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

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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 the stream channel through hyporheic exchange within the riparian corridor.
>
> *Protocol 3: Credit for Floodplain Reconnection Volume*-- This protocol provides an annual mass sediment and 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. These approaches are based on the best available data as of March 2013. Additional research on legacy sediment removal will be published later in 2013. The Panel will reconvene for a one day workshop in Fall 2013 to review this research and update the Protocols to incorporate these additional findings.

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 or other method	Measured N/P content in streambed and bank sediment
2	Instream Denitrification (B)	Pounds per year	TN	Define hyporheic box for reach	Measured unit stream denitrification rate
3	Floodplain Reconnection (S/B)	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 recognizes that the data available at this time does not allow a perfect understanding or prediction of stream restoration performance. As a result, 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
Bob Kerr	Kerr Environmental Services (VA)
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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Josh Burch	District Department of Environment
Dr. Robert C. Walter	Franklin and Marshall College
Dr. Sujay Kaushal	University of Maryland
Dr. Solange Filoso	University of Maryland
Julie Winters	US Environmental Protection Agency CBPO
Bettina Sullivan	Virginia Department of Environmental Quality
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. Although not reflected in the minutes, there were several conversations, email exchanges, and edits to the drafts from Panel members that are not reflected in the minutes.

Section 2: Stream Restoration in the Chesapeake Bay

Section 2.1

Urbanization, Stream Quality and Restoration

Declining stream quality in the Cheapeake Bay watershed is a function of historic land use and present day urbanization. Historic land use included land clearing for agricultural development, subsequent reforestation in the 20th century, low-head dam construction, and widespread stream channel straightening/relocation (Knox, 1972; Pizzuto et al., 2000; Merritts et al., 2011). A significant amount of sediment is stored in Piedmont floodplains that was delivered from accelerated erosion during historical land clearing and subsequent upland erosion (Trimble, 1974; Costa, 1975; Jacobson and Coleman, 1986). In addition, present day urbanization has led to stream quality decline, as documented by considerable research over the last two decades 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 largely derived from historic land clearing practices are highly enriched with respect to nutrients as a result of past soil erosion and subsequent alluvial and colluvial deposition in the stream valley (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, 2008; Kaushal et al., 2008; Klocker et al., 2009).

In 2008, the Chesapeake Bay Program's Sediment Work Group organized an information exchange workshop entitled "*Fine Sediment and the Chesapeake Bay Watershed*" (Smith et al., 2008) to identify the key knowledge gaps in watershed sediment modeling, monitoring and assessment and to identify the most effective BMPs for reducing fine sediment loads to the Chesapeake Bay. The workshop participants were comprised of watershed managers, scientists, regulators, engineers, and environmental restoration professionals. The conclusions from the workshop are that while much progress has been made in understanding the origins, transport, and fate of sediment, there is no consensus for immediate tools to make quantifiable progress towards improving Chesapeake Bay goals.

Despite this lack of consensus, watershed managers are continuing the widespread implementation of stream restoration to meet local water quality goals and will rely heavily on stream restoration as an important tool in meeting the water quality goals of the WIPs. It is therefore critical to develop a consistent set of protocols that managers can use throughout the Chesapeake Bay watershed that can be adapted as better information becomes available. Stream restoration projects that reduce bank erosion and create in-stream habitat features are a useful strategy as part of a comprehensive watershed approach to reduce sediment and nutrient export from urban and non-urban watersheds. In Section 3, the Panel analyzed the available evidence to define the functional benefits of restored versus non-restored streams.

It is important to note that watersheds can only be comprehensively restored by installing practices in upland areas, the stream corridor, and in appropriate settings, within the stream itself. The CBP currently has completed or launched a half dozen expert panels on urban BMPs, most of which are applied to upland areas, with the goal of providing a wide range of watershed tools to meet restoration goals.

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.

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.

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[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.

Functional Uplift - A general term for the ability of a restoration project in a degraded 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.

Legacy Sediment - Sediment that (1) was eroded from uplands during several centuries of land clearing, agriculture and other intensive uses; (2) accumulated behind ubiquitous dams in slackwater environments, resulting in thick accumulations of cohesive clay, silt and sand, which distinguishes "legacy sediment" from fluvial deposits associated with meandering streams; (3) collected along stream corridors and within valley bottoms, effectively burying natural floodplains, streams and wetlands; (4)altered and continues to impair the morphologic, hydrologic biologic, riparian and other ecological services and functions of aquatic resources; (5) can also accumulate as coarser grained more poorly sorted colluvial deposits, usually at valley margins; (6) can contain varying amounts of nutrients that can generate nutrient export via bank erosion processes. Widespread indicators of legacy sediment impairment include a history of damming, high banks and degree of channel incision, rapid bank erosion rates and high sediment loads. Other indicators include low channel pattern development, infrequent inundation of the riparian zone, diminished sediment storage capacity, habitat degradation, and lack of groundwater connection near the surface of the floodplain and/or riparian areas.

Legacy Sediment Removal (LSR) - A class of aquatic resource restoration that seeks to remove legacy sediments and restore the natural potential of aquatic resources including a combination of streams, floodplains, and palustrine wetlands. Although several LSR projects have been completed, the major experimental site was constructed in 2011 at Big Spring Run near Lancaster, PA. For additional information on the research project, consult Hartranft (2011).

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

Non-Urban - A subwatershed with less than 5% impervious cover, and is primarily composed of forest, agricultural or pasture land uses. Individual states may have alternative definitions.

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, base flow channel design, 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 minor increases in the stream stage for events much 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.

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.

Upland Restoration - The implementation of best management practices outside the stream corridor to reduce runoff volumes and pollutant loads in order to restore the quality of streams and estuaries.

Urban - Generally a subwatershed with more than 5% impervious cover, although individual states may have their own definition.

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. The Watershed Technical Work Group decided in their April 1, 2013 meeting as part of their review of this report that the interim rate will apply to historic projects and new projects that cannot conform to recommended reporting requirements as described in Section 7.1.

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 Run, 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 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).

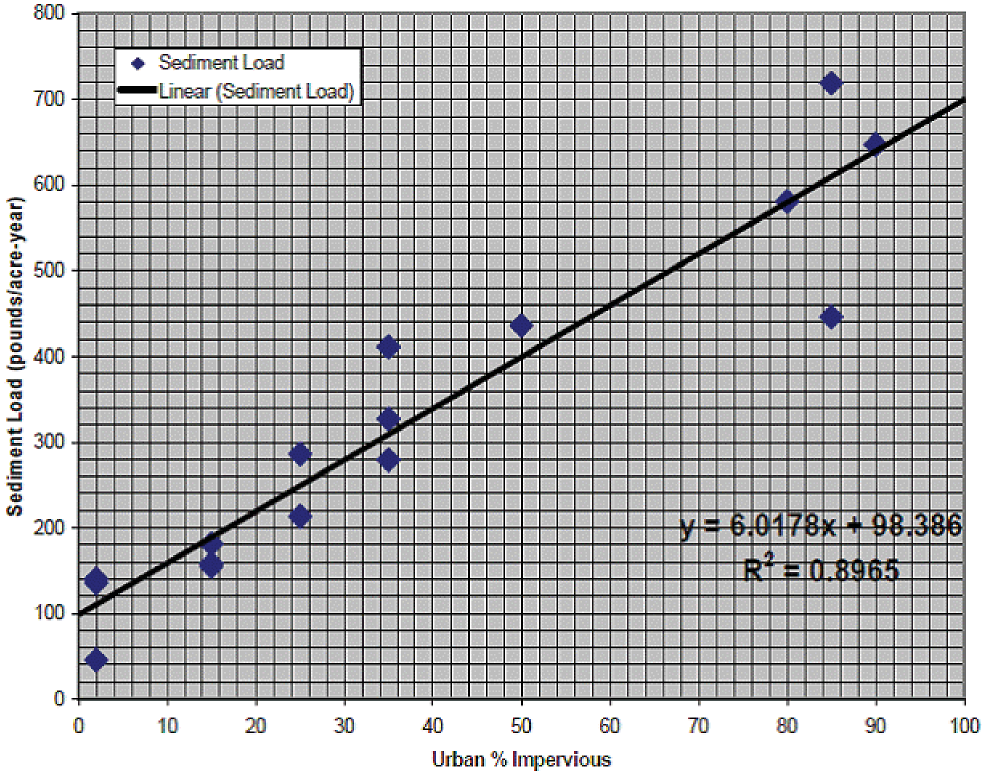

Figure 1. Relationship between Edge-of-Stream Urban Sediment Loads and Watershed Impervious Cover (Source: Langland and Cronin, 2003).

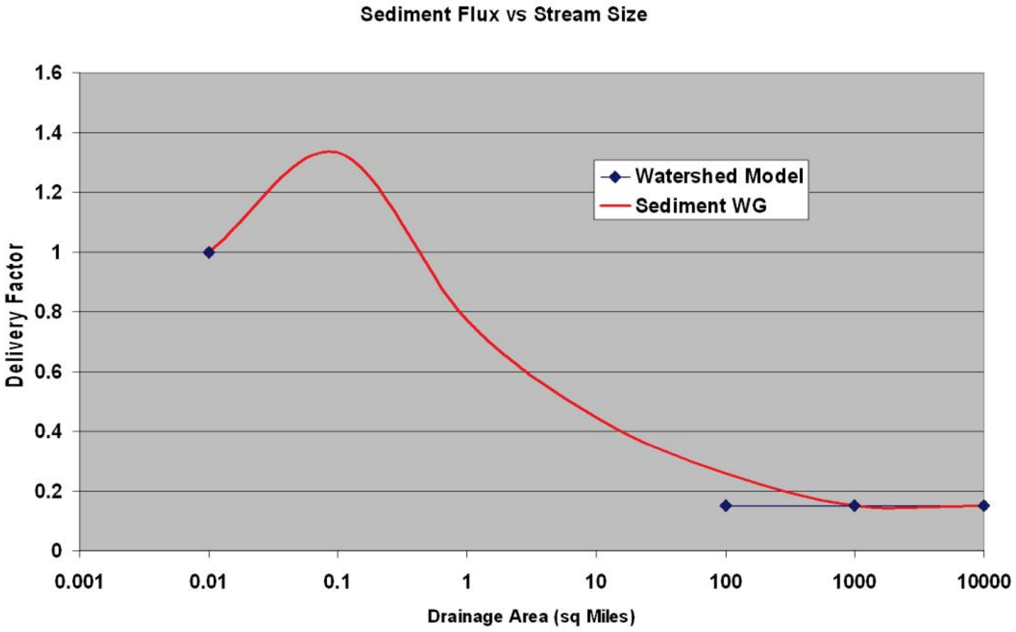

Figure 2. Edge of Stream Sediment Delivery Curve in CBWM

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, 655 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 0.7% 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. Total Urban Stream Restoration Expected by 2025 in Bay State Phase 2 Watershed Implementation Plans[1]

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	2,092,325 (396)	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	441 miles	214 miles

[1] Total miles under urban and non-urban stream restoration (including historical projects) 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
- Physical and chemical (nutrients) properties of stream sediments
- 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

Physical and Chemical (Nutrients) Properties of Stream Sediments

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 or reduce channel and/or floodplain energy to greatly limit the ability for erosive conditions 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 from channel degradation 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 2.28 pounds of TN per ton of sediment and 1.05 pounds of TP per ton of sediment, as documented by Walters et al. (2007). 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	**Mean TP**	**TP Range**	**Mean TN**	**TN Range**	**Location**	**Reference**
Upland Soils	0.18	0.01-2.31	3.2	0.2-13.2	MD	Pouyat et al., 2007
Street Solids	2.07	0.76-2.87	4.33	1.30-10.83	MD	Diblasi, 2008
Catch Basin [3]	1.96	0.23-3.86	6.96	0.23-25.08	MD	Law et al., 2008
BMP Sediments	1.17	0.06-5.51	5.86	0.44-22.4	National	Schueler, 1994
Streambank Sediments	0.439	0.19-0.90	--	--	MD	BDPW, 2006
	1.78		5.41		MD	Stewart, 2012
	1.43	0.93-1.87	4.4	2.8-6.8	PA	Land Studies, 2005 [2]
	1.05	0.68-1.92	2.28	0.83-4.32	PA	Walters et al., 2007 [2,4]

[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

[4] median TN and TP values are reported

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. (20o9) 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 vegetation, debris jams, instream woody debris, and where applicable, e re-expose hydric soils in the pre-settlement floodplain
- Reconnect the stream to floodplain and wetlands during both dry weather flow and storm flows through low floodplain benches, sand seepage wetlands, legacy sediment removal, 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 maximum hydrologic residence time;
- Install instream and floodplain wetland practices with a high surface area to depth ratio and in some cases add channel length or create multi-channel systems ;
- 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 baseflow and stormflow conditions could have a strong influence on sediment and nutrient reduction, depending on the characteristics of the floodplain connection project. .

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 and Functional Lift

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.

Others (Schnabel et al., 1995; Klapproth et al., 2009) have noted that non-forested riparian areas perform as well as forested riparian areas, and the data suggest other features, such as soils, surface and subsurface flow portioning, and other factors may be more important than vegetation type when it comes to nutrient and sediment retention. In addition, several studies have found that natural aquatic resources buried beneath legacy sediment are not exclusively forested and may provide substantial habitat and water quality benefits (Voli et al., 2009; Hilgartner et al., 2010; Merrits et al., 2011; Hartranft et al., 2011).

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 and non-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 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 riparian cover in its recommendations. An urban filter strips/stream buffer CBP Expert Panel was recently formed and held its first meeting in February 2013 to define stream buffer upgrades and how they can be applied in the CBWM. The results from this Panel will help determine the appropriate buffer conditions for stream restoration projects.

- Second, the research reinforces the notion that stream restoration should not be a stand-alone strategy for 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
Success of Stream Restoration Practices

An important part of the Panel charge was to define the success rate 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.

The monitoring data reviewed does not provide a perfect understanding of the benefits of stream restoration, but the results do conclusively demonstrate that stream restoration, when properly implemented, does have sediment and nutrient reduction benefits. The Panel felt there is sufficient monitoring information to develop the protocols in this document with the recognition of the need for refinement as better monitoring data becomes available.

Section 4: Basic Qualifying Conditions for Individual Projects

Section 4.1

Watershed-Based Approach for Screening and Prioritizing

A watershed-based approach for screening and prioritizing stream restoration projects is recommended to focus restoration efforts at locations that will provide the most benefit in terms of sediment and nutrient reduction, as well as improvement to stream function. Application of a model, such as the BANCS method described in Section 5 for Protocol 1, or other screening tools, at a watershed scale enables better reconciliation of the total sediment loadings from stream bank erosion at the watershed level to edge of field loadings predicted by the Chesapeake Bay Watershed Model. This can be a useful check to assure that the BANCS method is appropriately applied and that no single project will have disproportionate load reduction.

Section 4.2

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 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 and failing dams). Most projects will be located on first- to third-order streams, but if larger fourth and fifth order streams are found to contribute significant and uncontrolled amounts of sediment and nutrients to downstream waters, consideration for this BMP would be appropriate, recognizing that multiple and/or larger scale projects may be needed or warranted to achieve desired watershed treatment goals.

- The project must utilize a comprehensive approach to stream restoration design, addressing long-term stability of the channel, banks, and floodplain.

- 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 4.3
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.

- 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 in 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 existing riparian vegetation in the stream corridor, and compensate for any project-related riparian losses in project work areas as determined by regulatory agencies.
- 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 4.4
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) note 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 a functional assessment process, such as the stream functions pyramid (Harman et al., 2011) or functional equivalent. It is important to note that stream evolution theory is still evolving with widely divergent opinions and views, which should be considered in any functional assessment. In addition, most current assessment methods have not yet been calibrated to LSR and RSC projects. State approved methodologies should be considered when available. Regardless of the particular functional assessment method utilized, the basic steps should include:

- 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 4.5

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. Limited research exists to document the response of non-urban streams to stream restoration projects in comparison to the still limited, but more extensive literature on urban streams. However, many of the papers reviewed were from rural streams (Bukaveckas, 2007; Ensign and Doyle, 2005; Mulholland et al., 2009; and Merritts et al., 2010).

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

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 smaller 0 – 3rd order stream reaches not simulated in the Chesapeake Bay Watershed Model (CBWM). These protocols do not apply to sections of streams that are tidally influenced, which will be included in either the Shoreline Erosion Control Expert Panel or a pending future Expert Panel for tidal wetlands.

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. Qualifying projects receive credit under Protocol 1 and use this protocol to determine enhanced nitrogen removal through denitrification within the stream channel during base flow conditions. The credit is applied to a "theoretical" box where denitrification occurs through increased hyporheic exchange for that portion of the channel with hydrologic connectivity to the adjacent riparian floodplain.

Protocol 3: Credit for Floodplain Reconnection Volume-- This protocol provides an annual mass sediment and nutrient reduction credit for qualifying projects that reconnect stream channels to their floodplain over a wide range of storm events. Qualifying projects receive credit for sediment and nutrient removal under Protocol 1 and use this protocol to determine enhanced sediment and nutrient removal through floodplain wetland connection. 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.

Estimates of sediment loss are required as a basis to this protocol. The options to estimate stream sediment erosion rates and annual sediment loadings in Step 1 of this protocol include:

- Monitoring
- BANCS method
- Alternative modeling approach

Monitoring through methods such as cross section surveys and bank pins is the preferred approach, however can be prohibitive due to cost and staffing constraints. The extrapolation of monitoring data to unmeasured banks should be done with care and the monitored cross sections should be representative of those within the project reach. Based on these factors, the use of a method that can be applied to unmonitored stream banks and calibrated to monitoring data, such as the BANCS method described below, is a useful tool.

When monitoring is not feasible, the Panel recommends a modeling approach called the “Bank Assessment for Non-point Source Consequences of Sediment” or BANCS method (Rosgen, 2001; U.S. EPA, 2012; Doll et al., 2003) to estimate 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. Alternative modeling approaches, such as the Bank Stability and Toe Erosion Model (BSTEM) developed by the USDA-ARS National Sedimentation Laboratory, may also be used provided they are calibrated to measured stream channel erosion rates.

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.
- The BANCS method is not effective in predicting future channel incision and bank erodibility in reaches upstream of active head cuts. These zones upstream of active head cuts, failing dams, or recently lowered culverts/utility crossings often yield the greatest potential for long-term sediment degradation and downstream sediment/nutrient pollution.
- 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. States are encouraged to add parameters or stratify data for the BANCS Method to account for local conditions. 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, dendro-geomorphic studies of exposed roots and new shoots, time series channel surveys, and/or bank pins.
- 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.

$$S = \frac{\sum(cAR)}{2{,}000} \qquad \text{(Eq. 1)}$$

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. Note that if monitoring data or other models similar to the BANCS method are used, loading rates will also have to be adjusted for bulk density.

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 Walter et al. (2007), the phosphorus and nitrogen concentrations measured in streambank sediments are:

- 1.05 pounds P/ton sediment
- 2.28 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*

Stream bank erosion is estimated in Step 1, 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. This reduction efficiency is applied at the “edge of field.” Additional losses between the edge of field and Chesapeake Bay are accounted for in the Chesapeake Bay Watershed Model, as referenced below. 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. Qualifying projects receive credit under Protocol 1 and use this protocol to determine enhanced nitrogen removal through denitrification within the stream channel during base flow conditions. Hyporheic exchange between the stream channel and the floodplain rooting zone is improved, however is confined by the dimensions in Figure 3. In situations where the restored channel is connected to a floodplain wetland, this method no longer applies. Projects that qualify for credit under Protocol 3 cannot also receive credit under Protocol 2. Protocol 2 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 rooting zone and the stream channel.

The credit is determined only for the length of stream reach that has improved connectivity to the floodplain as indicated by a bank height ratio of 1.0 (bank full 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 stream restoration professionals. It is defined as the lowest bank height of the channel cross section divided by the maximum bank full depth. Care must be taken by design professionals on how to increase the dimensions of the hyporheic box in the restoration design. Raising the stream bed or overly widening the stream channel to qualify for this credit may not be appropriate because of other design considerations.

The above studies also demonstrated the importance of “carbon” availability in denitrification. To assure that sites have adequate carbon, localities should require extensive plant establishment 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 maximum depth of 5 feet beneath the stream invert with a width that includes the width of the channel added to 5 feet on either side of the stream bank (see Figure 3). The dimensions of the box apply only to sections of the reach where hyporheic exchange can be documented. Areas of bedrock outcroppings or confining clay layers should be excluded and the dimensions of the box adjusted accordingly. Geotechnical testing may be required to confirm the depth of hyporheic exchange.

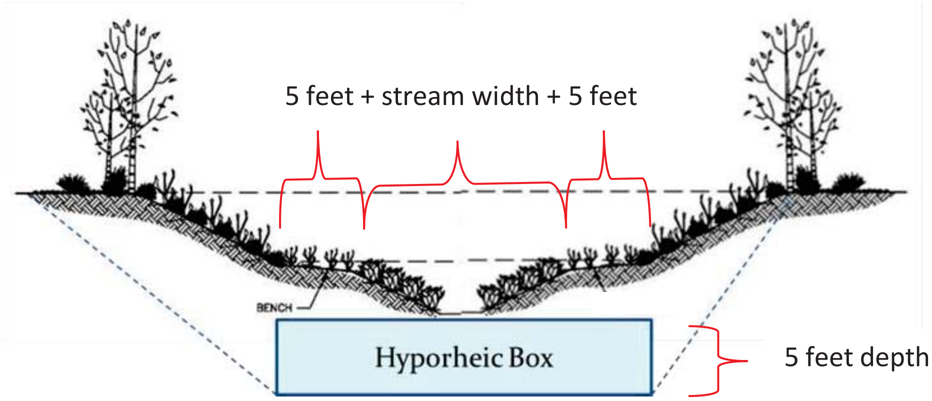

Figure 3. Hyporheic box that extends the length of the restored reach

The cross sectional area of the hyporheic box is multiplied by the length of the restored connected channel. The result is then multiplied by an average denitrification rate for restored low connected banks that represents the additional dentrification provided from restored sites versus unrestored sites from Kaushal et al. (2008) of 97.6 μg N/kg/day of soil (1.95 x 10^{-4} pounds/ton/day of soil). This 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.*

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 (1.95 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

This protocol provides an annual mass sediment and nutrient reduction credit for qualifying projects that reconnect stream channels to their floodplain over a wide range of storm events, from the small, high frequency events to the larger, less frequent events. Credit for baseflow is also given. Qualifying projects receive credit for sediment and nutrient removal under Protocol 1 and use this protocol to determine enhanced sediment and nutrient removal through floodplain wetland connection. This method assumes that sediment, 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). However, it will be critical for stream restoration designers to consult with a wetland specialist in designing or enhancing the floodplain wetlands to assure there is sufficient groundwater-surface water interaction to qualify for this benefit. 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 credit is discounted proportionally for projects that cannot meet this criteria. For instance, if the wetland to surface area ratio is 0.75% rather than the 1% minimum then the credit would be 75% of the full credit.

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 (or post restoration monitoring) of the subwatershed, stream and floodplain to estimate the potential floodplain connection volume. In addition, designers will need to show that 100-year regulatory floodplain elevations are maintained. 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.*

For urban watersheds, these loads are estimated by using the unit area TN, TP and TSS loading rates for pervious and impervious land derived for the river basin segment in which the project is located (i.e., CBWM version 5.3.2). These unit loads are readily available from CBP tools such as CAST, MAST and VAST. Similarly, unit loads for non-urban watersheds are available from the same CBP tools, but the delivered load is calculated from the total agricultural land use upon which the stream restoration is being applied.

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.

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[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.

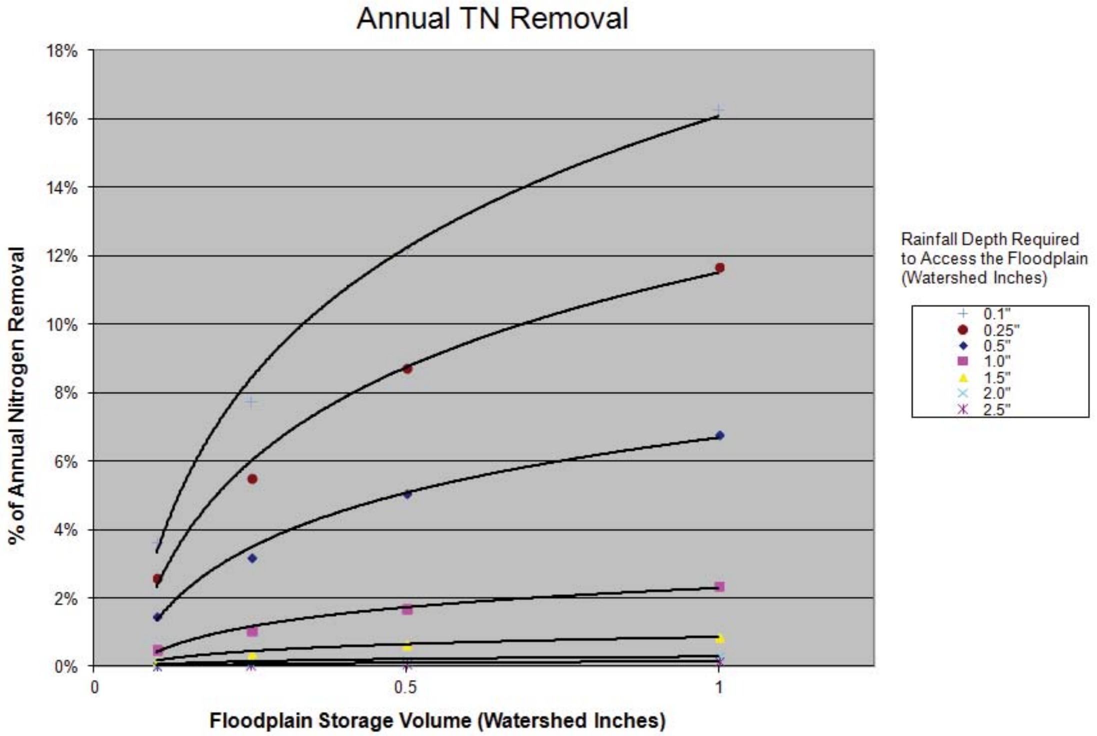

Figure 4. Annual TN removal as a function of floodplain storage volume for several rainfall thresholds that allow runoff to access the floodplain.

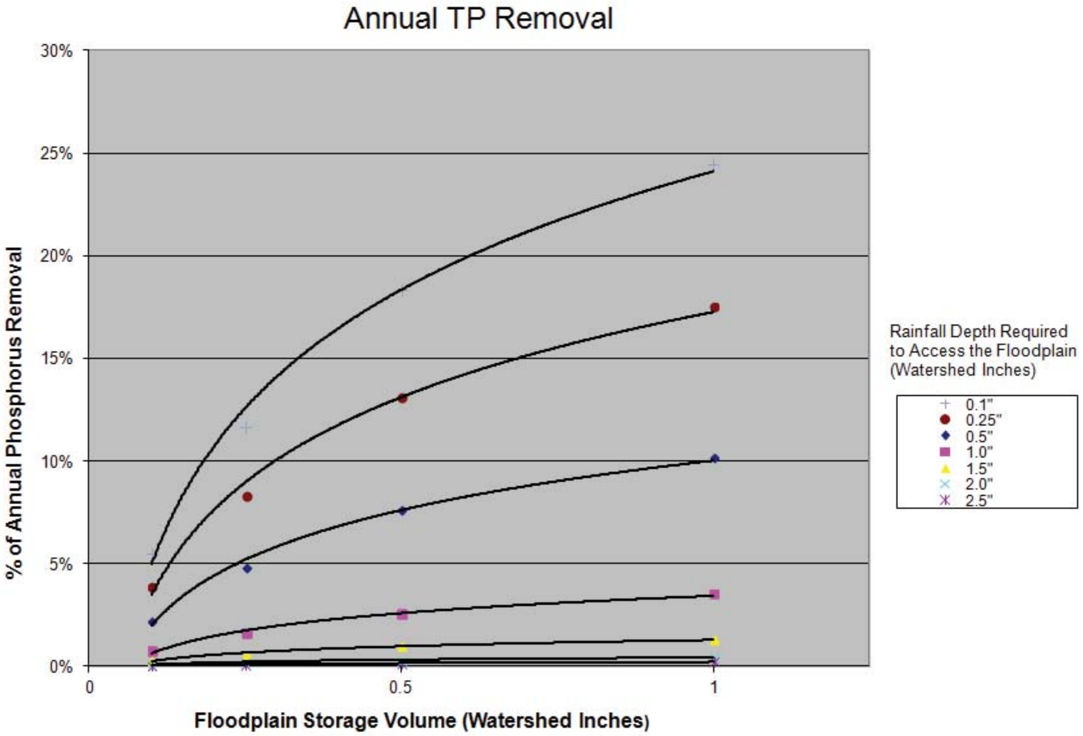

Figure 5. Annual TP removal as a function of floodplain storage volume for several rainfall thresholds that allow runoff to access the floodplain.

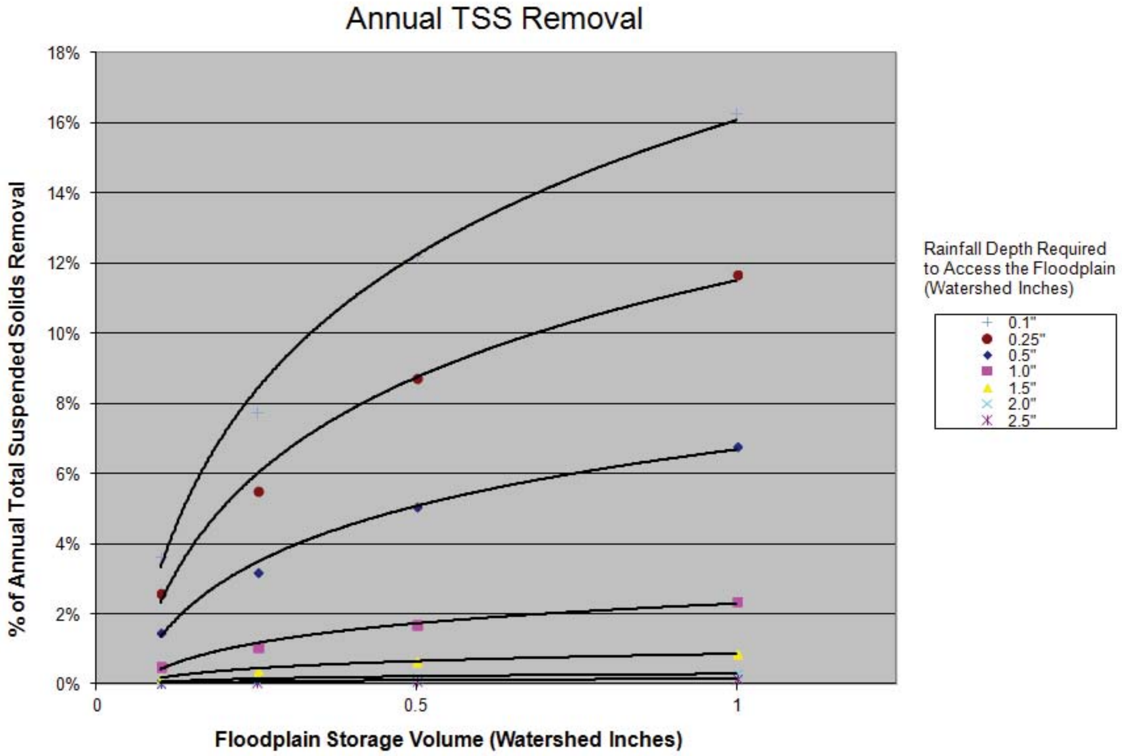

Figure 6. Annual TSS removal as a function of floodplain storage volume for several rainfall thresholds that allow runoff to access the floodplain.

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

If the wetland to watershed ratio is less than 1.0% the removal rates should be adjusted as described above. For instance a ratio of 0.5% would receive half the efficiency that a project with a 1.0% or larger efficiency.

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 are based on typical projects one might encounter in urban areas and 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

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[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).

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).

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

From Walter et al. (2007), the phosphorus and nitrogen concentrations measured in streambank sediments are:

- 1.05 pounds TP/ton sediment
- 2.28 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 = 1,416 pounds per year
Total Nitrogen = 3,076 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 = 708 pounds per year
Total Nitrogen = 1,538 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 also determine the nutrient reduction enhancement credits that would be earned if parts of the restoration design for Hickey Run resulted in improved connectivity of the stream channel to the floodplain 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. Also note that because floodplain connection to a functioning wetland is not possible, Protocol 2 is used to determine base flow load reduction and not Protocol 3.

Step 1. *Determine the total post construction stream length that has a bank height ratio of 1.0 or less.*

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 reconnection 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 × 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.

$$\frac{(30{,}000\ ft^3)(125\,lb/ft^3)}{2{,}000} = 1{,}875\ tons \qquad \text{(Eq. 2)}$$

Where: 2,000 = conversion from pounds to tons

The hyporheic exchange rate is 1.95×10^{-4} lb/ton/day of soil (conversion from 97.6 μg TN/kg/day of soil); therefore, the estimated TN credit is:

$$(1.95\ x\ 10^{-4}\ \ lb/ton/day)(1{,}875\ tons) = 0.37\ \ lb/day\ or\ 135\ \ lb/yr \qquad \text{(Eq. 3)}$$

Section 6.3
Design Example for Protocol 3
Credit for Floodplain Reconnection Volume

Bay City would like to determine the amount of additional sediment and nutrient credit they would receive by connecting the stream to the floodplain, as opposed to only receiving credit for denitrification during baseflow that is provided by Protocol 2. 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%.

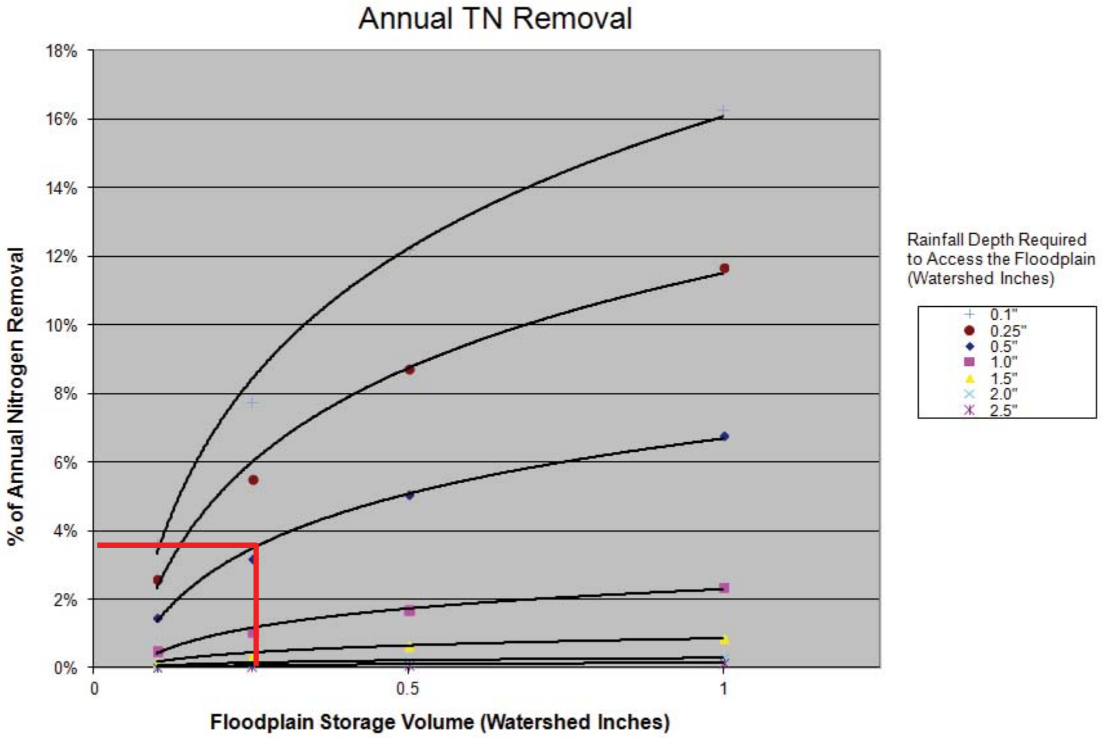

Figure 7. Annual TN removal as a function of 0.25 watershed inch floodplain storage volume and 0.5 inch rainfall depth required to access the floodplain.

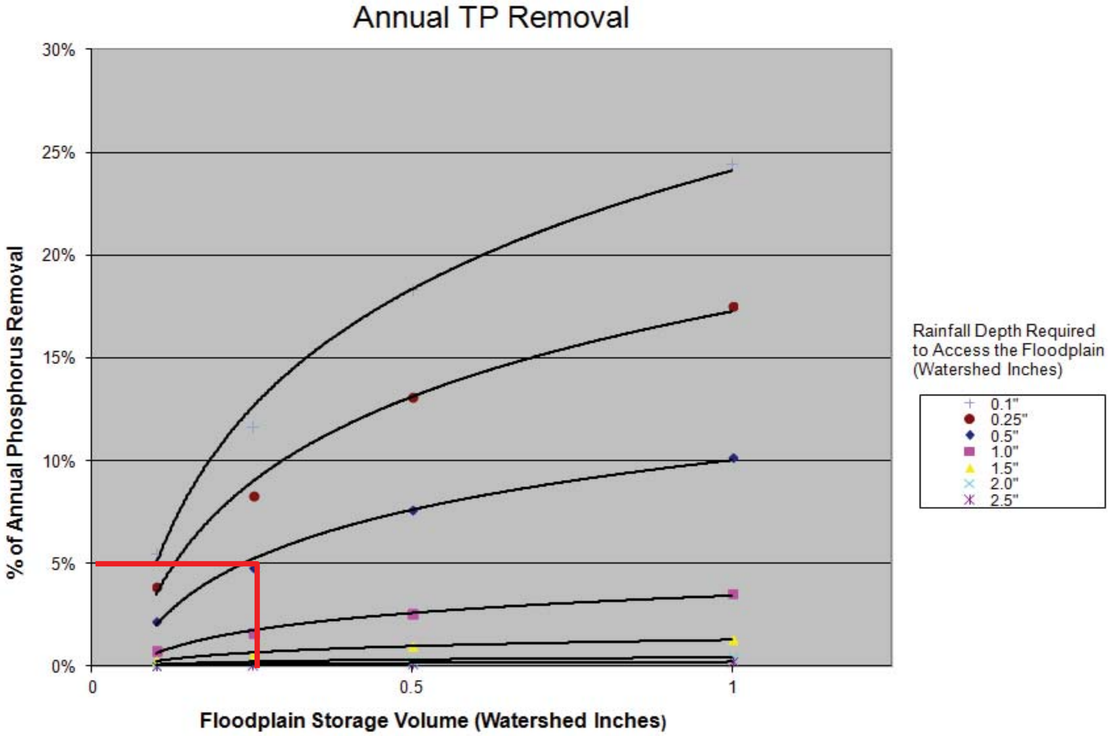

Figure 8. Annual TP removal as a function of 0.25 watershed inch floodplain storage volume and 0.5 inch rainfall depth required to access the floodplain.

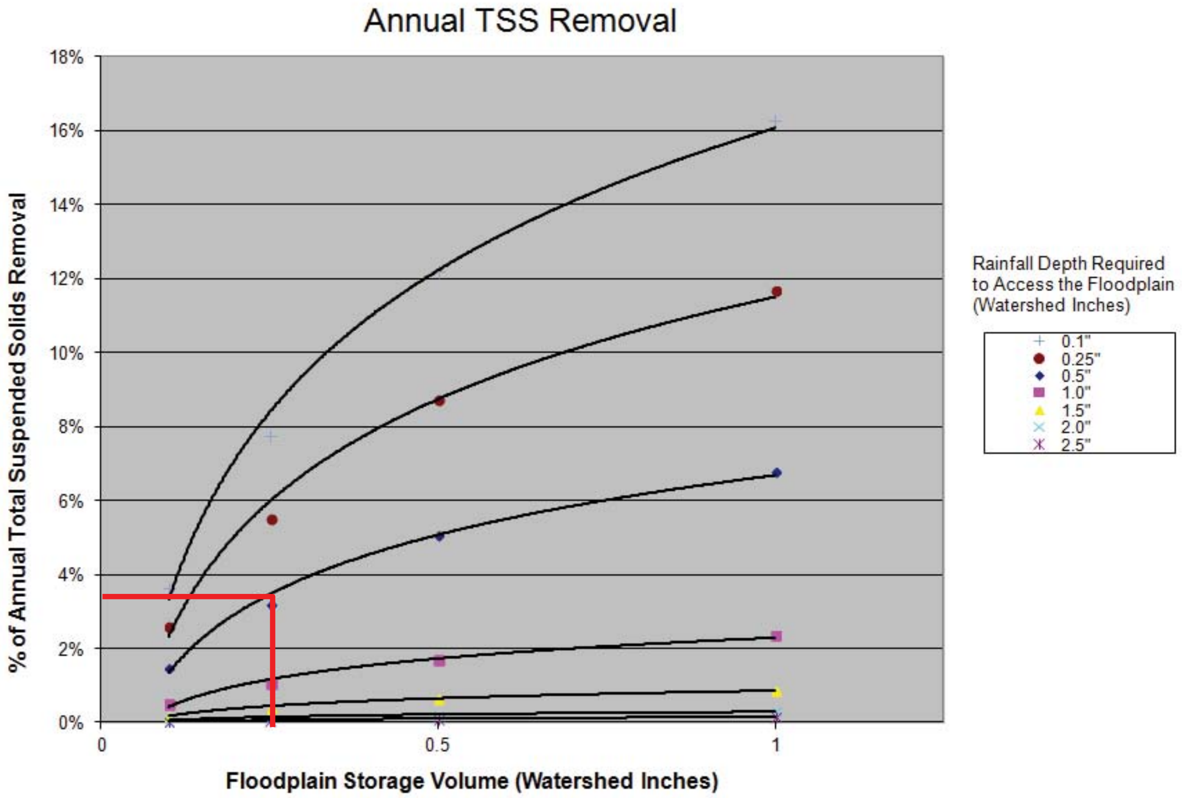

Figure 9. Annual TSS removal as a function of 0.25 watershed inch floodplain storage volume and 0.5 inch rainfall depth required to access the floodplain.

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%, the loading attributed to urban pervious and impervious land from Table 6 is:

TN= 12,912 pounds per year
TP= 1,389 pounds per year
TSS= 6.5×10^5 pounds per year

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

TN= 452 pounds per year
TP= 70 pounds per year
TSS= 22.6×10^3 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:

$$\frac{(RS)(12)}{IA} = x\ in \tag{Eq. 4}$$

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:

$$\frac{(0.167\ ac - ft)(12\ in/ft)}{(0.25)(8\ ac)} = 1.0\ in \qquad \text{(Eq. 5)}$$

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 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 7 shows that total sediment and nutrient reductions are additive when project design allows for more than one protocol to be used (Protocols 1 and 2 or Protocols 1 and 3). 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)

	Protocol 1 (BANCS)[1]	Protocol 2 (Hyporehic Box)[2]	Protocol 3 (Floodplain Reconnection)[3]	Interim Rate[4]
TN	1,754	135	452	1,552
TP	810	--	70	528
TSS[5]	236,000	--	22,600	420,926

[1] For the design conditions as outlined in protocol 1 example

[2] For the design conditions as outlined in protocol 2 example

[3] For the design conditions as outlined in protocol 3 example

[4] Applying the unit rate to 7,759 linear feet of the project

[5] 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 indefinitely 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. The Watershed Technical Work Group recommended at their April 1, 2013 meeting the following general reporting requirements.
    a. General
        i. Type, length and width of stream restoration project[4]
        ii. Location coordinates
        iii. Year of installation and maximum duration of credit
        iv. 12 digit watershed in which it is located
        v. Land uses and acres treated
        vi. Protocol(s) used
    b. Protocol 1
        i. Length
        ii. TSS, TP, TN load reduction (pounds per year)
    c. Protocol 2
        i. Information for right and left bank and pre and post restoration)
            1. Length, width (to thalweg), depth
            2. Average bank height ratio
            3. TN load reduction (pounds per year)
    d. Protocol 3
        i. Floodplain wetland area
        ii. Upstream watershed area
        iii. Rainfall depth when floodplain reconnection occurs (0.5”)
        iv. TSS, TP, TN loading rate reduction efficiencies (percent)

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.

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[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.

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.

8. *Credit for Previously Installed Projects and non-conforming projects*. Past projects and projects that do not conform to these reporting requirements, can receive credit using the *"interim rate" a*s described in Section 2.4. The new protocols can be applied to projects that have been installed less than 5 years to receive credit. However, the credit determined from the new protocols must then be used, regardless of whether it is higher or lower than the credit provided by the interim rate.

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. This workgroup consists of local, state and federal resource protection professionals who have recently drafted a series of principles and protocols for verification of stream restoration projects that expand in considerable detail upon the Panel recommendations with respect to project verification and assessment of functional uplift. Upon approval by the Habitat GIT, these principles will be a useful resource to guide and inform deliberations of state/federal permitting agencies.

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. The issues surrounding the potential for “credit stacking,” as commonly referred, must be left to the agencies that are responsible for the regulatory program development and oversight and not this Panel. This is a separate policy issue that the Panel was not asked to evaluate.

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 and non-urban stream restoration. For example:

- The majority of the available stream research has occurred in the Piedmont portion of the Bay watershed and western coastal plan, 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. In addition, there are no calibration stations within the coastal plain, and therefore, assumptions about sediment transport in this region are less accurate.

- 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.

- The denitrification rate in Protocol 2 is based on a single study and may not be representative of all streams in the Bay watershed. However, the Panel feels that the protocol was developed based on the best science available, and recognizing the Chesapeake Bay Program's adaptive management process can be updated based on the results of continued research.

- 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

- Limited literature exists to document the response of non-urban streams to stream restoration projects in comparison to the still limited, but more extensive literature on urban streams in the Bay watershed. The Panel would be more confident to the application of the protocols to non-urban streams if more research was available.

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. Additional research on legacy sediment removal will be published later in 2013. The Panel will reconvene for a one day workshop in Fall 2013 to review this research and update the Protocols to incorporate these additional findings.

- 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 and on-going maintenance needs that may be required to preserve the credits (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.

- Continued research on the performance of palustrine and wetland efficiencies over time to inform Protocol 3.

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 and also assisting 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 includes sediment loading from the smaller 0-3rd order streams as a part of either pervious or impervious urban and agricultural land classifications. However, the assumption from Langland and Cronin (2003) is that the majority of this sediment originates from small upland stream channels. The Center for Watershed Protection is working with the Modeling Team to determine how to better represent the smaller order streams, as well as modeling sediment transport in the next phase of model development. One possible model refinement involves modeling stream channel erosion from the smaller order streams separately from the urban and agricultural land use classifications. 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.

References Cited

Allmendinger, N., J. Pizzuto, G. Moglen and M. Lewicki. 2007. A sediment budget for an urbanizing watershed 1951-1996.Montgomery County, Maryland, USA. *JAWRA*. 43(6):1483-1497.

Altland, D. 2012. Cardno Entrix. Personal conversation with Bill Stack, Center for Watershed Protection.

Baldigo, B., A. Ernst, D. Warren and S. Miller. 2010. Variable responses of fish assemblages, habitat and stability to natural channel design restoration in Catskill mountain streams. *Transactions of the American Fisheries Society*. 139:449-467.

Baltimore Department of Public Works (BPDW). 2006. NPDES MS4 stormwater permit annual report for 2005. Submitted to Maryland Department of Environment. Water Management Administration. Baltimore, MD.

Bergmann, K. and A. Clauser. 2011. Using bank erosion and deposition protocol to determine sediment load reductions achieved for streambank erosion. Brandywine Valley Association, West Chester, PA.

Beisch, Doug. 2012. Williamsburg Environmental Group. Personal conversation with Bill Stack, Center for Watershed Protection

Bernhardt, E., Palmer, M., Allan, J., Alexander, G., Barnas, K., Brooks, S., Carr, J., Clayton, S., Dahm, C., Follstad-Shah, J., Galat, D., Gloss, S., Goodwin, P., Hart, D., Hassett, B., Jenkinson, R., Katz, S., Kondolf, G., Lake, P., Lave, R., Meyer, J., O'Donnell, T., Pagano, L., Powell, B., and E. Suddath. 2005. Synthesizing U.S. river restoration efforts. *Science*. 29(308): 636-637.

Booth, D. and P. Henshaw. 2001. Rates of channel erosion in small urban streams. *Water Science and Application*. 2:17-38.

Brown, K. 2000. *Urban stream restoration practices: an initial assessment*. Center for Watershed Protection. Ellicott City, MD.

Bukavekas, P. 2007. Effects of channel restoration on water velocity, transient storage, and nutrient uptake in a channelized stream. *Environmental Science and Technology*. 41:1570-1576.

Chesapeake Stormwater Network (CSN). 2011. Nutrient accounting methods to document local stormwater load reductions in the Chesapeake Bay Watershed. Technical Bulletin No. 9. Baltimore, MD. www.chesapeakestormwater.net

Cianfrani, C., W. Hession and D. Rizzo. 2006. Watershed impervious impacts on stream channel conditions in southeastern Pennsylvania. *Journal of American Water Resources Association*. 42(4):941-956.

DiBlasi, K. 2008. The effectiveness of street sweeping and bioretention in reducing pollutants in stormwater. Master of Science Thesis. Civil Engineering. University of Maryland, Baltimore College.

Costa J.E. 1975. Effects of agriculture on erosion and sedimentation in the Piedmont Province, Maryland. Geological Society of America Bulletin 86: 1281–1286.

Doll, B., G. Grabow, K. Hall, J. Halley, W. Harman, G. Jennings and D. Wise. 2003. *Stream Restoration-- A Natural Channel Design Handbook*. North Carolina State University. Raleigh, NC. 140 pp.

Doyle, M., E Stanley and J. Harbor. 2003. Hydro geomorphic controls and phosphorus retention in streams. *Water Resources Research*. 39(6): 1147-1164.

Ensign, S. and M. Doyle. 2005. In-channel transient storage and associated nutrient retention: evidence from experimental manipulation. *Limnology and Oceanography*. 50(6): 1740-1751.

Filoso, S and M. Palmer. 2011. Assessing stream restoration effectiveness at reducing nitrogen export to downstream waters. *Ecological Applications*. 21(6): 1989-2006.

Filoso, S. 2012. Sediment flux measurements in Anne Arundel County streams. Unpublished data presented at Expert Panel Research Workshop. January 25, 2012

Flores, H. 2011. Design guidelines for regenerative step pool storm conveyance. Revision 3. Anne Arundel County Department of Public Works. Annapolis, MD.

Flores, H. 2012. Anne Arundel County Department of Public Works. Personal communication with Bill Stack, Center for Watershed Protection.

Fraley, L., A. Miller and C. Welty. 2009. Contribution of in-channel processes to sediment yield in an urbanizing watershed. *Journal of American Water Resources Association*. 45(3):748-766.

Groffman, P., D. Bain, L. Band, K. Belt, G. Brush, J. Grove, R. Pouyat, I. Yesilonis and W. Zipperer. 2003. Down by the riverside: urban riparian ecology. *Frontiers in Ecology and Environment*. Ecological Society of America. 1(6): 98-104.

Haniman, Erik. 2012. Philadelphia Water Department. Personal communication with Bill Stack, Center for Watershed Protection.

Harman, W., R. Starr, M. Carter, K. Tweedy, M. Clemmons, K. Suggs and C. Miller. 2011. A function-based framework for developing stream assessments, restoration goals, performance standards and standard operating procedures. U.S. Environmental Protection Agency. Office of Wetlands, Oceans and Watersheds. Washington, D.C.

Harrison, M., P. Groffman, P. Mayer, S. Kaushal and T. Newcomer. 2011. Denitrification in alluvial wetlands in an urban landscape. *Journal of Environmental Quality*. 40:634-646.

Hartranft, J., D. Merritts, R. Walter and M. Rahnis, 2010. The Big Spring Run experiment: policy, geomorphology and aquatic ecosystems in the Big Spring Run watershed, Lancaster County, PA. Franklin and Marshall University. Lancaster, PA. Sustain: A Journal of Environmental and Sustainability Issues: Issue 24, p. 24-30. http://louisville.edu/kiesd/sustain-magazine

Hilgartner, W., D. Merritts, R. Walter, and M. Rhanis. 2010. Pre-settlement habitat stability and post-settlement burial of a tussock sedge (Carex stricta) wetland in a Maryland piedmont river valley. In 95th Ecological Society of America Annual Meeting, Pittsburg, PA. 1-6 August 2010.

Hill, T., E. Kulz, B. Munoz and J. Dorney. 2011. Compensatory stream and wetland mitigation in North Carolina: an evaluation of regulatory success. North Carolina Dept. of Environment and Natural Resources. Raleigh, NC.

Jacobson RB, Coleman DJ. 1986. Stratigraphy and recent evolution of Maryland Piedmont flood plains. American Journal of Science 286: 617–637.

Johnson, P., R. Tereska, and E. Brown. 2002. Using technical adaptive management to improve design guidelines for urban instream structures. *Journal of American Water Resources Association*. 38(4): 1143-1156.

Jordan, T. 2007. Wetland restoration and creation best management practice (agricultural). Definition of nutrient and sediment reduction efficiencies for use in calibration of the phase 5.0 Chesapeake Bay Program Watershed Model. Smithsonian Environmental Research Center. Edgewater, MD.

Kaushal, S., P. Groffman, L. Band, E. Elliott, C. Shields, and C. Kendall. 2011. Tracking nonpoint source nitrogen pollution in human-impacted watersheds. *Environmental Science & Technology*. 45(19): 8225-8232.

Kaushal, S., P. Groffman, P. Mayer, E. Striz and A. Gold. 2008. Effects of stream restoration on denitrification at the riparian-stream interface of an urbanizing watershed of the mid-Atlantic US. *Ecological Applications*. 18(3): 789-804.

Klapproth, J.C. and J.E. Johnson. 2009. Understanding the Science behind Riparian Forest Buffers: Effects on Water Quality. Virginia Cooperative Extension, Virginia Tech. VCE Pub# 420-150.

Klocker, C., S. Kaushal, P. Groffman, P, Mayer, and R. Morgan. 2009. Nitrogen uptake and denitrification in restored and unrestored streams in urban Maryland USA. *Aquatic Sciences*. 71:411-424.

Knox J. C. 1972. Valley alluviation in southwesternWisconsin. Annals of the Association of American Geographers 62: 401–410. DOI: 10.1111/j.1467-8306.1972.tb00872.x

Land Studies. 2005. Stream bank erosion as a source of pollution: research report.

Langland, M. and S. Cronin, 2003. A summary report of sediment processes in Chesapeake Bay and watershed. U.S. Geological Survey Water Resources Investigation Report 03-4123

Lautz L. and R. Fanelli. 2008. Seasonal biogeochemical hotspots in the streambed around stream restoration structures. *Biogeochemistry*. 91:85-104

Law, N., K. Diblasi, and U. Ghosh.2008. Deriving reliable pollutant removal rates for municipal street sweeping and storm drain cleanout programs in the Chesapeake Bay Basin. Center for Watershed Protection, Ellicott City. MD.

Martucci, S., Krstolic, J. Raffensperger, J., and K. Hopkins. 2006. Development of land segmentation, stream-reach network, and watersheds in support of Hydrologic Simulation Program-Fortran (HSPF) modeling, Chesapeake Bay watershed, and adjacent parts of Maryland, Delaware, and Virginia. U.S. Geological Survey. Scientific Investigations Report 2005-5073.

Mayer, P., P. Groffman, E. Striz, and S. Kaushal. 2010. Nitrogen dynamics at the groundwater and surface water interface of a degraded urban stream. *Journal of Environmental Quality*. 39:810-823.

Medina, D.E. and S. Curtis. 2011. “Comparing LID and Stream Restoration: Finding cost-effective ways to reduce sediment and nutrient loads.” *Stormwater Magazine*. September-October.

Merritts, D., Walter, R., Rahnis, M., Hartranft, J., Cox, S., Gellis, A., Potter, N., Hilgartner, W., Langland, M., Manion, L., Lippincott, C., Siddiqui, S., Rehman, Z., Scheid, C., Kratz.,L., Shilling, A., Jenschke, M., Datin, K., Cranmer, E., Reed, A., Matuszewski, D., Voli, M., Ohlson, E., Neugebauer, A., Ahamed, A., Neal, C., Winter, A., and S. Becker. 2011. Anthropocene streams and base flow controls from historic dams in the unglaciated mid-Atlantic region, USA. Philosophical Transactions of the Royal Society A. 369:976-1009,

Merritts, D. R. Walter and M. Rahnis. 2010. Sediment and nutrient loads from stream corridor erosion along breached mill ponds. Franklin and Marshall University.

Miller, J. and R. Kochel. 2010. Assessment of channel dynamics, instream structures, and post-project channel adjustments in North Carolina and its implications to effective stream restoration. *Environmental Earth Science*. 59:1681-1692.

Montana Department of Environmental Quality (MDEQ). 2009. Shields River watershed water quality planning framework and sediment TMDLs. Y02-TMDL-01A. Helena, MT

Morgan, R. K. Kline and S. Cushman. 2007. Relationships among nutrients, chloride and biological indices in urban Maryland streams. *Urban Ecosystems*. Springer

Mulholland, P., R. O. Hall, Jr., D. J. Sobota, W. K. Dodds, S. Findlay, , N. B. Grimm, S. K. Hamilton, W. H. McDowell, J. M. O'Brien, J. L. Tank, L.R. Ashkenas, L. W. Cooper, C. N. Dahm, S. V. Gregory, S. L. Johnson, J. L. Meyer, B. J. Peterson, G. C. Poole, H. M. Valett, J. R. Webster, C. Arango, J. J. Beaulieu, M. J. Bernot, A. J. Burgin, C. Crenshaw, A. M. Helton, L. Johnson, B. R. Niederlehner, J. D. Potter, R. W. Sheibley, and S. M. Thomas. 2009. Nitrate removal in stream ecosystems measured by N15 addition experiments: denitrification. *Limnology and Oceanography*. 54(3):666-680.

National Research Council (NRC). 2011. *Achieving Nutrient and Sediment Reduction Goals in the Chesapeake Bay: an evaluation of program strategies and implementation*. National Academy of Science Press . Washington, DC.

Northington, R. and A. Hershey. 2006. Effects of stream restoration and wastewater plant effluent on fish communities in urban streams. *Freshwater Biology*. 51-1959-1973.

Orzetti, L., R. Jones and R. Murphy. 2010. Stream conditions in Piedmont streams with restored riparian buffers in the Chesapeake Bay watershed. *Journal of American Water Resources Association*. 46(3): 473-485.

Palmer, M., Allan, J., Meyer, J., and E. Bernhardt. 2007. River restoration in the twenty-first century: data and experiential knowledge to inform future efforts. *Restoration Ecology*. 15(3): 472-481.

Paul, M. and J. Mayer. 2001. Streams in the urban landscape. *Annual Review of Ecology and Systematics*. 32: 33-65.

Pizzuto J.E, W.C. Hession, and M. McBride. 2000. Comparing gravel-bed rivers in paired urban and rural catchments of southeastern Pennsylvania. Geology 28: 79–82.

Pouyat, R., I. Yesilonis, J. Russell-Anelli, and N. Neerchal. 2007. Soil chemical and physical properties that differentiate urban land-use and cover types. *Soil Science Society of America Journal*. 71(3):1010-1019.

Richardson, C., N. Flanagan, M. Ho and J. Pahl. 2011. Integrated stream and wetland restoration: a watershed approach to improved water quality on the landscape. *Ecological Engineering*. 37:25-39.

Rosgen, D. 1996. *Applied River Morphology*. Wildland Hydrology. Pagosa Springs, CO.

Rosgen, D. 2001. A practical method of computing stream bank erosion rate. Proceedings of the Seventh Federal Interagency Sedimentation Conference. Vol. 2, pp. II - 9-15, March 25-29, 2001, Reno, NV.

Schnabel, R.R., L.F. Cornish, and W.L. Stout. 1995. Denitrification rates at four riparian ecosystems in the Valley and Ridge physiographic province, Pennsylvania. Pages 231-234. In: Clean Water, Clean Environment -21st Century. Volume III: Practices, Systems, and Adoption. Proceedings of a conference March 5-8, 1995 Kansas City, M. American Society of Agricultural Engineers, St. Joseph, Mich. 318 pages.

Schueler, T. 1994. Pollutant dynamics of pond muck. *Watershed Protection Techniques*. 1(2): 39-46.

Schueler, T., L. Fraley-McNeal, and K. Cappiella. 2009. Is Impervious Cover Still Important? A Review of Recent Research. *Journal of Hydrologic Engineering*. April, 2009.

Selvakumar, A., T. O'Connor and S. Struck. 2010. Role of stream restoration on improving benthic macroinvertebrates and in-stream water quality in an urban watershed: case study. *Journal of Environmental Engineering*. 136(1):127-136.

Simpson, T. and S. Weammert. 2009. Developing nitrogen, phosphorus, and sediment efficiencies for tributary strategy practices. BMP Assessment Final Report. University of Maryland Mid-Atlantic Water Program. College Park, MD.

Sivirichi, G., S. Kaushal, P. Mayer, C. Welty, K. Belt, K. Delaney, T. Newcomer and M. Grese. 2011. Longitudinal variability in streamwater chemistry and carbon and nitrogen fluxes in restored and degraded urban stream networks. *Journal of Environmental Monitoring*. 13:208-303.

Smith, S., L. Linker, and J. Halka. 2008. Fine sediment and the Chesapeake Bay watershed. Stream Information Exchange Conference Proceedings. September 17-18, 2008.

Starr, R. 2012. U.S. Fish and Wildlife Service. Personal communication with Bill Stack, Center for Watershed Protection.

Stewart, S. 2012. Baltimore County Department of Environmental Protection and Resource Management. Personal communication with Bill Stack, Center for Watershed Protection..

Stewart, S. 2008. Spring Branch subwatershed: small watershed action plan. Baltimore County Department of Environmental Protection and Resource Management. Towson, MD.

Stewart, S., E. Gemmill, and N. Pentz. 2005. An evaluation of the functions and effectiveness of urban riparian forest buffers. Baltimore County Department of

Environmental Protection and Resource Management. Final Report Project 99-WSM-4. Water Environment Research Foundation.

Striz, E., and P. Mayer. 2008. Assessment of near-stream ground water-surface water interaction (GSI) of a degraded stream before restoration. EPA/600/R-07/058. U.S. Environmental Protection Agency.

Sudduth, E., B. Hasset, P. Cada, and E. Bernhardt. 2011. Testing the field of dreams hypothesis: functional responses to urbanization and restoration in stream ecosystems. *Ecological Applications*. 21(6): 1972-1988.

Trimble SW. 1974. Man-induced Soil Erosion on the Southern Piedmont, 1700-1970. Soil Conservation Society of America: Ankeny.

Trimble, S. 1997. Contribution of stream channel erosion to sediment yield from an urbanizing watershed. *Science*. 278: 1442-1444.

Tullos, D., D. Penrose and G. Jennings. 2006. Development and application of a bioindicator for benthic habitat enhancement in the North Carolina Piedmont. *Ecological Engineering*. 27: 228-241.

U.S. EPA (U.S. Environmental Protection Agency). 2010. Chesapeake Bay Phase 5.3 Community Watershed Model. EPA 903S10002 - CBP/TRS-303-10. U.S. Environmental Protection Agency, Chesapeake Bay Program Office, Annapolis MD. December 2010.

U.S. EPA (U.S. Environmental Protection Agency). 2012. Bank Erosion Prediction (BEHI, NBS). http://water.epa.gov/scitech/datait/tools/warsss/pla_box08.cfm

Van Eps, M., J. Formica, T. Morris, J. Beck and A. Cotter. 2004. Using a bank erosion hazard index (BEHI) to estimate annual sediment loads from streambank erosion in the west fork white river watershed. Published by the American Society of Agricultural and Biological Engineers, St. Joseph, Michigan

Violin, C., P. Cada, E. Sudduth, B. Hassett, D. Penrose and E. Bernhardt. 2011. Effects of urbanization and urban stream restoration on the physical and biological structure of stream ecosystems. *Ecological Applications*. 21(6): 1932-1949.

Voli, M., D. Merritts, R. Walter, E. Ohlson, K. Datin, M. Rahnis, L. Kratz, W. Deng, W. Hilgartner, and J. Hartranft. 2009. Preliminary reconstruction of a pre-European settlement valley bottom wetland, southeastern Pennsylvania. Water Resources Impact 11, 11-13.

Walters, R., D. Merritts, and M. Rahnis. 2007. Estimating volume, nutrient content, and rates of stream bank erosion of legacy sediment in the piedmont and valley and ridge physiographic provinces, southeastern and central, PA. A report to the Pennsylvania Department of Environmental Protection.

Water Environment Federation (WEF) and American Society of Civil Engineers (ASCE). 2012. *Design of Urban Stormwater Controls*. Manual of Practice No. 23. McGraw-Hill. New York, NY.

Water Quality Goal Implementation Team (WQGIT). 2010. Protocol for the development, review and approval of loading and effectiveness estimates for nutrient and sediment controls in the Chesapeake Bay Watershed Model. US EPA Chesapeake Bay Program. Annapolis, MD.

Water Quality Goal Implementation Team (WQGIT). 2012. Final Approved Report: Recommendations of the Expert Panel to define removal rates for urban stormwater retrofit practices. Chesapeake Stormwater Network and EPA Chesapeake Bay Program.

Weller, D., M. Baker and T. Jordan. 2011. Effects of riparian buffers on nitrate concentrations in watershed discharges: new models and management implications. *Ecological Applications*. 21(5): 1679-1695.

Wenger, S. and 20 others. 2009. Twenty-six key research questions in urban stream ecology: an assessment of the state of the science. *Journal of the North American Benthological Society*. 28(4): 1080-1098.

Appendix A Annotated Bibliography

Allmendinger, N.E., Pizzuto, J.E., Moglen, G.E., & Lewicki, M. (2007). A sediment budget for urbanizing watershed, 1951-1996, Montgomery County, Maryland, U.S.A. *Journal of the American Water Resources Association,* 43 (6), 1483-1498.

The authors, a geomorphologist at Otak, Inc. and researchers at the University of Delaware, the University of Maryland, and the USDA Forest Service, used a variety of indirect and stratigraphic data to assess the sediment budget for the Good Hope Tributary watershed in Montgomery County, Maryland. Regression equations determined that channel cross-sectional area was correlated to development within the watershed. Results of their investigation indicated that upland erosion, channel enlargement, and floodplain storage are all significant components of the sediment budget and that the remobilized "legacy" sediments contribute less than 20% and are not a dominant component of sediment yield.

Anderson Jr., W.P., Anderson, J.L., Thaxton, C.S., & Babyak, C.M. (2010). Changes in stream temperatures in response to restoration of groundwater discharge and solar heating in a culverted, urban stream. *Journal of Hydrology,* 393, 309-320.

The authors, researchers at Appalachian State University and the University of South Carolina, used a Monte Carlo thermal mixing model to predict the effect of removing a 700-m-long culvert. The model incorporated cooling effect from restored baseflow and surface-heat exchange effects. Modeled temperatures suggest a decrease in summer stream temperatures in a hypothetically restored stream with removal of a long culvert.

Andrews, D.M., Barton, C.D., Kolka, R.K., Rhoades, C.C., & Dattilo, A.J. (2011). Soil and water characteristics in restored canebrake and forest riparian zones. *Journal of the American Water Resources Association,* 47 (4), 772-784.

The authors, a botanist at the Tennessee Valley Authority and researchers at Pennsylvania State University, the University of Kentucky, and the USDA Forest Service, evaluated the use of giant cane in riparian restoration to compare water quality and soil attributes between restored cane and forest communities. Experimental plots, some planted entirely with cane, some with a mixture of forest hardwood species, and some undisturbed, were combined with stream and groundwater sampling to determine water quality improvement. Significant differences in groundwater DO, NO_3-N, NH_4-N, and Mn between the two vegetation types seems to indicate that redox conditions were not similar. The authors concluded that additional monitoring is needed but that both vegetative communities are transitioning toward the undisturbed plots.

Baldigo, B.P., Ernst, A.G., Warren, D.R., & Miller, S.J. (2010). Variable responses of fish assemblages, habitat, and stability to natural-channel-design restoration in Catskill Mountain streams. *Transactions of the American Fisheries Society,* 139, 449-467.

The authors, researchers at the USGS, Cornell University, and the New York City Department of Environmental Protection, conducted fish and habitat surveys at stream sites in the Catskill Mountains of New York before and after restoration using natural-channel-design (NCD) to evaluate the effects of NCD on fish assemblages, habitat, and bank stability. They researchers noticed significant increases in community richness, diversity, species or biomass equitability, and total biomass in most of the restored reaches. They also found bank stability, stream habitat, and trout habitat suitability indices (HIS) improved at most of the restored reaches.

Baldwin, A.H. (2007). ***Urban Stream Restoration Best Management Practice*** **(Recommendations for Formal Approval by the Nutrient Subcommittee's Tributary Strategy and Urban Stormwater Workgroups). Chesapeake Bay Program: Author.**

The author, a researcher at the University of Maryland, performed a literature review to evaluate the effectiveness of stream restoration as a Best Management Practice and propose recommended removal efficiencies for use in the Chesapeake Bay Program's Phase 5.0 Watershed Model.

Beechie, T.J., Sear, D.A., Olden, J.D., Pess, G.R., Buffington, J.M., Moir, H., Roni, P., & Pollock, M.M. (2010). Process-based principles for restoring river ecosystems. ***BioScience,*** **60 (3), 209-222.**

The authors, research fish biologists at NOAA, a watershed program manager, research geomorphologists at the US Forest Service and the Macaulay Institute, and researchers at the University of Southampton and University of Washington, outline and illustrate four principles for process-based stream restoration to ensure sustainable actions in terms of the physical, chemical, and biological processes of streams. The authors discuss the key components of process-based restoration and give examples for a variety of applications.

Berg, J. (Ed.). (2009). A new paradigm for water resources management. ***Water Resources Impact,*** **11 (5).**

This issue, containing articles from several researchers from a variety of backgrounds, discusses the current situation of streams, suggesting that colonial land clearing practices changed stream valley morphologies from broad, shallow systems to narrow, deep channels. Case studies of these stream morphologies are discussed along with potential approaches for effective and efficient restoration and management.

Bergmann, K. Fava, J., & Clauser, A. (2011). ***Using a bank erosion and deposition protocol to determine sediment load reductions achieved for streambank restorations.*** **Poster session presented at the Delaware Estuary Science and Environmental Summit, Cape May, NJ.**

The authors of this poster, researchers from the Brandywine Valley Association and Clauser Environmental, used bank pins to measure erosion/deposition in three study reaches to determine efficiency of potential restorations. The authors found highest erosion/deposition values in the unstabilized, proposed restoration reach.

Bernhardt, E.S., Palmer, M.A., Allan, J.D., Alexander, G., Barnas, K., Brooks, S., Carr, J., Clayton, S., Dahm, C., Follstad-Shah, J., Galat, D., Gloss, S., Goodwin, P., Hart, D., Hassett, B., Jenkinson, R., Katz, S., Kondolf, G.M., Lake, P.S., Lave, R., Meyer, J.L., O'Donnell, T.K., Pagano, L., Powell, B., & Sudduth, E. (2005). Synthesizing U.S. river restoration efforts. *Science,* 308, 636-637.

The authors, researchers from several universities and government agencies, discussed the results of evaluating more than 37,000 river restoration projects in the U.S. as part of the National River Restoration Science Synthesis (NRRSS) database. The NRRSS database separated projects into 13 categories and classified each according to its stated restoration goal. Restoration efforts and costs varied greatly across geographic regions. The authors concluded that a comprehensive assessment of restoration progress within the U.S. is not feasible and that more monitoring is needed to determine the effectiveness of stream restoration projects.

Brush, G.S. (2008). Historical land use, nitrogen, and coastal eutrophication: a paleoecological perspective. *Estuaries and Coasts,* 32 (1), 18-28.

The author, a researcher at Johns Hopkins University, used sediment core analysis throughout the Chesapeake Bay watershed to establish that denitrification opportunities have decreased and nitrogen sources have increased over the past 300 years. This has led to an increasingly eutrophic and anoxic estuary. The author offers some options for reducing nitrogen from entering the estuary, including increasing opportunities for denitrification, retrofitting septic systems, and restoring wetlands.

Bukaveckas, P.A. (2007). Effects of channel restoration on water velocity, transient storage, and nutrient uptake in a channelized stream. *Environmental Science & Technology,* 41 (5), 1570-1576.

The author, a researcher at Virginia Commonwealth University, evaluated the effects of restoration on a 1-km segment of Wilson Creek in Kentucky by measuring water velocity, transient storage, and nutrient uptake in both channelized (unrestored) sections and naturalized (restored) sections. Injection experiments were performed in both study reaches, resulting in a 50% increase in median travel time and significantly higher first-order uptake rate coefficients for N and P in the restored section. The author suggests that decreased velocities and a longer, meandering channel enhances nutrient uptake in restored streams as opposed to channelized streams.

Cadenasso, M.L., Pickett, S.T.A., Groffman, P.M., Band, L.E., Brush, G.S., Galvin, M.F., Grove, J.M., Hagar, G., Marshall, V., McGrath, B.P., O'Neil-Dunne, J.P.M., Stack, W.P., & Troy, A.R. (2008). Exchanges across land-water-scape boundaries in urban systems. *Annals of the New York Academy of Sciences,* 1134, 213-232.

The authors, researchers at the University of California-Davis; the Cary Institute of Ecosystem Studies; the University of North Carolina; Johns Hopkins University; the Maryland Department of Natural Resources; the USDA Forest Service; the Parks and People Foundation in Baltimore;

Columbia University; Parsons, The New School for Design; the University of Vermont; and the Baltimore City Department of Public Works, examined two urban restoration projects aimed at reducing nitrate pollution. The authors present five types of strategies to enhance nitrogen storage in urban landscapes, focusing on biogeophysical strategies such as watershed alteration and stream restoration.

Craig, L.S., Palmer, M.A., Richardson, D.C., Filoso, S., Bernhardt, E.S., Bledsoe, B.P., Doyle, M.W., Groffman, P.M., Hassett, B.A., Kaushal, S.S., Mayer, P.M., Smith, S.M., & Wilcock, P.R. (2008). Stream restoration strategies for reducing river nitrogen loads. *Frontiers in Ecology and the Environment,* 6.

The authors, researchers from several universities, government agencies, and a non-profit research center, discuss a framework for prioritizing restoration sites. They suggest that small streams with larger nitrogen loads delivered during low to moderate flows offer the greatest opportunity for nitrogen removal. In their discussion, they use examples from the Chesapeake Bay watershed.

Doheny, E.J., Dillow, J.J.A., Mayer, P.M., & Striz, E.A. (2012). *Geomorphic Responses to Stream Channel Restoration at Minebank Run, Baltimore County, Maryland, 2002-08* (Scientific Investigations Report 2012-5012). Reston, VA: U.S. Geological Survey.

The authors, researchers at the USGS and the USEPA, collected data prior to and after restoration of Minebank Run to assess geomorphic characteristics and geomorphic changes over time. Among their findings, over six years of monitoring, the stream is maintaining an overall slope of the channel bed and water surface, on average, despite changes in location, distribution, and frequency of riffles, pools, and runs. Comparing pre and post restoration data suggests reduction of lateral erosion. They also found a relationship between channel geometry and discharge.

Doyle, M.W., & Ensign, S.H. (2009). Alternative reference frames in river system science. *Bioscience,* 59 (6), 499-510.

The authors, researchers at North Carolina at Chapel Hill, apply alternative reference frames on river systems. They illustrate the use of alternative reference frames compared to traditional methods using the following examples: sediment transport, fish migration, and river biogeochemistry. The researchers demonstrate how using alternative or non-intuitive reference frames can facilitate novel research questions and observations, potentially triggering new research trajectories.

Doyle, M.W., Stanley, E.H., & Harbor, J.M. (2003). Hydrogeomorphic controls on phosphorus retention in streams. *Water Resources Research,* 39 (6), 1-17.

The authors, researches at the University of North Carolina at Chapel Hill; the University of Wisconsin; and Purdue University, examined the influence of biochemical uptake process and hydrogeomorphology on molybdate reactive phosphorus (MRP) retention within a stream reach. The researchers focused on a stream reach that was undergoing channel adjustment in response to a downstream dam removal. They found that uptake rates should have a stronger influence on reach-scale MRP retention than changing channel morphology or hydrology.

Doyle, M.W., Stanley, E.H., Strayer, D.L., Jacobson, R.B., & Schmidt, J.C. (2005). Effective discharge analysis of ecological processes in streams. *Water Resources Research,* 41, 1-16.

The authors, researchers at the University of North Carolina at Chapel Hill; University of Wisconsin; Institute of Ecosystem Studies; the Columbia Environmental Research Center; and Utah State University, used the concept of effective discharge to analyze the interaction between frequency and magnitude of discharge events on selected stream ecological processes. Their results indicate that a range of discharges is important for different ecological processes in a stream. The researchers suggest four types of ecological response to discharge variability: discharge as a transport mechanism, regulator of habitat, process modulator, and disturbance.

Endreny, T.A., & Soulman, M.M. (2011). Hydraulic analysis of river training cross-vanes as part of post-restoration monitoring. *Hydrology and Earth System Sciences,* 15, 2119-2126.

The authors, researchers at State University of New York College of Environmental Science and Forestry, conducted post-restoration monitoring and simulation analysis for a Natural Channel Design (NCD) restoration project completed in 2002 in the Catskill Mountains, New York. The authors found that processing monitoring data with hydraulic analysis software provided better information that could help extend project restoration goals and structure stability.

Ensign, S.H., & Doyle, M.W. (2005). In-channel transient storage and associated nutrient retention: evidence from experimental manipulations. *Limnology and Oceanography,* 50 (6), 1740-1751.

The authors, researchers at the University of North Carolina at Chapel Hill, used experimental channel manipulation to examine the effect of in-channel flow obstructions on transient storage and nutrient uptake. In their study areas, they found that in-channel transient storage influenced nutrient uptake in a blackwater stream; however similar results could not be confirmed in an agricultural stream.

Filoso, S., & Palmer, M.A. (2011). Assessing stream restoration effectiveness at reducing nitrogen export to downstream waters. *Ecological Applications,* 21 (6), 1989-2006.

The authors, researchers at the University of Maryland, evaluated whether stream restoration projects in the Chesapeake Bay region is effective at reducing nitrogen transport to downstream waters. They found that in order for stream restoration to be most effective in reducing nitrogen fluxes transported downstream, strategic restoration designs should be used and include features that enhance the processing and retention of different forms of nitrogen for a wide range of flow conditions.

FISRWG. (1998). *Stream Corridor Restoration: Principles, Processes, and Practices* (GPO Item No. 0120-A). Federal Interagency Stream Restoration Working Group.

The authors, researchers from various federal agencies, collaborated to produce this technical reference on stream corridor restoration. The document reviews the elements of restoration, and provides a framework to plan restoration actions, including no action or passive approaches, partial intervention for assisted recovery, and substantial intervention for managed recovery. The information in the document can be applied to urban or rural setting, and applies to a range of stream types.

Fraley, L.M., Miller, A.J., & Welty, C. (2009). Contribution of in-channel processes to sediment yield of an urbanizing watershed. *Journal of the American Water Resources Association,* 45 (3), 748-766.

The authors, researchers at the Center for Watershed Protection and the University of Maryland, conducted a study to monitor sediment transport and storage in a tributary of the Schuylkill River in Pennsylvania. They found that bank erosion in their study reach contributed an estimated 43 percent of the suspended sediment load. Although bank erosion is a significant source of sediment, bed sediment storage and potential for remobilization are also important components of the sediment budget.

Harrison, M.D., Groffman, P.M., Mayer, P.M., & Kaushal, S.S. (2012). Microbial biomass and activity in geomorphic features in forested and urban restored and degraded streams. *Ecological Engineering,* 38, 1-10.

The authors, researchers at the University of Maryland, the Cary Institute of Ecosystem Studies, NOAA, and the US EPA, measured sediment denitrification potential (DEA), net nitrification, methanogenesis, and microbial variables in various stream features and in several different stream settings. They found that DEA was higher in organic debris dams and in forest streams, but their results were not statistically significant. They also found that DEA was related to microbial biomass nitrogen and sediment organic matter, and also methanogenesis was active in all stream geomorphic features. Overall, the results suggest that in-stream geomorphic features in urban restored and degraded sites have the potential to function as nitrogen sinks.

Harrison, M.D., Groffman, P.M., Mayer, P.M., Kaushal, S.S., & Newcomer, T.A. (2011). Denitrification in alluvial wetlands in an urban landscape. *Journal of Environmental Quality,* 40, 634-646.

The authors, researchers at the University of Maryland, the Cary Institute of Ecosystem Studies, and the US EPA, measured denitrification rates to compare the variation and magnitude in urban and forested wetlands in the Baltimore metropolitan area. They found that mean denitrification rates did not differ among wetland types, suggesting that urban wetlands have the potential to reduce nitrate in urban watersheds. Their findings also suggest that wetlands are sinks for nitrate year round.

Hartranft, J.L., Merritts, D.J., Walter, R.C., & Rahnis, M. (2011). The Big Spring Run restoration experiment: policy, geomorphology, and aquatic ecosystems in the Big Spring Run watershed, Lancaster County, PA. *Sustain,* 24, 24-30.

The authors, researchers at the Pennsylvania Department of Environmental Protection and Franklin and Marshall College, are investigating whether an anastomosing channel valley bottom floodplain systems can effectively restore critical zone function at Big Springs Run in Pennsylvania. Their approach includes: developing significant metrics to assess critical zone process; developing, implementing, and monitoring a restoration project that diagnoses the causes of impairments; and evaluate the implications of this restoration strategy. At the time of the paper, the researchers had completed three years of pre-restoration monitoring and were anticipating the commencement of restoration activities.

Henshaw, P.C. (1999). Restabilization of stream channels in urban watersheds. *Proceedings of the American Water Resources Association Annual Water Resources Conference on "Watershed Management to Protect Declining Species,"* Seattle, WA*.*

The author, a researcher at Northwest Hydraulic Consultants, used a variety of field and historical data from streams in urban and urbanizing watersheds to determine the rate and extent of change in channel form over time. The researcher found that restabilization of urbanized stream channels usually occurs in highly urbanized watersheds, and most stabilize within 10 to 20 years of constant land cover in the watershed. The possibility that a channel will restabilize depends mainly on hydrologic and geomorphic characteristics of the channel and its watershed, rather than the magnitude or rate of development.

Hill, T., Kulz, E., Munoz, B., & Dorney, J. (2011). *Compensatory stream and wetland mitigation in North Carolina: an evaluation of regulatory success.* North Carolina Department of Environment and Natural Resources: Author.

The authors, researchers at the North Carolina Department of Environment and Natural Resources and RTI International, investigated regulatory success rates of wetland and stream mitigation projects in North Carolina. They collected information to compare current statewide mitigation project conditions with regulatory requirements during 2007-2009 by reviewing files and directly observing sites. Overall, the researchers found that mitigation success rates, based on whether the mitigation site met the regulatory requirements for the project that were in place at the time of construction, were estimated at 74 percent for wetlands, and 75 percent for streams in North Carolina. They also found that wetland mitigation success rate has increased since the mid 1990's. In addition, the researchers performed a variety of statistical analyses to evaluate the success of mitigation based on various aspects including mitigation provider, method, project location, age, and size.

Hillman, M., & Brierly, G. (2005). A critical review of catchment-scale stream rehabilitation programmes. *Progress in Physical Geography,* 29 (1), 50-70.

The authors, researchers from Macquarie University and the University of Auckland, performed a literature review and examined case studies of contemporary catchment-wide programs. They found the following challenges in programs: generating an authentic and functional biophysical vision at the catchment scale, developing a proactive adaptive management approach, achieving genuine community participation, and integrating biophysical and social factors in a transdisciplinary framework. They suggest addressing issues of scale, natural variability and complexity to meet those challenges.

Johnson, P.A., Tereska, R.L., & Brown, E.R. (2002). Using technical adaptive management to improve design guidelines for urban instream structures. *Journal of the American Water Resources Association,* 38 (4), 1143-1152.

The authors, a researcher from Penn State University and engineers from Erdman, Anthony, Associates, Inc. and the Central Federal Lands Highway Division of the FHA, used technical adaptive management to update guidelines for effective use, design, and construction of instream structures. They note that monitoring, evaluation of data, and communication of results are crucial components of the adaptive management process to prevent future failures. They used three case studies of urban streams in Maryland to provide data for updating and improving the Maryland guidelines.

Kaushal, S.S., Groffman, P.M., Mayer, P.M., Striz, E., & Gold, A.J. (2008). Effects of stream restoration on denitrification in an urbanizing watershed. *Ecological Applications,* 18 (3), 789-804.

The authors, researchers at the University of Maryland, the Institute of Ecosystem Studies, the U.S. EPA, and the University of Rhode Island, used in situ measurements of ^{15}N tracer additions to determine if hydrologic reconnection of a stream to its floodplain could increase rates of denitrification in an urban stream. Mean rates of denitrification were significantly greater in restored reaches and restored riparian areas with hydrologically connected stream banks had higher rates of denitrification than similarly restored riparian areas with high, nonconnected banks. Stream restoration designed to reconnect stream channels and floodplains can increase denitrification rates but there can be substantial variability in the efficacy of restoration designs.

Klocker, C.A., Kaushal, S.S., Groffman, P.M., Mayer, P.M., & Morgan, R.P. (2009). Nitrogen uptake and denitrification in restored and unrestored streams in urban Maryland, USA. *Aquatic Sciences,* 71, 411-424.

The authors, researchers at the University of Maryland, the Cary Institute of Ecosystem Studies, and the US EPA National Risk Management Research Lab, analyzed nitrogen processes to quantify nitrate uptake in restored and unrestored streams in Baltimore, Maryland. They found that denitrification potential in sediments varied across streams, and nitrate uptake length appeared to be correlated to surface water velocity. Their results suggest restoration approaches that increase hydrologic “connectivity” with hyporheic sediments and increase hydrologic residence time may influence denitrification rates in stream reaches.

Kroes, D.E., & Hupp, C.R. (2010). The effect of channelization on floodplain sediment deposition and subsidence along the Pocomoke River, Maryland. *Journal of the American Water Resources Association,* 46 (4), 686-699.

The authors, an ecologist at the USGS and a botanist at the USGS, studied floodplain sediment dynamics at six sites along the Pocomoke River. They assessed the effects of channelization on sediment deposition, storage, and subsidence along the stream. They found that channelization resulted in limited sediment retention and an increase in sediment deposition in down-stream reaches. In addition, drainage of floodplains resulted in subsidence and release of stored carbon.

Lakly, M.B., & McArthur, J.V. (2000). Macroinvertebrate recovery of a post-thermal stream: habitat structure and biotic function. *Ecological Engineering,* 15, 87-100.

The authors, researchers at the University of Georgia and the Savannah River Ecology Laboratory, conducted a study of macroinvertebrate faunal assemblages, organic matter availability and in stream structural complexity in three systems to determine the current state of recovery of a post-thermal stream. They found that the abundance and diversity of the lower foodchain community has recovered since termination of thermal flows in 1988. They also found that the biotic communities remain structurally and functionally distinct as a result of the thermal disturbance.

Land Studies. (2005). *Stream bank erosion as a source of pollution: research report*. Author.

The author, Land Studies, performed a literature review of stream projects in the Lower Susquehanna watershed in Pennsylvania. Based on the projects they reviewed, they have found that stream bank erosion is a significant source of nonpoint sediment and nutrient pollution. They also mention that legacy sediments could potentially be a significant contributor of sediment and nutrients.

Lautz, L.K., & Fanelli, R.M. (2008). Seasonal biogeochemical hotspots in the streambed around restoration structures. *Biogeochemistry,* 91, 85-104.

The authors, researchers at the State University of New York College of Environmental Science and Forestry, examined the seasonal patterns of water and solute fluxes through a streambed near a stream restoration structure. They found that regardless of season of the year, anoxic zones were primarily located upstream of the structure, in a low-velocity pool, and oxic zones were typically located downstream of the structure in a turbulent riffle. They suggest that restoration structures that span the full channel, such as those used in natural channel design restoration, will influence the biogeochemical processing in the streambed.

Mayer, P.M., Groffman, P.M., Striz, E.A., & Kaushal, S.S. (2010). Nitrogen dynamics at the groundwater-surface water interface of a degraded urban stream. *Journal of Environmental Quality,* 39, 810-823.

The authors, researchers at the USEPA, the Cary Institute of Ecosystem Studies, and the University of Maryland, investigated groundwater ecosystem in an urban degraded stream near Baltimore, Maryland in the Chesapeake Bay watershed. Their objectives were to identify spatial and temporal extent of chemical, microbial, and hydrological factors that influence denitrification. Their results suggested that denitrification and removal of nitrate in groundwater were limited by dissolved organic carbon (DOC) availability. They observed that groundwater nitrate was highest when groundwater levels were highest, corresponding to high oxidation-reduction potential (ORP), suggesting high groundwater-surface water exchange.

McClurg, S.E., Petty, J.T., Mazik, P.M., & Clayton, J.L. (2007). Stream ecosystem response to limestone treatment in acid impacted watersheds of the Allegheny Plateau. *Ecological Applications,* 17 (4), 1087-1104.

The authors, researchers at West Virginia University and the West Virginia Division of Natural Resources, sampled stream chemistry in addition to collecting physical and biological data in three stream types, acidic, acidic streams treated with limestone, and reference streams in West Virginia. Their objectives were to assess acid-precipitation remediation programs in streams, identify attributes that could not be fully restored, and quantify temporal trends in ecosystem recovery. They did not observe temporal trends in recovery, and their results indicated that the application of limestone sand to acidic streams was effective in recovering some stream characteristics; however, recovery was less successful for others.

Merritts, D., Walter, R., & Rahnis, M.A. (2010). *Sediment and nutrient loads from stream corridor erosion along breached millponds.* Franklin & Marshall College: Author*.*

The authors, researchers at Franklin and Marshall College, assessed sediment production rates, nutrient contents, and erosion mechanisms of stream corridor sediments in the Chesapeake Bay watershed. They found that stream corridor erosion, especially stream bank erosion, is a major contributor to the suspended sediment and particulate-phosphorus loads, in addition to a substantial source of nitrogen loads.

Merritts, D., Walter, R., Rahnis, M., Hartranft, J., Cox, S., Gellis A., Potter, N., Hilgartner, W., Langland, M., Manion, L., Lippincott, S. S., Rehman, Z., Scheid, C., Kratz, L., Shilling, A., Jenschke, M., Datin, K., Cranmer, E., Reed, A., Matuszewski, D., Voli, M., Ohlson, E., Neugebauer, A., Ahamed, A., Neal, C., Winter, A., & Becker, S. (2011) *Philosophical Transactions of the Royal Society A,* 369, 976-1009.

The authors, researchers at Franklin and Marshall College, the PA Department of Environmental Protection, the USGS, Dickinson College, and Johns Hopkins University, used LIDAR, field data, and case studies of breached dams in rural and urban watersheds to determine whether stream incision, bank erosion, and increased sediment load is caused by land use changes. In the case of valleys impacted by milldams, modern incised streams represent a transient response to base-level forcing and major changes in historic land use.

Miller, J.R., & Kochel, R.C. (2010). Assessment of channel dynamics, in-stream structures and post-project channel adjustments in North Carolina and its implications to effective stream restoration. *Environmental Earth Sciences,* 59, 1681-1692.

The authors, researchers at Western Carolina University and Bucknell University, analyzed data collected during site assessments and monitoring of 26 restoration sites in North Carolina. Their results suggest that the channel reconfiguration of reaches in a state of equilibrium, which do not exhibit excessive erosion or deposition along highly dynamic rivers is currently problematic. They propose use of a conceptual framework based on geomorphic parameters to assess the likelihood of a project's success.

Montana Department of Environmental Quality. (2009). *Shields River Watershed Water Quality Planning Framework and Sediment TMDLs* (Y02-TMDL-01A). Helena, MT: Author.

The author, the Montana Department of Environmental Quality, used the BEHI method to estimate sediment delivery from stream banks. The method predicts stream erosion rate to sampled stream banks, creating an extrapolation factor from the results, and applying this extrapolation factor to the total length of the streams. The method was used in the Shields watershed to predict bank erosion rates based on BEHI ratings developed from collected field data.

Naiman, R.J., & Melillo, J.M. (1984). Nitrogen budget of a subarctic stream altered by beaver (Castor canadensis). *Oecologia,* 62, 150-155.

The authors, researchers at Woods Hole Oceanographic Institution and the Marine biological Laboratory, measured rates of nitrogen dynamics to construct a nitrogen budget and quantify the influence of beavers on stream eco-systems. They found that changes after impoundment include reduction in allochthonous nitrogen and an increase in nitrogen fixation by sediment microbes. In general, the modified section accumulated a significant amount of nitrogen than before alteration.

Niezgoda, S.L., & Johnson, P.A. (2007). Case study in cost-based risk assessment for selecting a stream restoration design method for a channel relocation project. *Journal of Hydraulic Engineering,* 133 (5), 468-481.

The authors, researchers at the University of Wyoming and Penn State University, used a case study of a stream in central Pennsylvania to illustrate a cost-based risk assessment method to address complexities and uncertainties involved with stream restoration design. During the case study, the researchers found that uncertainty and risk was reduced using the risk-based method by detecting design deficiencies that the initial design overlooked.

Northington, R.M., & Hershey, A.E. (2006). Effects of stream restoration and wastewater treatment plant effluent on fish communities in urban streams. *Freshwater Biology,* 51, 1959-1973.

The authors, researchers at the University of North Carolina at Greensboro, assessed fish community characteristics, resource availability and resource use in three headwater urban streams in North Carolina. The three site types the researchers looked at were a restored urban, an unrestored urban, and a forested sited located downstream of urbanization, and that was impacted by effluent from a wastewater treatment plant (WWTP). At sites sewage-influence sites, the researchers found that the WWTP affected isotope signatures in the biota and they observed lower richness and abundance of fish. They also observed that the restored sites tended to have higher fish richness and greater abundances, compared to unrestored sites. In addition, the researchers conducted additional isotope analysis to determine terrestrial influences on fish.

Northington, R.M., Benfield, E.F., Schoenholtz, S.H., Timpano, A.J., Webster, J.R., & Zipper, C. (2011). An assessment of structural attributes and ecosystem function in restored Virginia coalfield streams. *Hydrobiologia,* 671, 51-63.

The authors, researchers at Virginia Polytechnic Institute and State University, assessed restoration on stream sections affected by surface coal mining activities by evaluating structure and function ecosystem variables in restored and unrestored sections. They observed that in streams affected by mining, macroinvertebrate assemblages in streams were considered stressed and habitat ratings varied between fair and optimal. They found no site differences for any physicochemical or functional variables. In unrestored streams, invertebrate community metric scores tended to be higher.

Orzetti, L.L., Jones, R.C., & Murphy, R.F. (2010). Stream condition in Piedmont streams with restored riparian buffers in the Chesapeake Bay watershed. *Journal of the American Water Resources Association,* 46 (3), 473-485.

The authors, researchers at Ecosystem Solutions and George Mason University, evaluated the efficacy of restored forest riparian buffers along streams in the Chesapeake Bay watershed by examining habitat, water quality variables, and benthic macroinvertebrate community metrics. They found that in general, habitat, water quality, and benthic macroinvertebrate metrics improved with age of restored buffer, with noticeable improvements within 5 to 10 years following restoration.

Palmer, M. (2009). Western Chesapeake Coastal Plain stream restoration targeting. (319(h) program report). *Chesapeake Biological Laboratory – UMCES*.

The author, a researcher at the Chesapeake Biological Laboratory at the University of Maryland, monitored restored and degraded streams positioned in the headwater and the tidal boundary of a watershed in the Chesapeake Bay region. The project quantified nutrient reductions in restored streams where channel restoration practices had been implemented. The information in the project can be used to help develop a strategy for targeting stream restoration implementation in other watersheds in the same region, and to help improve predictions of nitrogen and TSS export in streams in Maryland.

Richardson, C.J., Flanagan, N.E., Ho, M., & Pahl, J.W. (2011). Integrated stream and wetland restoration: a watershed approach to improved water quality on the landscape. *Ecological Engineering,* 37, 25-39.

The authors, researchers at the Duke University Wetland Center, monitored water quality to assess the cumulative effect of restoring multiple portions of the Upper Sandy Creek and former adjacent wetlands. The researchers applied stream/riparian floodplain restoration, storm water reservoir/wetland complex, and a surface flow treatment wetland. The restoration resulted in functioning riparian hydrology that reduced downstream water pulses, nutrients, coliform bacteria, sediment, and stream erosion. They found that nitrate + nitrite loads were reduced by 64 percent, phosphorus loads were reduced by 28 percent, and sediment retention totaled almost 500 MT/year.

Rosgen, D.L. (2001). A practical method of computing streambank erosion rate. *Proceedings of the 7th Federal Interagency Sediment Conference.* Reno, Nevada.

The author, a researcher at Wildland Hydrology, Inc., uses a prediction model to quantitatively predict streambank erosion rates as a tool to apportion sediment contribution of streambank sediment source to the total load transported by a river. The model converts various stream parameter measurements and data to a normalization index for application for a range of stream types. The author also tested the indices against measured annual streambank erosion rates and presents various applications of the prediction method.

Selvakumar, A., O'Connor, T.P., & Struck, S.D. (2010). Role of stream restoration on improving benthic macroinvertebrates and in-stream water quality in an urban watershed: case study. *Journal of Environmental Engineering,* 136 (1), 127-139.

The authors, researchers at the USEPA and Tetra Tech, conducted pre and post restoration monitoring of a stream in Fairfax, Virginia to evaluate the effectiveness of stream bank and channel restoration as a way to improve in-stream water quality and biological habitat. After two years of monitoring, results indicated an improvement in biological quality for macroinvertebrate indices, however, all indices were below the impairment level, signifying poor water quality conditions. Their results also suggested that stream restoration alone had little effect on improving the conditions of in-stream water quality and biological habitat, although it lessened further degradation of stream banks.

Shields, C.A., Band, L.E., Law, N., Groffman, P.M., Kaushal, S.S., Savva, K., Fisher, G.T., & Belt, K.T. (2008). Streamflow distribution of non-point source nitrogen export from urban-rural catchments in the Chesapeake Bay watershed. *Water Resources Research,* 44, 1-13.

The authors, researchers at the University of North Carolina at Chapel Hill, the Center for Watershed Protection, the Institute of Ecosystem Studies, the University of Maryland, the USGS, and the USDA Forest Service, measured nitrogen concentration and discharge measurements to estimate loads. Their goal was to evaluate the impacts of urbanization on magnitude and export flow distribution of nitrogen in various urban and rural catchments. Forested, suburban, and agricultural catchments exported most of the total nitrogen and nitrate loads at lower flows, and conversely, urbanized sites exported total nitrogen and nitrate at higher and less frequent flows.

Sholtes, J.S., & Doyle, M.W. (2011). Effect of channel restoration on flood wave attenuation. *Journal of Hydraulic Engineering,* 137 (2), 196-208.

The authors, researchers at Brown and Caldwell, and the University of North Carolina at Chapel Hill, used a dynamic flood routing model to route floods in impaired and restored reach models, and examined the effectiveness of channel restoration on flood attenuation. Their analyses found that restoration most impacted floods of intermediate magnitude; however, their study shows that the current small scale of channel restoration will provide minimal enhancement to flood attenuation.

Sivirichi, G.M., Kaushal, S.S., Mayer, P.M., Welty, C., Belt, K.T., Newcomer, T.A., Newcomb, K.D., & Grese, M.M. (2010). Longitudinal variability in streamwater chemistry and carbon and nitrogen fluxes in restored and degraded urban stream networks. *Journal of Environmental Monitoring,* 13, 288-303.

The authors, researchers at the University of Maryland, the USEPA, and the USDA Forest Service, monitored surface and hyporheic water chemistry of restored and unrestored streams combined with a mass balance approach to investigate total dissolved nitrogen (TDN) and dissolved organic carbon (DOC) dynamics and in-stream retention and transformation processes. They found considerable reach-scale variability in biogeochemistry. TDN concentrations were typically higher than DOC in restored streams, and the opposite in unrestored streams. The mass balance in restored streams showed net uptake of TDN, and a net release of DOC, and the opposite pattern in unrestored streams.

Smith, S.M., & Prestegaard, K.L. (2005). Hydraulic performance of a morphology-based stream channel design. *Water Resources Research,* 41, 1-17.

The authors, researchers at the Maryland Department of Natural Resources and the University of Maryland, monitored a rehabilitation project in a reach of Deep Run in Maryland to assess commonly used approaches to channel design. They found that the constructed channel was morphologically and hydraulically different from the original channel, and was unsuitable. Their findings demonstrate the need for enhanced consideration of the relationship between channel stability and hydraulic conditions at multiple scales over a range of flow conditions in stream rehabilitation projects.

Sudduth, E.B., Hassett, B.A., Cada, P., & Bernhardt, E.S. (2011). Testing the Field of Dreams hypothesis: functional responses to urbanization and restoration in stream ecosystems. *Ecological Applications,* 21 (6), 1972-1988.

The authors, researchers at Duke University, compared ecosystem metabolism and nitrate uptake kinetics in restoration projects in urban watersheds, unrestored urban streams, and minimally disturbed forested watersheds. They found that stream metabolism did not differ between stream types in either summer or winter, and that nitrate uptake kinetics was not different between stream types in the winter. They observed restored streams had significantly higher rates of nitrate uptake during the summer, which they found could mostly be explained by stream temperature and canopy cover.

Swan, C.M., & Richardson, D.C. (2008). The role of native riparian tree species in decomposition of invasive tree of heaven (Ailanthus altissima) leaf litter in an urban stream. *Ecoscience,* 15 (1), 27-35.

The authors, researchers at the University of Maryland, analyzed decomposition rates of the invasive tree of heaven, and other native leaf species in an urban stream, complemented with laboratory methods. They found that the invasive leaf experienced rapid breakdown, but was slowed when mixed with native leaves. Their results suggest that the presence of native riparian tree species may mediate how invasive trees decompose in human-impacted streams.

Sweeney, B.W., Czapka, S.J., & Yerkes, T. (2002) Riparian forest restoration: increasing success by reducing plant competition and herbivory. *Restoration Ecology*, 10 (2), 392-400.

The authors, researchers at the Stroud Water Research Center, Ducks Unlimited, Inc., and the USDA Forest Service, assessed seedling survivorship and growth of several species of trees in response to various treatment methods over 4 years at two riparian sites near Chester River, Maryland. They found no significant difference in survivorship and growth between bare-root and containerized seedlings. The survivorship and growth was higher for sheltered versus unsheltered seedlings, and those protected from weeds using herbicide. Overall, the results suggest that crown closure over most small streams needing restoration can be achieve more rapidly by protecting seedlings with tree shelters and controlling competing vegetation with herbicides.

Tullos, D.D., Penrose, D.L, Jennings, G.D., & Cope, W.G. (2009). Analysis of functional traits in reconfigured channels: implications for the bioassessment and disturbance of river restoration. *Journal of the North American Benthological Society,* 28 (1), 80-92.

The authors, researchers at Oregon State University and North Carolina State University, compared physical habitat variables, taxonomic and functional-trait diversities, taxonomic composition, and functional-trait abundances in 24 pairs of control and restored sites in three land use type catchments. They observed that responses to restoration differ between agricultural/rural and urban catchments, and that channel reconfiguration disturbs food and habitat resources in stream ecosystems. Their results also suggest that taxa in restored habitats are environmentally selected for traits favored in disturbed environments.

Tullos, D.D., Penrose, D.L., & Jennings, G.D. (2006). Development and application of a bioindicator for benthic habitat enhancement in the North Carolina Piedmont. *Ecological Engineering,* 27, 228-241.

The authors, researchers at Oregon State University and North Carolina State University, describe the development, application, and evaluation of a method for assessing the effectiveness of stream restoration activities in enhancing four lotic habitats based on the presence of habitat specialists. They compared the presence of indicator genera in restored and unrestored sections to signify restoration success in re-establishing benthic habitats. Their results suggest that habitats in urban areas indicated the greatest enhancement, while the agricultural and rural sites did not show a clear trend of improvement or degradation in response to restoration activities.

U.S. EPA. (2010). *Chesapeake Bay Phase 5 Community Watershed Model. In preparation.* EPA 903S10002 – CBP/TRS-303-10, U.S. Environmental Protection Agency, Chesapeake Bay Program Office, Annapolis, MD.

The author, the USEPA, uses HSPF model code to simulate sediment transport as separate processes on the land and in the river. The document describes the three parts of sediment simulation in the Phase 5.3 Model to represent sediment sources, delivery, and transport in the watershed.

Violin, C.R., Cada, P., Sudduth, E.B., Hassett, B.A., Penrose, D.L., & Bernhardt, E.S. (2011). Effects of urbanization and urban stream restoration on the physical and biological structure of stream ecosystems. *Ecological Applications,* 21 (6), 1932-1949.

The authors, researchers at the University of North Carolina, Duke University, and North Carolina State University, compared the physical and biological structure of four urban degraded, four urban restored, and four forested streams in North Carolina to quantify the ability of reach-scale restoration to restore physical and biological structure. They observed that channel habitat complexity and watershed impervious cover were the best predictors of sensitive taxa richness and biotic index the reach and catchment scale, respectively. Macroinvertebrate communities in restored channels were compositionally similar to those in urban degraded channels. Their results suggest that reach-scale restoration is not successfully mitigating for the factors causing physical and biological degradation.

Waite, L. J., Goldschneider, F. K., & Witsberger, C. (1986). Nonfamily living and the erosion of traditional family orientations among young adults. American Sociological Review, 51 (4), 541-554.

The authors, researchers at the Rand Corporation and Brown University, use data from the National Longitudinal Surveys of Young Women and Young Men to test their hypothesis that nonfamily living by young adults alters their attitudes, values, plans, and expectations, moving them away from their belief in traditional sex roles. They find their hypothesis strongly supported in young females, while the effects were fewer in studies of young males. Increasing the time away from parents before marrying increased individualism, self-sufficiency, and changes in attitudes about families. In contrast, an earlier study by Williams cited below shows no significant gender differences in sex role attitudes as a result of nonfamily living.

Walter, R.C., & Merritts, D.J. (2008). Natural streams and the legacy of water-powered mills. *Science,* 319, 299-304.

The authors, researchers at Franklin and Marshall College, mapped and dated deposits along mid-Atlantic streams that formed the basis for the widely accepted model for gravel-bedded streams. The collected data, along with historical maps and records suggest streams were historically small anabranching channels with extensive vegetated wetlands that accumulated little sediment, and stored organic carbon. They suggest that large numbers of milldams have buried the wetlands with fine sediment. Their findings show that most floodplains along mid-Atlantic streams are actually fill terraces, and historically incised channels are not natural archetypes for meandering streams.

Weller, D.E., Baker, M.E., & Jordan, T.E. (2011). Effects of riparian buffers on nitrate concentrations in watershed discharges: new models and management implications. *Ecological Applications,* 21 (5), 1679-1695.

The authors, researchers at the Smithsonian Environmental Research Center, combined geographic methods with improved statistical models to test the effects of buffers along cropland flow paths on connecting stream nitrate concentrations in the Chesapeake Bay watershed. They developed models that predict stream nitrate concentration from land cover and physiographic province, and compared models with and without buffer terms. They found that on average buffers in the Coastal Plain watersheds had higher nitrate removal potential than other regions. Model predictions for the study watersheds estimated nitrate removals based on existing cropland and buffer distributions, compared to expected nitrate concentrations if buffers were removed. In the Coastal Plain watersheds, current buffers reduce average nitrate concentrations by 0.73 mg N/L, or 50 percent of inputs from cropland, 0.40 mg N/L, or 11 percent in the Piedmont, and 0.08 mg N/L or 5 percent in the Appalachian Mountains. The model also suggests that restoration to close all buffer gaps could further reduce nitrate concentrations.

Appendix B Protocol 1 Supplemental Details

Protocol 1 – Credit for Prevented Sediment during Storm Flow - is presented in Section 5 and an example using the protocol is presented in Section 6. This Appendix provides supplemental details for the protocol and example.

Bank and Nonpoint Source Consequences of Sediment (BANCS) Method

The BANCS Method, developed by Rosgen (2001) quantitatively predicts streambank erosion rates based on two commonly used bank erodibility tools: the Bank Erosion Hazard Index (BEHI) and Near Bank Stress (NBS).

The literature review in Table B-1 includes information from studies that have utilized the BANCS Method across the country. While many studies have applied the method, there are few that have collected actual measurements of streambank erosion to validate the results of the BANCS Method and establish a level of accuracy. The literature indicates that the BANCS Method generally predicts streambank erosion within an order of magnitude. Regional characteristics where the method is applied are important to consider and adjustments to the BEHI and NBS may be necessary to provide an adequate prediction of streambank erosion. For example, Sass and Keane (2012) found that woody vegetation plays a vital role in bank stability in Northeastern Kansas. By adjusting the vegetation portion of the BEHI they were able to improve the correlation between BEHI and streambank erosion.

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 justified.
- The BANCS method is not effective in predicting future channel incision and bank erodibility in reaches upstream of active head cuts. These zones upstream of active head cuts, failing dams, or recently lowered culverts/utility crossings often yield the greatest potential for long-term sediment degradation and downstream sediment/nutrient pollution.
- The method estimates sediment supply and not transport or 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, the literature indicates that further refinements to this method that can improve the adequacy. 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 this data may not be readily available, additional methodology 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, dendro-geomorphic studies of exposed roots and new shoots, time series channel surveys, and/or bank pins.
- 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.

Table B-1
Bank and Nonpoint Source Consequences of Sediment (BANCS) Method Literature Review

Source	Location	Application	Results/Recommendations
Shields River Watershed WQ Planning Framework & Sediment TMDLs (MDEQ, 2009a)	Shields River Watershed, south-central MT. Confined by mountains to the west and east and flows to the Yellowstone River	The BANCS Method was applied to HUC 6 watersheds at 16 reaches along Potter Creek and Shields River and in 13 additional tributary reaches within the TMDL Planning Area to estimate bank erosion for development of a sediment TMDL. The assessment method excluded 100% naturally eroding banks from the extrapolation and potential loads are assumed to be a combination of natural loads and anthropogenic loads	Bank erosion was found to contribute 103,000 tons of sediment annually to water bodies within the Shields River TMDL Planning Area. The bank erosion method focuses on both sediment production and sediment delivery and also incorporates large flow events via the method used to identify bank area and retreat rates. Therefore, a significant portion of the bank erosion load is based on large flow events versus typical yearly loading.

Table B-1 Bank and Nonpoint Source Consequences of Sediment (BANCS) Method Literature Review			
Source	**Location**	**Application**	**Results/Recommendations**
		associated with the use of reasonable land, soil, and water conservation practices.	Uncertainty in loading estimates is addressed through an adaptive management approach where the TMDL and allocations can be revised as additional information is collected.
Estimating Bank Erosion in the Wissahickon Creek Watershed - Conference Presentation (Haniman, 2009)	Wissahickon Creek Watershed near Philadelphia, PA	The BANCS Method was applied to 12 tributaries of the Wissahickon Watershed between Oct 2005 – Aug 2006. Bank pins were installed at 82 sites from 2006-2008.	The BANCS method predicted 4.2 million lbs of erosion/year. The bank pins estimated 2.3 million lbs of erosion/year (95% CI, +/- 2.5 million lbs/year). The BANCS Method predicts erosion within an order of magnitude. Bank erosion curves are difficult to develop. Understanding channel evolution is key.
Application of Rosgen's BANCS Model for NE Kansas and the Development of Predictive Streambank Erosion Curves (Sass and Keane, 2012)	The Black Vermillion Watershed, glaciated region of KS, northeast of the Flint Hills Ecoregion	3 subwatersheds were selected in the Vermillion Watershed with varied land uses and conservation practices, varied channel modification, and varied riparian corridor management. Each subwatershed included 3 study reaches. Streams in the watershed are low gradient (<0.01), typically entrenched, straightened through channelization, and have high vertical banks. The BANCS Method was conducted for the study reaches, in addition to streambank profiles (with erosion pins as a measurement check). The goal was to provide a tool that can accurately predict annual streambank erosion rates and sediment contributions from channel banks in Northeast Kansas.	The erosion prediction curves developed in this study displayed more variation than the original Yellowstone, Colorado, Piedmont, or Arkansas curves. Vegetation seems to play a vital role in maintaining bank stability in this region of NE KS. Erosion rates plotted against both BEHI score and NBS rating with each site's woody vegetation cover showed a clustering of sites with woody vegetation vs. sites without. Thus, the vegetation portion of the BEHI was modified and simplified, which resulted in consistent R^2 values of 0.84 and 0.88 and correct order of the BEHI adjective ratings. Bank materials may also play a vital role, as the soils are high in clay content that may act similar to bedrock when wetted.
Using BANCS Model to Prioritize Potential Stream Bank Erosion on	Birch Creek within Catskill State Park, NY	144 bank locations along 6.3 stream miles of Birch Creek (steep-gradient mountainous region) were assessed with the BANCS Method. Nine	The erosion processes accounted for in the BANCS model may differ in non-alluvial boundary conditions such as glacial till and/or glacio-lacustrine lake clays, and revetment

Table B-1
Bank and Nonpoint Source Consequences of Sediment (BANCS) Method Literature Review

Source	Location	Application	Results/Recommendations
Birch Creek, Shandaken, NY (Markowitz and Newton, 2011)		monumented stream bank cross-sections were installed and measured pre and post Hurricane Irene and Tropical Storm Lee flood events. The purpose of this investigation was to: 1) establish a baseline dataset to predict an annual stream bank erosion rate of Birch Creek using BANCS; 2) rank and prioritize site specific potential erosion; and 3) produce reach specific erosion ratings.	as observed in the study area. These boundary conditions may influence the erosion rates in ways not predicted by the BANCS model. No apparent trend was observed when data from the 9 monumented cross-sections were plotted against the BEHI and NBS ratings. The discrepancy appears to be because of the NBS method used. Only one out of the seven methods to assess NBS was applied to all geomorphic conditions along Birch Creek. When graphed separately it became apparent that the variables associated with the BEHI rating were a much more effective predictor of bank erosion than NBS.
Great Lakes Bank Erosion 516(e) Study – Conference Presentation (Creech, 2010)	Great Lakes Region	Used bank pins and bank profile measurements to develop regional curves for the BANCS method.	The presentation does not indicate how well the BANCS method predicted erosion found with the bank pins and profile measurements. It appears they are still doing measurements so may not have drawn conclusions yet.
Northwest Branch of the Anacostia River Bank Erosion Assessment – Conference Presentation (Crawford et al., 2009)	Anacostia River, Montgomery County, MD, 15.2 sq mile watershed that is 18% impervious. Streams have 700 – 1,000 ft forested floodplains.	Goal of the stream restoration project was to reconnect the channel with its floodplain. The BANCS method was used, along with bank profile surveys at 44 individual banks.	The calibrated NW-160 curve predicted 1,040 tons/year erosion, the Colorado curve predicted 1,298 tons/year, and the North Carolina curve predicted 910 tons/year. BANCS method seems to be a reasonable first estimate of bank erosion. Only utilized 2 NBS methods. Large woody debris is an important source of NBS. Trees on top of banks contribute to stability. BANCS method should not be used to calculate sediment delivered to downstream reaches as it does not take deposition into account.
Evaluating the BEHI on the Navajo Nation (Navajo Nation EPA, 2002)	Chuska Nation, Navajo Nation	Bank profiles and bank pins were surveyed and BEHI determined for 20 bank sites along 15 streams for the purpose of testing and calibrating the BANCS method.	Considerable error was found at most sites for the Yellowstone and Colorado regional curves. Although there is error, the model appears to operate qualitatively. All sites where erosion was predicted, experienced

Table B-1 Bank and Nonpoint Source Consequences of Sediment (BANCS) Method Literature Review			
Source	**Location**	**Application**	**Results/Recommendations**
			erosion. While considerable error exists at individual sites, values averaged or integrated across the project area were surprisingly accurate. The Yellowstone NP and Colorado USFS graphs underestimated erosion by 6% and 168% respectively. Given the great variability in bank composition, erosion mechanisms, and stream flow, it will take several additional years of data to determine the accurate predictive capability of the BEHI. Additional parameters may have to be developed to accurately characterize the Near Bank Stress in sand bed channels. Regardless of the quantitative merits of the BEHI, the field procedure provides a valuable qualitative assessment of stream bank stability for the technician, landowner, or manager.
Stony Run, Baltimore City, MD, Geomorphic Baseline Survey (Eng et al., 2007)	Stony Run, Baltimore City, MD	This study documents active channel adjustments, and will allow the City to compare pre- and post-restoration stream conditions to document the benefits of the restoration. 42 stream banks were assessed using the BANCS method. 9 existing monumented cross-sections were resurveyed, and 2 new cross-sections were surveyed.	A poor correlation was found between the measured erosion rates and the predicted erosion rate determined from the draft regional D.C. curve, which may have been due to changes in the BEHI and NBS procedures from Wildland Hydrology. Similar erosion rates were found at Moore's Run.
Impacts of land use on stream bank erosion in the NE Missouri Claypan region (Peacher, 2011)	Claypan region, NE Missouri	The goal of this project was to determine whether two ***modified*** Rosgen's Bank Erosion Hazard Index (BEHI) Procedures (SOP) used by the Michigan Department of Environmental Quality (MDEQ) would be applicable to streams in the Claypan region of NE Missouri.	The erosion rates for the eighteen treatment reaches were weakly negatively correlated with 2008 and 2011 SOP BEHI total scores, respectively. Both 2008 and 2011 total scores covered a fairly narrow range, which suggests that one or more of the variables were scored very similarly across the treatment

Table B-1 Bank and Nonpoint Source Consequences of Sediment (BANCS) Method Literature Review			
Source	**Location**	**Application**	**Results/Recommendations**
		The procedures were tested using erosion pin data collected over three years in two sub-watersheds of the Salt River Basin. The first procedure uses a ratio of bank height to bankfull height and the 2nd procedure includes adjustment factors for bank material and soil layer stratification.	reaches. Another caveat to consider is that Rosgen's method incorporates near-bank velocity gradients and shear stress distributions, which are not incorporated into the survey methods of either MDEQ SOP examined here. No conclusions about the effectiveness of the BANCS method can be made.
Using a BEHI to Estimate Annual Sediment Loads from Streambank Erosion in the West Fork White River Watershed (Van Eps et al., 2004)	West Fork White River Watershed, NW Arkansas, 79,400 ac watershed	The Arkansas Department of Environmental Quality utilized a BEHI and data collected from surveys of streambank profile measurements to develop a graphical model to estimate streambank erosion rates and to estimate the annual sediment load due to accelerated streambank erosion. 24 permanent survey sites were established within 8 reaches for erosion measurement with bank pins from 2002-2003. 192 streambanks were assessed for BEHI and NBS (2002-2004). By relating the BEHI rating, the local NBSS, and the measured erosion rate at each permanent survey site, a graphical model to predict streambank erosion rates was developed.	The study did not provide accuracy estimates for how well the measured erosion rates correlated with the model they developed (regional curve). Bankfull discharge was met or exceeded on many instances during the study period. The survey data should represent erosion rates for years where bankfull flow is approached, equaled, or slightly exceeded. Lateral erosion rates predicted by the model were less than half the rates predicted by the Colorado model for a BEHI and NBSS combination rating of moderate and high. However, for other combinations of BEHI and NBSS, erosion rates predicted by the WFWR model were higher than those predicted by the other models by a factor ranging from 1.3 to 2.8 times.
Streambank Erosion Source Assessment, Upper Gallatin TMDL Planning Area (PBS&J, 2009)	West Fork Gallatin River watershed of the Upper Gallatin TMDL Planning Area, Gallatin and Madison counties, Montana	Sediment loads due to streambank erosion were estimated based on the BANCS Method at 30 monitoring sites (204 streambanks) covering 5.2 miles of stream between July and October of 2008. The reaches were located in low-gradient portions of the study streams where sediment deposition is likely to occur.	Average annual sediment load from the assessed streambanks was estimated at 397 tons/year. 30% of the erosion sediment load was attributed to accelerated streambank erosion caused by historic or current human activities, while approximately 70% was attributed to natural erosional processes and sources.

Table B-1 Bank and Nonpoint Source Consequences of Sediment (BANCS) Method Literature Review			
Source	**Location**	**Application**	**Results/Recommendations**
			The watershed streambank sediment load was estimated at 1,821 tons/year based on the stream segment sediment load extrapolated from the assessed streambanks. 33% of this load is due to anthropogenic disturbances. Through the implementation of BMPs, it is estimated that the total sediment load from anthropogenically accelerated streambank erosion can be reduced by 31% (186 tons/year). Direct measurements of streambank erosion were not made, so no conclusions can be drawn about the accuracy of the results from the BANCS Method.
A Practical Method of Computing Streambank Erosion Rate (Rosgen, 2001)	Lamar Basin in Yellowstone National Park, Montana and the Front Range of Colorado on the USDA Forest Service, Arapaho and /Roosevelt and Pike/San Isabel National Forests.	The BANCS Method is presented and is based on the idea that streambank erosion can be traced to two major factors: stream bank characteristics (BEHI) and hydraulic / gravitational forces (NBS). In 1987 and 1988, direct measurements of annual erosion were made using bank pins and profiles to test the BEHI/NBS relationship. 49 sites were selected in the Front Range Colorado and 40 sites were selected in the Lamar River Basin, MT.	The coefficients of determination, or r^2 values, for the correlation of BEHI to NBS were found to be 0.92 for Colorado and 0.84 for Yellowstone. A subsequent study in NC found that the data plots closely to the Colorado dataset, possibly due to a similar alluvial bank composition. Research in the Illinois River in OK showed that either velocity gradients or shear stress ratios predict better than cross-sectional area ratio for NBS. This study also found that flows 4 times bankfull stage generated the measured erosion rate, compared to Colorado and Yellowstone, that are associated with flows at or near bankfull. Research in the Weminuche River found that data collected at low flow can provide comparable results to the higher flows associated with Colorado and Yellowstone. Stratification by geologic and soil types should be accomplished to establish a family of curves for various geologic and hydro-physiographic provinces. Once a

Table B-1 Bank and Nonpoint Source Consequences of Sediment (BANCS) Method Literature Review			
Source	**Location**	**Application**	**Results/Recommendations**
			quantitative relationship is obtained, mapping changes in the BEHI and NBS ratings can be used to estimate consequence of change in locations beyond where the measured bank erosion data is obtained.
Priority Setting for Restoration in Sentinel Watersheds (Lenhart et al., Ongoing)	Whitewater River in the Driftless Area in southeast Minnesota Elm Creek within Glacial Till Plains of the Blue Earth Basin in southern Minnesota Buffalo River within the Red River of the North Basin	This project will develop a modified BANCS model and calibrate it for different geomorphic regions of Minnesota using monitoring, modeling and historical data. BSTEM predicts erosion quantities from individual storm events, while CONCEPTS can model erosion, deposition and channel evolution over extended time periods. These analyses and assessments will be used to identify priority management zones for the intended purpose of reducing sediment and phosphorus loads in sentinel watersheds (areas that are representative of other watersheds in the same region).	This project is ongoing and is scheduled for completion December 2014.
Upper Jefferson River Tributary Sediment TMDLs and Framework Water Quality Improvement Plan (MDEQ, 2009b)	Impaired tributaries to the Upper Jefferson River - Big Pipestone, Little Pipestone, Cherry, Fish, Hells Canyon, and Whitetail creeks.	This document presents a TMDL and framework water quality improvement plan for six impaired tributaries to the Upper Jefferson River. Appendix G presents an assessment of sediment loading due to streambank erosion along stream segments listed as impaired due to sediment. The BANCS Method was done along 91 streambanks (3.89 miles of streambank).	A total sediment load of 742.4 tons/year was attributed to eroding streambanks within the monitoring sections. Erosion from the monitoring sites was extrapolated to the watershed scale. A total estimated sediment load of 44,576.3 tons/year was attributed to eroding streambanks. Direct measurements of streambank erosion were not made, so no conclusions can be drawn about the accuracy of the results from the BANCS Method.

TN and TP Concentration in Stream Bank Sediments

Table 5 in Section 5 shows the four Pennsylvania and Maryland studies in which the measured nutrient content of stream sediments consistently had 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 2.28 pounds of TN per ton of sediment and 1.05 pounds of TP per ton of sediment, as documented by Walters et al. (2007). 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. Steve provided the data in Table B-2 collected from stream bed and bank samples from Powdermill Run and Scotts Level Branch in Baltimore County, MD.

Table B-2 Concentration of TN and TP in Stream Bed and Bank Samples from Powdermill Run and Scotts Level Branch in Baltimore County, MD

	Mean	**Median**	**Sample size**
TP (mg/L)	1.78	1.61	77
TN (mg/L)	5.41	3.81	89

Sediment Delivery Ratio

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 (Section 2.5, Figure 1). These edge-of-stream loads were then converted to edge-of-field loads by comparing the average forest load estimates to Natural Resource Inventory average CBWM forest loads at the edge-of-field. For additional documentation, refer to Section 9 of U.S. EPA (2010).

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. 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).

The sediment loss between the edge-of-field and the edge-of-stream is incorporated into the CBWM as a sediment delivery ratio. This ratio is multiplied by the predicted edge-of-field erosion rate to estimate the eroded sediments actually delivered to a specific reach (U.S. EPA, 2010). Sediment delivery ratios in the Phase 5.3 CBWM range from 0.1 to 0.25. In the protocol 1 example in Section 6, the median of this range, 0.175, was used. Localities will not be required to apply the sediment delivery ratio 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 modeling tools.

Supplemental information for the Protocol 1 Example

The example for Protocol 1 uses actual stream bank data collected for Hickey Run in Washington, D.C, by the USFWS. The data consisted of five reaches that were subdivided into a total of 28 banks for BEHI and NBS assessments. The BEHI and NBS scores were taken for each bank and an estimated stream erosion rate was derived using the curve developed by the USFWS in Figure B-1. The bank height and length were used to convert the erosion rate from feet per year to tons per year using the equation described under Protocol 1 in Section 6.

Table B-3
Bank Erosion Potential for Hickey Run

Reach ID	Bank Length (ft)	Bank Height (ft)	Bank Area (ft^2)	BKF Height (ft)	BEHI	Near Bank Stress	Predicted Erosion Rate (ft/yr)	Predicted Erosion Sub-Total (ft^3/yr)	Predicted Erosion Sub-Total (tons/yr)	Predicted Reach Total Reach Erosion (tons/yr)	Predicted Erosion Rate (tons/ft/yr)
Reach 6											
Bank 1	376	10	3760	1.7	High	Low	0.4	1504.00	93.89		
Bank 2	260	4.5	1170	1.7	Low	Low	0.017	19.89	1.24		
Bank 3	144	6.5	936	1.7	High	Low	0.4	374.40	23.37		
Bank 4	578	15	8670	1.7	High	Low	0.4	3468.00	216.49		
Bank 5	329	8	2632	1.7	High	Low	0.4	1052.80	65.72		
Bank 6	381	12	4572	1.7	Very High	Low	0.4	1828.80	114.16	514.87	0.25
Reach 5											
Bank 7	160.5	10	1605	2.01	High	Low	0.4	642.00	40.08		
Bank 8	192	8.5	1632	2.01	Very High	Low	0.4	652.80	40.75		
Bank 9	122.4	2.3	281.5	1.4	Low	Low	0.017	4.79	0.30		
Bank 10	55	7	385	1.4	Very High	Low	0.4	154.00	9.61	90.74	0.17
Reach 4											

Bank 11	263.5	6.5	1713	2.59	Very High	Low	0.4	685.10	42.77		
Bank 12	73	6.5	474.5	2.34	Very High	Low	0.4	189.80	11.85		
Bank 13	195	7.5	1463	2.59	High	Low	0.4	585.00	36.52		
Bank 14	151	7.5	1133	2.2	High	Low	0.4	453.00	28.28		
Bank 15	352.5	7	2468	2.27	Very High	Low	0.4	987.00	61.61		
Bank 16	323	7	2261	2.71	High	Low	0.4	904.40	56.46		
Bank 17	395	7.5	2963	2.59	High	Low	0.4	1185.00	73.97		
Bank 18	59.4	7.5	445.5	2.2	High	Low	0.4	178.20	11.12		
Bank 19	231.5	6.5	1505	2.2	Very High	Low	0.4	601.90	37.57		
Bank 20	95.5	6.5	620.8	2.26	Low	Moderate	0.074	45.94	2.87	363.02	0.17
Reach 3											
Bank 21	132	6.5	858	1.88	Very High	Extreme	2.65	2273.70	141.94		
Bank 22	100	6.5	650	1.88	High	Low	0.4	260.00	16.23		
Bank 23	62.5	8	500	1.23	N/A	N/A	0	0.00	0.00		
Bank 24	50	20	1000	1.73	Very High	Extreme	2.65	2650.00	165.43		
Bank 25	175	3.5	612.5	1.48	Moderate	Low	0.11	67.38	4.21		
Bank 26	162.5	7.5	1219	1.48	Very High	Low	0.4	487.50	30.43	358.23	0.53
Reach 2	***Concrete Channel***										
Reach 1											
Bank 27	1170	7.5	8775	3.76	Low	Low	0.017	149.18	9.31		
Bank 28	1170	10.5	12285	4	Low	Low	0.017	208.85	13.04	22.35	0.01
									TOTAL	**1349.22**	**0.17**

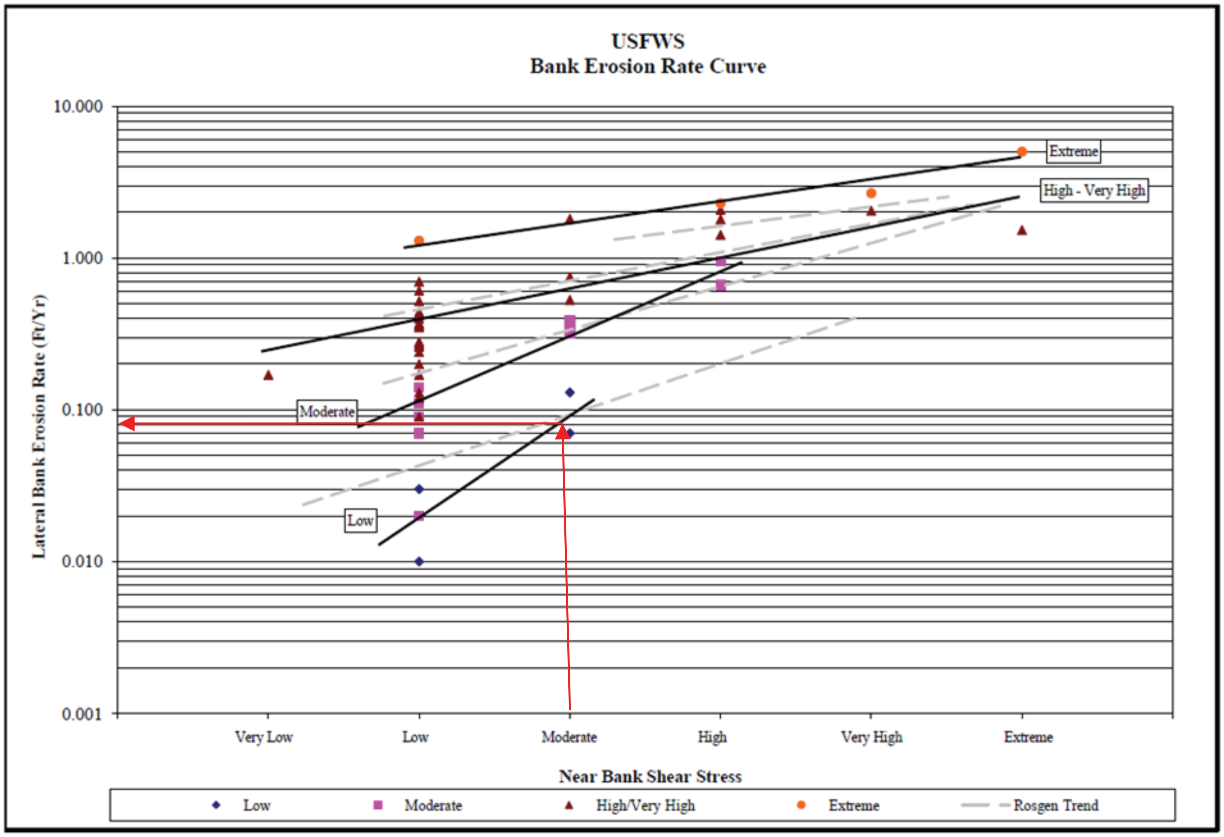


Figure B-1. Bank Erosion Rate Curve Developed by the USFWS

Stream bank erosion is predicted from the curve in Figure B-1 by first identifying the BEHI and NBS scores. For example, Bank 20 from Table B-3 had an NBS score of moderate and a BEHI score of low. By locating the moderate NBS score on the x axis of the Figure B-1 and following it straight up to the BEHI line for “low,” the vertical axis shows a predicted erosion rate of 0.07 feet per year, as indicated by the red arrows on the figure.

To convert the erosion rate from feet per year to tons per year, a soil bulk density of 125 pounds/ft^3 was used. This estimate was obtained from a study by Van Eps et al. (2010) that sampled coarse and fine grain layers of stream banks in the West Fork White River watershed in Northwestern Arkansas to determine the in-situ bulk density and particle size distribution. The 125 pounds/ft^3 value used in the Protocol 1 example was calculated as the mean of the coarse and fine grain average bulk density measurements obtained by Van Eps et al. (2010). The bulk density from this study was used only as an example of typical values that might be found. The original bulk density data from the USFWS was not available. The protocol recommends that each project require its own bulk density analysis at several locations in the stream channel as bulk density can be highly variable.

From Van Eps et al. (2010):

"The average in-situ bulk density for fine grain material samples was 1.4 g/cm^3 (1.2 ton/yd^3). By weight, 8% of the particles in the fine material samples were greater than 2 mm in particle size. The average in-situ bulk density for coarse samples was 2.6 g/cm^3 (2.2 ton/yd^3). By weight, 80% of the particles in coarse samples were greater than 2 mm in particle size."

References

Crawford, S., Jennings, K., and M. Hubbard. 2009. Northwest branch of the Anacostia River bank erosion assessment. 2009 Mid-Atlantic Stream Restoration Conference. November 3-5, 2009. Morgantown, WV.

Creech, C. 2010. Great Lakes bank erosion 516(e) study. USACE, Detroit District. Powerpoint presentation (unknown venue).

Eng. C., Fleming, K., and R. Starr. 2007. Stony Run, Baltimore City, Maryland, Geomorphic Baseline Survey. Stream Habitat Assessment and Restoration Program, U.S. Fish & Wildlife Service, Chesapeake Bay Field Office. CBFO-S06-03.

Haniman, E. 2009. Estimating bank erosion in the Wissahickon Creek watershed: A bank pin monitoring approach. Delaware Estuary Science and Environmental Summit 2009: Planning for Tomorrow's Delaware Estuary. Cape May, NJ, January 11-14, 2009.

Langland, M. and S. Cronin, 2003. A summary report of sediment processes in Chesapeake Bay and watershed. U.S. Geological Survey Water Resources Investigation Report 03-4123

Lenhardt, C., Nieber, J., and A. Birr. Ongoing. Priority setting for restoration in sentinel watersheds. University of Minnesota, Department of Bioproducts and Biosystems Engineering. St. Paul, MN.

Markowitz, G., and S. Newton. 2011. Project Report: Using Bank and Nonpoint Source Consequences of Sediment model to prioritize potential stream bank erosion on Birch Creek, Shandaken, NY. Ashokan Watershed Stream Management Program. Phoenicia, NY.

Montana Department of Environmental Quality (MDEQ). 2009a. Shields River watershed water quality planning framework and sediment TMDLs. Y02-TMDL-01A. Helena, MT

Montana Department of Environmental Quality (MDEQ). 2009b. Upper Jefferson River tributary sediment TMDLs and framework water quality improvement plan. M08-TMDL-01A. Helena, MT.

Navajo Nation Environmental Protection Agency. 2002. Evaluating the Bank Erosion Hazard Index on the Navajo Nation. Prepared by Natural Channel Design, Inc. Flagstaff, AZ.

PBS&J. 2009. Streambank erosion source assessment, Upper Gallatin TMDL Planning Area. Prepared for Blue Water Task Force, Inc. and Montana Department of Environmental Quality.

Peacher, R. 2011. Impacts of land use on stream bank erosion in Northeast Missouri Claypan Region. Graduate Theses and Dissertations Paper 10395. Iowa State University.

Rosgen, D. 2001. A practical method of computing streambank erosion rate. Proceedings of the Seventh Federal Interagency Sedimentation Conference. Vol. 2, pp. 9-15. March 25-29, 2001, Reno, NV.

Sass, C., and T. Keane. 2012. Application of Rosgen's BANCS model for NE Kansas and the development of predictive streambank erosion curves. *Journal of the American Water Resources Association*. 48(4): 774-787.

U.S. EPA (U.S. Environmental Protection Agency). 2010. Chesapeake Bay Phase 5.3 Community Watershed Model. EPA 903S10002 - CBP/TRS-303-10. U.S. Environmental Protection Agency, Chesapeake Bay Program Office, Annapolis MD. December 2010.

Van Eps, M., Formica, S., Morris, T., Beck, J., and A. Cotter. 2010. Using a bank erosion hazard index to estimate annual sediment loads from streambank erosion in the West Fork White River Watershed. Arizona Department of Environmental Quality, Environmental Preservation Division. Little Rock, AR.

Walters, R., D. Merritts, and M. Rahnis. 2007. Estimating volume, nutrient content, and rates of stream bank erosion of legacy sediment in the piedmont and valley and ridge physiographic provinces, southeastern and central, PA. A report to the Pennsylvania Department of Environmental Protection.

Appendix C Protocol 2 and 3 Supplemental Details

Protocol 2 – Credit for Instream and Riparian Nutrient Processing within the Hyporheic Zone during Base Flow and Protocol 3 – Credit for Floodplain Reconnection Volume- are presented in Section 5 and examples using the protocols are presented in Section 6. This Appendix provides supplemental details for the protocols and examples.

Protocol 2 Method Documentation

Protocol 2 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.

Striz and Mayer (2008) and Kaushal et al. (2008) conducted a study in Minebank Run, an urban stream in Baltimore County, MD to evaluate if particular stream restoration techniques improve ground water- surface water interaction (GSI) and if beneficial hydrologic exchanges between the stream and riparian/floodplain areas may be enhanced to improve water quality. Minebank Run is a second order stream located within the Piedmont physiographic region of Maryland with a drainage area of 3.24 square miles of mostly suburban land cover (25% impervious cover). Stream restoration techniques for the 1,800 foot channel followed the Natural Channel Design methodology and included filling the channel (and relocating in places) with sediment, cobbles, and boulders and constructing point bars, riffles, and meander features along the reach and creating step-pool sequences. The restoration also included a riparian corridor landscaping plan.

Their results show that a simple model splitting the stream into two compartments at the thalweg was sufficient to quantify the GSI flow (Figure C-1 below) and that significant differences in mean denitrification rates between restored and unrestored reaches and rates were higher at low-bank, hydrologically connected sites than at high-bank sites. Denitrification rates were 77.4 ± 12.6 μg N/kg/day of soil at restored sites and 34.8 ± 8.0 μg *N*/kg/day of soil at unrestored sites. The hydrologically connected, low-bank restored site consistently had significantly higher rates of denitrification than the other sites, with a mean in-situ denitrification of 132.4 μg *N*/kg/day of soil (2.65 x 10^{-4} pounds/ton/day of soil) (Table C-1). The Panel decided that this rate is representative of the denitrification that will occur as a result of Protocol 2. To determine the additional denitrification that occurs in a restored reach versus an unrestored reach, the average rate at unrestored sites (34.8 ± 8.0 μg N/kg/day of soil) was subtracted from the low-bank restored site rate (132.4 μg *N*/kg/day of soil) and resulted in a denitrification rate of 97.6 μg *N*/kg/day of soil (1.95 x 10^{-4} pounds/ton/day of soil).

To estimate the denitrification that would occur at a stream reach scale, Dr. Kaushal and Dr. Mayer, felt that a “hyporheic box” equal to the “restored” channel length multiplied times the width of the stream plus 5 feet on each sided and a depth of 5 feet below the stream channel would be very conservative and follow similar dimensions to the example in Figure C-1.

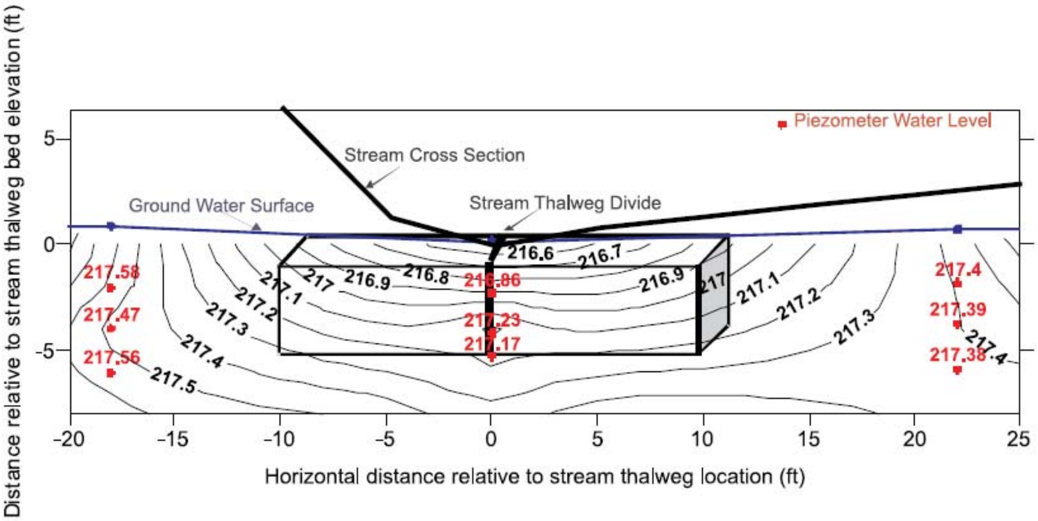
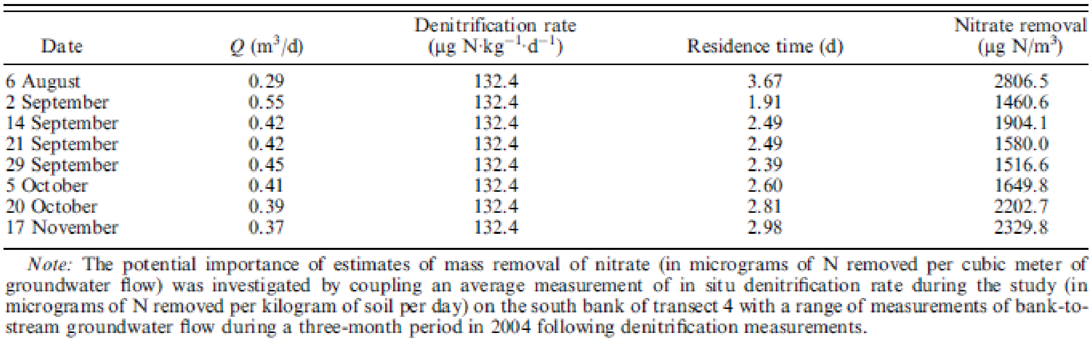


Figure C-1. Example vertical equipotential stream cross section with left bank and right bank compartments on either side of the stream thalweg divide from Striz and Mayer (2008).

Table C-1 Groundwater flow through a 1.5×1.5×1.5 m box adjacent to the restored reach of Minebank Run representing the riparian-zone-stream interface from Kaushal et al (2008)



Date	Q (m^3/d)	Denitrification rate ($\mu g\ N \cdot kg^{-1} \cdot d^{-1}$)	Residence time (d)	Nitrate removal ($\mu g\ N/m^3$)
6 August	0.29	132.4	3.67	2806.5
2 September	0.55	132.4	1.91	1460.6
14 September	0.42	132.4	2.49	1904.1
21 September	0.42	132.4	2.49	1580.0
29 September	0.45	132.4	2.39	1516.6
5 October	0.41	132.4	2.60	1649.8
20 October	0.39	132.4	2.81	2202.7
17 November	0.37	132.4	2.98	2329.8

Note: The potential importance of estimates of mass removal of nitrate (in micrograms of N removed per cubic meter of groundwater flow) was investigated by coupling an average measurement of in situ denitrification rate during the study (in micrograms of N removed per kilogram of soil per day) on the south bank of transect 4 with a range of measurements of bank-to-stream groundwater flow during a three-month period in 2004 following denitrification measurements.

The mean bank height in the “restored connected” reach in Minebank Run was 77 cm compared to 114.7 cm in the “unconnected” reach. Reconnection was not necessarily defined as “floodplain” reconnection but connection between the stream channel and riparian zone to the groundwater interface or hyporheic zone. To define when “reconnection” would occur for qualifying for credit under this protocol, the Panel had proposed using a bank height ratio of 1.0 or less as the definition. The bank height ratio is an indicator of floodplain connectivity and is a common measurement taken by steam restoration professionals using the natural channel design method. It is defined as the lowest bank height of the channel cross section divided by the maximum bank full depth. For projects that qualify for Protocol 3, credit for denitrification during base flow is given for designs where floodplain wetlands have been restored and groundwater-surface water interaction is occurring. Therefore Protocol 2 does not apply.

The Minebank Run study also demonstrated the importance of "carbon" availability in denitrification however the science determining how much is necessary is limited. Until more information becomes available, this protocol recommends that qualifying stream restoration projects include an extensive planting plan along the riparian corridor of the stream reach.

Protocol 3 Method Development and Spreadsheet Documentation

This credit is given when stream channels are reconnected to the floodplain resulting in hydromodification, where the floodplain is able to provide some level of pollution reduction volume to storms equal to or less than the one year storm event.

This method assumes that sediment and nutrient removal occurs only for that volume of annual flow that is captured within the floodplain area. The floodplain area is assumed to be a riparian wetland with a maximum depth of 1.0 feet and a minimum wetland area to watershed area ratio of 1.0% to assure adequate hydraulic retention time. Partial credit is allowed for projects that cannot meet the minimum 1% ratio. For instance if a ratio of 0.75% would receive 75% of the credit that a project that meets the 1% minimum would receive.

The reduction credit for total nitrogen (20%), total phosphorus (30%) and total suspended solids 20% is taken from Jordan (2007) and reflects work that was approved through the Chesapeake Bay Program process. For projects that result in restored or enhanced floodplain wetlands with groundwater/surface water interaction, credit for baseflow nutrient removal is provided here instead of protocol 2.

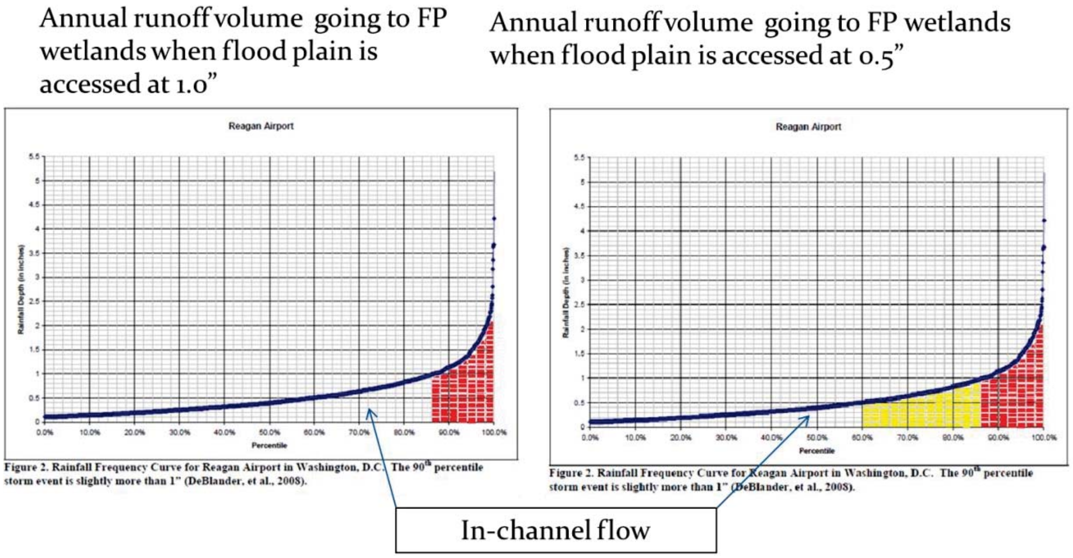
These rates are lower than rates used in earlier versions of this draft that were based on stormwater treatment wetland efficiencies. Several panel members pointed out that riparian wetlands behave differently from stormwater treatment wetlands, which typically have much greater hydraulic detention times that allow for settling of particulates.

In developing this method, the following basic questions were asked:

A. How much runoff enters the floodplain?
B. How much of the floodplain (volume) can be considered wetlands?
C. How much of the runoff entering the floodplain receives effective treatment?
D. What is the nutrient removal efficiency of the floodplain wetlands?
E. What is the loading coming from the watershed?

The steps outlined in more detail below reflect the process for developing the curves used in the spreadsheet.

A. The spreadsheet determines how much of the annual runoff volume enters the floodplain for a range of storm classes. Rainfall records at National Airport were used in developing the graphs. Using a model like HEC-RAS, the designer would determine the flow depth over the floodplain. For instance, the depth might be 2 ft for a given discharge. The discharge is converted to a precipitation depth so that the rainfall frequency distributions at National Airport can be used. Figure C-2 below shows the runoff amounts entering a floodplain at two connection depths; one corresponding to a rainfall depth of 0.5 in. and the other 1.0 in.


Annual runoff volume going to FP wetlands when flood plain is accessed at 1.0”

Annual runoff volume going to FP wetlands when flood plain is accessed at 0.5”

Figure 2. Rainfall Frequency Curve for Reagan Airport in Washington, D.C. The 90th percentile storm event is slightly more than 1" (DeBlander, et al., 2008).

Figure 2. Rainfall Frequency Curve for Reagan Airport in Washington, D.C. The 90th percentile storm event is slightly more than 1" (DeBlander, et al., 2008).

In-channel flow

Figure C-2. Runoff amount entering the floodplain a connection depths corresponding to a rainfall depth of 0.5 in. and 1.0 in. based on National Airport rainfall data.

For instance, if reconnection occurred at 0.5 in. of rainfall (expressed as watershed inches) then only discharges resulting from storms exceeding this amount will enter the floodplain. All discharges (or rainfall depths) above this threshold discharge have the potential for being “treated” in the floodplain wetlands. Discharges below this amount are conveyed by the stream channel. The spreadsheet accounts for the frequency of events of 0.5 in. and greater that occur in a given year.

B. Figure C-3 shows the different floodplain storage volumes expressed in watershed inches (to make them dimensionless) along the x- axis. The average storage floodplain volume should be used for the full range of storms. The designer would typically develop floodplain storage volumes for different depths using site topography.

C. The curves on the graph in Figure C-3 represent the rainfall depths (rainfall is used instead of runoff to allow the use of the rainfall frequency distributions). In the example above, if floodplain reconnection occurs at a discharge equivalent to a rainfall depth of 0.5 in. (3rd curve) and there is floodplain storage of 0.25 in. (x-axis), then approximately 16% of the total annual runoff volume enters the floodplain (y-axis). The curves are developed for the discrete distribution of rainfall depths above those associated with the floodplain connection threshold (0.5, 0.75, 1.0…).

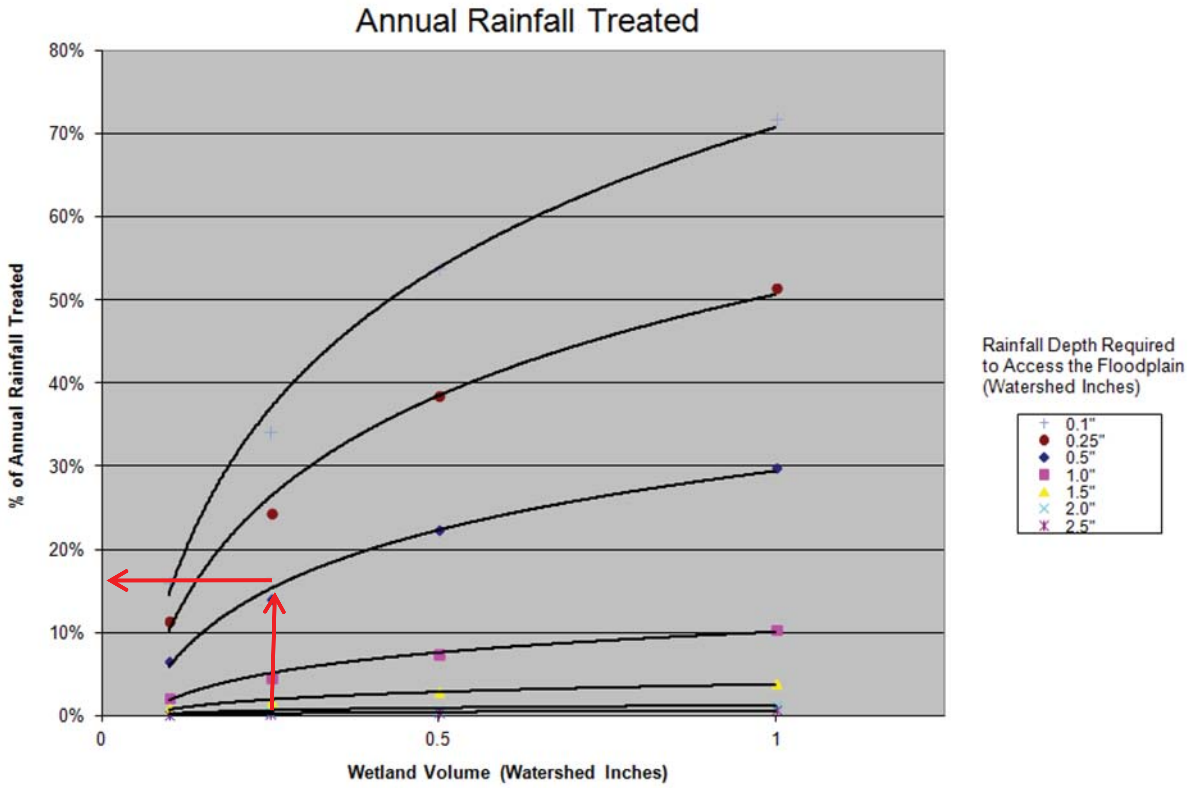


Figure C-3. Annual runoff volume treated as a function of floodplain storage volume for several rainfall thresholds that allow runoff to access the floodplain.

D. Once the fraction of annual runoff treated is determined, the wetland efficiencies from Jordan (2007) are used to convert these values to the percent TN, TP and TSS reduction. These graphs are shown on the Nitrogen, Phosphorus, and Sediment tabs (Figure C-4 for TN) of the spreadsheet. The y-axis is the percent along the y-axis from Figure C-3 multiplied by the reduction efficiencies from Jordan (2007). In the example above, if 16% of the annual rainfall runoff volume is being treated by the floodplain wetland, and the wetland efficiency for TN is 20% then the annual removal rate is determined by multiplying 16% by 20% or 3.2%.

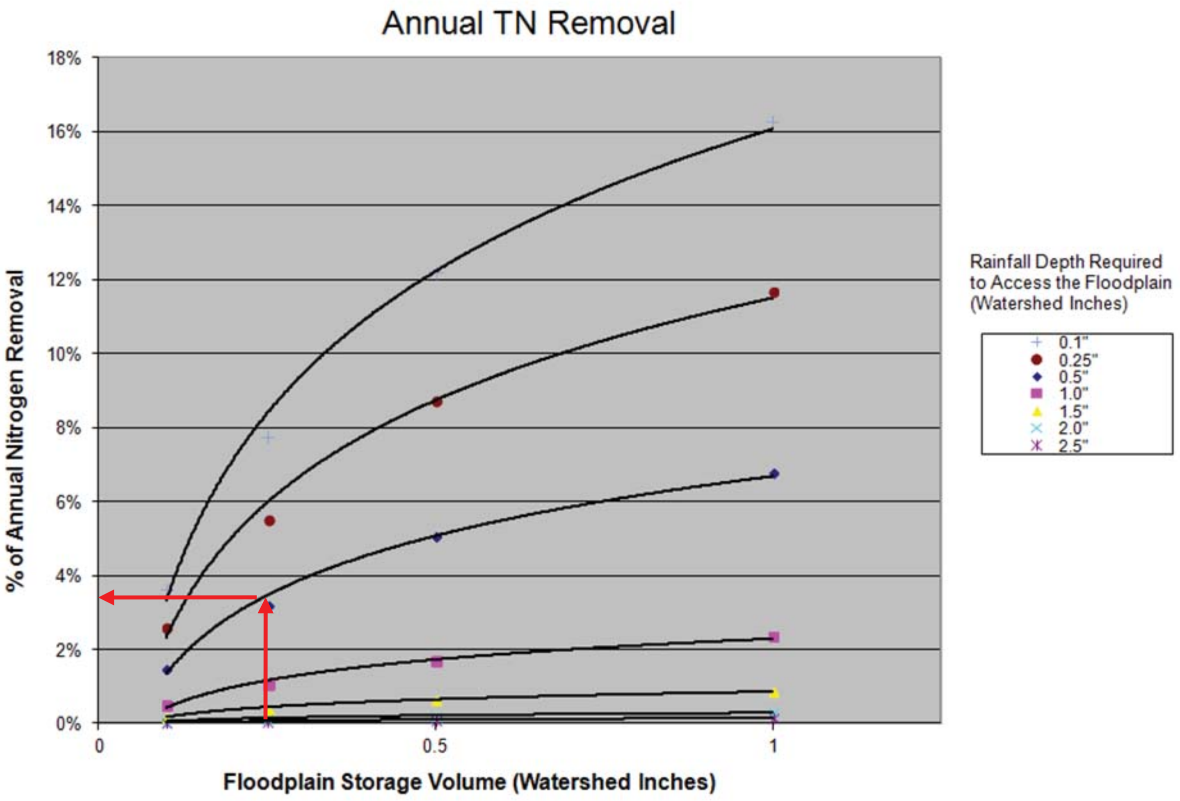


Figure C-4. Annual TN removal as a function of floodplain storage volume for several rainfall thresholds that allow runoff to access the floodplain.

E. The next step is to multiply the pervious and impervious watershed loading from the CBWM (Table C-1) by the reduction efficiencies from Figure C-4. 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. 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.

F. The final step is to make any adjustments to account for if the wetland surface area to drainage area ratio is less than 1.0%. As described earlier, if the ratio was 0.75%, the credit would be 75% of the annual load reduction estimated in F.

Table C-2. Edge of Stream Unit Loading Rates for Bay States Using CBWM v. 5.3.2

BAY STATE	Total Nitrogen	Total Phosphorus	Suspended Sediment

	Pounds/acre/year				Pounds/acre/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

A detailed description of the spreadsheet analysis is described below.

1. Ordered the daily rainfall events for 30 years of data from least to greatest, and removed all events of 0.1” or less.
2. Summed the total rainfall volume.
3. Set floodplain depths (in watershed inches) of 0.5” – 2.5”
4. Set treatment volumes (in watershed inches) of 0.25” – 2.25”
5. Determine the value for each combination of floodplain depth and watershed inches by:
    a. Adding up all of the rainfall amounts between the floodplain depth and the floodplain depth + the treatment volume.
    b. Subtracting the floodplain depth from each event in the above sum.
    c. Adding the treatment depth for all rainfall amounts above the floodplain depth + the treatment volume.
    d. Dividing the total of a-c above by the total rainfall volume.
6. This value represents the percentage of the total rainfall treated by a given combination of floodplain depth and treatment volume.

The 88% in the stream restoration spreadsheet is based upon the assumption that the removal efficiency percentages we have for nitrogen and phosphorus are tied to the 1” storm. The 1” storm represents 88% of the rainfall volume in a given year (when all storms smaller than 1” and 1” per storm for all larger storms are summed). The removal efficiency percentages are therefore tied to the “benchmark” of 88%. To calculate the removal efficiency percentage for a given practice, the percent of annual rainfall volume captured is compared to 88%, and the resulting ratio is multiplied by the removal efficiency for the 1” storm. We did this for the previous version that used the wetland efficiencies based on stormwater wetlands. This is the approach that the Retrofit Panel used to adjust the retrofit efficiencies to account for removals at greater than the water quality treatment volume (1.0 inch).

An example:

A floodplain does not begin to fill until 0.5” of rainfall is reached, and has a 0.25” treatment volume. Given 374 storms between 0.5 and 0.75, 471 storms between 0.76 and 5.19 and 1125 storms in total:

a. Add up all of the rainfall amounts between 0.5” and 0.75” = 228.41”
b. Subtract 0.5” x 374 events = 187”; 228.41” – 187” = 41.41” *- 0.5 inch has to be subtracted because this amount never gets into the floodplain. The storage volume is only treating a fraction of these storms*
c. Add 0.25” for all rainfall amounts above 0.75” = 0.25” x 471 = 117.75”: 41.41” + 117.75” = 159.16” - *treating the first .25 inches of storms greater than the bankfull*
d. Divide 159.16 by 1125.45” = 14.1% of total volume of runoff.

Alternative Method for Protocol 3 from Panel Member, Dan Medina

When detailed hydrologic and hydraulic data are available for the restored reach, the Protocol can be applied in a straightforward manner by following the steps below:

i. Calculate the volume of runoff that accesses the floodplain on an average annual basis
ii. Estimate the loads of nitrogen and phosphorus in that volume by multiplying the total pollutant load times the ratio of the floodplain runoff volume to the total runoff volume.
iii. Compute the nitrogen removal as 20% of the nitrogen load and the phosphorus removal as 30% of the phosphorus load.

Most of the complexity is in the first step but it is a straightforward calculationbecause hydrologic and hydraulic models are usually available as design tools. Below are two suggested procedures to accomplish this step, one for discrete storm modeling and another for continuous simulation.

Discrete storm modeling

1. Select a cross section representative of the restored reach
2. Using a hydraulic model such as HEC-RAS, compute the distribution of flows between the main channel and the “overbanks.” This is a standard capability of all one-dimensional hydraulic models and results in plots similar to Figure C-5. The main channel is defined by suitable geomorphic indicators, for instance bankfull elevation, or geometric features when bankfull is not appropriate.

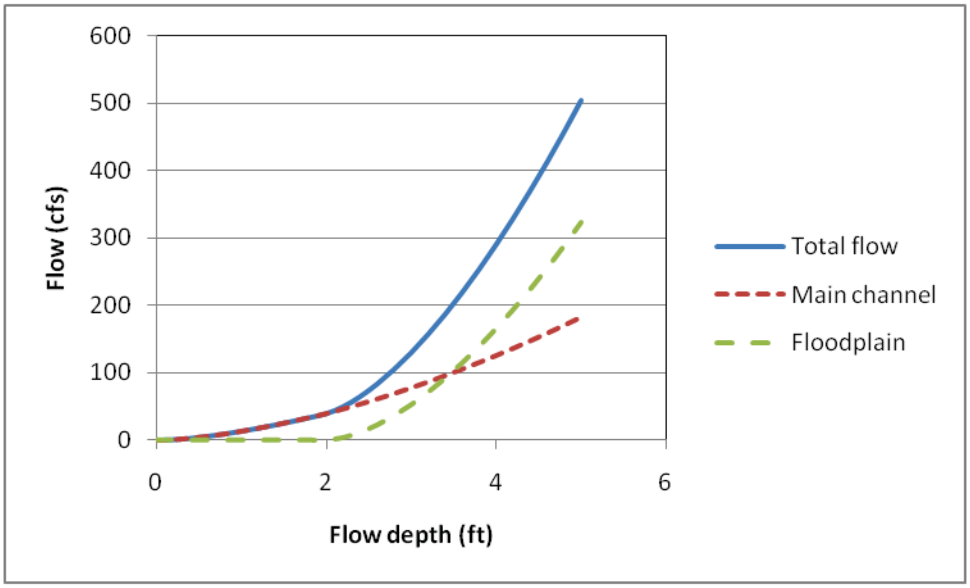


Figure C-5. Example flow distribution resulting from hydraulic modeling. This hypothetical example shows that the floodplain is accessed at a depth of two feet.

For application of Protocol 3, the tool needed is a plot of the floodplain flow as a function of the total flow as shown in Figure C-6. This relationship is a direct derivation from Figure C-5. For a given flow depth, the floodplain flow and total flow are plotted in Figure C-6.

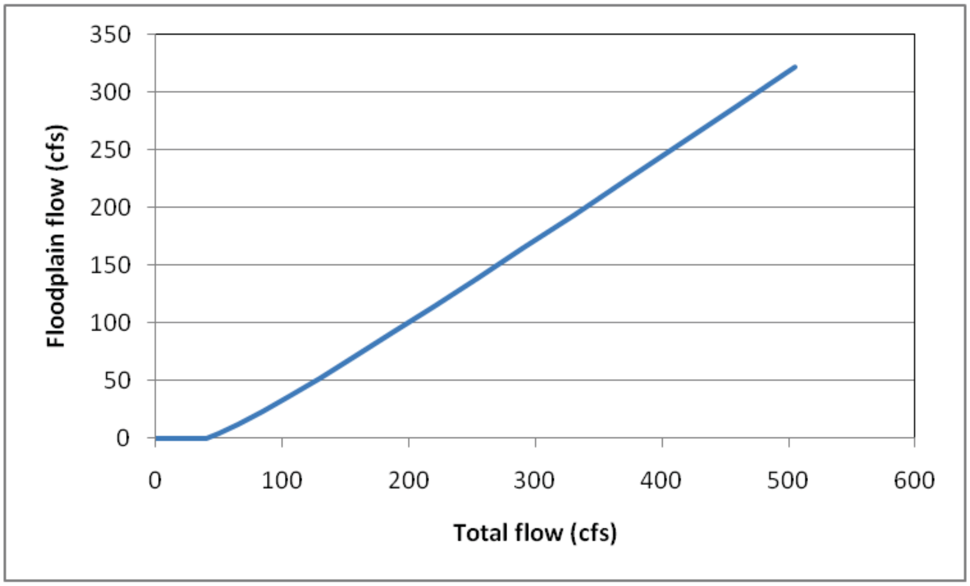


Figure C-6. Flow in the floodplain as a function of the total flow.

This relationship specifies how much of the discharge flows over the floodplain. For example, if the total flow is 200 cfs, about 100 cfs flow over the floodplain.

3. Run the hydrologic model for events of various return periods starting at the one-year flood.
4. Select the hydrograph corresponding to a given return period

5. Calculate the total runoff volume by computing the area under the hydrograph
6. Apply the relation in Figure C-6 to each ordinate of the total hydrograph and thus obtain the flow over the floodplains. If the flow depth over the floodplain is 1 ft or greater, then the flow for which credit is available is capped at the value corresponding to a depth of 1 ft over the floodplain. Figure C-7 shows a typical result.

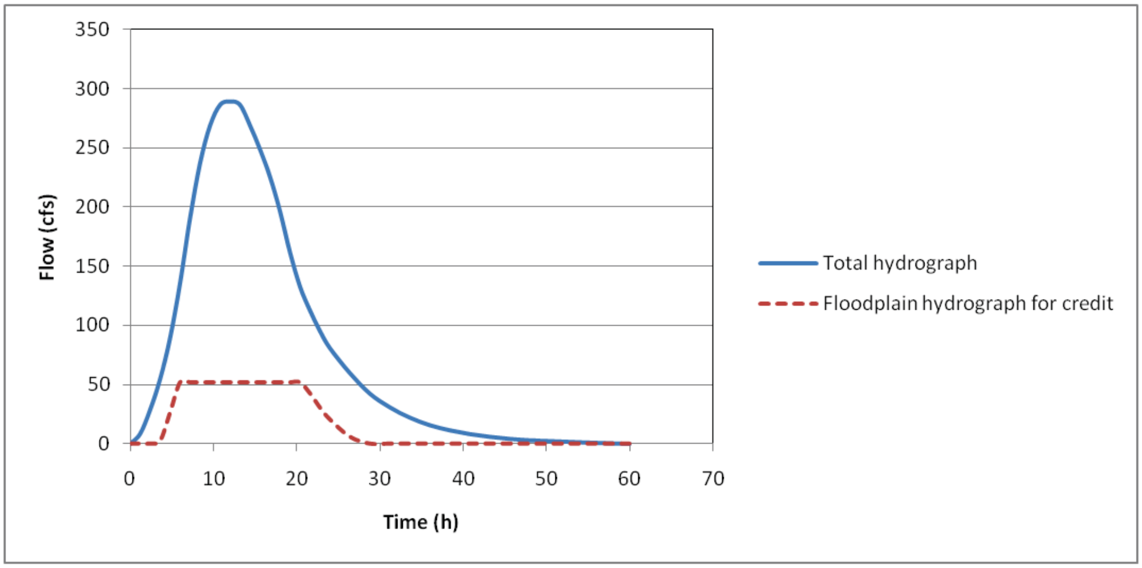


Figure C-7. Separation of the floodplain hydrograph. The horizontal portions at the beginning and end of the floodplain hydrograph indicate when the floodplain is not accessed. The horizontal portion in the middle indicates that the depth over the floodplain exceeds 1 ft and the maximum flow is set at the value corresponding to that depth.

7. Calculate the volume of runoff that flows through the floodplain by computing the area under the overbank hydrograph. For the example in Figure C-7, the total volume is about 383 ac-ft, whereas the floodplain volume is about 82 ac-ft.
8. Apply steps 4 through 7 for all other return periods
9. Construct a curve of the total runoff volumes versus their probabilities of exceedence, which are equal to the reciprocals of the return periods (e.g., the 5-year flood has a 1/5= 0.2 probability of being equaled or exceeded in any given year). The area under this curve is the average annual runoff volume
10. Construct another similar curve with the floodplain runoff volumes. The area under this curve is the average annual runoff volume that flows over the floodplains. The two curves are shown in Figure C-8.

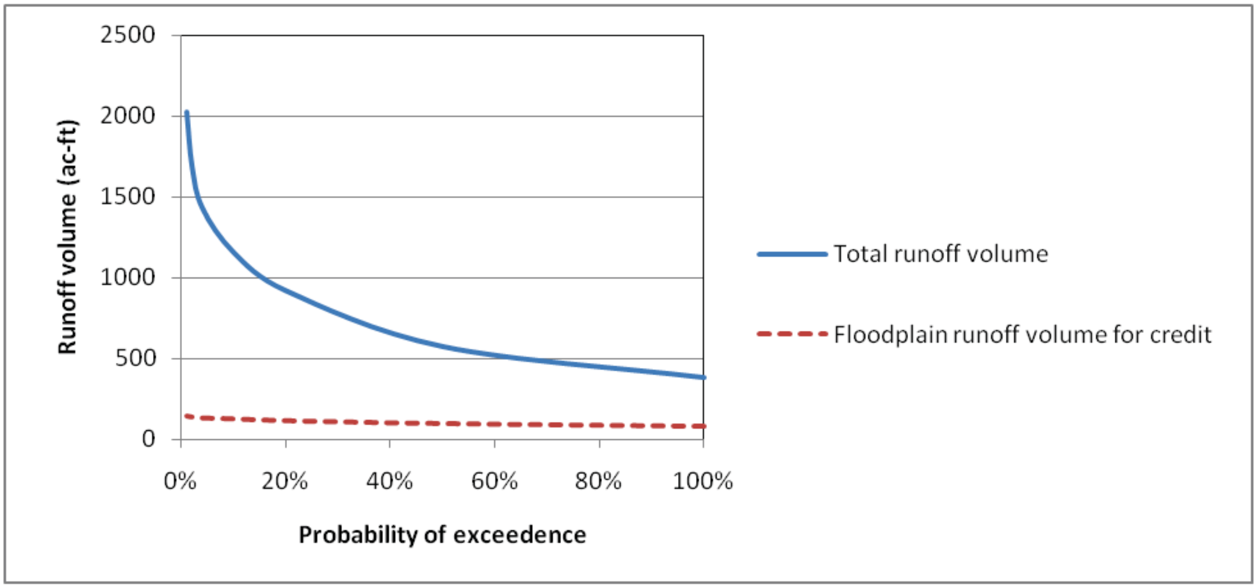


Figure C-8. Probability distribution of the total runoff volume and that flowing over the floodplain.

In this example, the average annual total runoff volume (the area under the solid curve) is 695 ac-ft, whereas the average annual runoff volume flowing over the floodplain is about 103 ac-ft.

11. The ratio of the floodplain runoff volume to the total volume is the fraction of the total runoff that comes in contact with the floodplain. For the example in Figure C-8, this ratio is 15%, which is the factor that will multiply the total pollutant loads coming from the entire watershed.

The loads from the watershed are determined from the CBWM. These loads must be modified to include the effect of upstream BMPs, which has two components: the load reduced by the treatment that takes place in the BMP, and the untreated load from the portions of large storms that bypass the BMP. Once the BMP effects are incorporated, the resulting loads are those that will come into contact with the floodplain. These loads have to be multiplied by the reduction efficiencies from Jordan (2007) for TN, TP and TSS.

Continuous Simulation

The discrete-storm approach is probably the most accessible to designers who are used to running hydrologic models for individual storms. However, increasingly more often, designers are beginning to apply continuous simulation to evaluate the performance of a design in response to a long-term period of rainfall, for example an average year, a wet year, of the full available rainfall record. Entering a continuous rainfall input dataset into the hydrologic model yields a continuous streamflow output dataset. In this case, the procedure outlined in Steps 1 and 2 is still carried out to derive the hydrograph separation relationship. This relationship is then applied to the continuous streamflow output from the hydrologic model in a manner analogous to Step 4. The result will be the continuous hydrograph over the floodplain.

The area under the hydrograph for the total flow is the total runoff volume in the period analyzed. Similarly, the area under the hydrograph for the floodplain is the runoff volume that accessed the floodplain during that period. The ratio of these two volumes is calculated and used as in Step 11.

References

Kaushal, S., Groffman, P., Mayer, P., Striz, E., and A. Gold. 2008. Effects of stream restoration in an urbanizing watershed. *Ecological Applications* 18(3): 789-804.

Striz, E., and P. Mayer. 2008. Assessment of near-stream ground water-surface water interaction (GSI) of a degraded stream before restoration. U.S. Environmental Protection Agency Office of Research and Development. EPA 600/R-07/058.

Appendix D Summary of Expert Panel Meeting Minutes

December 5, 2011
Meeting Minutes
Urban Stream Restoration Expert Panel

EXPERT BMP REVIEW PANEL Stream Restoration		
Panelist	**Affiliation**	**Present ?**
Deb Cappuccitti	MDE	Yes
Michael Bumbaco	Virginia Beach	Yes
Matt Myers	Fairfax County	Yes
Dan Medina	Atkins	Yes
Joe Berg	Biohabitats	Yes
Lisa Fraley McNeal	CWP	Yes
Steve Stewart	Baltimore County	No, Briefed on 11/23.
Dave Goerman	PA DEP	Yes
Natalie Hartman	WV DEP	Yes
Jeff Sweeney	EPA CBP	Yes
Josh Burch	DDOE	Yes
Robert Walter	Franklin and Marshall	Yes
Tom Schueler	CSN (FACILITATOR)	Yes

Summary of Action Items

The Panel directed Tom to (a) provide the sediment load/impervious cover model inherent in the Watershed Model and (b) Get Gary Shenk (EPA CBPO) to provide more detail on sediment and nutrient dynamics at its next meeting

Bob Walter agreed to provide Sujay with papers on sediment and phosphorus dynamics to add to the database. Tom requested that all panelists review the spreadsheet to determine if any important black and grey literature needs to be added to the spreadsheet, and if so, to provide the citation or pdf to Tom no later than December 20, 2011. Tom will forward these studies to Sujay and the panel as a whole. Sujay agreed to provide the entire non-Bay spreadsheet, and the panel agreed that each member would take on reviewing 10+ papers on the non-Bay list prior to our next meeting. Tom will work with the panel on doling out papers to the panel as a whole

The panel agreed to meet for a face to face meeting in Annapolis, tentatively scheduled for January 25th. The ¾ day meeting would have telephone connections for folks who cannot travel. The meeting would devote several hours on research presentations by Solange, McNeal (or Bill Stack), Kaushal, Walter, Stewart and others. Panelists who want to present their own data or nominate a colleague are asked to let Tom know by December 20.

1. **Call to Order and Panelist Introductions.** Tom Schueler called the meeting to order at 11 AM. Each of the panelists introduced themselves and explained their background in retrofit analysis and implementation in their jurisdiction. Tom briefly outlined the BMP review panel protocol by which the panel would conduct its business, and asked the panel whether they understood their role and had any questions about the protocol. Tom then outlined his role was to facilitate the panel, organize the research and methods, and document its progress, but not be involved in the decision-making process.

The Panel then discussed and approved the draft charge for the stream restoration panel. **The Panel** agreed that Regenerative Conveyance Systems (RCS) should be within the purview of the panels deliberation, with a majority of the panel concurring and no dissent. **Dave G** inquired whether it was within the charge to look at effect of stream restoration in less developed areas, and Tom indicated that the panel could make such recommendations if it felt they were justified. **Dan** inquired as to the nature of the panel's final product. Tom indicated that the under the BMP review protocol, it would be a technical memorandum that describes the definition, rates, qualifying conditions and reporting mechanisms with an appendix that summarizes the scientific data evaluated.

1. Background on the Original CBP Approved Nutrient Removal Rates

Tom presented some background on how the original stream restoration rates were derived eight years ago from Steve Stewart's single study. Tom noted that Steve's subsequent research on Spring Branch revealed higher rates, and that other studies in the Baltimore metro area reached similar conclusions.The key point being that the existing CBP-approved rate for urban stream restoration was no longer adequate and deserves updating. Tom also noted the many local governments in the Bay watershed were keenly interested in the panels' recommendations.

2. How Urban Sediment Delivery is Currently Modeled in the Chesapeake Bay Model

Jeff Sweeney (EPA CBPO) briefly described how urban stream sediment and nutrient dynamics are currently simulated in the current version of the Chesapeake Bay Watershed Model. **Joe** and **Bob** both noted the importance of stream channel erosion relative to upland sources of sediment and nutrient loads from urban lands. **Mark** noted that sediment loadings were scale dependent, with higher loadings discovered for zero and first order streams. The Panel directed Tom to (a) provide the sediment load/impervious cover model inherent in the Watershed Model and (b) Get Gary Shenk (EPA CBPO) to provide more detail on sediment and nutrient dynamics at its next meeting

3. University of Maryland Research Synthesis Project

Dr Kaushal concisely described their ongoing work to develop a research synthesis on nutrient and sediment dynamics associated with urban stream restoration projects. He provided an Excel spreadsheet (Attachment A) which contained a meta-data analysis on about 30 recent urban stream restoration research projects. **Dave** noted that the spreadsheet was dominated by nitrogen research, and **Bob Walter** agreed to provide **Sujay** with papers on sediment and phosphorus dynamics to add to the database. Tom requested that all panelists review the spreadsheet to determine if any important black and grey literature needs to be added to the spreadsheet, and if so, to provide the citation or pdf to Tom no later than December 20, 2011. Several panelists indicated they would like to see the non-Chesapeake Bay citations (which may number around 200 or so). **Sujay** agreed to provide the entire non-Bay spreadsheet, and the panel agreed that each member would take on reviewing 10+ papers on the non-Bay list prior to our next meeting. Tom will work with the panel on doling out papers to the panel as a whole.

4. Scoping of Technical Issues to Address

Several panel members indicated the importance of defining uncertainty in relation to the panel recommendation, and the need for practical definitions of various types of urban stream restoration practices, that reflect stream order, landscape position and restoration objectives. The panel agreed to take on these issues at its next meeting

January 25 2012
Urban Stream Restoration Expert Panel
RAPID STREAM RESTORATION DATA REVIEW WORKSHOP

Objective: Provide a forum for the panel to rapidly review urban stream restoration research in the Bay watershed as it relates to nutrient and sediment delivery

10:30 to 11:30	**Sediment/Nutrient Delivery in the Watershed Model**	G. Shenk, EPA
11:30 to 11:40:	**The Rapid Research Review Process**	Schueler/CSN
11:40 to 12:00:	**Spring Branch Data, Baltimore County**	S. Stewart/DEPRM
12:00 to 12:20:	**Baltimore City Stream Data**	B. Stack/ CWP
1:00 to 1:20	**Nitrogen Dynamics**	S. Kaushal/UMD
1:20 to 1:50	**Anne Arundel County Projects**	S. Filoso
1:50 to 2:20	**PA stream research**	Walter
2:20 to 2:40	**Virginia Sediment Work**	Medina/Atkins

NOTE: RESEARCH REVIEW POWERPOINT PRESENTATIONS AVAILABLE FROM CSN

Areas of Possible Concurrence

Stream restoration and the Bay Model

- The scale at which the CBWM simulates sediment dynamics are river segments that average about 60 to 100 square miles in size, and therefore do not explicitly simulate the contribution of channel erosion to enhanced sediment/nutrient loadings for most 1st, 2nd and 3rd order streams.

- The CBWM indirectly gets to this by assuming edge of stream sediment loads are a function of the impervious cover in the contributing watershed, using empirical relationships from Cronin and Langland (2004).

- The CBWM simulates only partial sediment delivery from the edge of stream to the main stem of the Bay (15 to 30%). This means there will be a strong scale effect in any estimate of urban stream restoration removal rates (i.e., a higher rate that occurs at the local project reach versus a lower rate for the sediment that actually reaches the Bay.

- Stream restoration as a BMP can be modeled in many different ways within the context of the current version of CBWM, a unit load reduction (BMP factor), a variable removal rate for edge of stream loads or a change in delivery factor. The rate can also be variable with respect to watershed space and flow (i.e., triggered over and above a flow threshold, differential rate between physiographic regions etc). The panel can utilize this versatility to best represent the suite of stream restoration practice(s).

- The CBWM does not currently account for differences in sediment grain size, and this could be an important refinement for the 2017 model revisions. The panel indicated a strong interest in working with the CBWM modeling team on recommendations for improving the simulation of urban stream and sediment, with an understanding that the model cannot necessarily incorporate a range of values

The Current EPA-Approved rate for urban stream restoration

- Several studies seemed to indicate that current estimate for stream restoration is extremely conservative (Stack/Stewart), and may need to be increased, at least for some classes of stream retrofit practices.

The prime objective of stream restoration is not pollutant reduction

- Stream restoration is a carefully designed intervention to improve the hydrologic, geomorphic, water quality and biological condition of degraded urban streams, and cannot and should 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, or require protection of critical public infrastructure.

- 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 (e.g., geomorphic evidence of active stream degradation, an IBI of fair or worse, hydrologic evidence of floodplain disconnection, etc.)

- In general, the effect of stream restoration on stream quality is amplified when BMPs are implemented upstream in the catchment to reduce runoff and stormwater pollutants and improve low flow hydrology. Projects that combine restoration with upland retrofits may merit an additional nutrient and/or sediment reduction.

Defining stream restoration practices

- The panel concluded that no single, universal removal rate could be applied to the wide range of stream restoration techniques that are being applied across the Bay, although it may be possible to develop rates or methods for certain categories of stream restoration.

- Several different classifications were proposed, including projects designed to provide:
    - natural channel design
    - floodplain reconnection
    - stream wetland complexes,
    - removal of legacy sediments (i.e., Big Spring)
    - woody debris
    - regenerative conveyance systems
    - stream bank stabilization

- The panel is encouraged to think through different possible classification schemes prior to the next meeting, depending on whether they are splitters or lumpers. Recommendations of the panel should have both a local and Bay-wide consideration.

- In doing so, they may need to identify a unique project design approach to define each stream restoration class (e.g., Rosgen analysis for Natural Channel Design) and determine if there are sufficient performance studies available for the class to estimate unique rates.

- Within each class, it may be important to define secondary characteristics that help define rates, such as landscape position, stream order and reach length.

A" Simple" Conceptual Model for an Improved Rate

The rate may be calculated as the combined effect of "prevented" channel enlargement and increased in-stream nutrient processing associated with the stream restoration project.

The Prevented Sediment Approach

- The primary effect of stream restoration is to prevent channel enlargement within the project reach, and retain bank and floodplain sediments (and attached nutrients) that would otherwise be lost from the reach.

- The mass of "prevented" sediment and nutrients by a stream restoration project depends on the monitoring design approach. Studies that rely on bank pins and soil nutrient content tend to provide robust estimates, over the long term for streams that are actively incising or enlarging. The effect can be masked in studies that measure changes in nutrient sediment concentration above/below the project reach (or in comparison to a reference reach) unless they capture enough of the storms that cause bank erosion.

- Several panelists provided predictive data on the effect of bank retreat and the nutrient content of bank and floodplain soils. The panel indicated a strong interest in comparing this and other data to see if it is possible to develop regionally specific rates.

- Bill Stack proposed a method using project specific design data to develop rates, based on bank height, bank erodibility hazard, and near bank stress. These parameters are currently measured/estimated in virtually every project that would qualify as stream restoration, and can be input into predictive equations by developed by Dave Rosgen, the U.S. Fish and Wildlife Service and others to derive expected bank retreat. Bill provided several other equations to convert into management units such as tons of sediments, and suggested that the Spring Branch efficiency method might be applied to the erosion rates. Several panel members were interested in looking at more detail for this option in further detail at the next meeting.

The In-stream Processing Approach:

- A great deal of recent science has looked at the impact of stream restoration on nutrient processing, with a strong emphasis on nitrogen. Based on a handful of studies in the piedmont and coastal plain, uptake and de-nitrification can reduce daily nitrate-N loads on the order of 0 to 40%. (Kaushal/Filoso). Other changes to other forms of nitrogen may occur, but probably do not change the mass exported through the reach. Several project factors may be associated with greater nitrogen reduction:
    - *Slow down stream flow (increased low flow retention time)*

  - *Add dissolved organic carbon(riparian reforestation and/or instream woody debris)*
  - *Reconnect stream to floodplain and/or wetlands*
  - *Upstream or lateral treatment by stormwater BMPs*

- It may be possible to identify specific design factors, individual practices, and riparian management factors associated with projects that might be expected to generally promote (or diminish) increased in-stream nutrient processing.

- There appears to be a connection between the length of a stream restoration project and the cumulative length of the upstream drainage network and/or the contributing drainage area 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.

Impact of stream restoration is influenced by the dominant flow regime.

- Although it can be masked by the study design, there are clear differences in sediment removal rates during storm flow and base flow conditions, and the relative proportion of both flows determines annual reductions.

- During base flow conditions, the nutrient reductions appear related to the retention time within the project reach.

- During storm flow conditions, the impact depends on the size of the storm and/or discharge event. Just a few large storms each year account for most of the reductions in sediment (and sometimes for nutrients).

- The value of groundwater is mostly unknown and potentially underestimated. Hydro-modification is an important aspect of stream restoration.

Legacy sediments.

- Most stream restoration projects ultimately need to be interpreted in the context of the extent and depth of legacy sediments that exist within the study reach.

- The removal of legacy sediments and the subsequent recreation of wet meadow floodplain system shows significant promise to produce significant sediment and nutrient reduction benefits (although monitoring has just commenced on the first major demonstration project in Big Spring, and space constraints in some urban stream corridors may preclude full implementation this approach).

March 5, 2012
Meeting Minutes
Urban Stream Restoration Expert Panel

EXPERT BMP REVIEW PANEL Stream Restoration		
Panelist	**Affiliation**	**Present ?**
Deb Cappuccitti	MDE	Yes
Michael Bumbaco	Virginia Beach	Yes
Matt Myers	Fairfax County	Yes
Dan Medina	Atkins	Yes
Joe Berg	Biohabitats	No
Bill Stack	CWP	Yes
Lisa Fraley McNeal	CWP	Yes
Steve Stewart	Baltimore County	Yes
Dave Goerman	PA DEP	No
Natalie Hartman	WV DEP	Yes
Jeff Sweeney	EPA CBP	No
Josh Burch	DDOE	Yes
Robert Walter	Franklin and Marshall	Yes
Sujay Kaushal	University of Maryland	Yes
Solange Filoso	University of Maryland	Yes
Julie Winters	EPA CBP	Yes
Gary Shenk	EPA CBP	No
Bettina Sullivan	VA DEQ	No
Norm Goulet	NVRC	Yes
Russ Dudley	Tetra Tech (FACILITATOR)	Yes
Tom Schueler	CSN (FACILITATOR)	Yes

Summary of Action Items

The Panel met via conference call for a 2-hour discussion that covered possible areas of concurrence, summaries of the compiled research, and approaches to determining nutrient and sediment reduction rates.

The panel initially reviewed the Possible Areas of Concurrence document. Tom Schueler will be revising the document based on comments made by the panelists.

Research review by the panelists resulted in some action items. Lisa Fraley-McNeal will look into monitoring requirements and distribute to the rest of the panel for discussion as an agenda item at a future meeting. Bill Stack will work with Steve Stewart and Solange Filoso dig deeper into any possible gap between erosion rates and load reductions observed in the field.

Bill Stack presented on the BANCS method and agreed to write it up and distribute to the rest of the panel.

The next meeting (via conference call) of the Urban Stream Restoration panel is tentatively scheduled for April 10, 2012.

1. **Review of Possible Areas of Concurrence.** The meeting began by reviewing the Possible Areas of Concurrence document developed from the previous meeting. Specific

language in the document will be modified based on panelist's comments. Below are comments raised for specific sections of the document.

Stream Restoration and the Bay Model
The goal is to reduce sediment but sediment from upstream sources is still needed to replenish downstream tidal wetlands.

The Current EPA-Approved rate for urban stream restoration
It is unclear whether we have enough information to claim that the current estimate for stream restoration is extremely conservative, although studies have shown that the sediment export is higher. Consideration should be given to the effect of stream restoration over time. Stream restoration should be separated from upland restoration practices.

The In-Stream Processing Approach
A great deal of discussion was had regarding this approach, including a discussion on dealing with phosphorus versus nitrogen. Hydromodification should not be considered an important aspect of stream restoration.

A "Simple" Conceptual Model for an Improved Rate
In-stream nutrient processing should be expanded to include the riparian area, groundwater exchange, and other factors that influence the nutrient cycle. The mass of "prevented" sediment is dependent on the location within the watershed.

2. **Other Panel Presentations on their Research Reviews.** Four panelists prepared slides discussing their review of urban stream restoration research papers. These are summarized below.

Josh Burch
Josh noticed a range of restoration effectiveness and suggested there should be a tiered approach to stream restoration values. Perhaps restorations could receive a low/medium/high ranking depending on the effectiveness of the technique for nutrient and sediment removal. Steve Stewart suggested we should work with Chesapeake Bay modelers to incorporate temporal changes to the restoration projects.

Lisa Fraley-McNeal
During Lisa's review she discovered that there are no real seasonal differences and that a common theme to pollutant load reduction was slowing down the flow. She highlighted the importance of effective monitoring and Bob Walters asked what we can recommend to practitioners to get the monitoring data we need. Lisa is going to check on monitoring recommendations and report back.

Deb Cappuccitti
Deb questioned whether the studies really represented the condition of all stream restorations and pointed out one project that seemed to be deteriorating. She noted a potential gap between measured load reductions and the load reductions observed in the field. Bill Stack is going to work with Steve and Solange to delve deeper into this.

Solange Filoso
Solange determined that estimates for sediment load reductions shouldn't be the same for all stream orders. She also summarized that nitrogen concentration and riparian buffer connection is important to nutrient reductions. She commented that restoration effects can

be negative and that the age of the restoration should be considered, siting some restoration projects in NC as an example.

3. **Concepts for Classifying Stream Restoration Projects.** This discussion centered around the question, “Are project factors more important than restoration classes?” Dan Medina suggested that the focus should be on the specific project and should consider the condition of the stream. Bob Walters noted that it’s important to diagnose the problem correctly before restoration to determine the success or failure of the project. Bill Stack suggested that monitoring is required to ensure restoration is functioning over time.

   Steve Stewart noted that research studies are largely based on design classifications and that most studies do not partition out individual functionality, making the assessment of project factors difficult. There was general discussion on the use of design technique terms such as Regenerative Stormwater Conveyance and Natural Channel Design and whether those terms are proprietary and should be avoided.

4. **The Prevented Sediment Approach.** Bill Stack presented on the BANCS approach using methods developed by Dave Rosgen. He mentioned using data from Steve Stewart to determine an actual reduction rate. Bob Walter commented that there are more factors that can create bank erosion than just shear stress (i.e. freeze/thaw). Bill will write up the method and share with the panel. The goal is to see if an approach like this can be developed that would attempt to account for location differences within the watershed. It is also important to see how this compares to monitored data in order to improve the degree of certainty.

April 24th, 2012
Meeting Minutes
Urban Stream Restoration Expert Panel

EXPERT BMP REVIEW PANEL Stream Restoration		
Panelist	***Affiliation***	***Present ?***
Deb Cappuccitti	MDE	Yes
Michael Bumbaco	Virginia Beach	No
Matt Meyers	Fairfax County	Yes
Dan Medina	Atkins	No
Joe Berg	Biohabitats	Yes
Bill Stack	CWP	Yes
Lisa Fraley McNeal	CWP	Yes
Steve Stewart	Baltimore County	Yes
Dave Goerman	PA DEP	Yes
Natalie Hartman	WV DEP	No
Jeff Sweeney	EPA CBP	Yes
Josh Burch	DDOE	Yes
Robert Walter	Franklin and Marshall	No
Sujay Kaushal	University of Maryland	Yes
Solange Filoso	University of Maryland	**No**
Julie Winters	EPA CBP	Yes
Gary Shenk	EPA CBP	N0
Bettina Sullivan	VA DEQ	Yes
Norm Goulet	NVRC	Yes
Tom Schueler, Cecilia Lane	CSN (facilitator)	Yes
Molly Harrington	CBPO	Yes
Non - Panelists: Russ Dudley - Tetra Tech,		

ACTION ITEMS

ALL Members to provide constructive comments in the next 2 weeks to create an improved draft of the framework document reviewed during the meeting.
ALL to work on Section 7 Future Research Needs
ALL to read through Lisa Fraley-McNeal's monitoring document and comment
Joe Berg to write up section describing RCS and the dry channel and wet channel options.
Joe Berg to write "Prevented channel erosion component (stormflow)" (Section 3, Protocol #1)
Josh Burch to write-up applicability to rural projects (Section 4)
Deb Cappuccitti to write-up "Dry Channel RCS effect" based on MDE guidance document (Section 3, Protocol #4)
Russ Dudley to write introduction to Section 3 on the Review of Available Science and can help with associated bullets.
Solange Filoso and **Sujay Kaushal** to write-up "Instream nutrient processing (denitrification) during baseflow" (Section 3, Protocol #2)
Bill Stack to consider Deb Cappuccitti's suggestion regarding estimating prevented sediment loss/ Protocol 1 and take the lead on writing up Accountability (Section 6)

Steve Stewart to write summary of uncertainties (Section 3)
Tom Schueler to work with Norm Goulet to check with Gary Shenk on how BMP degradation curves apply and draft "Definitions and Qualifying Conditions (Section 4)

MEETING MINUTES

Introduction/Announcements: Tom Schueler

- Objective of meeting to move from background review to recommendation determination.
- Seeking comments to the draft as a whole and pragmatic answers to questions/concerns raised

Review "Proposed Protocols for Defining Pollutant Reductions Achieved by Individual Stream Restoration Projects": The Panel spent time going through the draft document in the following structured manner:

- Overall reactions to document:
    - Josh Burch: Concern that protocol will add significantly to workload of stream restoration.
    - Deb Cappuccitti: Concerned that in the guidance for stream restoration credits, the process shows that local governments want specific numbers to plan for (eg budget figures prior to analysis).
    - Joe Berg: Protocol document shows great effort. Believes that Protocol 2, Option 2 has limited feasibility.
    - Matt Meyers: Intermediary between applied rate and monitoring data
        - Qualifying conditions to allow streams for mitigation to receive credit.
- Discussion of Protocol 1, Recommended Crediting Procedure for Prevented Sediment Loss during Storm Flow:
    - Method of converting bank erosion to pollutant loading: disadvantage of method is that it only accounts for nutrients associated with sediment.
    - Frost heaving may be contribute
    - Only takes into account sediment supplied, not delivered
    - A pictorial guide to support BEHI measurement procedures would be helpful
    - Spring Branch Study method: noted as the only study completed therefore justification for estimating the effect of BMPs, but not for using loading rate as constant across watershed.
        - **Deb Cappuccitti**: These numbers may be best because they reflect middle.
        - **Steve Stewart**: However, the numbers must work within the CBP model.
    - **Cappuccitti**: BANCs method results in numbers too high; Projects fail and lead to continued or increased loading; Spring Branch #'s in the middle and may be best to use
    - **Cappuccitti**: estimate erosion rate from a stable stream and subtract from nutrient loading estimates (Step 2) → **Bill Stack to consider this suggestion**

- Discussion of Protocol 2, In-stream Nutrient Processing:
    - Option 2 "Design Features" maybe superfluous: difficult to construct, hard to accomplish design required for reductions
    - **Julie Winters**: recommends keeping description to restoration, stay away from the term "credits".

DECISION: Option 1 in need of further work; however option 2 can be disregarded.

- Discussion of Protocol 3: Stream bank stabilization with flood plain reconnection and hydromodification
- This protocol is fairly rare
- Discussion of Protocol 4: Regenerative Stormwater Conveyance (RSC) Design
    - Protocol not developed
    - Joe Berg points to MDE 2011 guidance document for rates, notes there is a lack of monitoring data, use Bill Hunt data when panel reconvenes
    - Matt Meyers: Concern with outfalls/regenerative storm water conveyance systems

ACTION: **Joe Berg** to explore different types of channel designs to receive credits.

ACTION: **Norm Goulet** and **Tom Schueler** to check with Gary Shenk on how BMP degradation curves apply.

ACTION: Members to provide constructive comments in the next 2 weeks to create an improved draft.

- **Writing Assignments for Recommendations Memo:** The Panel was asked to take on specific sections for the final recommendations memo.
    - Section 3. **Russ Dudley** to write introduction and can help with associated bullets.
    - Section 3, Protocol #1. **Joe Berg** to write "Prevented channel erosion component (stormflow)"
    - Section 3, Protocol #2. **Solange Filoso** and **Sujay Kaushal** to write-up "Instream nutrient processing (denitrification) during baseflow"
    - Section 3, Protocol #4. **Deb Cappuccitti** to write-up "Dry Channel RCS effect" based on MDE guidance document
    - **Steve Stewart** to write summary of uncertainties (Section 3)
    - Section 4. **CSN** to draft "Definitions and Qualifying Conditions"
    - Section 4. **Josh Burch** to write-up applicability to rural projects
    - Section 6, Accountability. **Bill Stack** and **Lisa Fraley McNeal** to take the lead on
    - Section 7, Future Research Needs. **All** panelists to work on

- **Monitoring Research Summary:** Lisa Fraley McNeal discussed her review of existing stream restoration monitoring research.

ACTION: Come to a decision regarding a Monitoring Consortium.

- MD Stream Restoration Association, recommend Bay-wide monitoring consortium to increase monitoring efforts in concentration and rigor

June 11th, 2012
Meeting Minutes
Urban Stream Restoration Expert Panel

EXPERT BMP REVIEW PANEL Stream Restoration		
Panelist	***Affiliation***	***Present ?***
Deb Cappuccitti	MDE	Yes
Bob Kerr	Kerr Environmental Services Corp.	Yes
Matt Meyers	Fairfax County	Yes
Dan Medina	Atkins	Yes
Joe Berg	Biohabitats	Yes
Lisa Fraley McNeal	CWP	No
Steve Stewart	Baltimore County	Yes
Dave Goerman	PA DEP	No
Natalie Hartman	WV DEP	No
Josh Burch	DDOE	Yes
Robert Walter	Franklin and Marshall	No
Sujay Kaushal	University of Maryland	Yes
Solange Filoso	University of Maryland	Yes
Julie Winters	EPA CBP	Yes
Bettina Sullivan	VA DEQ	No
Tom Schueler	CSN (facilitator)	Yes
Panel Support and Observers: Russ Dudley – Tetra Tech, Debra Hopkins – Fish and Wildlife Service, Patrick Shearer. Kerr, Bill Stack, CWP, Norm Goulet, Chair USWG, Molly Harrington, CRC, Cecilia Lane, CSN, Emma Gutzler, Fairfax		

ACTION ITEMS

Bill, Lisa, Sujay, Solange and Tom: Meet in July to discuss modifications to protocol 2 on instream nitrogen processing

Sullivan, Burch, Goerman, Hartman, Cappuccitti: Send Tom basic info on state stream restoration permitting process and key contacts to include in a Table in final report. Also, please check to see whether the writeup on Pre and Post Construction Monitoring Requirements is consistent with what is required for permits in your state

Matt Meyers to produce a table comparing sediment loading from degraded vs. natural urban streams, provide a summary of the USGS research on urban stream restoration, and develop a design example for a real Fairfax County project would be credited under protocols 1 and 4

Steve Stewart to write summary of uncertainties and develop a real world design example (e.g., Upper Mine Bank Run project) on how credits would work

CSN to draft a version of recommendations memo by July 15 and send out to panel for review

ALL: put together your key stream research and modeling recommendations and send to Tom by end of July

MEETING MINUTES

Introduction/Announcements: Tom Schueler

- Tom Schueler thanks everyone for attending this pivotal meeting
- Deb and Joe put together a write-up for RSC
- Goal of this meeting is to get pretty close to recommendations and identify any remaining issues that need to be dealt with
- RTV will need to be dealt with: if too stringent, will be disincentive; too loose, people will game the system; should mitigation projects qualify?
- Fish and Wildlife and EPA informal group meeting in mid-July to meet on RSC permitting issues – would help to have qualifying conditions prior to that meeting
- Debra Hopkins from FWS reps Habitat WQGIT observing the meeting today
- Russ Dudley put together a bibliography for an appendix – thank you
- **Action**: The Panel approved the meeting minutes from April

Proposed Outline Discussion: Tom Schueler went through the proposed outline for the technical memo (Appendix C) and asked for the Panel's feedback. The following comments were made:

- Section 7 should include panel recommendations on how to improve the CBWM which can be included in the planned 2017 model refinements
- Section 7: research recommendations. It was agreed the panel should emphasize priority research that improve the quality of the protocols that are recommended?
- Section 7 **Deb** suggested that the title for Section 7 should be changed to "future research and implementation needs" to ensure permitting consistency by regulatory agencies, local outreach and training and other efforts to implement the recommendations. The panel concurred.
- **Steve Stewart** mentioned developing a spreadsheet tool to assist people with calculations for each of the protocols. Tom Schueler agreed that it should be listed as a recommendation but noted that we do not have the budget to develop such a tool.
- **Meyers**: would help to have a table to compare degraded vs. natural urban stream compared to a natural stream would produce **Meyers will produce,** Include curve of imperviousness to sediment concentration
- **Action:** The Panel accepted the draft outline with aforementioned changes

Discussion on Prevented Sediment Protocol: Bill Stack and Steve Stewart led the Panel in a discussion on the prevented sediment protocol, with an initial focus on the difference in edge of field vs edge of stream sediment loads, as simulated by the CBWM and calculated by protocol 1 (see stewart memo and stack response. After a lengthy discussion, the panel recommended that we address this issue in our modeling recommendations and get some additional feedback from CBP modeling team to ensure the load reductions under the protocol are consistent with CBWM. Tom and Bill to work Gary Shenk of CBP to resolve this issue.

There was some discussion about whether the BANCS method is applied to legacy sediment removal projects, and whether these rural projects had a higher streambank nutrient content (as suggested by the sediment nutrient table prepared by CSN). The Panel consensus was that the BANCS method as well as Protocol 3 would both probably apply to legacy sediment projects, and that Tom should consult with Walters to get his take on a 2-tier approach for urban and rural(ag) stream bank nutrient content approach. The panel agreed that the urban numbers appear reasonable and are fine as a default, but it would always be preferable to obtain nutrient content numbers directly from the project data.

Action: The Panel directed CSN to do a more detailed writeup on Protocol 2 reflecting their consensus

Dry and Wet Channel RSC Definitions and Proposed Rates: Joe Berg and Deb Cappuccitti led the Panel in this discussion. They noted that the report should reference Anne Arundel County's approved practice specification (Reg. Step Pool Conveyance System) and the 2011 MDE's NPDES MS4 permit document. They proposed a dry and wet definition, based on where the practice is implemented in the stream network, the appropriate environmental conditions, and the size of the drainage area. The dry channel RSC would be treated as a stormwater BMP with a fixed removal rate , whereas the wet channel would be calculated using the appropriate protocol(s) for which it qualifies.

Action: The panel concurred with this approach, but wanted to see more detail in the definition and writeups in the next draft

Refinement of Protocols for In-stream N processing Effect: Sujay Kaushal, Solange Filoso and Bill Stack led the Panel in a discussion of in-stream Nitrogen processing. There was considerable panel discussion on the proposed protocols, and although progress was made, no firm consensus was reached.

Action: Sujay, Solange, Lisa, Bill and Tom agreed to meet in July to further refine the protocol, and present a recommendation to the panel.

Some key themes of the discussion on instream processing (no reconnection):

- Need to come up with an operable definition of the floodplain, and the hydrologic volume that occurs during re-connection (for both baseflow and stormflow)
- If there is little or no floodplain reconnection, than the amount of instream nitrogen processing will be limited?
- There was some support for Protocol 2, Option 1 (Forestry workgroup method that looks at the effect of riparian forests and wetlands in the stream corridor), with some modifications.
- Need an operable definition of the stream baseflow component of N load (i.e, the only effective treatment would be during baseflow conditions
- What % of annual load is in baseflow? Stack estimates 20%. Steve Stewart, Bob Shedlock (USGS) say there's even more variability than that
- Tom proposed an alternative which was to use the actual CBWM pervious land loading rate (discounted by 40% to eliminate surface runoff from pervious lands). Some support for this approach
- Sujay: denitrification can happen in stream: algae, microbes – dependent on amount of light., C/N ratio, O2 levels in stream
    - Combining the options may be a good approach: b/c accounts for variability, allows for flexibility based on specific project
    - Quantitative assessment for contribution of groundwater and stormwater in the crediting process, understanding the site in advance, during baseflow to do a simple water balance preconstruction = b/c groundwater contribution is key to the crediting process

- Some key themes of the discussion on instream processing (w/ reconnection):

  - in-stream nutrient processing cuts off during high in-channel flows
  - Stewart: most of denitrification taking place in wetland/forest corridors;
  - More quantitative assessment of floodplain connectivity (Method 3) = can be done by bank height
  - **Stack**: bank height is included in Method 3, but may need to be spelled out a bit more
  - Not sure that Method 3 should be predicated on the 1" storm as the event to define the storm runoff volume that is captured in the floodplain. Perhaps a set of curves could be developed to express the new connection storm volume as a function of rainfall depth or runoff depth volume?
  - **Kaushal:** May want take a similar approach to baseflow reconnection but base on field measurement of baseflow in the study reach.
  - **Berg/Stewart**: challenge with monitoring small streams, accuracy is reduced. Also, daily cycle with baseflow, seasonal variation in baseflow, long-term variation, antecedent rainfall events will affect basefloew conditions
  - **Sujay:** could average longitudinal, and daily variation; even if underestimate the baseflow at the time, N is also variable conservative, general approach
  - **Solange**: important to determine what the dominant form of export of nutrients in urban streams prior to choosing protocol (possibly via LULC and topography) i.e. is stormflow the dominant form of export → Protocol 3 etc. The large storms define the Nutrient export of streams
  - Stewart: need 2 methods: local gov'ts need multiple options: an easy one for less credit, more advanced restoration technique that would allow for more credit keep local governments' resources (and knowledge base) under consideration.
  - **Stewart/Meyers:** to write up example projects on Upper Mine Bank Run and unspecified Fairfax County project: describe the project, how it would be credited

Discussion on Other Key Elements of Recommendations: The Panel discussed the proposed write-up on the key non-nutrient recommendations that was supplied in advance of the meeting

Action: The Panel directed CSN to proceed with a more detailed version to be included in the draft recommendations memo, and contributed the following insights

- Section 1: Environmental Considerations and Permitting
  - Medina: IBI only refers to biological health…not necessarily water quality
  - Solange: Meyers: reconnecting/maintaining the riparian corridor necessary, Need to add the following:
    - *A qualifying project maintains or enhances the riparian corridor, compensating for any project related losses*
- Section 2: Qualifying Conditions for Stream Restoration Projects
  - Should the minimum be 100'? Seems reasonable
    - Berg: Spot Treatments: Typical projects are several miles long but only stabilize sections of the stream: Need to differentiate between
    - "study reach" and "work areas" with prevented sediment credit for eroded areas defined by BANCS method and should be clearly articulated in a design example
  - Berg doesn't like qualifying conditions "state-approved design methods" b/c state has not pioneered these designs, Tom suggested adding **a table that indicates the state and federal permitting authorities that need to be consulted regarding restoration projects**
  - Existing Stream Restoration Projects

        - Old projects without BEHI curves will default to interim rate
- Section 4: Stream Mitigation and Nutrient Trading Issues
    - When a 404 permit it is issued there will be an impact
    - Nutrient trading: stream restoration is an option but more stringent requirements
    - Specific bullet for offset (different from trading)
- Section 5: Applicability of Protocols to Non-Urban Stream Projects
    - Berg: define rural vs. urban
    - Not prepared to make recommendations for ag streams for various reasons but the urban rate may apply however will be conservative
- Section 6: Provisions for Local Tracking, Reporting and Verification
    - Duration
        - Stewart: proposed 5 year verification timeframe should be linked to probability of failure i.e. stream restoration projects more likely to fail within the first 2 years; after that should go to 10 years
        - Bob Kerr: do we need a specific timeframe or just tie to TMDL updates?
- Section 7: Pre and Post Construction Monitoring Requirements
    - **Each of the state reps look at the general description and decide if it's good enough**

September 25th, 2012
Meeting Minutes
Urban Stream Restoration Expert Panel

EXPERT BMP REVIEW PANEL Stream Restoration		
Panelist	***Affiliation***	***Present ?***
Deb Cappuccitti	MDE	Yes
Bob Kerr	Kerr Environmental Services Corp.	No
Matt Meyers	Fairfax County	Yes
Dan Medina	Atkins	Yes
Joe Berg	Biohabitats	Yes
Lisa Fraley McNeal	CWP	Yes
Steve Stewart	Baltimore County	Yes
Dave Goerman	PA DEP	No
Natalie Hartman	WV DEP	Yes
Josh Burch	DDOE	Yes
Robert Walter	Franklin and Marshall	No
Sujay Kaushal	University of Maryland	No
Solange Filoso	University of Maryland	Yes
Julie Winters	EPA CBP	No
Bettina Sullivan	VA DEQ	Yes
Tom Schueler	CSN (facilitator)	Yes
Panel Support and Observers: Russ Dudley – Tetra Tech, Rich Starr – Fish and Wildlife Service, Lucinda Power, EPA CBPO, Jeff Sweeney, EPA CBPO, Matt Johnston, EPA CBPO, Bill Stack, CWP, Norm Goulet, Chair USWG, Jeremy Hanson, CRC, Cecilia Lane, CSN		

MEETING MINUTES

Review/Approval of June Panel Meeting Minutes and July Subgroup Minutes: Tom Schueler (CSN) began the meeting by thanking all of the panelists for their hard work and their feedback on the technical report.

ACTION: The Panel approved the meeting minutes from June Panel meeting and the July subgroup meeting. The Panel decided to accept comments on the technical report until October 12, 2012.

Tom noted that a number of panelists have contacted him regarding the framework of the permitting recommendations. **Tom** noted that Nick DiPasquale (Director, CBP) has formed a permitting workgroup for a regional permitting approach to address many of techniques being discussed in panel. The workgroup is entitled: *Stormwater Management, Stream Restoration and Wetland Restoration Workgroup*. **Joe Berg** (Biohabitats) noted that he doesn't think that the Panel is the appropriate place for recommending regulatory guidance rather it is the charge of the panel to focus on water quality TMDL issues. **Deb Cappuccitti** (MDE) noted that as an employee of a regulatory agency it would not be possible to divorce herself completely from any potential conflicts within her administration. **Tom** pointed out that this is not an uncommon situation for panelists, so panel members are encouraged to propose language that allows flexibility for state programs. **Solange Filoso** (UMD) noted that it might be appropriate to recommend an independent review of the final technical document.

Presentation on Stream Functional Assessment, *Rich Starr, US FWS*

Rich Starr discussed how the stream functions pyramid framework may be a useful tool to ensure that stream restoration projects provide more functional uplift than just increased nutrient removal. His main conclusions can be found in his presentation. The following are some of the discussion highlights:

- Difficult to make changes in level 1; practitioners have most influence in level 2 variables; Site selection is very critical if you want to achieve a healthy stream
- Goal to think about all parameters occur in stream corridor, how they are interrelated and if they are/not functioning
- Where you enter in the pyramid depends on one's goals and objectives
- Can change the performance standard to apply to a specific set of goals
- **Joe Berg** noted that floodplain connectivity and access to organic rich sediments and a good storage volume in the stream channel are all necessary for good stream restoration projects. **Rich** noted that while his examples were focused on NCD projects, other kinds of stream restoration projects could be assessed, as long as the appropriate performance indicators were selected.

Updates on the Floodplain Reconnection Protocol, *Bill Stack, CWP*

Bill briefly reviewed the changes to the floodplain reconnection protocols that were discussed at the July subgroup meeting, indicated how the curves were created for Protocol 3, and laid out the remaining technical decisions that the Panel needs to make on this topic. His main conclusions can be found in his presentation. The following are some of the discussion highlights:

- Basic premise is that denitrification occurs in stream channels and floodplain reconnection. The methods make the assumption that denitrification occurs b/c stream channel/floodplain behaves much like a wetland. Can use wetland studies to apply denitrification credit by estimating how stream channel behaves like a wetland.
- Baseflow (Protocol 2):
  - Surface area is critical to estimate denitrification credit
  - If we meet 1% threshold of the wetland to drainage area surface ratio can meet N removal rates in Table 6 (Step 2)
  - Unit loading rates for pervious areas only and adjusted for interflow
- Floodplain reconnection (Protocol 3):
  - Estimate how much storage volume available in floodplain area
  - Berg: if have floodplain that is connected at 1" return interval, no storage with the 1 year storm? Only get storage for volumes larger than that
    - Larger more infrequent storms have less floodplain reconnection
- Panel Comments:
  - **Solange**: Was skeptical of using wetlands data to project instream N Processing in Protocol 2, noting that wetland removal is greatest during growing season, but may export during fall/winter, no net removal and can lead to overestimation of nitrogen removal Also, wetlands that hold a lot of water can become anoxic, no conversion of ammonia to nitrate, volume of water is not sufficient, need to consider maximum depth
  - **Solange** thought that it might be appropriate to recommend an independent review of Protocol 1.

    - Panel: was somewhat skeptical of the "stream as a wetland" approach and that we should review the quality of research studies for both protocol 2 and 3 (issue of riparian buffer vs. palustrine wetland).
    - CSN/CWP to come back to the panel with some additional options
    - **Bill** to pass along wetland forestry document to panel (via Russ Dudley)
    - **Cappuccitti** –asked **Bill** if the Protocol 3 considers floodplain connection at various depths along the stream restoration project, **Bill** felt this was a good point, and suggested it was possible to develop estimates based on each reach
    - **Berg** thought it may be too difficult to develop such estimates even with many data points, further discounting not good
    - **Deb** suggested adding verbiage to explain how to possibly deal with situations with variable connection depths, e.g. break reach into segments or take an average.
    - **Panel**: Both Protocol 2 and 3 may need additional qualifying conditions regarding floodplain reconnection design (min residence time, max ponding depth, defined bank height ratio, etc.
    - **Solange**: On Protocol 3, new study from NC show frequency of inundation along floodplain, high frequency of flooding is more important than volume

ACTION: Tom and Bill to put together a draft of supplemental site design criteria to support Protocol 2; other panelists are encouraged to provide their input as Tom and Bill draft the list

ACTION: Tom and Bill to revisit wetland issue for Protocol 2 and check the scientific justification for wetland restoration efficiencies provided in Protocol 3

Rapid Feedback on First Draft of the Final Technical Memo Each panelist was asked to take 3 or 4 minutes to provide specific feedback on what they liked (and didn't like) about the first draft. Their main points are listed below. Due to the number of panelists who were unable to attend the meeting, the Panel decided to extend the comment period until **October 12, 2012**.

- **Dan Medina**:
    - One concern with the use of the word "meaningful" on page 25 in the following statement: "*…applicants should demonstrate that meaningful upland restoration practices and /or stormwater controls are being coincidentally installed*" - how to define meaningful?
- **Josh Burch**
    - Sections 4.1 and 4.2 need to be re-worded
    - Dry channel RSC referred to as Protocol 4 but if RSC is BMP then is it really a separate Protocol?
    - Concerned with Pre/post construction monitoring requirements – should the recommendations give people a choice of what to monitor.May not want to be prescriptive, what to monitor is dependent on objectives

ACTION: Panel decided to omit the monitoring protocol from the document

- **Natalie Hartman**
    - Need better definition of an urban stream
    - Non-urban stream restoration definition needs to be added
    - She was unsure how urban stream restoration ties into MS4 entities

  - **Tom** felt it would not be necessary to distinguish stream restoration for MS4 and non-MS4 areas since they are visible enough projects that require so many permits regardless of MS4 classification

- **Steve Stewart** decided to hold his comments until later

- **Lisa Fraley-McNeal**
    - Was curious about how the recommendations will tie into the Bay Watershed Model. **Tom** indicated he would follow up with Matt Johnston from CBPO modeling team about the issue

- **Solange Filoso**
  - Requested that she be allowed to submit her comments to **Tom** and the rest of the panel by email
  - Noted that there are a few studies in Anne Arundel county that the panel could use to validate the approaches (with observed data)

- **Joe Berg**
  - Reiterated his perspective that a meaningful floodplain connection should be considered under Protocols 1, 2, and 3 together.
  - Will work with Bill Stack and Tom on the floodplain reconnection section (Protocol 3) and to forward those edits to **Tom** and the rest of the panel

- **Matt Meyers**
  - Suggested that the a note be made at the end of each protocol regarding meeting local TMDLs
  - Commented that he would send a link to the USGS presentations on the Difficult Run study that was mentioned during the June panel meeting – data will help support the work that the panel is doing
  - **Note:** the Difficult Run presentations have been added to the sharepoint site

November 7th, 2012
Meeting Minutes
Urban Stream Restoration Expert Panel

EXPERT BMP REVIEW PANEL Stream Restoration		
Panelist	***Affiliation***	***Present ?***
Deb Cappuccitti	MDE	Yes
Bob Kerr	Kerr Environmental Services Corp.	No
Matt Meyers	Fairfax County	Yes
Dan Medina	Atkins	Yes
Joe Berg	Biohabitats	Yes
Lisa Fraley McNeal	CWP	Yes
Steve Stewart	Baltimore County	Yes
Dave Goerman	PA DEP	No
Natalie Hartman	WV DEP	Yes
Josh Burch	DDOE	Yes
Robert Walter	Franklin and Marshall	No
Sujay Kaushal	University of Maryland	Yes
Solange Filoso	University of Maryland	No
Julie Winters	EPA CBP	Yes
Bettina Sullivan	VA DEQ	No
Tom Schueler	CSN (facilitator)	Yes
Panel Support and Observers: Jeff Sweeney, EPA CBPO, Matt Johnston, EPA CBPO, Bill Stack, CWP, Jeremy Hanson, CRC, Cecilia Lane, CSN		

MEETING MINUTES

Review/Approval of September Panel Meeting Minutes: Tom Schueler (CSN) began the meeting by thanking all of the panelists for their hard work and their feedback on the technical report.

ACTION: The Panel approved the meeting minutes from September Panel meeting.

Update on Panel Next Steps: Tom briefed the panel on the next steps to get the recommendations approved through the CBP BMP review protocol process, including coordination with Bay modelers, informal review by other experts, and the agricultural work group, and the proposed approach to get input and approval from Urban Stormwater Workgroup, Watershed Technical Work group, the Habitat GIT and the Water Quality GIT. Tom also described how the various technical appendices will be developed.

- 11/20/12 Bay Program Modelers and Scenario Builder Team to make
- Coordinate with Ag Workgroup on non-Urban Stream Restoration recs
- Face-face in December at Fish Shack with USWG and WTWG and members of Ag workgroup
- 30 Day comment period for the states
- After which will be submitted to 3 GITs
- Will be working with CWP to develop the appendices, meeting minutes and technical documentation

- Lisa has volunteered to present recommendations at the workgroup meeting but all panelists would be welcome to attend and participate in the meeting.

Key Changes in Second Draft of Expert Report: Tom went over the key changes in the second draft of the panel report as follows:

- The Hyporheic Box Method: **Bill Stack** (CWP) presented an empirical method for determining N reduction via denitrification during baseflow that was recently developed by Sujay, Bill, Tom and Paul Mayer. This conservative approach defines the geometry of a hyporheic box associated with a stream restoration to which a unit denitrification rate is then applied. The Panel was asked to decide whether this approach is better than the existing Protocol 2 method.
    - **Dan Medina** noted the following:
        - Bank height ratio needs to be clarified
        - Asking for a degree of precision that will be difficult to meet by practitioners
    - **Deb Cappuccitti** asked about the average bulk density conversion rate
        - Tom clarified that an implementer must measure bulk density at each individual site
    - **Joe Berg** asked about the carbon content
    - The Panel generally likes the method, **allow for a 3-day period to establish better qualifying conditions and let Tom know of any questions or concerns**
- Use of Jordan (2007) CBP-approved nutrient removal rates for floodplain wetland restoration projects
- More general approach to stream functional assessment methods
- Reorganized and slightly modified Protocol 1
- Updated curves for floodplain reconnection
- Revised design examples
- Less prescriptive text on pre and post construction monitoring requirements
- *Floodplain Reconnection Criteria for Protocol 3*
    - **Dan Medina** commented
        - Tied to the 1-year event,
        - Floodplain surface area to drainage area
        - Bill to make a recommendation to define extent to floodplain
        - Frequency a component
        - Add a visual representation
    - **Joe Berg** said should remove the residence time condition
        - Surface area wetted and the frequency of wetting
    - **Tom** clarified that trying to prevent a 10-minute inundation of the floodplain qualifying for the credit
    - **Dan** suggested changing the x-axis
- Future research and management priorities
- A six month window to "test drive" the protocols to make sure they can be properly applied by users
    - **Deb** questioned why the extent should be limited to 6 mo
    - **Josh** supports the idea of a timeline approach

DECISION: The Panel decided the Hyporheic Box Method is a suitable replacement for Protocol 2 but will have until Monday, November 12, 2012 to establish any additional qualifying conditions.

Panel Feedback on the Key Changes: Tom asked the panel for their feedback on the second draft of the expert panel report. The following are a few major points that were made:

- Tom noted that sediment reduction had been left out of Protocol 3 due to the lack of existing data.
- Tom asked the Panel if it would be okay to add a sediment credit to Protocol 3
- The Panel noted that at a minimum Protocol 3 should receive credit for sediment removal equal to Protocol 1 but probably should be greater.
- **Matt Johnston** noted that streams should be consistent with the way BMPs are put into the model and recommended a comparison to the interim rate
- **The Panel** decided to create a comparison table that demonstrates the lbs/ft reductions associated with the different Protocols as (either individually or collectively) they compare to the interim rate.

ACTION: Any additional comments/edits on 2nd draft get to Tom/Bill by November 21st. Tom and Bill to put together the Appendices by the December meeting**.**

Panel Feedback on the Final Recommendations: Each panelist was asked to provide final comments on the report by **November 21st** and indicate whether they would be comfortable with endorsing the final recommendations as written, or identify specific changes that are needed to get their support. Based on the feedback, the Panel, as a whole, decided to approve the final report, contingent upon the completion of specific changes requested.

Tom thanked the panel for all of their hard work and commended them on a great set of recommendations and specifically thanked Bill Stack and Lisa for their help on the final recommendations. **Dan** thanked Tom for his leadership on the Panel.