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

FINAL REPORT

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Submitted to:
Urban Stormwater Work Group
Chesapeake Bay Partnership

December 17, 2012

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List of common acronyms used throughout the text:

BANCS	Bank Assessment for Nonpoint Source Consequences of Sediment
BEHI	Bank Erosion Hazard Index
BMP	Best Management Practices
CAST	Chesapeake Assessment Scenario Tool
CBP	Chesapeake Bay Program
CBWM	Chesapeake Bay Watershed Model
GIS	Geographic Information Systems
IBI	Index of Biotic Integrity
lf	Linear feet
LSR	Legacy Sediment Removal
MS4	Municipal Separate Storm Sewer System
NBS	Near Bank Stress
NCD	Natural Channel Design
RR	Runoff Reduction
RTVM	Reporting, Tracking, Verification and Monitoring
RSC	Regenerative Stormwater Conveyance
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
WIP	Watershed Implementation Plan
WQGIT	Water Quality Group Implementation Team
WTWG	Watershed Technical Work Group

Summary of Panel Recommendations

Over the last few decades, the Chesapeake Bay states have pioneered new techniques to restore urban streams using diverse approaches such as natural channel design, regenerative stormwater conveyance, and removal of legacy sediments. In the future, several Bay states are considering greater use of stream restoration as part of an overall watershed strategy to meet nutrient and sediment load reduction targets for existing urban development under the Chesapeake Bay TMDL.

The Panel conducted an extensive review of recent research on the impact of stream restoration projects in reducing the delivery of sediments and nutrients to the Bay. A majority of the Panel decided that the past practice of assigning a single removal rate for stream restoration was not practical or scientifically defensible, as every project is unique with respect to its design, stream order, landscape position and function.

Instead, the Panel elected to craft four general protocols to define the pollutant load reductions associated with individual stream restoration projects.

> *Protocol 1: Credit for Prevented Sediment during Storm Flow* -- This protocol provides 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.
>
> *Protocol 2: Credit for Instream and Riparian Nutrient Processing during Base Flow* -- This protocol provides an annual mass nitrogen reduction credit for qualifying projects that include design features to promote denitrification during base flow within a stream's hyporheic, riparian, and floodplain zones.
>
> *Protocol 3: Credit for Floodplain Reconnection Volumes during Storm Flow*-- This protocol provides an annual mass nutrient reduction credit for qualifying projects that reconnect stream channels to their floodplain over a wide range of storm events.
>
> *Protocol 4: Credit for Dry Channel Regenerative Stormwater Conveyance (RSC) as an Upland Stormwater Retrofit*-- This protocol provides an annual nutrient and sediment reduction *rate* for the contributing drainage area to a qualifying dry channel RSC project. The rate is determined by the degree of stormwater treatment provided in the upland area using the retrofit rate adjustor curves developed by the Stormwater Retrofit Expert Panel.

An individual stream restoration project may qualify for credit under one or more of the protocols, depending on its design and overall restoration approach.

Summary of Stream Restoration Credits for Individual Restoration Projects [1, 2]					
Protocol	*Name*	*Units*	*Pollutants*	*Method*	*Reduction Rate*
1	Prevented Sediment (S)	Pounds per year	Sediment TN, TP	Define bank retreat using BANCS	Measured N/P content in stream sediment
2	Instream Denitrification (B)	Pounds per year	TN	Define hyporheic box for reach	Measured unit stream denitrification rate
3	Stormflow Floodplain Reconnection (S)	Pounds Per year	Sediment TN, TP	Use curves to define volume for reconnection storm event	Measured removal rates for floodplain wetland restoration projects
4	Dry Channel RSC as a Retrofit (S/B)	Removal Rate	Sediment TN, TP	Determine stormwater treatment volume	Use adjustor curves from retrofit expert panel
[1] Depending on project design, more than one protocol may be applied to each project, and the load reductions are additive. [2] Sediment load reductions are further reduced by a sediment delivery ratio in the CBWM (which is not used in local sediment TMDLs) S: applies to stormflow conditions B: applies to base flow or dry weather conditions					

The report also includes examples to show users how to apply each protocol in the appropriate manner. In addition, the Panel recommended several important qualifying conditions and environmental considerations for stream restoration projects to ensure they produce functional uplift for local streams

The Panel also stressed that verification of the initial and long term performance of stream restoration projects is critical to ensure that projects are functioning as designed. To this end, the Panel recommends that the stream restoration credits be limited to 5 years, although the credits can be renewed based on a field inspection that verifies the project still exists, is adequately maintained and is operating as designed.

Important Disclaimer: The Panel recognizes that stream restoration projects as defined in this report may be subject to authorization and associated requirements from federal, State, and local agencies. The recommendations in this report are not intended to supersede any other requirements or standards mandated by other government authorities. Consequently, some stream restoration projects may conflict with other regulatory requirements and may not be suitable or authorized in certain locations.

Section 1: Charge and Membership of the Expert Panel

Expert BMP Review Panel for Urban Stream Restoration	
Panelist	***Affiliation***
Deb Cappuccitti	Maryland Department of Environment
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Matthew Meyers, PE	Fairfax County (VA) Department of Public Works and Environmental Services
Daniel E. Medina,Ph.D, PE	Atkins (MD)
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Steve Stewart	Baltimore County Dept of Environmental Protection and Sustainability (MD)
Dave Goerman	Pennsylvania Department of Environmental Protection
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Panel Support	
Tom Schueler Bill Stack	Chesapeake Stormwater Network (facilitator) Center for Watershed Protection (co-facilitator)
Other Panel Support: Russ Dudley – Tetra Tech, Debra Hopkins – Fish and Wildlife Service, Molly Harrington, CBP CRC, Norm Goulet, Chair Urban Stormwater Work Group, Gary Shenk, EPA CBPO, Jeff Sweeney, EPA CBPO, Paul Mayer, EPA ORD	

The initial charge of the Panel was to review all of the available science on the nutrient and sediment removal performance associated with qualifying urban stream restoration projects in relation to those generated by degraded urban stream channels.

The Panel was specifically requested to:

- Provide a specific definition of what constitutes effective stream restoration in the context of any nutrient or sediment reduction credit, and define the qualifying conditions under which a local stream restoration project may be eligible to receive the credit.

- Assess whether the existing Chesapeake Bay Program-approved removal rate is suitable for qualifying stream restoration projects, or whether a new protocol needs to be developed to define improved rates. In doing so, the Panel was asked to consider project specific factors such as physiographic region, landscape position, stream order, type of stream restoration practices employed and upstream or subwatershed conditions.

- Define the proper units that local governments will use to report retrofit implementation to the states to incorporate into the Chesapeake Bay Watershed Model (CBWM).

Beyond this specific charge, the Panel was asked to;

- Determine whether to recommend that an interim removal rate be established for one or more classes of stream restoration practices prior to the conclusion of the research for Watershed Implementation Plan (WIP) planning purposes.

- Recommend procedures for reporting, tracking, and verifying any recommended stream restoration credits over time.

- Critically analyze possible unintended consequences associated with the credit and the potential for over-counting of the credit, with a specific reference to any upstream BMPs installed.

While conducting its review, the Panel followed the procedures and process outlined in the Water Quality Goal Implementation Team (WQGIT) BMP review protocol (WQGIT, 2012). The process begins with BMP Expert Panels that evaluate existing research and make initial recommendations on removal rates. These, in turn, are reviewed by the Urban Stormwater Workgroup (USWG), the Watershed Technical Workgroup (WTWG) and the WQGIT to ensure they are accurate and consistent with the CBWM framework. Given the implications for stream habitat and wetland permitting, the panel recommendations will also be forwarded to both the Restoration and Habitat GITs for their independent review.

Appendix D documents the process by which the Expert Panel reached consensus, in the form of five meeting minutes that summarize their deliberations. Appendix E documents how the Panel satisfied the requirements of the BMP review protocol.

Section 2: Stream Restoration in the Chesapeake Bay

Section 2.1
Urbanization, Stream Quality and Restoration

Considerable research over the last two decades has documented the strong link between urbanization and declining stream quality in the Chesapeake Bay watershed. Declines in hydrologic, morphologic, water quality and biological indicators have been associated with increased watershed impervious cover (Paul and Mayer, 2001; Schueler et al., 2009). For example, Cianfrani et al. (2006) documented the relationship between impervious cover and degraded channel morphology in 46 urbanizing streams in southeast Pennsylvania.

Further research has shown increased rates of channel erosion and sediment yield in urbanizing streams (Trimble, 1997; Booth and Henshaw, 2001; Langland and Cronin, 2003; Allmendinger et al., 2007; Fraley et al., 2009). Other common impacts associated with urbanization are the hydrologic and hydraulic disconnection of the stream from its floodplain (Groffman et al., 2003), simplification of instream habitat, loss of riparian cover, and loss of diversity in aquatic life indicators.

The effect of urbanization on stream health also diminishes the functional capacity of streams to retain both sediments and nutrients. For example, sediment yields are more than an order of magnitude higher in urban streams compared to rural ones (Langland and Cronin, 2003). Floodplain and channel soils are highly enriched with respect to nutrients, so channel erosion can be an important nutrient source. The effect is exacerbated when urban streams are cutting through legacy sediments deposited as a result of past soil erosion and subsequent alluvial and colluvial deposition in the stream valley behind mill dams (Merritts et al., 2011).

Similarly, stream nitrate levels rise sharply at low levels of urbanization and remain high across greater levels of urbanization (Morgan and Kline, 2010). Other research has shown that degraded streams and disconnected floodplains have less capacity for internal nutrient uptake and processing, particularly with respect to denitrification (Lautz and Fannelli, 20008; Kaushal et al., 2008; Klocker et al., 2009).

Stream restoration projects that reduce bank erosion and create in-stream habitat features could be a useful strategy to reduce sediment and nutrient export from urban watersheds. In Section 3, the Panel analyzed the available evidence to define the functional benefits of restored versus non-restored urban streams.

Section 2.2
Stream Restoration Definitions

The discipline of stream restoration has spawned many different terms and nomenclature; therefore, the Panel wanted to precisely define the terms that are employed within this report.

Legacy Sediment Removal (LSR) - A class of stream and wetland restoration as advocated by Hartranft et al. (2011) that seeks to remove legacy sediments that have accumulated behind small mill dams and recreate the pre-colonial valley form of multiple thread channels in a wet meadow corridor. Although several LSR project have been completed in southeastern Pennsylvania, the major experimental site was constructed in 2010 in Big Spring Run near Lancaster, Pennsylvania.

Floodplain – For flood hazard management purposes, floodplains have traditionally been defined as the extent of inundation associated with the 100-year flood, which is a flooding event that has a one-percent probability of being equaled or exceeded in any one year[1]. However, in the context of this document, floodplains are defined as relatively flat areas of land between the stream channel and the valley wall that will receive excess storm flows when the channel capacity is exceeded. Therefore, water access the floodplain thus defined much more frequently than what is typically considered a flooding event.

Floodplain Reconnection Volume - This term quantifies the benefit that a given project may provide in terms of bringing streamflow in contact with the floodplain. The Floodplain Reconnection Volume is the additional annual volume of stream runoff and base flow from an upstream subwatershed that is effectively diverted onto the available floodplain, riparian zone, or wetland complex, over the pre-project volume. The volume is usually calculated using a series of curves provided in this report to convert unit rainfall depth thresholds in the contributing watershed to an effective annual volume expressed in watershed-inches.

Functional Uplift - A general term for the ability of a restoration project in a degraded urban stream to recover hydrologic, hydraulic, geomorphic, physiochemical, or biological indicators of healthy stream function.

Hyporheic Zone - The hyporheic zone is defined as the region below and alongside a stream, occupied by a porous medium where there is an exchange and mixing of shallow groundwater and the surface water in the channel. The dimensions of the hyporheic zone are defined by the hydrology of the stream, substrate material, its surrounding environment, and local groundwater sources. This zone has a strong influence on stream ecology, biogeochemical cycling, and stream water temperatures.

Natural Channel Design (NCD) - Application of fluvial geomorphology to create stable

[1] Floodplain management agencies use the term one-percent-annual chance to define this event, in part to dispel the misconception that the 100-year flood occurs once every 100 years. In this report, return periods instead of probabilities are used for convenience.

channels that maintain a state of dynamic equilibrium among water, sediment, and vegetation such that the channel does not aggrade or degrade over time. This class of stream restoration utilizes data on current channel morphology, including stream cross section, plan form, pattern, profile, and sediment characteristics for a stream classified according to the Rosgen (1996) classification scheme, but which may be modified to meet the unique constraints of urban streams as described in Doll et al. (2003).

Prevented Sediment - The annual mass of sediment and associated nutrients that are retained by a stable, restored stream bank or channel that would otherwise be eroded and delivered downstream in an actively enlarging or incising urban stream. The mass of prevented sediment is estimated using the field methods and desktop protocols presented later in this document.

Project Reach - the length of an individual stream restoration project as measured by the valley length (expressed in units of feet). The project reach is defined as the specific work areas where stream restoration practices are installed.

Regenerative Stormwater Conveyance (RSC) - Refers to two specific classes of stream restoration as defined in the technical guidance developed by Flores (2011) in Anne Arundel County, Maryland. The RSC approach has also been referred to as coastal plain outfalls, regenerative step pool storm conveyance, and other biofiltration conveyance. For purposes of this report, there are two classes of RSC: dry channel and wet channel.

> *Dry channel RSC* involves restoration of ephemeral streams or eroding gullies using a combination of step pools, sand seepage wetlands, and native plants. These applications are often located at the end of storm drain outfalls or channels. The receiving channels are dry in that they are located above the water table and carry water only during and immediately after a storm event. The Panel concluded that dry channel RSC should be classified as a stormwater retrofit practice rather than a stream restoration practice.
>
> *Wet channel RSCs* are located further down the perennial stream network and use instream weirs to spread storm flows across the floodplain at moderate increases in the stream stage for events smaller than the 1.5-year storm event, which has been traditionally been assumed to govern stream geomorphology and channel capacity. Wet channel RSC may also include sand seepage wetlands or other wetland types in the floodplain that increase floodplain connection or interactions with the stream. The optimal location for wet channel RSC systems is in intermittent or perennial channels that have a low sediment supply delivered from upstream sources and a low sediment transport capability.

Stream Restoration - Refers to any NCD, RSC, LSR or other restoration project that meets the qualifying conditions for credits, including environmental limitations and stream functional improvements. The Panel did not have a basis to suggest that any single design approach was superior, as any project can fail if it is inappropriately located, assessed, designed, constructed, or maintained.

Stream Functions Pyramid: A quantitative method that uses a series of performance standards developed by Harman et al. (2011) to assess how hydrologic, hydraulic, geomorphic, physiochemical, and biological functions in a stream change as a result of stream restoration.

Section 2.3
Derivation of the Original Chesapeake Bay Program-Approved Rate for Urban Stream Restoration

The original nutrient removal rate for stream restoration projects was approved by CBP in 2003, and was based on a single monitoring study conducted in Baltimore County, Maryland (Stewart, 2008). The Spring Branch study reach involved 10,000 linear feet of stream restoration located in a 481-acre subwatershed that primarily consisted of medium density residential development. The project applied natural channel design techniques as well as 9.7 acres of riparian reforestation.

The original monitoring effort encompassed two years prior to the project and three years after it was constructed. The preliminary results were expressed in terms of pounds reduced per linear foot and these values were subsequently used to establish the initial CBP-approved rate, as shown in Table 1 and documented in Simpson and Weammert (2009).

Table 1. Edge-of-Stream CBP-Approved Removal Rates per Linear foot of Qualifying Stream Restoration (lb/ft/yr)

Source	TN	TP	TSS
Spring Branch N=1	0.02	0.0035	2.55
See also: Simpson and Weammert (2009)			

Baltimore County continued to monitor the Spring Branch site for seven years following restoration and recomputed the sediment and nutrient removal rates for the project reach (Stewart, 2008). Both the nutrient and sediment removal rates increased when the longer term monitoring data were analyzed, regardless of whether they were expressed per linear foot or as a percent reduction through the project reach (see Table 2).

Table 2. Revised Removal Rates per Linear foot for Spring Branch, Based on Four Additional Years of Sampling and Data Re-Analysis (lb/ft/yr)

Source	TN	TP	TSS
Spring Branch N=1	0.227	0.0090	3.69 *
% Removal in Reach	42%	43%	83%

Source: Stewart (2008) and Steve Stewart presentation to Expert Panel 1/25/2012
* the project did not directly measure nutrient and sediment removal due to prevented stream bank erosion; therefore, the total reduction is expected to be greater.

In the last few years, the rates shown in Table 1 have been applied to non-urban stream restoration projects, presumably because of a lack of research on nutrient uptake and sediment removal for restoration projects located in rural or agricultural areas. As a result, the CBWM, Scenario Builder, and CAST all now include non-urban stream restoration rates equal to the urban values in Table 1. The Panel was not able to document when the informal decision was made by the CBP to apply the interim urban stream restoration rate to non-urban stream restoration projects. The Panel recommendations for addressing non-urban stream restoration projects are provided in Section 4.4 of this document.

Section 2.4
Derivation of the New Interim CBP-Approved Rate

Since the first stream restoration estimate was approved in 2003, more research has been completed on the nutrient and sediment dynamics associated with urban stream restoration. These studies indicated that the original credit for stream restoration was too conservative.

Chesapeake Stormwater Network (CSN) (2011) proposed a revised interim credit that was originally developed by the Baltimore Department of Public Works (BDPW, 2006). This credit included five additional unpublished studies on urban stream erosion rates located in Maryland and southeastern Pennsylvania. These additional studies were found to have substantially higher erosion rates than those originally measured at Spring Branch (Table 3).

The rationale of using the Baltimore City data review as the interim rate is based on the assumption that the higher sediment and nutrient export rates are more typical of urban streams undergoing restoration. The Commonwealth of Virginia requested that the higher rate in Table 3 be accepted as a new interim rate in December of 2011, and EPA Chesapeake Bay Program Office (CBPO) approved the rate in January 2012, pending the outcome of this Expert Panel.

Table 3. Edge-of-Stream 2011 Interim Approved Removal Rates per Linear Foot of Qualifying Stream Restoration (lb/ft/yr)			
Source	**TN**	**TP**	**TSS***
New Interim CBP Rate	0.20	0.068	310
Derived from six stream restoration monitoring studies: Spring Branch, Stony Run, Powder Mill Branch, Moore's Run, Beaver Run, and Beaver Dam Creek located in Maryland and Pennsylvania *The removal rate for TSS is representative of edge-of-field rates and is subject to a sediment delivery ratio in the CBWM to determine the edge-of-stream removal rate. Additional information about the sediment delivery ratio is provided in Appendix B.			

At its January 25, 2012 research workshop, the Panel concluded that there was no scientific support to justify the use of a single rate for all stream restoration projects (i.e., the lb/ft/yr rates shown in Tables 2 and 3). Sediment and nutrient load reductions will always differ, given the inherent differences in stream order, channel geometry, landscape position, sediment dynamics, restoration objectives, design philosophy, and quality of installation among individual stream restoration projects. Instead, the Panel focused on predictive methods to account for these factors, using various watershed, reach, cross-section, and restoration design metrics.

The Panel acknowledges that the new stream restoration removal rate protocols may not be easily integrated into existing CBP BMP assessment and scenario builder tools used by states and localities to evaluate options for watershed implementation plans (i.e., MAST, CAST, VAST and Scenario Builder). This limitation stems from the fact that each recommended protocol has its own removal rate, whereas the CBP tools apply a universal rate to all stream restoration projects.

Local watershed planners will often need to compare many different BMP options within their community. In the short term, the Panel recommends that CBP watershed assessment tools continue to use the interim rate approved by EPA CBPO in January 2012 (Table 3) for general watershed planning purposes. It should be noted that sediment removals will be reduced due to the sediment delivery ratio employed by the CBWM (see Section 2.5).

Over the long term, the Panel recommends that the WTWG develop a more robust average removal rate for planning purposes, based on the load reductions achieved by stream restoration projects reported to the states using the new reporting protocols.

Section 2.5
How Sediment and Nutrients are Simulated in the Chesapeake Bay Watershed Model

It is important to understand how sediment and nutrients are simulated in the context of the CBWM to derive representative stream restoration removal rates that are consistent with the scale and technical assumptions of the model. The technical documentation for how sediment loads are simulated and calibrated for urban pervious and impervious lands in the CBWM can be found in Section 9 and the documentation for nutrients can be found in Section 10 of U.S. EPA (2010). The following paragraphs summarize the key model assumptions that the Panel reviewed.

The scale at which the CBWM simulates sediment dynamics corresponds to basins that average about 60 to 100 square miles in area. The model does not explicitly simulate the contribution of channel erosion to enhanced sediment/nutrient loadings for smaller 1st, 2nd, and 3rd order streams not included as part of the CBWM reach network (i.e., between the edge-of-field and edge-of-stream), that is, scour and deposition with the urban stream channel network with these basins are not modeled.

Due to the scale issue, the CBWM indirectly estimates edge-of-stream sediment loads as a direct function of the impervious cover in the contributing watershed. The strong empirical relationships between impervious cover and sediment delivery for urban watersheds in the Chesapeake Bay were established from data reported by Langland and Cronin (2003), which included SWMM Model estimated sediment loads for different developed land use categories. A percent impervious was assigned to the land use categories to form a relationship between the degree of imperviousness and an associated sediment load (Figure 1).

The CBWM operates on the assumption that all sediment loads are edge-of-field and that transport and associated losses in overland flow and in low-order streams decrement the sediment load to an edge-of-stream input. The sediment loss between the edge-of-field and edge-of-stream is incorporated into the CBWM as a sediment delivery ratio (Figure 2). The ratio is multiplied by the predicted edge-of-field erosion rate to estimate the eroded sediments actually delivered to a specific reach.

Riverine transport processes are then simulated by HSPF as a completely mixed reactor at each time step of an hour to obtain the delivered load. Sediment can be deposited in a reach, or additional sediment can be scoured from the bed, banks, or other sources of stored sediment throughout the watershed segment. Depending on the location of the river-basin segment in the watershed and the effect of reservoirs, as much as 70 to 85% of the edge-of-field sediment load is deposited before it reaches the main-stem of the Bay (U.S. EPA, 2010).

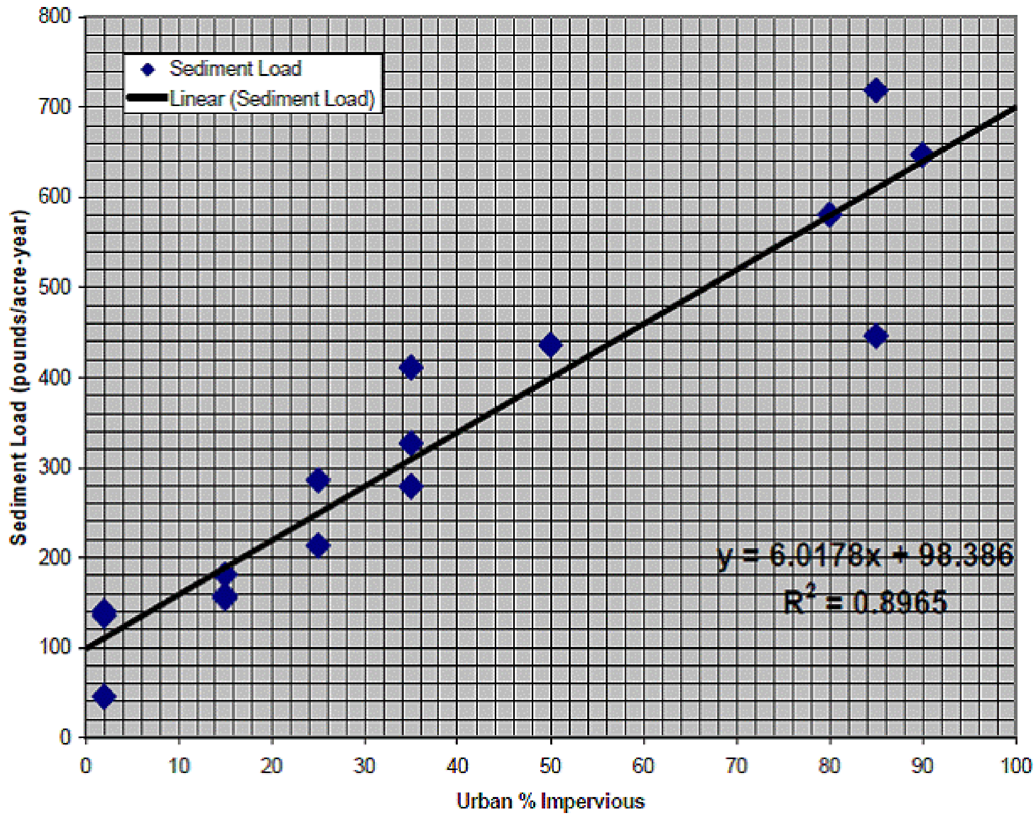

Figure 1. Relationship between Edge-of-Stream Urban Sediment Loads and Watershed Impervious Cover (Source: Langland and Cronin, 2003).

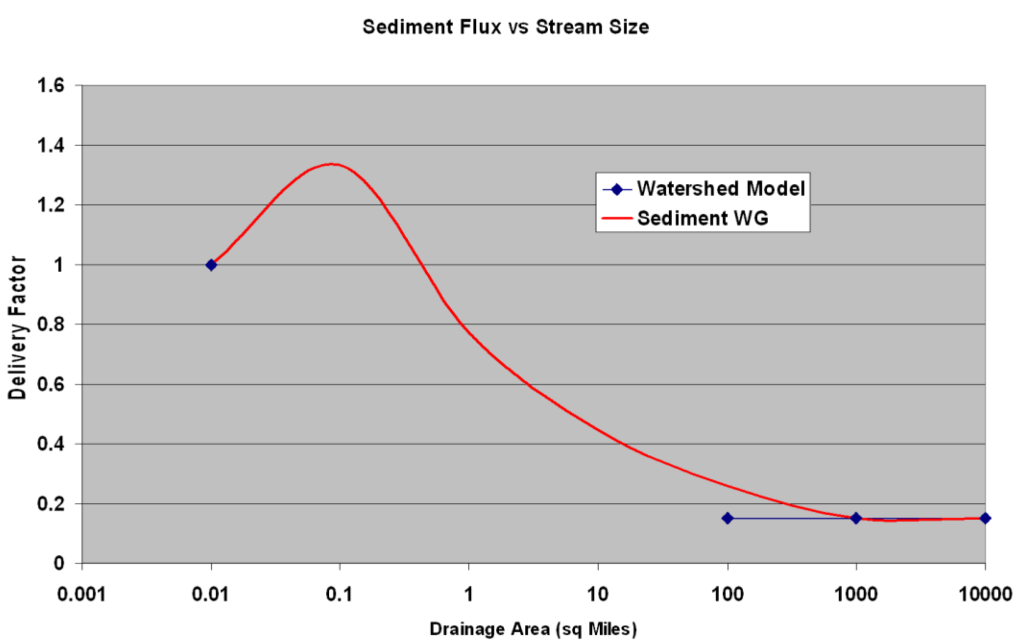

Figure 2. Edge of Stream Sediment Delivery Curve in CBWM

This means there will be a strong scale effect associated with any estimate of urban stream restoration removal rates, that is, a higher rate that occurs locally at the project reach compared with a lower rate for the sediment that actually reaches the Bay. Therefore, stream restoration projects may be much more effective in addressing local sediment impairments (i.e. TMDLs) than at the Chesapeake Bay scale.

Urban nutrient loads are modeled by build-up and wash-off from impervious areas and export in surface runoff, interflow, and groundwater flow from pervious land (see Section 10 in U.S. EPA, 2010). The unit area loading rates from both types of urban land are then checked to see if they correspond to loading targets derived from the literature. The resulting edge of stream nutrient loads for both urban and impervious areas are calibrated to monitoring data at the river-basin segment scale, and may be subject to regional adjustment factors and reductions due to presence of urban BMPs.

Unlike sediment, there is no delivery ratio for nutrients from the edge-of-field to the edge-of-stream; 100% of the nutrient load is assumed to reach the edge-of-stream. Significantly, any losses due to denitrification for the smaller 1st, 2nd, and 3rd order streams not included as part of the CBWM reach network (i.e., between the edge-of-field and edge-of-stream) are not explicitly simulated.

The fact that nutrients and sediment loads are simulated independently in the CBWM somewhat complicates the assessment of the effect of urban stream restoration on reducing them for several reasons. As previously noted, there are currently no mechanisms in the CBWM to adjust model parameters to account for enhanced instream nutrient uptake and/or denitrification associated with stream restoration. Additionally, there are no mechanisms in the model to account for the delivery of nutrients attached to sediments from eroding stream banks of small order streams. Lastly, the CBWM does not account for the interaction of the stream network with its floodplain, particularly with respect to nutrient and sediment dynamics in groundwater or during flood events.

Due to the preceding CBWM model limitations, the Panel decided that the effect of stream restoration could only be modeled as a mass load reduction for each individual restoration project at the river basin segment scale. The Panel also recommended several important model refinements for the 2017 CBWM revisions that could improve the simulation of urban streams and their unique sediment and nutrient dynamics. These recommendations can be found in Section 8.4.

Section 2.6
Stream Restoration in Phase 2 Watershed Implementation Plans

Stream restoration appears to be a significant strategy for many Bay states to achieve their load reduction targets over the next 15 years, according to a review of individual state WIPs submitted to EPA in 2012 (Table 4). As can be seen, nearly 4,000 stream miles of urban and non-urban stream restoration are anticipated by the year 2025, with most of the mileage projected for Maryland.

It should be noted that state WIPs are general planning estimates of the type and nature of BMPs being considered for implementation. The actual construction of stream restoration projects in the future, however, will largely depend on the watershed implementation plans being developed by local governments, and their ability to secure funding and environmental permits. Consequently, the mileage of future stream restoration is difficult to forecast.

Given that the proposed level of future stream restoration represents about 4% of the estimated 100,000 miles of perennial streams in the Bay watershed, the Panel was extremely mindful of the potential environmental consequences of poorly designed practices on existing stream health. Section 4 presents a series of environmental requirements and qualifying conditions the Panel developed to ensure projects create functional uplift in various indicators of stream health.

Table 4. Urban Stream Restoration Expected by 2025 in Bay State Phase 2 Watershed Implementation Plans

State	Urban Stream Restoration	Non-Urban Stream Restoration
	Linear Feet (Miles)	
Delaware	200 (0.02)	63,202 (12)
District of Columbia	42,240 (8)	0
Maryland	19,354,449 (3666)	73,975 (14)
New York	26,500 (5)	337,999 (64)
Pennsylvania	55,000 (10)	529,435 (100)
Virginia	116,399 (22)	104,528 (20)
West Virginia	0	19,618 (3.7)
TOTAL	3,711 miles	214 miles

[1] Acres under urban and non-urban stream restoration in each state by 2025 as reported in the Phase 2 Watershed Implementation Plan submissions to EPA in 2012, as summarized in May and July 2012 spreadsheets provided by Jeff Sweeney, EPA CBPO.

Section 3: Review of the Available Science

The Panel reviewed more than 100 papers to establish the state of the practice and determine the key components related to nutrient and sediment dynamics within streams. These papers were compiled mainly from research conducted within the Chesapeake Bay watershed or the eastern U.S. and included experimental studies of erosion and denitrification as well as case studies involving restored reaches. Papers and studies were obtained from a literature search as well as from academics, regulators, and consultants on the Panel involved with stream restoration research and application. An annotated summary of the key research papers is provided in Appendix A of this report.

Differences in measurement techniques and monitored parameters often made it difficult to directly compare individual stream restoration studies. In addition, the research varied greatly with respect to stream types, watershed characteristics, restoration objectives, and restoration design and construction techniques. Consequently, the Panel organized its review by looking at four major research areas to define the probable influence of stream restoration on the different nutrient and sediment pathways by measuring:

- Nutrient flux at the stream reach
- Bank erosion dynamics
- Internal nitrogen processing in streams
- Nutrient dynamics in palustrine and floodplain wetlands

Section 3.1
Measurements of Nutrient Flux at the Stream Reach Level

This group of studies measures the change in flow weighted nutrient and sediment concentrations above and below (and sometimes before and after) a stream restoration reach, and are often compared to an un-restored condition. Reach studies require frequent sampling during both storm and base flow conditions, and need to be conducted over multiple years to derive adequate estimates of nutrient and sediment fluxes. A good example of this approach was the nine year monitoring effort conducted on Spring Branch in Maryland by Stewart (2008).

Filoso and Palmer (2011) and Filoso (2012) recently completed sediment and nitrogen mass balance for eight low-order stream reaches located in Anne Arundel County, Maryland, based on a three-year base flow and storm flow sampling effort. The study reaches included four NCD restored streams, two RSC restored streams, and two un-restored control reaches. In terms of landscape position, the study reaches were situated in both upland and lowland areas, and were located in subwatersheds ranging from 90 to 345 acres in size. Individual stream reaches ranged from 500 to 1,500 feet in length.

Filoso noted that there was significant inter-annual variation in N and TSS loads and retention. The results suggest that two out of six restored reaches were clearly effective at reducing the export of TN to downstream waters. The capacity of stream restoration projects to reduce fluxes during periods of elevated flows was essential since most of the observed TSS and N export occurred during high water conditions.

Lowland channels were found to be more effective than upland channels, and projects that restored wetland-stream complexes were observed to be the most effective. Filoso also noted that the capacity of restoration practices to moderate discharge and reduce peak flows during high flow conditions seemed to be crucial to restoration effectiveness. Stream restoration of upland channels may have been effective at preventing sediment export and, therefore, might have reduced export downstream. However, without pre-and post- restoration data, they could not conclude that the upland streams were effective.

Filoso also noted that there appears to be a contrast between the length of a stream restoration project and the cumulative length of the upstream drainage network to the project reach. Short restoration projects in large catchments do not have enough retention time or bank protection to allow nutrient and sediment removal mechanisms to operate, especially during storm events.

Richardson et al. (2011) evaluated the effect of a stream restoration project in the North Carolina Piedmont that involved stream restoration, floodplain reconnection, and wetland creation. The project treated base flow and storm flow generated from a subwatershed with 30% impervious cover. Richardson reported significant sediment retention within the project, as well as a 64% and 28% reduction nitrate-N and TP loads, respectively. The study emphasized the need to integrate stream, wetland, and floodplain restoration together within the stream corridor to maximize functional benefits.

Other reach studies have focused on monitoring nitrogen dynamics under base flow conditions only (e.g., Sivirichi et al., 2011, Bukaveckas 2007, Ensign and Doyle 2005), and these are described in Section 3.3

Section 3.2
Measurements of Bank Erosion Dynamics

This group of studies evaluates the impact of stream restoration projects to prevent channel enlargement within a project reach, and retain bank and floodplain sediments (and attached nutrients) that would otherwise be lost from the reach. Stream restoration practices that increase the resistance of the stream bed and banks to erosion can be expected to reduce the sediment and nutrient load delivered to the stream. The magnitude of this reduction is a function of the pre-project sediment supply in direct proportion to the length of erosion-prone stream bed and banks that are effectively treated.

Sediment reduction due to stream restoration is largely attributed to the stabilization of the bed and banks within the channel. Sediment correlation studies indicate that upland erosion and channel enlargement are significant components of the sediment budget (Allmendinger et al., 2007) and erosion and deposition values are higher in unstable reaches (Bergmann and Clauser, 2011). In a study monitoring sediment transport and storage in a tributary of the Schuylkill River in Pennsylvania, Fraley et al. (2009) found that bank erosion contributed an estimated 43% of the suspended sediment load, with bed sediment storage and remobilization an important component of the entire sediment budget.

Most studies define the rate of bank retreat and estimate the mass of prevented sediment using bank pins and cross-sectional measurements within the restored stream reach. The studies may also sample the soil nutrient content in bank and floodplain sediments to determine the mass of nutrients lost via channel erosion. This measurement approach provides robust long-term estimates for urban streams that are actively incising or enlarging. The "prevented" sediment effect can be masked in other reach studies unless they capture the range of storms events that induce bank erosion.

Five of the six studies that were used to derive the new interim rate (see Table 3 in Section 2.4) used the prevented sediment approach to estimate nutrient and sediment export for urban streams in Maryland and Pennsylvania (BDPW, 2006; Land Studies, 2005). The loading rates attributed to stream channel erosion were found to be in the range of 300 to 1500 lb/ft/yr of sediment.

Nutrient content in stream bank and floodplain sediments is therefore a major consideration. Table 5 compares the TP and TN content measured in various parts of the urban landscape, including upland soils, street solids, and sediments trapped in catch basins and BMPs. As can be seen in Table 5, the four Pennsylvania and Maryland studies that measured the nutrient content of stream sediments consistently showed higher nutrient content than upland soils, and were roughly comparable to the more enriched street solids and BMP sediments.

Nutrient levels in stream sediments were variable. The Panel elected to use a value of 2.6 pounds of TN per ton of sediment and 1.2 pounds of TP per ton of sediment, as documented by Merritts et al. (2010). Although this study focused on legacy sediments, it is also the most robust, with a sample size of 228. In addition, these numbers align with recent findings from Baltimore County Department of Environmental Protection and Sustainability in comments to an earlier draft from Panelist Steve Stewart.

Table 5. TN and TP Concentrations in Sediments in Different Parts of the Urban Landscape [1]

Location	Median TP	TP Range	Median TN	TN Range	Location	Reference
Upland Soils	0.045	0.0025-0.577	0.8	0.05-3.3	MD	Pouyat et al., 2007
Street Solids	0.52	0.19-0.72	1.08	0.324-2.71	MD	Diblasi, 2008
Catch Basin [3]	0.49	0.057-0.97	1.74	0.055-6.27	MD	Law et al., 2008
BMP Sediments	0.29	0.014-1.38	1.47	0.11-5.6	National	Schueler, 1994
Streambank Sediments	0.439	0.19-0.90	--	--	MD	BDPW, 2006
	0.445	0.072-4.43	1.35	0.0015-4.13	MD	Stewart, 2008
	1.61		3.81		MD	Stewart, 2012
	0.357	0.23-4.69	1.1	0.7-1.7	PA	Land Studies, 2005 [2]
	1.2	--	2.6	--	PA	Merritts et al., 2010 [2]

[1] all units are lb/ton
[2] the Pennsylvania data on streambank sediments were in rural/agricultural subwatersheds
[3] catch basin values are for sediment only, excluding leaves

Several empirical tools exist to estimate the expected rate of bank retreat, using field indicators of the Bank Erosion Hazard Index (BEHI) and Near Bank Stress (NBS). Section 5 provides detailed guidance on how to properly apply these tools to estimate the mass of prevented sediments at restoration projects.

Section 3.3
Internal Nitrogen Processing in Streams and Floodplains

This group of research studies evaluates nitrogen dynamics in restored streams and floodplains using N mass balances, stream N tracer injections, N isotope additions, denitrification assays, and other methods, usually under base flow conditions. Most of the research studies have occurred in restored and non-restored streams, and floodplain wetlands in the Baltimore metropolitan area (Kaushal et al., 2008; Lautz and Fanelli, 2008; Klocker et al., 2009; Mayer et al., 2010; Harrison et al., 2011).

Mayer et al. (2010) examined N dynamics at groundwater-surface water interface in Minebank Run in Baltimore County, Maryland, and found the groundwater–surface water interface to be a zone of active nitrogen transformation. Increased groundwater residence time creates denitrification hot spots both in the hyporheic zone, particularly when sufficient organic carbon is available to the system. Increased groundwater and stream flow interaction can alter dissolved oxygen concentrations and transport N and organic matter to microbes in subsurface sediments, fostering denitrification hot spots and hot moments (Mayer et al., 2010; Klocker et al., 2009).

Lautz and Fanelli (2008) found that anoxic zones were located upstream of a stream restoration structure in a low velocity pool and oxic zones were located downstream of the structure in a riffle, regardless of the season. They also found the restored streambed can act as a sink for nitrate and other redox-sensitive solutes, and that water residence time in the subsurface hyporheic zone plays a strong role in determining the spatial patterns of these practices. They suggest that the installation of small dams in restoration projects may be a mechanism to create denitrification hotspots.

Kaushal et al. (2008) analyzed denitrification rates in restored and un-restored streams in Baltimore, and found higher denitrification rates in restored streams that were connected to the floodplain as compared to high bank restoration projects that were not. Kaushal also noted that longer hydrologic residence times are important to remove N. Additional research by Klocker et al. (2009) reinforces the notion that "restoration approaches that increase hydrologic connectivity with hyporheic sediments and increasing hydrologic residence time may be useful in stimulating denitrification".

Sivirichi et al. (2011) compared dissolved nitrogen and carbon dynamics in two restored stream reaches (Minebank Run and Spring Branch) and two un-restored reaches (Dead Run and Powder Mill) in Baltimore. They concluded that restored stream reaches were a net sink for TDN and a net source for DOC. By contrast, the un-restored urban reaches had a net release of TDN and net uptake for DOC.

High denitrification rates were observed in both summer and winter in urban riparian wetlands in Maryland (Harrison et al., 2011). Restored streams in NC had higher rates of nitrate uptake in the summer, but this can be explained by increased stream temperature and reduced forest canopy cover (Sudduth et al., 2011).

The maximum amount of internal stream and floodplain nitrogen reduction appears to be limited or bounded by the dominant flow regime that is delivering N to the stream reach. Internal N processing is greatest during base flow conditions, and is masked due to the short residence times of high flow events that quickly transit the stream reach. Stewart et al. (2005) measured the relative proportion of annual nutrient loads delivered during storm flow and base flow conditions for five urban watersheds in Maryland that had 25 to 50% imperviousness. Stewart found that base flow nitrate loads were 20 to 30% of total annual nitrogen load, with one outlier of 54% that appeared to be influenced by sewage sources of nitrogen.

The Panel identified a series of factors that could promote greater dry weather N reduction:

- Increase retention time in flood plain wetlands;
- Add dissolved organic carbon via riparian reforestation, debris jams, and instream woody debris;
- Reconnect the stream to floodplain and wetlands during both dry weather flow and storm flows through low floodplain benches, sand seepage wetlands or other techniques;
- Focus on streams with high dry-weather nitrate concentrations that are often delivered by sewage exfiltration;
- Ensure the restored reach is sufficiently long in relationship to the contributing channel network to achieve minimum hydrologic residence time;
- Install instream and floodplain wetland practices with a high surface area to depth ratio;
- Attenuate flows and reduce pollutants through upstream or lateral stormwater retrofits.

Section 3.4
Nutrient Dynamics in Restored Palustrine and Floodplain Wetlands

The Panel reviewed another line of evidence by looking at research that measured the input and output of nutrients from restored and created wetlands located in palustrine and floodplain areas. In this respect, the Panel relied on a previous CBP Expert Panel that comprehensively reviewed nutrient reduction rates associated with wetland restoration projects most of which were located in rural areas (Jordan, 2007). The majority of the research reviewed focused on restored wetlands that received stormflow (and, in some cases, groundwater), as opposed to engineered or created wetlands.

Jordan (2007) noted that restored wetlands had significant potential to remove nutrients and sediments, although the rates were variable. For example, Jordan notes the average TN removal for restored wetlands was 20%, with a standard error of 3.7 %

and a range of -12% to 52% (N=29 annual measurements). Similarly, Jordan found that the average TP removal rate for restored wetlands was 30%, with a standard error of 5%, and a range of -54% to 88%.

Jordan (2007) also explored how the removal rates were influenced by the size of the watershed contributing nutrients and sediments to the restored wetlands. He found that removal rates tended to increase as restored wetland area increased (expressed as a percent of watershed area), although the relationship was statistically weak. Most of the low performing wetland restoration projects had wetland areas less than 1% of their contributing watershed area. It should be noted that there were negative removal recorded but these data points were not included in the analysis.

More recently, Harrison et al. (2011) measured denitrification rates in alluvial wetlands in Baltimore and found that urban wetlands are potential nitrate sinks. The highest rates of denitrification were observed in wetlands with the highest nitrate concentrations, as long as a carbon source was available. The study supports the notion that stream restoration associated with floodplain reconnection and wetland creation may produce additional N reduction.

The Panel considered the previous research and concluded that the impact of restoration projects in reconnecting streams with their floodplains during stormflow conditions could have a strong influence on sediment and nutrient reduction, depending on the characteristics of the floodplain reconnection project and the size of the contributing watershed.

Section 3.5
Classification of Regenerative Stormwater Conveyance (RSC) Systems

The Panel classified dry channel RSC systems as an upland stormwater retrofit rather than a stream restoration practice. They rely on a combination of a sand filter, micro-bioretention, and wetland micro-pools. Therefore, when dry channel RSC systems are sized to a given runoff volume from their contributing drainage area, their removal rates are calculated using retrofit rate adjustor curves developed by the Stormwater Retrofit Expert Panel. In addition, RSC practices need to be designed to provide safe on-line passage for larger storm events without the need for flow splitters.

The Panel concluded that wet channel RSC systems were a stream restoration practice, and their pollutant removal rate can be estimated based on the appropriate protocols outlined in this document.

Section 3.6
Effect of Riparian Cover on Stream Restoration Effectiveness

Several recent studies have documented the critical importance of riparian cover in enhancing nutrient removal associated with individual restoration practices. Weller et al. (2011) evaluated the effect of 321 riparian buffers of the Chesapeake Bay watershed, and found forest buffers were a good predictor of stream nitrate concentrations in agricultural streams. Their watershed analysis integrated the prevalence of source areas, their nitrate source strength, the spatial pattern of buffers relative to sources, and buffer nitrate removal potential. In general, the effectiveness of forest buffers was maximized when they were located downhill from nutrient sources and were sufficiently wide.

Orzetti et al. (2010) explored the effect of forest buffers on 30 streams in the Bay watershed that ranged in age from zero to 50 years. They found that habitat, water quality, and benthic macroinvertebrate indicators improved with buffer age. Noticeable improvements were detected within 5 to 10 years after buffer restoration and significant improvements were observed 10 to 15 years after buffer restoration.

Three recent studies have documented that the construction of stream restoration projects can lead to local destruction of riparian cover within the project reach. The loss of riparian cover can adversely impact functional responses within the stream, including nutrient reduction. For example, Sudduth et al. (2011) and Violin et al. (2011) compared the functional services provided by four forest reference streams, four NCD-restored streams, and four non-restored urban streams in the North Carolina Piedmont. The studies concluded that the heavy machinery used to reconfigure channels and banks led to significant loss of riparian canopy cover (and corresponding increase in stream temperatures), and these were a major factor in the lack of functional uplift observed in restored streams, compared to non-restored streams.

Selvakumar et al. (2010) studied various functional metrics above and below, and before and after a NCD stream restoration was installed on a 1,800 foot reach in the North Fork of Accotink Creek in Fairfax County, Virginia. The conclusion from the two year study was that the restoration project had reduced stream bank degradation and slightly increased benthic IBI scores, but made no statistical difference in water quality parameters, including nutrients and bacteria. Once again, the loss of riparian cover associated with project construction was thought to be a factor in the low functional uplift observed.

By contrast, other studies have documented greater functional uplift associated with stream restoration practices (see Northington and Hershey, 2006; Baldigo et al., 2010; and Tullos et al., 2006).

It was outside the Panel's charge to resolve the scientific debate over the prospects of functional uplift associated with urban stream restoration (i.e., beyond nutrient and sediment reduction). The research does, however, have three important implications directly related to the Panel's final recommendations:

- First, the maintenance of riparian forest cover is a critical element in the ultimate success of any stream restoration project. Projects that involve extensive channel reconfiguration or remove existing riparian cover are likely to see less functional uplift, including nutrient removal, at least until the replanted areas achieve maturity (Orzetti et al., 2010). Consequently, the Panel included a key qualifying condition related to the reestablishment of forest cover in its recommendations.

- Second, the research reinforces the notion that stream restoration should not be a stand-alone strategy for urban watersheds, and that coupling restoration projects with upland retrofits and other practices can help manage the multiple stressors that impact urban streams (Palmer et al., 2007).

- Lastly, the Panel concluded that some type of stream functional assessment needs to be an important part of both project design and post-project monitoring of individual restoration projects to provide better scientific understanding of the prospects for functional uplift over time.

Section 3.7
Longevity of Stream Restoration Practices

An important part of the Panel charge was to define the success rate and longevity of stream restoration projects. Until recently, post-project monitoring has been rarely conducted to assess how well stream restoration projects meet their intended design objectives over time. For example, Bernhardt et al. (2005) compiled a national database of river restoration projects, and found that fewer than 6% of projects in the Chesapeake Bay watershed incorporated a post-construction monitoring or assessment plan. On a national basis, less than 10% of all restoration projects had clearly defined restoration objectives against which project success could be compared.

Brown (2000) investigated 450 individual stream restoration practices installed at 20 different stream reaches in Maryland, and found that 90% were still intact after four years, although only 78% were still fully achieving the intended design objective. Johnson et al. (2002) analyzed the manner and modes of failure at four Maryland stream restoration projects. Although the study did not quantify the rate of failure of individual practices, it did recommend changes in design guidelines for individual restoration practices.

Hill et al. (2011) conducted an extensive permit analysis of the success of 129 stream restoration projects constructed in North Carolina from 2007 to 2009. They reported that 75% of the stream restoration projects could be deemed "successful", as defined by whether the mitigation site met the regulatory requirements for the project at the time of construction (however, the actual degree of functional uplift or ecological improvement was not measured in the study). The authors noted that the success rate for stream restoration mitigation was less than 42% in the mid-1990s, and attributed the marked improvement to better hydrologic modeling during design, better soils analysis, and more practitioner experience.

Miller and Kochel (2010) evaluated post-construction changes in stream channel capacity for 26 stream restoration projects in North Carolina. While stream responses to restoration were variable at each project, the authors found that 60% of the NCD projects underwent at least a 20% change in channel capacity. The greatest post-construction changes were observed for channels with high sediment transport capacity, large sediment supply or easily eroded banks.

The Panel discussed whether to assign a discount rate to the removal credits to reflect project failure due to poorly conceived applications, inadequate design, poor installation, or a lack of maintenance. In the end, the Panel decided to utilize a stringent approach to verify the performance of individual projects over time, as outlined in Section 7.

The verification approach establishes measurable restoration objectives, project monitoring plans, and a limited five-year credit duration that can only be renewed based on verification that the project is still working as designed. The agency that installs the restoration practice will be responsible for verification. This approach should be sufficient to eliminate projects that fail or no longer meet their restoration objectives, and remove their sediment and nutrient reduction credit.

The Panel agreed that the verification approach could generate useful data on real world projects that would have great adaptive management value to further refine restoration methods and practices that could ultimately ensure greater project success.

Section 4: Basic Qualifying Conditions for Individual Projects

Section 4.1
Basic Qualifying Conditions

Not all stream restoration projects will qualify for sediment or nutrient reduction credits. The Panel recommended the following qualifying conditions for acceptable stream restoration credit:

- Stream restoration projects that are primarily designed to protect public infrastructure by bank armoring or rip rap do not qualify for a credit.
- The urban stream reach must be greater than 100 feet in length and be still actively enlarging or degrading in response to upstream development or adjustment to previous disturbances in the watershed (e.g., a road crossing). Most projects will be located on first- to third-order streams.
- The project must utilize a comprehensive approach to stream restoration design, involving the channel and banks.
- Special consideration is given to projects that are explicitly designed to reconnect the stream with its floodplain or create wetlands and instream habitat features known to promote nutrient uptake or denitrification.
- In addition, there may be certain project design conditions that must be satisfied in order to be eligible for credit under one or more of the specific protocols described in Section 5.

Section 4.2
Environmental Considerations and 404/401 Permits

- Each project must comply with all state and federal permitting requirements, including 404 and 401 permits, which may contain conditions for pre-project assessment and data collection, as well as post construction monitoring.

- Stream restoration is a carefully designed intervention to improve the hydrologic, hydraulic, geomorphic, water quality, and biological condition of degraded urban streams, and must not be implemented for the sole purpose of nutrient or sediment reduction.

- Urban stream restoration is generally only warranted in urban stream reaches that have been or are currently being degraded by upstream watershed development.

- There may be a few classes of legacy sediment stream restoration projects that do not fall into the preceding statement. Also, there may be instances where limited bank stabilization is needed to protect critical public infrastructure, which may need to be mitigated and does not qualify for any sediment or reduction credits.

- A qualifying project must meet certain presumptive criteria to ensure that high-functioning portions of the urban stream corridor are not used for in-stream stormwater treatment (i.e., where existing stream quality is still good). These may include one or more of the following:

    - Geomorphic evidence of active stream degradation (i.e., BEHI score)
    - An IBI of fair or worse
    - Hydrologic evidence of floodplain disconnection
    - Evidence of significant depth of legacy sediment in the project reach

- Stream restoration should be directed to areas of severe stream impairment, and the use and design of a proposed project should also consider the level of degradation, the restoration needs of the stream, and the potential functional uplift.

- In general, the effect of stream restoration on stream quality can be amplified when effective upstream BMPs are implemented the catchment to reduce runoff and stormwater pollutants and improve low flow hydrology.

- Before credits are granted, stream restoration projects will need to meet post-construction monitoring requirements, exhibit successful vegetative establishment, and have undergone initial project maintenance.

- A qualifying project must demonstrate that it will maintain or expand riparian vegetation in the stream corridor, and compensate for any project-related tree losses in project work areas.

- All qualifying projects must have a designated authority responsible for development of a project maintenance program that includes routine maintenance and long-term repairs. The stream restoration maintenance protocols being developed by Starr (2012) may serve as a useful guide to define maintenance triggers for stream restoration projects.

Section 4.3
Stream Functional Assessment

The Panel noted that it is critical for project designers to understand the underlying functions that support biological, chemical, and physical stream health to ensure successful stream restoration efforts. In particular, it is important to know how these different functions work together and which restoration techniques influence a given function. Harman et al. (2011) notes that stream functions are interrelated and build on each other in a specific order, a functional hierarchy they have termed the stream functions pyramid. Once the function pyramid is understood, it is easier to establish clear restoration objectives for individual projects and measure project success.

Consequently, the Panel recommends that proposed stream restoration projects be developed through some kind of functional assessment process, such as the stream functions pyramid (Harman et al., 2011) or functional equivalent. The basic method consists of the following steps:

- Set programmatic goals and objectives
- Site selection and watershed assessment
- Conduct site-level function-based assessment
- Determine restoration potential
- Establish specific restoration design objectives
- Select restoration design approach and alternative analysis
- Project design review
- Implement post-construction monitoring

In general, the level of detail needed to perform a function-based assessment will be based on the size, complexity and landscape position of the proposed project.

Section 4.4
Applicability to Non-Urban Stream Restoration Projects

As noted in Section 2.3, the CBP-approved removal rate for urban stream restoration projects has been extended to non-urban stream restoration projects. The Panel could find only four papers that measured nutrient reduction associated with stream restoration projects located in rural or agricultural settings (Bukaveckas, 2007; Ensign and Doyle, 2005; Mulholland et al., 2009; and Merritts et al., 2010). Due to the data limitations, the Panel had to rely on their "collective best professional judgment" to decide whether the recommended urban protocols should be applied to non-urban stream restoration projects.

The Panel was cognizant of the fact that urban and non-urban streams differ with respect to their hydrologic stressors, nutrient loadings and geomorphic response. At the same time, urban streams also are subject to the pervasive impact of legacy sediments observed in rural and agricultural watersheds (Merritts et al., 2011). The Panel further reasoned that the prevented sediment and floodplain reconnection protocols developed for urban streams would work reasonably well in rural situations, depending on the local severity of bank erosion and the degree of floodplain disconnection.

Consequently, the Panel recommends that the urban protocols can be applied to non-urban stream restoration projects, if they are designed using the NCD, LSR, RSC or other approaches, and also meet the relevant qualifying conditions, environmental considerations and verification requirements.

At the same time, the Panel agreed that certain classes of non-urban stream restoration projects would not qualify for the removal credit. These include:

- Enhancement projects where the stream is in fair to good condition, but habitat features are added to increase fish production (e.g., trout stream habitat, brook trout restoration, removal of fish barriers, etc.).
- Projects that seek to restore streams damaged by acid mine drainage
- Riparian fencing projects to keep livestock out of streams

The Panel notes that Protocol 3 (outlined in Section 5) will need to be modified when it is applied to non-urban stream restoration projects. Specifically, the pre-project load utilized will need to be adjusted to reflect the actual non-urban load being delivered to the rural project. The appropriate unit area loading rate for each non-urban land use can be directly determined from local CAST outputs for the geographic area in which the project is located.

Section 5: Recommended Protocols for Defining Pollutant Reductions Achieved by Individual Stream Restoration Projects

Based on its research review, the Panel crafted four general protocols that can be used to define the pollutant load reductions associated with individual stream restoration projects. The following protocols apply for stream reaches not simulated in the Chesapeake Bay Watershed Model (CBWM), which include reaches with mean annual streamflow less than 100 cubic feet per second (cfs) that do not have a calibration station and are roughly the size of 11-digit HUCs (Martucci et al., 2006; U.S. EPA, 2010):

Protocol 1: Credit for Prevented Sediment during Storm Flow -- This protocol provides 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.

Protocol 2: Credit for Instream and Riparian Nutrient Processing during Base Flow -- This protocol provides an annual mass nitrogen reduction credit for qualifying projects that include design features to promote denitrification during base flow within a stream's hyporheic zones. The credit is applied to a "theoretical" box where denitrification occurs through increased hyporheic exchange for that portion of the channel that has been reconnected to the floodplain.

Protocol 3: Credit for Floodplain Reconnection Volumes during Storm Flow-- This protocol provides an annual mass nutrient reduction credit for qualifying projects that reconnect stream channels to their floodplain over a wide range of storm events. A wetland-like treatment is used to compute the load reduction attributable to floodplain deposition, plant uptake, denitrification and other biological and physical processes.

Protocol 4: Credit for Dry Channel RSC as an Upland Stormwater Retrofit-- This protocol computes an annual nutrient and sediment reduction *rate* for the contributing drainage area to a qualifying dry channel RSC project. The rate is determined by the volume of stormwater treatment provided in the upland area using the retrofit rate adjustor curves developed by the Stormwater Retrofit Expert Panel (WQGIT, 2012).

An individual stream restoration project may qualify for credit under one or more of the protocols, depending on its design and overall restoration approach. The next four sections describe how each protocol is applied to individual stream restoration projects.

Protocol 1
Credit for Prevented Sediment during Storm Flow

This protocol follows a three step process to compute a mass reduction credit for prevented sediment:

1. Estimate stream sediment erosion rates and annual sediment loadings,

2. Convert erosion rates to nitrogen and phosphorus loadings, and
3. Estimate reduction attributed to restoration.

This protocol uses a modification to the "Bank Assessment for Non-point Source Consequences of Sediment" or BANCS method (Rosgen, 2001; U.S. EPA, 2012; Doll et al., 2003) for estimating sediment and nutrient load reductions. The BANCS method was developed by Rosgen (2001) and utilizes two commonly used bank erodibility estimation tools to predict stream bank erosion; the Bank Erosion Hazard Index (BEHI) and Near Bank Stress (NBS) methods.

The BANCS method has been used by others for the purpose of estimating stream erosion rates. For example, MDEQ (2009) used the BANCS method to develop sediment TMDLs. U.S. EPA has also recommended the BANCS method in its TMDL Guidance (U.S. EPA, 2012). The Philadelphia Water Department has used the BANCS method to prioritize streams for restoration (Haniman, 2012), although they did note some accuracy issues attributed to misuse of the BEHI and NBS methods.

Altland (2012) and Beisch (2012) have used a modified BANCS method with reasonable success and the general approach has been used in Anne Arundel County to prioritize their stream restoration projects (Flores, 2012) and in Fairfax County to evaluate cost-effectiveness of restoration projects (Medina and Curtis, 2011). More information on the technical derivation of Protocol 1 can be found in Appendix B.

The Panel identified a series of potential limitations to the BANCS method, including:

- The method is based on the NCD stream restoration approach, which uses assumptions regarding bank full storm frequency that are not shared in other design approaches (e.g., LGS, RSC).
- Some studies have found that frost heaving may be a better predictor of stream bank erosion than NBS.
- Estimates of BEHI and NBS can vary significantly among practitioners.
- Extrapolation of BEHI and NBS data to unmeasured banks may not be justifiable.
- BEHI is not effective in predicting bank erodibility in situations where there are head cuts or storm drain outfalls.
- This method estimates sediment supply and not transport or delivery. Refer to Appendix B for additional information about this method and sediment delivery.

Despite these concerns, the Panel felt that the use of a method that allows the estimation of stream bank erosion from an empirical relationship between standard assessment tools (BEHI and NBS) and in-stream measurements justified its use for the purposes of crediting stream restoration. Furthermore, a literature review of the BANCS Method in Appendix B indicates further refinements to this method that can improve the accuracy. The Panel recommended several steps to improve the consistency and repeatability of field scoring of BEHI and NBS, as follows:

- The development of a standardized photo glossary to improve standardization in selecting BEHI and NBS scores.

- Continued support for the development of regional stream bank erosion curves for the BANCS method using local stream bank erosion estimates throughout the watershed and a statistical analysis of their predicted results. Ideally, measured bank erosion rates within each subwatershed or County would be used to validate the BANCS method specific to that location. Given that these data may not be readily available, additional methodologies for adjusting the BEHI and NBS scores to accommodate local subwatershed characteristics may be useful. For example, adjustments to the BEHI to account for areas with predominantly sandy soils, agricultural channels, or legacy sediment.

- Using other methods to validate the BANCS method such as aerial photographs that can be used to estimate historical erosion rates.

- The BANCS method should only be performed by a qualified professional, as determined by each permitting authority.

- Extrapolation of BEHI and NBS to unmeasured banks should not be allowed unless photo documentation is used to provide the basis of extrapolation.

- If BEHI and NBS data are not available for *existing* stream restoration projects, the current CBP approved rate will apply.

Step 1. *Estimate stream sediment erosion rate*

Studies have shown that when the BANCS method is properly applied it can be an excellent predictor of the stream bank erosion rate (e.g., Rosgen, 2001; Starr, 2012, Doll et al., 2003). An estimate of the pre-project erosion rate is made by performing BEHI and NBS assessments for each stream bank within the restoration reach. BEHI and NBS scores are then used to estimate erosion rates as determined from a regional bank erosion curve. An example of a regional curve is shown in Appendix B, which shows the USFWS curve for Hickey Run in Washington, DC.

The pre-project erosion rate is then multiplied by the bank height, qualifying stream bank length and a bulk density factor to estimate the annual sediment loading rate (in tons/year) using Equation 1 below.

(Eq. 1)

where: S = sediment load (ton/year) for reach or stream
c = bulk density of soil (lbs/ft^3)
R = bank erosion rate (ft/year) (from regional curve)
A = eroding bank area (ft^2)
2,000 = conversion from pounds to tons

The summation is conducted over all stream reaches being evaluated. Bulk density measurements, although fairly simple, can be highly variable and each project site should have samples collected throughout the reach to develop site-specific bulk density estimates. Van Eps et al. (2004) describes how bulk density is applied using this approach.

Step 2. *Convert stream bank erosion to nutrient loading*

To estimate nutrient loading rates, the prevented sediment loading rates are multiplied by the median TP and TN concentrations in stream sediments. The default values for TP and TN are from Merritts et al. (2010) and are based on 228 bank samples in Pennsylvania and Maryland (Table 5). From Merritts et al. (2010), the phosphorus and nitrogen concentrations measured in streambank sediments are:

- 1.2 pounds P/ton sediment
- 2.6 pounds N/ton sediment

Localities are encouraged to use their own values for stream bank and stream bed nutrient concentrations, if they can be justified through local sampling data.

Step 3. *Estimate stream restoration efficiency*

The BANCS method estimates stream bank erosion but not the efficiency of stream restoration practices in preventing bank erosion. The Panel concluded that the mass load reductions should be discounted to account for the fact that projects will not be 100% effective in preventing stream bank erosion and that some sediment transport occurs naturally in a stable stream channel.

Consequently, the Panel took a conservative approach and assumed that projects would be 50% effective in reducing sediment and nutrients from the stream reach. The technical basis for this assumption is supported by the long term Spring Branch Study mentioned in Section 2.3 and the sediment and nutrient removal rates reported in Table 2.

An alternative approach is to use the erosion estimates from banks with low BEHI and NBS scores to represent “natural” conditions which is the approach taken by Van Eps et al. (2004) and to use the difference between the predicted erosion rate and the “natural” erosion rate as the stream restoration credit. The Philadelphia Water Department has also suggested using this approach (Haniman, 2012).

While the Panel felt the "natural background" approach had merit, it agreed that the recommended removal efficiency would provide a more conservative estimate, and would be less susceptible to manipulation.

For CBWM purposes, the calculated sediment mass reductions would be taken at the edge of field, and would be subject to a sediment delivery ratio included in the CBWM and to account for loss due to depositional processes between the edge-of-field and edge-of-stream. Riverine transport processes are then simulated by HSPF to determine the delivered load. Refer to Appendix B for additional information on the sediment delivery ratio. The calculated nutrient mass reductions are not subject to a delivery ratio and would be deducted from the annual load delivered to the river basin segment (edge-of-stream) in the CBWM.

Protocol 2
Credit for In-Stream and Riparian Nutrient Processing within the Hyporheic Zone during Base Flow

This protocol applies to stream restoration projects where in-stream design features are incorporated to promote biological nutrient processing, with a special emphasis on denitrification. The protocol also applies to situations where additional groundwater or base flow interaction occurs in the floodplain and can be measured. The protocol only provides a nitrogen removal credit; no credit is given for sediment or phosphorus removal. More detail on the technical derivation of Protocol 2 can be found in Appendix C.

This protocol relies heavily on in-situ denitrification studies in restored streams within the Baltimore metropolitan area (Kaushal et al., 2008; Striz and Mayer, 2008). After communication with two of the principal researchers of these studies, Dr. Sujay Kaushal and Dr. Paul Mayer, the Panel assumed that credit from denitrification can be conservatively estimated as a result of increased hyporheic exchange between the floodplain and the stream channel.

The credit is determined only for the length of stream reach that has been reconnected to the flood plain as indicated by a bank height ratio of 1.0 (bankfull storm) or less for projects that use the natural channel design approach. The bank height ratio is an indicator of floodplain connectivity and is a common measurement used by steam restoration professionals. It is defined as the lowest bank height of the channel cross section divided by the maximum bankfull depth.

Other design approaches that do not use the bankfull storm, such as flood plain valley restoration or regenerative stream channel restoration, should use as a criterion the return interval at which floodplain reconnection occurs. If the bank height where reconnection to the flood plain occurs is equivalent to a depth of 1.0 inches or less of rainfall then it can be assumed that hyporheic reconnection occurs.

The above studies also demonstrated the importance of "carbon" availability in denitrification. To assure that sites have adequate carbon, localities should require an extensive planting plan along the riparian corridor of the stream reach.

It is assumed that the denitrification occurs in a "box" that extends the length of the restored reach. The cross sectional area of the box extends to a depth 5 feet beneath the stream surface with a width that includes the width of the channel (at bankfull depth) added to 5 feet on either side of the stream bank (see Figure 3.)

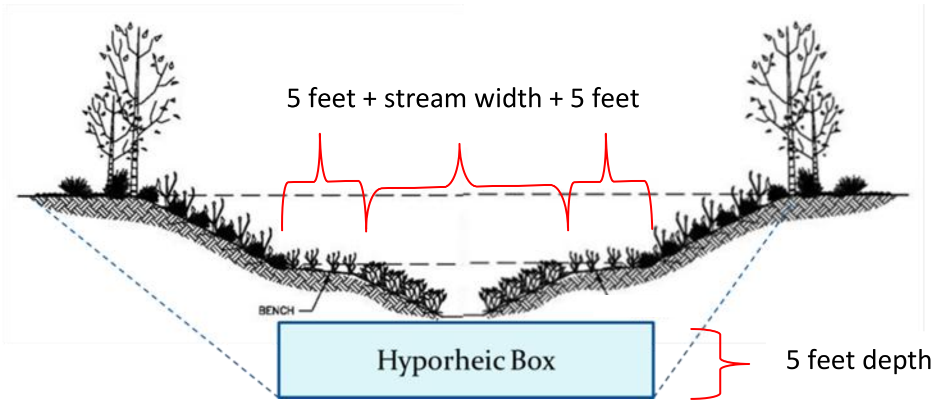

Figure 3. Hyporheic box that extends the length of the restored reach

The cross sectional area of the hyporheic box is multiplied by the length of the restored connected channel and the result is then multiplied by an average denitrification rate for restored low connected banks from Kaushal et al. (2008) of 132.4 μg N/kg/day of soil (2.65 x 10^{-4} pounds/ton/day of soil) which is the denitrification rate within the mass of stream sediment within the hyporheic box.

Step 1. *Determine the total post construction stream length that has been reconnected using the bank height ratio of 1.0 or less (for natural channel design projects) or the 1.0 inch storm (for other design approaches that do not use bank full storm).*

Step 2. *Determine the dimensions of the hyporheic box.*

The cross sectional area is determined by adding 10 ft (2 times 5 ft) to the width of the channel at bank full depth and multiplying the result by 5 ft. This assumes that the stream channel is connected on both sides, which is not always the case. The design example in Section 6 shows how this condition is addressed. Next, multiply the cross sectional area by the length of the restored connected channel from Step 1 to obtain the hyporheic box volume.

Step 3. *Multiply the hyporheic box mass by the unit denitrification rate (2.65 x 10^{-4} pounds/ton/day of soil).*

Note that this also requires the estimation of the bulk density of the soil within the hyporheic box.

Protocol 3
Credit for Floodplain Reconnection Volume during Storm Flow

This protocol provides an annual mass nutrient reduction credit for qualifying projects that reconnect stream channels to their floodplain over a wide range of storm events. This method assumes that nitrogen and phosphorus removal occurs only for that volume of annual flow that is effectively in contact with the floodplain. For planning purposes, a series of curves are used to relate the floodplain reconnection volume to the effective depth of rainfall treated in the floodplain, which in turn are used to define the nutrient removal rate that is applied to subwatershed loads delivered to the project. Project-specific calculations should be used instead when design details are available.

The extent of the credit depends on the elevation of the stream invert relative to the stage elevation at which the floodplain is effectively accessed. Designs that divert more stream runoff onto the floodplain during smaller storm events (e.g., 0.25 or 0.5 inches) receive greater nutrient credit than designs that only interact with the floodplain during infrequent events, for example the 1.5 year storm event. Wet channel RSC and LSR and specially designed NCD restoration projects may qualify for the credit.

The floodplain connection volume afforded by a project is equated to a wetland volume so that a wetland removal efficiency can be applied. The Panel reasoned that the function of the increased floodplain connection volume would behave in the same fashion as a restored floodplain wetland, for which there is robust literature to define long term nitrogen and phosphorus removal rates (Jordan, 2007). The Panel decided that the maximum ponded volume in the flood plain that receives credit should be 1.0 foot to ensure interaction between runoff and wetland plants.

A key factor in determining the wetland effectiveness is the hydraulic detention time. The TN, TP and TSS efficiencies used in this protocol are from Jordan (2007), who assumes that detention time is proportional to the fraction of watershed occupied by wetlands. To ensure that there is adequate hydraulic detention time for flows in the floodplain, there should be a minimum watershed to floodplain surface area ratio of one percent.

The recommended protocol is similar to the methods utilized by Altland (2012) for crediting stream restoration projects that reconnect to the floodplain. More detail on the technical derivation of the curves that are used in Protocol 3 can be found in Appendix C. Two examples are provided to illustrate how this approach can be applied using hydrologic and hydraulic modeling. The examples are using discrete storm modeling and continuous simulation.

Step 1: *Estimate the floodplain connection volume in the available floodplain area.*

The first step involves a survey of the potential additional runoff volume that could be diverted from the stream to the floodplain during smaller storm events. Designers will need to conduct detailed hydrologic and hydraulic modeling of the subwatershed, stream and floodplain to estimate the potential floodplain connection volume. In addition, designers will need to show that regulatory floodplain elevations are maintained, and that the stream channel has adequate sediment transport capacity. As a guide for project planning, the Center for Watershed Protection has developed a series of curves that define the fraction of annual rainfall that is treated under various depths of floodplain connection treatment (Appendix C, Figure 3).

Step 2: *Estimate the nitrogen and phosphorus removal rate attributable to floodplain reconnection for the floodplain connection volume achieved.*

The curves in Figures 4 -6 can be used to calculate an approximate removal rate for each project. When project-specific data are available, the loads can be estimated using the results of hydrologic and hydraulic modeling to calculate the volume of runoff that accesses the floodplain.

Step 3: *Compute the annual N, P and TSS load delivered to the project during storms.*

For urban watersheds, these loads are estimated by using the unit area TN, TP and TSS loading rates for impervious land derived for the river basin segment in which the project is located (i.e., CBWM version 5.3.2). The Panel decided that the loading rates for impervious land provided an estimation of the load delivered during storm flow. These unit loads are readily available from CBP tools such as CAST, MAST and VAST. BMPs installed within the drainage area to the project will reduce the delivered loads by serving as a treatment train. The modeling team will discuss the possibility of incorporating treatment train effects into the CBWM and CAST[2]. If treatment train effects cannot be explicitly modeled in the CBWM and CAST, another option could be to first input all upland BMPs into CAST to determine the delivered loads to the stream restoration project and then use the resulting reduced loads for this step.

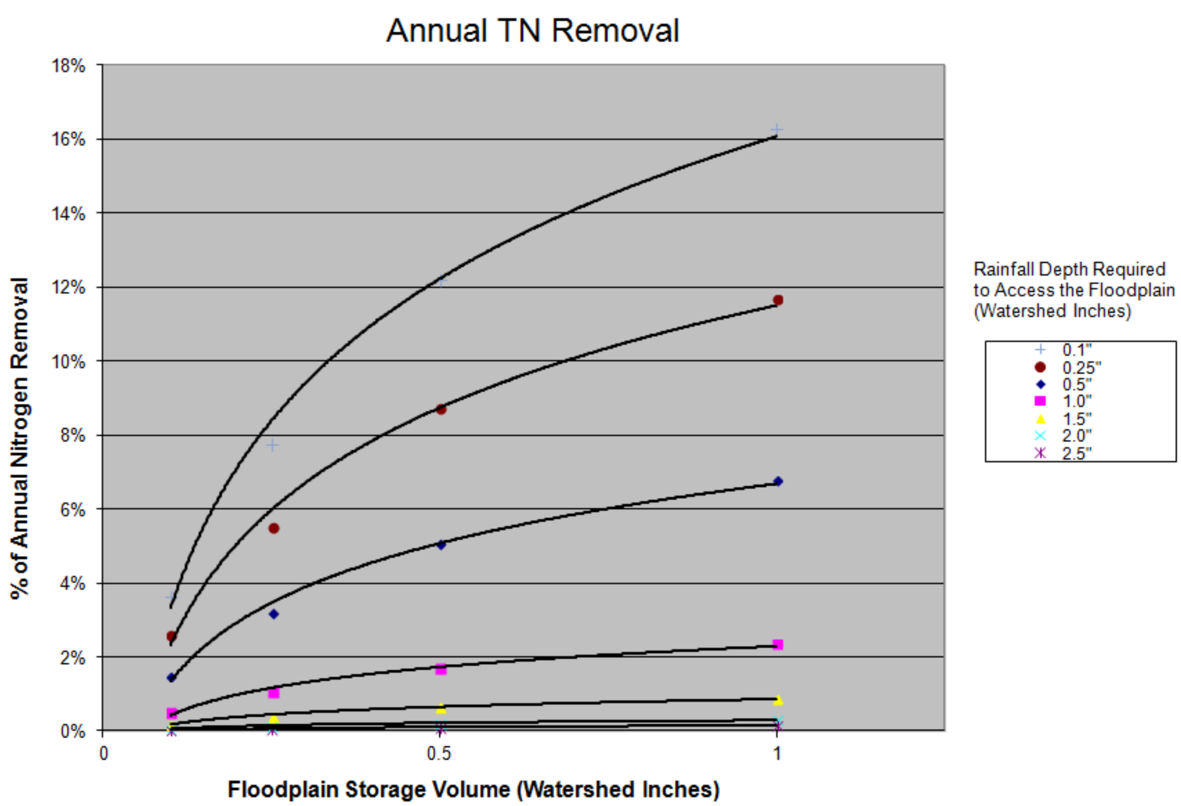

Figure 4. Annual TN removal as a function of floodplain storage volume for several rainfall thresholds that allow runoff to access the floodplain.

[2] A meeting is scheduled for 12/11/2012 between the modeling team and several Panel members to discuss the stream protocol and will include a discussion on modeling treatment train effects.

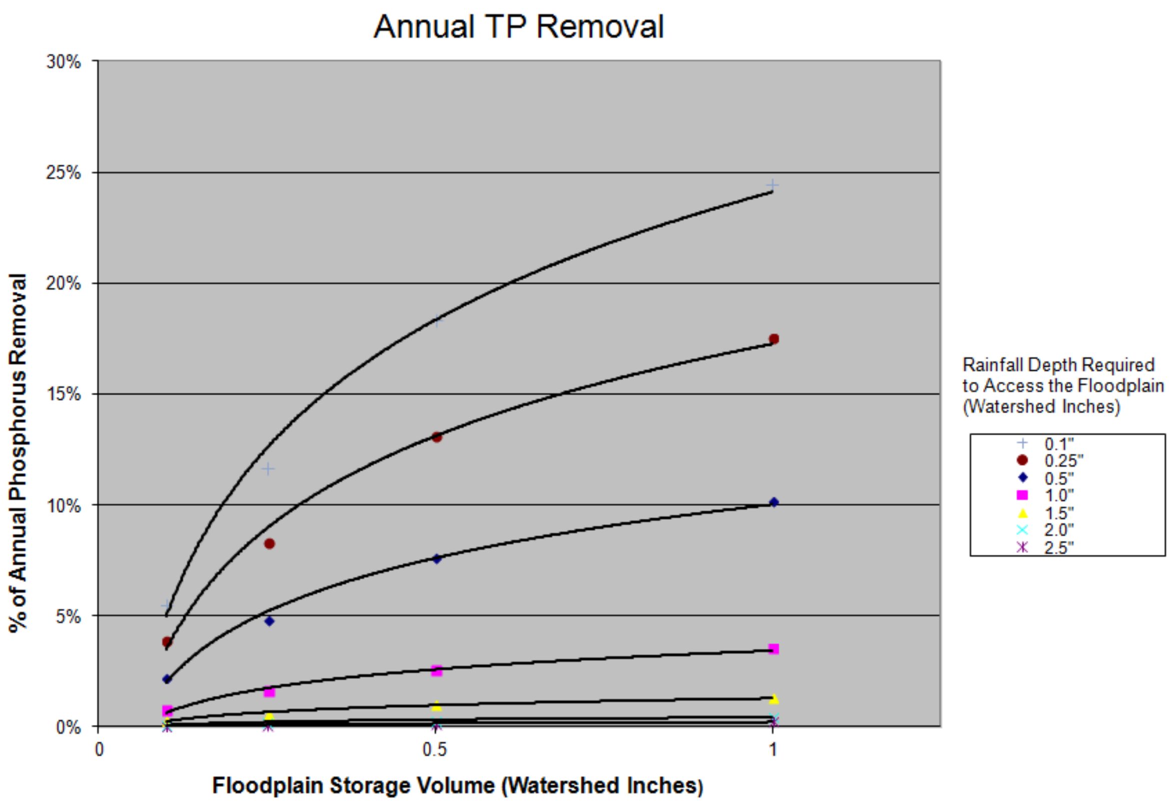

Figure 5. Annual TP removal as a function of floodplain storage volume for several rainfall thresholds that allow runoff to access the floodplain.

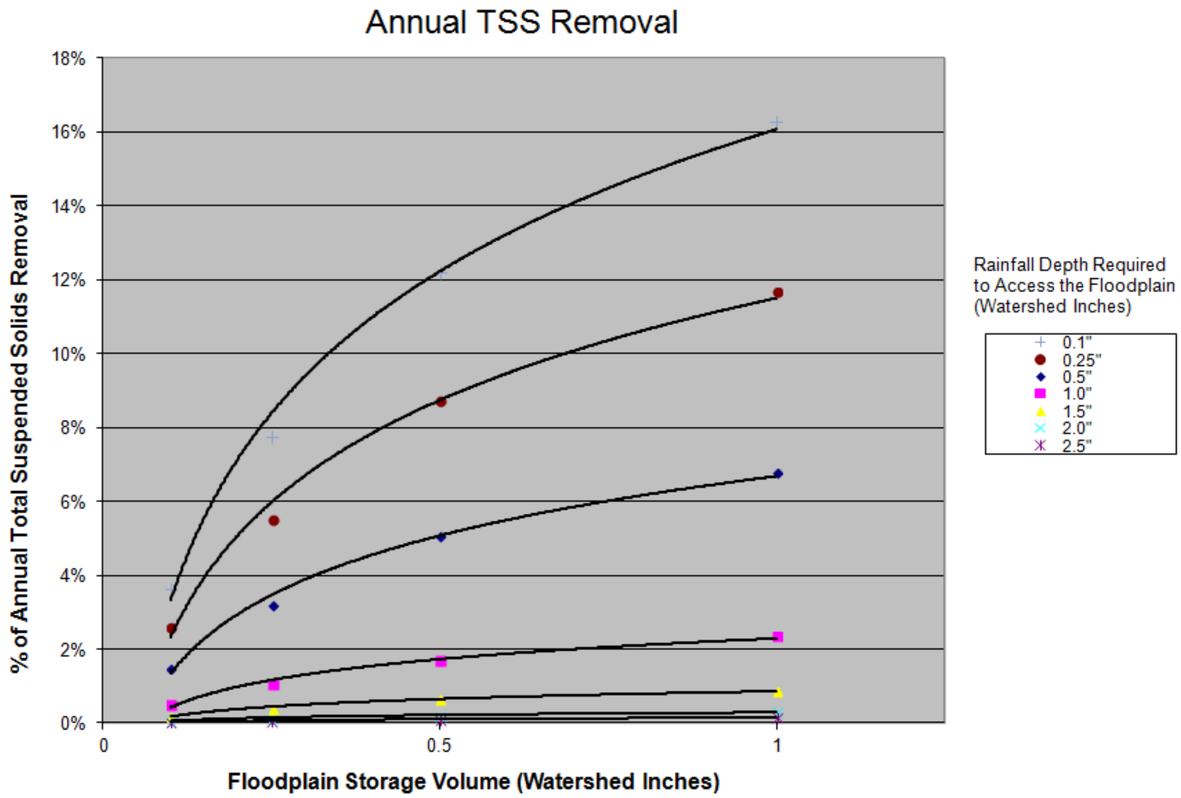

Figure 6. Annual TSS removal as a function of floodplain storage volume for several rainfall thresholds that allow runoff to access the floodplain.

Step 4: *Multiply the pollutant load by the project removal rate to define the reduction credit.*

Protocol 4
Dry Channel RSC as a Stormwater Retrofit

Because the Panel decided to classify dry channel RSC systems as an upland stormwater retrofit, designers should use the protocols developed by the Urban Stormwater Retrofit Expert Panel to derive their specific nutrient and sediment removal rates (WQGIT, 2012).

That Panel developed adjustor curves to determine TP, TN and TSS removal rates based on the depth of rainfall captured over the contributing impervious area treated by an individual retrofit. In general, dry channel RSCs should be considered retrofit facilities, and the runoff reduction (RR) credit from the appropriate retrofit removal adjustor curve may be used to determine project removal rates. The final removal rate is then applied to the entire drainage area to the dry channel RSC project.

Localities will need to check with their state stormwater agency on the specific data to report individual retrofit projects, and must meet the BMP reporting, tracking and verification procedures established by the Retrofit Expert Panel (WQGIT, 2012). In general, the following information will be reported:

a. Retrofit class (i.e., new retrofit facility)
b. Location coordinates
c. Year of installation (and ten year credit duration)
d. 12 digit watershed in which it is located
e. Total drainage area and impervious cover area treated
f. Runoff volume treated
g. Projected sediment, nitrogen, and phosphorus removal rates

Section 6: Credit Calculation Examples

The following examples have been created to show the proper application of the four protocols to determine the nutrient and sediment reductions associated with individual stream restoration projects. Depending on the project design, more than one protocol may apply to be used to determine the total load removed by the stream restoration project.

Section 6.1
Design Example for Protocol 1
Credit for Prevented Sediment during Storm Flow

Bay City, VA is planning on restoring 7,759 feet of Hickey Run [3]

Step 1. *Estimating stream sediment erosion rate*

Five reaches were subdivided into a total of 28 banks for BEHI and NBS assessment (Figure 1, Appendix B). The BEHI and NBS scores were taken for each bank and an estimated stream erosion rate was made using the curve developed by the USFWS. The bank height and length were used to convert the erosion rate from feet per year to pounds per year using Equation 1 from the description of Protocol 1 in Section 5. The data used in this calculation is provided in Appendix B.

The bank erosion estimates in feet per year were multiplied by the bulk density and the total eroding area (bank length in feet x bank height in feet) to convert the sediment loading to tons per year. The loading rates for each of the 5 reaches were totaled to give an estimated erosion rate for the entire 7,759 feet project length. The predicted erosion rate for the entire project length is 1,349 tons per year (348 pounds per linear foot per year).

[3] The data used for this example are taken from Hickey Run collected by the USFWS except for bulk density which was taken from Van Eps et al. (2004).

Step 2. *Convert erosion rate to nutrient loading rates*

From Merritts et al. (2010), the phosphorus and nitrogen concentrations measured in streambank sediments are:

- 1.2 pounds TP/ton sediment
- 2.6 pounds TN/ton sediment

A sediment delivery ratio of 0.175 is applied only to the sediment load to account for the loss that occurs because of depositional processes between the edge-of-field and edge-of-stream loads. This ratio is applied here for example purposes only and localities will not be required to make this calculation when submitting the load reduction attributed to stream restoration projects. The ratio is incorporated into the CBWM and is subject to change based on further refinements of the model. Refer to Appendix B for additional information about the sediment delivery ratio. Therefore, the total predicted sediment, phosphorus and nitrogen loading rates from the restoration area is:

Sediment =	236 tons per year
Total Phosphorus =	1,619 pounds per year
Total Nitrogen =	3,507 pounds per year

Step 3. *Estimate stream restoration efficiency*

Assume the efficiency of the restoration practice to be 50% (from Baltimore County DEP Spring Branch Study). Therefore, the sediment and nutrient credits are:

Sediment =	118 tons per year
Total Phosphorus =	810 pounds per year
Total Nitrogen =	1,754 pounds per year

Section 6.2
Design Example for Protocol 2
Credit for In-Stream and Riparian Nutrient Processing within the Hyporheic Zone during Base Flow

Bay City would like to determine what additional nutrient reduction enhancement credits could be earned if parts of the restoration design for Hickey Run resulted in the reconnection of the base flow channel as indicated by a post construction bank height ratio of 1.0. Note that the credits from this protocol should be added to the credits from Protocol 1.

Step 1. *Determine the total post construction stream length that has been reconnected using the bank height ratio of 1.0.*

It was determined that the stream restoration could improve the floodplain connectivity by reducing the bank height ratio to 1.0 for 500 feet of stream channel. Only one side of the stream meets the bank height ratio criterion because of an adjoining road embankment on the other side. In the study by Striz and Mayer (2008), the groundwater flow is split into left and right bank compartments allowing the hyporheic box to be split into a left and a right bank compartment on either side of the stream thalweg divide. In step 2, only half of the stream width is used to size the hyporheic box dimensions.

Step 2. *Determine the dimensions of the hyporheic box.*

This is done by adding 5 feet to the width of the stream channel taken from the thalweg to the edge of the connected side of the stream at mean base flow depth. Multiply the result by the 5 foot depth of the hyporheic box. This is the cross sectional area of the hyporheic box. Multiply the cross sectional area by the length of the restored connected channel from Step 1. The post construction stream width from the 500 foot channel segment at base flow will be on average 14 feet. To determine the width of the hyporheic box, 5 feet is added to width of half of the total stream width (7 feet) for a total width of 12 feet. The depth of the box is 5 feet. The total volume of the hyporheic box is $500(12 \times 5) = 30{,}000$ cubic feet.

Step 3. *Multiply the hyporheic box mass by the unit denitrification rate*

This step requires the estimation of the bulk density of the soil within the hyporheic box. Assume that the bulk density of the soil under a stream is 125 pounds per cubic foot. The total mass of the soil is calculated in Equation 2 below.

(Eq. 2)

Where: 2,000 = conversion from pounds to tons

The hyporheic exchange rate is 2.65×10^{-4} lb/ton/day of soil (conversion from 132.4 μg TN/kg/day of soil); therefore, the estimated TN credit is:

(Eq. 3)

Section 6.3
Design Example for Protocol 3
Credit for Floodplain Reconnection Volume during Storm Flow

Bay City is not satisfied with the credits from the above restoration approaches and wants to compare these approaches to one where the stream can be reconnected to the floodplain. The watershed area is 1,102 acres with an impervious cover of 41%.

Step 1: *Estimate the floodplain connection volume in the available floodplain area.*

Bay City determined that by establishing a floodplain bench and performing minor excavation the stream would spill into the floodplain at storm flows exceeding 0.5 inches of rainfall (from a hydraulic model such as HEC-RAS) and the volume of storage available in the floodplain for the storm being analyzed is 23 acre feet, which corresponds to 0.25 inches of rainfall.

Step 2: *Estimate the nitrogen and phosphorus removal rate attributable to floodplain reconnection for the floodplain connection volume achieved.*

The curves in Figures 7-9 can be used to estimate a removal rate for the project. The TN reduction efficiency is 3.5%, The TP efficiency is 5.0% and the TSS efficiency is 3.5%.

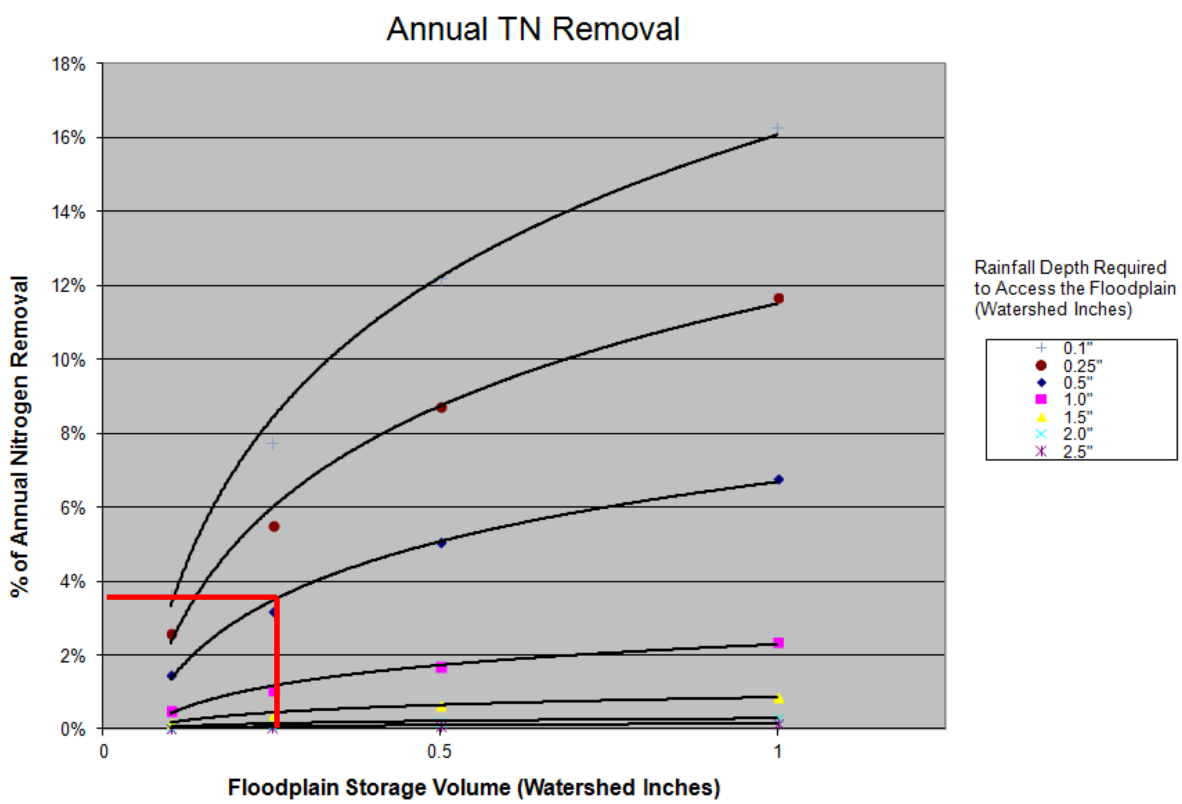

Figure 7. Annual TN removal as a function of 0.25 watershed inch floodplain storage volume and 0.5 inch rainfall depth required to access the floodplain.

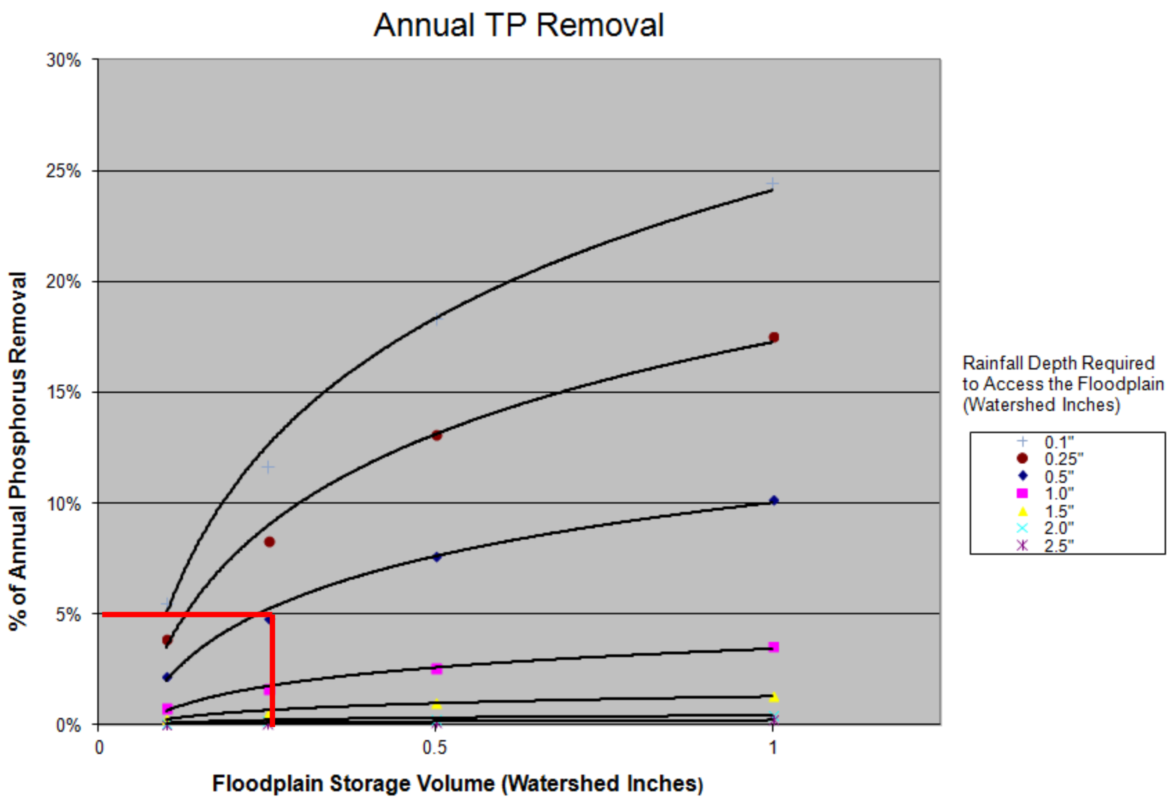

Figure 8. Annual TP removal as a function of 0.25 watershed inch floodplain storage volume and 0.5 inch rainfall depth required to access the floodplain.

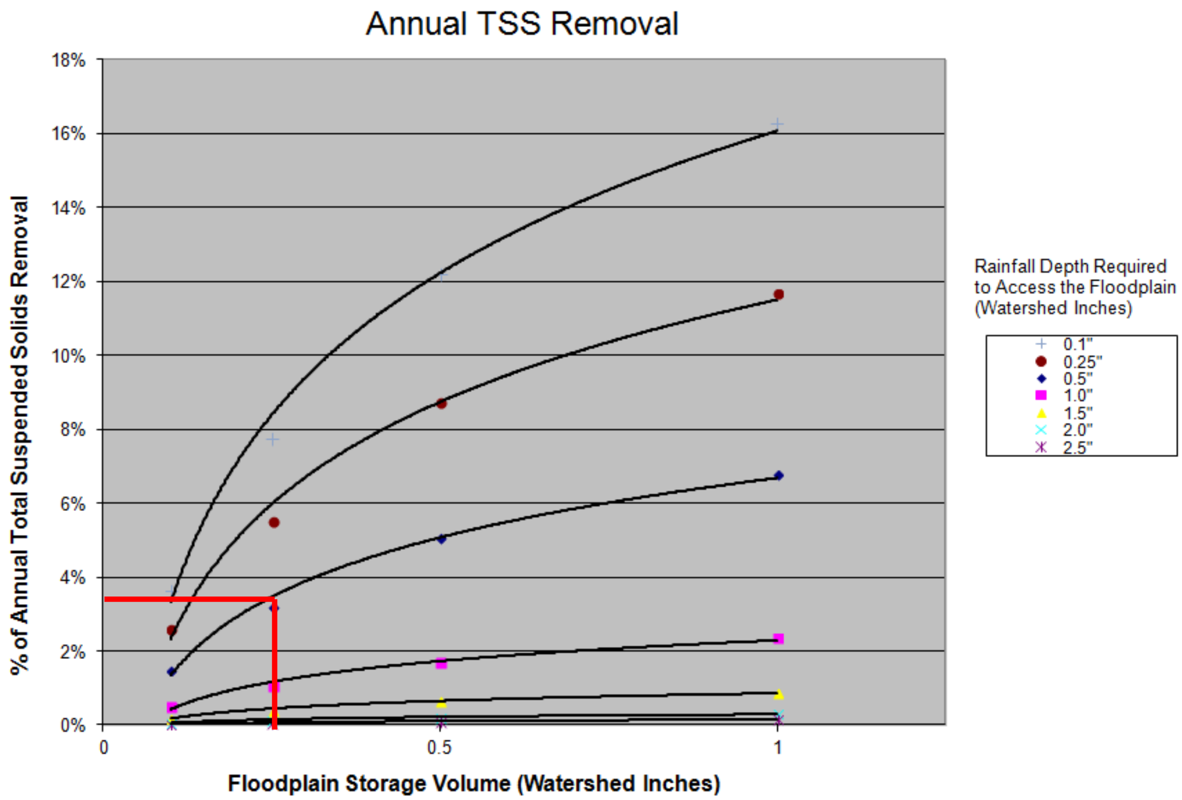

Figure 9. Annual TSS removal as a function of 0.25 watershed inch floodplain storage volume and 0.5 inch rainfall depth required to access the floodplain.

Step 3: *Compute the annual N, P and TSS load delivered to the project during storms*.

With the watershed area of 1,102 acres and impervious cover of 41%, assuming that the storm load is associated with the impervious cover only, the loading from Table 6 is:

TN= 6,280 pounds per year
TP= 999 pounds per year
TSS= 5.3×10^5 pounds per year

The efficiencies from Step 2 are multiplied by this result to yield the reduction credits.

TN= 220 pounds per year
TP= 50 pounds per year
TSS= 18.6×10^3 pounds per year

Table 6. Edge of Stream Unit Loading Rates for Bay States Using CBWM v. 5.3.2

BAY STATE	Total Nitrogen		Total Phosphorus		Total Suspended Sediment	
	lb/ac/year				lb/ac/year	
	IMPERV	PERV	IMPERV	PERV	IMPERV	PERV
DC	13.2	6.9	1.53	0.28	1165	221
DE	12.4	8.7	1.09	0.25	360	42
MD	15.3	10.8	1.69	0.43	1116	175
NY	12.3	12.2	2.12	0.77	2182	294
PA	27.5	21.6	2.05	0.61	1816	251
VA	13.9	10.2	2.21	0.60	1175	178
WV	21.4	16.2	2.62	0.66	1892	265

Source: Output provided by Chris Brosch, CBPO, 1/4/2012, "No Action" run (loading rates without BMPs), state-wide average loading rates, average of regulated and unregulated MS4 areas

Section 6.4
Design Example for Protocol 4
Dry Channel RSC as a Stormwater Retrofit

Bay County plans to install a Regenerative Stormwater Conveyance (RSC) on an eroding hill slope near a stream valley park. Because the project is located outside of waters of the US, it is classified as a dry channel RSC and the retrofit adjustor curves are used to define its sediment and nutrient removal rate (WQGIT, 2012).

The upland drainage area to the RSC project is an 8-acre residential neighborhood that has 25% impervious cover. The engineer has estimated that the retrofit storage (*RS*) associated with the RSC is 0.167 acre-feet. The engineer determines the number of inches that the retrofit will treat using the standard retrofit Equation 4:

(Eq. 4)

Where: RS = retrofit storage in acre-feet
12 = conversion from feet to inches
I = impervious cover percent expressed as a decimal
A = drainage area in acres

Equation 5 below incorporates the specifications for the Bay County RSC into the standard retrofit equation:

(Eq. 5)

The equation indicates that RSC will capture and treat 1.0 inch of rainfall. By definition, RSC is classified as a runoff reduction (RR) practice, so the RR retrofit removal curves in WQGIT are used. Consequently, the proposed RSC retrofit will have the following pollutant removal rates applied to the load generated from its upland contributing area:

TP	TN	TSS
52%	33%	66%

Section 6.5
Cumulative Load Reduction Comparison

The results from the design examples for Protocol 1-3 have been summarized in Table 7 so they can be compared to the total watershed loads as well as to the reductions achieved using the interim rate (Table 3). These results represent the edge-of-stream load reductions and were calculated based on an average 0.175 delivery ratio for TSS. While these results are representative of the anticipated load reductions, the actual results will vary slightly because the CBWM will apply the actual sediment delivery ratio.

The comparison in Table 3 shows that total sediment and nutrient reductions are additive when project design allows for more than one protocol to be used. In general, Protocol 1 yields the greatest load reduction. It should be noted that the magnitude of load reductions for Protocols 2 and 3 is extremely sensitive to project design factors, such as the degree of floodplain interaction and the floodplain reconnection.

The comparison in Table 7 also shows that load reductions achieved under the protocols, either individually or cumulatively, are generally consistent with those that are calculated using the new interim rate (Table 3). This observation reinforces the Panel's recommendation that the new interim rate is a useful planning tool within the context of CAST, VAST or MAST; i.e., the interim rate can be used to assess stream restoration strategies at the local level, and then the protocols can be applied to define the specific removal rates for individual projects.

Because the Chesapeake Bay model "lumps" stream bank erosion from small order streams into the urban impervious sediment load, a portion of the sediment load delivered to the floodplain from the watershed in Protocol 3 may be accounted for in the stream bank loading from Protocol 1. Improvements to how the watershed model models sediments from stream banks are one of the major research recommendations made in Section 8.

Table 7. Edge-of-Stream Load reductions for various treatment options (lb/year)

	Total Watershed Loading[1]	Protocol 1 (BANCS)[2]	Protocol 2 (Hyporehic Box)[3]	Protocol 3 (Floodplain reconnection)[4]	Total Load Reduction[5]	Interim Rate[6]
TN	12,896	1,754	181	220	2,155	1,552
TP	1,382	810	--	50	860	528
TSS[7]	642,226	236,000	--	18,600	254,600	420,926

[1] Edge of stream loadings calculated from Table 6, assuming watershed area of 1102 acres and 41% impervious cover
[2] For the design conditions as outlined in protocol 1 example
[3] For the design conditions as outlined in protocol 2 example
[4] For the design conditions as outlined in protocol 3 example
[5] Assuming the all three protocols are applied to the same project
[6] Applying the unit rate to 7,759 linear feet of the project
[7] For Protocol 1 and interim methods for TSS reductions, a sediment delivery ratio of 0.175 was applied.

Section 7: Accountability Mechanisms

The Panel concurs with the conclusion of the National Research Council (NRC, 2011) that verification of the initial and long term performance of stream restoration projects is a critical element to ensure that pollutant reductions are actually achieved and sustained across the watershed. The Panel also concurred with the broad principles for urban BMP reporting, tracking, and verification contained in the 2012 memo produced by the Urban Stormwater Workgroup.

Section 7.1
Basic Reporting, Tracking and Verification Requirements

The Panel recommends the following specific reporting and verification protocols for stream restoration projects:

1. *Duration of Stream Restoration Removal Credit*. The maximum duration for the removal credits is 5 years, although the credit can be renewed based on a field performance inspection that verifies the project still exists, is adequately maintained and is operating as designed. The duration of the credit is shorter than other urban BMPs, and is justified since these projects are subject to catastrophic damage from extreme flood events, and typically have requirements for 3 to 5 years of post-construction monitoring to satisfy permit conditions.

2. *Initial Verification of Performance*. The installing agency will need to provide a post-construction certification that the stream restoration project was installed

properly, meets or exceeds its functional restoration objectives and is hydraulically and vegetatively stable, prior to submitting the load reduction to the state tracking database. This initial verification is provided either by the designer, local inspector, or state permit authority as a condition of project acceptance or final permit approval.

3. *Restoration Reporting to the State*. The installing agency must submit basic documentation to the appropriate state agency to document the nutrient and sediment reduction claimed for each individual stream restoration project installed. Localities should check with their state agency on the specific data to report for individual projects. Some typical reporting information includes:

    a. Type, length and width of stream restoration project[4]
    b. Location coordinates
    c. Year of installation and maximum duration of credit
    d. 12 digit watershed in which it is located
    e. Protocol(s) used
    f. Projected sediment, nitrogen, and phosphorus load reduction

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

5. *Ongoing Field Verification of Project Performance*. The installing agency needs to conduct inspections once every 5 years to ensure that individual projects are still capable of removing nutrients and sediments. The protocols being developed by Starr (2012) may be helpful in defining performance indicators to assess project performance.

6. *Down-grading*. If a field inspection indicates that a project is not performing to its original specifications, the locality would have up to one year to take corrective maintenance or rehabilitation actions to bring it back into compliance. If the facility is not fixed after one year, the pollutant reduction for the project would be eliminated, and the locality would report this to the state in its annual MS4 report. Non-permitted municipalities would be expected to submit annual progress reports. The load reduction can be renewed, however, if evidence is provided that corrective maintenance actions have restored its performance.

7. *Pre and Post Construction Monitoring Requirements*. Stream restoration projects are different compared to urban BMPs, in that permit authorities often subject them to more extensive pre-project assessment and post-construction monitoring. The Panel feels that such data are important to define project success and continuously refine how projects are designed, installed and maintained.

[4] The length of the stream restoration project is defined as the linear feet of actual project work area and not the entire study reach. The stream valley length is the proper baseline to measure stream length.

The specific elements of the project monitoring requirements will always be established by state and federal permit authorities, and the Panel is encouraged by the knowledge that a new EPA/CBP/Corps of Engineers workgroup was launched in November, 2012 to provide more consistent project permitting and monitoring guidance for stream restoration projects.

The only specific recommendation that the Panel has to offer to the new work group is to maximize the adaptive management value of any project monitoring data collected. Specifically, the Panel encourages a more regional, comprehensive and systematic analysis of the individual project data, with an emphasis on how innovative and experimental restoration design approaches are working and the degree of functional uplift achieved (or not achieved). Such an effort could provide watershed managers with an improved understanding of not only how stream restoration can influence urban nutrient dynamics but also the degree of biological uplift (see Section 8).

Section 7.2
Issues Related to Mitigation and Trading

The Panel was clear that a stream restoration project must provide a net watershed removal benefit to be eligible for either a sediment or nutrient credit. Therefore, a removal credit cannot be granted for any project that is built to offset, compensate, or otherwise mitigate for an impact to a stream or waterway elsewhere in the watershed.

The Panel also recommends a more frequent and stringent inspection and verification process for any stream restoration project built for the purpose of nutrient trading or banking, in order to assure that the project is meeting its nutrient or sediment reduction design objectives.

Section 8: Future Research and Management Needs

Section 8.1
Panel's Confidence in its Recommendations

One of the key requirements of the BMP Review Protocol is for the Expert Panel to assign its degree of confidence in the removal rates that it ultimately recommends (WQGIT, 2010). While the Panel considers its current recommendations to be much superior to the previously approved CBP removal rates, it also clearly acknowledges that major scientific gaps still exist to our understanding of urban stream restoration. For example:

- The majority of the available stream research has occurred in the Piedmont portion of the Bay watershed, limited research within the coastal plain, and virtually none for the ridge and valley province or the Appalachian plateau. The dearth of data from these important physiographic regions of the watershed reduces the Panel's confidence in applications in these areas.

- Several parameters involved in Protocol 1 are based on intensive sampling in the Baltimore and Washington, DC metropolitan areas (e.g., nutrient content of bank and bed sediments, regional stream bank erosion curves). Given the sensitivity of the BANCS methods to these parameters, the Panel would be much more confident if more data were available from other regions of the watershed.

- While the floodplain connection protocol has a strong engineering foundation, the Panel would be more confident if more measurements of urban floodplain wetland nutrient dynamics were available, as well as more data on denitrification rates within the hyporheic zone.

- The Panel remains concerned about how urban sediment delivery is simulated at the river-basin segment scale of the CBWM and how this ultimately impacts the fate of the reach-based sediment and nutrient load reductions calculated by its recommended protocols

- The Panel is not confident on its recommendations for non-urban stream restoration projects, due to the limited research conducted on these systems in the Bay watershed.

Given these gaps, the Panel agreed that the recommended rates should be considered interim and provisional, and that a new Panel be reconvened by 2017 when more stream restoration research, better practitioner experience, and an improved CBWM model all become available to Bay managers.

Section 8.2
Research and Management Needs to Improve Accuracy of Protocols

The Panel acknowledges that the protocols it has recommended are new, somewhat complex and will require project-based interpretation on the part of practitioners and regulators alike. Consequently, the Panel strongly recommends that both groups should test the protocols on real world projects for a six month period of time.

Based on their collective experience, the practitioners and regulators should reconvene with the Expert Panel at a Bay-wide meeting to develop any additional supplemental information or procedures to effectively implement the protocols. Once these are finalized, the Panel recommends that a series of webcasts or workshops be conducted to deliver a clear and consistent message to the Bay stream restoration community on how to apply the protocols.

In the meantime, the Panel recommended several additional steps to increase the usefulness of the protocols to should be taken in the next 2 to 5 years:

- Provide support for the development of regional stream bank erosion curves for the BANCS method using local stream bank erosion estimates throughout the watershed and a statistical analysis of their predicted results. Ideally, measured bank erosion rates within each subwatershed or County would be used to validate the BANCS Method specific to that location. Given that these data may not be readily available, additional methodologies for adjusting the BEHI and NBS scores to accommodate local subwatershed characteristics may be useful. For example, adjustments to the BEHI to account for areas with predominantly sandy soils, agricultural channels, or legacy sediment.

- Form a workgroup comprised of managers, practicing geomorphologists, and scientists to develop more robust guidelines for estimating rates of bank retreat.

- Continued support for more performance research on legacy sediment removal projects, such as the ongoing research at Big Spring Run in Pennsylvania, as well as broader dissemination of the results to the practitioner community.

- Further work to increase the use of stream functional assessment methods at proposed stream restoration project sites to determine the degree of functional uplift that is attained.

- Establishment of an ongoing stream restoration monitoring consortium and data clearinghouse within the CBPO to share project data, train the practitioner and permitting community, and provide ongoing technical support.

- Ongoing coordination with state and federal wetland permitting authorities to ensure that stream restoration projects used for credit in the Bay TMDL are consistently applied and meet or exceed permitting requirements established to protect waters of the US.

- Additional research to test the protocols' ability to adequately estimate load reductions in coastal plain, ridge and valley, and Appalachian plateau locations, and to investigate sediment and nutrient dynamics associated with non-urban stream restoration projects in all physiographic regions of the Bay watershed.

Section 8.3
Other Research Priorities

The Panel also discussed other research priorities that could generally improve the practice of stream restoration. A good review of key stream restoration research priorities can be found in Wenger et al. (2009). Some key priorities that emerged from the Panel included:

- Subwatershed monitoring studies that could explore how much upland retrofit implementation is needed to optimize functional uplift when stream restoration and stormwater retrofits are installed as part of an integrated restoration plan.

- Development of a database of the different stream restoration projects that are submitted for credit under each protocol, and case studies that profile both failure and success stories (see Section 7.1).
- Further economic, sociologic, and ecological research to define the value and benefits of local stream restoration projects, beyond nutrient or sediment reduction.
- Rapid field assessment methods to assess project performance, identify maintenance problems, develop specific rehabilitation regimes, or down-grade nutrient credits where projects fail.
- Proper use and application of engineering hydrology, hydraulic, and sediment transport models to assess channel morphology.
- Development of improved design guidelines for individual in-stream restoration structures.
- Further refinement in stream restoration design methods that are habitat-based and watershed process-oriented.

Section 8.4
Recommended CBWM Model Refinements

The Center for Watershed Protection is now serving in the capacity of the Sediment Reduction and Stream Corridor Restoration Coordinator for the Chesapeake Bay Program. This work includes providing support to the key Panels related to sediment reduction such as the Stream Panel but to also assist the Watershed Technical Committee in helping to incorporate new and refined sediment reduction BMPs as they directly factor into the continued development and enhancement of Scenario Builder, the CBWM, and CAST.

Given that the sediment reduction credit of stream restoration could be greater than the existing approved rate by an order of magnitude, it is critical that the effect of this on the Watershed Model be clearly understood. Currently the model assigns the urban sediment load to either pervious or impervious urban land classifications. However, the assumption from Langland and Cronin (2003) is that the majority of this sediment originates from small upland stream channels. One possible model refinement might include a third land cover category (stream channel). Whether this will result in adjustments to the total amount of sediment being delivered to the Bay or a simpler reallocation remains to be determined.

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