	0.0077	0.00647
Proj XS 3 - Bar Sample 3	0.019	0.786	0.335	2.47	1.35	0.0051	0.00279
Prop Design Riffle - Bar Sample 1	0.016	0.775	0.7	2.7	2.28	0.0046	0.0039

Table 13. Entrainment Calculations

6. Vegetation Design

The riparian buffer is an integral part of the stream ecosystem, providing bank stability and nutrient uptake, serving as a food source for aquatic organisms, and providing terrestrial habitat and migration corridors for various types of wildlife, including migratory neotropical songbirds. Shading from the buffer moderates stream temperature and prevents excessive algal growth. Large woody debris derived from the buffer is an important component of aquatic habitat.

The COE is responsible for developing a stream restoration planting plan that utilizes native plant and shrub species in both the riparian and upland corridors. However, the Service did provide a minimum riparian buffer width needed for lateral stability based on the stream Meander Width Ratio (MWR) that is 3.5 times greater than the bankfull width (Refer to Little Beaver Kill 30% Design Plan set). It is important to note that the buffer will be planted parallel to the toe of valley rather than following the sinuosity of the stream channel.

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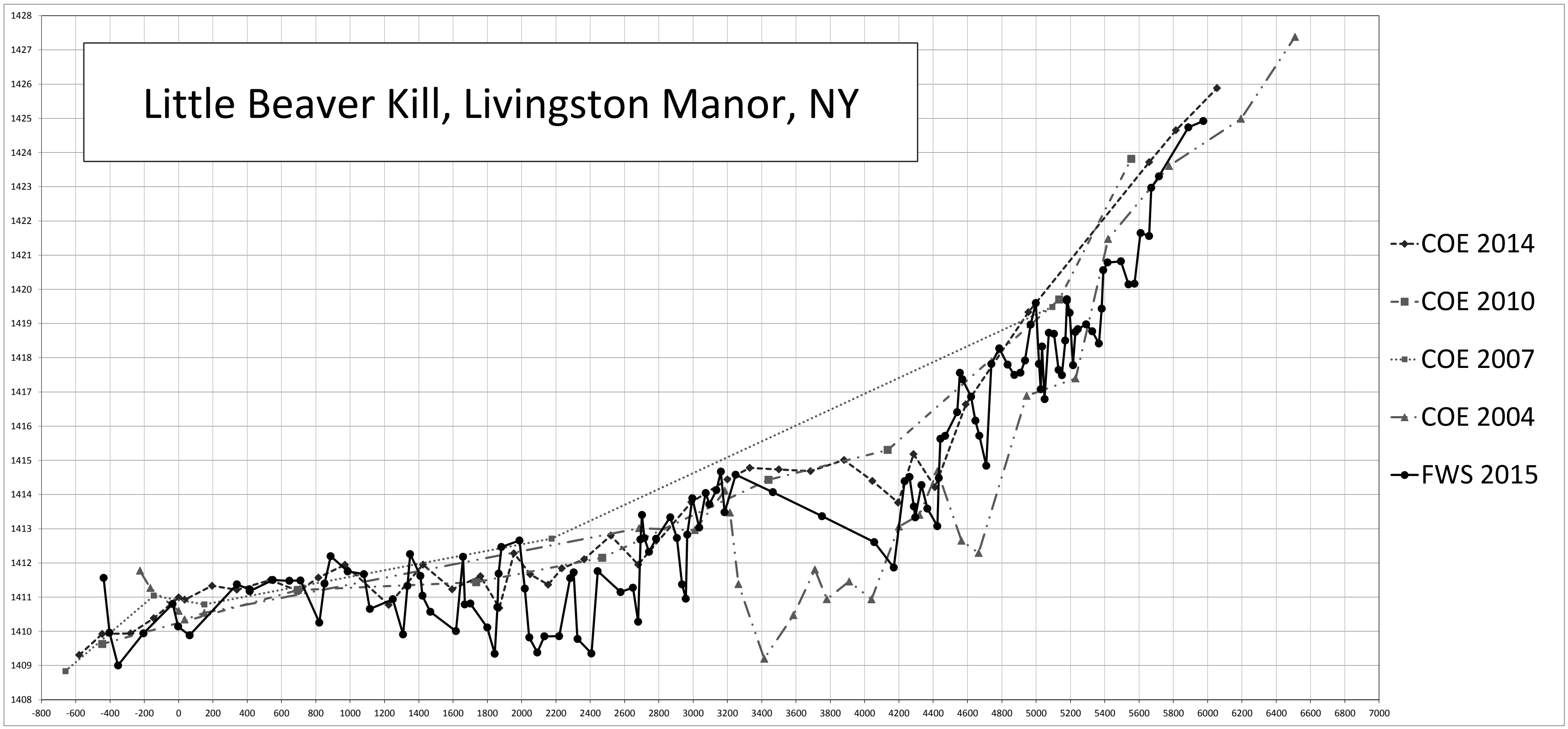
APPENDIX A



Little Beaver Kill, Livingston Manor, NY
COE 2014
COE 2010
COE 2007
COE 2004
FWS 2015
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1421
1420
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1418
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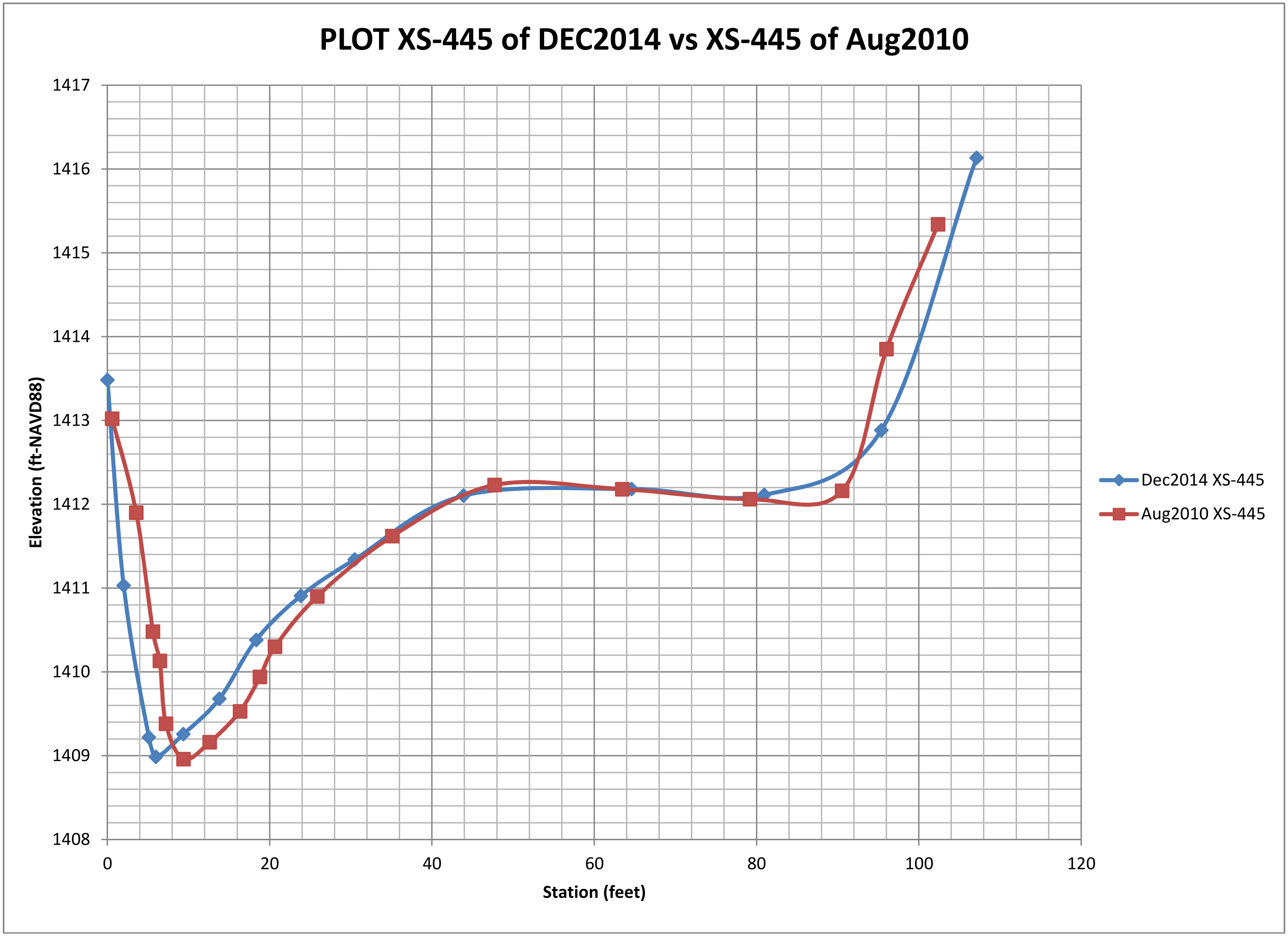
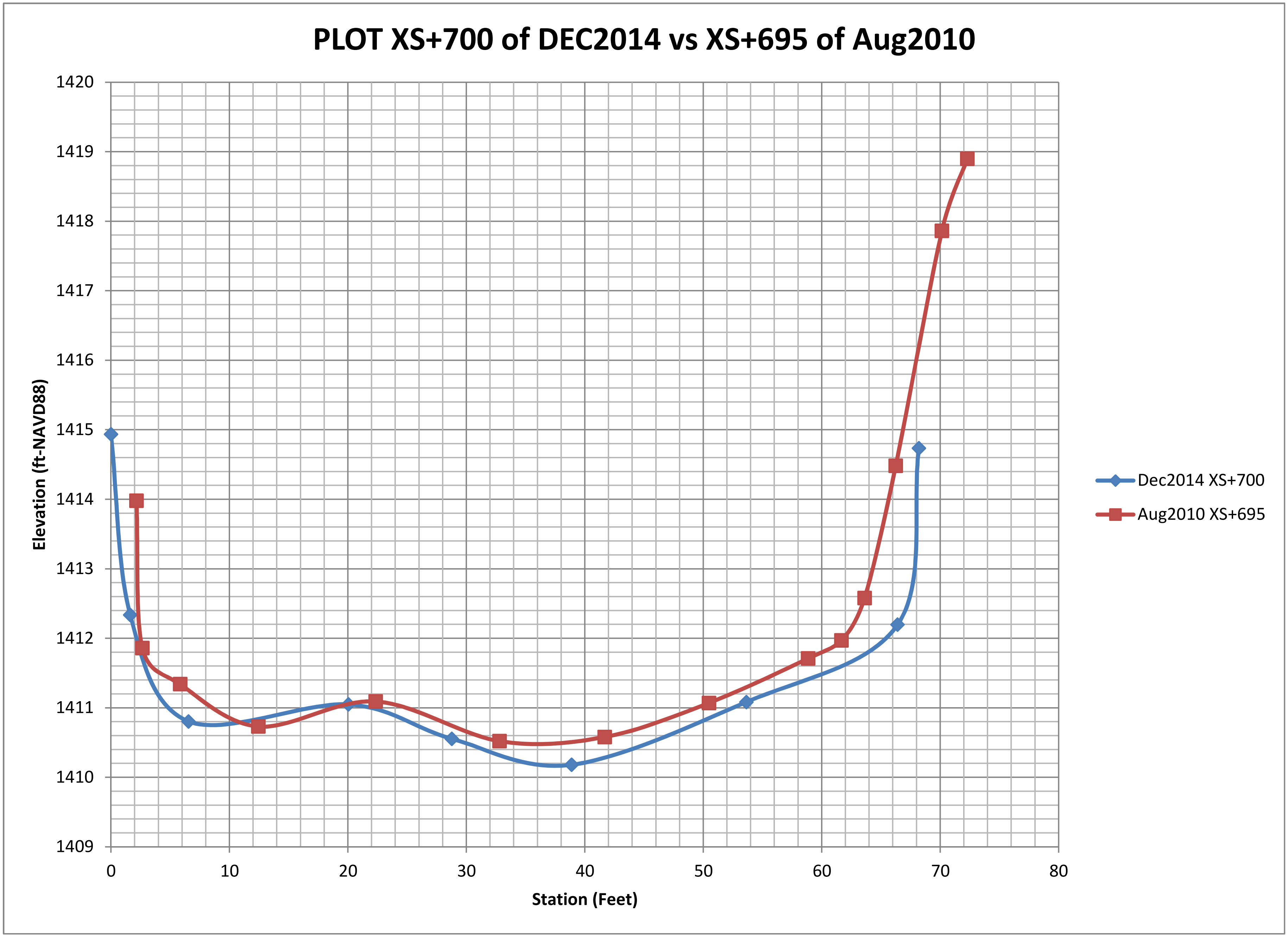
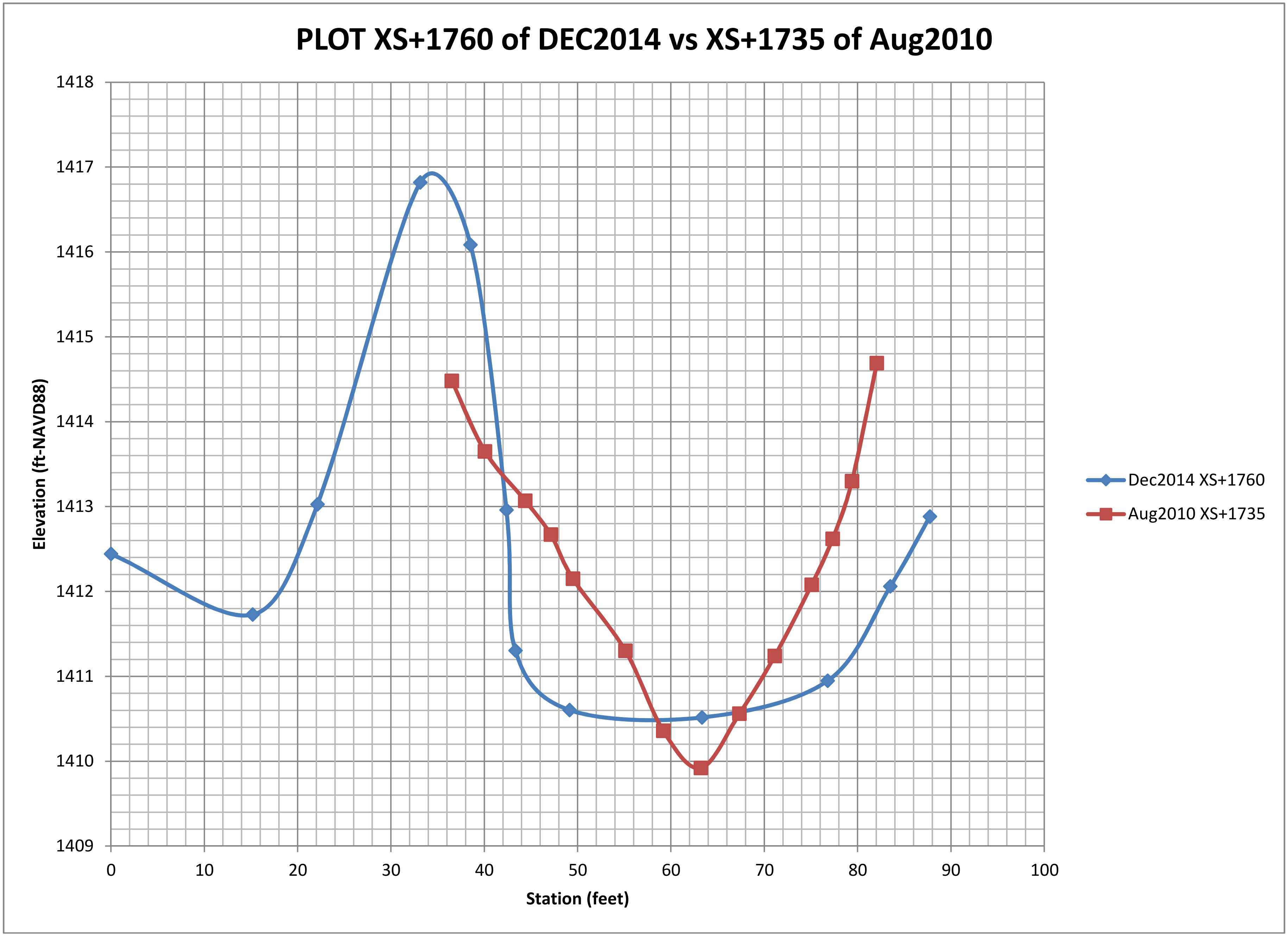


PLOT XS-445 of DEC2014 vs XS-445 of Aug2010
Elevation (ft-NAVD88)
1417
1416
1415
1414
1413
1412
1411
1410
1409
1408
0
20
40
60
80
100
120
Station (feet)
Dec2014 XS-445
Aug2010 XS-445


PLOT XS+700 of DEC2014 vs XS+695 of Aug2010
1420
1419
1418
1417
1416
1415
1414
1413
1412
1411
1410
1409
Elevation (ft-NAVD88)
0
10
20
30
40
50
60
70
80
Station (Feet)
Dec2014 XS+700
Aug2010 XS+695



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1416
1415
1414
1413
1412
1411
1410
1409
Elevation (ft-NAVD88)
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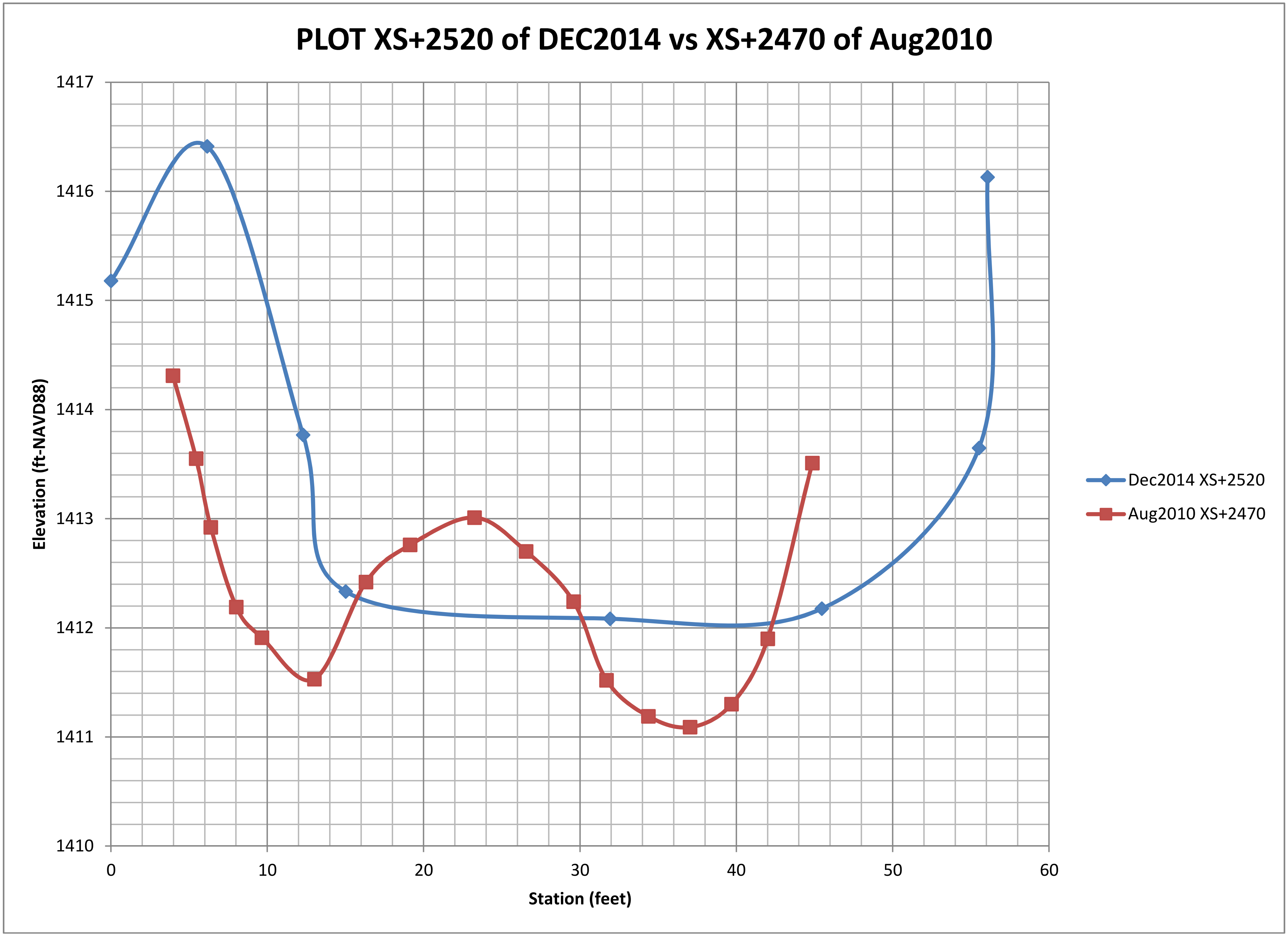
10
20
30
40
50
60
70
80
90
100
Station (feet)
Dec2014 XS+1760
Aug2010 XS+1735



PLOT XS+2520 of DEC2014 vs XS+2470 of Aug2010
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1415
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1411
1410
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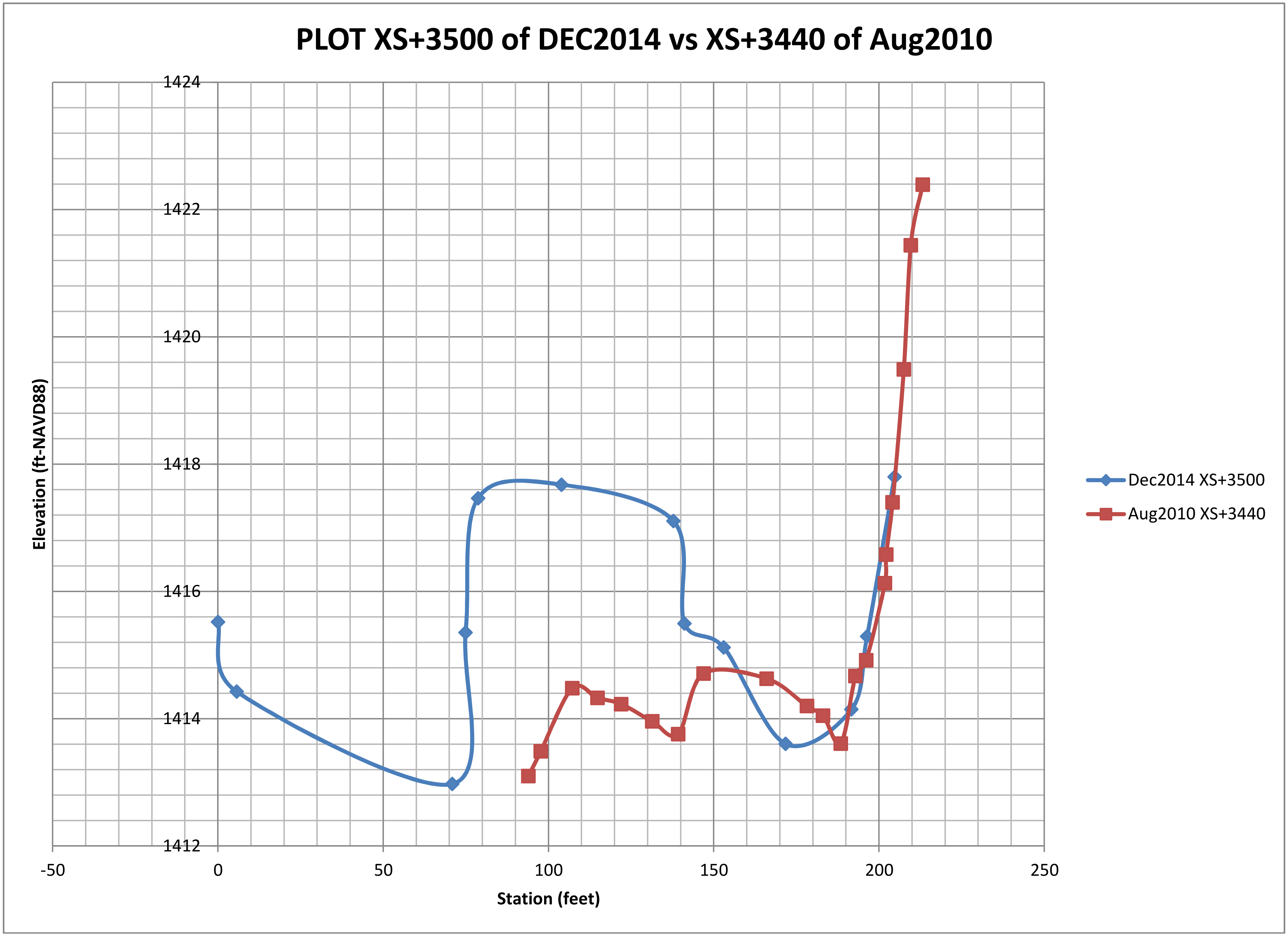
10
20
30
40
50
60
Station (feet)
Dec2014 XS+2520
Aug2010 XS+2470



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1420
1418
1416
1414
1412
Elevation (ft-NAVD88)
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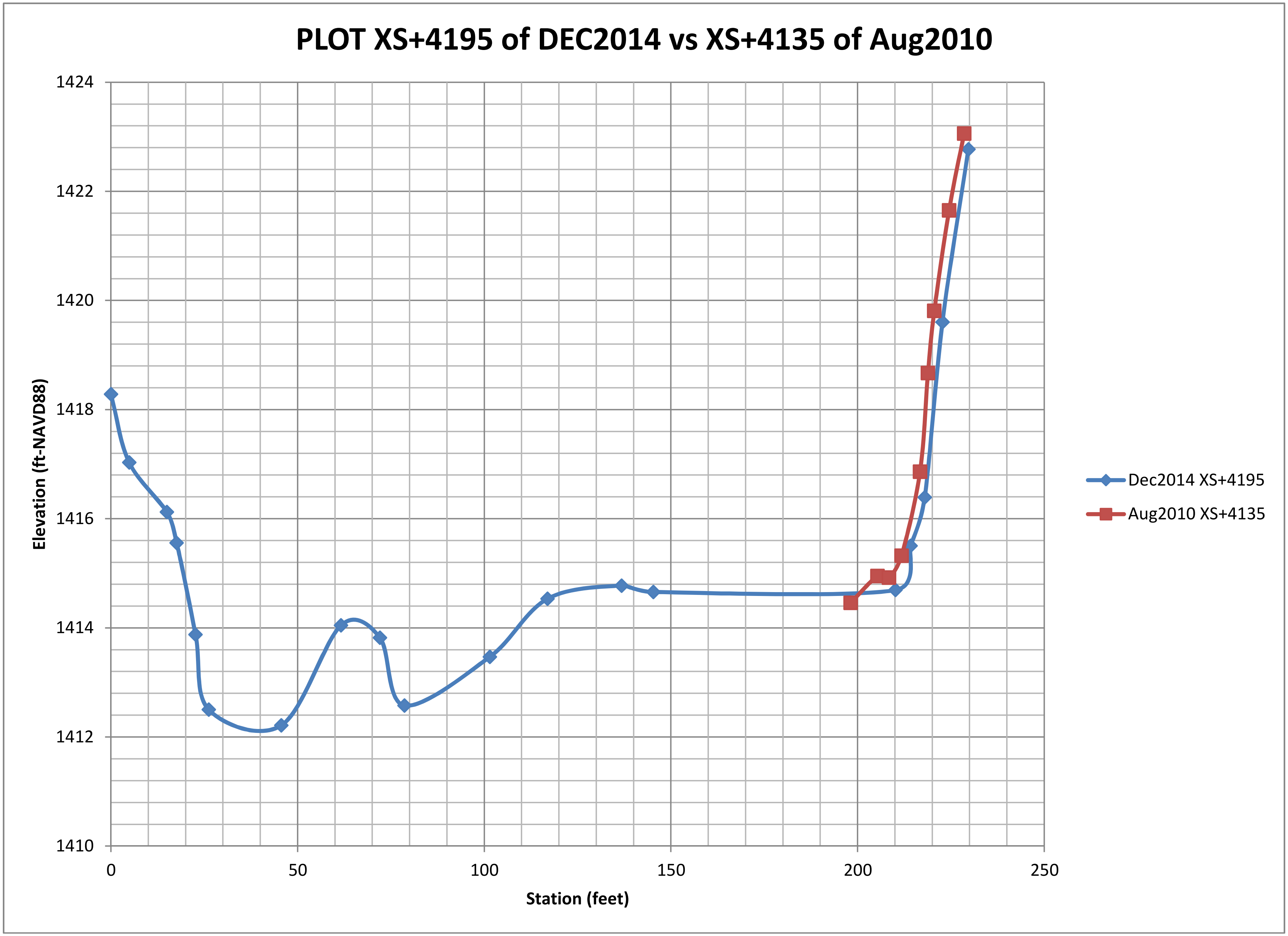
100
150
200
250
Station (feet)
Dec2014 XS+3500
Aug2010 XS+3440



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Elevation (ft-NAVD88)
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1422
1420
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1412
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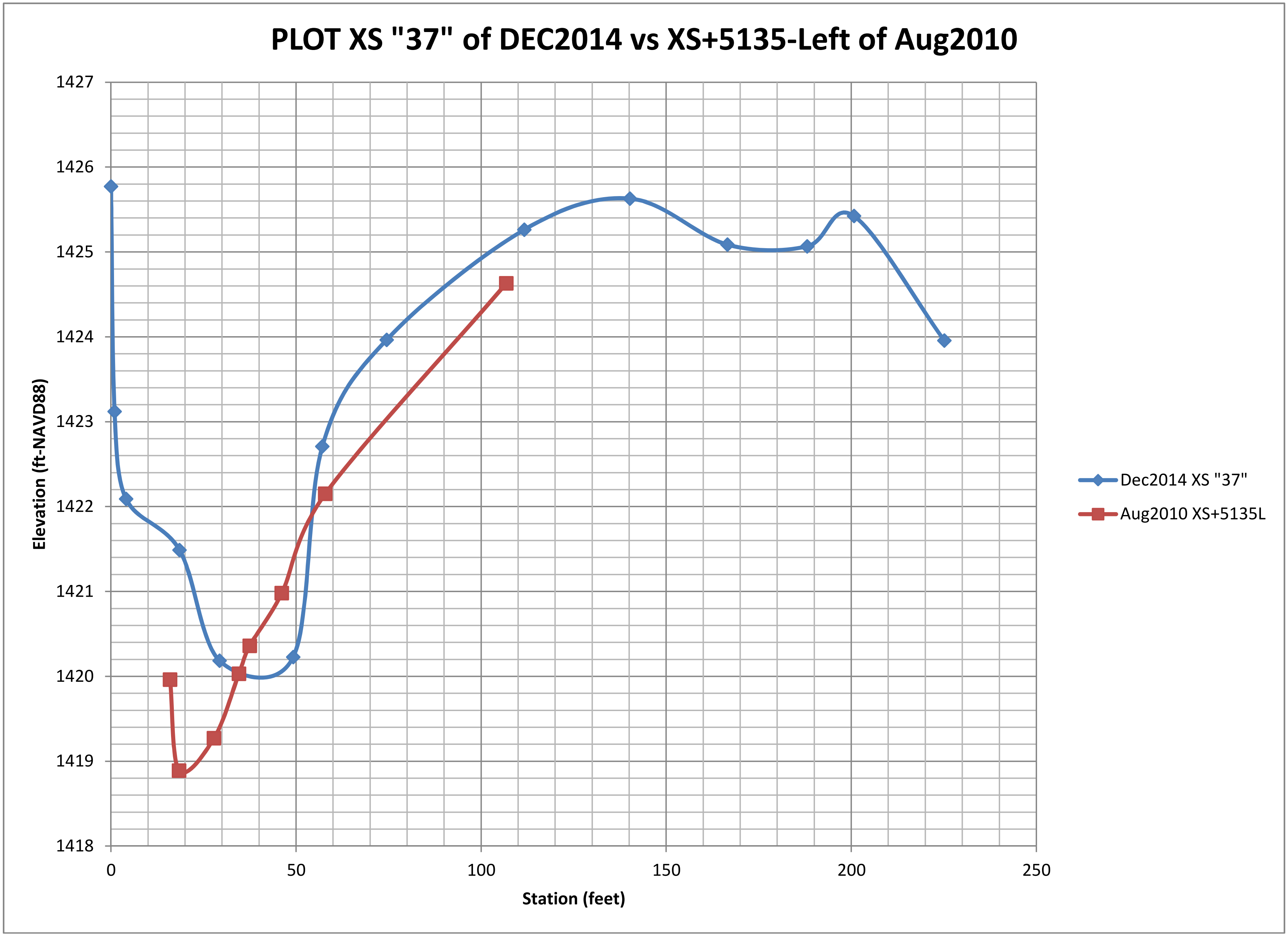
100
150
200
250
Station (feet)
Dec2014 XS+4195
Aug2010 XS+4135



PLOT XS "37" of DEC2014 vs XS+5135-Left of Aug2010
Elevation (ft-NAVD88)
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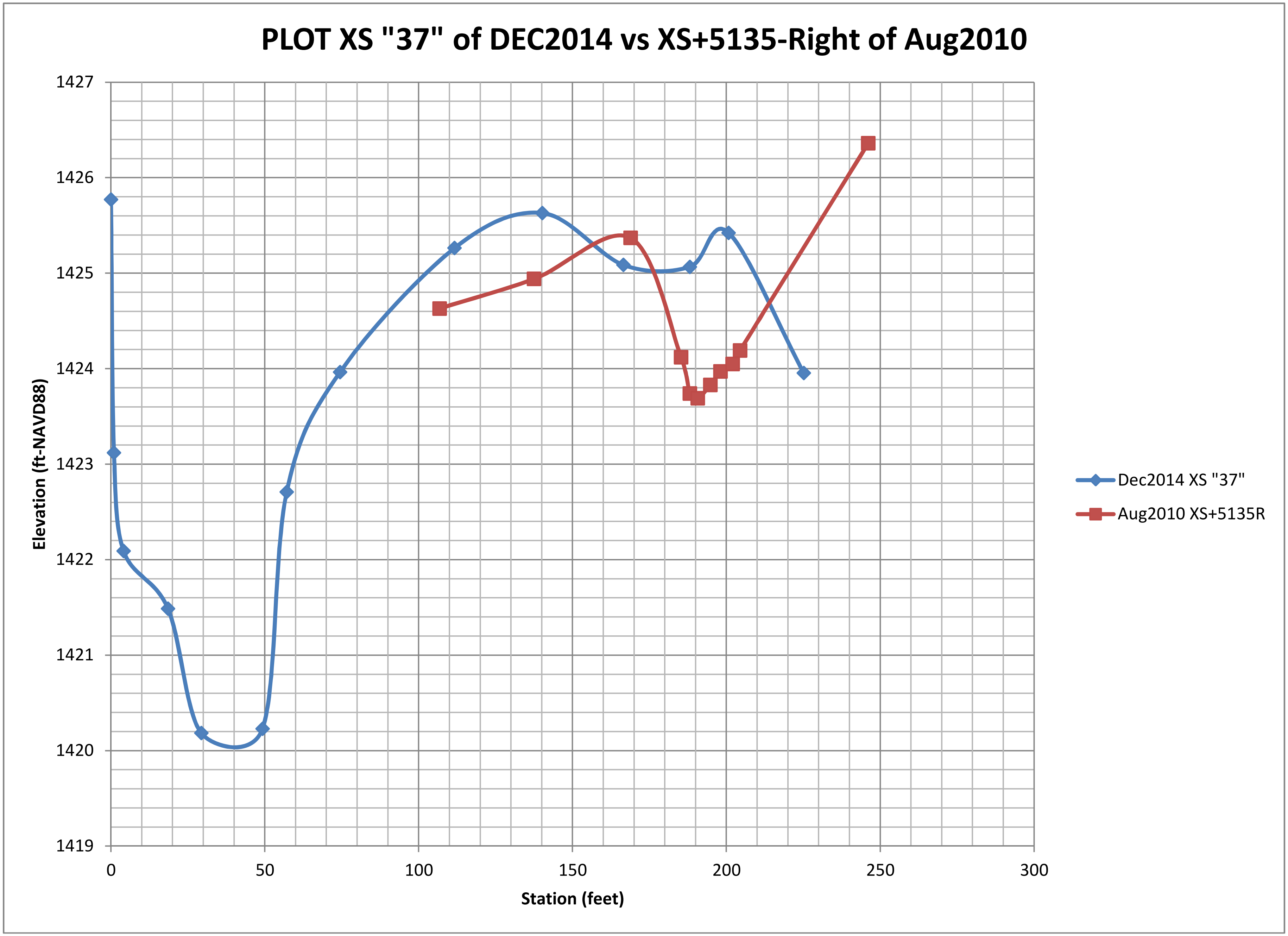
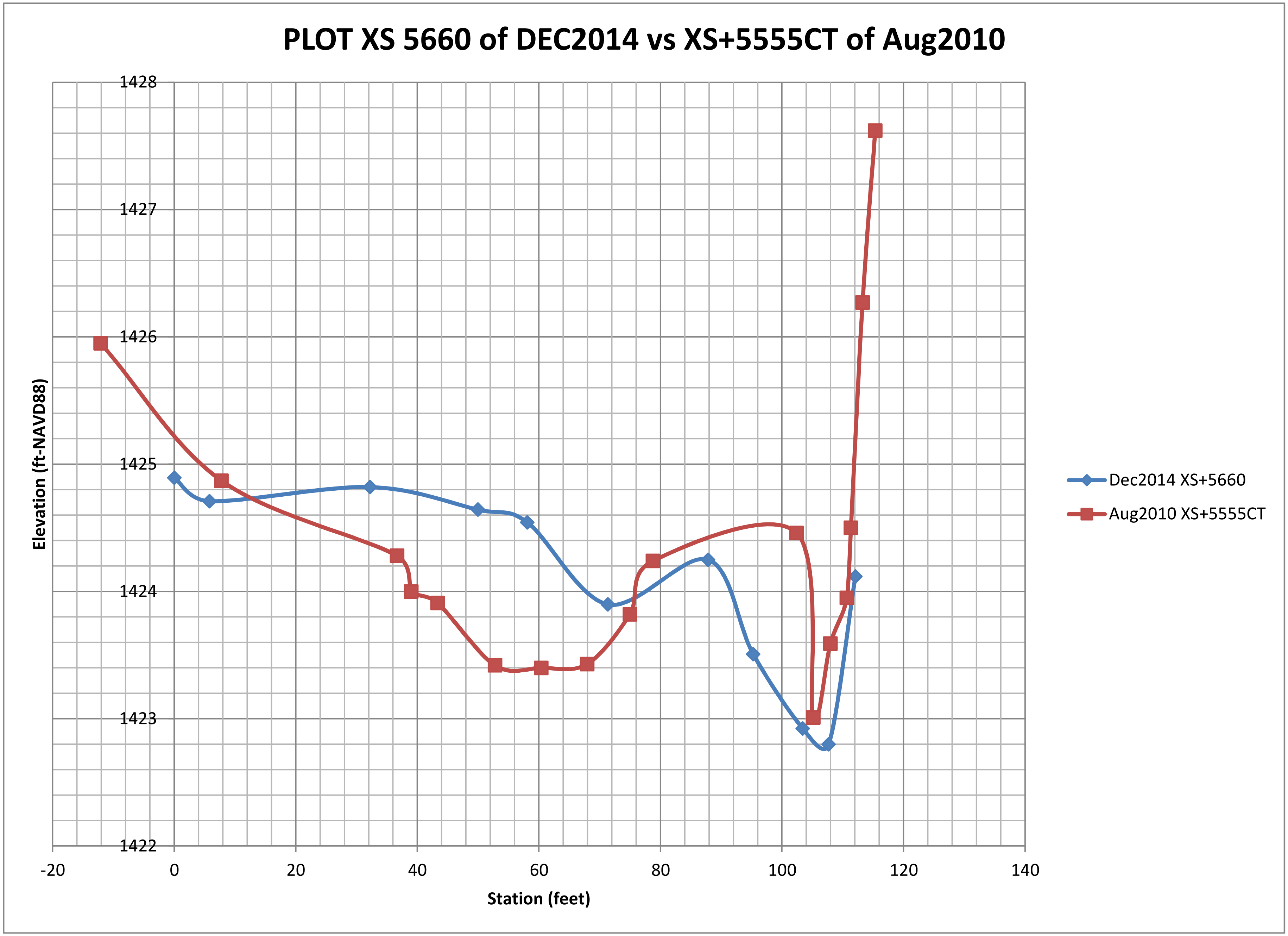
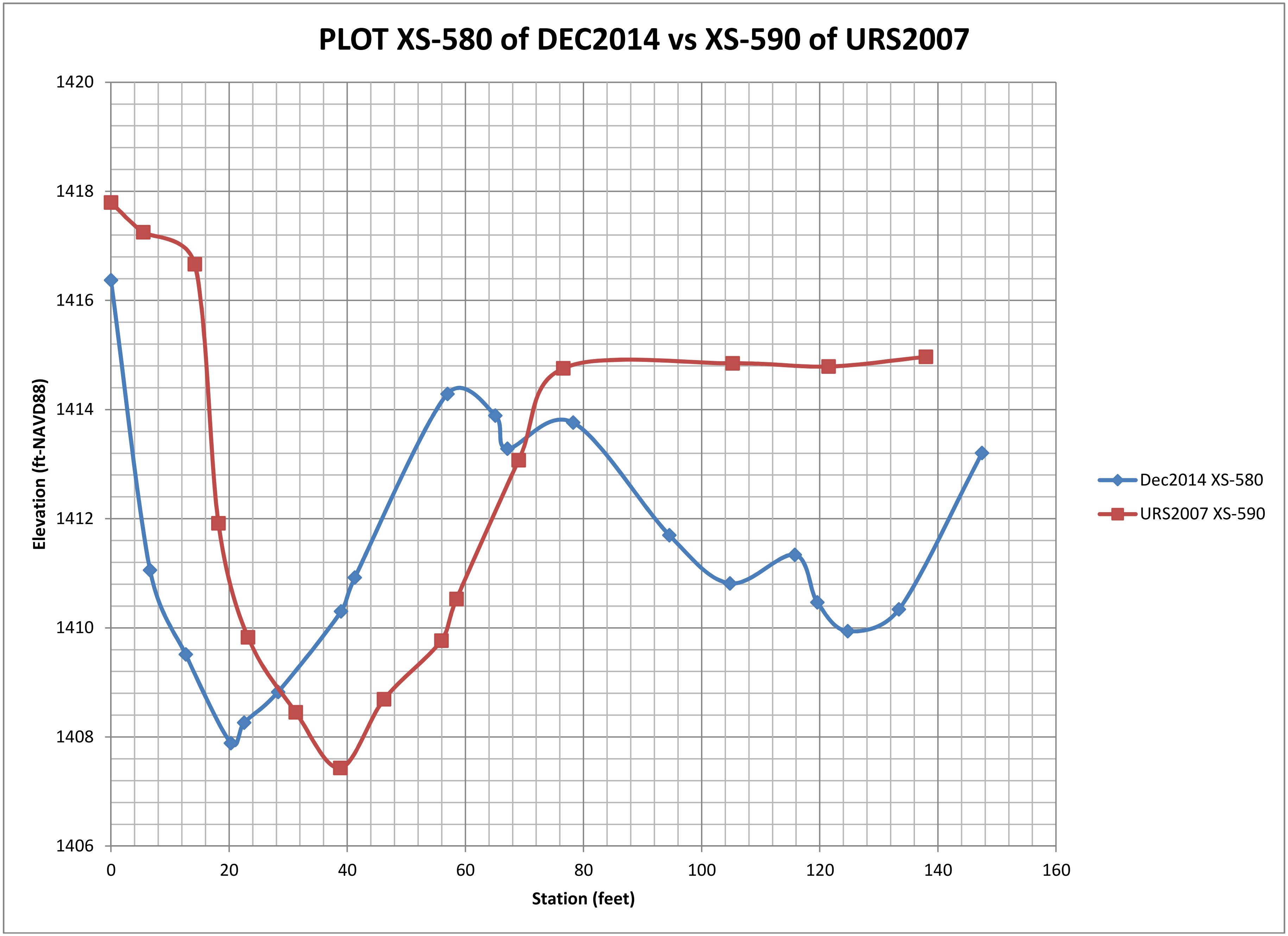
1419
1418
0
50
100
150
200
250
Station (feet)
Dec2014 XS "37"
Aug2010 XS+5135L

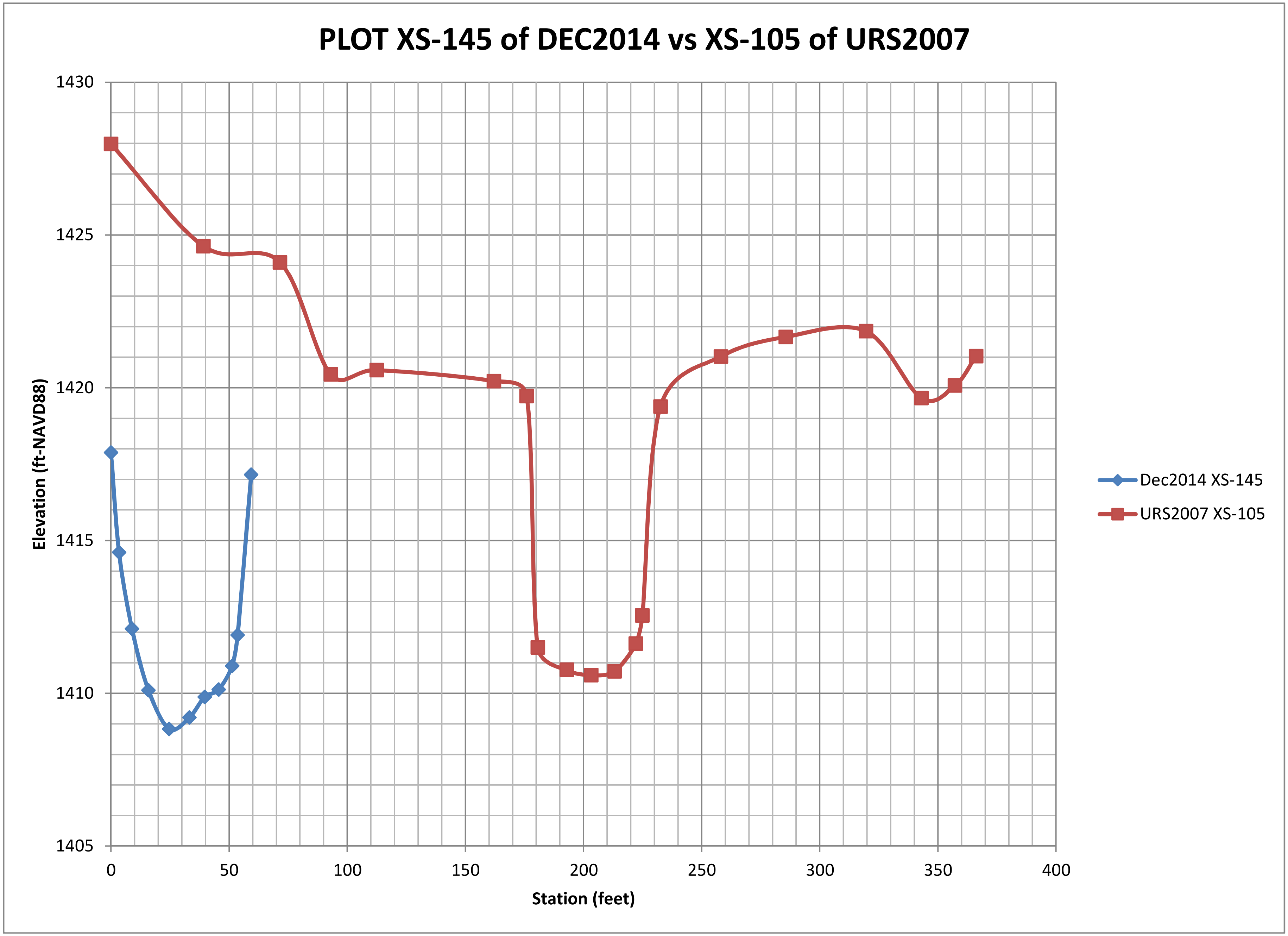


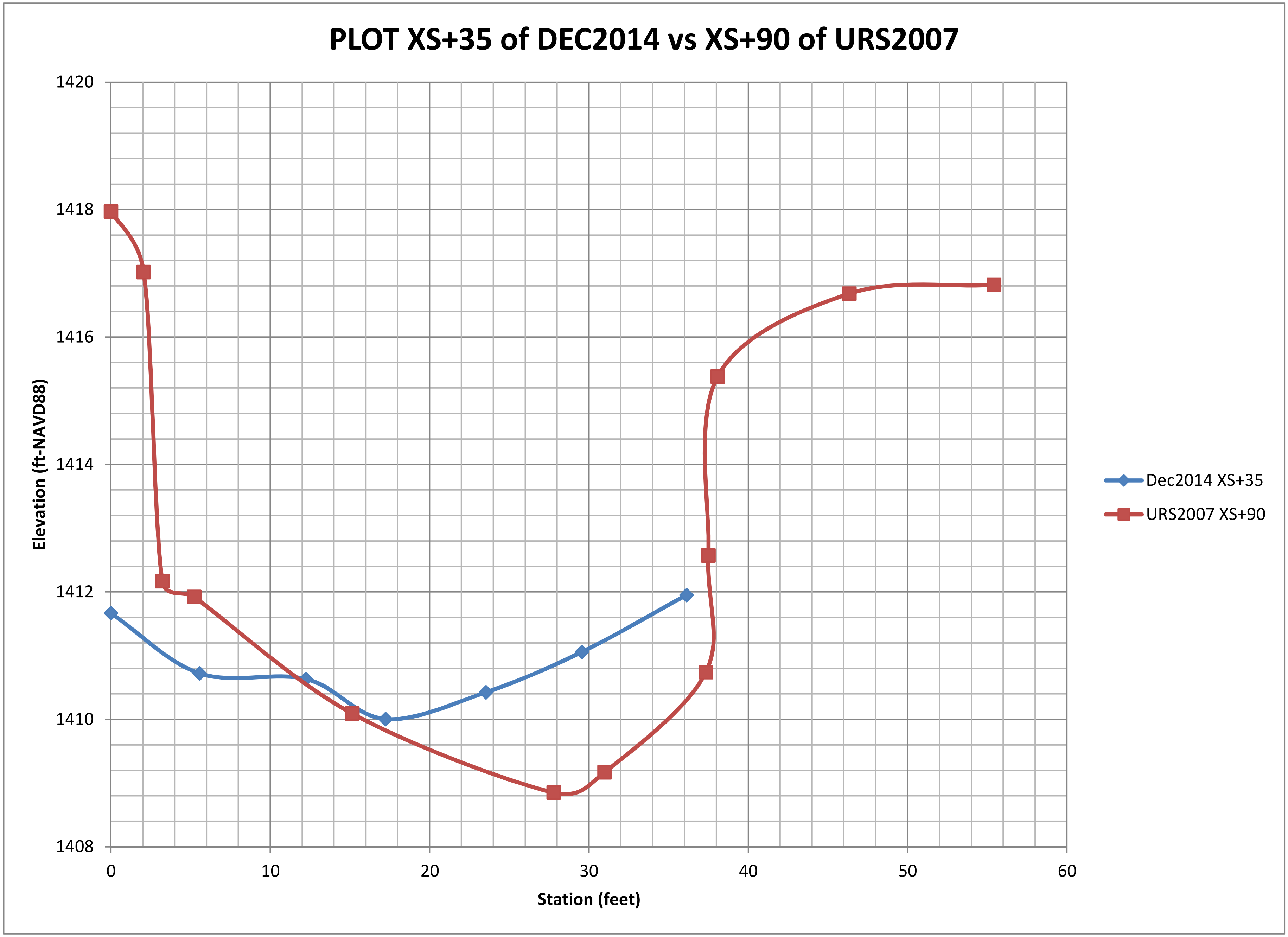
PLOT XS "37" of DEC2014 vs XS+5135-Right of Aug2010
1427
1426
1425
1424
1423
1422
1421
1420
1419
Elevation (ft-NAVD88)
0
50
100
150
200
250
300
Station (feet)
Dec2014 XS "37"
Aug2010 XS+5135R

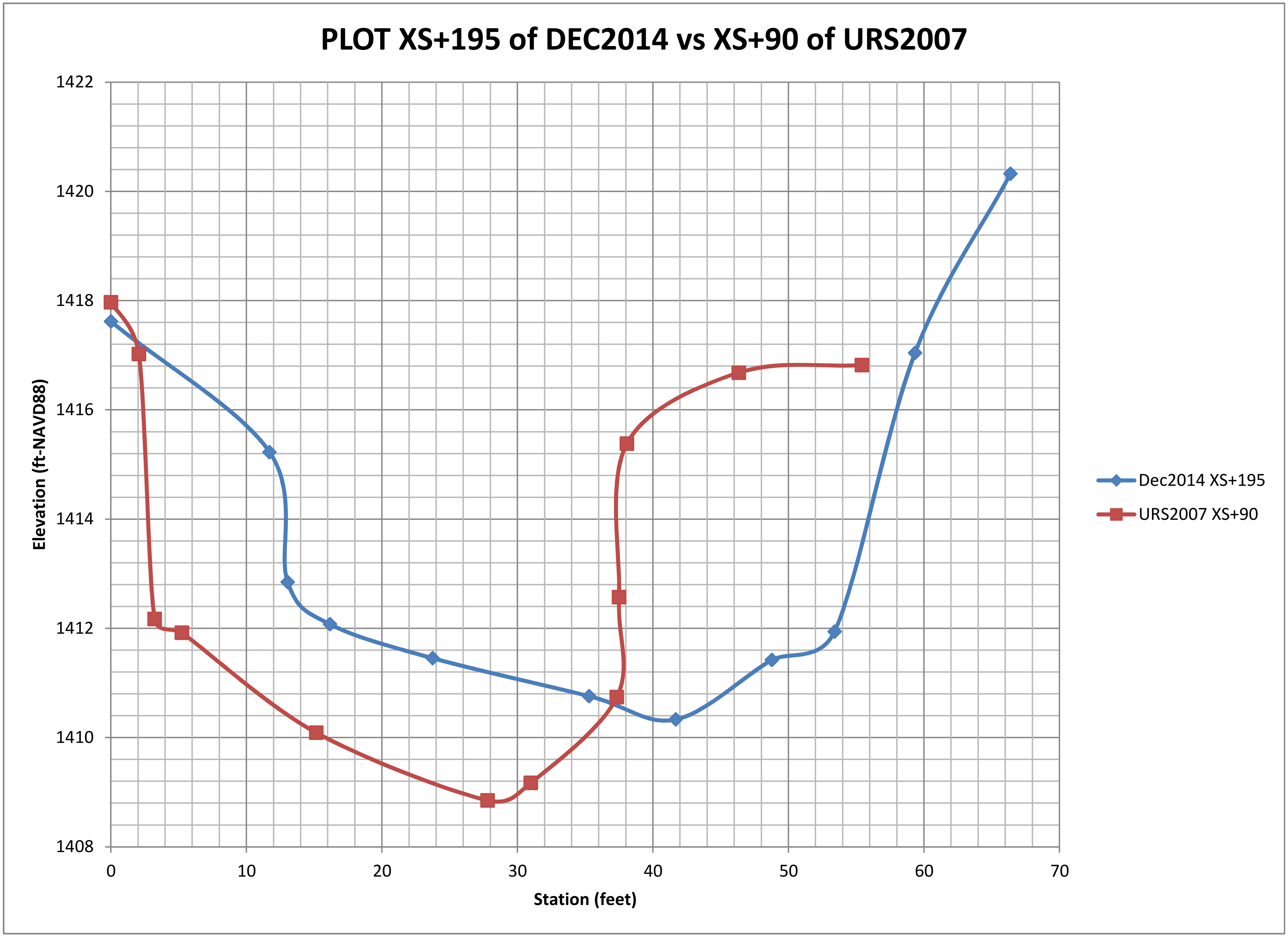


PLOT XS 5660 of DEC2014 vs XS+5555CT of Aug2010
1428
1427
1426
1425
1424
1423
1422
Elevation (ft-NAVD88)
-20
0
20
40
60
80
100
120
140
Station (feet)
Dec2014 XS+5660
Aug2010 XS+5555CT

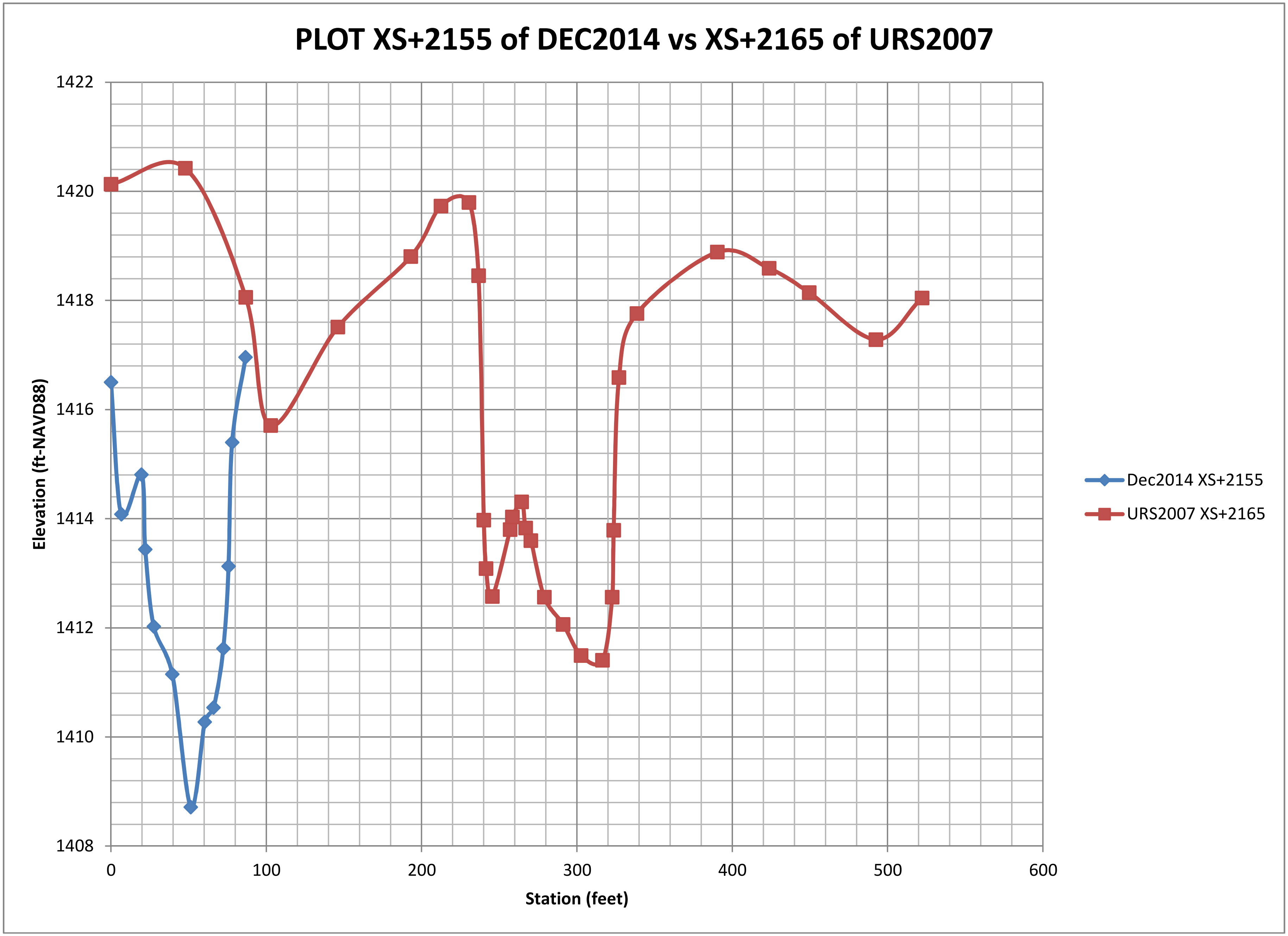

PLOT XS-580 of DEC2014 vs XS-590 of URS2007
1420
1418
1416
1414
1412
1410
1408
1406
Elevation (ft-NAVD88)
0
20
40
60
80
100
120
140
160
Station (feet)
Dec2014 XS-580
URS2007 XS-590

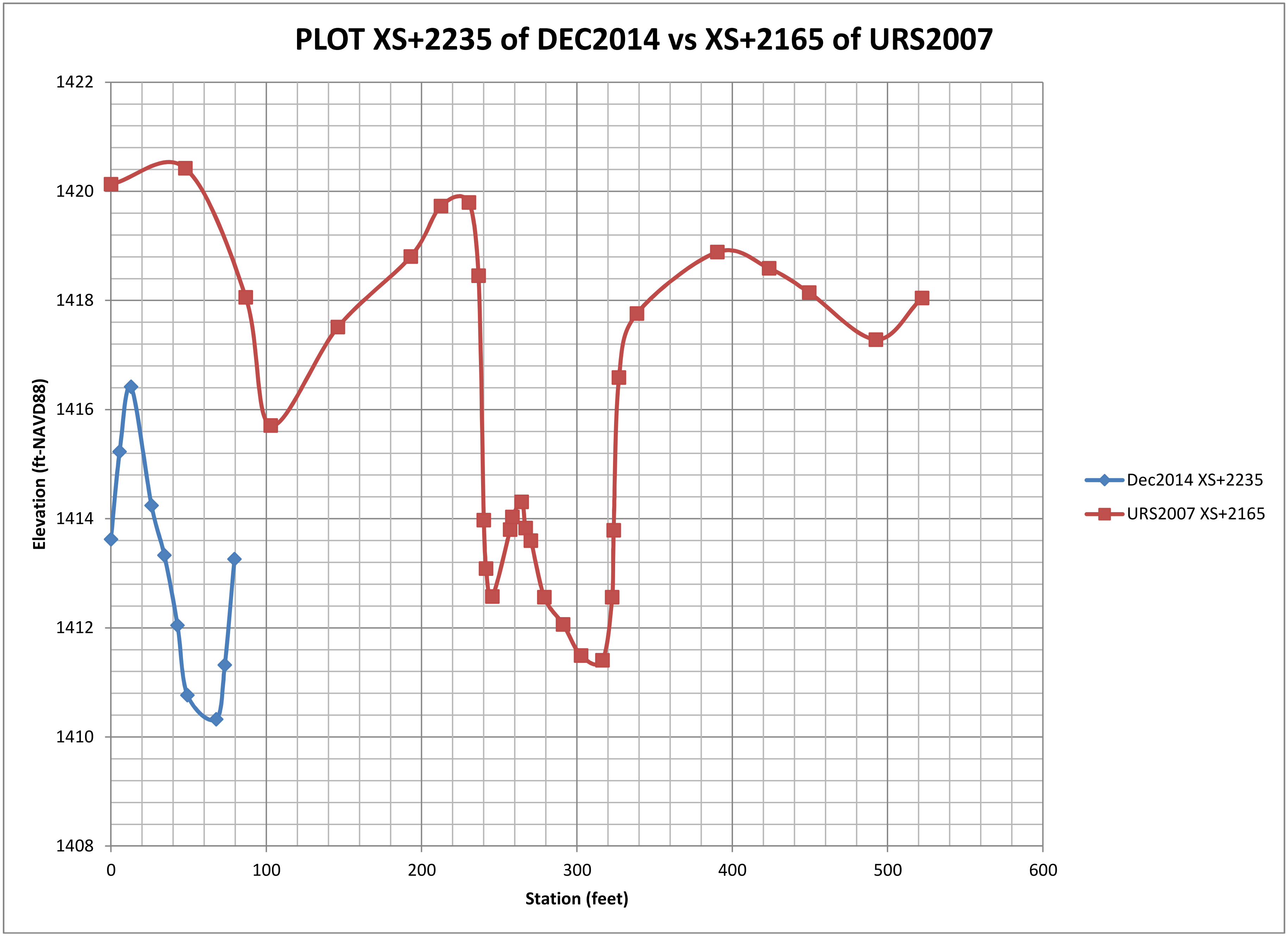

PLOT XS-145 of DEC2014 vs XS-105 of URS2007
1430
1425
1420
1415
1410
1405
Elevation (ft-NAVD88)
0
50
100
150
200
250
300
350
400
Station (feet)
Dec2014 XS-145
URS2007 XS-105

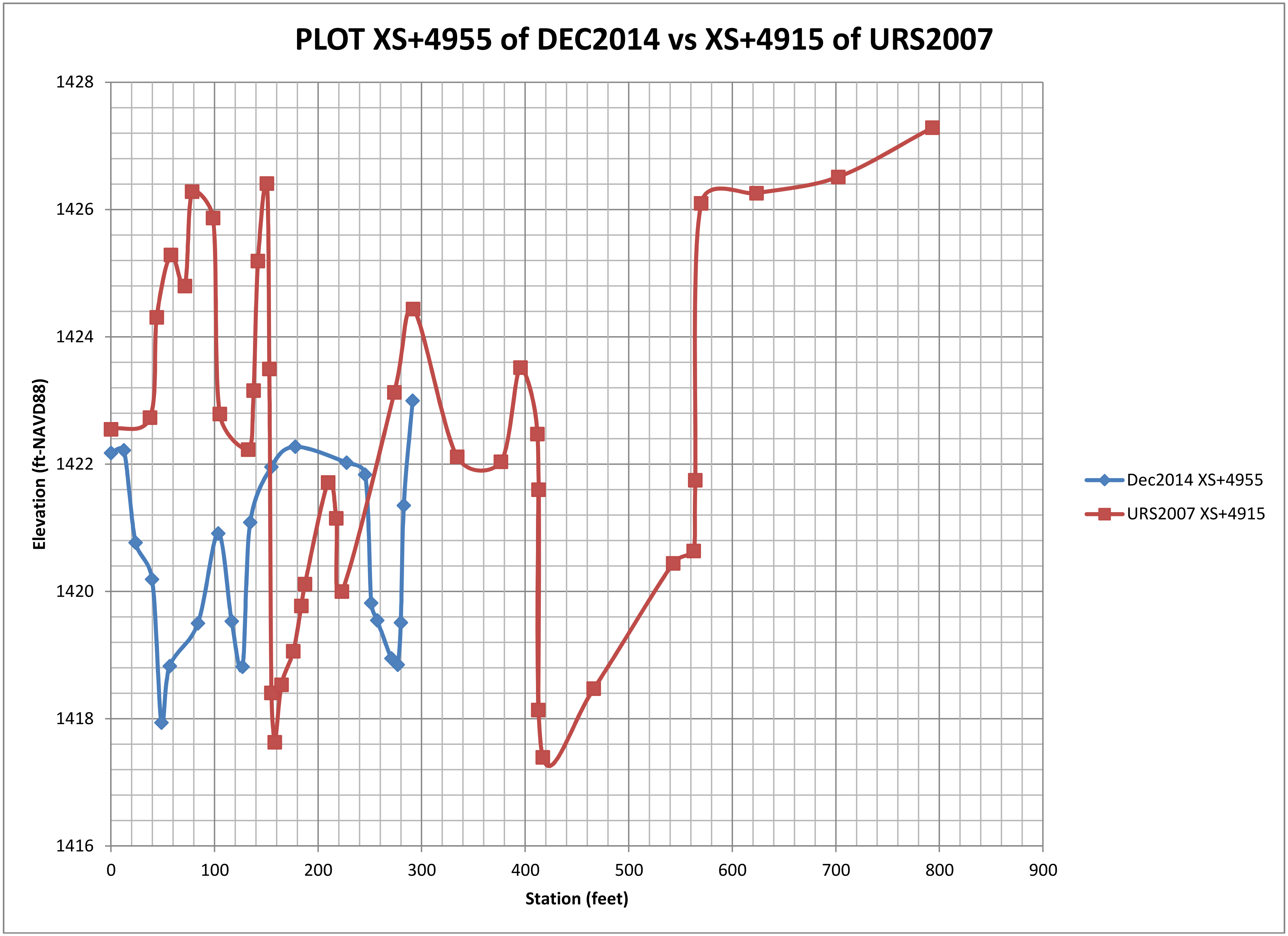

PLOT XS+35 of DEC2014 vs XS+90 of URS2007
1420
1418
1416
1414
1412
1410
1408
Elevation (ft-NAVD88)
0
10
20
30
40
50
60
Station (feet)
Dec2014 XS+35
URS2007 XS+90

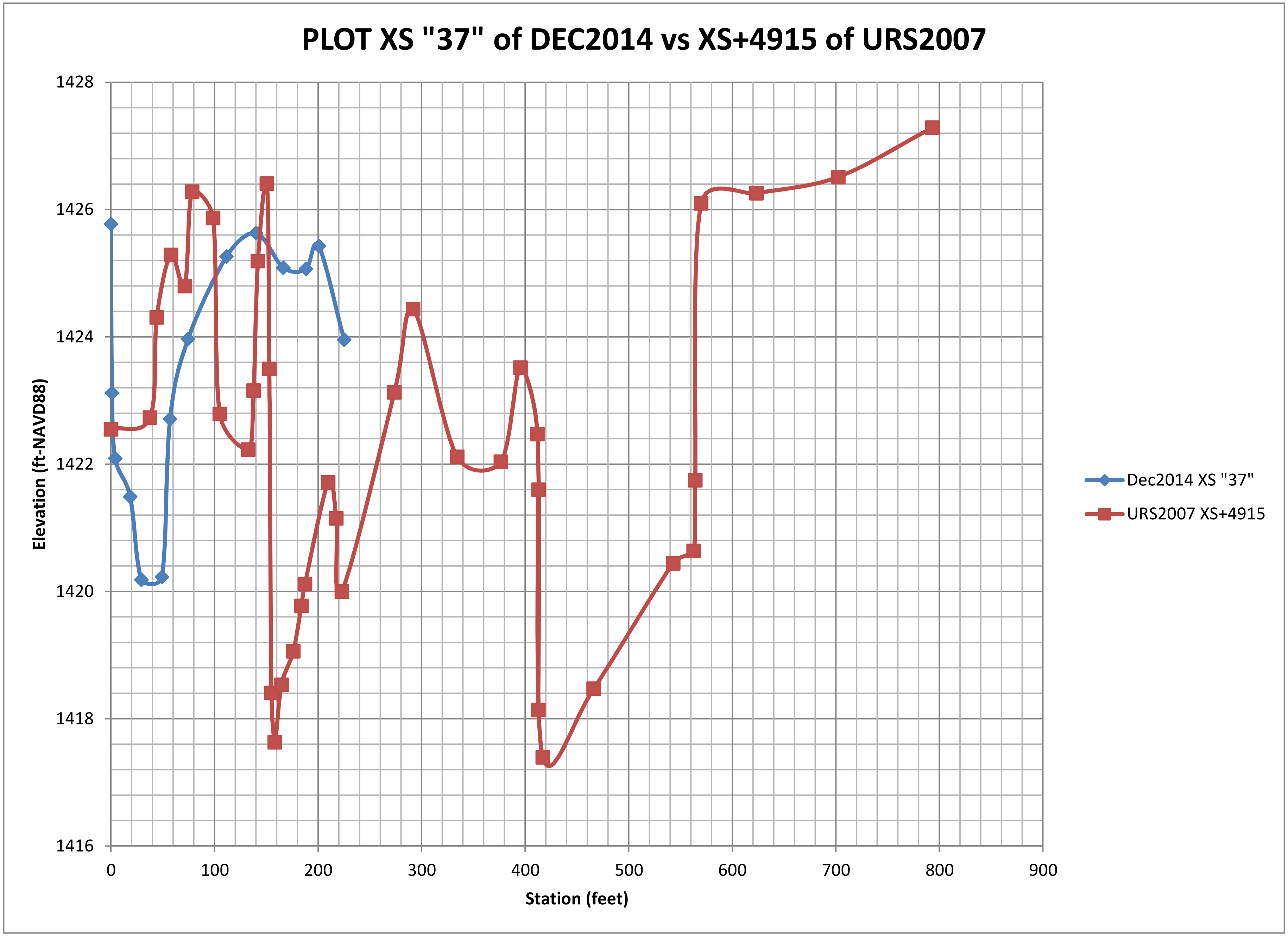


PLOT XS+195 of DEC2014 vs XS+90 of URS2007
Elevation (ft-NAVD88)
1422
1420
1418
1416
1414
1412
1410
1408
0
10
20
30
40
50
60
70
Station (feet)
Dec2014 XS+195
URS2007 XS+90


PLOT XS+2155 of DEC2014 vs XS+2165 of URS2007
Elevation (ft-NAVD88)
1422
1420
1418
1416
1414
1412
1410
1408
0
100
200
300
400
500
600
Station (feet)
Dec2014 XS+2155
URS2007 XS+2165


PLOT XS+2235 of DEC2014 vs XS+2165 of URS2007
Elevation (ft-NAVD88)
1422
1420
1418
1416
1414
1412
1410
1408
0
100
200
300
400
500
600
Station (feet)
Dec2014 XS+2235
URS2007 XS+2165


PLOT XS+4955 of DEC2014 vs XS+4915 of URS2007
Elevation (ft-NAVD88)
1428
1426
1424
1422
1420
1418
1416
0
100
200
300
400
500
600
700
800
900
Station (feet)
Dec2014 XS+4955
URS2007 XS+4915



PLOT XS "37" of DEC2014 vs XS+4915 of URS2007
1428
1426
1424
1422
1420
1418
1416
Elevation (ft-NAVD88)
0
100
200
300
400
500
600
700
800
900
Station (feet)
Dec2014 XS "37"
URS2007 XS+4915

APPENDIX B

Worksheet 5-3. Field form for Level II stream classification (Rosgen, 1996; Rosgen and Silvey, 2005).

Stream:	**Little Beaverkill, Reach - Reach 1**				
Basin:		Drainage Area:	**0** acres	**0**	mi^2
Location:					
Twp.&Rge: **;**		Sec.&Qtr.: **;**			
Cross-Section Monuments (Lat./Long.):	**0 Lat / 0 Long**			Date:	**10/21/14**
Observers:	**RS, CC, CD**			Valley Type:	VIII(c)

Bankfull WIDTH (W_{bkf}) WIDTH of the stream channel at bankfull stage elevation, in a riffle section.	**61.91**	ft
Bankfull DEPTH (d_{bkf}) Mean DEPTH of the stream channel cross-section, at bankfull stage elevation, in a riffle section ($d_{bkf} = A / W_{bkf}$).	**2.47**	ft
Bankfull X-Section AREA (A_{bkf}) AREA of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	**153.04**	ft^2
Width/Depth Ratio (W_{bkf} / d_{bkf}) Bankfull WIDTH divided by bankfull mean DEPTH, in a riffle section.	**25.06**	ft/ft
Maximum DEPTH (d_{mbkf}) Maximum depth of the bankfull channel cross-section, or distance between the bankfull stage and Thalweg elevations, in a riffle section.	**3.5**	ft
WIDTH of Flood-Prone Area (W_{fpa}) Twice maximum DEPTH, or (2 x d_{mbkf}) = the stage/elevation at which flood-prone area WIDTH is determined in a riffle section.		ft
Entrenchment Ratio (ER) The ratio of flood-prone area WIDTH divided by bankfull channel WIDTH (W_{fpa} / W_{bkf}) (riffle section).	**>2.2**	ft/ft
Channel Materials (Particle Size Index) D_{50} The D_{50} particle size index represents the mean diameter of channel materials, as sampled from the channel surface, between the bankfull stage and Thalweg elevations.	**45**	mm
Water Surface SLOPE (S) Channel slope = "rise over run" for a reach approximately 20–30 bankfull channel widths in length, with the "riffle-to-riffle" water surface slope representing the gradient at bankfull stage.	**0.0029**	ft/ft
Channel SINUOSITY (k) Sinuosity is an index of channel pattern, determined from a ratio of stream length divided by valley length (SL / VL); or estimated from a ratio of valley slope divided by channel slope (VS / S).	**1**	

Stream Type → **C4** ← (See **Figure 2-14**)

Worksheet 5-3. Field form for Level II stream classification (Rosgen, 1996; Rosgen and Silvey, 2005).

Stream:	**Little Beaverkill, Reach - Reach 2 (3)**			
Basin:		Drainage Area: **0** acres	**0**	mi^2
Location:				
Twp.&Rge: **;**		Sec.&Qtr.: **;**		
Cross-Section Monuments (Lat./Long.):	**0 Lat / 0 Long**		Date:	**10/21/14**
Observers:			Valley Type:	VIII(c)

Bankfull WIDTH (W_{bkf}) WIDTH of the stream channel at bankfull stage elevation, in a riffle section.	**104.14**	ft
Bankfull DEPTH (d_{bkf}) Mean DEPTH of the stream channel cross-section, at bankfull stage elevation, in a riffle section (d_{bkf} = A / W_{bkf}).	**1.52**	ft
Bankfull X-Section AREA (A_{bkf}) AREA of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	**158.11**	ft^2
Width/Depth Ratio (W_{bkf} / d_{bkf}) Bankfull WIDTH divided by bankfull mean DEPTH, in a riffle section.	**68.51**	ft/ft
Maximum DEPTH (d_{mbkf}) Maximum depth of the bankfull channel cross-section, or distance between the bankfull stage and Thalweg elevations, in a riffle section.	**3.54**	ft
WIDTH of Flood-Prone Area (W_{fpa}) Twice maximum DEPTH, or (2 x d_{mbkf}) = the stage/elevation at which flood-prone area WIDTH is determined in a riffle section.		ft
Entrenchment Ratio (ER) The ratio of flood-prone area WIDTH divided by bankfull channel WIDTH (W_{fpa} / W_{bkf}) (riffle section).	**>2.2**	ft/ft
Channel Materials (Particle Size Index) D_{50} The D_{50} particle size index represents the mean diameter of channel materials, as sampled from the channel surface, between the bankfull stage and Thalweg elevations.	**42.71**	mm
Water Surface SLOPE (S) Channel slope = "rise over run" for a reach approximately 20–30 bankfull channel widths in length, with the "riffle-to-riffle" water surface slope representing the gradient at bankfull stage.	**0.0029**	ft/ft
Channel SINUOSITY (k) Sinuosity is an index of channel pattern, determined from a ratio of stream length divided by valley length (SL / VL); or estimated from a ratio of valley slope divided by channel slope (VS / S).	**NA**	

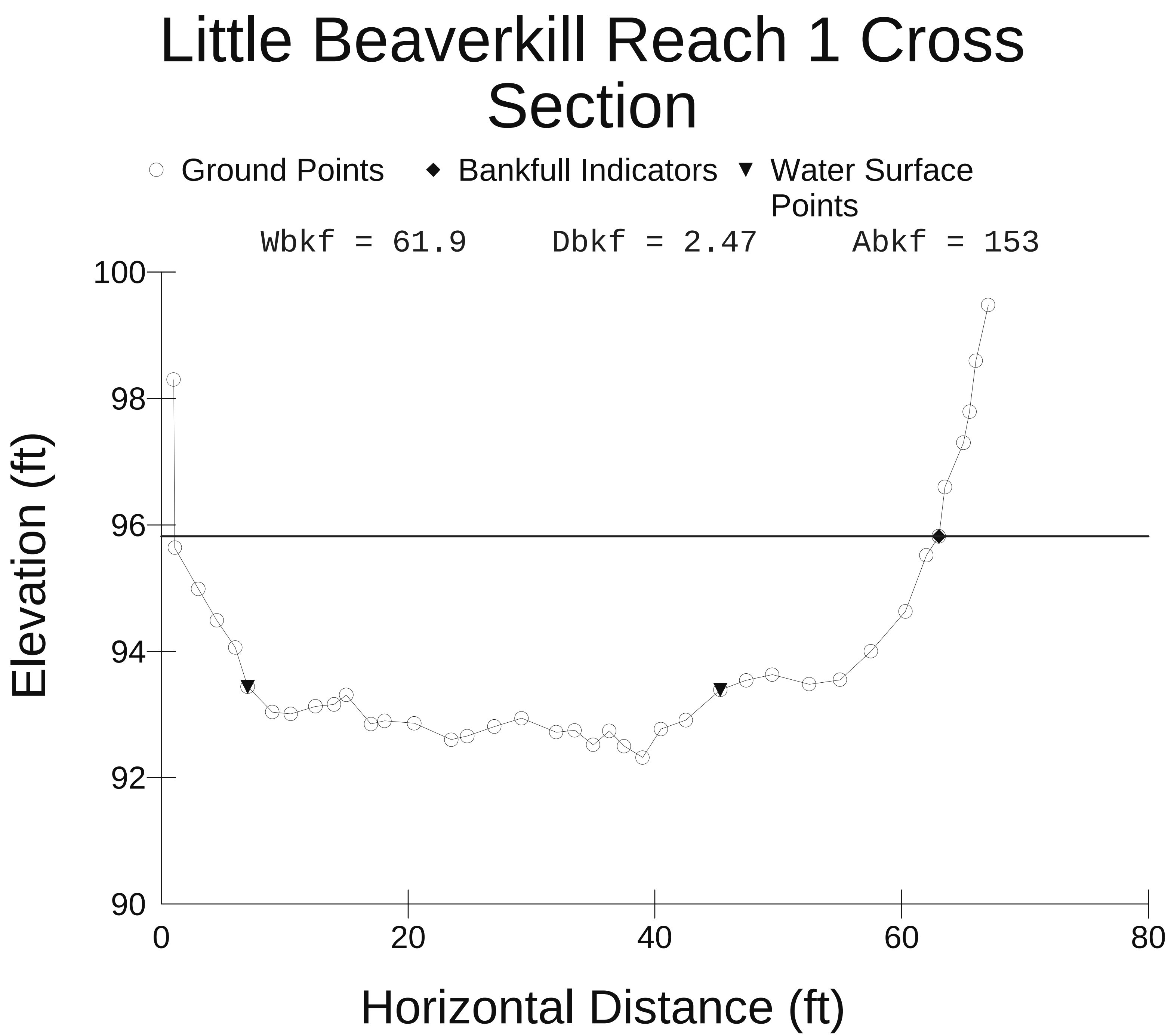
Stream Type **D4** (See **Figure 2-14**)

Worksheet 5-3. Field form for Level II stream classification (Rosgen, 1996; Rosgen and Silvey, 2005).

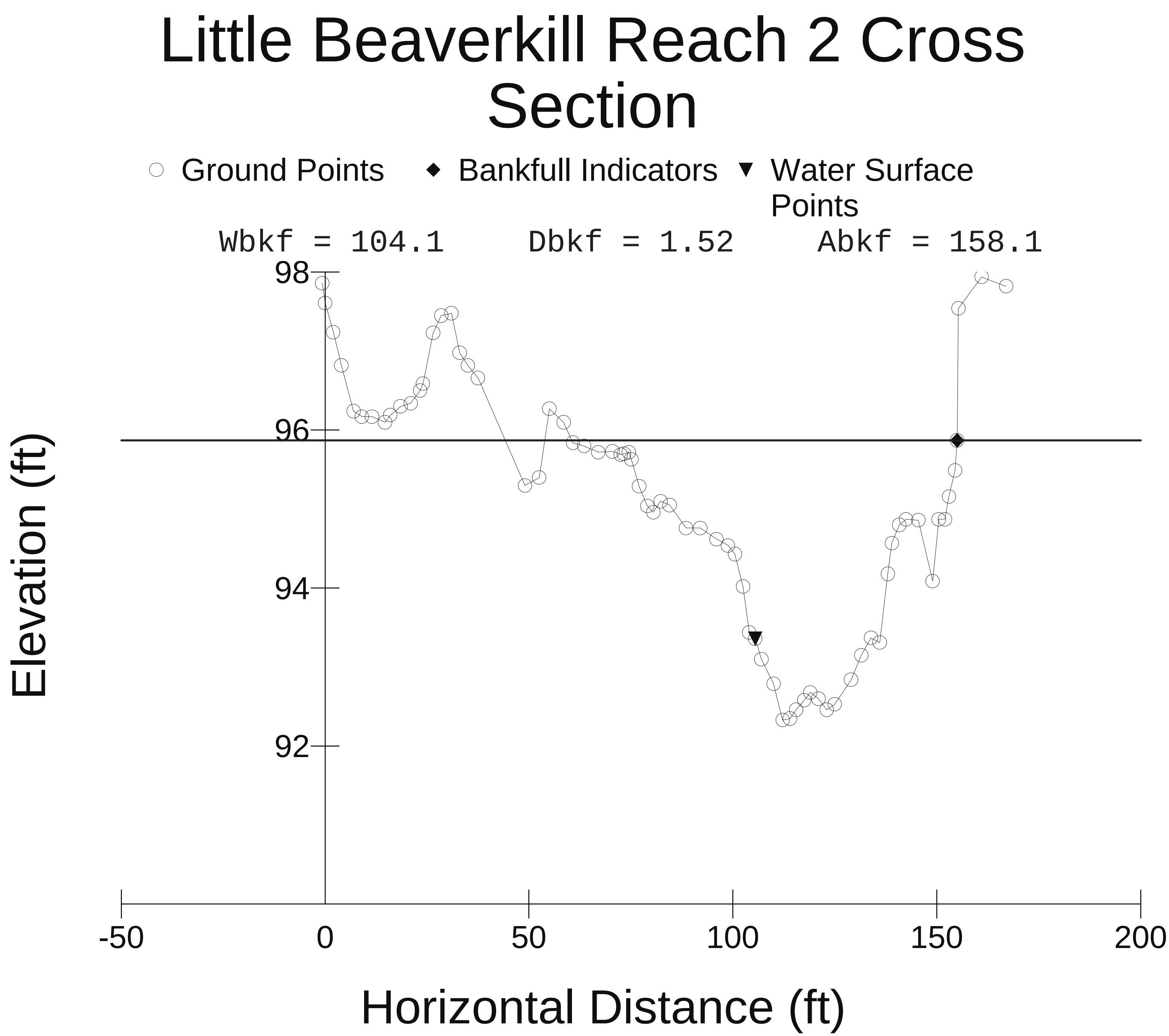
Stream:	**Little Beaverkill, Reach - Reach 3**			
Basin:		Drainage Area: **0** acres	**0**	mi^2
Location:				
Twp.&Rge: **;**		Sec.&Qtr.: **;**		
Cross-Section Monuments (Lat./Long.):	**0 Lat / 0 Long**		Date:	**10/21/14**
Observers:			Valley Type:	VIII(c)

Bankfull WIDTH (W_{bkf}) WIDTH of the stream channel at bankfull stage elevation, in a riffle section.	**58.64**	ft
Bankfull DEPTH (d_{bkf}) Mean DEPTH of the stream channel cross-section, at bankfull stage elevation, in a riffle section ($d_{bkf} = A / W_{bkf}$).	**2.47**	ft
Bankfull X-Section AREA (A_{bkf}) AREA of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	**144.79**	ft^2
Width/Depth Ratio (W_{bkf} / d_{bkf}) Bankfull WIDTH divided by bankfull mean DEPTH, in a riffle section.	**23.74**	ft/ft
Maximum DEPTH (d_{mbkf}) Maximum depth of the bankfull channel cross-section, or distance between the bankfull stage and Thalweg elevations, in a riffle section.	**4.26**	ft
WIDTH of Flood-Prone Area (W_{fpa}) Twice maximum DEPTH, or (2 x d_{mbkf}) = the stage/elevation at which flood-prone area WIDTH is determined in a riffle section.		ft
Entrenchment Ratio (ER) The ratio of flood-prone area WIDTH divided by bankfull channel WIDTH (W_{fpa} / W_{bkf}) (riffle section).	**>2.2**	ft/ft
Channel Materials (Particle Size Index) D_{50} The D_{50} particle size index represents the mean diameter of channel materials, as sampled from the channel surface, between the bankfull stage and Thalweg elevations.	**30.29**	mm
Water Surface SLOPE (S) Channel slope = "rise over run" for a reach approximately 20–30 bankfull channel widths in length, with the "riffle-to-riffle" water surface slope representing the gradient at bankfull stage.	**0.0029**	ft/ft
Channel SINUOSITY (k) Sinuosity is an index of channel pattern, determined from a ratio of stream length divided by valley length (SL / VL); or estimated from a ratio of valley slope divided by channel slope (VS / S).	**1.38**	

Stream Type → **C4** ← (See **Figure 2-14**)

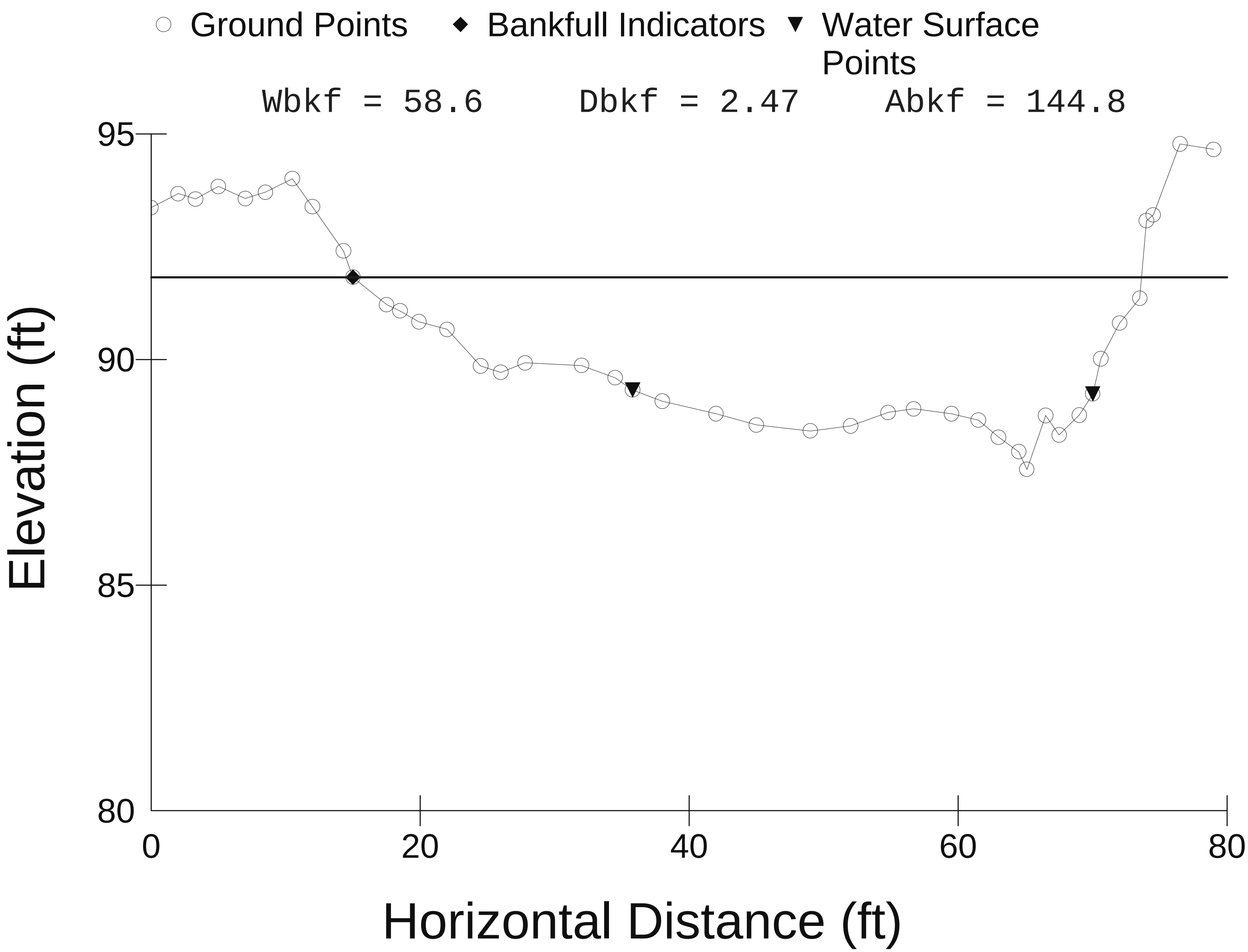


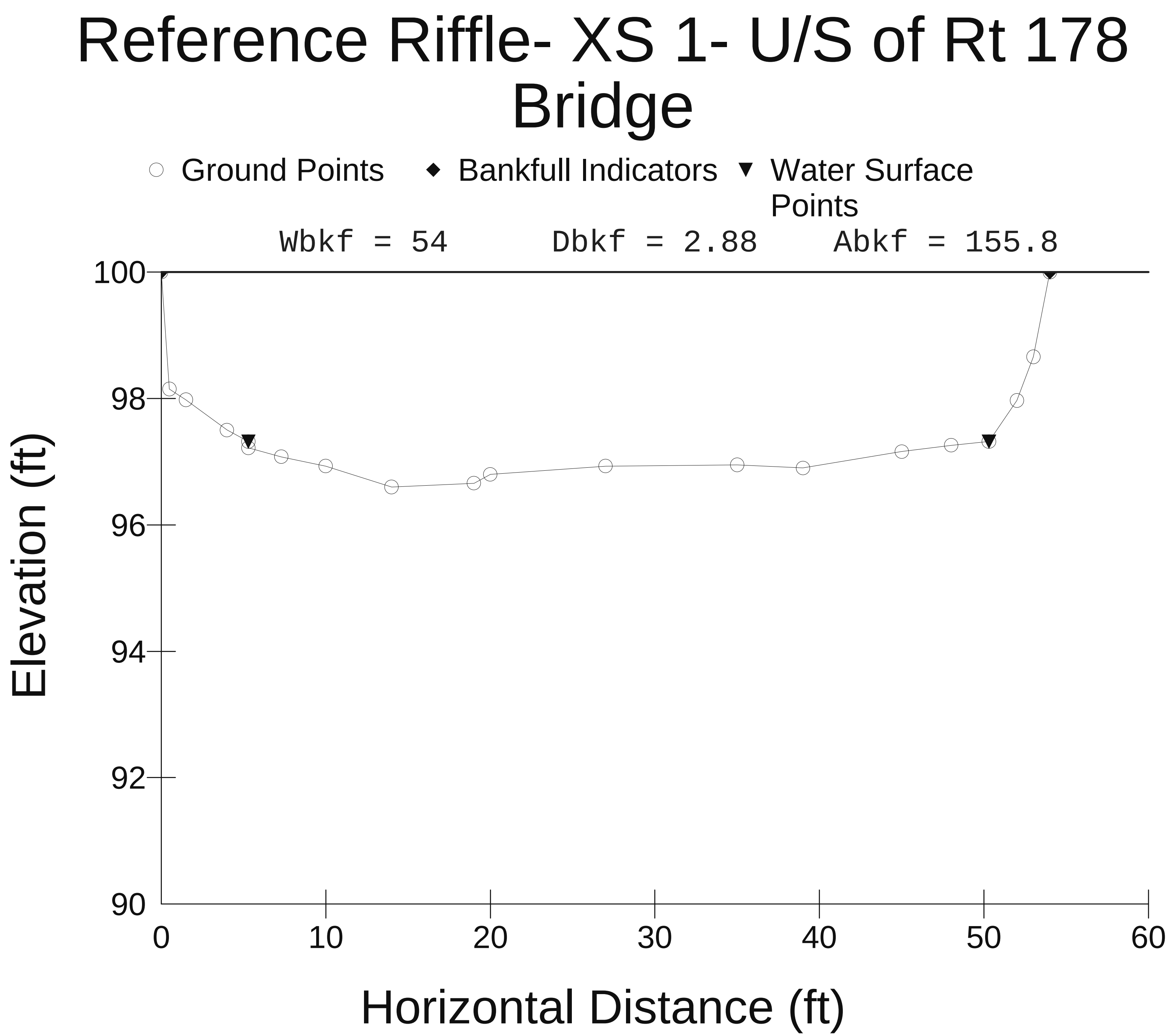
Little Beaverkill Reach 1 Cross Section
Ground Points
Bankfull Indicators
Water Surface Points
Wbkf = 61.9
Dbkf = 2.47
Abkf = 153
Elevation (ft)
100
98
96
94
92
90
0
20
40
60
80
Horizontal Distance (ft)



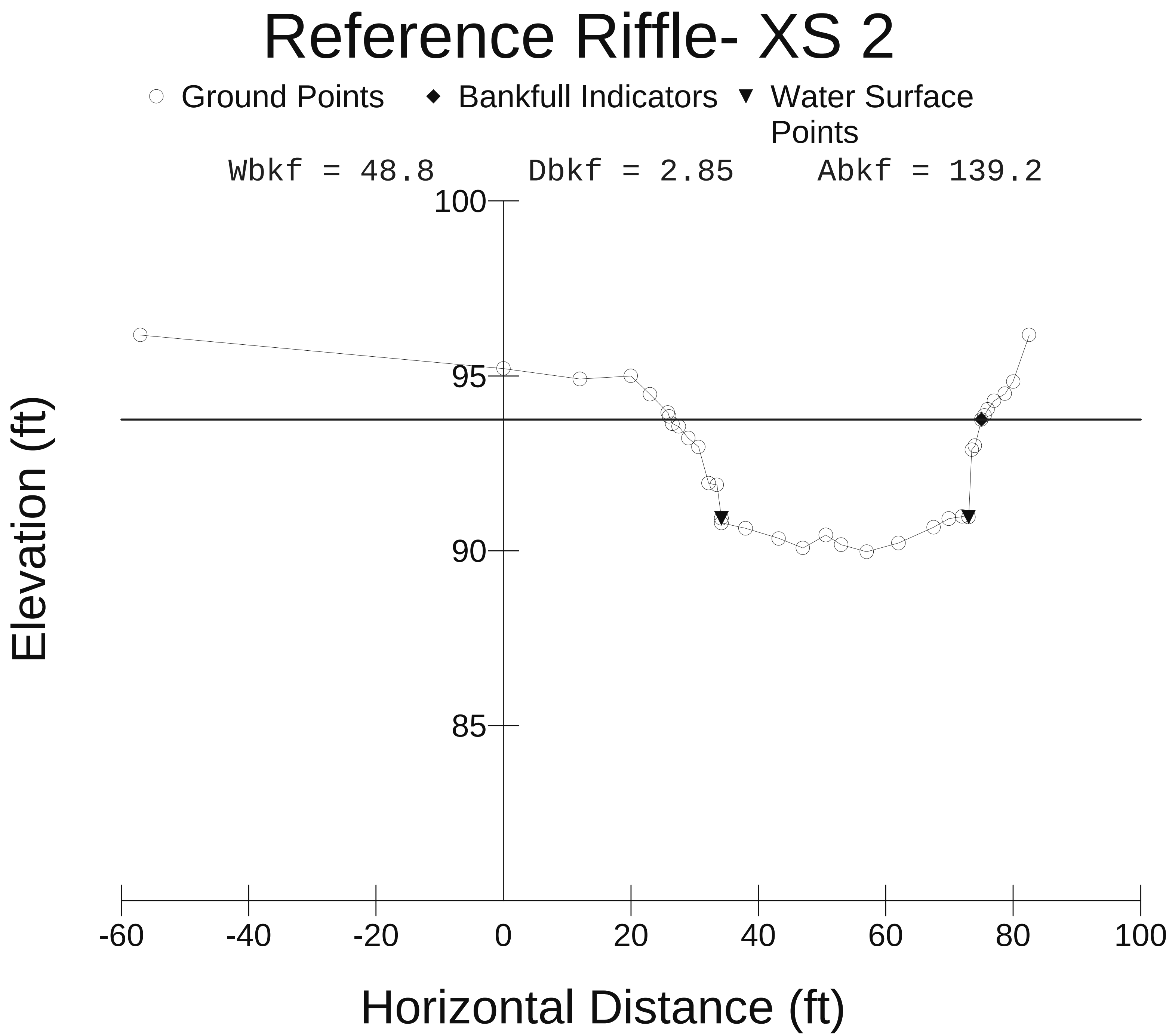
Little Beaverkill Reach 2 Cross Section
Ground Points
Bankfull Indicators
Water Surface Points
Wbkf = 104.1
Dbkf = 1.52
Abkf = 158.1
Elevation (ft)
98
96
94
92
-50
0
50
100
150
200
Horizontal Distance (ft)

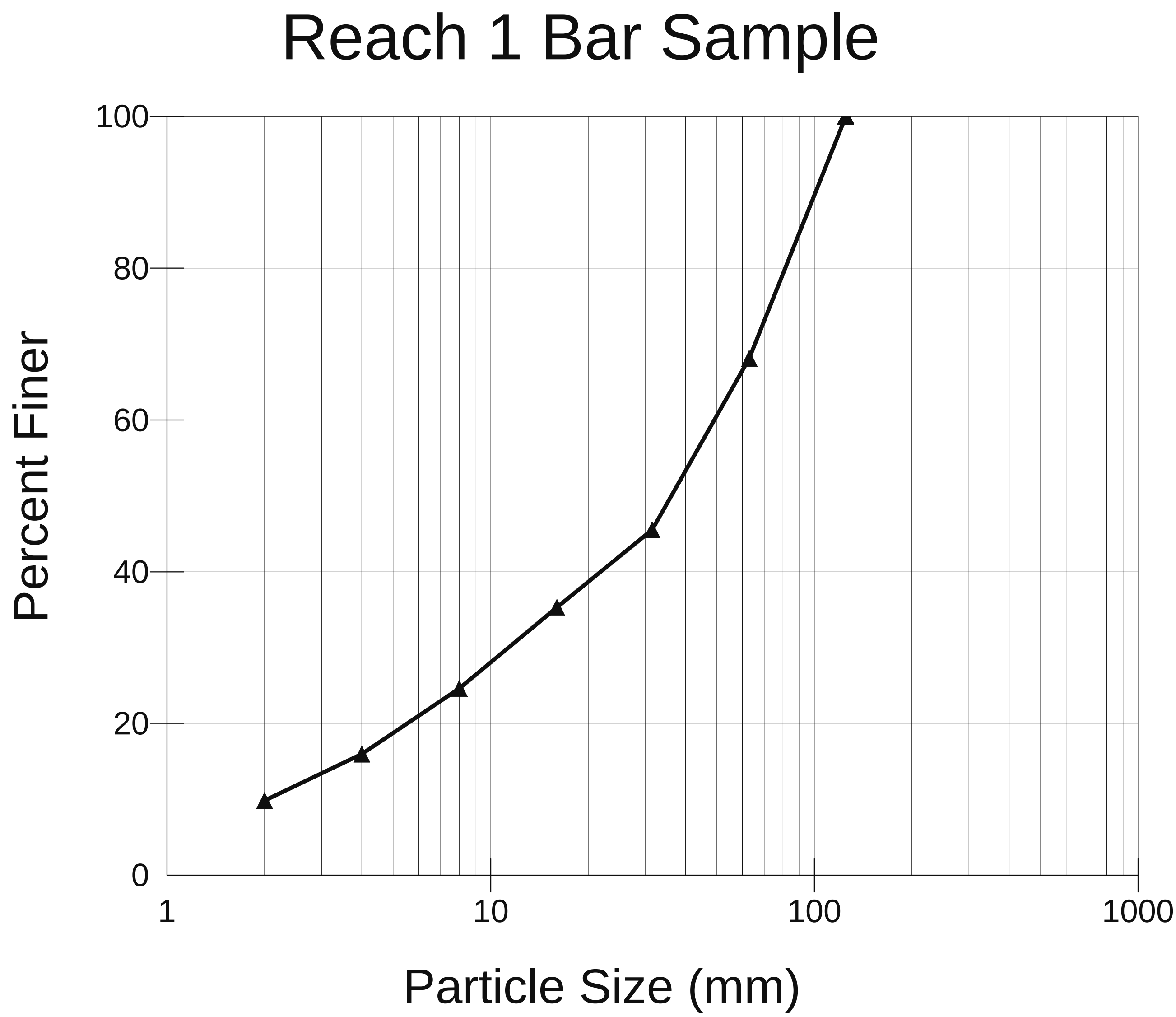
Little Beaverkill Reach 3 Cross Section

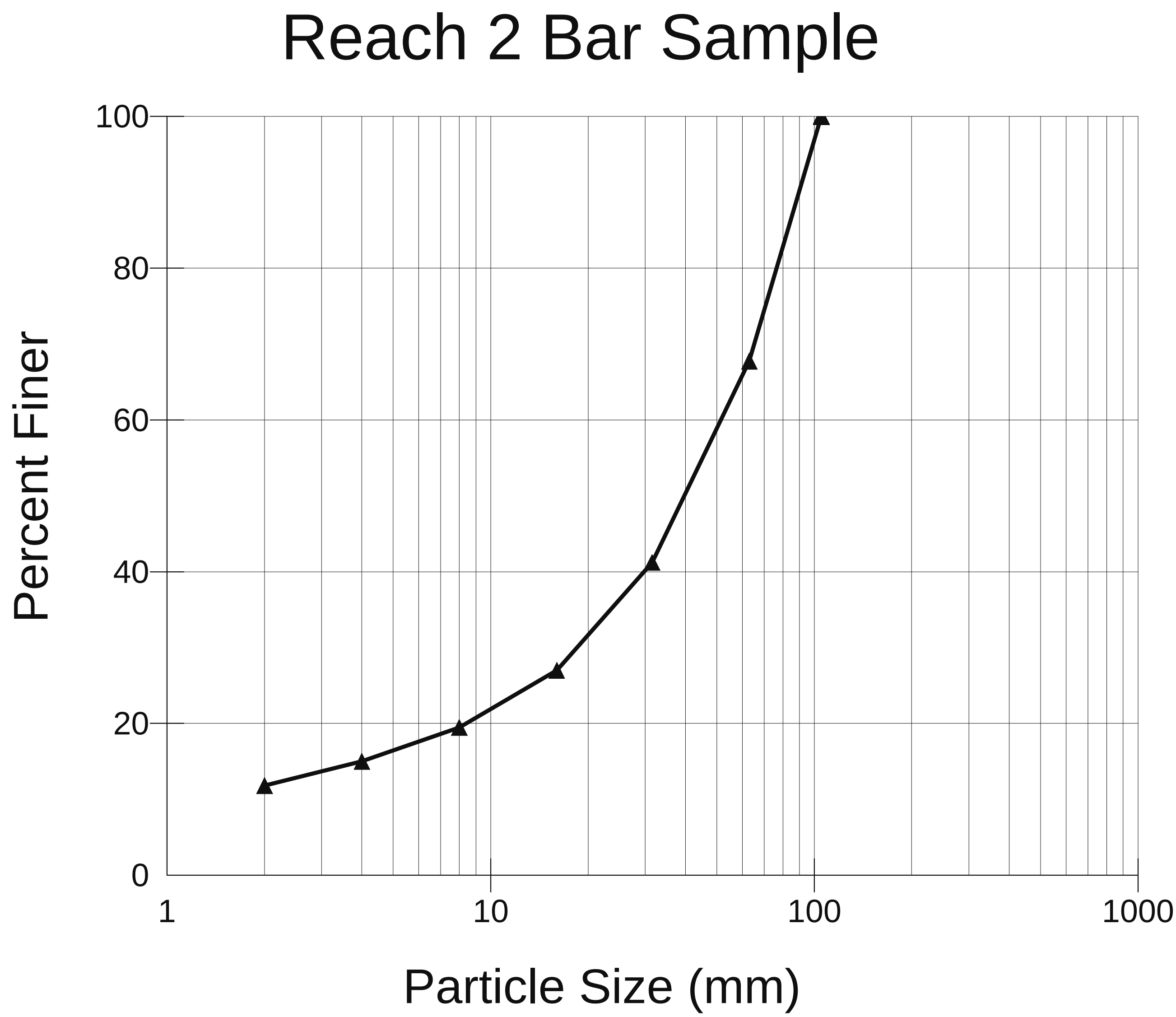


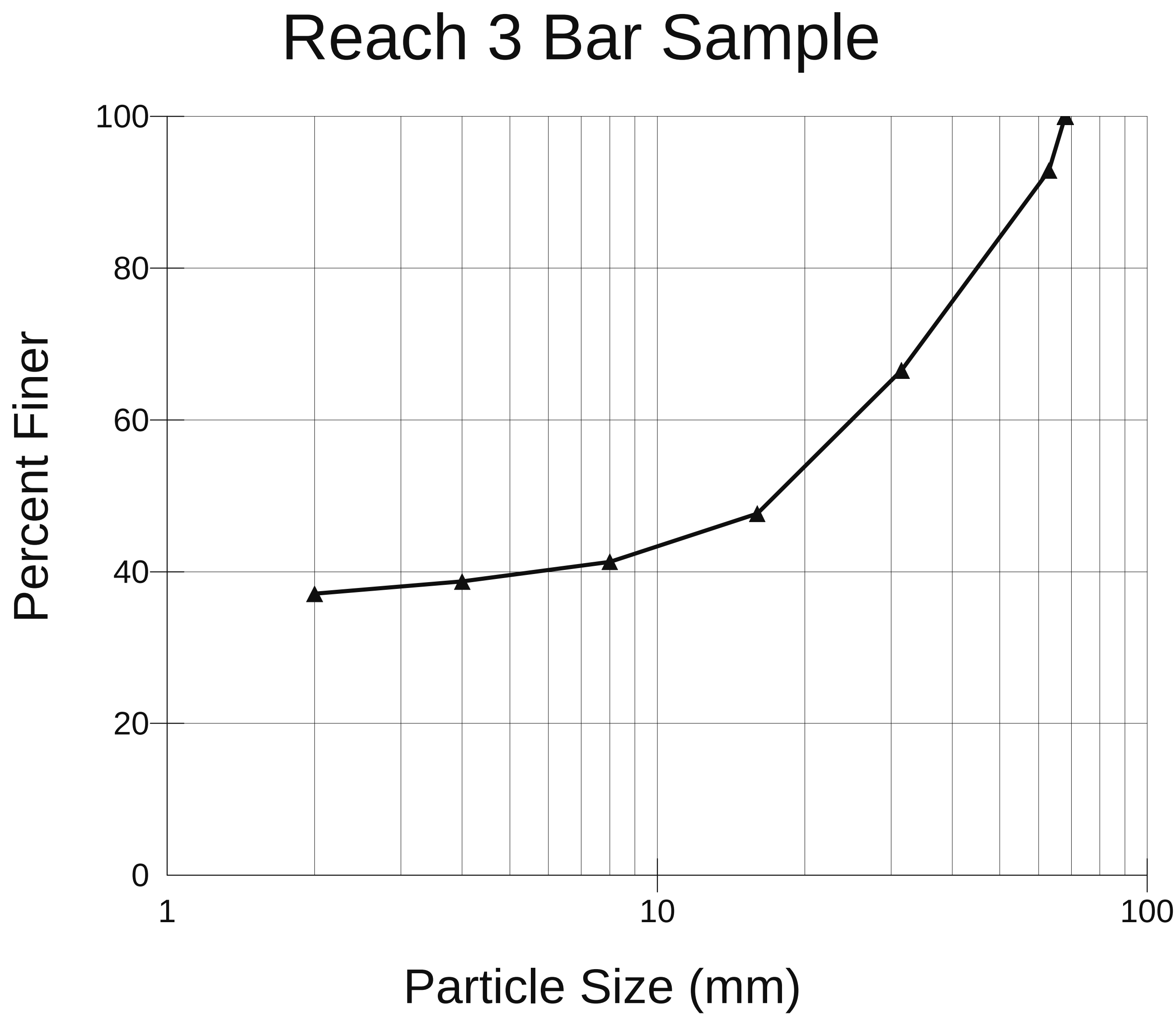


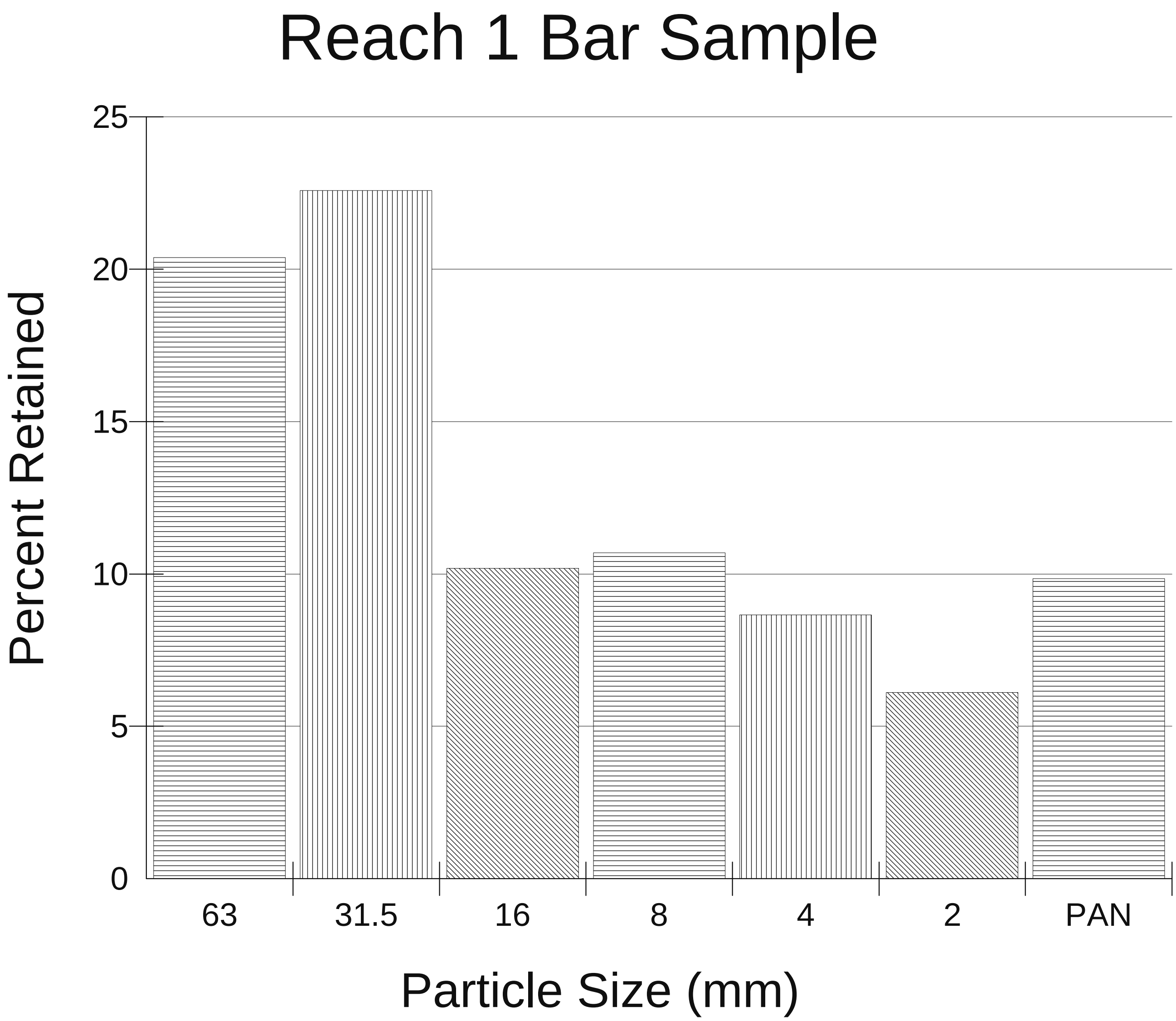
Reference Riffle- XS 1- U/S of Rt 178 Bridge
Ground Points
Bankfull Indicators
Water Surface Points
Wbkf = 54
Dbkf = 2.88
Abkf = 155.8
Elevation (ft)
100
98
96
94
92
90
0
10
20
30
40
50
60
Horizontal Distance (ft)


Reference Riffle- XS 2
Ground Points
Bankfull Indicators
Water Surface Points
Wbkf = 48.8
Dbkf = 2.85
Abkf = 139.2
Elevation (ft)
100
95
90
85
-60
-40
-20
0
20
40
60
80
100
Horizontal Distance (ft)

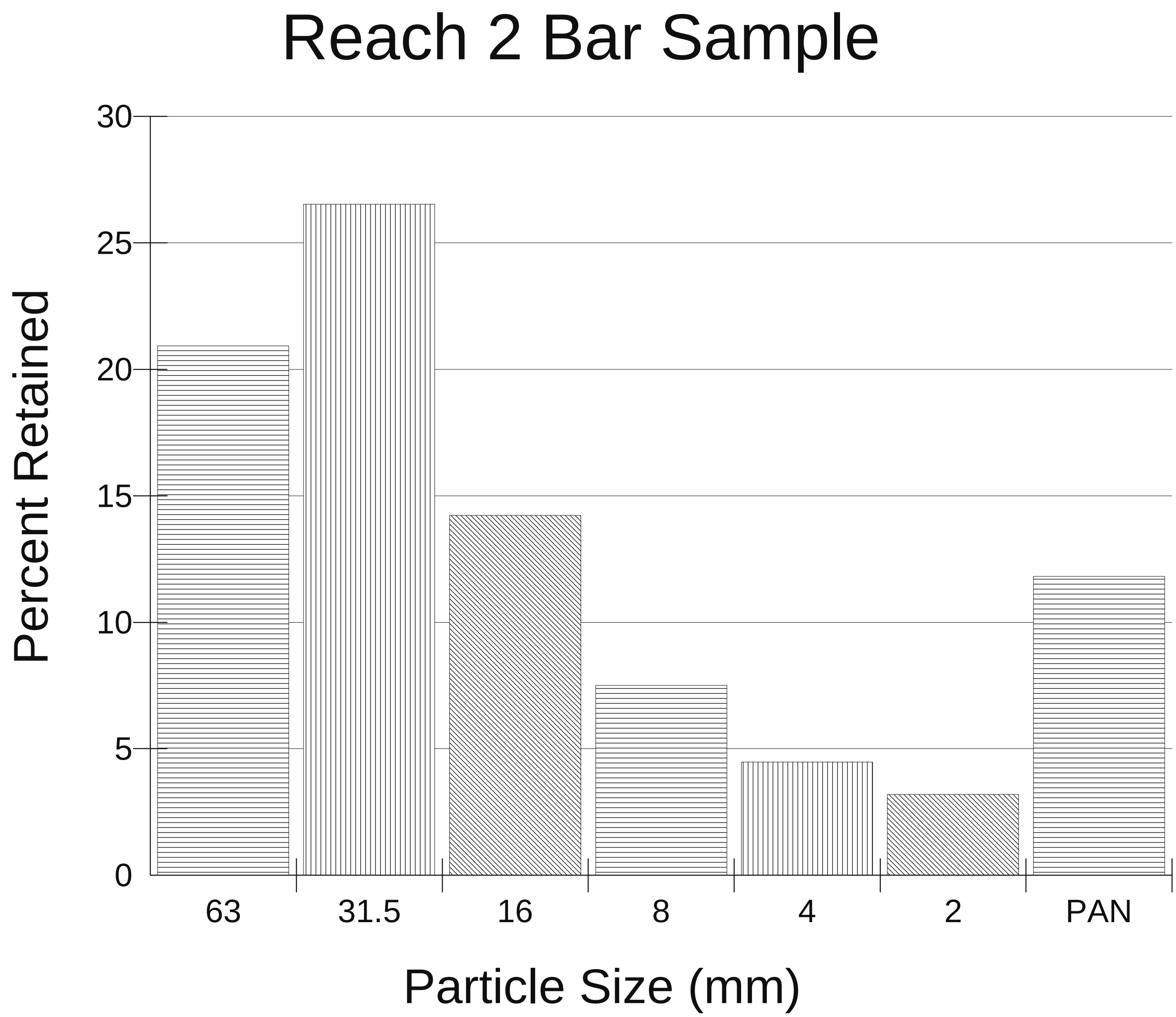

Reach 1 Bar Sample
Percent Finer
100
80
60
40
20
0
1
10
100
1000
Particle Size (mm)

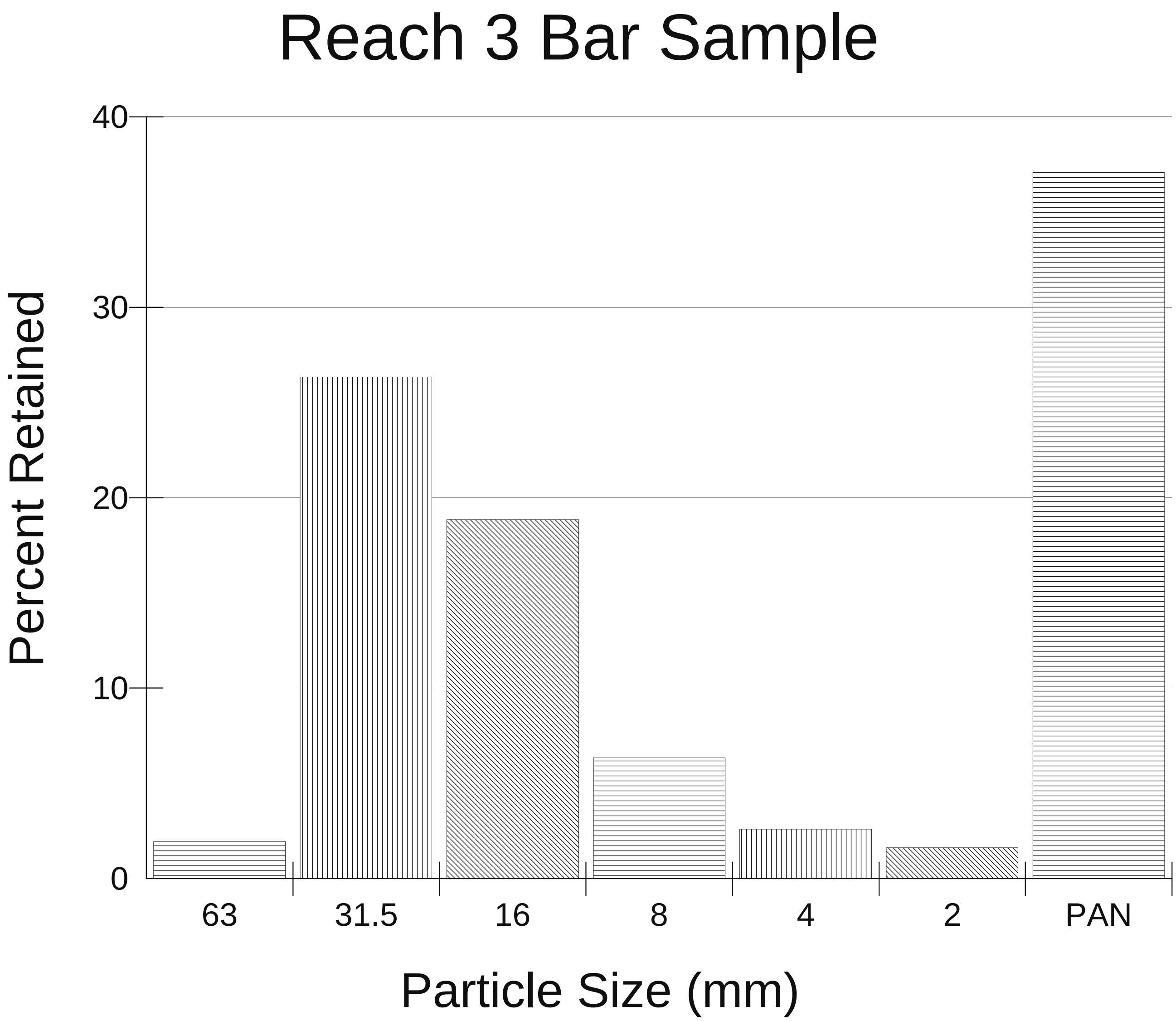

Reach 2 Bar Sample
Percent Finer
100
80
60
40
20
0
1
10
100
1000
Particle Size (mm)


Reach 3 Bar Sample
Percent Finer
100
80
60
40
20
0
1
10
100
Particle Size (mm)



Reach 1 Bar Sample
Percent Retained
0
5
10
15
20
25
63
31.5
16
8
4
2
PAN
Particle Size (mm)


Reach 2 Bar Sample
Percent Retained
30
25
20
15
10
5
0
63
31.5
16
8
4
2
PAN
Particle Size (mm)


Reach 3 Bar Sample
Percent Retained
40
30
20
10
0
63
31.5
16
8
4
2
PAN
Particle Size (mm)

Little Beaver Kill 10/21/14 RRS
1 of 7

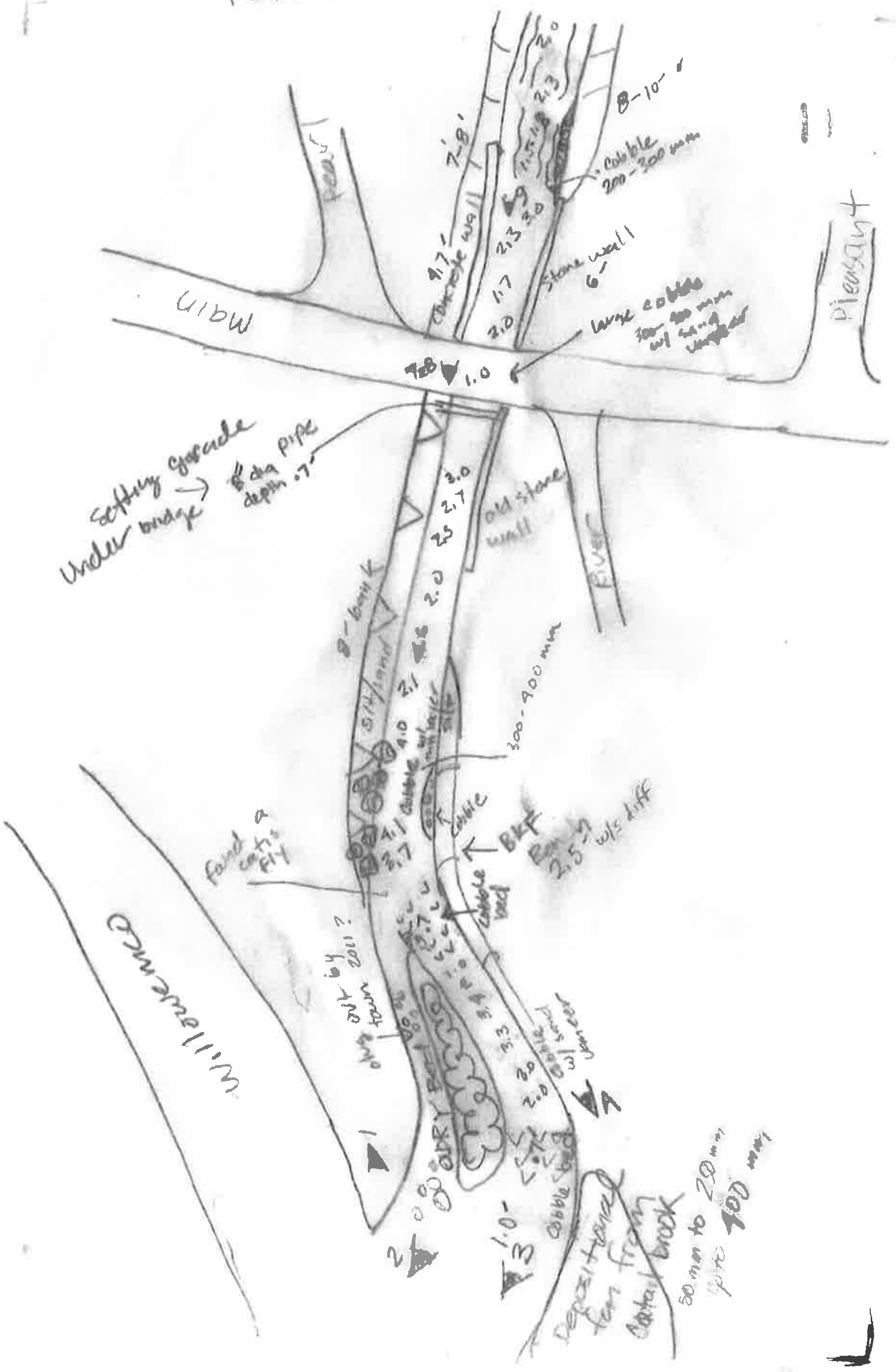


FIGURE 8

Little Beaver Kill 10/21/19 RRS

2 of 7

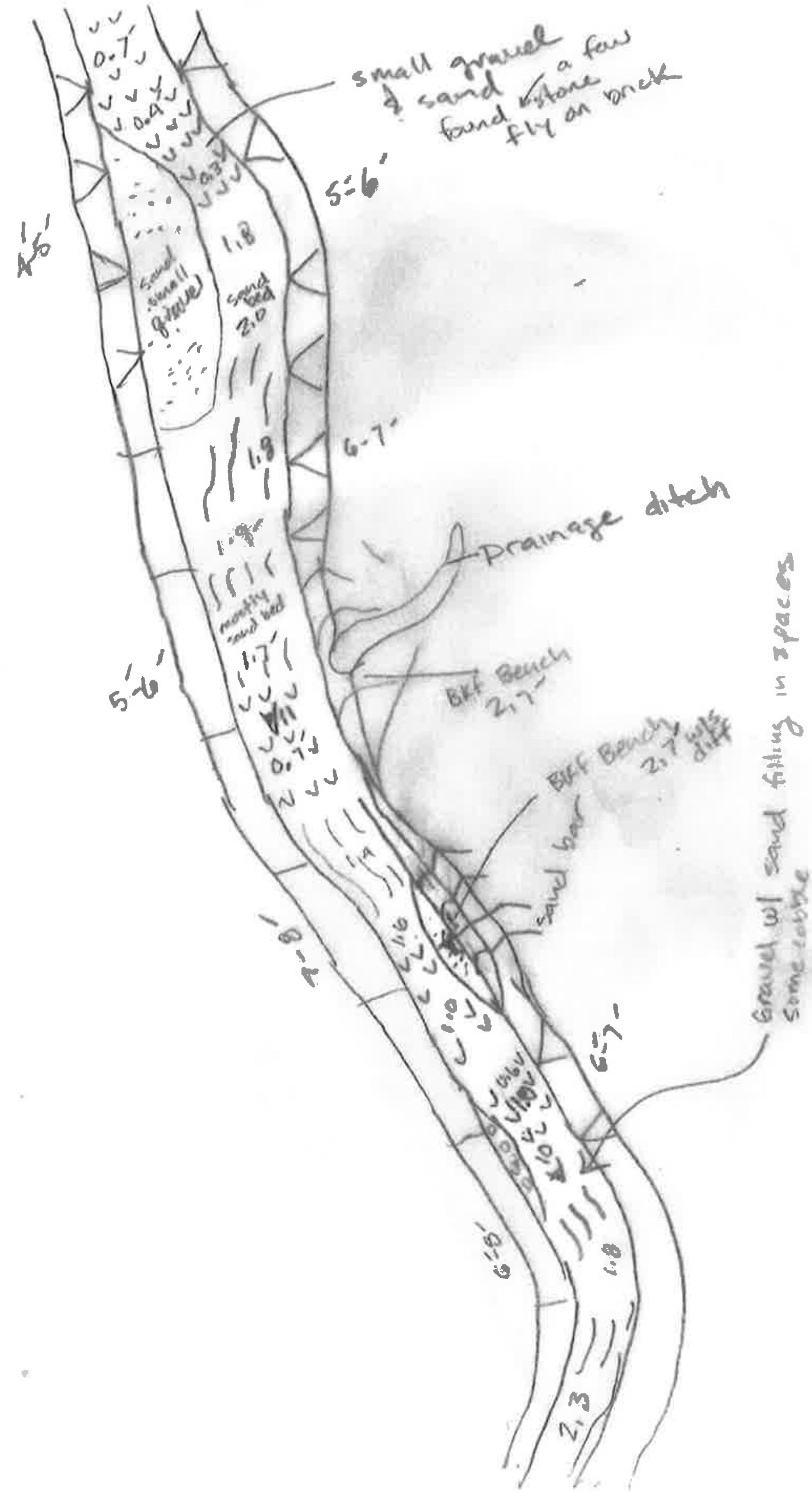


FIGURE 7

Little Beaver Kill 10/21/14 RRS

3 of 7

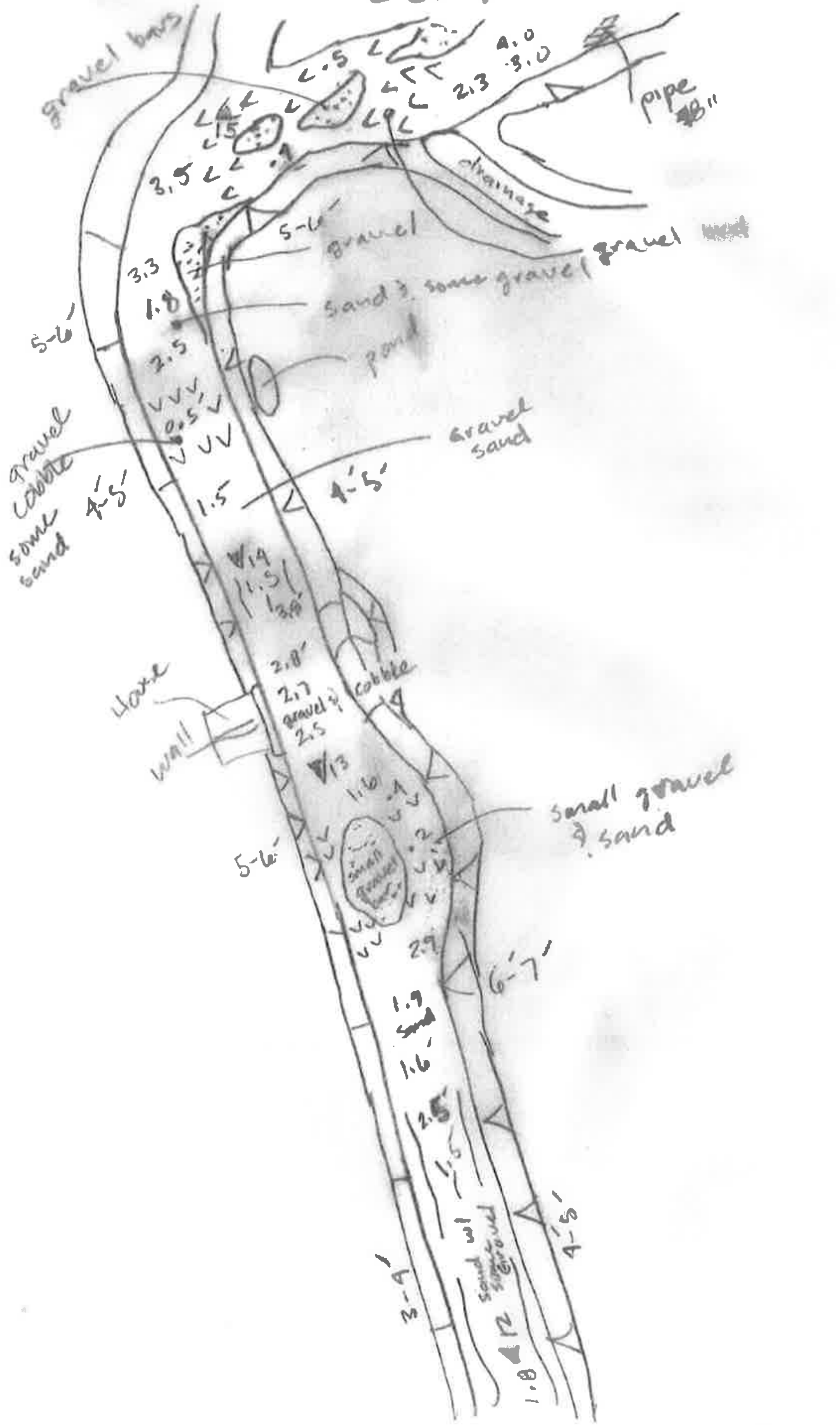


FIGURE 6

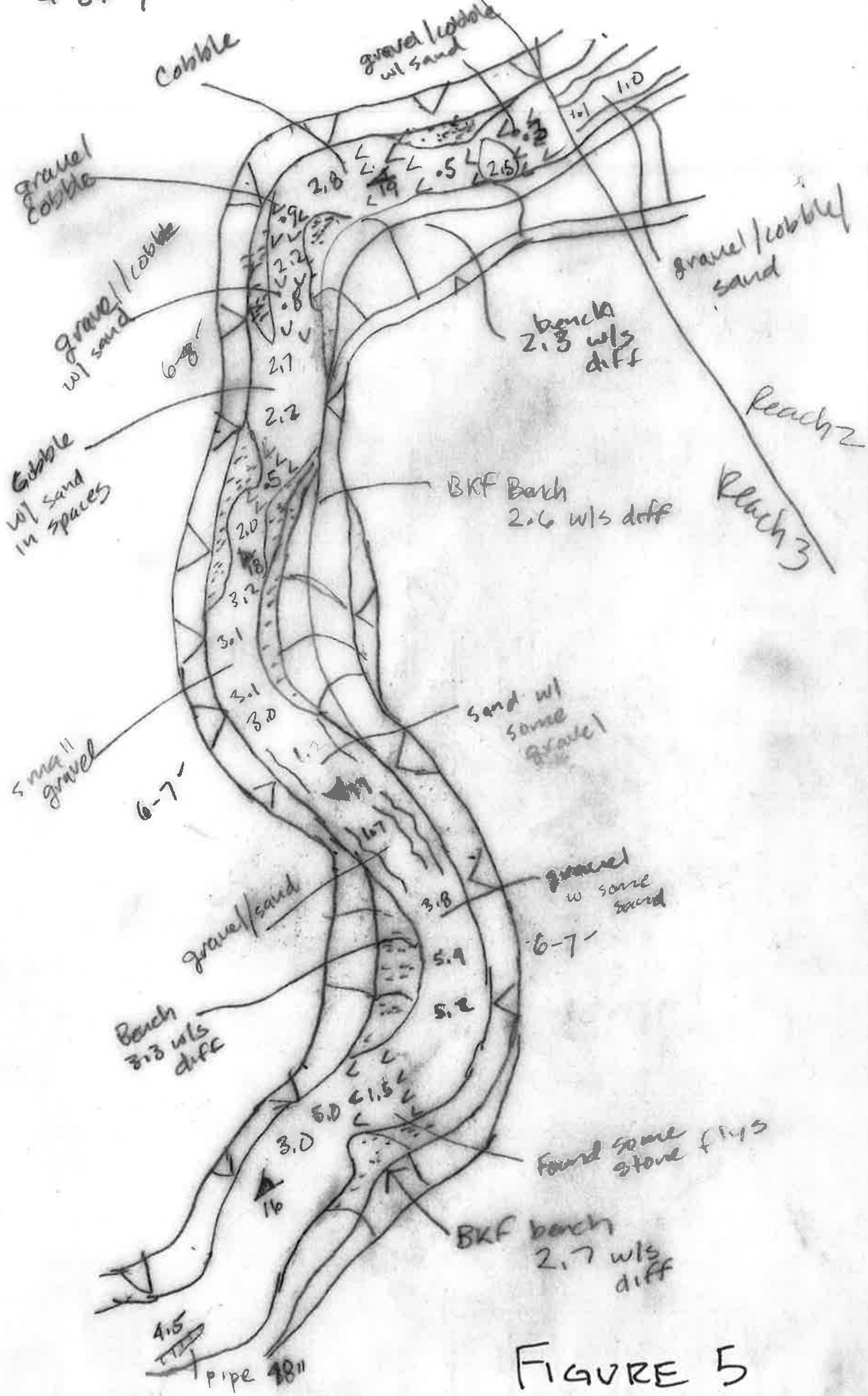

Cobble
gravel/cobble w/ sand
1.0
gravel cobble
2.8
.5
2.5
gravel/cobble w/ sand
2.2
.8
6-8'
2.1
2.2
.5
gravel/cobble sand
bench 2.3 w/s diff
Reach 2
Reach 3
Cobble w/ sand in spaces
BKF Bench 2.6 w/s diff
2.0
18
3.2
3.1
3.1
3.0
small gravel
sand w/ some gravel
1.2
6-7'
1.7
gravel w some sand
3.8
gravel/sand
6-7'
5.4
5.2
Bench 3.3 w/s diff
5.0
1.5
3.0
Found some stone flys
16
BKF bench 2.7 w/s diff
4.5
pipe 48"

FIGURE 5

Little Beaver Kill 10/21/14 KRS
5 of 7

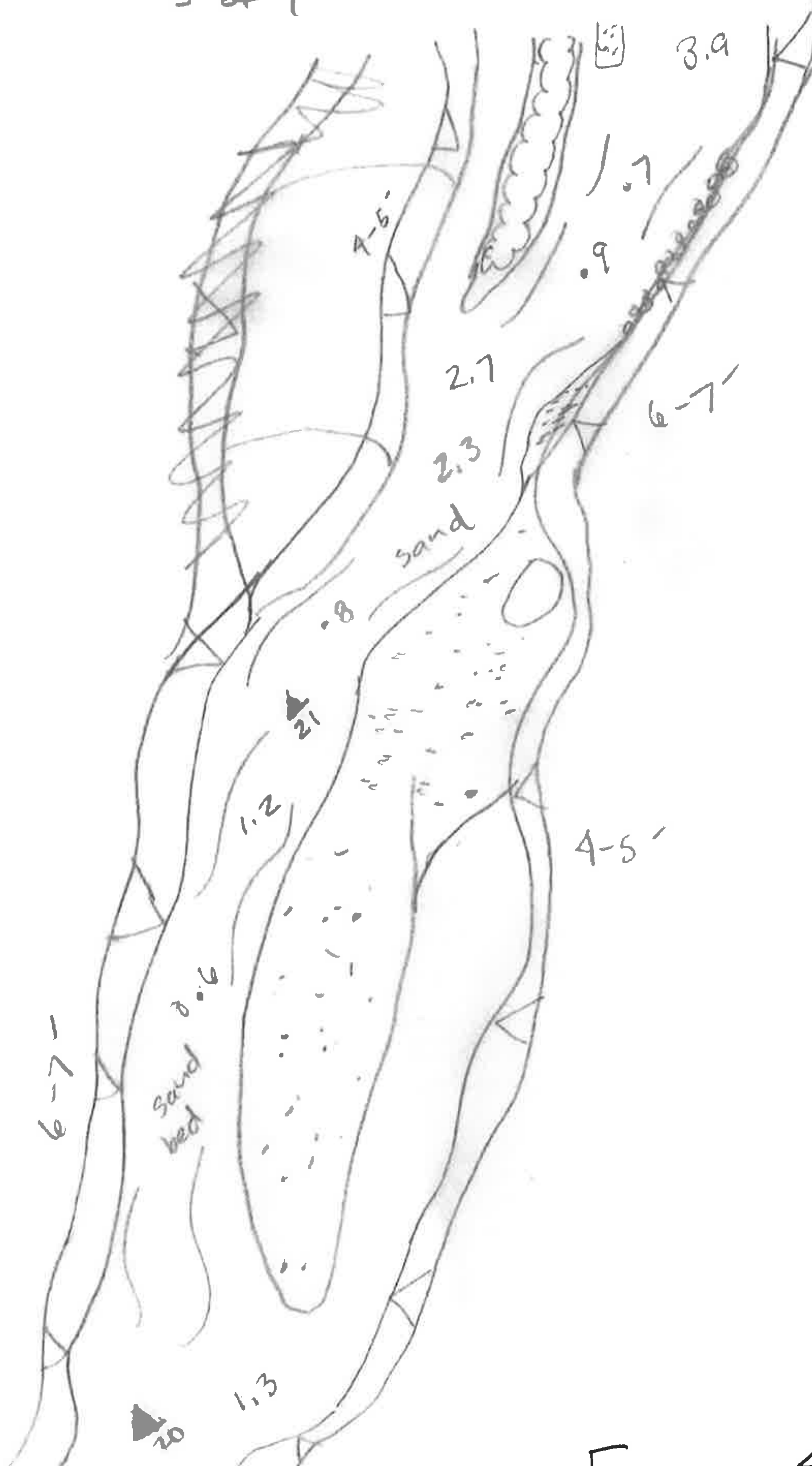


FIGURE 4

Little Beaver Kill 10/21/14 HRS

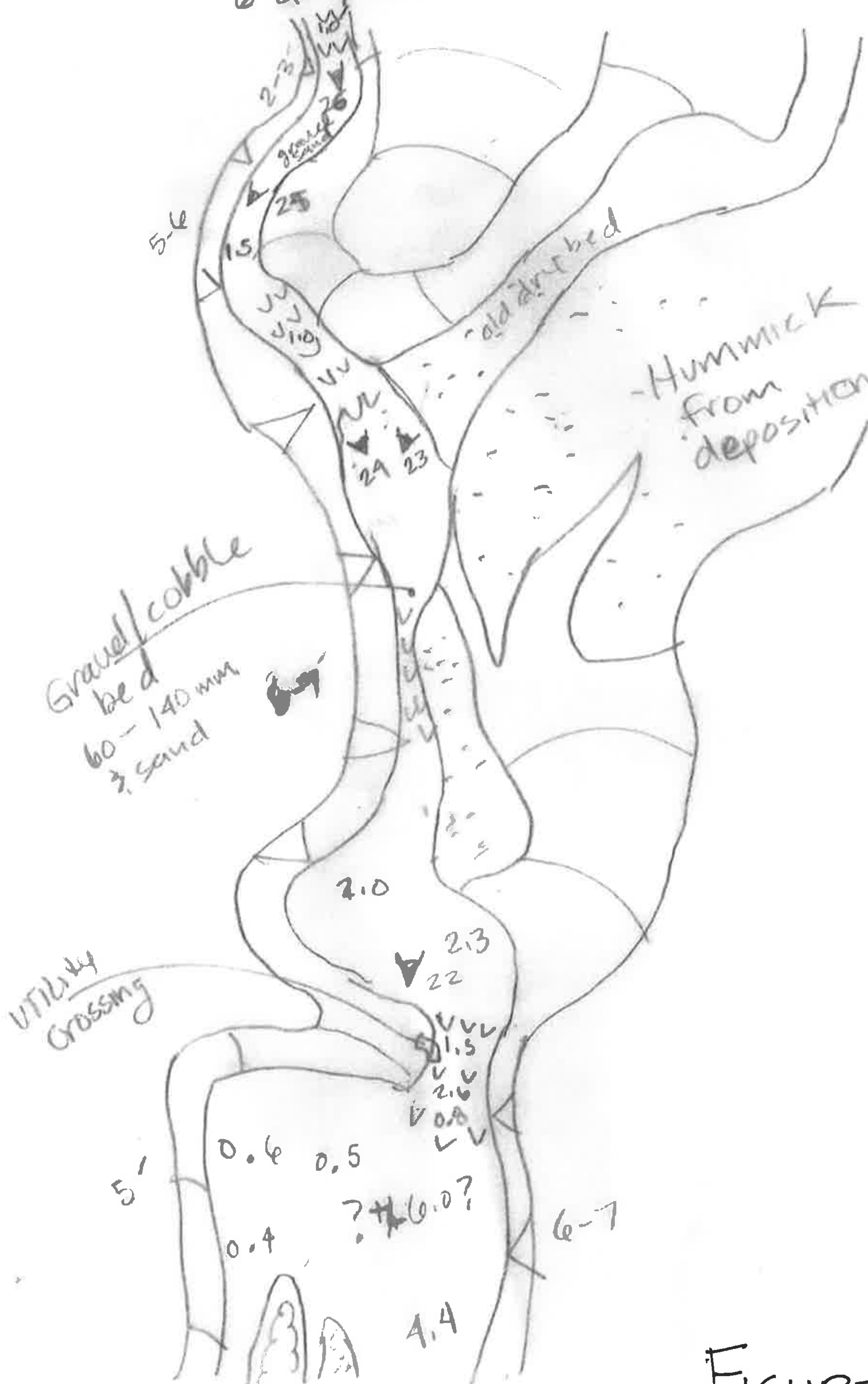


FIGURE 3

Little Beaver Kill 10/21/14 RTS
7 of 7

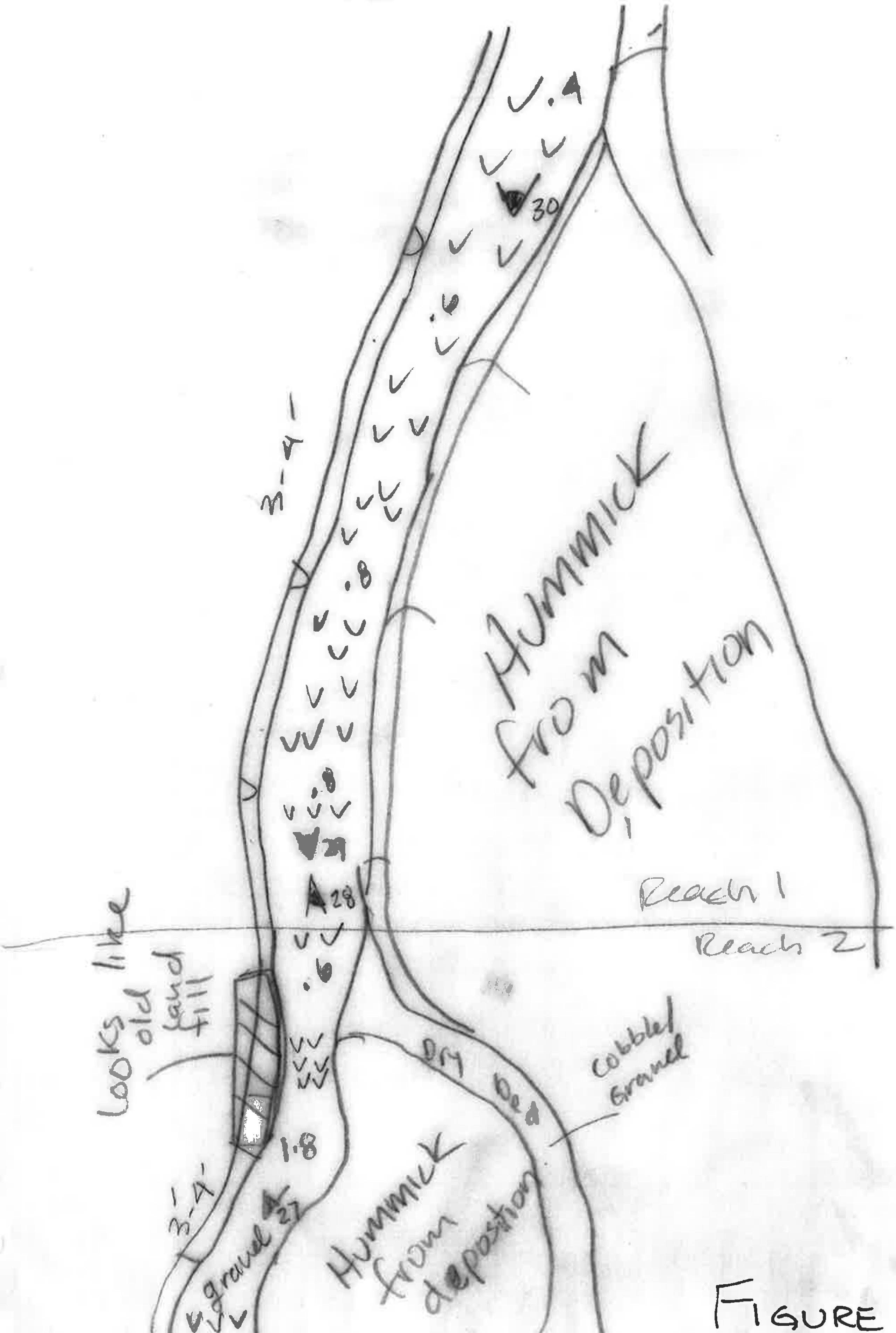


FIGURE 2

APPENDIX C

Design Criteria
UT6e Piney Run, Maryland

No.	Variable	Symbol	Units		Design Ratios and Criteria		Design Ratios and Criteria	
1	Stream type				C4		B4c	
2	Drainage area		mi^2	Mean	30.0		30.0	
				Range	NA		NA	
3	Riffle Bankfull width	W_{bkf}	feet	Mean	55.00		55.00	
				Range	49.00	60.00	49.00	60.00
4	Riffle Bankfull mean depth	d_{bkf}	feet	Mean	2.70		2.70	
				Range	2.50	2.90	2.50	2.90
5	Width depth ratio	W/d		Mean	14.00		14.00	
				Range	12.00	16.00	12.00	16.00
6	Riffle Bankfull cross sectional area	A_{bkf}	ft_2	Mean	150.00		150.00	
				Range	140.00	156.00	140.00	156.00
7	Bankfull mean velocity	V_{bkf}	ft/sec	Mean	5.20		5.20	
				Range	4.70	5.70	4.70	5.70
8	Bankfull discharge	Q_{bkf}	cfs	Mean	780.00		780.00	
				Range	740.00	820.00	740.00	820.00
9	Riffle Bankfull maximum depth	d_{max}	feet	Mean	3.60		3.60	
				Range	3.40	3.80	3.40	3.80
10	Max Riffle depth/ Mean riffle depth	d_{riff}/d_{bkf}		Mean	1.30		1.30	
				Range	NA		NA	
11	Low bank height to max d_{bkf} ratio			Mean	1.00		1.00	
				Range	NA		NA	
12	Width of flood prone area	W_{fpa}	feet	Mean	390.50		137.50	
				Range	121.00	660.00	77.00	198.00
13	Entrenchment Ratio	W_{fpa}/W_{bkf}		Mean	7.10		2.50	
				Range	2.20	12.00	1.4	3.60
14	Meander Length	L_m	feet	Mean	578			NA
				Range	385.00	770.00		NA
15	Ratio of meander length to bankfull width	L_m/W_{bkf}		Mean	10.50			NA
				Range	7.00	14.00		NA
16	Radius of curvature	R_c		Mean	138			NA
				Range	110.00	165.00		NA
17	Ratio: Radius of curvature to bankfull width	R_c/W_{bkf}		Mean	2.50			NA
				Range	2.00	3.00		NA
18	Belt Width	W_{blt}	feet	Mean	316			NA
				Range	192.50	440.00		NA
19	Meander width ratio	W_{blt}/W_{bkf}		Mean	5.80			NA
				Range	3.50	8.00		NA
20	Sinuosity	K		Mean	1.30			1.20
				Range	1.20	1.40		1.1 - 1.3
21	Valley Slope	S_{val}	ft/ft		0.0035		0.00038	
22	Average Water Surface Slope	S_{avg}	ft/ft	Mean	0.0029		0.00038	
				Range	N/A	N/A	N/A	N/A
23	Pool Water Surface Slope	S_{pool}	ft/ft	Mean	0.0011		0.0002	
				Range	0.0009	0.0014	0.0001	0.0002
24	Pool WS slope / Average WS slope	S_{pool}/S_{avg}		Mean	0.4000		0.40	
				Range	0.3000	0.5000	0.3	0.50
25	Riffle Water Surface slope	Sriff	ft/ft	Mean	0.0038		0.0006	
				Range	0.0034	0.0043	0.0004	0.0007
26	Riffle WS slope / Average WS slope	S_{rifF}/S_{avg}		Mean	1.4000		1.45	
				Range	1.2000	1.5000	1.1	1.80
27	Run WS Slope	S_{run}/S_{avg}	ft/ft	Mean	0.0019			NA
				Range	0.0014	0.0023		NA
28	Run WS slope / Average WS slope	S_{run}/S_{avg}	ft/ft	Mean	0.7000			NA
				Range	0.5000	0.8000		NA

Design Criteria
UT6e Piney Run, Maryland

No.	Variable	Symbol	Units		Design Ratios and Criteria		Design Ratios and Criteria	
29	Glide WS Slope	S_{glide}		Mean	0.0011		0.0002	
				Range	0.0009	0.0014	0.0001	0.0002
30	Glide WS slope / Average WS slope	S_{glide}/S_{avg}	ft/ft	Mean	0.4000		0.40	
				Range	0.3000	0.5000	0.3	0.50
31	Maximum pool depth	d_{pool}	feet	Mean	6.75		7.43	
				Range	4.05	9.45	5.40	9.45
32	Ratio of max pool depth to average bankfull depth	d_{pool}/d_{bkf}		Mean	2.50		2.75	
				Range	1.50	3.50	2.00	3.50
33	Max Run Depth	d_{run}	feet	Mean	5.27			NA
				Range	4.59	5.94		NA
34	Ratio of max run depth to average bankfull depth	d_{run}/d_{bkf}		Mean	2.00			NA
				Range	1.70	2.20		NA
35	Max Riffle Depth	d_{run}	feet	Mean	3.65		3.51	
				Range	3.24	4.05	3.24	3.78
36	Ratio of max riffle depth to average bankfull depth	d_{run}/d_{bkf}		Mean	1.35		1.30	
				Range	1.20	1.50	1.20	1.40
37	Max Glide Depth	d_{glide}	feet	Mean	4.32		4.32	
				Range	3.78	4.86	3.78	4.86
38	Ratio of max glide depth to average bankfull depth	d_{glide}/d_{bkf}	feet	Mean	1.60		1.60	
				Range	1.40	1.80	1.40	1.80
39	Pool width	W_{pool}	feet	Mean	79.75		71.50	
				Range	66.00	93.50	60.50	82.50
40	Ratio of pool width to bankfull width	W_{pool}/W_{bkf}		Mean	1.50		1.30	
				Range	1.20	1.70	1.10	1.50
42	Point bar slope	S_{pb}		Mean	8.00			NA
				Range	6.00	10		NA
43	Pool to pool spacing	p-p	feet	Mean	288.75		247.50	
				Range	192.50	385.00	220.00	275.00
44	Ratio of pool to pool spacing to bankfull width	$p\text{-}p/W_{bkf}$		Mean	5.30		4.50	
				Range	3.50	7.00	4.00	5.00
Materials								
	Particle Size Distribution Channel	D_{16}	mm		18.64			18.64
		D_{35}	mm		32.39			32.39
		D_{50}	mm		42.17			42.17
		D_{84}	mm		76.48			76.48
		D_{95}	mm		89.35			89.35
	Particle Size Distribution Bar	D_{16}	mm		4.88			4.88
		D_{35}	mm		24.73			24.73
		D_{50}	mm		41.94			41.94
		D_{84}	mm		84.17			84.17
		D_{95}	mm		98.49			98.49
Largest Particle Size			mm		105.00			105.00
Sediment Transport Validation								
Bankfull shear stress		t	lbs/ft^2					
Critical Sediment Size from Shield		D_{crit}	mm					
Minimum mean dbkf using critical		d_r	feet					

APPENDIX D

Worksheet 2-2. Computations of velocity and bankfull discharge using various methods (Rosgen, 2006b; Rosgen and Silvey, 2007).

Bankfull VELOCITY & DISCHARGE Estimates

Stream:	Little Beaverkill	Location:	Reach - Reach 1 (4)
Date:	10/21/2014	Stream Type: C4	Valley Type: VIII
Observers:	RS, CC, CD	HUC:	

INPUT VARIABLES			OUTPUT VARIABLES		
Bankfull Riffle Cross-Sectional AREA	153.04	A_{bkf} (ft^2)	Bankfull Riffle Mean DEPTH	2.47	d_{bkf} (ft)
Bankfull Riffle WIDTH	61.91	W_{bkf} (ft)	Wetted PERMIMETER ~ (2 * d_{bkf}) + W_{bkf}	63.21	W_p (ft)
D_{84} at Riffle	93.92	Dia. (mm)	D_{84} (mm) / 304.8	0.31	D_{84} (ft)
Bankfull SLOPE	0.0029	S_{bkf} (ft / ft)	Hydraulic RADIUS A_{bkf} / W_p	2.42	R (ft)
Gravitational Acceleration	32.2	g (ft / sec^2)	Relative Roughness R(ft) / D_{84} (ft)	7.86	R / D_{84}
Drainage Area	0.0	DA (mi^2)	Shear Velocity $u^* = (gRS)^{1/2}$	0.475	u* (ft/sec)

ESTIMATION METHODS	Bankfull VELOCITY		Bankfull DISCHARGE	
1. Friction Factor / Relative Roughness $u = [2.83 + 5.66 * Log \{ R / D_{84} \}] u^*$	3.76	ft / sec	574.66	cfs
2. Roughness Coefficient: a) Manning's *n* from Friction Factor / Relative Roughness (Figs. 2-18, 2-19) $u = 1.49*R^{2/3}*S^{1/2} / n$ n = 0.030	4.81	ft / sec	736.28	cfs
2. Roughness Coefficient: b) Manning's *n* from Stream Type (Fig. 2-20) $u = 1.49*R^{2/3}*S^{1/2} / n$ n = 0.031	4.66	ft / sec	712.55	cfs
2. Roughness Coefficient: c) Manning's *n* from Jarrett (USGS): $u = 1.49*R^{2/3}*S^{1/2} / n$ $n = 0.39*S^{0.38}*R^{-0.16}$ n = 0.037 Note: This equation is applicable to **steep, step/pool, high boundary roughness, cobble- and boulder-dominated stream systems**; i.e., for Stream Types A1, A2, A3, B1, B2, B3, C2 & E3	3.92	ft / sec	600.22	cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.) Darcy-Weisbach (Leopold, Wolman and Miller)	3.85	ft / sec	589.43	cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.) Chezy C	0.00	ft / sec	0.00	cfs
4. Continuity Equations: a) Regional Curves u = Q / A Return Period for Bankfull Discharge Q = 0.0 year	0.00	ft / sec	0.00	cfs
4. Continuity Equations: b) USGS Gage Data u = Q / A	5.72	ft / sec	823.00	cfs

Protrusion Height Options for the D_{84} Term in the Relative Roughness Relation (R/D_{84}) – Estimation Method 1

Option 1.	For **sand-bed** channels: Measure 100 **"protrusion heights"** of sand dunes from the downstream side of feature to the top of feature. Substitute the D_{84} sand dune protrusion height in ft for the D_{84} term in method 1.
Option 2.	For **boulder-dominated** channels: Measure 100 **"protrusion heights"** of boulders on the sides from the bed elevation to the top of the rock on that side. Substitute the D_{84} boulder protrusion height in ft for the D_{84} term in method 1.
Option 3.	For **bedrock-dominated** channels: Measure 100 **"protrusion heights"** of rock separations, steps, joints or uplifted surfaces above channel bed elevation. Substitute the D_{84} bedrock protrusion height in ft for the D_{84} term in method 1.
Option 4.	For **log-influenced** channels: Measure "**protrusion heights**" proportionate to channel width of log diameters or the height of the log on upstream side if embedded. Substitute the D_{84} protrusion height in ft for the D_{84} term in method 1.

Worksheet 2-2. Computations of velocity and bankfull discharge using various methods (Rosgen, 2006b; Rosgen and Silvey, 2007).

Bankfull VELOCITY & DISCHARGE Estimates

Stream:	**Little Beaverkill**	Location:	**Reach - Reach 2 (3)**
Date:	**10/21/2014** Stream Type: **??**	Valley Type:	**VIII**
Observers:		HUC:	

INPUT VARIABLES			OUTPUT VARIABLES		
Bankfull Riffle Cross-Sectional AREA	**158.11**	A_{bkf} (ft^2)	Bankfull Riffle Mean DEPTH	**1.52**	d_{bkf} (ft)
Bankfull Riffle WIDTH	**104.14**	W_{bkf} (ft)	Wetted PERMIMETER ~ $(2 * d_{bkf}) + W_{bkf}$	**105.38**	W_p (ft)
D_{84} at Riffle	**76.48**	Dia. (mm)	D_{84} (mm) / 304.8	**0.25**	D_{84} (ft)
Bankfull SLOPE	**0.0029**	S_{bkf} (ft / ft)	Hydraulic RADIUS A_{bkf} / W_p	**1.50**	R (ft)
Gravitational Acceleration	**32.2**	g (ft / sec^2)	Relative Roughness R(ft) / D_{84} (ft)	**5.98**	R / D_{84}
Drainage Area	**0.0**	DA (mi^2)	Shear Velocity $u^* = (gRS)^{1/2}$	**0.374**	u* (ft/sec)

ESTIMATION METHODS	Bankfull VELOCITY		Bankfull DISCHARGE	
1. Friction Factor / Relative Roughness $u = [2.83 + 5.66 * Log\{R / D_{84}\}] u^*$	**2.70**	ft / sec	**427.64**	cfs
2. Roughness Coefficient: a) Manning's *n* from Friction Factor / Relative Roughness (Figs. 2-18, 2-19) $u = 1.49*R^{2/3}*S^{1/2} / n$ $n =$ **0.030**	**3.50**	ft / sec	**552.91**	cfs
2. Roughness Coefficient: b) Manning's *n* from Stream Type (Fig. 2-20) $u = 1.49*R^{2/3}*S^{1/2} / n$ $n =$ **0.031**	**3.38**	ft / sec	**535.04**	cfs
2. Roughness Coefficient: c) Manning's *n* from Jarrett (USGS): $u = 1.49*R^{2/3}*S^{1/2} / n$ $n = 0.39*S^{0.38}*R^{-0.16}$ **Note:** This equation is applicable to **steep, step/pool, high boundary roughness, cobble- and boulder-dominated stream systems**; i.e., for Stream Types A1, A2, A3, B1, B2, B3, C2 & E3 $n =$ **0.040**	**2.64**	ft / sec	**417.89**	cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.) **Darcy-Weisbach (Leopold, Wolman and Miller)**	**2.76**	ft / sec	**436.11**	cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.) **Chezy C**	**0.00**	ft / sec	**0.00**	cfs
4. Continuity Equations: a) Regional Curves u = Q / A **Return Period for Bankfull Discharge** Q = **0.0** year	**0.00**	ft / sec	**0.00**	cfs
4. Continuity Equations: b) USGS Gage Data u = Q / A	**5.72**	ft / sec	**823.00**	cfs

Protrusion Height Options for the D_{84} Term in the Relative Roughness Relation (R/D_{84}) – Estimation Method 1

Option 1.	For **sand-bed** channels: Measure 100 **"protrusion heights"** of sand dunes from the downstream side of feature to the top of feature. Substitute the D_{84} sand dune protrusion height in ft for the D_{84} term in method 1.
Option 2.	For **boulder-dominated** channels: Measure 100 **"protrusion heights"** of boulders on the sides from the bed elevation to the top of the rock on that side. Substitute the D_{84} boulder protrusion height in ft for the D_{84} term in method 1.
Option 3.	For **bedrock-dominated** channels: Measure 100 **"protrusion heights"** of rock separations, steps, joints or uplifted surfaces above channel bed elevation. Substitute the D_{84} bedrock protrusion height in ft for the D_{84} term in method 1.
Option 4.	For **log-influenced** channels: Measure "**protrusion heights**" proportionate to channel width of log diameters or the height of the log on upstream side if embedded. Substitute the D_{84} protrusion height in ft for the D_{84} term in method 1.

Worksheet 2-2. Computations of velocity and bankfull discharge using various methods (Rosgen, 2006b; Rosgen and Silvey, 2007).

Bankfull VELOCITY & DISCHARGE Estimates

Stream:	**Little Beaverkill**	Location:	**Reach - Reach 3 (2)**
Date:	**10/21/2014** Stream Type: **F4**	Valley Type:	**VIII**
Observers:	**RS, CC, CD**	HUC:	

INPUT VARIABLES			OUTPUT VARIABLES		
Bankfull Riffle Cross-Sectional AREA	**144.79**	A_{bkf} (ft^2)	Bankfull Riffle Mean DEPTH	**2.47**	d_{bkf} (ft)
Bankfull Riffle WIDTH	**58.64**	W_{bkf} (ft)	Wetted PERMIMETER ~ (2 * d_{bkf}) + W_{bkf}	**60.93**	W_p (ft)
D_{84} at Riffle	**51.24**	Dia. (mm)	D_{84} (mm) / 304.8	**0.17**	D_{84} (ft)
Bankfull SLOPE	**0.0029**	S_{bkf} (ft / ft)	Hydraulic RADIUS A_{bkf} / W_p	**2.38**	R (ft)
Gravitational Acceleration	**32.2**	g (ft / sec^2)	Relative Roughness R(ft) / D_{84} (ft)	**14.17**	R / D_{84}
Drainage Area	**0.0**	DA (mi^2)	Shear Velocity $u^* = (gRS)^{1/2}$	**0.471**	u* (ft/sec)

ESTIMATION METHODS	Bankfull VELOCITY		Bankfull DISCHARGE	
1. Friction Factor / Relative Roughness $u = [2.83 + 5.66 * Log\{R / D_{84}\}] u^*$	**4.40**	ft / sec	**637.08**	cfs
2. Roughness Coefficient: a) Manning's *n* from Friction Factor / Relative Roughness (Figs. 2-18, 2-19) $u = 1.49 * R^{2/3} * S^{1/2} / n$ $n =$ **0.030**	**4.75**	ft / sec	**688.04**	cfs
2. Roughness Coefficient: b) Manning's *n* from Stream Type (Fig. 2-20) $u = 1.49 * R^{2/3} * S^{1/2} / n$ $n =$ **0.031**	**4.60**	ft / sec	**665.74**	cfs
2. Roughness Coefficient: c) Manning's *n* from Jarrett (USGS): $u = 1.49 * R^{2/3} * S^{1/2} / n$ $n = 0.39 * S^{0.38} * R^{-0.16}$ **Note:** This equation is applicable to **steep, step/pool, high boundary roughness, cobble- and boulder-dominated stream systems**; i.e., for Stream Types A1, A2, A3, B1, B2, B3, C2 & E3 $n =$ **0.037**	**3.86**	ft / sec	**559.32**	cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.) **Darcy-Weisbach (Leopold, Wolman and Miller)**	**4.58**	ft / sec	**662.71**	cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.) **Chezy C**	**0.00**	ft / sec	**0.00**	cfs
4. Continuity Equations: a) Regional Curves u = Q / A **Return Period for Bankfull Discharge Q =** 0.0 **year**	**0.00**	ft / sec	**0.00**	cfs
4. Continuity Equations: b) USGS Gage Data u = Q / A	**5.72**	ft / sec	**823.00**	cfs

Protrusion Height Options for the D_{84} Term in the Relative Roughness Relation (R/D_{84}) – Estimation Method 1

Option 1.	For **sand-bed** channels: Measure 100 **"protrusion heights"** of sand dunes from the downstream side of feature to the top of feature. Substitute the D_{84} sand dune protrusion height in ft for the D_{84} term in method 1.
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Option 3.	For **bedrock-dominated** channels: Measure 100 **"protrusion heights"** of rock separations, steps, joints or uplifted surfaces above channel bed elevation. Substitute the D_{84} bedrock protrusion height in ft for the D_{84} term in method 1.
Option 4.	For **log-influenced** channels: Measure "**protrusion heights**" proportionate to channel width of log diameters or the height of the log on upstream side if embedded. Substitute the D_{84} protrusion height in ft for the D_{84} term in method 1.

APPENDIX E

Draft Cross Section and Discharge Calculation - Little Beaver Kill, Livingston Manor, NY

Surveyed Cross Section	Channel Dimensions			Entrenchment	D50	Slope (ft/ft)	Rosgen Stream Type	Mannings "n" ($u=1.49*R^{2/3}*S^{1/2}/n$)	Velocity (ft/sec)	Calculated Bankfull Discharge (cfs)	Regional Curve Bankfull Data (NY Region 4a)			
	Mean Depth (ft)	Width (ft)	Area (sqft)								Discharge (cfs)	Mean Depth (ft)	Width (ft)	Area (sqft)
Reference XS 1	2.88	54	155.77	>2.2	gravel		C4				823	2.57	58	144
Reference XS 2	2.85	48.79	139.2	>2.2	gravel		C4				823	2.57	58	144
Project XS 1	2.47	61.91	153.04	>2.2	gravel	0.004	C4	0.030	4.81	736.28	823	2.57	58	144
Project XS 2	1.52	104.14	158.11	>2.2	gravel	0.004	D4	0.030	3.50	552.91	823	2.57	58	144
Project XS 3	2.47	58.64	144.79	>2.2	gravel	0.004	C4	0.030	4.75	688.04	823	2.57	58	144

December 10, 2012

Entrainment Calculations - Little Beaver Kill, Livingstion Manor, NY

Surveyed Cross Section	Riffle Pebble Count					Bar Sample						Dimensionaless Shear Stress (*t**)	*Existing Bankfull Shear Stress (t)*	*Predicted Bankfull Shear Stress (t)*	Existing Mean Depth (ft)	Required Mean Depth (ft)	Existing Slope (ft/ft)	Required Slope (ft/ft)	Vertical Stability
	D15	D35	D50	D84	D100	D15	D35	D50	D84	D100	Largest Particle								
Bar Sample 1	11.3	26.36	45	180	2047.97	4.02	15.77	37.78	93.92	125	125	0.016	0.709	0.617	2.47	2.62	0.004	0.00425	stable
Bar Sample 2	18.64	32.39	42.71	76.48	128	4.88	24.73	41.94	84.17	105	105	0.017	0.73	0.379	1.52	2.46	0.004	0.00647	aggrading
Bar Sample 3	12.24	20.74	30.29	51.24	128	0	0	17.94	52.42	68	68	0.019	0.786	0.617	2.47	1.72	0.004	0.00279	degrading

Worksheet 3-14. Sediment competence calculation form to assess bed stability.

Stream:	**Little Beaverkill**		Stream Type: **C4**		
Location:	**Reach 1 (4)**		Valley Type: **XIV**		
Observers:	**RS, CC, CD**		Date: **10/21/2014**		
Enter Required Information for Existing Condition					
45.0	D_{50}	Median particle size of riffle bed material (mm)			
37.8	$\hat{D}_{50}$	Median particle size of bar or sub-pavement sample (mm)			
0.410	D_{max}	Largest particle from bar sample (ft)	**125**	**(mm)**	304.8 mm/ft
0.00290	S	Existing bankfull water surface slope (ft/ft)			
2.47	d	Existing bankfull mean depth (ft)			
1.65	$\gamma_s - \gamma / \gamma$	Immersed specific gravity of sediment			

Select the Appropriate Equation and Calculate Critical Dimensionless Shear Stress				
1.19	$D_{50}/\hat{D}_{50}$	Range: 3 – 7	Use EQUATION 1: $\tau^* = 0.0834\ (D_{50}/\hat{D}_{50})^{-0.872}$	
2.78	D_{max}/D_{50}	Range: 1.3 – 3.0	Use EQUATION 2: $\tau^* = 0.0384\ (D_{max}/D_{50})^{-0.887}$	
0.016	τ^*	Bankfull Dimensionless Shear Stress	EQUATION USED:	**2**

Calculate Bankfull Mean Depth Required for Entrainment of Largest Particle in Bar Sample			
3.62	d	Required bankfull mean depth (ft) $d = \frac{\tau^*(\gamma_s - 1)D_{max}}{S}$	(use D_{max} in ft)
Calculate Bankfull Water Surface Slope Required for Entrainment of Largest Particle in Bar Sample			
0.00425	S	Required bankfull water surface slope (ft/ft) $S = \frac{\tau^*(\gamma_s - 1)D_{max}}{d}$	(use D_{max} in ft)

Check: ☑ Stable ☐ Aggrading ☐ Degrading

Sediment Competence Using Dimensional Shear Stress		
0.447		Bankfull shear stress $\tau = \gamma dS$ (lbs/ft^2) (substitute hydraulic radius, R, with mean depth, d) γ = 62.4, d = existing depth, S = existing slope
Shields **33.69**	CO **84.08**	Predicted largest moveable particle size (mm) at bankfull shear stress τ **(Figure 3-11)**
Shields **1.573**	CO **0.766**	Predicted shear stress required to initiate movement of measured D_{max} (mm) **(Figure 3-11)**
Shields **8.69**	CO **4.24**	Predicted mean depth required to initiate movement of measured D_{max} (mm) $d = \frac{\tau}{\gamma S}$ τ = predicted shear stress, γ = 62.4, S = existing slope
Shields **0.0102**	CO **0.0050**	Predicted slope required to initiate movement of measured D_{max} (mm) $S = \frac{\tau}{\gamma d}$ τ = predicted shear stress, γ = 62.4, d = existing depth

Check: ☑ Stable ☐ Aggrading ☐ Degrading

Worksheet 3-14. Sediment competence calculation form to assess bed stability.

Stream:	**Little Beaverkill**		Stream Type: **D4**		
Location:	**Reach 2 (3)**		Valley Type: **XIV**		
Observers:			Date: **10/21/2014**		
Enter Required Information for Existing Condition					
42.7	D_{50}	Median particle size of riffle bed material (mm)			
41.9	$\hat{D}_{50}$	Median particle size of bar or sub-pavement sample (mm)			
0.345	D_{max}	Largest particle from bar sample (ft)	**105**	**(mm)**	304.8 mm/ft
0.00290	S	Existing bankfull water surface slope (ft/ft)			
1.52	d	Existing bankfull mean depth (ft)			
1.65	$\gamma_s - \gamma / \gamma$	Immersed specific gravity of sediment			

Select the Appropriate Equation and Calculate Critical Dimensionless Shear Stress				
1.02	$D_{50}/\hat{D}_{50}$	Range: 3 – 7	Use EQUATION 1: $\tau^* = 0.0834\ (D_{50}/\hat{D}_{50})^{-0.872}$	
2.46	D_{max}/D_{50}	Range: 1.3 – 3.0	Use EQUATION 2: $\tau^* = 0.0384\ (D_{max}/D_{50})^{-0.887}$	
0.017	τ^*	Bankfull Dimensionless Shear Stress	EQUATION USED:	**2**

Calculate Bankfull Mean Depth Required for Entrainment of Largest Particle in Bar Sample			
3.39	d	Required bankfull mean depth (ft) $d = \frac{\tau^*(\gamma_s - 1)D_{max}}{S}$	(use D_{max} in ft)
Calculate Bankfull Water Surface Slope Required for Entrainment of Largest Particle in Bar Sample			
0.00647	S	Required bankfull water surface slope (ft/ft) $S = \frac{\tau^*(\gamma_s - 1)D_{max}}{d}$	(use D_{max} in ft)
		Check: ☐ Stable ☑ Aggrading ☐ Degrading	

Sediment Competence Using Dimensional Shear Stress		
0.275		Bankfull shear stress $\tau = \gamma dS$ (lbs/ft^2) (substitute hydraulic radius, R, with mean depth, d) γ = 62.4, d = existing depth, S = existing slope
Shields **20.31**	CO **58.83**	Predicted largest moveable particle size (mm) at bankfull shear stress τ **(Figure 3-11)**
Shields **1.331**	CO **0.605**	Predicted shear stress required to initiate movement of measured D_{max} (mm) **(Figure 3-11)**
Shields **7.35**	CO **3.34**	Predicted mean depth required to initiate movement of measured D_{max} (mm) τ = predicted shear stress, γ = 62.4, S = existing slope $d = \frac{\tau}{\gamma S}$
Shields **0.0140**	CO **0.0064**	Predicted slope required to initiate movement of measured D_{max} (mm) τ = predicted shear stress, γ = 62.4, d = existing depth $S = \frac{\tau}{\gamma d}$
		Check: ☐ Stable ☑ Aggrading ☐ Degrading

Worksheet 3-14. Sediment competence calculation form to assess bed stability.

Stream:	**Little Beaverkill**	Stream Type:	**C4**
Location:	**Reach 3 (2)**	Valley Type:	**XIV**
Observers:		Date:	**10/21/2014**

Enter Required Information for Existing Condition

30.3	D_{50}	Median particle size of riffle bed material (mm)			
17.9	$\hat{D}_{50}$	Median particle size of bar or sub-pavement sample (mm)			
0.223	D_{max}	Largest particle from bar sample (ft)	**68**	**(mm)**	304.8 mm/ft
0.00290	S	Existing bankfull water surface slope (ft/ft)			
2.47	d	Existing bankfull mean depth (ft)			
1.65	$\gamma_s - \gamma / \gamma$	Immersed specific gravity of sediment			

Select the Appropriate Equation and Calculate Critical Dimensionless Shear Stress

1.69	$D_{50}/\hat{D}_{50}$	Range: 3 – 7	Use EQUATION 1:	$\tau^* = 0.0834\,(D_{50}/\hat{D}_{50})^{-0.872}$
2.24	D_{max}/D_{50}	Range: 1.3 – 3.0	Use EQUATION 2:	$\tau^* = 0.0384\,(D_{max}/D_{50})^{-0.887}$
0.019	τ^*	Bankfull Dimensionless Shear Stress	EQUATION USED:	**2**

Calculate Bankfull Mean Depth Required for Entrainment of Largest Particle in Bar Sample

2.38	d	Required bankfull mean depth (ft)	$d = \dfrac{\tau^*(\gamma_s - 1)D_{max}}{S}$	(use D_{max} in ft)

Calculate Bankfull Water Surface Slope Required for Entrainment of Largest Particle in Bar Sample

0.00279	S	Required bankfull water surface slope (ft/ft)	$S = \dfrac{\tau^*(\gamma_s - 1)D_{max}}{d}$	(use D_{max} in ft)

Check: ☐ Stable ☐ Aggrading ☑ Degrading

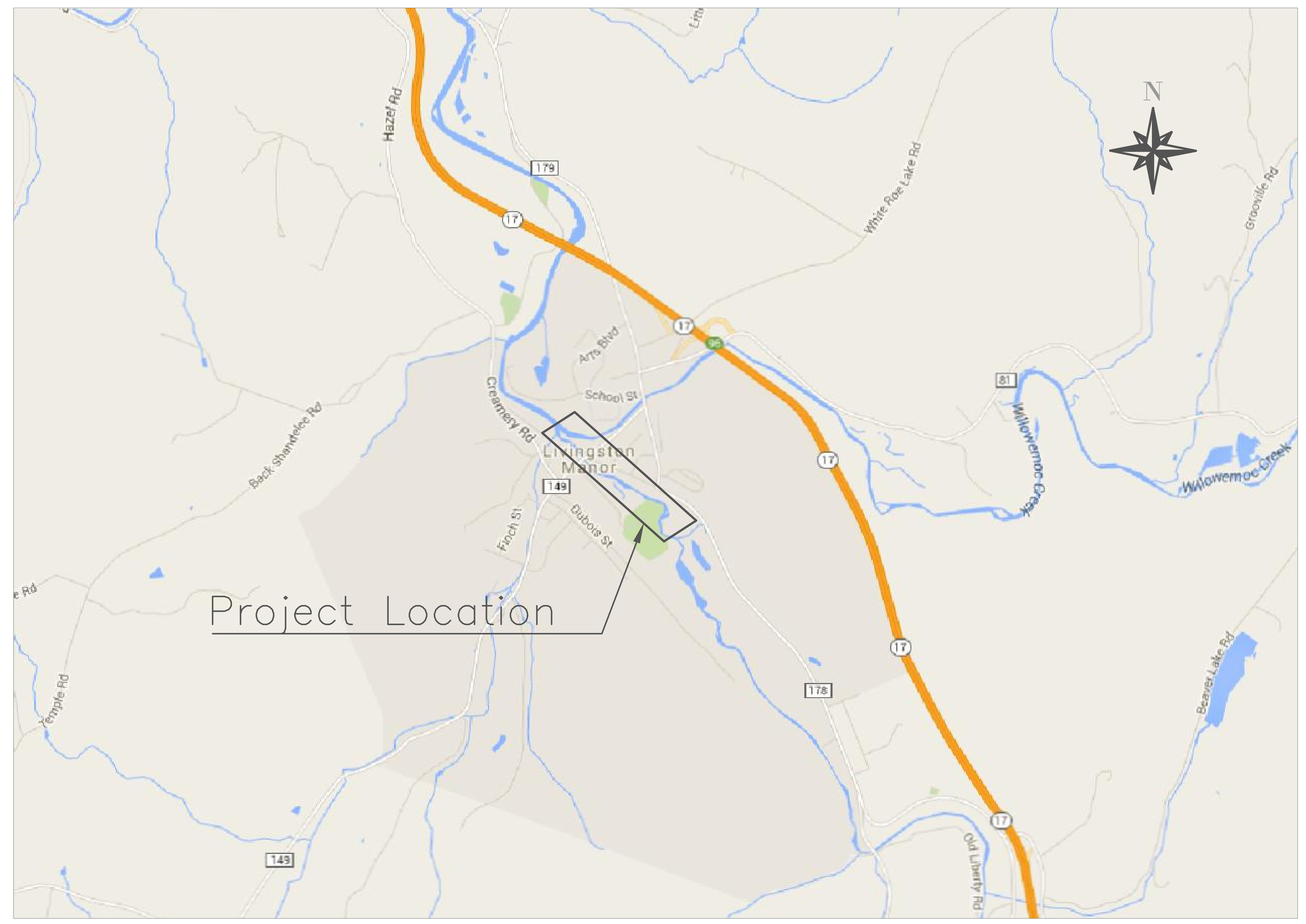
Sediment Competence Using Dimensional Shear Stress

0.447		Bankfull shear stress $\tau = \gamma dS$ (lbs/ft^2) (substitute hydraulic radius, R, with mean depth, d) γ = 62.4, d = existing depth, S = existing slope
Shields **33.69**	CO **84.08**	Predicted largest moveable particle size (mm) at bankfull shear stress τ **(Figure 3-11)**
Shields **0.877**	CO **0.335**	Predicted shear stress required to initiate movement of measured D_{max} (mm) **(Figure 3-11)**
Shields **4.85**	CO **1.85**	Predicted mean depth required to initiate movement of measured D_{max} (mm) τ = predicted shear stress, γ = 62.4, S = existing slope $d = \dfrac{\tau}{\gamma S}$
Shields **0.0057**	CO **0.0022**	Predicted slope required to initiate movement of measured D_{max} (mm) τ = predicted shear stress, γ = 62.4, d = existing depth $S = \dfrac{\tau}{\gamma d}$

Check: ☐ Stable ☐ Aggrading ☑ Degrading

APPENDIX F

LITTLE BEAVERKILL STREAM RESTORATION
LIVINGSTON MANOR, NY
DRAFT 30% DESIGN



LIST OF SHEETS

U.S. Fish & Wildlife Service
Chesapeake Bay Field Office
Stream Habitat Assessment and Restoration Program

177 Admiral Cochrane Drive
Annapolis, Maryland 21401

Tel. (410) 573-4583

Proposed Channel
Existing Channel
Project Limits for Stream Stability
Haul Roads
J–Hook
Cross Vane
Existing Roads
Wetland Area
Toe Wood

0 200 400 800 Feet

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LIVINGSTON MANOR

REVISIONS	
DATE	BY

DRAFT 30% DESIGN PLAN

PROJECT MANAGER: RRS
DRAFTING: KC
DESIGN: RRS
CHECKED BY: BH
SCALE: 1:200

SHEET 2 OF 10

PC–1

■ Proposed Thalweg Elevation

⬢ Proposed Bankfull Elevation

NOTE: Excavate floodplain, at proposed bankfull elevation, starting from channel TOB and extend to proposed wetland boundary or project limits, whichever is farthest from proposed channel edge.

0 80 160 Feet

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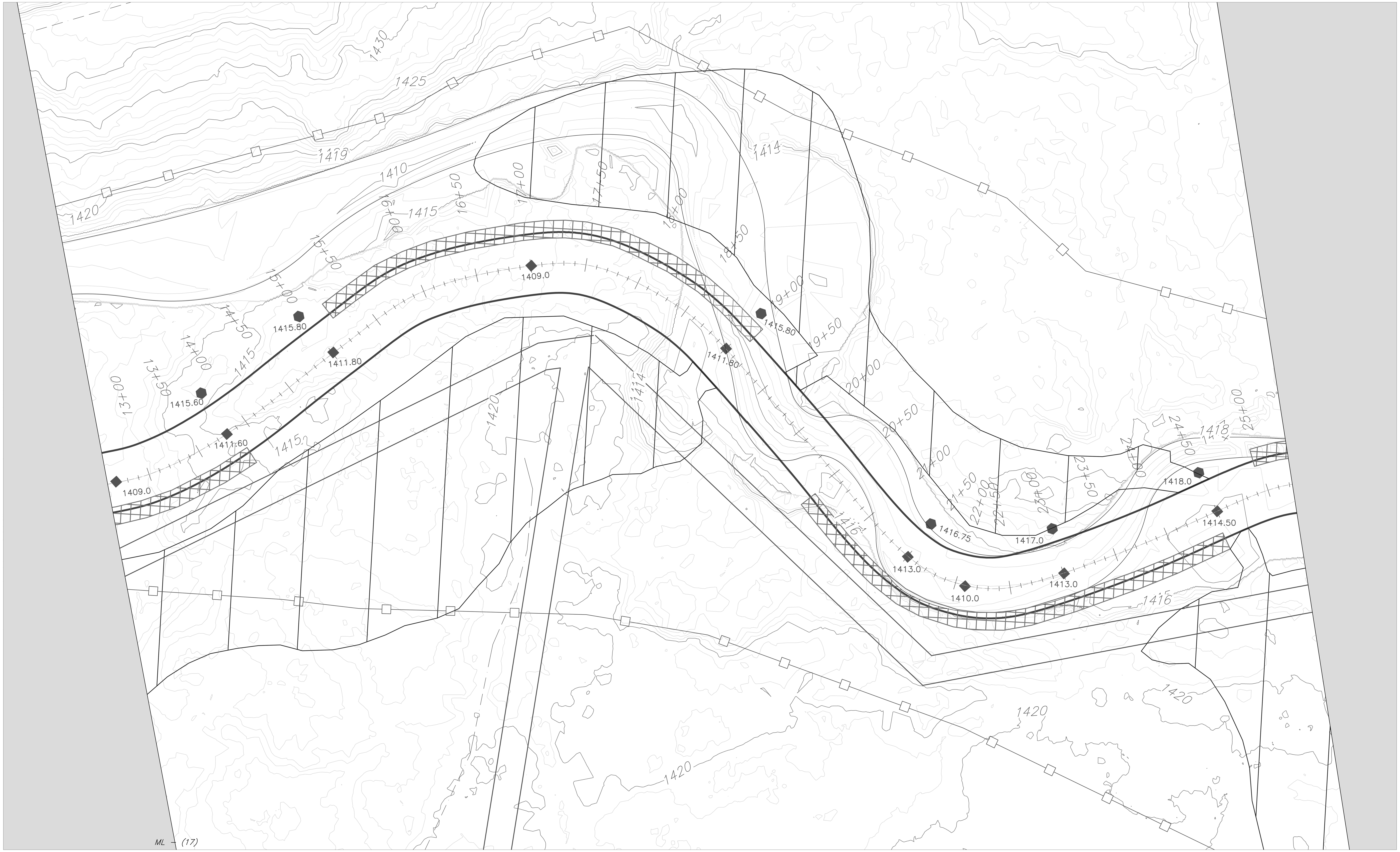
LIVINGSTON MANOR		SHEET
REVISIONS: DATE / BY	DRAFT 30% DESIGN PLAN	3 OF 10
PROJECT MANAGER: RRS	DRAFTING: KC	PC–2
DESIGN: RRS	CHECKED BY: BH	
SCALE: 1:40		



■ Proposed Thalweg Elevation

⬢ Proposed Bankfull Elevation

NOTE: Excavate floodplain, at proposed bankfull elevation, starting from channel TOB and extend to proposed wetland boundary or project limits, whichever is farthest from proposed channel edge.

0 80 160 Feet

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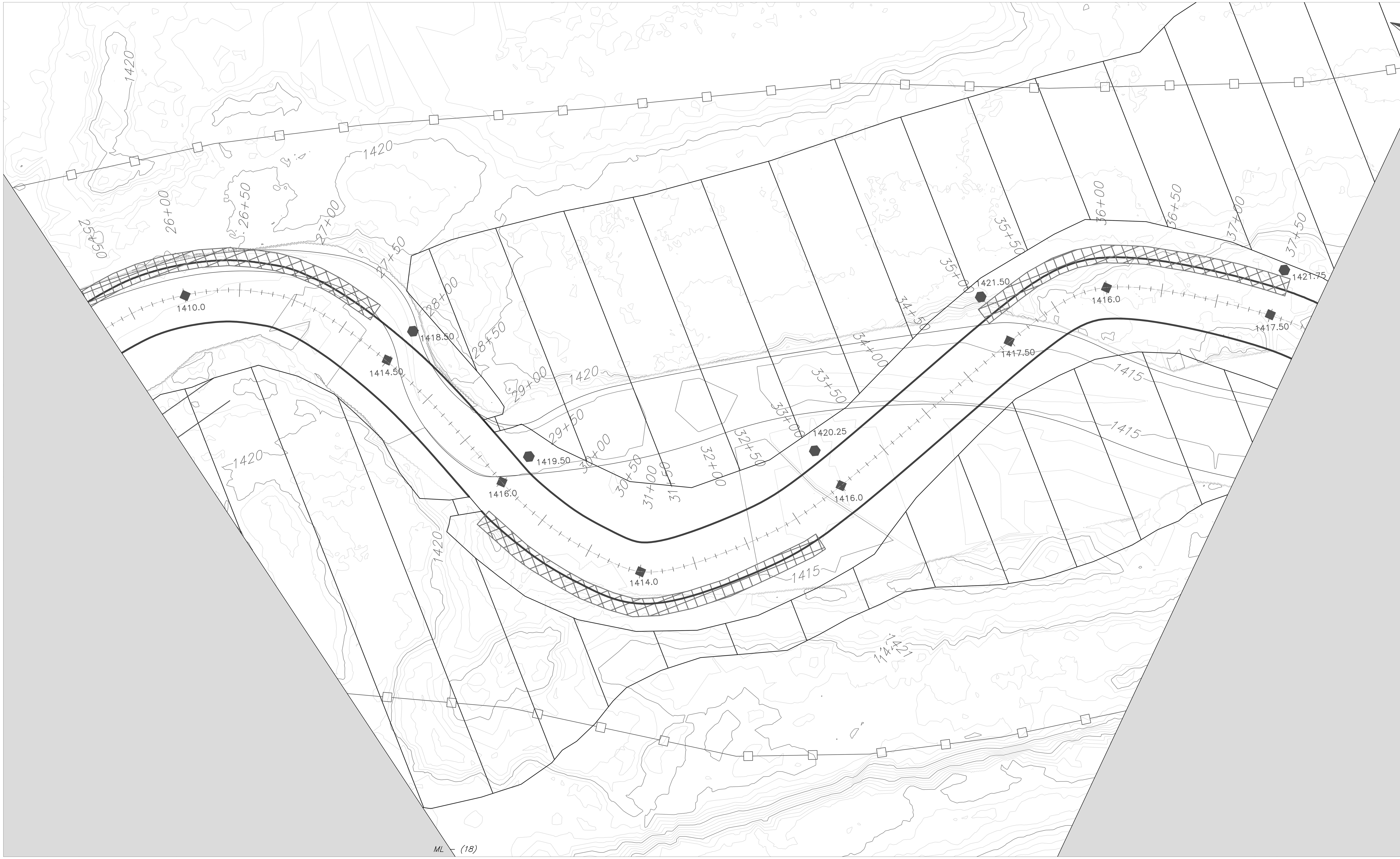
PROJECT MANAGER: RRS | DRAFTING: KC
DESIGN: RRS | CHECKED BY: BH
SCALE: 1:40

SHEET 4 OF 10

PC—3



■ Proposed Thalweg Elevation

⬢ Proposed Bankfull Elevation

NOTE: Excavate floodplain, at proposed bankfull elevation, starting from channel TOB and extend to proposed wetland boundary or project limits, whichever is farthest from proposed channel edge.

0 80 160 Feet

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LIVINGSTON MANOR		SHEET 5 OF 10
REVISIONS: DATE / BY	DRAFT 30% DESIGN PLAN	
PROJECT MANAGER: RRS	DRAFTING: KC	PC–4
DESIGN: RRS	CHECKED BY: BH	
SCALE: 1:40		

Proposed Thalweg Elevation

Proposed Bankfull Elevation

NOTE: Excavate floodplain, at proposed bankfull elevation, starting from channel TOB and extend to proposed wetland boundary or project limits, whichever is farthest from proposed channel edge.

0 80 160 Feet

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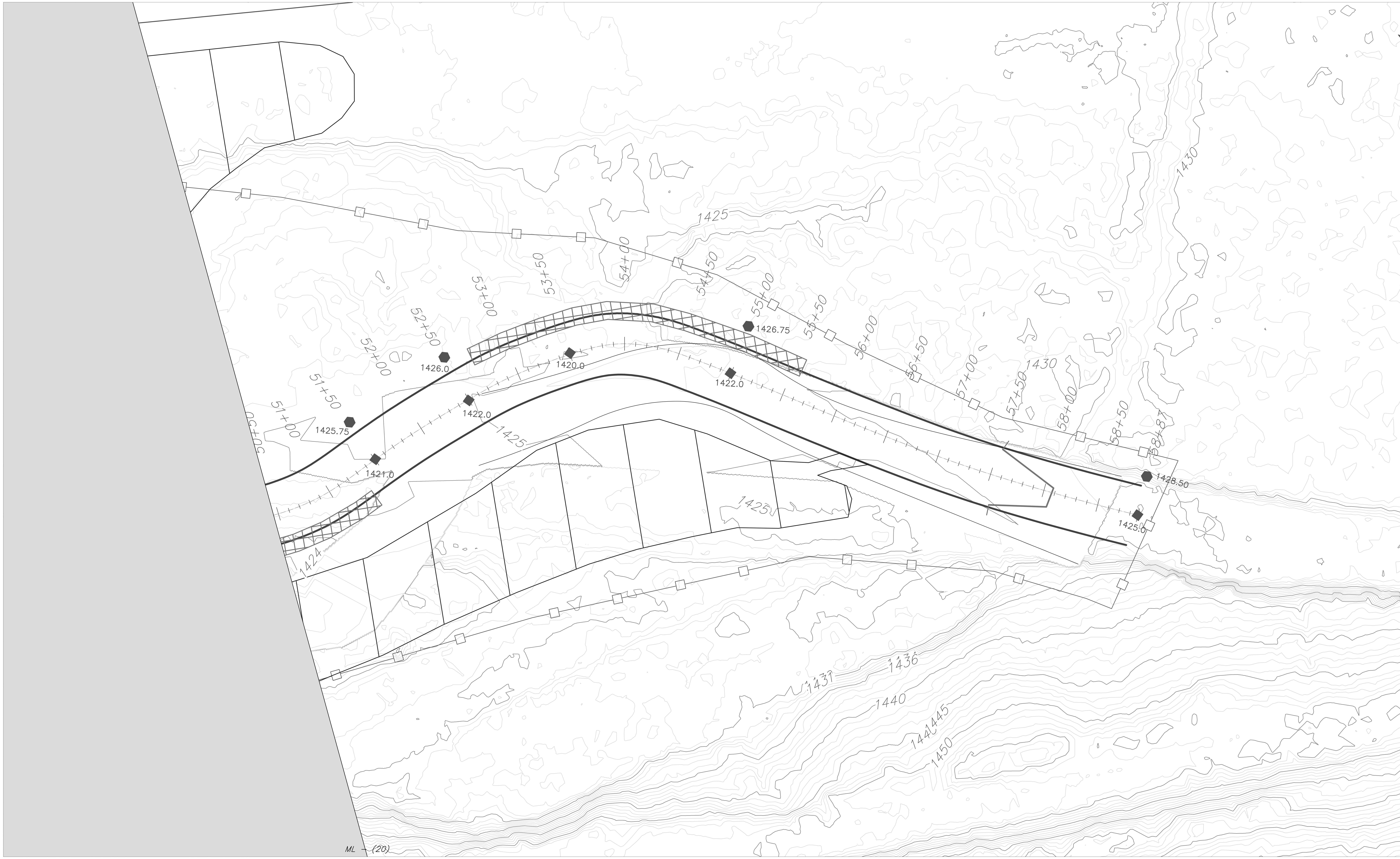
DESIGN: RRS	CHECKED BY: BH
SCALE: 1:40	

SHEET
6 OF 10

PC-5



Proposed Thalweg Elevation

Proposed Bankfull Elevation

NOTE: Excavate floodplain, at proposed bankfull elevation, starting from channel TOB and extend to proposed wetland boundary or project limits, whichever is farthest from proposed channel edge.

0 80 160 Feet

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LIVINGSTON MANOR

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DATE	BY

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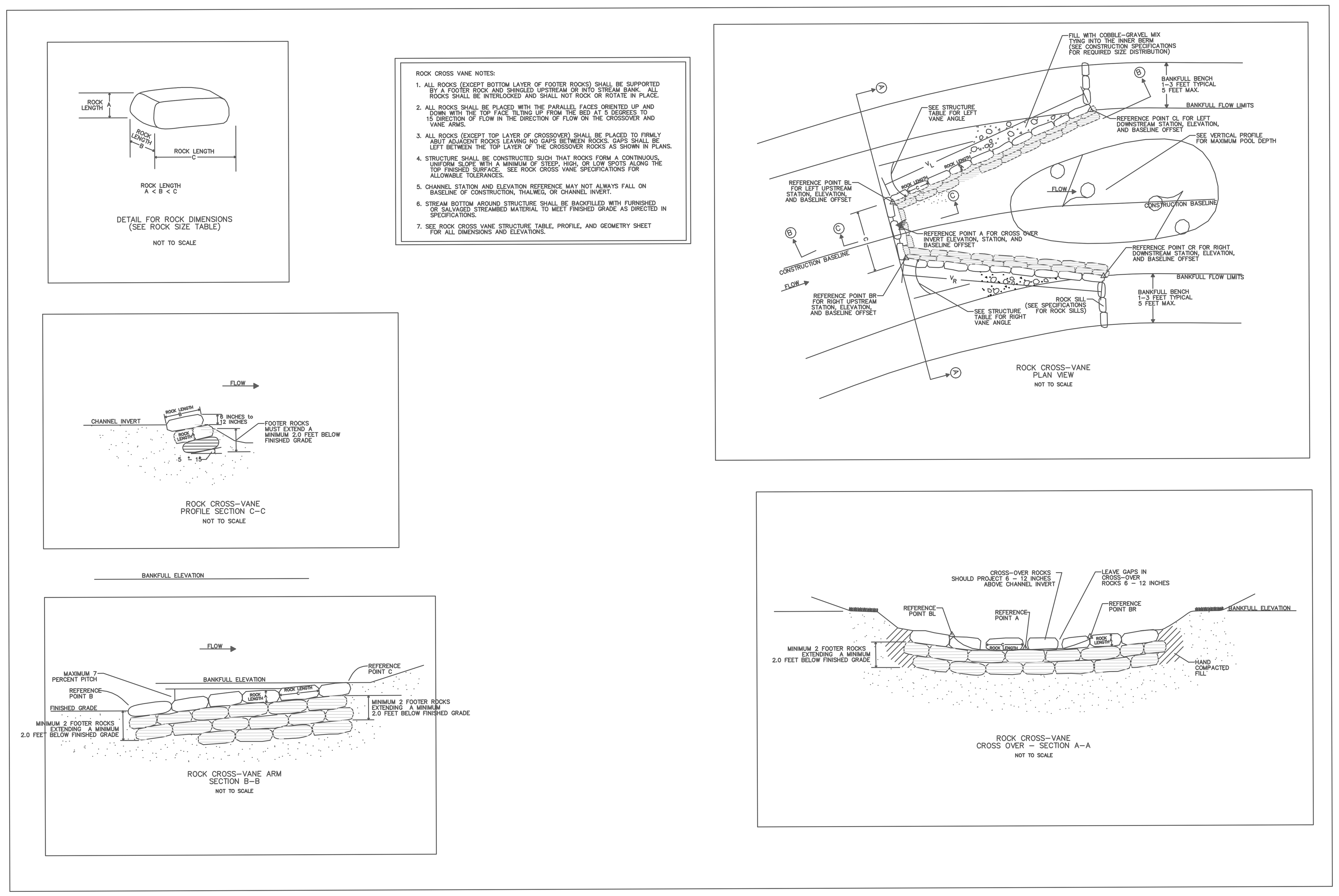
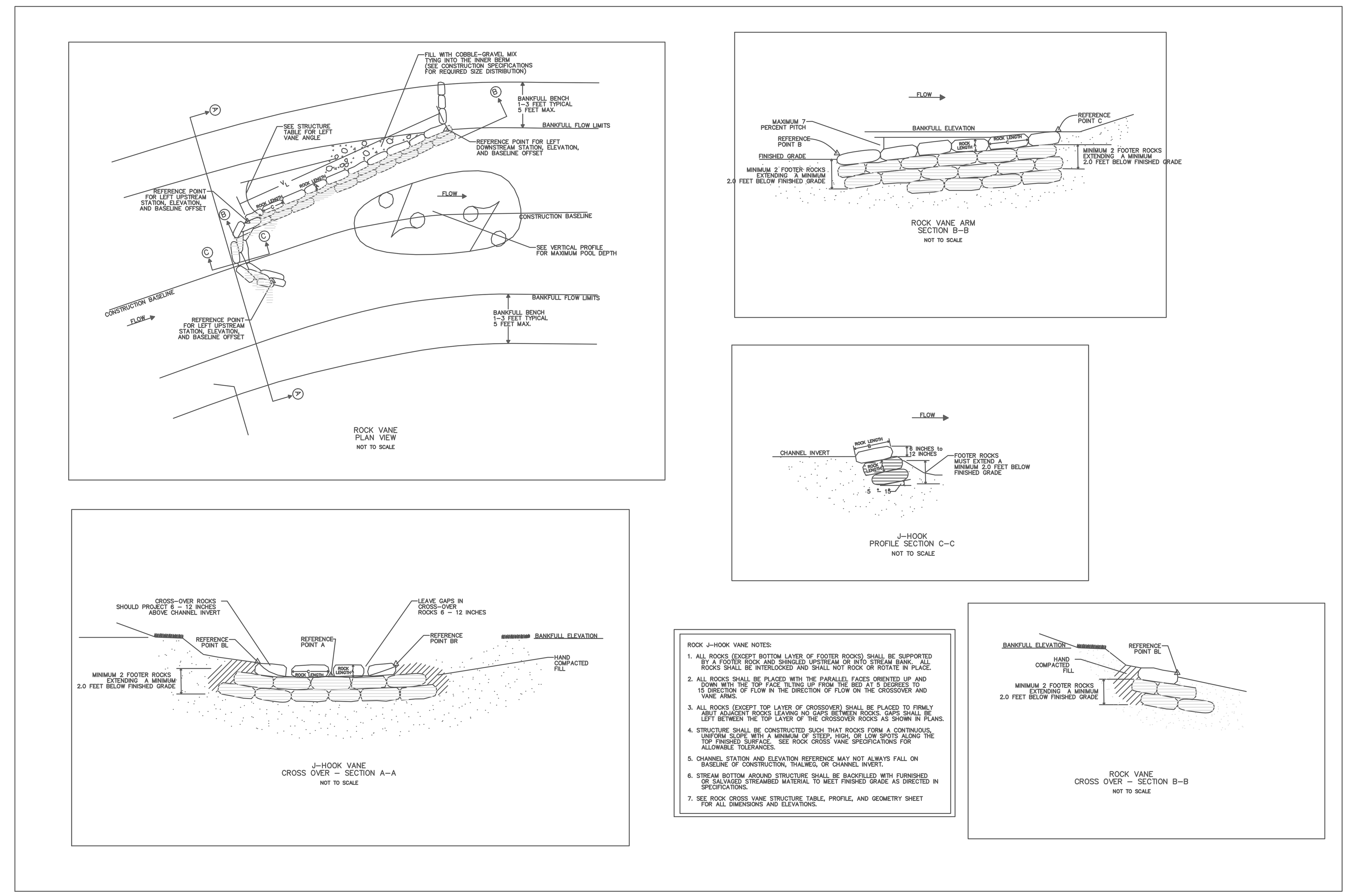
PROJECT MANAGER: RRS
DRAFTING: KC
DESIGN: RRS
CHECKED BY: BH
SCALE: 1:40

SHEET 7 OF 10

PC-6



ROCK CROSS VANE



J-HOOK VANE

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LIVINGSTON MANOR			SHEET 8 OF 10
REVISIONS DATE / BY	30% DESIGN TYPICAL DETAILS		
	PROJECT MANAGER: RRS	DRAFTING: KC	TD-1
	DESIGN: RRS	CHECKED BY BH:	

TOE WOOD DETAIL AND SPECS

The Toe Wood Structure

by Dave Rosgen

Objectives:

- Enhance fish habitat/food chains
- Stabilize streambanks
- Maintain a low width/depth ratio
- Provide a more natural appearance & improve visual values
- Be compatible with geomorphic settings
- Eliminate the need for toe rock
- Be cost effective with a lower risk

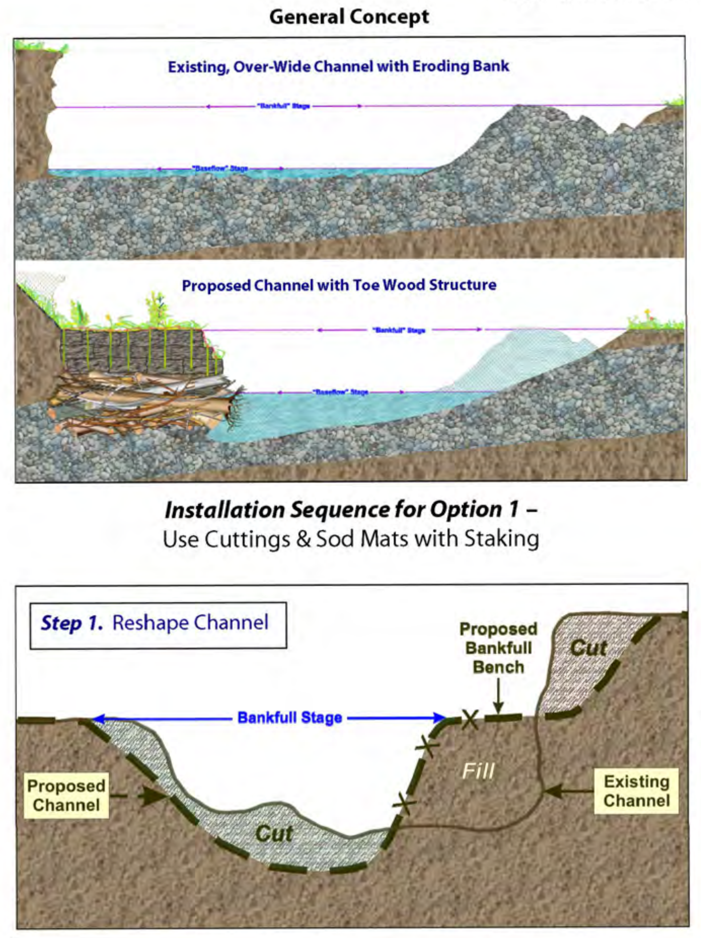
The Toe Wood Structure:

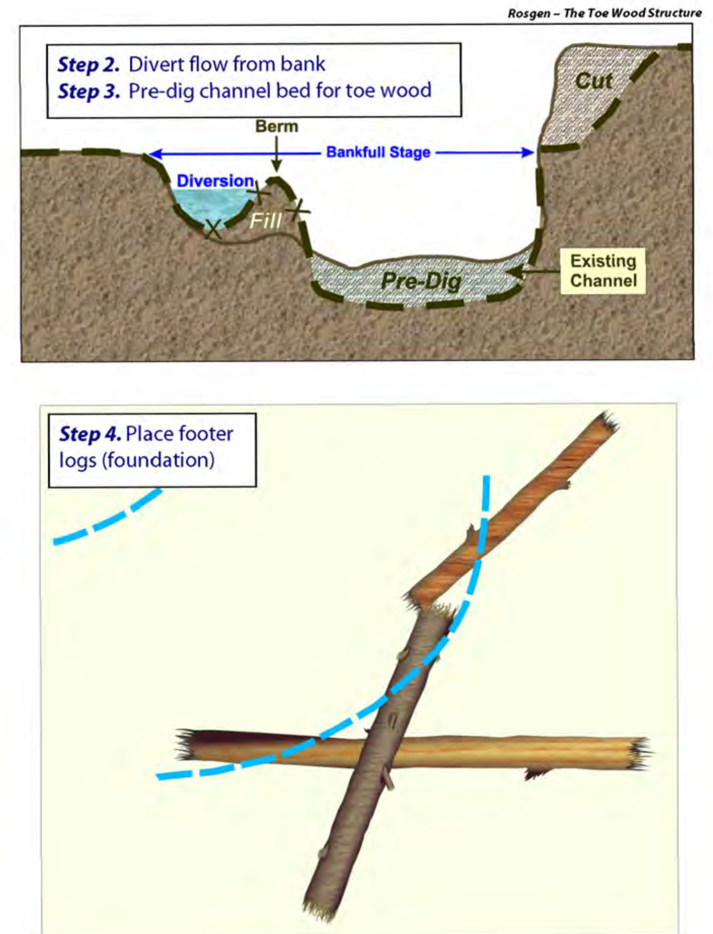
- Incorporates native woody material into a submerged undercut bank to replicate natural streambanks
- Toe wood is positioned on the lower 1/3 to 1/2 of bank to ensure it is submerged year round to prevent wood deterioration
- Cuttings with sod and live staking or woody transplants cover the toe wood and are installed up to the bankfull stage

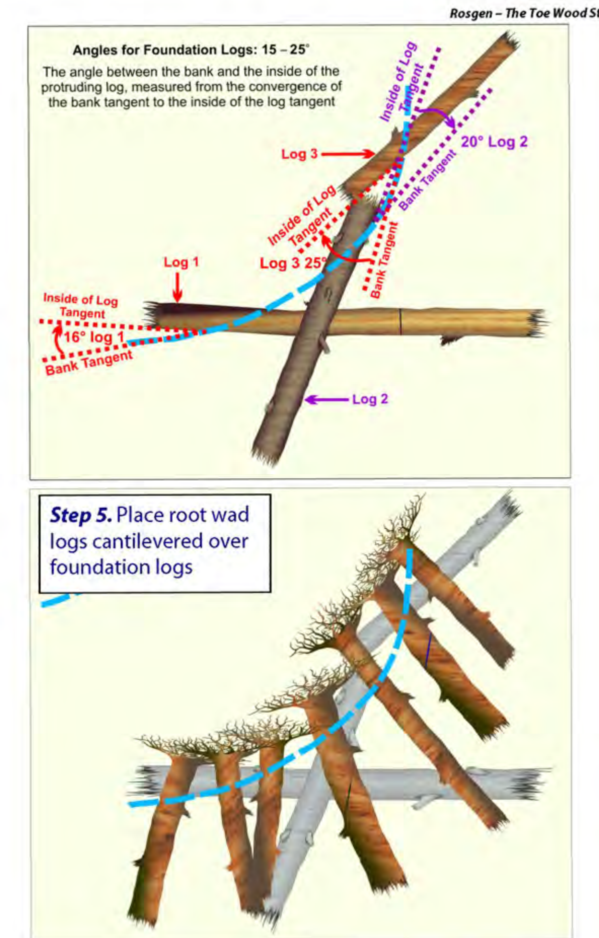
Variations in the Toe Wood Structure:

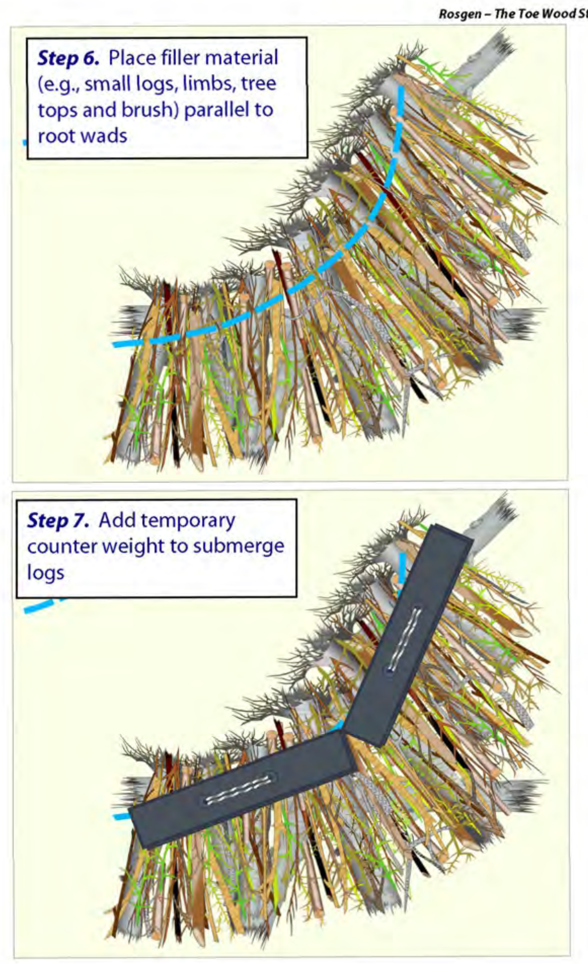
- ***Option 1*** – Use cuttings and sod mats that are staked and held down by interweaving shroud line
- ***Option 2*** – Instead of cuttings and sod mats, use woody transplants, such as willow, alder, cottonwood or dogwood
- ***Option 3*** – where sod mats and woody transplants are unavailable, use cuttings with "burrito" soil lifts

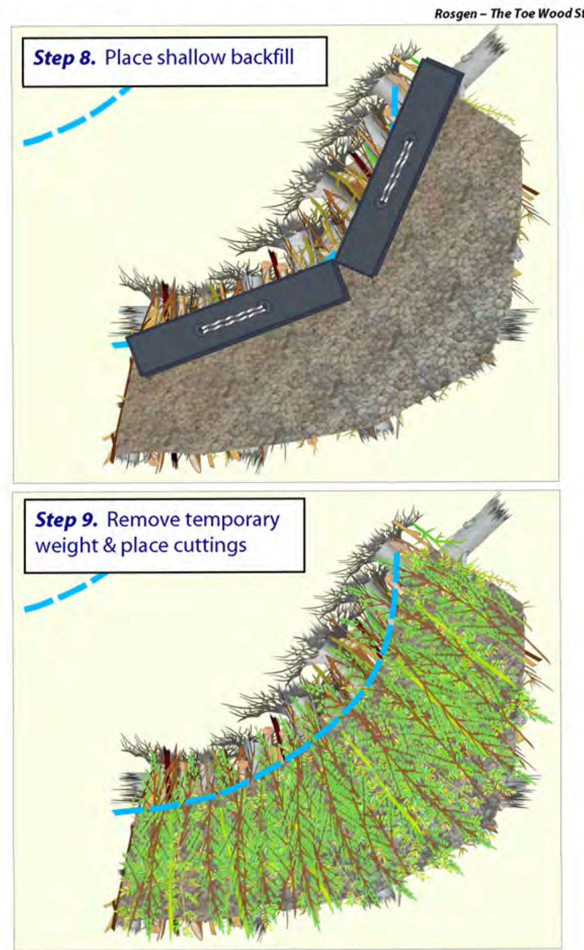
General Concept

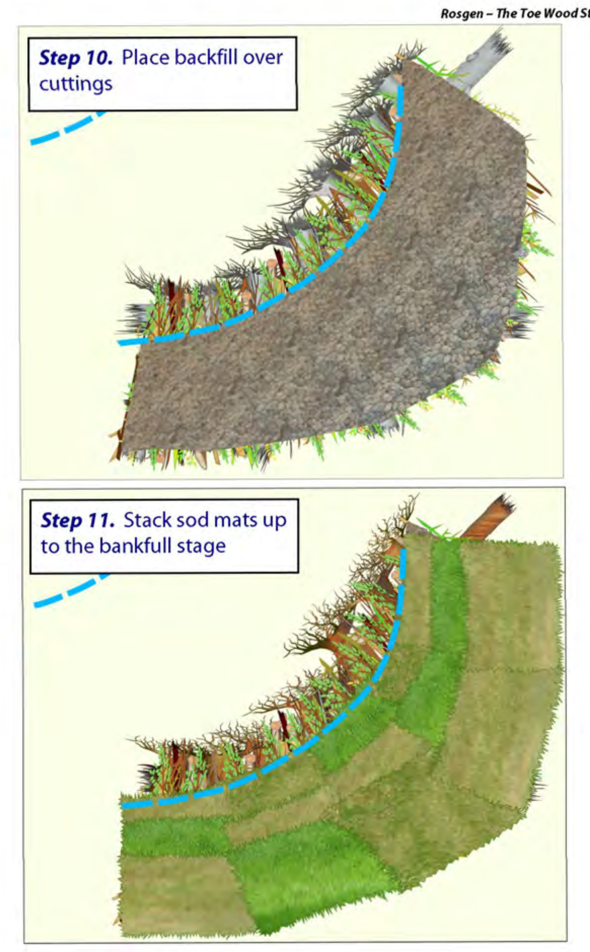


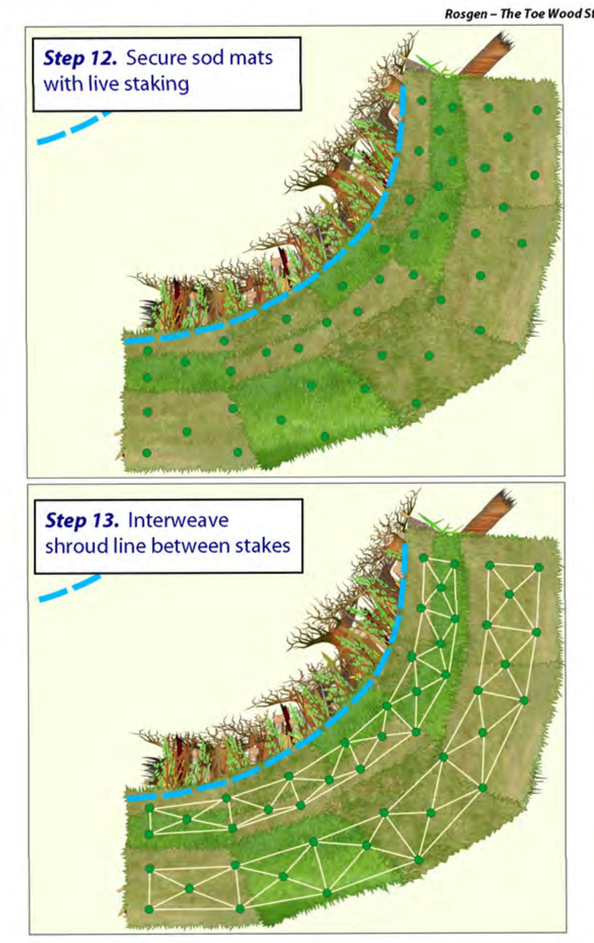


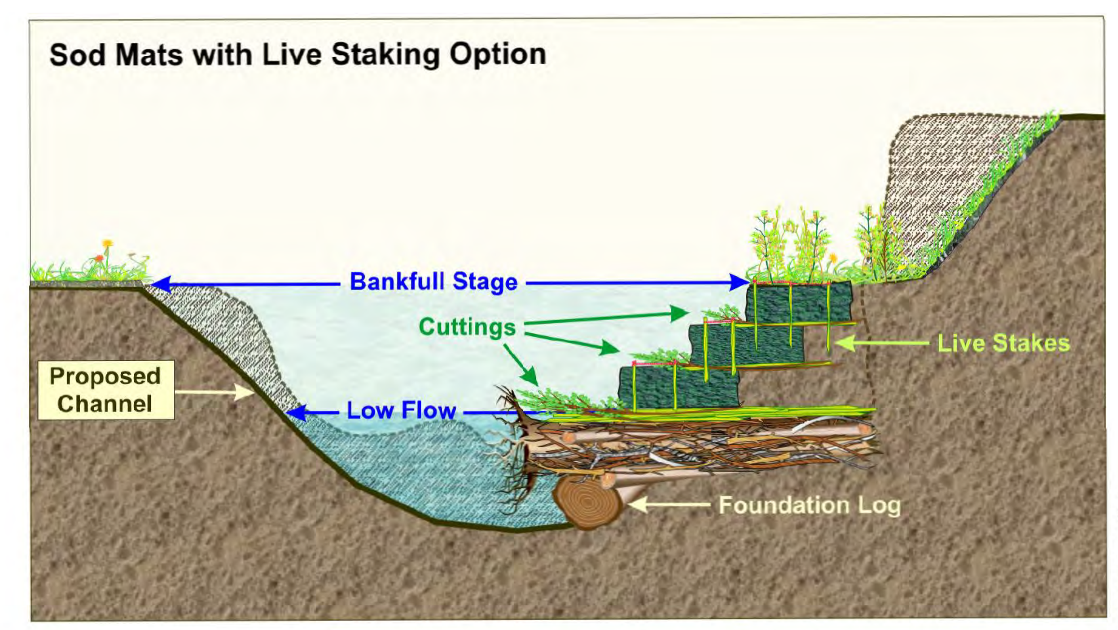












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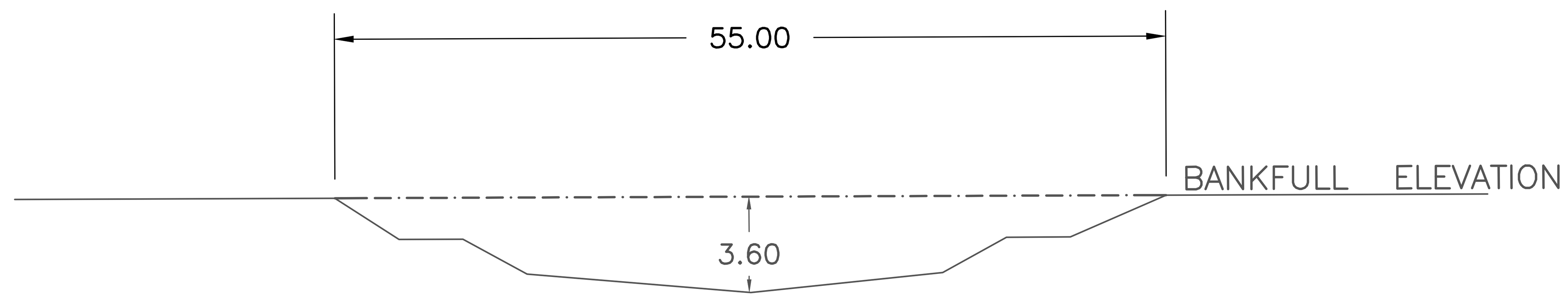
	PROJECT MANAGER: RRS	DRAFTING: KC	
	DESIGN: RRS	CHECKED BY: BH	

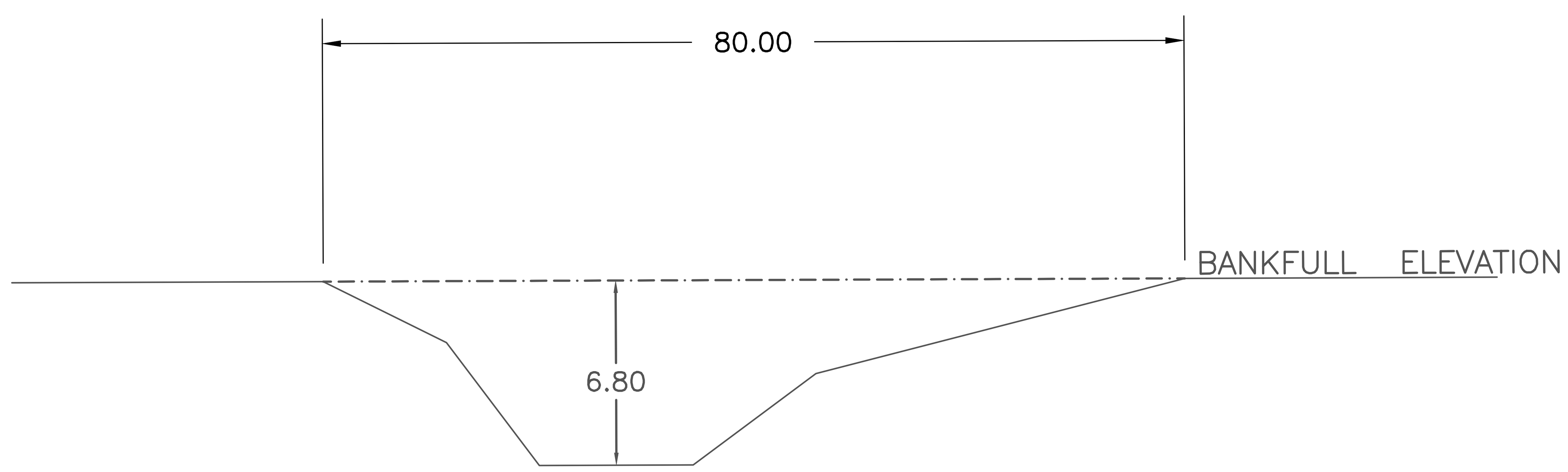
SHEET 9 OF 10

TD–2

DESIGN CRITERIA



TYPICAL RIFFLE X/S



TYPICAL POOL X/S

No.	Variable	Symbol	Units		Design Ratios and Criteria	Design Ratios and Criteria
1	Stream type				C4	B4c
2	Drainage area		mi^2	Mean	30.0	30.0
				Range	NA	NA
3	Riffle Bankfull width	W_{bkf}	feet	Mean	55.00	55.00
				Range	49 - 60	49 - 60
4	Riffle Bankfull mean depth	d_{bkf}	feet	Mean	2.70	2.70
				Range	2.5 - 2.9	2.5 - 2.9
5	Width depth ratio	W/d		Mean	14.00	14.00
				Range	12.0 - 16.0	12.0 - 16.0
6	Riffle Bankfull cross sectional area	A_{bkf}	ft_2	Mean	150.00	150.00
				Range	140 - 156	140 - 156
7	Bankfull mean velocity	V_{bkf}	ft/sec	Mean	5.20	5.20
				Range	4.7 - 5.7	4.7 - 5.7
8	Bankfull discharge	Q_{bkf}	cfs	Mean	780.00	780.00
				Range	740 - 820	740 - 820
9	Riffle Bankfull maximum depth	d_{max}	feet	Mean	3.60	3.60
				Range	3.4 - 3.8	3.4 - 3.8
10	Max Riffle depth/ Mean riffle depth	d_{riff}/d_{bkf}		Mean	1.30	1.30
				Range	NA	NA
11	Low bank height to max d_{bkf} ratio			Mean	1.00	1.00
				Range	NA	NA
12	Width of flood prone area	W_{fpa}	feet	Mean	500.00	140.00
				Range	450 - 550	77 - 200
13	Entrenchment Ratio	W_{fpa}/W_{bkf}		Mean	7.10	2.50
				Range	2.2 - 12.0	1.4 - 3.6
14	Meander Length	L_m	feet	Mean	578	NA
				Range	385 - 770	NA
15	Ratio of meander length to bankfull width	L_m/W_{bkf}		Mean	10.50	NA
				Range	7.0 - 14.0	NA
16	Radius of curvature	R_c		Mean	138	NA
				Range	110 - 165	NA
17	Ratio: Radius of curvature to bankfull width	R_c/W_{bkf}		Mean	2.50	NA
				Range	2.0 - 3.0	NA
18	Belt Width	W_{blt}	feet	Mean	317	NA
				Range	193 - 440	NA
19	Meander width ratio	W_{blt}/W_{bkf}		Mean	5.80	NA
				Range	3.5 - 8.0	NA
20	Sinuosity	K		Mean	1.30	1.20
				Range	1.2 - 1.4	1.1 - 1.3
21	Valley Slope	S_{val}	ft/ft		512.38	512.38
22	Average Water Surface Slope	S_{avg}	ft/ft	Mean	0.0040	0.00085
				Range	0.0033 - 0.0054	0.00071 - 0.00098
23	Pool Water Surface Slope	S_{pool}	ft/ft	Mean	0.0016	0.00034
				Range	0.0012 - 0.002	0.00026 - 0.00043
24	Pool WS slope / Average WS slope	S_{pool}/S_{avg}		Mean	0.40	0.40
				Range	0.3 - 0.5	0.3 - 0.5
25	Riffle Water Surface slope	Sriff	ft/ft	Mean	0.0056	0.0012
				Range	0.0048 - 0.006	0.00094 - 0.0015
26	Riffle WS slope / Average WS slope	S_{riff}/S_{avg}		Mean	1.40	1.45
				Range	1.20 - 1.50	1.1 - 1.8
27	Run WS Slope	S_{run}/S_{avg}	ft/ft	Mean	0.0028	NA
				Range	0.002 - 0.0032	NA
28	Run WS slope / Average WS slope	S_{run}/S_{avg}	ft/ft	Mean	0.70	NA
				Range	0.5 - 0.8	NA
29	Glide WS Slope	S_{glide}		Mean	0.0016	0.0003
				Range	0.0012 - 0.002	0.00026 - 0.00043
30	Glide WS slope / Average WS slope	S_{glide}/S_{avg}	ft/ft	Mean	0.40	0.40
				Range	0.3 - 0.5	0.3 - 0.5

No.	Variable	Symbol	Units		Design Ratios and Criteria	Design Ratios and Criteria
31	Maximum pool depth	d_{pool}	feet	Mean	6.80	7.40
				Range	4.1 - 9.5	5.4 - 9.5
32	Ratio of max pool depth to average bankfull depth	d_{pool}/d_{bkf}		Mean	2.50	2.75
				Range	1.5 - 3.5	2.0 - 3.5
33	Max Run Depth	d_{run}	feet	Mean	5.30	NA
				Range	4.6 - 6.0	NA
34	Ratio of max run depth to average bankfull depth	d_{run}/d_{bkf}		Mean	2.00	NA
				Range	1.7 - 2.2	NA
35	Max Riffle Depth	d_{run}	feet	Mean	3.60	3.50
				Range	3.2 - 4.0	3.2 - 3.8
36	Ratio of max riffle depth to average bankfull depth	d_{run}/d_{bkf}		Mean	1.35	1.30
				Range	1.2 - 1.5	1.2 - 1.4
37	Max Glide Depth	d_{glide}	feet	Mean	4.40	4.40
				Range	3.8 - 4.9	3.8 - 4.9
38	Ratio of max glide depth to average bankfull depth	d_{glide}/d_{bkf}	feet	Mean	1.60	1.60
				Range	1.4 - 1.8	1.4 - 1.8
39	Pool width	W_{pool}	feet	Mean	80.00	103.00
				Range	66 - 94	61 - 83
40	Ratio of pool width to bankfull width	W_{pool}/W_{bkf}		Mean	1.50	1.30
				Range	1.2 - 1.7	1.1 - 1.5
42	Point bar slope	S_{pb}		Mean	8.00	NA
				Range	6.0 - 10.0	NA
43	Pool to pool spacing	p-p	feet	Mean	289.00	248.00
				Range	193 - 385	220 - 275
44	Ratio of pool to pool spacing to bankfull width	$p\text{-}p/W_{bkf}$		Mean	5.30	4.50
				Range	3.5 - 7.0	4.0 - 5.0
Materials						
	Particle Size Distribution Channel	D_{16}	mm		18.64	18.64
		D_{35}	mm		32.39	32.39
		D_{50}	mm		42.17	42.17
		D_{84}	mm		76.48	76.48
		D_{95}	mm		89.35	89.35
	Particle Size Distribution Bar	D_{16}	mm		4.88	4.88
		D_{35}	mm		24.73	24.73
		D_{50}	mm		41.94	41.94
		D_{84}	mm		84.17	84.17
		D_{95}	mm		98.49	98.49
Largest Particle Size			mm		105.00	105.00

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LIVINGSTON MANOR

REVISIONS
DATE BY

30% DESIGN
TYPICAL DETAILS

PROJECT MANAGER: RRS
DRAFTING: KC
DESIGN: RRS
CHECKED BY: BH

SHEET
10 OF 10

TD-3