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Western Coastal Plain Reference Reach Survey

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WESTERN COASTAL PLAIN REFERENCE REACH SURVEY

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I. INTRODUCTION

The U.S. Fish and Wildlife Service (Service) - Chesapeake Bay Field Office and Anne Arundel County, Maryland (County) entered into a cooperative agreement (Agreement # 1902-5041) to collaborate on projects that will advance the understanding of streams and stream processes in the Western Coastal Plain physiographic region. One of the first efforts under this agreement was the development of a reference stream database. A reference stream database (reference data) is a collection of physical stream conditions from stable reference streams, which are then converted into reference condition relationships (i.e., dimensionless ratios). These relationships are valuable in the development of design criteria for stream restoration projects that use a natural channel design approach.

The collection of reference data can be time consuming and costly. Ideally, the best reference stream data should be collected either upstream or downstream of the proposed stream restoration project. However, theses stream reaches are often unstable, and furthermore, the existence of stable reaches within the proposed project watershed are rare. As an alternative, reference data can be collected from a set of stable streams in watersheds with similar hydrologic, geologic, and land use conditions. Still, finding stable streams in other watersheds is typically a time consuming effort because so many streams are unstable due to landscape disturbances. Therefore, the development of a reference database can significantly reduce the overall effort and cost of implementing stream restoration projects, which will benefit Federal, state, and local governments and non-governmental organization's projects. The preparation of this report will provide more time and funds for Service biologists and others to implement stream restoration projects that benefit Federal trust resources.

This report replaces the *Reference Stream Survey Report* prepared by the Service in 2006 (Secrist et al. 2006). The Service has included five additional stream reference sites to the database. The report contains a methodology description, summary of the site selection process, watershed characteristics, and channel characteristic dimensionless ratios. The technical appendices contain detailed reference data and dimensionless relationships for each reference site. It is important to note that these data only represent reference reach conditions and should not be applied directly as restoration design criteria. These data can be used as a basis to develop design criteria, but designers must develop the design criteria to address the specific conditions and fluvial processes that exist within the proposed restoration project reach and watershed.

The report also includes additional reference reach data, collected by other stream practitioners, in the appendices of this report. The Service did not verify the accuracy of the data or collection methods. However, the reader should always be familiar with the proper use and limitations of any reference stream data or design criteria.

II. METHODOLOGY

The methodology section includes brief descriptions of methods the Service and County used to complete the 2006 and 2008 surveys. The descriptions include office site selection, field reconnaissance site visits, field data collection, data entry, and data processing.

A. Site Selection

1. Selection Criteria and Procedures

For the 2006 and 2008 surveys, site selection was conducted using both office and field evaluations. The Service and the County conducted a comprehensive in-office investigation of potential sites within and outside the County using the following general criteria:

- Perennial flow
- Dominated by storm flow runoff
- Nontidal
- Non-urban (Forest cover > 50%)
- Single thread channel with natural features (pools, riffles, runs, etc.)
- Watershed soils, geology, and topography representative of Anne Arundel County
- Upstream drainage area between 0.1 and 20 square miles
- Rosgen B, C and E stream types

For the 2006 survey, County staff conducted a variety of GIS-based evaluations of potential study sites. The County's stream reach layer was overlaid upon 2000 aerial photography, after which a reconnaissance survey of potential sites was performed. Potential reaches were selected by the absence of developed land and the upstream drainage area size. Because of the distribution of development in the County, most of the potential sites were located in the southern and western areas of the County, where the majority of undeveloped and agricultural land is located. Sites with drainage areas less than 0.1 square miles (sq. mi.) were excluded from further consideration. Reaches in sites larger than 0.1 sq. mi. were subjected to Rosgen Level I classification using digital topographic data. The Service identified possible stream types of interest during Level I classification for additional consideration, as described in the next section. This approach generated approximately 35 sites, outside of Anne Arundel County, suitable for field reconnaissance.

For the 2006 and 2008 surveys, additional County office assessment work involved using data derived from recent watershed studies conducted in the Severn River and South River. These studies were performed as part of the County's development of a GIS-based watershed assessment and management procedure called the Watershed Management Tool (WMT). As part of these studies, the County performed stream walks that included habitat and infrastructure evaluations, along with extensive Rosgen Level I and II classifications. All of this information was compiled in a spatial database created

for the Severn and South Rivers. County staff used this information to search for potential sites in the Severn and South Rivers using the following criteria:

- Rosgen B, C or E stream types
- Habitat condition score of good
- Biological condition score of good
- ≥50% forest cover or ≤10% impervious cover in drainage area
- Minimal infrastructure impacts

Using these criteria for the 2006 and 2008 surveys, 31 sites within the Severn River and 67 sites within the South River were generated for evaluation and field reconnaissance. The Service and County visited six of the Severn River sites and 67 of the South River sites.

For the 2006 survey, the Service consulted with the Maryland Department of Natural Resources (DNR) to use data collected during the Maryland Biological Stream Survey (MBSS) to identify potential reference sites. Specifically, the Service evaluated Sentinel Sites that were selected by DNR, using a tiered system of land use and water quality conditions coupled with high quality biological communities (Prochaska 2005). DNR repeatedly surveyed these sites to assess the biological and habitat conditions. Using this information, the Service identified 42 potential sites for the 2006 survey.

During the 2006 and 2008 surveys, the Service and the County each considered potential sites identified by other agencies, either in previous assessments or in current work. Specifically for the 2008 survey, the Service also considered approximately 170 sites evaluated as part of their survey work for the U.S. 301 Environmental Stewardship Study conducted in the Piscataway, Mattawoman, Zekiah, and Port Tobacco watersheds. The Service identified over 50 and over 200 potential sites for the 2006 and 2008 site surveys, respectively.

2. Reconnaissance Site Visit

The Service conducted reconnaissance visits to over 250 potential sites to determine if these sites were suitable for inclusion in this study. The parameters used to evaluate potential sites included: site conditions (alteration, dams, headcuts, etc.), bank conditions, stream features (pools, riffles, runs), width/depth ratio, incision, entrenchment, and Rosgen stream type.

The Service used these parameters to evaluate the vertical and lateral stability of the stream. Sites judged unstable were excluded from the survey. The Service excluded potential sites affected by extensive agriculture, timber harvesting, and development. The Service also excluded potential sites because of extensive beaver activity, not a stream type of interest, or because access to the stream was denied by property owners. However, the majority of potential reference reach sites were excluded due to channel alterations and channel instabilities.

For those sites not excluded initially, the Service walked the reaches to locate a consistent geomorphic feature throughout the reach to identify bankfull. The Service compared the bankfull cross-sectional area, width, and mean depth of a measured cross section to the predicted values of the Coastal Plain regional curve (McCandless 2003). The comparison allowed the Service to validate the field-determined bankfull indicator(s). The Service did not automatically excluded sites with bankfull characteristics that did not compare well with the regional curve. Any differences only indicated the need for additional investigation to determine whether the site should be included in the study. Sites that passed this final evaluation were included in the reference reach survey.

Of the over 250 potential sites, the Service determined that only nine sites from across the Western Coastal Plain were suitable for inclusion in the reference reach report. The results of the reconnaissance site visits are provided in the Results (Site Selection) section of this report.

B. Field Data Collection

The Service conducted a Rosgen Level II assessment for the selected 2006 and 2008 reference reaches, and a partial Level III assessment for the 2006 selected reference reaches. The Rosgen Level II assessment details the existing morphological characteristics of a stream. The Service also used this information to classify the sites using the Rosgen Stream Classification system (Rosgen 1994).

The Rosgen Stream Classification system uses specific bankfull channel characteristics such as width, depth, cross-sectional area, entrenchment, sinuosity, water surface slope, and substrate composition to categorize streams into set groups that share similar fluvial geomorphic relationships.

For the 2006 survey, the Service conducted Rosgen Level III assessments to predict and monitor potential lateral adjustments (*e.g.*, bank erosion). The Service will combine this data with other Service bank erosion monitoring data to develop a bank erosion curve. The Service and the County will used this curve to predict bank erosion for other stream assessments.

The Service walked the reach and flagged the stream facet features (*i.e.*, pools, runs, glides, and riffles), and for the 2006 survey, the Service completed the following Rosgen Level III assessments: bank erosion hazard index (BEHI), near bank shear stress (NBS), and overall channel stability using the method developed by Pfankuch (1975). The Service conducted the BEHIs and NBS at the 2006 sites prior to the full survey to determine the range of bank stability conditions present amongst all of the sites. For the 2006 survey, at least one monumented cross section was measured for each BEHI and NBS condition existing amongst the sites. This enabled the Service to determine the minimum number of monumented cross sections for each site, thereby reducing the level of effort associated with the project. The monumented cross sections were used to validate bank stability predictions. The Service also developed a site map sketch for each reach showing locations of BEHIs, NBS, rebar benchmarks, cross sections, and adjacent

landuses. For the 2008 survey, the Service did not conduct Rosgen Level III assessments because the focus of this survey was to collect reference data and not bank erosion conditions. However, as before, the Service developed a site map for each reach showing the location of the cross sections and adjacent landuses. The Service conducted the total station surveys following established protocols (McCandless and Everett 2002) to characterize the stream dimension, pattern, and profile.

Specifically, the Service used the following steps at each survey site:

1. The Service surveyed monumented (2006 survey) and non-monumented cross sections (2008 survey). For the monumented cross sections, rebar monuments were placed at each endpoint of the classification cross section and the erosion cross sections. Cross section surveys note the elevations for the following features: top and ground surface at monuments, slope breaks, bankfull indicator, water surface at the edge of water, thalweg, and several points across the floodplain including the flood-prone elevation points. The Service did not establish monumented cross sections during the 2008 survey because of time and funding constraints. The purpose of the monumented cross sections was to allow resurvey of the cross section in order to measure bank erosion. The measurement of bank erosion is not necessary for the preparation of the reference reach data.
2. For the 2006 survey, the Service installed rebar toe pins on one or both banks and measured bank profiles at all monumented cross sections.
3. At each cross section, the Service took digital photographs upstream, downstream, and at both banks. The Service took additional digital photographs to document the condition of the reference reach.
4. For the longitudinal profile, the survey stationing included the flagged stream features, depths at the mid-point of features, bankfull indicators, points of maximum pool depths, and surveyed cross section locations. At each station, the Service measured the elevations corresponding to top of the lowest bank, bankfull indicator (if present), water surface, and thalweg. For the 2006 survey, the Service placed rebar monuments at the endpoints of the longitudinal survey to allow for resurvey of the longitudinal profile. In 2008, the Service did not place rebar monuments for the longitudinal survey because resurvey of the longitudinal profile was not necessary for the preparation of the reference reach data.
5. The Service characterized the substrate composition of the riffle or run using a modified Wolman pebble count. This pebble count was located in the same location as the Rosgen classification cross section or the cross section that best characterized the hydraulic features of the reach.
6. For the 2006 survey, if the survey reach had depositional bars, the Service obtained bar samples using the protocols established by Rosgen (Rosgen 2003).
7. For classification purposes, the Service conducted a modified Wolman pebble count in the reach to characterize the substrate composition.

8. For the 2006 survey, the Service measured coarse woody debris (CWD) using a method adapted from other stream practitioners (Robinson and Beschta 1990). The Service did not measure CWD during the 2008 survey because of time and funding constraints. The collection of CWD measurements is not necessary to prepare reference reach data.
9. For the 2006 survey, the Service only reported the distance for the meander straight length. For the 2008 survey, the Service reported the distance for the meander straight length and meander stream length (Hasfurther 1985). This adjustment reflects a change in the stream assessment and restoration design procedures of Wildland Hydrology, Inc. (Rosgen; personal communication 2009). The Service believes that this additional information will be a valuable addition to the reference reach data.
10. For 2006 survey, the Service determined Manning's 'n' using various roughness models that utilized particle size. However, using particle size often underestimates channel roughness for sand and clay bed streams, such as Plum Point, St. Mary's, and the Unnamed Tributary to Severn Run. For the 2008 survey, the Service revisited these sites to re-evaluate the bed roughness by measuring the protrusion of the ripple/dune features. The Service also visually assessed the stability of the study reach, and re-measured the cross sections and reach average slope to verify that the current conditions are similar to the original conditions.

C. Data Entry and Processing

The Service entered the data in Terramodel, RIVERMorph, and Excel spreadsheets. The Service used Terramodel, a survey program, to reduce the total station survey data. Cross sections, longitudinal profile, and plan form geometry were derived from the Terramodel data. The Service then entered the data into RIVERMorph, software that allows the user to enter data for one or many sites into one project file for processing and analysis. BEHI, Pfankuch, and summary data were entered into Excel spreadsheets. GISHYDRO was used to determine the drainage area and land use values for each site. Appendixes A to I provide the data collected for each site.

III. RESULTS

A. Site Selection

The Service and the County expanded the survey area outside of Anne Arundel County after not finding enough suitable sites for inclusion in the initial reconnaissance. The Service conducted reconnaissance visits at more than 250 potential sites at various locations within the Western Coastal Plain physiographic province. At the end of the reconnaissance visits, the Service and the County identified five sites to include in the 2006 survey and four sites in the 2008 survey (Figure 1).

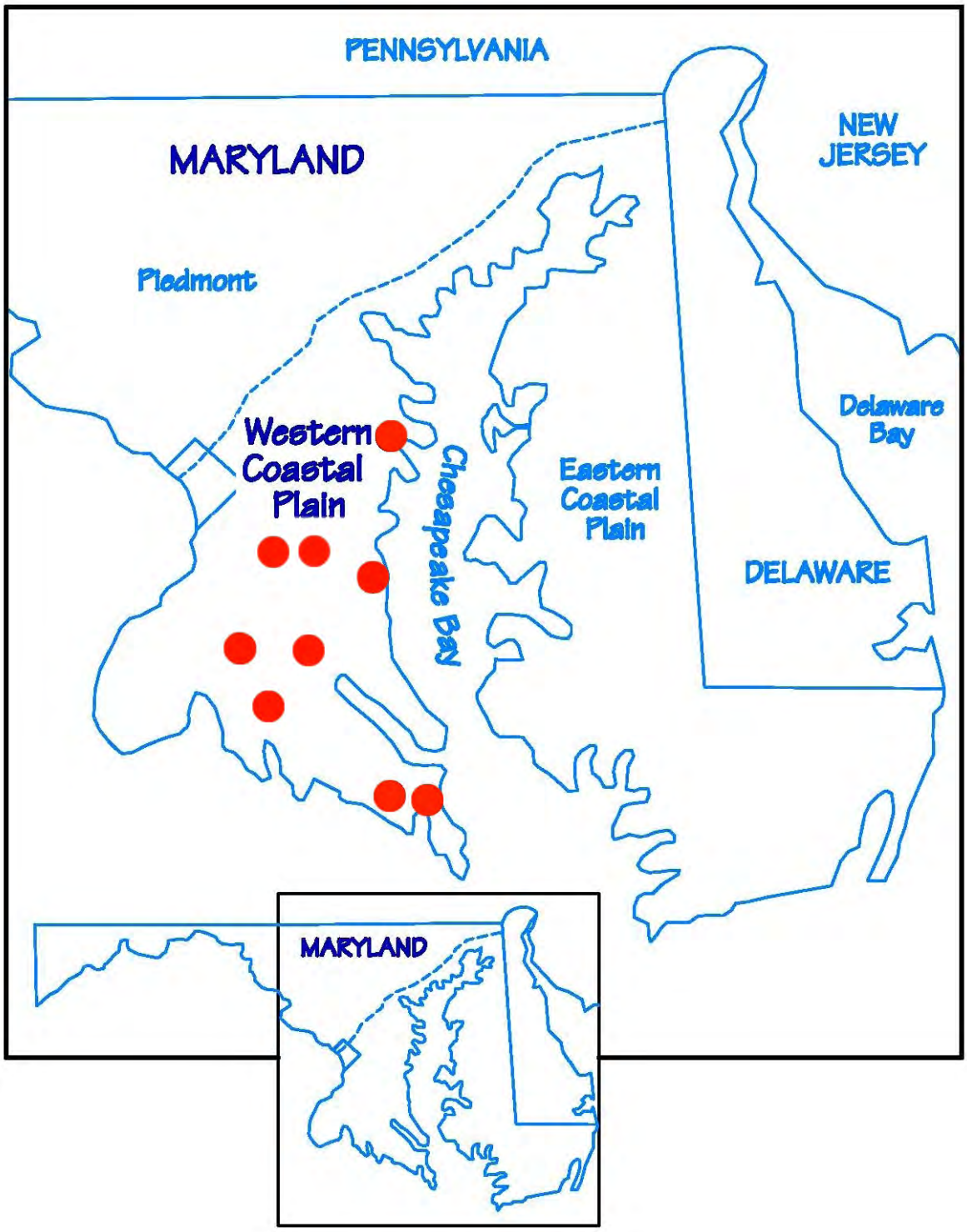


Figure 1. Survey site locations in the Western Coastal Plain, Maryland.

B. Watershed Descriptions

The nine sites selected for the survey are located in the Western Coastal Plain of Maryland. Drainage basin sizes range from 0.15 to 8.73 sq. mi. (Table 1). Percent impervious surface ranged from 0.5 – 7.9 percent in all but one watershed; Piney Run watershed had 47.0 percent. The watersheds of the sites were mainly forested with values ranging from 54 – 93 percent, except for Piney Run, which had only 20 percent forest. Agriculture and small amounts of urban made up the remaining land uses. Plum Point and the Unnamed Tributary to Severn Run had extensive forested wetlands associated with the study reaches.

Table 1. Site location summary for survey reaches.

Site	County	Drainage Area (sq. mi.)	River Basin
Unnamed Tributary to Hoghole Run	Charles	0.15	Potomac
Unnamed Tributary to Zekiah Swamp Run	Charles	0.52	Potomac
Mill Dam Run	Charles	0.60	Potomac
Unnamed Tributary to Severn River	Anne Arundel	0.73	Severn
Wolf Den Run	Charles	2.00	Potomac
Hilton Run	St. Mary's	2.40	Potomac
Piney Run	Charles	2.50	Potomac
Plum Point Creek	Calvert	3.96	Chesapeake Bay
St. Mary's River	St. Mary's	8.73	Potomac

Underlying the watershed of Unnamed Tributary to Zekiah Swamp Run are soils in the Beltsville, Gravelly Land, and Bourne series. Beltsville soils have moderate drainage and nearly level to moderately sloping topography that are located on uplands. Gravelly Land series are steep, gravelly deposits that may have once been Aura or Croom soils, but cannot be identified because of severe soil erosion. The Bourne series are moderately well-drained soils that are gently to moderately sloping and found mainly on broad ridgetops. In addition to those series, the floodplain consists of the Bibb series, a poorly drained soil with a level to nearly level topography (U.S. Department of Agriculture-Soil Conservation Service (USDA-SCS) 1974).

The St. Mary's River and Hilton Run watersheds consist of mainly Beltsville, Croom, and Bibb soils. The characteristics of the Beltsville and Bibb soils are the same as those describe above for the Unnamed Tributary to Zekiah Swamp Run. The Croom series are upland soils that are well drained and found on level to strongly sloping land (USDA-SCS 1973).

The Plum Point Creek watershed has soils in the Sassafras, Westphalia, and mixed alluvial series. Both the Sassafras and Westphalia series are deep, well-drained upland soils. The mixed alluvial soils consist of material deposited on the floodplains from the uplands. They are wet, poorly drained soils with materials that range from sand and gravel to silt and clay (USDA-SCS 1971).

The unnamed Tributary to Severn Run watershed consists of Bibb, Evesboro, Rumford, and Sassafras soils. The Evesboro series are very deep, well-drained to excessively drained soils while Rumford soils are deep, somewhat excessively drained soils. Both series are sandy upland soils. The Sassafras series are deep, well-drained upland soils and the Bibb series are floodplains soils.

The Piney Branch watershed consists of Bourne, Aura, and Croom soils. Aura series are deep, well-drained soils that have gravelly sandy clay loam upper subsoil and firm gravelly sandy clay loam lower subsoil. Most slopes are less than 5 percent but range up to 15 percent. The Mill Dam Run watershed consists of Bourne, Westphalia, and Sassafras soils. The Wolf Den Branch watershed consists of Evesboro, Bourne, and Croom soils. The Unnamed Tributary to Hoghole Run watershed consists of Aura and Bibb soils.

The soils for the sites included in the survey are representative of the soils found in Anne Arundel County. They consist of unconsolidated deposits of silt, sand, gravel, and clay. Drainage rates range from well-drained to poorly drained soils. The well-drained soils are located on the uplands, with the poorly drained soils located on the floodplains. The topography for the county ranges from nearly level to very steep (USDA-SCS 1973).

C. Reference Reach Summary Data

The Service developed summary data consisting of numerous values of channel dimension, pattern, profile, and bed materials (Appendix A - I). The Service prepared dimensionless ratios for each site using the bankfull characteristics at the classification cross section. The dimensionless ratios allow the development of dimension, pattern, and profile values for restoration designs based on the bankfull width of the design channel.

IV. DISCUSSION

The Service presents and discusses a summary of the reference reach characteristics and classification for each site. The Service also presents and discusses the dimensionless ratios for each stream type.

A. Reference Reach Classification Summary

All the sites were Rosgen E stream types, with the exception of the Unnamed Tributary to Hoghole Branch, which was a Rosgen B stream type (Table 2). In general, the classification characteristics were within the typical range for the identified stream types.

B. Table 2. Reference Reach Classification Summary

Site	Entrenchment	Width/Depth	Sinuosity	Slope	Channel Material	Bankfull Characteristics			Stream Type
						Width (ft)	Mean Depth (ft)	Area (ft)	
Hilton Run	22.21	5.79	1.60	0.0031	Gravel	10.31	1.78	18.33	E4
Mill Dam Run	24.29	8.68	1.34	0.0052	Gravel	8.07	0.93	7.48	E4
Piney Run	8.58	8.33	1.31	0.00028	Gravel	18.82	2.26	42.46	E4
Plum Point Creek	34.48	13.64	1.35	0.0022	Silt/Clay	14.46	1.06	15.39	E6
St. Mary's River	58.41	8.96	1.40	0.0024	Sand	17.02	1.90	32.38	E5
Unnamed Tributary to Hoghole Run	1.52	9.95	1.51	0.0210	Gravel	6.27	0.63	3.92	B4
Unnamed Tributary to Severn River	11.81	8.32	1.43	0.0048	Sand	4.74	0.57	2.68	E5
Unnamed Tributary to Zekiah Swamp	4.92	9.25	1.33	0.0066	Gravel	7.86	0.85	6.69	E4
Wolf Den Run	23.44	10.68	1.36	0.0027	Gravel	14.63	1.37	20.02	E4

The width/depth ratio for Plum Point Creek was slightly outside the typical range for a Rosgen E stream type. However, the Service determined that the conditions at Plum Point Creek were representative of a Rosgen E stream type, based on the continuum of physical variables, associated with the classification methodology.

For the Rosgen E stream types, nearly all the sinuosities were slightly outside the typical range for a Rosgen E stream type. The only exception was Hilton Run, which had a sinuosity within the range reported by Rosgen (1996). Again, the Service determined that the conditions at these sites were representative of a Rosgen E stream type based on the continuum of physical variables associated with the classification methodology.

All the sites were pool-dominated streams with at least 50 percent of the reach represented by pools. Eight of the nine sites have pool features representing greater than 70 percent of the reach.

The majority of the streams had a gravel substrate (i.e. Rosgen E4). However, the Unnamed Tributary to Severn River and St. Mary's River had a sand substrate, and Plum Point Creek had a silt/clay substrate (i.e. Rosgen E6).

C. Dimensionless Ratios for Rosgen E Stream Type

In general, Rosgen E stream types are found in low gradient valleys where there is a well-developed floodplain. These stream types are slightly entrenched, meaning storm flows can readily access a relatively wide floodplain. These low gradient, meandering streams also have a narrow and deep channel, which is reflected in their low width/depth ratio. These stream types are highly sensitive to disturbance but have good recovery potential.

The dimensionless ratios have a moderate range for the Rosgen E streams surveyed for this report. The width/depth ratio on average is 9.10 (Table 3) with most of the stream cross sections having a "v" rather than "u" shape for all the sites except Plum Point Creek and Piney Branch. Plum Point Creek, a Rosgen E6 stream type, had a more "u" shaped channel due to a mostly clay bed. Piney Branch also had a "u" shaped channel because it was a run-pool-dominated stream, where the channel width at the toe of the channel was similar to the bankfull width. Although Piney Branch is a Rosgen E4 stream type, it also has a high percentage of silt/clay, which also contributed to its channel shape.

Because these sites have a small drainage area (less than 10 sq. mi.) and low width/depth ratios, the pool widths are not significantly greater than the riffle or run widths. However, the overall pool area was slightly greater, and average maximum pool depth was greater than twice the riffle or run depths. There was little difference between run and glide depths overall (Table 3).

Table 3. Dimensionless Ratios - Cross Section. E Streams - Maryland Western Coastal Plain

RATIO	RANGE	AVERAGE
Width/Depth	5.73 to 12.83	9.10
$Width_{pool}/Width_{bkf}$	0.74 to 1.66	1.03
$Area_{pool}/Area_{bkf}$	0.86 to 2.11	1.29
Riffle $Depth_{max}$/Riffle $Depth_{bkf}$	1.05 to 1.98	1.50
Pool $Depth_{max}$/Riffle $Depth_{bkf}$	1.52 to 3.71	2.25
Run $Depth_{max}$/Riffle $Depth_{bkf}$	1.21 to 2.25	1.60
Glide $Depth_{max}$/Riffle $Depth_{bkf}$	1.08 to 2.76	1.59

The slope range for the survey sites was very slight (0.0003 – 0.0066), similar to measurements made for the regional curve development in the Maryland Coastal Plain (McCandless 2003). For many sites, wood was responsible for increasing riffle or run slopes. In rare situations, tree roots have grown across the stream channel creating steps, as observed at Mill Dam Run. On average, the riffles were 1.81 times steeper than the average water surface slope with the pool slopes nearly half of the average slope (Table 4).

Table 4. Dimensionless Ratios - Profile. E Streams - Maryland Western Coastal Plain

RATIO	RANGE	AVERAGE
Riffle Slope/Average Water Surface Slope	0.17 to 4.96	1.81
Pool Slope/Average Water Surface Slope	0.02 to 1.01	0.41
Run Slope/Average Water Surface Slope	0.04 to 6.68	1.19
Glide Slope/Average Water Surface Slope	0.02 to 1.82	0.50

Glide and run slopes for the gravel bed streams had less variability than the sand bed streams. However, on average, glides were half as steep as the average water surface slope, which is typical for stable streams since glides are most often associated with pools. The average run slope was slightly steeper than the average water surface slope, which is also typical for a stable stream since runs are most often associated with riffles. The variability in slope is due to the variability of bed features associated with the sand bed streams.

Sand bed streams can form eight distinctively different bed features, depending on whether sub-critical, critical or super critical flows have occurred in the reach of interest (Gordon et al 1992). During sub-critical flows, ripple and ripple/dune patterns form on the streambed. During critical flows, dunes, washed-out dunes, and plane bed patterns form on the streambed. During super critical flows, standing waves, antidunes, and chute and pool patterns form on the streambed. Each of these sand bed features have unique characteristics that directly influence glide and run slopes. However, it is difficult to

develop potential relationships between the ranges of slope measurements with only glide and run data from nine sites, two of which are sand bed streams. Additional glide and run data could possibly assist in developing the relationships.

The streams were moderately sinuous and met criteria for Rosgen E stream types (Rosgen 1994), although all sites were located in mature forest with dense root mass along the banks (Table 5). This is likely a factor in the low radius of curvature to bankfull width (average 1.89), as the bends typically had dense root mats from trees or from woody shrubs. Williams (1986) reports an average radius of curvature of 2.43, with one-third of the sites less than 2.0; however, Williams did not distinguish the sites by stream type.

Past land use activities and stream disturbances are other potential factors that may influence the sinuosity at the survey sites. Many streams in the Coastal Plain of Maryland have been straightened to allow for farming, development, and other such activities. Once the disturbance(s) ceased, these sites were able to recover and maintain a less sinuous planform because of the low shear stress associated with the low gradient valley slopes and rapid vegetation growth which provided high quality bank protection (i.e., heavily vegetated banks).

The ratio of straight meander length to bankfull width ranged from 3.53 to 13.5, with an average of 7.83. The ratio of stream meander length to bankfull width ranged from 1.84 to 26.48, with an average of 10.53. Williams (1986) reports an average of 7.5 and Leopold and Wolman (1960) report a slightly higher average of 10.0. The authors did not make a distinction between stream types for these averages. The Service did not measure meander length at Piney Run, because the study reach was less than an entire wavelength and the stream was unstable outside the study reach.

The meander width ratios, or the ratio of belt width to bankfull width, were also low for these sites (2.09 – 12.90). The range found in the Western Coastal Plain for Rosgen E stream types with a drainage area of 3 to 45 sq. mi., was 11 – 37, with an average of 21 (McCandless 2003). Rosgen (1996) reports a range of 20 – 40, with an average of 24 for E stream types.

Table 5. Dimensionless Ratios - Pattern. E Streams - Maryland Western Coastal Plain

RATIO	RANGE	AVERAGE
Sinuosity	1.31 to 1.60	1.39
Straight Meander Length/$Width_{bkf}$	3.53 to 13.50	7.58
Stream Meander Length/$Width_{bkf}$	1.84 to 26.48	10.53
Radius of Curvature/$Width_{bkf}$	1.00 to 4.61	1.89
Belt Width/$Width_{bkf}$	2.09 to 12.90	4.29
Pool to Pool Spacing/$Width_{bkf}$	2.27 to 15.56	5.22
Pool Length/$Width_{bkf}$	1.19 to 7.25	2.98

D. Dimensionless Ratios for Rosgen B Stream Type

Generally, Rosgen B stream types are found in higher gradient valleys with steeper valley slopes or terraces. These stream types are moderately entrenched, meaning storm flows are contained within a relatively narrow floodplain. These higher gradient (i.e., two to four percent slope), less meandering streams are moderately wider than they are deep. These stream types are moderately sensitive to change and have an excellent recovery potential.

The Unnamed Tributary to Hoghole Run was the only Rosgen B stream type surveyed for this study. Stream practitioners should keep in mind that the Service developed the dimensionless ratios for the B stream type from only one site, which may not represent the actual average and/or the full range of these ratios.

The stream consisted of riffle, step, and pool bed features, where tree roots created the steps. The riffles were located upstream of the steps, which occasionally created backwater conditions for some riffles. Measurements from riffles affected by backwater were not included in the reference data. Despite being in a forest, the stream contains little woody debris with the exception of the roots that form the steps.

In general, the stream's entrenchment ranged from 1.52 to 2.01, which is typical for a Rosgen B stream type. However, there were stream sections with a well-developed bankfull bench where the entrenchment was more characteristic of a Rosgen E stream type. These areas with higher entrenchment ratios are most likely associated with past localized disturbances that resulted in channel aggradation. The average width/depth is also more characteristic of a Rosgen E stream type than a B stream type. However, the Rosgen stream classification system recognizes the variability inherent in streams, and permits a two units allowance beyond the reported parameter ranges for each stream type. This was the case for this site, where the Service classified the site as a Rosgen B stream type instead of a Rosgen E stream type (Table 6).

The pool widths are not significantly greater than the riffle width for reasons similar to those discussed for the Rosgen E stream type. Despite the small drainage area and low width/depth, the pool area was slightly larger, and the average maximum pool depth was nearly two and half times larger than the riffle depth.

The riffle and step slopes show the greatest variability in measurement. The steps can influence riffle slopes by setting bed elevations, which can shorten or lengthen a riffle. The tree roots that form a step influence step slopes. In addition to setting step height, the fall of a step can be distributed over the width of the root mass. There was little difference between the run, pool, and glide slopes, because the runs and glides become shorter and less define in a step-pool stream.

Rosgen B stream types often do not have pattern measurements because geologic conditions and landforms, rather than fluvial processes, influence stream sinuosity, and as

a result, stream energy is typically dissipated vertically through step-pools rather than laterally along its channel pattern. However, this site had sufficient sinuosity for the Service to take some pattern measurements but not meander length because the entire study reach length of the Unnamed Tributary to Hoghole Run was less than an entire wavelength.

The pattern characteristics compared well with the available pattern measurements (Rosgen 1996). The average radius of curvature ratio was larger for this stream (2.94) than the Rosgen E streams (1.89). The heavily vegetated banks of the Rosgen E streams surveyed allow for tighter radius of curvatures and smaller radius of curvature ratio. The Service measured a belt width ratio of 3.17, which falls in the belt width ratio range of 2 to 8 reported by Rosgen (1996) for a B stream type.

Table 6. Dimensionless Ratios. B Streams - Maryland Western Coastal Plain

CROSS SECTION	RANGE	AVERAGE
Width/Depth	9.95 to 9.95	9.95
$Width_{pool}/Width_{bkf}$	0.74 to 1.04	0.91
$Area_{pool}/Area_{bkf}$	1.06 to 1.28	1.18
Riffle $Depth_{max}$/Riffle $Depth_{bkf}$	1.19 to 2.00	1.62
Pool $Depth_{max}$/Riffle $Depth_{bkf}$	1.38 to 3.03	2.44
Run $Depth_{max}$/Riffle $Depth_{bkf}$	1.38 to 2.17	1.79
Glide $Depth_{max}$/Riffle $Depth_{bkf}$	1.83 to 2.30	2.02
Step $Depth_{max}$/Riffle $Depth_{bkf}$	1.43 to 1.68	1.53
PROFILE	**RANGE**	**AVERAGE**
Riffle Slope/Average Water Surface Slope	0.74 to 2.72	1.47
Pool Slope/Average Water Surface Slope	0.005 to 0.07	0.03
Run Slope/Average Water Surface Slope	0.08 to 0.08	0.08
Glide Slope/Average Water Surface Slope	0.005 to 0.12	0.03
Step Slope/Average Water Surface Slope	7.43 to 15.68	12.63
PATTERN	**RANGE**	**AVERAGE**
Sinuosity	1.51 to 1.51	1.51
Straight Meander Length/$Width_{bkf}$	N/A	N/A
Stream Meander Length/$Width_{bkf}$	N/A	N/A
Radius of Curvature/$Width_{bkf}$	2.65 to 3.23	2.94
Belt Width/$Width_{bkf}$	3.17 to 3.17	3.17
Pool to Pool Spacing/$Width_{bkf}$	1.26 to 2.66	2.01
Pool Length/$Width_{bkf}$	0.77 to 1.89	1.19

E. Coarse Woody Debris

The Service conducted a coarse woody debris (CWD) survey as part of the 2006 survey to characterize the size, orientation, location, and influence of CWD on pool formation for all the survey sites. The Service did not conduct a detailed analysis to determine the influence of CWD on the development and maintenance of channel dimension, pattern, and profile. The Service used a method developed by Robinson and Beschta (1990). The survey method worked fairly well in characterizing the CWD with exception of the minimum size threshold. The method has a minimum size threshold of 0.65 feet in diameter. There was a significant number of CWD below this threshold existing within the survey sites and the Service believes that these CWD had an influence on channel characteristics. In particular, groups of CWD that were anchored solidly into the streambeds and/or stream banks often provided vertical and/or lateral stability, which directly influenced channel characteristics. Additonally, these smaller CWD influenced bed morphology. There were numerous instances where CWD created scour pools that would not exist if it were not for the CWD. Therefore, we recommend lowering the minimum size threshold for future CWD surveys. The Service did not measure CWD during the 2008 survey, because of time and funding constraints. The collection of CWD measurements is not necessary to prepare reference reach data.

Some sites had noticeably more CWD debris (Hilton Run – 8 pieces and St. Mary's River – 10 pieces) than other sites (Unnamed Tributary to Zekiah Swamp Run – 3 pieces, Plum Point Creek – 3 pieces, and Unnamed Tributary to Severn Run – 1 piece). A majority of the CWD were located in pools (76 percent) with a few located in riffles (13 percent) and runs (12 percent). Eighty percent of the CWD were within the active channel and the remaining 20 percent were on the streambanks. Their orientation to flow was fairly equal with 52 percent perpendicular to flow and 48 percent parallel to flow. Grouped versus ungrouped was nearly equal with 60 percent being ungrouped and 40 percent grouped. The size of CWD ranged from 0.5 feet (ft) to 1.6 ft in diameter, with a median of 0.9 ft, and 4.2 ft to 70 ft in length, with a median of 15 ft. Only 1 piece of CWD provided grade control and only 2 percent had some influence on pool formation.

F. Bankfull Discharge

The Service calculated Manning's roughness coefficient (Manning's 'n') and bankfull velocity by using various roughness models, including Limerinos (1970), Leopold (1964), Rosgen stream type (1996), and bed protrusion height. The Service compared the estimated roughness values calculated for each reference site to the roughness values calculated for the regional curve development in the Maryland Coastal Plain (McCandless 2003). The Service then used the estimated roughness values to calculate bankfull velocities and discharges for the reference sites. The estimated velocities and discharges were also compared to the Maryland Coastal Plain regional curve.

The Service found that Limerinos (1970) and Leopold (1964) produced Manning's 'n' values similar to the values calculated for the regional curve development in the Maryland Coastal Plain. Rosgen (1996) developed relationships between various stream types and Manning's 'n' values. However, the Manning's 'n' values by stream type did

not predict Manning's 'n' values close to the Maryland Coastal Plain values. Similarly, the Service found that Limerinos and Leopold produced roughness values most representative of the conditions at the reference sites.

For the gravel bed reference sites, the Service reports Manning's 'n' values that are an average of the Manning's 'n' values calculated from Limerinos and Leopold (Table 7). As reported in McCandless (2003), the Manning's 'n' values calculated for Western Coastal Plain streams ranged from 0.023 to 0.50, with a median of 0.030. All the Manning's 'n' for the reference sites fell within the range of the Coastal Plain sites, with a median of 0.029.

The Service had to use a different method to calculate Mannings 'n' for the sand and clay bed reference sites. Many roughness models use particle size in their calculations, specifically the riffle pebble count D_{84} of the frequency distribution. However, particle size often underestimates channel roughness for sand and clay bed streams, as was the case for Plum Point Creek, St. Mary's River, and the Unnamed Tributary to Severn Run. As a substitute for particle size at these sites, the Service measured ripple/dune protrusion heights and used the D_{84} of the frequency distribution. The Service used the D_{84}, as opposed to the D_{50} or another distribution, because the Service believes that the D_{84} better represents the roughness produced by the bed features, woody debris, and bank vegetation at these streams.

Table 7. Bankfull Discharge, Velocity and Manning's 'n'

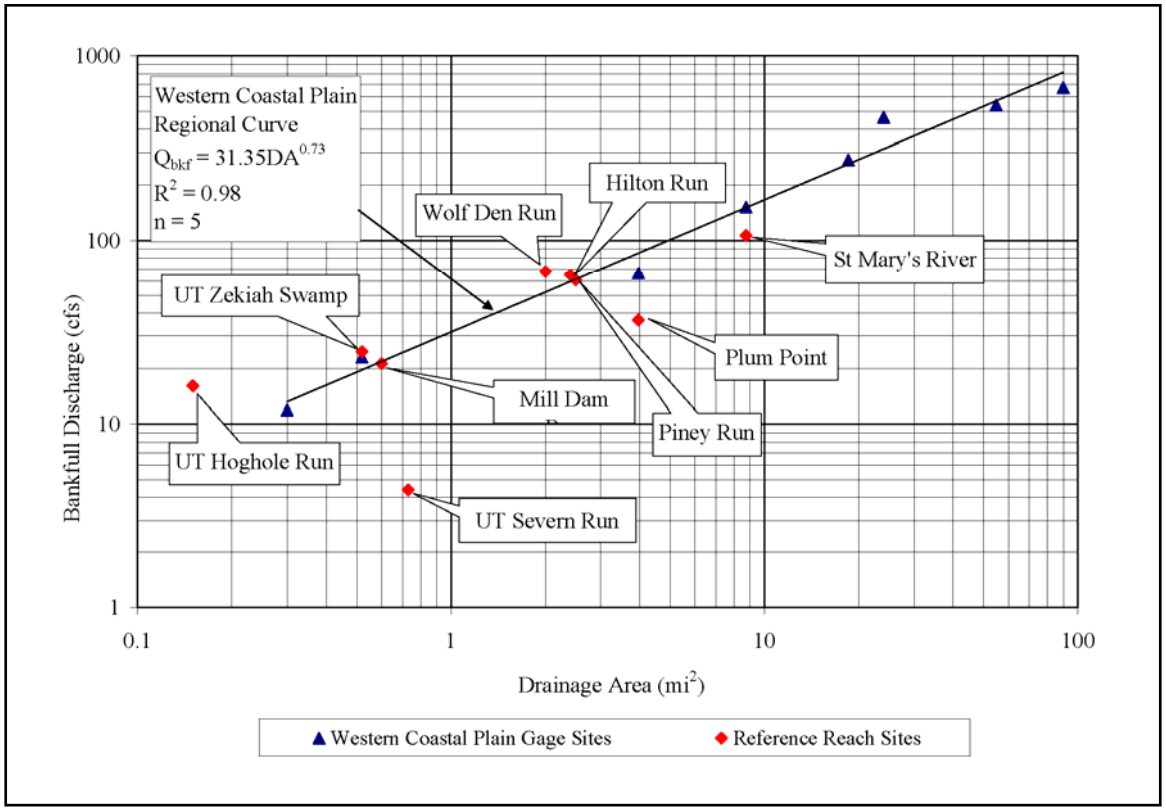
Reference Site	Bankfull Discharge (cfs)	Bankfull Velocity (ft/sec)	Manning's 'n'
Hilton Run	64.80	3.54	0.027
Mill Dam Run	21.20	2.83	0.028
Piney Branch	60.69	1.43	0.026
Plum Point Creek	36.67	2.38	0.028
St. Mary's River	106.45	3.29	0.030
Unnamed Tributary to Hoghole Run	16.09	4.11	0.037
Unnamed Tributary to Severn Run	4.41	1.65	0.037
Unnamed Tributary to Zekiah Swamp Run	24.60	3.68	0.025
Wolf Den Branch	67.68	3.38	0.027

The velocities calculated for the reference reaches also compared fairly well with the velocities reported in the Maryland Coastal Plain report (Table 7). The Maryland Coastal Plain velocities calculated for Western Coastal Plain streams ranged from 2.25 feet per second (ft/sec) to 4.54 ft/sec, with a median of 2.87 ft/sec. The velocities for the reference sites ranged from 1.43 ft/sec to 4.11 ft/sec, with a median of 2.92 ft/sec.

Calculated velocities for Piney Run and Unnamed Tributary to Severn Run were noticeably lower than velocities reported in the Maryland Coastal Plain report; however, the Service believes these velocities are correct. Piney Run has an average water surface slope of 0.00028 ft/ft, which is significantly lower than any site surveyed in the Maryland Coastal Plain report, and contributes to the lower bankfull velocity. The Service attributes the low bankfull velocity at the Unnamed Tributary to Severn Run to the extensive wetlands associated with the stream, which attenuates bankfull velocities by distributing stormflows across the wetland.

The Service used the Continuity Equation (i.e. discharge = cross section area * velocity) to determine the bankfull discharge using the field-determined cross section area and the calculated velocities (Table 7). All of the bankfull discharges calculated for the reference reaches compared well with the bankfull discharges reported in the Maryland Coastal Plain report (Figure 2). Interestingly, the influence of the wetlands on bankfull discharge is evident at the Unnamed Tributary to Severn Run. In addition to attenuating bankfull velocities, the wetlands reduce the bankfull discharge by providing storage for watershed runoff.

Figure 2. Discharge versus Drainage Area



V. CONCLUSION

Expansion of the data set would potentially allow inclusion of additional Rosgen stream types and selection of additional sites that encompass a wider range of watershed sizes. These sites represent conditions that are found in mature forested, although not pristine, conditions, with exception of Piney Run, which is primarily residential. In using this information for design, practitioners must consider specific site conditions accordingly. This information allows a framework for comparison against design ratios with specific site conditions.

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APPENDIX A – UNNAMED TRIBUTARY TO ZEKIAH SWAMP RUN
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1. Summary Sheet
2. Reach Photos
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5. Site Map
6. Longitudinal Profile Plot
7. Particle Size Distribution Plot
8. Reference Reach Data Summary
9. Coarse Woody Debris Data

UNNAMED TRIBUTARY TO ZEKIAH SWAMP RUN, CHARLES COUNTY, MD

Drainage Area (sq. mi.):	0.52	Rosgen Stream Type:	E4
Stream Order:	1	Survey Date:	April 2004
Percent Imperviousness:	1.70		

Land Use (%): Urban: 0.00 Agricultural: 7.00 Forest: 93.00

General Study Reach Description: The study reach is located on private property approximately 200 feet upstream of Estevez Road. The gravel bed stream is vertically and laterally stable with riffle/pool features. Both the pool and riffle features contain woody debris. The floodplain consists of forested wetlands, which results in the reach having undulating banks. The floodplain is densely forested with a canopy of tulip poplar, beech, and oak. The understory consists of a moderately dense layer of greenbrier, holly, and honeysuckle. Map and GPS coordinates are not provided for sites located on private property.

Photo 1. Upstream view of monumented Cross Section 1.

Photo 2. Upstream view of monumented Cross Section 2.

Photo 3. Downstream view of monumented Cross Section 3.

Photo 4. Upstream view of monumented Cross Section 4.

Photo 5. Downstream view of monumented Cross Section 5.

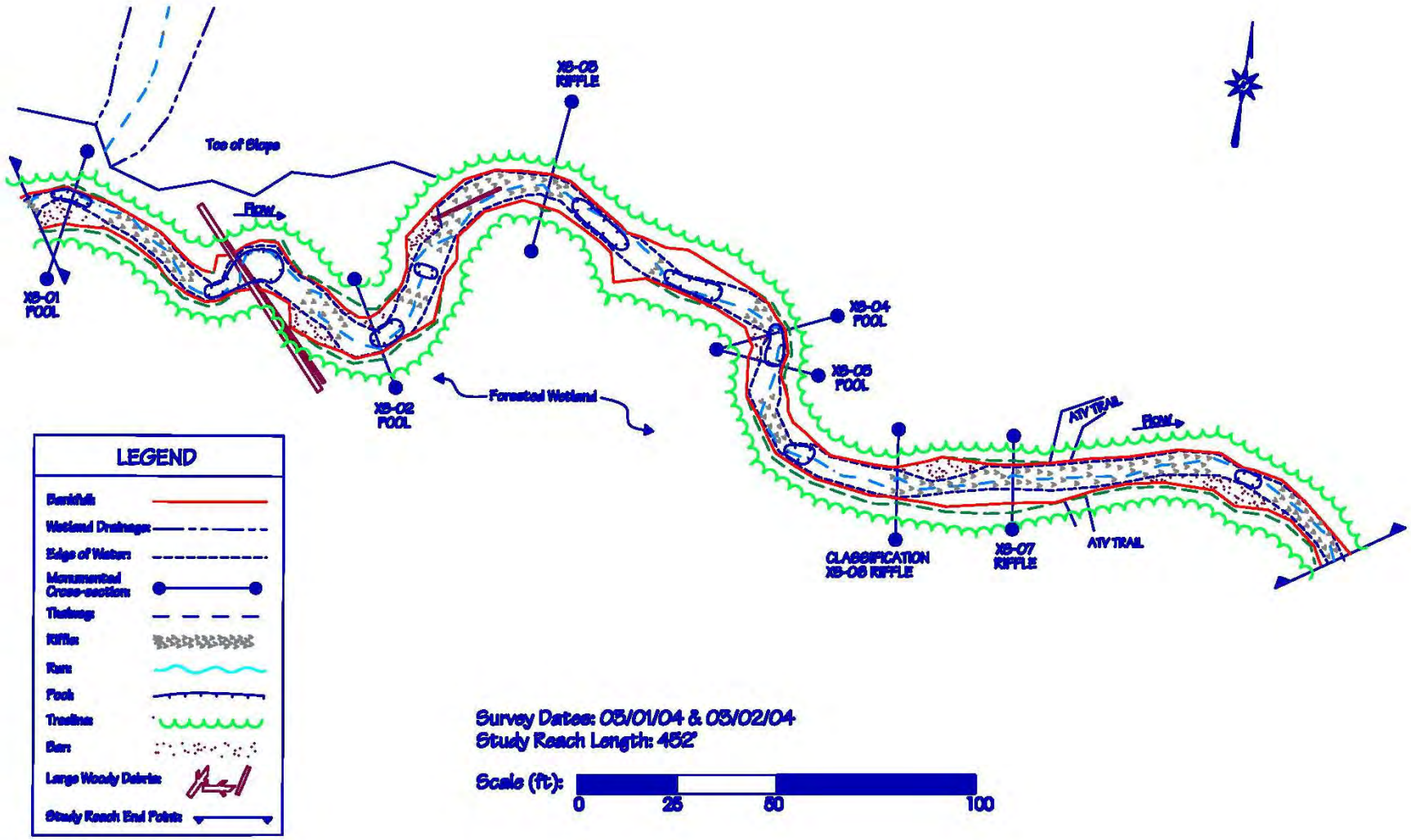
Photo 6. Upstream view of monumented classification Cross Section 6.

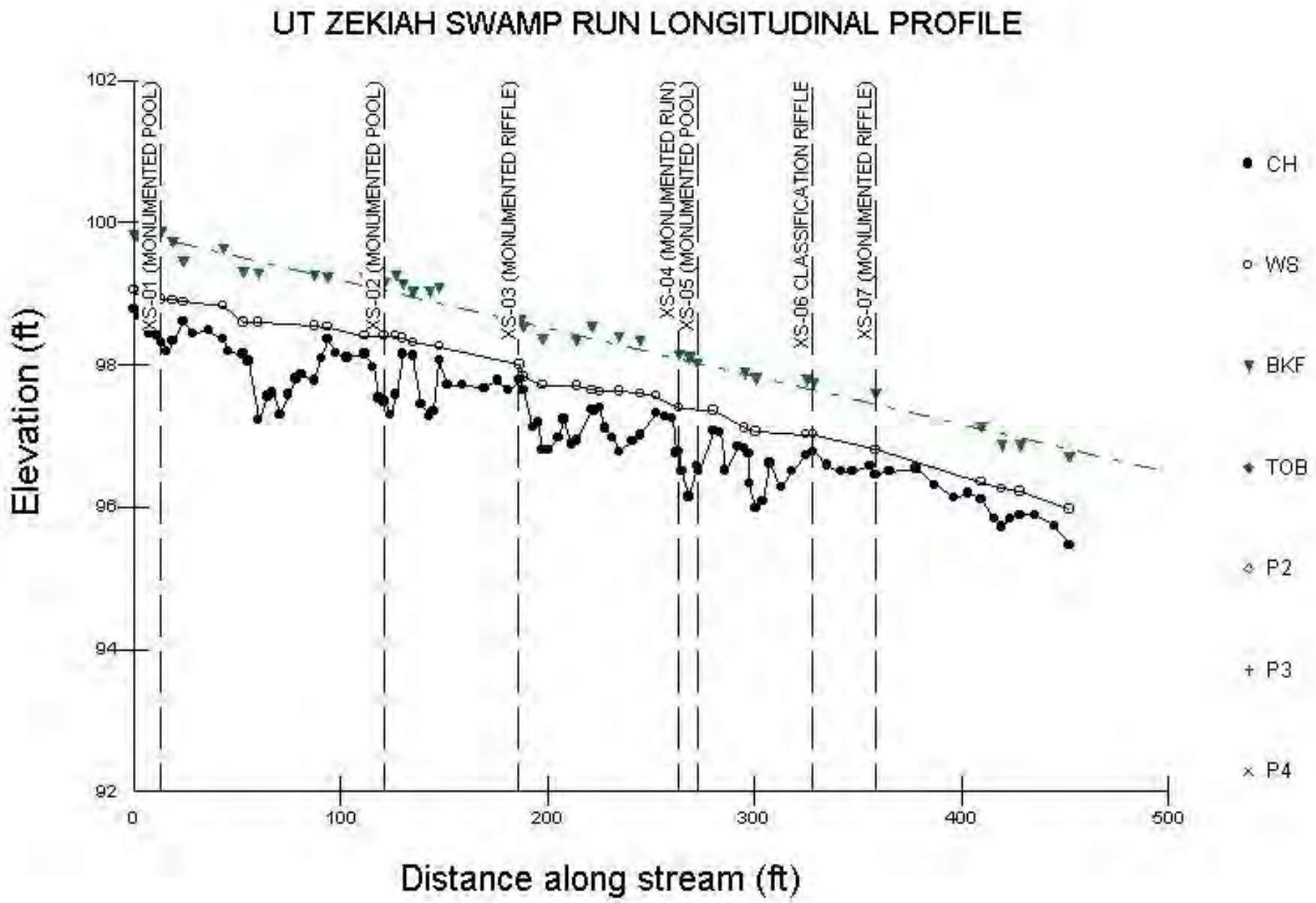
Photo 7. Upstream view of monumented Cross Section 7.

Cross Section Summary Table

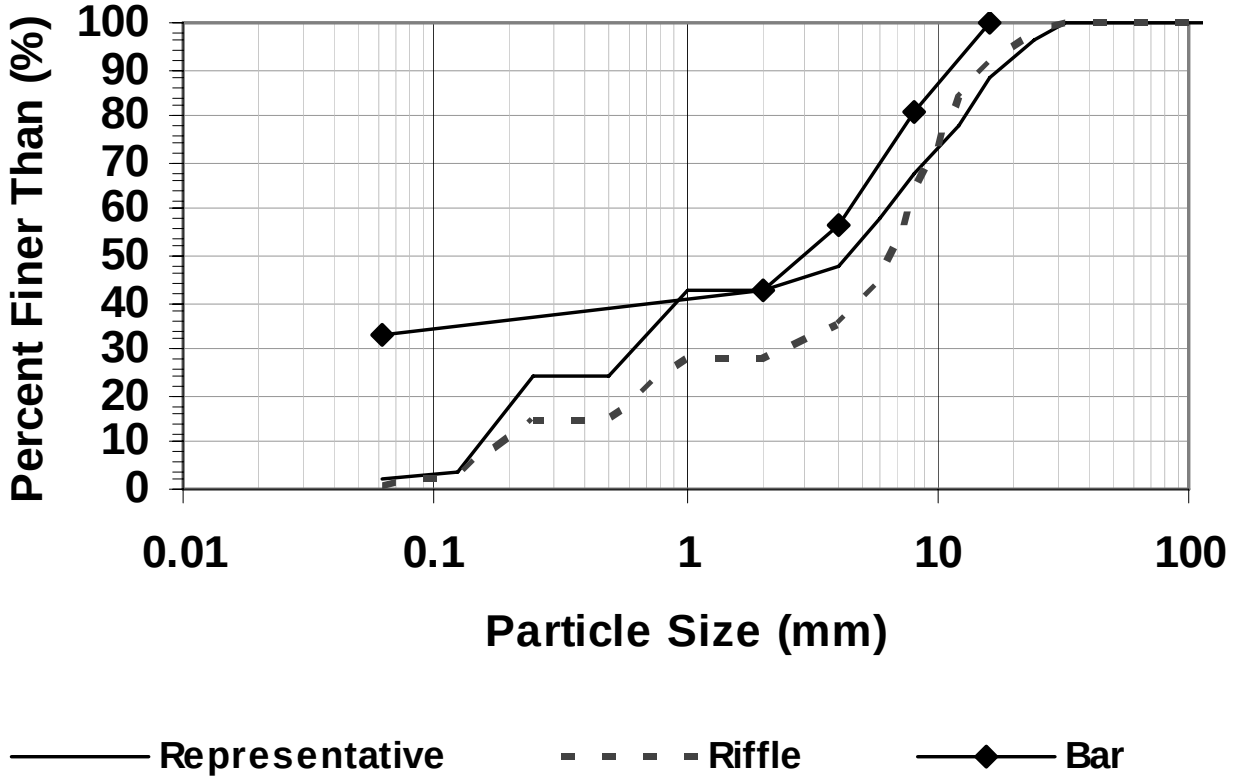
	Monumented						
	XS-01 Pool	**XS-02 Pool**	**XS-03 Riffle**	**XS-04 Run**	**XS-05 Pool**	**XS-06 Classification Riffle**	**XS-07 Riffle**
Bankfull Width (ft)	8.77	10.41	9.42	8.23	12.39	7.86	9.33
Bankfull Cross-sectional Area (ft^2)	7.83	9.77	8.63	5.26	7.43	6.69	7.08
Hydraulic Radius (ft)	0.65	0.77	0.71	0.50	0.50	0.66	0.69
Mean Bankfull Depth (ft)	0.89	0.94	0.92	0.64	0.60	0.85	0.76
Maximum Bankfull Depth (ft)	1.56	1.71	1.19	1.19	1.43	1.05	1.16
Wetted Perimeter (ft)	12.14	12.68	12.19	10.63	14.83	10.09	10.20
Width/Depth Ratio	9.85	11.07	10.24	12.86	20.65	9.25	12.28
Entrenchment Ratio	N/A	N/A	N/A	N/A	N/A	4.92	N/A

UNNAMED TRIBUTARY TO ZEKIAH SWAMP RUN
Charles County, MD




UT ZEKIAH SWAMP RUN LONGITUDINAL PROFILE
Elevation (ft)
Distance along stream (ft)
102
100
98
96
94
92
0
100
200
300
400
500
XS-01 (MONUMENTED POOL)
XS-02 (MONUMENTED POOL)
XS-03 (MONUMENTED RIFFLE)
XS-04 (MONUMENTED RUN)
XS-05 (MONUMENTED POOL)
XS-06 CLASSIFICATION RIFFLE
XS-07 (MONUMENTED RIFFLE)
CH
WS
BKF
TOB
P2
P3
P4

UT Zekiah Swamp Run Particle Size Distribution



Reference Reach Data Summary

No.	Variable	Symbol	Units	UT Zekiah Swamp Run	
1	Stream Type				E4
2	Drainage Area		mi^2		0.52
3	Riffle Bankfull Width	W_{bkf}	feet	Mean	8.87
				Min	7.86
				Max	9.42
4	Riffle Bankfull Mean Depth	d_{bkf}	feet	Mean	0.84
				Min	0.76
				Max	0.92
5	Width Depth Ratio	W/d		Mean	10.59
				Min	9.25
				Max	12.28
6	Riffle Bankfull Cross-Sectional Area	A_{bkf}	ft^2	Mean	7.47
				Min	6.69
				Max	8.63
7	Pool Bankfull Cross-Sectional Area	A_{pool}	ft^2	Mean	8.34
				Min	7.43
				Max	9.77
8	Riffle Bankfull Maximum Depth	d_{max}	feet	Mean	1.13
				Min	1.05
				Max	1.19
9	Max Riffle Depth/ Mean Riffle Depth	d_{riff}/d_{bkf}		Mean	1.33
				Min	1.24
				Max	1.40
10	Low Bank Height to Max D_{bkf} Ratio	LBH/d_{riff}		Mean	1.00
				Min	N/A
				Max	N/A
11	Width of Flood Prone Area	W_{fpa}	feet	Mean	38.69
				Min	N/A
				Max	N/A
12	Entrenchment Ratio	W_{fpa}/W_{bkf}		Mean	4.92
				Min	N/A
				Max	N/A
13	Straight Meander Length	L_m	feet	Mean	52.05
				Min	40.85
				Max	62.17
14	Straight Meander Length / Bankfull Width	L_m/W_{bkf}		Mean	6.62
				Min	5.20
				Max	7.91
15	Stream Meander Length	L_λ	feet	Mean	76.33
				Min	64.00
				Max	97.00
16	Stream Meander Length/ Bankfull Width	L_λ/W_{bkf}		Mean	7.52
				Min	6.21
				Max	9.41
17	Radius of Curvature	R_c	feet	Mean	17.68
				Min	8.51
				Max	36.25
18	Radius of Curvature / Bankfull Width	R_c/W_{bkf}		Mean	2.25
				Min	1.08
				Max	4.61
19	Belt Width	W_{blt}	feet	Mean	37.28
				Min	19.82
				Max	58.96

Reference Reach Data Summary

No.	Variable	Symbol	Units	UT Zekiah Swamp Run	
20	Meander Width Ratio	W_{blt}/W_{bkf}		Mean	4.74
				Min	2.52
				Max	7.50
21	Sinuosity	K			1.33
22	Valley Slope	S_{val}	ft/ft		0.0084
23	Average Water Surface Slope	S_{avg}	ft/ft		0.0066
24	Pool Water Surface Slope	S_{pool}	ft/ft	Mean	0.0029
				Min	0.0010
				Max	0.0061
25	Pool WS Slope / Average WS Slope	S_{pool}/S_{avg}		Mean	0.44
				Min	0.15
				Max	0.93
26	Riffle Water Surface Slope	S_{riff}	ft/ft	Mean	0.0097
				Min	0.0067
				Max	0.0128
27	Riffle WS Slope / Average WS Slope	S_{rifF}/S_{avg}		Mean	1.47
				Min	1.01
				Max	1.93
28	Run WS Slope	S_{run}	ft/ft	Mean	0.0077
				Min	0.0020
				Max	0.0200
29	Run WS Slope / Average WS Slope	S_{run}/S_{avg}		Mean	1.16
				Min	0.30
				Max	3.03
30	Glide WS Slope	S_{glide}	ft/ft	Mean	0.0049
				Min	0.0018
				Max	0.0094
31	Glide WS Slope / Average WS Slope	S_{glide}/S_{avg}		Mean	0.75
				Min	0.28
				Max	1.42
32	Maximum Pool Depth	d_{pool}	feet	Mean	1.73
				Min	1.29
				Max	2.26
33	Ratio of Max Pool Depth to Average Bankfull Depth	d_{pool}/d_{bkf}		Mean	2.03
				Min	1.52
				Max	2.66
34	Max Run Depth	d_{run}	feet	Mean	1.22
				Min	1.09
				Max	1.37
35	Ratio of Max Run Depth to Average Bankfull Depth	d_{run}/d_{bkf}		Mean	1.44
				Min	1.28
				Max	1.61
36	Max Glide Depth	d_{glide}	feet	Mean	1.22
				Min	1.03
				Max	1.39
37	Ratio of Max Glide Depth to Average Bankfull Depth	d_{glide}/d_{bkf}		Mean	1.44
				Min	1.21
				Max	1.64
38	Pool Length	L_{pool}	feet	Mean	24.56
				Min	12.64
				Max	40.69
39	Ratio of Pool Length to Bankfull Width	L_{pool}/W_{bkf}		Mean	3.12
				Min	1.61
				Max	5.18

Reference Reach Data Summary

No.	Variable	Symbol	Units	UT Zekiah Swamp Run	
40	Pool Width	W_{pool}	feet	Mean	10.52
				Min	8.77
				Max	12.39
41	Ratio of Pool Width to Bankfull Width	W_{pool}/W_{bkf}		Mean	1.34
				Min	1.12
				Max	1.58
42	Ratio of Pool Area to Bankfull Area	A_{pool}/A_{bkf}		Mean	1.25
				Min	1.11
				Max	1.46
43	Point Bar Slope	S_{pb}	ft/ft	Mean	0.14
				Min	N/A
				Max	N/A
44	Pool to Pool Spacing	p-p	feet	Mean	51.12
				Min	19.56
				Max	122.33
45	Ratio of Pool to Pool Spacing to Bankfull Width	$p\text{-}p/W_{bkf}$		Mean	6.50
				Min	2.49
				Max	15.56
46	Particle Size Distribution - Channel	D_{16}	mm		0.20
		D_{35}	mm		0.79
		D_{50}	mm		4.34
		D_{84}	mm		14.12
		D_{95}	mm		21.78
47	Particle Size Distribution - Riffle	D_{16}	mm		0.54
		D_{35}	mm		4.00
		D_{50}	mm		6.43
		D_{84}	mm		11.30
		D_{95}	mm		19.77
48	Particle Size Distribution - Bar	D_{16}	mm		0.00
		D_{35}	mm		2.22
		D_{50}	mm		6.07
		D_{84}	mm		18.46
		D_{95}	mm		22.27
49	Largest Particle Size		mm		35.00

USFWS-SHARP COARSE WOODY DEBRIS	
Stream: Unnamed Tributary to Zekiah Swamp Run	Page 1 of 1
Reach: Reference Reach	Date: 7/24/2004
adapted from E.G. Robinson and R.L. Beschta. 1990	Crew: MAS & KR

Survey total = Number of LWD pieces greater than 0.65 ft (20 cm) in diameter (small end) and 4.9 ft (1.5 m) in length

Reach Length (ft) =452				BF Width (ft) = 8				
Large end diam (ft)	Avg. diam (ft)	Length (ft)	Influence Zones	Horiz. Orient.	Rootwad instream/out	Debris Grouped / Ungrouped	Provides Grade Control	Notes (CWD location - pool, run, riffle, glide) (CWD responsible for pool formation: dominant, secondary, negligible)
0.90	0.80	19.0	2 3 4	45	Out	UG	N	Riffle
0.60	0.60	12.0	3 4	10	Out	UG	N	Riffle
1.10	1.40	5.5	3 4	130	Out	G	N	Pool-spans ch

Influence Zone and Horizontal Orientation - see back of sheet

Rootwad in/out refers to the rootwad being located in or out of the stream

Debris Grouped/Ungrouped: grouped debris is debris that is part of collection of debris, ungrouped debris is a single piece by itself

APPENDIX B – PLUM POINT CREEK
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PLUM POINT CREEK, CALVERT COUNTY, MD

Drainage Area (sq. mi.):	3.96	Rosgen Stream Type:	E6
Stream Order:	1	Survey Date:	April 2004
Percent Imperviousness:	1.30		

Land Use (%): Urban: 6.10 Agricultural: 19.90 Forest: 74.00

General Study Reach Description: The study reach starts approximately 500 feet upstream of Plum Point Road and is located on private property. Plum Point Creek is a clay bed stream that flows directly into the Chesapeake Bay. The stream has pool/run features and is vertically and laterally stable. Both the pool and run features contain woody debris. There are few depositional features in the channel. The floodplain consists of forested wetlands, which results in the reach having undulating banks at several locations where drainage from the wetlands enters the channel. The floodplain is densely forested with red maple and tulip poplar. The understory is sparse with spice bush and paw paw. Map and GPS coordinates are not provided for sites located on private property.

Photo 1. Looking upstream from top of study reach.

Photo 2. Looking downstream from Cross Section 1 at meander.

Photo 3. Looking upstream from Cross Section 3.

Photo 4. Looking downstream at bottom of study reach.

Photo 5. Upstream view of monumented Cross Section 1.

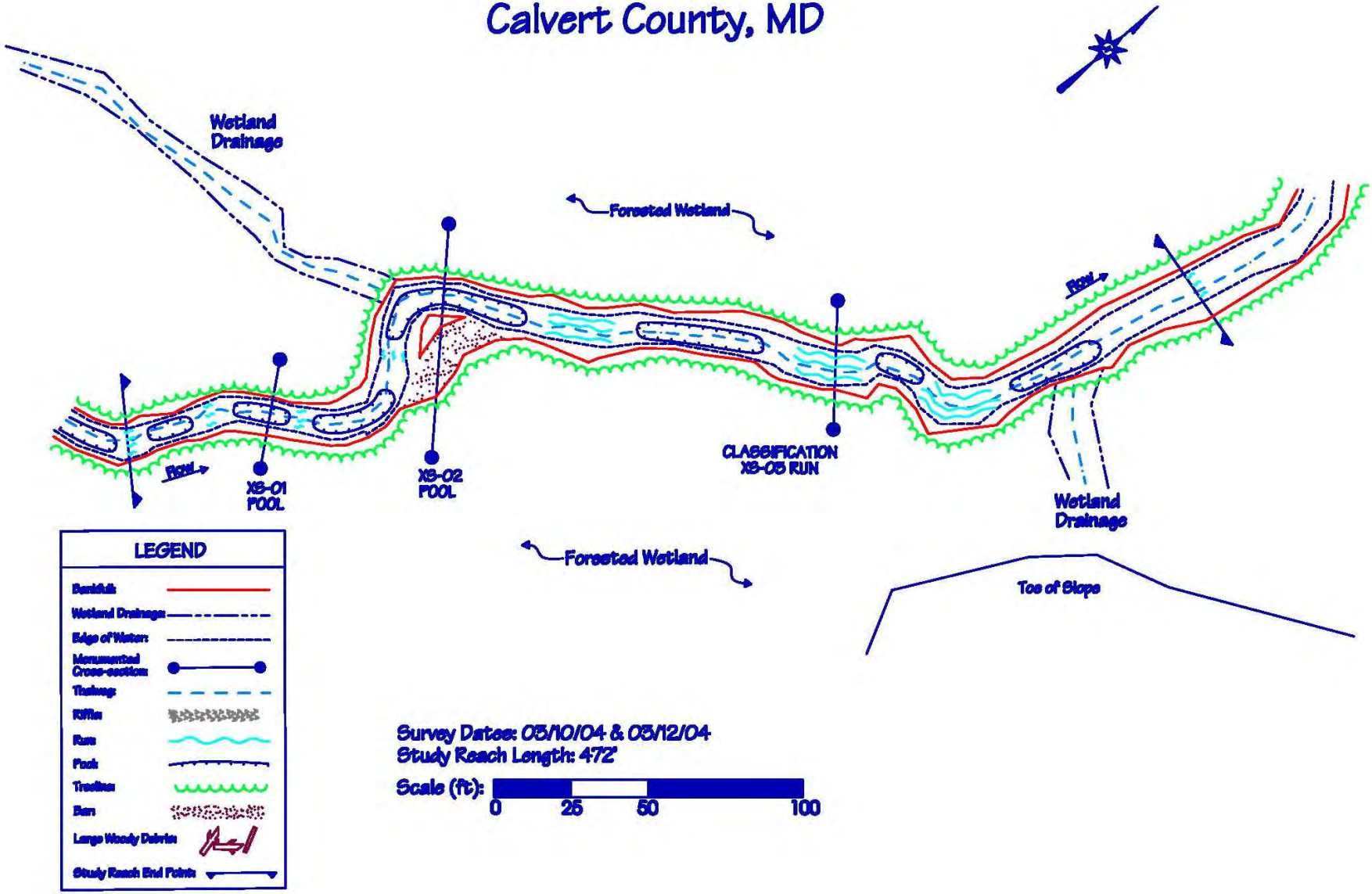
Photo 6. Upstream view of monumented Cross Section 2.

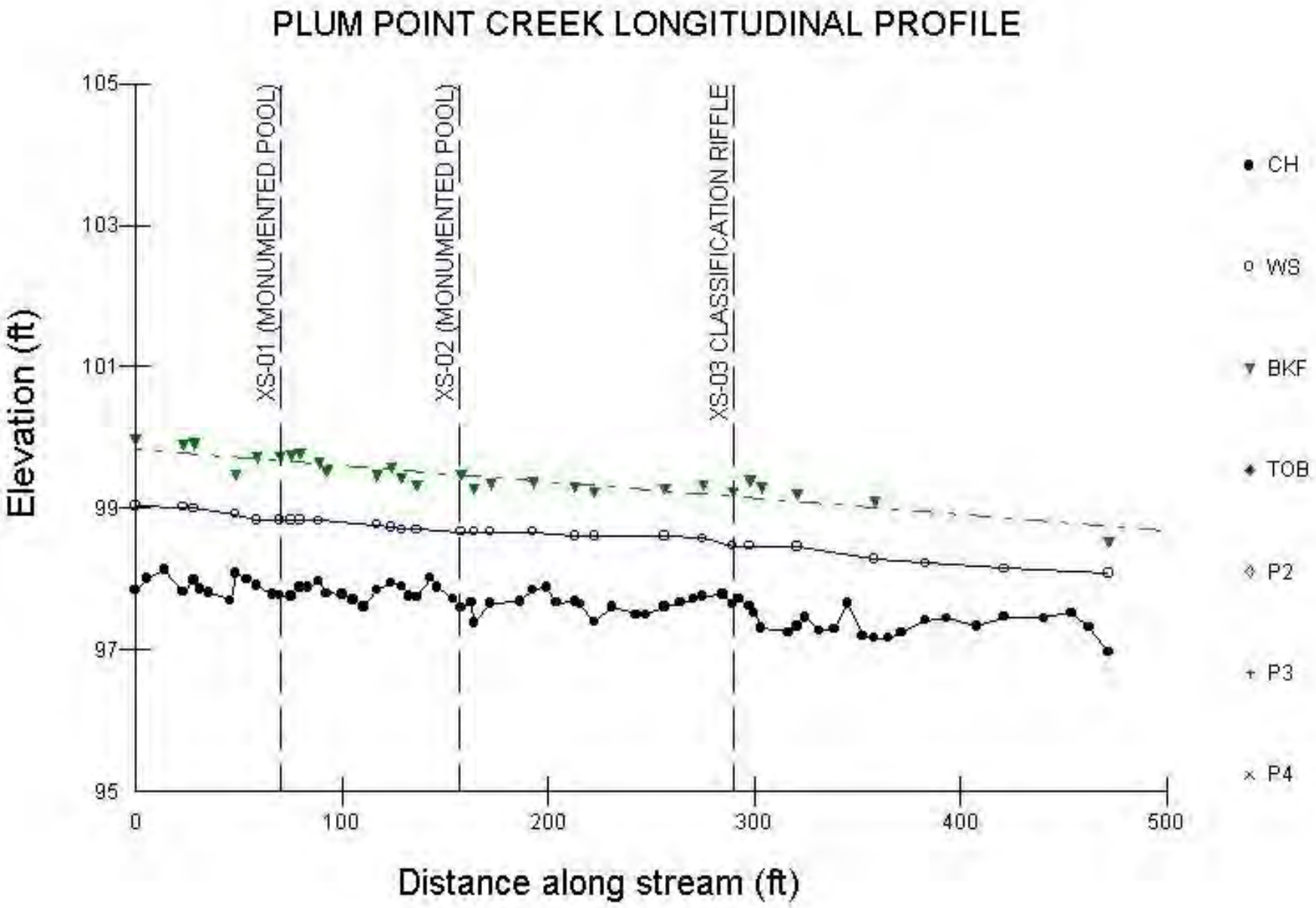
Photo 7. Downstream view of monumented classification Cross Section 3.

Cross Section Summary Table

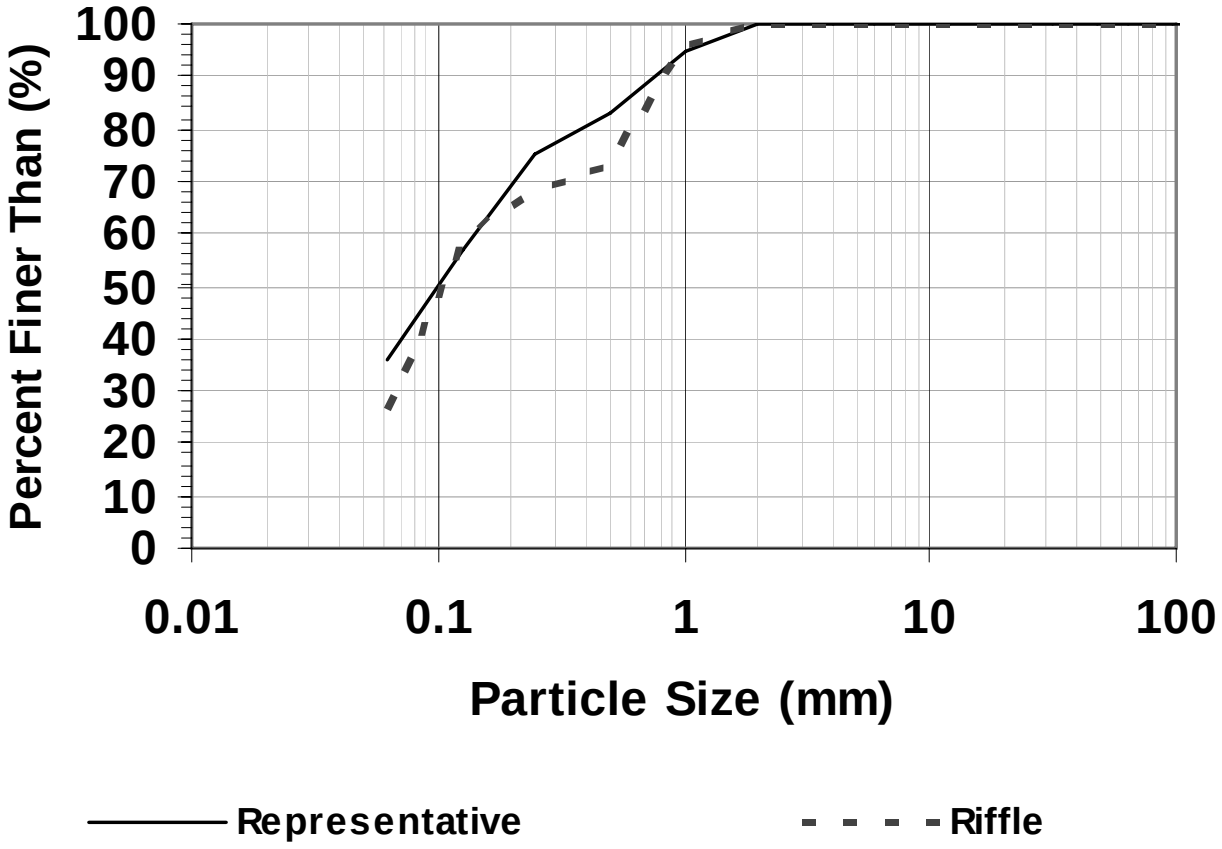
	Monumented		
	XS-01 Pool	**XS-02 Pool**	**XS-03 Classification Riffle**
Bankfull Width (ft)	12.58	11.06	14.46
Bankfull Cross-sectional Area (ft^2)	15.28	13.17	15.39
Hydraulic Radius (ft)	0.99	0.98	0.96
Mean Bankfull Depth (ft)	1.21	1.19	1.06
Maximum Bankfull Depth (ft)	1.94	1.88	1.65
Wetted Perimeter (ft)	15.39	13.43	15.98
Width/Depth Ratio	10.40	9.29	13.64
Entrenchment Ratio	N/A	N/A	34.48

PLUM POINT CREEK
Calvert County, MD




PLUM POINT CREEK LONGITUDINAL PROFILE
Elevation (ft)
105
103
101
99
97
95
0
100
200
300
400
500
Distance along stream (ft)
XS-01 (MONUMENTED POOL)
XS-02 (MONUMENTED POOL)
XS-03 CLASSIFICATION RIFFLE
CH
WS
BKF
TOB
P2
P3
P4

Plum Point Creek Particle Size Distribution



Reference Reach Data Summary

No.	Variable	Symbol	Units	Plum Point Creek	
1	Stream Type				E6
2	Drainage Area		mi^2		3.96
3	Riffle Bankfull Width	W_{bkf}	feet	Mean	14.09
				Min	12.02
				Max	16.48
4	Riffle Bankfull Mean Depth	d_{bkf}	feet	Mean	1.15
				Min	0.94
				Max	1.38
5	Width Depth Ratio	W/d		Mean	12.60
				Min	8.71
				Max	17.53
6	Riffle Bankfull Cross-Sectional Area	A_{bkf}	ft^2	Mean	15.60
				Min	14.69
				Max	16.63
7	Pool Bankfull Cross-Sectional Area	A_{pool}	ft^2	Mean	14.94
				Min	13.17
				Max	17.30
8	Riffle Bankfull Maximum Depth	d_{max}	feet	Mean	1.77
				Min	1.57
				Max	2.12
9	Max Riffle Depth/ Mean Riffle Depth	d_{riff}/d_{bkf}		Mean	1.60
				Min	1.43
				Max	1.93
10	Low Bank Height to Max D_{bkf} Ratio	LBH/d_{riff}		Mean	1.00
				Min	N/A
				Max	N/A
11	Width of Flood Prone Area	W_{fpa}	feet	Mean	500
				Min	N/A
				Max	N/A
12	Entrenchment Ratio	W_{fpa}/W_{bkf}		Mean	34.48
				Min	N/A
				Max	N/A
13	Straight Meander Length	L_m	feet	Mean	75.64
				Min	67.12
				Max	84.15
14	Straight Meander Length / Bankfull Width	L_m/W_{bkf}		Mean	5.22
				Min	4.63
				Max	5.80
15	Stream Meander Length	L_λ	feet	Mean	143.00
				Min	78.00
				Max	214.00
16	Stream Meander Length / Bankfull Width	L_λ/W_{bkf}		Mean	13.87
				Min	7.57
				Max	20.76
17	Radius of Curvature	R_c	feet	Mean	19.91
				Min	17.17
				Max	25.73
18	Radius of Curvature / Bankfull Width	R_c/W_{bkf}		Mean	1.37
				Min	1.18
				Max	1.77
19	Belt Width	W_{blt}	feet	Mean	46.84
				Min	39.31
				Max	54.37

Reference Reach Data Summary

No.	Variable	Symbol	Units	Plum Point Creek	
20	Meander Width Ratio	W_{blt}/W_{bkf}		Mean	3.23
				Min	2.71
				Max	3.75
21	Sinuosity	K			1.35
22	Valley Slope	S_{val}	ft/ft		0.0025
23	Average Water Surface Slope	S_{avg}	ft/ft		0.0022
24	Pool Water Surface Slope	S_{pool}	ft/ft	Mean	0.0008
				Min	0.0002
				Max	0.0017
25	Pool WS Slope / Average WS Slope	S_{pool}/S_{avg}		Mean	0.37
				Min	0.10
				Max	0.79
26	Riffle Water Surface Slope	S_{riff}	ft/ft	Mean	0.0045
				Min	0.0025
				Max	0.0066
27	Riffle WS Slope / Average WS Slope	S_{rifF}/S_{avg}		Mean	2.06
				Min	1.15
				Max	3.00
28	Run WS Slope	S_{run}	ft/ft	Mean	0.0011
				Min	0.0001
				Max	0.0041
29	Run WS Slope / Average WS Slope	S_{run}/S_{avg}		Mean	0.48
				Min	0.05
				Max	1.86
30	Glide WS Slope	S_{glide}	ft/ft	Mean	0.0017
				Min	0.0001
				Max	0.0040
31	Glide WS Slope / Average WS Slope	S_{glide}/S_{avg}		Mean	0.76
				Min	0.05
				Max	1.82
32	Maximum Pool Depth	d_{pool}	feet	Mean	1.94
				Min	1.84
				Max	2.08
33	Ratio of Max Pool Depth to Average Bankfull Depth	d_{pool}/d_{bkf}		Mean	1.76
				Min	1.67
				Max	1.89
34	Max Run Depth	d_{run}	feet	Mean	1.69
				Min	1.58
				Max	1.82
35	Ratio of Max Run Depth to Average Bankfull Depth	d_{run}/d_{bkf}		Mean	1.54
				Min	1.44
				Max	1.65
36	Max Glide Depth	d_{glide}	feet	Mean	1.69
				Min	1.52
				Max	1.85
37	Ratio of Max Glide Depth to Average Bankfull Depth	d_{glide}/d_{bkf}		Mean	1.53
				Min	1.38
				Max	1.68
38	Pool Length	L_{pool}	feet	Mean	41.15
				Min	20.48
				Max	63.60
39	Ratio of Pool Length to Bankfull Width	L_{pool}/W_{bkf}		Mean	2.84
				Min	1.41
				Max	4.39

Reference Reach Data Summary

No.	Variable	Symbol	Units	Plum Point Creek	
40	Pool Width	W_{pool}	feet	Mean	13.19
				Min	11.06
				Max	14.60
41	Ratio of Pool Width to Bankfull Width	W_{pool}/W_{bkf}		Mean	0.91
				Min	0.76
				Max	1.01
42	Ratio of Pool Area to Bankfull Area	A_{pool}/A_{bkf}		Mean	0.97
				Min	0.86
				Max	1.12
43	Point Bar Slope	S_{pb}	ft/ft	Mean	N/A
				Min	N/A
				Max	N/A
44	Pool to Pool Spacing	p-p	feet	Mean	71.70
				Min	51.19
				Max	81.80
45	Ratio of Pool to Pool Spacing to Bankfull Width	$p\text{-}p/W_{bkf}$		Mean	4.94
				Min	3.53
				Max	5.64
Materials					
46	Particle Size Distribution - Channel	D_{16}	mm		0.03
		D_{35}	mm		0.06
		D_{50}	mm		0.10
		D_{84}	mm		0.54
		D_{95}	mm		1.00
47	Particle Size Distribution - Riffle	D_{16}	mm		0.04
		D_{35}	mm		0.08
		D_{50}	mm		0.11
		D_{84}	mm		0.74
		D_{95}	mm		0.98
48	Particle Size Distribution - Bar	D_{16}	mm		N/A
		D_{35}	mm		N/A
		D_{50}	mm		N/A
		D_{84}	mm		N/A
		D_{95}	mm		N/A
49	Largest Particle Size		mm		N/A

USFWS-SHARP COARSE WOODY DEBRIS	
Stream: Plum Point Creek	Page 1 of 1
Reach: Reference Reach	Date: 7/29/2004
adapted from E.G. Robinson and R.L. Beschta. 1990	Crew: MAS & KR

Survey total = Number of LWD pieces greater than 0.65 ft (20 cm) in diameter (small end) and 4.9 ft (1.5 m) in length

Reach Length (ft) = 472				BF Width (ft) = 15				
Large end diam (ft)	Avg. diam (ft)	Length (ft)	Influence Zones	Horiz. Orient.	Rootwad instream/out	Debris Grouped / Ungrouped	Provides Grade Control	Notes (CWD location - pool, run, riffle, glide) (CWD responsible for pool formation: dominant, secondary, negligible)
0.80	0.72	65.0	3 4	70	Out	G	N	Run-spans ch
1.10	0.70	35.0	2 3 4	100	Out	G	N	Pool-spans ch
0.75	0.90	70.0	3 4	100	Out	G	N	Pool-spans ch

Influence Zone and Horizontal Orientation - see back of sheet

Rootwad in/out refers to the rootwad being located in or out of the stream

Debris Grouped/Ungrouped: grouped debris is debris that is part of collection of debris, ungrouped debris is a single piece by itself

APPENDIX C - ST. MARY'S RIVER
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1. Summary Sheet
2. Reach Photos
3. Cross Section Photos
4. Cross Section Summary Data
5. Site Map
6. Longitudinal Profile Plot
7. Particle Size Distribution Plot
8. Reference Reach Data Summary
9. Coarse Woody Debris Data

ST. MARY'S RIVER, ST. MARY'S COUNTY, MD

Latitude:	38º 16' 14.4"	Rosgen Stream Type:	E5
Longitude:	76º 30' 42.8"	Survey Date:	April 2004
ADC Map Coordinates:	St. Mary's Map 17/K8		

Drainage Area (sq. mi.):	8.73
Stream Order:	3
Percent Imperviousness:	2.60

Land Use (%): Urban: 8.00 Agricultural: 22.40 Forest: 69.60

General Study Reach Description: The study reach is located in the St. Mary's River State Park approximately 1.3 miles upstream of Indian Bridge Road. The sand bed stream is vertically and laterally stable with pool/riffle features. Both the pool and riffle features contain woody debris, with most of the riffles influenced by woody debris. There are few depositional features in the channel. The floodplain consists of forested wetlands, which results in the reach having undulating banks at many locations where drainage from the wetlands enters the channel. The floodplain is densely forested with red maple, river birch, and tulip poplar. The reach has a sparse understory of greenbrier.

Photo 1. Looking downstream from top of study reach.

Photo 2. Looking upstream from bottom of study reach.

Photo 3. Upstream view of monumented Cross Section 1.

Photo 4. Downstream view of monumented Cross Section 2.

Photo 5. Downstream view of monumented Cross Section 3.

Photo 6. Upstream view of non-monumented classification Cross Section 6.

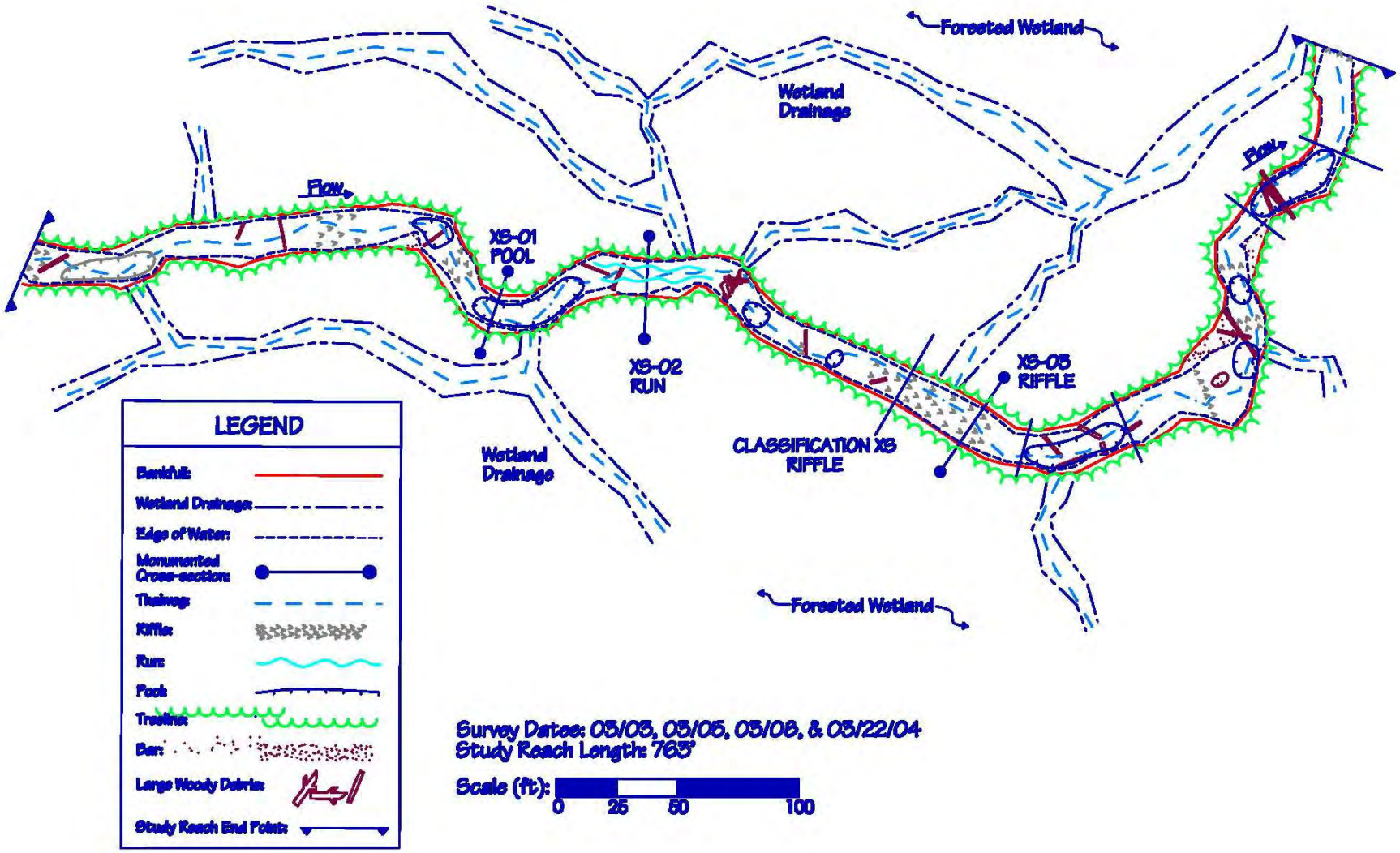
Cross Section Summary Table

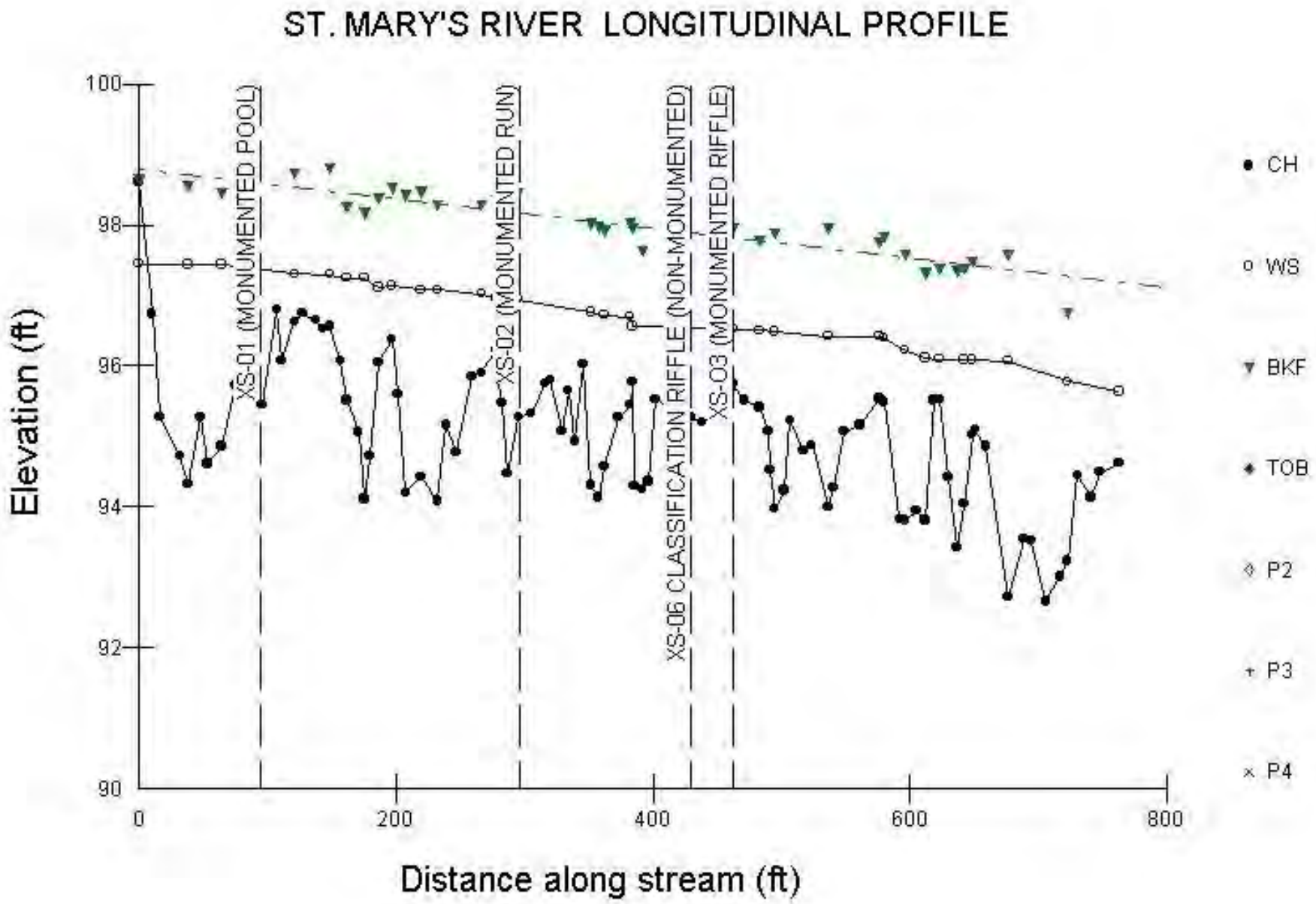
	Monumented			Non-monumented
	XS-01 Pool	**XS-02 Run**	**XS-03 Riffle**	**XS-06 Classification Riffle**
Bankfull Width (ft)	16.46	15.70	19.21	17.02
Bankfull Cross-sectional Area (ft^2)	37.48	43.36	36.58	32.38
Hydraulic Radius (ft)	1.83	1.76	1.60	1.76
Mean Bankfull Depth (ft)	2.28	2.76	1.90	1.90
Maximum Bankfull Depth (ft)	4.06	3.33	2.21	2.81
Wetted Perimeter (ft)	20.48	24.62	22.83	18.45
Width/Depth Ratio	7.22	5.69	10.11	8.96
Entrenchment Ratio	N/A	N/A	N/A	58.41

Monument Locations Table

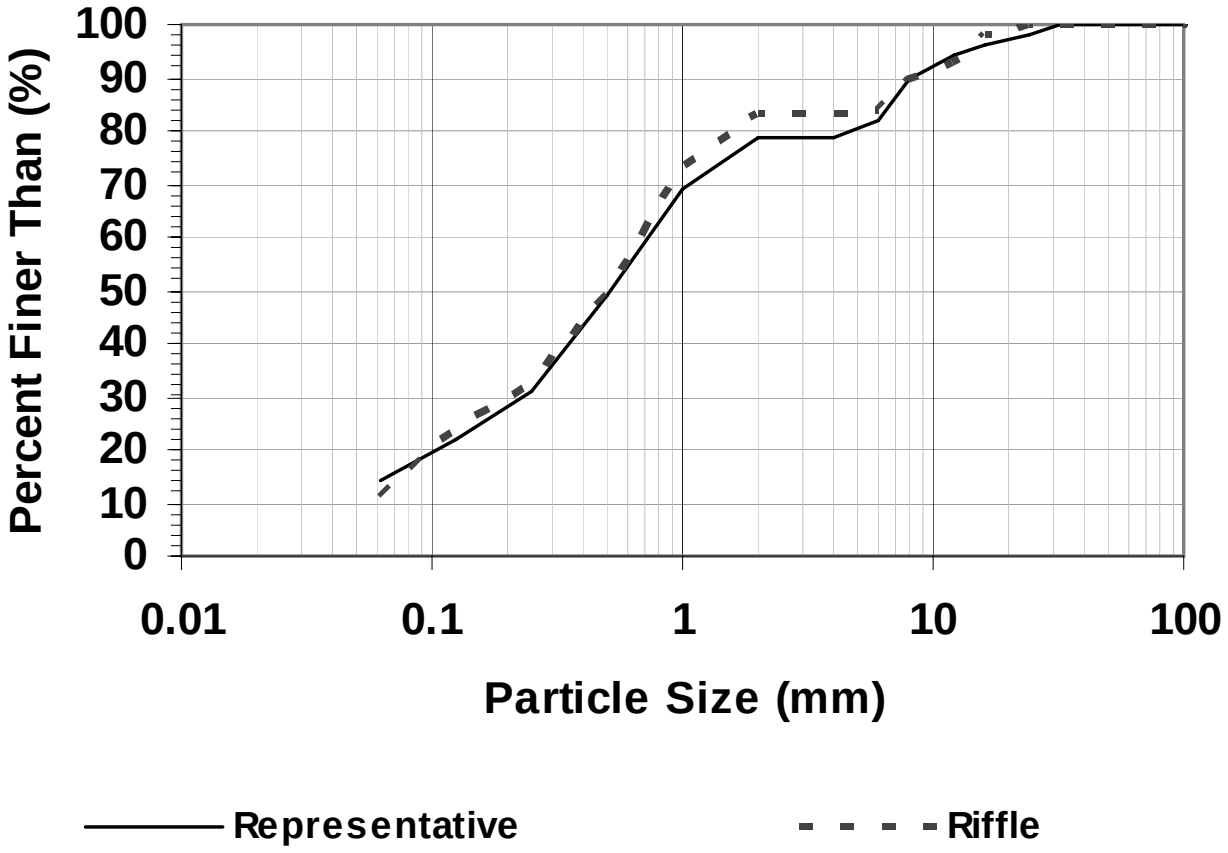
MONUMENT	GLOBAL POSITIONING SYSTEM (GPS) COORDINATE (NAD 83)
Cross Sections	
XS-01	
Left	N: 38° 16' 16.2" (± 21.4')
	W: 76° 30' 42.2" (± 21.4')
Right	N: 38° 16' 16.0" (± 24.2')
	W: 76° 30' 43.0" (± 24.2')
XS-02	
Left	N: 38° 16' 15.4" (± 22.0')
	W: 76° 30' 42.1" (± 22.0')
Right	N: 38° 16' 15.5" (± 16.4')
	W: 76° 30' 42.6" (± 16.4')
Classification XS-03	
Left:	N: 38° 16' 14.4" (± 33.6')
	W: 76° 30' 42.8" (± 33.6')
Right:	N: 38° 16' 14.1" (± 24.5')
	W: 76° 30' 43.6" (± 24.5')
Long Pro BM-01	
	N: 38° 16' 12.5" (± 42')
	W: 76° 30' 41.6" (± 42')

ST. MARY'S RIVER
St. Mary's County, MD




ST. MARY'S RIVER LONGITUDINAL PROFILE
Elevation (ft)
Distance along stream (ft)
100
98
96
94
92
90
0
200
400
600
800
XS-01 (MONUMENTED POOL)
XS-02 (MONUMENTED RUN)
XS-06 CLASSIFICATION RIFFLE (NON-MONUMENTED)
XS-03 (MONUMENTED RIFFLE)
CH
WS
BKF
TOB
P2
P3
P4

St. Mary's River Particle Size Distribution



Reference Reach Data Summary

No.	Variable	Symbol	Units	St. Mary's River	
1	Stream Type				E5
2	Drainage Area		mi^2		8.73
3	Riffle Bankfull Width	W_{bkf}	feet	Mean	17.43
				Min	16.28
				Max	19.21
4	Riffle Bankfull Mean Depth	d_{bkf}	feet	Mean	1.74
				Min	1.49
				Max	1.90
5	Width Depth Ratio	W/d		Mean	10.10
				Min	9.01
				Max	11.47
6	Riffle Bankfull Cross-Sectional Area	A_{bkf}	ft^2	Mean	30.33
				Min	25.35
				Max	36.58
7	Pool Bankfull Cross-Sectional Area	A_{pool}	ft^2	Mean	44.27
				Min	37.48
				Max	55.08
8	Riffle Bankfull Maximum Depth	d_{max}	feet	Mean	2.35
				Min	2.00
				Max	2.81
9	Max Riffle Depth/ Mean Riffle Depth	d_{riff}/d_{bkf}		Mean	1.24
				Min	1.05
				Max	1.48
10	Low Bank Height to Max D_{bkf} Ratio	LBH/d_{riff}		Mean	1.00
				Min	N/A
				Max	N/A
11	Width of Flood Prone Area	W_{fpa}	feet	Mean	1000
				Min	N/A
				Max	N/A
12	Entrenchment Ratio	W_{fpa}/W_{bkf}		Mean	58.41
				Min	N/A
				Max	N/A
13	Straight Meander Length	L_m	feet	Mean	160.65
				Min	119.35
				Max	231.05
14	Straight Meander Length / Bankfull Width	L_m/W_{bkf}		Mean	9.38
				Min	6.97
				Max	13.50
15	Stream Meander Length	L_λ	feet	Mean	181.00
				Min	116.00
				Max	273.00
16	Stream Meander Length / Bankfull Width	L_λ/W_{bkf}		Mean	17.56
				Min	11.25
				Max	26.48
17	Radius of Curvature	R_c	feet	Mean	26.28
				Min	19.62
				Max	38.62
18	Radius of Curvature / Bankfull Width	R_c/W_{bkf}		Mean	1.53
				Min	1.15
				Max	2.26
19	Belt Width	W_{blt}	feet	Mean	61.42
				Min	37.65
				Max	117.86

Reference Reach Data Summary

No.	Variable	Symbol	Units	St. Mary's River	
20	Meander Width Ratio	W_{blt}/W_{bkf}		Mean	3.59
				Min	2.20
				Max	6.88
21	Sinuosity	K			1.40
22	Valley Slope	S_{val}	ft/ft		0.0033
23	Average Water Surface Slope	S_{avg}	ft/ft		0.0024
24	Pool Water Surface Slope	S_{pool}	ft/ft	Mean	0.0013
				Min	0.0002
				Max	0.0019
25	Pool WS Slope / Average WS Slope	S_{pool}/S_{avg}		Mean	0.53
				Min	0.07
				Max	0.77
26	Riffle Water Surface Slope	S_{riff}	ft/ft	Mean	0.0043
				Min	0.0019
				Max	0.0059
27	Riffle WS Slope / Average WS Slope	S_{rifF}/S_{avg}		Mean	1.80
				Min	0.78
				Max	2.46
28	Run WS Slope	S_{run}	ft/ft	Mean	0.0030
				Min	0.0001
				Max	0.0110
29	Run WS Slope / Average WS Slope	S_{run}/S_{avg}		Mean	1.26
				Min	0.04
				Max	4.58
30	Glide WS Slope	S_{glide}	ft/ft	Mean	0.0011
				Min	0.0001
				Max	0.0030
31	Glide WS Slope / Average WS Slope	S_{glide}/S_{avg}		Mean	0.45
				Min	0.04
				Max	1.25
32	Maximum Pool Depth	d_{pool}	feet	Mean	4.03
				Min	3.75
				Max	4.41
33	Ratio of Max Pool Depth to Average Bankfull Depth	d_{pool}/d_{bkf}		Mean	2.12
				Min	1.97
				Max	2.32
34	Max Run Depth	d_{run}	feet	Mean	2.84
				Min	2.30
				Max	3.69
35	Ratio of Max Run Depth to Average Bankfull Depth	d_{run}/d_{bkf}		Mean	1.50
				Min	1.21
				Max	1.94
36	Max Glide Depth	d_{glide}	feet	Mean	2.78
				Min	2.45
				Max	2.99
37	Ratio of Max Glide Depth to Average Bankfull Depth	d_{glide}/d_{bkf}		Mean	1.46
				Min	1.29
				Max	1.57
38	Pool Length	L_{pool}	feet	Mean	69.87
				Min	25.41
				Max	118.88
39	Ratio of Pool Length to Bankfull Width	L_{pool}/W_{bkf}		Mean	4.08
				Min	1.48
				Max	6.94

Reference Reach Data Summary

No.	Variable	Symbol	Units	St. Mary's River	
40	Pool Width	W_{pool}	feet	Mean	16.81
				Min	15.27
				Max	18.70
41	Ratio of Pool Width to Bankfull Width	W_{pool}/W_{bkf}		Mean	0.98
				Min	0.89
				Max	1.09
42	Ratio of Pool Area to Bankfull Area	A_{pool}/A_{bkf}		Mean	1.37
				Min	1.16
				Max	1.70
43	Point Bar Slope	S_{pb}	ft/ft	Mean	N/A
				Min	N/A
				Max	N/A
44	Pool to Pool Spacing	p-p	feet	Mean	98.39
				Min	63.09
				Max	133.69
45	Ratio of Pool to Pool Spacing to Bankfull Width	$p\text{-}p/W_{bkf}$		Mean	5.75
				Min	3.69
				Max	7.81
Materials					
46	Particle Size Distribution - Channel	D_{16}	mm		0.08
		D_{35}	mm		0.31
		D_{50}	mm		0.53
		D_{84}	mm		6.27
		D_{95}	mm		13.65
47	Particle Size Distribution - Riffle	D_{16}	mm		0.09
		D_{35}	mm		0.29
		D_{50}	mm		0.52
		D_{84}	mm		5.70
		D_{95}	mm		13.18
48	Particle Size Distribution - Bar	D_{16}	mm		N/A
		D_{35}	mm		N/A
		D_{50}	mm		N/A
		D_{84}	mm		N/A
		D_{95}	mm		N/A
48	Largest Particle Size		mm		N/A

USFWS-SHARP COARSE WOODY DEBRIS	
Stream: St. Mary's River	Page 1 of 1
Reach: Reference Reach	Date: 8/9/2004
adapted from E.G. Robinson and R.L. Beschta. 1990	Crew: MAS & KR

Survey total = Number of LWD pieces greater than 0.65 ft (20 cm) in diameter (small end) and 4.9 ft (1.5 m) in length

Reach Length (ft) =				BF Width (ft) =				
Large end diam (ft)	Avg. diam (ft)	Length (ft)	Influence Zones	Horiz. Orient.	Rootwad instream/out	Debris Grouped / Ungrouped	Provides Grade Control	Notes (CWD location - pool, run, riffle, glide) (CWD responsible for pool formation: dominant, secondary, negligible)
0.80	0.70	18.0	1	120	In	UG	N	Run
0.90	0.80	9.0	1	180	In	UG	N	Pool-neg
0.80	0.90	11.0	1	160	In	UG	N	Pool-neg
0.90	0.70	12.0	1	90	In	UG	N	Pool-neg
0.90	0.80	7.0	1	130	In	UG	N	Run
0.90	0.80	14.0	1	160	In	UG	N	Pool-neg
1.4	1.00	15.0	1	0	In	UG	N	Pool-neg
1.9	1.60	15.0	1 2	120	In	UG	N	Pool-neg
1.1	0.80	17.0	1 2	85	In	G	N	Pool-neg
1.0	0.70	23.0	2	95	In	G	N	Pool-neg

Influence Zone and Horizontal Orientation - see back of sheet

Rootwad in/out refers to the rootwad being located in or out of the stream

Debris Grouped/Ungrouped: grouped debris is debris that is part of collection of debris, ungrouped debris is a single piece by itself

APPENDIX D – UNNAMED TRIBUTARY TO SEVERN RUN
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8. Reference Reach Data Summary
9. Coarse Woody Debris Data

UNNAMED TRIBUTARY TO SEVERN RUN, ANNE ARUNDEL COUNTY, MD

Latitude:	39º 04' 35.6"	Rosgen Stream Type:	E5
Longitude:	76º 37' 5.2"	Survey Date:	March 2005
ADC Map Coordinates:	Anne Arundel Map 14/A5		
Drainage Area (sq. mi.):	0.73		
Stream Order:	1		
Percent Imperviousness:	7.90		

Land Use (%): Residential: 30.31 Agricultural: 14.63 Forest: 54.66 Commercial: 0.40

General Study Reach Description: The study reach is located in the Severn Run Natural Environmental Area approximately 500 feet upstream of the confluence with Severn Run. The UT Severn Run watershed is surrounded by other watersheds that are highly developed. The reach is a vertically and laterally stable sand bed stream with riffle/pool features. Both the pool and riffle features contain woody debris. There are few depositional features in the channel. The floodplain consists of forested wetlands, which results in the reach having undulating banks at several locations where drainage from the wetlands enters the channel. The floodplain is densely forested with a canopy of tulip poplar, red maple, and oak. The understory consists of a dense layer of spice bush and greenbrier.

Photo 1. Looking downstream from top of reach.

Photo 2. Looking downstream from Cross Section 1.

Photo 3. Looking downstream towards Cross Section 2.

Photo 4. Looking downstream towards bottom of study reach.

Photo 5. Downstream view of monumented Cross Section 1.

Photo 6. Upstream view of monumented Cross Section 2.

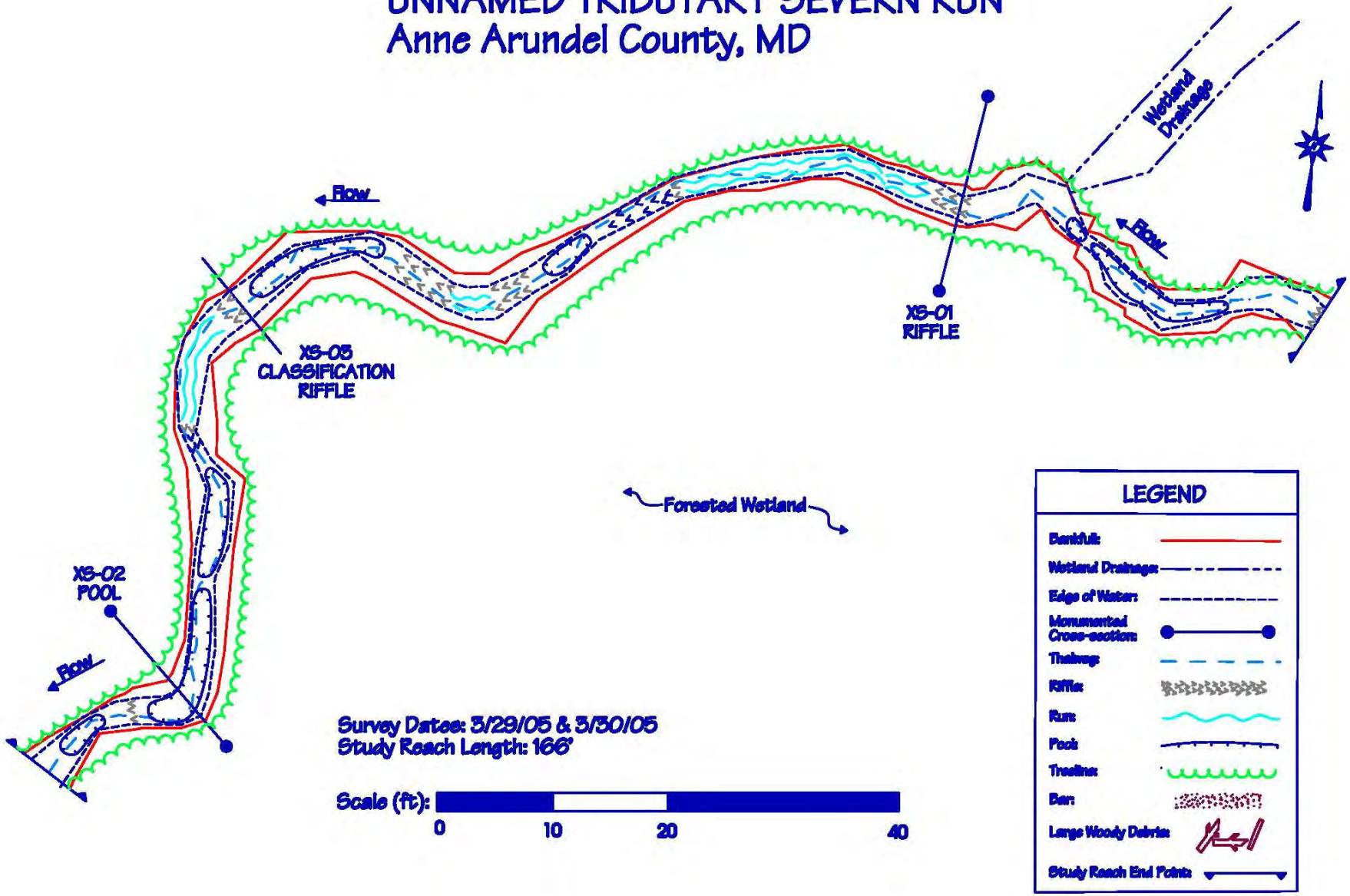
Cross Section Summary Table

	Monumented		Non-monumented
	XS-01 Riffle	**XS-02 Pool**	**XS-06 Classification Riffle**
Bankfull Width (ft)	3.66	4.25	4.74
Bankfull Cross-sectional Area (ft^2)	2.92	3.25	2.68
Hydraulic Radius (ft)	0.58	0.51	0.50
Mean Bankfull Depth (ft)	0.80	0.76	0.57
Maximum Bankfull Depth (ft)	1.07	1.11	0.92
Wetted Perimeter (ft)	5.01	6.52	5.39
Width/Depth Ratio	4.58	5.59	8.32
Entrenchment Ratio	N/A	N/A	11.81

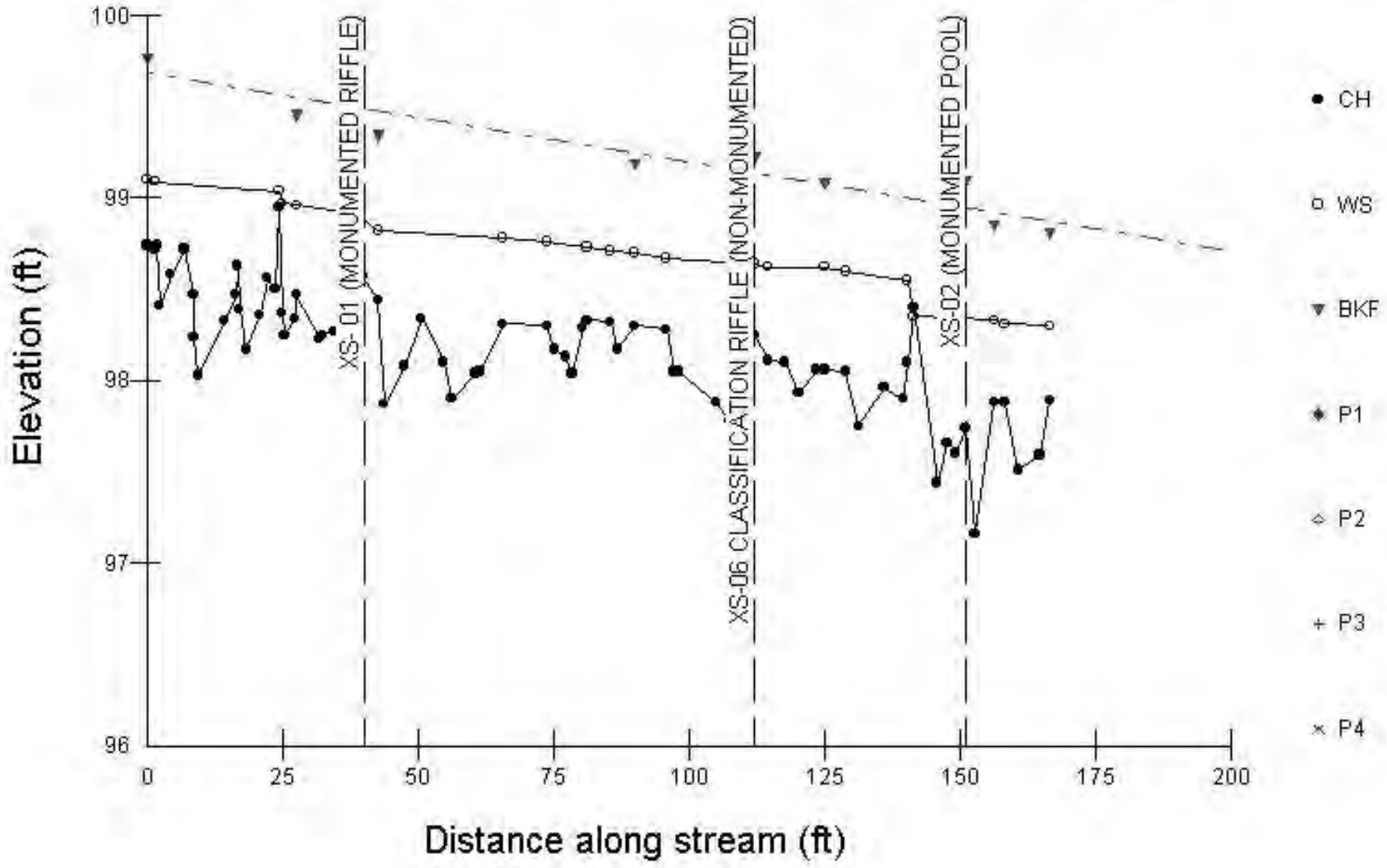
Monument Locations Table

MONUMENT	GLOBAL POSITIONING SYSTEM (GPS) COORDINATE (NAD 83)
Cross Sections	
XS-01	
Left	N: 39° 04' 34.8" (± 40.0')
	W: 76° 37' 05.7" (± 40.0')
Right	N: 39° 04' 34.5" (± 26.6')
	W: 76° 37' 05.7" (± 26.6')
XS-02	
Left	N: 39° 04' 35.6" (± 25.0')
	W: 76° 37' 05.2" (± 25.0')
Right	N: 39° 04' 35.4" (± 25.0')
	W: 76° 37' 05.4" (± 25.0')

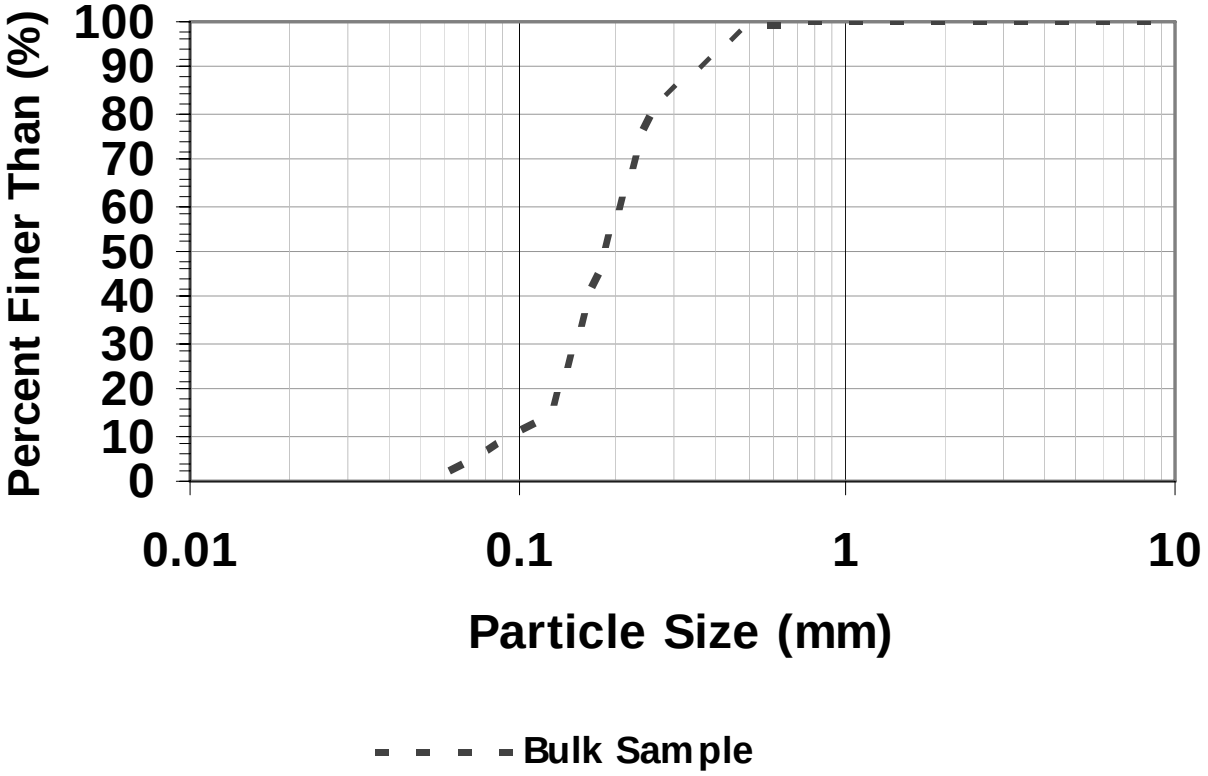
UNNAMED TRIBUTARY SEVERN RUN
Anne Arundel County, MD



UT SEVERN RUN LONGITUDINAL PROFILE



Unnamed Tributary to Severn Run Particle Size Distribution



Reference Reach Data Summary

No.	Variable	Symbol	Units	UT Severn Run	
1	Stream Type				E5
2	Drainage Area		mi^2		0.73
3	Riffle Bankfull Width	W_{bkf}	feet	Mean	3.81
				Min	2.98
				Max	4.74
4	Riffle Bankfull Mean Depth	d_{bkf}	feet	Mean	0.64
				Min	0.42
				Max	0.82
5	Width Depth Ratio	W/d		Mean	6.38
				Min	3.63
				Max	10.40
6	Riffle Bankfull Cross-Sectional Area	A_{bkf}	ft^2	Mean	2.38
				Min	1.83
				Max	2.92
7	Pool Bankfull Cross-Sectional Area	A_{pool}	ft^2	Mean	3.53
				Min	2.69
				Max	4.66
8	Riffle Bankfull Maximum Depth	d_{max}	feet	Mean	0.97
				Min	0.87
				Max	1.07
9	Max Riffle Depth/ Mean Riffle Depth	d_{riff}/d_{bkf}		Mean	1.70
				Min	1.53
				Max	1.88
10	Low Bank Height to Max D_{bkf} Ratio	LBH/d_{riff}		Mean	1.00
				Min	N/A
				Max	N/A
11	Width of Flood Prone Area	W_{fpa}	feet	Mean	56.00
				Min	N/A
				Max	N/A
12	Entrenchment Ratio	W_{fpa}/W_{bkf}		Mean	11.81
				Min	N/A
				Max	N/A
13	Straight Meander Length	L_m	feet	Mean	30.94
				Min	16.73
				Max	44.05
14	Straight Meander Length / Bankfull Width	L_m/W_{bkf}		Mean	6.53
				Min	3.53
				Max	9.29
15	Stream Meander Length	L_λ	feet	Mean	37.50
				Min	19.00
				Max	52.00
16	Stream Meander Length / Bankfull Width	L_λ/W_{bkf}		Mean	3.64
				Min	1.84
				Max	5.04
17	Radius of Curvature	R_c	feet	Mean	8.62
				Min	4.75
				Max	14.86
18	Radius of Curvature / Bankfull Width	R_c/W_{bkf}		Mean	1.82
				Min	1.00
				Max	3.14
19	Belt Width	W_{blt}	feet	Mean	26.34
				Min	12.44
				Max	40.23

Reference Reach Data Summary

No.	Variable	Symbol	Units	UT Severn Run	
20	Meander Width Ratio	W_{blt}/W_{bkf}		Mean	5.56
				Min	2.62
				Max	8.49
21	Sinuosity	K			1.43
22	Valley Slope	S_{val}	ft/ft		0.0068
23	Average Water Surface Slope	S_{avg}	ft/ft		0.0048
24	Pool Water Surface Slope	S_{pool}	ft/ft	Mean	0.0024
				Min	0.0010
				Max	0.0043
25	Pool WS Slope / Average WS Slope	S_{pool}/S_{avg}		Mean	0.51
				Min	0.21
				Max	0.90
26	Riffle Water Surface Slope	S_{riff}	ft/ft	Mean	0.0067
				Min	0.0047
				Max	0.0100
27	Riffle WS Slope / Average WS Slope	S_{riff}/S_{avg}		Mean	1.40
				Min	0.97
				Max	2.07
28	Run WS Slope	S_{run}	ft/ft	Mean	0.0031
				Min	0.0010
				Max	0.0069
29	Run WS Slope / Average WS Slope	S_{run}/S_{avg}		Mean	0.65
				Min	0.21
				Max	1.44
30	Glide WS Slope	S_{glide}	ft/ft	Mean	0.0040
				Min	0.0019
				Max	0.0057
31	Glide WS Slope / Average WS Slope	S_{glide}/S_{avg}		Mean	0.84
				Min	0.40
				Max	1.19
32	Maximum Pool Depth	d_{pool}	feet	Mean	1.45
				Min	1.26
				Max	1.78
33	Ratio of Max Pool Depth to Average Bankfull Depth	d_{pool}/d_{bkf}		Mean	2.55
				Min	2.21
				Max	3.12
34	Max Run Depth	d_{run}	feet	Mean	1.12
				Min	1.04
				Max	1.28
35	Ratio of Max Run Depth to Average Bankfull Depth	d_{run}/d_{bkf}		Mean	1.97
				Min	1.82
				Max	2.25
36	Max Glide Depth	d_{glide}	feet	Mean	1.11
				Min	1.02
				Max	1.19
37	Ratio of Max Glide Depth to Average Bankfull Depth	d_{glide}/d_{bkf}		Mean	1.95
				Min	1.79
				Max	2.09
38	Pool Length	L_{pool}	feet	Mean	13.56
				Min	7.35
				Max	22.99
39	Ratio of Pool Length to Bankfull Width	L_{pool}/W_{bkf}		Mean	2.86
				Min	1.55
				Max	4.85

Reference Reach Data Summary

No.	Variable	Symbol	Units	UT Severn Run	
40	Pool Width	W_{pool}	feet	Mean	5.25
				Min	4.25
				Max	6.21
41	Ratio of Pool Width to Bankfull Width	W_{pool}/W_{bkf}		Mean	1.11
				Min	0.90
				Max	1.31
42	Ratio of Pool Area to Bankfull Area	A_{pool}/A_{bkf}		Mean	1.32
				Min	1.00
				Max	1.74
43	Point Bar Slope	S_{pb}	ft/ft	Mean	N/A
				Min	N/A
				Max	N/A
44	Pool to Pool Spacing	p-p	feet	Mean	28.98
				Min	12.62
				Max	61.01
45	Ratio of Pool to Pool Spacing to Bankfull Width	$p\text{-}p/W_{bkf}$		Mean	6.11
				Min	2.66
				Max	12.87
Materials					
46	Particle Size Distribution - Channel	D_{16}	mm		N/A
		D_{35}	mm		N/A
		D_{50}	mm		N/A
		D_{84}	mm		N/A
		D_{95}	mm		N/A
47	Particle Size Distribution - Riffle	D_{16}	mm		N/A
		D_{35}	mm		N/A
		D_{50}	mm		N/A
		D_{84}	mm		N/A
		D_{95}	mm		N/A
48	Particle Size Distribution - Bar	D_{16}	mm		0.26
		D_{35}	mm		0.33
		D_{50}	mm		0.39
		D_{84}	mm		0.61
		D_{95}	mm		0.90
49	Largest Particle Size		mm		N/A

USFWS-SHARP COARSE WOODY DEBRIS	
Stream: Unnamed Tributary to Severn Run	Page 1 of 1
Reach: Reference Reach	Date: 6/1/2005
adapted from E.G. Robinson and R.L. Beschta. 1990	Crew: MAS & TLM

Survey total = Number of LWD pieces greater than 0.65 ft (20 cm) in diameter (small end) and 4.9 ft (1.5 m) in length

Reach Length (ft) = 166				BF Width (ft) = 5				
Large end diam (ft)	Avg. diam (ft)	Length (ft)	Influence Zones	Horiz. Orient.	Rootwad instream/out	Debris Grouped / Ungrouped	Provides Grade Control	Notes (CWD location - pool, run, riffle, glide) (CWD responsible for pool formation: dominant, secondary, negligible)
0.70	0.50	4.2	1 2	140	Out	UG	N	Pool-second

Influence Zone and Horizontal Orientation - see back of sheet

Rootwad in/out refers to the rootwad being located in or out of the stream

Debris Grouped/Ungrouped: grouped debris is debris that is part of collection of debris, ungrouped debris is a single piece by itself

APPENDIX E – HILTON RUN
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1. Summary Sheet
2. Reach Photos
3. Cross Section Photos
4. Cross Section Summary Data
5. Site Map
6. Longitudinal Profile Plot
7. Particle Size Distribution Plot
8. Reference Reach Data Summary
9. Coarse Woody Debris Data

HILTON RUN, ST. MARY'S COUNTY, MD

Drainage Area (sq. mi.):	2.40	Rosgen Stream Type:	E4
Stream Order:	2	Survey Date:	March 2005
Percent Imperviousness:	18.6		

Land Use (%): Residential: 21.76 Agricultural: 10.76 Forest: 57.31 Commercial: 10.17

General Study Reach Description: The study reach is located on private property approximately 4500 feet upstream of Point Lookout Road. The gravel bed stream is vertically and laterally stable with riffle/pool features. Both the pool and riffle features contain woody debris. There are few depositional features in the channel. The floodplain consists of forested wetlands, which results in the reach having undulating banks and several locations in which drainage from the wetlands enters the channel. The floodplain is densely forested with a canopy of tulip poplar, red maple, and oak. The understory consists of a sparse layer of holly and greenbrier. Map and GPS coordinates are not provided for sites located on private property.

Photo 1. Looking downstream from top of study reach.

Photo 2. Looking downstream from monumented Cross Section 4

Photo 3. Looking downstream at bottom of study reach.

Photo 4. Downstream view of monumented Cross Section 1.

Photo 5. Upstream view of monumented classification Cross Section 2.

Photo 6. Downstream view of monumented Cross Section 3.

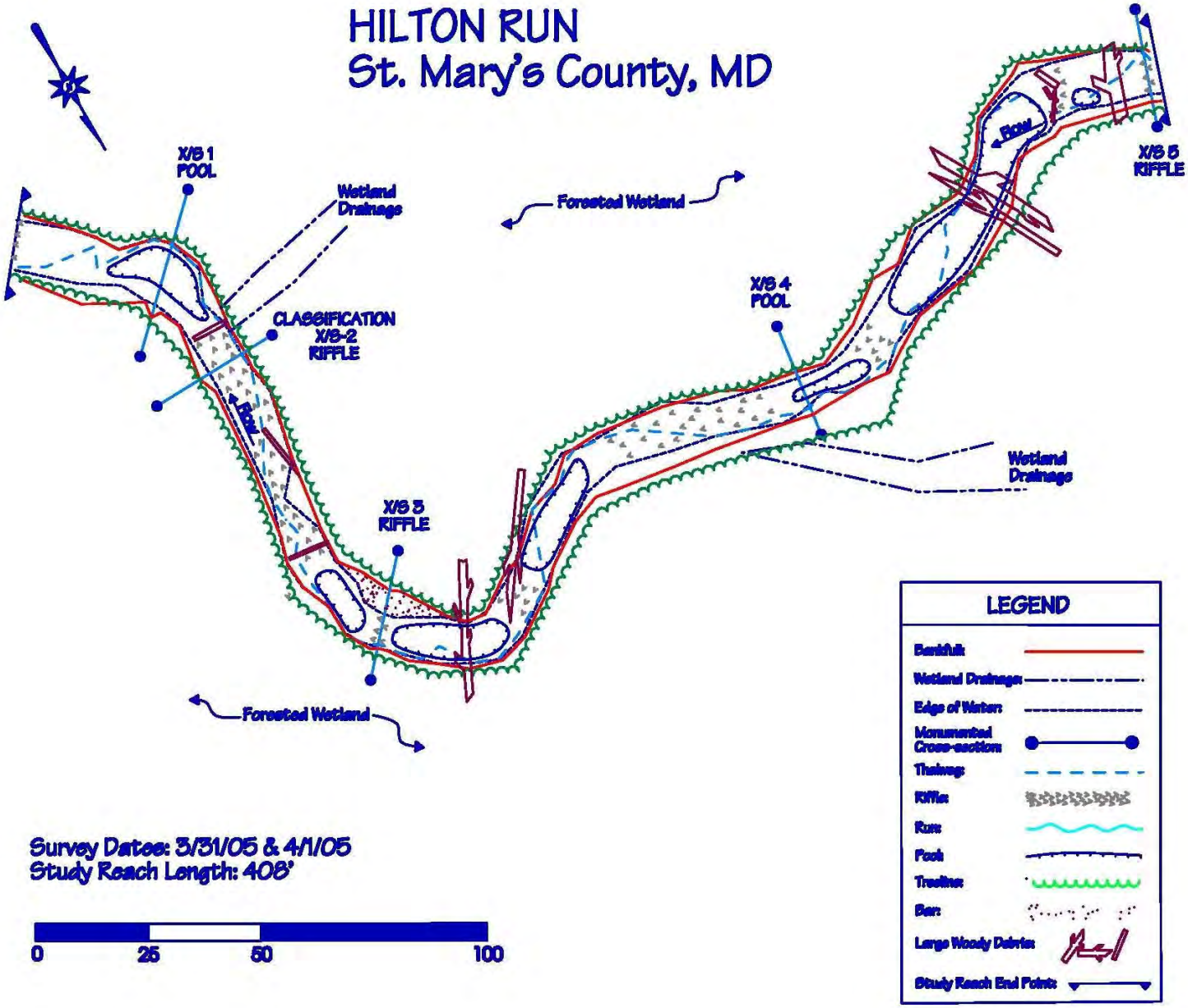
Photo 7. Downstream view of monumented Cross Section 4.

Photo 8. Upstream view of monumented Cross Section 5.

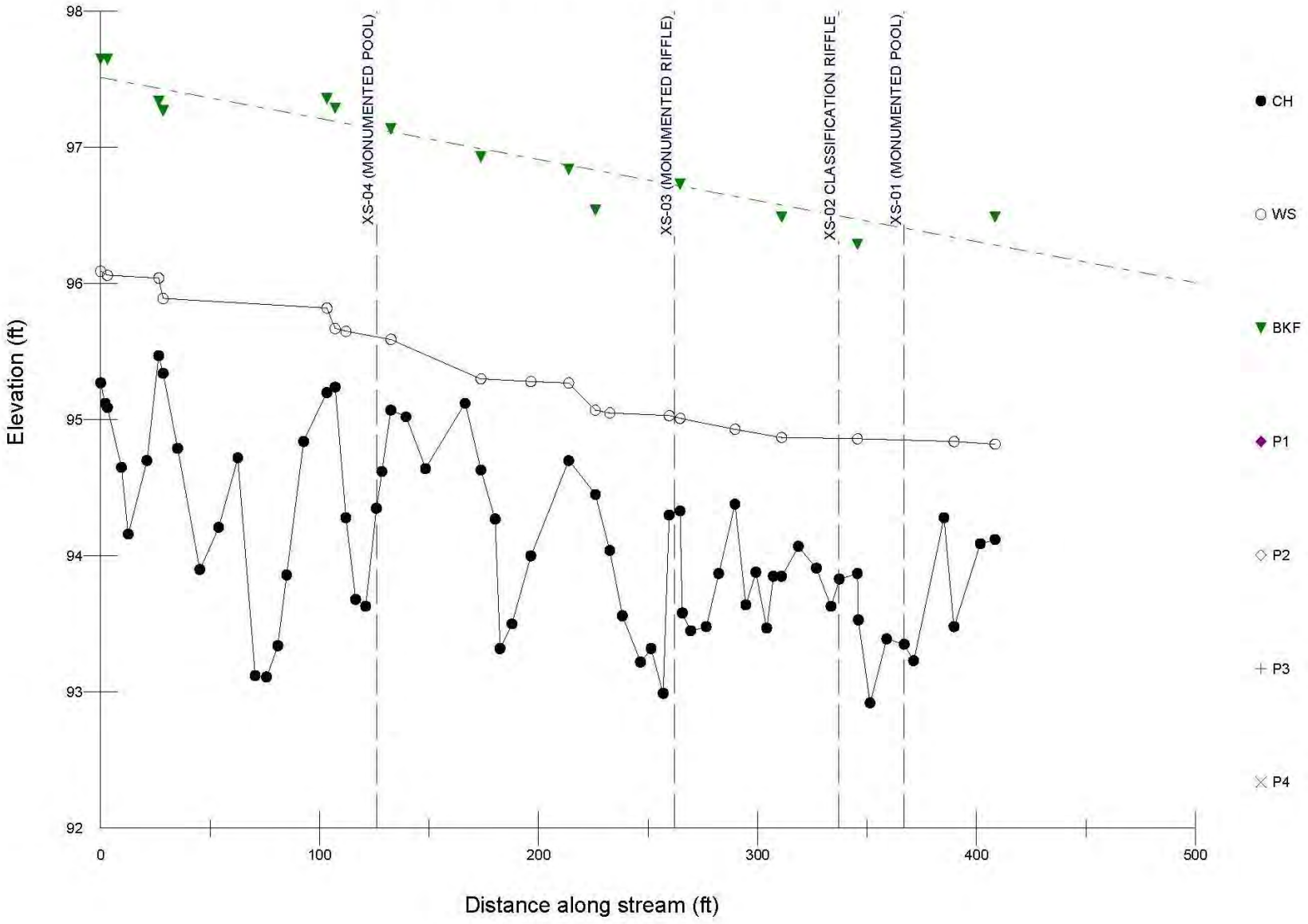
Cross Section Summary Table

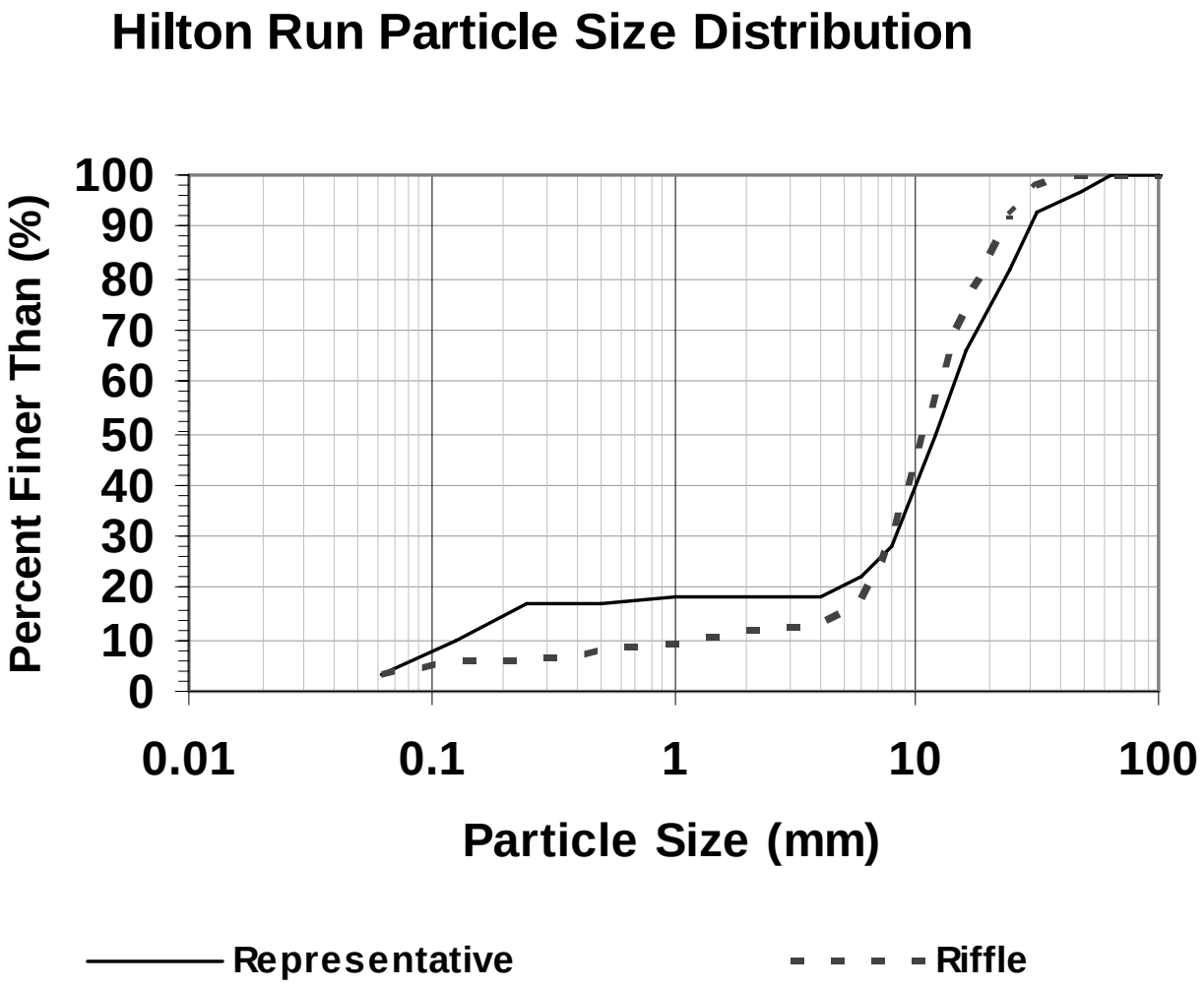
	Monumented				
	XS-01 Pool	**XS-02 Classification Riffle**	**XS-03 Riffle**	**XS-04 Pool**	**XS-05 Riffle**
Bankfull Width (ft)	17.10	10.31	13.09	11.21	12.34
Bankfull Cross-sectional Area (ft^2)	38.69	18.33	21.35	21.91	25.85
Hydraulic Radius (ft)	1.77	1.27	1.32	1.24	1.51
Mean Bankfull Depth (ft)	2.26	1.78	1.63	1.95	2.09
Maximum Bankfull Depth (ft)	2.97	2.65	2.50	2.77	2.78
Wetted Perimeter (ft)	21.90	14.43	16.19	17.71	17.10
Width/Depth Ratio	7.57	5.79	8.03	5.75	5.90
Entrenchment Ratio	N/A	22.21	N/A	N/A	N/A

HILTON RUN
St. Mary's County, MD



HILTON RUN LONGITUDINAL PROFILE




Hilton Run Particle Size Distribution
Percent Finer Than (%)
100
90
80
70
60
50
40
30
20
10
0
0.01
0.1
1
10
100
Particle Size (mm)
Representative
Riffle

Reference Reach Data Summary

No.	Variable	Symbol	Units	Hilton Run	
1	Stream Type				E4
2	Drainage Area		mi^2		2.40
3	Riffle Bankfull Width	W_{bkf}	feet	Mean	11.91
				Min	10.31
				Max	13.09
4	Riffle Bankfull Mean Depth	d_{bkf}	feet	Mean	1.83
				Min	1.63
				Max	2.09
5	Width Depth Ratio	W/d		Mean	6.58
				Min	5.79
				Max	8.03
6	Riffle Bankfull Cross-Sectional Area	A_{bkf}	ft^2	Mean	21.84
				Min	18.33
				Max	25.85
7	Pool Bankfull Cross-Sectional Area	A_{pool}	ft^2	Mean	29.31
				Min	21.91
				Max	38.69
8	Riffle Bankfull Maximum Depth	d_{max}	feet	Mean	2.64
				Min	2.50
				Max	2.78
9	Max Riffle Depth/ Mean Riffle Depth	d_{riff}/d_{bkf}		Mean	1.49
				Min	1.40
				Max	1.56
10	Low Bank Height to Max D_{bkf} Ratio	LBH/d_{riff}		Mean	1.00
				Min	N/A
				Max	N/A
11	Width of Flood Prone Area	W_{fpa}	feet	Mean	229
				Min	N/A
				Max	N/A
12	Entrenchment Ratio	W_{fpa}/W_{bkf}		Mean	22.21
				Min	N/A
				Max	N/A
13	Straight Meander Length	L_m	feet	Mean	104.87
				Min	61.96
				Max	132.16
14	Straight Meander Length / Bankfull Width	L_m/W_{bkf}		Mean	10.17
				Min	6.01
				Max	12.82
15	Stream Meander Length	L_λ	feet	Mean	127.25
				Min	93.00
				Max	155.00
16	Stream Meander Length / Bankfull Width	L_λ/W_{bkf}		Mean	12.34
				Min	9.02
				Max	15.03
17	Radius of Curvature	R_c	feet	Mean	27.10
				Min	18.60
				Max	43.08
18	Radius of Curvature / Bankfull Width	R_c/W_{bkf}		Mean	2.63
				Min	1.80
				Max	4.18
19	Belt Width	W_{blt}	feet	Mean	83.02
				Min	33.02
				Max	133.02

Reference Reach Data Summary

No.	Variable	Symbol	Units	Hilton Run	
20	Meander Width Ratio	W_{blt}/W_{bkf}		Mean	8.05
				Min	3.20
				Max	12.90
21	Sinuosity	K			1.60
22	Valley Slope	S_{val}	ft/ft		0.0050
23	Average Water Surface Slope	S_{avg}	ft/ft		0.0031
24	Pool Water Surface Slope	S_{pool}	ft/ft	Mean	0.0017
				Min	0.0004
				Max	0.0031
25	Pool WS Slope / Average WS Slope	S_{pool}/S_{avg}		Mean	0.55
				Min	0.13
				Max	1.01
26	Riffle Water Surface Slope	S_{riff}	ft/ft	Mean	0.0047
				Min	0.0030
				Max	0.0071
27	Riffle WS Slope / Average WS Slope	S_{riff}/S_{avg}		Mean	1.51
				Min	0.97
				Max	2.27
28	Run WS Slope	S_{run}	ft/ft	Mean	0.0022
				Min	0.0012
				Max	0.0037
29	Run WS Slope / Average WS Slope	S_{run}/S_{avg}		Mean	0.69
				Min	0.39
				Max	1.19
30	Glide WS Slope	S_{glide}	ft/ft	Mean	0.0013
				Min	0.0006
				Max	0.0025
31	Glide WS Slope / Average WS Slope	S_{glide}/S_{avg}		Mean	0.43
				Min	0.19
				Max	0.80
32	Maximum Pool Depth	d_{pool}	feet	Mean	3.59
				Min	3.25
				Max	4.19
33	Ratio of Max Pool Depth to Average Bankfull Depth	d_{pool}/d_{bkf}		Mean	2.02
				Min	1.83
				Max	2.35
34	Max Run Depth	d_{run}	feet	Mean	2.48
				Min	2.35
				Max	2.62
35	Ratio of Max Run Depth to Average Bankfull Depth	d_{run}/d_{bkf}		Mean	1.39
				Min	1.32
				Max	1.47
36	Max Glide Depth	d_{glide}	feet	Mean	2.35
				Min	2.19
				Max	2.55
37	Ratio of Max Glide Depth to Average Bankfull Depth	d_{glide}/d_{bkf}		Mean	1.32
				Min	1.23
				Max	1.43
38	Pool Length	L_{pool}	feet	Mean	39.85
				Min	17.02
				Max	74.79
39	Ratio of Pool Length to Bankfull Width	L_{pool}/W_{bkf}		Mean	3.87
				Min	1.65
				Max	7.25

Reference Reach Data Summary

No.	Variable	Symbol	Units	Hilton Run	
40	Pool Width	W_{pool}	feet	Mean	12.67
				Min	10.75
				Max	17.10
41	Ratio of Pool Width to Bankfull Width	W_{pool}/W_{bkf}		Mean	1.23
				Min	1.04
				Max	1.66
42	Ratio of Pool Area to Bankfull Area	A_{pool}/A_{bkf}		Mean	1.60
				Min	1.20
				Max	2.11
43	Point Bar Slope	S_{pb}	ft/ft	Mean	N/A
				Min	N/A
				Max	N/A
44	Pool to Pool Spacing	p-p	feet	Mean	58.75
				Min	41.73
				Max	80.07
45	Ratio of Pool to Pool Spacing to Bankfull Width	$p\text{-}p/W_{bkf}$		Mean	5.70
				Min	4.05
				Max	7.77
Materials					
45	Particle Size Distribution - Channel	D_{16}	mm		0.23
		D_{35}	mm		9.05
		D_{50}	mm		11.30
		D_{84}	mm		24.31
		D_{95}	mm		38.50
46	Particle Size Distribution - Riffle	D_{16}	mm		5.34
		D_{35}	mm		8.63
		D_{50}	mm		10.42
		D_{84}	mm		19.43
		D_{95}	mm		27.22
48	Particle Size Distribution - Bar	D_{16}	mm		N/A
		D_{35}	mm		N/A
		D_{50}	mm		N/A
		D_{84}	mm		N/A
		D_{95}	mm		N/A
49	Largest Particle Size		mm		N/A

USFWS-SHARP COARSE WOODY DEBRIS	
Stream: Hilton Run	Page 1 of 1
Reach: Reference Reach	Date: 6/3/2005
adapted from E.G. Robinson and R.L. Beschta. 1990	Crew: MAS & SD

Survey total = Number of LWD pieces greater than 0.65 ft (20 cm) in diameter (small end) and 4.9 ft (1.5 m) in length

Reach Length (ft) = 408				BF Width (ft) = 12				
Large end diam (ft)	Avg. diam (ft)	Length (ft)	Influence Zones	Horiz. Orient.	Rootwad instream/out	Debris Grouped / Ungrouped	Provides Grade Control	Notes (CWD location - pool, run, riffle, glide) (CWD responsible for pool formation: dominant, secondary, negligible)
1.2	0.9	45.0	1 2 3 4	90	Out	G	N	Pool - neg
1.0	0.8	13.0	1 2	90	Out	G	Y	Pool - sec
1.0	0.8	16.5	1 2 3 4	90	Out	G	N	Pool - neg
1.4	1.4	22.8	2 3 4	60	Out	G	N	Pool - neg
0.9	0.5	7.2	1	90	Out	UG	N	Riffle
0.7	0.6	29.5	1 2 3 4	70	In	UG	N	Pool - neg
1.0	1.0	8.0	3 4	90	Out	UG	N	Pool - neg
0.8	0.8	11.0	1 2 3	90	Out	UG	N	Pool - neg

Influence Zone and Horizontal Orientation - see back of sheet

Rootwad in/out refers to the rootwad being located in or out of the stream

Debris Grouped/Ungrouped: grouped debris is debris that is part of collection of debris, ungrouped debris is a single piece by itself

APPENDIX F – UNNAMED TRIBUTARY TO HOGHOLE RUN
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1. Summary Sheet
2. Reach Photos
3. Cross Section Photos
4. Cross Section Summary Data
5. Site Map
6. Longitudinal Profile Plot
7. Particle Size Distribution Plot
8. Reference Reach Data Summary

UNNAMED TRIBUTARY TO HOGHOLE RUN, CHARLES COUNTY, MD

Latitude:	38° 31' 18.4"	Rosgen Stream Type:	B4
Longitude:	77° 2' 10.6"	Survey Date:	June 2008
ADC Map Coordinates:	Charles County Map 16/G7		
Drainage Area (sq. mi.):	0.15		
Stream Order:	1		
Percent Imperviousness:	4.2		

Land Use (%): Urban: 0.00 Low Density: 17.00 Agricultural: 13.15 Forest: 69.85

General Study Reach Description: The Unnamed Tributary to Hoghole Run study reach is approximately 112 feet and is located in the Thomas Stone National Historical site. Unnamed Tributary to Hoghole Run is a gravel bed stream that consists of riffle/step/pool features. The step features are formed from tree roots and located downstream of riffle features. A well-developed bankfull bench is present in the less entrenched sections of the stream. In these sections, the cross sectional characteristics are similar to an E stream type. These areas, with higher entrenchment ratios, are most likely associated with past localized disturbances that resulted in channel aggradation. Unnamed Tributary to Hoghole Run is both vertically and laterally stable. Despite being forested, the stream contains little woody debris with the exception of the steps that are formed from tree roots. The floodplain consists of forested wetlands, consisting mainly of oak and tulip poplar. The understory is sparse with American holly.

Photo 1. Looking upstream at top of study reach.

Photo 2. Looking upstream from the second step feature.

Photo 3. Looking downstream at riffle classification cross section.

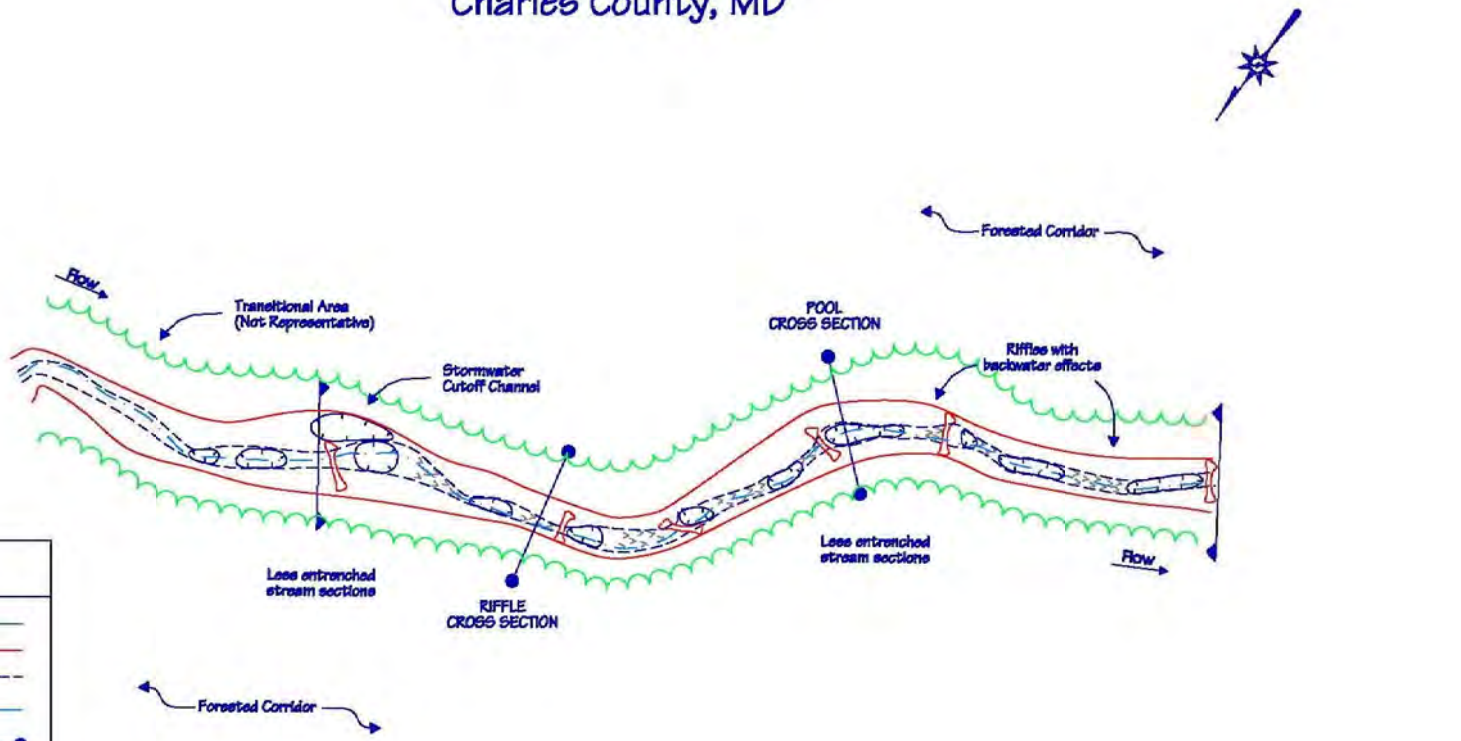
Photo 4. Looking upstream from the sixth step feature with the lower entrenched section in the background.

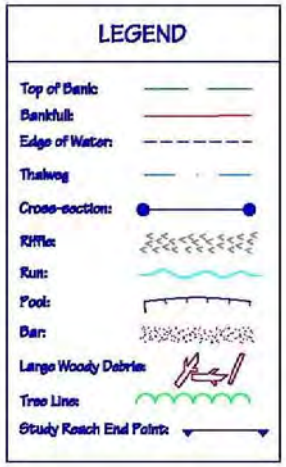
Photo 5. Looking upstream at downstream end of study reach.

Cross Section Summary Table

	XS-01 Riffle	XS-02 Classification Riffle	XS-03 Riffle	XS-03 Pool	XS-04 Pool	XS-05 Pool
Bankfull Width (ft)	5.21	6.27	5.48	4.62	6.50	6.00
Bankfull Cross-sectional Area (ft^2)	3.92	3.92	3.90	5.02	4.14	4.76
Hydraulic Radius (ft)	0.62	0.59	0.61	0.71	0.56	0.70
Mean Bankfull Depth (ft)	0.75	0.63	0.71	1.09	0.64	0.79
Maximum Bankfull Depth (ft)	1.02	0.96	1.05	2.38	1.41	1.21
Wetted Perimeter (ft)	6.31	6.71	6.36	7.04	7.46	6.76
Width/Depth Ratio	6.95	9.95	7.72	4.24	10.16	7.59
Entrenchment Ratio	N/A	1.52	N/A	N/A	N/A	N/A

UNNAMED TRIBUTARY TO HOGHOLE RUN
Charles County, MD

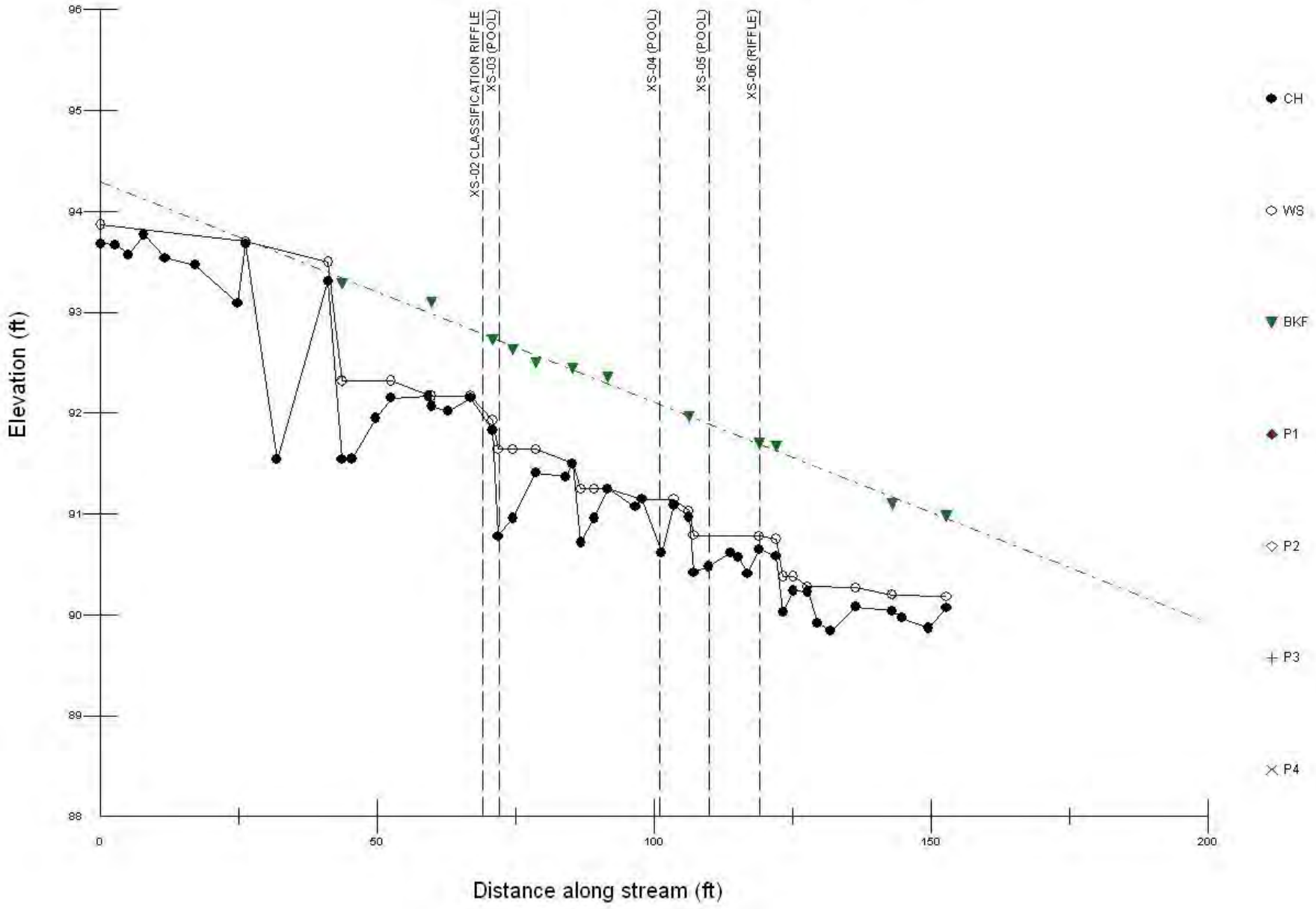


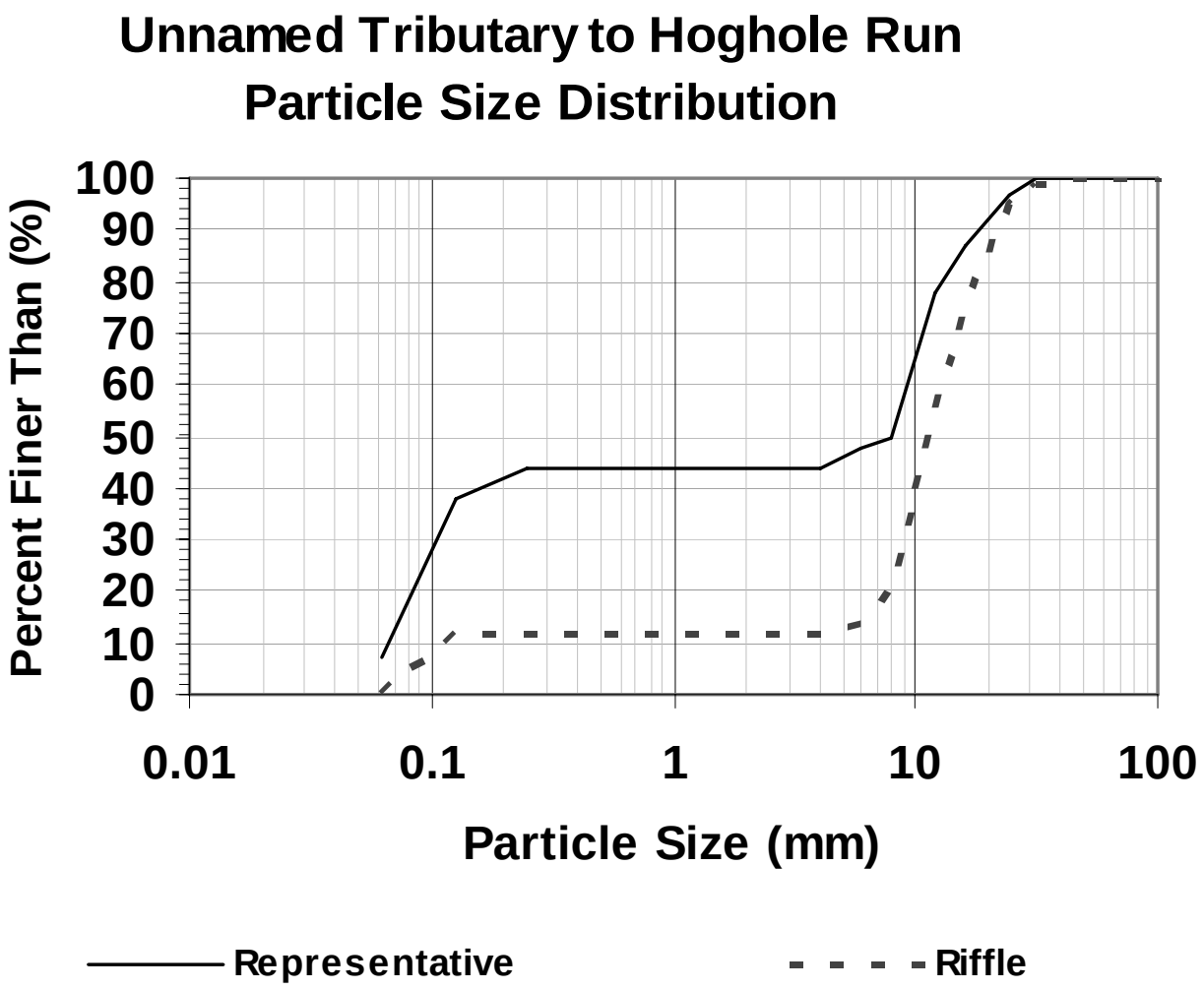


Survey Dates: 06/18/08 & 06/19/08
Study Reach Length: 112'

Scale (ft): 0 25 50

UT HOGHOLE RUN LONGITUDINAL PROFILE




Unnamed Tributary to Hoghole Run
Particle Size Distribution
Percent Finer Than (%)
100
90
80
70
60
50
40
30
20
10
0
0.01
0.1
1
10
100
Particle Size (mm)
Representative
Riffle

Reference Reach Data Summary

No.	Variable	Symbol	Units	UT Hoghole Run	
1	Stream Type				B4
2	Drainage Area		mi^2		0.15
3	Riffle Bankfull Width	W_{bkf}	feet	Mean	5.65
				Min	5.21
				Max	6.27
4	Riffle Bankfull Mean Depth	d_{bkf}	feet	Mean	0.70
				Min	0.63
				Max	0.75
5	Width Depth Ratio	W/d		Mean	8.21
				Min	6.95
				Max	9.95
6	Riffle Bankfull Cross-Sectional Area	A_{bkf}	ft^2	Mean	3.91
				Min	3.90
				Max	3.92
7	Pool Bankfull Cross -Sectional Area	A_{pool}	ft^2	Mean	4.64
				Min	4.14
				Max	5.02
8	Riffle Bankfull Maximum Depth	d_{max}	feet	Mean	1.01
				Min	0.96
				Max	1.05
9	Max Riffle Depth/ Mean Riffle Depth	d_{riff}/d_{bkf}		Mean	1.60
				Min	1.52
				Max	1.67
10	Low Bank Height to Max D_{bkf} Ratio	LBH/d_{riff}		Mean	1.00
				Min	1.00
				Max	1.00
11	Width of Flood Prone Area	W_{fpa}	feet	Mean	10.24
				Min	9.50
				Max	11.01
12	Entrenchment Ratio	W_{fpa}/W_{bkf}		Mean	1.83
				Min	1.52
				Max	2.01
13	Straight Meander Length	L_m	feet	Mean	N/A
				Min	N/A
				Max	N/A
14	Straight Meander Length / Bankfull Width	L_m/W_{bkf}		Mean	N/A
				Min	N/A
				Max	N/A
15	Stream Meander Length	L_λ	feet	Mean	N/A
				Min	N/A
				Max	N/A
16	Stream Meander Length / Bankfull Width	L_λ/W_{bkf}		Mean	N/A
				Min	N/A
				Max	N/A
17	Radius of Curvature	R_c	feet	Mean	18.43
				Min	16.60
				Max	20.25
18	Radius of Curvature / Bankfull Width	R_c/W_{bkf}		Mean	2.94
				Min	2.65
				Max	3.23
19	Belt Width	W_{blt}	feet	Mean	19.90
				Min	19.90
				Max	19.90

Reference Reach Data Summary

No.	Variable	Symbol	Units	UT Hoghole Run	
20	Meander Width Ratio	W_{blt}/W_{bkf}		Mean	3.17
				Min	3.17
				Max	3.17
21	Sinuosity	K			1.51
22	Valley Slope	S_{val}	ft/ft		0.031
23	Average Water Surface Slope	S_{avg}	ft/ft		0.021
24	Pool Water Surface Slope	S_{pool}	ft/ft	Mean	0.0006
				Min	0.0001
				Max	0.0016
25	Pool WS Slope / Average WS Slope	S_{pool}/S_{avg}		Mean	0.028
				Min	0.005
				Max	0.074
26	Riffle Water Surface Slope	S_{riff}	ft/ft	Mean	0.032
				Min	0.016
				Max	0.058
27	Riffle WS Slope / Average WS Slope	S_{rifF}/S_{avg}		Mean	1.47
				Min	0.74
				Max	2.72
28	Step WS Slope	S_{step}	ft/ft	Mean	0.27
				Min	0.16
				Max	0.34
29	Step WS Slope / Average WS Slope	S_{step}/S_{avg}		Mean	12.63
				Min	7.43
				Max	15.68
30	Run WS Slope	S_{run}	ft/ft	Mean	0.0017
				Min	0.0017
				Max	0.0017
31	Run WS Slope / Average WS Slope	S_{run}/S_{avg}		Mean	0.08
				Min	0.08
				Max	0.08
32	Glide WS Slope	S_{glide}	ft/ft	Mean	0.0007
				Min	0.0001
				Max	0.0026
33	Glide WS Slope / Average WS Slope	S_{glide}/S_{avg}		Mean	0.033
				Min	0.005
				Max	0.12
34	Maximum Pool Depth	d_{pool}	feet	Mean	1.49
				Min	0.90
				Max	1.91
35	Ratio of Max Pool Depth to Average Bankfull Depth	d_{pool}/d_{bkf}		Mean	2.44
				Min	1.43
				Max	3.03
36	Max Run Depth	d_{run}	feet	Mean	1.13
				Min	0.87
				Max	1.37
37	Ratio of Max Run Depth to Average Bankfull Depth	d_{run}/d_{bkf}		Mean	1.79
				Min	1.38
				Max	2.17
38	Max Glide Depth	d_{glide}	feet	Mean	1.27
				Min	1.15
				Max	1.45
39	Ratio of Max Glide Depth to Average Bankfull Depth	d_{glide}/d_{bkf}		Mean	2.02
				Min	1.83
				Max	2.30

Reference Reach Data Summary

No.	Variable	Symbol	Units	UT Hoghole Run	
40	Max Step Depth	D_{step}	feet	Mean	0.96
				Min	0.90
				Max	1.06
41	Ratio of Max Step Depth to Average Bankfull Depth	D_{step}/d_{bkf}		Mean	1.53
				Min	1.43
				Max	1.68
42	Pool Length	L_{pool}	feet	Mean	7.59
				Min	4.85
				Max	11.86
43	Ratio of Pool Length to Bankfull Width	L_{pool}/W_{bkf}		Mean	1.19
				Min	0.77
				Max	1.89
44	Pool Width	W_{pool}	feet	Mean	5.71
				Min	4.62
				Max	6.50
45	Ratio of Pool Width to Bankfull Width	W_{pool}/W_{bkf}		Mean	0.91
				Min	0.74
				Max	1.04
46	Ratio of Pool Area to Bankfull Area	A_{pool}/A_{bkf}		Mean	1.18
				Min	1.06
				Max	1.28
47	Point Bar Slope	S_{pb}	ft/ft	Mean	N/A
				Min	N/A
				Max	N/A
48	Pool to Pool Spacing	p-p	feet	Mean	12.59
				Min	7.89
				Max	16.70
49	Ratio of Pool to Pool Spacing to Bankfull Width	$p\text{-}p/W_{bkf}$		Mean	2.01
				Min	1.26
				Max	2.66
Materials					
50	Particle Size Distribution - Channel	D_{16}	mm		6.47
		D_{35}	mm		9.41
		D_{50}	mm		10.83
		D_{84}	mm		18.78
		D_{95}	mm		22.60
51	Particle Size Distribution - Riffle	D_{16}	mm		0.08
		D_{35}	mm		0.12
		D_{50}	mm		8.00
		D_{84}	mm		14.43
		D_{95}	mm		21.28
52	Particle Size Distribution - Bar	D_{16}	mm		N/A
		D_{35}	mm		N/A
		D_{50}	mm		N/A
		D_{84}	mm		N/A
		D_{95}	mm		N/A
53	Largest Particle Size		mm		N/A

APPENDIX G – WOLF DEN BRANCH
TABLE OF CONTENTS

1. Summary Sheet
2. Reach Photos
3. Cross Section Photos
4. Cross Section Summary Data
5. Site Map
6. Longitudinal Profile Plot
7. Particle Size Distribution Plot
8. Reference Reach Data Summary

WOLF DEN BRANCH, CHARLES COUNTY, MD

Latitude:	38° 38' 22.5"	Rosgen Stream Type:	E4
Longitude:	76° 49' 9.4"	Survey Date:	September 2008
ADC Map Coordinates:	Charles County Map 5/J12		
Drainage Area (sq. mi.):	2.0		
Stream Order:	2		
Percent Imperviousness:	5.8		

Land Use (%): Urban: 9.1 Agricultural: 9.5 Forest: 65.8

General Study Reach Description: Wolf Den Branch is a gravel bed stream located in the Cedarville State Forest. The study reach is 335 feet long and consists of riffle/pool features. Wolf Den Branch is laterally stable; however, it exhibits some localized vertical instability. There are lateral bars throughout the majority of the reach, and it is also slightly incised. The floodplain is densely forested, with an overstory consisting of oak, maples, and tulip poplar. The understory is made up of layers of holly and viburnum and there is a dense ground cover of fern.

Photo 1. Looking downstream from top of study reach.

Photo 2. Looking downstream from third riffle.

Photo 3. Looking downstream toward middle of reach.

Photo 4. Looking downstream at bottom of study reach.

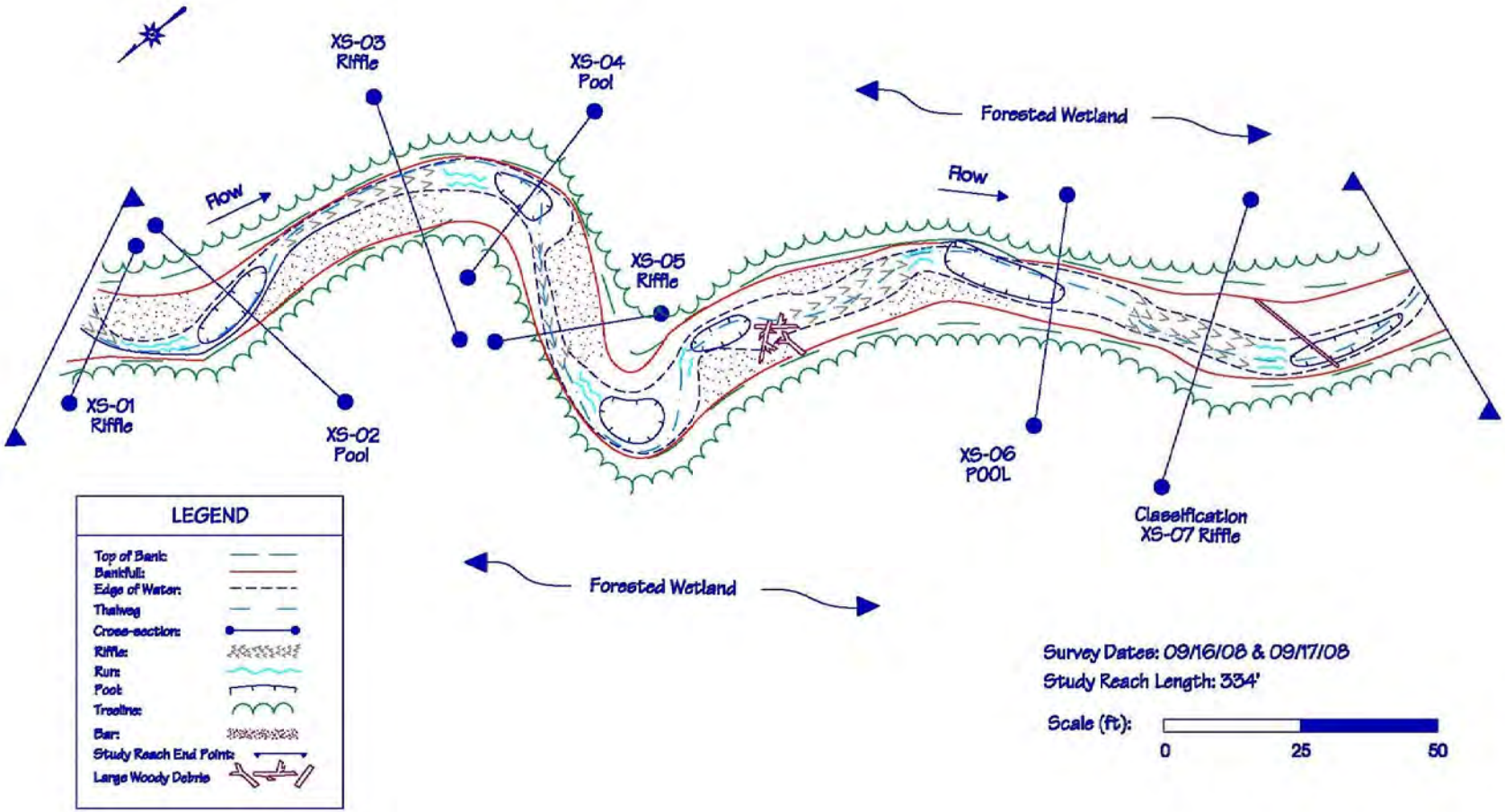
Photo 5. Upstream view of classification Cross Section 01.

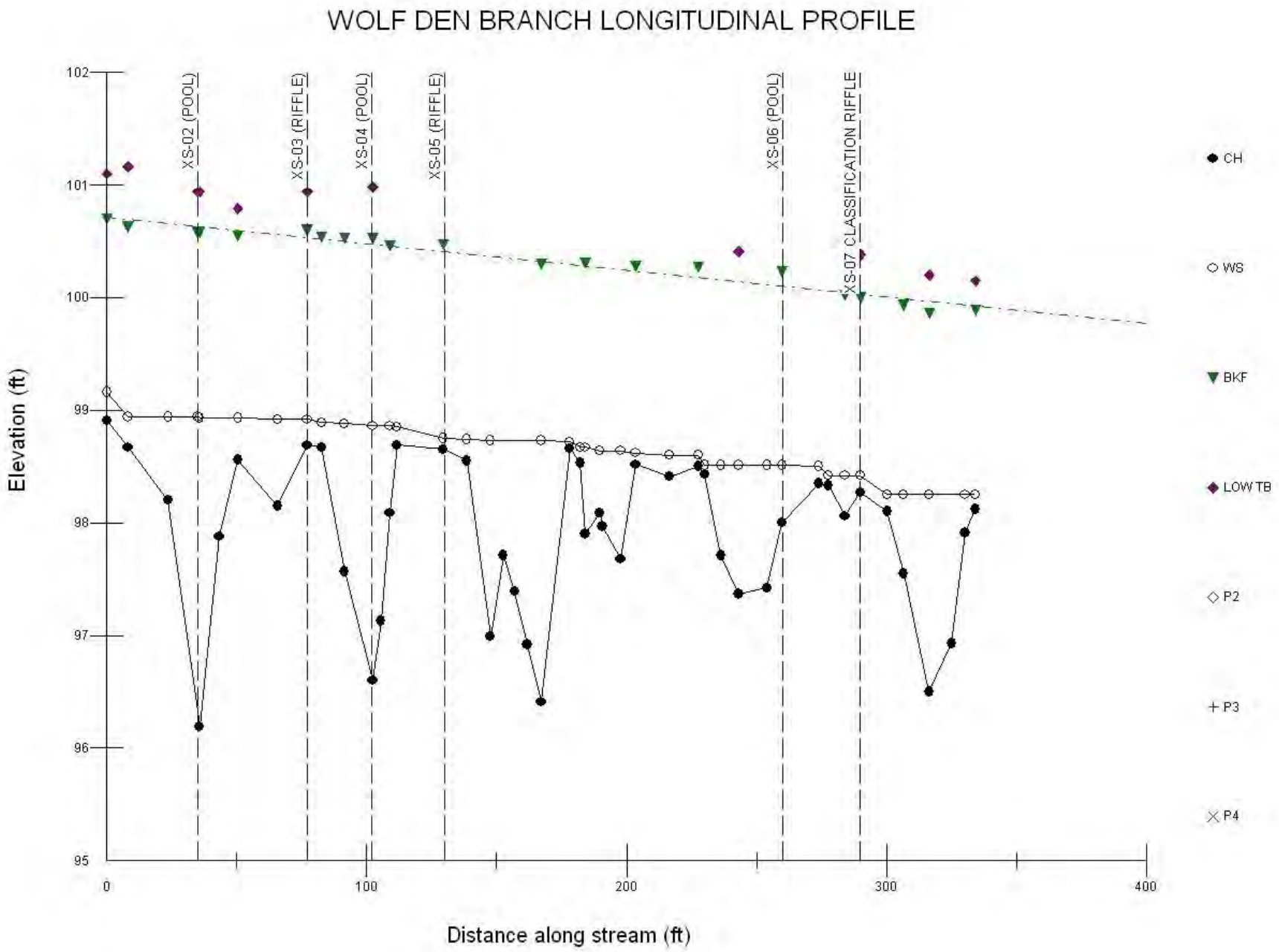
Photo 6. Right bank of classification Cross Section 01.

Cross Section Summary Table

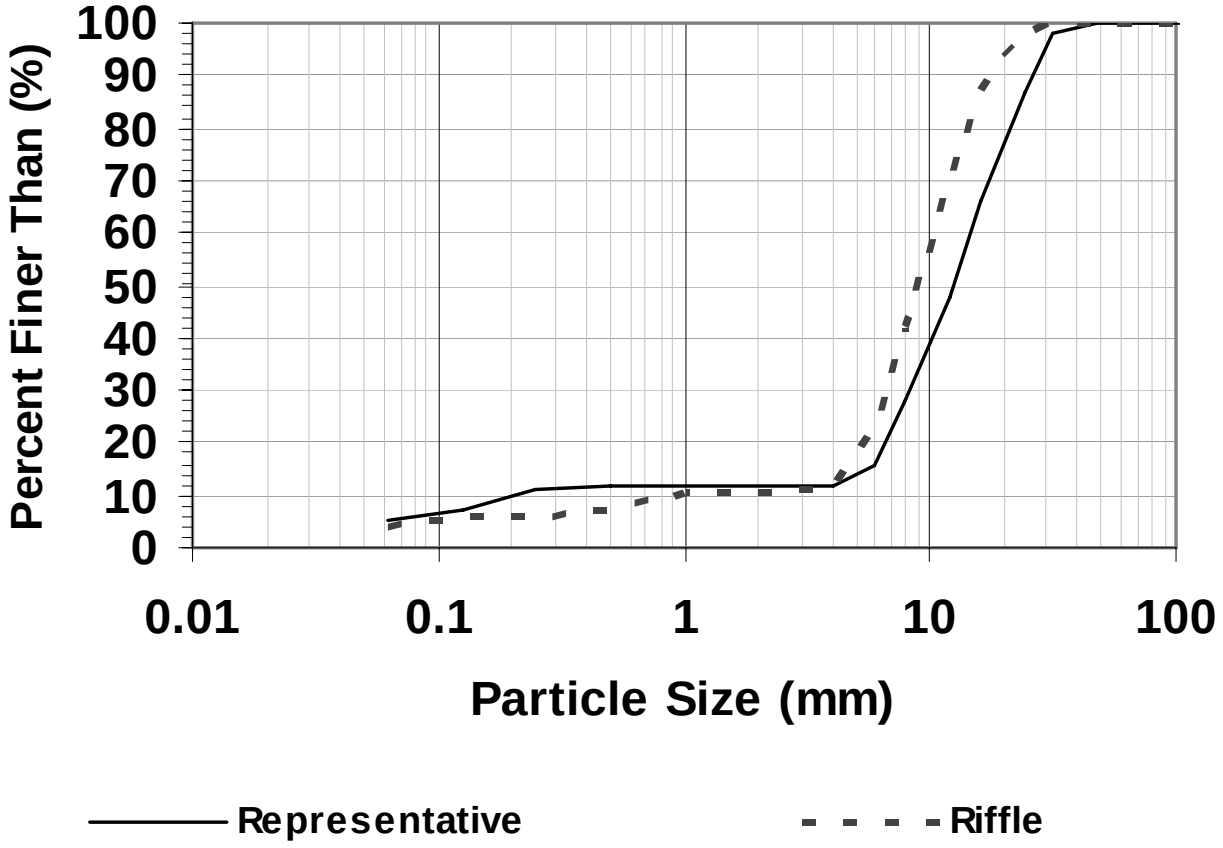
	XS-01 Riffle	XS-02 Pool	XS-03 Riffle	XS-04 Pool	XS-05 Riffle	XS-06 Pool	XS-07 Classification Riffle
Bankfull Width (ft)	14.14	10.81	12.17	13.30	14.34	12.25	14.63
Bankfull Cross-sectional Area (ft^2)	13.66	25.73	13.01	26.09	16.71	19.63	20.02
Hydraulic Radius (ft)	0.90	1.73	0.95	1.60	1.08	1.39	1.28
Mean Bankfull Depth (ft)	0.97	2.38	1.07	1.96	1.17	1.60	1.37
Maximum Bankfull Depth (ft)	1.78	4.39	1.89	3.93	1.82	2.25	1.74
Wetted Perimeter (ft)	15.18	14.84	13.75	16.32	15.41	14.09	15.61
Width/Depth Ratio	14.58	4.54	11.37	6.79	12.26	7.66	10.68
Entrenchment Ratio	N/A	N/A	N/A	N/A	N/A	N/A	23.44

WOLF DEN BRANCH
Charles County, MD




WOLF DEN BRANCH LONGITUDINAL PROFILE
XS-02 (POOL)
XS-03 (RIFFLE)
XS-04 (POOL)
XS-05 (RIFFLE)
XS-06 (POOL)
XS-07 CLASSIFICATION RIFFLE
CH
WS
BKF
LOW TB
P2
P3
P4
Elevation (ft)
Distance along stream (ft)
102
101
100
99
98
97
96
95
0
100
200
300
400

Wolf Den Branch Particle Size Distribution



Reference Reach Data Summary

No.	Variable	Symbol	Units	Wolf Den Branch	
1	Stream Type				E4
2	Drainage Area		mi^2		2.00
3	Riffle Bankfull Width	W_{bkf}	feet	Mean	13.82
				Min	12.17
				Max	14.63
4	Riffle Bankfull Mean Depth	d_{bkf}	feet	Mean	1.15
				Min	0.97
				Max	1.37
5	Width Depth Ratio	W/d		Mean	12.22
				Min	10.68
				Max	14.58
6	Riffle Bankfull Cross-Sectional Area	A_{bkf}	ft^2	Mean	15.85
				Min	13.01
				Max	20.02
7	Pool Bankfull Cross-Sectional Area	A_{pool}	ft^2	Mean	23.82
				Min	19.63
				Max	26.09
8	Riffle Bankfull Maximum Depth	d_{max}	feet	Mean	1.82
				Min	1.74
				Max	1.93
9	Max Riffle Depth/ Mean Riffle Depth	d_{riff}/d_{bkf}		Mean	1.42
				Min	1.29
				Max	1.66
10	Low Bank Height to Max D_{bkf} Ratio	LBH/d_{riff}		Mean	1.17
				Min	1.10
				Max	1.22
11	Width of Flood Prone Area	W_{fpa}	feet	Mean	343
				Min	N/A
				Max	N/A
12	Entrenchment Ratio	W_{fpa}/W_{bkf}		Mean	23.44
				Min	N/A
				Max	N/A
13	Straight Meander Length	L_m	feet	Mean	93.44
				Min	93.44
				Max	93.44
14	Straight Meander Length / Bankfull Width	L_m/W_{bkf}		Mean	6.39
				Min	6.39
				Max	6.39
15	Stream Meander Length	L_λ	feet	Mean	177
				Min	142
				Max	212
16	Stream Meander Length / Bankfull Width	L_λ/W_{bkf}		Mean	17.17
				Min	13.77
				Max	20.56
17	Radius of Curvature	R_c	feet	Mean	26.45
				Min	21.80
				Max	31.10
18	Radius of Curvature / Bankfull Width	R_c/W_{bkf}		Mean	1.81
				Min	1.49
				Max	2.13
19	Belt Width	W_{blt}	feet	Mean	49.20
				Min	46.40
				Max	52.00

Reference Reach Data Summary

No.	Variable	Symbol	Units	Wolf Den Branch	
20	Meander Width Ratio	W_{blt}/W_{bkf}		Mean	3.36
				Min	3.17
				Max	3.55
21	Sinuosity	K			1.36
22	Valley Slope	S_{val}	ft/ft		0.0037
23	Average Water Surface Slope	S_{avg}	ft/ft		0.0027
24	Pool Water Surface Slope	S_{pool}	ft/ft	Mean	0.0007
				Min	0.0001
				Max	0.0022
25	Pool WS Slope / Average WS Slope	S_{pool}/S_{avg}		Mean	0.25
				Min	0.037
				Max	0.81
26	Riffle Water Surface Slope	S_{riff}	ft/ft	Mean	0.01
				Min	0.0041
				Max	0.01
27	Riffle WS Slope / Average WS Slope	S_{rifF}/S_{avg}		Mean	2.52
				Min	1.51
				Max	3.52
28	Run WS Slope	S_{run}	ft/ft	Mean	0.0006
				Min	0.0001
				Max	0.0011
29	Run WS Slope / Average WS Slope	S_{run}/S_{avg}		Mean	0.23
				Min	0.04
				Max	0.42
30	Glide WS Slope	S_{glide}	ft/ft	Mean	0.0003
				Min	0.0001
				Max	0.0007
31	Glide WS Slope / Average WS Slope	S_{glide}/S_{avg}			0.11
					0.04
				Max	0.26
32	Maximum Pool Depth	d_{pool}	feet	Mean	3.51
				Min	2.54
				Max	4.47
33	Ratio of Max Pool Depth to Average Bankfull Depth	d_{pool}/d_{bkf}		Mean	2.56
				Min	1.85
				Max	3.26
34	Max Run Depth	d_{run}	feet	Mean	2.15
				Min	1.73
				Max	2.38
35	Ratio of Max Run Depth to Average Bankfull Depth	d_{run}/d_{bkf}		Mean	1.57
				Min	1.26
				Max	1.81
36	Max Glide Depth	d_{glide}	feet	Mean	2.11
				Min	1.93
				Max	2.38
37	Ratio of Max Glide Depth to Average Bankfull Depth	d_{glide}/d_{bkf}		Mean	1.54
				Min	1.41
				Max	1.74
38	Pool Length	L_{pool}	feet	Mean	22.60
				Min	17.39
				Max	30.51
39	Ratio of Pool Length to Bankfull Width	L_{pool}/W_{bkf}		Mean	1.54
				Min	1.19
				Max	2.09

Reference Reach Data Summary

No.	Variable	Symbol	Units	Wolf Den Branch	
40	Pool Width	W_{pool}	feet	Mean	12.12
				Min	10.81
				Max	13.30
41	Ratio of Pool Width to Bankfull Width	W_{pool}/W_{bkf}		Mean	0.83
				Min	0.74
				Max	0.91
42	Ratio of Pool Area to Bankfull Area	A_{pool}/A_{bkf}		Mean	1.19
				Min	0.98
				Max	1.30
43	Point Bar Slope	S_{pb}	ft/ft	Mean	N/A
				Min	N/A
				Max	N/A
44	Pool to Pool Spacing	p-p	feet	Mean	66.92
				Min	62.74
				Max	70.35
45	Ratio of Pool to Pool Spacing to Bankfull Width	$p\text{-}p/W_{bkf}$		Mean	4.57
				Min	4.29
				Max	4.81
Materials					
46	Particle Size Distribution - Channel	D_{16}	mm		5.70
		D_{35}	mm		9.16
		D_{50}	mm		11.82
		D_{84}	mm		21.66
		D_{95}	mm		29.44
47	Particle Size Distribution - Riffle	D_{16}	mm		4.69
		D_{35}	mm		7.17
		D_{50}	mm		8.96
		D_{84}	mm		15.14
		D_{95}	mm		20.73
48	Particle Size Distribution - Bar	D_{16}	mm		N/A
		D_{35}	mm		N/A
		D_{50}	mm		N/A
		D_{84}	mm		N/A
		D_{95}	mm		N/A
49	Largest Particle Size		mm		N/A

APPENDIX H – PINEY BRANCH
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1. Summary Sheet
2. Reach Photos
3. Cross Section Photos
4. Cross Section Summary Data
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6. Longitudinal Profile Plot
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PINEY BRANCH, CHARLES COUNTY, MD

Drainage Area (sq. mi.):	2.5	Rosgen Stream Type:	E4
Stream Order:	2	Survey Date:	July and August 2008
Percent Imperviousness:	47		

Land Use (%): Urban: 74.59 Agricultural: 1.83 Forest: 19.46

General Study Reach Description: The Piney Branch study reach is approximately 387 feet and is located on private property. Piney Branch is a gravel bed stream that consists of pool/run features; however, there is an unrepresentative riffle located in the higher width/depth ratio section. This riffle is unrepresentative due to a wetland drain entering directly upstream, as well as large woody debris immediately downstream of the riffle location. Piney Branch is both vertically and laterally stable. The pool and run features contain woody debris. There are some depositional features in the channel, mainly mid-channel bars associated with a debris jam or the higher width/depth ratio section. Piney Run has a very flat water surface slope due to backwater from an elevated utility crossing farther downstream. The floodplain consists of forested wetlands, consisting mainly of tulip poplar, sweet gum, and maple. The understory is sparse with American holly and spicebush. Map and GPS coordinates are not provided for sites located on private property.

Photo 1. Looking downstream from top of study reach.

Photo 2. Looking downstream at fallen log (near confluence of tributaries on right).

Photo 3. Looking downstream at pool cross section (downstream of fallen log) and run classification cross section (downstream of pool cross section).

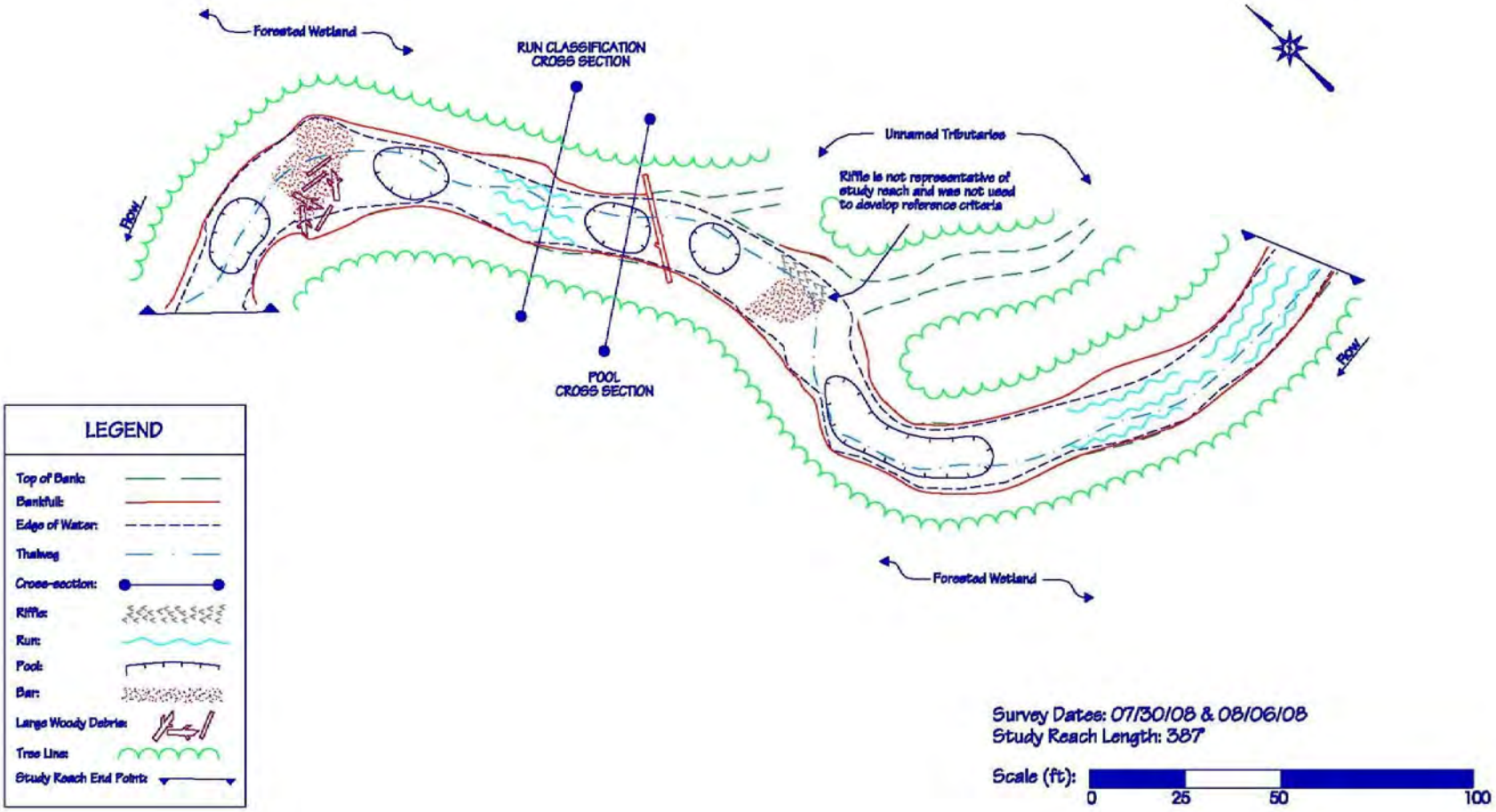
Photo 4. Looking at left bank near run classification cross section.

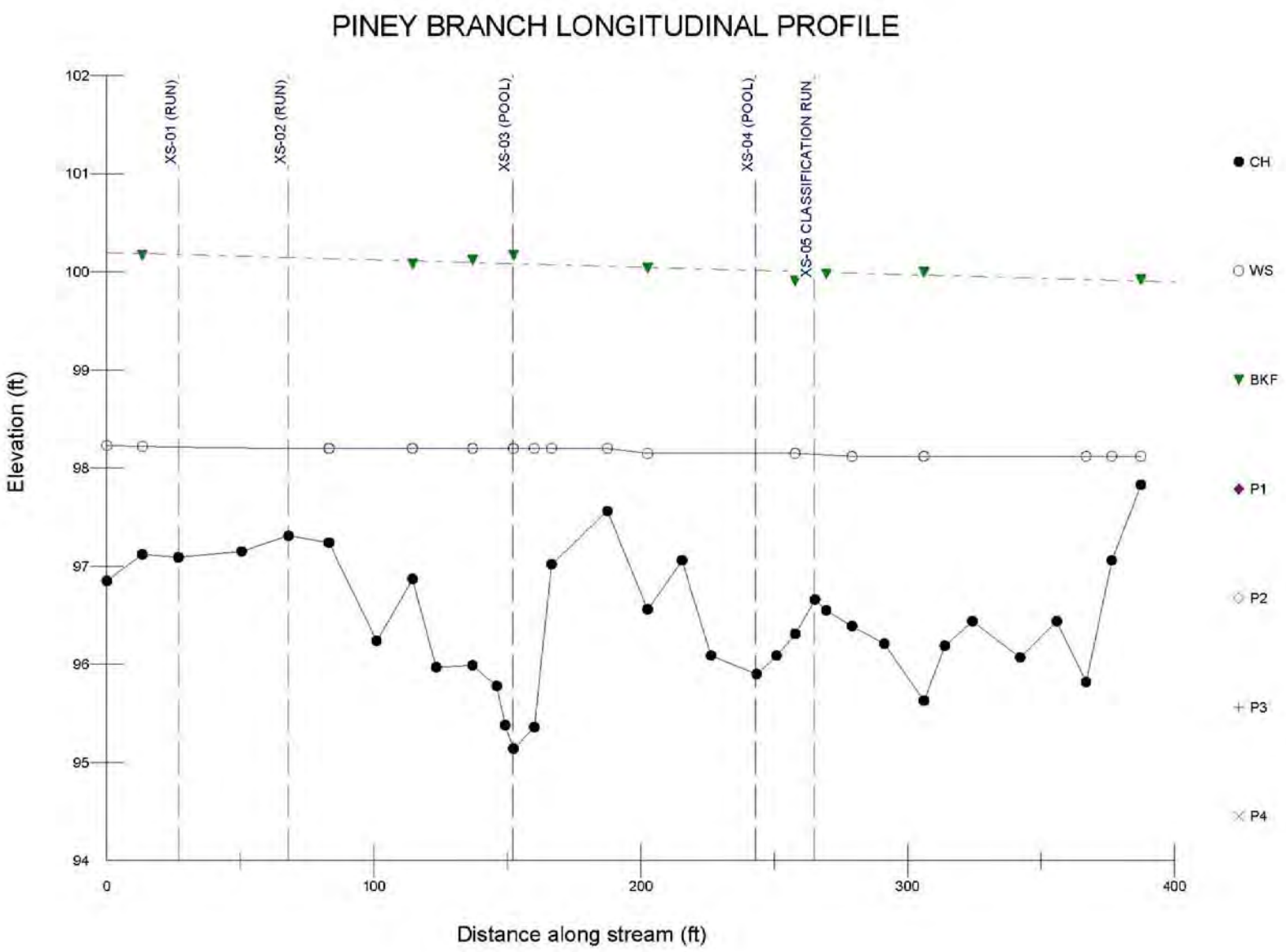
Photo 5. Looking downstream at downstream end of study reach.

Cross Section Summary Table

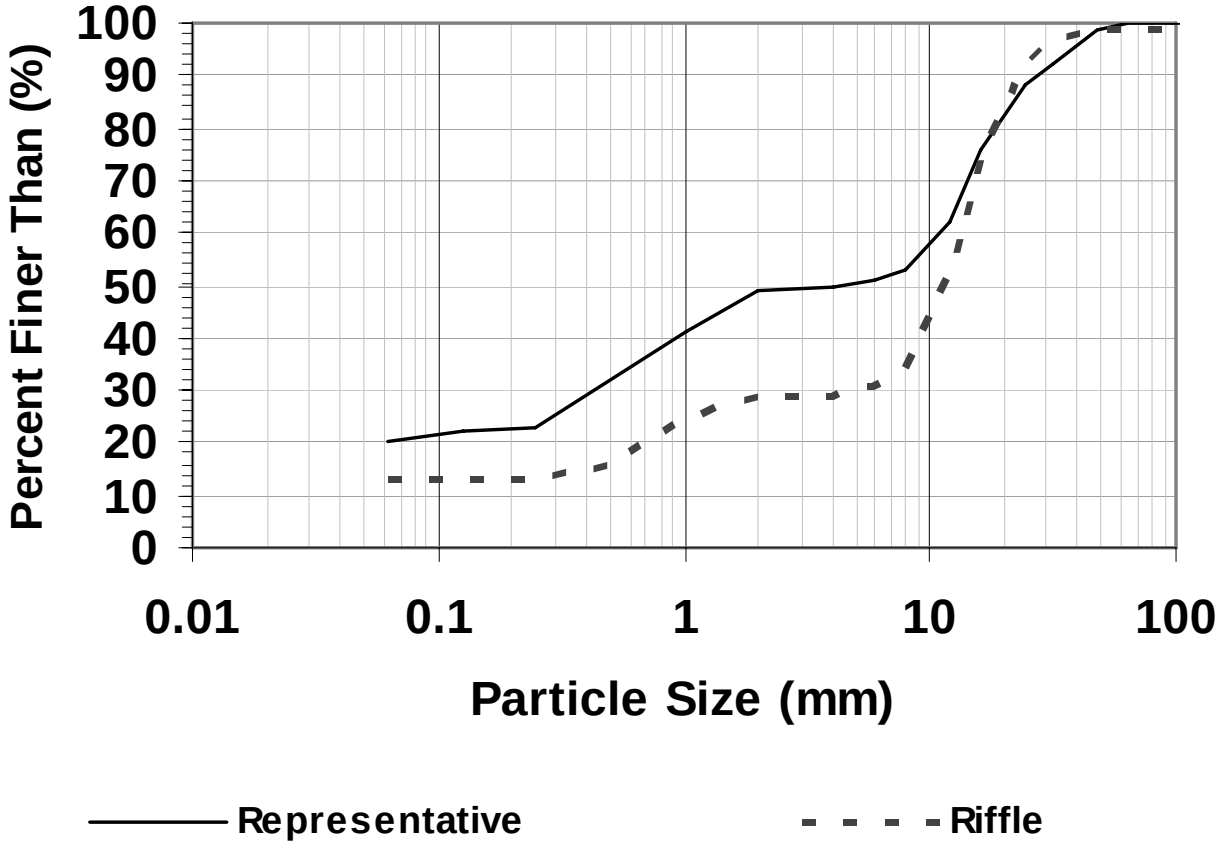
	XS-01 Run	XS-02 Run	XS-03 Pool	XS-04 Pool	XS-05 Classification Run
Bankfull Width (ft)	15.11	19.32	17.38	20.98	18.82
Bankfull Cross-sectional Area (ft^2)	40.69	37.78	53.76	52.83	42.46
Hydraulic Radius (ft)	2.14	1.71	2.31	2.08	2.00
Mean Bankfull Depth (ft)	2.69	1.96	3.09	2.52	3.08
Maximum Bankfull Depth (ft)	3.26	2.84	5.01	52.83	3.08
Wetted Perimeter (ft)	19.10	22.06	23.30	25.40	21.18
Width/Depth Ratio	5.62	9.86	5.62	8.33	8.33
Entrenchment Ratio	N/A	N/A	N/A	N/A	8.58

PINEY BRANCH
Charles County, MD




PINEY BRANCH LONGITUDINAL PROFILE
XS-01 (RUN)
XS-02 (RUN)
XS-03 (POOL)
XS-04 (POOL)
XS-05 CLASSIFICATION RUN
Elevation (ft)
102
101
100
99
98
97
96
95
94
0
100
200
300
400
Distance along stream (ft)
CH
WS
BKF
P1
P2
P3
P4

Piney Branch Particle Size Distribution



Reference Reach Data Summary

No.	Variable	Symbol	Units	Piney Run	
1	Stream Type				E4
2	Drainage Area		mi^2		2.50
3	Run Bankfull Width (Run Not Associated With Pool)	W_{bkf}	feet	Mean	17.75
				Min	15.11
				Max	19.32
4	Run Bankfull Mean Depth (Run Not Associated With Pool)	d_{bkf}	feet	Mean	2.30
				Min	1.96
				Max	2.69
5	Width Depth Ratio	W/d		Mean	7.93
				Min	5.62
				Max	9.86
6	Run Bankfull Cross-Sectional Area (Run Not Associated With Pool)	A_{bkf}	ft^2	Mean	40.31
				Min	37.78
				Max	42.46
7	Pool Bankfull Cross-Sectional Area	A_{pool}	ft^2	Mean	53.30
				Min	52.83
				Max	53.76
8	Riffle Bankfull Maximum Depth	d_{max}	feet	Mean	2.98
				Min	2.98
				Max	2.98
9	Max Riffle Depth/ Mean Riffle Depth (Not Representative)	d_{riff}/d_{bkf}		Mean	1.32
				Min	1.32
				Max	1.32
10	Low Bank Height to Max D_{bkf} Ratio	LBH/d_{riff}		Mean	1.00
				Min	1.00
				Max	1.00
11	Width of Flood Prone Area	W_{fpa}	feet	Mean	161.41
				Min	161.41
				Max	161.41
12	Entrenchment Ratio	W_{fpa}/W_{bkf}		Mean	8.58
				Min	8.58
				Max	8.58
13	Straight Meander Length	L_m	feet	Mean	N/A
				Min	N/A
				Max	N/A
14	Straight Meander Length / Bankfull Width	L_m/W_{bkf}		Mean	N/A
				Min	N/A
				Max	N/A
15	Stream Meander Length	L_λ	feet	Mean	N/A
				Min	N/A
				Max	N/A
16	Stream Meander Length / Bankfull Width	L_λ/W_{bkf}		Mean	N/A
				Min	N/A
				Max	N/A
17	Radius of Curvature	R_c	feet	Mean	32.91
				Min	26.50
				Max	37.48
18	Radius of Curvature / Bankfull Width	R_c/W_{bkf}		Mean	1.75
				Min	1.41
				Max	1.99
19	Belt Width	W_{blt}	feet	Mean	62.43
				Min	62.43
				Max	62.43

Reference Reach Data Summary

No.	Variable	Symbol	Units	Piney Run	
20	Meander Width Ratio	W_{blt}/W_{bkf}		Mean	1.31
				Min	0.0004
				Max	0.00028
21	Sinuosity	K			1.31
22	Valley Slope	S_{val}	ft/ft		0.0004
23	Average Water Surface Slope	S_{avg}	ft/ft		0.00028
24	Pool Water Surface Slope	S_{pool}	ft/ft	Mean	0.0001
				Min	0.0001
				Max	0.0001
25	Pool WS Slope / Average WS Slope	S_{pool}/S_{avg}		Mean	0.36
				Min	0.36
				Max	0.36
26	Riffle Water Surface Slope (Not Representative)	S_{riff}	ft/ft	Mean	0.0032
				Min	0.0032
				Max	0.0032
27	Riffle WS Slope / Average WS Slope (Not Representative)	S_{rifF}/S_{avg}		Mean	11.57
				Min	11.57
				Max	11.57
28	Run WS Slope (Run Not Associated With Pool)	S_{run}	ft/ft	Mean	0.0011
				Min	0.0003
				Max	0.0019
29	Run WS Slope / Average WS Slope (Run Not Associated With Pool)	S_{run}/S_{avg}		Mean	3.86
				Min	1.04
				Max	6.68
30	Run WS Slope	S_{run}	ft/ft	Mean	0.0001
				Min	0.0001
				Max	0.0001
31	Run WS Slope / Average WS Slope	S_{run}/S_{avg}		Mean	0.36
				Min	0.36
				Max	0.36
32	Glide WS Slope	S_{glide}	ft/ft	Mean	0.0001
				Min	0.0001
				Max	0.0001
33	Glide WS Slope / Average WS Slope	S_{glide}/S_{avg}		Mean	0.36
				Min	0.36
				Max	0.36
34	Max Run Depth (Not Associated With Pool)	d_{run}	feet	Mean	3.27
				Min	3.05
				Max	3.48
35	Ratio of Max Run Depth to Average Bankfull Depth	d_{run}/d_{bkf}		Mean	1.44
				Min	1.35
				Max	1.54
36	Maximum Pool Depth	d_{pool}	feet	Mean	4.45
				Min	4.09
				Max	4.94
37	Ratio of Max Pool Depth to Average Bankfull Depth	d_{pool}/d_{bkf}		Mean	1.97
				Min	1.81
				Max	2.19
38	Max Run Depth	d_{run}	feet	Mean	3.43
				Min	3.22
				Max	3.66
39	Ratio of Max Run Depth to Average Bankfull Depth	d_{run}/d_{bkf}		Mean	1.52
				Min	1.42
				Max	1.62

Reference Reach Data Summary

No.	Variable	Symbol	Units	Piney Run	
40	Max Glide Depth	d_{glide}	feet	Mean	2.92
				Min	2.45
				Max	3.52
41	Ratio of Max Glide Depth to Average Bankfull Depth	d_{glide}/d_{bkf}		Mean	1.29
				Min	1.08
				Max	1.56
42	Pool Length	L_{pool}	feet	Mean	64.42
				Min	42.40
				Max	85.26
43	Ratio of Pool Length to Bankfull Width	L_{pool}/W_{bkf}		Mean	3.42
				Min	2.25
				Max	4.53
44	Pool Width	W_{pool}	feet	Mean	19.18
				Min	17.38
				Max	20.98
45	Ratio of Pool Width to Bankfull Width	W_{pool}/W_{bkf}		Mean	1.02
				Min	0.92
				Max	1.11
46	Ratio of Pool Area to Bankfull Area	A_{pool}/A_{bkf}		Mean	1.26
				Min	1.24
				Max	1.27
47	Point Bar Slope	S_{pb}	ft/ft	Mean	N/A
				Min	N/A
				Max	N/A
48	Pool to Pool Spacing	p-p	feet	Mean	100.61
				Min	94.93
				Max	106.29
49	Ratio of Pool to Pool Spacing to Bankfull Width	$p\text{-}p/W_{bkf}$		Mean	5.35
				Min	5.04
				Max	5.65
Materials					
50	Particle Size Distribution - Channel	D_{16}	mm		0.05
		D_{35}	mm		0.67
		D_{50}	mm		4.00
		D_{84}	mm		20.40
		D_{95}	mm		37.57
51	Particle Size Distribution - Riffle	D_{16}	mm		0.50
		D_{35}	mm		8.18
		D_{50}	mm		10.93
		D_{84}	mm		19.67
		D_{95}	mm		28.24
52	Particle Size Distribution - Bar	D_{16}	mm		N/A
		D_{35}	mm		N/A
		D_{50}	mm		N/A
		D_{84}	mm		N/A
		D_{95}	mm		N/A
53	Largest Particle Size		mm		N/A

APPENDIX I – MILL DAM RUN
TABLE OF CONTENTS

1. Summary Sheet
2. Reach Photos
3. Cross Section Photos
4. Cross Section Summary Data
5. Site Map
6. Longitudinal Profile Plot
7. Particle Size Distribution Plot
8. Reference Reach Data Summary

MILL DAM RUN, CHARLES COUNTY, MD

Drainage Area (sq. mi.):	0.60	Rosgen Stream Type:	E4
Stream Order:	2	Survey Date:	December 2008
Percent Imperviousness:	3.5		

Land Use (%): Residential: 10.12 Agricultural: 30.25 Forest: 58.50 Commercial: 1.13

General Study Reach Description: The study reach is located on private property approximately 1000 feet upstream of Huckleberry Drive. The gravel bed stream is vertically and laterally stable with riffle/pool features. The reach contains several steps that have been created with woody debris and/or tree roots. The floodplain consists of forested wetlands, which results in the reach having undulating banks. The floodplain is densely forested with a canopy of tulip poplar, red maple, and oak. The understory consists of a sparse layer of holly and greenbrier. Map and GPS coordinates are not provided for sites located on private property.

Photo 1. Looking downstream from top of study reach.

Photo 2. Downstream view of the middle of the reach.

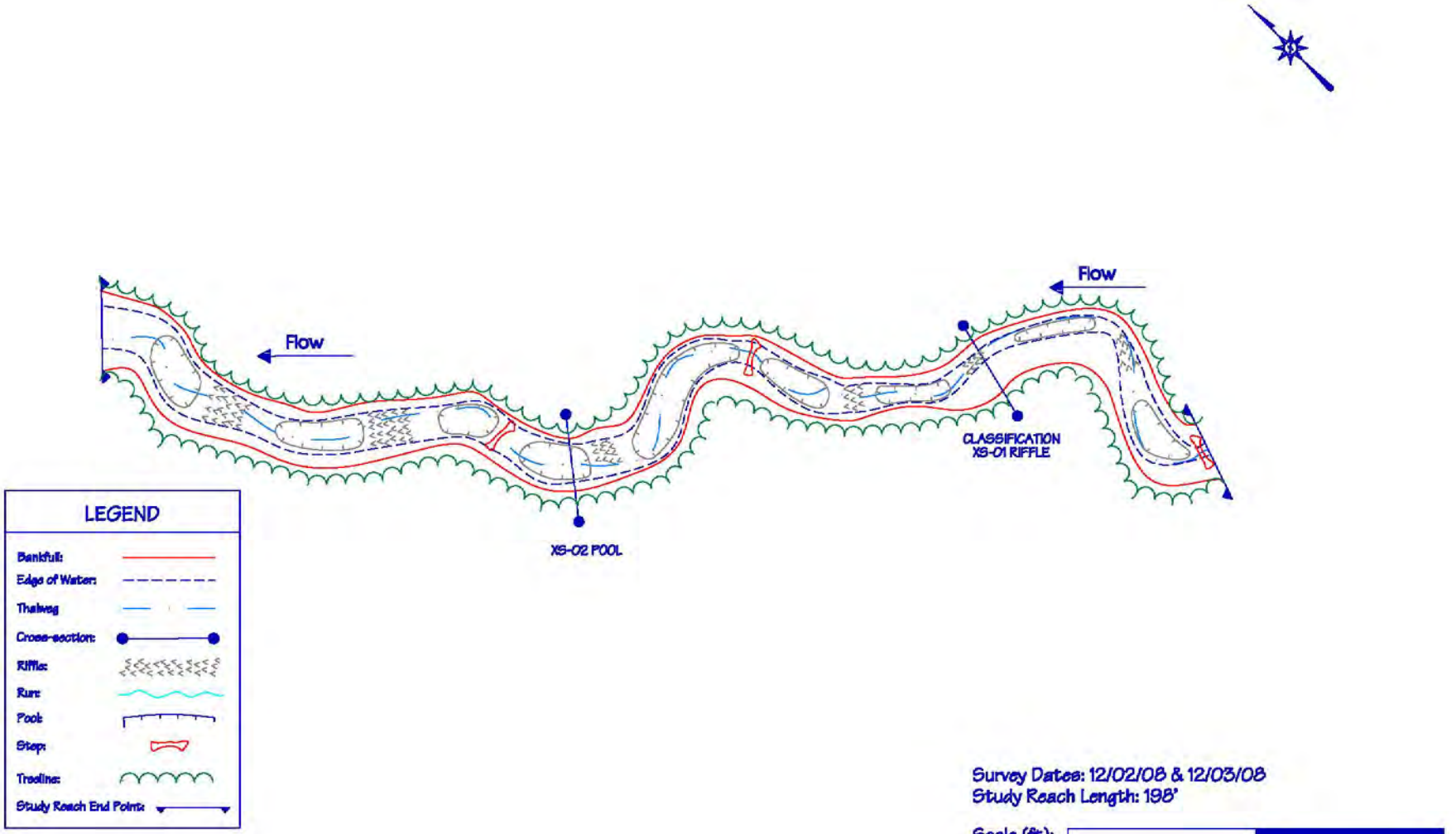
Photo 3. Looking at the right bank of the riffle classification cross section.

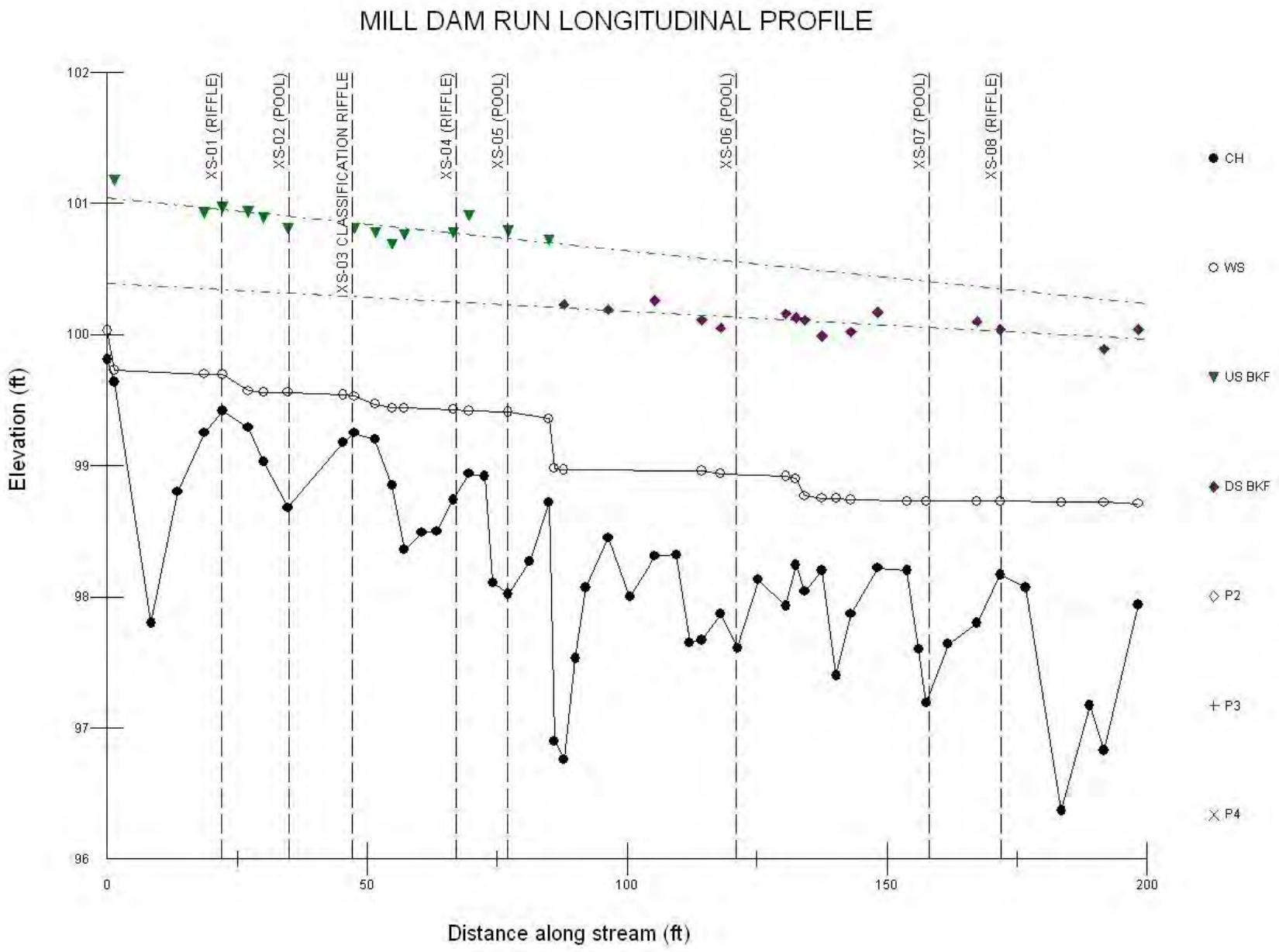
Photo 4. Looking upstream at riffle classification cross section.

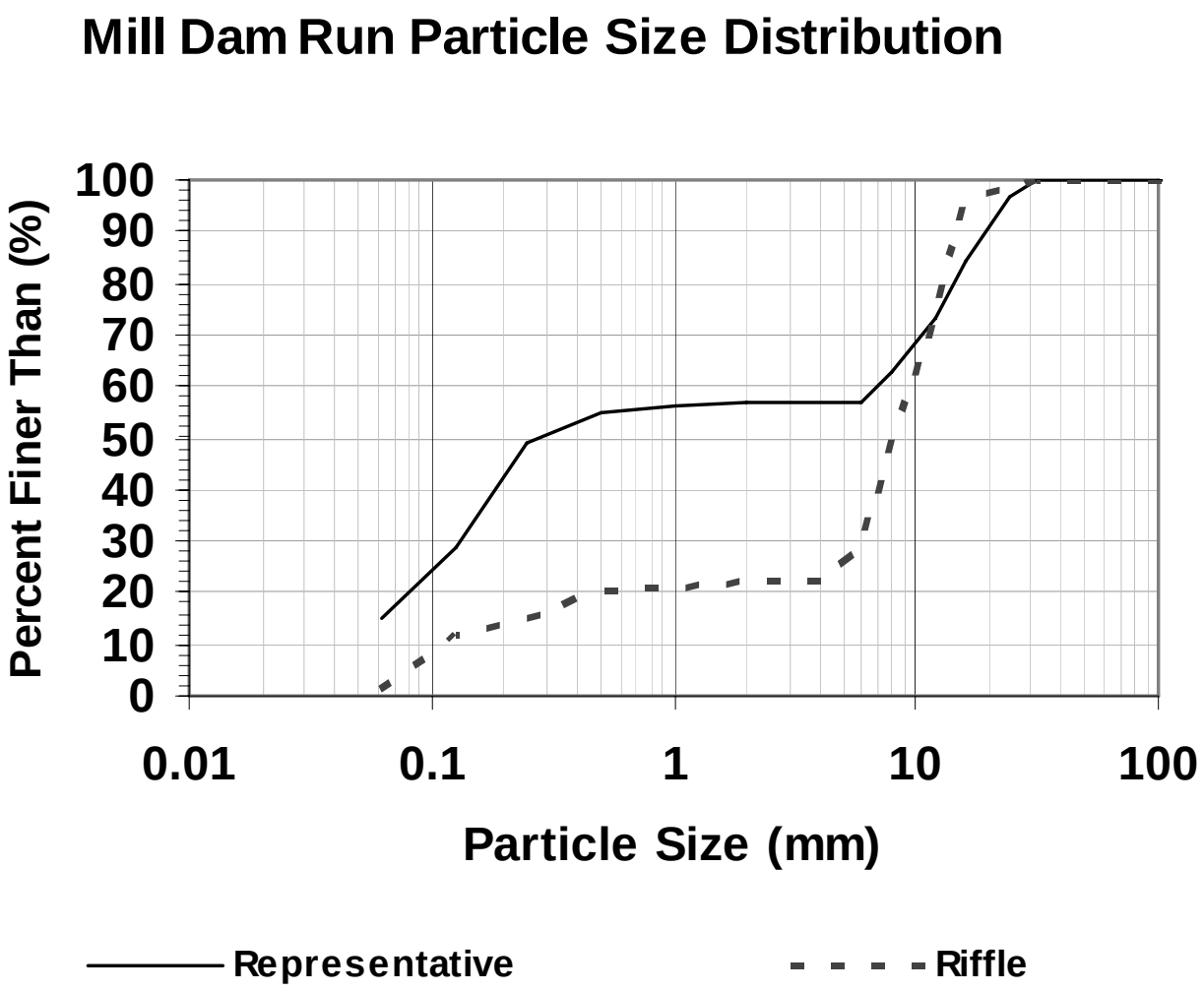
Cross Section Summary Table

	XS-01 Riffle	XS-02 Pool	XS-03 Classification Riffle	XS-04 Riffle	XS-05 Pool	XS-06 Pool	XS-07 Pool	XS-08 Riffle
Bankfull Width (ft)	6.20	6.70	8.07	5.60	6.40	6.50	6.80	6.10
Bankfull Cross-sectional Area (ft^2)	7.00	8.38	7.48	7.86	9.71	10.50	11.84	7.23
Hydraulic Radius (ft)	0.94	0.96	0.81	1.05	1.12	1.14	1.24	0.92
Mean Bankfull Depth (ft)	1.13	1.25	0.93	1.41	1.53	1.63	1.75	1.19
Maximum Bankfull Depth (ft)	1.55	2.21	1.65	2.04	2.57	2.45	2.86	1.83
Wetted Perimeter (ft)	7.49	8.75	9.22	7.49	8.65	9.22	9.52	7.82
Width/Depth Ratio	5.49	5.36	8.68	3.97	4.18	3.99	3.89	5.13
Entrenchment Ratio	N/A	N/A	24.29	N/A	N/A	N/A	N/A	N/A

MILL DAM RUN
Charles County, MD




MILL DAM RUN LONGITUDINAL PROFILE
XS-01 (RIFFLE)
XS-02 (POOL)
XS-03 CLASSIFICATION RIFFLE
XS-04 (RIFFLE)
XS-05 (POOL)
XS-06 (POOL)
XS-07 (POOL)
XS-08 (RIFFLE)
CH
WS
US BKF
DS BKF
P2
P3
P4
Elevation (ft)
102
101
100
99
98
97
96
0
50
100
150
200
Distance along stream (ft)


Mill Dam Run Particle Size Distribution
Percent Finer Than (%)
100
90
80
70
60
50
40
30
20
10
0
0.01
0.1
1
10
100
Particle Size (mm)
Representative
Riffle

Reference Reach Data Summary

No.	Variable	Symbol	Units	Mill Dam Run	
1	Stream Type				E4
2	Drainage Area		mi^2		0.60
3	Riffle Bankfull Width	W_{bkf}	feet	Mean	6.49
				Min	5.60
				Max	8.07
4	Riffle Bankfull Mean Depth	d_{bkf}	feet	Mean	1.18
				Min	0.93
				Max	1.41
5	Width Depth Ratio	W/d		Mean	5.82
				Min	3.97
				Max	8.68
6	Riffle Bankfull Cross-Sectional Area	A_{bkf}	ft^2	Mean	8.75
				Min	7.00
				Max	11.84
7	Pool Bankfull Cross-Sectional Area	A_{pool}	ft^2	Mean	10.11
				Min	8.38
				Max	11.84
8	Riffle Bankfull Maximum Depth	d_{max}	feet	Mean	1.71
				Min	1.56
				Max	1.84
9	Max Riffle Depth/ Mean Riffle Depth	d_{riff}/d_{bkf}		Mean	1.83
				Min	1.68
				Max	1.98
10	Low Bank Height to Max D_{bkf} Ratio	LBH/d_{riff}		Mean	1.00
				Min	1.00
				Max	1.00
11	Width of Flood Prone Area	W_{fpa}	feet	Mean	196.00
				Min	N/A
				Max	N/A
12	Entrenchment Ratio	W_{fpa}/W_{bkf}		Mean	24.20
				Min	N/A
				Max	N/A
13	Straight Meander Length	L_m	feet	Mean	70.60
				Min	70.39
				Max	70.80
14	Straight Meander Length / Bankfull Width	L_m/W_{bkf}		Mean	8.75
				Min	8.72
				Max	8.77
15	Stream Meander Length	L_λ	feet	Mean	87.00
				Min	86.00
				Max	88.00
16	Stream Meander Length / Bankfull Width	L_λ/W_{bkf}		Mean	8.44
				Min	8.34
				Max	8.54
17	Radius of Curvature	R_c	feet	Mean	15.62
				Min	1.19
				Max	25.47
18	Radius of Curvature / Bankfull Width	R_c/W_{bkf}		Mean	1.94
				Min	1.19
				Max	3.16
19	Belt Width	W_{blt}	feet	Mean	19.99
				Min	16.86
				Max	25.79

Reference Reach Data Summary

No.	Variable	Symbol	Units	Mill Dam Run	
20	Meander Width Ratio	W_{blt}/W_{bkf}		Mean	2.48
				Min	2.09
				Max	3.20
21	Sinuosity	K			1.34
22	Valley Slope	S_{val}	ft/ft		0.0089
23	Average Water Surface Slope	S_{avg}	ft/ft		0.0052
24	Pool Water Surface Slope	S_{pool}	ft/ft	Mean	0.0015
				Min	0.0001
				Max	0.0039
25	Pool WS Slope / Average WS Slope	S_{pool}/S_{avg}		Mean	0.29
				Min	0.02
				Max	0.75
26	Riffle Water Surface Slope	S_{riff}	ft/ft	Mean	0.0100
				Min	0.0009
				Max	0.0258
27	Riffle WS Slope / Average WS Slope	S_{rifF}/S_{avg}		Mean	1.93
				Min	0.17
				Max	4.96
28	Run WS Slope	S_{run}	ft/ft	Mean	0.0063
				Min	0.0034
				Max	0.0095
29	Run WS Slope / Average WS Slope	S_{run}/S_{avg}		Mean	1.22
				Min	0.65
				Max	1.83
30	Glide WS Slope	S_{glide}	ft/ft	Mean	0.0016
				Min	0.0001
				Max	0.0047
31	Glide WS Slope / Average WS Slope	S_{glide}/S_{avg}		Mean	0.31
				Min	0.02
				Max	0.89
32	Maximum Pool Depth	d_{pool}	feet	Mean	2.86
				Min	2.22
				Max	3.62
33	Ratio of Max Pool Depth to Average Bankfull Depth	d_{pool}/d_{bkf}		Mean	2.97
				Min	1.90
				Max	3.71
34	Max Run Depth	d_{run}	feet	Mean	1.84
				Min	1.77
				Max	1.97
35	Ratio of Max Run Depth to Average Bankfull Depth	d_{run}/d_{bkf}		Mean	1.98
				Min	1.90
				Max	2.12
36	Max Glide Depth	d_{glide}	feet	Mean	2.00
				Min	1.63
				Max	2.57
37	Ratio of Max Glide Depth to Average Bankfull Depth	d_{glide}/d_{bkf}		Mean	2.15
				Min	1.75
				Max	2.76
38	Pool Length	L_{pool}	feet	Mean	16.14
				Min	11.78
				Max	28.46
39	Ratio of Pool Length to Bankfull Width	L_{pool}/W_{bkf}		Mean	2.08
				Min	1.46
				Max	3.53

Reference Reach Data Summary

No.	Variable	Symbol	Units	Mill Dam Run	
40	Pool Width	W_{pool}	feet	Mean	6.60
				Min	6.40
				Max	6.80
41	Ratio of Pool Width to Bankfull Width	W_{pool}/W_{bkf}		Mean	0.82
				Min	0.79
				Max	0.84
42	Ratio of Pool Area to Bankfull Area	A_{pool}/A_{bkf}		Mean	1.35
				Min	1.12
				Max	1.58
43	Point Bar Slope	S_{pb}	ft/ft	Mean	N/A
				Min	N/A
				Max	N/A
44	Pool to Pool Spacing	p-p	feet	Mean	2.86
				Min	2.27
				Max	3.43
45	Ratio of Pool to Pool Spacing to Bankfull Width	$p\text{-}p/W_{bkf}$		Mean	0.63
				Min	0.50
				Max	0.76
Materials					
46	Particle Size Distribution - Channel	D_{16}	mm		0.07
		D_{35}	mm		0.16
		D_{50}	mm		0.29
		D_{84}	mm		16.00
		D_{95}	mm		21.58
47	Particle Size Distribution - Riffle	D_{16}	mm		0.30
		D_{35}	mm		6.36
		D_{50}	mm		8.00
		D_{84}	mm		13.44
		D_{95}	mm		15.79
48	Particle Size Distribution - Bar	D_{16}	mm		N/A
		D_{35}	mm		N/A
		D_{50}	mm		N/A
		D_{84}	mm		N/A
		D_{95}	mm		N/A
49	Largest Particle Size		mm		N/A

APPENDIX J – STREAM REFERENCE DATA DEVELOPED BY OTHERS

The Service has compiled additional reference reach data collected by other stream practitioners. The Service believes that the stream practitioners are reputable sources; however, the Service did not verify the accuracy of the data or collection methods. As with all the data included in this report, the reader should be familiar with the proper use and limitations of this data.

TABLE OF CONTENTS

1. Michael Baker Corporation Data
   Contact: Will Harman
   Phone: (919)459-9003
   http://www.mbakercorp.com/

2. Wildland Hydrology Data
   Contact: Dave Rosgen
   Phone: (970)568-0002
   http://www.wildlandhydrology.com/

3. USFWS-CBFO Data
   Contact: Mark Secrist
   Phone: (410)573-4551
   http://www.fws.gov/chesapeakebay/

4. ICC Reference Reach Study Baseline Report, December 2008 Coastal Resources, Inc. Only the study report is included in this document. Appendices A-G were not included due to their length. If you would like a copy of the report and appendices, please contact Coastal Resources or Maryland SHA.

Coastal Resources, Inc.	Maryland SHA
Contact: Chuck Weinkam	Contact: Robert Shreeve
Phone: (410)956-9000	Phone: (410)545-8644
http://coastal-resources.net/	http://www.sha.maryland.gov/home.aspx

Michael Baker Corporation Data

Common Reference Reach Ratios for C, E and B Stream Types

Data Collected from reference reach streams in North Carolina Mountains and Piedmont
13-Sep-07

Table 1: Design Criteria for C, E, and B stream types

	Common Design Ratios			
Parameter	**MIN**	**MAX**	**MIN**	**MAX**
Stream Type (Rosgen)	C/E 4		B4	
Bankfull Mean Velocity, Vbkf (ft/s)	3.5	5.0	4.0	6.0
Width to Depth Ratio, W/D (ft/ft)	**10.0**	14.0	12.0	18.0
Riffle Max Depth Ratio, Dmax/Dbkf	1.1	1.3	1.2	1.4
Bank Height Ratio, Dtob/Dmax (ft/ft)	1.0	1.1	1.0	1.1
Meander Length Ratio, Lm/Wbkf	7.0	12.0	N/a	N/a
Radius of Curvature Ratio, Rc/Wbkf	**2.0**	**3.0**	N/a	N/a
Meander Width Ratio, Wblt/Wbkf	3.5	8.0	N/a	N/a
Sinuosity, K	1.20	1.60	1.1	1.2
Valley Slope, Sval (ft/ft)	0.0050	0.0150	0.020	0.030
Riffle Slope Ratio, Srif/Schan	1.5	2.0	1.1	**1.8**
Run Slope Ratio, Srun/Srif	0.50	0.80	N/a	N/a
Glide Slope Ratio, Sglide/Schan	0.30	0.50	0.3	0.5
Pool Slope Ratio, Spool/Schan	0.00	0.20	0.0	0.4
Pool Max Depth Ratio, Dmaxpool/Dbkf	2.0	3.5	2.0	3.5
Pool Width Ratio, Wpool/Wbkf	**1.3**	**1.7**	1.1	1.5
Pool-Pool Spacing Ratio, Lps/Wbkf	4.0	7.0	1.5	5.0

Table 2: Common reference reach ratios for channel evolution and departure from stability analysis

	Common Reference Reach Ratios			
Parameter	**MIN**	**MAX**	**MIN**	**MAX**
Stream Type (Rosgen)	C/E 4		B4	
Bankfull Mean Velocity, Vbkf (ft/s)	3.5	5.0	4.0	6.0
Width to Depth Ratio, W/D (ft/ft)	**5.0**	12.0	12.0	18.0
Riffle Max Depth Ratio, Dmax/Dbkf	1.1	1.4	1.2	1.4
Bank Height Ratio, Dtob/Dmax (ft/ft)	1.0	1.1	1.0	1.1
Meander Length Ratio, Lm/Wbkf	7.0	12.0	N/a	N/a
Radius of Curvature Ratio, Rc/Wbkf	**1.2**	**2.0**	N/a	N/a
Meander Width Ratio, Wblt/Wbkf	**3.0**	8.0	N/a	N/a
Sinuosity, K	1.20	1.60	1.1	1.2
Valley Slope, Sval (ft/ft)	0.0050	0.0150	0.020	0.030
Riffle Slope Ratio, Srif/Schan	1.5	2.0	1.1	**2.5**
Run Slope Ratio, Srun/Srif	0.50	0.80	N/a	N/a

Michael Baker Corporation Data

Table 2 Cont: Common reference reach ratios for channel evolution and departure from stability analysis

	Common			
	Reference Reach Ratios			
Parameter	**MIN**	**MAX**	**MIN**	**MAX**
Glide Slope Ratio, Sglide/Schan	0.30	0.50	0.3	0.5
Pool Slope Ratio, Spool/Schan	0.00	0.20	0.0	0.4
Pool Max Depth Ratio, Dmaxpool/Dbkf	2.0	3.5	2.0	3.5
Pool Width Ratio, Wpool/Wbkf	**0.8**	**1.2**	1.1	1.5
Pool-Pool Spacing Ratio, Lps/Wbkf	4.0	7.0	1.5	5.0

Prepared By: Will Harman, PG
Michael Baker Corporation
Source: NC Department of Transportation reference reach database, evaluation of Baker Engineering projects

C4 Reference Reach Data (Average Values)

Pools	Ratio Pool Slope/Average Slope	=	0.10 – 0.30 (0.20)
	Ratio Pool Max Depth/Riffle Mean Depth	=	2.5 – 3.5 (3.0)
	Ratio Pool Width/Average Riffle Width	=	0.8 – 1.5 (1.3)
Riffles	Ratio Riffle Slope/Average Slope	=	1.5 – 3.5 (2.5)
	Ratio Riffle Max Depth/Riffle Mean Depth	=	1.3 – 1.6 (1.45)
Runs	Ratio Run Slope/Average Slope	=	1.0 – 2.0 (1.5)
	Ratio Run Max Depth/Riffle Mean Depth	=	1.8 – 2.2 (2.0)
Glides	Ratio of Glide Slope/Average Slope	=	0.1 – 0.5 (0.3)
	Ratio of Max Glide Depth/Riffle Mean Depth	=	0.9 – 1.4 (1.25)
	Ratio of Glide Width/Average Riffle Width	=	1.1 – 1.5 (1.3)

	C3	C4	B3
W/D	12 – 25 (ave=20)	12 – 18 (ave=15)	12 – 20 (ave = 16)
W/D for high bedload and rivers greater than 150′ Wide	20 – 40 (ave=30)	18 – 35 (ave=26)	18 – 40 (ave = 29)
R_c/W	3.0 – 3.5	2.5 – 3.0	N/A
R_c/W (High bedload, very coarse composite banks)	3.5 – 4.5	3.0 – 4.0	N/A
Pool to Pool Spacing	7 – 8W	4 – 7W	B_c 1-2% 4 – 5W 2-4% 3 – 4W 4-6% 2 – 3W 6-8% 1.5 – 2W 8+% 1 – 1.5W
L_m/W	12 – 14	8 – 14	N/A
L_m/W (High Bedload)	12	11 – 12	N/A

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USFWS-CBFO Data

Reference Reach Design Criteria										
No.	Variable	Symbol	Units		Maryland Piedmont		Rock Creek	Silas Creek	Daniels Run Proposed	
1	Stream Type				C4	B4/1c	B4/1c	B4/1c	C4	B4/1c
2	Drainage Area		mi^2	Mean	28.53	27.00		3.30	1.88	1.88
				Min	1.47					
				Max	101.00					
3	Riffle Bankfull Mean Depth	d_{bkf}	ft	Mean	3.09	4.00	3.84	1.75	1.27	1.44
				Min	1.63			1.63	2.11	1.69
				Max	6.01			1.86	0.70	1.22
4	Riffle Bankfull Width	W_{bkf}	ft	Mean	43.65	44.80	89.60	25.55	19.00	21.00
				Min	18.90			23.10		
				Max	66.80			28.00		
5	Width/Depth Ratio	W/d_{bkf}		Mean	15.00	11.20	23.33	14.60	15.00	14.60
				Min	9.00			12.42	9.00	12.42
				Max	27.00			17.18	18.00	17.18
6	Riffle Bankfull Cross Sectional Area	A_{bkf}	ft^2	Mean	158.05	179.31	344.00	43.70	29.28	33.81
				Min	31.13			38.50		
				Max	401.37			48.90		
7	Riffle Bankfull Maximum Depth	d_{max}	ft	Mean	4.06	4.74	5.59	2.67	1.71	2.20
				Min	2.77			2.10	1.52	1.86
				Max	6.72			3.23	1.90	2.50
8	Max. Riffle Depth/Mean Riffle Depth	d_{riff}/d_{bkf}		Mean	1.42	1.19	1.46	1.53	1.35	1.53
				Min	1.12			1.29	1.20	1.29
				Max	1.67			1.74	1.50	1.74
9	Mean Pool Depth	d_{bkfp}	ft	Mean	2.60				1.65	
				Min	1.50				1.39	
				Max	3.80				1.90	
10	Mean Pool Depth/Mean Riffle Depth	d_{bkfp}/d_{bkf}		Mean	1.30			4.50	1.30	
				Min	1.10			4.00	1.10	
				Max	1.50			5.00	1.50	
11	Pool Width	W_{bkfp}	ft	Mean	37.84			25.30	22.80	20.79
				Min	14.97			22.60	19.00	20.58
				Max	57.40			28.00	26.60	21.00
12	Pool Width/Riffle Width	W_{bkfp}/W_{bkf}		Mean	1.20			0.99	1.20	0.99
				Min	1.00			0.98	1.00	0.98
				Max	1.40			1.00	1.40	1.00
13	Pool Bankfull Cross Sectional Area	A_{pool}	ft^2	Mean	106.00			72.11	38.06	67.62
				Min	37.00			53.31	32.21	
				Max	205.00			90.46	43.92	
14	Pool Area/Riffle Area	A_{pool}/A_{bkf}		Mean	1.30			1.65	1.30	2.00
				Min	1.10			1.22	1.10	
				Max	1.50			2.07	1.50	
15	Max. Pool Depth	d_{mbkfp}	ft	Mean	4.96		9.22	4.50	3.04	3.70
				Min	3.51			4.00	2.41	3.52
				Max	6.44			5.00	3.93	3.87
16	Max. Pool Depth/Mean Riffle Depth	d_{mbkfp}/d_{bkf}		Mean	2.40		2.40	2.57	2.40	2.57
				Min	1.90			2.45	1.90	2.45
				Max	3.10			2.69	3.10	2.69
17	Low Bank Height	LBH	ft							

USFWS-CBFO Data

Reference Reach Design Criteria										
No.	Variable	Symbol	Units		Maryland Piedmont		Rock Creek	Silas Creek	Daniels Run Proposed	
18	Low Bank Height/Max. Riffle Depth	LBH/d_{mbkf}		Mean				1.00	1.00	1.00
				Min						
				Max						
19	Width of Flood Prone Area	W_{fpa}	ft	Mean	459.50			33.45	228.00	29.40
				Min	196.00			27.70	76.00	46.20
				Max	803.00			39.20	456.00	
20	Entrenchment Ratio	W_{fpa}/W_{bkf}		Mean	12.00		1.40	1.31	12.00	1.40
				Min	4.00			1.20	4.00	2.20
				Max	24.00			1.40	24.00	
21	Point Bar Slope	$S_{pt.\ bar}$	ft/ft	Mean						
				Min						
				Max						
22	Bankfull Mean Velocity	u_{bkf}	ft/sec	Mean	5.28			4.60	2.77	3.71
				Min	3.66					
				Max	6.38					
23	Bankfull Discharge	Q_{bkf}	cfs	Mean	902.09			199.00	109.47	125.59
				Min	114.50					
				Max	2562.00					
24	Meander Length	L_m	ft	Mean	378.00			187.00	159.60	153.72
				Min	73.00			130.00	72.20	118.23
				Max	699.00			245.00	254.60	183.75
25	Meander Length Ratio	L_m/W_{bkf}		Mean	8.40			7.32	8.40	7.32
				Min	3.80			5.63	3.80	5.63
				Max	13.40			8.75	13.40	8.75
26	Radius of Curvature	R_c	ft	Mean	142.00			38.64	53.20	31.71
				Min	19.00			18.48	19.00	16.80
				Max	434.00			58.80	123.50	44.10
27	Ratio of Radius of Curvature/Bankfull Width	R_c/W_{bkf}		Mean	2.80			1.51	2.80	1.51
				Min	1.00			0.80	1.00	0.80
				Max	6.50			2.10	6.50	2.10
28	Belt Width	W_{blt}	ft	Mean	117.00	102.00		45.50	55.10	37.38
				Min	58.00			40.00	34.20	30.03
				Max	310.00			51.00	114.00	38.22
29	Meander Width Ratio	W_{blt}/W_{bkf}		Mean	2.90	2.30		1.78	2.90	1.78
				Min	1.80			1.43	1.80	1.43
				Max	6.00			1.82	6.00	1.82
30	Individual Pool Length	L_{pool}	ft	Mean			166.00		28.50	
				Min					19.00	
				Max					38.00	
31	Pool Length/Riffle Width	L_{pool}/W_{bkf}		Mean			1.85		1.50	
				Min					1.00	
				Max					2.00	
32	Pool to Pool Spacing (based on pattern)	p-p	ft	Mean				76.60	114.00	63.00
				Min				27.20	95.00	24.78
				Max				126.00	133.00	94.50
33	Pool to Pool Spacing/ Bankfull Width	$p\text{-}p/W_{bkf}$		Mean				3.00	6.00	3.00
				Min				1.18	5.00	1.18
				Max				4.50	7.00	4.50

USFWS-CBFO Data

Reference Reach Design Criteria										
No.	Variable	Symbol	Units		Maryland Piedmont		Rock Creek	Silas Creek	Daniels Run Proposed	
34	Stream Length	SL	ft							
35	Valley Length	VL	ft							
36	Valley Slope	VS	ft/ft					0.0089		
37	Average Water Surface Slop	S	ft/ft		0.0055	0.0022	0.0037	0.0082	0.0047	0.0051
38	Sinuosity	K		SL/VL	1.29	1.19			1.20	1.20
				VS/S				1.07		
39	Riffle Slope (water surface facet slope)	S_{riff}	ft/ft	Mean			0.0141	0.0360	0.0106	0.0194
				Min			0.0053		0.0071	0.0073
				Max			0.0229		0.0141	0.0316
40	Ratio of Riffle Slope to Average Water Surface Slope	S_{riff}/S		Mean			3.81	4.39	2.25	3.81
				Min			1.43		1.50	1.43
				Max			6.19		3.00	6.19
41	Run Slope (water surface facet slope)	S_{run}	ft/ft	Mean			0.0033	0.0070	0.0031	0.0045
				Min			0.0001		0.0024	0.0001
				Max			0.0080		0.0038	0.0110
42	Ratio of Run Slope to Average Water Surface Slope	S_{run}/S		Mean			0.89	0.85	0.65	0.89
				Min			0.03		0.50	0.03
				Max			2.16		0.80	2.16
43	Pool Slope (water surface facet slope)	S_{pool}	ft/ft	Mean			0.0001	0.0000	0.0012	0.0001
				Min				0.0000	0.0009	
				Max				0.0819	0.0014	
44	Ratio of Pool Slope/ Average Water Surface Slope	S_{pool}/S		Mean			0.03	0.00	0.25	0.00
				Min				0.00	0.20	0.00
				Max				16.06	0.30	
45	Glide Slope (water surface facet slope)	S_{glide}	ft/ft	Mean			0.0001	0.0070	0.0019	0.0001
				Min					0.0014	
				Max					0.0024	
46	Ratio of Glide Slope/ Average Water Surface Slope	S_{glide}/S		Mean			0.03	0.85	0.40	0.03
				Min					0.30	
				Max					0.50	
47	Step Slope (water surface facet slope)	S_{step}	ft/ft	Mean			0.1200			0.1654
				Min			0.0600			0.0827
				Max			0.1700			0.2343
48	Ratio of Step Slope/ Average Water Surface Slope	S_{step}/S		Mean			32.43			32.43
				Min			16.22			16.22
				Max			45.95			45.95
49	Max. Run Depth	$d_{mbkfrun}$	ft	Mean			6.10	3.30	2.60	2.28
				Min			5.64		2.41	2.11
				Max			6.73		2.79	2.52
50	Ratio of Max. Run Depth/ Mean Bankfull Depth	$d_{mbkfrun}/d_{bkf}$		Mean			1.59	1.89	2.05	1.59
				Min			1.47		1.90	1.47
				Max			1.75		2.20	1.75
51	Max. Glide Depth	$d_{mbkfglide}$	ft	Mean			5.07	3.25		2.29
				Min						1.90
				Max						2.68

USFWS-CBFO Data

Reference Reach Design Criteria										
No.	**Variable**	**Symbol**	**Units**		**Maryland Piedmont**		**Rock Creek**	**Silas Creek**	**Daniels Run Proposed**	
52	Ratio of Max. Glide Depth/ Mean Bankfull Depth	$d_{mbkfglide}/d_{bkf}$		Mean			1.32	1.86		1.59
				Min						1.32
				Max						1.86
53	Max. Step Depth	$d_{mbkfstep}$	ft	Mean						
				Min						
				Max						
54	Ratio of Max. Step Depth/ Mean Bankfull Depth	$d_{mbkfstep}/d_{bkf}$		Mean						
				Min						
				Max						
Materials										
55	Particle Size Distribution of Stream	D_{16}	mm			N/A	0.36			
		D_{35}	mm			4.34	21.28			
		D_{50}	mm			19.04	54.50			
		D_{84}	mm			335.45	238.16			
		D_{95}	mm			Bedrock	401.97			
56	Particle Size Distribution of Channel Material (active bed)	D_{16}	mm			N/A		0.29		
		D_{35}	mm			4.68		0.90		
		D_{50}	mm			20.22		22.60		
		D_{84}	mm			47.91		200.00		
		D_{95}	mm			89.12		>2048		
57	Particle Size Distribution of Bar Material	D_{16}	mm					1.80		
		D_{35}	mm					15.00		
		D_{50}	mm					32.00		
		D_{84}	mm					96.00		
		D_{95}	mm					117.00		
58	Largest Size Particle at the Toe (Lower Third) of Bar		mm							

ICC Reference Reach Study Baseline Report

December 2008

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1. INTRODUCTION

Stream restoration is a major component of the Intercounty Connector (ICC) mitigation and environmental stewardship effort by the Maryland State Highway Administration (SHA). As many stream practitioners utilize an analog-empirical based methodology or reference reach approach (Rosgen 1996), stable reference reaches from multiple stream types are required for design. Although limitations to this approach have recently been summarized by Simon et al (2007), the reference reach methodology can be successful when appropriately applied (Skidmore et al 2001, Hey 2006).

Coastal Resources, Inc, (CRI) under contract to SHA, has identified and surveyed six reference stream sites that meet assessment criteria for geomorphic stability given the current hydrologic and watershed characteristics associated with the sites. The site names and Rosgen classification system stream types are:

- Camp Fretterd Tributary to Liberty Reservoir – B4
- Cooks Branch – B4c
- Little Paint Branch – C4
- Jabez Branch – E5
- Unnamed Tributary (UNT) to Bear Branch – C4
- UNT to Dead Run – C4b

The collection of baseline data for these selected reference reach sites provides the initial phase of a reference reach study. The study will require additional survey and assessment to monitor long-term stability of the sites and how they react to significant runoff events. The following is a description of the site selection process and survey methods used in the study. Data collected for each site are included in Appendices A through F.

2. METHODOLOGY

The methodology section describes the methods used to complete the survey. Descriptions include site selection, field data collection, and data entry and analysis.

2.1. Site Selection

Letter and email requests for information on potential reference reaches were sent to over 100 stream practitioners, federal, state, & local government agencies throughout Maryland and parts of northern Virginia. The written requests were then followed by phone calls to a number of the same agencies and consultants.

The letters and emails included the following search criteria:

- 1st through 4th order non-tidal streams. Streams larger than 4th order are typically too large to survey effectively with the staff and resources available.

- Rosgen stream types B, C and E.
- Preferably streams located in the Western Coastal Plain & Piedmont physiographic regions, but stable streams in other physiographic regions are acceptable (Hey 2006).
- Vertically and laterally stable.
- Minimal human disturbance- the stream is not influenced by artificial armoring or upstream/downstream infrastructure.
- A densely vegetated riparian zone for a stable boundary condition between the stream banks and flood prone area.
- Existing biological or habitat data.
- Available stream gage data and physical habitat ratings desirable.

The bulk of the candidate sites came from several sources which included:

- 2000+ sites - Maryland Biological Stream Survey (MBSS) (C. Millard, pers. comm. 2006 and Prochaska 2005) and Maryland State Wildlands (C. Gougen, pers. comm. 2006)
- 80 sites from the Maryland Department of the Environment's (MDE) Rapid Bioassessment Protocol (RBP) network (N. Primrose, pers. comm. 2006)
- 40+ sites from the U.S. Fish and Wildlife Service (USFW) (M. Secrist, pers. comm. 2007)
- Anecdotal information was also provided by stream practitioners and county governments: Maryland National Capital Park & Planning Commission (MNCPPC) (D. Redmond, pers. comm. 2006), Baltimore County Department of Environmental Protection and Resource Management (DEPRM) (E. Gemmil, pers. comm. 2006), Montgomery County Department of Environmental Protection (DEP) (J. Hollister, pers. comm. 2006)

All of the sites identified were then analyzed using a desktop survey. Sites that met the following criteria were selected for further investigation: riparian buffer width >10 meters, watershed forest cover >50%, highest scores for selected habitat values, aesthetics, channel alterations, and bank stability. Recent aerial photography was then reviewed for the selected sites in order to discard those with significant recent alterations to the stream or adjacent riparian zone.

The desktop survey identified 130 potential sites in five Maryland counties. An initial site reconnaissance of the 130 sites was conducted in order to assess the suitability of each site for use as a reference reach. One hundred of the 130 sites were eliminated as a result of the initial site reconnaissance. Reasons for exclusion included bedrock grade control, bedrock lateral control, land use, infrastructure such as dams, culverts, and sewer line crossings, channel incision, channelization, excessive stream bank erosion, beaver activity, braided channel, bed scour, and channel size that would limit access for detailed geomorphic assessments. The remaining 30 sites were visited again and more detailed data was collected (Appendix G, Table G2). Data included bankfull width, mean bankfull depth and estimated flood-prone width, and applicable reach length. Channel slope and bed material were also estimated. A cursory visual assessment of channel

stability, riparian buffer quality, and infrastructure that could impact the streams long term stability was performed as well.

None of the 30 sites met all the criteria, which is not surprising as pristine stream channels are rare in the Piedmont and Coastal Plain physiographic provinces of Maryland. Therefore, a second, less restrictive, screening method was developed. An effort was also made to utilize sites having watershed characteristics similar to the ICC stream restoration sites. Sites that were considered marginal during the initial site reconnaissance were re-evaluated using the following criteria:

- Length of the study reach was at least twenty times the bankfull width.
- Percentage of stable riffles within the reach.
- Consistency of Rosgen stream type classification throughout the reach.
- Occurrence of manmade infrastructure. This was not a definitive reason to eliminate a site as long as the overall area appeared stable.
- Existence of adequate bank vegetation and/or buffer in order to help stabilize the banks over the majority of the reach.
- Presence of road crossings or debris jams upstream and downstream. These were evaluated for conditions such as scour, embeddedness, and stability.
- Degree of entrenchment throughout the reach.
- Streams with similar Rosgen stream type classifications were compared to each other. The streams with the higher percentage of stable riffles and consistency of stream type were generally chosen.
- Access and travel time to the site was also taken into consideration to improve data collection efficiency.

Results of the revised screening method resulted in the final list of six sites presented in the introduction.

2.2. Field Data Collection

Rosgen Levels I through III methodologies described in *Applied Fluvial Morphology* (Rosgen 1996) were conducted in 2007 and 2008. Level IV methodologies have yet to be completed. Specifically, the field assessments included:

- A field map was sketched to document the stream's geomorphic features and the locations of large trees and infrastructure.
- Stream state categories, such as flow regime, stream order and size, meander patterns, depositional features, debris/blockages, and riparian composition, were determined in order to characterize the general hydrologic, channel pattern, sediment transport, and riparian characteristics of each reach.
- The Pfankuch Channel Stability assessment was performed as a rapid assessment of stream stability.
- Predicted total bank erosion was calculated using the Bank Erosion Hazard Index (BEHI) and Near Bank Stress (NBS) methodologies.

- Stream geometry measurements of radius of curvature, meander belt width, and meander length were determined from the detailed site survey.
- Sinuosity was determined by calculating the ratio of stream length to valley length.
- A longitudinal profile was surveyed to characterize the slope and length of each reach, as well as individual bed features.
- Cross sections, including a minimum of two riffles, a run, a pool, and a glide were surveyed at each reach to measure the channel form.
- Toe and bank pins were installed in the pool, classification riffle, and glide cross sections in order to measure bank erosion and lateral stability.
- Two scour chains were installed in the classification riffle and the glide cross sections to help determine vertical stability during the completion of Level IV methodologies.
- Photographs of each cross section were taken.
- Four pebble counts, including one active channel, one boundary riffle, one boundary pool, and one representative pebble count were collected to quantify substrate composition.
- A bar or subpavement sample was collected and wet sieved to predict the ability of the existing stream reach to transport its largest particle during bankfull flow.

2.3. Data Entry and Analysis

The data was entered into RIVERMorph® and The Reference Reach Spreadsheet for Channel Survey Data Management®. Data analysis included the determination of existing stream types and relations of morphologic variables, identification of stream valley types, examination of stream state categories, estimation of bankfull cross-sectional area and discharge, identification of stream types and bankfull channel dimensions, evaluation of morphological data such as channel dimension, pattern, profile and channel materials, and prediction of river stability and sediment supply. To facilitate the data analyses, the Geographic Information System (GIS) application GISHydro2000® was utilized to determine the drainage area, basin statistics, hydrologic, and land use characteristics of each site. RIVERMorph® and The Reference Reach Spreadsheet for Channel Survey Data Management® were used to compile, manipulate, and plot field data, and AutoCAD LT 2002® was used to analyze the planform of each assessment site. Maps were created using ARCMap Version 9.1®. Stream valley types were verified with U.S. Geological Survey 1:24,000 quadrangle topographic maps.

3. RESULTS AND DISCUSSION

3.1. Watershed Descriptions

The six sites selected for detailed survey are located in the Piedmont, Western Coastal Plain, and the Blue Ridge and Great Valley physiographic regions of Maryland. The locations of the survey sites are shown in ***Figure 1***. All of the survey sites, except Little Paint Branch, are first or second order streams and have watersheds ranging in size from 0.3 to 1.0 square miles. Little Paint Branch is a fourth order stream with a drainage area

of 8.8 square miles (***Table 1***). Impervious area ranges from 0% to 55% and percent forest ranges from 16% to 100%. Land uses generally consist of forest, urban (mostly residential), and agriculture. The most prevalent hydrologic soil group for each site is Group B (***Table 2***). Group B soils generally consist of silt loam or loam with a moderate infiltration rate. The Rosgen classification system stream types include four C channels, two B channels, and one E channel.

3.2. Valley Descriptions

According to natural channel design protocols, reference reach data should only be compared or applied to other streams that have the same valley type (Rosgen 1998). The Rosgen classification system valley types observed at the six selected reference sites include types VI and VIII. Valleys identified as type VI are topographically influenced by colluvium-forming processes and bedrock geology (Rosgen 1996). Some alluvium accumulation may also be present at the base of the type VI valleys (Rosgen 1996). All of the reference site type VI valleys are similar to type II (moderately steep, colluvium controlled) valleys, but were classified in the type VI category because bedrock outcrops indicate a structural control on the valley and stream morphology[1]. Additionally, only B and G stream types are found in type II valleys, and one of the reference reaches selected in these valleys classified as a C type stream. A larger range of stream types (including C) are found in the type VI valleys.

Type VIII valleys consist of low-gradient floodplains developed in fluvial or lacustrine sediments, often with multiple river terraces (Rosgen 1996). Type VIII is the most commonly found valley type in developed areas of central Maryland, and can contain stream types C through G. The Maryland Coastal Plain also includes areas of valley types X (wide coastal floodplains) and XI (deltas and tidal flats), but those valley types are typically found closer to the Chesapeake Bay interface. In urban locations, artificial stream confinement from building encroachment into floodplains, channelization, and rock or concrete stabilization structures can mimic a type IV valley (gorges and canyons).

3.3. ICC Site Descriptions

ICC restoration sites are located in Montgomery and Prince George's Counties close to the fall line between the Piedmont and Coastal Plain. Valley types in this area include II, VI, VIII, and IV in areas where streams have been artificially confined. All of the restoration sites are located in suburban areas, and many have a well-preserved riparian forest. Some of the stream reaches targeted for restoration have been channelized between buildings in concrete-lined channels. The restoration sites include first to fourth order streams with watershed drainage areas ranging from 0.2 to 15.2 square miles, and impervious area from 6% to 42%.

[1] Type II valleys should have colluvium depths that allow for channel incision. If bedrock acts as a vertical control for the channel, then the valley is classified as a Type VI (Rosgen, pers. comm. 2007).

Figure 1: Reference Reach Site Locations in Maryland
(physiographic province break lines from GISHydro2000)

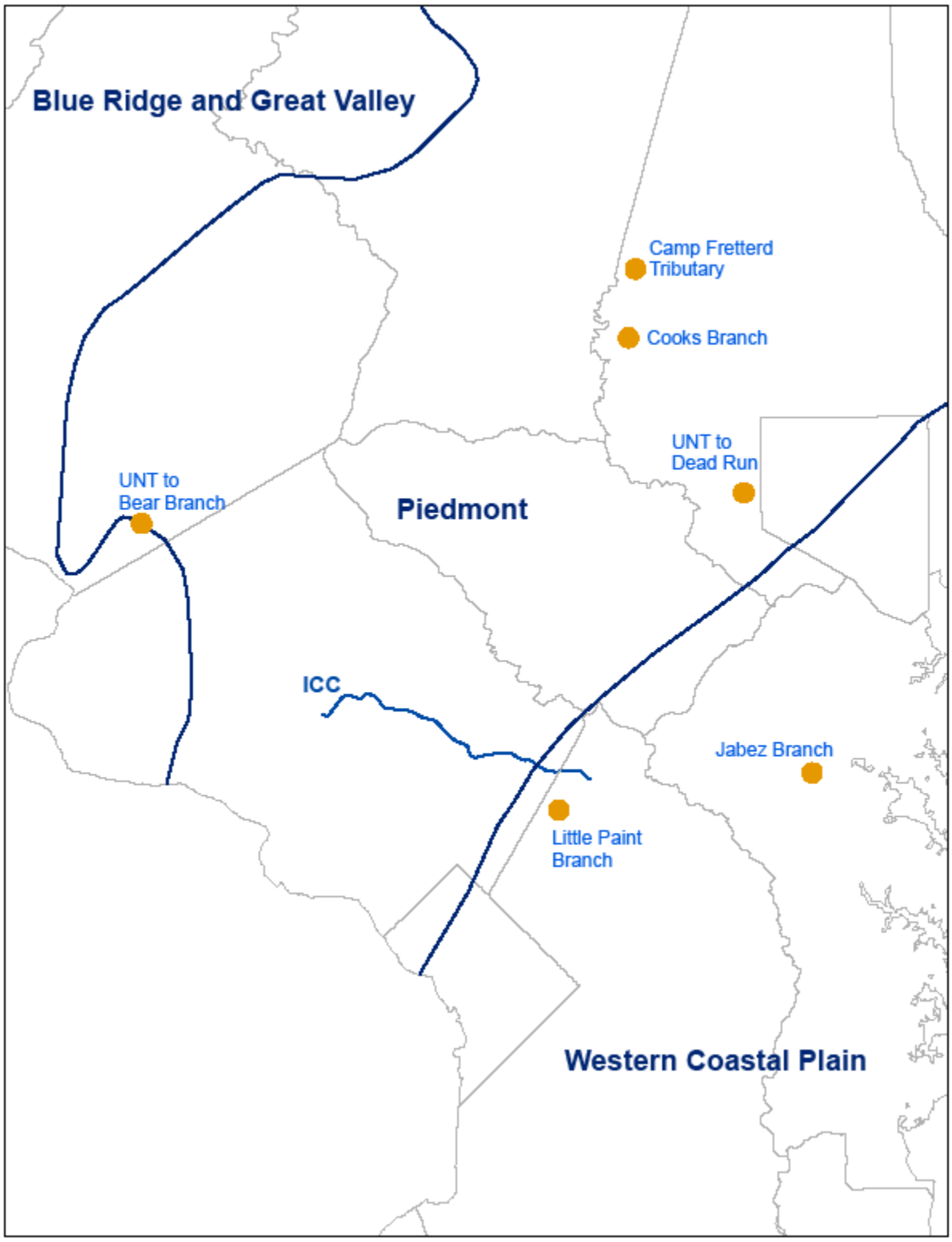

Table 1: Site Description Summary

Site	County	Drainage Area (mi^2)	River Basin	Physiographic Region	Rosgen Valley Type	Rosgen Stream Type	Stream Order
Camp Fretterd Tributary	Baltimore	0.5	Patapsco River	Piedmont	VI	B4	1
Cooks Branch	Baltimore	0.9	Patapsco River	Piedmont	VI	B4c	2
Little Paint Branch	Prince George's	8.8	Washington Metropolitan	Western Coastal Plain	VIII	C4	4
Jabez Branch	Anne Arundel	1.0	West Chesapeake Bay	Western Coastal Plain	VIII	E5	2
UNT to Bear Branch	Frederick	0.4	Middle Potomac River	Piedmont, Blue Ridge and Great Valley	VIII	C4	1
UNT to Dead Run	Baltimore	0.3	Patapsco River	Piedmont	VI	C4b	1

Table 2: Soil Summary

Stream	% A Soils	% B Soils	% C Soils	% D Soils
Camp Fretterd Tributary	0	90	3	7
Cooks Branch	0	78	22	0
Little Paint Branch	0	34	23	43
Jabez Branch	1	64	31	4
UNT to Bear Branch	0	26	73	1
UNT to Dead Run	0	55	16	29

3.4. Reference Reach Summary Data

Summary data for each site, including dimension, pattern, profile and bed materials can be found in Appendices A through F. For each Rosgen stream type, expected ranges of entrenchment ratio, width/depth ratio, sinuosity and slope were compared to the reference reaches in ***Table 3***.

Table 3: Reference Stream Types

	Entrenchment Ratio	**Width/Depth Ratio**	**Sinuosity**	**Slope**
Stream Type B4/B4c	Range: 1.4-2.2 Most Likely: 1.4-1.5	Range: 10.7-36.7 Most Likely: 12.0-20.0	Range: 1.2-1.7 Most Likely: 1.2-1.4	Range: 0.020-0.040 Most Likely: 0.020-0.030
Camp Fretterd Tributary	1.9	13.5	1.2	0.022
Cooks Branch	2.1	13.7	1.2	0.013
Stream Type C4/C4b	Range: 2.7-31.7 Most Likely: 2.7-10.0	Range: 13.5-75.0 Most Likely: 13.5-28.7	Range: 1.4-2.8 Most Likely: 1.8-2.1	Range: 0.001-0.018 Most Likely: 0.001-0.007
UNT to Bear Branch	2.7	12.2	1.3	0.020
UNT to Dead Run	2.4	18.0	1.2	0.026
Little Paint Branch	2.2	27.2	1.1	0.006
Stream Type E5	Range: 2.3-200.0 Most Likely: 2.3-20.0	Range: 2.0-10.0 Most Likely: 5.0-7.0	Range: 1.2-3.1 Most Likely: 2.0-3.0	Range: 0.001-0.020 Most Likely: 0.001-0.020
Jabez Branch	3.3	11.1	1.3	0.006

Note: Range and most likely values were obtained from Rosgen and Silvey, 1998.

Camp Fretterd Tributary had an entrenchment ratio within the range of a B4 stream, and was in the most likely range for the width/depth ratio and slope. Cooks Branch also had an entrenchment ratio within the range of a B4 stream, and was within the most likely range for width/depth ratio, but had a slope less than 0.020 that further classified it as a B4c stream. Both channels had a sinuosity value just below the range of typical B4 streams.

UNT to Bear Branch had an entrenchment ratio within the most likely range of a C4 stream, while UNT to Dead Run and Little Paint Branch had entrenchment ratios lower than the range, but still at least 2.2, the threshold for a C4 stream. UNT to Bear Branch had a width/depth ratio lower than the range, but still above the threshold of 12 for a C4 stream. UNT to Dead Run and Little Paint Branch had width/depth ratios within the most likely range of a C4 stream. All three of the channels had sinuosity values lower than the range of typical C4 streams. Little Paint Branch had a slope within the most likely range, while UNT to Bear Branch had a slope higher than the range but just at the threshold value (0.020) between C streams and Cb stream types. UNT to Dead Run had a slope higher than the range and higher than 0.020, further classifying it as a C4b stream.

The entrenchment ratio and slope of Jabez Branch were in the most likely range of E5 streams. Jabez Branch had a width/depth ratio higher than the range, but still less than 12, the threshold for an E4 stream. Jabez Branch had a sinuosity within the range of E5 stream channels.

3.4.1. Dimensionless Ratios

Cross section dimensionless ratios were calculated for each site using the classification riffle and pool cross sections, and are summarized in ***Table 4***. These dimensionless ratios can be used to design cross sections using the bankfull dimensions of the proposed channel for the same stream type in the same valley type.

Table 4: Cross Section Dimensionless Ratios

Stream	**Width/ Depth**	**$Width_{pool}$/ $Width_{bkf}$**	**$Area_{pool}$/ $Area_{bkf}$**	**Riffle $Depth_{max}$/ Riffle $Depth_{bkf}$**	**Pool $Depth_{max}$/ Riffle $Depth_{bkf}$**	**Pool $Depth_{bkfp}$/ Riffle $Depth_{bkf}$**
Camp Fretterd Tributary	13.5	N/A*	N/A*	1.3	N/A*	N/A*
Cooks Branch	13.7	0.8	1.6	1.3	2.6	2.0
Little Paint Branch	27.2	0.8	1.2	1.5	3.0	1.4
Jabez Branch	11.1	0.8	1.3	1.6	2.4	1.6
UNT to Bear Branch	12.2	0.7	0.8	1.7	1.4	1.0
UNT to Dead Run	18.0	0.4	0.5	1.8	1.6	1.3

* Pools were not found within the study reach

Profile dimensionless ratios were calculated for each site using the average water surface slope and are summarized in ***Table 5*** and ***Table 6***. When a stream is compared to a reference reach, these dimensionless ratios can be utilized to determine the departure from a stable condition of the same stream type in the same valley type.

Table 5: Profile Dimensionless Slope Ratios (mean, range in parentheses)

Stream	Riffle Slope/ Average Water Surface Slope	Pool Slope/ Average Water Surface Slope	Run Slope/ Average Water Surface Slope	Glide Slope/ Average Water Surface Slope
Camp Fretterd Tributary	1.1 (1.0-1.4)	NA*	0.5 (0.3-0.6)	0.6
Cooks Branch	1.6 (1.2-2.2)	0.2 (0.0-0.8)	2.3 (1.2-4.4)	0.3 (0.0-1.1)
Little Paint Branch	1.4 (0.6-2.2)	0.0 (0.0-0.7)	1.6 (0.0-5.2)	0.5 (0.0-2.6)
Jabez Branch	3.3 (0.5-11.7)	0.0 (0.0-0.9)	0.8 (0.2-1.6)	0.0 (0.0-2.3)
UNT to Bear Branch	2.1 (0.5-3.1)	0.4 (0.0-0.1)	1.1 (0.0-5.0)	0.4 (0.0-1.0)
UNT to Dead Run	1.5 (0.6-4.8)	0.3 (0.0-1.6)	1.5 (0.0-6.2)	0.0 (0.0-0.3)

* Pools were not found within the study reach

Table 6: Profile Dimensionless Depth Ratios (mean, range in parentheses)

Stream	Riffle Depth/ Average Riffle Depth	Pool Depth/ Average Riffle Depth	Run Depth/ Average Riffle Depth	Glide Depth/ Average Riffle Depth
Camp Fretterd Tributary	0.2 (0.2-0.3)	NA*	0.2	0.3
Cooks Branch	0.3 (0.0-0.4)	0.8 (0.3-1.7)	0.4 (0.3-0.6)	0.3 (0.1-0.4)
Little Paint Branch	0.3 (0.2-0.6)	1.0 (0.7-1.6)	0.5 (0.3-0.7)	0.3 (0.3-0.4)
Jabez Branch	0.3 (0.2-0.6)	1.7 (1.0-2.7)	0.9 (0.3-1.6)	0.4 (0.2-0.8)
UNT to Bear Branch	0.2 (0.1-0.4)	0.8 (0.6-1.1)	0.3 (0.2-0.6)	0.3 (0.2-0.5)
UNT to Dead Run	0.2 (0.1-0.3)	0.6 (0.3-0.9)	0.3 (0.2-0.5)	0.3 (0.1-0.3)

* Pools were not found within the study reach

Channel pattern dimensionless ratios were calculated for each site using the bankfull width of the channel at the classification riffle cross section and are summarized in ***Table 7***. These dimensionless ratios can be used to design the plan form using the bankfull width of the proposed channel for the same stream type in the same valley type.

Table 7: Channel Pattern Dimensionless Ratios (mean, range in parentheses)

Stream	Meander Length/ $Width_{bkf}$	Radius of Curvature/ $Width_{bkf}$	Belt Width/ $Width_{bkf}$	Pool to Pool Spacing/ $Width_{bkf}$	Pool Length/ $Width_{bkf}$
Camp Fretterd Tributary	12.6	2.7	6.7	N/A*	NA*
Cooks Branch	7.6 (7.0-8.2)	1.7 (0.9-3.0)	3.5 (3.1-3.9)	4.8 (2.7-10.0)	1.7 (0.2-4.4)
Little Paint Branch	10.7 (10.1-11.2)	2.1 (1.8-2.3)	3.2 (1.7-4.4)	2.5 (1.0-3.8)	0.7 (0.1-1.6)
Jabez Branch	9.5 (6.5-11.8)	2.0 (1.0-2.9)	5.4 (3.7-9.1)	5.9 (3.9-11.7)	2.1 (0.9-3.6)
UNT to Bear Branch	4.4 (3.5-5.4)	1.2 (0.6-2.4)	2.3 (1.5-4.5)	3.4 (1.1-7.4)	0.9 (0.4-1.4)
UNT to Dead Run	4.3 (4.1-4.6)	2.5 (0.6-6.6)	2.3 (1.6-3.6)	4.3 (1.3-7.8)	0.5 (0.1-0.8)

* Pools were not found within the study reach

3.4.2. Bankfull Discharge

The channel forming or dominant discharge concept is almost universally utilized in stream restoration design. Channel forming discharge is typically estimated by bankfull discharge (Q_{bkf}), effective discharge, or discharge of a certain recurrence interval. Rosgen (1996) makes no distinction between Q_{bkf}, effective discharge or dominant discharge, although Doyle et al. (2007) show that estimates of effective discharge and bankfull discharge can vary. Even with the limitations of assuming Q_{bkf} is always equal to the channel forming discharge, and with the problem of identifying Q_{bkf} consistently in the field, particularly in incised channels, it is the cornerstone of Rosgen's Level II analysis. Q_{bkf} is defined by Dunne and Leopold (1978) as "The bankfull stage corresponds to the discharge at which channel maintenance is the most effective…and generally doing work that results in the average morphologic characteristics of channels." The Q_{bkf} is an instantaneous flow that, on average, has a recurrence interval of 1.5 years determined by a flood frequency analysis (Dunne and Leopold 1978).

Bankfull discharge and bankfull velocity were calculated using the bankfull dimensions, average bankfull slope, and the substrate particle size of the classification riffle for each site, and are summarized in ***Table 8***. Roughness was calculated using the particle size distribution and hydraulic radius to determine relative roughness (Rosgen 2006).

Table 8: Bankfull Discharge, Velocity, and Manning's "n"

Stream	Bankfull Discharge (cfs)	Bankfull Velocity (ft/sec)	Manning's "n"
Camp Fretterd Tributary	42	3.8	0.049
Cooks Branch	46	3.2	0.049
Little Paint Branch	750	5.5	0.034
Jabez Branch	28	3.6	0.024
UNT to Bear Branch	35	3.7	0.051
UNT to Dead Run	86	4.9	0.045

3.5. Morphological Summary and Stability Predictions

The morphological summary and stability predictions are found in ***Table 9***. All reference reaches are predicted to be laterally and vertically stable, except for Jabez which is predicted to be moderately unstable laterally. Camp Fretterd Tributary and UNT to Bear Branch are predicted to have a slight increase in channel enlargement, Jabez Branch is predicted to have a moderate increase in channel enlargement, while Cooks Branch, Lower Paint Branch, and UNT to Dead Run are predicted to be stable. Predicted sediment supply is low for all reference reaches, except for Jabez Branch, which is predicted to have a moderate to high sediment supply. Dimensionless critical shear stress was calculated utilizing Rosgen's use of the Andrews equations (Andrews 1983, 1994), but as the armor ratio was beyond the recommended range, this method was only applicable to UNT to Bear Branch. Dimensionless critical shear stress values at the other sites were derived from Wilcock and Crowe (2003) as these reaches had bed material with a significant sand component.

Table 9: Morphological Summary and Stability Predictions

Morphological Summary and Stability Predictions	Camp Fretterd Tributary	Cooks Branch	Little Paint Branch	Jabez Branch	UNT to Bear Branch	UNT to Dead Run
Stream Type	B4	B4c	C4	E5	C4	C4b
Valley Type	VI	VI	VIII	VIII	VIII	VI
Width Depth Ratio	13.5	13.7	27.7	9.4	12.1	18.0
Entrenchment Ratio	1.9	2.1	2.2	4.0	4.7	2.4
Water Surface Slope (S) (ft/ft)	0.022	0.013	0.0057	0.0064	0.02	0.026
Riparian Buffer Quality	Forested Buffer >100ft	Forested Buffer >100ft	Forested Buffer <100ft, Impacted by Development	Forested Buffer >100ft	Forested Buffer >100ft	Forested Buffer <100ft, Impacted by Development
Bankfull Cross-sectional Area (ft^2)	11.0	14.2	135.8	8.0	9.6	17.3
Top of Bank Cross Section Area (ft^2)	27.5	31.3	135.8	21.8	16.2	17.3
Bankfull Discharge (cfs)	42.2	45.6	749.6	28.3	35.0	85.6
Dimensionless Critical Shear Stress	0.021	0.025	0.024	0.021	0.018	0.027
Degree of Incision	Stable to Slightly Incised	Stable	Stable	Slightly to Moderately Incised	Slightly Incised	Stable to Slightly Incised
Predicted Annual Streambank Erosion Rate	39.4 tons/yr 0.0511 tons/yr/ft	7.0 tons/yr 0.0132 tons/yr/ft	52.1 tons/yr 0.0422 tons/yr/ft	40.3 tons/yr 0.0359 tons/yr/ft	12.2 tons/yr 0.0237 tons/yr/ft	2.9 tons/yr 0.0029 tons/yr/ft
Lateral Stability	Stable	Stable	Stable	Moderately Unstable	Stable	Stable
Vertical Stability	Stable	Stable	Stable	Stable	Stable	Stable
Channel Enlargement	Slight Increase	Stable	Stable	Moderate Increase	Slight Increase	Stable
Sediment Supply	Low	Low	Low	Moderate to High	Low	Low

4. CONCLUSION

Six reference sites from various physiographic regions in Maryland were chosen to best represent stable streams. The Rosgen valley types represented were VI and VIII. Stream types included two B streams, three C streams, and one E stream. The reference reaches were generally within the expected range of the corresponding Rosgen stream type for entrenchment ratio, width/depth ratio, sinuosity, and slope. All of the reference reaches were predicted to be relatively stable. Efforts will be made in the future to validate the stability predictions.

The reference reach sites presented herein are in no way presented to infer that the channels are completely stable or dynamically stable throughout the reach. Areas of bank erosion and bed scour may be observed upon visual inspection. No attempt is being made to conceal the short comings of any of the study sites.

The search will continue for additional reference reach sites using the methods previously described. This may allow for the inclusion of additional Rosgen stream types in drainages with greater variability in size and character. Expansion of the information presented will occur as more data is collected.

These sites are presented with the following disclaimer and should be thoroughly evaluated by stream practitioners considering their use for natural channel design. Professional judgment should be applied prior to using the attached data as a basis for project design if the reference reach, or analog-empirical, method of design is appropriate.

Every attempt has been made to provide sites that depict the characteristics representative of the channel types referenced above. However, the particular channel type may not be consistent throughout a reference reach. Final determination of the applicability of these reference reaches is the responsibility of the designers who may utilize them in their own designs. The authors assume no responsibility for the use of their data during design of stream restoration projects by others.

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