External REVIEW DRAFT

Consensus Recommendations to Improve Protocols 2 and 3 for Defining Stream Restoration Pollutant Removal Credits

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Executive Summary

Two groups of more than 25 stream experts have worked over the last year on how to better apply protocols 2 and 3 to integrated stream and floodplain restoration projects (FR) (*Section 1*).

This class of stream restoration projects uses two basic design approaches to reconnect incised streams to their floodplains. The first approach, termed legacy sediment removal (FR-LSR), removes sediments to lower the floodplain surfaces, increasing out-of-bank flow and re-establishing the hyporheic exchange zone by reconnecting the floodplain with the hyporheic aquifer.

The second approach, known as raising the stream bed (RSB), involves several techniques to raise the elevation of an incised stream channel and shallow groundwater, thereby increasing the volume of runoff diverted into the floodplain for treatment. The group came to consensus on the key terms, definitions and qualifying conditions for both floodplain restoration design approaches (*Section 3*).

The groups reviewed the considerable research conducted over the last decade on the sediment and nutrient dynamics associated with FR projects (*Section 4*) and concluded that:

Denitrification can be enhanced when the hyporheic zone is expanded, floodplains are connected to aquifers or runoff, and roots and other organic matter provide a carbon source. Denitrification rates are variable in space and time, but tend to increase with greater geomorphic and floodplain complexity, greater supply of nitrogen, and as floodplain plant communities mature.

Both sediment and nutrients are effectively trapped by floodplains during larger storms, where they may be stored for many decades. Most of the trapping research has occurred in natural, un-restored floodplains in the Chesapeake Bay watershed, but there is strong evidence that FR projects that increase the annual volume of storm flow diverted to the floodplain can mimic this function.

The groups recommended changes to the existing crediting protocols to improve their accuracy and reliability in estimating pollutant reduction for restoration projects.

Protocol 2 (P-2): Hyporheic Box (*Section 5)*

While the 2014 Stream Restoration Expert Panel intended for the dimensions of the hyporheic box to be variable – applying to sections of the stream where hyporheic exchange could be documented and verified – the 5 ft depth was frequently applied as a default. The groups concluded that the fixed unit dimensions (5 ft) of the original hyporheic box were not consistent with recent stream research and field measurements and needed to be replaced with an "effective hyporheic zone" or EHZ, defined by actual site conditions.

For FR-LSR projects, the EHZ extends across the full width of the restored floodplain, but is typically very shallow for most projects. The lateral boundaries of the EHZ are defined by the restored floodplain elevations above the channel bed or low flow water elevation as confirmed by field measurements and shown on post-construction plans. A similar field investigation approach, using slightly different indicators, was developed to define EHZ boundaries for RSB projects.

The groups also agreed on an updated unit area denitrification rate to apply to the EHZ that reflects the current research consensus. A new equation was also developed to adjust the unit rate to account for individual site differences, such as baseflow conditions, aquifer conductivity and floodplain soil saturation.

The bank height ratio (≤1) requirement established by the original expert panel for Protocol 2 was eliminated, since it does not typically apply to most low-bank FR projects. The group also developed design examples to show how the changes to Protocol 2 would apply to typical floodplain restoration projects.

Protocol 3: Floodplain Reconnection (Section 6).

Both groups agreed on improved methods to define the extent of the floodplain treatment zone (FTZ), model flow diversions from the stream to floodplain, and compute sediment and nutrient reduction achieved in the floodplain by individual projects.

The groups concluded that hydraulic modeling that computes critical flow velocities in the floodplain could be used to define the boundaries of the FTZ, and that the one-foot elevation cap could be relaxed in certain circumstances.

They also agreed that downstream methods provide superior estimates of the annual volume of storm runoff diverted into the floodplain for treatment, and provided more detail on how to apply them to individual FR projects. These include standard baseflow channel definitions, acceptable techniques for separating storm flow from baseflow and methods to select and process appropriate USGS flow gage data.

Both groups also endorsed the use of the floodplain removal rates contained in the recently approved expert panel reports on non-tidal wetland (NTW) restoration, creation and rehabilitation. The project load reduction is computed by multiplying the nutrient and sediment loads delivered to the floodplain in the FTZ treatment volume by the most appropriate removal rate, given the wetland conditions encountered at individual floodplain restoration/rehabilitation projects.

Lastly, the groups decided to eliminate the upstream watershed to floodplain surface area ratio (>1) requirement. The original expert panel used this requirement to adjust the FTZ load reduction downward in certain upstream watershed situations, but the new groups concluded it was not needed.

Environmental Considerations and Practice Verification (*Section 7*).

The groups established new environmental and verification requirements for FR projects to ensure they minimize unintended environmental consequences and maintain their intended functions over time. Based on an extensive research review on environmental impacts, the groups recommended more than 20 "best practices" to follow during project assessment, design, construction, and operation. The groups also developed specific indicators for verifying the long-term performance and functions of individual projects.

FR projects require careful field assessment and use of best practices during design and construction to minimize detrimental environmental impacts.

Note on Non-Urban Practices

These recommendations do not apply to non-urban stream restoration practices, often associated with NRCS or federal farm bill conservation programs. The Chesapeake Bay Program's Agriculture Workgroup has been separately charged with convening an expert panel, or similar group, to evaluate NRCS stream restoration practices that do not adhere to the stream restoration protocols developed by the Urban Stormwater Workgroup and refined within this guidance document.

Note on Grandfathering of Existing Projects

The group recommends that all new definitions, qualifying conditions and changes to Protocol 2 and 3 methods take effect on July 1, 2021. This "ramp-up" period will allow practitioners the opportunity to adjust to meet the new guidelines set forth in this document. Any projects already in the ground or under contract as of July 1, 2021 should not be subject to the new recommendations, but should adhere to the definitions, qualifying conditions and Protocol 2 and 3 calculations laid out in the Stream Restoration Expert Panel Protocols (2014) unless these newer guidelines are adopted by the project team. The final authority for making crediting decisions for qualifying projects falls to the appropriate state regulatory agencies.

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The following memo documents proposed modifications for how pollutant reduction credits are calculated using the stream restoration protocols for denitrification within the hyporheic zone and pollutant removal due to floodplain treatment as outlined by policy approved by the Urban Stormwater Work Group (USWG, 2016).

1. Charge and Roster of the Working Group

In its report, "Recommendations of the Expert Panel to Define Removal Rates for Individual Stream Restoration Projects", the original expert panel recommended ways to define pollutant removal credits for several classes of stream restoration including LSR, NCD and RSC projects (USR EP, 2014). Over the last five years, a diverse group of stream restoration stakeholders requested that the original protocols be revisited, and four groups were formed in late 2018 to do so (USWG, 2018). The Urban Stormwater Workgroup (USWG) convened an ad hoc team to review the protocols, update the science and provide additional guidance on their application. The members of the team are provided in Table 1.

While the original expert panel recognized the critical importance of floodplain reconnection in the design of stream restoration projects, the panel had low confidence in the methods for how to effectively estimate the pollutant removal credits. Stakeholders from both the public and private sector have sought to re-examine protocols 2 and 3 to make sure they effectively capture the interaction of a stream and its floodplain.

Table 1. Roster for Group 4

Name	*Affiliation*	*E-mail Address*
Joe Berg	Biohabitats	jberg@biohabitats.com
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The group was charged to review and recommend in the following areas:

- Determine if any pollutant reduction protocols from past or current CBP expert panels on wetland creation/restoration can be used to address floodplain reconnection and wetland dynamics.

- Ensure protocols reflect our current understanding of stream and floodplain dynamics and investigate potential standard methods to define post-restoration floodplain storage and sediment trapping capacity within the project reach.

- Determine how far the hyporheic box can be extended from the stream channel into the adjacent floodplain, especially when the project restores or rehabilitates floodplain wetlands.

- Evaluate how landscape position influences the pollutant reduction capability of floodplain reconnection projects (i.e., the relationship between the contributing upland watershed, the original and proposed stream reaches and degree that they both interact with the adjacent floodplain).

- Assess any new qualifying conditions needed to ensure that floodplain protocols are properly applied.

As Group 4 deliberated, it became apparent that a specialized team should be formed to assess floodplain restoration projects involving the removal of legacy sediments (Table 2). Individual team members were interviewed in October and a day-long team workshop was conducted in York, PA on 11/6/19. Recommendations were finalized in response to e-mails comments and conference calls in 2019 and 2020.

Table 2. Members of the LSR Crediting Team

Name	*Affiliation*	*E-mail*
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2. Background on Protocols 2 and 3

The Need for New Protocol 2 and 3 Guidance

Stream restoration projects that qualify for credit using Protocol 2 (Denitrification in the Hyporheic Zone) and Protocol 3 (Floodplain Treatment Volume) are designed to reconnect degraded and incised streams with their floodplain throughout the restoration reach. By restoring the stream flow access and groundwater interaction with the floodplain, the restorations promote natural nutrient and sediment processes in the floodplain while reducing erosive flow velocities within the project area and downstream. A detailed description of how the original expert panel defined Protocol 2 and Protocol 3 is available in Appendix A.

Since the release of the first expert panel report (USR EP, 2014), hundreds of miles of new stream restoration projects have been implemented across the Chesapeake Bay watershed. When the expert panel developed its recommendations, Natural Channel Design (NCD) was the predominant design approach being used in the Chesapeake Bay Watershed. Therefore, many of the recommendations focused on the NCD approach.

In recent years, other approaches, including stream and floodplain restoration with legacy sediment removal (FR-LSR) and regenerative stormwater conveyance (RSC) have become more common, and research and monitoring results to assess their effectiveness are now available. With 5 years of additional experience, several key needs were identified to improve upon the original protocols:

- Guidance for how floodplain treatment may differ across design approaches (NCD, FR-LSR, RSC)
- Re-evaluation of the hyporheic box dimensions
- A protocol that more accurately estimates the pollutant removal credits for designs that restore natural floodplain processes and provide re-connection during frequent, small storm events
- Better alignment with the new Phase 6 Chesapeake Bay Watershed Model

Section 3. Key Practice Definitions and Qualifying Conditions

3.1 Common Terminology

The group agreed on the terms and acronyms and definitions in Table 3 to guide their discussions.

Table 3: Glossary of Key Project Crediting Terms	
EHZ	*Effective Hyporheic Zone:* The area of restored channels and floodplain wetlands used to calculate nitrogen reduction credits under P-2 (Figures 1, 2 and 3).
FTZ	*Floodplain Trapping Zone* where low energy conditions encourage trapping and filtering of sediments and organic matter in the floodplain during and shortly after storm events. Extends one foot above the baseline floodplain elevation, unless a higher elevation is justified by local H&H modeling.
HA	*Hyporheic Aquifer:* An aquifer within the HEZ with a high hydraulic conductivity that underlies a hydric surface soil layer, where shallow groundwater exchange with the bed and banks of the stream channel occurs
HEZ	*Hyporheic Exchange Zone:* Subsurface zone where nitrogen processing is highest and where denitrification credits are calculated for P-2. The HEZ is where surface water and groundwater interact with the channel banks and the plant root zones in the floodplain. The HEZ occurs where a hyporheic aquifer underlays and is in direct contact with the floodplain root zone, and the channel planform supports surface and groundwater exchange with the hyporheic aquifer.
*Note: D*efinitions for terms specific to the original expert panel report (Hyporheic Box, NCD, RSC), are found in the Urban Stream Restoration Expert Panel (2014).	

FR projects can be applied to many sub-watersheds. The restoration sites with the greatest potential occur where there is sufficient space available to restore a naturally wide floodplain, and incised and overwide channels have formed through unconsolidated sediments. The technique can be highly effective at legacy sediment "hotspots" with high downstream sediment delivery (e.g., active streambank erosion upstream of breached mill dams; upstream sub-watersheds that are rapidly urbanizing and delivering more storm runoff to the stream valley, Fleming et al, 2019). The FR approach has been effectively implemented in watersheds with urban, agricultural and forested land uses.

FR practices have been successfully applied in all physiographic regions of the Chesapeake Bay watershed, including the Piedmont, Coastal Plain, Ridge and Valley and Alleghany plateau provinces. These practices have also been successful in both carbonate and non-carbonate watersheds. The design for individual projects is adjusted to account for differences in underlying watershed geology.

3.2 Two Strategies for Floodplain Restoration: LSR and RSB

Table 4: Comparison of the Two Major Floodplain Restoration Strategies

Factor	Floodplain Restoration Strategy [1]	
	LSR Legacy Sediment Removal	**RSB** Raised Stream Bed
Strategy	"Lower the Floodplain"	"Raise the Stream"
Design Approach	Legacy sediments are removed to restore the floodplain, which reduces bank heights, expands hyporheic exchange, and reconnects a stream or increases existing connection of a stream to its floodplain and aquifer	Raise the stream bed either by (a) filling incised channels and/or (b) installing riffle/grade control practices To effectively lower bank heights, raise the shallow groundwater into the root zone, and more frequently access the floodplain
Boundaries and Zones	Both share common zones such as EHZ and FTZ, but use different indicators and field methods to define their precise vertical and lateral boundaries	
Project Qualifying Conditions	● Project EHZ and FTZ boundaries based on field investigations ● Avoid extended ponding/inundation of the floodplain	
	● Legacy sediment deposits are present ● LS removal primary restoration technique ● Floodplain reconnected to valley aquifer by removal of fine-grained sediment	● Upstream and downstream grade controls to maintain intended stream invert ● Maintain or improve pre-restoration baseflow characteristics
Floodplain Plant Community	Restore historical floodplain plant community (often wet meadow complexes)	Wider range of potential floodplain habitat outcomes, e.g., could also be forest, scrub-shrub, wet meadow, or emergent wetlands
Protocol 2: Adjustments	The dimensions of the EHZ are defined slightly differently across the stream and floodplain for each strategy, but both apply the same methods to calculate the total annual areal denitrification rate	
Protocol 3 Adjustments	Both approaches use the same methods to define the extent of the FTZ, model flow diversions from the stream to floodplain, and calculate the sediment and nutrient removal rate for the floodplain	

A decade ago, many urban stream restoration designs focused on channel geometry to accommodate the flows and sediment inputs to the project reach. While floodplain reconnection was often considered, reconnection in these designs only occurred several times a year during larger storm events. Over time, scientists and practitioners have realized the importance of reconnecting the stream with its floodplain. If space is available along the stream corridor, designers seek to restore streams and floodplains together, using a diversity of design approaches borrowed from NCD, LSR, RCS and other sources.

For purposes of crediting, however, the wide diversity in floodplain restoration projects can be divided into two broad strategies to reconnect streams with their floodplains:

- **Legacy Sediment Removal (FR-LSR):** a stream and floodplain restoration approach where legacy sediments are removed from the floodplain to lower the floodplain surfaces, enhancing hyporheic zone functions and increasing the annual stream runoff volume diverted into the floodplain. The primary goal, when feasible, is to reconnect the floodplain to the hyporheic aquifer, re-establishing the hyporheic exchange zone.
- **Raising the Stream Bed (RSB):** a restoration approach that raises the surface water level in an incised or degraded stream channel through two primary techniques. One technique fills the incised channel with native materials to elevate the stream invert, thereby increasing the annual stream runoff volume diverted into the floodplain. A second technique uses a series of elevated riffle grade control structures or beaver dam analogues to slow flow velocities and promote floodplain access during storm events.

These two strategies are depicted in Figures 2 and 3. In addition, Table 4 provides a more detailed comparison of the two strategies in the context of the recommendations of this memo.

3.3 Existing Qualifying Criteria

The Stream Restoration Expert Panel (2014) outlined a series of qualifying conditions that must be met for a project to be eligible for Chesapeake Bay TMDL reductions. The qualifying conditions were designed to promote a watershed-based approach for screening and prioritizing stream restoration projects to improve stream function and habitat. Qualifying conditions from the original expert panel report will still apply and are outlined, in their entirety, in Appendix B.

3.4 New Qualifying Criteria

In addition, the following new qualifying conditions and clarifications have been added for all FR projects:

1. *Meet applicable floodplain management requirements in the stream corridor*. Any individual stream restoration project should be assessed with hydrologic and hydraulic models to demonstrate whether it increases water surface elevations or adverse downstream flooding impacts. In general, these analyses are based on design storm events and flood risk conditions established by the appropriate local or state floodplain management agency (e.g., the 100-year storm event).
2. *Evaluate the duration of floodplain ponding in the context of the restoration goals*. Micro pools and long-duration ponding of water on the floodplain is essential for amphibian habitat, but large open water features may adversely impact the desired riparian vegetative community. In evaluating a potential restoration site and design, consider the potential adverse effects of extended open water ponding based on the soil conditions, desired plant community and aquatic and amphibious habitat goals.
3. *Designers should demonstrate consideration of potential unintended consequences of the restoration (Outlined in Section 7)*. The project should document that an impairment exists and that the interventions or restoration work proposed are appropriate to address the impairment and will result in a positive ecological functional uplift (or change) for the stream and associated riparian system. Decisions related to the evaluation of existing, high functioning stream and riparian habitats will be made on a state-by-state basis by the appropriate regulatory agencies.

There are also several qualifying conditions specific to the different design approaches:

FR-RSB Qualifying Conditions

There are three additional qualifying conditions that apply to FR-RSB projects, as defined by Group 4. Those conditions are outlined below:

1. *Project must demonstrate that it either provides, or is tied into existing upstream and downstream grade control* to ensure the project reach can maintain the intended stream invert to access the floodplain.
2. *Project must clearly define the boundary of the effective hyporheic zone*. For FR-RSB projects the EHZ is a maximum of 18 inches deep in the floodplain soil profile, and extends only to those areas that are regularly inundated after the streambed is raised. The actual dimensions must be confirmed by site investigations that define stream flow conditions, root zones, aquifer conditions and the pre-project water table conditions (see Section 5 for details).
3. *Project must demonstrate that baseflow conditions are not reduced as a result of the restoration (ex. change from perennial to seasonal intermittent flow).*

FR-LSR Qualifying Conditions

There are four additional qualifying conditions that apply to FR-LSR projects, as defined by Team 5. They are summarized below. For more detail please see Appendix C.

1. Confirm the presence of legacy sediment deposits
2. Demonstrate that the design approach restores channel and floodplain connection with the hyporheic aquifer and restoration of processes within a hyporheic exchange zone. When modern site constraints prevent directly connecting the restored channel and floodplain to the hyporheic aquifer, the design should include measures to interrupt flow within the hyporheic aquifer and elevate the hyporheic exchange zone into the restored floodplain.
3. Defined EHZ boundaries across channels/floodplain
4. Legacy sediment removal is the primary floodplain restoration technique

4. Summary of Recent Research

Since the most recent version of the Stream Restoration Expert Panel Report (2014), there has been a rapid increase in stream restoration projects to achieve the nutrient and sediment reductions for the Chesapeake Bay TMDL. In the past, many projects emphasized the prevented sediment approach to reduce bank erosion within the stream channel (Group 1, 2020). More recent efforts focus on stream restoration designs that reconnect stream channels with their floodplains and promote more interaction between stream flows and groundwater.

This section provides a synthesis of recent research on the nutrient and sediment dynamics of reconnected streams and floodplains. The group also reviewed recent research on potential unintended environmental consequences of stream restoration projects, which is profiled in Section 7.

Denitrification in the hyporheic zone

There are several recent studies measuring how streambed and floodplain denitrification rates are influenced by stream restoration and floodplain reconnection. The recent research generally supports the conclusions of the original expert panel, but also has refined our understanding of where and when denitrification occurs in stream and floodplain restoration projects. Table 5 summarizes some of the key recent denitrification studies that were reviewed by both groups, and supports the following general conclusions:

- *There is ample support for updating the fixed dimensions of the hyporheic box.* Clay lenses or bedrock layers often restrict hyporheic exchange and the depth of these layers can vary by physiographic region. Denitrification is also less likely to occur deeper below the floodplain surface due to distance from the root zone, which provides a critical carbon source for promoting denitrification (Mayer et al 2010, Hester et al 2016, Doll et al 2018, Duan et al 2019, Hartranft 2019).

- *Enhanced denitrification can occur in floodplain soils as well as in the channel.* Recent research also supports a shift from a hyporheic box focused primarily on the streambed to an expanded hyporheic zone that extends across the restored floodplain. Denitrification not only occurs within and below the stream channel, but also in hotspots throughout the restored floodplain. Denitrification can be enhanced when the hyporheic exchange zone is restored, floodplains are re-connected to aquifers or wetlands, and plants provide an active carbon source. Denitrification rates are variable in space and time, but tend to increase at restoration sites with high hydraulic conductivity, connectivity to stream channel surface water, and mature floodplain plant communities (Kaushal et al 2008, Craig et al 2008, Mulholland et al 2008, Mayer et al 2010, Harrison et al 2011, WEP 2016, CBP 2019, Forshay et al 2019, Hartranft 2019).

- *Increasing the geomorphic complexity of the stream/floodplain system promotes greater denitrification.* Restored streams that increase the connectivity of the floodplain and create greater geomorphic complexity are often linked to higher denitrification rates. This complexity can involve increasing channel sinuosity, creating multi-thread channels, and installing instream wood and riffle structures to reduce flow velocities and increase in-stream transient storage (Cluer and Thorne, 2014, Tuttle et al 2014, Hester et al 2018, Lammers and Bledsoe 2017).

- *A strong technical foundation exists to derive an average unit area denitrification rate for the hyporheic zones associated with restored streams and reconnected floodplains.* More than a hundred denitrification research studies from across the Chesapeake Bay watershed and globally provide a basis for updating the estimated hyporheic denitrification rate formulated by the original expert panel (see Table 5).

Table 5: Denitrification in Hyporheic Zones

Summary: Restoring stream channels by increasing floodplain connectivity increases denitrification rates compared to unrestored streams. Increased denitrification occurs in a series of hot-spots and hot-moments, driven by factors including floodplain connectivity with the hyporheic zone, hydraulic residence time, nitrate concentrations and the available supply of organic carbon.

Citation	*Region*	*SR Type*	*Duration*	*Key Measurements*
Kaushal et al 2008	CB	NCD	1-2 yr	Denitrification rates in reconnected floodplains
Mulholland et al 2008	CB, OCB	NRS	1-2 yr	Uptake and denitrification as a function of stream nitrate concentrations
Klocker et al 2009	CB	NCD	1-2 yr	Nitrate uptake in restored and unrestored streams
Mayer et al 2010	CB	NCD	2-5 yr	Factors that influence denitrification rates in restored streams
Harrison et al 2011	CB	NCD	1-2 yr	Denitrification rates in urban floodplain wetlands
Weller et al 2011	CB	NRS	1-2 yr	Stream nitrate levels as a function of riparian buffers
Tuttle et al 2014	OCB	NCD	1-2 yr	Denitrification rates in streambed sediments
Hester et al 2016 & 2018	CB	FR	N/A	Model simulated nitrate removal in hyporheic zone and floodplain
Newcomer-Johnson et al 2016	CB, OCB	FR	N/A	Meta-analysis of nutrient uptake in restored streams.
Lammers and Bledsoe 2017	CB, OCB	FR	N/A	Meta-analysis of streambed and riparian denitrification rates
Mcmillan and Noe 2017	OCB	NCD	1-2 yr	Sedimentation and nutrient processing in restored floodplains
Audie 2019	CB	LSR	5+ yr	Groundwater residence time, groundwater nitrogen
Duan et al 2019	CB + Lab	RSC	< 1 yr	Effect of carbon inputs on nitrogen retention
Forshay et al 2019	CB	LSR	5+ yr	Stream and groundwater nitrate vs. denitrification

Key

CB: Chesapeake Bay Watershed OCB: Outside the Chesapeake Bay Watershed	NCD: Natural channel design LSR: Legacy sediment removal RSC: Regenerative stormwater conveyance NRS: Non-restored stream FR: Floodplain restoration	Duration >1 yr 1-2 yr 2-5 yr 5+ yr

Floodplain Trapping and Attenuation

Stream restoration designs that promote floodplain reconnection and restored floodplain soils can achieve additional nutrient and sediment attenuation. Recent research, summarized in Table 6, supports the following takeaways:

- *Sediment and nutrient trapping rates in reconnected floodplains can be similar to "natural" floodplains*. A series of comprehensive monitoring studies, conducted as part of the Chesapeake Floodplain Network, have measured long-term sediment and nutrient trapping rates for natural floodplains across the Bay watershed (Noe 2013, Noe et al 2019a). The research indicates that both sediment and organic nutrients are effectively trapped by floodplains during larger storms, where they may be stored for many decades. While most of the research has occurred in un-restored floodplains, there is some evidence that FR projects that increase storm flow diverted to floodplains can mimic or replicate trapping function (McMillian and Noe 2017, Noe et al 2019b).

- *Trapping can occur across a wide range of storm events*. Another finding from recent research is that there is support for refining the treatable floodplain volume cap imposed by the original expert panel. This new research shows that sediment and nutrient retention occurs in the floodplain at a similar rate, regardless of the size of the storm event (Noe et al 2019a). On the other end of the spectrum, deposition can also occur in the frequent, small storm events for highly reconnected systems (McMillan and Noe 2017, Langland 2019).

- *Restoring the stream and floodplain system will ultimately improve nutrient and sediment retention capacity*. In addition to trapping, restoration projects that restore floodplain/geomorphic complexity and promote overbank flooding can enhance filtering and microbial uptake removal mechanisms in the floodplain (Noe et al 2013, Hilderbrand et al. 2014, WEP 2016, CBP 2019).

Table 6. Sediment and Organic Trapping in the Floodplain

Summary: Recent literature provides a good understanding of sediment trapping dynamics within un-restored floodplains. Restored streams that promote floodplain reconnection are inferred to provide trapping rates similar to these systems across a wide range of storm events.

Citation	*Region*	*SR Type*	*Duration*	*Key Measurements*
Hupp et al 2013	CB	NRS	2-5 yr	Bank erosion and floodplain deposition rates
Noe et al 2013	CB	NRS	1-2 yr	Soil net ammonification, nitrification, N, and P mineralization
Donovan et al 2015	CB	NRS	N/A	Gross erosion and deposition rates
Gellis et al 2017	CB	NRS	2-5 yr	Erosion and deposition rates in channels and floodplains
McMillian and Noe 2017	OCB	NCD	1-2 yr	Sedimentation and nutrient processing in restored floodplains
Gillespie et al 2018	CB	NRS		Inputs, cycling and losses of nutrients and sediment
Pizzuto et al 2018	CB	NRS		Sediment transport and storage
Noe et al 2019	CB	NRS	5+ yr	Sedimentation rates and nutrient deposition
Noe et al 2019b	CB	NRS	5+ yr	Sedimentation rates and nutrient deposition

Key

CB: Chesapeake Bay OCB: Outside the Chesapeake Bay Watershed	NCD: Natural Channel Design LSR: Legacy Sediment Removal RSC: Regenerative Stormwater Conveyance NRS: Non-Restored Stream	Duration >1 yr 1-2 yr 2-5 yr 5+ yr

Pollutant Dynamics in Restored Stream Channels

Fewer studies are available to demonstrate the actual change in pollutant loads as they pass through an individual stream restoration project. These experiments are very difficult, as they require long-term monitoring of very complex and dynamic systems over a wide range of flow conditions. Nutrient sampling is needed at the top and bottom of the reach, but may also be needed in the hyporheic zone, floodplain or aquifer to fully capture the nutrient transformations occurring in space and time. Lastly, the upstream nutrient and sediment loads delivered to the stream reach can be extremely variable and are not dictated by the stream restoration approach. Further, within reach contributions of nutrients from stormwater or groundwater sources complicate pollutant load comparisons.

Several notable long-term studies on pollutant dynamics in restored stream channels are summarized in Table 7 and outlined below:

- *Upstream and site conditions are an important factor in determining the in-stream nutrient levels of a restored reach.* Incoming nitrate concentrations are one of the most important factors in determining denitrification rates within a stream restoration. Further, the capacity of restored stream systems to trap and retain sediments and nutrients in the long-term may depend on the magnitude of sediment loads originating upstream and the physical setting (gradient, watershed position) of the restoration (Tuttle et al 2014, Filoso et al 2015, Mueller-Price et al 2016, Lammers and Bledsoe 2017).

- *Restored streams are dynamic systems and adjustments are expected over time.* The age of restoration can be an important factor in nutrient removal performance. This is particularly true for sites where new riparian vegetation was planted following construction. As vegetation becomes stable and more robust, carbon availability improves, increasing microbial activity (McMillian and Noe 2017, Forshay 2019; Hartranft, 2019)

Table 7. Nutrient Dynamics in Restored Stream Channels

Summary: Nutrient treatment and retention in restored stream systems are dynamic and variable based on site-specific conditions. Upstream nutrient and sediment loads as well as nutrient loads supplied through groundwater sources play a significant role in in-stream loads at restoration sites and measured reductions can change over time as channels adjust and riparian corridors mature.

Citation	*Region*	*SR Type*	*Duration*	*Key Measurements*
Tuttle et al 2014	OCB	NCD	1-2 yr	Denitrification rates in streambed sediments
Filoso et al, 2015	CB	RSC	2-5 yr	Input-output budgets of suspended sediment in a restored reach
Mueller-Price 2016	OCB	NCD/NRS	1-2 yr	Transient storage and nitrate uptake
Forshay et al 2019	CB	LSR	5+ yr	Surface water and groundwater nitrate and denitrification rates
Langland 2019	CB	LSR	5+ yr	N, P and TSS removal

Key

CB: Chesapeake Bay OCB: Outside the Chesapeake Bay Watershed	NCD: Natural Channel Design LSR: legacy sediment removal RSC: Regenerative Stormwater Conveyance NRS: Non-Restored Stream	Duration >1 yr 1-2 yr 2-5 yr 5+ yr

Big Spring Run Project

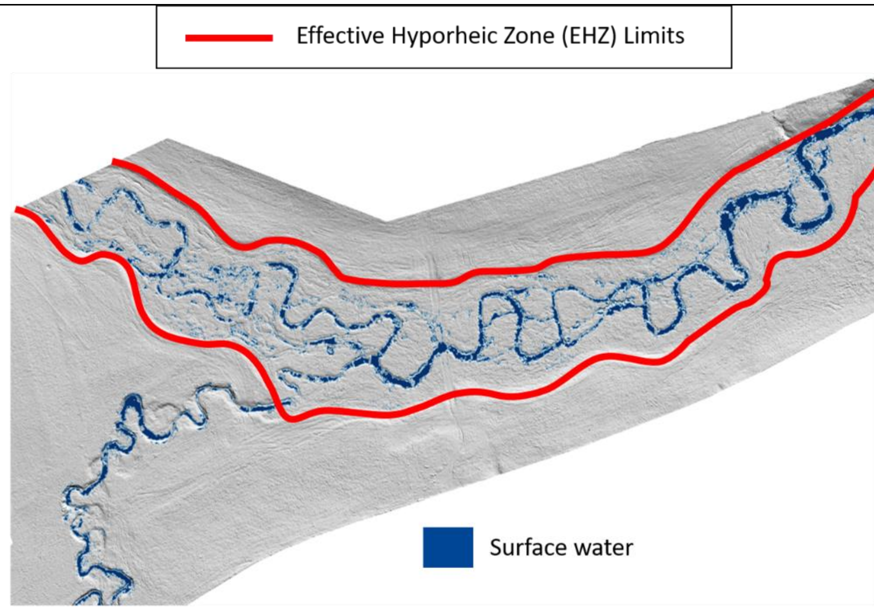
One of the best long-term monitoring studies of stream restoration project is the Big Spring Run project in Pennsylvania, which investigated improvements in ecosystem functions of a floodplain restoration projects that removed legacy sediments from the valley bottom. The initial research findings are described in a series of papers by Langland (2019), Hartranft et al. (2011) and Hartranft (2019), Fleming et al. (2019), and are reviewed in detail in Appendix C.

5. Recommendations for Modifying Protocol 2

The group found many areas of consensus for how to apply Protocol 2 to FR projects, which are profiled in Table 8.

Table 8. Summary of Areas of Consensus for Protocol 2
For FR-LSR Projects: • Replace the existing Hyporheic Box with an areal "Effective Hyporheic Zone". The lateral dimensions of the EHZ are defined by locations where the restored floodplain elevations are less than 18 inches above the channel or low flow water elevations (see Figures 1 and 2). • Define how the lateral boundaries for the EHZ should be measured in the field and shown on post-construction plans • The HEZ (Hyporheic Exchange Zone) will typically be shallow, often only 9 to 18 inches deep for most projects. Depths exceeding 12 inches would typically only occur in project reaches with large watersheds and/or large spring baseflows. • Guidance for on-site soil/groundwater testing to define EHZ *For FR-RSB Projects* • Replace the existing Hyporheic Box with an areal "Effective Hyporheic Zone". The lateral dimensions of the EHZ are defined by locations where the restored floodplain soil profile is less than 18 inches above the elevated water table, extending only to those areas that are regularly inundated after the streambed is raised (see Figures 1 and 3). • Define how the lateral boundaries for the EHZ should be measured in the field and shown on post-construction plans • Guidance for on-site soil/groundwater testing to define EHZ *For ALL FR Projects:* • Replace the existing denitrification rate (1.95×10^{-4} lbs/ton/day) with a new rate (2.69×10^{-3} lbs NO_3/sq ft/year) based on the latest science and adjust it based on site factors, such as seasonal streamflow, floodplain soil saturation and the underlying materials in the hyporheic aquifer (i.e., the Parola Equation). • Eliminate the bank height ratio (≤1) requirement, since these don't typically apply to most low-bank FR projects.

Figure 1. Depiction of EHZ boundaries in plan view. (Credit: Jeff Hartranft)



Big Spring Run post-restoration verified Effective Hyporheic Zone (EHZ) limits using ground based Lidar

For FR-LSR Projects: The Effective Hyporheic Zone

The group recommends replacing the existing hyporheic box with the concept of an areal, effective hyporheic zone (EHZ). The dimensions of the EHZ are as follows, and as shown in Figures 1 and 2.

- The floodplain area eligible for P-2 credit includes the lateral extent of a hyporheic aquifer composed of a layer of gravel, sand or fractured/degraded bedrock. The hyporheic aquifer also includes a thin layer of floodplain soils above this base layer and is encompassed with in the hyporheic exchange zone (HEZ).

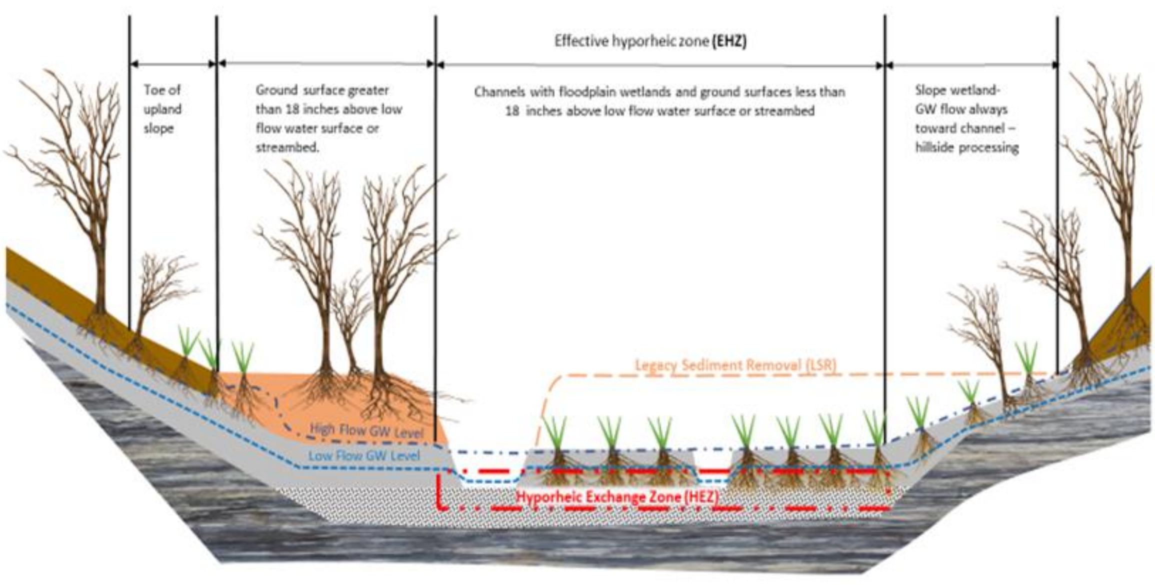
- Operationally, the EHZ extends laterally across all areas of the channel and floodplains that are less than 18 inches above the channel bed or low flow water elevations. Any area of high floodplain (i.e., elevation greater than 18 inches above channel bed or low flow water elevation) are excluded from any P-2 credit. See Figure 2. The 18 inch floodplain elevation is a nutrient crediting-based threshold and represents the depth of the root zone that facilitates hyporheic exchange and provides a carbon source for denitrification.

- Designers should assess site factors to demarcate the EHZ across the valley bottom, such as hydric or saturated soils, presence of carbon sources and/or active root zones, or other floodplain stratigraphy that is less than 18 inches above the channel bed or low flow water elevations. These factors are used to accurately map the lateral EHZ boundaries at the project site. These investigations can include:

- Trenches, direct push coring and/or tile probing analyses of exposed streambanks to document soil stratigraphy and identify buried floodplain soils, basal gravels, bedrock or groundwater elevations.
- Direct push coring provides similar information to trenches, but can cover more area with somewhat less precision
- Tile probes can identify depths to gravel and bedrock over a larger area in less time, but are limited to "feel" rather than sight.
- Radiocarbon dating of organic material combined with magnetic resonance imaging can constrain the ages of floodplain stratigraphy and target restored floodplain elevations.

- Methods should be tailored to reach conditions when defining the target elevations and boundaries for the project EHZ. Photogrammetric survey or LIDAR methods can also be used to create a digital elevation terrain model to define the lateral boundaries of the EHZ.

Figure 2. Effective Hyporheic Zone for FR-LSR Projects (Credit: Art Parola)

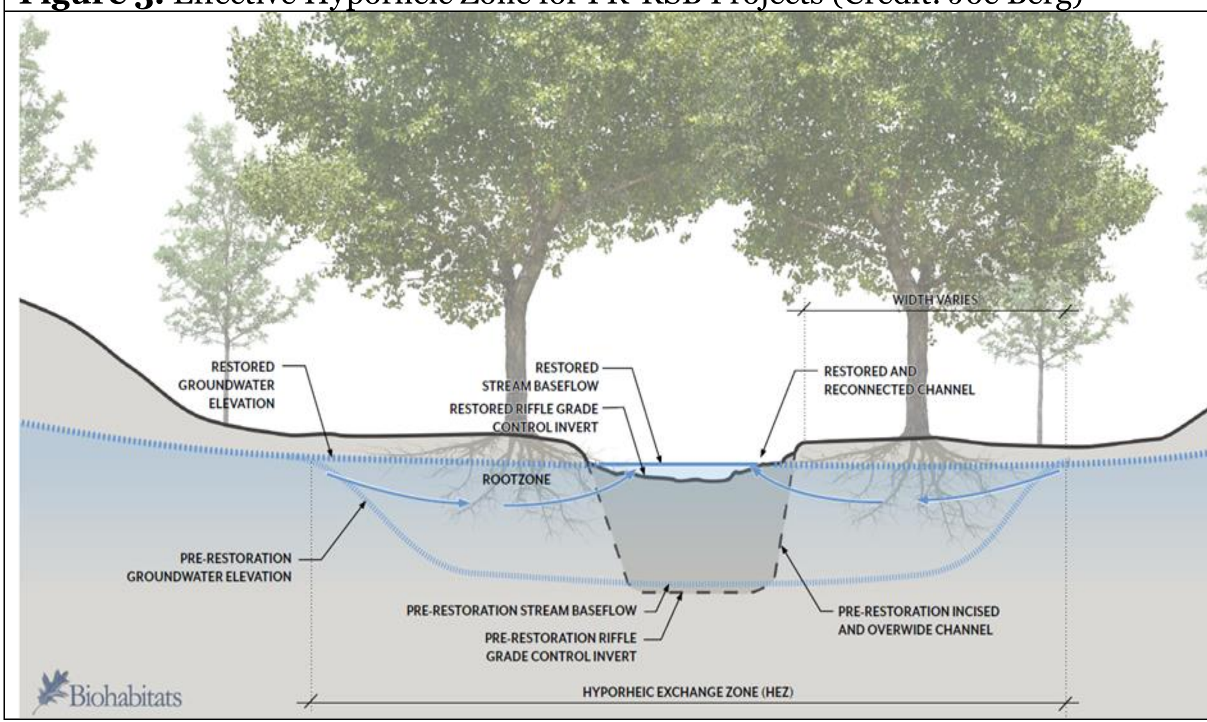


For FR-RSB Projects: The Effective Hyporheic Zone

The group recommends replacing the existing hyporheic box with the concept of an areal, effective hyporheic zone (EHZ). The dimensions of the EHZ are as follows, and as shown in Figures 1 and 3.

- The floodplain area eligible for P2 credit in FR-RSB projects is the region below and alongside a stream, occupied by a porous medium where there is an exchange and mixing of shallow groundwater and the surface water in the channel. The dimensions of the effective hyporheic zone are defined by the hydrology of the stream, substrate material, its surrounding environment, and local groundwater sources.
- Operationally, the EHZ that is expanded by FR-RSB projects will extend laterally across the floodplain to areas where the floodplain soil profile is less than 18 above the elevated water table and extends only to those areas that are regularly inundated after the streambed is raised. The actual dimensions must be confirmed by site investigations that define stream flow conditions, root zones, aquifer conditions and the pre-project water table conditions.
- Groundwater testing must be conducted in the floodplain within a year after construction to confirm that the intended water table elevations have been achieved. These testing locations should be shown on construction plans as filed indicators for future verification efforts.

Figure 3. Effective Hyporheic Zone for FR-RSB Projects (Credit: Joe Berg)



Revisiting the denitrification rate

Since the original expert panel report was published, several new studies have reviewed nitrogen removal rates in restored streams. Their findings are summarized in Table 9.

Table 9. Comparison of several nitrogen removal studies published since 2012.

Study	*Sites*	*Unrestored*	*Restored*	*Method*	*Units*
Newcomer Johnson et al 2014	4	43.3 – 490.8	8.5 – 588.7	Denitrification	µg N/kg soil/day
Newcomer Johnson et al 2016	12, 32	median: 0.42	median: 1.8	Nitrate uptake	$\mu g/m^2/s$
Lammers and Bledsoe 2017	69	--	1.85	Denitrification	mg N/ m^2/hr
Hester et al 2016	1	--	-3.1%	Change in N received by reach due to denitrification	Percent change

The group decided to replace the old denitrification rate (1.95×10^{-4} lbs/ton/day) with a new, areal rate of 1.50 mg $NO_3/m^2/hr$ (2.69×10^{-3} lbs NO_3/sq ft/year). The new rate is based on the difference in median nitrate uptake rate between restored and unrestored streams from Newcomer-Johnson et al. (2016) -- 4.96 mg $NO_3/m^2/hr$. The rate was then adjusted to assume that 30% of this uptake is from denitrification based on data on urban streams from Mulholland et al. (2008).[1]

The old rate was based heavily on in-situ denitrification studies in restored streams within the Baltimore metropolitan area (Kaushal et al., 2008; Striz and Mayer, 2008). The new rate combines the most up to date, comprehensive review of nitrate uptake literature, with the most comprehensive denitrification study to produce a more defensible rate. Furthermore, this areal denitrification rate provides a more relevant metric for calculating nitrogen removal based on the area of the EHZ.

Adjusting the Base Denitrification Rate for Site Conditions

The group's review of the recent research (summarized in Section 2) emphasized the importance of site-specific factors that appear to influence denitrification capacity within the reconnected floodplain.

The first factor relates to the type of materials found in the proposed EHZ. Groundwater movement in the EHZ is closely related to the hydraulic conductivity of the underlying hyporheic aquifer. In general, groundwater movement is enhanced by gravel or sandy layers, and is more constrained when they are composed of tighter silts and clays (which

[1] Calculation for the final areal denitrification rate: 1.8-0.42 = 1.38 $\mu g/m^2/s$ = 4.96 mg $NO_3/m^2/hr$ (from Newcomer Johnson et al. 2016). 4.96 x 0.3 = 1.488 mg $NO_3/m^2/hr$ (from Mulholland et al. 2008).

were often deposited in the legacy sediment layer). The aquifer conductivity reduction factor accounts for the relative differences in material hydraulic conductivity between soil types (Domenico and Schwartz, 1990) and was then adjusted based on best professional judgment to account for additional porosity added by the floodplain root zone.

The second factor involves sustained saturated soil in the rootzone, which is strongly related to the type of wetland and non-wetland vegetation found in the EHZ. The duration of hyporheic exchange throughout the year and reliable anaerobic conditions are important indicators for enhanced denitrification in the root zone. Where soil saturation is very close to the floodplain surface (0-20 cm) for long durations, herbaceous and scrub shrub wetlands thrive. As the depth from the floodplain surface to groundwater increases, trees (excluding certain highly tolerant species such as cypress and tupelo) are much more prolific as a result of groundwater being deeper and/or the water table dropping for portions of the growing season.

The last factor includes the seasonality of streamflow within the hyporheic zone, which varies depending where the reach is located in the stream network. The importance of valley slope was also considered as a factor but was excluded to avoid further complication.

Parola et al. (2019) developed a simple equation to adjust the base denitrification rate to account for these three site factors, which is shown in Table 10. Guidance is also provided on how to estimate reduction factors for baseflow, soil saturation and aquifer conductivity conditions found at individual sites. The group recommends that this equation be used to adjust the denitrification rate for all floodplain restoration projects.

Table 10: Site Specific Discount Factors for Adjusting the Denitrification Rate (Parola et al, 2019)					
HEZ N credit = (Base Rate) (EHZ) (B_f) (S_f) (A_f)					
Baseflow Reduction Factor (B_f)		Soil Saturation Reduction Factor [1] (S_f)		Aquifer Conductivity Reduction Factor [2] (A_f)	
Perennial baseflow	1.0	Channel	1.0	Gravel, sandy gravel or clean sand	1.0
Baseflow in all but late summer/fall	0.75	Herbaceous or scrub shrub wetland	1.0	Silty sand or silty gravel loam	0.6
Baseflow in winter/spring	0.50	Forested wetland	0.6	Silt	0.2
Baseflow only during wet seasons	0.25	Non-wetland forest	0.2	Clayey silt	.05
Flow only during runoff events	0.10	Non-wetland herb. Scrub shrub	0.1	Clay	.001

[1] Vegetative cover is used as a proxy for soil saturation that controls riparian plant community types. Sustained saturated soil in the rootzone is a key to reliable and consistent high rates of denitrification.

[2] This refers to an aquifer capacity factor based on the dominant hyporheic materials immediately below the floodplain soil, and is loosely based on hydraulic conductivity

HEZ: Total annual N uptake credit calculated within the Hyporheic Exchange Zone

The “Base Rate” is the mean areal floodplain denitrification rate (pounds/square foot/yr), as recommended by Group 4.

EHZ: Effective Hyporheic Zone (square feet)

Table 11. Simplified design examples to show how the revised P2 works for LSR and RSB projects

FR-LSR Design Example

A 1,000 ft FR-LSR project is completed. The resulting stream-wetland complex has the following characteristics:

- Perennial baseflow
- Reconnected floodplain that extends 100 feet laterally on either side of the stream channel for the entire length of the restoration. The new channel is 5 ft wide.
- Nearly all of the legacy sediments were removed, providing floodplain reconnection with the hyporheic aquifer. However, due to site constraints, several limited pockets of legacy sediment remained perched more than 18 inches above the streambed or low flow water surface elevations. Those areas, identified during site-assessments, equal 10% of the restored floodplain area.

Step 1. <u>Define the Extent of the EHZ.</u>

Calculate the area of the restored floodplain:

- 1,000 ft x 200 ft = 200,000 sq ft

Calculate the area of the restored channel:

- 1,000 ft x 5 ft = 5,000 sq ft

Reduce by 10% to account for the floodplain area that is perched more than 18" above the low flow water surface or streambed elevations:

- 200,000 sq ft x 0.9 = 180,000 sq ft

Step 2. Apply the Denitrification Rate to the EHZ

- 180,000 sq ft x 0.00269 lbs/sq ft/year = 484 lbs NO_3/year
- 5,000 sq ft x 0.00269 lbs/sq ft/year = 13.45 lbs NO_3/year

Step 3. Apply the Site Specific Discount Factors

The site has perennial baseflow, sandy-gravel hyporheic soils and an herbaceous wetland plant community throughout the restored floodplain. Therefore, for the floodplain area, each factor is 1.0 and no discount is applied. The factors for the channel area would also all be 1.0.

- 484 lbs/year x 1.0 x 1.0 x 1.0 = 484 lbs NO_3/year
- 13.45 lbs/year x 1.0 x 1.0 x 1.0 = 13.45 lbs NO_3/year

Step 4. Add the floodplain and the channel and convert from NO_3 to TN.

- 484 lbs NO_3/year + 13.45 lbs NO_3/year = 497.45 lbs NO_3/year
- 497.45 lbs NO_3/year ÷ 4.427 = 112.37 lbs TN/year

FR- RSB Design Example

A 1,000 ft FR-RSB project is completed. The resulting stream-wetland complex has the following characteristics:

- Perennial baseflow
- Predominantly silty sand soils in the floodplain
- Reconnected, forested floodplain that extends 100 feet laterally on either side of the stream channel for the entire length of the restoration. Groundwater testing shows the water table is only regularly within 18 inches of floodplain surface across 70 feet on each side of the channel. The new channel is 5 ft wide.

Step 1. Define the Extent of the EHZ.

Calculate the area of the floodplain EHZ:

- 1,000 ft x 140 ft = 140,000 sq ft

Calculate the restored channel area:

- 1,000 ft x 5 ft = 5,000 sq ft

Total EHZ area: 145,000 sq ft

Step 2. Apply the Denitrification Rate to the EHZ

- 140,000 sq ft x .00269 lbs/sq ft/year = 376.6 lbs NO_3/year
- 5,000 sq ft x .00269 lbs/sq ft/year = 13.45 lbs NO_3/year

Step 3. Apply the three Site Specific Discount Factors

The site has perennial baseflow, silty sand hyporheic soils in the hyporheic zone and a forested floodplain. Therefore, the following discount factors are applied:

- 376.6 x 1.0 x 0.6 x 0.6 = 135.6 lbs NO_3/year

The channel area has the same baseflow conditions and soil type, but will have a different soil saturation factor:

- 13.45 x 1.0 x 1.0 x 0.6 = 8.1 lbs NO_3/year

Step 4. Add the floodplain and the channel and convert from NO_3 to TN.

- 135.6 lbs NO_3/year + 8.1 lbs NO_3/year = 143.7 lbs NO_3/year

143.7 lbs NO_3/year ÷ 4.427 = 32.5 lbs TN/year

6. Recommendations for Modifying Protocol 3

The group explored options to modify P-3 to improve how it estimates pollutant reduction achieved by FR projects due to increased connection between the stream and its floodplain. The group recommended three key changes to overhaul P-3:

1. *Dimensions:* Define the vertical and lateral dimensions of the FTZ to reflect a project's increased floodplain reconnection.

2. *Diversions:* Recommend "downstream" methods over "upstream" methods to model the diversion of stream runoff into the floodplain for treatment.

3. *Reduction Rates:* Assign an appropriate annual removal rate for the stream runoff treated within the FTZ, given recent expert panel reports that investigated pollutant removal by non-tidal wetland restoration projects

Defining the Dimensions of the Floodplain Trapping Zones:

The group specified the on-site data needed to establish channel flow and floodplain capacity and define the future boundaries of the floodplain trapping zone. These methods can include spatial data from field-run topographic field surveys, LIDAR data or drone surveys to delineate the above-ground FTZ volume within the project reach. The group agreed that modeled hydraulic parameters such as critical shear stress velocities could be used to define FTZ boundaries.

The team recommends replacing the one-foot floodplain elevation cap for crediting with a variable cap based on critical floodplain velocities. The group recommends that the upper limit of the floodplain trapping zone be defined by floodplain elevations that remain below critical floodplain velocities, as defined by 1-D HEC-RAS or 2-D hydrodynamic models.

The one-foot maximum floodplain elevation limit would remain as the default but can be relaxed when modeled floodplain flow velocities are below 2 ft/sec (up to 3 feet or the 10-year water surface elevation, whichever is lower). To standardize this assessment, an assumed Manning's n roughness on the floodplain of 0.07 and in the stream channel of 0.035 should be used. A summary of the analysis that led to this recommendation, conducted by Coleman and Altland (2020) is presented in Appendix D.

A Downstream Approach to Diversion Modeling

Two contrasting approaches have been used to model how stream flow is diverted into the floodplain. The "upstream" approach relies on upstream watershed models to compute flows to the project site using long-term rainfall/runoff statistics, whereas the "downstream" approach relies on scaling USGS flow data measured at long-term gages. The USGS gage(s) may be located in the same watershed or within an adjacent or nearby watershed with similar land use or geology.

The group recommends replacing the upstream approach that is currently embedded in Protocol 3 of the expert panel report (2014), with the downstream approach. In the short term, the team suggests that it is acceptable to use existing upstream rainfall models, but they should be phased out in the coming years.

The Group concluded that upstream methods tend to under-estimate annual reconnection volumes for low-bank projects that are highly reconnected to their floodplain, and that downstream methods provide more accurate estimates since they rely on measured baseflow and runoff rates from gage data.

Upstream Approach. The upstream approach is the one currently embedded in P-3 (USR EPR, 2014). Over the last five years, practitioners have created many spreadsheet models to simplify the upstream design approach, which vary greatly in terms of the hydrologic models and technical assumptions employed.

The two most common upstream methods include the rainfall to runoff method and the discrete method developed by Medina (Method 1 and 2 in USR EPR, 2014). Uncertainty is created by these methods, however, because they rely on standard hydrologic models to compute runoff that are best suited to predict large infrequent storm events and not the smaller, more common flow events that are important in floodplain reconnection.

Downstream Approach. The downstream approach estimates the floodplain diversion volume using stream flow data derived from USGS 15-minute interval flow gages that have similar watershed characteristics as the project site being evaluated.

The range of flow statistics are then related to the channel capacity of the project reach to compute the estimated overflow frequency and volume to the floodplain, given its new channel/floodplain dimensions. Several methods have been explored by Altland et al (2019), Doll et al (2018) and Lowe (2016).

Each downstream method uses flow duration curves, hydrograph separation and other flow processing techniques to define a range of flow conditions using USGS gage data (15-minute time step). The key flow conditions include: baseflow, channel flow, treatable floodplain flows (w/in one foot of floodplain invert) and untreatable floodplain flows (that are more than a foot deep).

Altland et al (2019) compared upstream vs. downstream models for computing the annual volume diverted into the reconnected floodplain for multiple FR-LSR projects of various scales and conditions, including the BSR project that has been extensively monitored. They concluded that upstream methods tend to under-estimate annual reconnection volumes for low-bank LSR projects, and that downstream methods provide more accurate estimates since they rely on measured baseflow and runoff rates from gage data (and compared well with treatment rates measured at the BSR site). A summary of their modeling results for five projects can be found in Table 12.

Table 12: Comparison of Floodplain Treatment Volume for 5 Projects Using Different Upstream and Downstream Methods

Site Factors	FR-LSR Restoration Projects				
	Israel Creek	Bens Branch	Talbot Branch	Furnace Ck	Big Spring Run
Drainage Area (mi^2)	29.1	2.4	0.3	1	1.9
IC (%)	5.0%	5.4%	1.0	45.9	14.0
Length (ft)	3666	4180	3392	4753	2592
Method	Percent of Annual Flow Volume Diverted to Floodplain for Treatment				
Upstream 1	8.6%	11.2	19.9	12.7	14.1
Upstream 2	20.4%	78.6	81.0	78.7	84.4
Downstream 1	48.1%	30.6	19.1	64.6	83.1
Wetland RR	0.2%	2.8	14.3	7.6	2.1
Modeling analysis by Altland et al (2019).					

Altland et al (2019) suspects the USGS gage approach may be more sensitive to differences in flow distributions due to varying watershed characteristics (e.g., carbonate vs. non-carbonate watersheds, rural, suburban or urban watersheds). Consequently, the team developed guidance on improved methods to derive regional flow curves from USGS gage data to estimate floodplain flow diversions (see Appendix E). The new methods can be used for all projects in a region to standardize the computation methods and reduce credit variability.

The new methods "scale" regional flow gage data by contributing watershed area for individual projects, using flow duration curves and hydrograph separation of mean baseflow using 15-minute flow data. Appendix E also outlines how post-restoration credits are calculated using the proposed channel and floodplain dimensions and discharge inputs to an individual FR-LSR project.

Selecting an Annual Floodplain Wetland Removal Rate

The original expert panel report relied on wetland removal rates and technical assumptions largely developed by Jordan (2007). In the original formulation of P-3, the pollutant load treated by the floodplain was multiplied by a base wetland removal rate. Since then, two new panels conducted a comprehensive literature review of the pollutant removal capability of non-tidal wetland restoration practices (WEP 2016; NTW EP 2019). The expanded data analyses contained in these two reports provide new insight into the nutrient and sediment capability of floodplain wetlands, and a stronger technical foundation to support a base wetland removal rates. The most recent expert panel established the increase in removal rates for three different categories of non-tidal wetland "restoration", as shown in Table 13.

Table 13. Floodplain Wetland Removal Rates in Prior CBP Expert Panel Reports

Wetland BMP Category	Pollutant Removal Rate (compared to pre-restoration)		
	Total N	Total P	TSS
NTW Restoration	42%	40%	31%
NTW Creation	30%	33%	27%
NTW Rehabilitation	16%	22%	19%

[1] as outlined in expanded lit review and recently approved EPR (NTW EP, 2020)

Group 4 recommends that the pollutant removal rate applied to the floodplain treatment volume should reflect the appropriate floodplain wetland category(s) present at the site, as defined in Table 14.

Wetland delineations are normally required as part of the stream restoration permit approval process. Consequently, designers should have adequate field delineation data to determine how much project floodplain area falls into each restoration category and choose the correct rate to calculate pollutant removal within its FTZ.

Table 14. Definitions of Restoration Categories from NTW EP (2020)

Restoration: Manipulate physical, and biologic characteristics of a site with the goal of returning natural/historic functions to a former wetland:

- No wetland currently exists or has been extensively degraded
- Hydric soils are present
- "prior converted"

Creation: Manipulate site characteristics to develop a new wetland that did not previously exist at the site:

- No wetland currently exists
- Hydric soils are not present
- Functional gain due to new wetland features

Rehabilitation: Manipulate site characteristics with the goal of repairing natural/historic functions to a degraded wetland:

- Wetland present
- Wetland condition or function is degraded

Lastly, Group 4 found no evidence in the most recent series of NTW restoration expert panel reports to justify the continued use of Step 4 (from the 2014 Expert Panel Report) for P-3. The original stream restoration panel (USR EPR, 2014) added Step 4 to adjust the FTZ load reduction downward in situations where the upstream watershed to floodplain surface area ratio was less than one. The group noted that sediment and nutrient trapping in the FTZ was governed more by actual flow velocities in the FTZ that occur during storm events which are considered in the new methods to define its boundaries.

7. Environmental Considerations for Stream and Floodplain Restoration Projects

7.1 Key Findings on Unintended Environmental Consequences

Stream restoration projects have the potential to exert unintended environmental consequences, particularly if they are poorly assessed, located, designed or constructed. The group reviewed the most recent monitoring and research studies that identified unintended consequences of stream restoration projects in the Chesapeake Bay watershed and discussed how these potential impacts can be managed by adopting "best practices" during restoration project planning, design, and construction. The group offers the following caveats about their recommendations:

- The guidance provided on the environmental impacts of stream restoration projects is advisory in nature and is intended to promote best practices to minimize potential impacts for individual projects to the extent to which they apply.

- State and federal permitting agencies reserve the discretion to apply this guidance to support better permit decisions and always retain the authority to make permit decisions and/or establish permit conditions for TMDL-driven stream restoration projects.

- While this section primarily focuses on floodplain restoration projects, some of the research reviewed was drawn from other types of stream restoration projects or from unrestored streams or floodplains in the Bay watershed.

The group listened to more than a dozen presentations from researchers and regulators on the unintended environmental consequences and co-benefits associated with stream restoration projects. Many of the presentations involved floodplain reconnection projects, and all are included in Appendix G.

All stream restoration design approaches (i.e., NCD, RSC, LSR and their variants) can cause unintended consequences that degrade the quality of streams and/or floodplains. These consequences have been documented in a series of recent research studies in the mid-Atlantic region and elsewhere, which are profiled in Table 15.

Unintended environmental impacts have been observed in restored stream channels, floodplains and downstream ecosystems. Some common examples are shown in Figure 4. A more comprehensive summary of the scientific literature supporting Table 15 can be found in Appendix F.

Table 15: Review of Potential Unintended Consequences Associated w/ Floodplain Restoration Projects [1]

Impact [2]	Evidence	Notes
Project Stream Channel		
Depleted DO	M, P [3,4]	Associated with stagnant surface waters and high dissolved organic carbon. Often observed as seasonal.
Iron Flocculation	M, P	Observed in both restored and unrestored streams. Associated with high dissolved organic carbon, anoxic conditions and the use/presence of ironstone.
Warmer Stream Temps	M, P	Associated with loss of tree canopy in the riparian corridor. Exposure of groundwater seeps can help mitigate increased temperatures.
More Acidic Water	M, E	Associated with disturbance of channel and floodplain soils during construction.
More Primary Production	M, P	Associated with loss of canopy cover in the riparian corridor.
Benthic IBI Decline	M, P	Associated with construction disturbance, with recovery to pre-project levels in some cases.
Construction Turbidity	M, E	Sediment erosion during construction, especially when storm flows overwhelm instream ESC practices
Floodplain/Valley Bottom		
Project Tree Removal	M, P	Riparian/floodplain forest losses are common due to clearing for design and construction access.
Post-Project Tree Loss	M, P	Lab studies show that long-term soil inundation results in mortality and morphological changes in tree species.
Invasive Plant Species	M	Construction disturbance and frequent inundation of the floodplain can serve as vectors for invasive species along restored and unrestored streams.
Change in Wetland Type or Function	M	Changes in vascular plant communities as a result of floodplain inundation are expected and may be desirable or undesirable depending on the habitat outcome.
Downstream Ecosystems and Infrastructure		
Increased Flooding	E	Well-designed floodplain restoration projects should result in local flood stage reductions
Infrastructure Damage	E	Well-designed floodplain restoration projects should result in avoidance of flood damages to local infrastructure. Damage due to failure can occur in restored and unrestored streams.
Downstream Benthic Decline	M	Associated with changes in habitat conditions, and construction disturbance. Changes may be temporary and may be desirable or undesirable depending on project goals.
Blockage of Fish Passage	M	Incision, large drops or structure failures can impede passage. More study needed

Notes:
[1] Adapted from summaries presented by Clearwater (2019), Guignet (2019), Mayer (2019) and Williams (2019).
[2] Impacts are defined in relation to the stressors measured in a comparable unrestored urban stream/floodplain system.
[3] Evidence includes impact (M): observed or monitored at many restoration sites or (P): documented in a scientific report/paper or (E): observed at some project failures.
[4] References profiled in Appendix F.

Figure 4: Un-intended Environmental Impacts Caused by Poor Stream Restoration Projects

(a) Riparian Tree Loss Can be Severe During Construction unless Extreme Care is taken to Preserve and Protect Existing Trees

(b) Upstream Passage of Fish and other Aquatic Life can be Impeded by PoorlyDesigned In-stream Structures that Create Vertical Drops

(c) Excessive Pooling or Higher Groundwater Levels Can Kill Remaining Trees in the Floodplain that are not Adapted to the Changed Conditions

(d) Poor Designs Can Cause Water Quality Impacts to the Restored Stream Channel, such as stream warming, lower DO and iron flocculation (shown above)

Photo sources: (a-c) CSN files (d) courtesy M. Williams (2019)

Strong variability is frequently observed in the severity of impacts at individual projects. This variability is often related to:

- Site-specific or reach factors
- Exposure to extreme flow events, and
- Care taken during project assessment, design and construction.

It is generally acknowledged that restoration project construction often exerts short-term adverse environmental impacts. Years of ecosystem maturation may be needed before a project fully meets its long-term restoration objectives and realizes its full environmental benefits. There are few long-term monitoring studies available to confidently state the probability of long-term adverse impacts, though some failures are anticipated.

Perhaps the most visible project impacts involve vegetation disturbance and tree loss either direct removal during construction or mortality afterwards due to increased groundwater elevations and/or extended inundation of the floodplain, compaction and root disturbance from construction activities, or a variety of other reasons. A substantial literature review documents the response of forest and wetland plant species to changes in floodplain inundation frequency and root saturation. Some examples include Angelov et al (1996), Anderson and Pezeshki (1999), Pezeshki and Delaune (2012), Folzer et al (2006), Garssen et al, (2015), Teskey and Hinckley (1977 a,b, 1978) and Simon and Collison (2002).

Kaushal et al. (2019) provisionally demonstrated that tree removal during stream restoration construction can trigger sub-surface fluxes of nutrients out of the riparian zone and into the stream. The significance and duration of these fluxes and their influence on stream nutrient dynamics is still be investigated. In addition, water quality impacts have been observed in some restored stream channels, including lower dissolved oxygen, iron flocculation and stream warming. Appendix F provides a more detailed summary of available research on each of these impacts.

7.2 Best Practices for Floodplain Restoration Projects

The original expert panel recognized the potential for unintended consequences and outlined a set of general environmental qualifying conditions for all stream restoration projects (USR EPR, 2014—excerpted in Appendix A). These general recommendations were designed to promote a watershed-based approach to screen restoration projects to improve their stream function and habitat.

While Group 4 concurs and reaffirms the prior expert panel recommendations, they concluded that future projects should apply a specific list of “best practices” to reduce the potential for un-intended environmental impacts. Further, the group agreed that best practices need to be applied over the entire project life-cycle – beginning with initial site assessment, project planning and design, construction, and operation over the lifetime for which the credit is generated.

Our current understanding of best practice is always evolving as new science sheds light on how aquatic ecosystems respond to restoration interventions along the stream and its floodplain. At this time, the group strongly recommends adoption of the following best practices for stream and floodplain restoration projects:

Best Practices During Project Planning and Design

1. Planners should evaluate options for combining stream and floodplain restoration with stormwater, forestry and agricultural BMPs in the contributing watershed area. It is generally accepted that individual stream and floodplain restoration projects are more effective when pollutant loads delivered from the contributing watershed also are reduced. The CBP has developed numerous BMP options that can be applied for pollutant reduction credit within contributing watershed areas:

    - Stormwater retrofits (of ponds, ditches and new practices)
    - Impervious cover disconnection or removal
    - Landscaping practices, such as rain gardens and conservation landscapes
    - Tree planting and reforestation projects
    - Urban nutrient plans for managed turf
    - Street and storm drain cleaning
    - Investigations at stormwater outfalls to trace pollutant discharges

2. Identify and remedy site-specific source(s) of impairment in the stream and floodplain (e.g. sedimentation, flow alterations and/or habitat degradation). Use both reference form and processes to assess impairment and provide the basis for restoration designs. Individual project designs should apply the restoration principles outlined in US EPA (2000).
3. Follow guidance from the appropriate federal, state or local regulatory authority regarding assessment of existing high-quality habitat and ecosystem functions. The following are considerations that may be required:

    - Assess existing habitat characteristics and functions across the project during project planning and design phases and compare with predicted post-construction conditions to evaluate uplift
    - Conduct intensive surveys when high quality stream or wetland resources are identified within or immediately downstream of the project reach
    - Avoid restoration projects at sites where aquatic diversity metrics indicate that the stream is currently in good or excellent condition.
    - Avoid restoration projects at sites where floodplain or wetland metrics indicate that the current floodplain plant community is functioning well.
    - Carefully survey existing forests minimize tree clearing during construction and identify individual trees that should be saved.

4. Give special consideration to protecting freshwater mussels and their host fish if they are present within or immediately downstream of the project reach.

Common, rare, threatened and endangered species all deserve conservation consideration per the findings of Kreeger et al (2018). The site should be surveyed for mussels as soon as possible. Freshwater mussels can be inconspicuous and as such a thorough survey is important. Site designs should consider the presence of live mussels and avoid disturbances. It may be helpful to view their presence similar to infrastructure or wetlands (Blevins et al. 2019). Mussels represent one of the priority species of conservation in these ecosystems, and as such stream restoration designs which leads to known disturbance of these organisms would be counterproductive and inappropriate.

5. Ensure that all aquatic life that (e.g. fish, eels, etc.) can safely pass through the project reach through careful design of instream structures.

6. Avoid designs that:

    - Create stagnant pools within the stream channel and long-term inundation or ponding across the floodplain width. Creation of vernal and temporary pools within the floodplain as a habitat feature is acceptable.
    - Rely on extensive bank armoring using rock or other fixed structures and disregard the maximum armoring limits adopted by Group 3 (2020).
    - Dewater perennial stream channels. Rather, irrigation curtains and other techniques can be used to maintain consistent baseflow conditions.

7. Clearly describe how the proposed project will affect local and downstream elevations of the 100-year floodplain, and conform to federal and state floodplain management requirements through appropriate H&H modeling.

8. Assess potential for toxics contamination in floodplains located within highly urban areas or brownfields and watersheds that have a history of potential contamination through soil investigations. Avoid disturbing acidic soils if they are present at the project site.

Best Practices During Project Construction

1. Reduce the use of "iron-stone" rock or sand and other iron-rich construction materials when raising the streambed to avoid iron flocculation during anoxia.

2. Decrease the use of labile organic matter added to the stream bed (e.g., compost) to avoid mobilization of metals or phosphorus.

3. If required by the appropriate federal, state or local regulatory authority, minimize removal of mature trees in the existing riparian zone, as specified in the project's forest conservation plan.

4. Minimize disturbance caused by construction access and use appropriate equipment to reduce compaction of the stream's bed, banks and floodplain.

5. Work "in the dry" during project construction to reduce potential for downstream bed sedimentation or turbid discharges.

6. Recycle wood from any trees cleared during construction to introduce carbon sources and restore habitat features within the restoration project site.

Best Practices for Post Construction Phase

1. Verify that stream restoration projects continue to meet their performance objectives for hyporheic exchange and floodplain reconnection functions. Individual floodplain restoration projects should be inspected every five years using the visual indicators, numeric triggers and failure thresholds outlined by Group 1 (2019). Some of the key indicators for this class of projects focus on maintaining the:

    - Pre-restoration baseflow conditions in the stream channel
    - Intended bank heights along the project reach to achieve the desired frequency of floodplain reconnection
    - Desired density and species targets in the restored floodplain plant community.

2. Implement a vegetation management plan to maintain the post-restoration vegetation target for the banks and floodplain (including invasive species management).

3. Allow for adjustment of instream structures to lower water elevations if they are responsible for unacceptable inundation or pooling over the surface of the floodplain. If this is a concern, the inspection frequency may need to be increased.

7.3 Project Verification and Measuring Functional Uplift

The original expert panel did not outline procedures for verifying the performance of stream restoration projects built for pollutant removal credit. This was rectified in 2019, when the USWG approved procedures for field verification of stream restoration projects, after their original construction permit monitoring requirements expire (Group 1, 2019).

The new field verification approach utilizes a two-stage inspection process of the entire project reach. The first stage involves a rapid inspection to assess project condition, relying on simple visual indicators. The second stage involves a forensic inspection to diagnose the nature and cause(s) of the failure and whether project functions can be recovered by additional work.

While Group 4 supports the visual indicators developed by Group 1 for P2 and P3, it does suggest a few specific modifications to account for the unique low-bank conditions of FR projects. The modifications help ensure that the desired elevation(s) for stream/floodplain reconnection are maintained in the face of future upstream storm flows or head-cuts advancing from downstream. These modifications are shown in Tables 16 and 17, respectively.

<table>
<tr><td colspan="2">Table 16. Defining Loss of P-2 Pollutant Reduction Function for FR Projects (Denitrification in the EHZ) [1]</td></tr>
<tr><td>Criteria</td><td>Key Visual Indicators for all FR Projects</td></tr>
<tr><td rowspan="5">Evidence that the reach does not meet the design assumptions for the EHZ (such as when channel incision reduces access to hyporheic zone).</td><td>• Less than 80% of ground or canopy cover established in the project’s EHZ
• Stream lacks any observable baseflow during normal dry weather conditions</td></tr>
<tr><td>Key Visual Indicators for FR-LSR Projects</td></tr>
<tr><td>• Bank height (floodplain height over streambed) greater than 18 inches, due to post-construction floodplain deposition or channel incision</td></tr>
<tr><td>Key Visual Indicators for FR-RSB Projects</td></tr>
<tr><td>• Bank height (floodplain height over streambed) greater than 18 inches, due to post-construction floodplain deposition or channel incision
• Failure of riffle-grade control practices used to raise water levels</td></tr>
<tr><td colspan="2">[1] Modified from Group 1 (2019)</td></tr>
</table>

<table>
<tr><td colspan="2">Table 17. Defining Loss of P-3 Pollutant Reduction Function for FR Projects [1]</td></tr>
<tr><td>Criteria</td><td>Key Visual Indicators for all FR Projects</td></tr>
<tr><td rowspan="5">Channel incision or floodplain sediment deposition increases effective bank height, thereby reducing intended annual stream flow volume diverted to floodplain</td><td>• Inability to meet 80% ground or canopy cover targets within the project’s designed FTZ
• No evidence of overbank deposition and floodplain retention, as signified by a lack of sediment deposition, terraces, wrack-lines or leaf clumps in floodplain</td></tr>
<tr><td>Key Visual Indicators for FR-LSR Projects</td></tr>
<tr><td>• Restored floodplain elevation (floodplain height over streambed) greater than 18 inches above channel or low flow water elevation due to post-construction floodplain deposition or channel incision</td></tr>
<tr><td>Key Visual Indicators for FR-RSB Projects</td></tr>
<tr><td>• Incision or downcutting of channel fill that causes an increase post-restoration bank height
• Failure of channel grade control practices used to raise water levels</td></tr>
<tr><td colspan="2">[1] Modified from Group 1 (2019)</td></tr>
</table>

The group also recommended that:

- Field crews observe indicators in a manner that adequately cover the surface area of any EHZ or FTZ created for the project to ensure it is still functioning as originally designed.

- Post-construction as-built plans should clearly show EHZ or FTZ areas to assist in future verification and define average bank elevations.

7.4 Measuring Functional Uplift at Floodplain Restoration Projects

The original expert panel report emphasized the importance of demonstrating functional uplift within a stream as part of any TMDL restoration project (USR EPR, 2013). The expert panel reviewed several methods to measure uplift, and ultimately adopted the functional pyramid approach developed by Harman et al (2011).

The group concurs with the need to measure functional uplift but notes that this assessment should be done across the entire reconnected stream and floodplain together. In addition, the reference condition to measure functional improvement should be the entire valley bottom ecosystem, with an emphasis on the connection of the root zone to the groundwater/aquifer.

Several recent assessment tools developed by Starr and Harman (2015 a,b) and Starr et al (2016) may be useful for measuring functional uplift at floodplain restoration projects, possibly in combination with traditional wetland functional assessment methods such as FHWA, HGM, WET and others.

The group agreed that basic research to define and test new metrics to effectively measure functional uplift in floodplains was an urgent management priority.

Critical Research to Fill Priority Management Needs:

The group agreed on four research priorities that can fill gaps in our understanding of how stream restoration projects can be improved to enhance their ecosystem functions:

- Long-term, interdisciplinary research studies on how streams and floodplains respond to innovative design approaches that emphasize how sediment and nutrient dynamics and ecosystem functions change in projects over time. A good example of the scope for effective multi-year investigations is the Big Spring Run research project, which is profiled in Appendix B-2 of Group 5 (2020).

- Shorter term research efforts focused on the effectiveness of specific best practices in mitigating unintended environmental impacts caused by stream restoration projects. One of the most urgent research priorities is measuring how stream nutrient dynamics respond to different levels of riparian tree loss during and after construction.

- Detailed forensic investigations to identify the causes of failure for projects that do not pass their post-construction verification inspections, per Group 1 methods.

- Basic research to define and test new metrics that can effectively predict and measure the degree of functional uplift and/or functional losses achieved by floodplain restoration projects over short- and longer time frames.

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APPENDIX A. CONDENSED SUMMARY OF ORIGINAL PROTOCOLS 2 and 3 (USR EPR, 2014)

Summary of Protocol 2: Denitrification in the Hyporheic Zone

Stream restoration designs that increase hyporheic exchange between the floodplain rooting zone and the stream channel help promote biological nutrient processing. To account for the additional denitrification occurring in these restoration projects, the original expert panel developed Protocol 2. The method assumed that most of the denitrification occurs in a "box" that runs the length of the restored reach. The box extends 5 feet beneath the stream invert and 5 feet to either side of the streambank of the median baseflow channel. The full method is summarized in Table A-1.

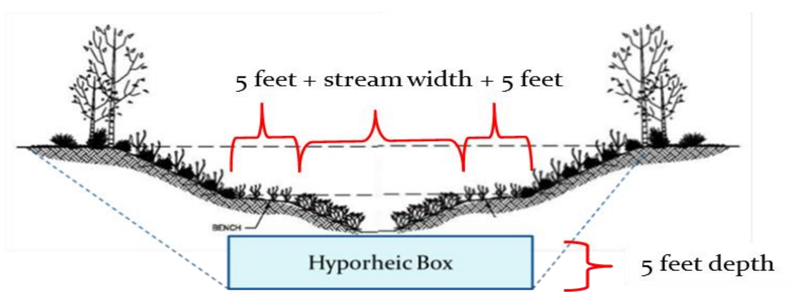
Table A-1: Summary of Protocol 2: Denitrification in the Hyporheic Zone

Step 1: Determine the total post construction stream length that has been reconnected using a bank height ratio of 1.0 or less (for NCD projects) or the 1.0 inch storm (other design approaches).

The bank height ratio is an indicator of floodplain connectivity and is a useful proxy for how much of the stream length is interacting with the root zone. It is defined as the lowest bank height of the channel cross section divided by the maximum bank full depth.

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 baseflow 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.



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 by the unit denitrification rate

Measure the bulk density of the soil to determine the tons of sediment within the hyphorheic box volume you calculated in Step 2. Then, multiply the sediment load by 1.06 x 10-4 pounds/ton/day of soil to determine your total nitrogen reduction.

Summary of Protocol 3: Floodplain Reconnection Volume

Stream restoration projects that reconnect the stream channel to its floodplain over a range of storm events promote settling and filtering processes that remove sediments and nutrients. Protocol 3 was developed to calculate the annual mass sediment and nutrient removal based upon the volume of annual flow that is effectively in contact with the floodplain. The full method is summarized in Table A-2.

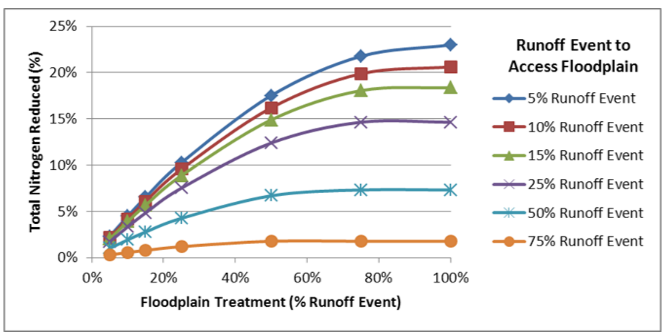
Table A-2: Summary of Protocol 3: Floodplain Reconnection

Step 1: Estimate the floodplain connection volume.

Designers conduct detailed hydrologic and hydraulic modeling (or post restoration monitoring) of the subwatershed, stream and floodplain to estimate the increase in runoff volume diverted from the stream to the floodplain compared to pre-restoration conditions.

Step 2: Estimate the nutrient and sediment removal rates.

A series of curves show pollutant removal as a function of floodplain storage volume for several runoff events that allow runoff to access the floodplain. The removal rates are based on the wetland pollutant removal efficiencies from Jordan (2007).



Step 3: Compute the annual N, P and TSS load delivered to the project

The Chesapeake Bay Program modeling tools (CAST) estimate the pollutant loads being delivered to the project site based on land use loading rates and existing upland BMPs.

Step 4. Multiply the pollutant load by the project removal rate

If the wetland to watershed ratio is less than 1.0% the removal rates should be adjusted.

Appendix B. Condensed Summary of Original Qualifying Conditions for Stream Restoration (USR EPR, 2014)

The Stream Restoration Expert Panel (2013) outlined the following qualifying conditions that a project must meet to be eligible for nutrient and sediment reductions under the Chesapeake Bay TMDL:

- 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.

The 2013 Expert Panel also outlined the following environmental considerations:

- 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.

Appendix C.
Excerpts of Group 5 Memo
for Crediting Floodplain Restoration Projects
Involving Legacy Sediments
Not Directly Incorporated into Main Memo

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Bill Stack, Joe Sweeney and Jeff White

Released: April 10, 2020

Background:

In recent years, a diverse group of stream restoration stakeholders have sought to revisit the original protocols, and four groups were formed in late 2018 to do so (USWG, 2018). As these four groups deliberated, however, it was apparent that a specialized team was needed to assess floodplain restoration projects involving the removal of legacy sediments. Recommendations were finalized in response to comments and conference calls held in 2019 and 2020. The consensus findings contained in their memo were incorporated into the final decisions to modify the crediting protocols presented in the main body of this report.

Floodplain Restoration Involving Legacy Sediment Removal:

Floodplain restoration involves careful modifications to valley bottoms that contain legacy sediments to increase the interaction of the stream with its floodplain and the hyporheic aquifer. This usually involves restoring smaller baseflow channel(s) and removing legacy sediments to effectively lower the floodplain to promote interaction of surface flows with the underlying hyporheic aquifer, which produces riparian wetland conditions over much of the floodplain.

This class of projects is defined in several ways:

1. The projects modify the vertical profile of floodplain sediments that often follows a prescribed sequence from top to bottom: surface vegetation, legacy sediments, organic layer, gravel layer and bedrock.

2. The projects reduce the elevation of the floodplain which, in turn, reduces the height of stream banks, enabling stream runoff to access the floodplain more frequently, expansively and for longer periods.

3. The width and depth of the existing channel are typically reduced in size, and anastomosing baseflow channels are allowed to develop over time within the floodplain.

4. The project restores a vegetative community that includes a diverse mosaic of herbaceous plants, shrubs and water-loving trees and less continuous and drier floodplain forest cover. The restored vegetative community seeks to mimic the natural reference condition for the valley bottom that is supported by historical accounts.

5. The design of floodplain restoration projects is often influenced by the upstream contributing drainage area (in relation to available floodplain project area), as well as any adjacent drainage area.

6. After initial adjustment, the restored floodplain conditions act to enhance sediment and nutrient removal in both the stream and floodplain during storm flow events and baseflow.

Minimum Qualifying Conditions for FR-LSR Projects

To qualify for credits, the team agreed that all projects should meet the following minimum qualifying conditions:

1. *Presence of legacy sediment deposits or other floodplain impairment.* Legacy sediments must be present in the project reach to a depth that has impaired aquatic ecosystem function. Legacy sediment includes any deposits that have occurred since European settlement, including very recent sediment deposits, often created by features such as mill dams, road embankments, floodplain fill and other kinds of stream corridor impairment.

   The presence of legacy sediments should be confirmed by on-site investigations of soil stratigraphy and other evidence that characterize stream valley bottom materials (e.g., such as buried hydric soils, woody material or leaf pack, etc.).

   Other information that can corroborate legacy sediments includes land records, historical atlases and maps, past aerial photographs or current LIDAR measurements. Land Studies (2017) provides a good example of how historical research methods were used to define and interpret legacy sediments for a valley bottom restoration project in Brubaker Run, PA.

2. *Floodplain connection to valley bottom aquifer.* The design objective is to restore a plant/groundwater connection within the floodplain, so that most of the root mass of the floodplain vegetation is in direct contact with the underlying hyporheic aquifer. In cases where the historic hyporheic aquifer cannot be accessed due to modern controls (i.e., culverts or utility crossings), the objective is to plug the flow of the underlying aquifer so as to create a new hyporheic zone using cobbles, gravel and/or sandy materials.

   For effective root zone interaction, the streambed should be on or within the underlying hyporheic aquifer and the surface of the floodplain should not extend more than 18 inches above either the channel bed (in riffles) or residual pool water surface elevation (i.e., during minimal flow).

Field investigations may be needed to identify the current groundwater elevations relative to hydric soils, existing root zones and the stratigraphy of the floodplain.

3. *Defined boundaries for the channel(s), floodplain and valley bottom*. The restored channel and floodplain dimensions are based on field testing that define the key vertical and lateral sediment boundaries of the existing floodplain and the hyporheic aquifer beneath it.

   These boundaries can be measured by a combination of the following methods: direct push soil coring, trenching, test wells, LIDAR surveys, photogrammetry or other site investigations. The objective is to define conditions at critical soil layers in the floodplain profile, and document how the active root zone of the plant community will be connected to the hyporheic aquifer during sustained baseflow periods.

4. *Removal of legacy sediments is the primary means to restore floodplain reconnection at most sites*. This memo applies to projects that primarily remove LS to reconnect the floodplain, and not projects that primarily do so by raising the streambed.

5. *Meet applicable floodplain management requirements in the stream corridor*. Any individual stream restoration project should be assessed with hydrologic and hydraulic models to demonstrate whether it increases water surface elevations or adverse downstream flooding impacts. In general, these analyses are based on design storm events and flood risk conditions established by the appropriate local or state floodplain management agency (e.g., the 100-year storm event).

Summary of Big Spring Run (BSR) Research Findings

A team of researchers investigated the long-term improvements in ecosystem functions in floodplain restoration projects featuring removal of legacy sediments. The impaired stream reach was about 3,000 feet in length and had a contributing drainage area of about 1,000 acres (Figure 9). Approximately 22,000 tons of legacy sediment were removed from the BSR site. The BSR monitoring program and research findings are described in a series of papers by Langland, (2019), Hartranft et al (2011), Hartranft (2019) and in https://chesapeakestormwater.net/download/9913/

The restoration project was designed in the context of a wider research program on how legacy sediments have influenced stream and floodplain functions in Pennsylvania valley bottoms. Some notable references include Merritts et al (2010, 2011), Walters et al (2007) and Walter and Merritts (2008). Another watershed perspective on floodplain connection research was summarized in a recent Chesapeake Bay Program STAC workshop (Miller et al, 2019). The following section summarizes key research findings on how the BSR restoration project performed in capturing and treating runoff, sediment and nutrients.

Flow and groundwater dynamics in the channel and floodplain. Three years after restoration, surveys confirmed that the wetland-floodplain surface remained stable and there was minimal change in ground elevation (Hartranft, 2019). H&H models showed lower shear stress across the restoration reach during storms and more frequent overtopping of banks by floodwaters, at both lower flow stages and over a greater area than pre-restoration conditions (Parola and Merritts, 2014). The peak discharge rate for storms was extended by 17 minutes following restoration (Walter et al, 2019).

Changes in groundwater residence time were highly variable following floodplain restoration, with several wells showing an increase in residence time and others showing a decrease (Audie, 2019). Groundwater monitoring indicated that groundwater nitrate concentrations decreased after the third year following restoration, and in response to increased storage in relation to groundwater nitrogen concentrations (Forshay, 2019).

Summary of nutrient and sediment reductions reported for the Big Spring Run restoration project			
Pollutant	*Reduction*	*Percent Reduction*	*Source*
TSS Load	600 tn/yr	71%	Langland, 2019
TSS Concentration	482 mg/L/yr	87%	Langland, 2019
TP Load	1,380 lb/yr	71%	Walter et al, 2019
TP Concentration	0.15 mg/L	79%	Langland, 2019
Soluble Reactive P Load	--	37%	Forshay et al, 2019
TN Load	1,740 lb/yr	71%	Walter et al, 2019
Nitrate-N Load	--	32%	Forshay et al, 2019

Sediment and nutrient removal efficiency. Monitoring of surface water quality was conducted by USGS and EPA for three years prior to restoration and five years afterward. Prior to restoration, the stream bank erosion rate averaged 875 ton/yr across the BSR reach (Langland, 2019). The BSR project was found to highly effective in reducing both the concentration and mass loads of upstream nutrient and sediments.

Decreases in suspended sediment and dissolved phosphorus were observed the year immediately following restoration (Langland 2019; Forshay, 2019), while surface water nitrate decreased gradually over the five-year monitoring period. Nitrate removal is closely tied to organic carbon availability; the delayed nitrate improvements were attributed to the lag time for floodplain vegetation to develop and mature after restoration (Forshay, 2019).

Local Co-Benefits of Floodplain Reconnection

When done properly, floodplain restoration can create many environmental co-benefits in the riparian corridor beyond pollutant removal, when compared to pre-restoration conditions. Many of these local co-benefits have been documented at Big Spring Run and other PA LSR restoration sites (Appendix B-2 and Hartranft, 2019) and may include:

- Surface water thermal regulation (i.e., cooler summer stream temperatures, Land Studies, 2016)
- Improved stream clarity (i.e., reduced turbidity)
- Detention of extreme flood events (Land Studies, 2017)
- Lower flood peak discharges from floods (Land Studies, 2017).
- Carbon sequestration in the floodplain and particulate carbon retention in stream channel
- Restoration of stream, wetland and riparian aquatic ecosystems
- Restored native plant and animal species diversity and habitat
- Wetland bird, wildlife and pollinator habitat restoration
- Increased groundwater recharge rates
- Increased baseflow in stream and more resilience to drought
- Increased hydrophytic vegetation biomass and species richness
- Restored habitat for threatened and endangered species, such as bog turtles

Other community co-benefits that are often associated with well-designed FR-LSR projects include:

- Reduced damage to public infrastructure, such as roads and sewers
- Reduced flood water surface elevations especially for more frequent storm events
- Creation of an open space amenity and potential greenway/trail corridor
- Can be a cost-effective option in relation to other urban BMPs used to meet MS4 sediment and nutrient pollutant reduction targets (Fleming et al, 2019)

Obviously, the degree of environmental and community benefits created by any floodplain restoration project are strongly influenced by site conditions and how it is assessed, designed, constructed and managed over time.

Review of Potential Unintended Consequences for LSR Projects

Stream restoration projects have the potential to exert unintended environmental consequences, particularly when they are poorly assessed, located, designed or constructed. The team evaluated potential unintended consequences associated with floodplain restoration projects involving legacy sediment removal, with a focus on monitoring at BSR and other PA sites. This team summarized its assessment of the potential risks associated with FR-LSR projects in the table below.

Review of Potential Negative Impacts by FR-LSR Projects [1,2]		
Stream Channel		
Impact	*Risk?*	*Notes*
Depleted DO	Low	Minor summer DO reduction measured at some sites, but less common than at other stream projects that create slow-moving steps and pools.
Iron Flocculation	Mod	Frequently observed but temporary at both restored and non-restored stream sites. LSR projects do not import materials into the stream that promote iron-fixing bacteria, but may expose iron-rich materials from degraded bedrock.
Warmer Stream Temps belo	Low to Zero	Monitoring shows restoration projects that connect with the aquifer can have cooler summer stream temps, especially when high hyporheic exchange is achieved and scrub-shrub wetland vegetation is established (Land Studies, 2016 and others).
More Acidic Water	Low	Uncommon and temporary for LSR projects, but could occur if underlying acidic soils are exposed during construction
Hi Primary Production	Mod	Some evidence of higher primary vs. detrital production, which is consistent with non-forested stream ecosystems.
Benthic IBI Decline	???	BSR monitoring indicates healthier post-restoration macro-invertebrate community, but not always supported by forest-based IBI scoring metrics
Floodplain/Valley Bottom		
Impact	*Risk?*	*Notes*
Project Tree Loss	High	Loss of riparian forest due to project clearing or construction access. Upland trees growing on legacy sediments are not endemic to the riparian wetland community, tree community may need to shift from upland/dry to wet/floodplain-adapted species in the valley bottom
Post-Project Tree Loss	Mod	Existing tree mortality can occur due to more frequent inundation/higher water table in the restored floodplain, but these are intended to shift from upland to wetland community of herbs, shrubs and trees
Invasive Plant Species	Mod to High	Project monitoring indicates that construction disturbance is a vector for invasive plant species in any stream restoration project. Risk may be lower for connected vs. disconnected floodplains. Post-construction invasive management is critical to establish a sustainable wetland plant community
Wetland Function	Low to Zero	Some degradation of excavated "toe of slope" or perched wetlands has been observed, but these are replaced by more extensive wetland complexes in the stream corridor that generally increase wetland functions.
Stream Habitat	Changes In Type, not Quality	Shift from high to low stress habitats in the stream channel (e.g., long, deep pools and steep in cobble and boulder steps are replaced by more sinuous, shallow and multi-thread channels connected to wetland or beaver habitats).
Downstream Ecosystems and Infrastructure		
Impact	*Risk?*	*Notes*
Increased Flooding?	Low risk, may mitigate	This is assessed by H&H modeling during project design, but local flood elevations are usually reduced due to the increased flood storage provided in the restored valley bottom, which may be useful in some subwatersheds
Infrastructure Damage	Low or Zero	No evidence yet of damage to sewers, culverts, bridges and other infrastructure
Decline in Benthic IBI	Low or Zero	LSR projects may shift downstream benthic species and taxa, but this reflects differences in forested vs. wetland floodplain ecosystems.

[1] The list of potential stream restoration impacts is adapted from Clearwater, Guignet, Mayer and Williams (2019), and the complete assessment and data table can be found in Group 4 (2020). Does not include impacts due to disturbance during the construction phase

[2] Each Bay state resource agency regulates project impacts based on water quality standards and wetland protection considerations in the 401 and 404 permitting process.

In general, they found that FR-LSR projects frequently have positive environmental benefits, both in the stream and floodplain. Indeed, when properly designed and constructed, these projects can often avoid or minimize many unintended consequences (reviewed by Group 4, 2019).

The severity of any potential negative consequences associated with FR-LSR projects can be minimized by using various "best practices" in project assessment, design, construction and management. The team concurs with the recommended best practices to minimize unintended consequences for all classes of stream restoration projects developed by Group 4 (2020).

Appendix D. Restored Floodplain Velocity Case Study Analysis

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MEMORANDUM

To: David Wood, Tom Schueler

From: Jason Coleman, Drew Altland

Date: February 7, 2020

Subject: Restored Floodplain Velocity Case Study Analysis

RK&K performed an analysis to evaluate the velocity of 2 feet per second (ft/s) as an upper limit velocity for floodplain treatment above one foot of depth. Five floodplain restoration sites were evaluated hydraulically using HEC-RAS to estimate velocities at different depths in the restored condition. All sites used for this analysis removed legacy sediment to restore the floodplains and incorporate a small baseflow sized channel that accesses the restored floodplain area during most runoff events.

A range of discharges were entered into the model to produce a rating curve of depth versus velocity at each modeled cross section. Therefore, the discharges don't necessarily represent a yearly return interval. One cross section for each project reach was selected to assess the reach-wide representative depth and velocity. For each project comparisons are provided for the average floodplain velocity at 1' of depth, 3' of depth, and at the depth produced by the 100-year discharge. The results are summarized in the following table:

Project	Valley Slope	Ave. FP Velocity @ 1' Depth (ft/s)	Ave. FP Velocity @ 3' Depth (ft/s)	Ave. FP Velocity @ 100-Year Depth (ft/s)	Notes	Recommended Treatment Depth (ft)
Israel Creek	0.21 %	0.41	0.84	2.31	3' depth occurs at ~1-yr discharge	3'
Furnace Creek	0.40 %	1.33	2.65	2.79	3' depth is between 50- and 100-yr discharges	~2'
Bens Branch	1.10 %	1.60	3.35	4.07	3' depth occurs at ~25 yr discharge	~1.5'
Talbot Branch Trib	1.50 %	2.45	n/a	2.72	100-year depth is ~1.3'	1'
Piscataway Creek Trib	6.00 %	n/a	n/a	2.93	100-year depth is ~0.5'	1'

All sites analyzed used a floodplain Manning's n roughness of 0.07 in the floodplain and 0.035 in the channel. Therefore, the velocity is primarily dependent on valley slope and depth. The floodplains with steeper slopes, such as the Talbot Branch Trib and Piscataway Creek Trib case studies, often produce higher velocities that exceed 2 ft/s. However, since these streams have smaller watersheds, the flow depths, even at the 100-year discharge, are minimal. In these conditions, it is expected that the filtering in the floodplain is enhanced due to the shallow flood depths and the increased contact with vegetation. As the valley slopes decreased, velocities generally decrease, and depth increases. As the velocity decreases, increased sediment trapping occurs along with the filtering.

Based on this case study analysis, the floodplain treatment to one foot of depth seems to be a reasonable default depth for all projects. Additionally, floodplain treatment up to three feet of depth also seems reasonable in settings where the energy slope is low and additional trapping can occur. The threshold of 2 ft/s seems to be a reasonable upper limit for velocity based on this case study analysis and observed deposition and filtering at these case study sites that have been constructed.

Appendix E. Developing regional flow diversion curves

This appendix provides guidance on improved methods to estimate floodplain flow diversions for a particular project reach. The new methods are based on the work by Altland (2019) and "scale" down regional flow gage data for individual projects, using available USGS hydrograph separation methods. This appendix also outlines how post-restoration channel dimensions for FR projects are defined, using low flow statistics such as spring baseflow rates.

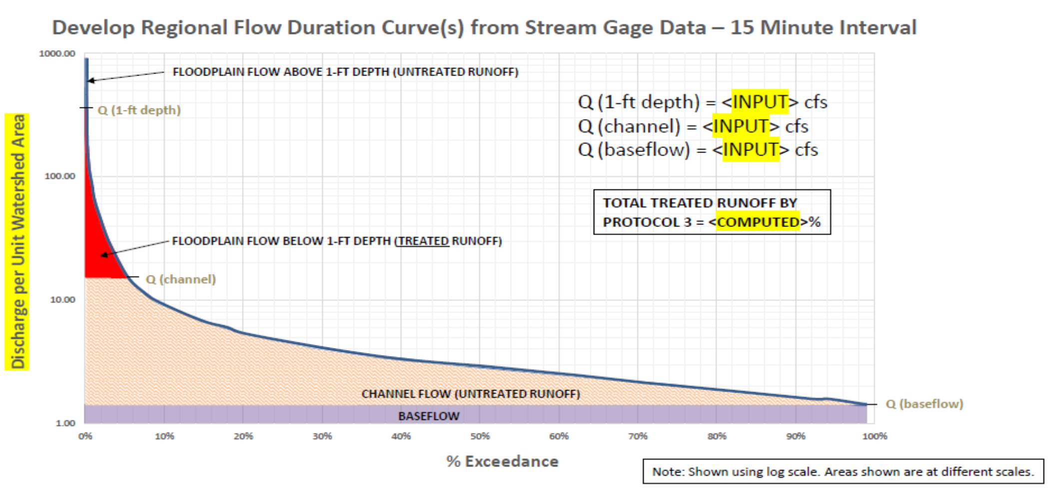
The Regional Flow Curve Approach

For this approach, 15-minute flow data from USGS gage stations would be used to create a series of curves that represent stream discharge as a function of the size of the storm event. Unique curves would be developed for each physiographic region in the Chesapeake Bay Watershed, and for different watershed land use conditions so they are representative of the project site conditions.

By adjusting these curves to the specific project site drainage areas and developing companion spreadsheet tools to run the pollutant removal calculations, a 3-step process can be used to determine the treatable flow:

1. Select the appropriate regional flow duration curve and regional baseflow curve for your project site. Use the baseflow curve to define the baseflow discharge for the 50% recurrence interval.
2. Using HEC-RAS or a similar model, determine the channel flow (the flow that would just fill the existing channel without overtopping its banks) and the floodplain flow at 1ft floodplain inundation depth.
3. Input the channel flow, flow at 1 foot of floodplain inundation, and baseflow into a spreadsheet tool to calculate the percent of flow that can be treated by the floodplain.

Figure E-1. *Flow Duration Curve for calculating floodplain treatment (Altland 2019).*



Developing the Regional Flow Duration Curves

Regional flow duration curves would be developed for the Piedmont, Coastal Plain, and Ridge & Valley provinces using the best available or most appropriate USGS gage data (evaluation of up to 50 total gages). Stations with 15-minute or better and 10+ years of data are preferred when feasible. The data are scaled by comparing the drainage area of gage site to project site drainage area.

From these 50 gage sites, one curve per province would be developed; however, more than one curve may be needed for each province to address varying watershed conditions. Other critical parameters that would be assessed include: similar watershed land cover, watershed slope, and percent karst. It is assumed that no more than 3 curves would be required for each province to address these varying conditions.

For the same 50 gage sites, average base flow values will be developed using hydrograph separation methods for the 50% exceedance interval. Hydrograph separation can be performed using the USGS HySep computer program, which is part of the Groundwater Toolbox program. There are 8 different methods to perform the HySep computations, which can be averaged for this computation.

Finally, a series of spreadsheet tools would then be produced to easily compute Protocol 3 treatment efficiency as described in Step 3 above. The spreadsheets would allow users to input the channel flow, baseflow, and flow at 1ft depth above the floodplain in order to calculate the treatment efficiency. There would be one spreadsheet per regional flow duration curve. It is estimated that the development of all of these products would require between 200 and 250 hours and approximately $35,000.

Appendix F. Review of References for Potential Impacts of Stream Restoration Projects

Depleted Dissolved Oxygen				
Summary: Seasonal, low dissolved oxygen has been observed in some restoration projects. Low DO is associated with stagnant surface waters and high dissolved organic carbon.				
Reference[1]	*Region*	*Duration*	*Type*	*Method Notes*
Williams et al (2016)	CB	2-5 yr	RSC	?
Duan et al (2019)	CB + Lab	< 1 yr	RSC	Field: restoration vs paired control Lab: Change with increasing DOC
Jordan et al (2019)	CB	2-5 yr	RSC	Surface water: outlet vs inlet Groundwater: pre vs post
Iron Flocculation				
Summary: Iron flocculation has been observed in both restored and unrestored streams. Iron flocculation is associated with high dissolved organic carbon, anoxic conditions and the use/presence of ironstone.				
Reference	*Region*	*Duration*	*Type*	*Notes*
Williams et al (2016)	CB	2-5 yr	RSC	Pre-post. Causes of mobilization
Duan et al (2019)	CB + Lab	< 1 yr	RSC	Field: restoration vs paired control Lab: Change with increasing DOC
Jordan et al (2019)	CB	2-5 yr	RSC	Pre-post
Warmer Stream Temperatures				
Summary: Increased surface water temperatures following a restoration are associated with loss of tree canopy in the riparian corridor. Exposure of groundwater seeps can mitigate increased temperatures.				
Reference	*Region*	*Duration*	*Type*	*Notes*
Lessard and Hayes (2003)	OCB	1-2 yr	NRS	Impact of small dams on downstream temps
Johnson (2004)	OCB	<1 yr	NRS	Impacts of shading and substrate on stream temperature
Moore et al (2005)	OCB	N/A	NRS	Impact of riparian forest harvesting on stream temperatures
Cristea and Janisch (2007)	OCB	N/A	NRS	Modeled impact of riparian vegetation on stream temperature
Fanelli and Lautz (2008)	OCB			
Hildebrand et al (2014)	CB		NRS	Thermal sensitivity of stream systems
Mbaka et al (2015)	OCB	N/A	NRS	Impact of small impoundments on stream temperature.
Land Studies Inc (2016)	CB	2-5 yr	LSR	Pre-Post. Change in stream sensitivity to thermal radiation
Weber et al (2017)	OCB	5+ yr	NRS	Impact of natural beaver dam and beaver dam analogues on stream temperature
Dugdale et al (2018)	OCB	1-2 yr	NRS	Impact of riparian plant community on stream temperature

Fanelli (2019)				
Water pH				
Summary: Lower pH following restoration is associated with disturbance of channel and floodplain soils during construction.				
Reference	*Region*	*Duration*	*Type*	*Notes*
Mayer (2019)	CB	< 1 yr	RSC	Restoration vs paired control
Primary Production				
Summary: Increase in primary production in restoration sites is associated with loss of canopy cover in the riparian corridor.				
Reference	*Region*	*Duration*	*Type*	*Notes*
Potopova et al (2016)	CB		LSR	Pre-post Change in diatom diversity
Levi and McIntire (2020)	OCB	<1 yr	NCD	GPP in restored vs paired control
Local Benthic IBI				
Summary: Local benthic IBI does not consistently show improvement following restoration activities. Local benthic decline has been observed, associated with construction disturbance, with recovery to pre-project levels in some cases.				
Reference	*Region*	*Duration*	*Type*	*Notes*
Revetta 2014	OCB	1-2 yr	LSR	Change in biomass and community structure
Fanelli et al (2019)				
Project Tree Removal				
Summary: Riparian/floodplain forest losses are common due to clearing for design and construction access.				
Reference	*Region*	*Duration*	*Type*	*Notes*
Palmer et al (2014)	CB	1-2 yr	RSC	Measuring hydrologic changes and nutrient removal. Tree removal noted but not quantified.
Kaushal et al (2019)	CB	N/A	Mixed	Area of trees cleared at restoration sites
Post Project Tree Loss				
Summary: Lab studies show that long term soil inundation results in mortality and morphological changes in tree species.				
Reference	*Region*	*Duration*	*Type*	*Notes*
Teskey and Hinckley (1977a)	CB + OCB	N/A	NRS	Describes species ability to survive inundation
Angelov (1996)	OCB	Lab	N/A	Impact of permanent pooling on survival of upland seedling species
Pezeshki et al. (1999)	OCB	Lab	N/A	Impact of 70 day inundation on seedling elemental uptake
Anderson and Pezeshki (1999)	OCB	Lab	N/A	Impact of intermittent flooding on seedling survival
Folzer et al. (2006)	OCB	Lab	N/A	Impact of flooding on tree morphology

Pezeshki and DeLaune (2012)	OCB	Lit Review	N/A	Impact of soil flooding in wetlands on plant morphology
Garsson et al. (2015)	OCB	Lit Review	N/A	Impact of time of inundation on seedling survival
Invasive Plant Species				
Summary: Construction disturbance and frequent inundation of the floodplain can serve as vectors for invasive species.				
Reference	*Region*	*Duration*	*Type*	*Notes*
Coastal Resources Inc (2000)	CB	< 1 yr	Mixed	Post-restoration plant survey
Cuda et al (2017)	OCB	< 1 yr	NRS	Plant survey
Change in Wetland Type or Function				
Summary: Changes in vascular plant communities as a result of floodplain inundation are expected and may be desirable or undesirable depending on the habitat outcome.				
Reference	*Region*	*Duration*	*Type*	*Notes*
Fleming et al (2019)	CB	5+ yr	LSR	Pre-post. Change in vascular plant community structure
Change in Aquatic Habitat Quality				
Summary: No references at this time				
Reference	*Region*	*Duration*	*Type*	*Notes*
Salant et al (2012)				
Garsson et al (2015)	OCB	Lit Review	N/A	Impact of time of inundation on riparian plant community
Hale and Swearer (2017)				
Increased Flooding				
Summary: Well-designed floodplain restoration projects should result in local flood stage reductions. Changes to floodplain elevations resulting from the project should be reported to the appropriate regulatory authority.				
Reference	*Region*	*Duration*	*Type*	*Notes*
Jacobson et al (2015)	OCB	Modeled Study	FR	Modeled floodplain storage
Cizek et al (2017)				
Koryto et al (2017)				
Infrastructure Damage				
Summary: Well-designed floodplain restoration projects should result in avoidance of flood damages to local infrastructure.				
Reference	*Region*	*Duration*	*Type*	*Notes*
Miller and Kochel (2010)				
Hawley et al (2013)				
Jacobson et al (2015)	OCB	Modeled Study	FR	Modeled floodplain storage
Biological Diversity				
Summary: Changes in benthic community structure may result from stream restoration projects.				

Those changes are associated with changes in habitat conditions, and construction disturbance. Changes may be temporary and may be desirable or undesirable depending on project goals.				
Reference	*Region*	*Duration*	*Type*	*Notes*
Lessard and Hayes (2003)	OCB	1-2 yr	NRS	Shift in macroinvertebrate and fish species composition downstream of small dams
Brown and Conway (in prep)	CB	5+ yr	LSR	Pre-post. Amphibian captures
Fanelli et al (2019)				
Blockage of Fish Passage				
Summary: Special consideration should be given to protecting freshwater mussels and their host fish if they are suspected to be present in the restoration reach.				
Reference	*Region*	*Duration*	*Type*	*Notes*
Noonan et al (2012)				
Kreeger et al (2018)	CB	Lit Review	NRS	Summary of freshwater mollusk capacity to provide WQ benefit
Key: NRS = Non-Restored Stream RSC = Regenerative Stormwater Conveyance NCD = Natural Channel Design LSR = Legacy Sediment Removal FR = Floodplain Reconnection (unspecified design approach)				Key: CB: Chesapeake Bay Watershed OCB: Outside CB Watershed
[1] Full citations available in Section 8 of this memo.				

Appendix G. CBP Presentations on Unintended Environmental Consequences and Co-benefits of Stream Restoration Projects: 2018/2019

Presentation	Link
June 2018	
Presenter: Rebecca Cope (EPA) *Title:* RSC Introduction and Monitoring Results	https://www.chesapeakebay.net/channel_files/25884/epa_1_rcope_rsc_uswg.pdf
Presenter: Paul Mayer (EPA) *Title:* Effects of RSC on Water Quality	https://www.chesapeakebay.net/channel_files/25884/epa_3_mayer_etal_-_uswg_webinar_-_19_june_2018.pdf
Presenter: Kyle Hodgson (MD DNR) *Title:* Water Quality and Macroinvertebrates in Muddy Creek	https://www.chesapeakebay.net/channel_files/25884/epa_4_muddy_creek_ppt_061018_epa.pdf
March 2019	
Presenter: Tom Jordan (SERC) *Title:* Effects of a Stream Restoration on Water Quality and Fluxes of Nutrients and Suspended Solids	https://www.chesapeakebay.net/channel_files/32639/jordan_muddycr_urbanstormwaterworkgroup.pdf
October 2019	
Presenter: Michelle Audie (EPA) *Title:* Influence of groundwater residence time on biogeochemical transformations after legacy sediment removal from a headwater stream in Lancaster County, Pennsylvania	https://www.chesapeakebay.net/channel_files/37046/bsr_graphs_10.2019_v3.pdf
Presenter: Ken Forshay (EPA) *Title:* Restoring stream-floodplain connection with legacy sediment removal increases denitrification and nitrate retention, Big Spring Run, PA USA	https://www.chesapeakebay.net/channel_files/37046/chesapeakebc2019fin.pdf
Presenter: Sujay Kaushal (UMD) *Title:* Tree Trade-Offs in Stream Restoration Projects: Impact on Riparian Groundwater Quality	https://chesapeakestormwater.net/download/9857/
November 2019	
Presenter: Jeff Hartranft (PADEP) *Title*: Big Spring Run Restoration Project Background & Monitoring Results	https://chesapeakestormwater.net/events/big_spring_run_research/
Presenter: Dave Guignet (MDE) Title: Community Floodplain Regulations to Participate in NFIP	https://chesapeakestormwater.net/download/9861/
Presenter: Denise Clearwater (MDE) *Title:* Floodplain Reconnection Unintended Consequences	https://chesapeakestormwater.net/download/9865/
Presenter: Paul Mayer (EPA) *Title:* Unintended Consequences of Urban Stream Restoration	https://chesapeakestormwater.net/download/9869/
Presenter: Michael Williams (UMD) *Title*: Unintended/Negative Consequences of Stream Restoration	https://chesapeakestormwater.net/download/9873/