UPPER WATTS BRANCH STREAM RESTORATION
30 PERCENT DESIGN REPORT

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Prepared in cooperation with:

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EXECUTIVE SUMMARY

The District of Columbia (District), Department of Health, Environmental Health Administration (DOH) and the U.S. Fish and Wildlife Service (Service) – Chesapeake Bay Field Office (CBFO) are developing stream restoration plans for Watts Branch. Watts Branch is a perennial stream severely impacted by urbanization. The Service's stream assessment of Watts Branch (Eng 2002) found that Watts Branch is laterally and vertically unstable due to stream incision, stream straightening, and loss of connection between the Watts Branch channel and its floodplain. Water quality in the steam is poor due to contamination from urban stormwater runoff, leakage from sanitary sewers, and litter. Because most of the Watts Branch watershed is developed and covered with impervious surfaces and most tributary streams have been replaced with storm sewers, baseflow is limited.

The Service and DOH are developing plans to restore the portion of Watts Branch within the District that extends from Southern Avenue to Minnesota Avenue using natural channel design methods. An earlier report (Shea *et al.,* 2005)[1] presents objectives for the stream restoration and describes the Service's approach to restoring Watts Branch. This report supplements the previous report and documents the geomorphic analysis used to develop detailed stream planform, profile, and pattern for the 30 Percent Concept Plans.

[1] Shea, C.C., R. R. Starr, T. L. McCandless, and C.K. Eng 2005. *Upper Watts Branch Stream Restoration, 10 Percent Preliminary Concepts,* U.S. Fish and Wildlife Service , Chesapeake Bay Field Office, Stream Habitat Assessment and Restoration Program, Annapolis, MD, CBFO-S05-02.

I. INTRODUCTION

In 2002, the District of Columbia (District), Department of Health, Environmental Health Administration (DOH) and the U.S. Fish and Wildlife Service (Service) - Chesapeake Bay Field Office (CBFO) implemented a partnership agreement (Agreement 1902-0172) to pursue restoration efforts for the Potomac River, the Anacostia River, and their tributaries.

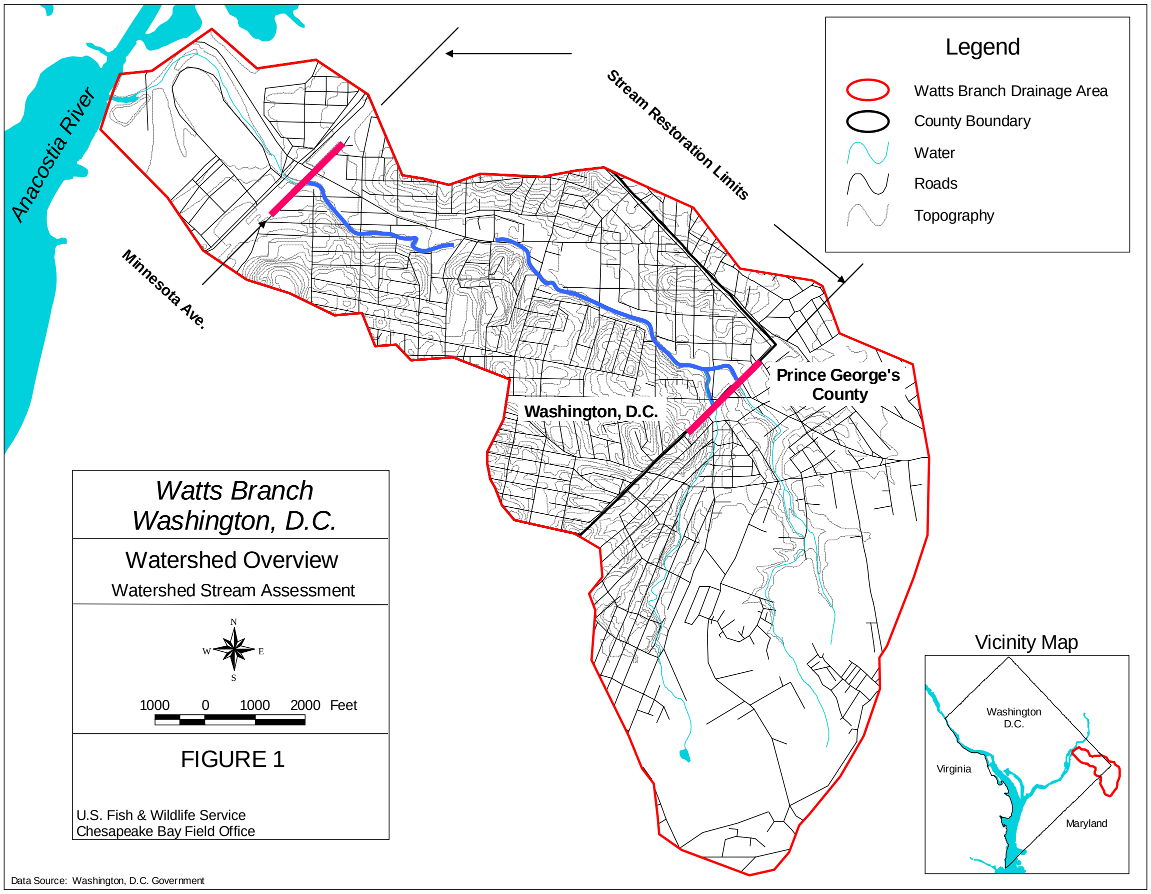
Under this agreement, the Service prepared a watershed and stream assessment of Watts Branch, a tributary to the Anacostia River (Eng 2002). Based on assessment results, the Service recommended that the District undertake a comprehensive stream and watershed restoration of the District's portions of Watts Branch. The objectives of stream restoration are to restore natural stream stability and to create habitat by reconfiguration of the stream using natural stream design principles. Stream restoration would be combined with on-going watershed restoration efforts including stormwater retrofits to reduce storm flow impacts on Watts Branch. Improvements to the riparian buffer and stream improvements would improve habitat and water quality, and reduce bank erosion. The Service recommended also that Prince Georges County, Maryland restore the portions of Watts Branch and its tributaries lying within the county.

In 2004, the DOH and the Service agreed to prepare full stream restoration design plans for the portion of Watts Branch that extends from where Watts Branch enters the District at Southern Avenue to the Minnesota Avenue, N.E.[2] crossing of Watts Branch (Figure 1). To facilitate development of design, the reaches undergoing restoration were divided into 11 Project Areas (Shea *et al*, 2005). The limits of each Project Area are shown in Figures 2 and 3.

The Service's first task in developing the restoration plans was to collect field data to support preparation of plans. The Service then identified stream restoration objectives, identified and reviewed alternatives, and developed preliminary restoration concepts. This work was presented in the 10 Percent Preliminary Concept Report (Shea *et al.*, 2005) and 10 Percent Preliminary Concept Plans (10 Percent Plans). The plans showed preliminary alignments for stream restoration, locations of potential stormwater management retrofits, and potential grading impacts. The plans and report were presented to DOH and restoration partners (District Department of Parks and Recreation (DPR), Washington Parks and People (WPP), District Department of Transportation (DDOT), and the District of Columbia Water and Sewer Authority (WASA)). Review comments were used to refine alignments.

The purpose of this report is to document development of the next phase of design plans, the 30 Percent Concept Plans (30 Percent Plans). The 30 Percent Plans shows detailed

[2] The portion of Watts Branch that extends from Southern Avenue to Minnesota Avenue N.E. is hereafter referred to as Upper Watts Branch. The portion of Watts Branch that extends from Minnesota Avenue N.E. to the Anacostia River is referred to as Lower Watts Branch. The portion of Watts Branch lying upstream of Southern Avenue is located within Prince Georges County, Maryland and is referred to as the Prince Georges portion of Watts Branch.



stream profiles, stream alignments, stream grading, and location and dimensions of in-stream structures. Design of stream morphology is based on natural channel design principles.

II. 30 PERCENT DESIGN DEVELOPMENT

A. NATURAL CHANNEL DESIGN METHODOLOGY

The Service used natural channel design methodology to design the stream profile, cross sections, and planform for restoring Watts Branch. The objective of natural channel design is to make adjustments in stream planform, cross-section, and profile such that restored streams accommodate their regimes of flows and sediment supply without creating erosion or deposition impacts within, upstream, or downstream of restored reaches. Natural channel design methodology employs geomorphic measurements from stable, natural streams as a template for designing the restored stream. Measurements from stable streams are scaled by ratios of bankfull mean depth, bankfull width, and bankfull discharge to develop planform, cross section, and vertical profiles for restored streams.

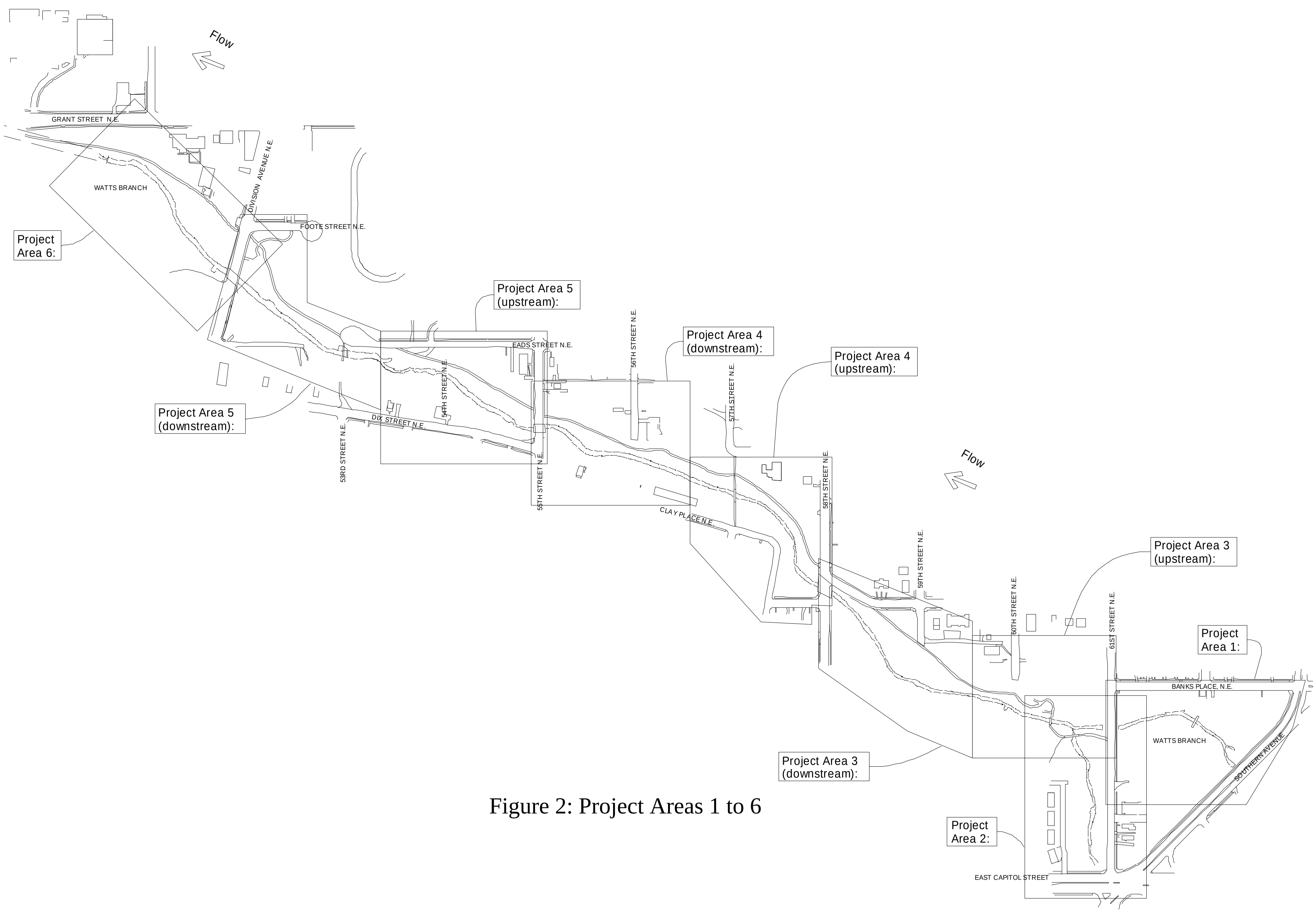


Figure 2: Project Areas 1 to 6

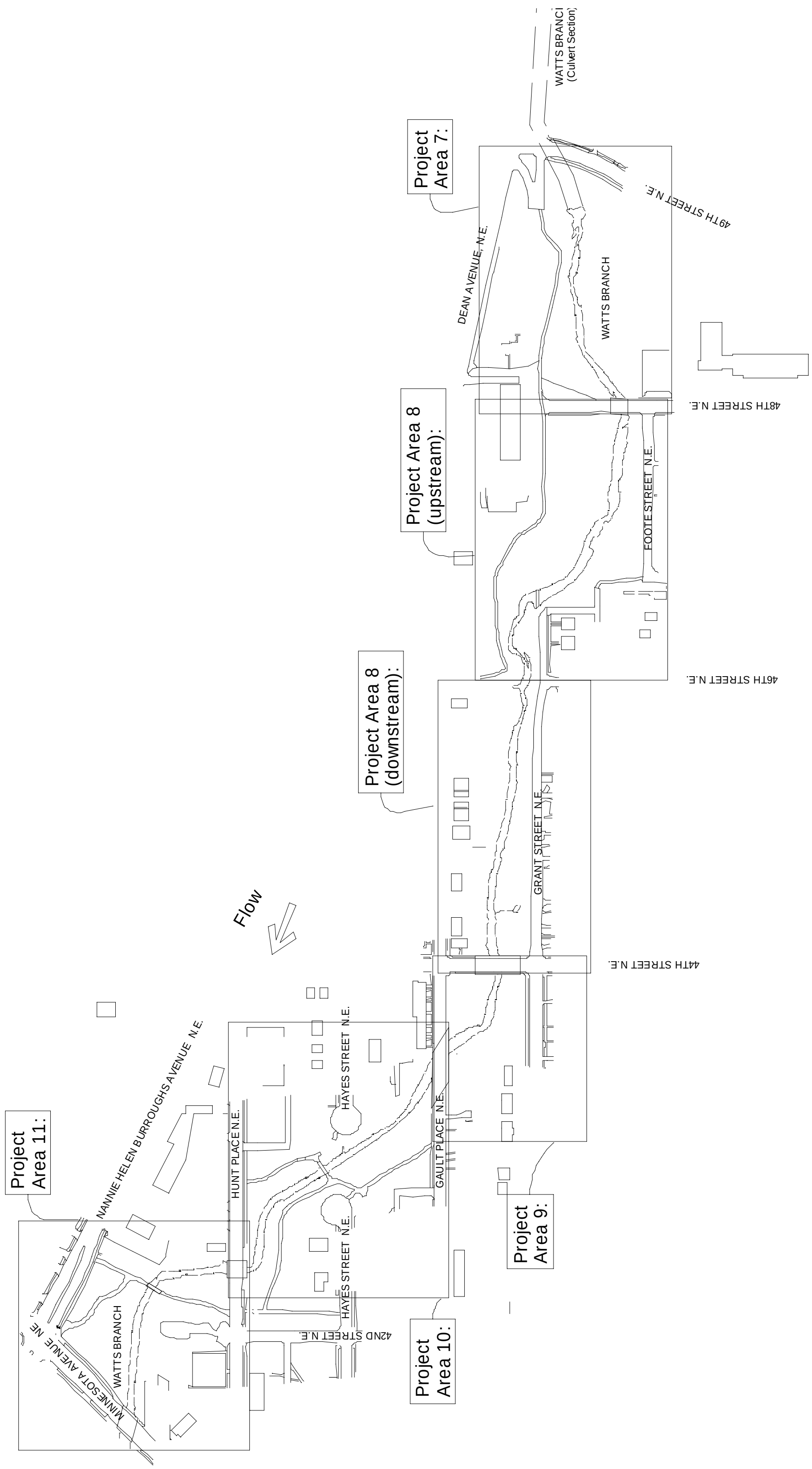


Figure 3: Project Areas 7 to 11

B. STREAM ASSESSMENT AND RESTORATION OBJECTIVES

Prior to undertaking natural channel design, it is important to access the condition and geomorphic characteristics of the impaired stream. The Service conducted detailed stream assessments of all of Watts Branch (Eng, 2002). The Service measured and assessed stream sinuosity, bankfull width, bankfull mean depth, floodprone width, stream substrate characteristics, stream slope, and discharge characteristics.

The Service found that Watts Branch and its tributaries have been significantly altered by channelization, urbanization, and floodplain loss. Portions of the stream have been straightened, relocated, or replaced by culverts. Within the District, all the tributaries to Watts Branch have been filled in, enclosed in pipes, or confined in concrete channels, with the exception of 500 linear feet of one tributary. The highly urbanized watershed results in flashy storm flows with low base flow between storm events. The remaining open stream reaches are severely entrenched, resulting in high bank stress and bank erosion.

The portions of the Watts Branch main stem located within the District are predominantly F4 stream types[3] with a few limited reaches of G4, B4c, and C4 stream types. Table A-1 reports morphological characteristics for each of the stream types. Most of Watts Branch is entrenched. As flow levels rise above bankfull depth, there is little increase in stream width. Shear stress increases with depth during major flow events increasing bank erosion potential. In streams with low entrenchment, shear stress decreases when flow overtops the floodplain at discharges greater than bankfull. Stormflow events in Watts Branch completely mobilize the bed of the stream creating extensive reaches of flat plane beds (*i.e.*, very few pools and wide shallow flow). Flow conditions between flow events consist of shallow flow extending across the plane stream bed that produces very poor aquatic habitat.

The Service recommended stream restoration to restore stream stability, to improve riparian and aquatic habitat, to improve water quality, and to reduce bank erosion. Specific objectives for stream restoration are presented in the 10 Percent Preliminary Concepts Report (Shea *et al.*, 2005). Among the objectives for stream restoration are specific goals for restoring the stream that include:

- reducing the high bank erosive forces and stream stresses associated with frequent stormflow events;
- increase the floodprone width of the stream to dissipate stormflow energies associated with stormflow events; and
- improve the depth and increase the number of pools to improve aquatic habitat.

C. NATURAL CHANNEL DESIGN FOR WATTS BRANCH

1. Restoration Stream Type

[3] Streams are classified in accordance with the Rosgen Stream Classification System (Rosgen, 1996).

In the 10 Percent Preliminary Concept Report, the Service recommended restoring Upper Watts Branch by converting the stream type from a F4 stream type to a combination of C4 and B4c stream types. An F4 stream type has an entrenchment ratio of less than 1.4. A C4 stream type has an entrenchment ratio greater than 2.2 ("slightly entrenched"); while a B4c stream type has an entrenchment ratio of between 1.4 and 2.2 ("moderately entrenched"). Conversion from an F4 stream type to either a C4 or B4c stream type would increase the floodprone width of the cross section and reduce high shear stresses experienced during channel forming flow events.

If feasible, conversion to a C4 stream type is preferable because stream entrenchment is reduced more than with a B4c stream type. Additionally, C4 stream types tend to dissipate energy more efficiently than B4c stream type. C4 stream types are more sinuous and dissipate energy through planform meandering. B4c streams dissipate energy through turbulence at vertical grade controls. If the stream is significantly entrenched, however, the amounts of disturbance and excavation required for a C4 stream type conversion may be excessive and result in the loss of significant vegetation.

As the design progressed from the 10 Percent Plans, it became apparent that it would not be feasible to employ a C4 stream type for the restoration of Watts Branch. It is not possible to implement the meandering and belt width required for a stable C4 stream type in Watts Branch without significant stream excavation and disturbance. Further, relocation of the stream in many areas of Watts Branch is constrained by the presence of buried and exposed sanitary sewers, road crossings, structures, and bike paths.

Because a C4 stream type was infeasible, the restoration design developed for the 30 Percent Design converts the existing F4 stream type to a B4c stream type. The B4c stream type possesses lower sinuosity and lower stream entrenchment than a C4 stream type, but provides much better habitat and stability than an F4 stream type. Energy is dissipated in B4c stream types through in-stream turbulence created by drops and pools, rather than by meanders. In natural occurring B4c streams, naturally forming structural controls such as bed rock outcrops, rock sills, or step pools dissipate energy. Natural channel design methods use in-stream structures such as cross-vanes and constructed step-pools to replicate this function in restored streams.

2. Reference Reach

Natural channel design methodology employs the characteristics of stable streams as a template for designing restored streams. Selection of a (Rosgen) stream type identifies the broad characteristics for the restored stream, but does not provide sufficient design parameters to develop stream restoration plans. Additional geomorphic measurements must be collected from stable streams that fully detail the characteristics of a stable stream's cross section, planform, and profile. A stream possessing stable characteristics is termed a "reference reach." The geomorphic characteristics of the reference reach are used as a template for designing stream restoration projects. The primary requirement of a reference reach is that the stream reach is stable. Reference reaches are not required to be in a natural, undisturbed state.

A suitable reference reach should possess similar hydrologic, geologic, and physiographic characteristics to the reach that is to be restored. The shape of a particular stream represents the balance between erosive forces applied to a stream by water flowing down a slope and the resistive forces supplied by native stream substrate and streambanks. Streams formed in differing types of alluvium or rock respond differently to the same hydrology. Likewise, streams of the same lithology and geology exhibit differing forms if subjected to differing hydrologic regimes. For example, compare two streams within the same area, one of which possesses an undeveloped watershed and the other possessing an urbanized watershed. Because urbanization changes the timing and volume of stormflows, the urbanized stream will enlarge. Because of differences in the response of streams to differences in boundary conditions (*i.e.*, stream flow, vegetation, geology, and lithology), it is important to select a reference reach with similar hydrophysiographic characteristics. Generally, this would be a stream located in the same general area with similar land use, physiography, valley characteristics, and lithology.

Finding reference reaches for urban stream restoration is difficult. It is rare to locate a stream that possesses both an urban discharge regime and stable stream characteristics. If a suitable reference reach can not be located, streams from remote locations may be used for reference reaches if there is close similarity in physiographic conditions (Hey, in press). The Service was unable to locate a reference reach (*i.e.,* a stable stream) in close vicinity to Watts Branch that is both stable and a suitable match to Watts Branch's hydrology and physiographic setting. Therefore, the Service collected data from B4c reference reaches with physiographic conditions similar to Watts Branch. Table A-2 presents selected morphological parameters for three areas. The reference sites include:

- *Silas Creek in Winston-Salem, NC*: Silas Creek is a B4c stream type. Reference Reach data was collected by Rocky Powell, Clear Creek Consulting, Inc. and provided to the Service.
- *Rock Creek above Boulder Bridge, Rock Creek National Park, Washington, DC*: A short section of B4c stream type is located in Rock Creek between a steeper B3/B4 stream type and a C4 stream type. The Service surveyed the reach in 2005. Because the reach was limited in size, the Service was not able to collect a full set of reference reach data. Although the Rock Creek data set is incomplete, it does reflect conditions within the District on a stream subject to urbanized flows.
- *Maryland Characteristic B4/1c Streams:* Characteristic data for several B4/1c[4] steam types was obtained from a comprehensive survey of streams in Maryland that the Service collected to develop regional relationships between bankfull discharge, bankfull width, bankfull mean depth, and drainage area (McCandless and Everett, 2002; McCandless, 2003). The Maryland stream survey data contains many of the relationships that are required to develop natural stream designs. The data was not necessarily collected from stable streams so it is not truly reference reach data. The data does, however, represent typical conditions found for this stream type in Maryland and is useful as a check.

[4] The B4/1c stream type is similar to the B4c stream type except that bedrock control is present.

3. Bankfull Discharge

Bankfull discharge is the maximum discharge that an unentrenched stream can convey before flow starts to exceed the channel capacity and flow onto a stream's floodplain. Bankfull discharge has been found to be an effective surrogate to characterize 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 (or channel-forming) discharge within the stream. Many important stream morphological features (*e.g.*, bankfull width, drainage area, etc.) are strongly correlated to bankfull discharge. Thus, bankfull discharge is used in natural channel design procedures as a scale factor to convert morphological parameters from a reference reach with a given drainage area to a disturbed reach with a different sized drainage area.

The opportunities to establish bankfull discharge through physical measurements of streamflow are often elusive, so the value of bankfull discharge is often estimated through indirect methods. The Service uses regional stream relationships between drainage area and bankfull discharge, such as developed by McCandless 2003, to develop broad estimates of bankfull discharge. Through assessments of streams in the District (Eng 2002, Brown *et al.*, 2003, Starr and McCandless, 2005), the Service has developed an understanding of the location and form of bankfull indicators in urban streams in the District. From field measurements in Watts Branch and other streams in the District, the Service developed estimates of bankfull discharge for Watts Branch. The Service was able to calibrate bankfull discharge estimates using 15-minute records of discharge recorded by the United States Geological Survey (USGS) Watts Branch stream gage[5], and through field measurements of discharge during several stormflow events.

An important feature of urban streams in the District is the presence of an inner channel within the bankfull channel. The limits of the inner channel appear to correspond to the area of active gravel transport during stormflow events. We refer to the inner channel as the "active channel". Field observations of discharge and sediment transport indicate that the depth of the active channel corresponds to the depth required to initiate transport of the gravels making up the channel bed. The Service considers maintenance of the active channel an important feature of the restoration design. The active channel features that are included in our designs create the shear required to initiate sediment transport at the water levels that fill the active channel. The Service estimated and calibrated active channel discharge using the same methods that were used to estimate and calibrate bankfull discharge.

The magnitude of bankfull and active channel discharge vary directly with drainage area. The magnitude of the Watts Branch drainage area varies across the project from 1.1 square miles (sq. mi.) at 61st Street N.E. to 3.3 sq. mi. at Minnesota Avenue N.E. Hence, the magnitude of bankfull discharge varies from 192 cubic feet per second (cfs) at 61st Street N.E. to 319 cfs at Minnesota Avenue N.E. Active channel discharge varies from 35 (cfs) at 61st Street N.E. to 66 cfs at Minnesota Avenue N.E.

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[5] USGS Gage 01651800, Watts Branch at Washington, D.C.:, LOCATION.--Lat 38°54'04.0", Long 76°56'31.9", District of Columbia, Hydrologic Unit 02070010, on right bank 5 ft downstream from footbridge, 200 ft upstream from Minnesota Ave., and 1.0 mi upstream from mouth.

To account for variance in drainage area, the bankfull and active channel discharges were estimated at six hydrologic computation points (see Figures 2 and 3):

- 61st Street N.E.
- At the mouth of the East Capitol Street Tributary.
- 58th Street N.E.
- At the entrance to the Culvert below Division St. N.E.
- 46th Street N.E.
- Minnesota Avenue N.E.

Bankfull geomorphic parameters were estimated using District relationships at each of the hydrologic computation points. Values of geomorphic parameters used to design each Project Area are listed in Table A-3.

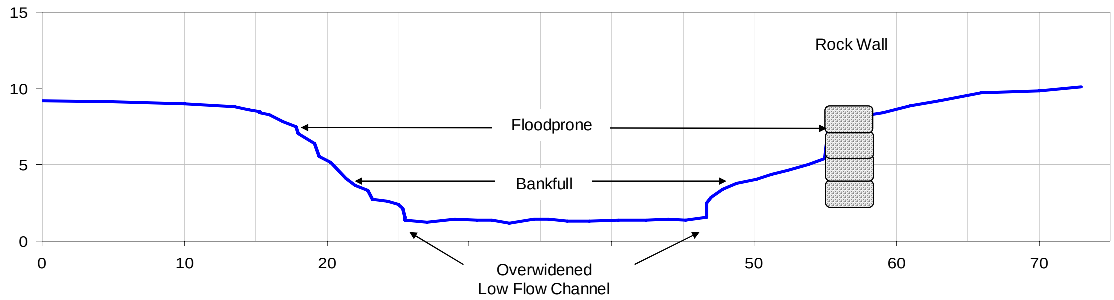
The bankfull discharge is used to scale morphological parameters from reference reaches to the restored reach. Table A-2 lists the morphological characteristics of the reference reaches and the values of morphological parameters developed for the restoration reaches.

4. Restoration Strategy

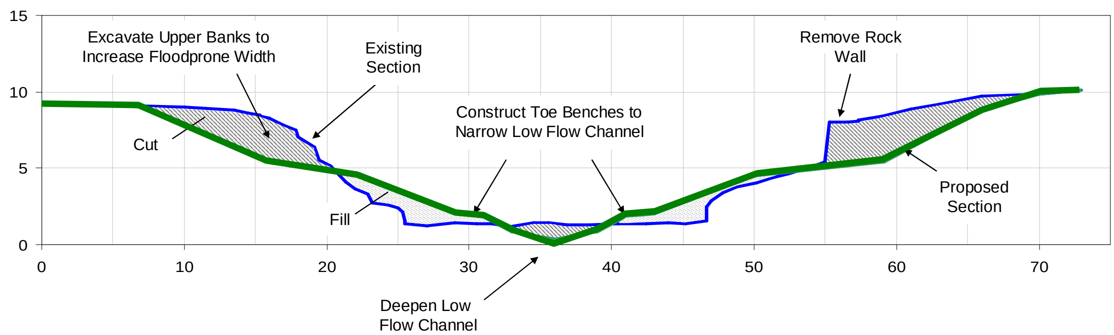
Conversion of the stream from an F4 to B4c stream type follows a Priority 3 restoration strategy for incised streams (Rosgen 1997). Changes to the stream grade are limited because flood conveyance at the numerous roadway bridges that cross Watts Branch must be maintained. Channel cross section conversion requires narrowing the low flow, active channel, and bankfull channel widths while providing an increase in floodprone width. This will be accomplished by excavating the top of existing stream banks and constructing toe benches to frame the active channel within the bankfull channel. Toe-benches will be constructed from fill and held in place by rock, woody debris, and riparian shrubs. Figure 4 (from Shea *et al*., 2005) illustrates the conversion.

In-stream structures and riparian plantings will be installed to stabilize the stream cross section. In-stream structures will consist of Cross-vanes (constructed using both rock and salvaged logs), and rock step-pools. The in-stream structures will be designed to steer the flow through tight bends, dissipate energy through turbulence, and prevent high shear stress on streambanks.

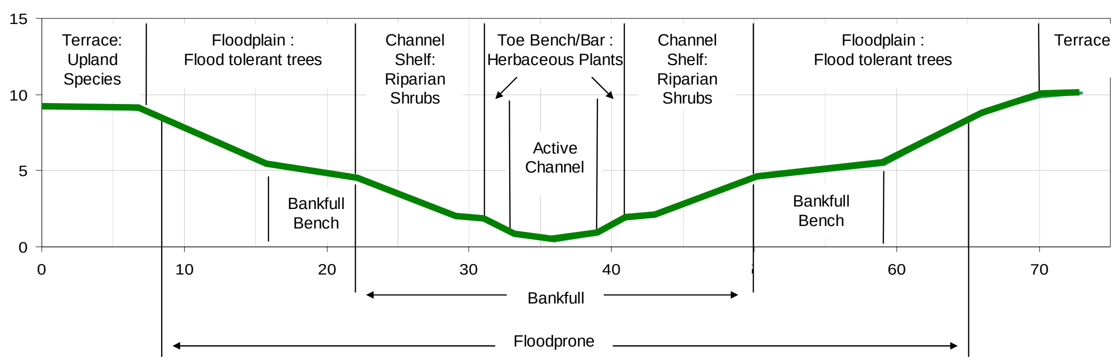
The in-stream structures provide a skeleton for the stream, but in the long-term, it is the riparian plantings that will maintain stream stability. Riparian plantings will provide rooting to increase the strength of streambanks, riparian habitat, and increase stream roughness that will slow down stream stormflow velocities. No planting occurs within the low flow or active channel. The active channel area is where stream gravel transport occurs. The toe-benches are located between the top of the active channel and bankfull depth. The top of the toe-benches (or channel shelf) is a frequently flooded area located below bankfull elevation. Riparian vegetation that can withstand frequent flooding and provide strong rooting will be planted in this zone. Large woody debris will be placed in the channel shelf during construction to provide some initial channel roughness and for habitat. The floodplain zone starts above bankfull. This area will contain



(a) Typical Existing Stream Cross Section (units in feet)



(b) Cross Section Adjustments



(c) Proposed Cross Section Features and Vegetation Zones

Figure 4: Cross Section Adjustments – F4 Stream to B4c Stream

trees that can withstand occasional inundation. The bankfull bench is a flat or shallowly sloped zone above bankfull that slows high velocity flows during flows above bankfull. Flow velocities at the outer edge of the bankfull bench will be too slow to erode the steeper banks connecting the bench to the flood-prone area.

5. Cross Section Design

The Service developed a series of typical sections for use in each project area (See Table A-3). Each series of typical sections consists of a riffle cross section, a glide cross section, and a pool cross section. The sections were developed through an iterative design process. The Service determined target values of bankfull and active channel width/depth ratios, and bankfull and active channel cross section area using regional relationships and the reference reach data. Trial bankfull and active channel depths were used to develop a nested riffle cross section with the appropriate areas and width-depth ratios for the bankfull and active channel. The Service estimated discharge for the cross section using the reach slope. The Service evaluated the shear stress at active channel discharge and made adjustments in the cross section to replicate the existing active channel shear stress. The Service made slight adjustments in the cross section dimensions until the computed discharge matched the target discharge.

Once the riffle cross section was completed, the pool cross sections were constructed in a similar manner. The Service used target values for pool cross sections based on ratios of pool cross section area to riffle cross section area, pool width to riffle width, and maximum pool depth to mean riffle depth. Ratios were used to develop active channel and bankfull channel dimensions.

The glide cross section was constructed to meet several criteria describing the relationship between riffle cross sections and glide cross sections:

- mean depth (riffle < glide)
- width (riffle < glide)
- cross section area (riffle < glide)
- max depth / mean depth ratio (riffle > glide)

The Service adjusted glide cross section shape until the evaluation criteria for the active and bankfull channels were satisfied.

Summaries of cross section parameters for each set of typical sections are presented in Appendix B. Project Area 5 (55th Street N.E. to Division Street N.E.) has two sets of typical sections because the vertical profile required two different slopes. Plots of typical cross sections are shown in the 30 Percent Plans.

D. DEVELOPMENT OF RESTORATION DESIGN PLANS

1. Base Mapping

The Service developed a base map of Watts Branch from surveys conducted by others and detailed stream channel surveys conducted by Service personnel.

- Property boundaries, planimetric features (roads, buildings, trees, etc.), benchmarks and survey control traverses were taken from mapping prepared for DPR.
- DDOT and its consultant provided mapping of the realigned bike path that will be constructed in the spring of 2006. DDOT provided utility mapping.
- WASA provided digital images of their counter maps, which show the alignments of storm and sanitary sewers. The Service found some discrepancies between DDOT's mapping, WASA counter maps, and field surveys. We expect to revisit the utility mapping with WASA to see if as-builts are available that might provide more accurate information.
- WPP provided preliminary plans on redevelopment of Lady-Bird Park (Project Area 11) and improvements to the area of Watts Branch Park in the vicinity of Division Street (Project Areas 5 and 6).
- The District Office of the Chief Technology Officer (OCTO) provided topographic data from the District Geographic Information System.
- The Service conducted a detailed survey of the stream channel in fall 2004 and winter 2004 – 2005. The Service's survey provided an accurate depiction of existing stream conditions that was not available from other sources.

Base mapping was converted to Terramodel® CADD format.

2. Planform, Profile, and Grading

The Service revisited the preliminary horizontal alignments prepared for the 10 Percent Plans. Adjustments were made in the alignments to produce better agreement with the geomorphic properties developed from reference reach data. Alignments were adjusted also in response to comments received on the 10 Percent Plans, to minimize impacts to fixed infrastructure such as foot-bridges and structures, and to reduce grading and vegetation impacts.

Preliminary vertical alignments were developed. The Service employed a spreadsheet to adjust the depths of the vertical profiles so that the depth of riffles, glides, pools, and runs were in the appropriate range developed from reference reach data. The vertical alignments were evaluated and adjusted for vertical conflicts with sanitary sewers. The Service prepared grading and proposed contours using Terramodel.

3. Structures

The Service proposes using two types of in-stream structures in the restoration design: cross-vanes and step-pools.

Cross-vanes are used to control features of both vertical and horizontal alignments. In surveys of low gradient, entrenched channels (*i.e.*, Bc stream types), the Service observed that the horizontal alignments are often controlled vertical grade controls such as rock or log weirs, sills, or bedrock and boulder outcrops. The B4c streams have low sinuosity except for sudden bends at the location of vertical grade controls. The direction of flow is turned and pools form at vertical grade controls. Cross-vanes were developed by

Rosgen (2001) to reduce shear stress along the outer banks of meander curves, but may be used also to steer and redirect the direction of flow through bends.

Cross-vanes consist of a sill used to set grade elevation that is placed in the central third of the bankfull stream; and two vanes that extend from each end of the sill in the downstream direction at an angle of 20-30 degrees from the centerline of the stream, with a vertical pitch of two to seven percent (upward in the downstream direction, and typically tie into the stream banks at the bankfull elevation. The vanes of cross-vanes provide bank protection by redirecting flow away from banks. The zone of bank protection created by the vanes extends for approximately one vane length downstream of the end of the vane and about one half vane lengths upstream of the sill. Vanes in Watts Branch will be oriented at 20-22 degree from the centerline to increase the zone of bank protection and to achieve a lower pitch in the vane angle.

The Service uses step-pools in several reaches to facilitate steep sections of stream that required sudden increases in vertical profile to raise the stream to pass over sanitary sewers. Step-pools are natural features that form on steeper streams as a means of dissipating energy.

There are several locations where sanitary sewers cross the stream alignment. In-stream structures were placed just downstream of sanitary sewer crossings. The channel invert elevations of the in-stream structures were set to at least one-half foot above the elevation of the top of the sanitary sewer crossings. The new streambed will cover exposed sanitary sewers. The in-stream structures will serve as grade controls and prevent future exposure.

The extent and configuration of step-pools and cross-vanes are shown as a schematic on the 30 Percent Plans. Structure tables and construction details will be added to the 65 percent plan set.

III. FUTURE WORK

The next step in the design process is to undertake hydraulic modeling of existing conditions and to prepare preliminary hydraulic modeling of proposed conditions. The 30 Percent Plans will be modified based on comments received from partners and other reviewers, and on results of hydraulic modeling. Grading plans and profiles will be evaluated for compliance with geomorphic design criteria, sediment transport capabilities, and floodplain hydraulics. Additional design work will include preparation of stormwater retrofit designs, preparation of erosion and sediment control plans, and preparation of construction specifications.

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APPENDIX A

GEOMORPHIC VARIABLES

Table A-1: Watts Branch Existing Conditions
Selected Morphological Characteristics

No.	Variable	Symbol	Units		Existing Conditions Watts Branch WB-02	WB-08 & WB-11	WB-09	WB-13
1	Stream type				G4	F4	B4c	C4
2	Drainage area		mi^2	Mean				
				Range				
3	Riffle Bankfull width	W_{bkf}	feet	Mean	24.80	30.55	34.30	35.96
				Range	23.70-25.90	28.90-32.20	34.30	35.70-36.22
4	Riffle Bankfull mean depth	d_{bkf}	feet	Mean	2.52	2.05	1.97	2.27
				Range	2.45-2.59	1.86-2.23	1.97	2.18-2.36
5	Width depth ratio	W/d		Mean	9.86	15.14	17.41	15.86
				Range	9.15-10.57	12.96-17.31	17.41	15.35-16.38
6	Riffle Bankfull cross sectional area	A_{bkf}	ft_2	Mean	62.48	62.14	67.52	81.69
				Range	61.46-63.50	59.95-64.32	67.52	77.87-85.50
7	Bankfull mean velocity	V_{bkf}	ft/sec	Mean	4.42	4.64	4.97	3.46
				Range	5.75	5.85	5.71	4.42
8	Bankfull discharge	Q_{bkf}	cfs	Mean	276.16	288.31	335.57	282.65
				Range	347.39	363.49	385.54	361.07
9	Riffle Bankfull maximum depth	d_{max}	feet	Mean	3.32	2.98	3.31	2.90
				Range	3.08-3.55	2.90-3.06	3.31	2.87-2.92
10	Max Riffle depth/ Mean riffle depth	d_{riff}/d_{bkf}		Mean	1.31	1.48	1.68	1.28
				Range	1.26-1.37	1.30-1.65	1.68	1.22-1.34
11	Low bank height to max d_{bkf} ratio			Mean	1.96	1.23	1.19	1.00
				Range	1.82-2.18	1.00-1.45	1.19	1.00
12	Width of flood prone area	W_{fpa}	feet	Mean	33.50	38.00	58.00	85.00
				Range	32.00-35.00	37.00-39.00	58.00	80.00-90.00
13	Entrenchment Ratio	W_{fpa}/W_{bkf}		Mean	1.36	1.25	1.69	2.36
				Range	1.24-1.48	1.21-1.28	1.69	2.24-2.48
14	Meander Length	L_m	feet	Mean	n/a	n/a	267	n/a
				Range	n/a	n/a	235-300	n/a
15	Ratio of meander length to bankfull width	L_m/W_{bkf}		Mean	n/a	n/a	7.78	n/a
				Range	n/a	n/a	6.85-8.75	n/a
16	Radius of curvature	R_c		Mean	n/a	n/a	44.60	n/a
				Range	n/a	n/a	24.00-55.00	n/a
17	Ratio: Radius of curvature to bankfull width	R_c/W_{bkf}		Mean	n/a	n/a	1.30	n/a
				Range	n/a	n/a	0.70-1.60	n/a
18	Belt Width	W_{blt}	feet	Mean	n/a	n/a	102	n/a
				Range	n/a	n/a	40-164	n/a
19	Meander width ratio	W_{blt}/W_{bkf}		Mean	n/a	n/a	2.97	n/a
				Range	n/a	n/a	1.17-4.78	n/a
20	Sinuosity	K		Mean	1.02	1.06	1.21	1.02
				Range	1.02	1.04-1.08	1.21	1.02
21	Valley Slope	S_{val}	ft/ft		n/a	n/a	n/a	n/a
22	Average Water Surface Slope	S_{avg}	ft/ft	Mean	0.0034	0.0040	0.0054	0.0022
				Range	0.0034	0.0039-0.0041	0.0047-0.0061	0.0022
23	Pool Water Surface Slope	S_{pool}	ft/ft	Mean	0.0002	0.0002	0.0006	0.0004
				Range	0.0000-0.0006	0.0001-0.0003	0.0003-0.0009	0.0001-0.0007
24	Pool WS slope / Average WS slope	S_{pool}/S_{avg}		Mean	0.1	0.1	0.1	0.2
				Range	0.0000-0.1765	0.0250-0.0750	0.0556-0.1667	0.0454-0.3182
25	Riffle Water Surface slope	Sriff	ft/ft	Mean	0.0162	0.0148	0.0121	0.0099
				Range	0.0048-0.0270	0.0074-0.0247	0.0086-0.0245	0.0064-0.0172

Table A-1: Watts Branch Existing Conditions
Selected Morphological Characteristics

No.	Variable	Symbol	Units		Existing Conditions Watts Branch			
					WB-02	WB-08 & WB-11	WB-09	WB-13
26	Riffle WS slope / Average WS slope	$S_{rifF/}S_{avg}$		Mean	4.8	3.7	2.2	4.5
				Range	1.4-7.9	1.9-6.2	1.59-4.54	2.91-7.82
27	Run WS Slope	S_{run}/S_{avg}	ft/ft	Mean	0.0000	0.0015	0.0073	0.0006
				Range	0.0000	0.0001-0.0029	0.0006-0.0139	0.0001-0.0015
28	Run WS slope / Average WS slope	$S_{run/}S_{avg}$	ft/ft	Mean	0.0	0.4	1.3	0.3
				Range	0.0	0.0250-0.7250	0.1111-2.574	0.0454-0.6818
29	Glide WS Slope	S_{glide}		Mean	0.0000	0.0002	0.0007	0.0007
				Range	0.0000	0.000-0.0003	0.0004-0.0011	0.0005-0.0009
30	Glide WS slope / Average WS slope	$S_{glide/}S_{avg}$	ft/ft	Mean	0.0	0.0	0.1300	0.3000
				Range	0.0	0.000-0.0750	0.07-0.20	0.2273-0.4091
31	Maximum pool depth	d_{pool}	feet	Mean	4.79	4.68	4.24	4.19
				Range	3.52-6.42	3.83-5.52	2.70-5.93	3.54-5.31
32	Ratio of max pool depth to average bankfull depth	d_{pool}/d_{bkf}		Mean	1.90	2.29	2.15	1.85
				Range	1.39-2.55	1.87-2.69	1.37-3.01	1.559-2.339
33	Max Run Depth	d_{run}	feet	Mean	3.40	3.24	2.57	3.35
				Range	3.24-3.50	3.19-3.29	2.31-2.82	3.27-3.41
34	Ratio of max run depth to average bankfull depth	d_{run}/d_{bkf}		Mean	1.35	1.58	1.30	1.47
				Range	1.29-1.39	1.56-1.60	1.17-1.43	1.441-1.502
35	Max Glide Depth	d_{glide}	feet	Mean	3.36	3.43	2.30	3.17
				Range	3.19-3.52	3.13-3.73	2.14-2.51	3.03-3.38
36	Ratio of max glide depth to average bankfull depth	d_{glide}/d_{bkf}	feet	Mean	1.33	1.68	1.17	1.40
				Range	1.27-1.40	1.53-1.82	1.09-1.27	1.335-1.489
37	Pool width	W_{pool}	feet	Mean	n/a	23.91	n/a	32.90
				Range	n/a	23.91	n/a	32.90
38	Ratio of pool width to bankfull width	W_{pool}/W_{bkf}		Mean	n/a	0.74	n/a	0.91
				Range	n/a	0.74	n/a	0.91
39	Ratio of pool area to bankfull area	A_{pool}/A_{bkf}		Mean	n/a	0.94	n/a	1.08
				Range	n/a	0.94	n/a	1.08
40	Point bar slope	S_{pb}		Mean	n/a	n/a	n/a	n/a
				Range	n/a	n/a	n/a	n/a
41	Pool to pool spacing	p-p	feet	Mean	183	182	127	188
				Range	108-310	182	127	70-393
42	Ratio of pool to pool spacing to bankfull width	$p\text{-}p/W_{bkf}$		Mean	7	6	4	5
				Range	4-13	6	4	2-11
Materials								
Particle Size Distribution Channel		D_{16}	mm		2.72	n/a	n/a	n/a
		D_{35}	mm		6.00	n/a	n/a	n/a
		D_{50}	mm		11.09	n/a	n/a	n/a
		D_{84}	mm		36.95	n/a	n/a	n/a
		D_{95}	mm		44.23	n/a	n/a	n/a
Particle Size Distribution Bar		D_{16}	mm		n/a	n/a	2.12	2.85
		D_{35}	mm		n/a	n/a	4.08	5.02
		D_{50}	mm		n/a	n/a	5.13	6.30
		D_{84}	mm		n/a	n/a	7.61	9.16
		D_{95}	mm		n/a	n/a	11.58	11.11
Largest Particle Size			mm				110.00	88.00

Table A-2: Watts Branch: Reference Reach and Proposed Selected Morphological Characteristics

No.	Variable	Symbol	Units		Maryland Characteristic B4/1c Streams	North Carolina Silas Creek, Winston	Rock Creek Washington, DC	Typical Section 1 B4c	Typical Section 2 B4c	Typical Section 3 B4c	Typical Section 4 B4c	Typical Section 5 B4c
								Project Areas	Project Areas	Project Areas	Project Areas	Project Areas
								1	3	4, 5, & 6	7, 8, & 9	10 & 11
1	Stream type				B4/1c	B4/1c		B4/1c	B4/1c	B4/1c	B4/1c	B4/1c
2	Drainage area		mi^2	Mean	102	3.3		1.1	2.1	2.7	3.1	3.3
				Range	102	3.3						
3	Riffle Bankfull width	W_{bkf}	feet	Mean	117.43	25.55	78.18	29.4	32.8	34.1	35.0	35.9
				Range	115.88-119.15	23.10-28.00	62.5 - 89.5					
4	Riffle Bankfull mean depth	d_{bkf}	feet	Mean	5.00	1.75	3.95	1.68	1.84	1.91	2.01	2.04
				Range	4.78-5.32	1.63-1.86	3.45 - 4.57					
5	Width depth ratio	W/d		Mean	23.49	14.60	20.3	17.47	17.83	17.85	17.41	17.60
				Range	23.49	12.42-17.18	13.7 - 23.9					
6	Riffle Bankfull cross sectional area	A_{bkf}	ft_2	Mean	587.04	43.70	305	49.3	60.2	65.2	70.3	73.3
				Range	553.37-633.43	38.50-48.90	285 - 343					
7	Bankfull mean velocity	V_{bkf}	ft/sec	Mean	4.64	4.60	5.85	4.07	4.30	4.46	4.41	4.35
				Range	4.64		4.94 - 6.83					
8	Bankfull discharge	Q_{bkf}	cfs	Mean	2,726.00	199.00	1,760	201	259	291	310	319
				Range	2,726.00		1640 - 1950					
9	Riffle Bankfull maximum depth	d_{max}	feet	Mean	7.23	2.67	5.60	2.69	3.04	3.20	3.40	3.48
				Range	6.79-7.97	2.10-3.23	4.82 - 6.40					
10	Max Riffle depth/ Mean riffle depth	d_{riff}/d_{bkf}		Mean	1.45	1.53	1.42	1.60	1.65	1.68	1.69	1.71
				Range	1.36-1.59	1.29-1.74	1.40 - 1.46					
11	Low bank height to max d_{bkf} ratio			Mean	1.00	1.00		1.00	1.00	1.00	1.00	1.00
				Range	1.00	1.00						
12	Width of flood prone area	W_{fpa}	feet	Mean	219.67	33.45	129	52.60	56.40	59.70	61.80	63.20
				Range	188-268	27.70-39.20	105 - 158					
13	Entrenchment Ratio	W_{fpa}/W_{bkf}		Mean	1.87	1.31	1.66	1.79	1.72	1.75	1.77	1.76
				Range	1.87	1.20-1.40	1.39 - 1.82					
14	Meander Length	L_m	feet	Mean	n/a	187.00		n/a	n/a	n/a	n/a	n/a
				Range	n/a	130-245						
15	Ratio of meander length to bankfull width	L_m/W_{bkf}		Mean	n/a	7.32		n/a	n/a	n/a	n/a	n/a
				Range	n/a	5.63-8.75						
16	Radius of curvature	R_c		Mean	n/a	38.64		n/a	n/a	n/a	n/a	n/a
				Range	n/a	18.48-58.80						
17	Ratio: Radius of curvature to bankfull width	R_c/W_{bkf}		Mean	n/a	1.51		n/a	n/a	n/a	n/a	n/a
				Range	n/a	0.80 - 2.10						
18	Belt Width	W_{blt}	feet	Mean	157.00	45.50		n/a	n/a	n/a	n/a	n/a
				Range	157.00	40.0-51.0						
19	Meander width ratio	W_{blt}/W_{bkf}		Mean	1.34	1.78		n/a	n/a	n/a	n/a	n/a
				Range	1.34	1.43-1.82						
20	Sinuosity	K		Mean	1.93	1.07		1.07	1.10	1.05	1.08	1.13
				Range	1.93					1.02 - 1.08	1.05 - 1.13	1.09 - 1.16
21	Valley Slope	S_{val}	ft/ft		n/a	0.0089		0.0068	0.0057	0.0059	0.0039	0.0057
22	Average Water Surface Slope	S_{avg}	ft/ft	Mean	0.0023	0.0082		0.0073	0.0063	0.0062	0.0042	0.0064
				Range	0.0023			--	--	0.0043 - 0.0074	0.0034 - 0.0069	0.0055 - 0.0077
23	Pool Water Surface Slope	S_{pool}	ft/ft	Mean	0.0000	-0.0410		0.0015	0.0015	0.0015	0.0012	0.0015
				Range	0.0000	(-0.1638) - .0819						
24	Pool WS slope / Average WS slope	S_{pool}/S_{avg}		Mean	0.0000	-5.0000		0.21	0.24	0.24	0.29	0.23
				Range	0.0000	(-20) - 10						
25	Riffle Water Surface slope	Sriff	ft/ft	Mean	0.0051	0.0360		0.0110	0.0095	0.0093	0.0063	0.0096
				Range	0.00398-0.00570					0.0065 - 0.0111	0.0051 - 0.0104	0.0083 - 0.0116

Table A-2: Watts Branch: Reference Reach and Proposed
Selected Morphological Characteristics

No.	Variable	Symbol	Units		Maryland Characteristic B4/1c Streams	North Carolina Silas Creek, Winston	Rock Creek Washington, DC	Typical Section 1 B4c	Typical Section 2 B4c	Typical Section 3 B4c	Typical Section 4 B4c	Typical Section 5 B4c
								Project Areas 1	Project Areas 3	Project Areas 4, 5, & 6	Project Areas 7, 8, & 9	Project Areas 10 & 11
26	Riffle WS slope / Average WS slope	S_{riff}/S_{avg}		Mean	2.19	4.39		1.50	1.50	1.50	1.50	1.50
				Range	1.73-2.48							
27	Run WS Slope	S_{run}/S_{avg}	ft/ft	Mean	0.0009			0.0183	0.0158	0.0155	0.0105	0.0160
				Range	0.0003-0.00134					0.0108 - 0.0185	0.0085 - 0.0173	0.0138 - 0.0193
28	Run WS slope / Average WS slope	S_{run}/S_{avg}	ft/ft	Mean	0.3966			2.50	2.50	2.50	2.50	2.50
				Range	0.1304-0.5826							
29	Glide WS Slope	S_{glide}		Mean	0.0000	0.0070		0.0045	0.0045	0.0045	0.0030	0.0045
				Range	0.0000							
30	Glide WS slope / Average WS slope	S_{glide}/S_{avg}	ft/ft	Mean	0.0000	0.8537		0.6164	0.7143	0.7258	0.7143	0.7031
				Range	0.0000							
31	Maximum pool depth	d_{pool}	feet	Mean	7.60	4.50		4.30	4.60	4.90	5.00	5.10
				Range	7.48-7.72	4.00 - 5.00						
32	Ratio of max pool depth to average bankfull depth	d_{pool}/d_{bkf}		Mean	1.52	2.57		2.56	2.50	2.57	2.49	2.50
				Range	1.50-1.54	2.45 - 2.69						
33	Max Run Depth	d_{run}	feet	Mean	7.50	3.30		3.25	3.50	3.70	3.85	3.90
				Range	7.38-7.61							
34	Ratio of max run depth to average bankfull depth	d_{run}/d_{bkf}		Mean	1.50	1.89		1.93	1.90	1.94	1.92	1.91
				Range	1.48-1.52							
35	Max Glide Depth	d_{glide}	feet	Mean	6.57	3.25		3.10	3.40	3.60	3.70	3.75
				Range	6.20-6.93							
36	Ratio of max glide depth to average bankfull depth	d_{glide}/d_{bkf}	feet	Mean	1.31	1.86		1.85	1.85	1.88	1.84	1.84
				Range	1.24-1.39							
37	Pool width	W_{pool}	feet	Mean	120.87	25.30		33.80	38.00	40.00	40.30	40.90
				Range	120.87	22.60 - 28.00						
38	Ratio of pool width to bankfull width	W_{pool}/W_{bkf}		Mean	1.03	0.99		1.15	1.16	1.17	1.15	1.14
				Range	1.03	0.98- 1.00						
39	Ratio of pool area to bankfull area	A_{pool}/A_{bkf}		Mean	1.06	1.65		1.39	1.43	1.46	1.38	1.36
				Range	1.06	1.22 - 2.07						
40	Point bar slope	S_{pb}		Mean	n/a			n/a	n/a	n/a	n/a	n/a
				Range	n/a							
41	Pool to pool spacing	p-p	feet	Mean	626.00	76.60		125.9	112.5	132.8	129.7	122.0
				Range	591-661	27.20 -126		88.7- 167.9	86.9 - 140.0	83.4 - 169.6	96.7 - 170.4	90.0 - 134.4
42	Ratio of pool to pool spacing to bankfull width	$p\text{-}p/W_{bkf}$		Mean	5.33	3.00		4.29	3.43	3.89	3.71	3.40
				Range	5.03-5.63	1.18 -4.50		3.0 - 5.7	2.6 - 4.3	2.4 - 5.0	2.8 - 4.9	2.5 - 3.7
Materials												
	Particle Size Distribution Channel	D_{16}	mm			0.29		2.72				
		D_{35}	mm			0.90		6.00				
		D_{50}	mm			22.60		11.09				
		D_{84}	mm			200.00		36.95				
		D_{95}	mm			>2048		44.23				
	Particle Size Distribution Bar	D_{16}	mm			1.80		n/a				
		D_{35}	mm			15.00		n/a				
		D_{50}	mm			32.00		n/a				
		D_{84}	mm			96.00		n/a				
		D_{95}	mm			117.00		n/a				

Table A-3: Project Area Channel Relationships and Design Data

Project Area							Hydrologic Computation Point		Bankfull				Active Channel			
#	Location	Drainage Area (mi^2)	Length (ft)	Average Bed Slope	Sinuosity	Typical Section	Location	Drainage Area (mi^2)	Discharge (cfs)	XSEC Area (ft^2)	Width (ft)	Mean Velocity (ft/sec)	Discharge (cfs)	XSEC Area (ft^2)	Width (ft)	Mean Velocity (ft/sec)
1	Southern Avenue to 61st Street N.E.	1.1	574	0.0075	1.07	1	At 61th Street, N.E.	1.1	191.7	53.2	21.3	3.60	35.1	13.8	14.6	2.54
2	East Capitol Tributary to Mainstem	0.8	--	--	--	--	At Confluence with Mainstem	0.8	165.4	49.2	19.1	3.36	29.2	11.3	12.7	2.59
3	61st Street N.E. to 58th Street N.E.	2.2	1361	0.0065	1.10	2	At 58th Street, N.E.	2.2	264.4	63.2	27.0	4.19	52.2	21.5	19.9	2.43
4	58th Street N.E. to 55th Street N.E.	2.6	1370	0.0059	1.06	3										
5	55th Street N.E. to Division Street N.E.	2.7	1364	0.0073	1.02	3, 6	At Culvert Entrance	2.7	285.8	65.8	28.6	4.34	57.4	23.9	21.5	2.41
6	Division Avenue N.E. to Culvert Entrance	2.7	705	0.0045	1.08	3										
7	49th Street N.E. (Culvert Exit) to 48th Place N.E.	2.9	509	0.0052	1.13	4										
8	48th Place N.E. to 44th Street N.E.	3.0	1535	0.0035	1.07	4	At 46th Street, N.E.	3.0	305.4	68.2	30.0	4.48	62.3	26.1	22.9	2.39
9	44th Street N.E. to Gault Place N.E.	3.1	231	0.0078	1.05	4										
10	Gault Place N.E. to Hunt Place N.E.	3.2	725	0.0053	1.09	5	At Minnesota Avenue, N.E.	3.3	319.2	69.8	31.0	4.57	65.8	27.8	23.9	2.37
11	Hunt Place N.E. to Minnesota Avenue	3.3	518	0.0077	1.16	5										

APPENDIX B

TYPICAL CROSS SECTION SUMMARIES

Typical Cross Section Set 1 for Project Area 1

			Riffle		Pool		Glide	
Symbol	Quantity	Units	Active	Bankfull	Active	Bankfull	Active	Bankfull
Z_0	Thalweg Elevation		9.60	9.60	8.10	8.10	9.30	9.30
Q_{bf}	Bankfull Discharge (computed)	ft^3/sec	35	205				
A_{bf}	Bankfull Area	ft^2	12.2	49.3	25.2	68.7	18.5	59.1
d_{bf}	Mean Bankfull Depth	ft	0.81	1.68	1.53	2.03	1.13	1.86
W_{bf}	Bankfull Width	ft	15.0	29.4	16.4	33.8	16.4	31.8
W_{bf}/d_{bf}	Width/Depth ratio		18.4	17.5	10.7	16.6	14.6	17.1
W_{fp}/W_{bf}	Entrenchment Ratio		1.88	1.79	2.99	1.98	2.43	1.82
d_{max}	Maximum Depth	ft	1.30	2.80	2.80	4.30	1.60	3.10
n_{bf}	Bankfull Composite "n"		0.036	0.041	0.040	0.043	0.036	0.040
R_{bf}	Bankfull Hydraulic Radius	ft	0.80	1.64	1.45	1.95	1.09	1.80
V_{bf}	Average Bankfull Velocity	ft/sec	2.87	4.16	2.81	2.98	3.53	4.39
τ_o	Bankfull Shear Stress	lbs/ft^2	0.32	0.68	0.32	0.37	0.44	0.73
Fr_{bf}	Froude (Bankfull)		0.56	0.57	0.40	0.37	0.59	0.57
D_{crit}	Critical Sediment Size at Bankfull	mm	32	67	31	36	44	72
P_{bf}	Bankfull Wetted Perimeter	ft	15.3	30.1	17.4	35.2	16.9	32.8
Z_{fp}	Floodprone Elevation	ft	12.20	15.20	13.70	16.70	12.50	15.50
Q_{fp}	Floodprone Discharge (computed)	ft^3/sec	170	1069	474	1482	242	1357
A_{fp}	Floodprone Area	ft^2	43.5	172.7	127.0	301.0	62.7	209.1
d_{fp}	Mean Floodprone Depth	ft	2.60	5.60	5.60	8.60	3.20	6.20
W_{fp}	Floodprone Width	ft	28.2	52.6	49.0	67.0	39.8	57.8
n_{fp}	Floodprone Composite "n"		0.040	0.043	0.043	0.044	0.041	0.043
R_{fp}	Floodprone Hydraulic Radius	ft	1.51	3.19	2.50	4.31	1.54	3.50
V_{fp}	Average Floodprone Velocity	ft/sec	3.90	6.19	3.74	4.93	3.86	6.49
τ_o	Floodprone Shear Stress	lbs/ft^2	0.61	1.33	0.55	0.81	0.62	1.42
D_{crit}	Critical Sediment Size at Floodprone	mm	60	131	54	80	62	140
P_{fp}	Floodprone Wetted Perimeter	ft	28.9	54.2	50.8	69.8	40.8	59.7

Typical Cross Section Set 2 for Project Area 3

Symbol	Quantity	Units	Riffle		Pool		Glide	
			Active	Bankfull	Active	Bankfull	Active	Bankfull
Z_0	Thalweg Elevation		9.36	9.36	7.80	7.80	9.00	9.00
Q_{bf}	Bankfull Discharge (computed)	ft^3/sec	53	257	113	283	106	348
A_{bf}	Bankfull Area	ft^2	17.1	59.3	36.8	86.6	26.7	73.9
d_{bf}	Mean Bankfull Depth	ft	0.91	1.81	1.72	2.28	1.34	2.04
W_{bf}	Bankfull Width	ft	18.8	32.8	21.4	38.0	20.0	36.2
W_{bf}/d_{bf}	Width/Depth ratio		20.7	18.1	12.5	16.7	15.0	17.7
W_{fp}/W_{bf}	Entrenchment Ratio		1.87	1.72	2.48	1.87	2.20	1.71
d_{max}	Maximum Depth	ft	1.54	3.04	3.10	4.60	1.90	3.40
n_{bf}	Bankfull Composite "n"		0.036	0.040	0.040	0.042	0.036	0.040
R_{bf}	Bankfull Hydraulic Radius	ft	0.89	1.77	1.65	2.20	1.30	1.99
V_{bf}	Average Bankfull Velocity	ft/sec	3.09	4.34	3.06	3.26	3.96	4.71
τ_o	Bankfull Shear Stress	lbs/ft^2	0.36	0.71	0.36	0.41	0.53	0.81
Fr_{bf}	Froude (Bankfull)		0.57	0.57	0.41	0.38	0.60	0.58
D_{crit}	Critical Sediment Size at Bankfull	mm	36	70	35	41	52	79
P_{bf}	Bankfull Wetted Perimeter	ft	19.1	33.5	22.3	39.4	20.6	37.2
Z_{fp}	Floodprone Elevation	ft	12.44	15.44	14.00	17.00	12.80	15.80
Q_{fp}	Floodprone Discharge (computed)	ft^3/sec	255	1316	692	1842	422	1755
A_{fp}	Floodprone Area	ft^2	60.6	202.9	163.5	349.5	90.8	249.8
d_{fp}	Mean Floodprone Depth	ft	3.08	6.08	6.20	9.20	3.80	6.80
W_{fp}	Floodprone Width	ft	35.2	56.4	53.0	71.0	44.0	62.0
n_{fp}	Floodprone Composite "n"		0.040	0.042	0.043	0.044	0.041	0.042
R_{fp}	Floodprone Hydraulic Radius	ft	1.69	3.49	2.98	4.73	2.01	3.90
V_{fp}	Average Floodprone Velocity	ft/sec	4.21	6.49	4.23	5.27	4.65	7.03
τ_o	Floodprone Shear Stress	lbs/ft^2	0.68	1.39	0.65	0.89	0.82	1.58
D_{crit}	Critical Sediment Size at Floodprone	mm	68	138	64	87	80	156
P_{fp}	Floodprone Wetted Perimeter	ft	35.9	58.1	54.9	73.8	45.1	64.1

Typical Cross Sections Set 3 for Project Areas 4, 5 (below foot bridge), and 6

			Riffle		Pool		Glide	
Symbol	Quantity	Units	Active	Bankfull	Active	Bankfull	Active	Bankfull
Z_0	Thalweg Elevation		9.20	9.20	7.50	7.50	8.80	8.80
Q_{bf}	Bankfull Discharge (computed)	ft^3/sec	63	280	129	320	127	402
A_{bf}	Bankfull Area	ft^2	19.6	65.0	40.8	95.2	30.7	82.1
d_{bf}	Mean Bankfull Depth	ft	0.97	1.91	1.80	2.38	1.43	2.16
W_{bf}	Bankfull Width	ft	20.1	34.1	22.7	40.0	21.5	38.1
W_{bf}/d_{bf}	Width/Depth ratio		20.7	17.9	12.6	16.8	15.1	17.7
W_{fp}/W_{bf}	Entrenchment Ratio		2.04	1.75	2.52	1.90	2.16	1.71
d_{max}	Maximum Depth	ft	1.65	3.20	3.35	4.90	2.05	3.60
n_{bf}	Bankfull Composite "n"		0.036	0.040	0.040	0.042	0.036	0.040
R_{bf}	Bankfull Hydraulic Radius	ft	0.96	1.86	1.72	2.30	1.39	2.10
V_{bf}	Average Bankfull Velocity	ft/sec	3.23	4.30	3.16	3.36	4.14	4.90
τ_o	Bankfull Shear Stress	lbs/ft^2	0.39	0.67	0.38	0.43	0.56	0.85
Fr_{bf}	Froude (Bankfull)		0.58	0.55	0.42	0.38	0.61	0.59
D_{crit}	Critical Sediment Size at Bankfull	mm	38	67	37	42	55	84
P_{bf}	Bankfull Wetted Perimeter	ft	20.4	34.9	23.7	41.5	22.1	39.2
Z_{fp}	Floodprone Elevation	ft	12.50	15.60	14.20	17.30	12.90	16.00
Q_{fp}	Floodprone Discharge (computed)	ft^3/sec	282	1436	830	2156	514	2026
A_{fp}	Floodprone Area	ft^2	68.8	225.0	188.1	394.3	104.4	277.3
d_{fp}	Mean Floodprone Depth	ft	3.30	6.40	6.70	9.80	4.10	7.20
W_{fp}	Floodprone Width	ft	41.1	59.7	57.2	75.8	46.5	65.1
n_{fp}	Floodprone Composite "n"		0.041	0.042	0.043	0.044	0.041	0.042
R_{fp}	Floodprone Hydraulic Radius	ft	1.64	3.66	3.18	5.00	2.19	4.12
V_{fp}	Average Floodprone Velocity	ft/sec	4.09	6.38	4.41	5.47	4.93	7.30
τ_o	Floodprone Shear Stress	lbs/ft^2	0.67	1.32	0.69	0.94	0.89	1.67
D_{crit}	Critical Sediment Size at Floodprone	mm	66	131	68	92	88	165
P_{fp}	Floodprone Wetted Perimeter	ft	41.9	61.5	59.2	78.8	47.7	67.3

Typical Cross Section Set 4 for Project Areas 7, 8, and 9

			Riffle		Pool		Glide	
Symbol	Quantity	Units	Active	Bankfull	Active	Bankfull	Active	Bankfull
Z_0	Thalweg Elevation		9.00	9.00	7.40	7.40	8.73	8.73
Q_{bf}	Bankfull Discharge (computed)	ft^3/sec	69	307	126	337	119	416
A_{bf}	Bankfull Area	ft^2	20.9	70.3	40.5	98.5	29.4	84.0
d_{bf}	Mean Bankfull Depth	ft	1.01	2.01	1.76	2.44	1.38	2.19
W_{bf}	Bankfull Width	ft	20.6	35.0	23.0	40.3	21.2	38.3
W_{bf}/d_{bf}	Width/Depth ratio		20.3	17.4	13.1	16.5	15.3	17.5
W_{fp}/W_{bf}	Entrenchment Ratio		2.04	1.77	2.47	1.90	2.17	1.72
d_{max}	Maximum Depth	ft	1.75	3.40	3.35	5.00	2.02	3.67
n_{bf}	Bankfull Composite "n"		0.036	0.038	0.040	0.042	0.036	0.040
R_{bf}	Bankfull Hydraulic Radius	ft	1.00	1.96	1.69	2.36	1.35	2.13
V_{bf}	Average Bankfull Velocity	ft/sec	3.32	4.37	3.12	3.42	4.06	4.95
τ_o	Bankfull Shear Stress	lbs/ft^2	0.40	0.61	0.37	0.44	0.55	0.87
Fr_{bf}	Froude (Bankfull)		0.58	0.54	0.41	0.39	0.61	0.59
D_{crit}	Critical Sediment Size at Bankfull	mm	40	60	36	44	54	85
P_{bf}	Bankfull Wetted Perimeter	ft	20.9	35.8	24.0	41.8	21.8	39.4
Z_{fp}	Floodprone Elevation	ft	12.50	15.80	14.10	17.40	12.77	16.07
Q_{fp}	Floodprone Discharge (computed)	ft^3/sec	329	1547	820	2252	486	2097
A_{fp}	Floodprone Area	ft^2	74.2	245.4	186.2	406.7	100.3	284.5
d_{fp}	Mean Floodprone Depth	ft	3.50	6.80	6.70	10.00	4.04	7.34
W_{fp}	Floodprone Width	ft	42.0	61.8	56.9	76.7	45.9	65.7
n_{fp}	Floodprone Composite "n"		0.039	0.041	0.043	0.044	0.041	0.042
R_{fp}	Floodprone Hydraulic Radius	ft	1.73	3.85	3.16	5.10	2.13	4.19
V_{fp}	Average Floodprone Velocity	ft/sec	4.44	6.30	4.40	5.54	4.84	7.37
τ_o	Floodprone Shear Stress	lbs/ft^2	0.70	1.20	0.69	0.95	0.86	1.70
D_{crit}	Critical Sediment Size at Floodprone	mm	69	119	68	94	85	168
P_{fp}	Floodprone Wetted Perimeter	ft	42.8	63.7	58.9	79.8	47.1	68.0

Typical Cross Section Set 5 for Project Areas 10 and 11

			Riffle		Pool		Glide	
Symbol	Quantity	Units	Active	Bankfull	Active	Bankfull	Active	Bankfull
Z_0	Thalweg Elevation		8.92	8.92	7.30	7.30	8.65	8.65
Q_{bf}	Bankfull Discharge (computed)	ft^3/sec	73	324	128	343	123	432
A_{bf}	Bankfull Area	ft^2	21.7	73.3	40.5	100.3	30.1	86.5
d_{bf}	Mean Bankfull Depth	ft	1.04	2.04	1.81	2.45	1.40	2.23
W_{bf}	Bankfull Width	ft	21.0	35.9	22.4	40.9	21.5	38.8
W_{bf}/d_{bf}	Width/Depth ratio		20.3	17.6	12.4	16.7	15.4	17.4
W_{fp}/W_{bf}	Entrenchment Ratio		2.05	1.76	2.57	1.90	2.16	1.71
d_{max}	Maximum Depth	ft	1.80	3.48	3.42	5.10	2.07	3.75
n_{bf}	Bankfull Composite "n"		0.036	0.038	0.040	0.042	0.036	0.040
R_{bf}	Bankfull Hydraulic Radius	ft	1.02	2.00	1.73	2.36	1.36	2.17
V_{bf}	Average Bankfull Velocity	ft/sec	3.37	4.42	3.16	3.42	4.09	5.00
τ_o	Bankfull Shear Stress	lbs/ft^2	0.41	0.62	0.38	0.44	0.55	0.88
Fr_{bf}	Froude (Bankfull)		0.58	0.54	0.41	0.38	0.61	0.59
D_{crit}	Critical Sediment Size at Bankfull	mm	41	61	37	44	55	87
P_{bf}	Bankfull Wetted Perimeter	ft	21.3	36.7	23.5	42.4	22.1	39.9
Z_{fp}	Floodprone Elevation	ft	12.52	15.88	14.14	17.50	12.79	16.15
Q_{fp}	Floodprone Discharge (computed)	ft^3/sec	353	1641	849	2341	510	2202
A_{fp}	Floodprone Area	ft^2	78.1	256.5	191.3	419.3	103.9	294.1
d_{fp}	Mean Floodprone Depth	ft	3.60	6.96	6.84	10.20	4.14	7.50
W_{fp}	Floodprone Width	ft	43.0	63.2	57.6	77.9	46.5	66.4
n_{fp}	Floodprone Composite "n"		0.039	0.041	0.043	0.044	0.041	0.042
R_{fp}	Floodprone Hydraulic Radius	ft	1.78	3.94	3.20	5.17	2.18	4.28
V_{fp}	Average Floodprone Velocity	ft/sec	4.52	6.40	4.44	5.58	4.91	7.49
τ_o	Floodprone Shear Stress	lbs/ft^2	0.72	1.23	0.70	0.97	0.88	1.74
D_{crit}	Critical Sediment Size at Floodprone	mm	71	121	69	96	87	171
P_{fp}	Floodprone Wetted Perimeter	ft	43.9	65.1	59.7	81.1	47.7	68.7

Typical Cross Section Set 6 for Project Area 5 (above footbridge)

			Riffle		Pool		Glide	
Symbol	Quantity	Units	Active	Bankfull	Active	Bankfull	Active	Bankfull
Z_0	Thalweg Elevation		9.20	9.20	7.40	7.40	8.80	8.80
Q_{bf}	Bankfull Discharge (computed)	ft^3/sec	68	291	137	345	130	513
A_{bf}	Bankfull Area	ft^2	20.8	82.3	43.6	101.8	31.6	99.8
d_{bf}	Mean Bankfull Depth	ft	0.99	2.11	1.77	2.40	1.40	2.34
W_{bf}	Bankfull Width	ft	21.1	38.9	24.7	42.4	22.5	42.7
W_{bf}/d_{bf}	Width/Depth ratio		21.4	18.4	14.0	17.7	16.0	18.3
W_{fp}/W_{bf}	Entrenchment Ratio		1.79	1.70	2.44	1.87	2.19	1.67
d_{max}	Maximum Depth	ft	1.65	3.50	3.45	5.00	2.05	3.90
n_{bf}	Bankfull Composite "n"		0.036	0.040	0.040	0.042	0.036	0.040
R_{bf}	Bankfull Hydraulic Radius	ft	0.97	2.07	1.70	2.32	1.37	2.28
V_{bf}	Average Bankfull Velocity	ft/sec	3.27	3.54	3.13	3.39	4.10	5.14
τ_o	Bankfull Shear Stress	lbs/ft^2	0.39	0.45	0.37	0.43	0.56	0.92
Fr_{bf}	Froude (Bankfull)		0.58	0.43	0.42	0.39	0.61	0.59
D_{crit}	Critical Sediment Size at Bankfull	mm	39	45	37	43	55	91
P_{bf}	Bankfull Wetted Perimeter	ft	21.4	39.8	25.6	43.8	23.1	43.8
Z_{fp}	Floodprone Elevation	ft	12.50	16.20	14.30	17.40	12.90	16.60
Q_{fp}	Floodprone Discharge (computed)	ft^3/sec	346	1467	917	2339	535	2571
A_{fp}	Floodprone Area	ft^2	74.6	277.2	203.5	420.9	109.3	332.8
d_{fp}	Mean Floodprone Depth	ft	3.30	7.00	6.90	10.00	4.10	7.80
W_{fp}	Floodprone Width	ft	37.7	66.3	60.2	79.3	49.3	71.5
n_{fp}	Floodprone Composite "n"		0.040	0.042	0.043	0.043	0.041	0.042
R_{fp}	Floodprone Hydraulic Radius	ft	1.94	4.06	3.27	5.11	2.17	4.51
V_{fp}	Average Floodprone Velocity	ft/sec	4.64	5.29	4.51	5.56	4.89	7.73
τ_o	Floodprone Shear Stress	lbs/ft^2	0.79	0.89	0.71	0.96	0.88	1.83
D_{crit}	Critical Sediment Size at Floodprone	mm	78	88	70	94	87	180
P_{fp}	Floodprone Wetted Perimeter	ft	38.5	68.3	62.2	82.3	50.5	73.9