U.S. Fish & Wildlife Service

Little Tuscarora Stream Restoration Project Frederick, MD

Project Summary and Design Report

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LITTLE TUSCARORA CREEK RESTORATION, FREDERICK COUNTY, MARYLAND: FUNCTION-BASED PROJECT SUMMARY AND DESIGN REPORT

By: John B. Hutzell and Richard R. Starr

Stream Habitat Assessment and Restoration Program
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EXECUTIVE SUMMARY

Trout Unlimited (TU), and the U.S. Fish and Wildlife Service (Service) - Chesapeake Bay Field Office have collaborated on a brook trout restoration project on approximately 1,500 linear feet of Little Tuscarora Creek, located in Frederick County, Maryland. The Little Tuscarora flows east 4.1 miles from its source in Gambrill State Park into Tuscarora Creek, which flows into the Monocacy River and ultimately enters the Chesapeake Bay via the Potomac River near Washington DC. The project goal of the Little Tuscarora Creek Stream Restoration is to create suitable habitat for brook trout not currently found within the project area.

The stream is on privately owned property and Service, TU and Maryland Department of Natural Resources (MDNR) conducted a rapid assessment to determine the restoration potential of the proposed site. The area has been impacted by agriculture practices, specifically row crops and livestock grazing, which have led to unstable stream banks, disconnected floodplain, poor bedform diversity, stream bed siltation, little to no riparian vegetation or buffer, and increased water temperatures. The Service, TU and MDNR felt (based on a preliminary site visit) that many, if not all of these impacts can be restored. Furthermore, the Frederick County Division of Public Works, Eastern Brook Trout Joint Venture and Maryland Brook Trout Alliance (CAMBI) has identified the Little Tuscarora watershed as a high priority brook trout watershed. Given the potential restoration lift and the focus on the watershed, the Service and TU felt that the proposed site would be an excellent candidate for brook trout habitat restoration.

The project process used for this project follows the approach outlined in *A Function-Based Framework for Stream Assessment and Restoration Projects* (SFPF) (Harman et al., 2012). The SFPF is based on the premise of a hierarchal relationship among stream functions where lower-level functions support higher-level functions and that they are all influenced by local geology and climate, which underlies the Pyramid. The SFPF was integrated throughout the entire project process to ensure the most appropriate design approach would be selected. The project process consists of the following steps: *Programmatic/Project Goals, Watershed Assessment, Reach-Scale Function-based Assessment, Restoration Potential, Design, Design Alternatives Analysis, Design Development,* and *Monitoring Plan*.

The focus of the watershed assessment was to determine the influence of the watershed health on the proposed project area. Specifically, watershed characteristics are evaluated to document hydrology (i.e., flow regime), sediment transport load (i.e., sources and amount), water quality (i.e., types and sources) and biology (i.e., locations and health). By understanding watershed conditions, we are able to determine if programmatic goals are achievable and determine the restoration potential of our project reach. Based on this assessment, the Little Tuscarora Creek watershed is a watershed going through "growing pains". The watershed has a fairly even mixture of low density residential, agricultural and forested areas and 13 % impervious surface that are underlain by 41 percent karst topography. While the flows have increased as a result of these land uses, the flow regime is still considered non-flashy meaning the proposed project will have a ground water recharge source and flood flows will not be elevated. Additionally, decades of poor agriculture practices have compromised much of the physical integrity of the channel and riparian corridor. As a result, there is widespread lateral instability throughout the watershed.

Therefore, the proposed project area will have a sediment supply that must be addressed in the proposed design. Lastly, the increased impervious surfaces and poor riparian buffers have increased water temperatures entering the proposed project area. However, it should be noted the Little Tuscarora Creek watershed is dominated by coldwater springs which does have a positive effect on water temperatures.

The reach-scale function-based assessment methodology was guided by the project goal of brook trout habitat restoration. Identifying functions that are not currently supporting brook trout are critical in determining restoration potential and selecting the appropriate design approach. The following assessment parameters, by pyramid level, were evaluated as part of this project:

Level 1 - Hydrology – flow regime
Level 2 - Hydraulics – floodplain connectivity and flow dynamics
Level 3 - Geomorphology – bedform diversity, lateral stability and riparian vegetation
Level 4 -Physicochemical – temperature, pH, dissolved oxygen, conductivity and turbidity
Leve 5 - Biology – macroinvertebrate communities and fish communities

Each assessment parameter had at least one measurement method to quantify the existing function-based condition. Then each measurement method value was rated either *functioning, function-at-risk, or not functioning* based on set performance standards. The Service determined that the overall function-based condition of the Little Tuscarora Creek project area is ***Functioning-at-Risk*** and is trending towards future instability before equilibrium can be reached (Table 1).

Table 1. Overall Function-Based Existing Condition and Restoration Potential

Level and Category	Parameter	Pre-Restoration Rating	Restoration Potential
1 - Hydrology	Channel-Forming Discharge	N/A	N/A
2 - Hydraulics	Floodplain Connectivity	Functioning-at-Risk	Functioning
3 - Geomorphology	Bed Form Diversity	Functioning-at-Risk	Functioning
	Channel Evolution	Not Functioning	Functioning
	Riparian Vegetation	Not Functioning	Functioning
	Lateral Stability	Functioning-at-Risk	Functioning
4 - Physicochemical	Water Quality	Not Functioning	Functioning-at-Risk
5 - Biology	Macroinvertebrate Communities	Functioning-at-Risk	Functioning-at-Risk
	Fish Communities	Functioning-at-Risk	Functioning-at-Risk

The Service then determined the restoration potential of the proposed project area. Restoration potential is the highest level of restoration or functional lift that can be achieved given the watershed health, reach-level function-based condition, stressors, and constraints. (Harman et al., 2012). The Service determined that pyramid levels 2 - Hydraulics and 3 - Geomorphology can be restored to fully functional and levels 4 – Physicochemical and 5 – Biology can have partial functional lift (Table 1). Restoration of levels 2 and 3 functions are typically the most easiest to achieve since it involves direct, physical manipulation of stream channel dimension, pattern and profile. However, typically lift for levels 4 and 5 functions cannot be constructed and rely on the functionality of lower level functions and watershed health. Furthermore, it takes time for levels 4 and 5 functions to respond to changes in lower level functions and watershed health.

While the Service has predicted that lift can occur through level 5, there are watershed stressors and constraints that influence the ability for brook trout to populate the proposed project area. The first is water temperature. Existing temperatures during the summer season can reach, at times, upwards of 10° Celsius higher than desired for brook trout populations. However, the numerous cold-water springs in the watershed and shade from high quality riparian vegetation may reduce the occurrence of elevated water temperatures and increase the duration of when brook trout can seasonally occupy the proposed project area. It should be noted that the watershed-level brook trout restoration efforts of CAMBI could increase the duration of brook trout presence at the site and allow for brook trout presence year round.

The Service generated design objectives based on Service and TU missions, project goals and the restoration potential of the proposed project area. Design objectives should be quantifiable and describe how the proposed project will be implemented (Harman et al., 2012). The design objectives of the proposed project focus on level's 2, 3 and 4 of the Pyramid and support level 5 functions (Table 2). The design objectives will also be used as monitoring performance standards.

Table 2. Little Tuscarora – Design Objectives. *The underlined words under the objectives are parameters or measurement methods from the* ***Stream Functions Pyramid Framework*** *(Harman, et al. 2012.)*

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

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

There are a variety of design approaches available to restore stream functions of highly degraded stream systems. Typical design approaches used in Maryland include 1) Natural Channel Design, 2) Valley Restoration Design, 3) Analytical Design, and 4) Regenerative Storm Conveyance Design. Each of these design approaches can result in functional uplift at the proposed project area. However, there is one critical function that only two of the approaches can address and that is sediment transport. The watershed and reach-level assessments identified that there a sediment supply being delivered to the project area. The transport of sediment is a critical factor in developing a design.

Therefore, the Service focused on design approaches that could transport sediment: Natural Channel Design and Analytical Design. Both design approaches use models and equations to test stream channel cross section dimension stability. However, only the Natural Channel Design approach uses reference reach data to design stream channel plan form and profile. Typically, the Analytical Design approach does not use stream channel plan form and profile design criteria. This can lead to undesired stream channel adjustments over time that could adversely affect geomorphic stability, water quality and biology. Therefore the Service selected Natural Channel Design as the design approach for the proposed project area.

The design proposed by the Service calls for the combination of channel reconfiguration in conjunction with floodplain complexity. The design calls for two different Rosgen stream types to be built within the project area. The first stream type, B4c, will be built to dissipate energy vertically through the use of structures and closer pool-to-pool spacing. This method is required directly downstream of the bridge on Opossumtown Road to maintain proper stream alignment with the bridge. When the hydraulic influence from the bridge is no longer a consideration, the Service has proposed a more sinuous C4 stream type with a low width to depth ratio to dissipate energy laterally across the floodplain. Since the elevation of the bed could not be increased or decreased due to infrastructure (i.e., sewer and bridge crossings), the Service proposes light excavation of the floodplain in order for more frequent out of bank events.

The Service and TU has also developed a monitoring plan based on the project goals and design objectives outlined in the report to evaluate the performance of the stream restoration project. The monitoring plan will include as-built surveys, rapid/visual geomorphic monitoring, monumented geomorphic surveys, and biological surveys. As-built surveys will be used to confirm that the project was built to design standards and will provide as baseline data for future monitoring. The rapid/visual geomorphic surveys will follow the methodologies outlined in the *Rapid Stream Restoration Monitoring Protocols* (Davis et al., 2014) developed by the Service. The biological surveys will follow the Maryland Biological Stream Survey methodologies and be conducted by MDNR.

This report documents the findings of the function-based watershed assessment, function-based reach-scale assessment and design development process used by the Service to develop the restoration plan for the Little Tuscarora Creek Stream Restoration.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

APPENDICES

I. INTRODUCTION

Trout Unlimited (TU), and the U.S. Fish and Wildlife Service (Service) - Chesapeake Bay Field Office are involved in a collaborative effort to restore in-stream habitat and re-establish brook trout in approximately 1,500 linear feet of Little Tuscarora Creek, located in Frederick County, Maryland. It flows east 4.1 miles from its source in Gambrill State Park into Tuscarora Creek, which flows into the Monocacy River and ultimately enters the Chesapeake Bay via the Potomac River near Washington DC. This project will draw on the experience and expertise of Federal, state and county agencies, non-governmental organizations and local volunteers to design, construct, monitor and maintain the restored area.

This report documents the findings of the function-based watershed assessment, function-based reach-scale assessment and design development process used by the Service to develop the restoration plan for the Little Tuscarora Creek Stream Restoration.

II. SITE SELECTION

A private landowner interested in having his stream restored approached TU and the Service and inquired about the suitability of the site for a restoration project. The Service, TU and Maryland Department of Natural Resources (MDNR) conducted a rapid assessment to determine the restoration potential of the proposed site. Restoration potential is the highest level of restoration or functional lift that can be achieved given the site constraints and health of the watershed. The proposed project area has been impacted by agriculture practices, specifically row crops and livestock grazing. These impacts have led to unstable stream banks, disconnected floodplain, poor bedform diversity, stream bed siltation, little to no riparian vegetation or buffer, and increased water temperatures. Due to these conditions, the stream reach lacks the appropriate functions to support healthy populations of brook trout. However, the Service, TU and MDNR felt that many, if not all of these functions could be restored.

Furthermore, the Frederick County Division of Public Works, Eastern Brook Trout Joint Venture and Maryland Brook Trout Alliance has identified the Little Tuscarora watershed in their working draft document titled “Catoctin, Antietam, and Monocacy Brookie Initiative” (Moore, 2011) as a high priority brook trout watershed. The alliance, abbreviated as “CAMBI”, aims to protect and restore existing brook trout habitat, unite brook trout populations, and educate residents and stream side landowners while also influencing developing practices in these priority watersheds to minimize impacts that new development may cause.

Given the efforts of CAMBI and the restoration potential, the Service and TU felt that the proposed site is an excellent candidate for brook trout habitat restoration.

III. PROJECT PROCESS METHODOLOGY

The project process used follows the approach outlined in the document: *A Function-Based Framework for Stream Assessment and Restoration Projects* (Harman et al., 2012). This document is based on the premise of a hierarchal relationship of stream functions where lower-level functions support higher-level functions and that they are all influenced by local geology and climate, which underlies the Pyramid (Figure 1). The Pyramid consists of five critical categories that evaluate stream functions. The framework of the Streams Functions Pyramid, (commonly called SFPF) is shown below in Figure 2. The Broad-Level View is the Stream Functions Pyramid graphic that was discussed above and shown in Figure 1. The remainder of the framework is a "drilling down" approach that provides more detailed forms of analysis and quantification of functions. The function-based parameters describe and support the functional statements within each functional category. The "measurement methods" are specific tools, equations, assessment methods, etc. that are used to quantify the function-based parameter. There can be more than one measurement method for a single function-based parameter. How the SFPF is specifically applied to the watershed and reach-level assessments is described below.

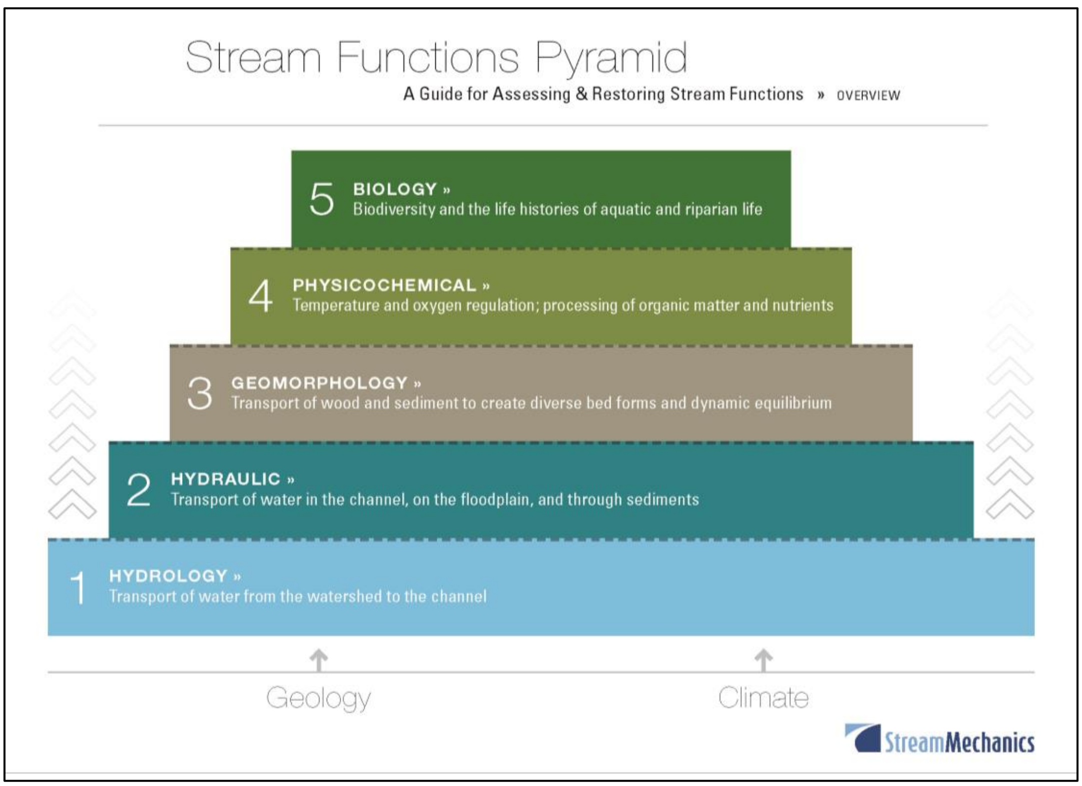

Figure 1. Stream Function Pyramid (Harman et al., 2012)

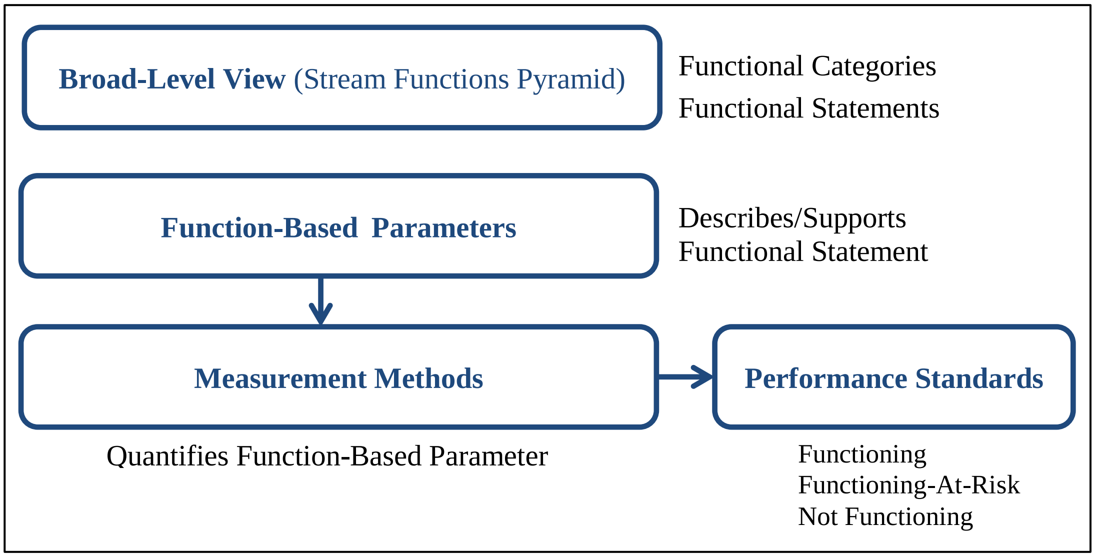

Figure 2. Stream Functions Pyramid Framework (Harman et al., 2012)

The SFPF was integrated throughout the entire project process to ensure selection of the most appropriate design approach. This was to ensure consistency from beginning to end and allow the Service to accurately determine if the project goals and design objectives were achieved. The project process consists of the following steps:

Programmatic/Project Goals – Documents what is driving the project and why the project is being proposed.

Watershed Assessment – Determines the health of the watershed and its influence on the proposed project area.

Reach-Scale Function-based Assessment – Establishes the existing function-based condition, determines stressors, identifies constraints, and determines channel functional evolution.

Restoration Potential – Determines the highest level of restoration that can be achieved given the watershed conditions, function-based assessment results, stressors, and constraints. Also, it is at this point that the actual amount of potential functional lift will be determined.

Design Objectives – Establishes design objectives based on the project goals, results of the watershed and reach-scale function-based assessment, constraints and restoration potential. Design objectives define how the project is going to be completed.

Design Alternatives Analysis – Determines the restoration design approach that best meets the project goals, objectives and restoration potential of the site. The focus is on how a design approach can change stream functions.

Design Development – Documents the design development process, ensures project feasibility, determines project implementation costs, and produces a constructible design set along with specifications and materials.

Monitoring Plan – Determines if the quantifiable project objectives are achieved and that existing functioning parameters remain functioning.

IV. PROGRAMMATIC/PROJECT GOALS

The project goal of the Little Tuscarora Creek Stream Restoration is to create suitable habitat for brook trout that are not currently found within the project area. Brook trout are found higher in the watershed, but have been extirpated (Hudy et al., 2006) from this area due to increased water temperatures and lack of suitable habitat. The Service and TU will employ restoration practices to reduce water temperatures in order to provide seasonal refuge to brook trout in the watershed. The secondary project goal is to reduce sediment levels from the project area by stabilizing and vegetating the stream banks that are currently contributing nearly 200 tons per year of sediment. While these goals will enhance the function-based condition of Little Tuscarora Creek through Level 3 (Geomorphology) of the SFPF, there is a chance restoration can occur through Level 5 (Biology) if brook trout populate the area seasonally. The successful completion of the Little Tuscarora stream restoration project will satisfy strategic objectives put in place by the President's Chesapeake Bay Initiative, as well as the US Fish & Wildlife Service strategic plan for trust species.

V. WATERSHED AND REACH ASSESSMENT

This section presents a brief summary of the methods used by the Service to conduct a limited watershed assessment (Figure 3) and a detailed function-based stream assessment. The findings are also presented and discussed. The purpose of the watershed assessment is to determine the influence of the watershed health on the proposed project area. Specifically, watershed characteristics are evaluated to document hydrology (i.e., flow regime), sediment transport load (i.e., sources and amount), water quality (i.e., types and sources) and biology (i.e., locations and health). By understanding watershed conditions, we are able to determine if programmatic goals are achievable, as well as determine the restoration potential of the project reach.

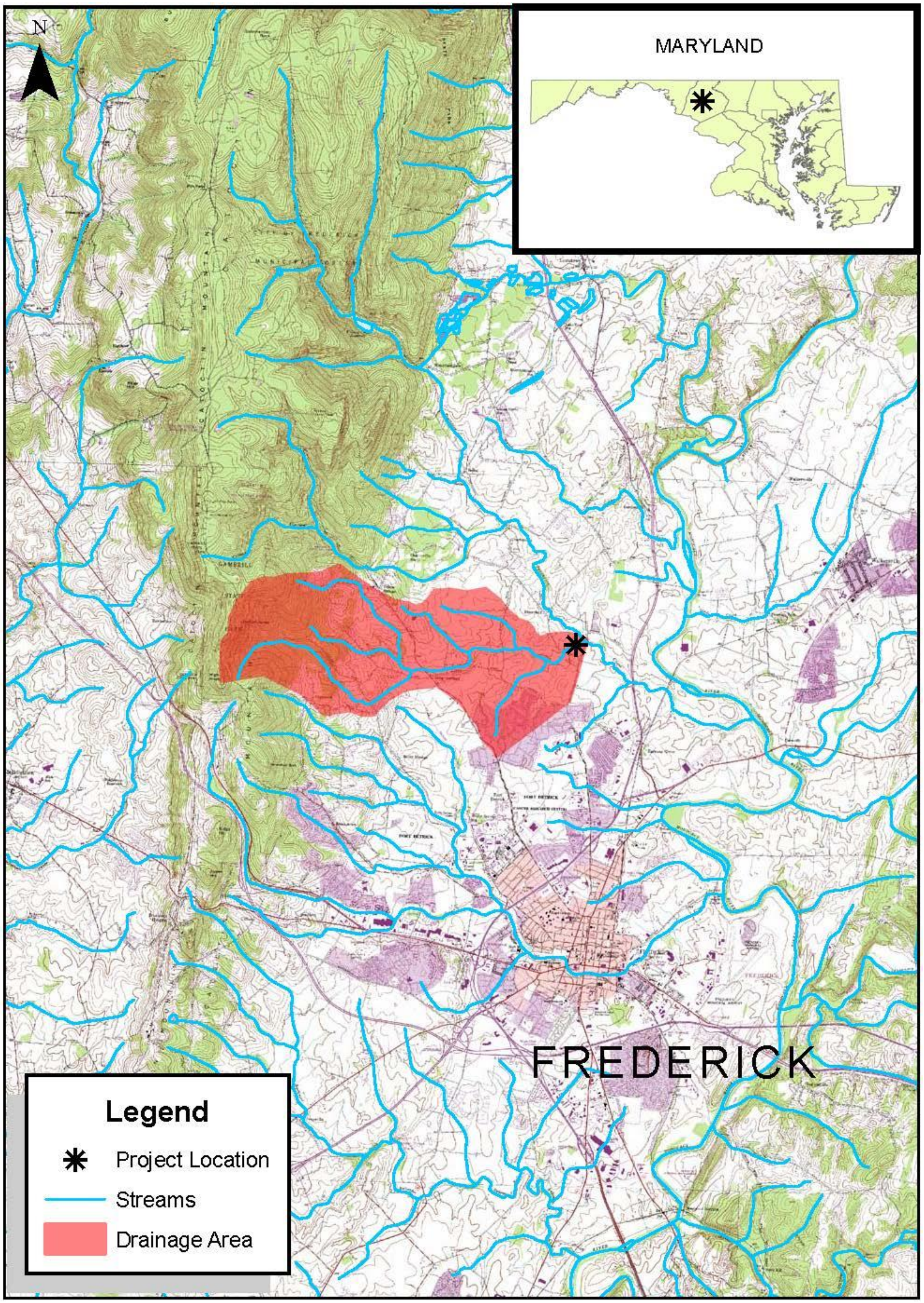

Figure 3. Project drainage area shaded in red

A. WATERSHED ASSESSMENT

The watershed assessment involved two levels of assessment: stream-based assessment and land-based assessment. The stream-based assessment involved a visual assessment of stream character and stability condition upstream and downstream of the project area. The fluvial geomorphic conditions observed included channel dimensions, pattern, profile, and substrate material, vertical and lateral stability, sediment supply potential, Rosgen stream type, and channel evolution. The land-based assessment analyzed land use/land cover patterns, soils, geology, hydrology, valley type, existing water quality and biological data, and watershed development.

1. Geology and Soils

The Little Tuscarora Creek watershed is unique due to that fact that it lies within two distinctly different physiographic provinces. As much as 92.5 percent of the watershed area is within the Blue Ridge and Great Valley physiographic province and the remaining 7.5 percent is located in the Lowland section of the Piedmont Plateau province, which lies in between the Blue Ridge and Coastal Plain provinces. Unlike the Coastal Plain and Piedmont Plateau provinces, the Blue Ridge, Ridge and Valley, and Appalachian Plateaus provinces are underlain mainly by folded and faulted sedimentary rocks. The rocks of the Blue Ridge province in western Frederick County are exposed in a large anticlinal fold whose limbs are represented by Catoctin Mountain and South Mountain. These two ridges are formed by Lower Cambrian quartzite, a rock that is very resistant to the attack of weathering and erosion. A broad valley floored by Precambrian gneiss and volcanic rock lies in the core of the anticline between the two ridges. For many years the limestone formations have been used as local sources of agricultural lime and building stone. Modern uses include crushed stone for aggregate and cement. A pure, white sandstone in the western region of the province is suitable for glass manufacturing. The Piedmont Plateau province is composed of hard, crystalline igneous and metamorphic rocks and extends from the inner edge of the Coastal Plain westward to Catoctin Mountain, to the eastern boundary of the Blue Ridge province. Bedrock in the eastern part of the Piedmont consists of schist, gneiss, gabbro, and other highly metamorphosed sedimentary and igneous rocks of probable volcanic origin. In several places, these rocks have been intruded by granitic plutons and pegmatite. Deep drilling has revealed that similar metamorphic and igneous rocks underlie the sedimentary rocks of the Coastal Plain. Several domal uplifts of Precambrian gneiss mantled with quartzite, marble, and schist are present in Baltimore County and in parts of adjacent counties. Differential erosion of these contrasting rock types has produced a distinctive topography in this part of the Piedmont (Maryland Geological Survey). Detailed bedrock formation mapping for the Little Tuscarora Creek basin can be found in Appendices A and B.

Little Tuscarora Creek has been identified to be within a karst geologic region. U.S. Geological Survey estimates that 41 percent of this watershed is underlain by limestone geology. Aside from bedrock formations (ie. faults and folds), karst regions can be identified by the presence of things like groundwater springs, active depressions and sinkholes. Appendix C shows the active karst features found in the Little Tuscarora drainage basin. A watershed that exhibits karst features can be subject to a variety of attributes not typically found in other physiographic regions. Karst topography tends to have greater groundwater interaction, which better regulates water temperatures and reduces seasonal temperature spikes. Streams influenced by high concentrations of springs are less affected by dry periods or droughts and are able to sustain more consistent base flows. In some cases, "swallow holes" reduce or eliminate surface flow that is lost to underground conduits. Similarly, "springs" can occur where the water table meets the land surface. Because of this, surface flow or channel discharge can differ significantly throughout streams in a karst-dominated watershed.

A report by Meisner in 1990 suggests that a brook trout's range in a stream is related to ground water temperature. Since Little Tuscarora Creek has numerous springs (Shultz et al., 2005) and ample groundwater interaction, it is plausible that temperatures could be appropriate for brook trout inhabitation in our project area for seasonal use. In addition, intact brook trout populations exist higher in the Clifford Branch area of the watershed and public reports describe a historically abundant fishery (Shultz et al., 2005) likely due to the appropriate habitat and temperature conditions. TU has monitored water temperatures in the project area for two summer seasons. While summer temperatures exceed maximum temperatures for brook trout survival (Raleigh R. F. 1982), the data collected by TU supports seasonal habitation. This information will be discussed further in the *Project Reach Function-Based Assessment* portion of this report.

The Little Tuscarora Creek project area primarily consists of two soil types (i.e., Bermudian silt loam and Birdsboro silt loam). The Bermudian silt loam consists of very deep, somewhat well drained soils and is typically located in floodplains with convex, linear side slopes. Permeability is 0.60 to 6.00 in/hr throughout but is limited by capacity. Slopes range from 0 to 3 percent. Mean annual precipitation is about 37 - 48 inches, and mean annual temperature is about 45 - 55 degrees F. The Birdsboro silt loam consists of very deep, somewhat well drained soils and is typically located in floodplains with convex, concave side slopes. Permeability is 0.57 to 1.98 in/hr throughout but is limited by capacity. Slopes range from 0 to 3 percent. Mean annual precipitation is about 37 - 46 inches, and mean annual temperature is about 45 - 59 degrees Fahrenheit.

A soils map of the Little Tuscarora Creek project area can be found in Appendix D. Both the Bermudian and Birdsboro silt loam found in the project area has a Kw factor of 0.37 and is generally considered as a moderately erosive soil due to its texture, structure, organic matter and permeability (Soil Survey Staff). Due to the surrounding land uses, riparian condition and the soils erosive properties, existing bank conditions have a high potential to erode. Erosion can be reduced if these soils are well vegetated, but mixed land use and impervious surface have accelerated bank erosion throughout the watershed. Since these soil types exist throughout the entire watershed the deterioration of raw or eroding stream banks upstream of the project area will continue to be a constant source of sediment.

2. Existing Land use/Land cover

The Service used aerial photographs and land use/land cover maps (Appendix E) to estimate the land use/land cover percentages for the Little Tuscarora watershed. Based on Maryland Department of Planning data from 2010, the primary land use in the watershed is Low Density Residential, accounting for over 29 percent of the coverage. Medium and Low Density Residential, Institutional, Agriculture, Forest and Other land use make up the remaining 71 percent. A more detailed distribution can be found in Table 1. Based on the 2010 Frederick County Comprehensive Land Use Plan, the land use distributions of this watershed will remain mostly unchanged through 2025. Currently, the watershed consists of less than 13 percent impervious surfaces. While there is not specific data that describe the adverse effects of impervious surfaces in this particular watershed, there are many sources that support that impervious surfaces often negatively impact water temperature and water quality. Altered biologic functions by increasing water temperatures, reducing valuable riparian filtration times and increasing channel discharges are just a few of the things that can be caused by impervious surfaces. Collectively, these stressors can negatively impact habitat and channel stability which are crucial to project success. While current levels of impervious surfaces cannot be altered and are considered a watershed wide constraint, steps can be taken to reduce the effects of impervious surface related runoff through dense riparian planting and improved development practices. As was stated earlier, the Frederick County Division of Public Works, Eastern Brook Trout Joint Venture and Maryland Brook Trout Alliance has identified the Little Tuscarora as a high priority brook trout watershed and the efforts they are proposing could help alleviate the adverse impacts associated with impervious surfaces.

Currently, the project area consists of 100 percent agriculture, which likely contributed to the degraded stream bank conditions. While this current land use presents stability challenges if left unaltered, the proposed restoration plan aims to establish a dense riparian buffer to curb the effects of streamside farming practices on the site.

Little Tuscarora Landuse Values			
Land Use	**Land Use Code**	**Acreage**	**% Watershed Covered**
Low Density Residential	11	1990.81	29.0%
Medium Density Residential	12	602.53	8.8%
High Density Residential	13	20.21	0.3%
Institutional	16	86.11	1.3%
Agriculture	21 & 22	1818.22	26.5%
Forest	41 & 42	1737.97	25.3%
Other Developed Land	191 & 192	600.64	8.8%
Source: Maryland Department of Planning, 2010			

Table 1. Little Tuscarora Land Use Values

3. Hydrology & Hydraulics

The Little Tuscarora Creek watershed is a sub-watershed of the Monocacy River, which is the largest Maryland tributary to the Potomac River. The Little Tuscarora Creek watershed is a short, broad basin covering approximately 5.6 square miles (Figure 3) at the project location and is in the Blue Ridge hydrologic region. The valley type at the project area, as defined by Rosgen (1996), is a valley type VIII; a wide, gentle valley slope with a well-developed floodplain adjacent to river terraces. These alluvial floodplains are maintained by the river and are dynamic in form. However, further up in the watershed, the valley type can by described as a Rosgen valley type II; moderately steep, gentle sloping side slopes often found in colluvial valleys. As valley type changes, there is also a change in the stream types within the Little Tuscarora Creek watershed. While the upper portions of the watershed contain reaches of Little Tuscarora Creek that are consistent, as defined by Rosgen (1996), with a stream type B3, the project area is best described as a C4; exhibiting a slope of less than 0.02 ft/ft, a sinuosity of 1.2 or greater and a width to depth ratio of greater than 12. While B3 stream types are stable and contribute only small amounts of sediment during run off events, C4 stream types have banks generally composed of unconsolidated, heterogeneous, non-cohesive, alluvial materials that are finer than the gravel-dominated bed material. Consequently, the stream is susceptible to accelerated bank erosion. Rates of lateral adjustment are influenced by the presence and condition of riparian vegetation (Rosgen 1996), as well as other factors.

Little Tuscarora Creek exhibits a flow regime typical of streams found in semi-rural areas. While the watershed receives an average 42.8 inches of precipitation annually

(U.S. Geological Survey, 2012), most runoff is absorbed into the soils, recharging the water table. Precipitation amounts for the two-year, twenty-four hour rain event are 3.09 inches, which deliver as much as 197 cfs to the site in 3.0 hours of time using the W.O Thomas, Jr. Equation. This data suggests that the watershed is not "flashy" based on comparisons of like sized urban watersheds with similar basin relief. Since Little Tuscarora Creek lies within a karst topographic region (Appendix C) with underlying limestone accounting for 41 percent of its geology (U.S. Geological Survey, 2012), it has a high amount of groundwater interaction and is predominantly spring fed. The presence of these springs is crucial to brook trout since springs provide more regulated water temperatures that brook trout need to survive. Spring fed creeks similar to Little Tuscarora Creek are unique to this part of Maryland and allow for sustainable brook trout populations that would not exist otherwise.

While knowing the hydrology of a watershed is important, it usually cannot be manipulated. However, the watershed hydrology must be understood in order to develop a sound restoration plan. The Little Tuscarora watershed hydrology is not complex and is typical for the region. The findings of the limited hydrology study do not show any limitations or constraints to the restoration plan and therefore do not show cause for additional research.

4. Geomorphology

The Little Tuscarora watershed contains a few distinguishable valley and stream type transitions from its start in the Frederick City Municipal Forest to its terminus at its confluence with Tuscarora Creek. The uppermost portion of the watershed consists of a stable B3 type (Rosgen) channel in a high relief basin with coarse cobble substrate, while the lower portion of the watershed contains meandering C3/4 Rosgen type channels with lower relief and a gravel substrate. While the upper portion of the watershed was observed to be stable, the lower portion of the watershed shows localized areas of vertical instability and widespread lateral instability. Localized vertical instability was observed in the form of head cuts, over steepened riffles, and poorly defined pools, glides and riffles. Widespread lateral instability was observed in the form of eroding streambanks and sparsely vegetated vertical banks and riparian corridors. Areas with greater amounts of vegetation typically have less erosion but since a large amount of the watershed is impacted by agriculture and low-density development, most areas have inadequate buffers. Watershed-wide observations support that there is a large available sediment source from stream bank erosion that must be transported through the system, as evidenced by depositional features such a point bar formations, mid-channel bars and inner berm features, as well as deposition throughout the floodplain. This watershed-scale sediment source defines Little Tuscarora Creek as a conveyance type channel, which plays a critical role in determining and selecting the correct design methodology.

5. Physicochemical and Biology

Physicochemical functions include the interaction of physical and chemical processes to create the basic water quality of the stream (including temperature, dissolved oxygen, conductivity, pH and turbidity), as well as to facilitate nutrient and organic carbon processes. These parameters provide both direct and indirect indications of stream condition and its ability to support biological conditions (Harman et al., 2012). The Little Tuscarora watershed has a number of influential factors that must be considered in order to determine if the reach-scale restoration can have any impact on the existing physicochemical functions or if these variables cannot be influenced. External discharges from upstream, point source and non-point source contributions, effects of land-use change and climate factors all influence physicochemical function. Based on the 2010 Frederick County Comprehensive Land Use Plan, the land use distributions of this watershed will remain mostly unchanged through 2025. Housing developments in the lower half of the watershed contribute some warm water discharge in the form of storm-water basin outfalls. There are no known point source pollutants found in the watershed, but Frederick County's Upper Monocacy River Watershed Restoration Action Strategy Report (Shultz et al., 2005) indicates that the Little Tuscarora watershed has moderate nitrogen concentrations; and high and excessive yields in the downstream portion of the watershed. Phosphorus pollution is generally baseline or moderate in the watershed. These findings are attributed primarily to the grazing of livestock and adjacent agriculture practices.

The SFPF (Harman et al., 2012) suggests that the ability of the lotic system to support biological processes is dependent upon the hydrology, hydraulic, geomorpholgy and physicochemical functions. A disruption in any one of the previously mentioned functions would result in loss of biologic diversity and abundance. While comprehensive watershed data is not widely available for the Little Tuscarora Creek watershed, the MDDNR has documented brook trout in the upper portion of the watershed. As a low-tolerant species, this basic information solidifies that the lower-tier functions are currently supporting the biology function-based parameters in upper portions of the watershed, but not in the lower portion, where the Little Tuscarora Creek Stream Restoration project area exists. These parameters include microbial communities, macrophyte communities, benthic macroinverterbrate communities, fish communities and landscape connectivity. Additional reach-scale physicochemical and biology data has been collected and will be discussed later in this report.

6. Watershed Assessment Summary

The Little Tuscarora Creek watershed could be described as a watershed going through "growing pains". The watershed is unique in part by the fact that its area consists of two physiographic regions and that it is underlain by 41 percent karst topography. These things alone are known to alter flow volumes and duration. Additionally, decades of poor agriculture practices have compromised much of the physical integrity of the channel and riparian corridor. The more recent land use changes, including increased development, has led to higher percentages of impervious surface, which contributes to higher flows and thermal loading. While the flows have increased, the flow regime is still considered non-flashy meaning the proposed project will have a ground water recharge source and flood flows will not be elevated. However, these higher flows, coupled with poor riparian buffers and erosive soils, have led to widespread lateral instability throughout the watershed. Therefore, the proposed project area will have a sediment supply that must be addressed in the proposed design. Lastly, the increased impervious surfaces increases water temperatures. This adversely affects the proposed project area the ability to improve functions for brook trout. However, as noted by Frederick County's CAMBI report (Moore, 2011), the Little Tuscarora Creek watershed is "dominated by coldwater springs" which is a positive effect on water temperatures.

Collectively, these "stressors" impact the restoration potential of the proposed project area. While these stressors cannot currently be addressed at the watershed level as part of this project, they can be addressed at the reach-level with the appropriate design approach. As mention earlier, the Frederick County Division of Public Works, Eastern Brook Trout Joint Venture and Maryland Brook Trout Alliance has identified this watershed as a high priority for brook trout restoration in their working draft CAMBI report (Moore, 2011). Additionally, the upper, less impacted, portion of the watershed still holds and nourishes an intact brook trout population. This, along with Frederick County efforts, is enough to support the project goal of creating a habitat suitable for seasonal brook trout usage.

B. BASE MAPPING

The Service conducted a baseline survey and produced 1-foot ground survey information to accurately map (Appendix F) and represent the project area. The Service used this information to assess base line conditions and to develop and illustrate a restoration design plan. Plan form, longitudinal profile, and topographic information is represented.

C. PROJECT REACH FUNCTION-BASED ASSESSMENT

The Service conducted a function-based assessment of Little Tuscarora Creek. This function-based assessment approach is based on the SFPF (Harman et al., 2012). The assessment methodology is guided by the programmatic and project goals. Since the programmatic goal of this project is related to brook trout, critical assessment parameters that support brook trout must be assessed. Identifying functions that are not currently supporting brook trout is critical in determining restoration potential and selecting the appropriate design approach.

The following assessment parameters, by pyramid level, were evaluated:

Level 1 - Hydrology – flow regime
Level 2 - Hydraulics – floodplain connectivity and flow dynamics
Level 3 - Geomorphology – bedform diversity, lateral stability and riparian vegetation
Level 4 - Physicochemical – temperature, pH, dissolved oxygen, conductivity and turbidity
Level 5 - Biology – macroinvertebrate communities and fish communities

Each assessment parameter had at least one measurement method to quantify the existing function-based condition. Then each measurement method value was rated either *functioning, functioning-at-risk, or not functioning* based on set performance standards. Specific measurements for each assessment parameter can be found in Appendix G and the results of the assessment are described below.

1. Hydrology

The hydrology assessment focuses on the watershed flow regime, which is the amount and rate of flows reaching the proposed project area. Understanding the flow regime influences how the stream channel and floodplain must be designed to address shear stresses (the amount of stress applied to channel and floodplain surfaces) and flood flow storage.

The Service determined that that hydrology at this particular site was dependent on parameters that include regional precipitation data/climate zones, land use and soils. Given the size of the watershed and the scope of the proposed project, the flow regime cannot be altered. Therefore, it will not have a rating and be used only to model pre-restoration conditions as they compare to proposed design conditions. The 2-year, 24-hour precipitation for this project area is 3.09 inches and the mean annual precipitation is 42.94 inches. The watershed had an average curve number of 71 with 345.7 feet of basin relief. Time of concentration to the inlet of the project area was 3.0 hours using the W.O. Thomas, Jr. Equation and 3.1 hours to the outlet of the project area. Based on this information and the watershed assessment, the proposed project area has a non-flashy flow regime.

Since no gage station information was available for this site, a regional curve (Pennsylvania/Maryland Carbonate Regional Curve, Chaplin, 2005) was used to determine the approximate channel forming discharge and was later validated using information from the geomorphic assessment. The 2, 10 and 100-year peak discharge events were determined by using GISHydro (Version 1.8.11) in combination with the USGS regression equation for that particular watershed.

The table below summarizes the findings from above as they relate to actual discharge at the Little Tuscarora Project site.

Channel Forming Discharge				
Level and Category	**Parameter**	**Measurement Method**	**Pre-Restoration Condition**	
			Value	**Rating**
1 - Hydrology	Channel Forming Discharge (Bankfull)	Regional Curves	132 cfs	N/A
		Bankfull Validation	116 cfs	N/A
	2-Year Peak Flow	USGS	197 cfs	N/A
	10-Year Peak Flow	USGS	540 cfs	N/A
	100-Year Peak Flow	USGS	1292 cfs	N/A

Table 2. Channel Forming Discharge

2. Hydraulics

Evaluating the hydraulics of a stream system is an important component to any assessment because it gives a better understanding of how water and sediment are transported through the channel and its associated floodplain. The Service identified and assessed two major hydraulic components during the Little Tuscarora Creek function-based assessment: Floodplain connectivity and Flow Dynamics. However, before you can determine floodplain connectivity, you must first understand and determine the bankfull discharge at the project area as this value serves as the basis for all geomorphic dimensionless ratios.

a. Bankfull Validation

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

i. Regional Relationships

During the Little Tuscarora Creek assessment, the Service identified bankfull stage using geomorphic indicators formed by the stream as described by McCandless and Everett (2002). Figure 3 depicts significant geomorphic indicators typically found in the Mid-Atlantic. Based on these indicators, the Service identified a consistent geomorphic feature at Little Tuscarora Creek. This geomorphic indicator was typically a significant slope break or back of bench found throughout the project area. These indicators were measured to determine width and depth and then compared to the "USGS Carbonate Great Valley Section of the Ridge and Valley Province" regional curve.

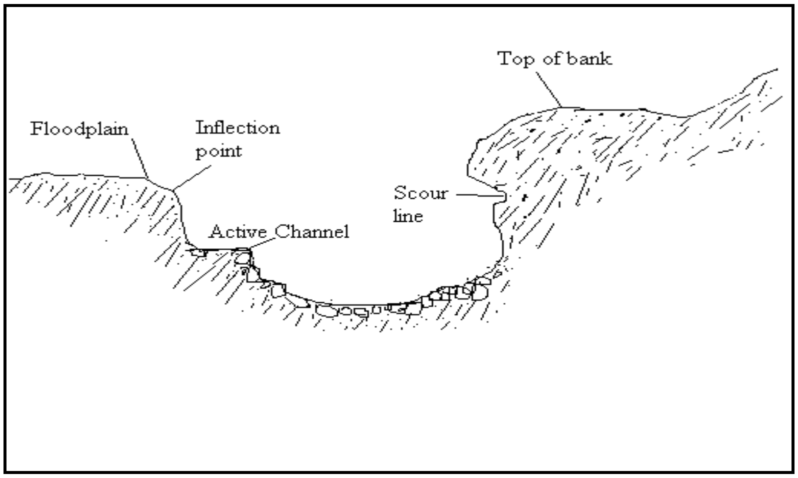

Figure 4. Typical Bankfull Indicators (McCandless and Everett, 2002)

The regional curve estimates channel discharge based on a linear regression equation derived from gaged sites across the same physiographic region with similar characteristics. Using only the drainage area, the Service was able to derive the estimated channel width, depth, cross sectional area and discharge. This information was then compared with field measurements to determine congruency. The Service does not recommend using only regional curve information to determine bankfull discharges and characteristics, rather it serves better as a first step for estimation. The Service took additional field based geomorphic measurements including cross sectional area, channel slope and particle distribution to validate bankfull dimension and discharge as well as performed extensive hydrologic calculations and modeling as shown in the following sections and documented in Appendices F through I.

Regional Curve Bankfull Characteristic Comparison		
Bankfull Characteristics	**Existing Representative Cross Section**	**USGS Carbonate Regional Curve**
Area (ft^2)	35.24	30.53
Width (ft)	23.11	21.31
Depth (ft)	1.53	1.46
Velocity (ft/s)	3.35	4.32
Discharge (cfs)	118.20	132.03
1. Maryland Stream Survey: Bankfull Discharge and Channel Characteristics of Streams in the PA MD Carbonate Region (Chaplin, 2002)		

Table 3. Regional Curve Bankfull Characteristic Comparison

b. <u>Floodplain Connectivity</u>

Floodplain connectivity is defined as the frequency of stream flows that access a streams floodplain. These frequent, out-of-bank flows encourage dense riparian cover and riparian wetlands that are invaluable to the overall functioning condition of a stream system. Historically, streams in most of the eastern part of the U.S. have been subject to channelization, a common practice to lessen the effects of overland flooding and increase flood flow capacity. While effective in flood reduction, channelization often leads to the loss of wetlands, lowering of the groundwater table, reduced species composition and increased sedimentation. Floodplain connectivity is a driving force for many of the geomorphic and ecologic functions (Wohl, 2004; Shields et al., 2010). Therefore, reconnecting floodplains is a major goal when working in watersheds that have channelized streams (Harman et al., 2012).

i. Bank Height Ratio

There are a number of measurements methods used to determine floodplain connectivity. The first, and perhaps easiest way to determine whether or not a stream is connected to its floodplain is by determining the bank height ratio (BHR). The BHR is simply the average height of the top of the low bank divided by the bankfull height.

The Service determined that Little Tuscarora Creek exhibited a degree of incision equal to 1.4 times its bankfull height. This measurement, or bank height ratio, was derived by first determining the correct bankfull height at our project area and then comparing that to typical top of low bank measurements throughout the project area. The value represents a ratio that means that the average low bank heights are 1.4 times taller than the elevation of the bankfull flow. Bank height values greater than “1” indicate that the channel exhibits a degree of channel incision and does not interact with its floodplain as often as it should which reduces stream function, increases bank erosion and limits vegetative filtration necessary to reduce TMDL levels. By using the performance standards found in the SFPF, the Service determined that Little Tuscarora Creek is ***Functioning-at-Risk*** due to its limited interaction with its floodplain.

ii. Entrenchment Ratio

The entrenchment ratio (ER) is a measure of the floodprone area width in relation to the bankfull width (Rosgen 1996). The ER is calculated by dividing the bankfull width by the available floodprone width at a water surface elevation two times greater than that of bankfull in a riffle cross section. A higher ER value means a higher availability of floodplain area for energy dissipation and flood storage. When coupled with the BHR, these measurement techniques provide a quick way to determine floodplain connectivity in the field.

The Service determined that Little Tuscarora creek had an entrenchment ratio of 2.5, meaning when stage is two times greater than the bankfull maximum depth, the available floodplain measures 2.5 times the bankfull width, in this case, 51.25 feet. By using the performance standards found in the SFPF, the Service determined that Little Tuscarora Creek is ***Functioning*** due to the amount and accessibility of available floodplain.

Floodplain Connectivity				
Level and Category	**Parameter**	**Measurement Method**	**Pre-Restoration Condition**	
			Value	**Rating**
2 - Hydraulics	Floodplain Connectivity	Bank Height Ratio	1.4	Functioning-at-Risk
		Entrenchment Ratio	2.48	Functioning

Table 4. Floodplain Connectivity

c. <u>Flow Dynamics</u>

While there are no performance standards for flow dynamics, they play an important part in developing restorations designs. The Service used tractive force calculations as well as HEC-RAS to conduct a hydraulic assessment of this particular reach to assure the restoration design would not cause any unsafe rise in hydraulic forces within the channel or effect flood flows around the culvert crossing on Opossumtown Pike. Twenty-six separate cross sections were modeled to compare the existing and proposed hydraulic conditions. The model was run using a bankfull flow of 116 cfs which was derived from the resistance relationship using existing and design channel geometry. A Manning's roughness coefficient of 0.35 was used for in-channel roughness, which is common among low gradient, meandering streams and provided similar results to those predicted by the Pennsylvania / Maryland Carbonate Regional Curve (Chaplin, 2005). The design maximized the use of the available floodplain within the project area. The results below (Table 4) represent the range of values found throughout the twenty-six existing and proposed cross sections. A detailed results table can also be found in Appendix I.

The SFPF (Harman et al., 2012) states that shear stress and stream power are important input parameters for assessing sediment transport; however, there are other geomorphology parameters and measurement methods that are better for developing performance standards. Stream velocity can be used as a flow dynamics performance standard, especially for evaluating the appropriate bankfull discharge (and flow area) and for fish passage. Using the SFPF performance standards for a "C" stream type, the Service determined that the stream velocity of Little Tuscarora Creek is ***Functioning***. These velocities do not pose any risk to the ability of fish to migrate; however, lower velocities sometimes cause sediment transport challenges.

Flow Dynamics				
Level and Category	**Parameter**	**Measurement Method**	**Pre-Restoration Condition**	
			Value	**Rating**
2 - Hydraulics	Flow Dynamics	Stream Velocity	3.35	Functioning
		Shear Stress	0.02 - 1.67	N/A
		Stream Power	0.02 - 10.03	N/A

Table 5. Flow Dynamics

3. Geomorphology

Geomorphology functions integrate both hydrology and hydraulic functions by establishing a relationship between flowing water, sediment transport and the channels physical dimension. This relationship serves as the means for creating bed form diversity and aquatic habitat, and drives channel aggradation, degradation or dynamic equilibrium. Evaluating and understanding channel geomorphology is necessary to properly understand the function-based condition and develop a proper restoration design. The Service identified and assessed bedform diversity, bed material characterization, sediment transport competency, sediment transport capacity, riparian vegetation, lateral stability and channel evolution.

a. Bedform Diversity

Bedform diversity is relatively simple to assess. Measurements of bed form diversity are structural measurements that can be used to predict sediment loading, transport capability and is also critical in assessing habitat requirements of aquatic species. A longitudinal profile of a stream channel provides detailed information about the bed form and can be used to quantify diversity (Harrelson et al., 1994). The Service assessed both pool-to-pool spacing and pool depth variability to determine the function-based condition of Little Tuscarora Creek. Both measurements could be extracted from the detailed longitudinal profile.

i. Pool-to-pool Spacing

Pool-to-pool spacing measures the frequency of pools in the stream reach and is the distance measured along the stream centerline of thalweg, between the deepest point of two pools (Harman et al. 2012). Studies have found that C and E stream types with pool-to-pool spacing with ratios greater than 5 are at greater risk to develop vertical instability problems. The Service determined that Little Tuscarora had a Pool-to-pool spacing range of 2.28 – 5.63 meaning it is ***Functioning-at-Risk***.

ii. Pool Depth Variability

Pool depth variability is desirable for high pool habitat diversity. Streams with similar pool depths or a narrow range of pool depths have limited habitat and the pools are filled with sediment. Pool depth variability is determined by dividing the mean riffle depth measured at a representative cross section by maximum pool depths measured from bankfull. This dimensionless ratio is referred to as the pool max depth ratio (Rosgen, 2009). The range of pool depth variability at Little Tuscarora Creek was found to be 2.45 – 2.87. Based on the performance standards of the SFPF, pool depth variability is considered ***Functioning***.

iii. <u>Depositional Patterns</u>

Depositional patterns describe the nature and extent of bar features in rivers (Rosgen, 1996). While many of these features may be dynamic in nature, they are often stable geomorphic features. For instance, point bars on stable C4 stream types are stable depositional features. Alternatively, depositional features can be indicators of excess deposition, which can lead to channel enlargement and/or aggradation. Depositional features like mid-channel bars, islands, chute cut-offs and side bars can be indicators of excess sediment or the inability of a channel to transport its sediment supply. These depositional categories have been identified and categorized by Dave Rosgen (Rosgen, D.L., 2009) to aid in the assessment of lateral and vertical stability. The Service used Rosgen's existing Depositional Pattern Worksheet to classify observed depositional features at Little Tuscarora Creek. Based on findings, the Service interpolated Rosgen's stability rating to Harman's SFPF rating system. Using this standard, the Service found B1, B2 and B4 depositional patterns at the Little Tuscarora Creek project area classing this segment of stream as ***Functioning-at-Risk*** but trending toward stability.

Bedform Diversity				
Level and Category	**Parameter**	**Measurement Method**	**Pre-Restoration Condition**	
			Value	**Rating**
3 - Geomorphology	Bedform Diversity	Pool-to-pool Spacing	2.28 - 5.63	Functioning-at-Risk
		Pool Depth Variability	2.45 - 2.87	Functioning
		Depositional Pattern	B1, B2, B4	Functioning-at-Risk

Table 6. Bedform Diversity

b. <u>Bed Material Characterization</u>

Analyzing the substrate of a stream is often one of the first steps in basic stream survey. Understanding substrate composition is important when analyzing things like bed form, sediment transport values, macroinvertebrate habitat and fish habitat because it influences each one. Typically, gravel bed streams are used to show functional lift after restoration. Overall coarsening of the streambed would indicate less fine materials are available or able to embed, meaning the stream has the energy and ability to deposit those materials in the floodplain or out of the project reach, which is often the goal of restoration in gravel bed streams. This is the case in the Little Tuscarora Creek stream restoration. Baseline bed material classification was gathered by using the Wolman (1954) pebble count procedure. Complete findings are shown in **Figure 2** below, but it was found that the d50 was equal to 29.35 mm which confirms that Little Tuscarora Creek is a gravel bed stream. While there is no performance standard associated with the Wolman (1954) pebble count procedure, the findings serve as a monitoring benchmark. Future samples can be compared to one another to see the streambed coarsen over time.

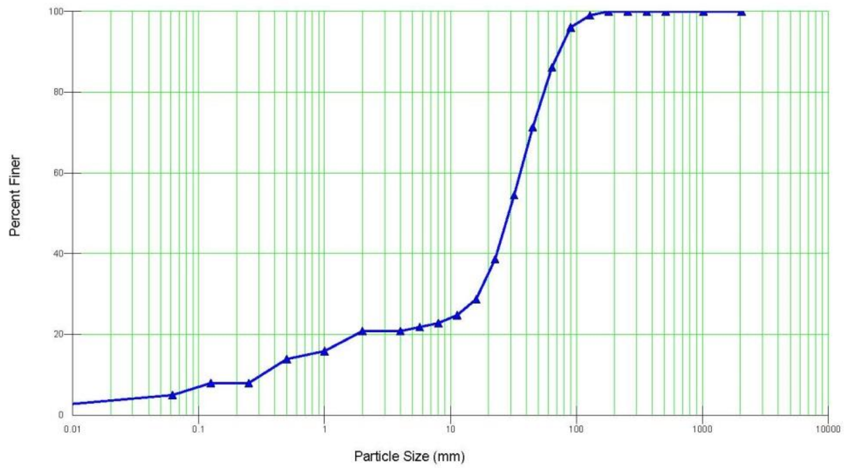

Figure 5. Little Tuscarora Creek Reach Scale Particle Distribution

c. <u>Sediment Transport Capacity</u>

Sediment transport capacity is typically defined as the amount of sediment that a stable riffle cross section can pass at bankfull flows. This information is unique to the stream system and is important to understand when developing restoration plans. If a stream system is receiving sediment from upstream, it must have the ability to transport that amount through the project area in order to maintain dynamic equilibrium, or not aggrade or degrade. Transport capacity studies can be intensive and cost prohibitive and yield marginally accurate results. Therefore, the Service used field indicators (i.e., bar formation, bedform diversity, and floodplain deposition) to assess sediment capacity conditions.

The watershed assessment showed that there is a sediment supply entering the project reach. However, the reach-level showed that the sediment supply is not excessive. There are some mid-channel and point bar formations, but these bars are well vegetated. If sediment supply was excessive, vegetation could not establish because the sediment would smother it. Within the stream channel, existing riffles consist of coarse, gravelly material. If there were excessive sediment, these riffles would be covered with fine sediment. Lastly, there are no large amounts of deposition within the adjacent floodplain. If the sediment supply was excessive, there would be numerous depositional areas, typically consisting of coarse-large sand materials, through the floodplain.

d. <u>Sediment Transport Competency</u>

Sediment transport competency is typically defined as the size of sediment that a stable riffle cross section can pass at bankfull flows. This information is valuable as it allows a designer to determine what stream dimensions and channel shear stresses necessary to create and maintain dynamic equilibrium. This is also an important parameter to assess when determining a stream's vertical stability. If a stream is unable to pass even the smallest sizes associated with the sediment supply, it will aggrade which would mean it is vertically unstable. If a stream can move the largest size associated with the sediment supply, it will degrade which also indicates vertical instability.

While there is more than one method to assess sediment transport competency, the Service used a method developed by Rosgen (2006) where required depths and slopes are used to determine competency. This method involves sampling bed material from either the riffle pavement/subpavement layer or material from a point bar. The Service took a sample from a representative bar feature and sieved the sample to determine the bar's distribution. Results can be seen below in Figure 3. The Service determined that the d100 of the bar sample was 75 mm and while the existing channel had the necessary slope to move a particle of that size, it did not have the depth necessary to move particles of that size during bankfull flows. These findings are consistent with the deposition patterns observed. A summary table of the results can be found below in Table 7 and a more detailed explanation of these findings can be seen in Appendix O.

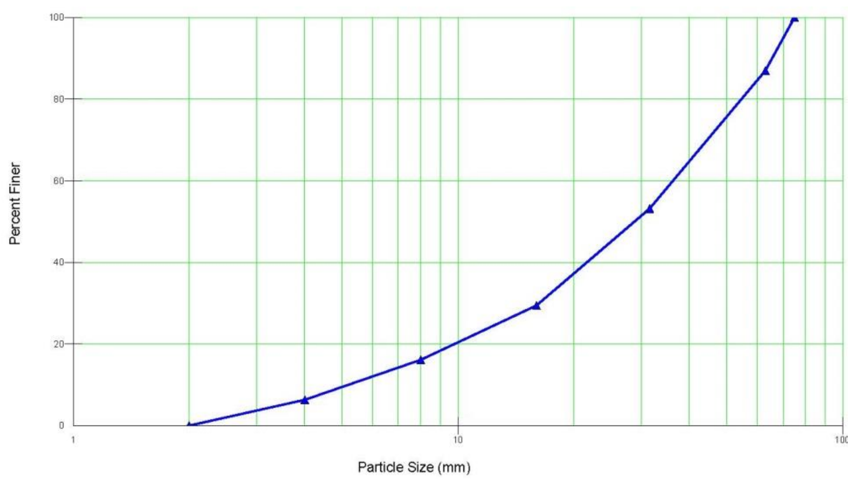

Figure 6. Little Tuscarora Creek Bar Sample Particle Distribution

Sediment Transport Competency				
Level and Category	**Parameter**	**Measurement Method**	**Pre-Restoration Condition**	
			Design	**Required**
3 - Geomorphology	Sediment Transport Competency	Required Depth	1.75	1.72
		Required Slope	0.004	0.004

Table 7. Sediment Transport Competency

e. Riparian Vegetation

Riparian vegetation plays an important role, not only from a geomorphic stability standpoint, but also from a wildlife habitat and water quality perspective. Some benefits of a healthy riparian corridor include energy dissipation by capturing sediments from upslope overland flow (Magette et al., 1989), bank stabilization by roots that extend throughout the bank (Wynn et al., 2004) and landscape connectivity for animals traveling along the stream corridor (Fisher et al., 1998). Research has also shown that a well-managed restored buffer can trap and/or convert up to 75 percent of nitrogen and 70 percent of phosphorus from nonpoint source runoff, if the source is from land uses that are adjacent to the stream corridor (Orzetti et al.,2010; Claussen et al., 2000; Lee et al., 2003; Schoonover and Williard, 2005). Additional research has shown 50 percent to 80 percent reductions in sediment loads from adjacent nonpoint source pollution (Orzetti et al., 2010; Cooper et al., 1987; Daniels and Gilliam, 1996; Lowrance and Sheridan, 2005; Schoonover and Williard, 2005; Tomer et al., 2007). It is obvious that a properly functioning riparian corridor is crucial to the overall function of a stream system and that assessing the condition of the riparian vegetation is a first step in determining possible functional lift.

The Little Tuscarora Creek Stream Restoration project area exists within a mixed use agricultural setting. A portion of the project area has been tilled for rotating crops and some of the adjacent land has remained planted in grasses to be mowed for hay production. The buffer width ranges from approximately 0 to 50 feet and consists of native and non-native grasses, shrubs, understory trees, and mature canopy trees. However, the majority of the project (Figure 4) exists within an area that is dominated by agriculture that consists of mowed/tilled edges and little to no canopy cover. While there are a variety of riparian condition measurement methods available, the Service chose to measure riparian vegetation condition by using the Proper Functioning Condition assessment tool, as well as determining buffer width based on belt width.

i. Proper Functioning Condition

A proper functioning condition (PFC) evaluation method developed by the Bureau of Land Management (Prichard et al., 1998) was used to determine the functionality of the riparian corridor surrounding Little Tuscarora Creek. PFC is less quantitative than bank profiles, cross sections or the bank stability to erosion model. However, it is the only method here that assesses the stream channel and the riparian buffer to determine bank stability (Harman et al. 2012). Using the

Lentic Standard Checklist (Appendix J), the Service determined that the riparian corridor was Nonfunctional which is equivalent to ***Not Functioning*** using on the SFPF.

ii. <u>Buffer Width</u>

Buffer width measurements can be as simple as measuring the width of the riparian corridor from the top of the stream bank, perpendicular to the fall line of the valley and moving away from the channel (Harman et al., 2012). An average width can be determined by taking a number of measurements at a variety of locations throughout the stream valley. The Service measured the riparian buffer width as it compared to the meander belt width of the channel. The meander belt width measurement is used to standardize the buffer width measurement and to create a baseline for the buffer width condition. A stable, meandering (sinuosity of 1.2 or greater) stream is said to have at least 15 feet of vegetative buffer measured from their outside meander bends towards the valley toe, in addition to a meander belt width of at least 3.5 times greater than its bankfull width. Measuring meander belt width is done by measuring the distance (perpendicular to the fall of the valley) between the apex of two consecutive meander bends. This method is desirable for creating straight riparian corridors that are easier to manage. The Service found that belt width of Little Tuscarora Creek was less than 3.5 times the bankfull width and had less than 10 feet of riparian vegetation extending out from the outside meander bends to the toe of valley. Meaning, that there was very little available buffer and is considered to be ***Not Functioning*** by the performance standards in the SFPF.

Riparian Vegetation				
Level and Category	**Parameter**	**Measurement Method**	**Pre-Restoration Condition**	
			Value	**Rating**
3 - Geomorphology	Riparian Vegetation	PFC	Nonfunctional	Not Functioning
		Buffer Width from Meander Belt Width	Meander belt width ≤ 3.5	Not Functioning

Table 8. Riparian Vegetation

Figure 7. Project area (outlined in red)

f. Lateral Stability

There are a variety of methods to determine lateral stability, each of which has specificity in their use as well as a range of precisions. One of the more precise methods involves profiling the bank with a detailed survey, then returning after a specified amount of time or discharge event to re-survey that bank. This method gives you an exact value of erosion at that specific location and can be compared to the associated span of time since last surveyed. This method is often used to monitor both reference and restoration sites and to calibrate erosion rate curves. While precise, bank profiles are time consuming and other methods suffice when estimating erosion rates. The lateral stability of Little Tuscarora was assessed by taking cross section measurements at stream features that most represented the conditions of the project area as well as plan form measurements to determine meander width ratios (MWR). Additionally, the Bank Assessment for Non-point source Consequences of Sediment (BANCS) Method, which uses Bank Erosion Hazard Index (BEHI) and Near Bank Stress (NBS) classifications of individual bank segments, was used to estimate bank erosion rate. A photo of typical stream bank conditions at the Little Tuscarora Creek project site can be seen in Figure 5 and findings are summarized in Table 8.

i. Lateral Erosion Rate

The BANCS model, is a method developed by Dave Rosgen (Rosgen, D.L., 2009) to rapidly estimate the amount of erosion of a particular bank segment by quantifying the banks physical condition. This method, BEHI, includes estimations of bank length, height, slope, materials, stratification, vegetative cover and root depth and density. When combined with the NBS estimate (also developed by Rosgen) it is possible to determine erosion quantity and rate. This method uses a combination of observed BEHI and NBS values which are plotted against the USFWS Erosion Rate Curve (USFWS, 2005). The USFWS Erosion Rate Curve has been found to produce very accurate estimates throughout the Mid-Atlantic as well as other regions. The Service employed these methods to quantify the amount and rate of sediment being lost from bank erosion throughout the Little Tuscarora Creek project area. The Service assessed all eroding banks within the reach, a total of 16 bank segments, and found that the system was contributing approximately 245 tons of sediment per year at a rate of about 0.13 tons per foot per year (Appendix K). The dominate BEHI condition was found to be high and the dominate NBS condition was found to be moderate and based on the SFPF has rated that condition to be ***Functioning-at-Risk.***

Figure 8. Eroding outside meander

ii. <u>Meander Width Ratio</u>

The meander width ratio (MWR) is a combination of two separate measurements, meander belt width divided by bankfull width. Dividing these values gives a ratio that can be compared to other streams and more specifically, reference condition streams. The minimum MWR for meandering streams (C and E types) is between 3.0 and 3.5; this ratio is required to create a sinuosity of at least 1.2, the most common break point between meandering and non-meandering streams (Rosgen, 1996; Leopold and Wolman, 1957). Alternatively, estimations can be made on the amount of lateral movement a stream will undergo if the current MWR of a meandering stream is below 3.5 by multiplying the stream's bankfull width by 3.5. This measurement can be rapidly determined by plan form survey as well as aerial imagery. The Service found that the MWR at Little Tuscarora Creek had an average of 3.6 which is considered to be ***Functioning*** by the SFPF (Harman et al., 2012).

Lateral Stability				
Level and Category	**Parameter**	**Measurement Method**	**Pre-Restoration Condition**	
			Value	**Rating**
3 - Geomorphology	Lateral Stability	Lateral Erosion Rate - Moderate BEHI Curve	Low to High NBS	Functioning-at-Risk
		Meander Width Ratio (C and E Stream Types)	3.6	Functioning

Table 9. Lateral Stability

g. <u>Channel Evolution</u>

The Service used the Rosgen Stream Classification system (Rosgen, D.R. 1996) in order to classify Little Tuscarora Creek. The Rosgen Stream Classification system uses physical features of a stream such as width, depth, pattern, and bed material, to group streams into a type denoted by alphanumeric codes.

Understanding the current stream classification helps determine what stage of channel evolution the system is in and make predictions about stream trend. The reason for including channel evolution is to show the current channel condition and how it could change over time (Harman et al. 2012). Using the Rosgen Stream Type Evolution Stages model, the Service determined that the 1,450 linear foot project area shows indices of an unstable Rosgen C4/1 channel with poorly defined characteristics and widespread instability (Appendix L). It can be theorized that the channel started out as a stable E or C stream type but due to the vertical instability of Tuscarora Creek (found directly downstream) and an increase in runoff (due to land use changes and agriculture practices), Little Tuscarora Creek began to incise. This down cutting continued until a vertical equilibrium was met. Now, the stream has begun to adjust latterly to form a floodplain within itself. This will be the "High Width/Depth Ratio C" stage. Only when a new, more adequate floodplain is formed, will Little Tuscarora Creek finally return to a stable C or E stream type. This scenario calls for years, if not decades of continuing instability. The succession is as follows: E/C →Incised C→High width/depth C→C/E. While this exact pattern is not found in Rosgen's stream type scenarios, Simons model (Simon, 2006) can be applied to our findings. Little Tuscarora Creek is currently at the "Class IV" stage indicating degradation and widening. This unstable state will cause severe bank erosion which will negatively impact water quality and in-stream biology. Little Tuscarora Creek's current channel evolution condition is categorized as ***Not Functioning*** based on the Simon model found in the SFPF.

Channel Evolution				
Level and Category	**Parameter**	**Measurement Method**	**Pre-Restoration Condition**	
			Value	**Rating**
3 - Geomorphology	Channel Evolution	Rosgen	Incised C	Not Functioning

Table 10. Channel Evolution

4. Physicochemical

While hydrology, hydraulics and geomorphology are all very important functions, biologic function is not possible if the physicochemical function is compromised or impaired. Measurement of physicochemical functions require an understanding of what influential variables are present that cannot be affected by restoration at the reach scale. These variables include external discharges from upstream, point source and non-point source contributions, and the effects of land-use changes in the watershed (Harman et al., 2012). While there are many measurement methods that can define water quality, the most common and most important to brook trout are temperature, pH, turbidity, conductivity and dissolved oxygen. There are a variety of other factors that can influence water quality such as soil composition and climate factors but typically these factors cannot be influenced by reach scale restoration.

a. Temperature

Water temperature is a defining factor in determining suitability for aquatic species. Most species have a defined range of temperatures at which they can exist and reproduce. This parameter is measured by basic temperature logging sondes that can be deployed for months at a time. Stream temperatures are influenced by climate, stream flow and depth, sunlight exposure and the riparian canopy (Harman et al., 2012). Sunlight can be the most influential factor for stream temperatures, particularly in open waters (Hynes, 1970). The MDDNR estimates that "stream sections with no forested riparian buffer could increase in temperature by more than 7°C at sites over 6 km downstream from buffered riparian areas (Barton et al., 1985). This baseline information is critical to obtain if there are specific project goals and objectives that will determine success based on suitable conditions for a specific plant or animal species. For instance, it is a goal of the Little Tuscarora Creek restoration to provide suitable habitat for seasonal use by brook trout. Research done by Raleigh (1982) indicates that brook trout thrive in water temperatures less than 18.3 degrees Fahrenheit and tolerate brief periods of up to 22.3 degrees Fahrenheit. While the specific duration is unknown, additional research was done by Wehrly et al. (2007) to determine the period of time a brook trout can be exposed to greater water temperatures than those presented above. Knowing this information provides a target water temperature and we can quickly determine how the water temperature of Little Tuscarora Creek compares. TU deployed a water temperature probe during the summer seasons of 2011 and 2012 in order to see if temperatures exceeded those required by brook trout for survival. TU found that the highest recorded temperature was 30 degrees Celsius, which greatly exceeds a target limit of 22.3 degrees Celsius. Based on these findings, it can be determined that the Little Tuscarora Creek temperature rating is ***Not Functioning*** for brook trout survival for year-long refuge, but can be suitable for seasonal cover. The Habitat Suitibility Index (HSI) indicates that in some streams, the major factor limiting salmonid densities may be the amount of adequate overwintering habitat rather than summer rearing habitat (Bustard and Narver, 1985a). Additionally, Everest (1969) suggested that some salmonid population levels were regulated by the availability of suitable overwintering areas.

b. <u>Dissolved Oxygen</u>

Dissolved oxygen (DO) is necessary for all aquatic organisms to survive in a body of water. Oxygen enters the water column primarily through diffusion from the atmosphere. Stream flow creates turbulence, which leads to additional entrainment of oxygen from the atmosphere (USEPA, 1997b). The amounts of DO are also influenced by temperature, altitude and salinity. The water column is considered saturated when the DO concentration is in equilibrium with oxygen in the atmosphere (Harman et al., 2012). Little Tuscarora Creek exhibits characteristics that are synonymous with good DO levels. Aeration is provided by the riffle complexes and course bed material and a variety of fish species can be observed throughout the project area. The Service has determined, with the help of the Maryland Biological Stream Survey (MBSS) group, that the dissolved oxygen is not a limiting factor at our project area. It should be noted however, that dissolved oxygen levels should not fall below 50 percent saturation for brook trout survival with optimum conditions near saturation (Raleigh R. F. 1982). The Service has not collected a specific DO value as of yet, nor is it reported in Table 10 below, but the Service plans to deploy water quality sondes to monitor DO during and after the implementation process.

c. <u>Turbidity</u>

Turbidity is a measure of water clarity based on how much light passes through the water column (USEPA, 1997b). An accumulation of suspended and dissolved materials from erosive conditions causes the water to become cloudy which increases turbidity levels. When the water is turbid, temperatures increase due to higher absorption of heat by the suspended particles. Dissolved oxygen can be reduced as a result of increased temperatures and reduced photosynthetic activity when light penetration is impeded. Biological lifecycles and habitat are negatively affected by high turbidity (Harman et al., 2012). Turbidity is measured in units of "JTU's" or *Jackson Turbidity Units*. This measurement represents the attenuation of a light beam through a column of water. For instance, optimum turbidity values for brook trout growth are approximately 0-30 JTU's, with a range of 0 – 130 JTU's (adapted from Sykora et al., 1972). An accelerated rate of sediment deposition in streams may reduce local brook trout production because of the adverse effects on production of food organisms, smothering of eggs and embryos in the redd, and loss of escape and overwintering habitat (Raleigh, R. F. 1982). The main contributing factor to turbidity levels are discharge, bank erosion and soil composition. The Service was not able to gather baseline turbidity data in the Little Tuscarora project area, but improved bank stability will contribute less sediment to the system and reduce turbidity levels within the project area. Turbidity levels may be monitored during construction, but there will be no pre- or post restoration values given for this project and therefore will not be populated in Table 10 below.

d. <u>Conductivity</u>

Conductivity is the measure of the water's ability to conduct electrical current through dissolved ions (Harman et al., 2012). Concentrations of inorganic dissolved solids, like the anions chloride, nitrate, sulfate and phosphate, as well as cations like sodium, magnesium and calcium, all effect the conductivity of the water column. Conductivity is primarily used as a baseline chemical indicator of stream health and is a good screening tool for some restoration projects. Conductivity can be used to measure changes in discharge characteristics, external flow contributions, pollutant load and other factors affecting the chemical composition of streamflow (USEPA, 1997b). Knowing the conductivity is an important physicochemical parameter because it can be used comparatively to assess differences between reference condition streams and impaired streams. Typically, conductivity levels are lower in stream systems that have established riparian buffers that allow for increased filtration and provide shade to reduce water temperature. The Service has not collected specific conductivity values as of yet, shown on Table 10 below, but plans to deploy water quality sondes to monitor conductivity after the implementation process.

e. <u>pH</u>

Measurements of pH indicate the relative acidity or alkalinity of water (Harman et al., 2012). When the pH drops below 7.0, the water is considered acidic; when the pH is above 7.0, water is considered alkaline (USEPA, 1997b). Stream pH can have a significant effect on biological communities, most prefer pH values in the 6.5 to 8.0 range (Harman et al., 2012). Like conductivity, pH is a good screening tool for stream restoration projects. At low pH values, ions from metals and toxic compounds can be released into the water column and negatively impact biological communities (Allan and Castilla, 2007). Specifically, brook trout occur in waters with a wide range of alkalinity and specific conductance, although high alkalinity and high specific conductance usually increase brook trout production (Cooper and Scherer 1967). Brook trout appear to be more tolerant than other trout species to low pH (Dunson and Matin 1973; Webster 1975). Laboratory studies indicate that brook trout are tolerant of pH values of 3.5 – 9.8 (Daye and Garsie 1975). The Service has determined, with the help of MBSS group that the pH of Little Tuscarora Creek is not a limiting factor for brook trout to use the project are as seasonal refuge. This information will be collected during subsequent project monitoring. For that reason, the value is not populated on Table 10.

Water Quality				
Level and Category	**Parameter**	**Measurement Method**	**Pre-Restoration Condition**	
			Value	**Rating**
4 - Physicochemical	Water Quality	Temperature	25.72°C (Summer)	Not Functioning
		pH	N/A	N/A
		Turbidity	N/A	N/A
		Conductivity	N/A	N/A
		Dissolved Oxygen	N/A	N/A

Table 11. Water Quality

5. Biology

Achieving biologic function is the result of the culmination of hydrology, hydraulic, geomorphology and physicochemical function, as described previously. Collectively, these functions support the life histories of aquatic and riparian plants and animals. The biology function-based parameters include microbial communities, macrophyte communities, benthic macroinvertebrate communities, fish communities and landscape connectivity (Harman et al., 2012). The Service decided to use the MDDNR to do biologic surveys to determine a biologic baseline for the Little Tuscarora Creek project. DNR followed guidance from their MBSS methodology (Kayzak, P. F, 2001) to asses for both cold water benthic macroinvertebrate communities as well as cold water fish communities. Specific data for Little Tuscarora Creek can be found in Appendix M. The results were adapted to the SFPF to provide a function-based rating. The methods and ratings can be found in the following paragraphs.

a. Benthic Macroinvertebrate Communities

Benthic macroinvertebrate sampling is conducted in 75 meter stream segments utilized for fish, habitat, and water quality sampling. The intent of benthic sampling is to qualitatively describe the community composition and relative abundance of favorable habitat (habitats supporting the greatest benthic diversity) within the sampling segment (Kayzak, 2001). The sampling collection procedures used allow for calculation of an index of biotic integrity (IBI) as described in Stribling et al. (1998). The proposed project area scored a MBSS IBI score of 3 which is considered ***Functioning-at-Risk***.

b. Fish Communities

The objective of fish sampling for MBSS is to assess the fishability and ecological health of fish communities in the non-tidal, flowing waters of Maryland. Quantitative, double-pass electrofishing is conducted in the same 75 meter stream segment as macroinvertebrate sampling to describe abundance and community composition for ecological health assessment. Information on gamefish lengths is also collected

(Kayzak, 2001). The proposed project area scored a MBSS IBI score of 4 which is considered ***Functioning-at-Risk***.

Aquatic Communities				
Level and Category	**Parameter**	**Measurement Method**	**Pre-Restoration Condition**	
			Value	**Rating**
5 - Biology	Macroinvertebrate Communities	MBSS IBI Score	3	Functioning-at-Risk
	Fish Communities	MBSS IBI Score	4	Functioning-at-Risk

Table 12. Aquatic Communities

6. Summary

The Service determined that the overall function-based condition of the Little Tuscarora Creek project area is ***Functioning-at-Risk*** and is trending towards a future of instability before any sort of equilibrium can be reached (Table 12). The determination of this rating is based on an accumulation of ratings at two different levels. First, each pyramid level is rated based on the individual rating results of each measurement method used to evaluate the assessment parameters (Table 12, Column Pre-Restoration Condition - Level). Second, the overall reach rating is based on the individual ratings of each pyramid level (Table 12, Column Pre-Restoration Condition – Overall Reach). Below is a summary description, by pyramid level, that supports the overall reach rating.

The Hydrology level, Level 1, is currently ***functioning*** mostly because current land uses within the watershed have not significantly influenced the amount and rate of flood flows reaching the project area, resulting in a non-flashy flow regime. This will specifically support such functions as floodplain connectivity, lateral erosion, and ground water recharge. While the flow regime has not been significantly altered by current watershed land uses, the current land uses may adversely affect water temperature functions and marcoinvertebrate and fish communities. The potential impacts are associated with impervious surfaces within the watershed, which can increase water temperatures and input other contaminants that influence the health of marcoinvertebrate and fish communities. However, the potential does exist for some of these impacts to be reduced by the number of springs within the watershed supplying cooler water temperatures.

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

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

The Physicochemical level, Level 4, is currently ***Not Functioning*** for brook trout based on warm water temperatures. The increased water temperatures are directly related to the impervious surfaces with the watershed and lack of quality riparian vegetation within the proposed project area. While warm water macroinvertebrates and fishes are found in abundance within the proposed project area, it does not support the brook trout goal of the project.

The Biology level, Level 5, is currently ***Functioning-at-Risk*** for brook trout based on warm water temperatures, poor bed form diversity, lateral erosion, and lacking riparian vegetation. These poorly functioning processes have created habitat conditions not suitable for brook trout and as a result, brook trout no longer inhabit the proposed project area. The biology level was given a functioning-at-risk versus a not function rating because the proposed project area does have good warm water species diversity and presence.

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

Summary Table

Level and Category	Parameter	Measurement Method	Pre-Restoration Condition			
			Value	Rating	Level	Overall Reach
1 - Hydrology	Channel Forming Discharge (Bankfull)	Regional Curves	132 cfs	N/A	Functioning	Functioning-at-risk
		Bankfull Validation	116 cfs	N/A		
	2-Year Peak Flow	USGS	197 cfs	N/A		
	10-Year Peak Flow	USGS	540 cfs	N/A		
	100-Year Peak Flow	USGS	1292 cfs	N/A		
2 - Hydraulics	Floodplain Connectivity	Bank Height Ratio	1.4	Functioning-at-risk	Functioning-at-risk	
		Entrenchment Ratio	2.48	Functioning		
	Flow Dynamics	Stream Velocity	3.35	Functioning		
		Shear Stress	1.08 - 12.70	N/A		
		Stream Power	2.52 - 90.73	N/A		
3 - Geomorphology	Bedform Diversity	Pool-to-pool Spacing	2.28 - 5.63	Functioning-at-risk	Functioning-at-risk	
		Pool Depth Variability	2.45 - 2.87	Functioning		
		Depositional Pattern	B1, B2, B4	Functioning-at-risk		
	Channel Evolution	Rosgen	Incised C	Not Functioning		
	Riparian Vegetation	PFC	Poor	Not Functioning		
		Buffer Width from Meander Belt Width	Meander belt width ≤ 3.5	Not Functioning		
	Lateral Stability	Lateral Erosion Rate - Moderate BEHI Curve	Low to High NBS	Functioning-at-risk		
		Meander Width Ratio (C and E Stream Types)	3.6	Functioning		
4 - Physicochemical	Water Quality	Temperature	25.72°C (Summer)	Not Functioning	Not Functioning	
		pH	N/A*	N/A		
		Turbidity	N/A*	N/A		
		Conductivity	N/A*	N/A		
		Dissolved Oxygen	N/A*	N/A		
5 - Biology	Macroinvertebrate Communities	MBSS IBI Score	3	Functioning-at-risk	Functioning-at-risk	
	Fish Communities	MBSS IBI Score	4	Functioning-at-risk		

Table 13. Summary Table

VI. PRELIMINARY DESIGN

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

A. RESTORATION POTENTIAL

Restoration potential is the highest level of restoration or functional lift that can be achieved given the watershed health, reach-level function-based condition, stressors, and constraints. (Harman et al., 2012). Based on these factors, the Service determined that pyramid levels 2 - Hydraulics and 3 - Geomorphology can be restored to fully functional and levels 4 – Physicochemical and 5 – Biology can have partial functional lift (Table 13). Restoration of levels 2 and 3 functions are typically the easiest to achieve since it involves direct, physical manipulation of stream channel dimension, pattern and profile. Stream channel parameters such as beltwidth, bank heights, wave lengths, facet feature lengths, slopes and depths can be constructed to specifications considered functioning.

However, typically lift for levels 4 and 5 functions cannot be constructed and rely on the functionality of lower level functions and watershed health. Furthermore, it takes time for levels 4 and 5 functions to respond to changes in lower level functions and watershed health. Research has shown that it can take up to 10 to 15 years to see biological lift (Orzetti, 2010). This holds true for the proposed project area. Uplift in macroinvertebrate communities can occur as a result of improvements to level 3 functions and suitable brook trout habitat can be achieved for part of the year through reductions in water temperatures.

There are, however, watershed stressors and constraints that influence the ability of brook trout to populate the proposed project area. The first is water temperature. Existing temperatures during the summer season can reach, at times, upwards of 10° Celsius higher than desired for brook trout populations. However, the numerous cold-water springs in the watershed and shade from high quality riparian vegetation may reduce the occurrence of elevated water temperatures and increase the duration of when brook trout can seasonally occupy the proposed project area.

A constraint that influences the ability of the brook trout to occupy the proposed project area is the length of degraded stream reaches between the intact brook trout populations at the headwaters of the watershed and the proposed project area. However, this may be addressed through the efforts of CAMBI, which aims to protect and restore existing brook trout habitat within Little Tuscarora watershed.

Lastly, there are a few reach-level constraints, which will influence design objectives more than restoration potential. They include a vehicular bridge crossing at the farthest upstream portion of the proposed project area, two sanitary sewer utility stream crossings, and one aerial power line utility.

Overall Function-Based Restoration Potential			
Level and Category	**Parameter**	**Pre-Restoration Rating**	**Restoration Potential**
1 - Hydrology	Channel-Forming Discharge	Functioning	Functioning
2 - Hydraulics	Floodplain Connectivity	Functioning-at-Risk	Functioning
3 - Geomorphology	Bed Form Diversity	Functioning-at-Risk	Functioning
	Channel Evolution	Not Functioning	Functioning
	Riparian Vegetation	Not Functioning	Functioning
	Lateral Stability	Functioning-at-Risk	Functioning
4 - Physicochemical	Water Quality	Not Functioning	Functioning-at-Risk
5 - Biology	Macroinvertebrate Communities	Functioning-at-Risk	Functioning-at-Risk
	Fish Communities	Functioning-at-Risk	Functioning-at-Risk

Table 14. Overall Function-Based Restoration Potential

B. DESIGN OBJECTIVES

The Service generated design objectives based on Service and TU missions, project goals and the restoration potential of the proposed project area. Design objectives should be quantifiable and describe how the proposed project will be implemented (Harman et al., 2012). These design objectives of the proposed project are focused on levels 2, 3 and 4 of the SFPF and support level 5 functions (Table 14). These design objectives will also be used as monitoring performance standards.

Table 15. Little Tuscarora – Design Objectives. *The underlined words under the objectives are parameters or measurement methods from the* ***Stream Functions Pyramid Framework*** *(Harman, et al. 2012.)*

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

Table 15. Design Objectives

C. DESIGN ALTERNATIVES ANALYSIS

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

1. Potential Design Alternatives

There are a variety of design approaches available to restore stream functions of highly degraded stream systems. Typical design approaches used in Maryland include 1) Natural Channel Design, 2) Valley Restoration Design, 3) Analytical Design, and 4) Regenerative Storm Conveyance Design. Each of these design approaches can result in functional uplift at the proposed project area. However, there is one critical function that only two of the approaches can address and that is sediment transport. The watershed and reach-level assessments identified that there a sediment supply being delivered to the project area. The transport of sediment is a critical factor in developing a design. If a particular design approach cannot transport sediment, it could be bad or good. If the sediment deposition occurs at a rate that vegetation cannot establish and hold the sediment in place, it prohibits bank stability if rooted vegetation cannot take hold. This means that the stream channel and floodplain in a constant state of flux adversely affecting water quality and biology. If the sediment deposition occurs at a rate that vegetation can establish and hold the sediment in place, it allows for rooted vegetation to establish. However, over time the sediment deposition will eventually form a stream channel that can transport sediment.

Therefore, the Service focused on the design approaches that could transport sediment and those are Natural Channel Design and Analytical Design.

2. Potential Functional Uplift and Loss

a. Analytical Design Approach

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

This approach, if implemented, will result in functional uplift to floodplain connectivity, riparian vegetation and water temperature (Table 13). However, since it does not explicitly prescribe methods for laying out the channel planform and profile, undesired stream channel adjustments could occur over time that would adversely affect geomorphic stability, water quality and biology. Specially, bedform and lateral adjustments can occur. Bedform features such as facet lengths, slopes and depths and planform features such as sinuosity significantly influence dissipation of stream energy. If these stream parameters are not designed correctly, then they will adjust causing functional impacts. As facet features adjust, habitat for aquatic species can be scoured out in some locations and smothered with excessive sediment in other areas. Water quality can become turbid from excessive sediment associated with the scouring and riparian vegetation can be lost because of lateral stream channel migration. Since these potential impacts could occur, it makes this approach a moderate to high risk project. Therefore, the Service eliminated the Analytical Design Approach as a feasible design approach.

Design Alternatives Analysis

Level and Category	Parameter	Measurement Method	Pre-Restoration Condition		NCD Approach		Analytical Desing Approach	
			Value	Rating	Value	Rating	Value	Rating
1 - Hydrology	Channel Forming Discharge (Bankfull)	Regional Curves	132 cfs	N/A	132 cfs	N/A	132 cfs	N/A
		Bankfull Validation	116 cfs	N/A	116 cfs	N/A	116 cfs	N/A
	2-Year Peak Flow	USGS	197 cfs	N/A	197 cfs	N/A	197 cfs	N/A
	10-Year Peak Flow	USGS	540 cfs	N/A	540 cfs	N/A	540 cfs	N/A
	100-Year Peak Flow	USGS	1292 cfs	N/A	1292 cfs	N/A	1292 cfs	N/A
2 - Hydraulics	Floodplain Connectivity	Bank Height Ratio	1.4	Functioning-at-risk	1	Functioning	1	Functioning
		Entrenchment Ratio	2.48	Functioning	2.48	Functioning	2.48	Functioning
	Flow Dynamics	Stream Velocity	3.35	Functioning	3.35	Functioning	3.35	Functioning
		Shear Stress	1.08 - 12.70	N/A	1.08 - 12.70	N/A	1.08 - 12.70	N/A
		Stream Power	2.52 - 90.73	N/A	2.52 - 90.73	N/A	2.52 - 90.73	N/A
3 - Geomorphology	Bedform Diversity	Pool-to-pool Spacing	2.28 - 5.63	Functioning-at-risk	4 to 5	Functioning	<3.0	Functioning-at-risk
		Pool Depth Variability	2.45 - 2.87	Functioning	2.45 - 2.87	Functioning	<1.5	Functioning-at-risk
		Depositional Pattern	B1, B2, B4	Functioning-at-risk	B1	Functioning	B2	Functioning-at-risk
	Channel Evolution	Rosgen	Incised C	Not Functioning	C	Functioning	C	Functioning
	Riparian Vegetation	PFC	Nonfunctional	Not Functioning	Proper Functioning Condition	Functioning	Functioning-at-risk	Functioning-at-risk
		Buffer Width from Meander Belt Width	Meander belt width ≤ 3.5	Not Functioning	>3.5	Functioning	<3.5	Functioning-at-risk
	Lateral Stability	Lateral Erosion Rate - Moderate BEHI Curve	Low to High NBS	Functioning-at-risk	Low	Functioning	Mod to High	Functioning-at-risk
		Meander Width Ratio (C and E Stream Types)	3.6	Functioning	>3.5	Functioning	<3.5	Functioning-at-risk
4 - Physicochemical	Water Quality	Temperature	25.72°C (Summer)	Not Functioning	20 -23°C (Summer)	Functioning-at-risk w/ fuctional uplift	20 -23°C (Summer)	Functioning-at-risk w/ fuctional uplift
5 - Biology	Macroinvertebrate Communities	MBSS IBI Score	3	Functioning-at-risk	3	Functioning-at-risk w/ fuctional uplift	3	Functioning-at-risk
	Fish Communities	MBSS IBI Score	4	Functioning-at-risk	4	Functioning-at-risk w/ fuctional uplift	4	Functioning-at-risk

Table 16. Design Alternatives Analysis

b. Natural Channel Design Approach

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

This approach, if implemented, will result in function uplift through level 5 – biology (Table 13). Assessment parameters in level 2 - hydraulics and level 3 – geomorphology will be fully functional while assessment parameters in level 4 – physicochemical and level – 5 biology will remain functioning-at-risk but have functional uplift. As was stated in the restoration potential section, restoration of levels 2 and 3 functions are typically the easiest to achieve since it involves direct, physical manipulation of stream channel dimension, pattern and profile. Functional uplift for levels 4 and 5 functions cannot be constructed and rely on the functionality of lower level functions and watershed health. The expected level 4 uplift will be associated with water temperature reductions. Currently the proposed project area lacks adequate riparian vegetation to provide shading. One of the design objectives is to restore the riparian vegetation and research has shown that providing shade to stream could reduce water temperatures by 1.9^{o} Celsius (Fink 2008). This reduction is an improvement, but temperatures too high for brook trout will still occur during the summer. The expected level 5 uplift will be associated with improvements to macroinvertebrate and fish communities through the increase of available instream habitat. The increase of available instream habitat is a result of improved bedform diversity functions associated with level 2 proposed restoration objectives.

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

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

D. DESIGN DEVELOPMENT

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

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

1. Design Criteria

Design criteria was compiled by standardizing existing channel plan, profile, and dimension of design criteria developed by the Service and other sources (Harman 2011). In addition, the Service was also able to locate a stable riffle within the project reach to model the design geometry criteria. The measurements from this cross section were verified and extrapolated using the regional curve calculations, resistance equations and natural channel design reference ratios for B4c and C4 Rosgen stream type channels. The tables below show reference geometry as well as summarize reference ratios and design criteria.

Bankfull Riffle Characteristics		
Bankfull Characteristics	**Reference Cross Section**	**Design Cross Section**
Area (sq. ft)	35.24	35.00
Width (ft)	23.11	20.00
Depth (ft)	1.53	1.75
Velocity (ft/s)	3.35	3.34
Discharge (cfs)	116.20	116.46
Maryland Stream Survey: Bankfull Discharge and Channel Characteristics of Stream in the PA MD Carbonate Regions (USGS)		

Table 17. Bankfull Riffle Characteristics

Table 18. Design Criteria						
Stream Name		Little Tuscarora Creek				
Drainage Area		5.6 mi²				
Stream Type					B4c	C4
#	**Variable**	**Symbol**	**Units**			
1	**Riffle Bankfull width**	W_{bkf}	**feet**	**Mean**	20	20
				Range		
2	**Riffle Bankfull mean depth**	d_{bkf}	**feet**	**Mean**	1.75	1.75
				Range		
3	**Width depth ratio**	**W/d**		**Mean**	15	15
				Range	12.0 - 18.0	12.0 - 18.0
4	**Riffle Bankfull cross sectional area**	A_{bkf}	ft_2	**Mean**	35	35
				Range		
5	**Bankfull mean velocity**	V_{bkf}	**ft/sec**	**Mean**	3.34	3.34
				Range	3.5 - 5.0	4.0 - 6.0
6	**Bankfull discharge**	Q_{bkf}	**cfs**	**Mean**	116	116
				Range		
7	**Riffle Bankfull maximum depth**	d_{max}	**feet**	**Mean**	2.28	2.37
				Range	2.1 - 2.45	2.1 - 2.63
8	**Max Riffle depth/ Mean riffle depth**	d_{riff}/d_{bkf}		**Mean**	1.3	1.35
				Range	1.2 - 1.4	1.2 - 1.5
9	**Low bank height to max d_{bkf} ratio**			**Mean**	1.05	1.05
				Range	1.0 - 1.1	1.0 - 1.1
10	**Width of flood prone area**	W_{fpa}	**feet**	**Mean**	33	80
				Range	28 - 44	44 +
11	**Entrenchment Ratio**	W_{fpa}/W_{bkf}		**Mean**	1.7	4
				Range	1.4 - 2.2	2.2 +
12	**Meander Length**	L_m	**feet**	**Mean**		210
				Range		140 - 280
13	**Ratio of meander length to bankfull width**	L_m/W_{bkf}		**Mean**		10.5
				Range		7.0 - 14.0
14	**Radius of curvature**	R_c	**feet**	**Mean**		50
				Range		40 - 60
15	**Ratio: Radius of curvature to bankfull width**	R_c/W_{bkf}		**Mean**		2.5
				Range		2.0 - 3.0

Table 18. Little Tuscarora Design Criteria

Table 18. *Continued*						
16	**Belt Width**	**W_{blt}**	**feet**	**Mean**		115
				Range		70 - 160
17	**Meander width ratio**	**W_{blt}/W_{bkf}**		**Mean**		5.75
				Range		3.5 - 8.0
18	**Sinuosity**	**K**		**Mean**	1.2	1.3
				Range	1.1 - 1.3	1.2 - 1.4
19	**Valley Slope**	**S_{val}**	**ft/ft**		0.006	0.006
21	**Average Water Surface Slope**	**S_{avg}**	**ft/ft**	**Mean**	0.004	0.004
				Range		
21	**Pool Water Surface Slope**	**S_{pool}**	**ft/ft**	**Mean**		0.0006
				Range		0 - 0.0012
22	**Pool WS slope / Average WS slope**	**S_{pool}/S_{avg}**		**Mean**		0.15
				Range		0.00 - 0..30
23	**Riffle Water Surface slope**	**Sriff**	**ft/ft**	**Mean**	0.0058	0.0058
				Range	0.0044 - 0.0072	0.0048 - 0.006
24	**Riffle WS slope / Average WS slope**	**S_{rifF}/S_{avg}**		**Mean**	1.45	1.45
				Range	1.1 - 1.8	1.2 - 1.5
25	**Run WS Slope**	**S_{run}/S_{avg}**	**ft/ft**	**Mean**		0.0026
				Range		0.02 - 0.0032
26	**Run WS slope / Average WS slope**	**S_{run}/S_{avg}**	**ft/ft**	**Mean**		0.65
				Range		0.5 -0.8
27	**Glide WS Slope**	**S_{glide}**		**Mean**	0.0016	0.0016
				Range	0.0012 - 0.002	0.0012 - 002
28	**Glide WS slope / Average WS slope**	**S_{glide}/S_{avg}**	**ft/ft**	**Mean**	0.4	0.4
				Range	0.3 - 0.5	0.3 - 0.5
29	**Maximum pool depth**	**d_{pool}**	**feet**	**Mean**	55	50
				Range	40 - 70	30 - 70
30	**Ratio of max pool depth to average bankfull depth**	**d_{pool}/d_{bkf}**		**Mean**	2.75	2.5
				Range	2.0 - 3.5	1.5 - 3.5
31	**Max Run Depth**	**d_{run}**	**feet**	**Mean**		39
				Range		34 - 44
32	**Ratio of max run depth to average bankfull depth**	**d_{run}/d_{bkf}**		**Mean**		1.95
				Range		1.7 - 2.2
33	**Max Glide Depth**	**d_{glide}**	**feet**	**Mean**		32
				Range		28 - 36

Table 18. ***Continued***						
34	**Ratio of max glide depth to average bankfull depth**	d_{glide}/d_{bkf}	**feet**	**Mean**		1.6
				Range		1.4 - 1.8
35	**Pool width**	W_{pool}	**feet**	**Mean**	28.6	29
				Range	22 - 30	24 - 34
36	**Ratio of pool width to bankfull width**	W_{pool}/W_{bkf}		**Mean**	1.3	1.45
				Range	1.1 - 1.5	1.2 - 1.7
37	**Ratio of pool area to bankfull area**	A_{pool}/A_{bkf}		**Mean**		
				Range		
38	**Point bar slope**	S_{pb}		**Mean**		30
				Range		20 - 40
39	**Pool to pool spacing**	**p-p**	**feet**	**Mean**	75	105
				Range	30 - 120	70 - 140
40	**Ratio of pool to pool spacing to bankfull width**	$p\text{-}p/W_{bkf}$		**Mean**	3.75	5.25
				Range	1.5 - 6.0	3.5 - 7.0

2. Proposed Design

The proposed design calls for two different Rosgen stream types to be built within the project area. The first stream type, B4c, will be built to dissipate energy vertically through the use of structures and close pool to pool spacing. This method is required directly downstream of the bridge on Opossumtown Road to maintain proper stream alignment with the bridge. When the hydraulic influence from the bridge is no longer a consideration, the Service has proposed a more sinuous C4 stream type with a low width to depth ratio to dissipate energy laterally across the floodplain. Since the elevation of the bed could not be increased or decreased due to infrastructure (i.e., sewer and bridge crossings), the Service proposed light excavation of the floodplain in order for more frequent out of bank events. Based on hydrologic conditions, out of bank events can occur every 1.5 years or more frequently. This floodplain excavation will enable the Service to achieve the level 2 - hydraulic goal of returning the bank height ratio to a factor of 1 via floodplain reconnection. To achieve the level 3 lateral stability goals, the Service plans to re-align the stream channel in order to create meanders and belt widths that would promote increased lateral stability. In order to promote bed form diversity, in-stream structures will be installed to promote pool scour and glide and riffle formation while protecting adjacent banks. While proper plan form is important, the Service has recognized that stability cannot be achieved without the proper riparian conditions. The Service has proposed dense riparian plantings that will extend beyond the limits of the design belt width to increase the stability of the system. These things combined will meet the Level 3 goals and objectives. These restoration activities on Little Tuscarora Creek will also aid in achieving the Services' level 4 goal of reducing water temperatures. Lastly, oxbow or vernal pool floodplain features connected to the stream channel will be used to provide habitat for fish rearing as well as enhance the floodplain complexity for additional aquatic species. Combined with enhancements to levels 2 – 4, the Service aims to achieve biologic lift through level 5 and attempt to provide seasonal habitat and shelter for brook trout. Detailed existing and proposed plans can be found in Appendix F and Appendix N.

3. In-Stream Structures

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

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

a. Cross-Vane

The cross-vane (Figure 8) will establish grade control, reduce bank erosion, create a stable width/depth ratio and maintain channel capacity, while maintaining sediment transport capacity, and sediment competence. The cross-vane also provides for the proper natural conditions of secondary circulation patterns commensurate with channel pattern, but with high velocity gradients and boundary stress shifted from the near-bank region. The cross-vane is also a stream habitat improvement structure due to: 1) an increase in bank cover as a result to a differential raise of the water surface in the bank region; 2) the creation of holding and refuge cover during both high and low flow periods in the deep pool; 3) the development of feeding lanes in the flow separation zones (the interface between fast and slow water) due to the strong down welling and upwelling forces in the center of the channel; and 4) the creation of spawning habitat in the tail-out or glide portion of the pool (Rosgen, D.R., 2010). While the figure below shows a structure consisting of large boulders, the cross-vane can be constructed using other materials such as logs and rootwads.

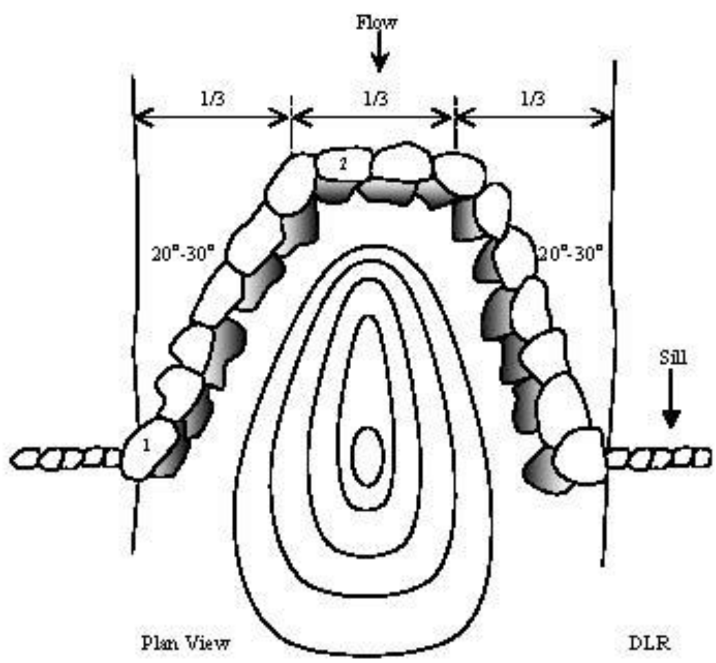

Figure 9. Cross Vane in Plan View

b. J-Hook Vane

The j-hook vane is an upstream directed, gently sloping structure composed of natural materials. The structure can include a combination of boulders, logs and root wads (Figure 9) and is located on the outside of stream bends where strong down welling and upwelling currents, high boundary stress, and high velocity gradients generate high stress in the near-bank region. The structure is designed to reduce bank erosion by reducing near-bank slope, velocity, velocity gradient, stream power and shear stress. Redirection of the secondary cells from the near-bank region does not cause erosion due to back-eddy re-circulation. The vane portion of the structure occupies 1/3 of the bankfull width of the channel, while the hook occupies the center 1/3 as shown in Figure 9 (Rosgen D.R., 2010).

Maximum velocity, shear stress, stream power and velocity gradients are decreased in the near-bank region and instead redirected towards the center of the channel. Sediment transport competence and capacity can be maintained as a result of the increased shear stress and stream power in the center of the channel. Backwater is created only in the near-bank region, reducing active bank erosion (Rosgen D. R., 2010). While the figure below shows a structure consisting of large boulders, the j-hook vane can be constructed using other materials such as logs and root wads.

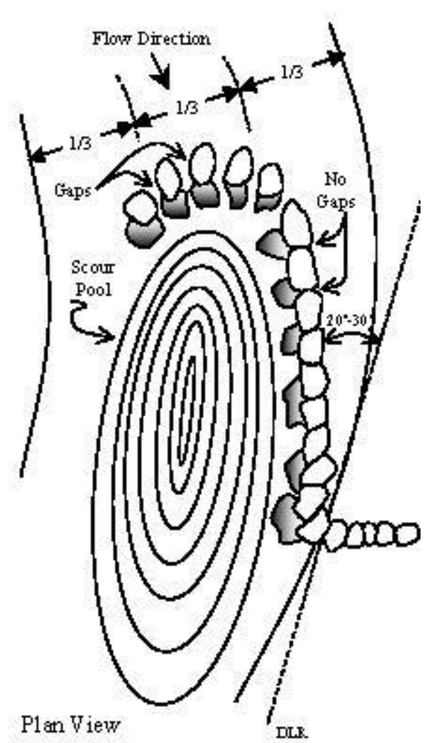

Figure 10. J-Hook Vane in Plan View

c. <u>Log Roller</u>

The log roller structure is an alternative to hardened riffles. These structures act as a grade control, but instead of holding the grade of a glide feature, they instead hold the grade of the top of riffle feature. The log roller consists of alternatively angled and sloped logs that are placed at low grades in an effort to “roll” water back and forth while still concentrating energy towards the center of the channel. The structure is typically used in straight as they are effective in generating aeration and increased dissolved oxygen concentration by creating hydraulic rises and falls while still directing stream energy towards the center of the channel. These structures also add woody debris into the stream system promoting increased habitat for aquatic species. Figure 10 shows a typical drawing for a log roller.

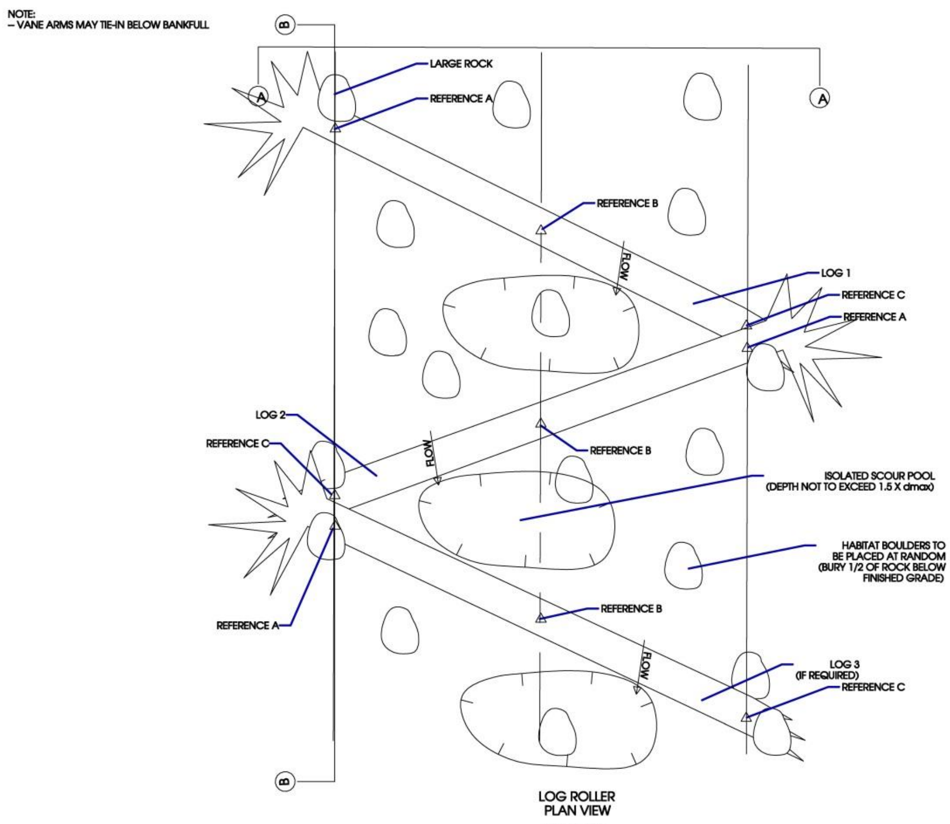

Figure 11. Log Roller Structure

d. Toe Wood

The toe wood structure (Figure 11) incorporates native woody material into a submerged undercut bank to replicate natural streambanks. Toe wood is positioned on the lower 1/3 to 1/2 of bankfull height to ensure it is submerged year round to prevent wood deterioration. Cuttings with sod and live staking or woody transplants cover the toe wood and are installed up to the bankfull stage. Not only does toe wood act as an area of increased roughness which promotes reduction in shear stresses to the outside of the meander, it also serves as a haven for benthic macroinvertebrates and fish communities.

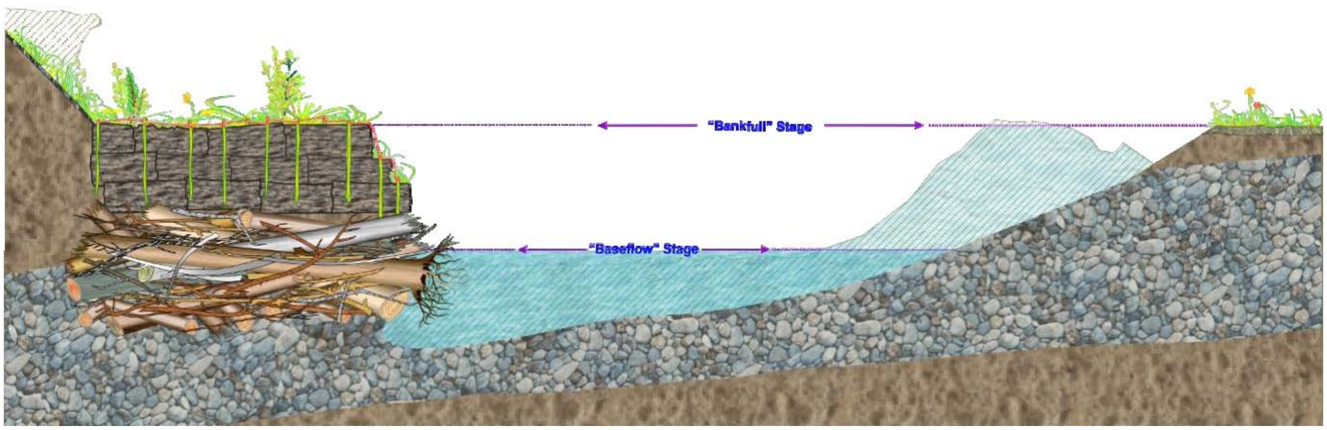

Figure 12. Toe Wood

e. Oxbow / Vernal Pool Features

Oxbow lakes (Figure 12) are formed when river erosion wears through the bank between two consecutive bends. Most water travels through the new channel, and the old bend is cut out, with water only passing through it very slowly. This slow speed causes sediment that is suspended in the river water to settle on the old bend's riverbed. Eventually, enough sediment settles in the old bend to close it off from the new channel and an oxbow lake is formed (DK Books, Lake Formation).

The Service utilized abandoned sections of the original stream alignment to create oxbow features in the Little Tuscarora Creek design for a variety of reasons. The introduction of these discontinuous oxbow pool features provide additional rearing habitat for fish species as well as excellent refuge for other aquatic species. Beavers are also naturally drawn to these areas and since they serve as a preferred location for dens and dams. This prevents beavers from impacting or influencing channel flow and minimizes the threat of beaver-related damming and ponding of the restored stream reach.

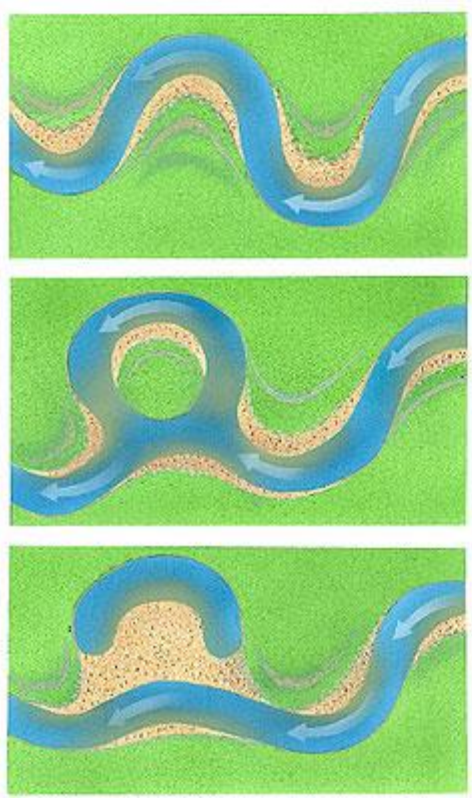

Figure 13. Oxbow Creation

4. Hydrology & Hydraulics Analysis

The Service used tractive force calculations as well as HEC-RAS to conduct a hydraulic assessment of the restoration reach to assure the restoration design would not cause any unsafe rise in hydraulic forces within the channel or effect flood flows around the culvert crossing on Opossumtown Pike. Twenty-six separate cross sections were modeled to compare the existing and proposed hydraulic conditions. The model was run using a bankfull flow of 116 cfs, a 2-Year flow of 197 cfs, a 10-Year flow of 540 cfs and a 100-Year flow of 1292 cfs. These flows were derived from the resistance relationship using existing and design channel geometry. A Manning's roughness coefficient of 0.35 was used for in-channel roughness, which is common among low gradient, meandering streams and provided similar results to those predicted by the Pennsylvania / Maryland Carbonate Regional Curve (Chaplin, 2005). The design maximized the use of the available floodplain within the project area. Therefore, the design objective is to have similar or slightly higher velocities and shear stresses to encourage necessary particle entrainment while allowing floodwater onto the floodplain without raising the 100-yr water surface elevation. An abbreviated summary can be found in Table 15 below and more detailed results table can be found in Appendix P.

HEC-RAS Model Results		
Bankfull Characteristics	**Existing Conditions**	**Design Conditions**
Tractive force in riffle (lbs/ft2)	0.38	0.44
Channel Shear Stress (lbs/ft2)	0.02 - 1.67	0.13 - 3.13
Stream Power (lb/ft s)	0.02 - 10.03	0.25 - 9.16
Velocity (ft/s)	1.26 - 6.01	2.02 - 5.79
1. Results derived from multiple cross sections using a bankfull flow of 116 cfs		

Table 19. HEC-RAS Model Results

a. Resitance Relationships

There are several methods to estimate bankfull discharge and velocity using resistance relationships. These methods typically make use of the cross sectional area, flow depth, representative particle size of channel substrate, channel slope and a determined roughness coefficient, or "friction factor". The Service used the Roughness Coefficient equation to determine discharge. This equation, $\boldsymbol{u = 1.49 * R^{2/3} * S^{1/2}/n}$, uses the hydraulic radius of the representative cross section, the channel slope and a known Manning's *n* (based on stream type) to determine velocity and discharge values. This method closely matched the back calculated roughness coefficient and was in agreement with the regional relationship findings and proved to be an appropriate estimate for bankfull discharge. A summary can be found in Table

20 and detailed information can be found on the "Computation of Velocity and Bankfull Discharge" worksheet in Appendix Q.

Design and Regional Curve Bankfull Characteristics			
Bankfull Characteristics	**Existing Cross Section**	**Design Cross Section**	**USGS Regional Carbonate Curve**
Area (sq. ft)	35.24	35	30.53
Width (ft)	23.11	20	21.31
Depth (ft)	1.53	1.75	1.46
Velocity (ft/s)	3.35	3.34	4.32
Discharge (cfs)	116.2	116.46	132.03
Maryland Stream Survey: Bankfull Discharge and Channel Characteristics of Stream in the PA MD Carbonate Regions (USGS)			

Table 20. Design and Regional Curve Bankfull Characteristics

5. Sediment Analysis

The objective of sediment transportation for the project is to design Little Tuscarora Creek with the competency to entrain the largest measured particle size of the bar sample (75 mm) determined by the sieve analysis conducted by the Service. Initial competency findings showed that Little Tuscarora did not have the required depth to initiate movement of this particle size. This is further supported by field observed deposition patterns which included some mid-channel bar formation as well as lateral bars. While these deposition formations are isolated, they do indicate a reduction in sediment competency related to a shallowing condition that is a result of channel widening. The Service aims to reduce channel width, while maintaining cross sectional area to increase mean depth to increase the channel's sediment transport competency. The increased depth meets the required depth as shown by Rosgen's power trend line on Shields critical shear stress relationship. The predicted particle size that can be moved is 83 mm which is just slightly larger than the largest particle size (75 mm) collected in the bar sample, but smaller than the riffle d100. This ensures the channel will not degrade over time.

The main stability problems within Little Tuscarora Creek are mostly related to lateral instability problem (e.g., widespread bank erosion). A sediment capacity analysis was not conducted since Little Tuscarora Creek does not appear to have a significant aggradation or degradation stability problem. Table 21 summarizes the Service's findings and detailed information can be found in Appendix R.

Sediment Transport Competency				
Level and Category	**Parameter**	**Measurement Method**	**Restoration Condition**	
			Design	**Required**
3 - Geomorphology	Sediment Transport Competency	Required Depth	1.75	1.72
		Required Slope	0.004	0.004

Table 21. Sediment Transport Competency

6. <u>Vegetation Design</u>

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

The Service developed a stream restoration planting plan that utilizes native plant and shrub species in both the riparian and upland corridors. The riparian buffer width will be based on the stream MWR and will not be any less than 3.5 times greater than the bankfull width in any area and where possible, go to the toe of valley. It is important to note that the buffer will be planted parallel to the toe of valley rather than following the sinuosity of the stream channel. The species selected are consistent with native riparian species found in the Great Valley physiographic province of Maryland. The detailed planting plan can be found in Appendix S.

VII. MAINTENANCE AND MONITORING PLANS

A. <u>MAINTENANCE PLAN</u>

The Service will collaborate with TU, MDDNR, Frederick County and the landowner to develop a maintenance plan that will ensure the success of the restoration objectives and goals. Plan duration and responsible parties will also be determined at that time.

B. <u>MONITORING PLAN</u>

The Service will conduct an as-built survey directly following completion of the restoration. This survey will be used to confirm that the project was built to design standards and will serve as baseline data for future monitoring. The Service will compare this data to the design criteria and produce a brief report summarizing any implementation adjustments or discrepancies.

A well-developed post-restoration monitoring plan will allow the partners to determine the success of the project, and address any problems that may arise. The Service, TU, MDDNR and Frederick County have developed a monitoring plan based on the restoration goals and objectives outlined in Section 6B, to evaluate the performance of the stream restoration project. This will take place after the successful completion of the Little Tuscarora Creek Restoration.

In cooperation with the Service, MBSS will conduct pre and post- restoration biological monitoring for brook trout and other fish species. One site above the project area and one site in the project will be sampled using MBSS sampling methods for fish sampling and macroinvertebrate sampling. The two sites will be sampled to collect baseline data prior to restoration. Post project monitoring will be conducted one year after restoration implementation and again 5 years later. A backpack electrofishing unit will be used to conduct depletion sampling in order to assess the species assemblage and obtain a species population estimate.

A Rapid Monitoring Protocol (RMP), developed by the Service, will be used to monitor the physical characteristics of the restoration projects. The RMP is a tiered approach for rapid restoration assessment that visually evaluates the stability and qualitative functional success of the restoration project. If there are indications of potential failure, the methodology requires that the project evaluators conduct a more intensive monitoring survey, which is the second tier survey. However, if a severe problem is identified (*e.g.* complete structure failure, excessive bank erosion, vertical incision > 1.3) the second tier may be skipped to go directly to the third tier – remediation/repair. During the second tier survey, project evaluators take measurements of the existing stream conditions and compare them to the proposed design criteria and reference data, to determine if remediation is required. If remediation/repair is required, the evaluators will perform a third tier survey that includes restoration design and implementation. The success of the riparian buffer plantings will also be monitored by visually quantifying bare areas, invasive species distribution, native recruitment and survivability of planted species. The Service will monitor the stream 1, 3, 5 and 7 years post restoration and provide a brief monitoring summary report for each year of monitoring.

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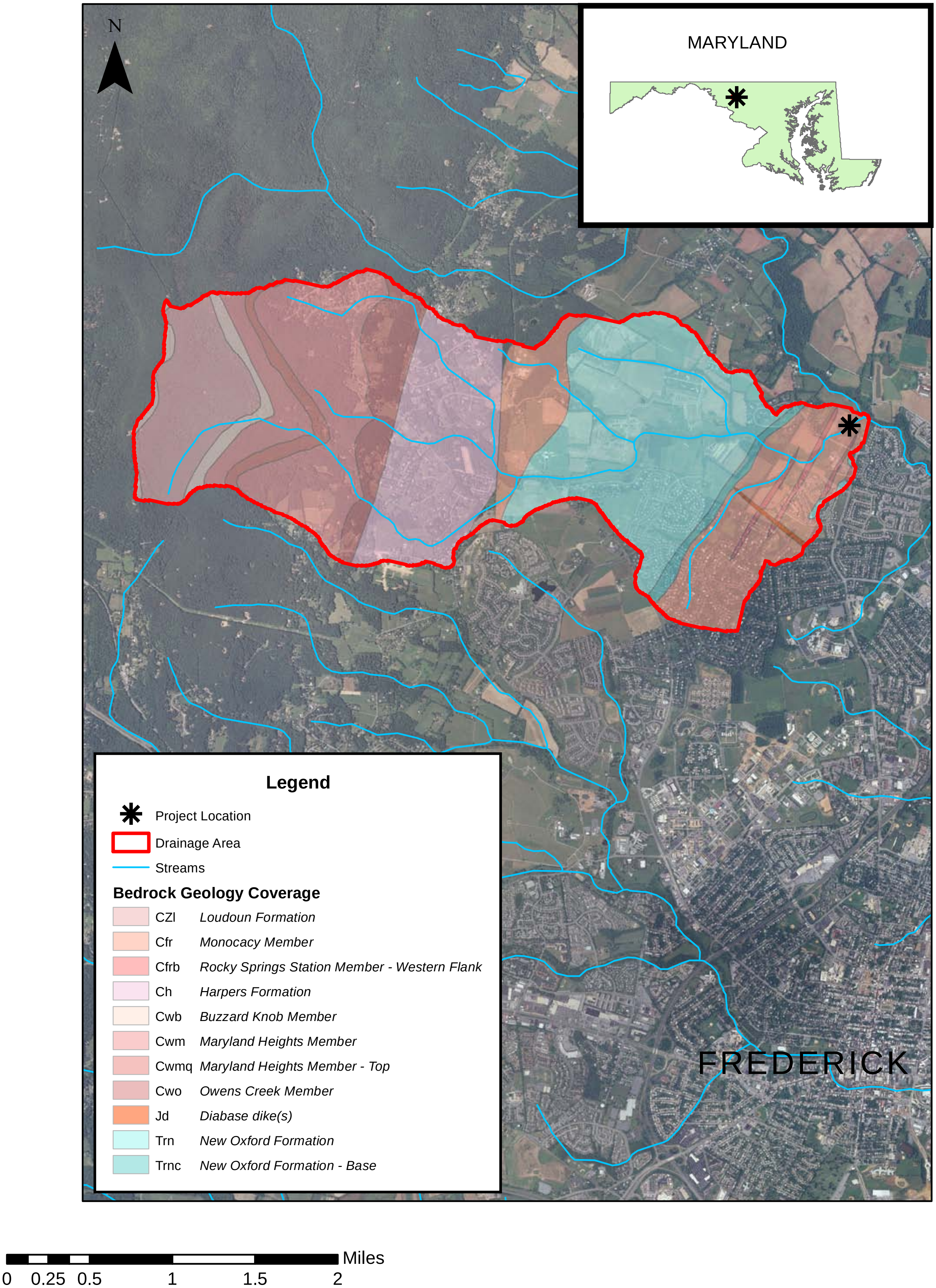
APPENDIX A

Bedrock Geology Map

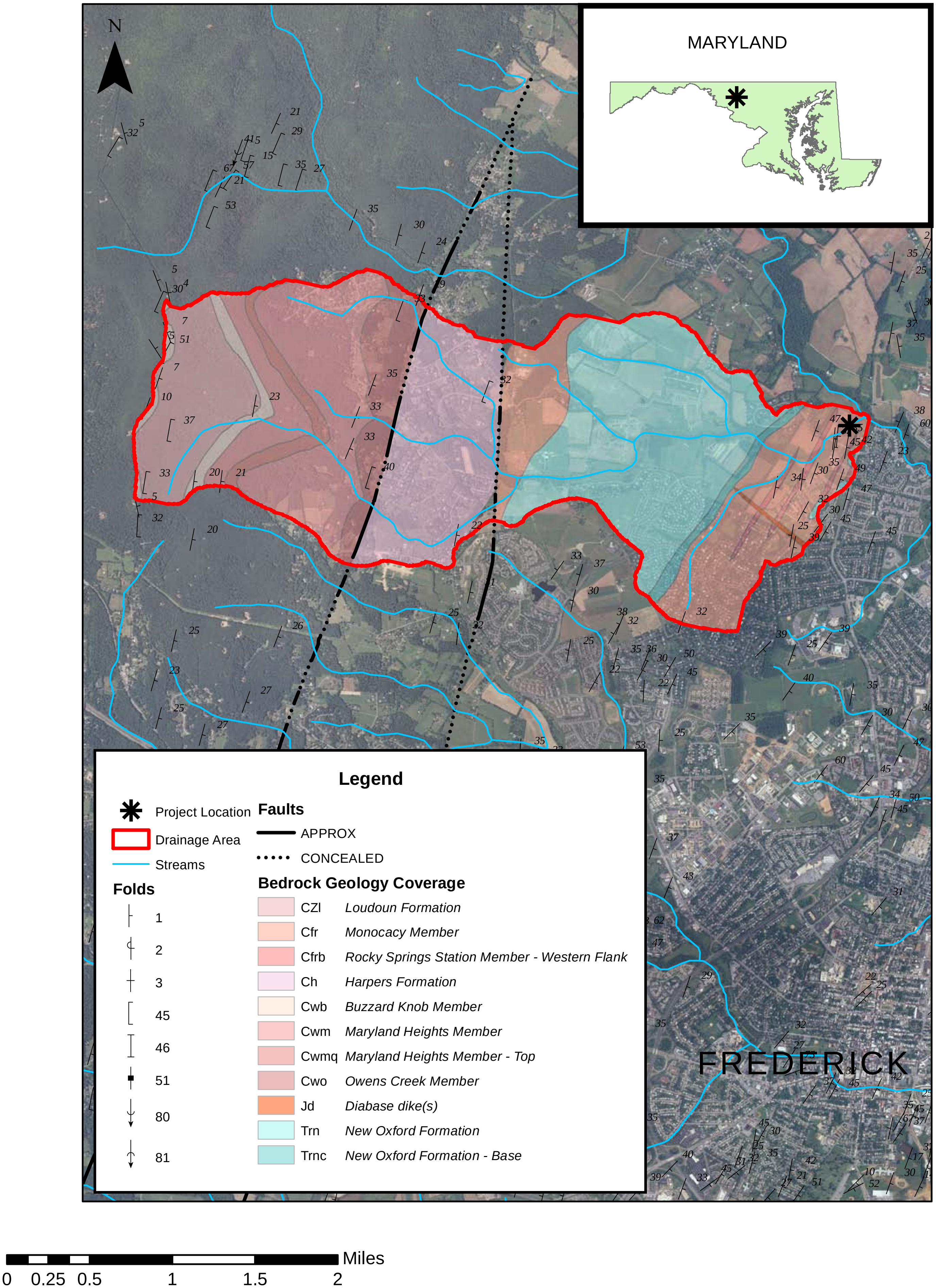
Little Tuscarora Creek
Bedrock Geology Map



APPENDIX B

Faults and Folds Map

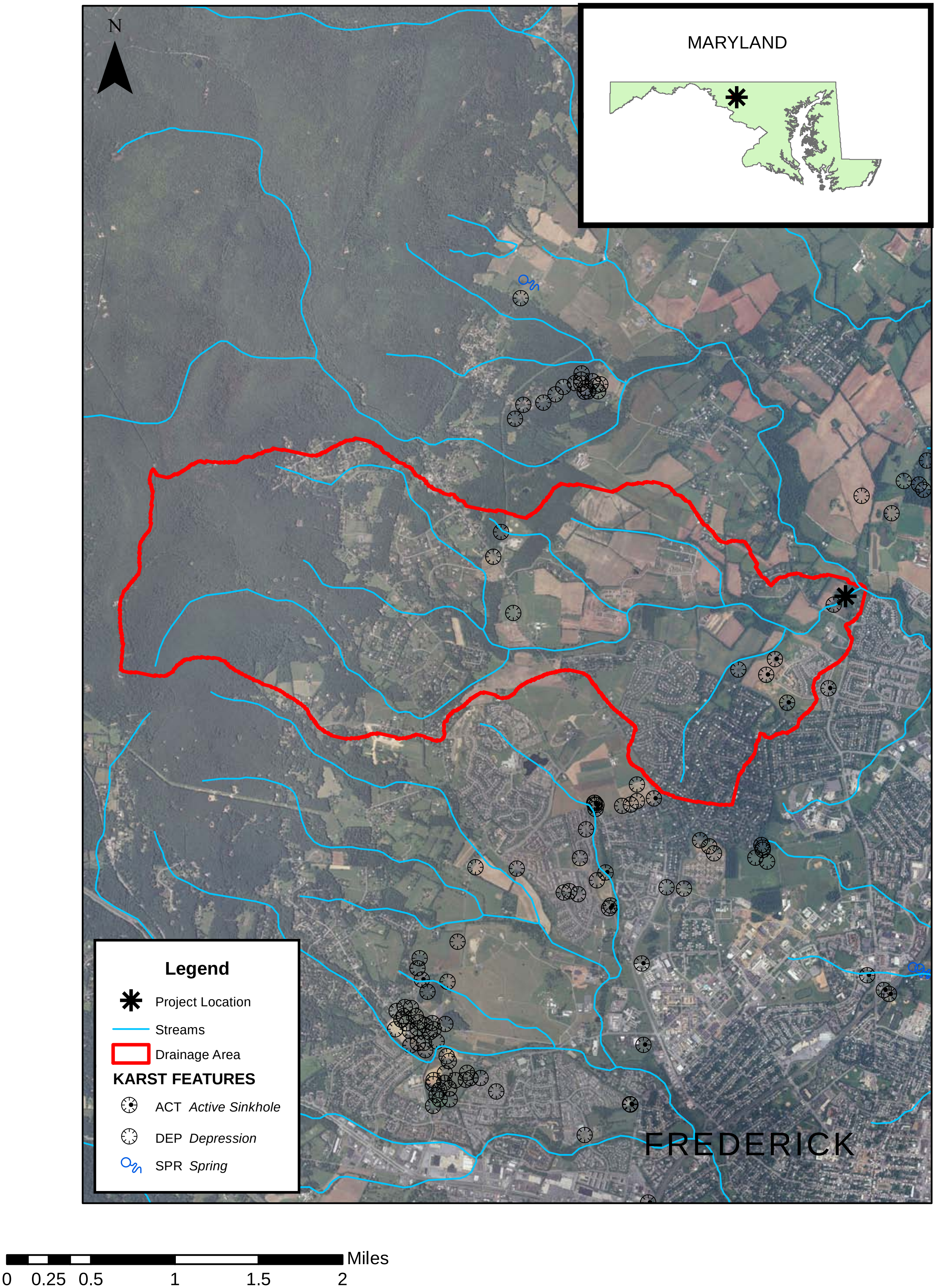
Little Tuscarora Creek
Faults and Folds Map



APPENDIX C

Karst Area Map

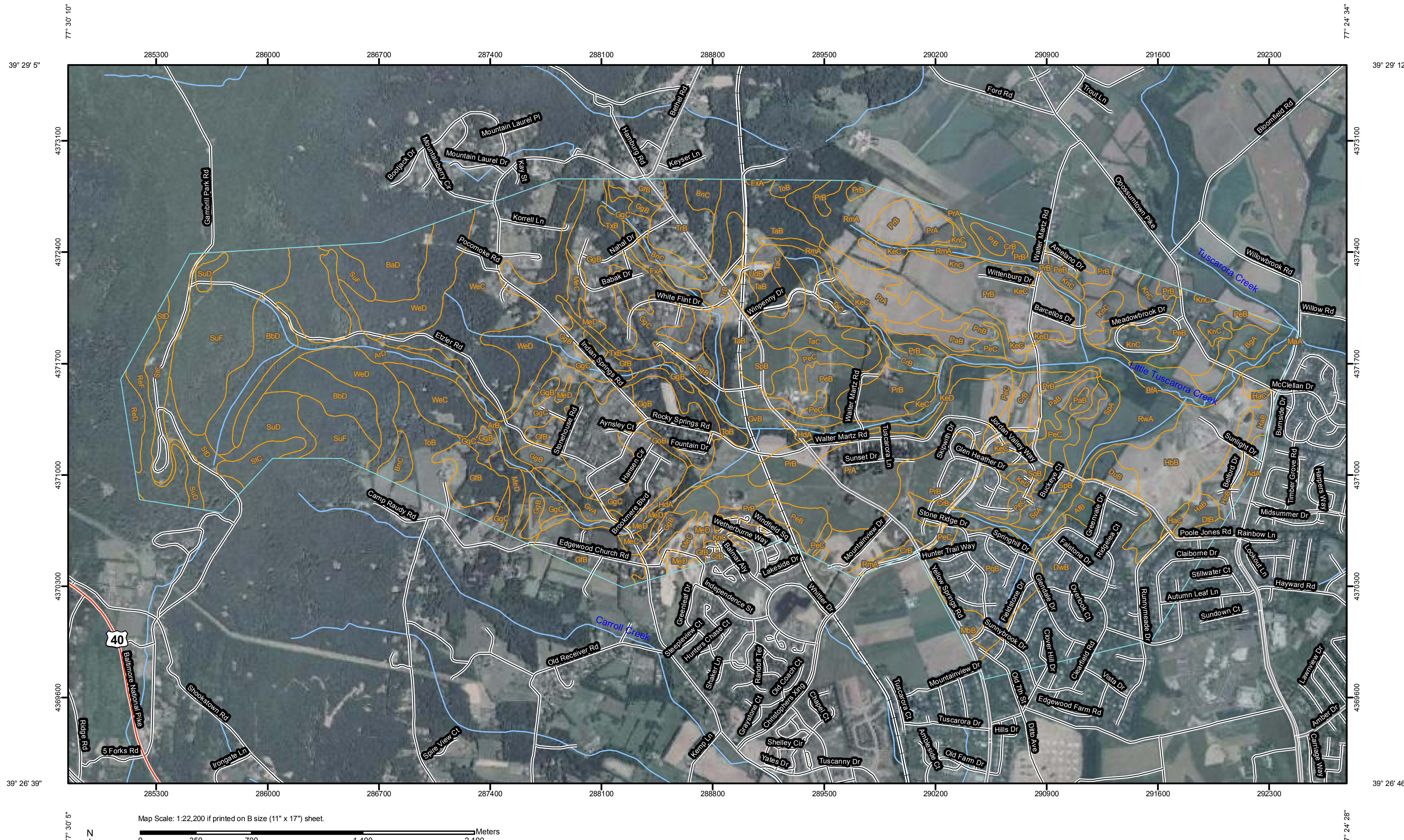
Little Tuscarora Creek
Karst Area Map



APPENDIX D

Soils Map – Upper Watershed

Soil Map—Frederick County, Maryland
(Little Tuscarora Creek Upper Watershed)



Map Scale: 1:22,200 if printed on B size (11" x 17") sheet.

N

Meters: 0, 350, 700, 1,400, 2,100

Feet: 0, 1,000, 2,000, 4,000, 6,000

MAP LEGEND

Area of Interest (AOI)
Area of Interest (AOI)

Soils
Soil Map Units

Special Point Features
- Blowout
- Borrow Pit
- Clay Spot
- Closed Depression
- Gravel Pit
- Gravelly Spot
- Landfill
- Lava Flow
- Marsh or swamp
- Mine or Quarry
- Miscellaneous Water
- Perennial Water
- Rock Outcrop
- Saline Spot
- Sandy Spot
- Severely Eroded Spot
- Sinkhole
- Slide or Slip
- Sodic Spot
- Spoil Area
- Stony Spot
- Very Stony Spot
- Wet Spot
- Other

Special Line Features
- Gully
- Short Steep Slope
- Other

Political Features
- Cities

Water Features
- Streams and Canals

Transportation
- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

MAP INFORMATION

Map Scale: 1:22,200 if printed on B size (11" × 17") sheet.

The soil surveys that comprise your AOI were mapped at 1:12,000.

Please rely on the bar scale on each map sheet for accurate map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: UTM Zone 18N NAD83

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Frederick County, Maryland
Survey Area Data: Version 9, Aug 9, 2010

Date(s) aerial images were photographed: 6/8/2005

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Map Unit Legend

Frederick County, Maryland (MD021)			
Map Unit Symbol	**Map Unit Name**	**Acres in AOI**	**Percent of AOI**
AdA	Adamstown silt loam, 0 to 3 percent slopes	0.1	0.0%
AfB	Adamstown-Funkstown complex, 0 to 8 percent slopes	7.1	0.2%
ArB	Airmont cobbly loam, 3 to 8 percent slopes, extremely stony	9.4	0.3%
ArD	Airmont cobbly loam, 8 to 25 percent slopes, extremely stony	45.1	1.2%
BaD	Bagtown cobbly loam, 15 to 25 percent slopes, extremely stony	38.3	1.0%
BbD	Bagtown cobbly loam, 15 to 25 percent slopes, rubbly	124.3	3.4%
BfA	Bermudian silt loam, 0 to 3 percent slopes	33.8	0.9%
BgA	Birdsboro silt loam, 0 to 3 percent slopes	19.1	0.5%
BnC	Braddock gravelly loam 8 to 15 percent slopes	27.5	0.8%
CrB	Croton-Abbottstown silt loams, 3 to 8 percent slopes	65.5	1.8%
DtB	Duffield-Ryder silt loams, 3 to 8 percent slopes	4.0	0.1%
DuB	Duffield and Ryder channery silt loams, 3 to 8 percent slopes	11.2	0.3%
DwB	Duffield-Hagerstown-Urban land complex, 3 to 8 percent slopes	216.6	5.9%
FxA	Foxville and Hatboro soils, 0 to 3 percent slopes	11.4	0.3%
GfB	Glenelg silt loam, 3 to 8 percent slopes	150.3	4.1%
GgB	Glenelg gravelly loam, 3 to 8 percent slopes	183.6	5.0%
GgC	Glenelg gravelly loam, 8 to 15 percent slopes	165.0	4.5%
GoB	Glenville silt loam, 3 to 8 percent slopes	5.0	0.1%
GvA	Glenville-Codorus complex, 0 to 3 percent slopes	11.7	0.3%
GvB	Glenville-Codorus complex, 3 to 8 percent slopes	65.3	1.8%
HaB	Hagerstown loam, 3 to 8 percent slopes	36.0	1.0%
HaC	Hagerstown loam, 8 to 15 percent slopes	4.7	0.1%
HbB	Hagerstown silt loam, 3 to 8 percent slopes	94.3	2.6%
HcB	Hagerstown-Opequon silty clay loams, 3 to 8 percent slopes, rocky	23.3	0.6%
HdA	Hatboro-Codorus silt loams, 0 to 3 percent slopes	25.1	0.7%
KeC	Klinesville very channery loam, 8 to 15 percent slopes	24.5	0.7%
KeD	Klinesville very channery loam, 15 to 25 percent slopes	21.5	0.6%

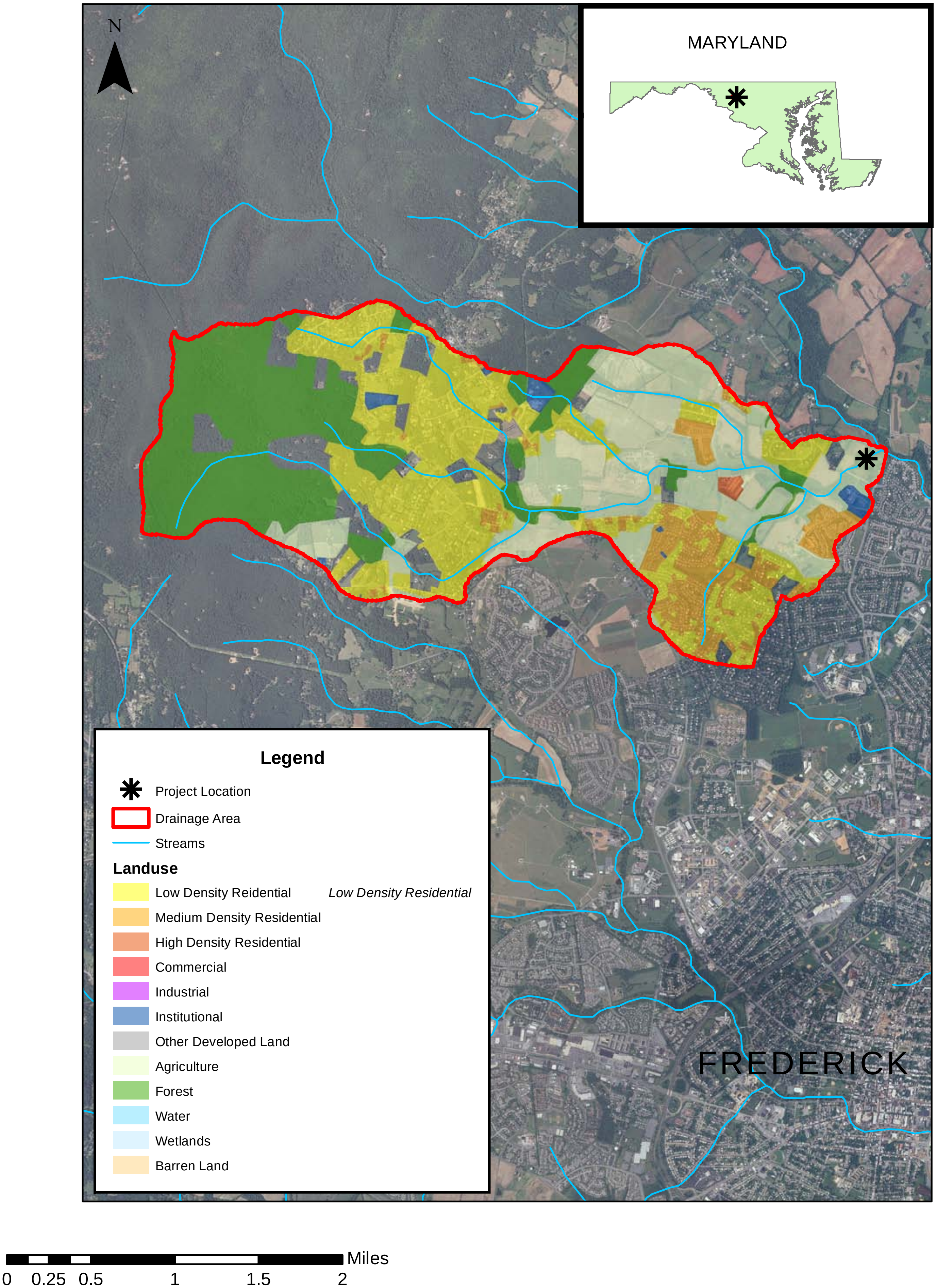
Frederick County, Maryland (MD021)			
Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
KnC	Klinesville channery silt loam, 8 to 15 percent slopes	72.1	2.0%
MaA	Melvin-Lindside silt loams, 0 to 3 percent slopes	0.0	0.0%
MbB	Morven loam, 3 to 8 percent slopes	11.8	0.3%
MeC	Mt. Airy channery loam, 8 to 15 percent slopes	36.6	1.0%
MeD	Mt. Airy channery loam, 15 to 25 percent slopes	32.9	0.9%
PaB	Penn loam, 3 to 8 percent slopes	33.7	0.9%
PeB	Penn channery loam, 3 to 8 percent slopes	115.6	3.2%
PeC	Penn channery loam, 8 to 15 percent slopes	77.0	2.1%
PnB	Penn silt loam, 3 to 8 percent slopes	17.9	0.5%
PqB	Penn-Reaville-Urban land complex, 0 to 8 percent slopes	80.8	2.2%
PrA	Penn-Reaville silt loam, 0 to 3 percent slopes	197.8	5.4%
PrB	Penn-Reaville silt loams, 3 to 8 percent slopes	296.8	8.1%
ReD	Ravenrock-Highfield-Rock outcrop complex, 15 to 25 percent slopes	12.2	0.3%
ReF	Ravenrock-Highfield-Rock outcrop complex, 25 to 65 percent slopes	34.0	0.9%
RmA	Reaville silt loam, 0 to 3 percent slopes	71.4	2.0%
RwA	Rowland silt loam, 0 to 3 percent slopes	120.2	3.3%
SpA	Springwood gravelly loam, 0 to 3 percent slopes	25.8	0.7%
SpB	Springwood gravelly loam, 3 to 8 percent slopes	31.3	0.9%
SqB	Springwood-Rock outcrop complex, 3 to 8 percent slopes	2.8	0.1%
StC	Stumptown-Rock outcrop complex, 8 to 15 percent slopes	55.8	1.5%
StD	Stumptown-Rock outcrop complex, 15 to 25 percent slopes	31.4	0.9%
SuD	Stumptown-Bagtown-Rock outcrop complex, 15 to 25 percent slopes	45.8	1.3%
SuF	Stumptown-Bagtown-Rock outcrop complex, 25 to 65 percent slopes	155.2	4.2%
TaB	Thurmont gravelly loam, 3 to 8 percent slopes	137.4	3.8%
TaC	Thurmont gravelly loam, 8 to 15 percent slopes	46.6	1.3%
ToB	Trego gravelly loam, 3 to 8 percent slopes	54.6	1.5%
TrB	Trego cobbly loam, 3 to 8 percent slopes	50.7	1.4%
TxB	Trego-Foxville complex, 0 to 8 percent slopes	14.5	0.4%
UdB	Udorthents, smooth, 0 to 8 percent slopes	4.6	0.1%

Frederick County, Maryland (MD021)			
Map Unit Symbol	**Map Unit Name**	**Acres in AOI**	**Percent of AOI**
WeC	Weverton-Hazel complex, 8 to 15 percent slopes, very stony	197.2	5.4%
WeD	Weverton-Hazel complex, 15 to 25 percent slopes, very stony	163.9	4.5%
Totals for Area of Interest		**3,652.0**	**100.0%**

APPENDIX E

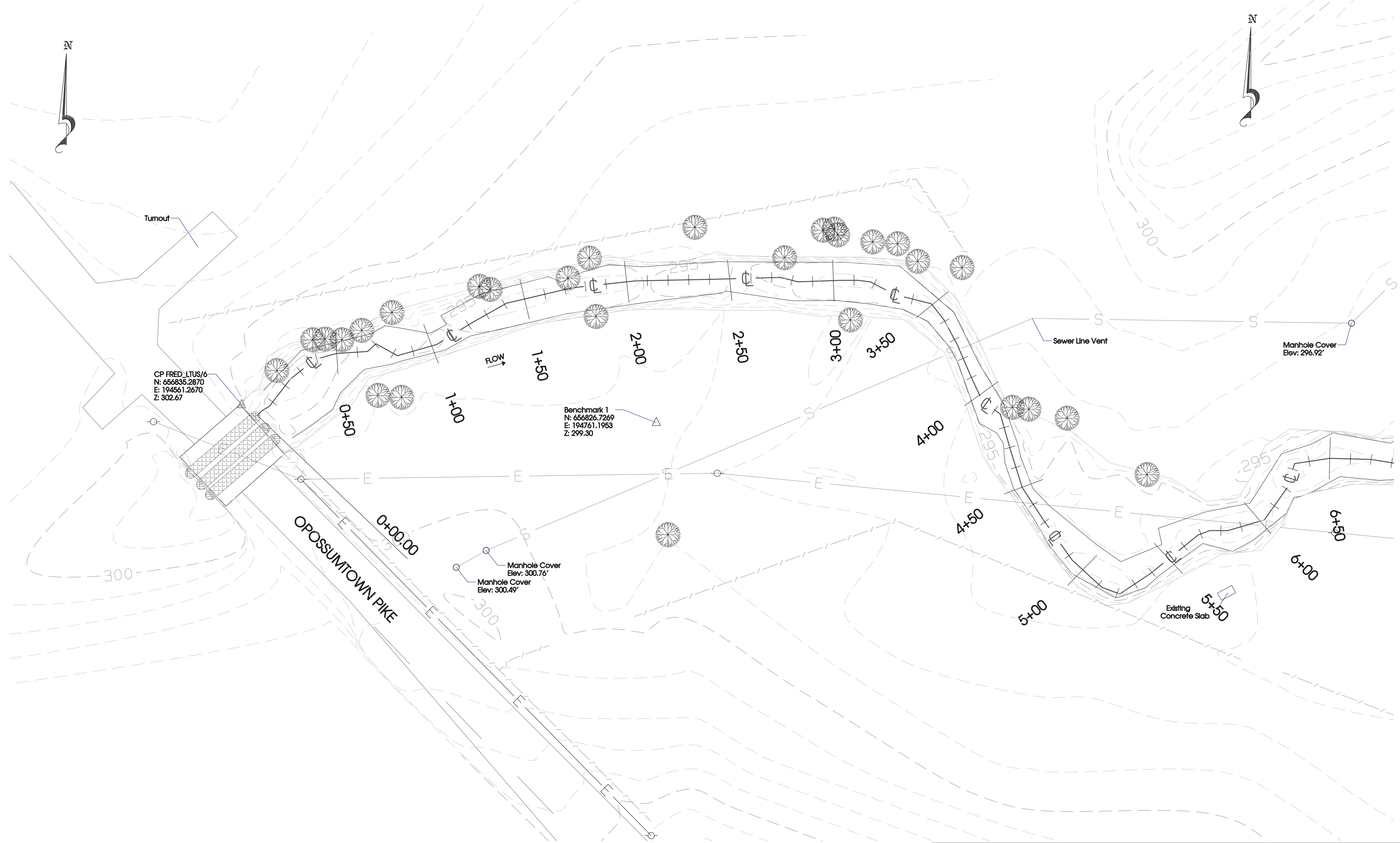
Land Use Map

Little Tuscarora Creek
Landuse Map



APPENDIX F

Existing Conditions



Contour Interval = 1.0 Foot

Scale:

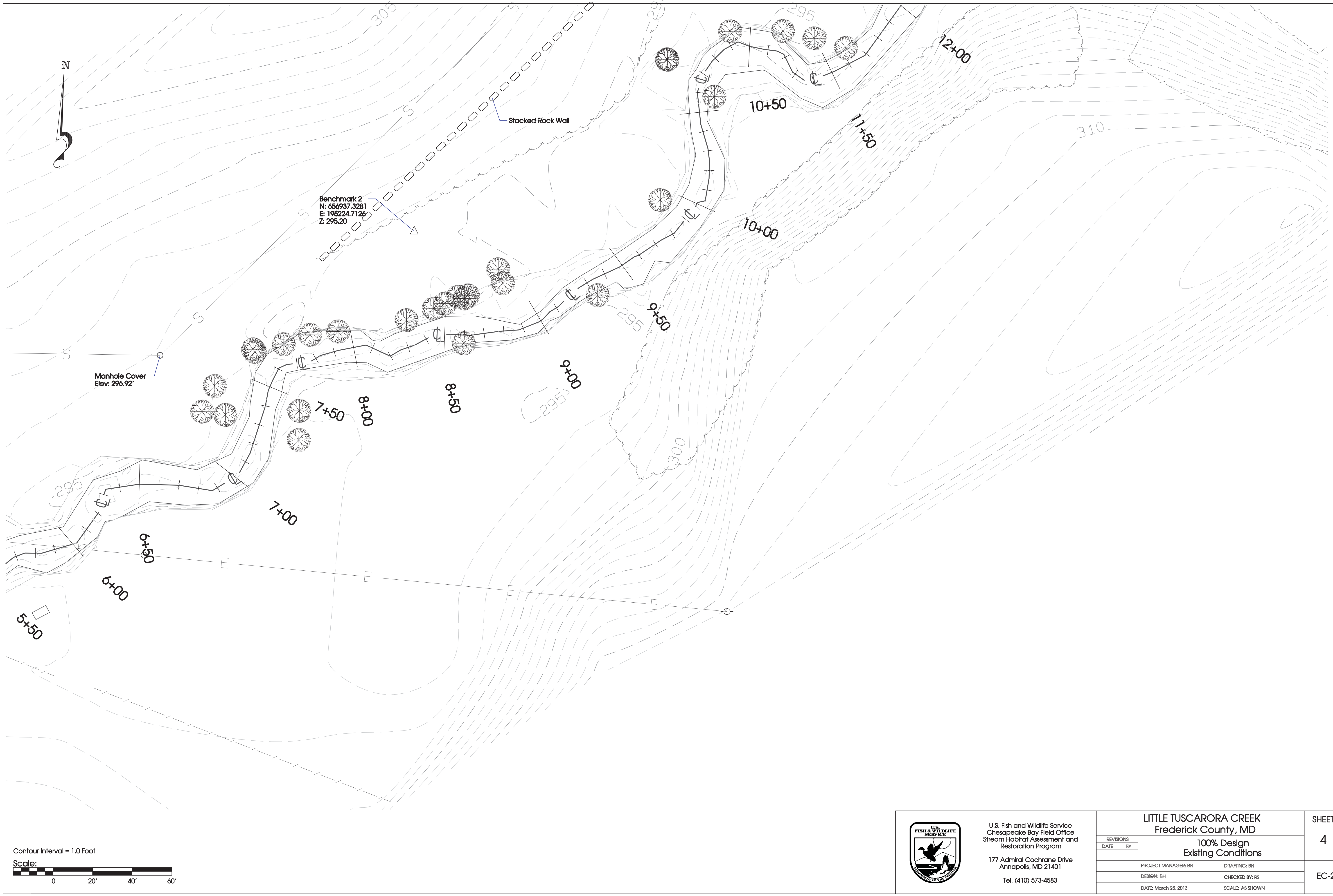
0 20' 40' 60'

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

177 Admiral Cochrane Drive
Annapolis, MD 21401

Tel. (410) 573-4583

LITTLE TUSCARORA CREEK Frederick County, MD		SHEET 3
REVISIONS: DATE / BY	100% Design Existing Conditions	
PROJECT MANAGER: BH	DRAFTING: BH	EC-1
DESIGN: BH	CHECKED BY: RS	
DATE: March 25, 2013	SCALE: AS SHOWN	



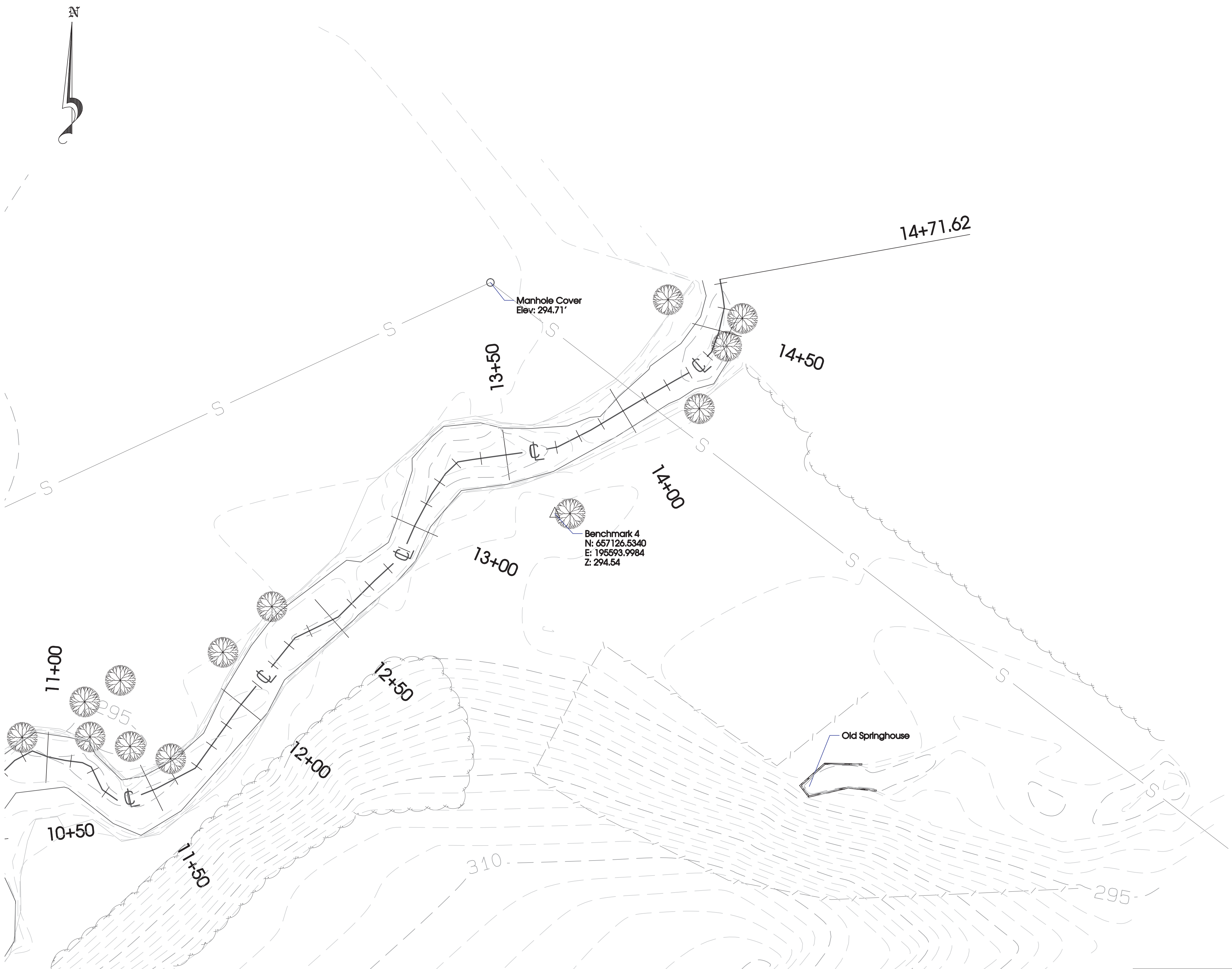
U.S. Fish and Wildlife Service
Chesapeake Bay Field Office
Stream Habitat Assessment and Restoration Program

177 Admiral Cochrane Drive
Annapolis, MD 21401

Tel. (410) 573-4583

LITTLE TUSCARORA CREEK Frederick County, MD			SHEET 4
REVISIONS (DATE / BY)	100% Design Existing Conditions		
	PROJECT MANAGER: BH	DRAFTING: BH	EC-2
	DESIGN: BH	CHECKED BY: RS	
	DATE: March 25, 2013	SCALE: AS SHOWN	

2
2



Contour Interval = 1.0 Foot

Scale: 0 20' 40' 60'

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

177 Admiral Cochrane Drive
Annapolis, MD 21401

Tel. (410) 573-4583

LITTLE TUSCARORA CREEK Frederick County, MD			SHEET 5
REVISIONS (DATE / BY)	100% Design Existing Conditions		
	PROJECT MANAGER: BH	DRAFTING: BH	EC-3
	DESIGN: BH	CHECKED BY: RS	
	DATE: March 25, 2013	SCALE: AS SHOWN	

3

3

APPENDIX G

Function-Based Data Collection Form

Function	Parameter	Measurment Method	Collection Method	Field	Done?
Hydrology					
	Channel-Forming Discharge	Regional Curves	PA/MD Carbonate Curve	N	✓
	Precipitation / Runoff Relationship	Rational Method, HEC-HMS, USGS Regression equations	Win TR-55	N	✓
	Flood Frequency	Bulletin 17b	1.2 - 1.5/year	N	✓
	Flow Duration	Flow Duration Cure, Crest Gage, Monitoring Devices, Indicators	Not Collecting	N	✗
Hydraulics					
	Floodplain Connectivity	Bank Height Ratio, Entrenchment Ratio, Dimensionaless rating curve	Long Profile and Cross Section Survey	Y	✓
	Flow Dynamics	Bankfull Velocity for C and E stream types (ft/s)	HEC-RAS/ Long pro / Cross Sections	Y	✓
	Ground/Surface Water Exchange	Peizometers, tracers and seepage meters	Not Collecting	N	✗
Geomorphology					
	Sediment Transport Competency	Shear Stress Curve, Required Depth and Slope, Modeling	Particle Data	Y	✓
	Sediment Transport Capacity	FLOWSED and POWERSED	Bar Sample, Particle Data	Y	✓
	LWD Transport and Storage	Large Woody Debris Index	Worksheet	Y	✗
	Channel Evolution	Rosgen Stream Type Succession Scenarios	Worksheet	Y	✓
	Bank Migration / Lateral Stability	Meander Width ratio, cross-sections, BEHI	Long profile and Cross Section Survey and BEHI	Y	✓
	Riparian Vegetation	Proper Functioning Protocol	Proper Functioning Protocol	Y	✓
	Bed Form Diversity	% Riffle/Pool, Facet Slopes, P-P Spacing, Depth Variability	Long Profile	Y	✓
	Bed Material Characterization	Pebble Count	Pebble Count	Y	✓
Function	**Parameter**	**Measurment Method**	**Collection Method**	**Field**	**Done?**
Physiochemical					
	Water Quality	Temp, DO, Conductivity, pH and Turbidity	Grab Samples / Lab Analysis	Y	✓
	Nutrients	Laboratory Analysis	Grab Samples / Lab Analysis	Y	✓
	Organic Carbon	Laboratory Analysis	Grab Samples / Lab Analysis	Y	✓
Biology					
	Microbial Communities	Taxonomic Methods, Non-Taxonomic Methods, Bio Indices	MD DNR MBSS	Y	✗
	Macrophyte Communities	Taxonomic Methods, Non-Taxonomic Methods, Bio Indices	MD DNR MBSS	Y	✗
	Benthic Macroinvertebrates	Taxonomic Methods, Non-Taxonomic Methods, Bio Indices	MD DNR MBSS	Y	✓
	Fish Communities	Taxonomic Methods, Non-Taxonomic Methods, Bio Indices	MD DNR MBSS	Y	✓
	Landscape Connectivity	Taxonomic Methods, Non-Taxonomic Methods, Bio Indices	MD DNR MBSS	Y	✗

APPENDIX H

Computations of Velocity and Bankfull Discharge Using Various Methods

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

Bankfull VELOCITY & DISCHARGE Estimates

Stream:	Little Tuscarora Creek	Location:	Reach - Staley Property
Date:	11/21/2012	Stream Type: C4	Valley Type: VIII
Observers:	BH, CB, MS	HUC:	2070009

INPUT VARIABLES			OUTPUT VARIABLES		
Bankfull Riffle Cross-Sectional AREA	31.16	A_{bkf} (ft^2)	Bankfull Riffle Mean DEPTH	1.52	d_{bkf} (ft)
Bankfull Riffle WIDTH	20.52	W_{bkf} (ft)	Wetted PERMIMETER ~ (2 * d_{bkf}) + W_{bkf}	22.04	W_p (ft)
D_{84} at Riffle	68.86	Dia. (mm)	D_{84} (mm) / 304.8	0.23	D_{84} (ft)
Bankfull SLOPE	0.0038	S_{bkf} (ft / ft)	Hydraulic RADIUS A_{bkf} / W_p	1.41	R (ft)
Gravitational Acceleration	32.2	g (ft / sec^2)	Relative Roughness R(ft) / D_{84} (ft)	6.24	R / D_{84}
Drainage Area	5.6	DA (mi^2)	Shear Velocity $u^* = (gRS)^{½}$	0.416	u* (ft/sec)

ESTIMATION METHODS	Bankfull VELOCITY		Bankfull DISCHARGE	
1. Friction Factor / Relative Roughness $u = [2.83 + 5.66 * Log\{R / D_{84}\}] u^*$	3.06	ft / sec	95.22	cfs
2. Roughness Coefficient: a) Manning's *n* from Friction Factor / Relative Roughness (Figs. 2-18, 2-19) $u = 1.49*R^{2/3}*S^{1/2} / n$ n = 0.0353	3.27	ft / sec	102.02	cfs
2. Roughness Coefficient: b) Manning's *n* from Stream Type (Fig. 2-20) $u = 1.49*R^{2/3}*S^{1/2} / n$ n = 0.031	3.73	ft / sec	116.17	cfs
2. Roughness Coefficient: c) Manning's *n* from Jarrett (USGS): $u = 1.49*R^{2/3}*S^{1/2} / n$; $n = 0.39*S^{0.38}*R^{-0.16}$ n = 0.044. **Note:** This equation is applicable to **steep, step/pool, high boundary roughness, cobble- and boulder-dominated stream systems**; i.e., for Stream Types A1, A2, A3, B1, B2, B3, C2 & E3	2.60	ft / sec	81.11	cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.) Darcy-Weisbach (Hey)	3.37	ft / sec	104.87	cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.) Chezy C	3.23	ft / sec	100.62	cfs
4. Continuity Equations: a) Regional Curves u = Q / A. Return Period for Bankfull Discharge Q = 1.5 year	4.24	ft / sec	132.00	cfs
4. Continuity Equations: b) USGS Gage Data u = Q / A	0.00	ft / sec	0.00	cfs

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

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

APPENDIX I

Existing H&H Results

HEC-RAS Plan: EX River: LITTLETUSCARORA Reach: REACH1

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl	Shear Chan	Power Chan
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)		(lb/sq ft)	(lb/ft s)
REACH1	1250	BKF	116.00	293.08	297.14		297.16	0.000386	1.26	91.71	37.27	0.14	0.06	0.07
REACH1	1250	2YR	197.00	293.08	297.89		297.93	0.000491	1.63	120.83	39.91	0.17	0.09	0.14
REACH1	1250	10YR	540.00	293.08	299.78		299.88	0.000728	2.64	225.46	101.75	0.22	0.20	0.53
REACH1	1250	100YR	1292.00	293.08	301.25		301.47	0.001221	4.10	429.67	188.75	0.29	0.44	1.82
REACH1	1200	BKF	116.00	294.98	296.89	296.34	297.09	0.006561	3.65	31.76	21.68	0.53	0.57	2.08
REACH1	1200	2YR	197.00	294.98	297.59	296.78	297.85	0.005605	4.14	47.59	23.58	0.51	0.66	2.73
REACH1	1200	10YR	540.00	294.98	299.21	298.13	299.76	0.006246	5.98	96.51	65.48	0.58	1.18	7.04
REACH1	1200	100YR	1292.00	294.98	300.42	300.42	301.27	0.007834	8.26	234.77	157.59	0.69	2.02	16.69
REACH1	1150	BKF	116.00	293.46	296.86	295.25	296.93	0.001226	2.15	53.89	22.59	0.25	0.17	0.36
REACH1	1150	2YR	197.00	293.46	297.55	295.70	297.67	0.001648	2.82	69.85	23.95	0.29	0.27	0.77
REACH1	1150	10YR	540.00	293.46	299.16	297.10	299.49	0.002787	4.70	133.55	78.96	0.40	0.67	3.14
REACH1	1150	100YR	1292.00	293.46	300.24	300.06	300.81	0.004509	6.93	313.28	215.01	0.53	1.35	9.37
REACH1	1100	BKF	116.00	293.23	296.81	295.14	296.88	0.001046	2.01	57.72	23.77	0.23	0.15	0.29
REACH1	1100	2YR	197.00	293.23	297.48	295.56	297.59	0.001446	2.66	74.03	25.06	0.27	0.24	0.64
REACH1	1100	10YR	540.00	293.23	299.02	296.91	299.35	0.002927	4.63	128.18	143.98	0.40	0.66	3.08
REACH1	1100	100YR	1292.00	293.23	300.27	299.79	300.57	0.002746	5.36	441.51	294.26	0.41	0.81	4.36
REACH1	1050	BKF	116.00	294.08	296.65	295.61	296.78	0.003205	2.93	39.65	21.89	0.38	0.34	1.00
REACH1	1050	2YR	197.00	294.08	297.26	296.13	297.47	0.003872	3.67	53.65	24.02	0.43	0.50	1.84
REACH1	1050	10YR	540.00	294.08	298.47	297.55	299.10	0.007720	6.36	86.03	38.90	0.64	1.36	8.64
REACH1	1050	100YR	1292.00	294.08	299.84	299.84	300.35	0.005752	6.94	354.13	327.01	0.58	1.44	10.00
REACH1	1000	BKF	116.00	293.49	296.57	295.29	296.65	0.001790	2.35	49.44	24.80	0.29	0.21	0.50
REACH1	1000	2YR	197.00	293.49	297.16	295.73	297.30	0.002365	3.05	64.63	26.68	0.35	0.34	1.02
REACH1	1000	10YR	540.00	293.49	298.22	297.06	298.73	0.005922	5.69	94.89	80.97	0.56	1.08	6.13
REACH1	1000	100YR	1292.00	293.49	299.02	298.68	299.80	0.009086	8.08	278.60	296.85	0.72	2.03	16.38
REACH1	950	BKF	116.00	293.63	296.25	295.66	296.48	0.007014	3.86	30.09	20.26	0.56	0.63	2.42
REACH1	950	2YR	197.00	293.63	296.67	296.18	297.06	0.009735	5.05	38.99	22.28	0.67	1.02	5.16
REACH1	950	10YR	540.00	293.63	297.83	297.83	298.36	0.009277	6.42	120.00	116.48	0.70	1.44	9.27
REACH1	950	100YR	1292.00	293.63	299.00	298.78	299.32	0.005093	6.09	409.77	340.18	0.55	1.15	6.99
REACH1	900	BKF	116.00	293.99	295.42	295.42	295.85	0.026407	5.22	22.22	26.34	1.00	1.38	7.18
REACH1	900	2YR	197.00	293.99	295.87	295.79	296.38	0.019714	5.75	34.25	27.94	0.92	1.48	8.51
REACH1	900	10YR	540.00	293.99	297.53	297.17	297.89	0.005583	5.26	154.24	170.91	0.55	0.94	4.97
REACH1	900	100YR	1292.00	293.99	298.74	298.20	299.00	0.003692	5.43	413.44	249.80	0.48	0.89	4.85
REACH1	850	BKF	116.00	292.05	295.33	293.85	295.36	0.000954	1.47	78.81	51.05	0.21	0.09	0.13
REACH1	850	2YR	197.00	292.05	296.07	294.39	296.12	0.000865	1.65	119.57	61.51	0.21	0.10	0.17
REACH1	850	10YR	540.00	292.05	297.64	295.30	297.71	0.000825	2.31	272.80	154.54	0.22	0.17	0.39
REACH1	850	100YR	1292.00	292.05	298.67	296.56	298.85	0.001480	3.70	470.26	224.37	0.31	0.40	1.48
REACH1	800	BKF	116.00	292.40	295.11	294.25	295.26	0.004121	3.15	36.83	22.44	0.43	0.41	1.28
REACH1	800	2YR	197.00	292.40	295.81	294.73	296.01	0.004842	3.65	53.99	29.81	0.48	0.53	1.92
REACH1	800	10YR	540.00	292.40	297.36	296.30	297.62	0.004021	4.17	141.82	124.85	0.46	0.61	2.56
REACH1	800	100YR	1292.00	292.40	298.17	297.87	298.68	0.006344	6.31	282.72	189.63	0.61	1.28	8.07
REACH1	750	BKF	116.00	291.72	295.09	293.35	295.14	0.000963	1.86	62.22	27.44	0.22	0.13	0.24
REACH1	750	2YR	197.00	291.72	295.78	293.81	295.87	0.001273	2.40	81.92	29.92	0.26	0.20	0.48
REACH1	750	10YR	540.00	291.72	297.29	295.12	297.46	0.001718	3.57	224.67	207.80	0.31	0.39	1.40
REACH1	750	100YR	1292.00	291.72	298.01	297.53	298.35	0.003403	5.60	396.53	263.86	0.45	0.92	5.13
REACH1	700	BKF	116.00	291.94	294.92	293.94	295.06	0.003033	2.92	39.78	20.70	0.37	0.33	0.98
REACH1	700	2YR	197.00	291.94	295.54	294.39	295.75	0.003819	3.73	52.84	43.46	0.43	0.51	1.91
REACH1	700	10YR	540.00	291.94	296.41	295.85	297.21	0.010252	7.24	80.81	144.67	0.72	1.77	12.83
REACH1	700	100YR	1292.00	291.94	297.87	297.23	298.09	0.003142	5.15	449.10	260.47	0.43	0.79	4.07
REACH1	650	BKF	116.00	292.65	294.40	294.18	294.74	0.015521	4.70	24.66	21.50	0.77	1.03	4.85
REACH1	650	2YR	197.00	292.65	295.12	294.67	295.45	0.010105	4.63	42.59	27.58	0.66	0.90	4.17
REACH1	650	10YR	540.00	292.65	296.47	295.95	296.70	0.004573	4.46	192.27	204.07	0.48	0.70	3.13
REACH1	650	100YR	1292.00	292.65	297.76	296.90	297.92	0.002388	4.19	488.05	245.79	0.37	0.54	2.28
REACH1	600	BKF	116.00	290.78	294.39	292.85	294.47	0.001718	2.35	49.28	23.43	0.29	0.21	0.50
REACH1	600	2YR	197.00	290.78	295.05	293.34	295.19	0.002142	3.02	65.16	24.55	0.33	0.32	0.98
REACH1	600	10YR	540.00	290.78	296.32	294.85	296.52	0.002484	4.10	208.15	165.26	0.37	0.53	2.17
REACH1	600	100YR	1292.00	290.78	297.56	296.67	297.78	0.002427	4.90	440.14	204.34	0.38	0.69	3.37
REACH1	550	BKF	116.00	291.95	294.14	293.55	294.32	0.006036	3.41	34.04	23.77	0.50	0.50	1.71
REACH1	550	2YR	197.00	291.95	294.78	293.97	295.02	0.005612	3.93	50.17	26.62	0.50	0.61	2.39
REACH1	550	10YR	540.00	291.95	296.04	295.31	296.34	0.004875	4.86	161.40	143.28	0.51	0.81	3.93
REACH1	550	100YR	1292.00	291.95	297.34	296.59	297.62	0.003658	5.39	372.30	181.81	0.47	0.88	4.75
REACH1	500	BKF	116.00	291.59	293.45		293.85	0.014832	5.02	23.10	18.11	0.78	1.12	5.65
REACH1	500	2YR	197.00	291.59	294.17		294.62	0.010809	5.34	36.86	20.30	0.70	1.14	6.09
REACH1	500	10YR	540.00	291.59	295.70		296.03	0.007395	5.13	141.91	128.47	0.61	0.97	5.00
REACH1	500	100YR	1292.00	291.59	297.15		297.43	0.003918	5.22	349.49	158.06	0.48	0.85	4.45
REACH1	450	BKF	116.00	290.73	293.31	292.37	293.46	0.003403	3.08	37.61	19.69	0.39	0.37	1.15
REACH1	450	2YR	197.00	290.73	294.03	292.84	294.25	0.003832	3.75	52.51	23.07	0.43	0.52	1.94
REACH1	450	10YR	540.00	290.73	295.44	294.36	295.76	0.003898	4.99	148.55	91.80	0.46	0.80	3.98
REACH1	450	100YR	1292.00	290.73	296.65	296.02	297.18	0.005187	6.98	277.24	121.46	0.56	1.42	9.90
REACH1	400	BKF	116.00	290.90	293.19		293.27	0.003543	2.27	51.13	46.11	0.38	0.24	0.54
REACH1	400	2YR	197.00	290.90	294.01		294.08	0.001755	2.10	93.90	56.33	0.29	0.18	0.37
REACH1	400	10YR	540.00	290.90	295.48		295.59	0.001383	2.79	222.62	118.83	0.28	0.26	0.71
REACH1	400	100YR	1292.00	290.90	296.70		296.93	0.001960	4.15	387.49	146.21	0.35	0.51	2.12
REACH1	350	BKF	116.00	289.43	293.22	290.69	293.23	0.000136	0.83	139.77	47.59	0.09	0.02	0.02
REACH1	350	2YR	197.00	289.43	294.02	291.00	294.04	0.000182	1.10	178.69	48.63	0.10	0.04	0.04
REACH1	350	10YR	540.00	289.43	295.47	291.83	295.54	0.000426	2.06	308.19	150.78	0.16	0.12	0.25
REACH1	350	100YR	1292.00	289.43	296.66	293.11	296.82	0.000896	3.44	503.04	182.40	0.24	0.32	1.09

HEC-RAS Plan: EX River: LITTLETUSCARORA Reach: REACH1 (Continued)

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl	Shear Chan	Power Chan
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)		(lb/sq ft)	(lb/ft s)
REACH1	300	BKF	116.00	290.05	293.09	291.84	293.20	0.002236	2.68	43.35	27.54	0.33	0.27	0.73
REACH1	300	2YR	197.00	290.05	293.84	292.31	294.01	0.002569	3.31	59.68	41.73	0.36	0.39	1.29
REACH1	300	10YR	540.00	290.05	295.32	293.81	295.49	0.001972	3.90	247.31	246.00	0.34	0.46	1.81
REACH1	300	100YR	1292.00	290.05	296.63	295.18	296.75	0.001453	4.02	649.31	371.93	0.30	0.45	1.81
REACH1	250	BKF	116.00	289.84	292.98	291.72	293.09	0.002238	2.64	43.88	21.23	0.32	0.27	0.71
REACH1	250	2YR	197.00	289.84	293.71	292.22	293.87	0.002660	3.27	60.24	25.55	0.36	0.38	1.26
REACH1	250	10YR	540.00	289.84	295.23	293.69	295.38	0.001968	3.76	263.00	262.01	0.33	0.44	1.66
REACH1	250	100YR	1292.00	289.84	296.57	295.48	296.67	0.001226	3.62	681.54	347.89	0.28	0.37	1.33
REACH1	200	BKF	116.00	290.27	292.51	292.10	292.85	0.010771	4.72	24.60	16.12	0.67	0.94	4.45
REACH1	200	2YR	197.00	290.27	293.19	292.68	293.60	0.012614	5.12	38.48	25.63	0.74	1.11	5.69
REACH1	200	10YR	540.00	290.27	294.18	294.18	295.05	0.019099	7.52	73.86	55.85	0.95	2.19	16.50
REACH1	200	100YR	1292.00	290.27	295.56	295.55	296.41	0.011233	8.23	211.91	276.23	0.79	2.20	18.10
REACH1	150	BKF	116.00	288.11	292.68	289.96	292.71	0.000357	1.38	84.26	27.19	0.14	0.06	0.09
REACH1	150	2YR	197.00	288.11	293.36	290.47	293.42	0.000564	1.91	103.23	45.37	0.18	0.12	0.22
REACH1	150	10YR	540.00	288.11	294.12	291.82	294.40	0.002536	4.31	127.19	164.63	0.38	0.57	2.48
REACH1	150	100YR	1292.00	288.11	295.70	293.75	296.00	0.002327	5.14	367.56	315.44	0.38	0.73	3.77
REACH1	100	BKF	116.00	290.39	292.03	292.03	292.60	0.024523	6.01	19.30	17.18	1.00	1.67	10.03
REACH1	100	2YR	197.00	290.39	292.56	292.56	293.27	0.023049	6.74	29.23	20.86	1.00	1.95	13.15
REACH1	100	10YR	540.00	290.39	293.86	293.86	294.13	0.009868	5.09	175.14	349.00	0.68	1.04	5.28
REACH1	100	100YR	1292.00	290.39	295.83	294.14	295.86	0.000516	1.88	1007.96	415.54	0.18	0.11	0.21
REACH1	50	BKF	116.00	289.92	291.53	290.84	291.61	0.002910	2.31	50.24	38.39	0.36	0.23	0.54
REACH1	50	2YR	197.00	289.92	292.26	291.13	292.36	0.002533	2.44	80.77	51.09	0.34	0.24	0.60
REACH1	50	10YR	540.00	289.92	293.35	292.12	293.58	0.003510	3.82	144.25	221.20	0.43	0.52	1.99
REACH1	50	100YR	1292.00	289.92	295.81	293.74	295.84	0.000305	1.79	1132.45	420.88	0.14	0.09	0.16
REACH1	0	BKF	116.00	288.95	291.27	290.37	291.43	0.003966	3.24	35.76	29.68	0.42	0.42	1.36
REACH1	0	2YR	197.00	288.95	291.97	290.86	292.19	0.003968	3.83	58.88	92.52	0.43	0.54	2.06
REACH1	0	10YR	540.00	288.95	293.14	292.60	293.39	0.003972	4.80	175.99	281.42	0.45	0.76	3.63
REACH1	0	100YR	1292.00	288.95	295.80	293.41	295.82	0.000233	1.70	1268.16	415.98	0.12	0.08	0.13

APPENDIX J

Lentic Standard Checklist

Lentic Standard Checklist

Name of Riparian-Wetland Area: LITTLE TUSCARORA CRK.

Date: 2/22/12 Area/Segment ID: ______ Acres: ______

ID Team Observers: BH

Yes	No	N/A	HYDROLOGY
	X		1) Riparian-wetland area is saturated at or near the surface or inundated in "relatively frequent" events
	X		2) Fluctuation of water levels is not excessive
	X		3) Riparian-wetland area is enlarging or has achieved potential extent
X			4) Upland watershed is not contributing to riparian-wetland degradation
X			5) Water quality is sufficient to support riparian-wetland plants
X			6) Natural surface or subsurface flow patterns are not altered by disturbance (i.e., hoof action, dams, dikes, trails, roads, rills, gullies, drilling activities)
X			7) Structure accommodates safe passage of flows (e.g., no headcut affecting dam or spillway)

Yes	No	N/A	VEGETATION
	X		8) There is diverse age-class distribution of riparian-wetland vegetation (recruitment for maintenance/recovery)
	X		9) There is diverse composition of riparian-wetland vegetation (for maintenance/recovery)
	X		10) Species present indicate maintenance of riparian-wetland soil moisture characteristics
	X		11) Vegetation is comprised of those plants or plant communities that have root masses capable of withstanding wind events, wave flow events, or overland flows (e.g., storm events, snowmelt)
	X		12) Riparian-wetland plants exhibit high vigor
	X		13) Adequate vegetative cover is present to protect shorelines/soil surface and dissipate energy during high wind and wave events or overland flows
	X		14) Frost or abnormal hydrologic heaving is not present
	X		15) Favorable microsite condition (i.e., woody debris, water temperature, etc.) is maintained by adjacent site characteristics

Yes	No	N/A	EROSION/DEPOSITION
	X		16) Accumulation of chemicals affecting plant productivity/composition is not apparent
	X		17) Saturation of soils (i.e., ponding, flooding frequency and duration) is sufficient to compose and maintain hydric soils
	X		18) Underlying geologic structure/soil material/permafrost is capable of restricting water percolation
	X		19) Riparian-wetland is in balance with the water and sediment being supplied by the watershed (i.e., no excessive erosion or deposition)
		X	20) Islands and shoreline characteristics (i.e., rocks, course and/or large woody debris) are adequate to dissipate wind and wave event energies

(Revised 1998)

APPENDIX K

Stream Bank Erosion Summary

Project Name	Little Tuscarora Creek - Staley Project				Location	Frederick County, MD		
					Date	2/23/2012		
Observers	BH, MS, CB		Valley Type	VIII	Stream Type	C 4/1		
Feature Feature I.D. (Bank., Headcut or Deposition I.D.)	Length, ft (Bank or deposition)	Height, ft (Bank or Headcut)	BEHI Rating	NBS Rating	Predicted Rate of Bank Erosion (ft/year)	Predicted Erosion Amount (ft^3/year)	Predicted Erosion Amount (tons/year)	Predicted Erosion Rate (tons/year/ft)
Bank 1	264.0	4.0	High	Moderate	0.64	675.84	19.25	0.12
Bank 2	378.0	4.0	High	Moderate	0.64	967.68	27.57	0.12
Bank 3	83.0	4.5	High	High	1.00	373.50	10.64	0.22
Bank 4	122.0	3.5	Low	Moderate	0.07	29.89	0.85	0.01
Bank 5	117.0	3.5	Low	Moderate	0.07	28.67	0.82	0.01
Bank 6	368.0	3.5	Very High	High	1.00	1288.00	36.70	0.17
Bank 7	100.0	3.5	High	Moderate	0.64	224.00	6.38	0.11
Bank 8	78.0	3.5	High	Very High	1.75	477.75	13.61	0.29
Bank 9	297.0	3.5	High	High	1.00	1039.50	29.62	0.17
Bank 10	230.0	3.5	High	Moderate	0.64	515.20	14.68	0.11
Bank 11	146.0	4.0	Very High	Very High	1.75	1022.00	29.12	0.34
Bank 12	347.0	3.5	High	Moderate	0.64	777.28	22.14	0.11
Bank 13	190.0	3.75	High	Moderate	0.64	456.00	12.99	0.12
Bank 14	111.0	3.75	High	Very High	1.75	728.44	20.75	0.32
Bank 15	100.0	3.0	Very Low	Low	0.01	3.00	0.09	0.00
Bank 16	100.0	3.0	Very Low	Low	0.01	3.00	0.09	0.00
TOTAL	**3031.0**	**N/A**	**N/A**	**N/A**	**N/A**	**8609.7**	**245.3**	**2.2**

APPENDIX L

Stream Classification Worksheet

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

Stream:	**Little Tuscarora Creek, Reach - Staley Property**			
Basin:	**Tuscarora Creek**	Drainage Area: **3584** acres	**5.6**	mi^2
Location:	**Frederick County, MD**			
Twp.&Rge:	**;**	Sec.&Qtr.: **;**		
Cross-Section Monuments (Lat./Long.):	**39.46942 Lat / 77.41714 Long**		Date:	**02/23/12**
Observers:	**BH, MS, CB**		Valley Type:	VIII

Bankfull WIDTH (W_{bkf}) WIDTH of the stream channel at bankfull stage elevation, in a riffle section.	**23.11**	ft
Bankfull DEPTH (d_{bkf}) Mean DEPTH of the stream channel cross-section, at bankfull stage elevation, in a riffle section ($d_{bkf} = A / W_{bkf}$).	**1.53**	ft
Bankfull X-Section AREA (A_{bkf}) AREA of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	**35.24**	ft^2
Width/Depth Ratio (W_{bkf} / d_{bkf}) Bankfull WIDTH divided by bankfull mean DEPTH, in a riffle section.	**15.1**	ft/ft
Maximum DEPTH (d_{mbkf}) Maximum depth of the bankfull channel cross-section, or distance between the bankfull stage and Thalweg elevations, in a riffle section.	**1.89**	ft
WIDTH of Flood-Prone Area (W_{fpa}) Twice maximum DEPTH, or (2 x d_{mbkf}) = the stage/elevation at which flood-prone area WIDTH is determined in a riffle section.	**101.93**	ft
Entrenchment Ratio (ER) The ratio of flood-prone area WIDTH divided by bankfull channel WIDTH (W_{fpa} / W_{bkf}) (riffle section).	**4.41**	ft/ft
Channel Materials (Particle Size Index) D_{50} The D_{50} particle size index represents the mean diameter of channel materials, as sampled from the channel surface, between the bankfull stage and Thalweg elevations.	**29.35**	mm
Water Surface SLOPE (S) Channel slope = "rise over run" for a reach approximately 20–30 bankfull channel widths in length, with the "riffle-to-riffle" water surface slope representing the gradient at bankfull stage.	**0.00381**	ft/ft
Channel SINUOSITY (k) Sinuosity is an index of channel pattern, determined from a ratio of stream length divided by valley length (SL / VL); or estimated from a ratio of valley slope divided by channel slope (VS / S).	**1.24**	

Stream Type → **C 4/1** ← (See **Figure 2-14**)

APPENDIX M

MBSS Physical Habitat Rating

Physical Habitat

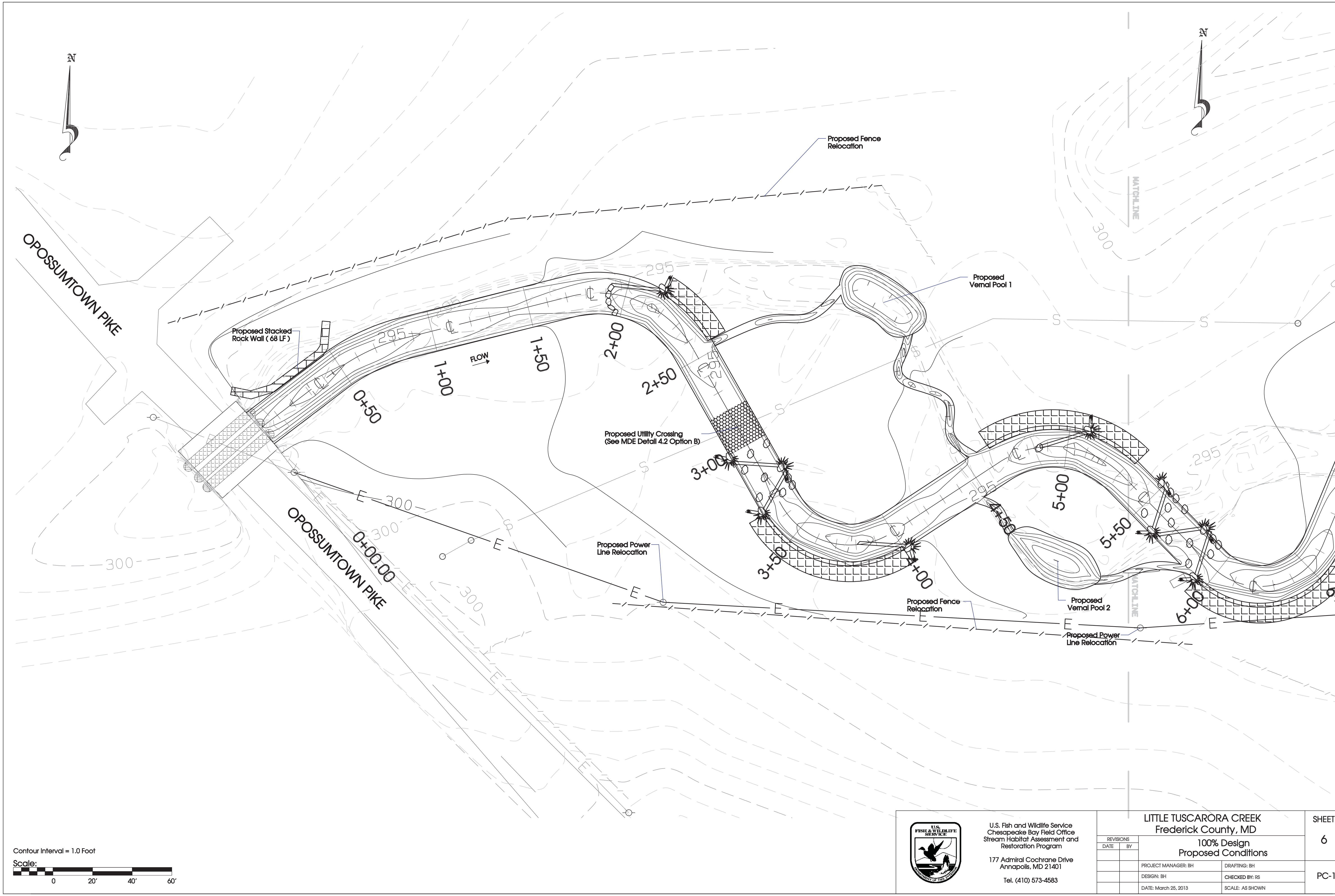
	Little Tuscarora Creek		Reference Sites		
	Downstream	**Upstream**	**Buzzard Branch**	**Jones Falls**	**Timber Run**
Bank Erosion Area (square meters)	104.4	6.4	30.4	11.3	53.7
Bank Erosion Height (m)	1.2	0.8	0.8	0.2	1.0
Erosion Severity	Severe/Moderate	Minor	Minor	Moderate/Minor	Moderate
Bar Formation (Deposition)	Minor (Sand and Silt)	None	Extensive	Extensive	Extensive
Maximum Depth (cm)	64	71	54	79	54
Mean Depth (cm)	27.5	31.3	26	24.8	19
Depth Range (cm)	15-38 (23)	21-49 (28)	20-33(13)	15-43(28)	12-36(24)
Mean Width (m)	3.6	4	5.05	6.83	2.8
Width Range (m)	1.7-5.7 (4.0)	2.6-6.9 (4.3)	3.5-6.1(2.6)	5.8-7.4(1.6)	2.0-3.2(1.2)
Mean Width/Depth Ratio	13.1	12.8	19.4	27.5	14.7
Mean Width/Max Depth Ratio	5.6	5.6	9.4	8.6	5.2
Discharge (cfs)	5.59	4.33	1.46	4.74	1.12
Mean Thalweg Velocity (m/s)	0.353	0.358	0.288	0.385	0.138
Velocity Range (m/s)	0.13-0.95(0.82)	0.07-0.69(.62)	0.0-0.49(0.49)	0.11-1.08(0.97)	0.07-0.21(0.14)
Habitat Scores					
Instream Habitat (Fish habitat)	13	13	18	17	15
Epifaunal Substrate (Benthic Habitat)	9	11	17	15	16
Velocity/depth/diversity	12	16	15	12	12
Pool Quality	12	12	16	12	14
Riffle Quality	16	15	19	15	14
Total Habitat Score	62	67	85	71	71
Riffle Embeddedness	40%	35%	5%	65%	35%
Shading	25%	10%	95%	40%	80%
Pool Extent	65%	83%	40%	58%	68%
Riffle Extent	45%	39%	76%	46%	53%
Gradient (% drop over 75 m)	0.44%	0.48%	4.2%	1.2%	1.4%

	Little Tuscarora Creek Spring 2013		Little Tuscarora Creek Summer 2012		Reference Sites		
Metric	UMON 298	UMON 299	UMON 298	UMON 299	Jone-315-S	LIBE-102-S	UMON-119-S
Total Number of Taxa	30	25	27	23	29	31	20
Number of EPT Taxa	10	10	8	6	13	11	11
Number Ephemeroptera Taxa	3	3	4	3	5	3	3
% Intolerant Urban	13.3	20.5	0	0	9.735	44.628	93.388
% Tanytarsini	3.8	0.9	0.813	1.887	1.77	0.826	0
% Scrapers	17.1	15.2	26.016	41.509	0.885	7.438	18.182
% Swimmers	2.9	3.6	21.138	16.981	4.425	13.223	3.306
% Diptera	50.5	65.2	13.821	6.604	70.796	49.587	71.074
BIBI Score	**2.75**	**3.00**	**3.75**	**3**	**3.667**	**3.667**	**3**
Narrative Rating	**Poor**	**Fair**	**Fair**	**Fair**	**Fair**	**Fair**	**Fair**

	Little Tuscarora Creek		Reference Sites		
	Downstream (UMON 299)	Upstream (UMON 298)	Buzzard Branch	Jones Falls	Timber Run
Fish IBI score	4	3.67	3.50	3	4.33
Benthic Insect IBI (Summer)	3	3.75	N/A	N/A	N/A
Benthic Insect IBI (Spring)	3	2.75	3.667	3.667	3
RTE Species	0	1	1	0	0
Migratory Species	0	0	0	0	0
Trout Abundance	0	0	24	36	0
Number of Salamander Spp	1	1	2	2	1
Coldwater Insects present	0	0	0	0	1

APPENDIX N

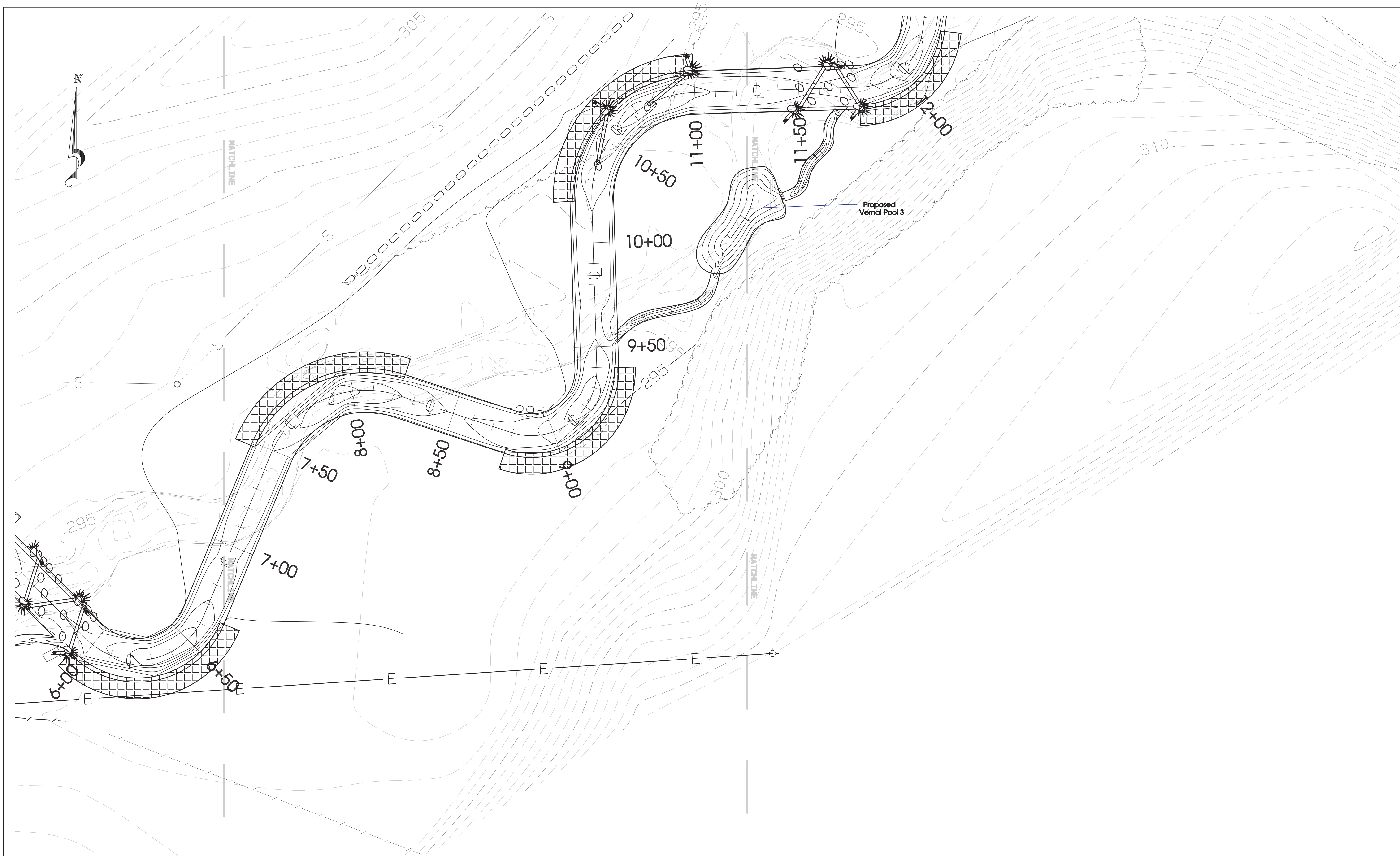
Proposed Restoration Design



U.S. Fish and Wildlife Service Chesapeake Bay Field Office Stream Habitat Assessment and Restoration Program 177 Admiral Cochrane Drive Annapolis, MD 21401 Tel. (410) 573-4583	LITTLE TUSCARORA CREEK Frederick County, MD	SHEET 6
REVISIONS: DATE / BY	100% Design Proposed Conditions	
PROJECT MANAGER: BH	DRAFTING: BH	PC-1
DESIGN: BH	CHECKED BY: RS	
DATE: March 25, 2013	SCALE: AS SHOWN	

1

5

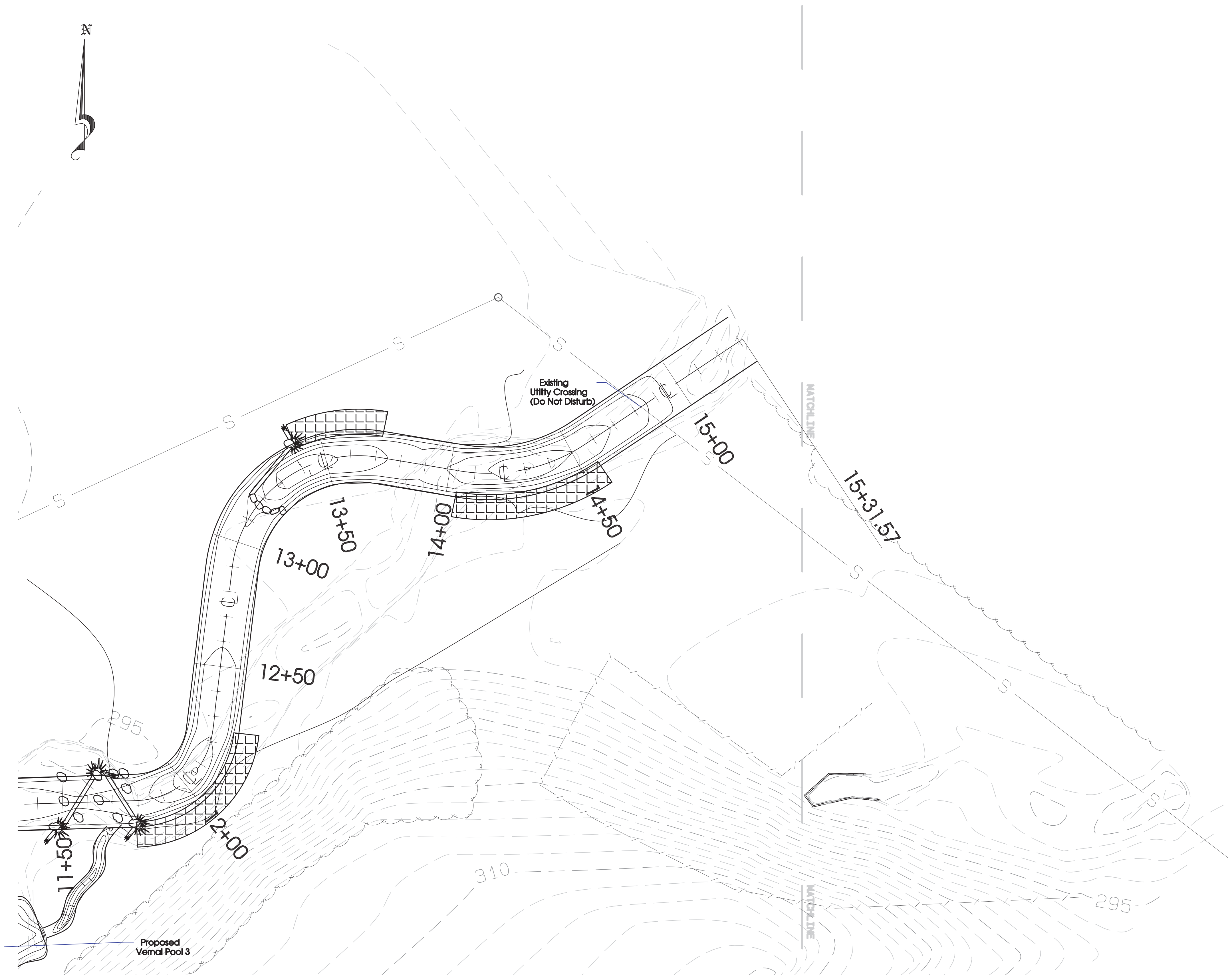


Contour Interval = 1.0 Foot

Scale:

0 20' 40' 60'

U.S. Fish and Wildlife Service Chesapeake Bay Field Office Stream Habitat Assessment and Restoration Program 177 Admiral Cochrane Drive Annapolis, MD 21401 Tel. (410) 573-4583	LITTLE TUSCARORA CREEK Frederick County, MD		SHEET
	REVISIONS: DATE / BY	100% Design Proposed Conditions	7
	PROJECT MANAGER: BH	DRAFTING: BH	
	DESIGN: BH	CHECKED BY: RS	PC-2
	DATE: March 25, 2013	SCALE: AS SHOWN	



Contour Interval = 1.0 Foot

Scale:
0 20' 40' 60'

U.S. Fish and Wildlife Service Chesapeake Bay Field Office Stream Habitat Assessment and Restoration Program 177 Admiral Cochrane Drive Annapolis, MD 21401 Tel. (410) 573-4583	LITTLE TUSCARORA CREEK Frederick County, MD		SHEET 8
REVISIONS DATE / BY	100% Design Proposed Conditions		
	PROJECT MANAGER: BH	DRAFTING: BH	PC-3
	DESIGN: BH	CHECKED BY: RS	
	DATE: March 25, 2013	SCALE: AS SHOWN	

3

7

APPENDIX O

Sediment Transport Competency - Existing

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

Stream:	**Little Tuscarora Creek - Existing**		Stream Type: **C 4/1**		
Location:	**Staley Property**		Valley Type: **VIII**		
Observers:	**BH, MS, CB**		Date: **02/23/2012**		
Enter Required Information for Existing Condition					
29.8	D_{50}	Median particle size of riffle bed material (mm)			
47.9	$\hat{D}_{50}$	Median particle size of bar or sub-pavement sample (mm)			
0.246	D_{max}	Largest particle from bar sample (ft)	**75**	**(mm)**	304.8 mm/ft
0.00400	S	Existing bankfull water surface slope (ft/ft)			
1.53	d	Existing bankfull mean depth (ft)			
1.65	$\gamma_s - \gamma / \gamma$	Immersed specific gravity of sediment			
Select the Appropriate Equation and Calculate Critical Dimensionless Shear Stress					
0.62	$D_{50}/\hat{D}_{50}$	Range: 3 – 7 Use EQUATION 1: $\tau^* = 0.0834\,(D_{50}/\hat{D}_{50})^{-0.872}$			
2.52	D_{max}/D_{50}	Range: 1.3 – 3.0 Use EQUATION 2: $\tau^* = 0.0384\,(D_{max}/D_{50})^{-0.887}$			
0.017	τ^*	Bankfull Dimensionless Shear Stress	EQUATION USED:		**2**
Calculate Bankfull Mean Depth Required for Entrainment of Largest Particle in Bar Sample					
1.72	d	Required bankfull mean depth (ft) $d = \frac{\tau^*(\gamma_s - 1)D_{max}}{S}$ (use D_{max} in ft)			
Calculate Bankfull Water Surface Slope Required for Entrainment of Largest Particle in Bar Sample					
0.00449	S	Required bankfull water surface slope (ft/ft) $S = \frac{\tau^*(\gamma_s - 1)D_{max}}{d}$ (use D_{max} in ft)			
Check: ☑ Stable ☐ Aggrading ☐ Degrading					

Sediment Competence Using Dimensional Shear Stress		
0.382		Bankfull shear stress $\tau = \gamma dS$ (lbs/ft^2) (substitute hydraulic radius, R, with mean depth, d) γ = 62.4, d = existing depth, S = existing slope
Shields **28.59**	CO **74.89**	Predicted largest moveable particle size (mm) at bankfull shear stress τ **(Figure 3-11)**
Shields **0.964**	CO **0.383**	Predicted shear stress required to initiate movement of measured D_{max} (mm) **(Figure 3-11)**
Shields **3.86**	CO **1.53**	Predicted mean depth required to initiate movement of measured D_{max} (mm) $d = \frac{\tau}{\gamma S}$ τ = predicted shear stress, γ = 62.4, S = existing slope
Shields **0.0101**	CO **0.0040**	Predicted slope required to initiate movement of measured D_{max} (mm) $S = \frac{\tau}{\gamma d}$ τ = predicted shear stress, γ = 62.4, d = existing depth
Check: ☑ Stable ☐ Aggrading ☐ Degrading		

APPENDIX P

Existing vs. Proposed H&H Results

HEC-RAS River: LITTLETUSCARORA Reach: REACH1

Reach	River Sta	Profile	Plan	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl	Shear Chan	Power Chan
				(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)		(lb/sq ft)	(lb/ft s)
REACH1	1250	BKF	EX	116.00	293.08	297.14		297.16	0.000386	1.26	91.71	37.27	0.14	0.06	0.07
REACH1	1250	BKF	PROP	116.00	294.00	298.19		298.25	0.000858	2.02	58.36	29.10	0.21	0.14	0.28
REACH1	1250	2YR	EX	197.00	293.08	297.89		297.93	0.000491	1.63	120.83	39.91	0.17	0.09	0.14
REACH1	1250	2YR	PROP	197.00	294.00	298.76		298.87	0.001258	2.75	81.71	49.79	0.26	0.25	0.68
REACH1	1250	10YR	EX	540.00	293.08	299.78		299.88	0.000728	2.64	225.46	101.75	0.22	0.20	0.53
REACH1	1250	10YR	PROP	540.00	294.00	299.60		299.99	0.003613	5.39	136.79	87.32	0.46	0.88	4.73
REACH1	1250	100YR	EX	1292.00	293.08	301.25		301.47	0.001221	4.10	429.67	188.75	0.29	0.44	1.82
REACH1	1250	100YR	PROP	1292.00	294.00	300.64		301.35	0.006090	8.08	263.15	142.72	0.62	1.83	14.82
REACH1	1200	BKF	EX	116.00	294.98	296.89	296.34	297.09	0.006561	3.65	31.76	21.68	0.53	0.57	2.08
REACH1	1200	BKF	PROP	116.00	294.54	298.10		298.19	0.001535	2.43	48.17	28.30	0.28	0.21	0.52
REACH1	1200	2YR	EX	197.00	294.98	297.59	296.78	297.85	0.005605	4.14	47.59	23.58	0.51	0.66	2.73
REACH1	1200	2YR	PROP	197.00	294.54	298.64		298.79	0.002020	3.19	76.16	75.39	0.33	0.34	1.10
REACH1	1200	10YR	EX	540.00	294.98	299.21	298.13	299.76	0.006246	5.98	96.51	65.48	0.58	1.18	7.04
REACH1	1200	10YR	PROP	540.00	294.54	299.42		299.77	0.004237	5.40	154.28	112.50	0.49	0.92	4.94
REACH1	1200	100YR	EX	1292.00	294.98	300.42	300.42	301.27	0.007834	8.26	234.77	157.59	0.69	2.02	16.69
REACH1	1200	100YR	PROP	1292.00	294.54	300.08	300.04	300.92	0.009541	9.02	234.07	133.14	0.76	2.42	21.86
REACH1	1150	BKF	EX	116.00	293.46	296.86	295.25	296.93	0.001226	2.15	53.89	22.59	0.25	0.17	0.36
REACH1	1150	BKF	PROP	116.00	295.63	297.83	297.20	298.04	0.005919	3.67	31.59	20.09	0.52	0.56	2.05
REACH1	1150	2YR	EX	197.00	293.46	297.55	295.70	297.67	0.001648	2.82	69.85	23.95	0.29	0.27	0.77
REACH1	1150	2YR	PROP	197.00	295.63	298.30	297.69	298.61	0.006738	4.58	51.95	75.37	0.57	0.80	3.68
REACH1	1150	10YR	EX	540.00	293.46	299.16	297.10	299.49	0.002787	4.70	133.55	78.96	0.40	0.67	3.14
REACH1	1150	10YR	PROP	540.00	295.63	299.04	299.04	299.50	0.008832	6.48	137.75	141.48	0.69	1.45	9.36
REACH1	1150	100YR	EX	1292.00	293.46	300.24	300.06	300.81	0.004509	6.93	313.28	215.01	0.53	1.35	9.37
REACH1	1150	100YR	PROP	1292.00	295.63	299.86	299.86	300.46	0.010285	8.32	278.73	198.13	0.78	2.19	18.22
REACH1	1100	BKF	EX	116.00	293.23	296.81	295.14	296.88	0.001046	2.01	57.72	23.77	0.23	0.15	0.29
REACH1	1100	BKF	PROP	116.00	295.46	297.02	296.96	297.51	0.021463	5.59	20.76	18.61	0.93	1.45	8.08
REACH1	1100	2YR	EX	197.00	293.23	297.48	295.56	297.59	0.001446	2.66	74.03	25.06	0.27	0.24	0.64
REACH1	1100	2YR	PROP	197.00	295.46	297.61	297.55	298.05	0.020897	5.33	37.20	41.04	0.92	1.34	7.14
REACH1	1100	10YR	EX	540.00	293.23	299.02	296.91	299.35	0.002927	4.63	128.18	143.98	0.40	0.66	3.08
REACH1	1100	10YR	PROP	540.00	295.46	298.61	298.51	298.97	0.008985	5.44	144.33	173.54	0.67	1.12	6.09
REACH1	1100	100YR	EX	1292.00	293.23	300.27	299.79	300.57	0.002746	5.36	441.51	294.26	0.41	0.81	4.36
REACH1	1100	100YR	PROP	1292.00	295.46	299.73	299.24	299.98	0.004623	5.23	394.82	255.40	0.52	0.89	4.67
REACH1	1050	BKF	EX	116.00	294.08	296.65	295.61	296.78	0.003205	2.93	39.65	21.89	0.38	0.34	1.00
REACH1	1050	BKF	PROP	116.00	293.64	297.14		297.22	0.001246	2.20	53.95	39.26	0.25	0.18	0.38
REACH1	1050	2YR	EX	197.00	294.08	297.26	296.13	297.47	0.003872	3.67	53.65	24.02	0.43	0.50	1.84
REACH1	1050	2YR	PROP	197.00	293.64	297.64		297.76	0.001634	2.85	90.76	105.43	0.30	0.28	0.79
REACH1	1050	10YR	EX	540.00	294.08	298.47	297.55	299.10	0.007720	6.36	86.03	38.90	0.64	1.36	8.64
REACH1	1050	10YR	PROP	540.00	293.64	298.54		298.73	0.002480	4.21	217.89	167.45	0.38	0.55	2.32
REACH1	1050	100YR	EX	1292.00	294.08	299.84	299.84	300.35	0.005752	6.94	354.13	327.01	0.58	1.44	10.00
REACH1	1050	100YR	PROP	1292.00	293.64	299.58		299.82	0.003006	5.45	460.13	300.80	0.44	0.85	4.64
REACH1	1000	BKF	EX	116.00	293.49	296.57	295.29	296.65	0.001790	2.35	49.44	24.80	0.29	0.21	0.50
REACH1	1000	BKF	PROP	116.00	295.17	296.62	296.57	297.02	0.021563	5.12	22.66	23.65	0.92	1.27	6.50
REACH1	1000	2YR	EX	197.00	293.49	297.16	295.73	297.30	0.002365	3.05	64.63	26.68	0.35	0.34	1.02
REACH1	1000	2YR	PROP	197.00	295.17	297.24	297.21	297.56	0.010170	4.75	53.76	103.99	0.68	0.94	4.46
REACH1	1000	10YR	EX	540.00	293.49	298.22	297.06	298.73	0.005922	5.69	94.89	80.97	0.56	1.08	6.13
REACH1	1000	10YR	PROP	540.00	295.17	298.41	297.87	298.54	0.002946	3.75	233.28	232.64	0.40	0.48	1.81
REACH1	1000	100YR	EX	1292.00	293.49	299.02	298.68	299.80	0.009086	8.08	278.60	296.85	0.72	2.03	16.38
REACH1	1000	100YR	PROP	1292.00	295.17	299.48	298.53	299.61	0.002562	4.36	553.55	346.23	0.40	0.59	2.56
REACH1	950	BKF	EX	116.00	293.63	296.25	295.66	296.48	0.007014	3.86	30.09	20.26	0.56	0.63	2.42
REACH1	950	BKF	PROP	116.00	293.36	296.46		296.62	0.003141	3.17	36.59	37.14	0.38	0.38	1.21
REACH1	950	2YR	EX	197.00	293.63	296.67	296.18	297.06	0.009735	5.05	38.99	22.28	0.67	1.02	5.16
REACH1	950	2YR	PROP	197.00	293.36	296.89		297.20	0.005376	4.47	44.07	39.84	0.51	0.73	3.27
REACH1	950	10YR	EX	540.00	293.63	297.83	297.83	298.36	0.009277	6.42	120.00	116.48	0.70	1.44	9.27
REACH1	950	10YR	PROP	540.00	293.36	298.23		298.39	0.002744	4.25	253.07	247.60	0.39	0.57	2.44
REACH1	950	100YR	EX	1292.00	293.63	299.00	298.78	299.32	0.005093	6.09	409.77	340.18	0.55	1.15	6.99
REACH1	950	100YR	PROP	1292.00	293.36	299.37		299.49	0.001943	4.27	609.87	357.01	0.34	0.53	2.27
REACH1	900	BKF	EX	116.00	293.99	295.42	295.42	295.85	0.026407	5.22	22.22	26.34	1.00	1.38	7.18
REACH1	900	BKF	PROP	116.00	294.80	296.19		296.36	0.009269	3.39	37.10	75.01	0.61	0.55	1.88
REACH1	900	2YR	EX	197.00	293.99	295.87	295.79	296.38	0.019714	5.75	34.25	27.94	0.92	1.48	8.51
REACH1	900	2YR	PROP	197.00	294.80	296.74		296.86	0.004034	3.03	84.40	97.47	0.43	0.38	1.15
REACH1	900	10YR	EX	540.00	293.99	297.53	297.17	297.89	0.005583	5.26	154.24	170.91	0.55	0.94	4.97
REACH1	900	10YR	PROP	540.00	294.80	298.09		298.17	0.001637	2.94	292.01	215.41	0.31	0.29	0.86
REACH1	900	100YR	EX	1292.00	293.99	298.74	298.20	299.00	0.003692	5.43	413.44	249.80	0.48	0.89	4.85
REACH1	900	100YR	PROP	1292.00	294.80	299.16		299.29	0.001819	3.84	554.41	273.51	0.34	0.44	1.70
REACH1	850	BKF	EX	116.00	292.05	295.33	293.85	295.36	0.000954	1.47	78.81	51.05	0.21	0.09	0.13
REACH1	850	BKF	PROP	116.00	292.19	296.11		296.20	0.001298	2.32	55.36	78.36	0.25	0.19	0.44
REACH1	850	2YR	EX	197.00	292.05	296.07	294.39	296.12	0.000865	1.65	119.57	61.51	0.21	0.10	0.17
REACH1	850	2YR	PROP	197.00	292.19	296.64		296.74	0.001460	2.78	102.39	100.54	0.28	0.26	0.72
REACH1	850	10YR	EX	540.00	292.05	297.64	295.30	297.71	0.000825	2.31	272.80	154.54	0.22	0.17	0.39
REACH1	850	10YR	PROP	540.00	292.19	297.99		298.09	0.001328	3.36	284.18	179.54	0.28	0.34	1.13
REACH1	850	100YR	EX	1292.00	292.05	298.67	296.56	298.85	0.001480	3.70	470.26	224.37	0.31	0.40	1.48
REACH1	850	100YR	PROP	1292.00	292.19	298.98		299.17	0.002161	4.91	495.56	247.87	0.37	0.67	3.29
REACH1	800	BKF	EX	116.00	292.40	295.11	294.25	295.26	0.004121	3.15	36.83	22.44	0.43	0.41	1.28
REACH1	800	BKF	PROP	116.00	294.23	295.56	295.56	295.99	0.026959	5.23	22.17	26.68	1.01	1.39	7.26
REACH1	800	2YR	EX	197.00	292.40	295.81	294.73	296.01	0.004842	3.65	53.99	29.81	0.48	0.53	1.92
REACH1	800	2YR	PROP	197.00	294.23	295.94	295.94	296.49	0.025128	5.98	32.94	30.69	1.02	1.67	9.97
REACH1	800	10YR	EX	540.00	292.40	297.36	296.30	297.62	0.004021	4.17	141.82	124.85	0.46	0.61	2.56
REACH1	800	10YR	PROP	540.00	294.23	297.61		297.94	0.005114	5.02	155.82	161.90	0.54	0.86	4.33
REACH1	800	100YR	EX	1292.00	292.40	298.17	297.87	298.68	0.006344	6.31	282.72	189.63	0.61	1.28	8.07
REACH1	800	100YR	PROP	1292.00	294.23	298.26	298.24	298.89	0.009013	7.69	271.31	193.66	0.74	1.88	14.44
REACH1	750	BKF	EX	116.00	291.72	295.09	293.35	295.14	0.000963	1.86	62.22	27.44	0.22	0.13	0.24
REACH1	750	BKF	PROP	116.00	291.22	295.23	293.36	295.34	0.001792	2.67	43.52	16.53	0.29	0.26	0.68
REACH1	750	2YR	EX	197.00	291.72	295.78	293.81	295.87	0.001273	2.40	81.92	29.92	0.26	0.20	0.48
REACH1	750	2YR	PROP	197.00	291.22	295.65	294.02	295.88	0.003391	3.89	50.68	17.48	0.40	0.53	2.06

HEC-RAS   River: LITTLETUSCARORA   Reach: REACH1 (Continued)

Reach	River Sta	Profile	Plan	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl	Shear Chan	Power Chan
				(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)		(lb/sq ft)	(lb/ft s)
REACH1	750	10YR	EX	540.00	291.72	297.29	295.12	297.46	0.001718	3.57	224.67	207.80	0.31	0.39	1.40
REACH1	750	10YR	PROP	540.00	291.22	295.97	295.88	297.39	0.018886	9.56	56.50	18.21	0.96	3.13	29.96
REACH1	750	100YR	EX	1292.00	291.72	298.01	297.53	298.35	0.003403	5.60	396.53	263.86	0.45	0.92	5.13
REACH1	750	100YR	PROP	1292.00	291.22	297.90	297.90	298.45	0.006513	7.73	332.78	256.99	0.61	1.75	13.51
REACH1	700	BKF	EX	116.00	291.94	294.92	293.94	295.06	0.003033	2.92	39.78	20.70	0.37	0.33	0.98
REACH1	700	BKF	PROP	116.00	293.38	294.83	294.73	295.11	0.013445	4.57	31.40	43.62	0.76	0.95	4.35
REACH1	700	2YR	EX	197.00	291.94	295.54	294.39	295.75	0.003819	3.73	52.84	43.46	0.43	0.51	1.91
REACH1	700	2YR	PROP	197.00	293.38	295.33	295.08	295.58	0.008529	4.64	59.74	85.87	0.64	0.87	4.03
REACH1	700	10YR	EX	540.00	291.94	296.41	295.85	297.21	0.010252	7.24	80.81	144.67	0.72	1.77	12.83
REACH1	700	10YR	PROP	540.00	293.38	296.46	295.97	296.59	0.003371	4.14	241.09	207.32	0.44	0.58	2.41
REACH1	700	100YR	EX	1292.00	291.94	297.87	297.23	298.09	0.003142	5.15	449.10	260.47	0.43	0.79	4.07
REACH1	700	100YR	PROP	1292.00	293.38	297.72	296.64	297.85	0.002192	4.29	524.30	252.86	0.38	0.55	2.36
REACH1	650	BKF	EX	116.00	292.65	294.40	294.18	294.74	0.015521	4.70	24.66	21.50	0.77	1.03	4.85
REACH1	650	BKF	PROP	116.00	291.69	294.68	293.45	294.80	0.002599	2.94	50.33	54.03	0.34	0.33	0.95
REACH1	650	2YR	EX	197.00	292.65	295.12	294.67	295.45	0.010105	4.63	42.59	27.58	0.66	0.90	4.17
REACH1	650	2YR	PROP	197.00	291.69	295.14	294.21	295.30	0.003164	3.59	81.03	86.82	0.39	0.46	1.66
REACH1	650	10YR	EX	540.00	292.65	296.47	295.95	296.70	0.004573	4.46	192.27	204.07	0.48	0.70	3.13
REACH1	650	10YR	PROP	540.00	291.69	296.34	295.68	296.45	0.001998	3.66	273.41	200.21	0.33	0.42	1.55
REACH1	650	100YR	EX	1292.00	292.65	297.76	296.90	297.92	0.002388	4.19	488.05	245.79	0.37	0.54	2.28
REACH1	650	100YR	PROP	1292.00	291.69	297.63	296.38	297.74	0.001580	3.94	564.50	241.65	0.31	0.45	1.76
REACH1	600	BKF	EX	116.00	290.78	294.39	292.85	294.47	0.001718	2.35	49.28	23.43	0.29	0.21	0.50
REACH1	600	BKF	PROP	116.00	293.00	294.35		294.56	0.010140	3.75	34.86	57.20	0.65	0.66	2.48
REACH1	600	2YR	EX	197.00	290.78	295.05	293.34	295.19	0.002142	3.02	65.16	24.55	0.33	0.32	0.98
REACH1	600	2YR	PROP	197.00	293.00	294.97		295.10	0.004129	3.26	78.93	80.29	0.44	0.43	1.39
REACH1	600	10YR	EX	540.00	290.78	296.32	294.85	296.52	0.002484	4.10	208.15	165.26	0.37	0.53	2.17
REACH1	600	10YR	PROP	540.00	293.00	296.20		296.33	0.002319	3.53	233.01	159.82	0.37	0.42	1.47
REACH1	600	100YR	EX	1292.00	290.78	297.56	296.67	297.78	0.002427	4.90	440.14	204.34	0.38	0.69	3.37
REACH1	600	100YR	PROP	1292.00	293.00	297.47		297.64	0.002180	4.36	465.21	201.76	0.38	0.56	2.46
REACH1	550	BKF	EX	116.00	291.95	294.14	293.55	294.32	0.006036	3.41	34.04	23.77	0.50	0.50	1.71
REACH1	550	BKF	PROP	116.00	290.71	294.21		294.33	0.002156	2.81	41.74	22.88	0.32	0.29	0.82
REACH1	550	2YR	EX	197.00	291.95	294.78	293.97	295.02	0.005612	3.93	50.17	26.62	0.50	0.61	2.39
REACH1	550	2YR	PROP	197.00	290.71	294.72		294.92	0.002941	3.73	65.27	73.42	0.39	0.48	1.79
REACH1	550	10YR	EX	540.00	291.95	296.04	295.31	296.34	0.004875	4.86	161.40	143.28	0.51	0.81	3.93
REACH1	550	10YR	PROP	540.00	290.71	295.99		296.19	0.002674	4.54	206.51	145.62	0.39	0.63	2.85
REACH1	550	100YR	EX	1292.00	291.95	297.34	296.59	297.62	0.003658	5.39	372.30	181.81	0.47	0.88	4.75
REACH1	550	100YR	PROP	1292.00	290.71	297.27		297.51	0.002642	5.40	416.23	179.74	0.41	0.81	4.39
REACH1	500	BKF	EX	116.00	291.59	293.45		293.85	0.014832	5.02	23.10	18.11	0.78	1.12	5.65
REACH1	500	BKF	PROP	116.00	292.33	294.08		294.19	0.004026	2.67	44.76	56.82	0.42	0.31	0.84
REACH1	500	2YR	EX	197.00	291.59	294.17		294.62	0.010809	5.34	36.86	20.30	0.70	1.14	6.09
REACH1	500	2YR	PROP	197.00	292.33	294.64		294.75	0.002716	2.80	86.62	89.95	0.37	0.31	0.86
REACH1	500	10YR	EX	540.00	291.59	295.70		296.03	0.007395	5.13	141.91	128.47	0.61	0.97	5.00
REACH1	500	10YR	PROP	540.00	292.33	295.94		296.06	0.001735	3.21	241.16	138.26	0.32	0.34	1.08
REACH1	500	100YR	EX	1292.00	291.59	297.15		297.43	0.003918	5.22	349.49	158.06	0.48	0.85	4.45
REACH1	500	100YR	PROP	1292.00	292.33	297.18		297.38	0.002106	4.41	423.76	158.81	0.37	0.57	2.51
REACH1	450	BKF	EX	116.00	290.73	293.31	292.37	293.46	0.003403	3.08	37.61	19.69	0.39	0.37	1.15
REACH1	450	BKF	PROP	116.00	289.77	294.01		294.08	0.001045	2.13	55.09	94.43	0.23	0.16	0.34
REACH1	450	2YR	EX	197.00	290.73	294.03	292.84	294.25	0.003832	3.75	52.51	23.07	0.43	0.52	1.94
REACH1	450	2YR	PROP	197.00	289.77	294.57		294.66	0.001166	2.55	109.77	101.77	0.25	0.22	0.55
REACH1	450	10YR	EX	540.00	290.73	295.44	294.36	295.76	0.003898	4.99	148.55	91.80	0.46	0.80	3.98
REACH1	450	10YR	PROP	540.00	289.77	295.87		295.98	0.001254	3.31	249.73	113.43	0.27	0.32	1.07
REACH1	450	100YR	EX	1292.00	290.73	296.65	296.02	297.18	0.005187	6.98	277.24	121.46	0.56	1.42	9.90
REACH1	450	100YR	PROP	1292.00	289.77	297.01		297.25	0.002157	5.03	388.20	130.00	0.37	0.70	3.51
REACH1	400	BKF	EX	116.00	290.90	293.19		293.27	0.003543	2.27	51.13	46.11	0.38	0.24	0.54
REACH1	400	BKF	PROP	116.00	291.68	293.84		293.98	0.003819	3.02	38.47	26.18	0.42	0.37	1.12
REACH1	400	2YR	EX	197.00	290.90	294.01		294.08	0.001755	2.10	93.90	56.33	0.29	0.18	0.37
REACH1	400	2YR	PROP	197.00	291.68	294.39		294.55	0.003417	3.41	74.58	85.04	0.41	0.44	1.49
REACH1	400	10YR	EX	540.00	290.90	295.48		295.59	0.001383	2.79	222.62	118.83	0.28	0.26	0.71
REACH1	400	10YR	PROP	540.00	291.68	295.75		295.89	0.002120	3.73	217.56	126.11	0.35	0.44	1.65
REACH1	400	100YR	EX	1292.00	290.90	296.70		296.93	0.001960	4.15	387.49	146.21	0.35	0.51	2.12
REACH1	400	100YR	PROP	1292.00	291.68	296.86		297.12	0.002920	5.27	372.52	148.69	0.43	0.80	4.24
REACH1	350	BKF	EX	116.00	289.43	293.22	290.69	293.23	0.000136	0.83	139.77	47.59	0.09	0.02	0.02
REACH1	350	BKF	PROP	116.00	291.64	293.06	293.06	293.55	0.025450	5.61	20.67	21.29	1.00	1.52	8.53
REACH1	350	2YR	EX	197.00	289.43	294.02	291.00	294.04	0.000182	1.10	178.69	48.63	0.10	0.04	0.04
REACH1	350	2YR	PROP	197.00	291.64	293.51	293.51	294.14	0.023019	6.41	30.74	23.97	1.00	1.81	11.59
REACH1	350	10YR	EX	540.00	289.43	295.47	291.83	295.54	0.000426	2.06	308.19	150.78	0.16	0.12	0.25
REACH1	350	10YR	PROP	540.00	291.64	294.79	294.79	295.54	0.013283	7.34	90.61	83.96	0.84	1.93	14.17
REACH1	350	100YR	EX	1292.00	289.43	296.66	293.11	296.82	0.000896	3.44	503.04	182.40	0.24	0.32	1.09
REACH1	350	100YR	PROP	1292.00	291.64	296.21	295.90	296.67	0.006236	6.87	300.85	167.29	0.62	1.45	9.93
REACH1	300	BKF	EX	116.00	290.05	293.09	291.84	293.20	0.002236	2.68	43.35	27.54	0.33	0.27	0.73
REACH1	300	BKF	PROP	116.00	289.75	293.12		293.18	0.000953	1.90	61.55	34.30	0.22	0.13	0.25
REACH1	300	2YR	EX	197.00	290.05	293.84	292.31	294.01	0.002569	3.31	59.68	41.73	0.36	0.39	1.29
REACH1	300	2YR	PROP	197.00	289.75	293.73		293.82	0.001130	2.42	100.37	101.95	0.25	0.20	0.48
REACH1	300	10YR	EX	540.00	290.05	295.32	293.81	295.49	0.001972	3.90	247.31	246.00	0.34	0.46	1.81
REACH1	300	10YR	PROP	540.00	289.75	294.94		295.06	0.001336	3.31	258.48	154.90	0.29	0.33	1.09
REACH1	300	100YR	EX	1292.00	290.05	296.63	295.18	296.75	0.001453	4.02	649.31	371.93	0.30	0.45	1.81
REACH1	300	100YR	PROP	1292.00	289.75	296.31		296.44	0.001331	4.00	623.64	329.15	0.30	0.44	1.75
REACH1	250	BKF	EX	116.00	289.84	292.98	291.72	293.09	0.002238	2.64	43.88	21.23	0.32	0.27	0.71
REACH1	250	BKF	PROP	116.00	290.98	292.52	292.52	293.00	0.025592	5.58	20.78	21.57	1.00	1.51	8.43
REACH1	250	2YR	EX	197.00	289.84	293.71	292.22	293.87	0.002660	3.27	60.24	25.55	0.36	0.38	1.26
REACH1	250	2YR	PROP	197.00	290.98	293.23	292.94	293.65	0.011754	5.26	40.78	54.10	0.73	1.14	5.97
REACH1	250	10YR	EX	540.00	289.84	295.23	293.69	295.38	0.001968	3.76	263.00	262.01	0.33	0.44	1.66
REACH1	250	10YR	PROP	540.00	290.98	294.78	294.16	294.96	0.002993	4.17	202.43	182.88	0.41	0.57	2.38
REACH1	250	100YR	EX	1292.00	289.84	296.57	295.48	296.67	0.001226	3.62	681.54	347.89	0.28	0.37	1.33
REACH1	250	100YR	PROP	1292.00	290.98	296.25	295.03	296.36	0.001502	3.82	622.39	335.04	0.31	0.42	1.60

HEC-RAS River: LITTLETUSCARORA Reach: REACH1 (Continued)

Reach	River Sta	Profile	Plan	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl	Shear Chan	Power Chan
				(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)		(lb/sq ft)	(lb/ft s)
REACH1	200	BKF	EX	116.00	290.27	292.51	292.10	292.85	0.010771	4.72	24.60	16.12	0.67	0.94	4.45
REACH1	200	BKF	PROP	116.00	289.28	292.53	291.08	292.63	0.001941	2.58	44.93	20.42	0.31	0.25	0.64
REACH1	200	2YR	EX	197.00	290.27	293.19	292.68	293.60	0.012614	5.12	38.48	25.63	0.74	1.11	5.69
REACH1	200	2YR	PROP	197.00	289.28	293.17	291.61	293.34	0.002566	3.36	59.94	37.73	0.36	0.40	1.33
REACH1	200	10YR	EX	540.00	290.27	294.18	294.18	295.05	0.019099	7.52	73.86	55.85	0.95	2.19	16.50
REACH1	200	10YR	PROP	540.00	289.28	294.55	293.53	294.80	0.002723	4.57	172.99	150.67	0.40	0.64	2.93
REACH1	200	100YR	EX	1292.00	290.27	295.56	295.55	296.41	0.011233	8.23	211.91	276.23	0.79	2.20	18.10
REACH1	200	100YR	PROP	1292.00	289.28	295.82	294.96	296.21	0.003502	6.22	320.20	306.07	0.47	1.08	6.72
REACH1	150	BKF	EX	116.00	288.11	292.68	289.96	292.71	0.000357	1.38	84.26	27.19	0.14	0.06	0.09
REACH1	150	BKF	PROP	116.00	288.37	292.48	290.38	292.55	0.001255	2.17	53.38	22.30	0.25	0.17	0.37
REACH1	150	2YR	EX	197.00	288.11	293.36	290.47	293.42	0.000564	1.91	103.23	45.37	0.18	0.12	0.22
REACH1	150	2YR	PROP	197.00	288.37	293.08	290.99	293.21	0.002119	2.85	70.44	55.70	0.32	0.29	0.84
REACH1	150	10YR	EX	540.00	288.11	294.12	291.82	294.40	0.002536	4.31	127.19	164.63	0.38	0.57	2.48
REACH1	150	10YR	PROP	540.00	288.37	294.44	292.85	294.66	0.002377	4.07	179.65	212.93	0.37	0.52	2.11
REACH1	150	100YR	EX	1292.00	288.11	295.70	293.75	296.00	0.002327	5.14	367.56	315.44	0.38	0.73	3.77
REACH1	150	100YR	PROP	1292.00	288.37	295.67	294.70	296.02	0.003094	5.61	344.38	313.82	0.44	0.90	5.03
REACH1	100	BKF	EX	116.00	290.39	292.03	292.03	292.60	0.024523	6.01	19.30	17.18	1.00	1.67	10.03
REACH1	100	BKF	PROP	116.00	290.33	291.82	291.82	292.34	0.024922	5.79	20.05	19.23	1.00	1.58	9.16
REACH1	100	2YR	EX	197.00	290.39	292.56	292.56	293.27	0.023049	6.74	29.23	20.86	1.00	1.95	13.15
REACH1	100	2YR	PROP	197.00	290.33	292.35	292.35	292.91	0.024180	6.02	32.78	29.52	1.00	1.66	10.02
REACH1	100	10YR	EX	540.00	290.39	293.86	293.86	294.13	0.009868	5.09	175.14	349.00	0.68	1.04	5.28
REACH1	100	10YR	PROP	540.00	290.33	293.51	293.51	294.34	0.014865	7.56	82.38	296.48	0.88	2.08	15.69
REACH1	100	100YR	EX	1292.00	290.39	295.83	294.14	295.86	0.000516	1.88	1007.96	415.54	0.18	0.11	0.21
REACH1	100	100YR	PROP	1292.00	290.33	295.83	294.18	295.86	0.000455	2.11	1038.24	415.48	0.17	0.13	0.27
REACH1	50	BKF	EX	116.00	289.92	291.53	290.84	291.61	0.002910	2.31	50.24	38.39	0.36	0.23	0.54
REACH1	50	BKF	PROP	116.00	289.92	291.53	290.84	291.61	0.002910	2.31	50.24	38.39	0.36	0.23	0.54
REACH1	50	2YR	EX	197.00	289.92	292.26	291.13	292.36	0.002533	2.44	80.77	51.09	0.34	0.24	0.60
REACH1	50	2YR	PROP	197.00	289.92	292.26	291.13	292.36	0.002533	2.44	80.77	51.10	0.34	0.24	0.60
REACH1	50	10YR	EX	540.00	289.92	293.35	292.12	293.58	0.003510	3.82	144.25	221.20	0.43	0.52	1.99
REACH1	50	10YR	PROP	540.00	289.92	293.36	292.12	293.58	0.003643	3.80	144.92	229.08	0.44	0.52	1.98
REACH1	50	100YR	EX	1292.00	289.92	295.81	293.74	295.84	0.000305	1.79	1132.45	420.88	0.14	0.09	0.16
REACH1	50	100YR	PROP	1292.00	289.92	295.81	293.73	295.84	0.000306	1.77	1132.54	420.89	0.14	0.09	0.16
REACH1	0	BKF	EX	116.00	288.95	291.27	290.37	291.43	0.003966	3.24	35.76	29.68	0.42	0.42	1.36
REACH1	0	BKF	PROP	116.00	288.95	291.27	290.37	291.43	0.003966	3.24	35.76	29.68	0.42	0.42	1.36
REACH1	0	2YR	EX	197.00	288.95	291.97	290.86	292.19	0.003968	3.83	58.88	92.52	0.43	0.54	2.06
REACH1	0	2YR	PROP	197.00	288.95	291.97	290.85	292.19	0.003967	3.83	58.88	92.52	0.43	0.54	2.06
REACH1	0	10YR	EX	540.00	288.95	293.14	292.60	293.39	0.003972	4.80	175.99	281.42	0.45	0.76	3.63
REACH1	0	10YR	PROP	540.00	288.95	293.14	292.60	293.39	0.003972	4.80	175.99	281.41	0.45	0.76	3.63
REACH1	0	100YR	EX	1292.00	288.95	295.80	293.41	295.82	0.000233	1.70	1268.16	415.98	0.12	0.08	0.13
REACH1	0	100YR	PROP	1292.00	288.95	295.80	293.40	295.82	0.000233	1.70	1268.16	415.98	0.12	0.08	0.13

APPENDIX Q

Velocity and Discharge Calculations

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

Bankfull VELOCITY & DISCHARGE Estimates

Stream:	Little Tuscarora Creek - Existing	Location:	Reach - Staley Property
Date:	2/9/2015	Stream Type: C4	Valley Type: VIII
Observers:	BH	HUC:	

INPUT VARIABLES			OUTPUT VARIABLES		
Bankfull Riffle Cross-Sectional AREA	35.24	A_{bkf} (ft^2)	Bankfull Riffle Mean DEPTH	1.53	d_{bkf} (ft)
Bankfull Riffle WIDTH	23.11	W_{bkf} (ft)	Wetted PERIMETER ~ $(2 * d_{bkf}) + W_{bkf}$	24.04	W_p (ft)
D_{84} at Riffle	69.31	Dia. (mm)	D_{84} (mm) / 304.8	0.23	D_{84} (ft)
Bankfull SLOPE	0.0038	S_{bkf} (ft / ft)	Hydraulic RADIUS A_{bkf} / W_p	1.47	R (ft)
Gravitational Acceleration	32.2	g (ft / sec^2)	Relative Roughness R(ft) / D_{84} (ft)	3.26	R / D_{84}
Drainage Area	5.6	DA (mi^2)	Shear Velocity $u^* = (gRS)^{1/2}$	0.425	u* (ft/sec)

ESTIMATION METHODS	Bankfull VELOCITY		Bankfull DISCHARGE	
1. Friction Factor / Relative Roughness $u = [2.83 + 5.66 * Log \{R / D_{84}\}] u^*$	3.14	ft / sec	110.75	cfs
2. Roughness Coefficient: a) Manning's *n* from Friction Factor / Relative Roughness (Figs. 2-18, 2-19) $u = 1.49 * R^{2/3} * S^{1/2} / n$ *n* = 0.0353	3.35	ft / sec	118.20	cfs
2. Roughness Coefficient: b) Manning's *n* from Stream Type (Fig. 2-20) $u = 1.49 * R^{2/3} * S^{1/2} / n$ *n* = 0.031	3.82	ft / sec	134.58	cfs
2. Roughness Coefficient: c) Manning's *n* from Jarrett (USGS): $u = 1.49 * R^{2/3} * S^{1/2} / n$; $n = 0.39 * S^{0.38} * R^{-0.16}$ *n* = 0.044. Note: This equation is applicable to **steep, step/pool, high boundary roughness, cobble- and boulder-dominated stream systems**; i.e., for Stream Types A1, A2, A3, B1, B2, B3, C2 & E3	2.68	ft / sec	94.41	cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.) Darcy-Weisbach (Leopold, Wolman and Miller)	3.29	ft / sec	115.77	cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.) Chezy C	0.00	ft / sec	0.00	cfs
4. Continuity Equations: a) Regional Curves u = Q / A. Return Period for Bankfull Discharge Q = 0.0 year	0.00	ft / sec	0.00	cfs
4. Continuity Equations: b) USGS Gage Data u = Q / A	0.00	ft / sec	0.00	cfs

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

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

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

Bankfull VELOCITY & DISCHARGE Estimates

Stream:	**Little Tuscarora Creek - Design**	Location:	**Reach - Staley Property**
Date:	**2/9/2015**	Stream Type: **C4**	Valley Type: **VIII**
Observers:	**BH**	HUC:	

INPUT VARIABLES			OUTPUT VARIABLES		
Bankfull Riffle Cross-Sectional AREA	**35.00**	A_{bkf} (ft^2)	Bankfull Riffle Mean DEPTH	**1.75**	d_{bkf} (ft)
Bankfull Riffle WIDTH	**20.00**	W_{bkf} (ft)	Wetted PERIMETER ~ $(2 * d_{bkf}) + W_{bkf}$	**22.88**	W_p (ft)
D_{84} at Riffle	**69.31**	Dia. (mm)	D_{84} (mm) / 304.8	**0.23**	D_{84} (ft)
Bankfull SLOPE	**0.0040**	S_{bkf} (ft / ft)	Hydraulic RADIUS A_{bkf} / W_p	**1.45**	R (ft)
Gravitational Acceleration	**32.2**	g (ft / sec^2)	Relative Roughness R(ft) / D_{84} (ft)	**6.39**	R / D_{84}
Drainage Area	**5.6**	DA (mi^2)	Shear Velocity $u^* = (gRS)^{1/2}$	**0.432**	u* (ft/sec)

ESTIMATION METHODS	Bankfull VELOCITY		Bankfull DISCHARGE	
1. Friction Factor / Relative Roughness $u = [2.83 + 5.66 * Log\{R / D_{84}\}] u^*$	**3.34**	ft / sec	**116.76**	cfs
2. Roughness Coefficient: a) Manning's *n* from Friction Factor / Relative Roughness (Figs. 2-18, 2-19) $u = 1.49 * R^{2/3} * S^{1/2} / n$; *n* = **0.0347**	**3.60**	ft / sec	**125.90**	cfs
2. Roughness Coefficient: b) Manning's *n* from Stream Type (Fig. 2-20) $u = 1.49 * R^{2/3} * S^{1/2} / n$; *n* = **0.031**	**4.03**	ft / sec	**140.91**	cfs
2. Roughness Coefficient: c) Manning's *n* from Jarrett (USGS): $u = 1.49 * R^{2/3} * S^{1/2} / n$; $n = 0.39 * S^{0.38} * R^{-0.16}$; *n* = **0.045** **Note:** This equation is applicable to **steep, step/pool, high boundary roughness, cobble- and boulder-dominated stream systems**; i.e., for Stream Types A1, A2, A3, B1, B2, B3, C2 & E3	**2.79**	ft / sec	**97.72**	cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.) **Darcy-Weisbach (Leopold, Wolman and Miller)**	**3.76**	ft / sec	**131.57**	cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.) **Chezy C**	**0.00**	ft / sec	**0.00**	cfs
4. Continuity Equations: a) Regional Curves u = Q / A **Return Period for Bankfull Discharge** Q = **0.0** year	**0.00**	ft / sec	**0.00**	cfs
4. Continuity Equations: b) USGS Gage Data u = Q / A	**0.00**	ft / sec	**0.00**	cfs

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

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

APPENDIX R

Sediment Transport Competency - Design

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

Stream:	**Little Tuscarora Creek - Design**	Stream Type:	**C 4/1**
Location:	**Staley Property**	Valley Type:	**VIII**
Observers:	**BH, MS, CB**	Date:	**02/23/2012**

Enter Required Information for Existing Condition

29.8	D_{50}	Median particle size of riffle bed material (mm)			
47.9	$\hat{D}_{50}$	Median particle size of bar or sub-pavement sample (mm)			
0.246	D_{max}	Largest particle from bar sample (ft)	**75**	**(mm)**	304.8 mm/ft
0.00400	S	Existing bankfull water surface slope (ft/ft)			
1.75	d	Existing bankfull mean depth (ft)			
1.65	$\gamma_s - \gamma / \gamma$	Immersed specific gravity of sediment			

Select the Appropriate Equation and Calculate Critical Dimensionless Shear Stress

0.62	$D_{50}/\hat{D}_{50}$	Range: 3 – 7	Use EQUATION 1: $\tau^* = 0.0834\ (D_{50}/\hat{D}_{50})^{-0.872}$
2.52	D_{max}/D_{50}	Range: 1.3 – 3.0	Use EQUATION 2: $\tau^* = 0.0384\ (D_{max}/D_{50})^{-0.887}$
0.017	τ^*	Bankfull Dimensionless Shear Stress	EQUATION USED: **2**

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

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

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

0.00393	S	Required bankfull water surface slope (ft/ft)	$S = \frac{\tau^*(\gamma_s - 1)D_{max}}{d}$	(use D_{max} in ft)

Check: ☑ Stable ☐ Aggrading ☐ Degrading

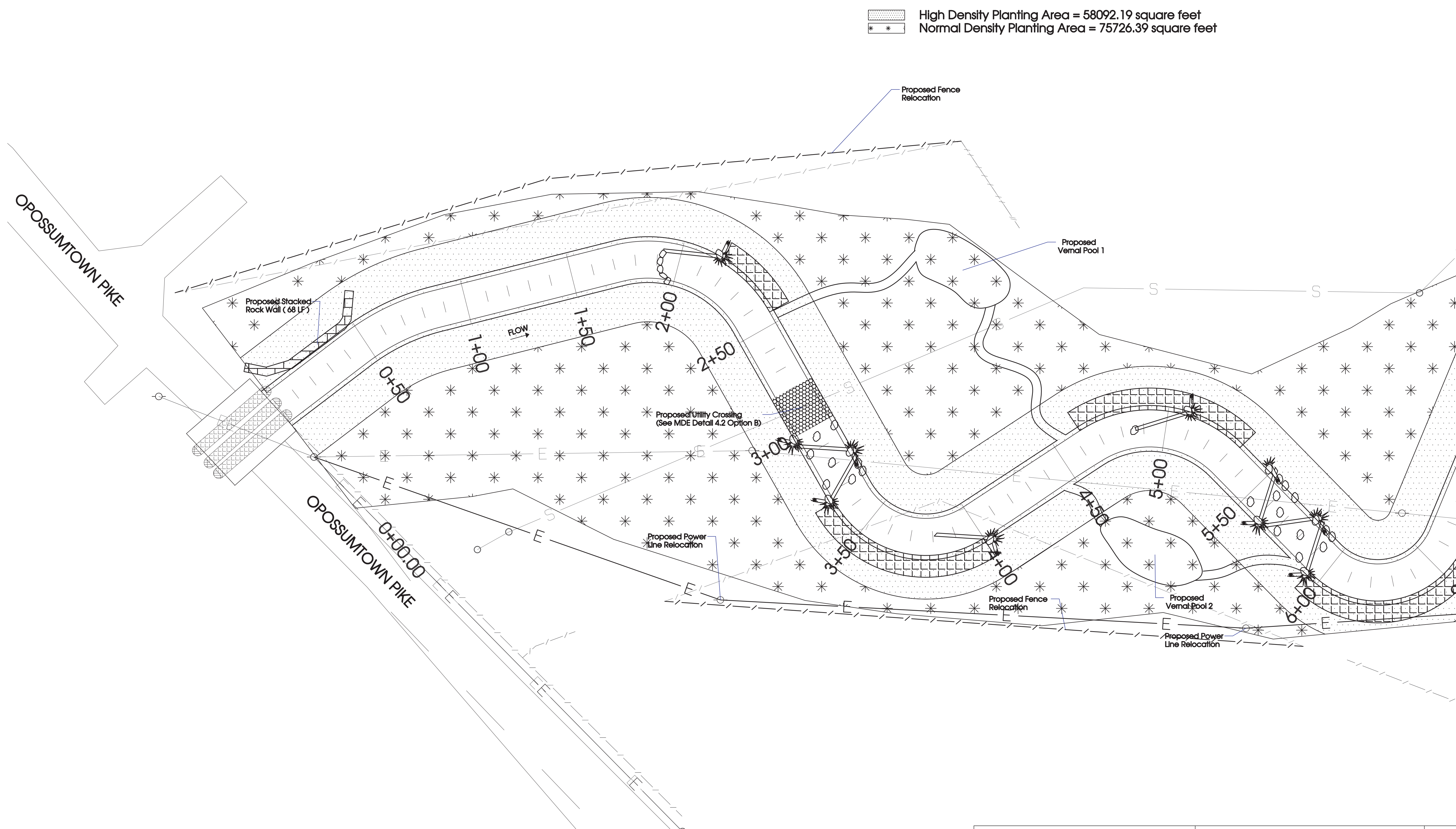
Sediment Competence Using Dimensional Shear Stress

Shields	CO	
0.437		Bankfull shear stress $\tau = \gamma dS$ (lbs/ft^2) (substitute hydraulic radius, R, with mean depth, d) γ = 62.4, d = existing depth, S = existing slope
32.89	**82.67**	Predicted largest moveable particle size (mm) at bankfull shear stress τ **(Figure 3-11)**
0.964	**0.383**	Predicted shear stress required to initiate movement of measured D_{max} (mm) **(Figure 3-11)**
3.86	**1.53**	Predicted mean depth required to initiate movement of measured D_{max} (mm) $d = \frac{\tau}{\gamma S}$; τ = predicted shear stress, γ = 62.4, S = existing slope
0.0088	**0.0035**	Predicted slope required to initiate movement of measured D_{max} (mm) $S = \frac{\tau}{\gamma d}$; τ = predicted shear stress, γ = 62.4, d = existing depth

Check: ☑ Stable ☐ Aggrading ☐ Degrading

APPENDIX S

Planting Plan



Scale:
0 20' 40' 60'

U.S. Fish and Wildlife Service
Chesapeake Bay Field Office
Stream Habitat Assessment and Restoration Program
177 Admiral Cochrane Drive
Annapolis, MD 21401
Tel. (410) 573-4583

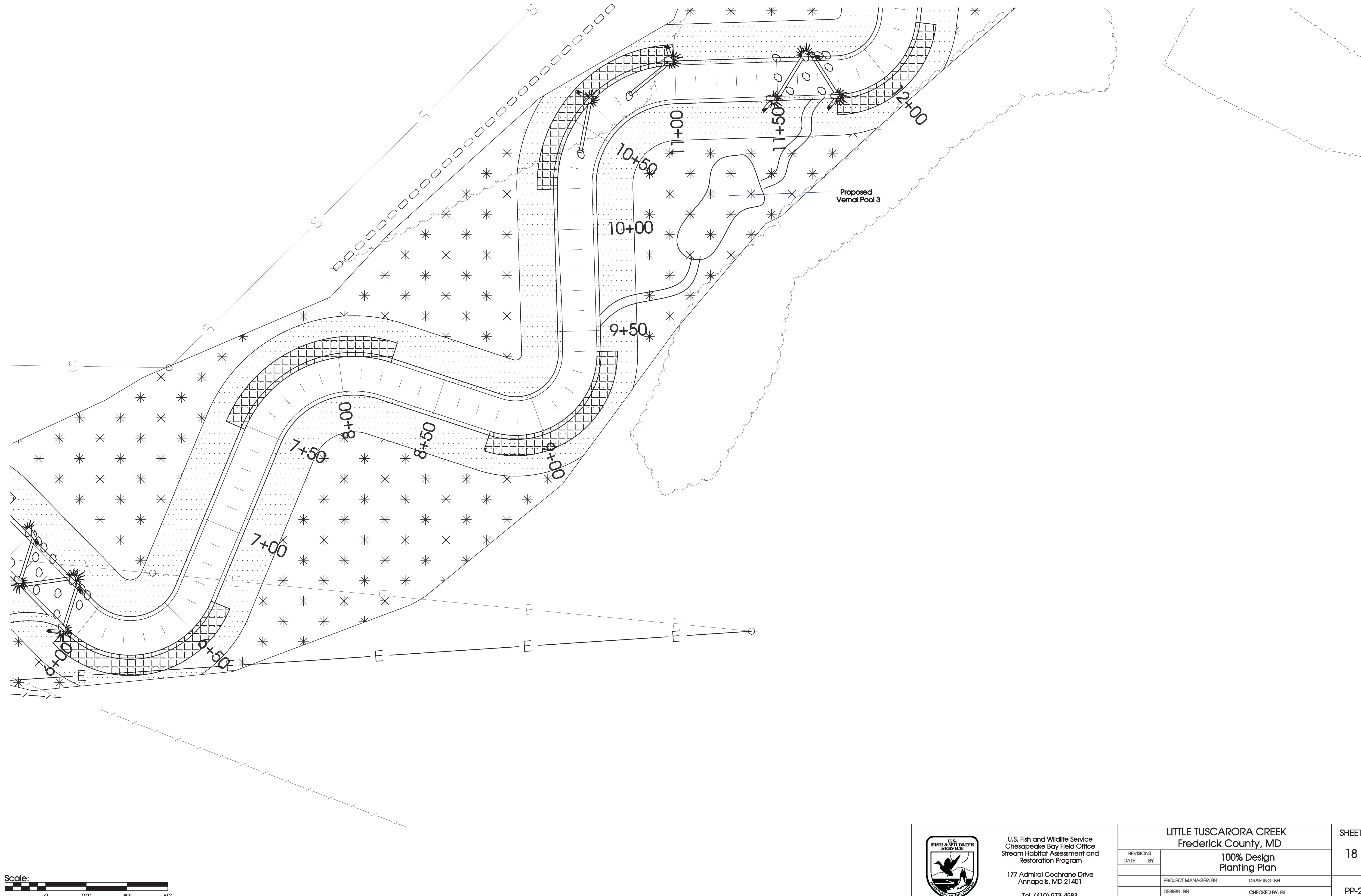
LITTLE TUSCARORA CREEK
Frederick County, MD

100% Design
Planting Plan

REVISIONS	
DATE	BY

PROJECT MANAGER: BH	DRAFTING: BH
DESIGN: BH	CHECKED BY: RS
DATE: March 25, 2013	SCALE: AS SHOWN

SHEET
17
PP-1



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

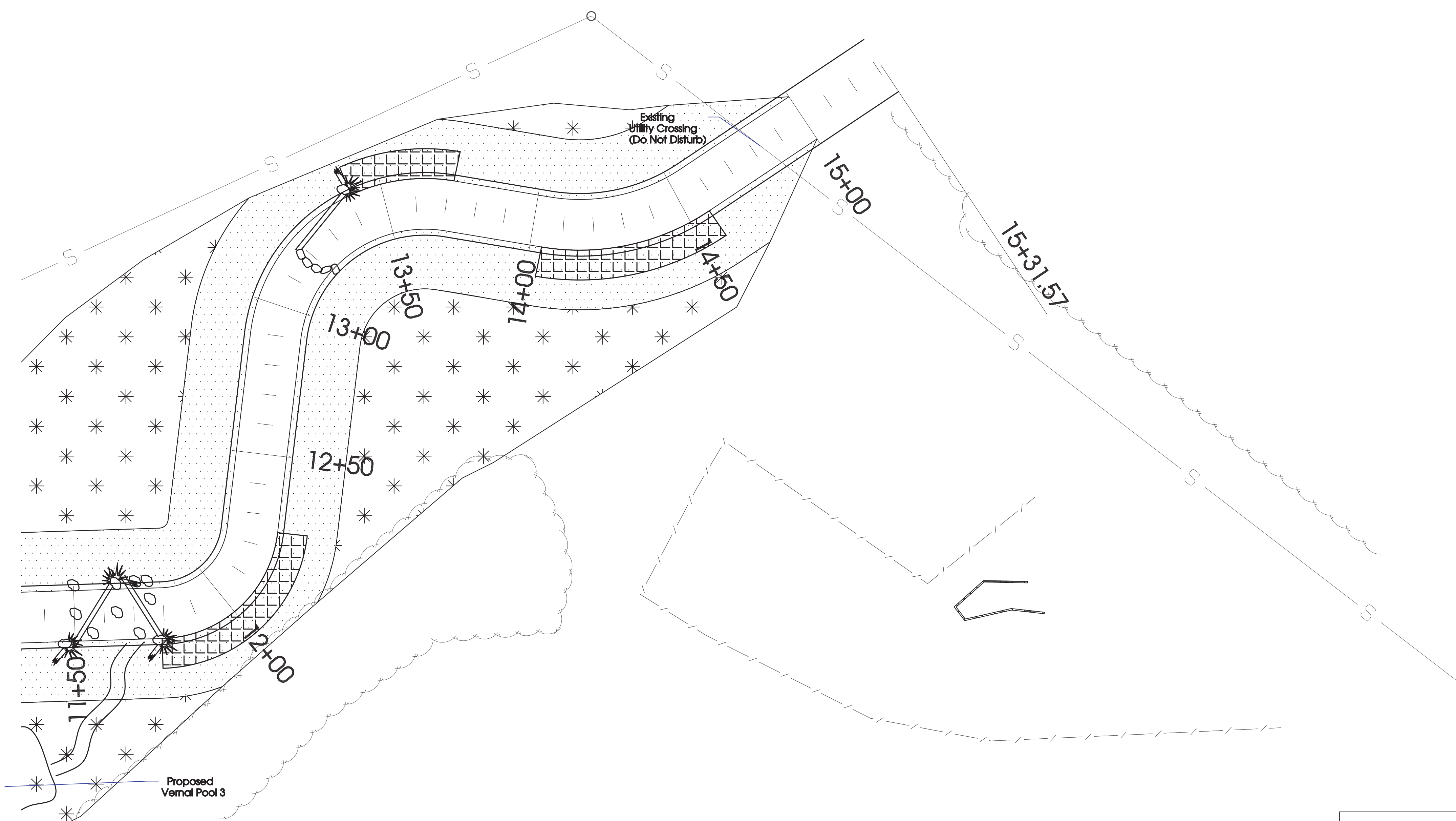
177 Admiral Cochrane Drive
Annapolis, MD 21401

Tel. (410) 573-4583

LITTLE TUSCARORA CREEK Frederick County, MD		SHEET 18
REVISIONS (DATE / BY)	100% Design Planting Plan	
PROJECT MANAGER: BH	DRAFTING: BH	PP-2
DESIGN: BH	CHECKED BY: RS	
DATE: March 25, 2013	SCALE: AS SHOWN	

2

15



Scale:
0 20' 40' 60'

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

177 Admiral Cochrane Drive
Annapolis, MD 21401

Tel. (410) 573-4583

LITTLE TUSCARORA CREEK
Frederick County, MD

100% Design
Planting Plan

REVISIONS	
DATE	BY

PROJECT MANAGER: BH	DRAFTING: BH
DESIGN: BH	CHECKED BY: RS
DATE: March 25, 2013	SCALE: AS SHOWN

SHEET
19

PP-3

APPENDIX T

Assessment Review Checklist and Design Review Checklist

Detailed Function-based Stream Assessment Review Checklist

Detailed Function-based Stream Assessment Checklist

Reviewer: ______________________

Date: ______________________

Project: Little Tuscarora Creek Stream Restoration

Assessor: USFWS

Item	Submitted (Y/N)	Acceptable (Y/N)	Page #	Comments
1.0 Programmatic Goals				
1.0a Are the project purpose and need(s) described?			4	
1.0b Does the project have clear programmatic goals?			4	
2.0 Site Selection				
2.0a Was a description/rationale provided stating how the site was selected?			1	
2.0b Was some level of assessment completed to justify the site selection?			1	
2.0c Did the assessment(s) accurately document watershed and reach conditions?			1	
2.0d Have project goals been developed based on the site selection assessment?			4	
2.0e Are the project goals appropriate for the site?			4	
2.0f Have watershed and reach level assessment parameters been identified for the detailed function-based assessments?			4 & 12	
2.0g Are the watershed and reach level assessment parameters appropriate to determine whether the proposed site will meet project goals?			4 & 12	
2.0h Overall site selection comments.				
3.0 Watershed Assessment				
3.0a Was the watershed assessment methodology described?			2 - 4	
3.0b Did the watershed assessment accurately document the existing and potential future health of the watershed?			4 - 12	
3.0c Did the watershed assessment accurately describe the existing and potential future influence of the watershed on the proposed site?			4 - 12	
3.0d Overall watershed assessment comments.				
4.0 Reach Level Function-based Assessment				
4.0a Was the reach level assessment methodology described?			2,3 & 12	
4.0b Were the measurement methods appropriate to document exsiting conditions?			12	

Detailed Function-based Stream Assessment Review Checklist

Item	Submitted (Y/N)	Acceptable (Y/N)	Page #	Comments
4.0c Did the reach level assessment accurately document the existing and potential future "without-project" function-based conditions?			12 - 32	
4.0d Did the reach level assessment accurately identify the "cause and effect" relationship(s) of the reach level conditions?			12 - 32	
4.0e Did the reach level assessment determine channel evolution?			26	
4.0f Overall reach level assessment comments.				
5.0 Restoration Potential and Constraint Analysis				
5.0a Was the restoration potential described?			34	
5.0b Was the restoration potential based on the results of the watershed and reach level assessments and constraints analysis?			34	
5.0c Did the restoration potential accurately identify which impaired functions can be restored and not restored?			34	
5.0d Did the restoration potential determine whether the site can still meet the project goals and if not, describe how the project will proceed?			34	
5.0e Was a constraints analysis completed?			34	
5.0f Did the constraints analysis accurately identify constraints and stressors?			34	
5.0g Overall restoration potential comments.				
6.0 Design Objectives				
6.0a Were design objectives provided?			35 - 36	
6.0b Were design objectives developed based on the restoration potential?			35 - 36	
6.0c Are the design objectives quantifiable and measurable?			35 - 36	
6.0d Are the design objectives appropriate and achievable for the site?			35 - 36	
6.0e Do the design objectives meet the project goals and if not, is it described how the project will proceed?			35 - 36	
6.0f Overall design objectives comments.				
7.0 Design Alternatives Analysis				

Detailed Function-based Stream Assessment Review Checklist

Item	Submitted (Y/N)	Acceptable (Y/N)	Page #	Comments
7.0a Was a design alternatives analysis performed?			37 - 39	
7.0b Did the alternatives analysis evaluate appropriate design solutions that could meet project goals and deisgn objectives?			37 - 39	
7.0c Were the alternatives analysis screening criteria provided and based on the results of the restoration potential, project goals and deisgn objectives?			37 - 39	
7.0d Did the alternatives analysis accurately document potential uplift and impacts (including access and construction impacts)?			37 - 39	
7.0e If there are potential project impacts, is there a description on how the impacts will be addressed?			37 - 39	
7.0f Was the most appropriate alternative selected based on the screening criteria?			37 - 39	
7.0g Overall design alternatives analysis comments.				
8.0 Monitoring Plan				
8.0a Was a monitoring plan provided?			52 - 53	
8.0b Does it state who is required to conduct the monitoring?			52 - 53	
8.0c Does it have measurable and quantifiable performance standards?			52 - 53	
8.0c Are the performance standards based on the project goals and objectives?			52 - 53	
8.0d Is the monitoring period and frequency appropriate based on the time required for uplift to occur?			52 - 53	
9.0 Overall Assessment Review				
9.0a Does the project assessment address the project goals and objectives?				
9.0b Are there any assessment components that are missing or could adversely affect the success of the project?				
9.0c Does the project have a high potential for success?				

NATURAL CHANNEL DESIGN REVIEW CHECKLIST

Project Design Checklist **Reviewer:** ______
Date: ______

Project: Little Tuscarora Creek Stream Restoration
Engineer: Ben Hutzell (USFWS), Keith D. Moore (Frederick Seibert and Associates)

Item	Submitted (Y/N)	Acceptable (Y/N)	Page #	Comments
1.0 Basemapping and Hydraulic Assessment				
1.1 Basemapping				
1.1a Does the project include basemapping?			Plan Set	
1.2 Hydraulic Assessment				
1.2a Was the project drainage area provided?			Report P.9	
1.2b Was a hydraulic assessment completed?			Report P.13	
1.2c Was stream velocity, shear stress and stream power shown in relation to stage and discharge?			Report p.18 & Appendix I & P	
1.3 Bankfull Verification				
1.3a Were bankfull verification analyses completed?			Report P.14	
1.3b Were USGS gages or regional curves used to validate bankfull discharge and area?			Report P.14	
1.3c If a regional curve was used, was the curve data representative of the project data?			Report P.14	
1.3d If gages or regional curves were not available, were other methods, such as hydrology and hydraulic models used?			N/A	
2.0 Preliminary Design				
2.1 Sediment Transport				
2.1a Did the sediment transport analysis include an evaluation of sediment supply (i.e., sediment supply amount and source(s))?			Report P.20 & P.51	
2.1b Was a model used to calculate sediment transport described, including assumptions and applicability to project reach conditions?			Report P.21 & P51	
2.1c Was SAM, HEC-RAS modelling or other tools used to determine stable channel and floodplain dimensions based on sediment transport and/or resistance to shear stress?			Report P51 & Appendix P	
2.1d Was a sediment transport analysis completed upstream (supply) and within project reach using a range of sediment transport rates?			Report P.21	
2.1e Was sediment transport measured?			Report P.21	
2.1f Were multiple discharges used to evaluate channel and floodplain stability?			Appendix I & P	
2.1g Did the sediment analysis show the potential for the stream channel and floodplain to aggrade or degrade after analyzing multiple discharges?			Report P. 51	
2.1h If the reach has a sediment supply, does the design state how it will be addressed?			Report P.51	

Project Design Checklist **Reviewer:** ____________________
Date: ____________________

Project: Little Tuscarora Creek Stream Restoration
Engineer: Ben Hutzell (USFWS), Keith D. Moore (Frederick Seibert and Associates)

Item	Submitted (Y/N)	Acceptable (Y/N)	Page #	Comments
2.2 Goals and Restoration Potential				
2.2a Does the project have clear goals and measurable objectives?			Report P.35	
2.2b Was the restoration potential based on the assessment data provided?			Report P.34	
2.2c Was a restoration strategy developed and explained based on the restoration potential?			Report P.39	
2.3 Design Criteria				
2.3a Were design criteria provided and explained?			Report P.40 - 43	
2.3b Were multiple methods used to prepare design criteria?			Report P.40	
2.3c Are the design criteria appropriate given the site conditions and restoration potential?			Report P.40	
2.4 Conceptual Design				
2.4a Was the conceptual channel alignment provided and developed within the design criteria?			N/A	
2.4b Were typical bankfull cross sections provided and developed within the design criteria?			N/A	
2.4c Were typical drawings of in-stream structures provided and their use and location explained?			N/A	
2.4d Was a draft planting plan provided?			N/A	
2.4e Overall Conceptual Design Comment(s)				
3.0 Final Design				
3.1 Natural Channel Design				
3.1a Was a proposed channel alignment provided and developed within the design criteria?			Plan Set	
3.1b Were proposed channel dimensions provided and developed within the design criteria?			Plan Set	
3.1c Do the proposed channel dimensions show the adjacent floodplain or flood prone area?			Plan Set	
3.1d Was a proposed channel profile provided and developed within the design criteria?			Plan Set	
3.1e If there is limited to no sediment supply, was an analysis done to show that the stream bed would not degrade during multiple flood flows?			Report Appendix P	
3.1f Did project constraints like right-of-ways or flood control requirements affect the width/depth/slope section? If so, was the risk of instability described?			Report P.44	
3.1g Will the project tie-ins have no change to upstream and downstream existing stability conditions?			Plan Set	
3.1h Were specifications for materials and construction procedures provided and explained for the project (i.e., in-stream structures and erosion control measures)?			Report P.44	

Project Design Checklist **Reviewer:** ______
Date: ______

Project: Little Tuscarora Creek Stream Restoration
Engineer: Ben Hutzell (USFWS), Keith D. Moore (Frederick Seibert and Associates)

Item	Submitted (Y/N)	Acceptable (Y/N)	Page #	Comments
3.2 In-Stream Structures				
3.2a Based on the assessment and design, were in-stream structures necessary for lateral stability?			Report P.44	
3.2b Based on the assessment and design, were in-stream structures needed for vertical stability?			Report P.44	
3.2c If needed, was the reason for their location and use explained?			Report P.44	
3.2d Will the in-stream structures provide the intended stability?			Report P.44	
3.2e Were in-stream structures (or changes to geometry) needed to provide stability at tie-in locations with the existing channel?			Report P.44	
3.2f Were detail drawings provided for each type of in-stream structure?			Plan Set	
3.3 Vegetation Design				
3.3a Was a vegetation design provided?			Plan Set	
3.3b Does the design address the use of permanent vegetation for long term stability?			Report P.52	
3.3c Overall Final Design Comment(s)				
4.0 Overall Design Review				
4.0a Does the design address the project goals and objectives?				
4.0b Are there any design components that are missing or could adversely affect the success of the project?				
4.0c Does the project have a high potential for success?				