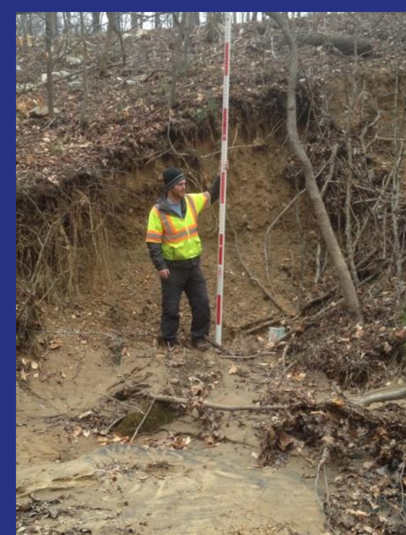
Alternative Headwater Channel And Outfall Crediting Protocol

Maryland Department of Transportation State Highway Administration

April 2018





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AGENDA

- **Why do we need an Alternative Headwater Crediting Method?**
- **What is the proposed protocol?**
- **How will the protocol be implemented?**
  - Case Studies
- **Recommendations**

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Why Is An Alternative Headwater Credit Protocol Needed?

- **MDOT SHA has over 36,000 outfalls in the MS4 counties, majority in headwater channels**
  - Met current design standards at time
  - Many receive off-site drainage beyond control of MDOT SHA
- **Restoration / Enhancement Potential**
  - ~12% of the outfalls assessed to date have potential for restoration/enhancement
- **Headwater channels for credit are retrofitted for these reasons**
  1. Change in hydrologic/hydraulic conditions since original design
  2. Downstream headcut migration changed base level conditions

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What do the Outfall Channels Look Like?

MD 210,
Site 3:
Moderate Erosion

I-270 at Montrose Road:
Extreme Erosion

Example Eroded Outfalls

MD 210, Site 10: ***Severe Erosion***

MD 210, Site 4: ***Channel Erosion***

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What Is The Basis for MDOT SHA's Proposed Alternative Headwater Channel Credit Protocol?

- **Based on Literature Review**
- **Looks at Source of Sediment –** Upland erosion from sources such as outfalls and slope erosion are significant sediment sources in the watershed.
  - "*Erosion of upland land surfaces and erosion of stream corridors (banks and channels) are the two most important sources of sediment coming from the watershed.*[1]"
  - "*Sediment yield from suburban first order watersheds was the largest of the land classes (suburban, forest and agricultural land cover)*[2]"

1 - A Summary Report of Sediment Processes in the Chesapeake Bay and Watershed. WRI Report 03-4123 (2003).
2 – Upland Sediment Supply and its relation to watershed sediment delivery in the contemporary mid-Atlantic Piedmont, Geomorphology 232 (2015) 33-46.

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Why not use the 2 acre maximum credit for outfall treatment?

- To maintain a safe highway system, many of the eroded outfalls could be treated with drop structures and/or retaining walls within MDOT SHA right of way
  - Does not address downstream channel erosion
  - Does not prevent additional erosion and sediment loss from occurring in downstream channel until channel stabilizes
  - Does not consider resiliency and long term stability of downstream channel
- Restoring the entire downstream channel to a stable base level often requires MDOT SHA to act beyond its current right of way
  - Increased costs
  - Increased need to acquire right of way
- Extra effort to improve downstream water quality should receive additional credit proportional to the amount of sediment loss prevented.

Alternative Headwater Channel Credit Method

- Started with Protocol 1: Credit for Preventing Sediment During Storm Flows for Stream Restoration Projects
  - Annual sediment loading
  - Convert to annual TN and TP loading
  - Pollution reduction of project

- Goals for Alternative Headwater Channel Credit Method
  - Develop a defensible, repeatable method to compute annual sediment loading for headwater and outfall channels
  - Conversion to impervious area equivalent

Recommendations of the Expert Panel to Define Removal Rates for Individual Stream Restoration Projects

Joe Berg, Josh Burch, Deb Cappuccitti, Solange Filoso, Lisa Fraley-McNeal, Dave Goerman, Natalie Hardman, Sujay Kaushal, Dan Medina, Matt Meyers, Bob Kerr, Steve Stewart, Bettina Sullivan, Robert Walter and Julie Winters

Accepted by Urban Stormwater Work Group: **February 19, 2013**
Approved by Watershed Technical Work Group: **April 5, 2013**
Final Approval by Water Quality Goal Implementation Team: **May 13, 2013**

Prepared by:
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and
Bill Stack, Center for Watershed Protection

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Alternative Headwater Channel Credit Method

- Compares existing condition versus future equilibrium state
- Sediment load reduction is computed by comparing the difference between the existing surface and the equilibrium surface.
- Future surface is based on:
  - Equilibrium Bed Slope
  - Base Level Selection

    Defines wedge of potential sediment loss
  - Bank Angle
  - Bottom Width

    Defines new stable cross section template
- Output = Total Sediment Yield per Year (CF/CY)

Determination of Base Level Control

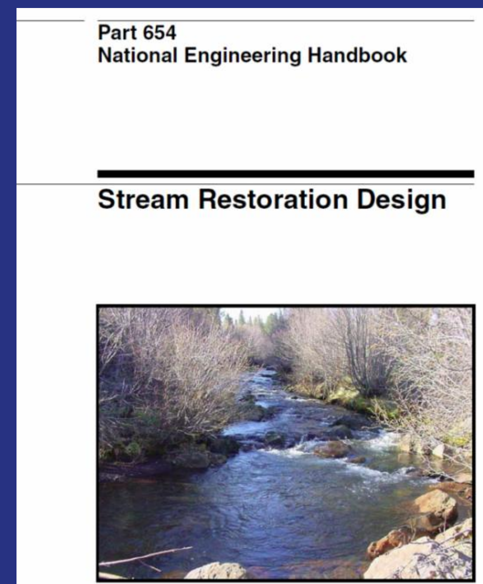
Three methods can be used to establish the base level control.

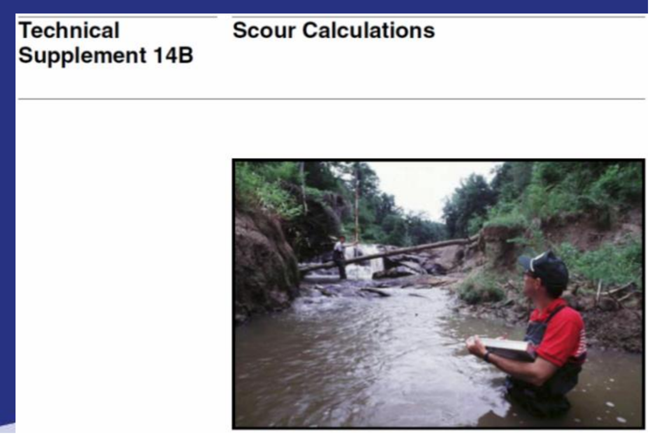
1. **Hard Point Control –** most permanent base level control, represents a channel condition which has the strength to withstand any expected condition within project lifespan
    1. Bedrock or existing infrastructure
2. **Confluence with Downstream Channel** – when outfall channel meets a stable larger receiving stream
3. **Equilibrium Slope** – when the existing channel is within 5% of the equilibrium slope, it is assumed to be a stable base level condition

Case 1 & 2 were used for all of the case studies. Case 3 is also a potential, but we anticipate that it will be infrequently used.

Computation of Equilibrium Bed Slope

- **Future (Equilibrium) Bed Slope**
- **Headwater Channels are typically supply limited –** slope adjustment in a sediment deficient reach occurs by degradation proceeding from upstream to downstream where the downstream end is often limited by a base level control.
- **Function of drainage area -** S_{eq} are greater for smaller drainage areas and therefore must be computed on a reach by reach basis.
- Equations are based on existing channel bed materials and upstream sediment supply. Refer to table TS 14B-5 for specific details





From Technical Supplement 14B Scour Calculations of NRCS Stream Restoration Manual (Part 654 of NEH)

Computation of Equilibrium Bed Slope

- For I-97 Example:
  - Equilibrium slopes were computed at three cross section locations within each study reach
    - Average, Min and Max Slopes
    - 1.5-yr, 10-yr and 100-yr recurrence intervals
  - Sand Bed Reach: Range of potential S_{eq} values ranged from 0.0537 to 0.0983 percent for the three Q's assessed
    - Selected 0.0733 percent (10-yr recurrence interval) for the sand bed reach
  - Riprap Reach: Range of potential S_{eq} values ranged from 2.06 to 2.80 percent
    - Selected 2.4 percent (10-yr recurrence interval) for the riprap reach

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I-97 Outfall – Pre & Post Construction

Pre-Construction

Post – Construction
May 2016

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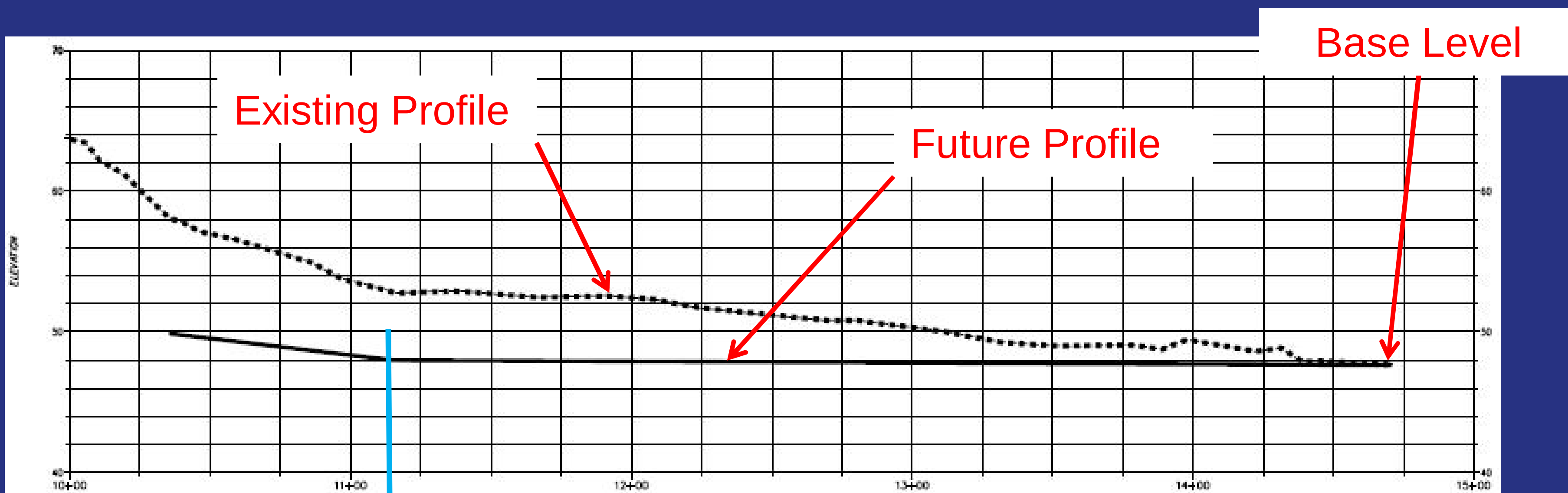
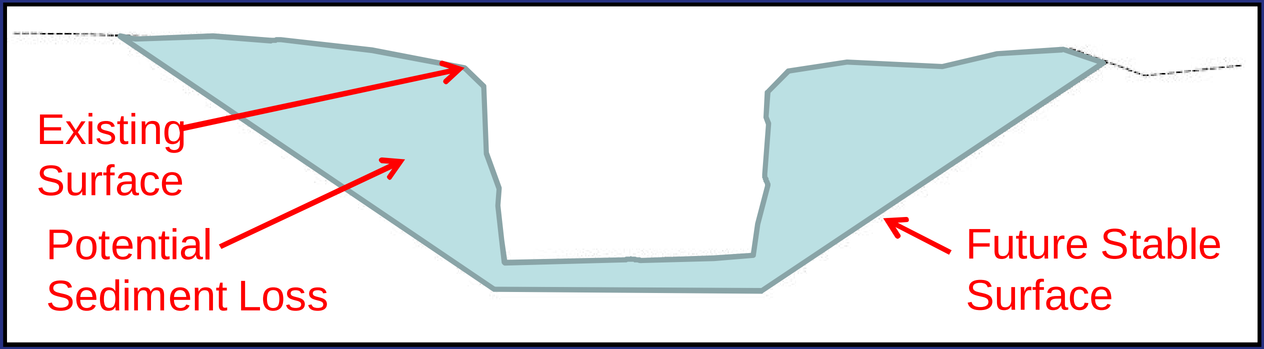
Computation of Equilibrium Bed Slope
I-97 Example



Riprap reach –
note steeper equilibrium
slope of 2.4 percent

Sand bed reach –
note flatter equilibrium slope of 0.0733 percent

Bank Stability



Relationships for:

- No Seepage – evaluating slope stability above water table
- Seepage Flowing generally parallel to slope – soils with minimal layering
- Seepage Flowing generally along horizontal flow paths – soils with layered alluvial deposits

Future banks angle

- mH:1V
- Utilizing a constant bank slope was assumed to be the best approach and is consistent with recent modeling efforts for bed and bank evolution (Cantelli et al 2007)

From Technical Supplement 14A Soil Properties and Special Geotechnical Problems of NRCS Stream Restoration Manual (Part 654 of NEH)

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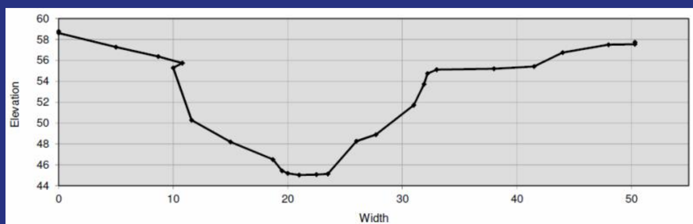
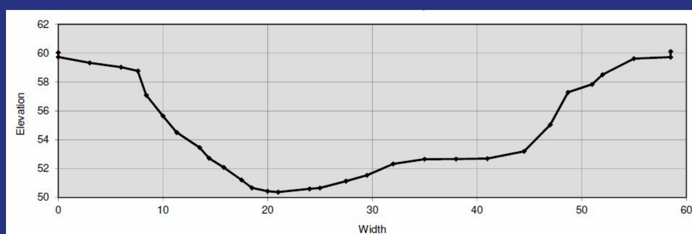
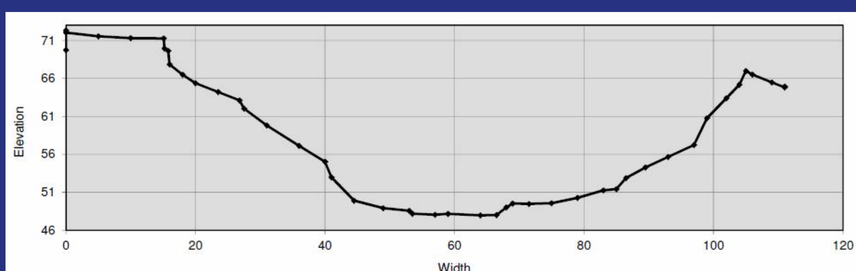
Bottom Width



Upstream



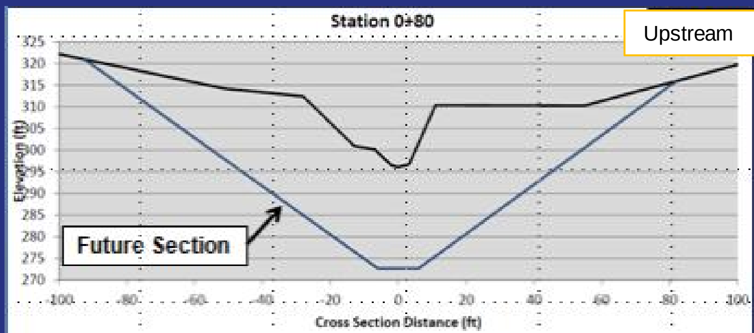
Middle

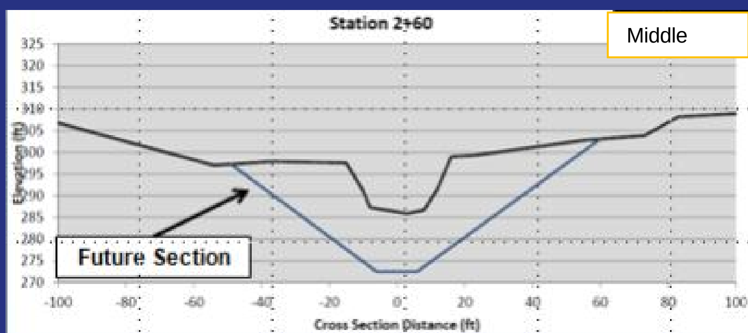


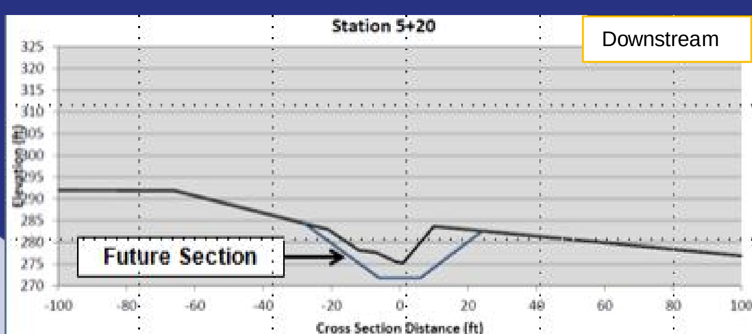
Downstream

- **Limited ability to predict (calculate) future bottom width**
- **For headwaters, the most appropriate predictor of bottom width is assumed to be within the study reach**
    - Bottom width should be average of the reference cross sections within study area
- **Project specific, determined by taking multiple field measurements**

Computation of Equilibrium Bank Slope I-270 Example







- **Template Cross Section**
  - 12 ft bottom width
  - Medium dense sand bank material
  - Future bank angle = 1.76:1 (H:V)
- Upstream & Middle Reaches
  - Avg Slope = 4.3%
  - Sand bed (D_{50} = 1.6 mm)
  - Future slope = 0.15%
- Downstream Reach
  - Avg Slope = 3.5%
  - Gravel bed (D_{50} = 20 mm)
  - Future slope = 0.33%

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Summary
Alternative Headwater Channel Prevented Sediment Credit Method

Future Slope + Future Bank Angle + Future Bottom Width → Future Surface

- Provides total volume or mass of sediment to be eroded
  - No credit given for sediment already lost
- Convert to annual time frame
  - Time frames in literature varied between 15 and 50 years.
  - 15 is least conservative, 50 most conservative
  - 30 years is an average assumption and can be supported in literature
- MDOT SHA Case Studies Completed for a variety of scenarios
- Alternative Method – Assumes credit in perpetuity for properly inspected & maintained sites

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Sample Credit Computation

- Step 1: Collect Base Site Data
- Step 2: Compute Volume of Erosion
- Step 3: Convert Volume of Erosion to Weight of Erosion
- Step 4: Determine Nutrient Concentration (either measured or assumed)
- Step 5: Compute Total Nutrient/Pollutant Removal
- Step 6: Convert Total Nutrient/Pollutant Removal to Nutrient Removal Per Yr
- Step 7: Determine Average Pollutant Load Reduction (lbs/ac/yr)
- Step 8: Determine Impervious Acre Conversion Factor for all pollutants
- Step 9: Compute Average of TN, TP and TSS
- Step 10: Compute Avg Acres of Treatment per Linear Foot
- Step 11: Multiply Length of treatment x Avg Acres of Treatment Per Linear Foot
- Step 12: Compute Impervious Area Equivalent

Sample Credit Computation

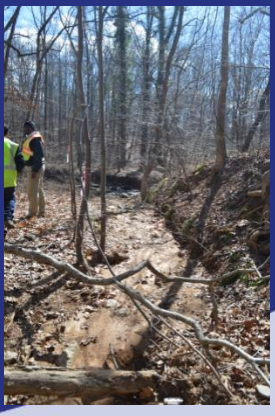
- Step 1: Collect Base Site Data
  - Watershed area
  - Geomorphic survey (cross section & profile)
  - Bank and bed material
  - Determine number of unique assessment reaches

	Step 1																			
Site Name	Site Length (Linear Feet)	Watershed Area (Acres)	10-year Discharge (cfs)	Number of Unique Assessment Reaches	Representative Channel Bed Grain Size (mm or as noted) *			Representative Cross Sections			Relationships Used to Estimate Future Slope **			Average Future Slope (%)			Bank Material Description	Internal Friction Angle (degrees)	Bank Slope (H:V)***	Bottom Width (feet)
					Reach 1	Reach 2	Reach 3	Reach 1	Reach 2	Reach 3	Reach 1	Reach 2	Reach 3	Reach 1	Reach 2	Reach 3				
I-97	450	30	120	3	Class III Riprap	Class I Riprap	D50 = 0.6 mm	--	XS-1; XS-2; XS-3	XS-1; XS-2; XS-3	--	S&FG	M&S; MPM; SE; HF	--	2.4	0.073	Sand (Medium Dense)	32	1.76:1	31
I-270 at Montrose Road	580	18.1	70.0	2	D50 = 0.7 mm; D50 = 1.6 mm	Dm = 18 mm; D50 = 20 mm; D90 = 64 mm	--	XS-1; XS-2	XS-3	--	S&FG	M&S; MPM; SE; HF	--	0.15	0.33	--	Sand (Medium Dense)	32	1.76:1	12.0
Furnace Avenue	300	30.3	61.1	2	Class I Riprap	Dm = 22 mm; D50 = 26 mm; D90 = 150 mm	--	XS-1	XS-2	--	M&S; MPM; SE; HF	M&S; MPM; SE; HF	--	3.8	0.53	--	Silt Load; Silt Clay Loam	28	2.16:2	5.5

I-270: Upper

I-270: Middle

I-270: Lower



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Sample Credit Computation

- Step 2: Compute Volume of Erosion
  - Compute difference between existing and future surface
- Step 3: Convert Volume of Erosion to Weight of Erosion
  - Need Bulk Density – can be measured or assumed at expert panel value
  - For test cases, 11 out of 12 bulk densities were measured within the project area
  - For the MD 210 outfalls, two of the seven sites had measured bulk densities. The remaining 5 sites were assumed based on the two local samples.
  - I-270 project is still in design and bulk density measurements were not yet available

		Step 2		Step 3		
Site Name	Site Length (Linear Feet)	Volume of Erosion		Bulk Density		Weight of Erosion (tons)
		ft^3	yd^3	Value (lbs/ft^3)	Measured or Assumed	
I-97	450	69,964	2,591	74.7	Measured	2,613
I-270 at Montrose Road	580	851,277	31,529	80	Assumed	34,051
Furnace Avenue	300	55,230	2,046	86.6	Measured	2,391

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Sample Credit Computation

- Step 4: Determine Nutrient Concentration
  - For each independent project, nutrient concentrations have been measured.
  - For MD 210 project, nutrient concentrations were measured at one site and applied to the rest of the outfalls in the corridor.
- Step 5: Compute Total Nutrient/Pollutant Removal
  - Total Nutrient Removal (lbs) = Nutrient Concentration (lbs/ton) x Weight of Erosion (tons)
  - Apply 56% Efficiency Factor (Step 5A)

		Step 4			Step 5			Step 5A - Apply 56% Efficiency Factor		
Site Name	Site Length (Linear Feet)	Nutrient Concentration			Total Nutrient/Pollutant Removal			Total Nutrient/Pollutant Removal		
		TN (lbs/ton)	TP (lbs/ton)	Measured or Assumed	TN (lbs)	TP (lbs)	TSS (tons)	TN (lbs)	TP (lbs)	TSS (tons)
I-97	450	0.7	0.25	Measured	1829	653	2613	1,024	366	1,463
I-270 at Montrose Road	580	1.03	0.43	Measured	35,073	14,642	34,051	19,641	8,200	19,069
Furnace Avenue	300	3.92	1.18	Measured	9,375	2,822	2,391	5,250	1,580	1,339

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Sample Credit Computation

- Step 6: Convert Total Nutrient/Pollutant Removal to Nutrient Removal Per Year (lbs/yr)
  - Yearly credit is based on selected annual time frame
  - 30 year time frame chosen for analysis
  - Annual Nutrient Removal (lbs/yr) = Total Nutrient Removal (lbs) / 30 year average time frame
- Step 6A: Apply Sediment Delivery Factor (SDF)*
  - Total Annual Pollutant Load Reduction x 0.181 (For stream in Non-Coastal Plain)

							Step 6			Step 6A		
				Delta Impervious Surface and Forest			Total Annual Pollutant Load Reduction (30 yr)			Apply SDF (Non-Coastal Plain - 0.181)		
Site Name	Site Length (Linear Feet)	Total Watershed Area (Acres)	Impervious Watershed Area	TN (lbs/acre/yr)	TP (lbs/acre/yr)	TSS (tons/acre/yr)	TN (lbs/yr)	TP (lbs/yr)	TSS (tons/yr)	TN (lbs/yr)	TP (lbs/yr)	TSS (tons/yr)
I-97	450	30	16.5	7.69	1.91	0.43	34	12	49	6	2	9
I-270 at Montrose Road	580	18.1	9.4	7.69	1.91	0.43	655	273	636	118	49	115
Furnace Avenue	300	30.3	2.3	7.69	1.91	0.43	175	53	45	32	10	8

** SDF is dependent upon Chesapeake Bay Model. May change with next model update.*

Sample Credit Computation

- Step 7: Compute Average Pollutant Load Reduction (lbs/acre/yr)
  - Average Pollutant Load Reduction (lbs/acre/year) = Total Annual Pollutant Load (lbs/yr) / Watershed Area (ac)

							Step 7		
Site Name	Site Length (Linear Feet)	Total Watershed Area (Acres)	Impervious Watershed Area	Delta Impervious Surface and Forest			Average Pollutant Load Reduction		
				TN (lbs/acre/yr)	TP (lbs/acre/yr)	TSS (tons/acre/yr)	TN (lbs/acre/yr)	TP (lbs/acre/yr)	TSS (tons/acre/yr)
I-97	450	30	16.5	7.69	1.91	0.43	0.2	0.1	0.3
I-270 at Montrose Road	580	18.1	9.4	7.69	1.91	0.43	6.5	2.7	6.4
Furnace Avenue	300	30.3	2.3	7.69	1.91	0.43	1.0	0.3	0.3

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Sample Credit Computation

- Step 8: Compute the Impervious Area Conversion Factor for All Pollutants
  - Impervious Acre Conversion Factor = Avg Pollutant Load Reduction (lbs/ac/yr) / Delta Between Impervious Surface & Forest
- Step 9: Compute Average Impervious Acre Conversion Factor (TN, TP & TSS)
  - Average Impervious Acre Conversion Factor = Average (TN, TP & TSS)

							Step 8			Step 9
				Delta Impervious Surface and Forest			Impervious Acre Conversion Factor (AC/AC)			
Site Name	Site Length (Linear Feet)	Total Watershed Area (Acres)	Impervious Watershed Area	TN (lbs/acre/yr)	TP (lbs/acre/yr)	TSS (tons/acre/yr)	TN	TP	TSS	Average
I-97	450	30	16.5	7.69	1.91	0.43	0.03	0.04	0.68	0.25
I-270 at Montrose Road	580	18.1	9.4	7.69	1.91	0.43	0.85	1.43	14.78	5.69
Furnace Avenue	300	30.3	2.3	7.69	1.91	0.43	0.14	0.16	0.62	0.31

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Sample Credit Computation

- Step 10: Compute Average Acres of Treatment per Linear Foot
  - = Average Impervious Acre Conversion Factor x (Watershed Area (ac) / Site Length (lf))
- Step 11: Compute Average Acres of Treatment Per 100 Linear Feet
- Step 12: Calculate Uncapped Total Impervious Acre Equivalent (ac)
  - = Average Acres of Treatment Per Linear Foot x Site Length (lf)
- Step 13: Calculate Capped Total Impervious Acre Equivalent (ac)
  - = Greater of Total Impervious Area in Watershed or Uncapped Total Impervious Area Equivalent

				Step 8			Step 9	Step 10	Step 11	Step 12	Step 13
				Impervious Acre Conversion Factor (AC/AC)							
Site Name	Site Length (Linear Feet)	Total Watershed Area (Acres)	Impervious Watershed Area	TN	TP	TSS	Average	Averge Acres of Treatment for Nutrients and Sediment per Linear Foot	Averge Acres of Treatment for Nutrients and Sediment per 100 Linear Feet	Calculated Total Impervious Acre Equivalent (Acres)	Capped Total Impervious Acre Treatment (Acres)
I-97	450	30	16.5	0.03	0.04	0.68	0.25	0.02	2	7.5	7.5
I-270 at Montrose Road	580	18.1	9.4	0.85	1.43	14.78	5.69	0.18	18	103.0	9.4
Furnace Avenue	300	30.3	2.3	0.14	0.16	0.62	0.31	0.03	3	9.3	2.3

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Alternative Headwater Channel Prevented Sediment Crediting Protocol Results

For 11 Case Studies,

- Total Pollutant Load Reductions & Impervious Acre Equivalents are shown below

							Step 7			Step 12	Step 13
Site Name	Site Length (Linear Feet)	Total Watershed Area (Acres)	Impervious Watershed Area	Delta Impervious Surface and Forest			Average Pollutant Load Reduction			Calculated Total Impervious Acre Equivalent (Acres)	Capped Total Impervious Acre Treatment (Acres)
				TN (lbs/acre/yr)	TP (lbs/acre/yr)	TSS (tons/acre/yr)	TN (lbs/acre/yr)	TP (lbs/acre/yr)	TSS (tons/acre/yr)		
I-97	450	30	16.5	7.69	1.91	0.43	0.2	0.1	0.3	7.5	7.5
I-270 at Montrose Road	580	18.1	9.4	7.69	1.91	0.43	6.5	2.7	6.4	103.0	9.4
Furnace Avenue	300	30.3	2.3	7.69	1.91	0.43	1.0	0.3	0.3	9.3	2.3
MD 210 - Site 1	24	4.9	1.2	7.69	1.91	0.43	0.2	0.1	0.1	0.5	0.5
MD 210 - Site 2 - Main Channel	99	20.7	0.0	7.69	1.91	0.43	0.1	0.1	0.1	1.3	0.0
MD 210 - Site 2 - Ditch	95	4.5	3.3	7.69	1.91	0.43	0.2	0.1	0.1	0.6	0.6
MD 210 - Site 3 - Main Channel	28	26.7	1.0	7.69	1.91	0.43	0.0	0.0	0.0	0.3	0.3
MD 210 - Site 3 - Ditch	34	7.9	0.8	7.69	1.91	0.43	0.0	0.0	0.0	0.2	0.2
MD 210 - Site 4	85	9.4	2.1	7.69	1.91	0.43	0.5	0.3	0.3	2.8	2.1
MD 210 - Site 8	332	13.6	3.4	7.69	1.91	0.43	4.0	2.4	2.4	33.0	3.4
MD 210 - Site 10	143	5.3	1.9	7.69	1.91	0.43	3.6	2.2	2.1	11.5	1.9
Total	**2,170**	**171**	**42**	**--**	**--**	**--**	**--**	**--**	**--**	**170.0**	**28.3**

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Alternative Headwater Channel Prevented Sediment Crediting Protocol Results

For 11 Case Studies,

- Comparison Versus MDE's *Accounting for Stormwater Wasteload Allocations and Impervious Acres Treated*, August 2014

				Step 12	Step 13	For comparison versus current methodology (WLA August 2014)		
Site Name	Site Length (Linear Feet)	Total Watershed Area (Acres)	Impervious Watershed Area	Calculated Total Impervious Acre Equivalent (Acres)	Capped Total Impervious Acre Treatment (Acres)	Interim Outfall Only, Total Impervious Acre Equivalent (Acres)	Interim Stream Only, Total Impervious Acre Equivalent (Acres)	Interim Total Stream/Outfall Total Impervious Acre Equivalent (Acres)
I-97	450	30	16.5	7.5	7.5	0.4	4.5	4.8
I-270 at Montrose Road	580	18.1	9.4	103.0	9.4	1.4	4.2	5.6
Furnace Avenue	300	30.3	2.3	9.3	2.3	0.2	2.8	3.0
MD 210 - Site 1	24	4.9	1.2	0.5	0.5	0.7	0.0	0.7
MD 210 - Site 2 - Main Channel	99	20.7	0.0	1.3	0.0	0.3		0.3
MD 210 - Site 2 - Ditch	95	4.5	3.3	0.6	0.6		1.1	1.1
MD 210 - Site 3 - Main Channel	28	26.7	1.0	0.3	0.3	0.9		0.9
MD 210 - Site 3 - Ditch	34	7.9	0.8	0.2	0.2		0.3	0.3
MD 210 - Site 4	85	9.4	2.1	2.8	2.1	0.9		0.9
MD 210 - Site 8	332	13.6	3.4	33.0	3.4	0.4	3.2	3.6
MD 210 - Site 10	143	5.3	1.9	11.5	1.9	0.9	0.5	1.4
Total	**2,170**	**171**	**42**	**170.0**	**28.3**	**6.0**	**16.5**	**22.6**

~25% Increase in Total Impervious Acre Equivalence between two methods.

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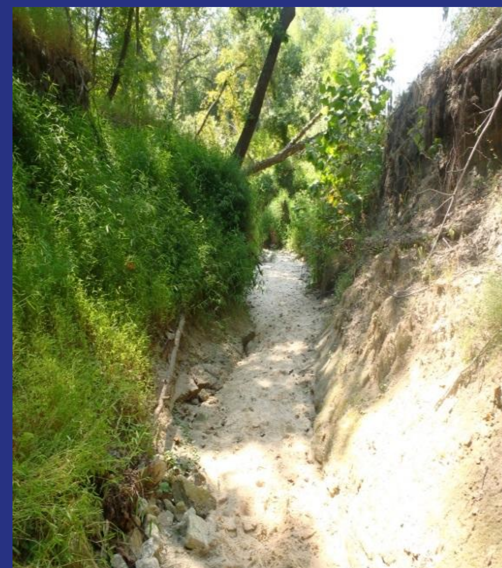
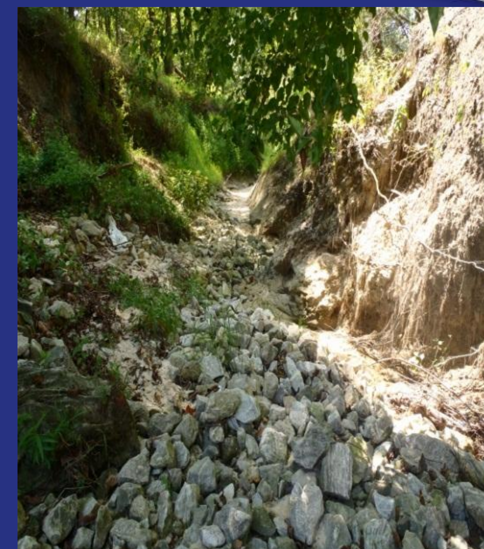
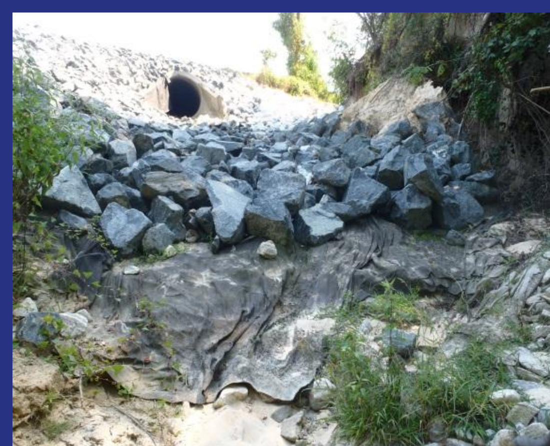
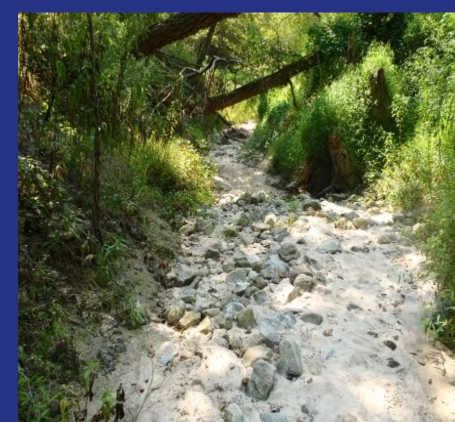
Case Studies

- **11 Sites selected in varying conditions**
  - Low Erosion
  - Moderate Erosion
  - High/Extreme Erosion
- **Computed volume of erosion and Impervious Area Equivalents for each site**
- **Sites selected across MS4 area**
  - Howard, Montgomery, Prince George's & Anne Arundel Counties

Ex #1:
High Erosion

High Erosion: I-97 Outfall Repair	
Outfall size	52” RCP
Drainage area	30 ac
Impervious area	16.5 ac
Receiving water	WUS, Severn Run
County	Anne Arundel
Notes: Highly erodible banks, reduced in-stream habitat, high potential for further instability	

Existing Condition Photos taken August 2013

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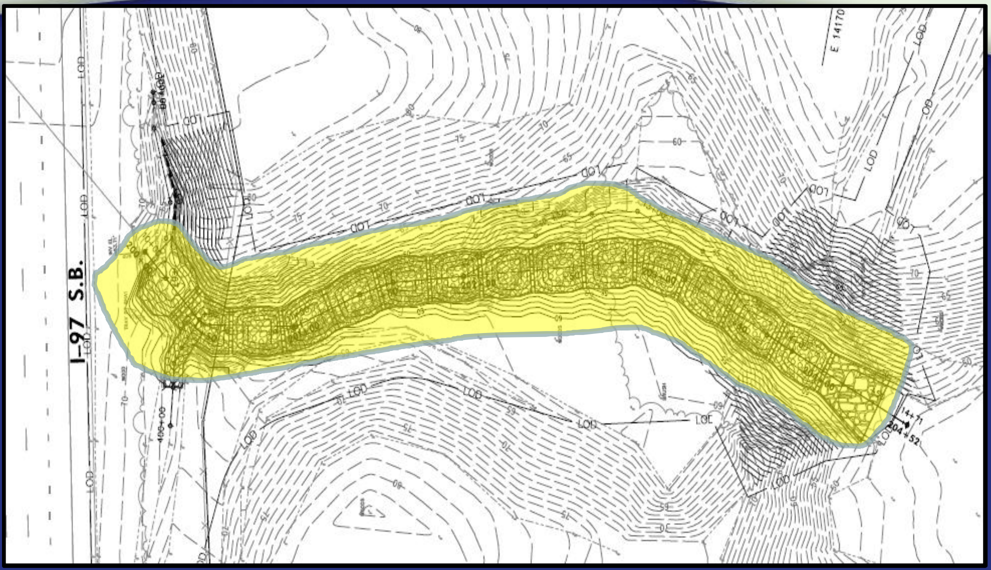
Ex #1: High Erosion

High Erosion: I-97 Outfall Repair, Crediting	
Stream stabilized ($Length_{Site}$)	450 lf
Estimated erosion	2,591 cy
Average acreage treated for nutrients and sediment (Avg_{treat})	0.02 ac/lf
Impervious Area Equivalent (Avg_{treat} * $Length_{site}$)	7.5 ac

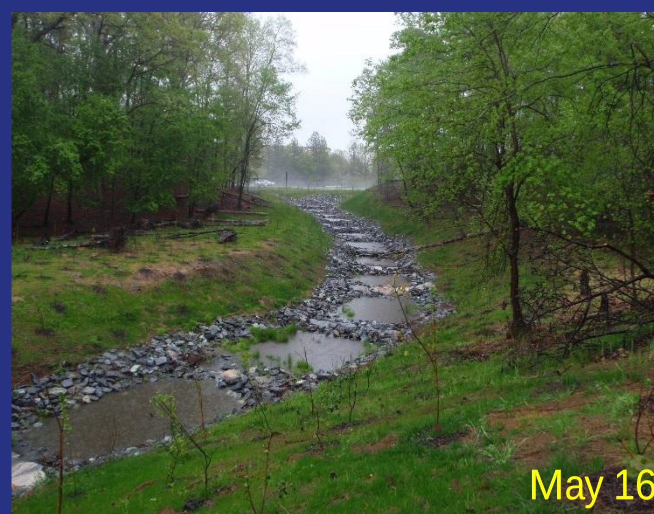


Plan view above, Post-Construction photos below

Ex #1:
High Erosion

Post-Construction Photos

- Step pool morphology
- Encourage infiltration in pools
- Graded banks
- Riparian plantings



Ex #2:
High erosion

MD 210: Site #10	
Outfall size	24" CMP
Drainage area	5.3 ac
Impervious area	1.9 ac
Receiving water	WUS, unnamed tributary to Piscataway Creek
County	Prince George's
Notes: Result of pipe failure coming from the roadway embankment eroding	

June 2016 Update: Erosion progressed dramatically during May 2016 due to heavy rains. Upper portion of erosion moved as quickly as 3 feet between two storms.

Downstream sediment deposition – January 2015

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Ex #2: Erosion Progression

Feb '16

May '16

Prior to 2016, this site had experienced several feet of slope retreat per year.

In May '16, the Site lost >3 ft of top of slope within a 3 week period undermining the road shoulder/travel lane.

A roadway lane closure/detour had to be quickly established and the site moved forward in construction.

May '16

May'16

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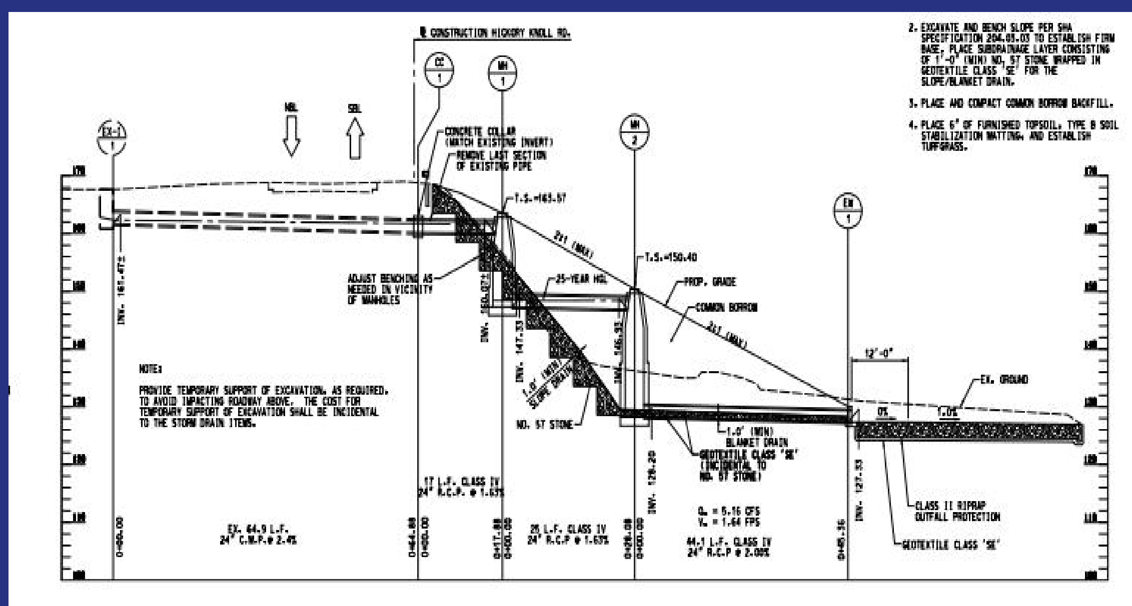
Site #2: High erosion

MD 210: Site #10	
Stream stabilized ($Length_{Site}$)	143 lf
Estimated erosion	2,849 cy
Average acreage treated for nutrients and sediment (Avg_{treat})	0.08 ac/lf
Impervious Area Equivalent (Avg_{treat} * $Length_{site}$)	11.5 ac (1.9 ac capped)



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Site #2:
High erosion

March 2017 repair above

April 2018, looking downstream at confluence with main channel

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Impervious Acre Equivalents

- 12 sites produced
  - Maximum treatment = 9.4 ac
  - Median treatment = 1.9 ac
  - Average treatment = 2.6 ac
  - Minimum treatment = 0.2 ac
- Largest site produced
  - 9.4 acres of treatment over 600 lf of channel
- 9 sites produced
  - 3.5 acres or less of equivalent impervious area treatment

Largest site contains over 600 lf of active erosion and sediment loss

Conclusions

- Eroded outfalls are delivering large volumes of sediment to our downstream receiving waters
- Outfalls that were constructed to best engineering practices at the time still face downstream channel erosion issues due to changes in upstream hydrology and/or headcuts working upstream
- Restoring the unstable channel downstream of an outfall instead of a hard engineering approach within MDOT SHA's right of way provides more environmental benefit and ultimately greater water quality improvements to the overall watershed hence it should receive a greater credit for sediment loss prevented than the 2 acre maximum outfall credit
- Using MDE's "equivalent impervious area credit" is an appropriate methodology to convert volume/weight of erosion to an equivalent impervious area treated.

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Potential Overlap with Existing Stream Restoration Practices and Protocols

- Permit concerns/Conflicts with FAQ
  - Separation of Stream and Headwater Segments
  - Headwater Channel Delineation
  - Ephemeral Channels
  - Base level Control Points
  - Stability of Infrastructure Elements
  - Structural Elements at Outfalls
  - Reporting Loads vs. Impervious Area Equivalencies

THANK YOU!

MARYLAND DEPARTMENT OF TRANSPORTATION
STATE HIGHWAY ADMINISTRATION

MDOT SHA
Alternate Headwater and Outfall Channel Protocol
Sample Computations
April 2018

Site Name	Site Length (Linear Feet)	Watershed Area (Acres)	10-year Discharge (cfs)	Number of Unique Assessment Reaches	Representative Channel Bed Grain Size (mm or as noted) *			Representative Cross Sections			Relationships Used to Estimate Future Slope **			Average Future Slope (%)			Bank Material Description	Internal Friction Angle (degrees)	Bank Slope (H:V)***	Bottom Width (feet)	Notes
	Step 1																				
					Reach 1	Reach 2	Reach 3	Reach 1	Reach 2	Reach 3	Reach 1	Reach 2	Reach 3	Reach 1	Reach 2	Reach 3					
I-97	450	30	120	3	Class III Riprap	Class I Riprap	D50 = 0.6 mm	--	XS-1; XS-2; XS-3	XS-1; XS-2; XS-3	--	S&FG	M&S; MPM; SE; HF	--	2.4	0.073	Sand (Medium Dense)	32	1.76:1	17	Reach 1, with Class III riprap assumed to remain stable.
I-270 at Montrose Road	580	18.1	70.0	2	D50 = 0.7 mm; D50 = 1.6 mm	Dm = 18 mm; D50 = 20 mm; D90 = 64 mm	--	XS-1; XS-2	XS-3	--	S&FG	M&S; MPM; SE; HF	--	0.15	0.33	--	Sand (Medium Dense)	32	1.76:1	12.0	
Furnace Avenue	300	30.3	61.1	2	Class I Riprap	Dm = 22 mm; D50 = 26 mm; D90 = 150 mm	--	XS-1	XS-2	--	M&S; MPM; SE; HF	M&S; MPM; SE; HF	--	3.8	0.53	--	Silt Load; Silt Clay Loam	28	2.16:2	5.5	Reach 1 stable slope is steeper than existing; therefore, existing slope is stable.
MD 210 - Site 1	24	4.9	6.4	1	Sand (D50 = 1 mm); Gravel (Dm = 11 mm; D50 = 11 mm; D90 = 30 mm)	--	--	XS-1	--	--	S&FG; M&S; MPM; SE; HF	--	--	0.57	--	--	Medium Dense Sand	32	1.76:1	2.0	Average future slope is an average of the future slope based on sand substrate (0.55%) and gravel substrate (0.58%). Bank material assumed to be consistent with MD 210 Sites 4 and 8.
MD 210 - Site 2 - Main Channel	99	20.7	32.4	2	D50 = 1 mm	D50 = 1 mm	--	XS-1	XS-2	--	S&FG	S&FG	--	0.20	0.26	--	Medium Dense Sand	32	1.76:1	7.0	Assumed an average slope of 0.23% for the entire site. Bank material assumed to be consistent with MD 210 Sites 4 and 8.
MD 210 - Site 2 - Ditch	95	4.5	20.0	1	D50 = 1 mm	--	--	XS-1	--	--	S&FG	--	--	0.19	--	--	Medium Dense Sand	32	1.76:1	4.5	Bank material assumed to be consistent with MD 210 Sites 4 and 8.
MD 210 - Site 3 - Main Channel	28	26.7	51.0	1	Dm = 16 mm; D50 = 16 mm; D90 = 43 mm	--	--	XS-1	--	--	M&S; MPM; SE; HF	--	--	0.33	--	--	Medium Dense Sand	32	1.76:1	3.0	Bank material assumed to be consistent with MD 210 Sites 4 and 8.
MD 210 - Site 3 - Ditch	34	7.9	15.0	1	Dm = 16 mm; D50 = 16 mm; D90 = 43 mm	--	--	XS-1	--	--	M&S; MPM; SE; HF	--	--	0.74	--	--	Medium Dense Sand	32	1.76:1	1.5	Calculations only for area between the point where the two concrete channels combine and the confluence with the main channel. Bank material assumed to be consistent with MD 210 Sites 4 and 8.
MD 210 - Site 4	85	9.4	30.4	1	Dm = 23 mm; D50 = 26 mm; D90 = 71 mm	--	--	XS-1; XS-2	--	--	M&S; MPM; SE; HF	--	--	0.63	--	--	USCS Class. of SM and SW-SM	32	1.76:1	3.5	USCS classification of SM represents Silty Sands, Sand-Silt Mixtures and SW represents Well-graded Sands, Gravelly Sands, Little or No Fines--assumed medium dense sand to determin bank slope.
MD 210 - Site 8	332	13.6	27.6	1	Dm = 7 mm; D50 = 10 mm; D90 = 38 mm	--	--	XS-1; XS-2; XS-3	--	--	M&S; MPM; SE; HF	--	--	0.21	--	--	Sandy Loam; Sandy Clay Loam; Loam	32	1.76:1	5	MD 210 Site 8 bank material described as Sandy Loam, Sandy Clay Loam, and Loam. Typical internal friction angles are close to the value for medium dense sand.
MD 210 - Site 10	143	5.3	5.2	1	Dm = 38 mm; D50 = 38 mm; D90 = 104 mm	--	--	XS-1	--	--	M&S; MPM; SE; HF	--	--	3.2	--	--	Medium Dense Sand	32	1.76:1	3	Grain sizes assumed based on visual estimation. XS-1 based on MD 210 Site 10 DTM. Bank material assumed to be consistent with MD 210 Sites 4 and 8.

* Dm is mean grain size
** S&FG = Sand and Fine Gravel; M&S = Manning and Shields; MPM = Meyer-Peter Muller; SE = Schoklitsch Equation; HF = henderson Formula; CB = Cohesive Beds
*** Based on No Seepage relationship

MDOT SHA
Alternate Headwater and Outfall Channel Protocol
Sample Computations
April 2018

		Step 2		Step 3			Step 4			Step 5			Step 5A - Apply 56% Efficiency Factor			Step 6		
Site Name	Site Length (Linear Feet)	Volume of Erosion		Bulk Density		Weight of Erosion (tons)	Nutrient Concentration			Total Nutrient/Pollutant Removal			Total Nutrient/Pollutant Removal			Annual Nutrient Removal (Based on 30-year Time Frame)		
		ft^3	yd^3	Value (lbs/ft^3)	Measured or Assumed		TN (lbs/ton)	TP (lbs/ton)	Measured or Assumed	TN (lbs)	TP (lbs)	TSS (tons)	TN (lbs)	TP (lbs)	TSS (tons)	TN (lbs/yr)	TP (lbs/yr)	TSS (tons/yr)
I-97	450	69,964	2,591	74.7	Measured	2,613	0.7	0.25	Measured	1829	653	2613	1,024	366	1,463	34	12	49
I-270 at Montrose Road	580	851,277	31,529	80	Assumed	34,051	1.03	0.43	Measured	35,073	14,642	34,051	19,641	8,200	19,069	655	273	636
Furnace Avenue	300	55,230	2,046	86.6	Measured	2,391	3.92	1.18	Measured	9,375	2,822	2,391	5,250	1,580	1,339	175	53	45
MD 210 - Site 1	24	3,021	112	86.2	Assumed	130	1.704	1.038	Assumed	222	135	130	124	76	73	4	3	2
MD 210 - Site 2 - Main Channel	99	8,513	315	86.2	Assumed	367	1.704	1.038	Assumed	625	381	367	350	213	206	12	7	7
MD 210 - Site 2 - Ditch	95	3,984	148	86.2	Assumed	172	1.704	1.038	Assumed	293	178	172	164	100	96	5	3	3
MD 210 - Site 3 - Main Channel	28	2,296	85	86.2	Assumed	99	1.704	1.038	Assumed	169	103	99	95	58	55	3	2	2
MD 210 - Site 3 - Ditch	34	1,397	52	86.2	Assumed	60	1.704	1.038	Assumed	103	62	60	58	35	34	2	1	1
MD 210 - Site 4	85	18,045	668	90.2	Measured	814	1.704	1.038	Assumed	1,387	845	814	777	473	456	26	16	15
MD 210 - Site 8	332	222,527	8,242	85.1	Measured	9,469	1.704	1.038	Measured	16,134	9,828	9,469	9,035	5,504	5,303	301	183	177
MD 210 - Site 10	143	76,933	2,849	86.2	Assumed	3,316	1.704	1.038	Assumed	5,650	3,442	3,316	3,164	1,928	1,857	105	64	62
Total	**2,230**	**1,320,453**	**48,906**	**--**	**--**	**53,795**	**--**	**--**	**--**	**71,394**	**33,416**	**53,795**	**39,981**	**18,713**	**30,125**	**1,333**	**624**	**1,004**

MDOT SHA

Alternate Headwater and Outfall Channel Protocol

Sample Computations

April 2018

							Step 6			Step 6A			Step 7			Step 8			Step 9	Step 10	Step 11	Step 12	Step 13	methodology (WLA August 2014)	
Site Name	Site Length (Linear Feet)	Total Watershed Area (Acres)	Impervious Watershed Area	Delta Impervious Surface and Forest			Total Annual Pollutant Load Reduction (30 yr)			Apply SDF (Non-Coastal Plain - 0.181)			Average Pollutant Load Reduction			Impervious Acre Conversion Factor (AC/AC)				Averge Acres of Treatment for Nutrients and Sediment per Linear Foot	Averge Acres of Treatment for Nutrients and Sediment per 100 Linear Feet	Calculated Total Impervious Acre Equivalent (Acres)	Capped Total Impervious Acre Treatment (Acres)	Interim Outfall Only, Total Impervious Acre Equivalent (Acres)	Interim Stream Only, Total Impervious Acre Equivalent (Acres)
				TN (lbs/acre/yr)	TP (lbs/acre/yr)	TSS (tons/acre/yr)	TN (lbs/yr)	TP (lbs/yr)	TSS (tons/yr)	TN (lbs/yr)	TP (lbs/yr)	TSS (tons/yr)	TN (lbs/acre/yr)	TP (lbs/acre/yr)	TSS (tons/acre/yr)	TN	TP	TSS	Average						
I-97	450	30	16.5	7.69	1.91	0.43	34	12	49	6	2	9	0.2	0.1	0.3	0.03	0.04	0.68	0.25	0.02	2	7.5	7.5	0.4	4.5
I-270 at Montrose Road	580	18.1	9.4	7.69	1.91	0.43	655	273	636	118	49	115	6.5	2.7	6.4	0.85	1.43	14.78	5.69	0.18	18	103.0	9.4	1.4	4.2
Furnace Avenue	300	30.3	2.3	7.69	1.91	0.43	175	53	45	32	10	8	1.0	0.3	0.3	0.14	0.16	0.62	0.31	0.03	3	9.3	2.3	0.2	2.8
MD 210 - Site 1	24	4.9	1.2	7.69	1.91	0.43	4	3	2	1	0	0	0.2	0.1	0.1	0.02	0.05	0.21	0.09	0.02	2	0.5	0.5	0.7	0.0
MD 210 - Site 2 - Main Channel	99	20.7	0.0	7.69	1.91	0.43	12	7	7	2	1	1	0.1	0.1	0.1	0.01	0.03	0.14	0.06	0.01	1	1.3	0.0	0.3	
MD 210 - Site 2 - Ditch	95	4.5	3.3	7.69	1.91	0.43	5	3	3	1	1	1	0.2	0.1	0.1	0.03	0.07	0.30	0.13	0.01	1	0.6	0.6		1.1
MD 210 - Site 3 - Main Channel	28	26.7	1.0	7.69	1.91	0.43	3	2	2	1	0	0	0.0	0.0	0.0	0.00	0.01	0.03	0.01	0.01	1	0.3	0.3	0.9	
MD 210 - Site 3 - Ditch	34	7.9	0.8	7.69	1.91	0.43	2	1	1	0	0	0	0.0	0.0	0.0	0.01	0.01	0.06	0.03	0.01	1	0.2	0.2		0.3
MD 210 - Site 4	85	9.4	2.1	7.69	1.91	0.43	26	16	15	5	3	3	0.5	0.3	0.3	0.06	0.16	0.68	0.30	0.03	3	2.8	2.1	0.9	
MD 210 - Site 8	332	13.6	3.4	7.69	1.91	0.43	301	183	177	55	33	32	4.0	2.4	2.4	0.52	1.28	5.47	2.42	0.10	10	33.0	3.4	0.4	3.2
MD 210 - Site 10	143	5.3	1.9	7.69	1.91	0.43	105	64	62	19	12	11	3.6	2.2	2.1	0.47	1.15	4.92	2.18	0.08	8	11.5	1.9	0.9	0.5
Total	**2,170**	**171**	**42**	**--**	**--**	**--**	**1,323**	**618**	**998**	**239**	**112**	**181**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**170.0**	**28.3**	**6.0**	**16.5**