

**Final Memo**  
**Urban Stormwater Work Group Approved**  
**Revised September 30, 2019**

**Recommendations for  
Crediting Outfall and Gully Stabilization Projects  
in the Chesapeake Bay Watershed**



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A group of experts was formed in 2018 to recommend methods to credit pollutant removal achieved by individual outfall restoration practices built to meet the Chesapeake Bay TMDL (USWG, 2018). The experts were asked to adapt the existing crediting protocols contained in the original stream restoration expert panel report (CBP, 2014). The group met five times and developed the consensus recommendations that are outlined in this technical memo. The memo is organized as follows:

1. Group Charge and Roster
2. Background on Outfall and Gully Stabilization Projects
3. Definitions and Qualifying Conditions
4. Protocol 5 Alternative Prevented Sediment for Outfalls
5. Technical Rationale for New Protocol
6. Environmental Assessment for Outfall Projects
7. Reporting and Record Keeping Requirements
8. Verifying Outfall and Gully Stabilization Projects
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Technical Appendices:

- A: The Three Step Method to Calculate Watershed Sediment Delivery
- B: Example Outfall Restoration Projects (MDOT SHA)
- C. New Site Screening Appendix

## Section 1: Charge and Roster of the Working Group

Table 1 profiles the team of experts who evaluated the feasibility of an alternative stream restoration crediting protocol for outfall restoration projects and agreed on the consensus recommendations outlined in this memo.

<b>Table 1: Outfall Restoration Crediting Team</b>		
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Jeremy Hanson (VA Tech), David Wood (CSN) and Tom Schueler (CSN) facilitated the team. Several consultants provided valuable technical support to the group on how to apply the new protocol to real world outfall erosion problems. The contributions of Kelly Lennon, Scott Lowe, Megan McCollough and Cory Anderson are gratefully acknowledged.		

*Charge for the Group:*

The group was asked to review the MDOT SHA (2018) outfall crediting proposal to determine if it could be adapted to calculate sediment and nutrient reduction associated with this class of projects. In particular, the team was asked to:

- Provide clear definitions of the specific channel conditions that apply to the new protocol (i.e., zero order streams) and whether any of these channels are potentially jurisdictional and subject to further environmental review and permitting
- Outline any other conditions that must be satisfied to receive credit, and justify whether the existing “100 foot” minimum project length condition (used for other stream restoration practices) can be relaxed for this class of projects.
- Work with the CBPO modeling team to determine the appropriate land use/stream segment in the Phase 6 model to credit the load reductions.
- Decide whether the prevented sediment calculations should be adjusted to (a) exclude coarse grained sediment particles that would not be delivered to the Bay or (b) exclude some fraction of the sediment mass that might never have been eroded had the stabilization project not been built (c) and/or apply the same 50% restoration efficiency rate utilized in Protocol 1.
- Determine whether soil samples need to be collected to define key parameters for the prevented sediment calculations, and if so, the specific methods for collecting and analyzing them
- Evaluate any unintended consequences associated with the practice, with an emphasis on the quality of downstream ecosystems, and issues regarding iron flocculation.
- Determine the extent to which functional uplift will be measured and achieved by the practice.

The working group met five times from September, 2018 to March, 2019, as it developed its consensus recommendations.

## Section 2: Background on Outfall Stabilization and Restoration

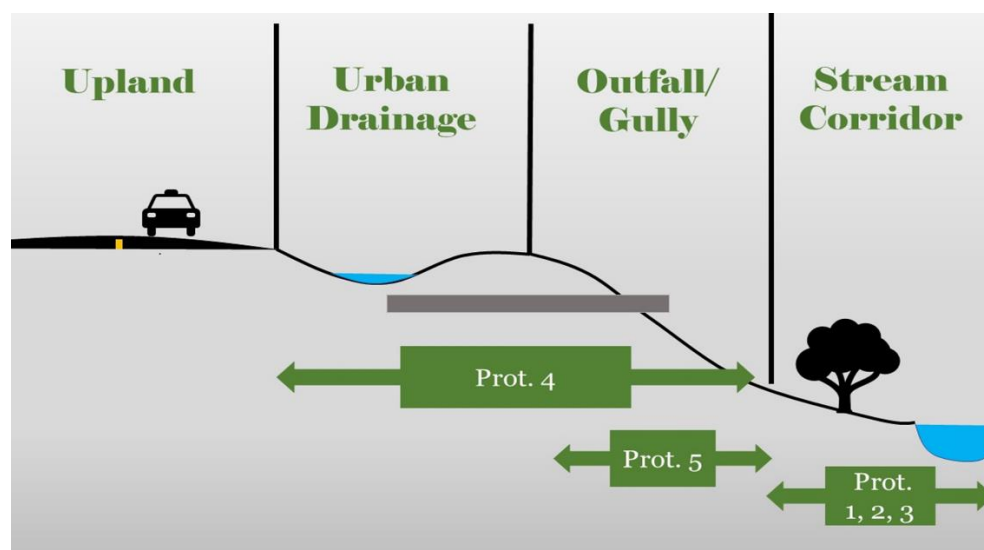
This section introduces the problem of outfall erosion, how they deliver high sediment loads to urban streams and how they can be fixed to reduce that sediment load.

### *The headwater transition zone*

At the outset, it is important to define the term “headwater transition zone”. It represents the transition zone from upland land uses into altered urban drainage (swales, ditches and storm drain pipes) that stormwater discharges into the beginning of the urban stream network. These zones experience higher rates of both vertical and lateral erosion and are responsible for high sediment delivery to downstream reaches.

A schematic showing the key features of the headwater transition zone can be found in Figure 1.

**Figure 1.** Schematic of the Headwater Transition Zone



### *Importance of headwater streams*

Kaplan et al (2010) provide a compelling literature synthesis on the value of headwater streams in maintaining the structure, function and diversity of larger stream and river ecosystems. Despite their short lengths, headwater streams comprise a majority of the length of the entire drainage network of major rivers.

### *Streambank erosion and urban sediment yield.*

Recent research has confirmed the importance of bank erosion in urban sediment yield. For example, Donovan et al (2015) found that bank erosion accounted for an average of 70% of annual sediment yield in 18 small watersheds sampled in Baltimore County, MD.



The headwater stream network was the source of most of the measured erosion, a majority of which were derived from legacy sediments.

Their findings are generally consistent with other recent geomorphic research conducted across much of the Bay watershed (Gellis et al 2017, Allemendiger et al 2007, Bergman and Clausen 2011, Fraley et al 2009, Merritts et al 2010, Miller and Kochel 2010, Alexander et al, 2007, Smith and Wilcock, 2015 and Pizzutto et al, 2018). The research also reinforces the notion that stream bank erosion represents a major fraction of the sediment yield from urban watersheds, especially those with extensive legacy sediment deposits in their floodplains.

#### *The headwater transition zone as an urban sediment erosion hotspot*

The headwater transition zone acts as a watershed “hotspot” for sediment erosion and downstream delivery (Lowe, 2018). The headwater transition zone has many characteristics that promote high rates of erosion and sediment delivery (see Figure 2). These include:

- Erosive force of flows discharged from storm drain outfalls
- High channel slopes and energy conditions
- Exposed and non-cohesive soils
- Poor vegetative cover
- Floodplains that are narrow or absent

Consequently, outfall erosion is a major problem in the headwater transition zone, which usually caused by a combination of the following:

- Uncontrolled stormwater runoff from upstream development
- Inadequate energy dissipation structures below the outfall
- Nick points migrating upstream that reach the outfall
- Poor slope stabilization or fill spoils presents below the outfall
- Extreme storm events that exceed design capacity of the channel.

While the group analyzed many engineering calculations showing very high potential sediment delivery from the headwater transition zone, they were only able to find two watershed monitoring studies that measured erosion rates in this zone (Smith and Wilcox, 2015 and Downs et al, 2018).

**Figure 2. Examples of Severe Outfall Erosion in the Headwater Transition Zone**



1. Extremely incised vertical walls with failed outfall structure.
2. Eroding channel and threatened outfall structure caused by migrating knickpoint.
3. Highly incised and widened outfall channel caused by migrating headcut.
4. Eroding roadway embankment with severe incision and threatened infrastructure.

### *Limited erosion control versus outfall and gully stabilization projects*

When outfall erosion begins to threaten public infrastructure, such as roads and sewers, the traditional response has been to fill the gully by dumping large rock (known as rip-rap) down the slope to create a more stable channel. This **Limited Erosion Control** often requires repeated application since the underlying channel stressors are generally not addressed and it is not considered to be a permanent engineering solution.

**Outfall and Gully Stabilization Projects (OGSP)** are an engineering approach to design a stable channel to dissipate energy that extends from the upland source to the stream channel. The new channel is designed and constructed to achieve an equilibrium state where future sediment loss is minimized or eliminated altogether. Acceptable OGSP practices provide a permanently stable connection between upland runoff sources and receiving streams by utilizing engineering practices such as grading, step-pools, cascades, and rock toe protection within the typically steep headwater transition zone.

In limited cases where site constraints such as steepness, erodible soils, limited right-of-way, hydraulic factors, or existing buildings/infrastructure are not suited to the practices mentioned above, other stable engineering solutions may also be considered.

These can include elements such as drop structures, extension of an existing storm drain pipe or stormwater collection features, and scour protection, if minimized to what is necessary to manage site constraints.

Any drop structures and/or pipe extensions that are beyond what is necessary to manage site constraints are not be granted credit. The specific practices that are applied depend on site conditions and the need to effectively dissipate energy at the site.

While drop structures and/or pipe extensions may be applied in the headwater transition zone if the site conditions dictate they are needed to effectively dissipate energy, these structures are not eligible for credit in perennial or intermittent streams. In all cases, pipe systems may not be used if they introduce aquatic organism passage issues. Each OGSP project should be assessed based on the guidance provided by the applicable permitting authorities, the best professional judgment of experts in the field, and should be consistent with the principles of ecological restoration.

Projects or portions of projects that utilize other hard armoring practices such as dumped riprap, trapezoidal concrete channels and gabion features will be subject to the armoring definitions and crediting limitations defined by the Prevented Sediment Group and are not acceptable for OGSP credit.

Some examples of different outfall restoration practices are provided in Figure 3 and more detail on OGSP applications can be found in the example projects found in Appendix B.



**Figure 3. Examples of Outfall Restoration Projects**

PRE-RESTORATION	POST-RESTORATION
	<div data-bbox="625 415 860 489"> <ul style="list-style-type: none"> <li>• Drop Structure</li> <li>• Step Pool Pattern</li> </ul> </div> 
	<div data-bbox="625 699 795 772"> <ul style="list-style-type: none"> <li>• Rock Outlet Protection</li> </ul> </div> 
	<div data-bbox="625 1014 889 1087"> <ul style="list-style-type: none"> <li>• Step Pool Sequence</li> <li>• Vegetative Plantings</li> </ul> </div> 
	<div data-bbox="625 1287 889 1360"> <ul style="list-style-type: none"> <li>• Plunge Pool</li> <li>• Step Pool Structures</li> </ul> </div> 
	<div data-bbox="625 1623 885 1728"> <ul style="list-style-type: none"> <li>• Retaining Wall</li> <li>• Concrete Pipe</li> <li>• Rip Rap Plunge Pool</li> </ul> </div> 

### *Summary of Protocol 1: Prevented Sediment Credit*

Since the proposed protocol is an alternative to the prevented sediment protocol, it is worth describing how Protocol 1 is applied to stream restoration projects, and some of its key technical assumptions.

Protocol 1 calculates an annual mass nutrient and sediment reduction credit for qualifying stream restoration practices that prevent channel or bank erosion that would otherwise be delivered downstream from an actively enlarging or incising urban stream. The three key steps for applying the protocol are provided in Table 2.

<b>Table 2: Summary of Protocol 1: The Prevented Sediment Credit</b>
<p><b>Step 1: Estimate stream sediment erosion rates</b></p> <p>The most common technique to estimate bank erosion rate is the BANCS Method (Rosgen, 2001), where field surveys are used to calculate BEHI and NBS scores, which in turn, are entered into regional bank erosion curves to determine the annual rate of streambank retreat. Designers also have the option to actually measure the rate of bank retreat in the project reach using bank pins and cross section surveys. The final option employs LIDAR surveys and hydraulic engineering models to calculate expected bank retreat over time. The specific methods allowed for this option are now being developed by Group 3 (2019).</p> <p>The pre-restoration erosion rate for the project reach is then entered into the following equation to determine its potential prevented sediment load:</p> $S = \frac{\sum(cAR)}{2,000} \quad (\text{Eq. 1})$ <p>where: <math>S</math> = sediment load (ton/year) for reach or stream  <math>c</math> = bulk density of soil (lbs/ft<sup>3</sup>)  <math>R</math> = bank erosion rate (ft/year) (from regional curve)  <math>A</math> = eroding bank area (ft<sup>2</sup>)  2,000 = conversion from pounds to tons</p> <p><b>Step 2: Convert erosion rates to nitrogen and phosphorus loadings.</b></p> <p>In this step, the nutrient load associated with the prevented sediments are calculated using a unit conversion, based on the measured or default estimate of its sediment nutrient content. The current default values are provided below for reference, but it is likely that they will either be reduced or required to be measured later this year (Group 3, 2019).</p> <p>1.05 pounds P per ton of sediment  2.28 pounds N per ton of sediment</p> <p><b>Step 3: Estimate restoration reduction efficiency.</b></p> <p>In the last step, sediment and nutrient load reductions are conservatively reduced by 50% to account for the presumed efficiency of stream restoration practices.</p>



### *Note on Sediment Delivery from the Stream to Head of Bay*

Some fraction of the sediment load is deposited on downstream channels and floodplains, where they may be stored for decades or more. Sediment storage complicates the issue how sediments travel from the headwaters to the head of the bay estuary. The original expert panel recommended a fixed sediment delivery ratio, depending on whether a stream was located in the coastal plain or not. After some significant improvements in sediment modeling were adopted, the Phase 6 Chesapeake Watershed Model (CBP, 2018) now explicitly calculates sediment delivery for individual stream reaches.

If you know the geographic address of your project, its specific sediment delivery ratio from the stream reach to the Bay can be quickly determined using the Chesapeake Assessment and Scenario Tool (CAST - EPA, CBP, 2018). Some guidance on a step by step method to estimate the unique sediment delivery factor for the land-river segment in which a project resides can be found in Appendix A.

## **Section 3: Definitions and Qualifying Conditions**

*Definitions:* The group established the following definitions to assist the reader in understanding the terminology relating to outfall stabilization. For the reader's convenience, additional technical, engineering or design terms are defined in the glossary presented in Section 10.

**Base-level control:** Base-level control features consist of channel features, such as bedrock and existing infrastructure that are anticipated to withstand expected channel erosion processes. Confluence locations, an existing stable condition downstream, or the downstream limits of proposed bed stabilization features can be used as base level controls in cases where no hard point controls are present within the channel.

**Channel conditions:** the current or future potential for erosion of the channel bed or banks to subsequently deliver sediment and other pollutants downstream.

**Dry channel regenerative stormwater conveyance (RSC)** involves restoration of ephemeral streams or eroding gullies using a combination of step pools, sand seepage wetlands, and native plants (see An, 2018). The receiving channels are located above the water table and only carry water during and immediately after storms. Protocol 4 is used to define pollutant reduction achieved by this stormwater retrofit treatment practice.

**Ephemeral Stream:** A stream that flows briefly and only in direct response to local precipitation and whose channel is always above the water table (NRCS 2005).

**Equilibrium slope** is the ground surface slope wherein channel bed and bank slopes within the hydrologic regime and erosion substantially decreases or ceases. Based on slope stability analysis.

**Equilibrium bank angle** is the angle at which a channel or stream bank reaches a stable condition, thereby minimizing or eliminating bank erosion within the hydrological regime.

**Headwater channels** are stream segments connected to open or closed channel segments within zero to first order channels where water first originates in a stream system. These channels can be ephemeral, intermittent, or perennial and often adjust to storm flows through gully and rill formation and therefore can produce significant vertical and lateral rates of erosion.

**Headwater transition zone:** The slope or channel that extends from an upland runoff source to the perennial stream network. This zone has an exceptionally high potential for sediment erosion and is the focus of OGSPs. It lacks perennial or seasonal flow.

**Intermittent Stream:** A stream in contact with the groundwater table that flows only at certain times of the year as when the groundwater table is high and/or when it receives water from springs or from some surface source (e.g., melting snow in mountainous areas). It ceases to flow above the stream bed when losses from evaporation or seepage exceed the available streamflow (NRCS 2005).

**Limited erosion control:** refers to traditional methods to repair erosion problems at or near outfalls that involve regrading and placement of stone riprap to stabilize the eroding channel and temporarily protect the outfall. These repairs typically do not involve engineering analysis and are usually only a temporary fix.

**Outfalls** are the outlets, conveyances and discharge points from storm drain networks, often located at headwater stream systems or are direct connections to closed storm drain networks. Does not include outfalls that produce overflows from separate or combined sewer systems

**Outfall and gully stabilization projects (OGSP)** refers to newer methods that seek to restore an eroding outfall channel to an equilibrium or near-equilibrium state, such that future sediment loss is minimal or eliminated altogether. These can include structural and non-structural energy dissipation techniques. For the purposes of this protocol, OGSPs utilize bank height, equilibrium slope and equilibrium bank angle to compute sediment and nutrient load reductions.

**Perennial Stream:** A stream that flows continuously throughout the year (NRCS 2005).

**Pipe Conditions:** the current or future status of the discharge pipe associated with the given outfall and channel.

**Predictive Indicators** (for severe erosion): Visible and measurable indicators that severe erosion is imminent in a bank face, bank toe, or channel bed in an outfall or headwater stream channel. These include indicators of fluvial erosional processes and mass failure mechanisms such as: a higher value of existing slope to equilibrium slope of greater than 25%, observations of tension cracks in a sediment profile upstream of a stream bed, knickpoints or head cuts greater than 6 inches in height, bulging of material at a headwater feature toe of slope indicative of planar/slab failures, rotational failures, or composite bank failures.

**Project reach** refers to the length of an individual outfall stabilization project as measured by the restored channel length (expressed in units of feet). The project reach is defined as the specific work areas where outfall and gully stabilization practices are installed.

**Stream restoration (SR)** refers to any natural channel design (NCD), regenerative stormwater conveyance (RSC), legacy sediment removal (LSR) or other restoration project that meets the qualifying conditions for pollutant removal crediting as described by the Stream Restoration Expert Panel (CBP, 2014).

### **Qualifying Conditions for the Practice:**

The Expert Panel also outlined a series of qualifying conditions that must be met for a project to be eligible for credit. To be consistent with the report, the group agreed that OGSPs should meet the following qualifying conditions:

- The channel or gully slope below the source must exhibit predictive indicators for severe erosion or hill-slope failure and must be observed to be actively enlarging or degrading. These indicators are defined in Section 3.
- The project should utilize a comprehensive approach to stream channel design, addressing long-term stability and resiliency of the channel, banks, and floodplain.
- Each project must comply with all state and federal permitting requirements, including 404 and 401 permits, which usually contain conditions for pre-and post-project assessment and post construction monitoring.
- Before credits are granted, OGSPs will need to meet post-construction stability criteria and successfully establish needed vegetation. Projects should maintain or improve existing native riparian vegetation in the headwater stream corridor to the extent possible. Projects should follow regulatory agency guidance regarding compensation for any losses of forest, wetlands and sensitive habitats within project work areas.

In addition, the group felt that some of the qualifying conditions that apply to other stream restoration practices could be relaxed due to the unique conditions of outfall restoration projects located in the headwater transition zone in ephemeral channels. For example:

- Limited use of pipe systems are eligible for credit if they are needed to sustain channel stability and do not introduce new aquatic organism passage issues. Projects should always seek to improve passage of aquatic organisms where possible. Refer to Section 2 for criteria and limitations for acceptable projects.
- OGSPs do not need to meet the minimum project reach length that applies to downstream stream restoration projects (100 feet). This is allowable due to inherent slope/degradation issues in steep systems and the relatively large pollutant releases that can occur in reaches less than 100 feet. Actual project length for OGSPs is typically determined by equilibrium slope analysis, but usually are less than 500 feet in length. The length of projects is typically constrained by the distance from an outlet to the confluence with a receiving channel or the base level control point.

OGSPs are typically applicable to the HTZ that lacks perennial or seasonal flow. However, headcuts within perennial and intermittent stream channels are a major source of sediment erosion, and the OGSP protocol is intended to provide a better option for estimating prevented sediment erosion in headwater channels with severe vertical incision (progressive bed-lowering). Therefore, the OGSP protocol may be applied as an alternative to Protocol 1, only in headcut areas of perennial or intermittent channels (the credit is not additive), if it meets the following criteria:

- The project **MUST** meet the more stringent stream restoration qualifying criteria outlined in the Stream Restoration Expert Panel report for Protocol 1, in addition to the qualifying criteria outlined earlier in this document.
- The project **MUST** meet the conditions of any and all state and federal permits.
- The project **MUST NOT** introduce barriers or challenges to aquatic organism passage or degrade instream habitat. Projects should always seek to improve passage of aquatic organisms and aquatic habitat where possible.
- Drop structures, extension of an existing storm drain pipes, stormwater collection features, and scour protection or other hard armoring techniques used in OGSPs are not eligible for credit in perennial channels.

OGSPs should provide functional lift within the project reach, typically as indicated by improvements of Levels 2 (Hydraulics) and when possible 3 (Geomorphology) of the stream functions pyramid (Harman et al , 2011). OGSPs usually will not require special project monitoring to assess stream functions Level 4 and 5 because these functions are

usually minimal or absent in the headwater transition zone prior to any restoration. Promoting lift for Level 4 and 5 is encouraged when applicable.

A visual inspection of accessible downstream waters should occur after construction and throughout applicable monitoring (permit required special conditions) and verification (state level inspections for credit) processes to document function and stability.

In addition, Protocol 5 is restricted in how it applies to, or is combined with, stream restoration practices constructed under the other four crediting protocols.

Protocol 5 cannot overlap Protocol 1 (Prevented Sediment) within the same project reach. Protocol 5 can overlap Protocols 2 and 3 in the same project reach, if it meets the conditions for hyporheic exchange and/or floodplain reconnection, which is exceedingly unlikely. Protocol 1 or 5 applications should be based on which best fits the dominant erosion mechanism along the channel profile. Protocol 1 should be used in reaches dominated by lateral erosion and Protocol 5 in areas of vertical degradation.

Wet-channel RSC practices installed on perennial or intermittent stream channels may be credited using either Protocol 1 or 5 but the two credits *cannot* overlap.

Dry-channel RSC practices installed in ephemeral stream channels can be credited as both a stormwater retrofit (Protocol 4) and an OGSP (Protocol 5). Protocol 4 reductions are subtracted from the pollutant load generated from upland impervious cover, whereas the Protocol 5 reductions are subtracted from the urban stream bank load.

The pollutant reduction impact of outfall restoration projects is *independent* of any reduction achieved by upstream retrofits or other approved urban practices in the contributing drainage area.

The group did not suggest that any single design approach was superior to others, as any OGSP can fail if it is inappropriately located, assessed, designed, constructed, or maintained. Design should focus on providing sustainable and resilient systems that provide improved physicochemical and biologic conditions where applicable.

#### **Section 4: Protocol 5 -- Alternative Prevented Sediment for Outfalls**

This protocol, originally developed by MDOT SHA, uses a 5-step process to define the equilibrium headwater channel condition as a means of estimating prevented sediment loss from outfall and gully stabilization projects (MDOT SHA 2018). The alternate SHA protocol is based on the assumptions that bed and bank incision will cease once the channel reaches equilibrium slope and bank angle based on physical characteristics of the soil material. This approach accounts for sediment loss through vertical incision that is common at stormwater outfalls, but is not fully captured by Protocol 1.



The group developed the following process for practitioners in other Bay states. The simplified process involves 5-steps, as follows:

1. Define the Existing Channel Conditions
2. Define the Equilibrium Channel Conditions
3. Calculate Total Volume of Prevented Sediment Erosion
4. Convert Total Sediment Volume to Annual Prevented Sediment Load
5. Determine Annual Prevented Nutrient Loads

It is recommended that practitioners in Maryland continue to use the more detailed MDOT SHA alternate method to perform their computations.

#### *Step 1: Define the Existing Channel Conditions*

The following measurements need to be collected from the existing headwater channel:

- Length of Proposed Project Reach (ft)
- Channel Slope (ft/ft)
- Bank Height (ft)
- Bottom Width (ft)
- Top Width (ft)
- Bulk Density (lb/ft<sup>3</sup>)

The channel slope, bank height and top and bottom width should be taken at three representative cross-sections within the project reach prior to construction. The average of the three cross sections will be used for the calculations. Bulk density samples should be taken roughly every 200 ft along the project reach. For sites shorter than 200 ft, one sample is sufficient.

#### *Step 2: Define the Equilibrium Channel Conditions*

There are four components of an equilibrium channel that must be defined:

- Base Level Control
- Equilibrium Bed Slope (ft/ft)
- Equilibrium Bank Slope (ft/ft)
- Future Channel Width (ft)

##### *Base Level Control:*

Base level controls are the site constraints that bound the upstream and downstream extent of the equilibrium channel design and define the maximum extent of vertical scour at the project site in the absence of stabilization. Determine if the prospective project reach contains any of the following base level controls:

- Hard Point Control (ex. bedrock or existing infrastructure)
- Confluence (elevation of larger, stable, receiving stream)
- Channel at equilibrium (existing slope is within 5% of the equilibrium slope)
- Upstream Limit of Erosion (pipe outfall or other defining infrastructure)
- Downstream limits of equilibrium slope must be set at the downstream limits of project bed stabilization features

The upstream limit of the credit calculation method may not always be defined by a pipe outfall or defining infrastructure. Migrating knickpoints caused by the breach of mill dams (Merritts et al. 2013) are an example of a vertical erosion force where a pipe outfall may not be the defining upstream limit. If no pipe outfall or other defining infrastructure is present upstream of the restoration site, the upstream limit is determined by the equation:

$$L_{\max} = 153A_d^{0.6}$$

Where  $L_{\max}$  is the maximum upstream channel length (ft) from a given point, and  $A_d$  is the drainage area (acres). Upstream limits of erosion should be field verified.

#### *Equilibrium Bed Slope:*

To calculate the equilibrium bed slope, use the equation(s) in Table 3 for the applicable bed conditions at the project site. The equilibrium slope analysis is based on methods from Technical Supplement 14B (TS14B)—Scour Calculations—of Part 654 of the National Engineering Handbook—Stream Restoration Design (Natural Resource Conservation Service (NRCS), 2007).

<b>Table 3. Equilibrium Bed Slope Equations</b>	
Cohesive Bed	$S_{eq} = 0.0028A^{-0.33}$
Sand and Fine Gravel (0.1-5mm particle size)	$S_{eq} = 0.06 / (y * 62.43)$
Beds Coarser than Sand (>5mm particle size)	Average of 4 Equations Details can be found in 2.1.3 of Appendix A.
$S_{eq}$ is equilibrium slope (m/m or ft/ft), A is drainage area (km <sup>2</sup> ), and y is mean flow depth (ft). When estimating the critical shear stress, a 10-year recurrence interval can be used for the design discharge, and intermediate suspended sediment concentration (1,000 to 2,000 ppm) can be assumed.	

#### *Equilibrium Bank Slope*

The equilibrium bank slope for this analysis has been defined as 1.76:1. According to methods from Technical Supplement 14A (NRCS 2007), it has been shown that equilibrium bank slopes range from 1.4:1 to 2.1:1 in the absence of the influence of

seepage. Utilizing the equilibrium bank slope for medium dense sand of 1.76:1 provides a conservative estimate for this analysis.

*Future Bottom Width:*

Select a representative reach within the study reach (from the groundwater origin or outfall location to the selected base level control feature) and take the average of three reference cross sections. This average will represent the future bottom width.

*Step 3: Calculate the Total Prevented Sediment*

To calculate the total volume of prevented sediment, you must take the difference between the equilibrium channel condition and the existing channel condition. This can be done using 3D surface modeling programs, such as *InRoads* or *Geopak*. To run this analysis, you will need the information summarized in Table 4.

<b>Table 4. Summary of Information Needed for 3D Surface Analysis</b>		
	<i>Parameter</i>	<i>Source</i>
<i>Pre-Restoration Channel</i>	Length of Project Reach	Measured
	Average Bank Height	3 measured cross sections
	Average Bottom Width	3 measured cross sections
	Average Top Width	3 measured cross sections
	Base Level Controls	Fixed start and end points determined by bedrock, existing infrastructure or downstream confluence
<i>Equilibrium Channel</i>	Equilibrium Bed Slope	Equations in Table 1
	Equilibrium Bank Slope	1.76 : 1
	Average Bottom Width	3 measured cross-sections from reference reach

Three-dimensional surface modeling can be a time and labor-intensive process. To aid local municipalities with initial site evaluation and project screening. Appendix C provides examples of good candidate sites for outfall restoration. Example calculations are also provided for select sites. Following a preliminary site inspection, municipalities can decide whether to pursue additional data collection and analysis.

*Step 4: Convert the Total Sediment Volume to Annual Prevented Sediment Load*

To convert the total volume of prevented sediment erosion to an annual timescale, divide the total volume by 30. Thirty years is recommended as a conservative estimate of the amount of time it would take an eroding outfall channel to export the total volume of sediment calculated in Step 3.

To maintain consistency with the Stream Restoration Expert Panel report, the mass load reductions should then be discounted to account for the fact that projects will not be 100% effective in preventing bed and bank erosion and that some sediment transport occurs naturally in a stable stream channel.

Consequently, a conservative approach assumes that projects will be 50% effective in reducing sediment and nutrients from the channel reach. Efficiencies greater than 50% should be allowed for projects that have shown through monitoring that the higher rates can be justified subject to approval by the states. This conservative factor should be multiplied by the annual prevented sediment load.

$$S_p = 0.5 (S_v / 30)$$

Where  $S_p$  represents the annual volume of prevented sediment and  $S_v$  represents the total volume of prevented sediment calculated in Step 3.

The annual volume of prevented sediment must also be adjusted by the bulk density of the soil to determine the final annual prevented sediment load. Bulk density measurements can be highly variable and each project site should have one sample collected every 200 ft throughout the reach to determine a representative bulk density value. The NRCS Soil Series data (NRCS 2019) may be used to provide an estimate value for preliminary calculations. Multiply the annualized sediment volume by the bulk density to determine the annual prevented sediment load.

#### *Step 5: Determine the Annual Prevented Nutrients*

Pollutant load reduction credits are awarded based on the amount of pollutant—TN, TP, and sediment—reduction estimated to occur as a result of the proposed project. The amount of TN and TP present along a project reach is determined by applying TN and TP concentrations to the annual sediment loading rate. CBP (2014) provided two methods for estimating or measuring TN and TP concentrations in project soils. These methods are currently under review by Group 3, and are likely to be revised when they make their final recommendations (Group 3, 2019).

#### *Planning for Sediment Delivery*

In the new Phase 6 Chesapeake Bay Watershed Model, calculated nutrient and sediment reductions are reported to the state without applying a sediment delivery factor. However, some practitioners and localities may wish to know the sediment delivery rate for a proposed site for planning purposes. Please use the 3-step guide in Appendix A to determine the sediment delivery rate for your project reach.

### **Section 5: Technical Rationale for New Protocol**

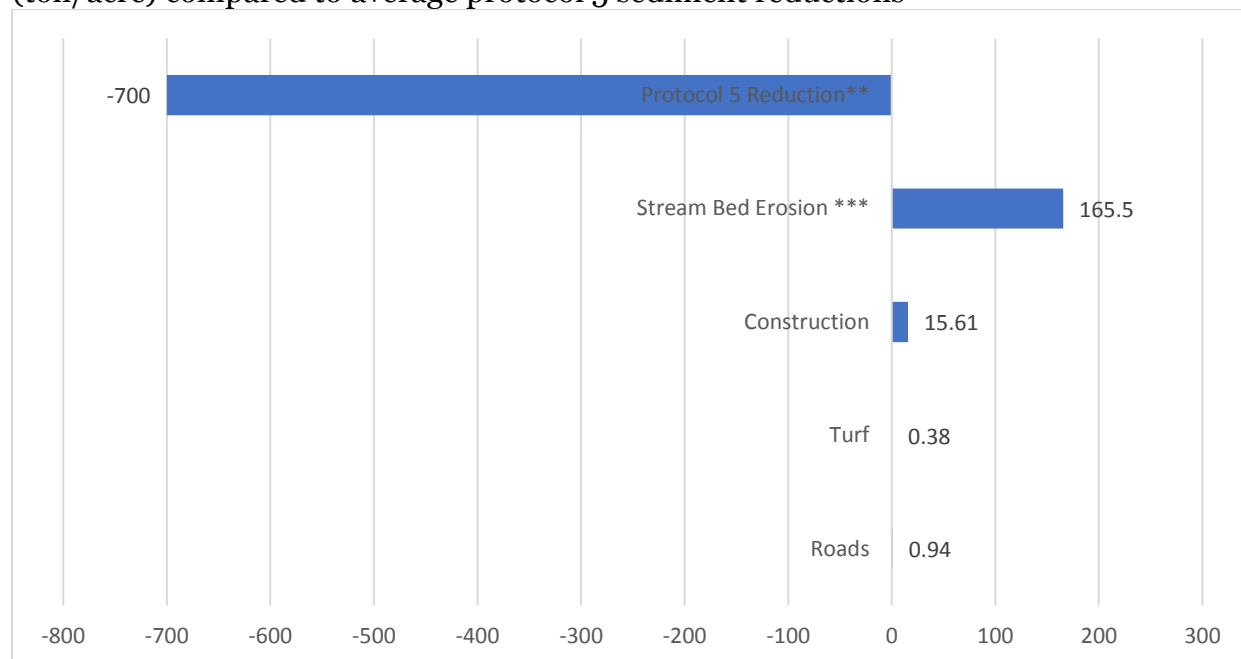
This section documents why Protocol 5 is consistent with, but different from, Protocol 1. It describes the technical analyses the group conducted to support its conclusions that a

new protocol is merited within the headwater transition zone, and why the method presented in MDOT SHA (2018) is technically supportable.

Figure 4 compares the unit area sediment loads for upland urban land uses and downstream urban channels, as simulated in the calibrated Phase 6 watershed model. Upland sediment loads tend to be much lower than those generated by the network of urban stream channels, even when under active construction. Even higher sediment loading rates are inferred for the headwater transition zone, based on the engineering calculations that Lennon and Lowe (2018) and McCollough and Andersen (2018) provided to the group.

The group also analyzed a series of example projects to determine how the sediment reductions achieved under the new credit compare to those calculated under the prevented sediment protocol. The comparison is shown in Table 5. As can be seen, the proposed Protocol 5 credit earns about an order of magnitude higher sediment reduction compared to Protocol 1, although most OGSP are installed on shorter project reaches.

**Figure 4.** Comparison of upland and stream channel sediment loading rates\* (ton/acre) compared to average protocol 5 sediment reductions



\*Average loading rates are for MS4 land uses in the Phase 6 Chesapeake Bay Watershed Model

\*\* Average reduction at edge of stream, based on 81 Maryland sites, with 50% reduction efficiency.

\*\*\* Average Chesapeake Floodplain Network sediment flux (62.69 lb/ft/yr) where 1 mile = 1 acre



<b>Table 5.</b> Comparison of Sediment Reduction Potential for the Three Protocols					
Sediment Reduction Protocol	Typical Reach Length	Default	Min	Mean	Max
	ft	lbs of sediment per linear ft restored <sup>1</sup>			
Protocol 1 <sup>2</sup>	1000 to 4000	248	3	375	3,750
Protocol 4 <sup>3</sup>	100 to 300	NA	5	7	8
Protocol 5 <sup>4</sup>	50 to 500	NA	40	1,060	17,300
<b>Notes:</b> <sup>1</sup> Estimate is at edge of stream with no efficiency factor applied. <sup>2</sup> Using Hickey Run Curve where bulk density=75lb/ft <sup>3</sup> over a 2500 ft reach. Min uses Low/Low (NBS/BEHI) with 2ft average bank heights. Mean uses High/High with 5ft average bank heights. Max uses Extreme/Extreme with 10ft average bank heights. <sup>3</sup> Using RR adjustor curve. Min treats 0.5 in, Mean treats 1 in, and Max treats 2 in. All scenarios calculated as 200ft project treating 1 acre of “average” MS4 Roads land use. <sup>4</sup> Estimates based on 81 sites in Maryland analyzed by MD SHA.					

## Section 6: Environmental Assessment for OGSP Projects

Defining the origin of headwater streams has been a matter of debate for scientists and regulators for many decades, and this group does not plan to wade into this controversy except to note that:

- (a) Headwater streams are extremely important to downstream ecosystems (see Kaplan et al, 2010 for a concise review), and,
- (b) All Bay states regulate construction activity within portions of headwater transition zones, which usually require some form of stream, wetland and/or forest field assessment to delineate resources and account for impacts.

The original expert panel strongly endorsed the need to show functional uplift for stream projects primarily built for pollutant reduction credit (USR EP, 2013). They also recommended that stream function assessment resources developed by Harman et al (2011), and subsequently Davis et al (2014) and Starr and Harman (2016) be used to assess stream response to restoration efforts.

This group concluded its recommendations should be descriptive rather than prescriptive and should reinforce ongoing environmental assessment efforts by state and federal permitting agencies. The group offers some general guiding principles for the environmental assessment of OGSPs and their future management:

- Projects should be assessed to understand existing aquatic organism passage at the site, including functions and conditions.

- The primary purpose of OGSPs is to prevent excess sediment delivery and flow velocities from impairing habitat and ecosystem function in downstream reaches.
- Better opportunities for instream habitat creation will normally exist further downstream.
- Designers should focus on demarcating upstream and downstream limits of the OGSP crediting area. The upstream limit should be set by the location of the existing pipe segment or the limits as computed and field verified as instructed in the guidance. The downstream limits will typically be defined as the location of the base level control point or from the downstream most grade control feature of the proposed restoration, as long as the depth of the grade control is equal to or deeper than the base level control elevation.
- Project documentation should indicate how future vegetation will be managed within the project limits to promote enhanced forest cover where appropriate, while allowing for vegetation management to ensure stability of the restored channel over time. In areas that trees could compromise safety or infrastructure, the project documentation should indicate improved vegetative cover through the appropriate vegetation type.

## **Section 7: OGSP Reporting and Record-keeping Requirements**

The information that is required to be reported to the Chesapeake Bay Program to earn credit for stream restoration practices has been streamlined since the expert panel report was first published in 2013. The current reporting criteria for stream restoration practices are outlined in Wood et al (2018) and includes:

- *BMP Name:* Stream Restoration
- *Length Restored:* (ft)
- *Protocol(s) Name and associated unit amount (lbs):*
  - Protocol 1 TN; Protocol 1 TP; Protocol 1 TSS;
  - Protocol 2 TN;
  - Protocol 3 TN; Protocol 3 TP; Protocol 3 TSS
  - Protocol 5 TN; Protocol 5 TP; Protocol 5 TSS
- *Land Use:* The default land use is Stream Bed and Bank
- *Geographic Location:* (see NEIEN for details)
- *Date of Implementation:* year the project was completed

In addition, the group recommends that the following additional information be collected for OGSP projects:

- Outfall pipe diameter (in)
- Drainage area (acres) and its impervious cover (%) [MD only]
- Primary outfall restoration technique using the armoring definitions developed by Group 3.

- Non-creditable armoring
- Creditable armoring, with limitations
- Creditable armoring

The current record-keeping requirements for stream restoration practices were outlined in the original EPR report, and stipulated that:

“the installing agency should maintain an extensive project file for each stream restoration project installed (i.e., construction drawings, credit calculations, digital photos, any post-construction monitoring, inspection records, and maintenance agreement). The file should be maintained for the lifetime for which the load reduction will be claimed”

This group concurs with the need for good project documentation, especially to support the future inspection needed to verify the long-term performance of OGSP. Some good examples of OGSP project documentation can be found in Lennon and Lowe (2018).

In addition, the verification group is recommending better industry standards for post-construction project drawings/surveys (Group 1, 2019). Specifically, post-construction redlines, surveys or as-builts should identify fixed photo stations or cross-sections along the project reach to determine future sediment stability. If possible, specific control sections should be monumented at reach locations that are most vulnerable to erosion and high shear stress.

## **Section 8: Verifying OGSP Projects**

The original expert panel outlined general requirements to verify stream restoration practices that are submitted for TMDL credit (CBP, 2014). These requirements preceded the partnership’s broader decisions to establish more detailed guidance on how to verify BMPs (USWG, 2014 and CBP, 2014b). A working group was established in 2018 to provide more specific guidance on how to verify stream restoration practices (USWG, 2018) and its recommendations were recently approved by the CBP partnership (Group 1, 2019).

The general verification requirements outlined by the original expert panel are excerpted below:

- The installing agency needs to conduct visual inspections once every 5 years (after the original permit conditions expire) to ensure that individual projects are still capable of removing nutrients and sediments.
- Duration of the credit (5 years) is shorter than other urban BMPs, as these projects are:
  - subject to catastrophic damage from extreme flood events

- have requirements for 3 to 5 years of post-construction monitoring to satisfy permit conditions
- If a project does not pass inspection, there is 1 year to take corrective action prior to loss of credit

### *Recommended field verification methods*

This section builds on the basic verification methods for stream restoration practices developed by Group 1 (2019) and assumes that the same two-stage inspection process used for Protocol 1 projects would also be applied to outfall restoration projects.

The first stage involves a rapid inspection of the project reach to assess its condition, preferably at predefined photo stations or cross-sections, relying on simple visual indicators, as shown in Table 6. An example of Protocol 1 indicators that also apply to OGSPs can be found in Figure 5. The guiding rule is that inspectors are looking for severe departures from the intended design that are clearly compromising its pollutant reduction functions.

The basic approach is to walk the entire project reach to assess the prevented sediment crediting protocol. The rapid initial inspection is intended to look for any potential loss of pollutant reduction function in some or all of the project reach. In some cases, observations or measurements may be made at predefined photo stations or cross-sections shown on the post construction project drawings. More details on the inspection fieldwork can be found in the USWG-approved verification memo (Group 1, 2019).

<b>Table 4</b> Defining Loss of Pollutant Reduction Function for Protocol 1 (Prevented Sediment)	
<b>Criteria for Loss</b>	<b>Key Visual Indicators</b>
Evidence of bank or bed instability such that the project delivers more sediment downstream than designed, as defined by exposed soils/fresh rootlets	<ul style="list-style-type: none"> <li>• Bank erosion (e.g., exposed bare earth or undercutting bank)</li> <li>• Departure of more than 20% from average post-construction design bank height <sup>1</sup></li> <li>• Incised channel, as indicated by loss of defined pools and riffles and/or presence of an active head cut</li> <li>• Flanking or scour of in-channel structures</li> <li>• Failure or collapse of allowable bank protection practices</li> <li>• Less than 80% ground or canopy cover in the restoration zone <sup>2</sup></li> </ul>
<sup>1</sup> as measured at riffles from the project as-built drawing, preferably from pre-designated control sections established at its most vulnerable locations <sup>2</sup> depending on the long-term vegetative community objectives established for the project, may be expressed as a measure of exposed surface soil (>20%) or canopy cover (<80%)	



In the second stage, each project is graded on a pass/fail basis, based on the proportion of the reach deemed to be seriously compromised or failing. Inspectors rapidly inspect the project reach using the visual indicators. The reach is analyzed to compute the percentage of each reach that is:

- Functioning or showing minor compromise
- Showing major compromise
- Project failure

More details on how stream projects are managed based on their assessed function can be found in Group 1 (2019).

**Figure 5.** Visual Indicators Showing Failures in the Field for Protocol 1



*Exposed Soil on Banks*



*Extreme Undercutting*



*Outflanking of Instream Structures*



*Bank Armoring Collapse*

Source: (Group 1 2019)



## Section 9: Potential Unintended Consequences

The qualifying conditions (Section 3) and environmental assessment guidance (Section 6) are critical for reducing potential unintended consequences associated with OGSPs. These conditions provide criteria for the site and project conditions under which nitrogen, phosphorous, and sediment load reductions should or should not be provided to a project.

Restoration and stabilization practices should always be tailored to individual site conditions. However, due to the large potential TMDL credit and reduced qualifying conditions compared to the original Stream Restoration Protocols, this protocol may unintentionally incentivize the use of OGSPs even in cases where they may not be the most appropriate course of action. Furthermore, these credits may inadvertently incentivize work in-stream instead of addressing potentially inadequate stormwater infrastructure above the stream channels. Where possible, opportunities located out of the stream network should be evaluated first or in conjunction with OGSP or stream restoration efforts.

Specifically, great care should be taken when proposing or approving the use of pipe extensions, drop structures, and scour protection as part of eligible OGSP projects. The flexibility incorporated into the protocol does not include specific limitations on the length of these practices, which provide stability, but do not provide restoration to a pre-impact or natural reference standard condition. While these techniques are only allowable if they are needed to sustain channel stability and do not pose barriers to aquatic organism passage, piping and over-hardening of channels may eliminate or reduce any existing habitat function within the reach. Incorrectly installed or excessive scour protection may also have adverse impacts on channel morphology, hydrology, and habitat. Piping and armoring may also increase stream velocity, creating the potential for exacerbated erosion, flooding, or habitat impacts downstream. Piping of streams is typically considered an impact and may require mitigation if there is a loss of function; restriction of these practices to gullies or erosional channels that have minimal function beyond hydrologic conveyance of flow would reduce concerns for potential adverse impacts

Each OGSP project should be assessed based on the guidance provided by the applicable permitting authorities, the best professional judgment of experts in the field, and should be consistent with the principles of ecological restoration, as supported by the guidance presented in this document. Adherence to these guidelines should reduce the risk of these unintended consequences.

Using this protocol to address headcuts in perennial streams in addition to the HTZ creates some additional concerns regarding potential direct impacts on species or habitat for fish, macroinvertebrates, and other aquatic species, including state or federal species of special concern such as bivalves and crayfish. Additionally, it raises concerns that the protocol may be used to attempt to “fix” drops in streams that are stable nick points (such as those that are bedrock-controlled) that may be misidentified

as headcuts. As these do not cause stream degradation, attempted stabilization of these areas would not likely result in an environmental benefit.

Stream functions may be altered by any potential stabilization or restoration effort. Although excessive erosion contributes to sedimentation downstream, it must be kept in mind that streams are dynamic systems and sediment transport is a natural and critical function of streams. Streams will adjust to changes in upstream hydrology; attempts to keep them in place may be unsuccessful over the long-term, especially if upstream stormwater sources are not addressed. Also, any work in streams or gullies should evaluate and avoid downstream disruption of hydrology from seasonal or perennial groundwater sources such as seeps and springs. Failure to recognize these sources could create risks not only to downstream water quality and hydrology but also project stability.

As with any project, potential tradeoffs should be carefully evaluated and avoided if possible. For example, while Section 6 indicates that the project documentation should include consideration of vegetation management to promote enhanced forest cover where appropriate, removal of vegetation in the project area could represent a long-term loss, particularly if large trees are removed since it may take several or many decades for them to reach pre-impact size and maturity. As trees and other vegetation are critical for nutrient and sediment retention as well as habitat, stability, and shading, disturbance to trees should be minimized where possible. Tree removal may also create concerns for adjacent communities or landowners.

It should also be noted that any disturbance may lead to introduction or spread of invasive species. Disturbance in the HTZ or riparian corridors may lead to the downstream spread of these species beyond the project area. Construction plans should include measures that prevent the spread of invasive species and post-construction management may be necessary.

In summary, there are a number of potential unintended consequences, all of which are not described here. One method to document that project implementation is not resulting in unforeseen adverse environmental impacts is to thoroughly assess and document pre-project conditions and monitor the impacts over a period of time in the project reach, upstream, and downstream. If it is found that projects do have adverse unintended consequences, revising the protocol may be appropriate.

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## Section 10 Glossary

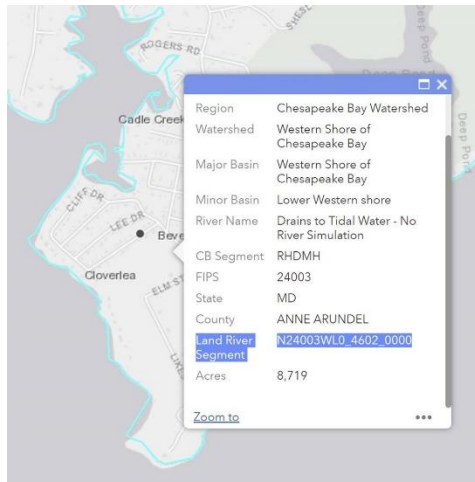
Glossary of Engineering Terms	
<i>Term</i>	<i>Description</i>
Channel bottom width	Width of the channel at the downstream section.
Critical shear stress	The minimum amount of shear stress exerted by stream currents or erosive forces to initiate soil particle motion or erosion. <i>See shear stress</i>
Hydraulic radius	The ratio of the cross-sectional area of a channel or pipe in which a fluid is flowing to the wetted perimeter of the conduit.
Internal friction angle (of soil)	The ability of a unit of rock or soil to withstand shear stress; the measure of shear strength of soils due to friction. The internal friction angles for different soil particles or soil types are available in technical reference sources, e.g., NRCS (2007), Technical Supplement 14A.
Kinematic viscosity	The ratio between the dynamic viscosity and the density of a fluid, often expressed in m <sup>2</sup> /s or Stoke (St) units.
Particle settling velocity	Basically, the rate at which a particle will settle downward in a fluid (water) under gravity. Expressed in units of velocity, e.g., meters per second (m/s).
Particle size (or grain size)	Diameter or a soil particle (or grain of soil material).
Particle size distribution	The amounts of the various soil separates (silt, clay, sand) in a soil sample, usually expressed as weight percentages (Weil and Brady, 15 <sup>th</sup> ed.). The distribution can be determined through particle size analysis. The median particle size (D <sub>50</sub> ) is the midpoint of the distribution.
Slope stability	The potential of soil-covered slopes to withstand and undergo movement, i.e. the resistance of an inclined surface to failure by sliding or collapsing. Stability is determined by the balance of shear stress and shear strength.
Shear strength	The capacity of an object or surface to resist shear.
Shear stress	The force acting on an object or surface parallel to the slope or plane in which that object or surface lies; this force produces shear. Represented by Greek character $\tau$ (tau) and typically expressed in Pascal units (Pa).
Soil consistence	Combination of soil properties that determine its resistance to crushing and its ability to be molded or changed in shape. Terms such as loose, friable, firm, soft, plastic and sticky are used to describe soil consistence. (Weil and Brady, 15 <sup>th</sup> ed.)
Soil plasticity	A plastic soil is capable of being molded or deformed continuously and permanently, by relatively moderate

	<p>pressure, into various shapes. (Weil and Brady, 15<sup>th</sup> ed.) Soil plasticity is measured by the plasticity index (PI) of a soil. The PI is the difference between the liquid limit and plastic limit of a soil. Soils with a high PI tend to be clay; those with lower PI tend to be silt. Soils with PI &lt;7 are considered slightly plastic; PI between 7 and 17 is considered medium plastic; PI &gt;17 is highly plastic.</p>
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## Appendix A: Four Step Method

Step 1: Determine the total load reduction from the protocols.

Step 2: Visit <https://gis.chesapeakebay.net/mpa/scenarioviewer/>, and enter the nearest physical address or the practice. Once entered, click the identify button on the upper-left-hand corner of the screen, and click on the land surrounding your physical address. This will open a window that contains the land-river segment within which your practice is located. See highlighted land-river segment in screen shot included below.



Step 3: Download CAST Source Data at <https://s3.amazonaws.com/cast-reports.chesapeakebay.net/public/SourceData.xlsx>, and click on the “Delivery Factors” worksheet. Once there, you can filter the spreadsheet for your land-river segment and you load source. In the case of stream restoration, your load source would be Stream Bed and Bank. See the screen shot below. Here, I have a delivery factor from the stream to the river for sediment of 0.44 and from the river to the Bay of 1. Multiply those two factors together to determine a combined delivery factor from the stream to the Bay of 0.44.

A	B	C	D	E	F	G	H	I	J	K	L
LandRiverSegment	LoadSource	Lan	Lan	L	StreamToRiver_TN_Factor	StreamToRiver_TP_Factor	StreamToRiver_SED_Factor	RiverToBay_TN_Factor	RiverToBay_TP_Factor	RiverToBay_SED_Factor	
N24003WLO_4602_0000	Stream Bed and Bank				0.88	0.74	0.44	1.00	1.00	1.00	

Step 4: Multiply reduction found in Step 1 by combined delivery factor found in Step 3 to determine pounds of sediment reduced to the Bay from your stream restoration project.

Example:

Step 1: Edge-of-Stream Reduction = 1,000 lbs sediment

Step 2: BMP located within LRSEG N24003WLO\_4602\_0000

Step 3: Combined Delivery factor =  $0.44 \times 1.0 = 0.44$

Step 4: Edge-of-Tide Reduction =  $1,000 \text{ lbs sediment} \times 0.44 = 440 \text{ lbs sediment}$

## **Appendix B: Examples of Projects from MDOT SHA**



# MDOT SHA PERMITTING STRATEGY

- MD Department of Environment – Wetlands and Waterways
  - Letter of Authorizations
  - Authorization to Proceed
  - Non-Tidal Wetland and Waterways Permit
  - Water Quality Certification (401)
- US ACOE
  - MDSPGP-5 (404)
  - BAY TMDL RGP
  - NW 27 (404)
  - Individual Permit (404)
- NPDES Permit for Stormwater Associated with Construction Activity
- MD Stormwater and Erosion & Sediment Control
- Forest Conservation
  - Roadside Tree Permits
  - Forest Conservation Exemptions (Stream Restoration for TMDL)



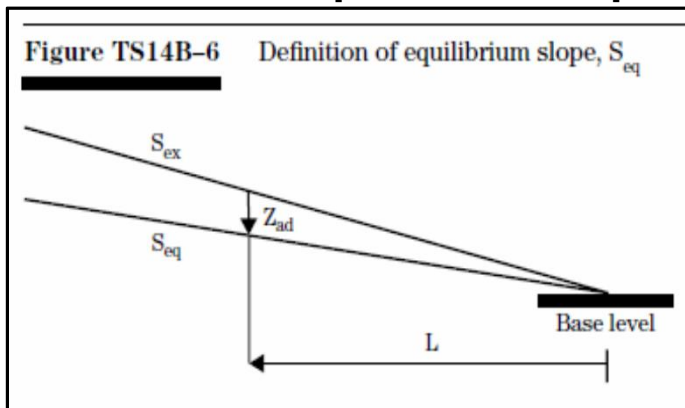
# SITE EXAMPLES

- I-270 at Montrose
  - Severe Erosion (~16' drop at pipe with base level control 600 feet downstream)
  - Threatened roadway ramp
  - Combined Drop Structure and Step-Pool Channel Approach
  - Alignment selected through iterative process with MNCPPC to avoid tree loss
- White Marsh Tributary at MD43
  - Multiple Headcuts (4' and 6')
  - Interface with Stormwater Pond Outfall, erosion threatened pond outfall stability
  - Step-pool Cascade Approach
- MD 210 Site 10
  - Severe Drop at Roadway embankment (~30' drop at over a 60% slope)
  - Safety issue for road, required lane closure prior to completion due to safety concerns
  - Combined Drop Structure and Threshold Channel with Restored Valley Approach
- I-97
  - Roadway embankment threatened, safety issue for major interstate roadway
  - Moderate to Severe Erosion (8-10' drop at pipe, steep slope to base level control)
  - Step-Pool with Infiltration Window Approach in Sand Bed Coastal Plain System
- Avalon – Patapsco State Park
  - Moderate to Severe Erosion with severe headcut (~8' drop)
  - Combined Step-Pool with Threshold Channel with Restored Valley Approach
  - Side channel to prevent drainage of adjacent wetland



# PROTOCOL QUICK SUMMARY

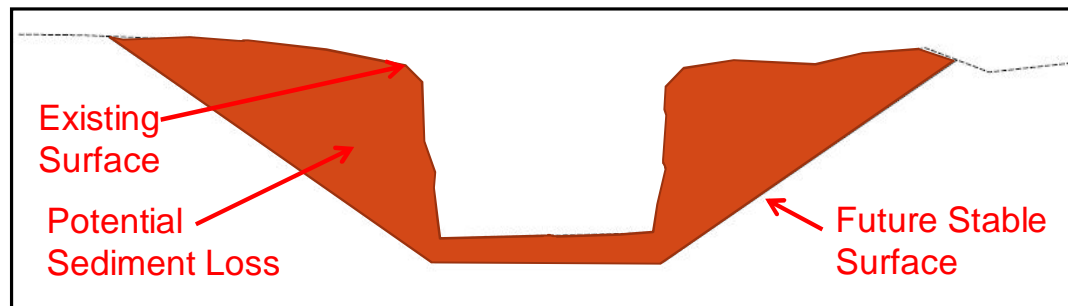
## Base level & Equilibrium Slope



CALCULATE THE FUTURE SURFACE DEPENDENT  
UPON TWO KEY PARAMETERS

**Equilibrium Slope:** When sediment transport capacity exceeds sediment supply, channel degradation occurs until an armor layer forms that limits further degradation or until the channel bed slope is reduced so much that the boundary shear stress is less than a critical level needed to entrain the bed material.

## Comparative Cross Section



# DOCUMENT PHASE 6 LOAD REDUCTIONS

- Clarify load reductions for TN, TP and TSS to be used

	TN (lb/ft/yr)	TP (lb/ft/yr)	TSS (lb/ft/yr)
Proposed Rates (v6)	0.075	0.068	248

- Application of Delivery Ratios (Bay vs Locals)







## I-270 AT MONTROSE

- Montgomery County, Maryland
- Length of project = 570 lf
- Construction Completed = Spring 2018
- Key Project components
  - HDPE pipe
  - Manhole installation
  - Step pool pattern
  - Cascade structures
  - Plunge pool
  - Slope stabilization
  - Vegetative plantings

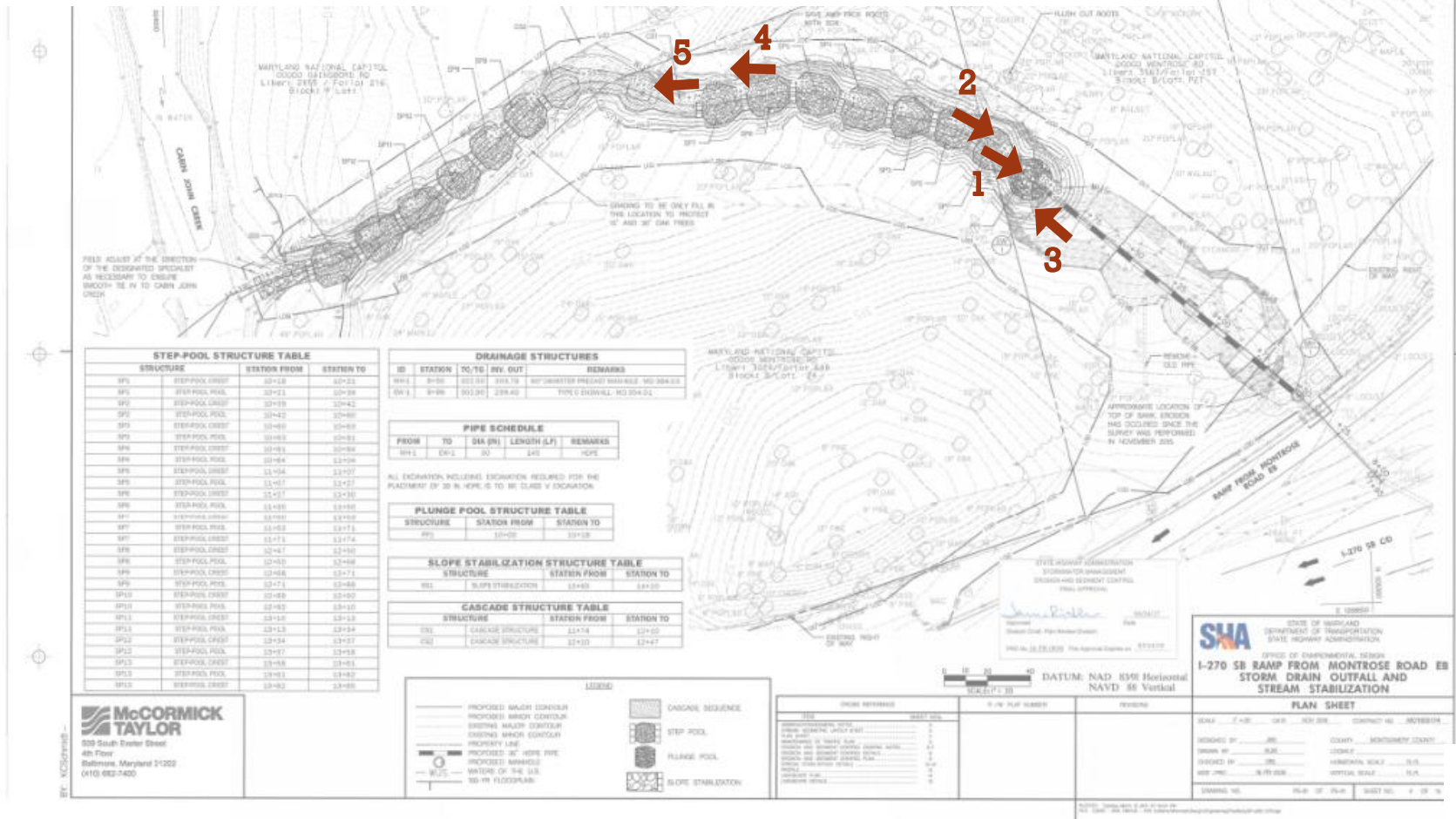


# I-270 AT MONTROSE ROAD - PERMITS

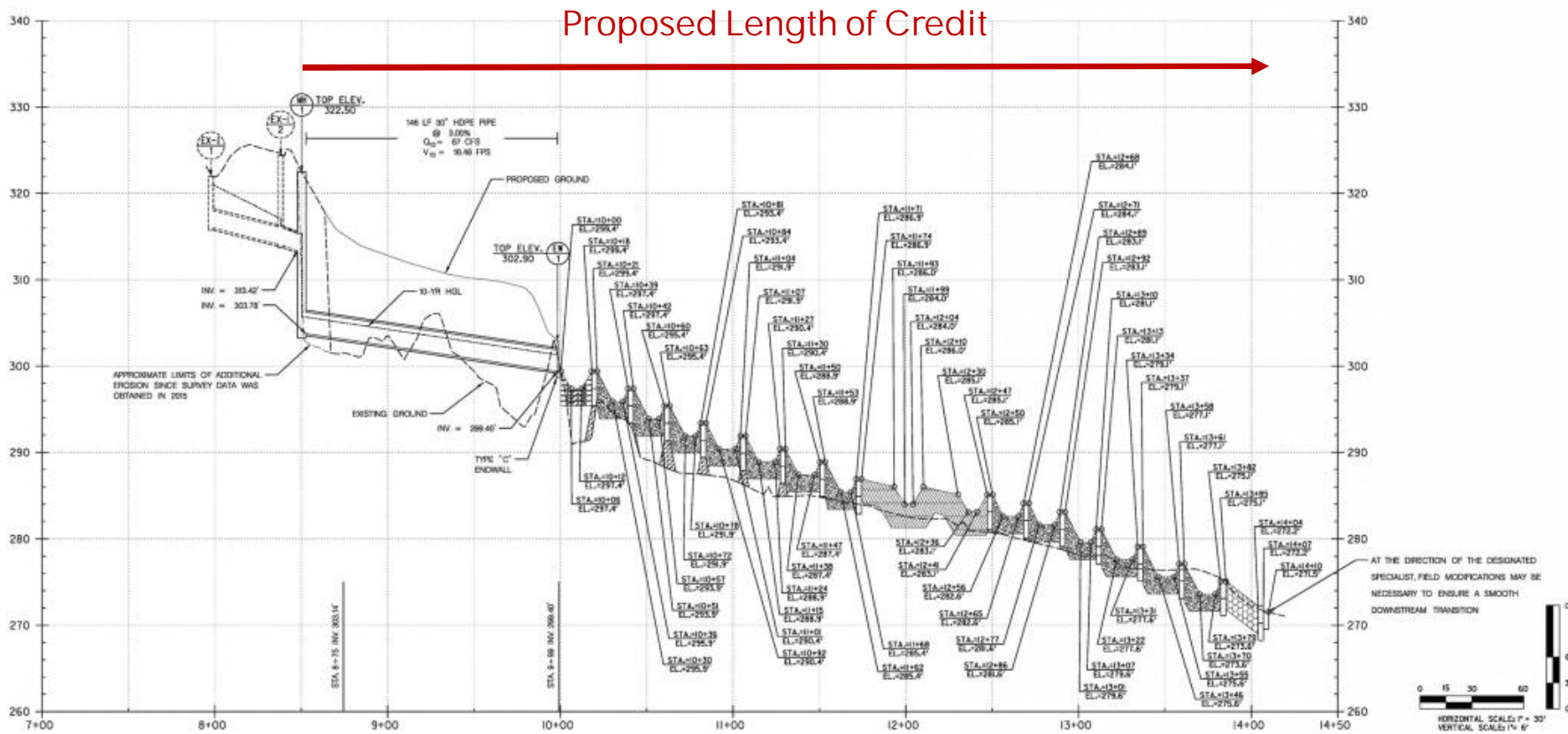
- MDE Authorization to Proceed (ATP)
- MD State Programmatic General Permit (MDSPGP-5)
- As-Built Drawings completed as part of construction
- US ACOE - TMDL RGP
- Stormwater Management and Erosion & Sediment Control Permit
- NPDES NOI
- MD Forest Conservation Exemption



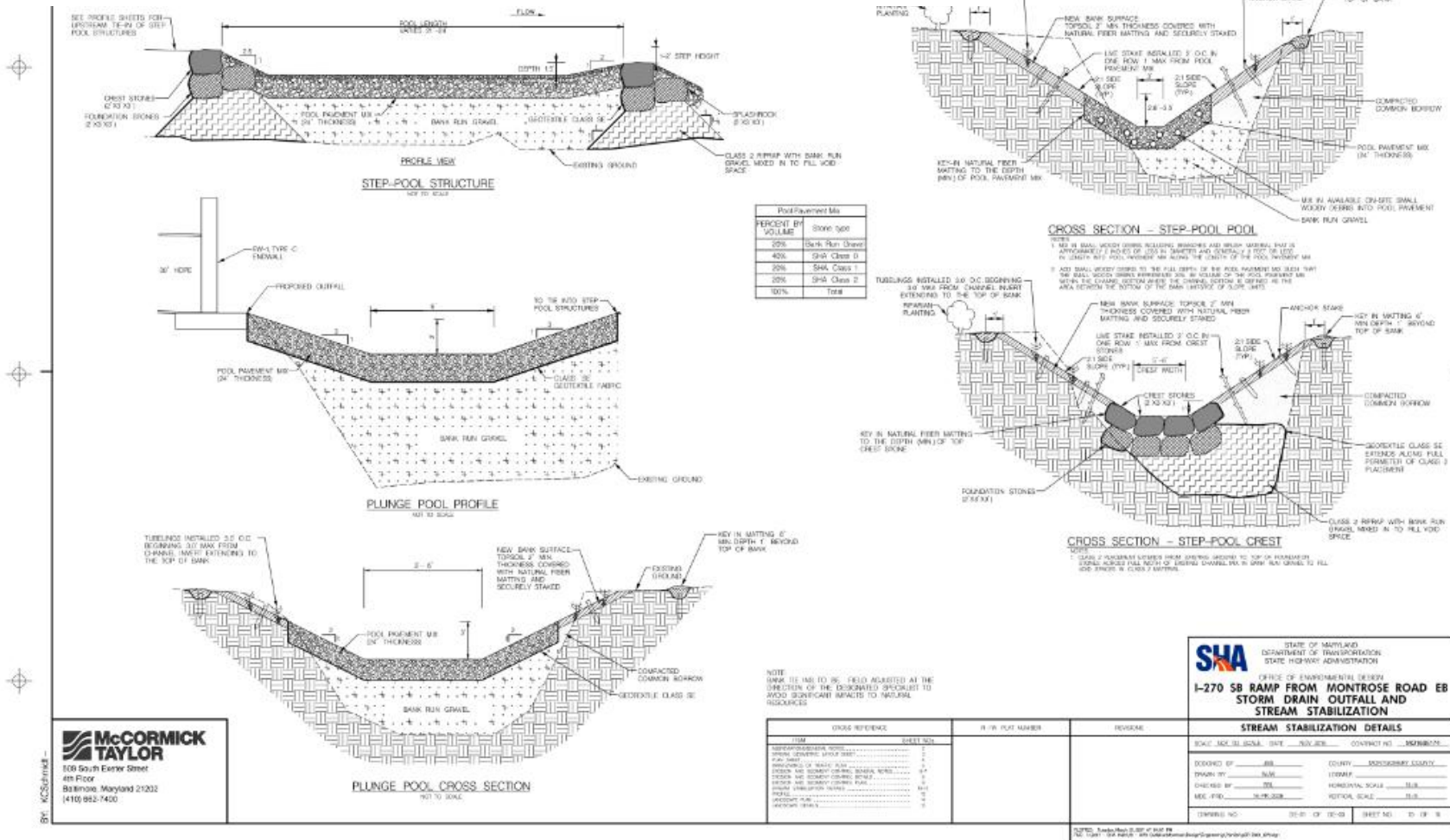
# I-270 AT MONTROSE — PLAN VIEW



# I-270 AT MONTROSE — PROFILE VIEW

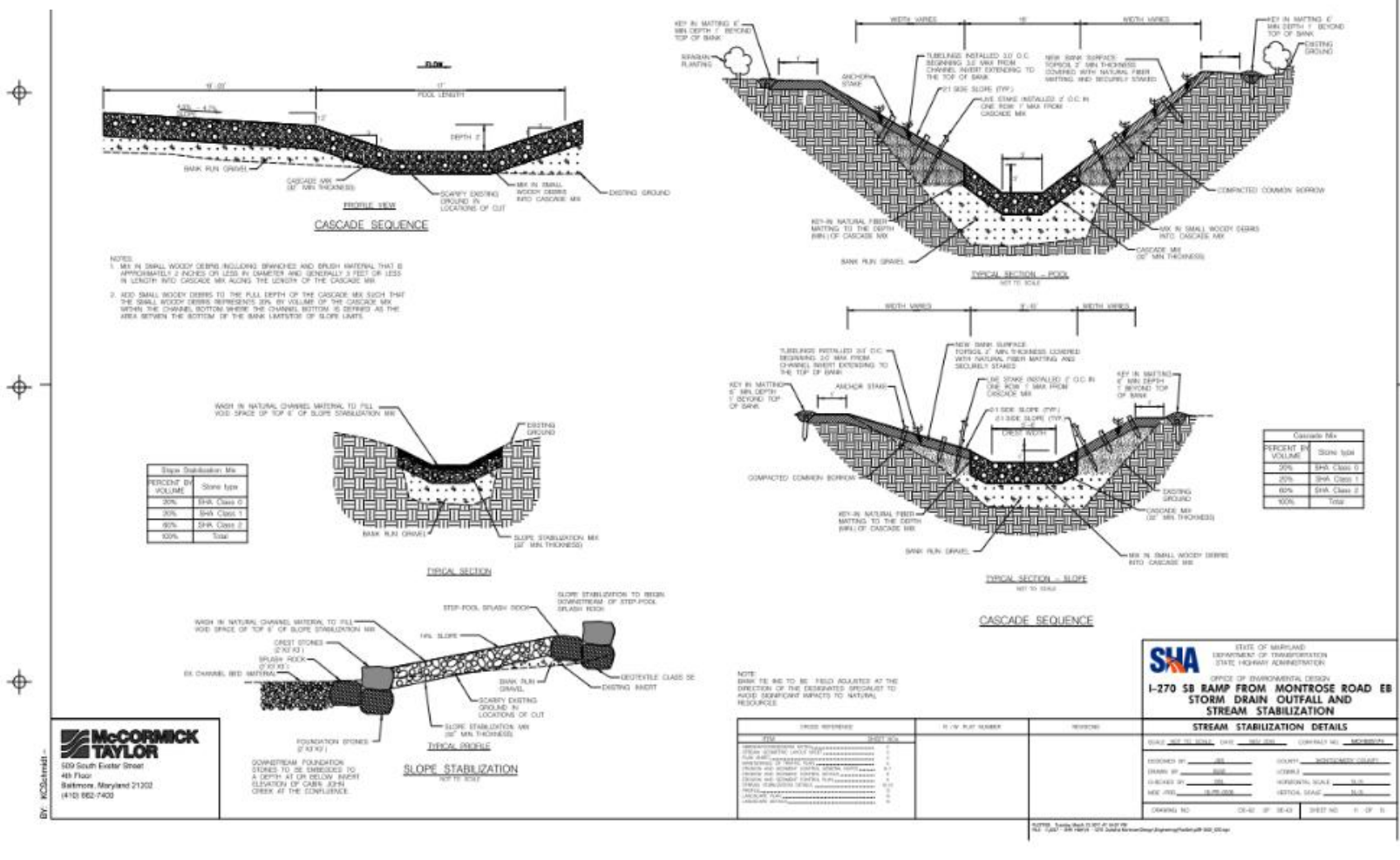


# I-270 AT MONTROSE — DETAIL



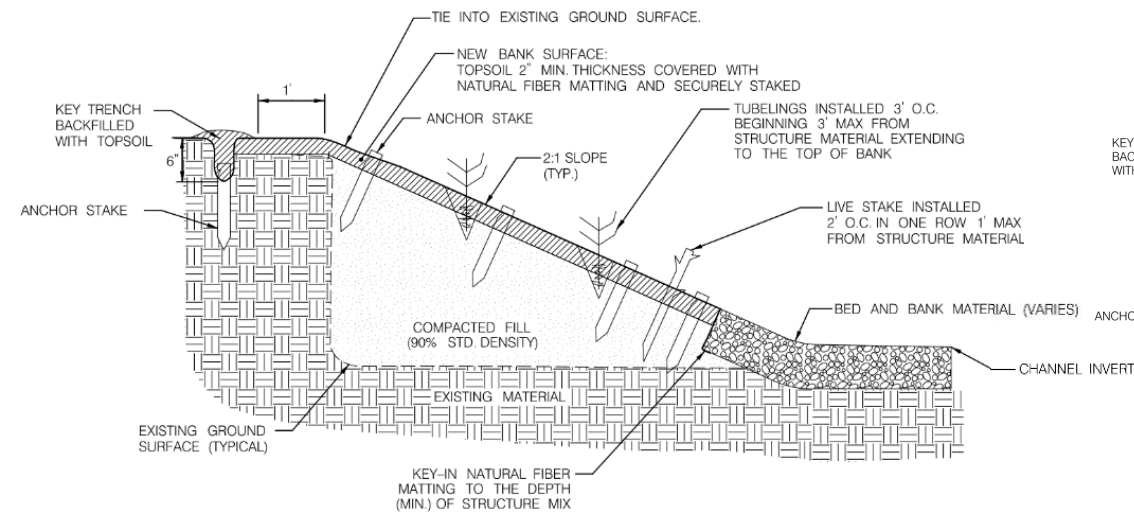


# I-270 AT MONTROSE — DETAIL



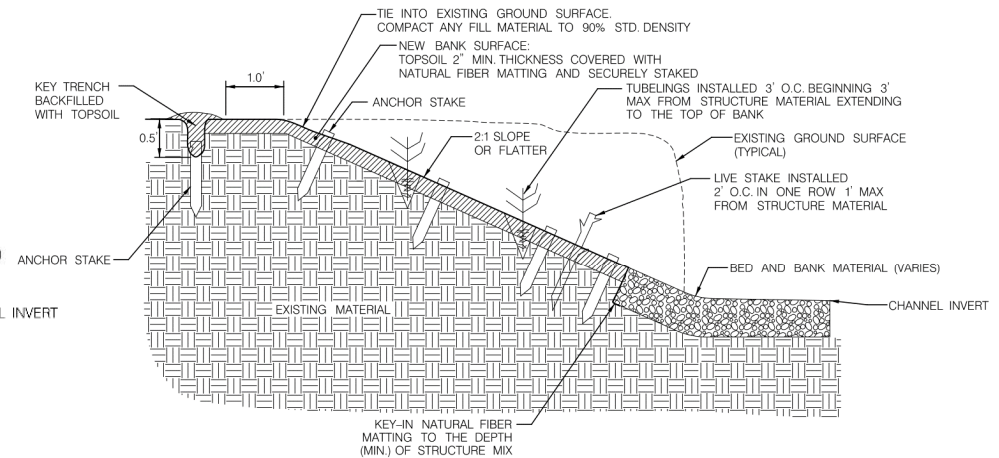


# I-270 AT MONTROSE — DETAIL



TYPICAL STREAMBANK STABILIZATION IN FILL

NOT TO SCALE



TYPICAL STREAMBANK STABILIZATION IN CUT

NOT TO SCALE



PRE - CONSTRUCTION: EXISTING EXTREMELY  
INCISED VERTICAL WALLS  
AND FAILED OUTFALL STRUCTURE , 2/29/2016



POST - CONSTRUCTION ,

11/7/2018

I-270 AT MONTROSE- PHOTO LOCATION 1





PRE – CONSTRUCTION: EXISTING EXTREMELY INCISED VERTICAL WALLS AND FAILED OUTFALL STRUCTURE, 2/29/2016



POST – CONSTRUCTION,

11/7/2018

## I-270 AT MONTROSE– PHOTO LOCATION 2





PRE-CONSTRUCTION: EXISTING  
ENTRENCHED OUTFALL CHANNEL ,

2/29/2016



POST – CONSTRUCTION ,

11/7/2018

## I-270 AT MONTROSE – PHOTO LOCATION 3





PRE – CONSTRUCTION: EXISTING, ENTRENCHED OUTFALL  
CHANNEL 2/29/2016



POST – CONSTRUCTION,

11/7/2018

I-270 AT MONTROSE – PHOTO LOCATION 4





PRE – CONSTRUCTION: EXISTING  
ENTRENCHED OUTFALL CHANNEL,

2011



POST – CONSTRUCTION,

11/7/2018

## I-270 AT MONTROSE – PHOTO LOCATION 5





POST - CONSTRUCTION

11/7/18

## WHITE MARSH TRIBUTARY AT MD-43

- Baltimore County, Maryland
- Length of project = 630 lf
- Construction Completed = Fall 2018
- Key Project components
  - Step pool sequence
  - Rock outlet protection
  - Cascade structures
  - Riffle structures
  - Log sills
  - Large woody debris
  - Vegetative plantings

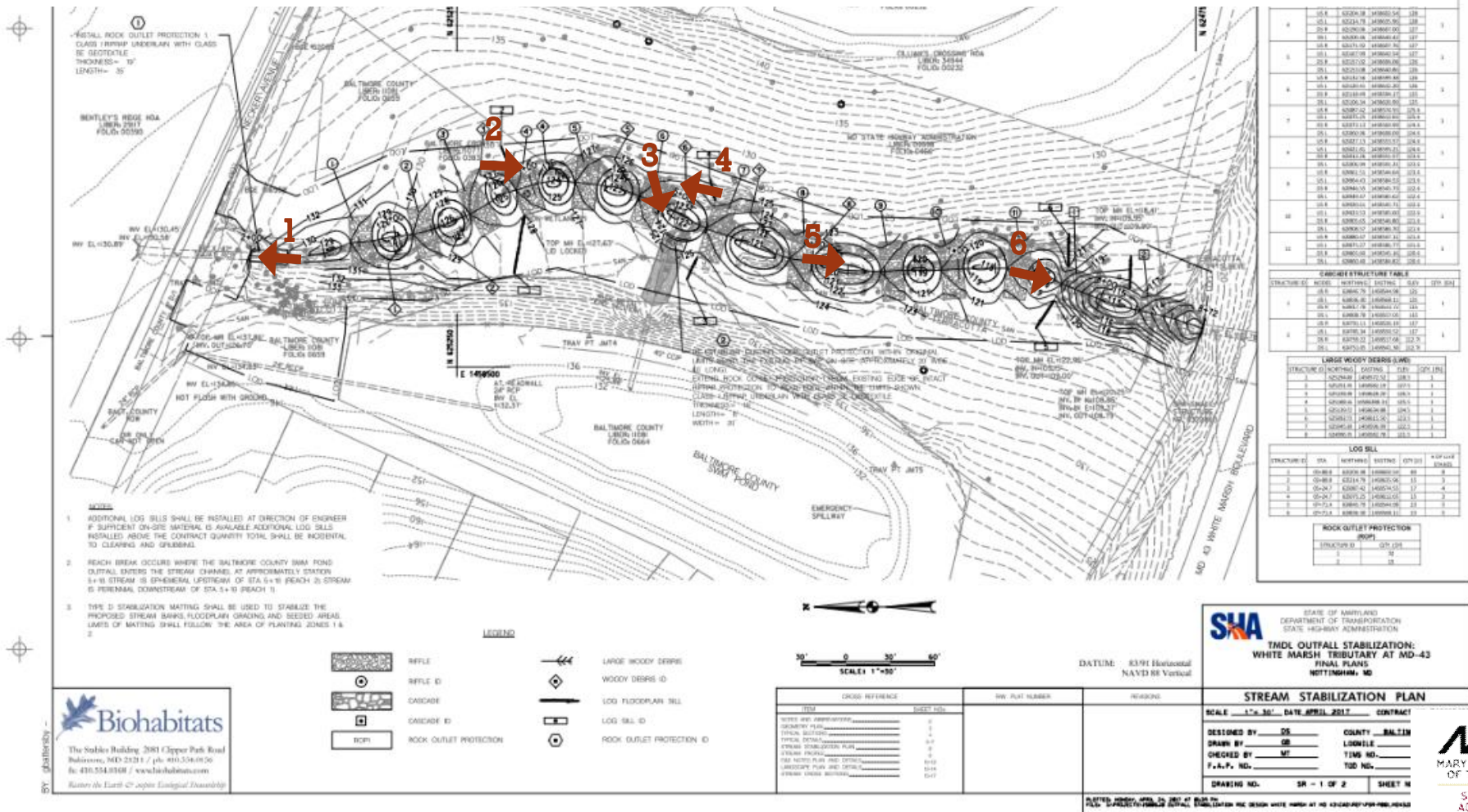
# WHITE MARSH TRIBUTARY AT MD 43- PERMITS

- MDE Non-Tidal Wetland & Waterway Permit
- MDE Authorization to Proceed
- US ACOE - TMDL RGP
- Stormwater Management and Erosion & Sediment Control Permit
- NPDES NOI
- MD Forest Conservation Act Approval
- As-Built Drawings completed as part of construction

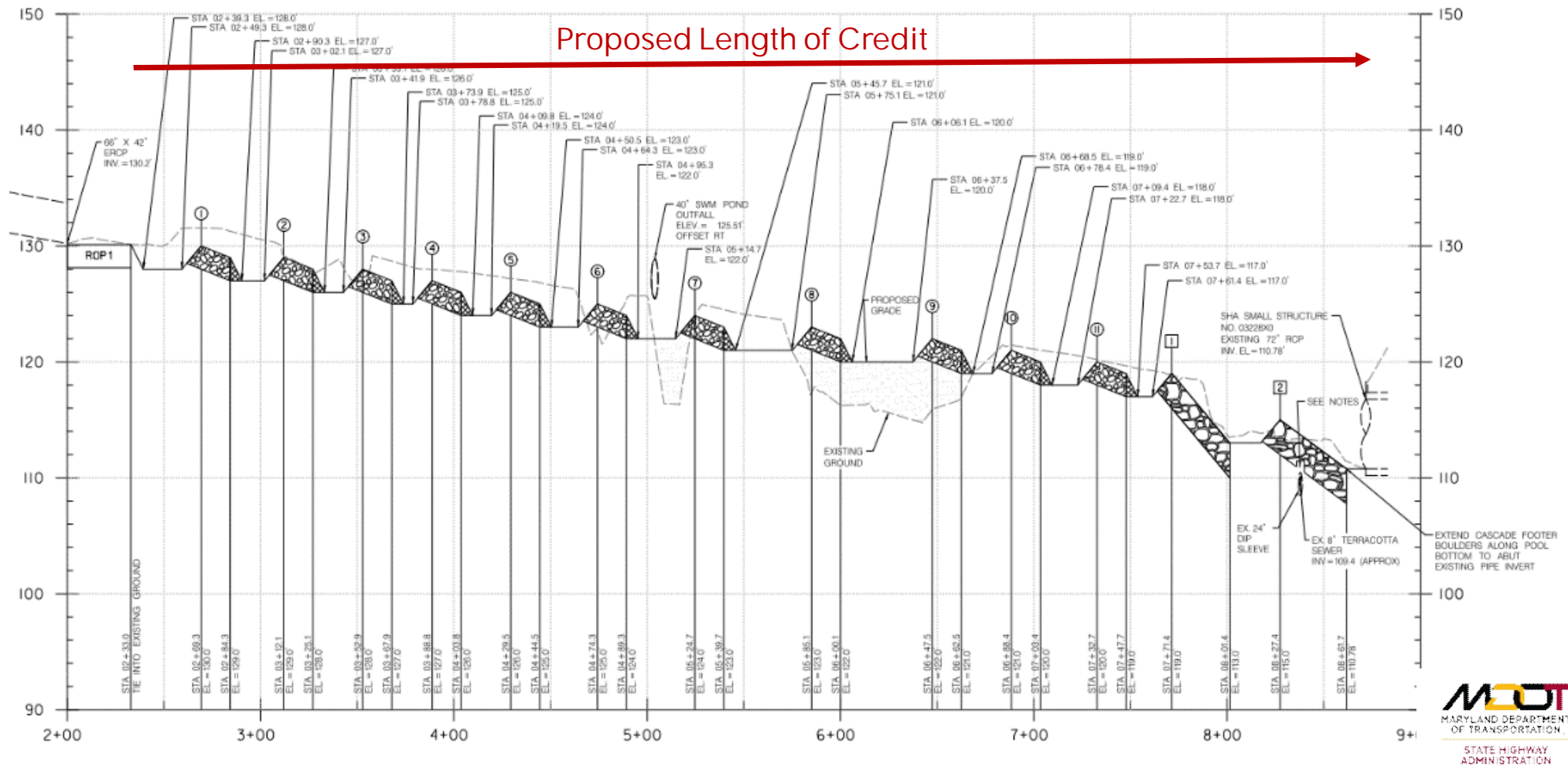




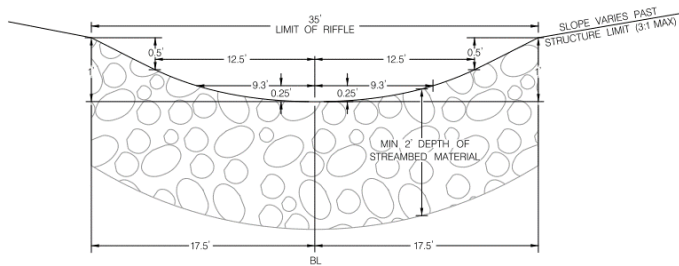
# WHITE MARSH TRIBUTARY AT MD-43— PLAN VIEW



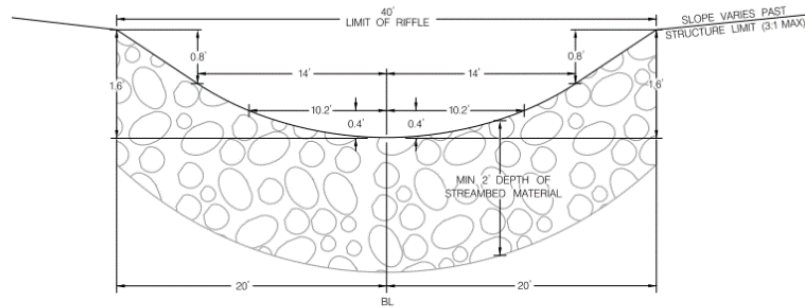
# WHITE MARSH TRIBUTARY AT MD-43 — PROFILE VIEW



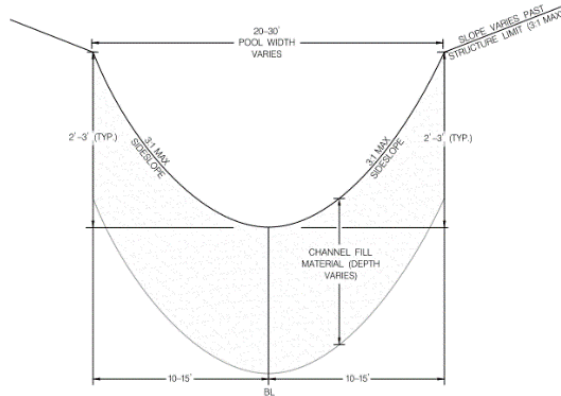
# WHITE MARSH TRIBUTARY AT MD 43 — RIFFLE AND CASCADE DETAIL



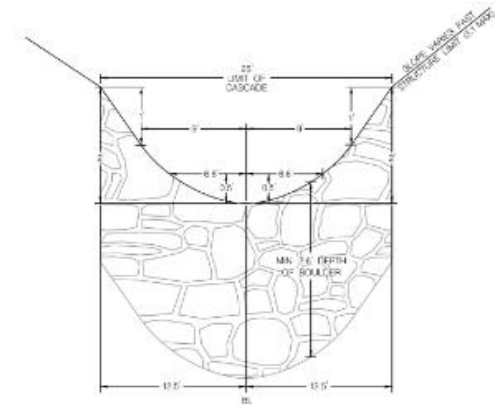
RIFFLE CREST SECTION  
STATION 2+00 TO 5+00  
RIFFLES # 1 - 6



RIFFLE CREST SECTION  
STATION 5+00 TO 7+60  
RIFFLES # 7-11



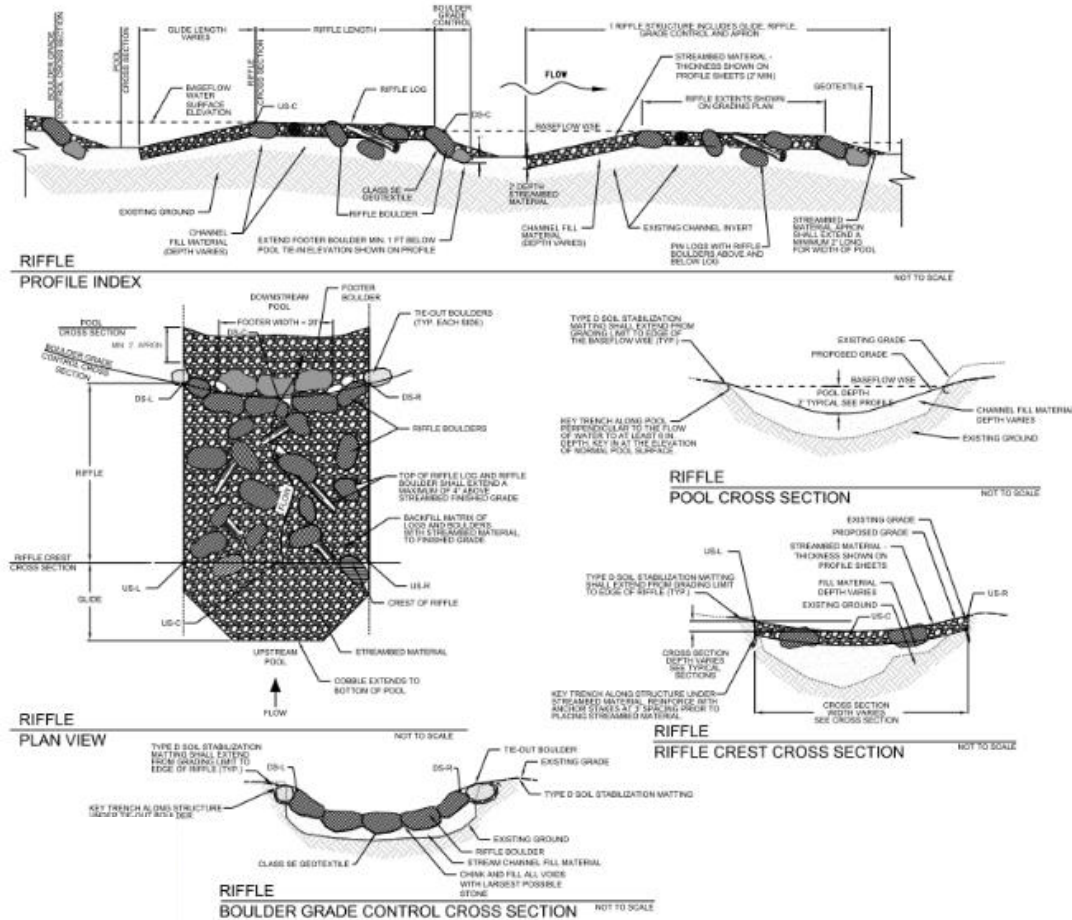
POOL SECTION  
STATION 3+00 TO 7+60



CASCADE CREST SECTION  
STATION 7+60 TO 8+70  
CASCADES #1-2



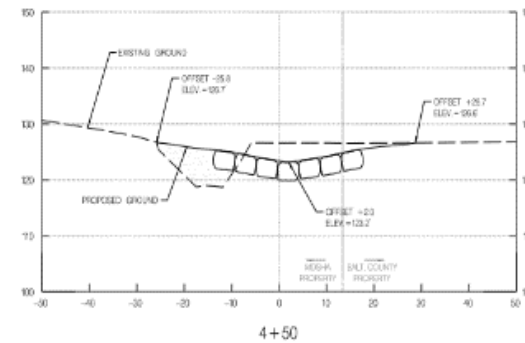
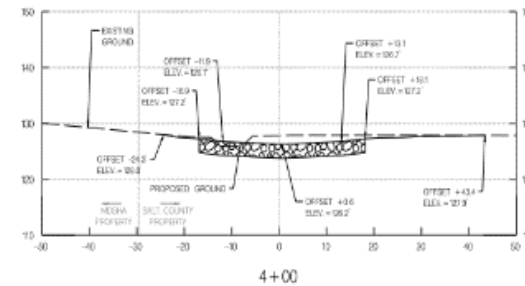
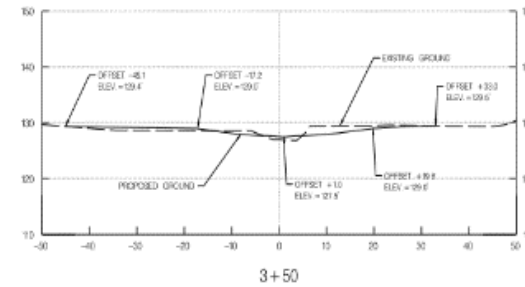
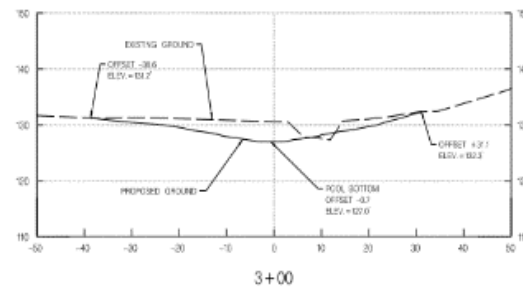
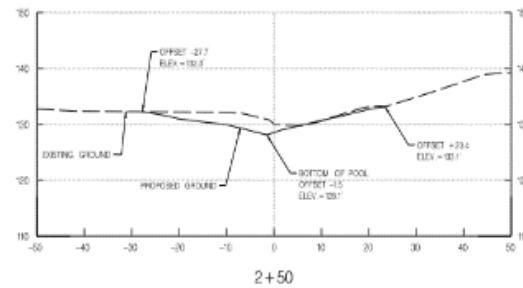
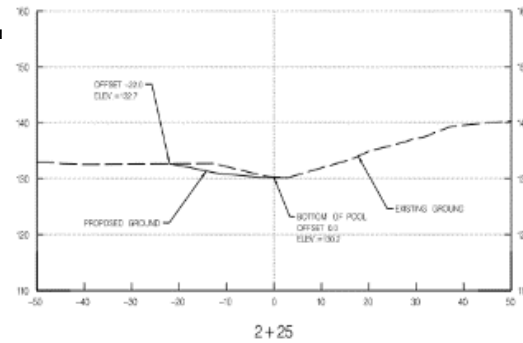
# WHITE MARSH TRIBUTARY AT MD 43 — RIFLE AND CASCADE DETAIL



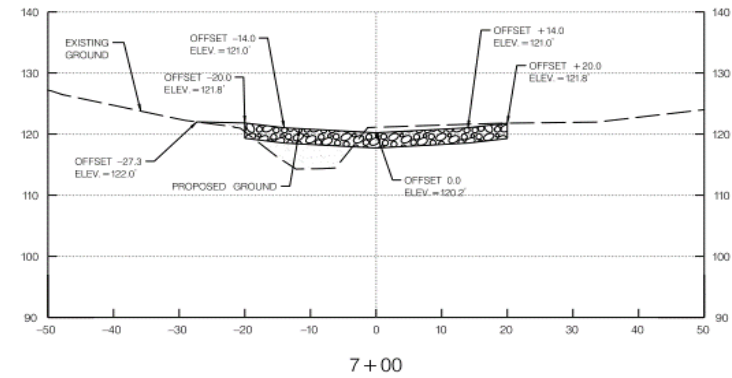
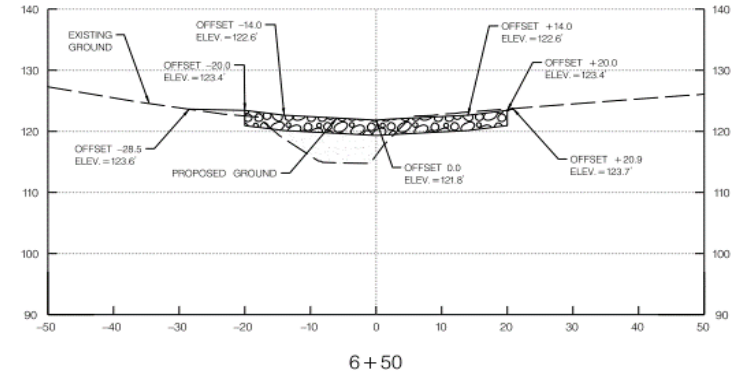
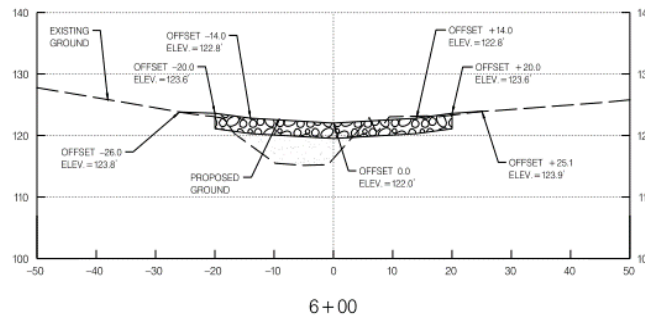
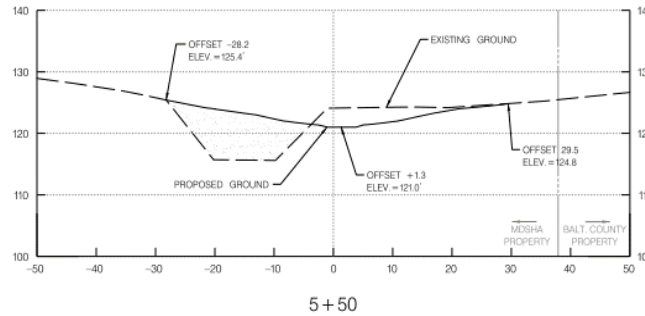
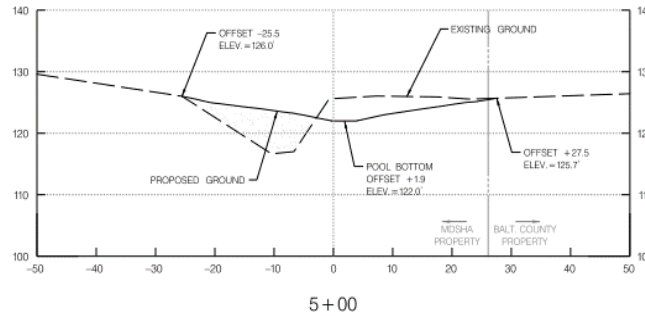




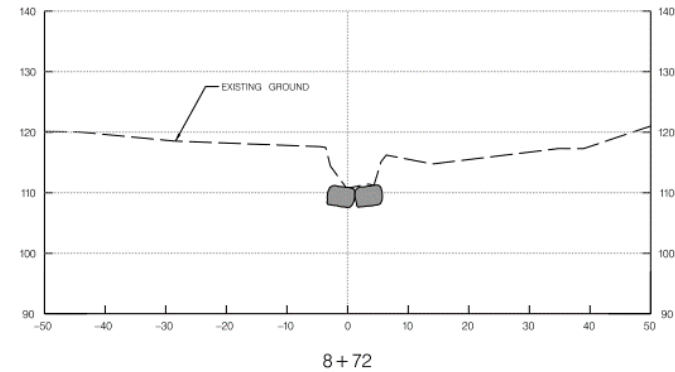
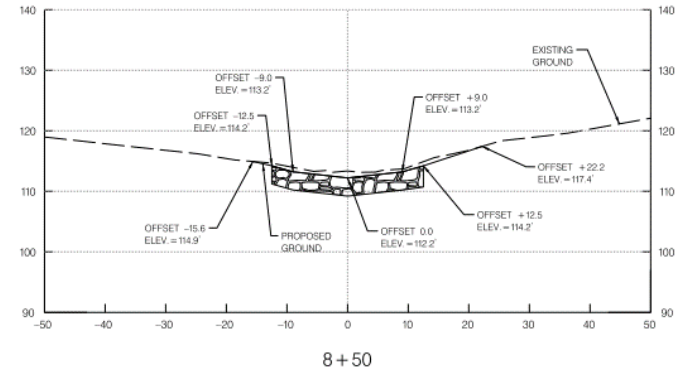
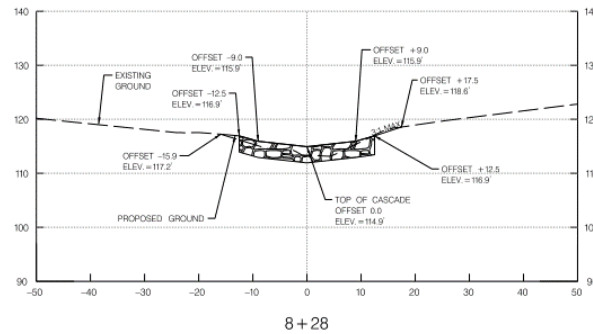
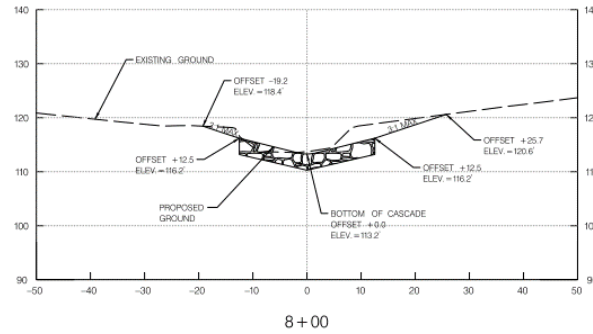
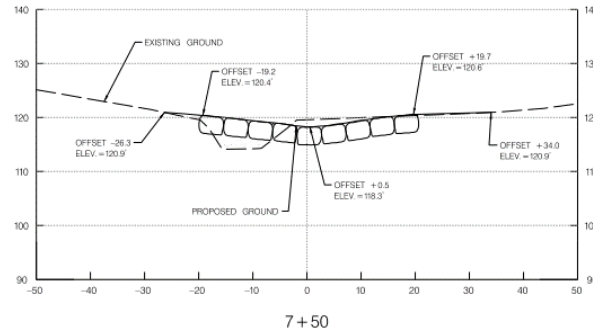
# WHITE MARSH TRIBUTARY AT MD 43 — STREAM CROSS SECTION



# WHITE MARSH TRIBUTARY AT MD 43 — STREAM CROSS SECTION



# WHITE MARSH TRIBUTARY AT MD 43 — STREAM CROSS SECTION







PRE – CONSTRUCTION: PIPE OUTFALL 5/18/2016



POST – CONSTRUCTION 11/7/2018

WHITE MARSH TRIBUTARY AT MD 43 – PHOTO LOCATION 1





PRE - CONSTRUCTION: HIGHLY ENTRENCHED  
CHANNEL, DOWNCUT AND WIDENED DUE TO  
ACTIVELY MIGRATING HEADCUT

5/18/2016



POST - CONSTRUCTION

11/7/2018

## WHITE MARSH TRIBUTARY AT MD 43 - PHOTO LOCATION 2





PRE – CONSTRUCTION: HEADCUT , LOOKING TOWARDS  
POND OUTFALL  
5/18/2016



POST – CONSTRUCTION,

11/7/2018

## WHITE MARSH TRIBUTARY AT MD 43 – PHOTO LOCATION 3





PRE – CONSTRUCTION: HIGHLY ENTRENCHED  
CHANNEL, BANK HEIGHT 7 FEET HIGH

5/18/2016



POST – CONSTRUCTION

11/7/2018

## WHITE MARSH TRIBUTARY AT MD 43 – PHOTO LOCATION 4





PRE – CONSTRUCTION

5/18/2016



POST – CONSTRUCTION

11/7/2018

WHITE MARSH TRIBUTARY AT MD 43 – PHOTO LOCATION 5





PRE- CONSTRUCTION: SAND GRAVEL  
DEPOSITION AT DOWNSTREAM CULVERT

5/18/2016



POST – CONSTRUCTION

11/7/2018

WHITE MARSH TRIBUTARY AT MD 43 – PHOTO LOCATION 6





## MD 210 SITE 10

- Prince George's County, Maryland
- Length of project = 350 lf
- Construction Completed = 2016
- Key Project components
  - Riprap outfall protection
  - Reinforced concrete pipe
  - Manhole installation
  - Vegetative plantings

# MD 210, SITE 10 - PERMITS

- MDE Authorization to Proceed (ATP)
- MD State Programmatic General Permit (MDSPGP-4), US ACOE authorization
- As-Built Drawings completed as part of construction
- Stormwater Management and Erosion & Sediment Control Permit
- NPDES NOI
- MD Roadside Tree Permit





# MD 210 SITE 10 — PLAN VIEW



VICINITY MAP  
SCALE: 1" = 2,000'

BASELINE CONTROL COORDINATES		
DESCRIPTION	NORTH	EAST
POT STA. 10+00.00	366,329.6355	1,309,515.1820
POT STA. 14+00.00	366,626.9750	1,309,841.6242

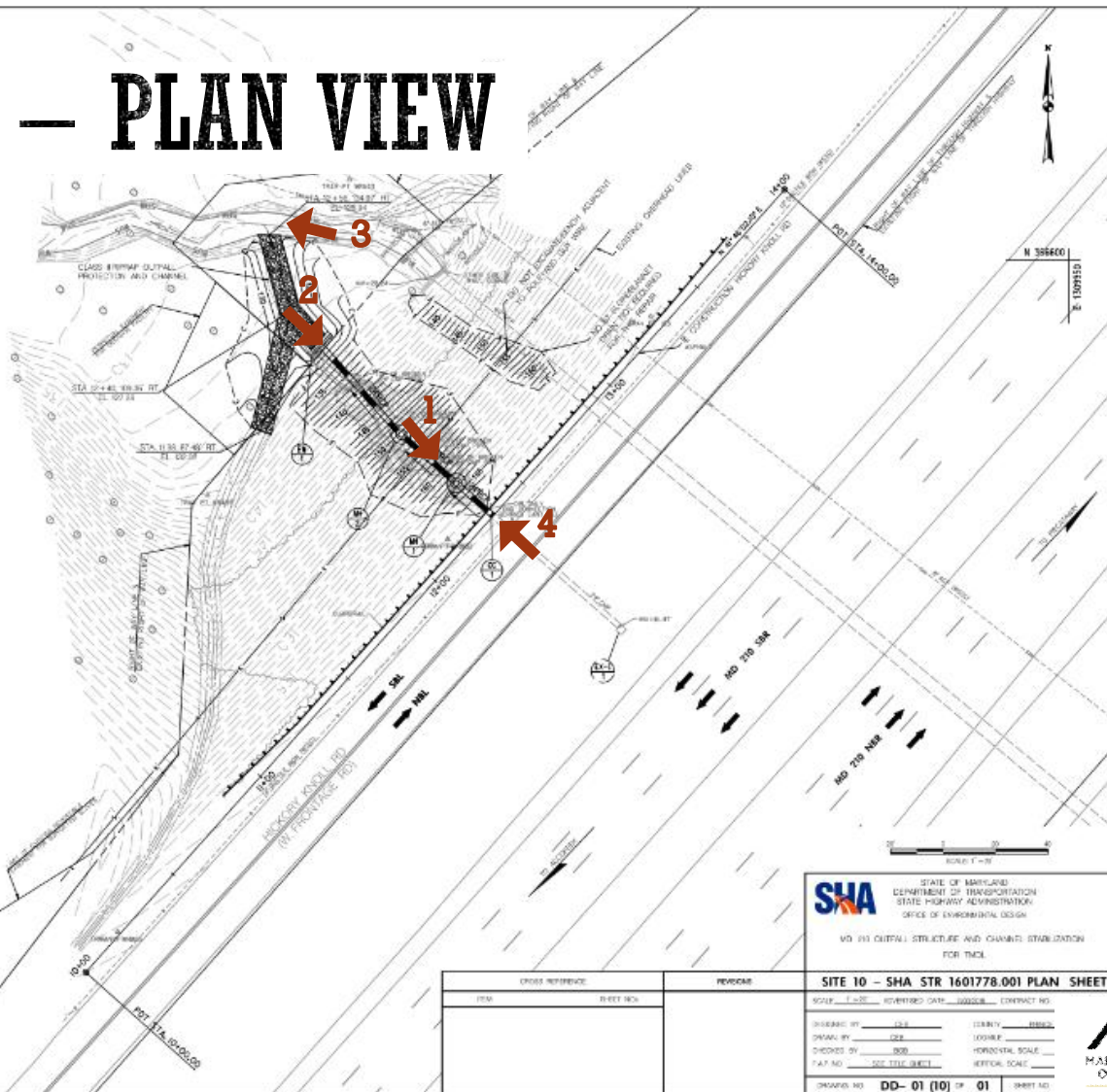
TRAVERSE POINTS		
TRAV. POINT NO.	NORTH	EAST
TRAV. PT. WEA52	366,495.6037	1,309,715.1545
TRAV. PT. WEA51	366,630.7622	1,309,675.6751
TRAV. PT. WEA54	366,510.3579	1,309,621.6667
TRAV. PT. WEA55	366,343.9345	1,309,567.3753

CC 00000	CLASS I EXCAVATION
NO C.Y.	MEASUREMENT NO. STA 0+00.00 TO STA 10+00.00 LT
CC 00005	COMMON BORROW
NO C.Y.	MEASUREMENT NO. STA 0+00.00 TO STA 0+40.00 LT
NO C.Y.	MEASUREMENT NO. STA 0+40.00 TO STA 0+80.00 LT
CC 00010	SELECTED RACETAIL USING ASHITO MIST AGGREGATE
NO C.Y.	MEASUREMENT NO. STA 0+00.00 TO STA 0+40.00 LT
CC 00020	CLASS II RIPRAP DITCH
NO C.Y.	MEASUREMENT NO. STA 0+00.00 LT
CC 00030	BOTTOM CUTOFF WALLS FOR CLASS II RIPRAP
NO C.Y.	MEASUREMENT NO. STA 0+00.00 LT
CC 00040	MAX. 2 CONCRETE FOR MISCELLANEOUS STRUCTURES
NO C.Y.	MEASUREMENT NO. STA 0+00.00 LT
CC 00050	REMOVE AND REPLACE TRAFFIC BARRIER IN BEAR
NO C.Y.	MEASUREMENT NO. STA 0+00.00 TO STA 0+40.00 LT
CC 00060	TYPE X TRAFFIC BARRIER END TREATMENT, ANY OPTION
NO C.Y.	MEASUREMENT NO. STA 0+00.00 LT

**Alvi Associates, Inc.**  
CONSULTING ENGINEERS  
BALTIMORE, MARYLAND

N 366601  
E 1309510

N 366403  
E 1309510



STATE OF MARYLAND  
DEPARTMENT OF TRANSPORTATION  
STATE HIGHWAY ADMINISTRATION  
OFFICE OF ENVIRONMENTAL DESIGN

MD 210 CUTOFF STRUCTURE AND CHANNEL STABILIZATION  
FOR TRUCK

**SITE 10 — SHA STR 1601778.001 PLAN SHEET**

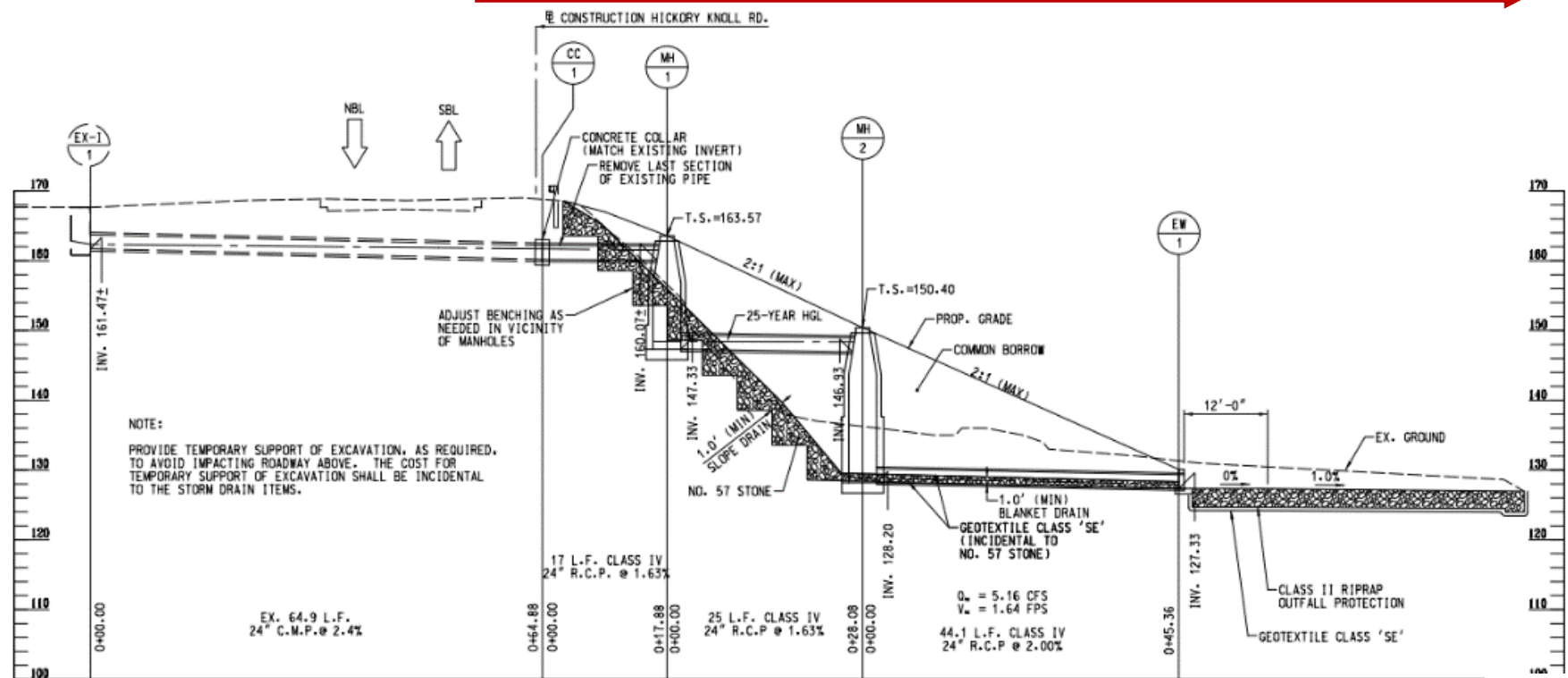
SCALE: 1" = 20'	REVISIONS	CONTRACT NO.
DESIGNED BY: JLS	DATE: 10/10/01	
CHECKED BY: JLS	DATE: 10/10/01	
DATE: 10/10/01	DATE: 10/10/01	
PROJECT NO. DD-01 (10) OF 01	SHEET NO.	



STATE HIGHWAY  
ADMINISTRATION

# MD 210 SITE 10 – PROFILE VIEW

Proposed Length of Credit – Erosion had expanded to beneath SB lanes prior to construction.







PRE – CONSTRUCTION: ERODED  
ROADWAY EMBANKMENT , SPRING 2016



POST – CONSTRUCTION, 11/7/2018

MD 210 SITE 10 – PHOTO LOCATION 1





PRE – CONSTRUCTION: ERODED  
ROADWAY EMBANKMENT, SPRING 2016



POST – CONSTRUCTION 11/7/2018

MD 210 SITE 10 – PHOTO LOCATION 2





PRE – CONSTRUCTION: ENTRENCHED CHANNEL  
SPRING 2016

MD 210 SITE 10 – PHOTO LOCATION 3



POST – CONSTRUCTION  
11/7/2018





PRE - CONSTRUCTION: FAILED PIPE AND ERODED ROADWAY EMBANKMENT , SPRING 2016



POST - CONSTRUCTION

11/7/2018

## MD 210 SITE 10 – PHOTO LOCATION 4





## I-97 OUTFALL

- Anne Arundel County, Maryland
- Length of project = 450 lf
- Construction Completed = 2016
- Key Project components
  - Manhole installation
  - Step pool pattern
  - Plunge pool infiltration window
  - Plunge pool
  - Slope stabilization
  - Vegetative plantings

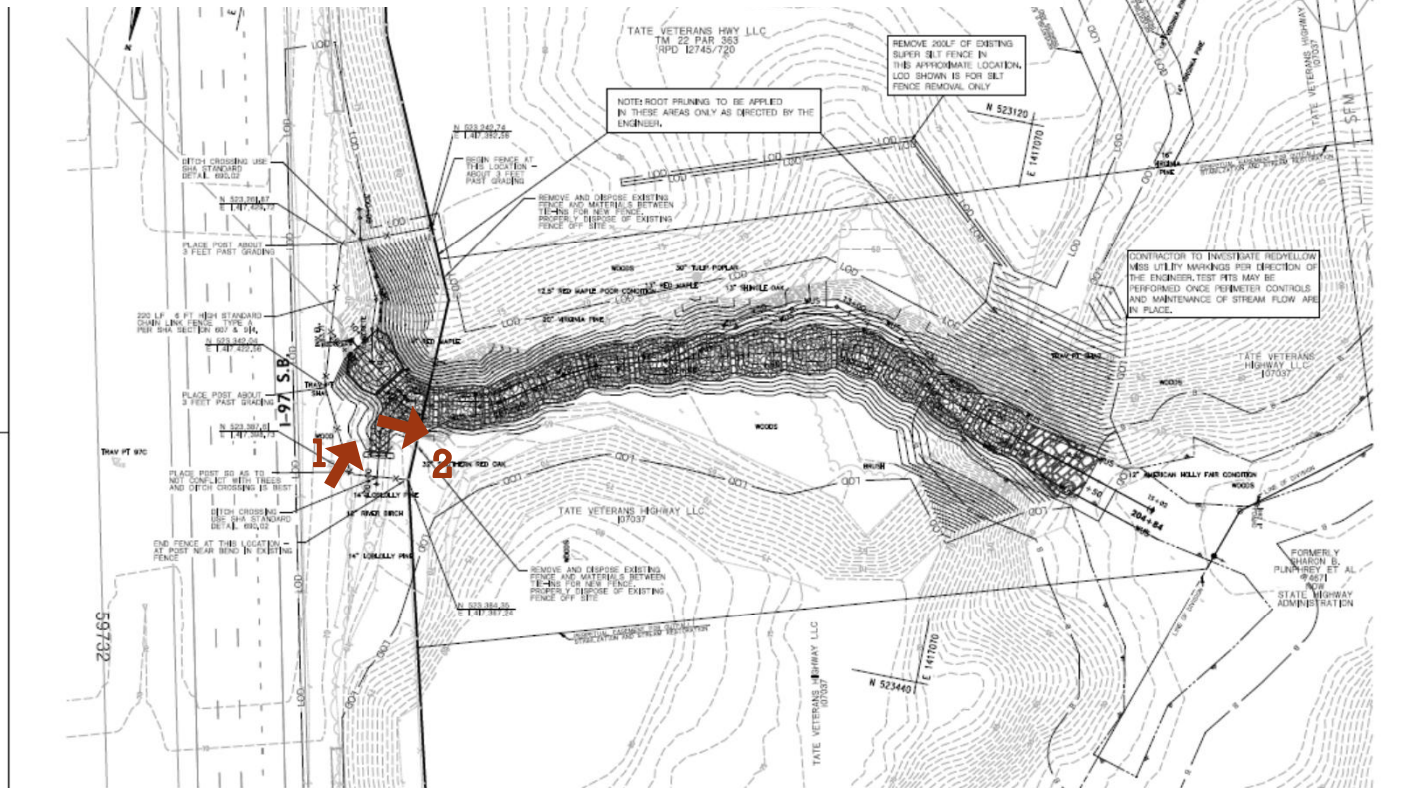
# I-97 - PERMITS

- Maryland Department of the Environment NTWW
  - Letter of Authorization
- ACOE - MDSPGP
- Forest Conservation Plan
- Anne Arundel Soil Conservation District
- Stormwater Management and Erosion & Sediment Control Permit
- NPDES NOI





# I-97 OUTFALL - PLAN VIEW



**McCormick Taylor**  
509 South Exeter Street  
4th Floor  
Baltimore, Maryland 21202  
(410) 862-4000

**LEGEND**

- TOE BOULDER
- STEP-POOL STRUCTURE
- COBBLE RIFFLE
- PLUNGE POOL/INFILTRATION TREATMENT FOREBAY
- DRAINAGE STABILIZATION

ITEM	CROSS REFERENCE	SHEET NO.	S. / W. PLAT NUMBER	REMARKS
ADDITIONS / CORRECTIONS		1		
ACCESS PLAN		2		
GEOTECHNICAL LOGS		3		
HYDROLOGICAL DATA		4		
STREAM RESTORATION PLAN SHEET		5		
UNIFORM AND VARIATION CONTROL SHEETS		6		
MAINTENANCE OF TRAFFIC SHEET		7		
UNIFORM SHEET		8		
STREAM PROFILES		9		
CROSS SECTIONS		10		

QUANTITY NOTES

STEP-POOL STRUCTURE TABLE		
STRUCTURE	STATION FROM	STATION TO
STEP-POOL CREST	200+31	200+36
STEP-POOL POOL	200+36	200+59
STEP-POOL CREST	200+59	200+64
STEP-POOL POOL	200+64	200+67
STEP-POOL CREST	200+67	200+92
STEP-POOL POOL	200+92	201+10
STEP-POOL CREST	201+10	201+20
STEP-POOL POOL	201+20	201+43
STEP-POOL CREST	201+43	201+48
STEP-POOL POOL	201+48	201+71
STEP-POOL CREST	201+71	201+76
STEP-POOL POOL	201+76	201+99
STEP-POOL CREST	201+99	202+04
STEP-POOL POOL	202+04	202+27
STEP-POOL CREST	202+27	202+32
STEP-POOL POOL	202+32	202+55
STEP-POOL CREST	202+55	202+60
STEP-POOL POOL	202+60	202+83
STEP-POOL CREST	202+83	202+88
STEP-POOL POOL	202+88	203+11
STEP-POOL CREST	203+11	203+16
STEP-POOL POOL	203+16	203+39
STEP-POOL CREST	203+39	203+44
STEP-POOL POOL	203+44	203+69
STEP-POOL CREST	203+69	203+74
STEP-POOL POOL	203+74	203+99
STEP-POOL CREST	203+99	204+04

**PLUNGE POOL/INFILTRATION TREATMENT FOREBAY**

STATION FROM	STATION TO
200+05	200+31

**COBBLE RIFFLE**

STATION FROM	STATION TO
204+04	204+44

**TOE BOULDER PROTECTION**

STATION FROM	STATION TO
300+20, LT	300+70, LT

**DRAINAGE STABILIZATION**

STATION FROM	STATION TO
400+15	400+45

**SHA** STATE OF MARYLAND  
DEPARTMENT OF TRANSPORTATION  
STATE HIGHWAY ADMINISTRATION  
OFFICE OF ENVIRONMENTAL DESIGN  
**I-97 SB OUTFALL STABILIZATION**  
**WEST OF EAST-WEST BOULEVARD**

**STREAM RESTORATION PLAN SHEET**

SCALE	DATE	CONTRACT NO.	ADDRESS
1"=40'	8/1/01		

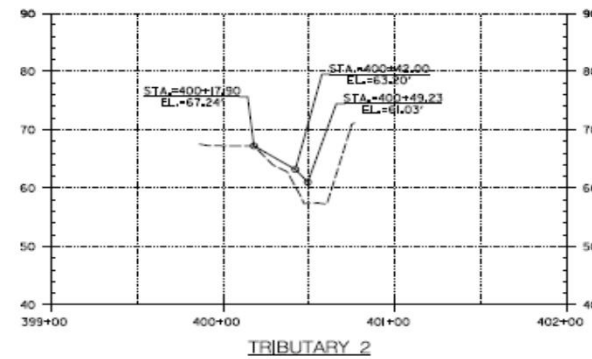
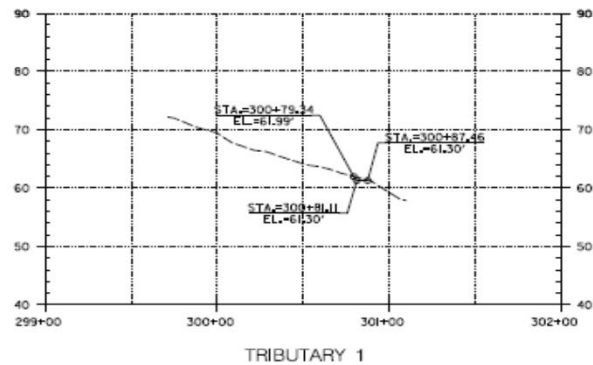
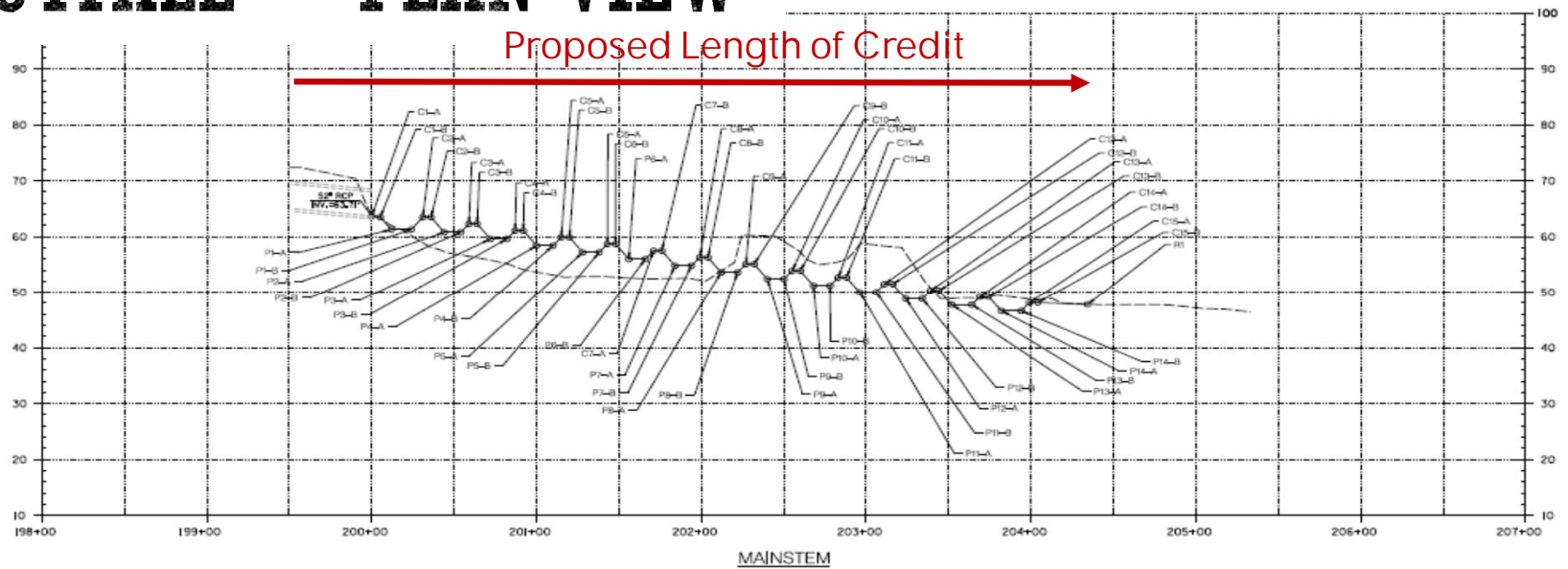
DESIGNED BY	CHECKED BY	DATE	COUNTY	JANE ARNOLD COUNTY
W. J. WILSON	W. J. WILSON	8/1/01		

LOCATION	HORIZONTAL SCALE	VERTICAL SCALE
1/4"=10'	1"=40'	1"=40'

DRAWING NO.	SHEET OF	SHEET NO.	OF
10000000	1	1	1



# I-97 OUTFALL — PLAN VIEW





PRE - CONSTRUCTION: OUTFALL CHANNEL,  
LOOKING DOWNSTREAM

6/10/2013

## I-97 OUTFALL - PHOTO LOCATION 1



POST - CONSTRUCTION

11/14/2018





PRE – CONSTRUCTION: OUTFALL  
CHANNEL FACING DOWNSTREAM

6/10/2013



POST – CONSTRUCTION – LOOKING UPSTREAM  
11/14/2018

I-97 OUTFALL – PHOTO LOCATION 2





POST - CONSTRUCTION

2/26/18

## AVALON SITE

- Patapsco Valley State Park
- Howard County, Maryland
- Length of project = 240 lf
- Construction Completed = 2018
- Key Project components
  - Plunge pool
  - Step pool structures
  - Vegetative plantings
  - Rock cascade
  - Floodplain creation

# AVALON- PERMITS

- MDE Letter of Authorization
- US ACOE TMDL RGP
- As-Built Drawings completed as part of construction
- Stormwater Management and Erosion & Sediment Control Permit
- NPDES NOI



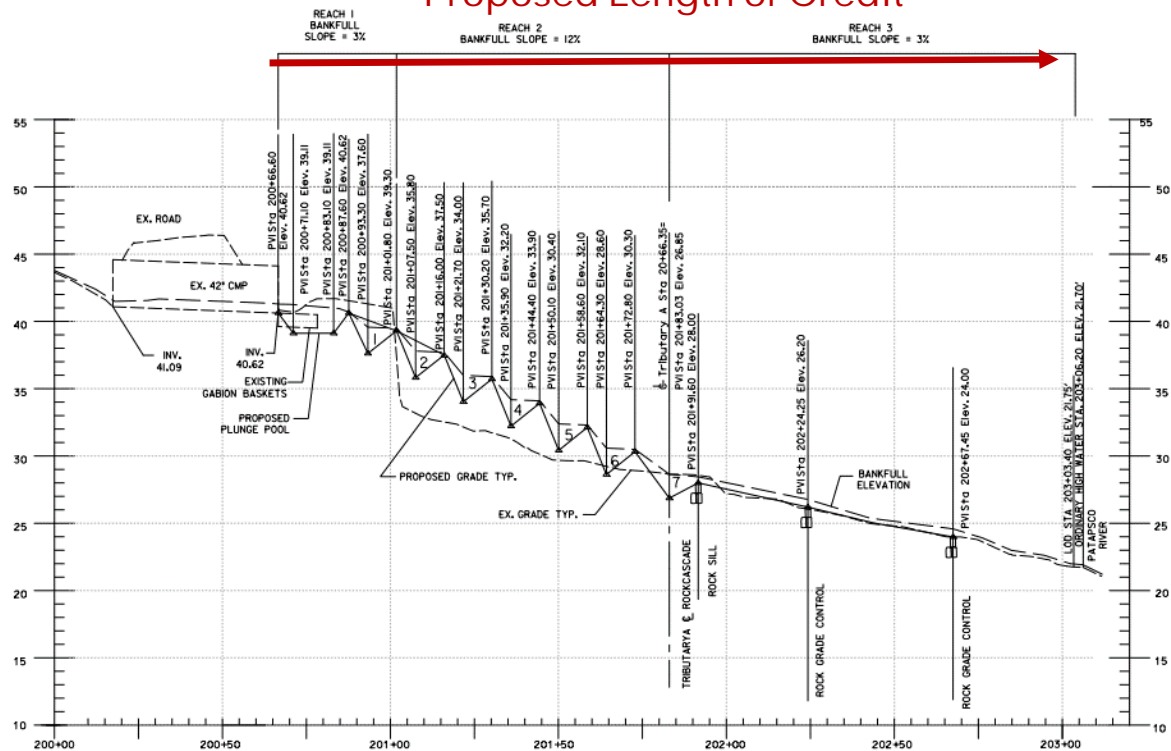






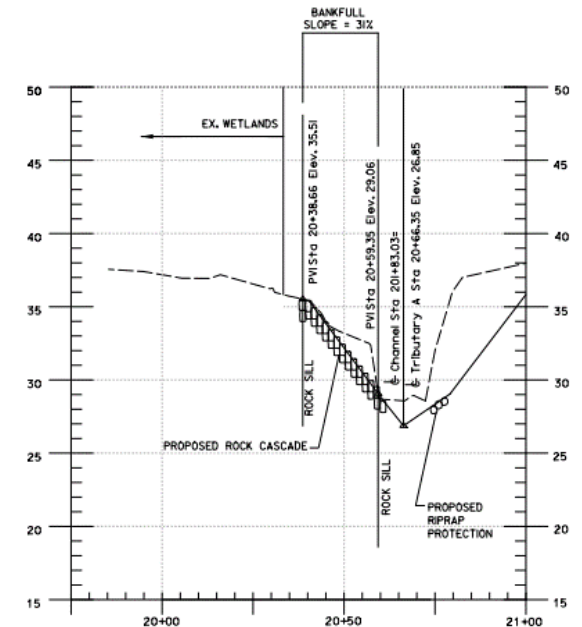
# AVALON — PROFILE VIEW

Proposed Length of Credit



AVALON — PROFILE THROUGH CENTERLINE OF STREAM

SCALE: HOR. 1" = 20'  
VERT. 1" = 5'



PROFILE THROUGH TRIBUTARY A

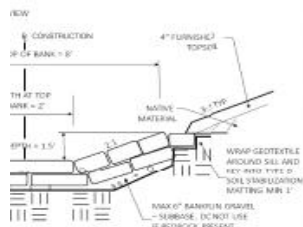
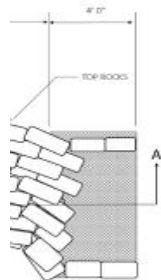
SCALE: HOR. 1" = 20'  
VERT. 1" = 5'

# AVALON — DETAIL

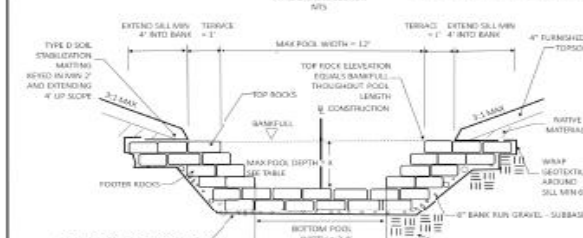
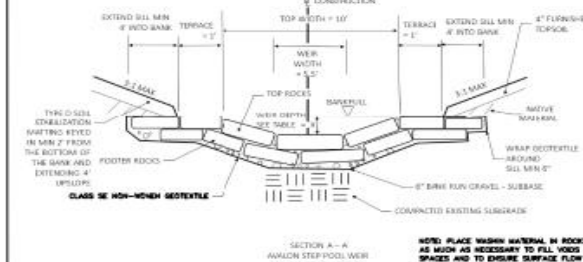
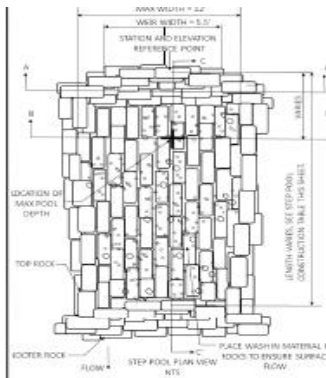
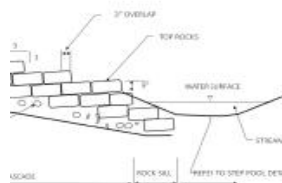
PTS	HEIGHT (FT)
0.75	
0.75	

EACH DIMENSION

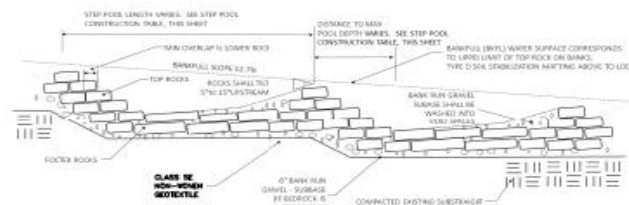
FOR  
PLATE: RAMP IN OVERFLOW  
GRAVEL - SUBBASE TO TOP ROCKS  
TO ENSURE POSITIVE FLOW



NOTE: PLACE WASH MATERIAL IN ROCKS  
ON TOP ROCKS TO ENSURE  
SURFACE FLOW



STRUCTURE #	FEATURE	STATION	LEFT OFFSET DISTANCE (FT)	LEFT TYPICAL ELEVATION (FT)	DL ELEVATION (FT)	RIGHT OFFSET DISTANCE (FT)	RIGHT TYPICAL ELEVATION (FT)	X DEPTH (FT)
1	WTR	200+00.0	5	80.0	80.0	5	80.0	0.2
2	POOL	200+00.0	0	79.5	79.5	0	79.5	2
3	WTR	200+00.0	5	79.5	79.5	5	79.5	0.2
4	WTR	200+00.0	5	79.5	79.5	5	79.5	0.2
5	WTR	200+00.0	5	79.5	79.5	5	79.5	0.2
6	WTR	200+00.0	5	79.5	79.5	5	79.5	0.2
7	WTR	200+00.0	5	79.5	79.5	5	79.5	0.2
8	WTR	200+00.0	5	79.5	79.5	5	79.5	0.2
9	WTR	200+00.0	5	79.5	79.5	5	79.5	0.2
10	WTR	200+00.0	5	79.5	79.5	5	79.5	0.2



ROCK WALL	LENGTH (FT)	WIDTH (FT)	HEIGHT (FT)
TOP ROCK	2.0	1.25	0.75
FOOTER ROCK	2.0	1.25	0.75

A TOLERANCE OF ±0.1" IS ALLOWED FOR EACH DIMENSION

NOTE: PLACE WASH MATERIAL IN ROCKS AS MUCH AS POSSIBLE TO ENSURE POSITIVE FLOW

NOTE: IF BEDROCK IS PRESENT IN THE AREA OF INSTALLATION, COVER ROCKS SHALL BE INSTALLED AT THE DISCRETION OF THE ENGINEER

### DETAIL D-4-2 PLUNGE POOL

**CONSTRUCTION SPECIFICATIONS**

- USE SPECIFIED GRADE OF BRICK.
- USE NONWATER-RESISTANT BRICK AS SPECIFIED IN SECTION D-4-1 MATERIALS, AND PROTECT FROM FLOODING, CORROSION, AND OTHER DAMAGE BY COVERING WITH A MINIMUM OF 2" OF GRAVEL OR OTHER MATERIAL OVER THE EXPOSED SURFACE OF THE BRICK. THE GRAVEL SHALL BE PLACED IN A MANNER THAT IT WILL NOT BE DISLOADED BY THE FORCE OF THE WATER.
- REPAIR THE BRICKWORK FOR THE PLUNGE POOL TO THE ORIGINAL CONDITION AND FINISH. REPAIRS SHALL BE MADE TO THE BRICKWORK TO A DEPTH OF AT LEAST 2" AND TO THE SURROUNDING BRICKWORK TO A DEPTH OF AT LEAST 4".
- REMOVE THE BRICKWORK TO A DEPTH OF AT LEAST 2" AND TO THE SURROUNDING BRICKWORK TO A DEPTH OF AT LEAST 4".
- AT THE PLUNGE POOL, BRICK SHALL BE PLACED TO THE SURFACE OF THE BRICKWORK.
- BRICKWORK SHALL BE PLACED TO THE SURFACE OF THE BRICKWORK.

APPROVED: **STATE OF MARYLAND**  
DEPARTMENT OF TRANSPORTATION  
STATE HIGHWAY ADMINISTRATION  
OFFICE OF ENVIRONMENTAL DESIGN  
TMDL STREAM RESTORATION  
AT PATAPSCO VALLEY STATE PARK - (AVALON)

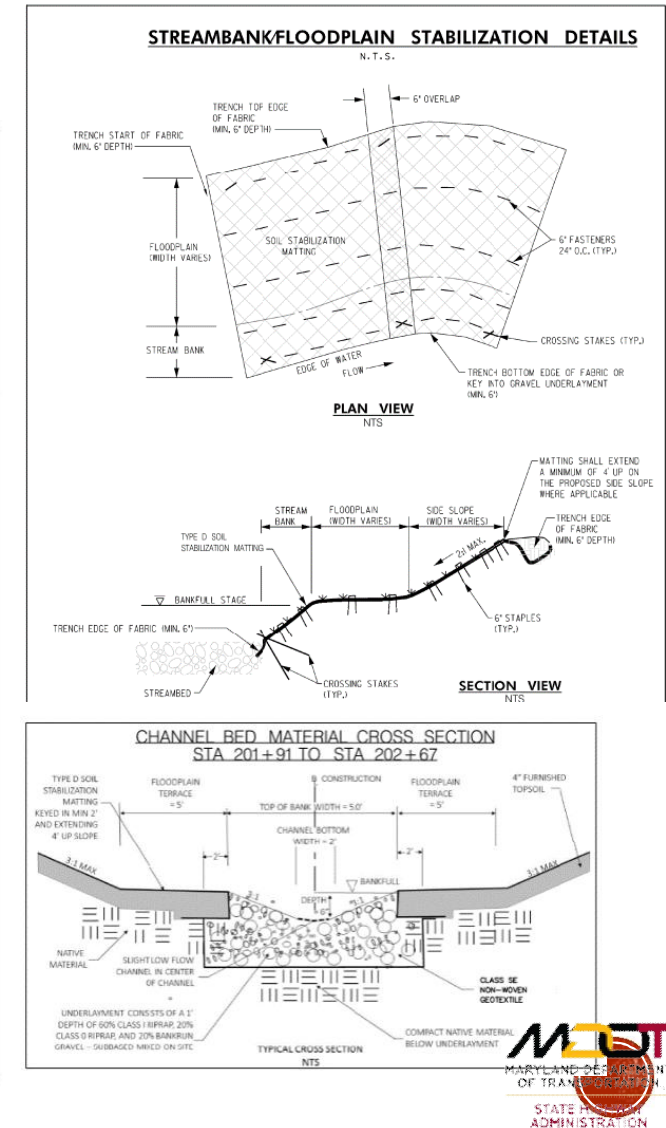
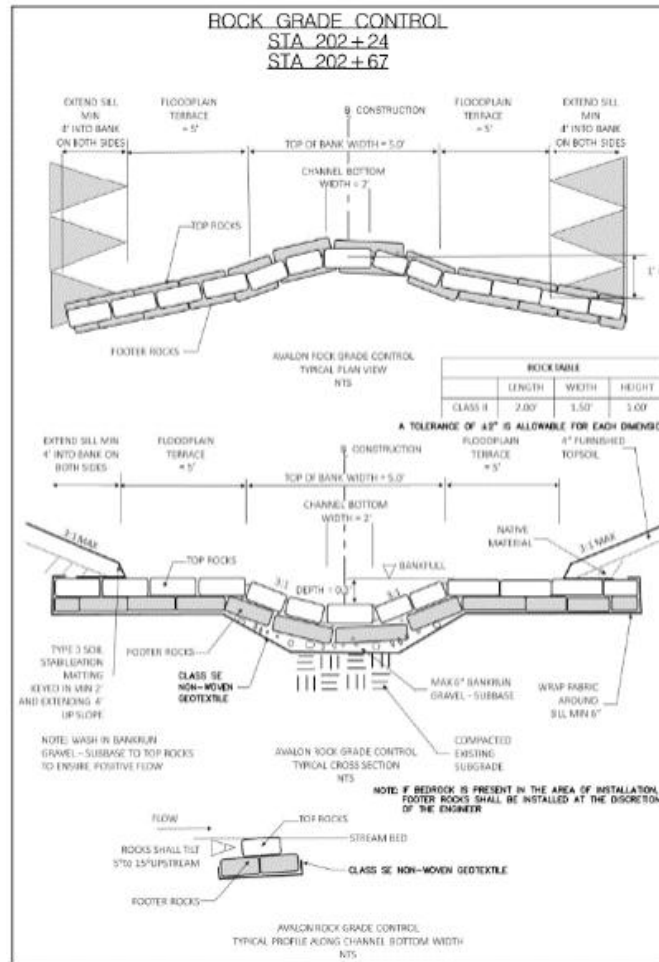
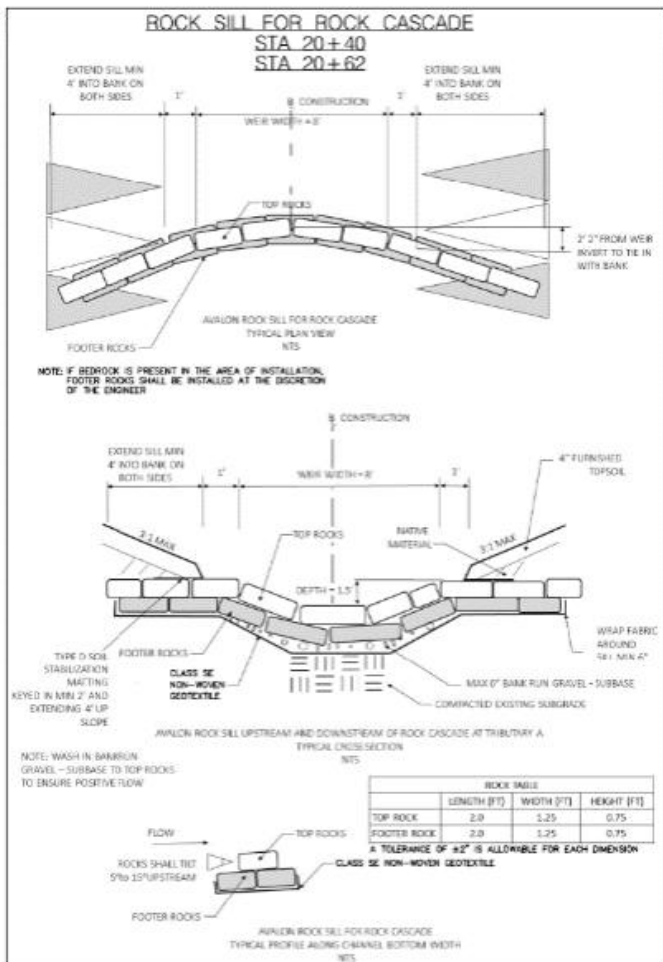
### TYPICAL SECTIONS AND DETAILS

DESIGNED BY: COUNTY:

DRAWN BY: LOCALITY:

CHECKED BY: HORIZONTAL SCALE:

# AVALON — DETAIL







PRE-CONSTRUCTION: PIPE OUTFALL

6/27/2014



POST - CONSTRUCTION

11/7/2018

AVALON - PHOTO LOCATION 1





PRE – CONSTRUCTION: NEAR VERTICAL  
BANKS AND UNDERCUT TREES

6/27/2014



POST – CONSTRUCTION

11/7/2018

# AVALON – PHOTO LOCATION 2





PRE – CONSTRUCTION: OUTFALL AT  
THE PATAPSCO RIVER

3/1/2013



POST – CONSTRUCTION

11/7/2018

AVALON – PHOTO LOCATION 3



## **Appendix C. Guidance for Screening Potential OGSP Sites**

Evaluation for the Relative Comparison of Erosion Potential between  
Potential Project Sites

and

How to Use the Concept as a Planning Tool

# Method 1: GIS Analysis for Ranking Potential Sites in Site Searches

## **Compile GIS data for:**

- Stormwater infrastructure (outfalls, pipes, inlets, etc.)
- Right-of-way
- Digital Elevation Model (DEM)
- Stream and ditch network

## **GIS Analysis**

- Develop an automated GIS model that will analyze outfall and/or headwater channel locations to determine the downstream distance from the outfall to the edge of right-of-way and the net change in elevation over this distance.
- The GIS model can generate a polyline feature class with lines originating from the outfalls and extending along the stream network to the edge of right-of-way. For each line generated by the model, attributes will be populated for a unique outfall identifier, the distance of the line, the elevation at the start of the line, the elevation at the end of the line, and the net change in elevation.
- After processing, potential projects lists can be generated for each watershed, ranked in distance to the right-of-way and in elevation change. Outfalls with the greatest distance and elevation change are prioritized for future detailed assessment.



# Method 2 - Development of a Planning Tool Using One Field Visit

(Likely Higher Accuracy than GIS method)

- Locate outfall assets and/or headwater channels, identify length of site and location of headcut features and base level control
- Digitally connect a stream centerline to site features (available data, low point in topography, flow path derivation analysis)
- Snap each knickpoint to the stream centerline (via map markup or GPS).
- Delineate the stream centerline at the downstream most knickpoint. Everything upstream of the most downstream knickpoint is considered the “reach”. Verify/document the closest downstream and upstream base control (road crossing, utility, bed rock, etc.)
- Working the way upstream, if multiple knickpoints are evident within the reach line, set breaks at each knickpoint, designate as “segments”.
- For each segment, compute the depth as the cumulative total of the knickpoint depths located downstream. Labeled the depth of each knickpoint in the mapping, along with the cumulative segment depth.
- Stream width should be calculated using an appropriately selected Regional Curve relationship (based on Physiographic Province and Drainage Area). Or top and bottom channel widths can be measured.
- Compute the volume for each segment (length \* width \* cumulative depth). (Slope is not used, depth is assumed to follow slope)
- Convert to proper units using bulk density and nutrient concentration assumptions

## Method 3 - Development of a Planning Tool Using GIS and Empirical Data

- Locate outfall assets, identify length of site from outfall to confluence or other base level control point
- Digitally connect to a stream centerline as a reach (available data, low point in topography, flow path derivation analysis)
- Determine the elevation change from the asset to the control point (most often will be confluence)
- Calculate elevation change x Site Length metric
- For each reach use the equations identified on the next slide within these data set ranges:
  - Elevation Change x Site Length between 0 and 1,200
  - Elevation Change x Site Length between 1,200 and 17,000
- Convert to proper units using bulk density and nutrient concentration assumptions

# Erosion Potential for Sites with Elevation Change x Site Length between 0 and 17,000

