of the edge-of-field sediment load is deposited before it reaches the tidal waters of the Bay (U.S. EPA, 2010).

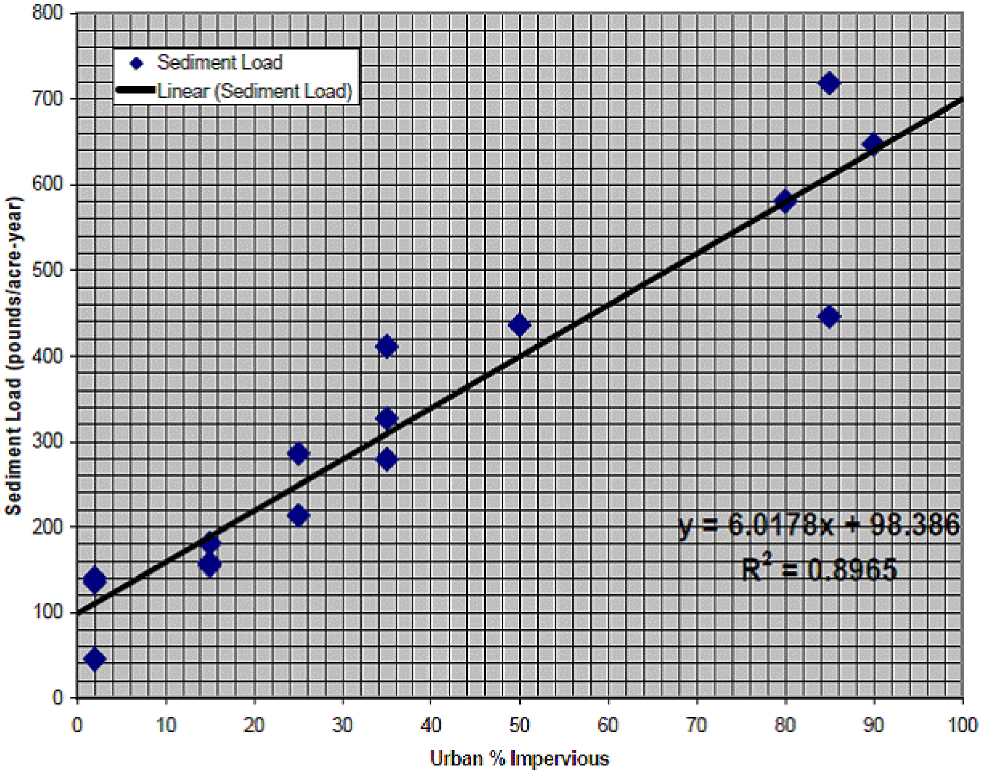


Figure 1. Relationship between Edge-of-Stream Urban Sediment Loads and Watershed Impervious Cover (Source: Langland and Cronin, 2003).

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, nutrients are simulated as being directly delivered to the edge of stream. Losses due to denitrification are not explicitly simulated 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). The edge-of-field nutrient loads and the delivery to the edge-of-stream are not specified in the model.

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. Furthermore, the WTWG recommended that nutrient attenuation within the stream network be characterized, if adequate literature supports such an effort, prior to the Phase 6 Model.

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 default 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 Walter 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	Walter 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 in the hyporheic zone, particularly when sufficient organic carbon is available to the system. Increased groundwater and stream flow interaction can alter dissolved oxygen concentrations and transport N and organic matter to microbes in subsurface sediments, fostering denitrification hot spots and hot moments (Mayer et al., 2010; Klocker et al., 2009).

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

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

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

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

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

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

- Increase retention time in flood plain wetlands;
- Add dissolved organic carbon via riparian vegetation, debris jams, instream woody debris, and where applicable, 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 Protocols 1 and 2 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).

The protocols are additive, and an individual stream restoration project may qualify for credit under one or more of the protocols, depending on its design and overall restoration approach however the WTWG recommended that the aggregate load reductions from a practice should not exceed estimated loads in the Watershed Model for any given land-river segment. 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 are included below. States are encouraged to select an approach to estimate stream bank erosion rates that best fits their unique conditions and capabilities. In addition, they are encouraged to pursue their own more robust methods to yield the most accurate estimates possible.

- 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 bank 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 Walter et al. (2007) and are based on bank samples in Pennsylvania (Table 5):

- 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. The Panel felt that efficiencies greater than 50% should be allowed for projects that have shown through monitoring that the higher rates can be justified subject to approval by the states. This will hopefully promote monitoring (e.g., Big Spring Run in Pennsylvania) of stream restoration projects.

The 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 which should be applied to account for loss due to depositional processes between the edge-of-field and edge-of-stream. Sediment delivery ratios have been averaged for coastal plain (0.061) and non-coastal plain (0.181) streams and should be multiplied by the erosion rate to determine the sediment load reduction that is reported. Riverine transport processes are then simulated by HSPF to determine the delivered load. See design example in section 6.1 to see how the sediment delivery ratio is applied. Additional information on the sediment delivery ratio can be found in Appendix B. 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. Situations where the restored channel is connected to a floodplain wetland are also eligible for additional credit under Protocol 3. 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. Additional design and construction guidelines that promote in-stream nutrient removal should be followed and are available in Appendix G.

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 median base flow channel and 5 feet added on either side of the stream bank (see Figure 2). 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.

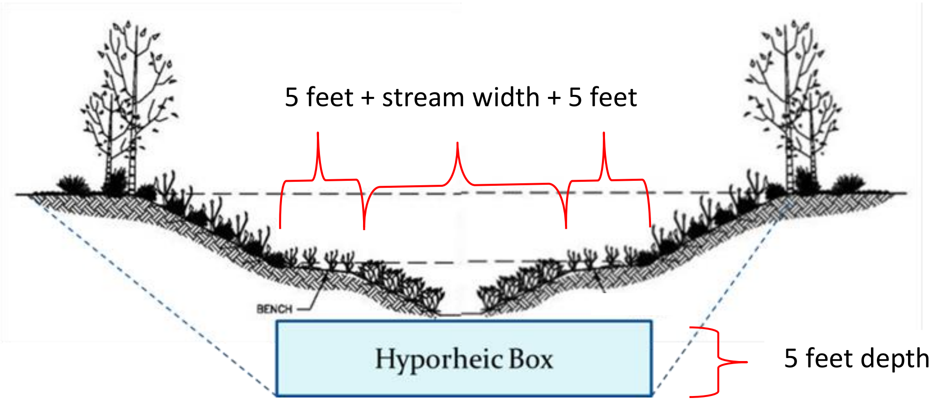


Figure 2. Hyporheic box that extends the length of the restored reach

The cross sectional area of the hyporheic box is multiplied by the length of the restored connected channel. In actuality, because not all of the restored channel will meet the qualifying conditions described above, there may be several smaller disconnected hyporheic boxes that are averaged across the reach. The result is then multiplied by an average denitrification rate that represents the additional dentrification provided from restored sites versus unrestored sites from Kaushal et al. (2008) of 48.2 μg N/kg/day of soil (1.06 x 10^{-4} pounds/ton/day of soil). This is the denitrification rate within the mass of stream sediment within the hyporheic box.

The Expert Panel felt that a cap was necessary given the excessively high nitrogen reductions in some of the test drive results. An initial cap was suggested based on a study by Klocker et al. (2009), who found that 40% of the daily load of nitrate in Minebank Run could be removed through denitrification. However, the WTWG recommended the 40% cap be placed on total nitrate loads entering the stream for any given land-river segment rather than total nitrogen loads as denitrification only impacts nitrate.

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 median base flow depth (as determined by gage station data) 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 (1.06 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.

Step 4: *Check to make sure the watershed cap is not exceeded.*

Since nitrate loadings are highly variable spatially, the Chesapeake Bay Program Modeling Team should be contacted for the total nitrate loading to assure that the load reductions from this and other projects do not exceed the 40% cap for any given land-river segment.

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 base flow is also given. Qualifying projects receive credit for sediment and nutrient removal under Protocol 1 and denitrification in Protocol 2 (if applicable) 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 conceptual curves were developed that 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. The results of Protocol 3 will vary depending on which hydrologic model is used for estimating floodplain connection volume. Appendix G provides further explanation and an alternative curve example. Project-specific calculations should be used 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 criterion. 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 can be diverted from the stream to the floodplain during storm events. Credit for this protocol applies only to the additional runoff volume diverted to the floodplain beyond what existed prior to restoration. 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).

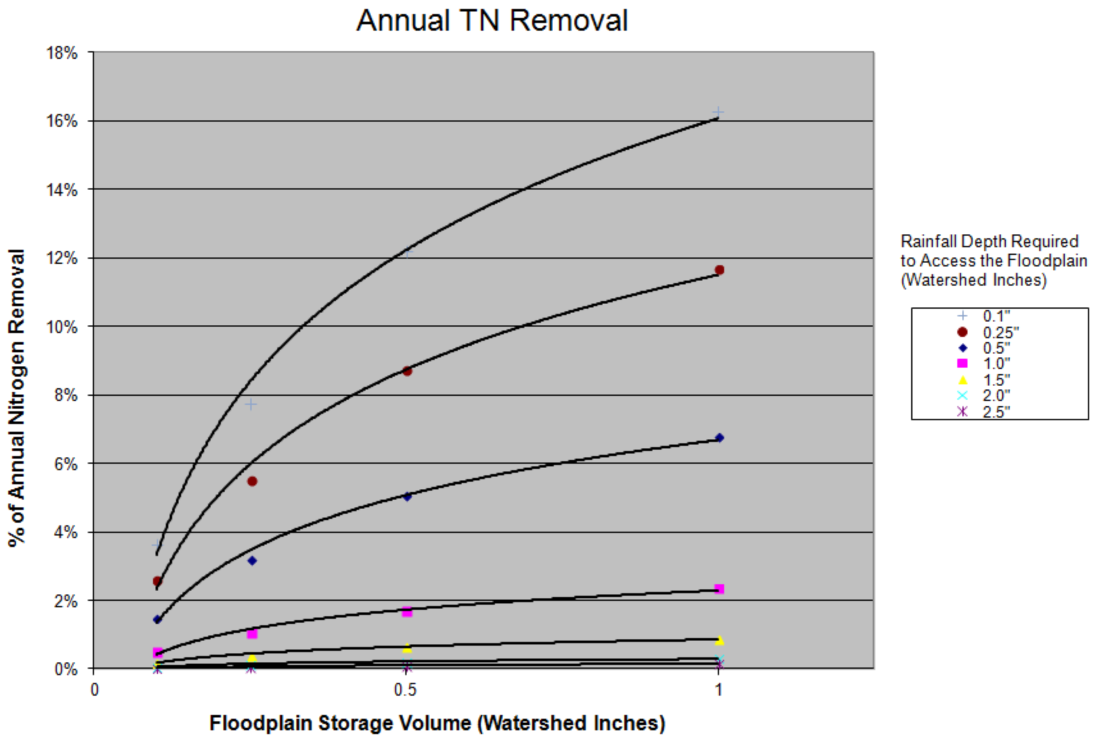
Step 2: *Estimate the nitrogen and phosphorus removal rate attributable to floodplain reconnection for the floodplain connection volume achieved.*

The curves in Figures 3 -5 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.

1. BMPs installed within the drainage area to the project will reduce the delivered loads by serving as a treatment train. The hydrologic models/methods used for this protocol are specific to a watershed and should already account for load reductions associated with runoff reduction practices. If the assumptions that were used in the models used for this protocol have changed substantially within the 5 yr verification period because of the implementation of upstream BMPs, then the protocol should be updated accordingly.
2. However, jurisdictions should account for any appreciable load reductions attributed to non-run-off reduction practices. Appendix F provides an explanation of treatment train effects and how they are accounted for in Scenario Builder.



3.

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

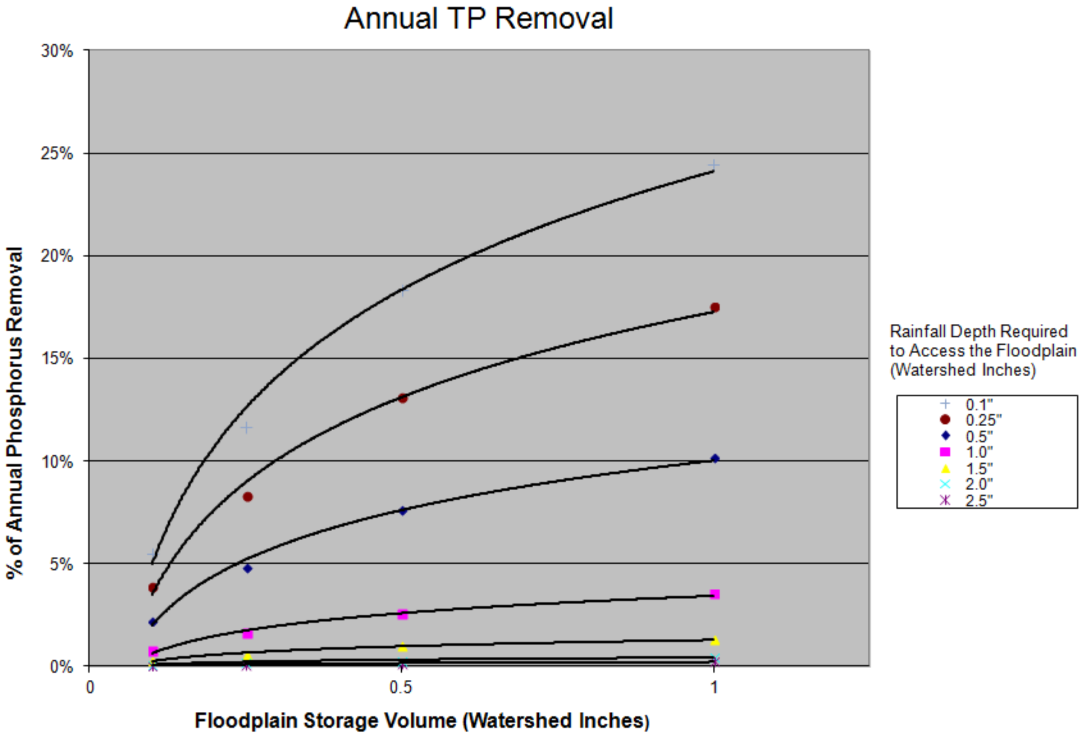


Figure 4. Annual TP removal as a function of floodplain storage volume for several rainfall thresholds that allow runoff to access the floodplain.

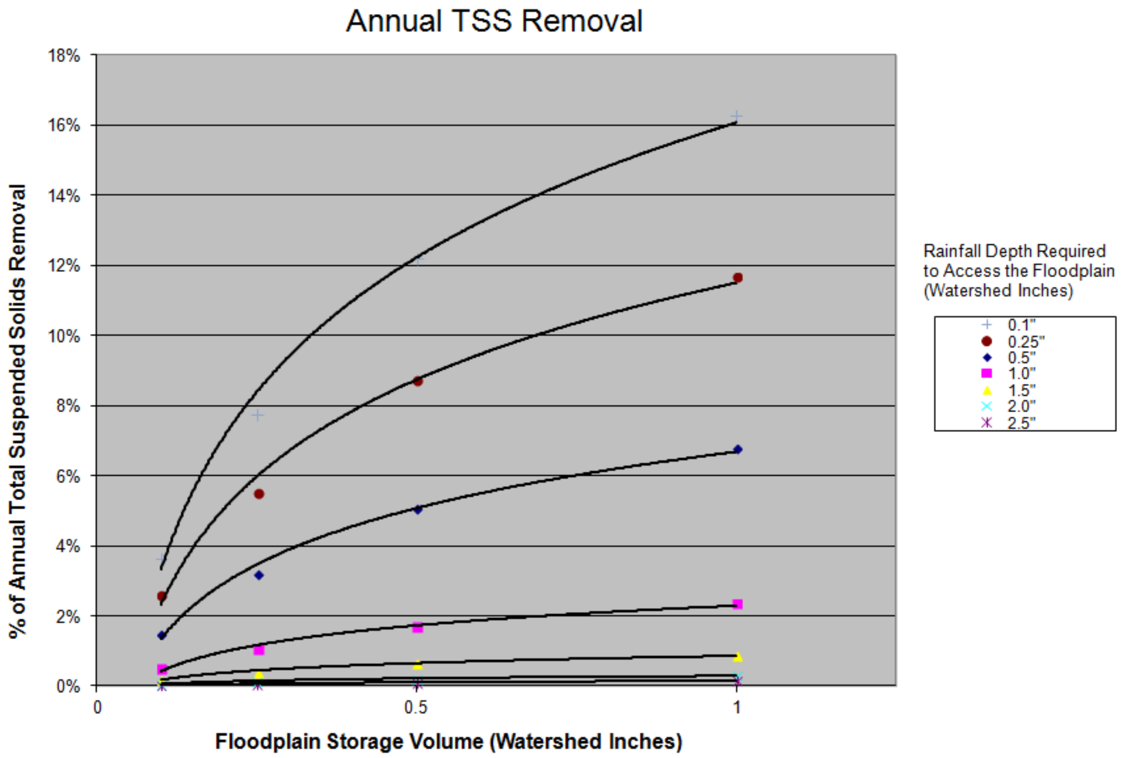


Figure 5. Annual TSS removal as a function of floodplain storage volume for several rainfall thresholds that allow runoff to access the floodplain.

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[2]

Step 1. *Estimating stream sediment erosion rate*

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

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

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

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

From 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 0.181 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 and it was determined that the stream is outside of the coastal plain. 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 =	244 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 =	122 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 through in-stream and riparian nutrient processing within the hyporheic zone during base flow 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. The watershed area is 1,102 acres with an impervious cover of 41%.

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 median 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 1.06×10^{-4} lb/ton/day of soil (conversion from 48.2 μg TN/kg/day of soil); therefore, the estimated TN credit is:

$$(1.06\ x\ 10^{-4}\ \ lb/ton/day)(1{,}875\ tons) = 0.20\ \ lb/day\ or\ 73\ \ lb/yr \qquad \text{(Eq. 3)}$$

Step 4: *Check to make sure the watershed cap is not exceeded.*

Since nitrate loadings are highly variable spatially, the Chesapeake Bay Program Modeling Team should be contacted for the total nitrate loading to assure that the load reductions from this and other projects do not exceed the 40% cap for any given land-river segment.

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

The stream currently accesses its floodplain only during extreme storm events (> 2 year). 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.

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 are 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%. (Note that Figures 6 – 8 should not be used for actual designs. Appendix G explains how to use more robust hydrological methods with this protocol).

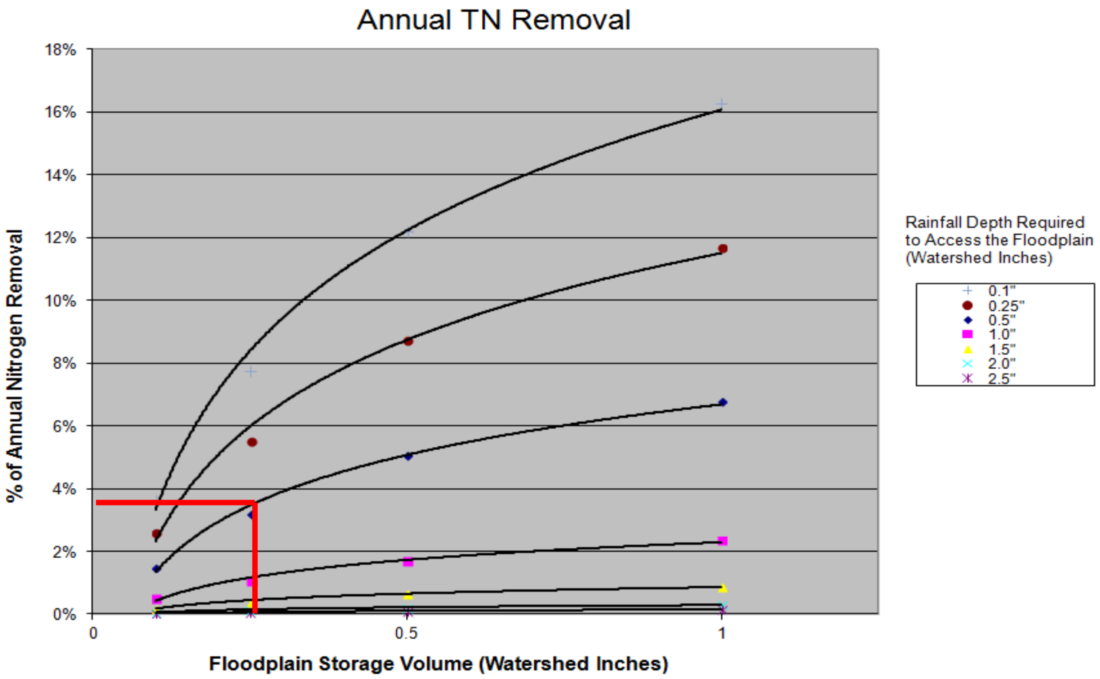

Figure 6. Annual TN removal as a function of 0.25 watershed inch[3] floodplain storage volume and 0.5 inch rainfall depth required to access the floodplain.

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[3] 1 watershed inch = the volume of the watershed area to 1" of depth.

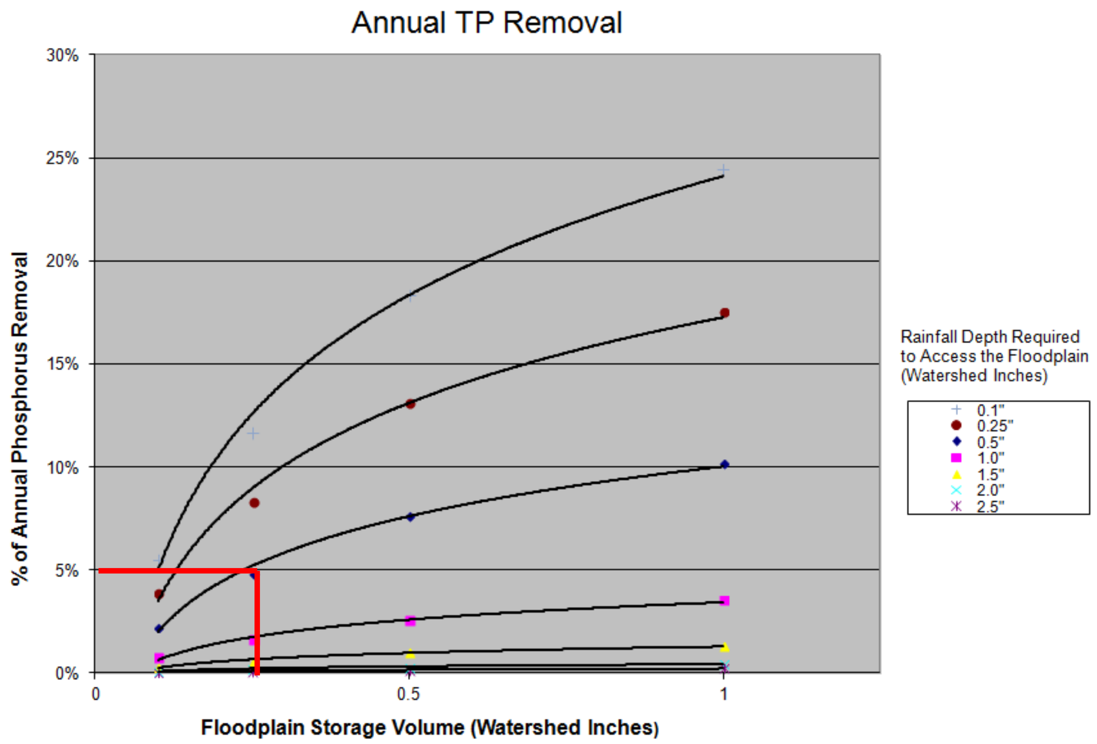

Figure 7. Annual TP removal as a function of 0.25 watershed inch floodplain storage volume and 0.5 inch rainfall depth required to access the floodplain.

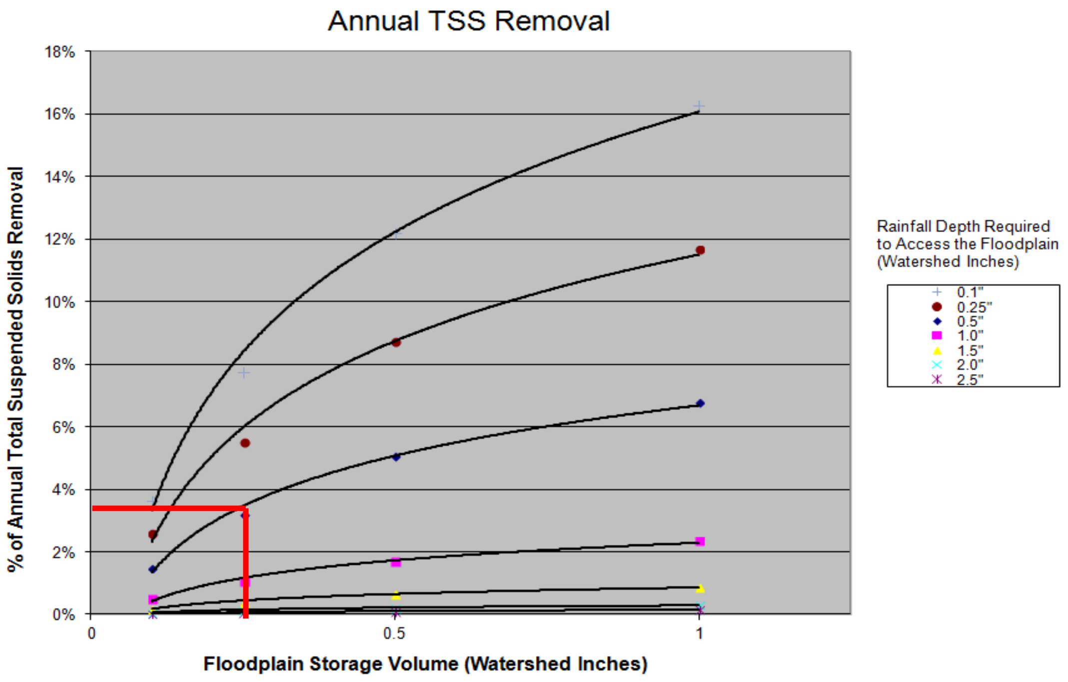

Figure 8. Annual TSS removal as a function of 0.25 watershed inch floodplain storage volume and 0.5 inch rainfall depth required to access the floodplain.

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 x 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 x10^3 pounds per year

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:

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

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 revised default rate (Table 3, Row 3). These results represent the edge-of-stream load reductions and were calculated based on an average 0.181 delivery ratio for TSS.

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. 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 6 also shows that load reductions achieved under the protocols for TP and TN are higher than that for the revised interim rate and the load reductions using the revised interim rate are higher for TSS. It is difficult to say whether this pattern will hold for other projects using these protocols. The Panel recommends the use of the protocols because they use site data and are believed to provide more accurate load reductions. The interim rate has value when this is not possible. Also, the interim rate is a useful planning tool within the context of CAST, VAST, or MAST and can be used to assess stream restoration strategies at the local level. The protocols can then 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 6. 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]	Total Load Reduction from Protocols 1-3	Revised Default Rate[4]
TN	1,538	73	452	2,063	582
TP	708	--	70	778	528
TSS[5]	244,000	--	22,600	258,600	348,224

[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 revised unit rate to 7,759 linear feet of the project
[5] For Protocol 1 and default rate for TSS reductions, a sediment delivery ratio of 0.181 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:

4. *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. If the assumptions that were used in the protocols have changed substantially within the 5 yr verification period because of the implementation of upstream BMPs, then the protocols should be reapplied.

5. *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.

6. *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 and length 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 (pre and post restoration)
            1. Stream length connected to floodplain where bank height ratio is 1.0 or less
            2. Width of the stream channel taken from the thalweg to the edge of connected side of stream, as indicated by a bank height ratio of 1.0 or less
            3. TN load reduction (pounds per year)
            4. Watershed area
    d. Protocol 3
        i. Floodplain wetland area
        ii. Upstream watershed area
        iii. TSS, TP, TN loading rate reduction efficiencies (percent)
        iv. TSS, TP, TN load reduction (pounds per year)

7. *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.

8. *Ongoing Field Verification of Project Performance*. The installing agency needs to conduct inspections once every 5 years to ensure that individual projects are

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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.

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.

9. *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.

10. *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.

11. *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 *"revised 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, a six month "test-drive" period was allowed for practitioners and regulators to test the protocols on real world projects. Findings from the test-drive are included in Appendix G and reflect revisions to this report since initial approval by the WQGIT in May 2013. Once the protocols 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 that should be taken in the next 2 to 5 years:

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

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

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

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

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

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

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

Section 8.3
Other Research Priorities

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

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

- Development of a database of the different stream restoration projects that are submitted for credit under each protocol, and case studies that profile both failure and success stories 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.

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Attachment E3: Urban Stream Restoration Fact Sheet

U-4 URBAN STREAM RESTORATION

PRACTICE AT A GLANCE

- New techniques have been pioneered in the Chesapeake Bay watershed to restore urban streams using diverse approaches such as natural channel design, regenerative stream channel, and removal of legacy sediments.

- Stream restoration improves the health of aquatic resources, and, when combined with upland restoration practices, is one of the more cost-effective practices to remove sediment and nutrients from urban watersheds.

- Credit is only given when stream restoration projects meet stringent qualifying conditions and can produce functional uplift for local streams so they provide a net environmental benefit in the watershed.

- Thus, not every stream restoration project will qualify for credit. For example, no credit can be granted for any project built to offset, compensate, or otherwise mitigate for an impact elsewhere in the watershed. The same is true for stream bank stabilization projects that are primarily designed to protect public infrastructure by bank armoring or rip rap.

- Stream restoration projects undergo extensive regulatory review and require state and federal permits.

PRACTICE DESCRIPTION

Stream restoration projects work to remove pollutants in several ways. First, the projects retain the sediment and attached nutrients in a stable, restored stream bank or channel that would otherwise be delivered downstream by an actively eroding stream. Some projects can also increase the interaction of the stream baseflow with groundwater, and promote conditions that lead to nitrogen removal. Lastly, projects that reconnect a stream to its floodplain help trap and retain sediment and nutrients carried in smaller floods.

Three different approaches can be used to restore streams:

- *Natural Channel Design* applies the principles of stream geomorphology to maintain a state of dynamic equilibrium among water, sediment, and vegetation that creates a stable channel.

- *Legacy Sediment Removal* seeks to remove legacy sediments from the stream and its floodplain and thereby restore the natural potential of aquatic resources including a combination of streams, floodplains, and wetlands.

- *Regenerative Stream Channel* uses in-stream weirs in perennial streams to increase the interaction with the floodplain during smaller storm events. These projects may also include sand seepage wetlands and other habitats to increase the stream's connection with its floodplain.

Many projects use a combination of these three techniques. Each approach is eligible for pollutant removal credits, as long it meets qualifying conditions, environmental permitting requirements and improves stream health.

WHERE TO FIND THE BEST OPPORTUNITIES IN YOUR COMMUNITY

Stream restoration projects can occur almost anywhere where streams are badly eroding including urbanized areas. They are best implemented when:

- As part of a comprehensive watershed approach
- Geomorphic evidence shows active stream degradation
- The index of biological diversity for the stream scores as fair or worse
- Hydrologic evidence shows the floodplain is disconnected from the stream
- Evidence shows that legacy sediments are prevalent in the project reach
- Evidence that stream functions can be improved
- Adjacent land becomes available through eminent domain due to flooding and offers opportunities for flood-plain reconnection
- Some of the best locations are streams that run through public parks and municipal land

The best opportunities are in areas with severely incised streams that have adjacent flood plain areas to which the stream can be reconnected. Property ownership is a key issue so it is critical to involve adjoining property owners from the get-go.

STREAM RESTORATION APPROACHES

Natural Channel Design

Legacy Sediment Removal

Regenerative Stream Channel

Likewise, the best projects are part of a comprehensive watershed restoration plan to assure better outcomes of the project goals. This plan should identify key upland practices in the watershed as well as priority areas for stream restoration.

GENERAL COST INFORMATION

Despite the fact that they are cost-effective in terms of pollutants removed per dollar expended, stream restoration projects are not cheap. Their cost can range from $150 to $400 per linear foot restored, which means most projects will cost several hundred thousand dollars or more to construct. Therefore, it is critical to assess multiple candidate stream restoration projects to find the most cost-effective ones.

Most communities finance the construction of their stream restoration projects through their long term capital improvement budgets and may require grant funding to implement the project.

TIPS FOR GETTING STARTED IN YOUR COMMUNITY

It can typically take anywhere between one and three years to go from project concept to construction of stream restoration projects, and even longer if there are contentious permit issues. In addition, the design of most stream restoration projects requires a lot of upfront monitoring and survey work, and there may also be additional post-construction monitoring, as well.

Most streams and floodplains are classified as wetlands, and any activity within them is regulated under state and federal wetland permits. Getting a permit to proceed with construction can be a very lengthy process, and is not automatic. Consequently, it is essential to consult with the Corps of Engineers, U.S. EPA and other wetland regulators very early in the process to get feedback on permitting.

Another key tip is to involve the public during the stream restoration design process; particularly if there will be significant construction impacts, such as the removal of large trees.

WHAT DEGREE OF TECHNICAL SUPPORT IS NEEDED

Stream restoration design, permitting and construction can be very complex, and requires a lot of skill in engineering, project management and construction oversight. Most communities will need to hire experienced consultants to do most of the work, but will need good in-house talent to effectively manage the projects.

Stream restoration requires a multidiscipline team including the following:

- Stream restoration should be part of a comprehensive watershed restoration strategy requiring the skills of a watershed planner and those skilled in monitoring and assessment.

- A stream restoration project should be designed by a professional engineer with appropriate training in geomorpholgy. The design team should also consult with a professional biologist to consider what stream functions can be improved or what stream functions might be lost as a result of the project.

- The construction of a stream restoration project also requires an experienced contractor that specializes in stream restoration installation.

- To receive credits, all qualifying projects must have a designated authority responsible for project maintenance that includes both routine maintenance and long-term repairs.

COMPUTING THE POLLUTANT REMOVAL CREDIT

There are three general protocols to define the pollutant load reductions associated with individual stream restoration projects. The protocols are additive, and an individual stream restoration project may qualify for credit under one or more of the protocols, depending on its design and overall restoration approach. A general description is provided below. Jurisdictions may find it beneficial to perform the calculations as part of their design contracting to optimize the project's pollutant load reductions.

Default Rate. Historic projects and new projects that cannot conform to recommended reporting requirements of the Chesapeake Bay Program may be able to receive credit through a default rate (**Table 1**).

Table 1. Interim Approved Removal Rates per Linear Foot of Qualifying Stream Restoration (lb/ft/yr)

Source	TN	TP	TSS*
Revised Default Rate	**0.075**	**0.068**	**44.88 non-coastal plain** **15.13 coastal plain**

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

*To convert edge of field values to edge of stream values a sediment delivery ratio (SDR) was applied to TSS. The SDR was revised to distinguish between coastal plain and non-coastal plain streams. The SDR is 0.181 for non-coastal plain streams and 0.061 for coastal plain streams.

Protocol 1. Credit for Prevented Sediment During Storm Flow

This protocol provides a 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.

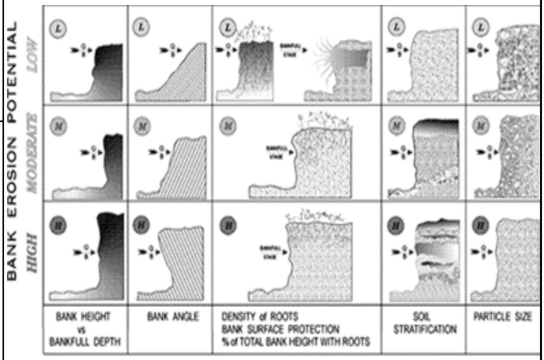
This protocol follows a three step process to compute a mass reduction credit for prevented sediment:

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 (50% default rate) or use monitoring data.

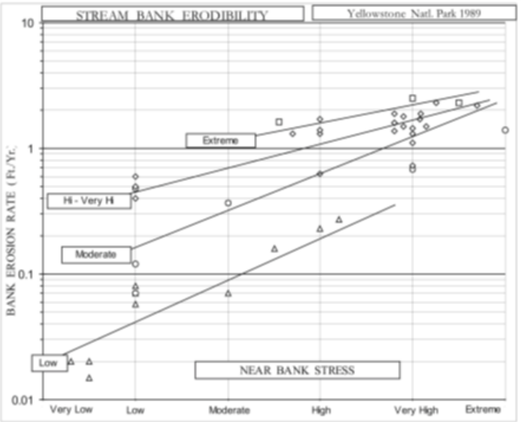
- Monitoring using methods such as cross section surveys and bank pins is the preferred approach.
- When monitoring is not feasible, use the “Bank Assessment for Non-point Source Consequences of Sediment” or BANCS method to estimate sediment and nutrient load reductions.
- The BANCS method utilizes two commonly used bank erodibility estimation tools to predict stream bank erosion: the Bank Erosion Hazard Index (BEHI) and Near Bank Stress (NBS) methods.

BANCS METHOD

1. Assess BEHI score based on criteria below



2. Use field measurements to determine BEHI score

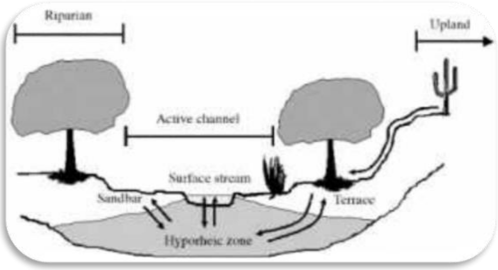


3. Estimate erosion rate using BEHI and near bank stress.

Protocol 2. Credit for In-stream Nitrogen 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 enhanced surface water/groundwater exchange (hyporheic zone) within the riparian corridor. This protocol relies heavily on denitrification research in restored streams within the Baltimore metropolitan area.

- This protocol applies to stream restoration projects where in-stream design features are incorporated to enhance nutrient processing, such as denitrification.
- Qualifying projects receive credit for enhanced nitrogen removal within the stream channel during base flow conditions.
- Protocol 2 only provides a nitrogen removal credit; no credit is given for sediment or phosphorus removal.

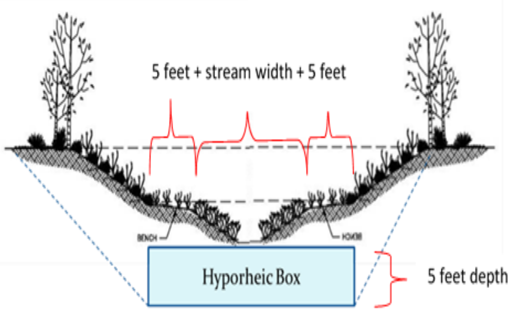


Functional ecomorphology: Feedbacks between form and function in fluvial landscape ecosystems. Stuart G. Fisher, , James B. Heffernan, Ryan A. Sponseller, Jill R. Welter

1. Surface and groundwater interaction described as "hyporheic exchange" between the stream channel and the floodplain

2. Restored stream with improved hyporheic connection

- 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 bottom with a width that includes the median base flow channel and 5 feet added on either side of the stream bank (see Figure 3 to the right). The dimensions of the box apply only to sections of the stream where hyporheic exchange can be documented.
- The volume of the "box" is multiplied by a denitrification rate.

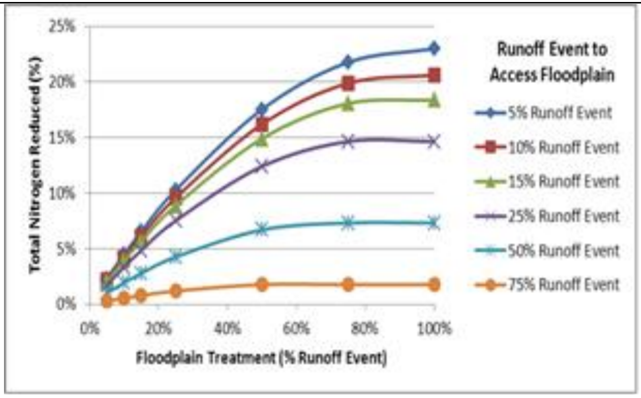


3. Volume used to compute enhance denitrification The credit is determined only for the length of stream reach that has improved connectivity to the floodplain as indicated by a bank height ratio of 1.0 (bank full storm) or less for projects that use the natural channel design approach.

Protocol 3. Credit for Reconnection to the Floodplain

This protocol provides a 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.

- Qualifying projects receive credit for sediment and nutrient removal under Protocol 1 and denitrification in Protocol 2 (if applicable) 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.
- A series of curves were developed that 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.



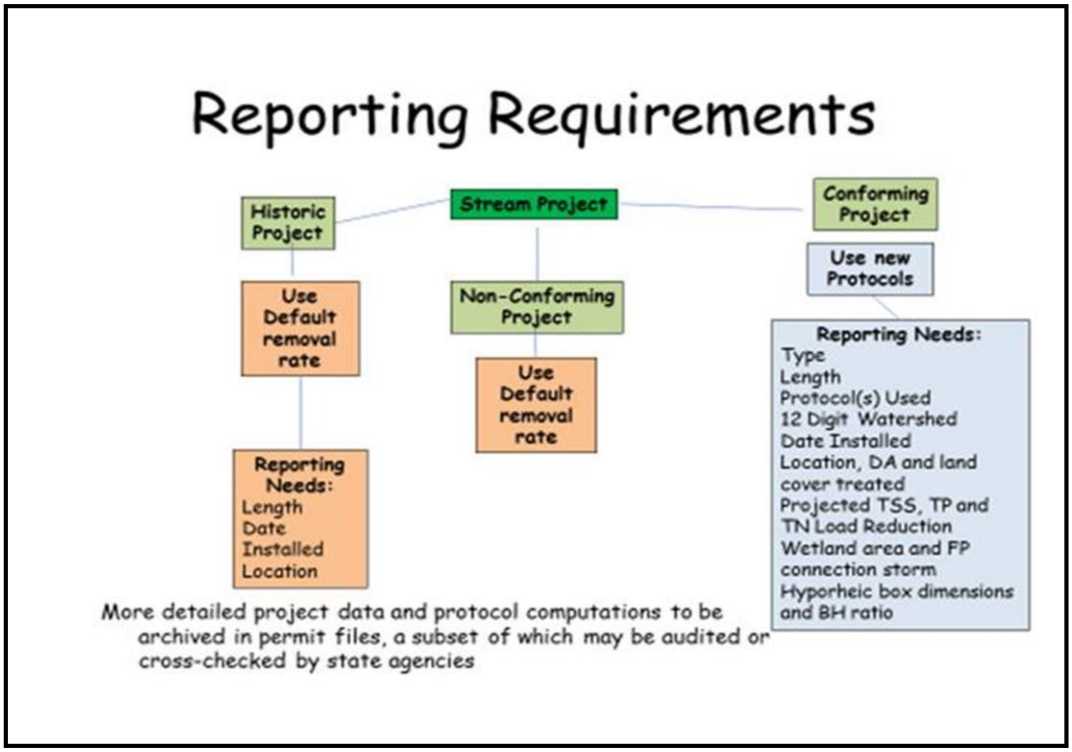
Higher bank in lower picture translates to lower frequency of floodplain access than upper photo and consequently lower reduction efficiencies.

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.

The floodplain connection volume afforded by a project is equated to a wetland volume so that a wetland removal efficiency for TN, TP and TSS can be applied.

HOW TO REPORT THE PRACTICE TO THE STATE

Basic reporting requirements are presented in the figure below. 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.



More detailed project data and protocol computations to be archived in permit files, a subset of which may be audited or cross-checked by state agencies

WHAT IS REQUIRED TO VERIFY THE PRACTICE OVER TIME

- The installing agency needs to certify that the stream restoration project was installed properly, meets or exceeds its functional restoration objectives and is hydraulically and vegetatively stable, prior to submitting it for credit 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.

- The installing agency inspects the project once every 5 years to ensure that it is still capable of removing nutrients and sediments.

- If the field inspection indicates the project is not performing to its original specifications, the locality has one year to take corrective maintenance or rehabilitation actions to bring it back into compliance.

RESOURCES

The following resources are available for help with all aspects of this practice:

Type of Resource	Title of Resource	Web link
Expert Panel Report	Recommendations of the Expert Panel to Define Removal Rates for Individual Stream Restoration Projects (2014) – Short Version	http://chesapeakestormwater.net/wp-content/uploads/dlm_uploads/2013/10/stream-restoration-short-version.pdf
	Recommendations of the Expert Panel to Define Removal Rates for Individual Stream Restoration Projects (2014) – Long Version	http://chesapeakestormwater.net/wp-content/uploads/dlm_uploads/2013/05/stream-restoration-merged.pdf
Archived webcast(s)	Urban Stream Restoration Protocols and Frequently Asked Questions Webcast (2014)	http://chesapeakestormwater.net/events/webcast-urban-stream-restoration/
Expert Panel Appendix A	Appendix A: Annotated Literature Review	http://chesapeakestormwater.net/wp-content/uploads/dlm_uploads/2015/03/Appendix-A.-Annotated-Literature-Review.pdf
Expert Panel Appendix B	Appendix B: Protocol 1 Supplemental Details	http://chesapeakestormwater.net/wp-content/uploads/dlm_uploads/2015/03/Appendix-B.-Protocol-1-Supplemental-Details.pdf
Expert Panel Appendix C	Appendix C: Protocol 2 and 3 Supplemental Details	http://chesapeakestormwater.net/wp-content/uploads/dlm_uploads/2015/03/Appendix-B.-Protocol-1-Supplemental-Details.pdf
Paper	Harman, W., et al. "A Function-Based Framework for Stream Assessment and Restoration Projects." (2012).	http://chesapeakestormwater.net/wp-content/uploads/dlm_uploads/2015/03/A_Function-Based_Framework-2.pdf
Stream Restoration Manual	Urban Subwatershed Restoration Manual Series Manual 10: Unified Stream Assessment: A User's Manual	http://chesapeakestormwater.net/wp-content/uploads/dlm_uploads/2014/09/Manual-10.pdf
More Tools & Resources		http://chesapeakestormwater.net/training-library/urban-restoration-techniques/stream-restoration/

Section F

SECTION F - IDENTIFY FUNDING MECHANISM

Highspire Borough plans to consider many sources of funding to implement the proposed stormwater BMPs identified in this Plan. Since the proposed BMP is located on municipal-owned and/or -operated property, the Borough will have greater control over the implementation schedule and funding options. The anticipated funding source to implement the stormwater BMP may include any of the following:

Highspire Borough Stormwater Fund: Highspire Borough and the Borough Authority have recently enacted a temporary stormwater fee for funding their stormwater management program, and they are currently conducting a stormwater fee study to determine the final stormwater fees for property owners.

PENNVEST: The Pennsylvania Infrastructure Investment Authority (PENNVEST) provides funding for urban stormwater and agricultural BMPs.

Growing Greener Grants: Growing Greener provides state funds to address environmental concerns, including the negative effects of stormwater pollution on water quality. These grants vary in availability and total funding dollars.

PA DEP’s Urban Stormwater BMP Grants: As part of the Local Stormwater BMP Implementation Program, PA DEP has provided grants to communities located in the Chesapeake Bay Watershed to reduce stormwater runoff to local waterways. These grants vary in availability and total funding dollars.

Collaboration: The Borough will continue to look for other funding opportunities to implement stormwater BMPs by collaborating with other environmental organizations including but not limited to the Dauphin County Conservation District, Susquehanna River Basin Commission, and various watershed organizations.

Section G

SECTION G - IDENTIFY RESPONSIBLE PARTIES FOR OPERATION AND MAINTENANCE (O&M) OF BMPs

The Burd Run stream stabilization project must be maintained on a regular basis, after fully implemented, to continually achieve the water quality benefits and pollutant reductions identified in this plan.

Parties Responsible for ongoing O&M: Highspire Borough will be fully responsible for all O&M activities associated with the stream project.

Activity involved with O&M for each BMP and the frequency at which O&M activities occur:

After the Burd Run streambank project is completed, regular inspection and maintenance activities will occur as follows:

- Since vegetation establishment is a critical component of the long-term stability of the streambank, monthly inspections should occur for the first year after the project is complete. A minimum 85% plant survival rate should be achieved and documented.
- Weeds and invasive plants threaten the survival of native plants, and should be aggressively controlled by herbicides, mowing, and/or weed mats for the first four years after implementation.
    - Applying herbicides for the first two to three years may be necessary to control weeds. This activity is regulated by the PA Department of Agriculture, and proper care should be taken in a streamside setting.
    - Mowing grasses should occur twice each growing season with a mower height set to eight to twelve inches.
    - Weed mats suppress weed growth around newly planted vegetation, and should be removed once trees have developed a canopy sufficient to shade out the weeds.
- Once the vegetation has been established, regular maintenance should be minimal.