U.S. Fish & Wildlife Service

Daniels Run Stream Restoration Fairfax, Virginia

Survey and Alternative Analysis Report

CBFO-S06-04
July 2006

DANIELS RUN STREAM RESTORATION, FAIRFAX, VIRGINIA: SURVEY AND ALTERNATIVE ANALYSIS REPORT

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CBFO-S06-04

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Annapolis, MD
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I. INTRODUCTION

The Army Navy Country Club (ANCC) and the U.S. Fish and Wildlife Service (Service) – Chesapeake Bay Field Office have entered into a partnership agreement (Agreement 51410-1902-5091) to assess and restore a portion of stream reach on Daniels Run flowing through the ANCC property.

Daniels Run is a perennial stream located in the City of Fairfax, Virginia (Figure 1). Daniels Run originates in the central portion of the city and flows in a general northeastern direction until it combines with Accotink Creek. Daniels Run enters the ANCC property along the southwestern perimeter of the site, continues on-site for approximately 2,800 feet, and exits along the northeastern perimeter of the site. Several small tributaries also join Daniels Run on the ANCC property.

The goal of stream restoration is to return the stream to a stable, self-maintaining state, while meeting the aesthetic goals of the ANCC. Stream stability is not a static state but a dynamic process with a tendency towards equilibrium between stream discharge, sediment transport and channel dimension, plan form, and longitudinal profile. Restoring a stream to this stable state and restoring its riparian buffer will address a number of aquatic and riparian habitat concerns. A successful stream restoration will also improve water quality by reducing sediment and nutrients, which are significant issues for the Chesapeake Bay and its natural resources.

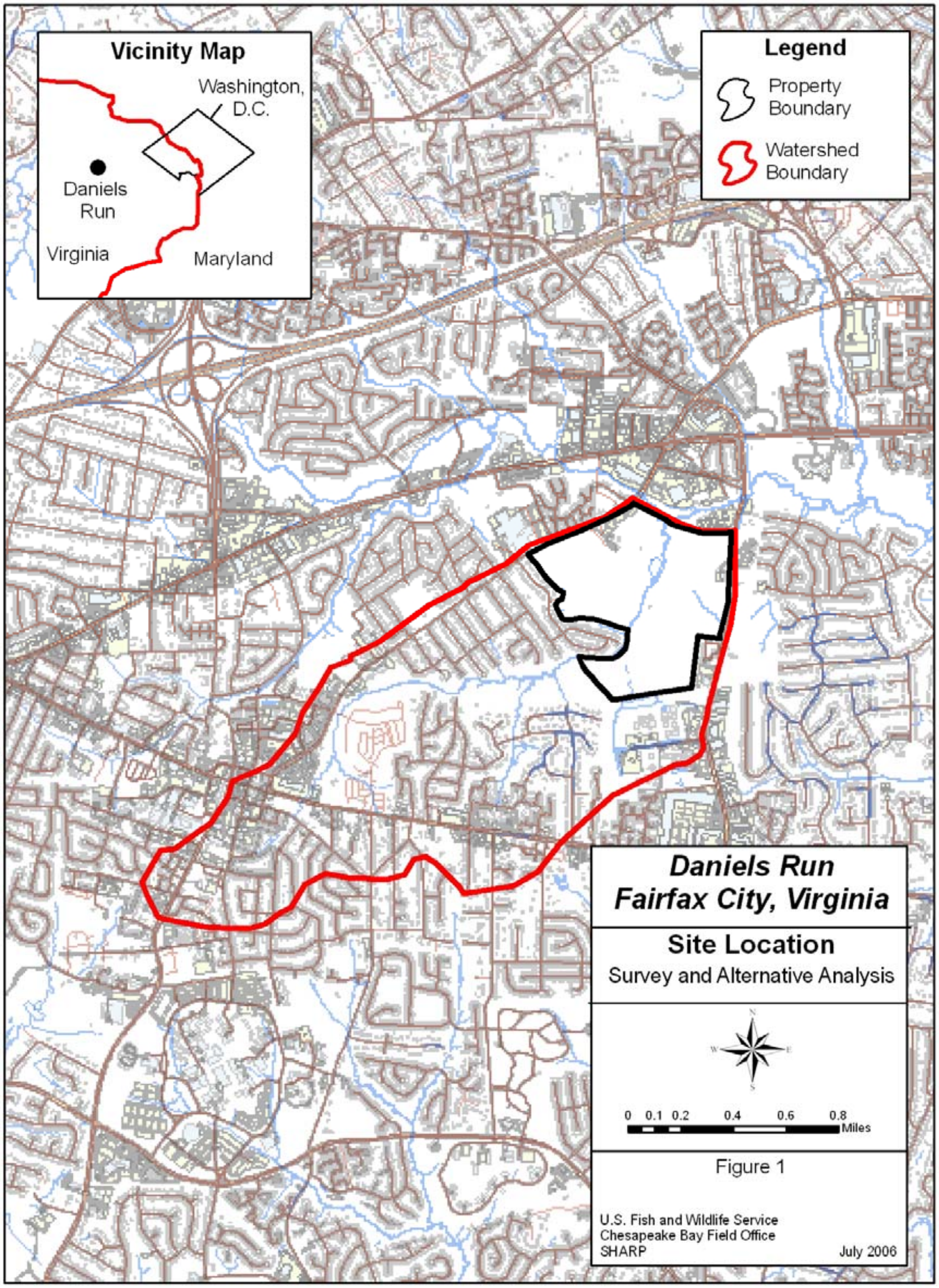
The purpose of this report is to present the findings of a limited watershed and stream assessment and the recommendations of the restoration alternative analysis. Specifically, this report contains the methodologies used by the Service; a brief watershed characterization; a brief stream characterization and stability condition description; the results of the stream restoration alternative analysis; and stream restoration recommendations.

II. METHODOLOGY

This section presents a brief summary of the methods used by the Service to conduct a limited watershed and stream assessment, develop restoration objectives, and conduct a restoration alternative analysis. Detailed survey procedures are presented in the manual *Stream channel reference sites: An illustrated guide to field technique* (Harrelson et al. 1994).

A. Watershed and Stream Assessment

The limited watershed assessment involved two levels of assessment: stream-based assessment and land-based assessment. The stream-based assessment involved a visual assessment of stream character and stability condition upstream and downstream of the project area. The fluvial geomorphic conditions observed included channel dimensions, pattern, profile, and substrate material, vertical and lateral stability, sediment supply potential, Rosgen stream type, and channel evolution.


Vicinity Map
Washington, D.C.
Daniels Run
Virginia
Maryland
Legend
Property Boundary
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Fairfax City, Virginia
Site Location
Survey and Alternative Analysis
0 0.1 0.2 0.4 0.6 0.8
Miles
Figure 1
U.S. Fish and Wildlife Service
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The land-based assessment analyzed land use/land cover patterns, soils, geology, hydrology, valley type, existing water quality and biological data, and watershed development. The assessment was predominantly an office exercise with field verification. The Service used the stream-based data and land-based data to develop a cause and effect relationship between watershed land use activities and stream processes.

B. Stream Assessment

The Service conducted limited Rosgen Level II and III assessments to assess the portion of Daniels Run on the ANCC property. The Rosgen Level II assessment describes the existing morphological character of the stream and classifies the stream using the Rosgen stream classification system (Rosgen 1994). The Rosgen stream classification system uses physical features of a stream such as width, depth, pattern, and bed material, to group streams into a "type" denoted by alphanumeric codes. The Service used the Rosgen Level III assessment to determine the stability condition of the stream. As part of the Level III assessment, the Service assessed channel parameters (incision, entrenchment, with/depth ratio, and confinement), bank stability conditions, near bank stress, critical shear stress, depositional pattern, meander pattern, and channel evolution. The Service documented a majority of this data during the geomorphic mapping of Daniels Run. The Service recorded the location and direction of instability conditions on the geomorphic map and described the potential cause of the instability. The Service used the Rosgen Level III data as a basis to identify areas in need of restoration.

C. Bankfull Determination

The bankfull discharge is the discharge (or range of discharges) which is responsible for the formation and maintenance of the stream channel dimensions, plan form, and longitudinal profile. The stream typically develops bankfull indicator(s), such as a significant slope break and floodplain feature, along the stream banks at the bankfull stage. An accurate determination of the bankfull indicator(s) is one of the most critical aspects of assessing and restoring a stream because surveyors will base the entire survey, assessment, and restoration on its determination.

To insure an accurate determination of the bankfull discharge, the Service compared the bankfull discharge and channel dimensions with the regional discharge relationships presented in the report Maryland Stream Survey: Bankfull Discharge and Channel Characteristics in the Piedmont Hydrologic Region (McCandless 2002). These regional relationships allow the Service to validate its bankfull determination with gaged streams that have similar stream and watershed conditions, in the same hydro-physiographic region.

D. **Alternative Analysis**

The Service conducted an alternative analysis to select the most appropriate stream restoration solution for Daniels Run. The alternative analysis involved the identification of stability problems, establishment of restoration objectives, development of potential restoration solutions, development of a decision matrix, and evaluation of the restoration solutions using the decision matrix. The Service identified stability problems from the watershed and stream assessment. The Service and AANC established the restoration objectives based on Service missions and

AANC needs and desires. The Service considered only natural channel design solutions for the potential restoration solutions. A natural channel design provides a self-sustaining stream system, which is a restoration objective of both the Service and AANC.

The decision matrix consisted of the restoration objectives and solutions. Each of the restoration objectives have weighted values based on the importance of the objective. The Service scored the restoration objectives from one to ten, with ten being the highest rating, based on how well the restoration solution achieved the objective. The Service multiplied the scores by the weighting value to determine the weighted objective scores for each restoration objective. The Service totaled the weighted objective scores for each restoration solution. The solution with the highest score represented the most appropriate stream restoration solution.

III. EXISTING CONDITIONS AND PROBLEM IDENTIFICATION

This section presents the findings of the watershed and stream assessments, stream instability evaluation, and the cause and effect relationship determination.

A. Watershed Characterization

The Daniels Run watershed is a sub-watershed of the Accotink River, and is comprised of Daniels Run mainstem, nine unnamed tributaries, stormwater drainage from the upper portion of the watershed, and instream ponds. The watershed is approximately 1.88 square miles and is in the Piedmont hydrologic region (Schmidt, Jr. 1993). The valley type, as defined by Rosgen (1996) is a valley type VIII; a wide, gentle valley slope with a well developed floodplain adjacent to the river. Valley slope of the mainstem (measured from headwaters near Courthouse Drive) is 1 percent, and basin relief from the headwaters to the Accotink River confluence is approximately 125 feet.

1. Geology and Soils

The Daniels Run watershed is located in the Outer Piedmont physiographic sub-province, generally characterized by broad uplands with low to moderate slopes. The geology of Daniels Run watershed is located entirely in the Western Piedmont geologic terrane, characterized by Early Paleozoic meta-sedimentary and igneous rocks. The Daniels Run watershed contains two soil associations (*i.e.*, Chewacla-Wehadkee, and Glenelg-Elioak-Manor). The soils in the Chewacla-Wehadkee association are poorly drained to moderately well drained, subject to flooding or associated with stream floodplains. The soils associated with the Glenelg-Elioak-Manor association are well drained to excessively drained upland soils, typically occupying large areas with undulating to rolling interstream divides and ridges.

2. Land use/Land cover

The Service used aerial photographs and land use/land cover maps to estimate the land use/land cover percentages for the Daniels Run watershed. Medium density residential (*i.e.*, 45 percent) and industrial/commercial (*i.e.*, 20 percent) development are the primary land uses in the watershed (Figure 1). This development is primarily located in the upper two-thirds of the watershed. The remaining 35 percent of the watershed consists primarily of forested natural areas and the Army-Navy Country Club. The ANCC was included in this land use/land cover category because of its land management practices. The ANCC property generally consists of mowed fairways, manicure tee boxes and greens, and lightly forested areas. Daniels Run and its tributaries dissect the watershed with portions of the tributaries contained in a culvert. In addition, three significant ponds are located in the central portion of the watershed.

3. Hydrology

The Daniels Run watershed consists of a network of stormwater pipes and open stream channels with natural bed materials. Within the watershed, there are 4.3 miles of natural channel. Most likely there was there was a greater number of miles of open channels before development of the watershed. Typically, development results in a high drainage density. Drainage density is the ratio of the drainage system (open channels and stormwater pipes) to the watershed drainage area. Higher drainage densities are associated with higher flood peaks (Dunne and Leopold 1978). In an undeveloped watershed, the stream channel and adjacent wetlands provide storage for runoff. Loss of this storage capacity (typically associated with development) creates a "flashy" flow regime, with peak flows exhibiting a rapid response to runoff events. Additionally, the lower roughness and increased hydraulic efficiency associated with piping increases the velocity and erosive force of the water entering the stream and causes stream erosion. Streambank and bed erosion increases sediment loading, which the Service noted in several locations throughout the watershed.

4. Riparian Vegetation

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 project area exists within a golf course setting. The riparian buffer of the upstream portion of the reach, approximately 1,746 feet, is mostly mowed grass with a few mature canopy trees. The riparian buffer of the downstream portion of the reach, approximately 1,150 feet, is low density forest. The buffer width ranges from approximately 10 to 100 feet and consists of native and non-native grasses, shrubs, understory trees, and mature canopy trees.

B. Stream Geomorphology

This section describes the existing conditions of Daniels Run, within the project area, and identifies the stability problems and their causes.

1. Bankfull Determination

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 Daniels Run. 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.

During the Daniels Run assessment, the Service identified bankfull stage using physical indicators of bankfull stage described by McCandless and Everett (2002). Figure 2 depicts significant geomorphic indicators typically found in Maryland. Based on these indicators, the Service identified a consistent geomorphic feature at Daniels Run. This geomorphic indicator was typically a significant slope break or back of bench found throughout the project area. However, in some locations, the indicators were less defined or absent because of active erosion or where the stream has a high entrenchment; and non-existent where there were bank revetments.

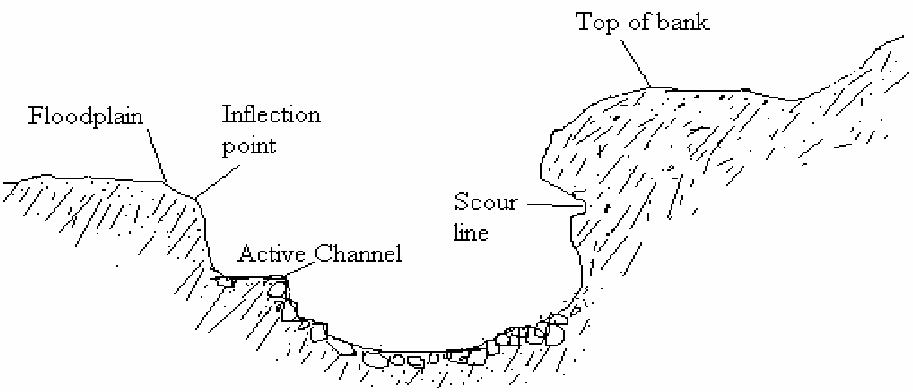


Figure 2: Typical Bankfull Indicators (McCandless and Everett 2002)

Several methods are commonly used to estimate channel roughness and bankfull velocity for ungaged streams. The Service used Limerinos (1970) to estimate bankfull velocity for Daniels Run. Limerinos uses the relationships between friction factor and relative roughness to estimate velocities. Relative roughness is the ratio of flow depth to the representative substrate particle size. The Limerinos equation was derived from gravel bed streams similar in characteristics to Daniels Run, and is therefore appropriate for determining bankfull discharge at Daniels Run.

The Service compared representative cross section dimensions and discharges to the regional relationships of the same parameters developed for the Maryland Piedmont (McCandless and Everett 2002) physiographic regions for verification (Table 1). The representative cross section dimensions and bankfull discharges, using the Limerinos, compared well to the Maryland Piedmont data. Therefore, the Service determined that the bankfull discharge for Daniels Run ranges between 105 and 126 cubic feet per second (cfs) with a Manning's 'n' roughness of 0.04 and a velocity range of 3.74 to 4.26 feet per second (ft/s).

Table 1. Daniels Run and Regional Curve Bankfull Characteristics			
Bankfull Characteristics	**Reach 1 Representative Cross Section**	**Reach 2 Representative Cross Section**	**Maryland Piedmont Regional Curve[1]**
Area (ft^2)	29.28	33.81	27.62
Width (ft)	16.25	21.44	18.91
Depth (ft)	1.80	1.58	1.46
Discharge (cfs)	104.47	125.59	136.62
1. Maryland Stream Survey: Bankfull Discharge and Channel Characteristics of Streams in the Piedmont Hydrologic Region (McCandless and Everett 2002)			

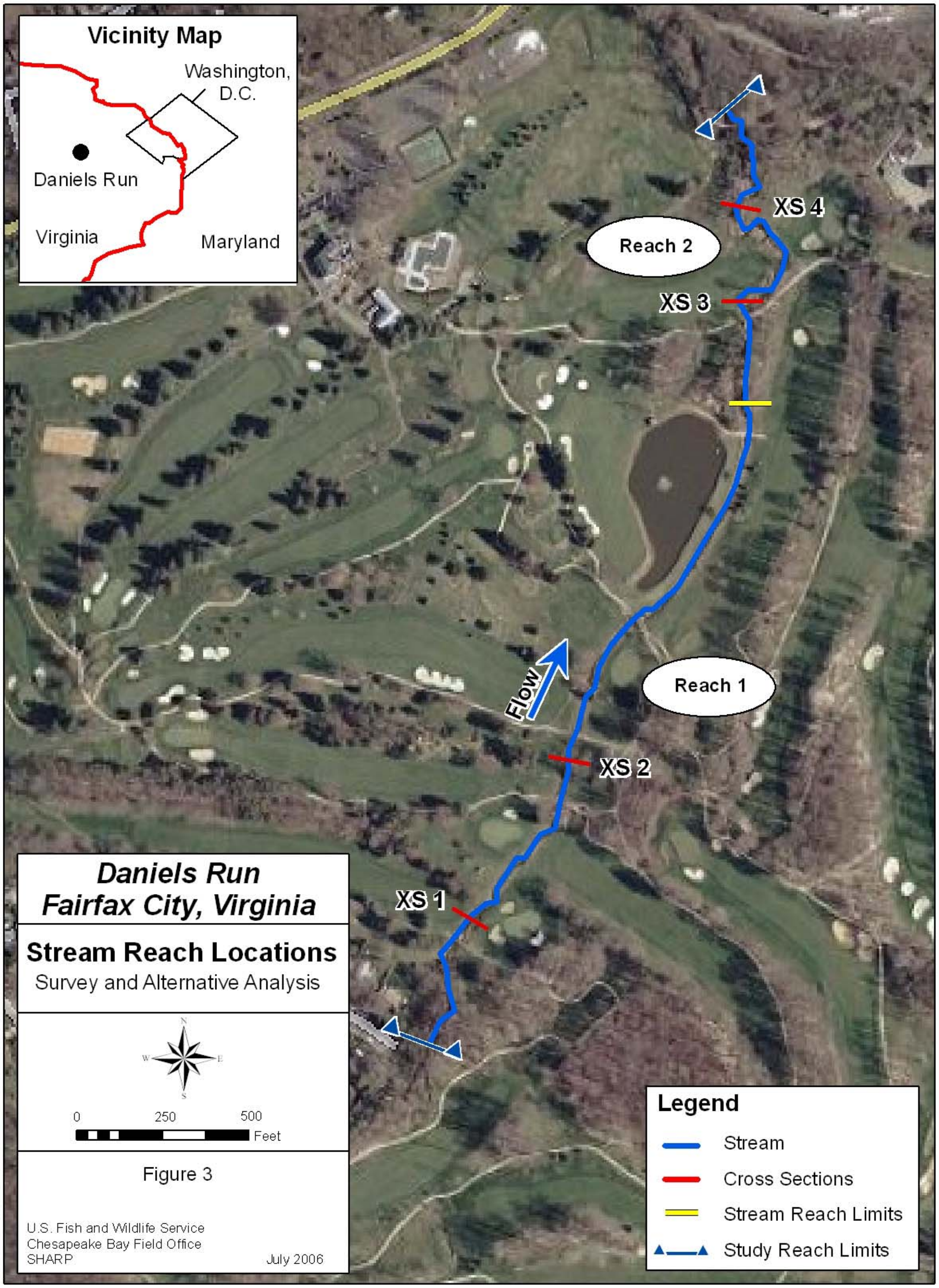
2. Representative Reaches

The Service delineated three Rosgen stream types (*i.e.*, E4 F4, and B4c) in the Daniels Run project area based on geomorphologic characteristics and stability conditions (Rosgen 1996) (Figure 3). The letter associated with the stream type indicates general stream characteristics (*e.g.*, entrenchment, width/depth ratio, and sinuosity). The "*4*" suffix indicates a gravel channel substrate and the *"c"* suffix indicates a lower than typical stream slope.

Reach 1, the upstream portion of the project area, is an E4 stream type transitioning to a F4 stream type, and represents 62 percent of the project area (Table 2). The evolution of a stream from an E4 stream type to a F4 stream type also includes two intermediary stream types (*i.e.*, C4 and G4c). The Service did not conduct a cross section survey for all these stream types; however, all these stream types currently exist in the reach or were present in the past, developed through fluvial or anthropogenic processes. The E4 stream type is slightly entrenched with good access to its floodplain, low width/depth ratio, low gradient, and a gravel substrate. Watershed and stream impacts caused Daniels Run to transition to a C4 stream type. Rosgen C4 stream types are slightly entrenched with good access to its floodplain, moderate width/depth ratio, moderately steep gradient, and a gravel substrate. As the stream degrades, it transitions to a G4c stream type. Rosgen G4c stream types are entrenched with poor access to its floodplain, low width/depth ratio, and a lower than typical stream slope. Storm flows are contained in the stream channel because the stream has downcut and abandoned its floodplain. In an attempt to create its floodplain, the stream has increased its width, transitioning to a F4 stream type. Rosgen F4 stream types are entrenched with moderate width/depth ratio, moderately steep slopes, and a gravel substrate.

Reach 2 is a Rosgen B4c stream type transitioning to a F4 stream type and represents 38 percent of the project area. The evolution of a stream from a B4c stream type to a F4 stream type has a G4c intermediary stream type. Rosgen B4c stream types are moderately entrenched with moderate width/depth ratio, and lower than typical stream slope, with a gravel substrate. The remaining stream types are similar to those discussed for Reach 1.

Table 2. Rosgen Stream Type Classification Delineation Values							
Reach	**Classification Cross Section**	**Entrenchment Ratio**	**Width/Depth Ratio**	**Sinuosity**	**Reach Slope (ft/ft)**	**Rosgen Stream Type**	**Substrate**
1	XS 1	2.83	9.03	1.07	0.0047	E	Gravel (4)
	XS 2	1.21	40.18			F	
2	XS 3	1.69	13.57	1.32	0.0051	Bc	
	XS 4	1.61	16.31			Bc	


Vicinity Map
Washington, D.C.
Daniels Run
Virginia
Maryland
XS 4
Reach 2
XS 3
Reach 1
Flow
XS 2
XS 1
Daniels Run
Fairfax City, Virginia
Stream Reach Locations
Survey and Alternative Analysis
0
250
500
Feet
Figure 3
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Legend
Stream
Cross Sections
Stream Reach Limits
Study Reach Limits

a. Reach 1 – Upper Reach

Reach 1 begins where Daniels Runs crosses the ANCC's southern property line and flows northward for approximately 1,746 ft, ending at an in-line wet-well inlet. The reach is a Rosgen E stream type that is adjusting to an F stream type. In general, the E4 stream type has a bankfull width of 16.25 feet, bankfull depth of 1.80 feet, cross-sectional area of 29.28 square feet, sinuosity of 1.07, and water surface of 0.0047 ft/ft. Banks are generally 3 to 5 feet in height and channel incision is low. The F4 stream type has a bankfull width of 35.36 feet, bankfull depth of 0.88 feet, and a cross-sectional area of 31.10 square feet (Photograph 1). Riprap revetments armor approximately 20 percent of the banks. Most of the riprap armoring is located on the right bank of the downstream portion of the reach (*i.e.*, approximately 600 feet). This section of the reach is also adjacent to the golf course water irrigation pond. The 8-foot high earthen dam of the pond runs parallel to the left bank of the stream. Instream habitat is poor to fair with slightly defined pools and riffles. The riparian buffer consists of mowed grass and a few mature canopy trees. Two storm drain outfalls enter the reach at the immediate upstream portion. There is a 40-inch outfall on the left bank and a 24-inch outfall on the right bank. There are also four golf cart bridges and one pedestrian bridge crossing the stream within this reach.

This reach is vertically stable because of the grade control provided by the wet-well inlet at the downstream end of the reach (Photograph 2). The wet-well inlet, constructed of concrete and riprap, has halted the headcut[1] that migrated through Reach 2. However, there is widespread lateral instability throughout the reach, even with the riprap revetments. Approximately 60 percent of the banks are actively eroding. A stream requires a certain sinuosity, based on fluvial processes, in order to remain stable (Leopold *et al* 1964). If the sinuosity is less than what is required, the stream will erode its banks on alternating sides of the stream until it develops a stable sinuosity (Photograph 3). Reach 1 was likely straightened in the past and is now attempting to increase its sinuosity by eroding its streambanks. Additional factors that contribute to reach instability include watershed development and riparian buffer loss. This type of stream has a high potential for sediment supply input, highly sensitive to disturbance and is unlikely to recover on its own. Significant adjustments need to occur for the stream to reach a stable channel dimension, pattern and profile. During that adjustment period, significant inputs of sediment will occur with adverse impacts to aquatic species and instream habitat.

b. Reach 2 - Lower Reach

Reach 2 begins at the in-line wet-well and flows northward for approximately 1,050 ft, ending at the confluence with Accotink Creek. The reach is a B4c stream type that is adjusting to a F4 stream type (Photograph 4). It has a bankfull width of 21.44 feet, bankfull depth of 1.58 feet, cross-sectional area of 33.81 square feet, sinuosity of 1.32, and water surface of 0.0051 ft/ft. Banks are generally 6 to 12 feet in height and channel incision is moderate to high. Riprap revetments armor approximately 15 percent of the banks. Most of the riprap armoring is located upstream and downstream of the golf cart bridge crossing the reach. Instream habitat is poor to fair with slightly defined pools and riffles. The riparian buffer consists of native and non-native grasses, shrubs, understory trees, and mature canopy trees, and its width ranges from approximately 10 to 100 feet.

[1] Channel erosion represented by a retreat, vertical or nearly vertical of the channel bed.

Photograph 1. Typical existing condition of Reach 1.

Photograph 2. ANCC wet-well inlet.

Photograph 3. Alternating bank erosion as stream adjusts to increase sinuosity.

Photograph 4. Typical existing condition of Reach 2.

One 24-inch storm drain outfall enters the reach immediately upstream of the golf cart bridge on the left bank. There is a manhole on the right bank approximately 60 feet downstream of the golf cart bridge. Along with the one golf cart bridge, there is one pedestrian bridge.

The reach appears vertically stable; however, sometime in the past a headcut moved through the reach and degraded the streambed by an average of 6 to 9 feet. The headcut was likely the result of a decrease in the base level at Accotink Creek. When there is a change in the base level of a stream, the streambeds of all tributaries to that stream will also degrade until stream equilibrium is re-established (Leopold 1994). The change in base level causes an increase in stream slope and erosive forces, resulting in stream degradation and abandonment of the active floodplain.

The reach has widespread lateral instability. Approximately 60 percent of the banks are actively eroding, even where there is riprap armoring (Photograph 5). The severity of the bank erosion is much greater than Reach 1 because of the high incision and deep entrenchment of Reach 2. The high incision and deep entrenchment contain large flood flows within the channel and significantly influences the rate of streambank erosion. The stream is attempting to rebuild a floodplain and bank erosion will continue until the stream re-establishes its floodplain (Rosgen 2001). This type of stream has a high potential for sediment supply input, is highly sensitive to disturbance and is unlikely to recover on its own. Significant adjustments need to occur for the stream to reach a stable channel dimension, pattern and profile. During that adjustment period, significant inputs of sediment will occur with adverse impacts to aquatic species and instream habitat.

3. Bridges

There are five golf cart bridges and two pedestrian bridges crossing Daniels Run within the project area. The bridges are wooden and set on wooden pylons (Photographs 6 and 7). The Service conducted a preliminary bridge analysis to determine if bridge modifications or relocations would be necessary as part of the stream restoration effort. The bridge analysis involved the determining of: 1) whether the bridge openings can pass the bankfull discharge and 2) whether the bridges openings could accommodate the appropriate stream entrenchment. The Service determined that all the bridges could pass the bankfull discharge. Most of the bridges could accommodate the appropriate stream entrenchment; those bridges that could not accommodate the appropriate entrenchment will require additional stream design engineering.

Currently, the relocation or removal of only one bridge was required as part of the stream restoration effort. This bridge is the farthest downstream pedestrian bridge approximately 100 feet downstream from Blue One golf cart bridge. Preservation of the pedestrian bridge was not possible because realignment of the stream channel was necessary to achieve a stable stream plan form. Additionally, the Service has determined, based on a preliminary evaluation, that the relocation of the Blue One golf cart bridge will not be necessary at this time. This determination may change as the Service further develops the restoration design, and relocation of this bridge may be required to achieve a stable stream design.

Photograph 5. Typical bank erosion in Reach 2.

Photograph 6. Typical golf cart bridge.

Photograph 7. Typical pedestrian bridge.

IV. Alternative Analysis

The Service conducted an alternative analysis to select the most appropriate stream restoration solution for Daniels Run. The Service developed potential restoration alternatives based on restoration objectives and the stability problems identified during the watershed and stream assessment. The Service used a weighted decision matrix to evaluate and select the most appropriate restoration alternative.

A. Restoration Objectives

The Service generated objectives based on Service missions and ANCC generated objectives based on golf course purposes and needs. The objectives were then discussed and combined into one list and include the following:

- Restore a natural, self-sustaining stream
- Apply natural channel design principles
- Maintain golf course playability
- Improve instream habitat (*i.e.*, diversity and quality)
- Establish a native riparian buffer without affecting golfing activities
- Improve water quality (*e.g.*, reduce temperatures and sediment)
- Require low maintenance
- Improve potential for restoration success

B. Restoration Alternatives

The Service developed stream restoration alternatives based on the restoration objectives and the stability problems identified during the watershed and stream assessment. The Service only considered restoration alternatives based on natural channel design (NCD) principles. Therefore, such alternatives like riprap revetments, concrete channels, and bioengineering techniques were not included in the alternative analysis.

The results of the watershed and stream assessment showed widespread lateral instability in both Reach 1 and 2. Reach 2 also had incision and entrenchment problems. As a result, the restoration effort will involve restoration of the entire stream channel, which includes adjustments to the channel dimension, plan form, and longitudinal profile. The Service evaluated three NCD restoration alternatives (*i.e.*, soil fabric lifts, rock and log structures, and a combination of soil fabric lifts and rock and log structures) that will successfully address the instability, incision, and entrenchment problems of Daniels Run.

1. Soil Fabric Lifts

Soil fabric lifts are layers of soil held temporally in-place with a bio-degradable fabric (Photographs 8 and 9). The soil lifts are vegetated with a grass seed mix and live cuttings are place in between the soil layers. Roots from the grass and live cutting establish and naturally maintain the soil layers, replacing the degrading fabric. Adjustments to the vegetation plan may be required to accommodate golf playability.

Soil fabric lifts provide long and short-term bank stability, and are less complicated to install than the other restoration alternatives. Originally, this alternative was not designed to provide vertical channel stability or create instream habitat; however, the Service will incorporate design techniques to provide both vertical stability and habitat. These techniques are less successful at developing and maintaining habitat features (*e.g.*, runs, pools, and glides) compared to other restorations techniques (*e.g.*, cross vanes). Additionally, soils lifts are not designed to convey stream flows through constricted bridge crossings, which are the same type of bridges that exist on Daniels Run.

2. Rock and Log Structures

Rock and log structures are instream structures, made of rocks and logs, used to divert erosive stream flows away from streambanks and maintain streambed elevations. The most typical rock and log structures used from stream restoration are vanes and j-hooks (Photographs 10, and 11). The rock and log structures provide streambed and bank stability and allow the streambed to naturally armor and the riparian vegetation to establish.

These structures are more complex to install than soil fabric lifts. While they provide excellent long-term streambed and bank stability, there are other alternatives (*e.g.*, soil lifts) that provide better short-term stability, especially when creating new streambanks. They do however, provide excellent instream habitat and convey stream flows through constricted bridge crossings.

Photograph 8. Soil fabric lifts under construction.

Photograph 9. Soil fabric lifts 17 months after construction.

Photograph 10. Example of a log/rock j-hook.

Photograph 11. Example of a rock cross vane.

3. Soil Fabric Lifts and Rock and Log Structures

The soil fabric lifts and rock and log structures alternative is a combination of both restoration methods (Photographs 12). This alternative is typically used for stream restoration projects that have site or restoration objective constraints (*e.g.*, infrastructure and stream confinement.). The benefit to this alternative is that it combines the advantages associated with each of these methods, but design and implementation can be more complex.

Photograph 12. Example of a rock cross vane and soil fabric lifts.

C. Selection Matrix and Recommended Alternative

The Service used a weighted decision matrix to evaluate and select the most appropriate restoration alternative, based on the restoration objectives developed by the Service and ANCC. Table 3 shows the results of the alternative analysis.

The soil fabric lifts had the lowest score because it was least capable of fulfilling the restoration objectives. This alternative has limited ability to maintain vertical stability, develop and maintain habitat features, and convey flow through the bridges. The vertical stability provided by rock sills, typically used with this alternative, may be insufficient in maintaining the streambed in Reach 2, especially if there is another change in base level. The rock sills are also less successful at developing and maintaining habitat features. Lastly, this alternative was not designed to direct stream flows through constricted bridges with confined floodplains, as is the case with the bridges in the project area.

Table 3. Restoration Alternative Selection Matrix

Criteria		Restoration Alternatives					
Description	**Weighted Value**	**Soil Lifts**		**Structures**		**Structures & Soil Lifts**	
		Value	**Sub-Total**	**Value**	**Sub-Total**	**Value**	**Sub-Total**
Design Objectives							
1. Cost (linear feet)	8	10	80	8	64	6	48
2. Channel stability (*i.e., vertical, lateral, and*		8	0	9	0	10	0
a. *Short-term channel stability*	10	8	80	9	90	10	100
b. *Long-term channel stability*	10	9	90	10	100	10	100
3. Restoration reliability							
a. *Potential for success*	10	8	80	9	90	10	100
b. *Adaptivity*	7	7	49	8	56	9	63
c. *Establishment time*	5	10	50	8	40	9	45
d. *Low Maintenance*	8	9	72	9	72	7	56
4. Ease of Implementation							
a. *Design complexity (e.g., installation)*	8	10	80	8	64	7	56
b. *Site complexity (e.g., utilities)*	2	6	12	8	16	6	12
c. *Natural resources impacts (e.g., trees)*	2	6	12	8	16	6	12
Service Objectives							
5. Instream habitat							
a. *Diversity of velocity and depths*	9	7	63	10	90	10	90
b. *Diversity and quality of cover*	9	6	54	9	81	9	81
c. *Shading*	7	6	42	6	42	6	42
d. *Spawning habitat*	5	8	40	10	50	10	50
6. Riparian habitat (*i.e., width, diversity, native*	8	8	64	8	64	8	64
7. Water Quality							
a. *Sediment reduction*	10	10	100	9	90	9	90
b. *Nutrient reduction*	6	9	54	9	54	9	54
ANCC Objectives							
8. Channel stability							
a. *Short-term channel stability*	10	8	80	9	90	10	100
b. *Long-term channel stability*	10	9	90	10	100	10	100
9. Restoration reliability	10	6	60	8	80	10	100
10. Water Quality							
a. *Sediment reduction*	7	10	70	9	63	9	63
11. Riparian habitat							
a. *Aesthetics*	8	8	64	10	80	10	80
b. *Low Maintenance*	8	10	80	10	80	10	80
c. *Wildlife habitat improvements*	5	8	40	8	40	8	40
d. *Native planting*	6	9	54	9	54	9	54
		Total	**1560**	**Total**	**1666**	**Total**	**1680**

The rock and log structures had only the second highest score because of its lower potential for success. Although these structures do provide long-term bank stability, they are not as successful as other alternatives in providing short-term bank stability. This is especially critical for the restoration of Daniels Run since the construction of new streambanks, from unconsolidated bank material, will most likely be part of the restoration effort.

The Service recommends the structures and soil lifts restoration alternative for the restoration of Daniels Run. This alternative scored the highest because it was the most successful alternative at achieving the restoration objectives, specifically for channel stability, potential for success, and instream habitat diversity. Combining the two restoration alternatives also addresses the individual limitations of other alternatives discussed above.

Although this restoration alternative (*i.e.*, structures and soil lifts) scored the highest for the potential for success, all the restoration alternatives may require maintenance following their installation. This alternative may require more maintenance because of the complexity of combining two different restoration methods, specifically connecting the two methods together during construction. Stream restoration is not an exact science, so it is common that some maintenance is required to fine-tune the restoration to specific site conditions

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Appendix A
Field Data

Cross Sections

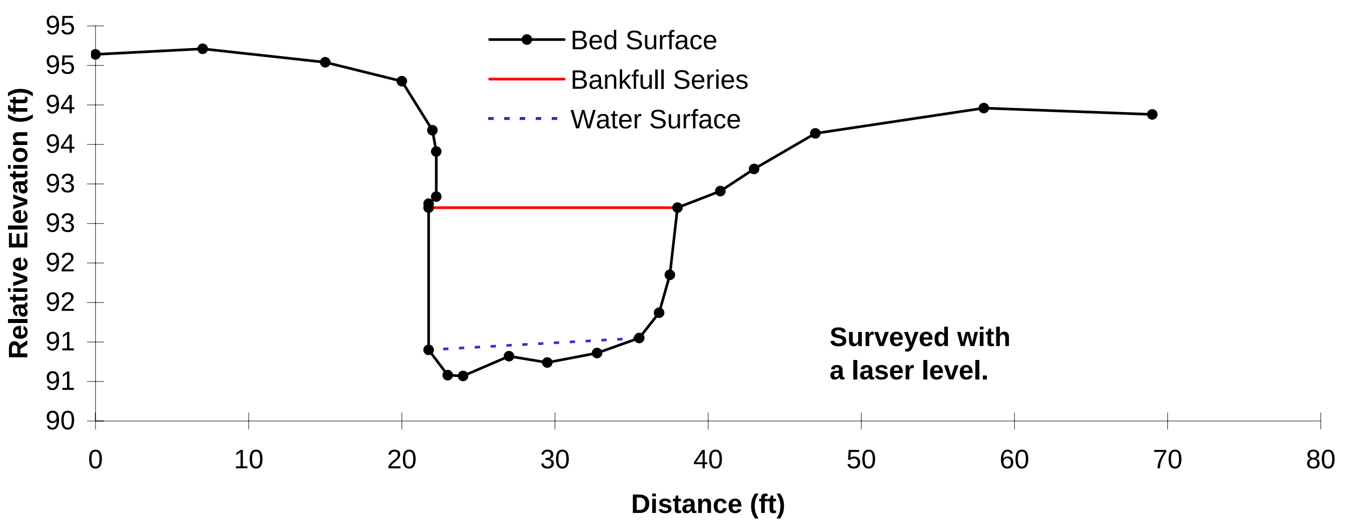
DANIELS RUN
UPSTREAM REACH

STREAM: Daniels Run
REACH & XS: XS 1 (Upstream Reach)
DATE: 03/28/06

CREW: RRS, CE, KF
DATA: KF
QA/QC: CE

Width (ft)	Cross-Sectional Area (Sq.ft)	Mean Depth (ft)	Maximum Depth (ft)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	
16.25	29.28	1.80	2.13	18.78	1.56	Bankfull
13.75	2.65	0.19	0.35	13.81	0.19	Water Surface

Identifier	Distance (ft)	Elevation (ft)	Identifier	Distance (ft)	Elevation (ft)
GS	0.0	94.64	REW	35.5	91.05
GS	7.0	94.71	TOE	36.8	91.37
GS	15.0	94.54	SLP BRK	37.5	91.85
GS	20.0	94.30	RBF	38.0	92.70
LTOB	22.0	93.68	GS	40.8	92.91
SLP BRK	22.3	93.41	GS	43.0	93.19
SLP BRK	22.3	92.84	GS	47.0	93.64
UNDERCUT	21.8	92.75	GS	58.0	93.96
LBF	21.8	92.70	GS	69.0	93.88
LEW	21.8	90.90			
CS	23.0	90.58			
CS	24.0	90.57			
CS	27.0	90.82			
CS	29.5	90.74			
CS	32.8	90.86			



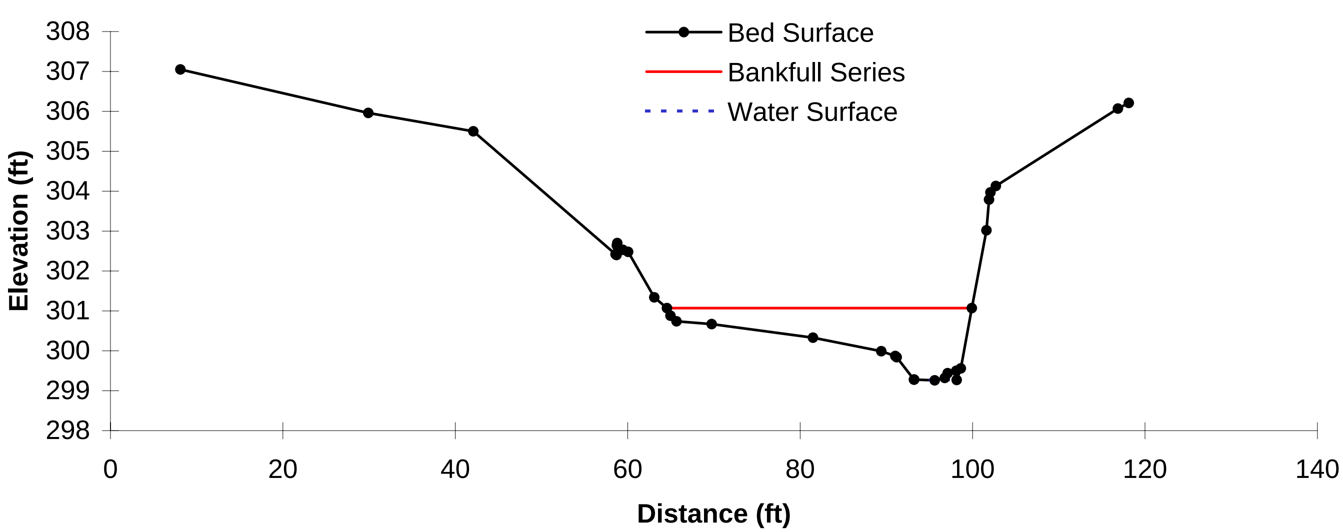
DANIELS RUN
UPSTREAM REACH

STREAM: Daniels Run
REACH & XS: XS 2 (Upstream Reach)
DATE: 03/28/06

CREW: RRS, CE, KF
DATA: KF
QA/QC: CE

	Width (ft)	Cross-Sectional Area (Sq.ft)	Mean Depth (ft)	Maximum Depth (ft)	Wetted Perimeter (ft)	Hydraulic Radius (ft)
Bankfull	35.36	31.10	0.88	1.81	36.51	0.85
Water Surface	4.93	-0.24	-0.05	0.02	5.14	-0.05

Identifier	Distance (ft)	Elevation (ft)	Identifier	Distance (ft)	Elevation (ft)	Identifier	Distance (ft)	Elevation (ft)
GS	8.1	307.05	CS	89.4	299.99	SLP BRK	102.7	304.13
GS	29.9	305.96	CS	91.0	299.87	GS	116.9	306.07
GS	42.1	305.50	CS	91.2	299.84	GS	118.1	306.21
SLP BRK	58.6	302.42	CS	93.2	299.28			
SLP BRK	58.7	302.40	LEW	93.2	299.28			
SLP BRK	58.7	302.64	CS	95.6	299.26			
SLP BRK	58.8	302.70	CS	96.8	299.32			
SLP BRK	59.4	302.53	CS	97.1	299.44			
SLP BRK	60.1	302.48	CS	98.1	299.50			
SLP BRK	63.1	301.34	REW	98.2	299.27			
LBF	64.6	301.07	CS	98.6	299.56			
CS	65.0	300.88	RBF	99.9	301.07			
CS	65.7	300.74	SLP BRK	101.6	303.02			
CS	69.7	300.67	SLP BRK	101.9	303.79			
CS	81.5	300.33	SLP BRK	102.1	303.97			



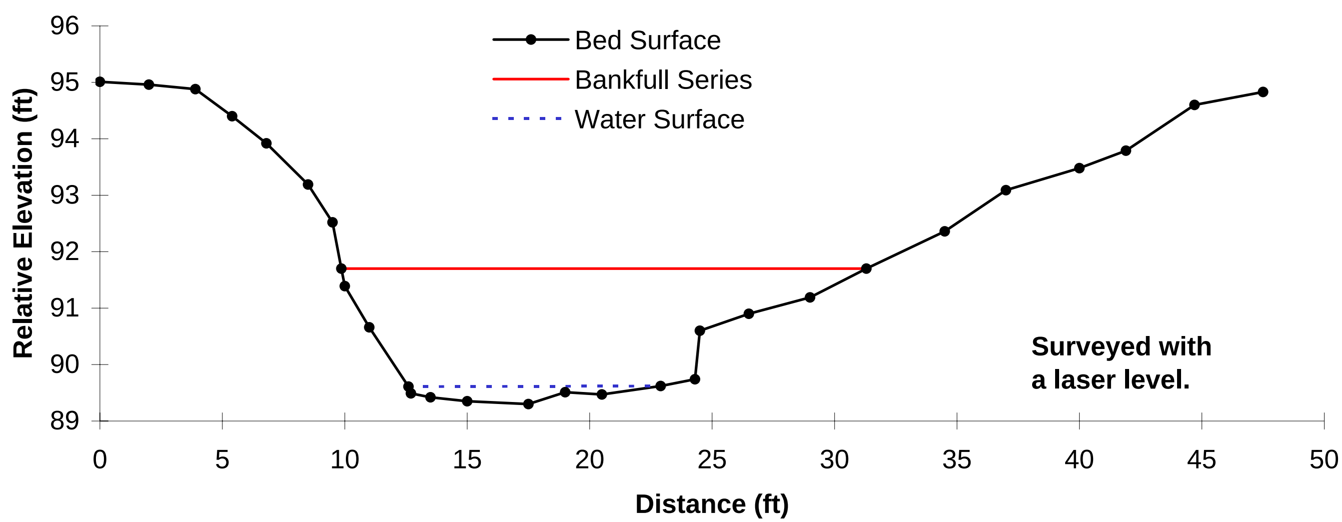
DANIELS RUN
DOWNSTREAM REACH

STREAM: Daniels Run
REACH & XS: XS 3 (Downstream Reach)
DATE: 03/28/06

CREW: RRS, CE, KF
DATA: KF
QA/QC: CE

Width (ft)	Cross-Sectional Area (Sq.ft)	Mean Depth (ft)	Maximum Depth (ft)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	
21.44	33.81	1.58	2.40	23.06	1.47	Bankfull
10.30	1.88	0.18	0.31	10.38	0.18	Water Surface

Identifier	Distance (ft)	Elevation (ft)	Identifier	Distance (ft)	Elevation (ft)
GS	0.0	95.01	CS	19.0	89.51
GS	2.0	94.96	CS	20.5	89.47
LTOB	3.9	94.88	REW	22.9	89.62
SLP BRK	5.4	94.40	TOE	24.3	89.74
SLP BRK	6.8	93.92	IP	24.5	90.60
SLP BRK	8.5	93.19	FLAT	26.5	90.90
IP	9.5	92.52	BCK FLAT	29.0	91.19
LBF	9.9	91.70	RBF	31.3	91.70
SLP BRK	10.0	91.39	SLP BRK	34.5	92.36
SLP BRK	11.0	90.66	SLP BRK	37.0	93.09
LEW	12.6	89.61	SLP BRK	40.0	93.48
CS	12.7	89.49	SLP BRK	41.9	93.79
CS	13.5	89.42	FLAT	44.7	94.60
CS	15.0	89.35	GS	47.5	94.83
CS	17.5	89.30			

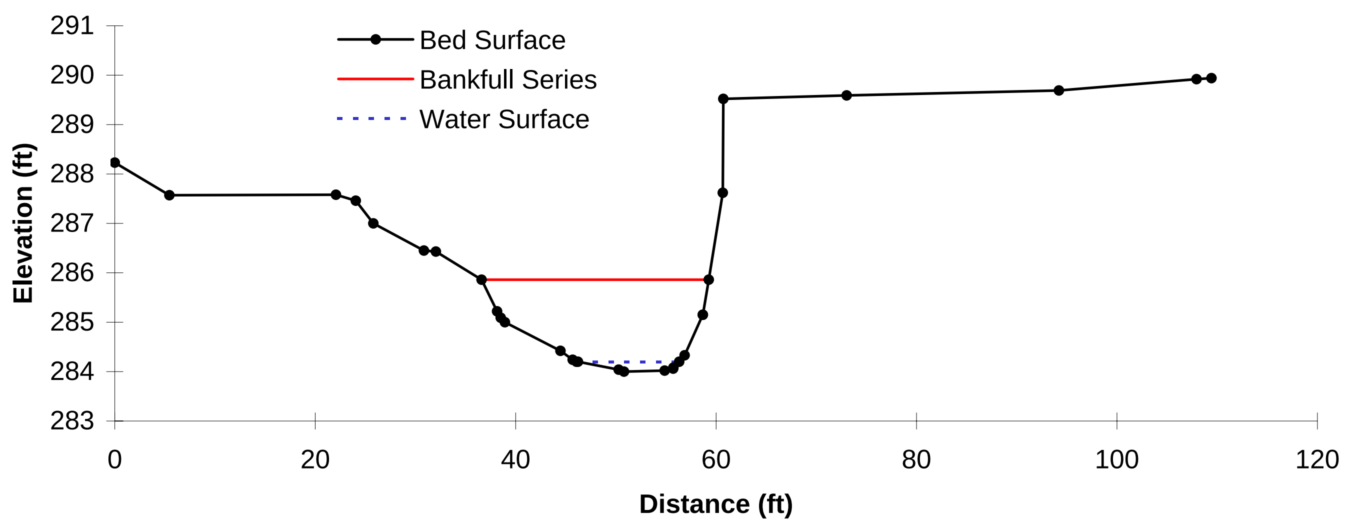


DANIELS RUN
DOWNSTREAM REACH

Width (ft)	Cross-Sectional Area (Sq.ft)	Mean Depth (ft)	Maximum Depth (ft)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	
22.67	31.44	1.39	1.86	23.43	1.34	Bankfull
10.10	1.36	0.14	0.20	10.13	0.13	Water Surface

STREAM: Daniels Run
REACH & XS: XS 4 (Downstream Reach)
DATE: 03/28/06
CREW: RRS, CE, KF
DATA: KF
QA/QC: CE

Identifier	Distance (ft)	Elevation (ft)	Identifier	Distance (ft)	Elevation (ft)	Identifier	Distance (ft)	Elevation (ft)			
	0.0	288.23	CS	50.3	284.04	GS	109.4	289.94			
GS	5.5	287.57	CS	50.8	284.00						
GS	22.1	287.58	CS	54.9	284.02						
GS	24.1	287.46	CS	55.7	284.06						
SLP BRK	25.8	287.00	CS	55.7	284.08						
SLP BRK	30.9	286.45	REW	56.3	284.20						
SLP BRK	32.0	286.43	CS	56.9	284.33						
LBF	36.6	285.86	SLP BRK	58.7	285.15						
SLP BRK	38.2	285.22	SLP BRK	58.7	285.15						
CS	38.5	285.09	RBF	59.3	285.86						
CS	38.9	285.00	SLP BRK	60.7	287.62						
CS	44.5	284.42	GS	60.7	289.52						
CS	45.7	284.24	GS	73.0	289.59						
CS	46.1	284.20	GS	94.2	289.69						
LEW	46.2	284.20	GS	107.9	289.92						



Pebble Counts

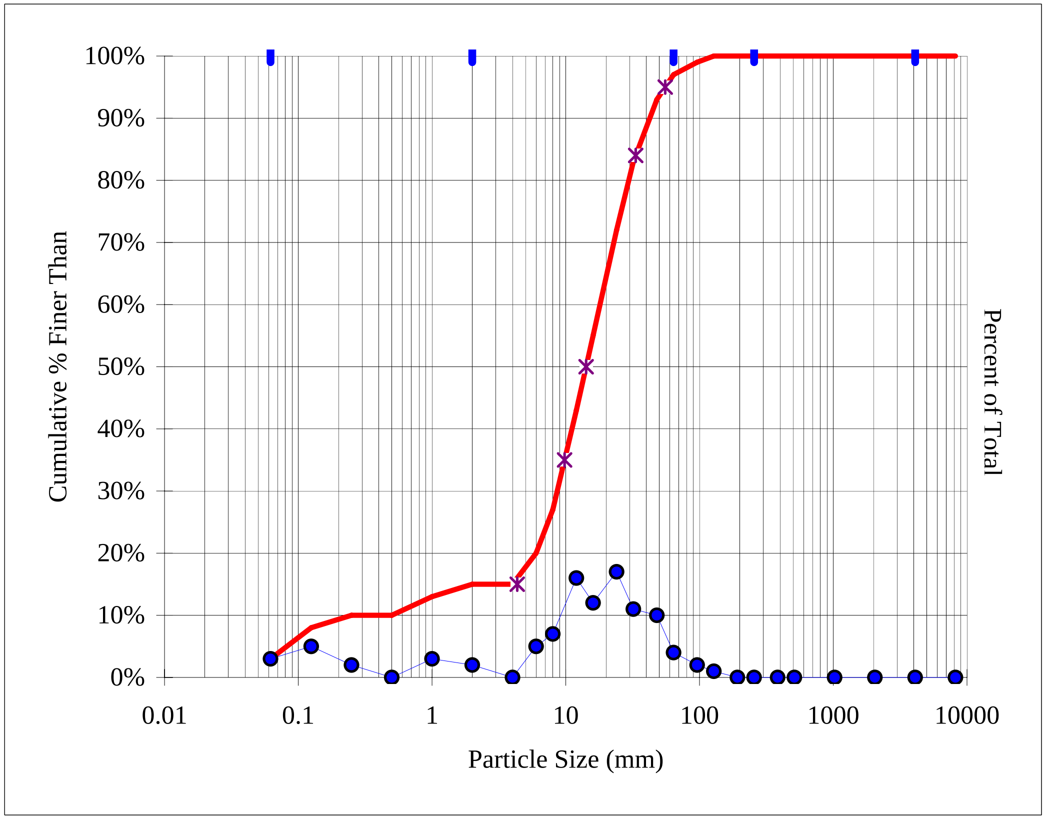
DANIELS RUN - REACH AVERAGE PEBBLE COUNT

Pebble Count Worksheet

Particle Size (mm)	% finer than	Total Count
<0.062	3%	3
0.062 - 0.125	8%	5
0.125 - 0.25	10%	2
0.25 - 0.5	10%	0
0.5 - 1.0	13%	3
1 - 2	15%	2
2 - 4	15%	0
4 - 6	20%	5
6 - 8	27%	7
8 - 12	43%	16
12 - 16	55%	12
16 - 24	72%	17
24 - 32	83%	11
32 - 48	93%	10
48 - 64	97%	4
64 - 96	99%	2
96 - 128	100%	1
128 - 192	100%	0
192 - 256	100%	0
256 - 384	100%	0
384 - 512	100%	0
512 - 1024	100%	0
1024 - 2048	100%	0
2048 - 4096	100%	0
> 4096	100%	0

STREAM NAME: Daniels Run
USGS ID #:
FWS ID #:
DATE: 4/6/2006
CREW: CE, KF

Particle Size Distribution (mm)	D16	D35	D50	D84	D95
	4.34	9.80	14.19	33.32	55.43



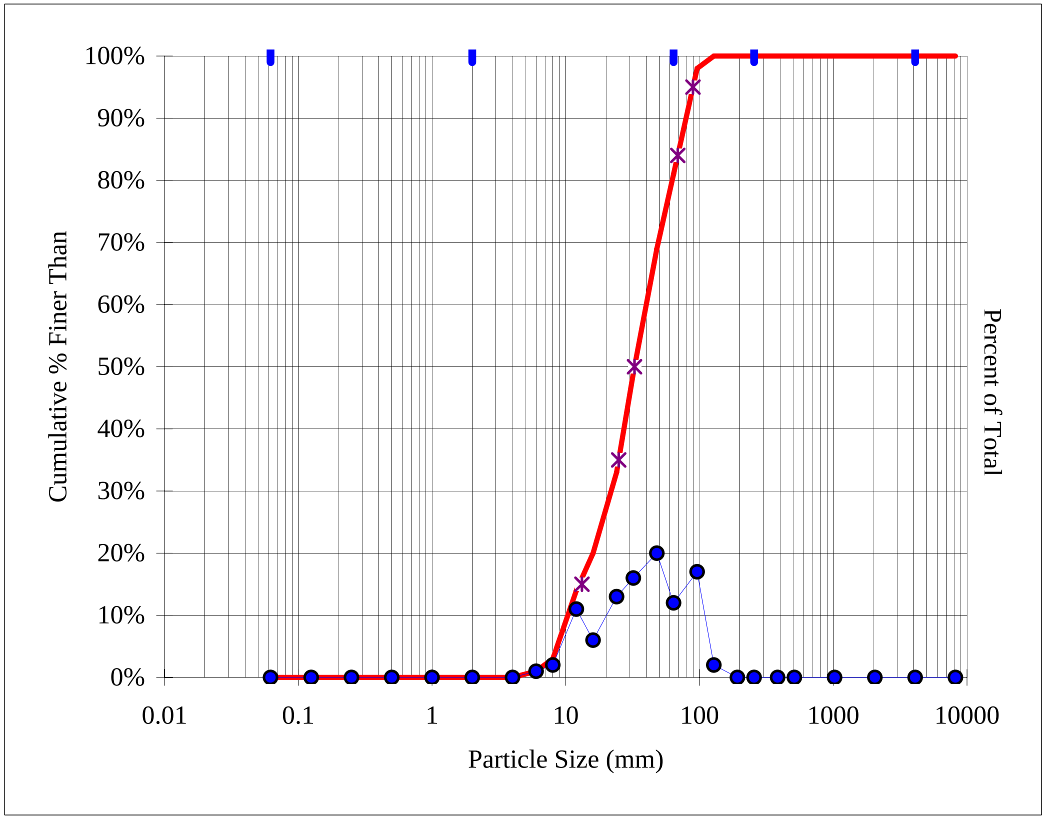
DANIELS RUN - UPSTREAM RIFFLE PEBBLE COUNT

Pebble Count Worksheet

Particle Size (mm)	% finer than	Total Count
<0.062	0%	0
0.062 - 0.125	0%	0
0.125 - 0.25	0%	0
0.25 - 0.5	0%	0
0.5 - 1.0	0%	0
1 - 2	0%	0
2 - 4	0%	0
4 - 6	1%	1
6 - 8	3%	2
8 - 12	14%	11
12 - 16	20%	6
16 - 24	33%	13
24 - 32	49%	16
32 - 48	69%	20
48 - 64	81%	12
64 - 96	98%	17
96 - 128	100%	2
128 - 192	100%	0
192 - 256	100%	0
256 - 384	100%	0
384 - 512	100%	0
512 - 1024	100%	0
1024 - 2048	100%	0
2048 - 4096	100%	0
> 4096	100%	0

STREAM NAME: Daniels Run
USGS ID #:
FWS ID #:
DATE: 4/6/2006
CREW: CE, KF

Particle Size Distribution (mm)	D16	D35	D50	D84	D95
	13.21	24.88	32.66	68.75	89.37



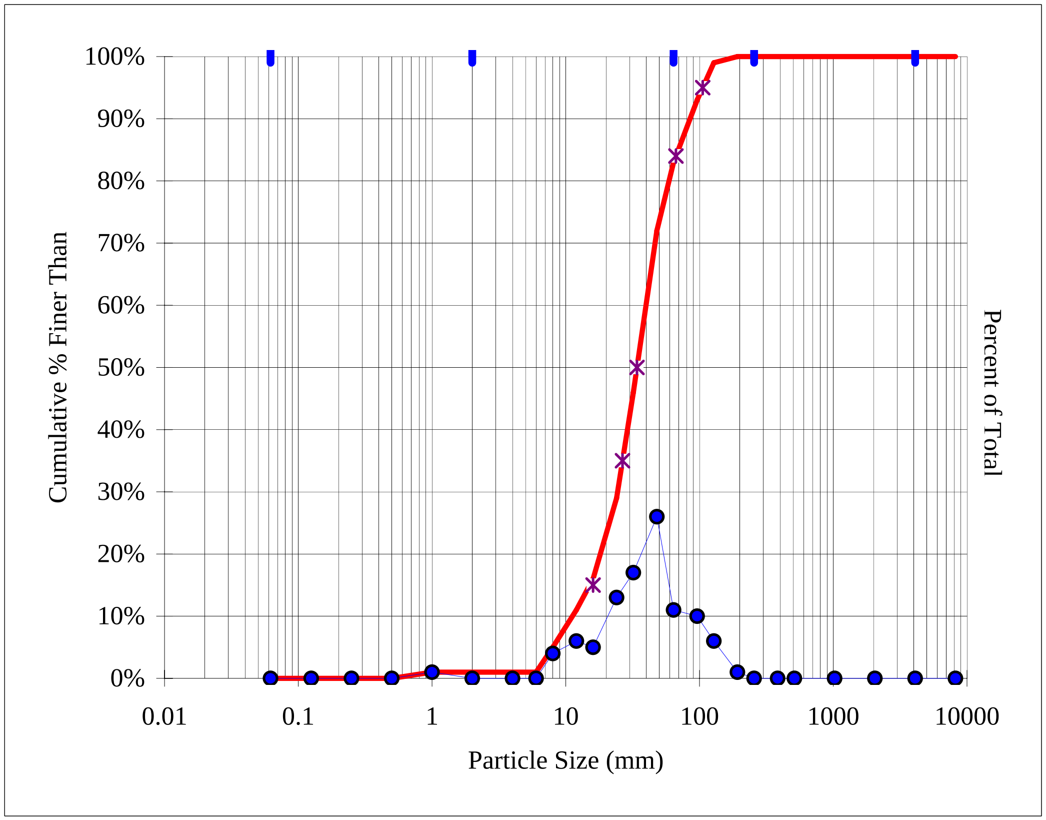
DANIELS RUN - DOWNSTREAM RIFFLE PEBBLE COUNT

Pebble Count Worksheet

Particle Size (mm)	% finer than	Total Count
<0.062	0%	0
0.062 - 0.125	0%	0
0.125 - 0.25	0%	0
0.25 - 0.5	0%	0
0.5 - 1.0	1%	1
1 - 2	1%	0
2 - 4	1%	0
4 - 6	1%	0
6 - 8	5%	4
8 - 12	11%	6
12 - 16	16%	5
16 - 24	29%	13
24 - 32	46%	17
32 - 48	72%	26
48 - 64	83%	11
64 - 96	93%	10
96 - 128	99%	6
128 - 192	100%	1
192 - 256	100%	0
256 - 384	100%	0
384 - 512	100%	0
512 - 1024	100%	0
1024 - 2048	100%	0
2048 - 4096	100%	0
> 4096	100%	0

STREAM NAME: Daniels Run
USGS ID #:
FWS ID #:
DATE: 4/6/2006
CREW: CE, KF

Particle Size Distribution (mm)	D16	D35	D50	D84	D95
	16.00	26.56	34.06	66.65	105.66



Bar Samples

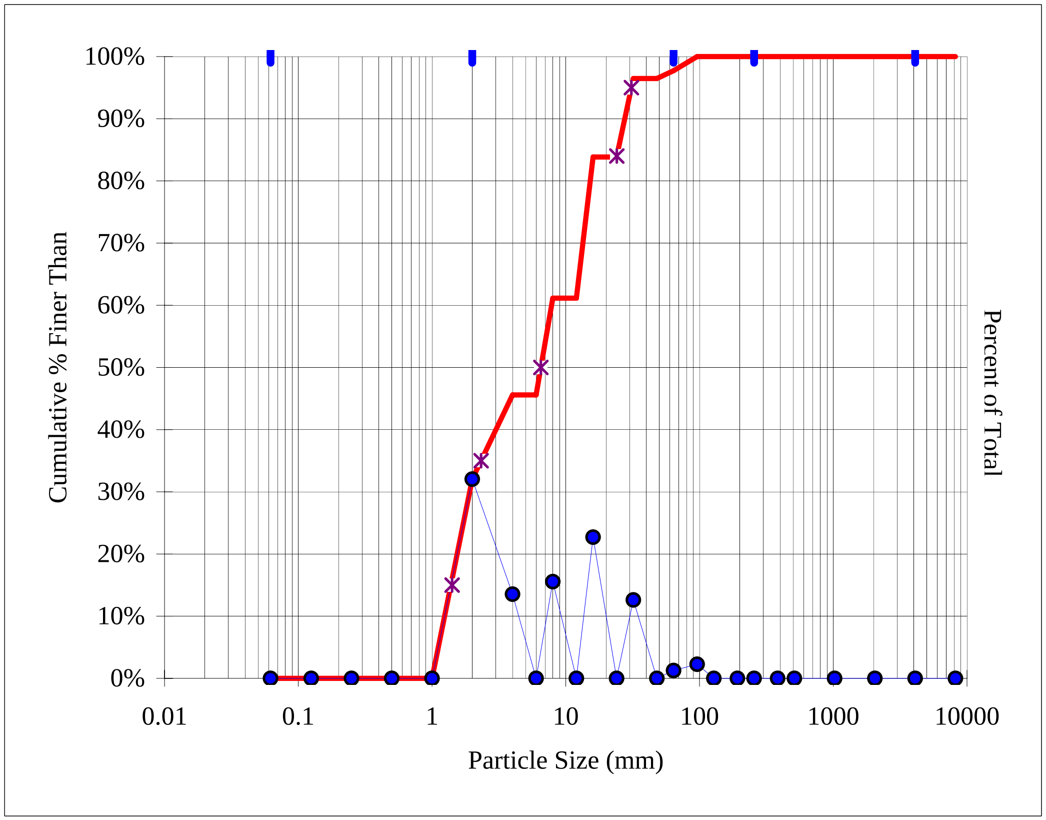
DANIELS RUN - UPSTREAM BAR SAMPLE

Pebble Count Worksheet

Particle Size (mm)	% finer than	Total Count
<0.062	0%	
0.062 - 0.125	0%	
0.125 - 0.25	0%	
0.25 - 0.5	0%	
0.5 - 1.0	0%	
1 - 2	32%	381
2 - 4	46%	161
4 - 6	46%	
6 - 8	61%	185
8 - 12	61%	
12 - 16	84%	270
16 - 24	84%	
24 - 32	96%	150
32 - 48	96%	
48 - 64	98%	15
64 - 96	100%	27
96 - 128	100%	0
128 - 192	100%	0
192 - 256	100%	0
256 - 384	100%	0
384 - 512	100%	0
512 - 1024	100%	0
1024 - 2048	100%	0
2048 - 4096	100%	0
> 4096	100%	0

STREAM NAME: Daniels Run
USGS ID #:
FWS ID #:
DATE: 4/6/2006
CREW: CE, KF

Particle Size Distribution (mm)	D16	D35	D50	D84	D95
	1.41	2.33	6.51	24.08	30.95



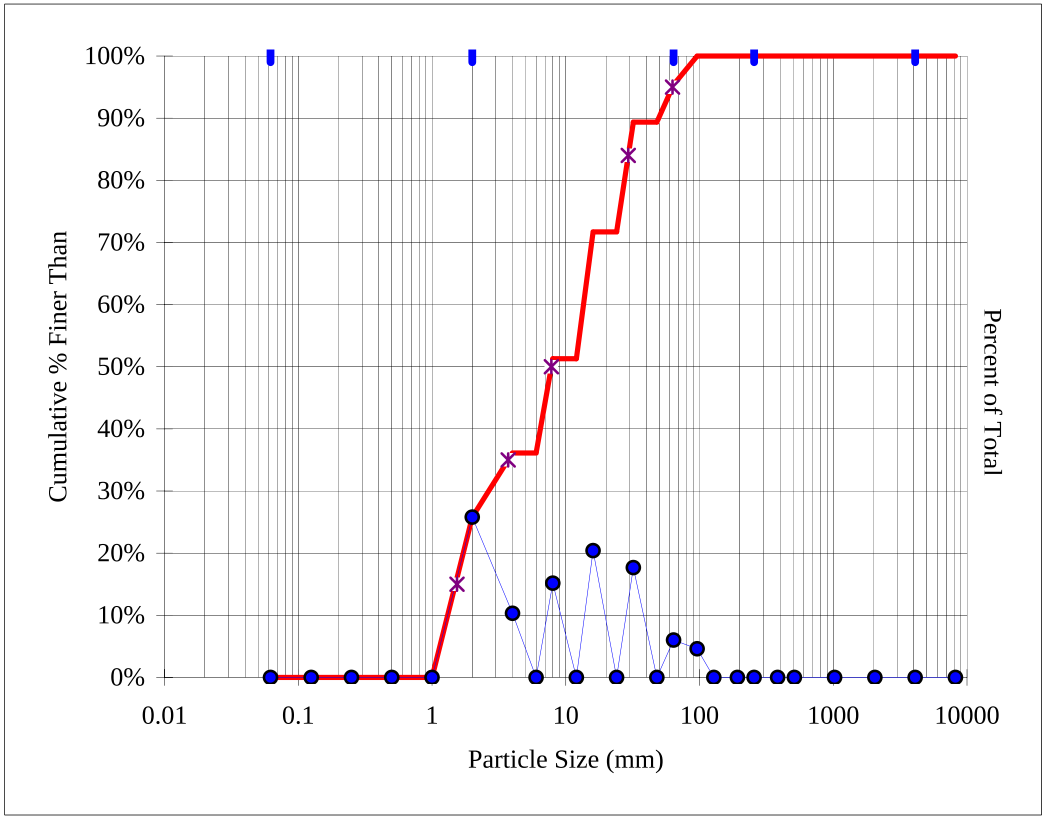
DANIELS RUN - DOWNSTREAM BAR SAMPLE

Pebble Count Worksheet

Particle Size (mm)	% finer than	Total Count
<0.062	0%	
0.062 - 0.125	0%	
0.125 - 0.25	0%	
0.25 - 0.5	0%	
0.5 - 1.0	0%	
1 - 2	26%	330
2 - 4	36%	132
4 - 6	36%	
6 - 8	51%	194
8 - 12	51%	
12 - 16	72%	261
16 - 24	72%	
24 - 32	89%	226
32 - 48	89%	
48 - 64	95%	77
64 - 96	100%	59
96 - 128	100%	0
128 - 192	100%	0
192 - 256	100%	0
256 - 384	100%	0
384 - 512	100%	0
512 - 1024	100%	0
1024 - 2048	100%	0
2048 - 4096	100%	0
> 4096	100%	0

STREAM NAME: Daniels Run
USGS ID #:
FWS ID #:
DATE: 4/6/2006
CREW: CE, KF

Particle Size Distribution (mm)	D16	D35	D50	D84	D95
	1.54	3.71	7.81	29.32	62.83



Appendix B
Entrainment and Velocity Calculations

Entrainment Calculations

ENTRAINMENT CALCULATION FORM

Stream:	Daniels Run
Reach:	Upstream
Location:	Riffle
Date:	April 6, 2006
Observer(s):	CE, KF
Comments:	

Existing Conditions

32.66	D_{50}	Riffle Bed Material (mm)	0.0047	S_e	Existing Bankfull Water Surface Slope
6.51	$\hat{D}_{50}$	Bar Material (mm)	1.80	d_e	Existing Bankfull Mean Depth (ft)
0.29	*Di*	Largest Particle from Bar Sample (ft)	1.56	*R*	Hydraulic Radius (ft)
88.10	*Di*	Largest Particle from Bar Sample (mm)	1.65	γ_s	Submerged Specific Weight of Sediment (may change with sediment type (i.e. basalt))

Select the Appropriate Equation and Calculate Critical Dimensionless Shear Stress

τ^*_{ci} = 0.0834 $(D_{50} / \hat{D}_{50})^{-0.872}$		τ^*_{ci} = 0.0384 $(D_i / D_{50})^{-0.887}$	
5.02	$D_{50} / \hat{D}_{50}$ (Range 3.0 - 7.0)	2.70	D_i / D_{50} (Range 1.3 - 3.0)
0.02	τ^*_{ci} Critical Dimensionless Shear Stress	0.0159	τ^*_{ci} Critical Dimensionless Shear Stress

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

2.09	Required Bankfull Mean Depth (ft) $d_r = (\tau^*_{ci}\ \gamma_s\ D_i) / S_e$	1.63	Required Bankfull Mean Depth (ft) $d_r = (\tau^*_{ci}\ \gamma_s\ D_i) / S_e$
Aggrading	Stability Condition (d_e / d_r)	Degrading	Stability Condition (d_e / d_r)

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

0.0054	Required Water Surface Slope (ft) $S_r = (\tau^*_{ci}\ \gamma_s\ D_i) / d_e$	0.0042	Required Water Surface Slope (ft) $S_r = (\tau^*_{ci}\ \gamma_s\ D_i) / d_e$
Aggrading	Stability Condition (S_e / S_r)	Degrading	Stability Condition (S_e / S_r)

Validate Sediment Transport

0.45	$\tau_c = \gamma R S_e$ Bankfull Shear Stress (lb/ft^2)	
28.00	Best-Fit	Movable particle size (mm) at bankfull shear stress (predicted by the Shields Diagram: The River Field Book, pg. 238 or the Reference Reach Field Book, pg. 190.
105.00	High Outlier	
1.08	Best-Fit	Shear stress required to initiate movement of Di (mm) (predicted by the Shields Diagram: The River Field Book, pg. 238 or the Reference Reach Field Book, pg. 190.
0.37	High Outlier	

1) If the predicted shear stress can entrain the largest particle in the bar sample (D_i) the stream is degrading. If the predicted shear stress can not entrain the D_i, check the required depth and slope to validate aggradation. An aggrading stream may not be able to entrain the D_i at bankfull.

2) To evaluate aggradation for high W/D streams (W/D>100) calculate entrainment for the study reach at a stable or higher transport reach)

ENTRAINMENT CALCULATION FORM

Stream:	Daniels Run
Reach:	Downstream
Location:	Riffle
Date:	April 2, 2006
Observer(s):	CE, KF
Comments:	

Existing Conditions			
34.06	D_{50} Riffle Bed Material (mm)	0.0051	S_e Existing Bankfull Water Surface Slope
7.81	$\hat{D}_{50}$ Bar Material (mm)	1.58	d_e Existing Bankfull Mean Depth (ft)
0.30	*Di* Largest Particle from Bar Sample (ft)	1.47	*R* Hydraulic Radius (ft)
92.50	*Di* Largest Particle from Bar Sample (mm)	1.65	γ_s Submerged Specific Weight of Sediment (may change with sediment type (i.e. basalt))
Select the Appropriate Equation and Calculate Critical Dimensionless Shear Stress			
$\tau^*_{ci} = 0.0834\,(D_{50} / \hat{D}_{50})^{-0.872}$		$\tau^*_{ci} = 0.0384\,(D_i / D_{50})^{-0.887}$	
4.36	$D_{50} / \hat{D}_{50}$ (Range 3.0 - 7.0)	2.72	D_i / D_{50} (Range 1.3 - 3.0)
0.02	τ^*_{ci} Critical Dimensionless Shear Stress	0.02	τ^*_{ci} Critical Dimensionless Shear Stress
Calculate Bankfull Mean Depth Required for Entrainment of Largest Particle in Bar Sample			
2.25	Required Bankfull Mean Depth (ft) $d_r = (\tau^*_{ci}\, \gamma_s\, D_i) / S_e$	1.54	Required Bankfull Mean Depth (ft) $d_r = (\tau^*_{ci}\, \gamma_s\, D_i) / S_e$
Aggrading	Stability Condition (d_e / d_r)	Degrading	Stability Condition (d_e / d_r)
Calculate Bankfull Water Surface Slope Required for Entrainment of Largest Particle in Bar Sample			
0.0073	Required Water Surface Slope (ft) $S_r = (\tau^*_{ci}\, \gamma_s\, D_i) / d_e$	0.0050	Required Water Surface Slope (ft) $S_r = (\tau^*_{ci}\, \gamma_s\, D_i) / d_e$
Aggrading	Stability Condition (S_e / S_r)	Degrading	Stability Condition (S_e / S_r)
Validate Sediment Transport			
0.47	$\tau_c = \gamma R S_e$ Bankfull Shear Stress (lb/ft^2)		

30.00	Best-Fit	Movable particle size (mm) at bankfull shear stress (predicted by the Shields Diagram: The River Field Book, pg. 238 or the Reference Reach Field Book, pg. 190.
107.00	High Outlier	
1.10	Best-Fit	Shear stress required to initiate movement of Di (mm) (predicted by the Shields Diagram: The River Field Book, pg. 238 or the Reference Reach Field Book, pg. 190.
0.41	High Outlier	

1) If the predicted shear stress can entrain the largest particle in the bar sample (D_i) the stream is degrading. If the predicted shear stress can not entrain the D_i, check the required depth and slope to validate aggradation. An aggrading stream may not be able to entrain the D_i at bankfull.

2) To evaluate aggradation for high W/D streams (W/D>100) calculate entrainment for the study reach at a stable or higher transport reach)

Velocity Calculations

VELOCITY CALCULATION FORM

Stream:	Daniels Run
Reach:	Upstream
Location:	Riffle
Date:	April 6, 2006
Observer(s):	CE, KR
Comments:	

Existing Conditions					
29.28	A_{BKF}	Bankfull Cross-Sectional Area (ft^2)	0.23	D_{84}	Riffle D_{84} (ft)
16.25	W_{BKF}	Bankfull Width (ft)	0.0047	S	Water Surface Slope
1.80	D_{BKF}	Bankfull Mean Depth (ft)	6.54	R/D_{84}	R/D_{84} (ft/ft)
19.85	WP	Wetted Perimeter (ft)	32.20	g	Gravitational Acceleration (ft/s^2)
1.47	R	Hydraulic Radius (ft)	1.88	DA	Drainage Area (mi^2)
68.75	D_{84}	Riffle D_{84} (mm)			

R/D84, u/u*, Mannings "n" Relative Roughness vs. Resistance Relationship Graphs		
u/u* (using R/D_{84}: see Reference Reach Field Book (p.188), River Field Book (p.233))	7.46	ft/s/ ft/s
Manning's "n" (see Reference Reach Field Book (p.189), River Field Book (p.236)	0.0365	
Velocity (using Manning's equation: $u=1.49R^{(2/3)}S^{(1/2)}/n$)	3.63	ft/s
Discharge (using $Q=A_{BKF}u$)	106.17	cfs
Resistance as a function of Relative Roughness (Leopold 1994) u/u* = 2.83+5.7log(R/D84)		
u*: (using $u^*=(gRS)^{0.5}$)	0.47	ft/s
Velocity (using $u=u^*(2.83+5.7\log(R/D_{84}))$)	3.53	ft/s
Discharge (using $Q=A_{BKF}u$)	103.44	cfs
Manning's "n" by Stream Type		
Stream Type	C4	
Manning's "n" (see Reference Reach Field Book (p.187), River Field Book (p.237)	0.03	
Velocity (using Manning's equation: $u=1.49R^{(2/3)}S^{(1/2)}/n$)	4.28	ft/s
Discharge (using $Q=A_{BKF}u$)	125.41	cfs
Limerinos Equation (1970)		
Manning's "n" (using "n"=$(R^{(1/6)}0.0926)/(1.16+2\log(R/D84))$)	0.04	
Velocity (using Manning's equation: $u=1.49R^{(2/3)}S^{(1/2)}/n$)	3.74	ft/s
Discharge (using $Q=A_{BKF}u$)	109.47	cfs
Jarretts Equation for Estimating Manning's n		
$n = 0.39\ S^{0.38}\ R^{-0.16}$	0.05	
Velocity (using Manning's equation: $u=1.49R^{(2/3)}S^{(1/2)}/n$)	2.77	ft/s
Discharge (using $Q=A_{BKF}u$)	81.06	cfs
Continuity Equation		
Q_{BKF} (from Maryland - Allegheny Plateau/Valley and Ridge Regional Curve (USFWS))	61.58	cfs
Q_{BKF} (from Maryland - Piedmont Regional Curve (USFWS))	136.62	cfs
Q_{BKF} (from Maryland - Western Coastal Plain Regional Curve (USFWS))	49.70	cfs
Q_{BKF} (from Maryland - Eastern Coastal Plain Regional Curve (USFWS))	23.67	cfs

VELOCITY CALCULATION FORM

Stream:	Daniels Run
Reach:	Downstream
Location:	Riffle
Date:	April 6, 2006
Observer(s):	CE, KR
Comments:	

Existing Conditions					
33.81	A_{BKF}	Bankfull Cross-Sectional Area (ft^2)	0.22	D_{84}	Riffle D_{84} (ft)
21.44	W_{BKF}	Bankfull Width (ft)	0.0051	S	Water Surface Slope
1.58	D_{BKF}	Bankfull Mean Depth (ft)	6.29	R/D_{84}	R/D_{84} (ft/ft)
24.59	WP	Wetted Perimeter (ft)	32.20	g	Gravitational Acceleration (ft/s^2)
1.37	R	Hydraulic Radius (ft)	1.88	DA	Drainage Area (mi^2)
66.64	D_{84}	Riffle D_{84} (mm)			

R/D84, u/u*, Mannings "n" Relative Roughness vs. Resistance Relationship Graphs		
u/u* (using R/D_{84}: see Reference Reach Field Book (p.188), River Field Book (p.233))	7.37	ft/s/ ft/s
Manning's "n" (see Reference Reach Field Book (p.189), River Field Book (p.236)	0.0375	
Velocity (using Manning's equation: $u=1.49R^{(2/3)}S^{(1/2)}/n$)	3.51	ft/s
Discharge (using $Q=A_{BKF}u$)	118.61	cfs
Resistance as a function of Relative Roughness (Leopold 1994) u/u* = 2.83+5.7log(R/D84)		
u*: (using $u^*=(gRS)^{0.5}$)	0.48	ft/s
Velocity (using $u=u^*(2.83+5.7\log(R/D_{84}))$)	3.51	ft/s
Discharge (using $Q=A_{BKF}u$)	118.58	cfs
Manning's "n" by Stream Type		
Stream Type	C4	
Manning's "n" (see Reference Reach Field Book (p.187), River Field Book (p.237)	0.03	
Velocity (using Manning's equation: $u=1.49R^{(2/3)}S^{(1/2)}/n$)	4.26	ft/s
Discharge (using $Q=A_{BKF}u$)	143.95	cfs
Limerinos Equation (1970)		
Manning's "n" (using "n"=($R^{(1/6)}$0.0926)/(1.16+2log(R/D84))	0.04	
Velocity (using Manning's equation: $u=1.49R^{(2/3)}S^{(1/2)}/n$)	3.71	ft/s
Discharge (using $Q=A_{BKF}u$)	125.59	cfs
Jarretts Equation for Estimating Manning's n		
$n = 0.39\ S^{0.38}\ R^{-0.16}$	0.05	
Velocity (using Manning's equation: $u=1.49R^{(2/3)}S^{(1/2)}/n$)	2.64	ft/s
Discharge (using $Q=A_{BKF}u$)	89.19	cfs
Continuity Equation		
Q_{BKF} (from Maryland - Allegheny Plateau/Valley and Ridge Regional Curve (USFWS))	61.58	cfs
Q_{BKF} (from Maryland - Piedmont Regional Curve (USFWS))	136.62	cfs
Q_{BKF} (from Maryland - Western Coastal Plain Regional Curve (USFWS))	49.70	cfs
Q_{BKF} (from Maryland - Eastern Coastal Plain Regional Curve (USFWS))	23.67	cfs