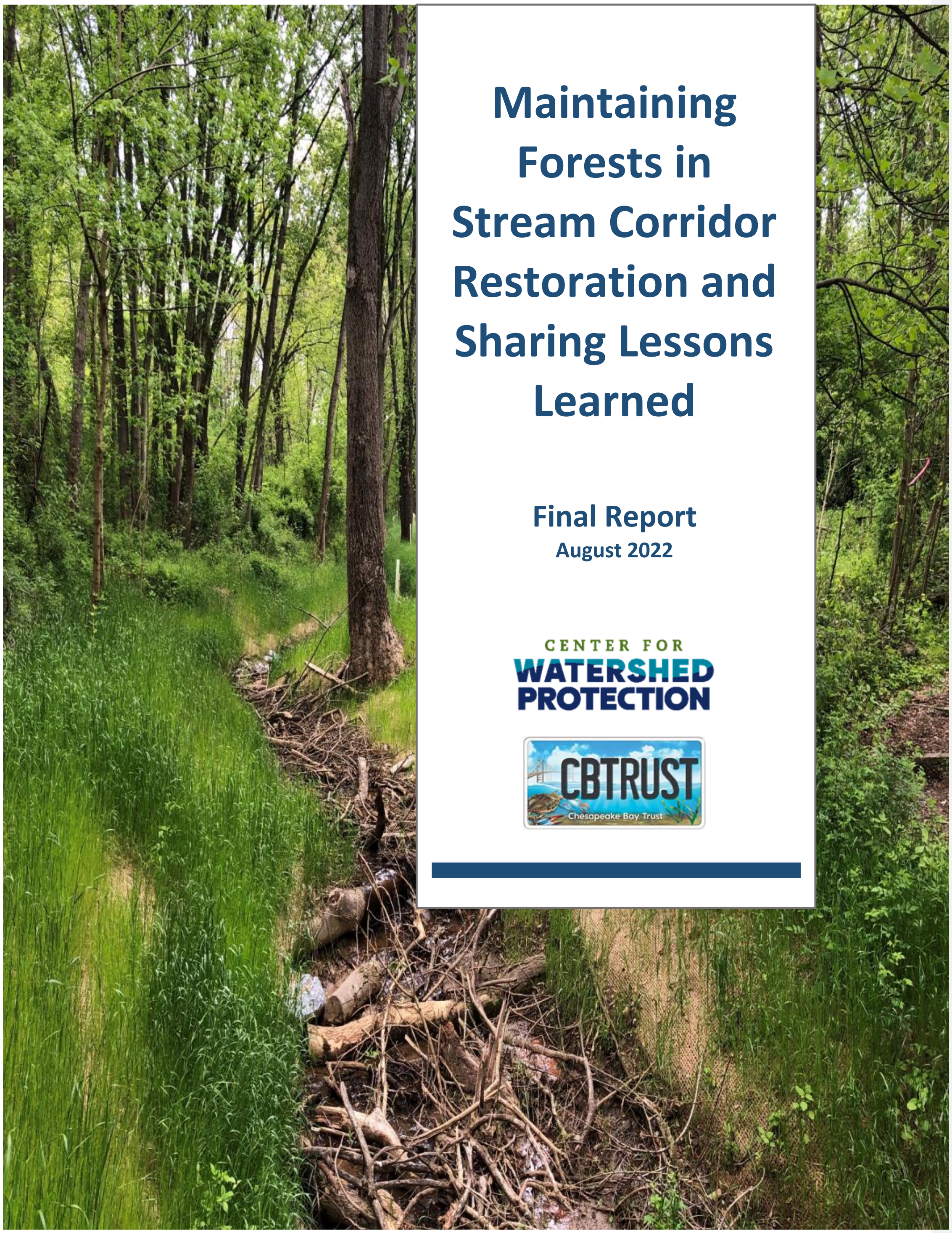

Maintaining Forests in Stream Corridor Restoration and Sharing Lessons Learned

Final Report

August 2022

CENTER FOR WATERSHED PROTECTION

CBTRUST
Chesapeake Bay Trust

Maintaining Forests in Stream Corridor Restoration and Sharing Lessons Learned

Prepared by:
Lisa Fraley-McNeal
Bill Stack, PE
Jordan Fox
Chris Swann
Alexandria Wilkins
Ari Daniels, PE

Center for Watershed Protection, Inc.

August 2022

This project has been funded wholly or in part by the United States Environmental Protection Agency under assistance agreement CB96374201 to the Chesapeake Bay Trust. The contents of this document do not necessarily reflect the views and policies of the Environmental Protection Agency, nor does the EPA endorse trade names or recommend the use of commercial products mentioned in this document.

Contents

Tables

Acronyms and Abbreviations

Acronym/Abbreviation	Definition
BIBI	Benthic Index of Biotic Integrity Score
BMP(s)	Best Management Practice(s)
CAD	PLACEHOLDER
CAST	Chesapeake Assessment Scenario Tool
CBP	Chesapeake Bay Program
CBP STAC	Chesapeake Bay Program Scientific and Technical Advisory Committee
CWP	Center for Watershed Protection, Inc.
GIS	Geographic Information System
IRT	Interagency Review Team at Maryland Department of Natural Resources
LOD(s)	Limit(s) of Disturbance
MD DNR	Maryland Department of Natural Resources
MD FCA	Maryland Forest Conservation Act
MDE	Maryland Department of the Environment
MS4	Municipal Separate Storm Sewer System
MWCOG	Metropolitan Washington Council of Governments
NAIP	National Agriculture Imagery Program
NCD	Natural Channel Design
NRCS	Natural Resources Conservation Service
NWP	Nationwide Permit
PA DCNR	Pennsylvania Department of Conservation and Natural Resources
PA DEP	Pennsylvania Department of Environmental Protection
QA	Quality Assurance
QC	Quality Control
QAPP	Quality Assurance Project Plan

Acronym/Abbreviation	Definition
QMP	Quality Management Plan
TMDL	Total Maximum Daily Load
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
US EPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
VA DCR	Virginia Department of Conservation and Recreation
VA DEQ	Virginia Department of Environmental Quality
WIP(s)	Watershed Implementation Plan(s)
WQGIT	Water Quality Goal Implementation Team

Executive Summary

The importance of forest buffers for stream health has been widely documented. With growing interest and implementation of stream restoration in the Chesapeake Bay Watershed, there is an increasing need for research about how to protect riparian buffers and minimize their impact during stream restoration construction. The CBP Stream Restoration Expert Panel Report (Schueler and Stack, 2014) and recent work group updates (Wood et al., 2021) intended for the stream restoration crediting protocols to be part of a holistic watershed approach and included qualifying conditions that offer some protection for riparian vegetation. However, stream restoration projects are commonly implemented with the main goal of obtaining TMDL credits and the qualifying conditions for riparian vegetation have not been consistently met. Because stream restoration and expanding forest buffers are a large component of state Watershed Implementation Plans (WIPs) and the 2014 Chesapeake Bay Agreement, it is imperative to better synergize efforts and investments to minimize negative trade-offs impacts/outcomes.

The Center for Watershed Protection, Inc. (CWP) worked collaboratively with the CBP and stakeholders to evaluate methods to reduce impacts of stream restoration projects on existing riparian ecology and forest buffers in Maryland, Pennsylvania, and Virginia. This report was developed to support the "Scope of Work 3: Maintaining Forests in Stream Corridor Restoration and Sharing Lessons Learned" project identified in the 2020 Chesapeake Bay Trust-Technical Assistance - Chesapeake Bay Program Goals and Outcomes request for proposals. Results from final project report were used to inform development of a guidance document for local governments on the best practices to minimize unintended adverse outcomes to riparian forests and identify opportunities for coupling these practices to improve water quality and habitat improvements. The intention of the project is to help improve selection, permitting, and funding processes for stream restoration projects in the Chesapeake Bay watershed. A summary of the best practices for minimizing impacts to riparian forests, as well as programmatic and research recommendations are provided in Table 1.

Table 1. Summary of best practices and programmatic and research recommendations		
General Best Practice	**Specific Best Practices**	**Programmatic and Research Recommendations**
Site Selection	• Follow a watershed-based approach for screening and prioritizing stream restoration projects that target restoration to areas in need instead of existing high-quality areas. • Evaluate options for combining stream restoration with stormwater, forestry and agricultural BMPs in the contributing watershed.	• State agencies should develop guidance that defines "high-quality" existing areas that should be avoided. • Conduct a comprehensive review of the scientific and grey literature related to stream restoration and upland stormwater controls.
Establishing Goals and Objectives	• Develop stream restoration projects through a functional assessment process. • Review the project goals with all stakeholders to determine if forested riparian conditions are appropriate and achievable within the current, historic, and projected future conditions of a project site.	• Define and test new metrics that can effectively predict and rapidly measure the degree of functional uplift and/or functional losses achieved by floodplain restoration projects over short- and longer time frames. • State agencies should consider integrating CBP riparian buffer goals as part of the review process for stream restoration projects.
Design and Permitting	• Configure the restoration design to unique site conditions instead of the site to a specific type of practice. • Conduct a comparative analysis of different restoration approaches to evaluate the impacts of temporary construction landscaping relative to the creation of a long-term, sustainable system. • Rank on-site trees during the planning process based on factors such as tree health, location, size, value, bank proximity, root mass erosion status, and amount of shade cast. • Develop (and implement) planting plans that prioritize native species and consider impacts of invasive species. • Consider planting techniques to provide higher degrees of canopy coverage in shorter amounts of time. • Conduct pre-application meetings with state and federal permitting agencies.	• State agencies should clearly define stream restoration and use consistent terminology for permit processing. • A comprehensive review of county-level regulations should be conducted to determine how well they incorporate state-level requirements such as the MD Forest Conservation Act, and the extent to which they include enforceability measures. • State agencies should encourage and coordinate collaboration between forest agencies and local governments to ensure they are involved with project design. Forest agency participation during the pre-application meetings should also be encouraged or required. • State agencies should develop checklists based on the best practices recommended in this report.
Stakeholder Engagement	• Pre-restoration community engagement, including getting local stakeholders involved, communication about the project, setting expectations, and gathering consensus on the project's goals and objectives. • Coordinate with federal, state, and local governments, as well as practitioners, forest agencies, contractors, landowners, and local community	• State agencies and local governments should consider developing outreach materials to help the public and landowners better understand the stream restoration process.

Table 1. Summary of best practices and programmatic and research recommendations		
General Best Practice	**Specific Best Practices**	**Programmatic and Research Recommendations**
	stakeholders to come to consensus on the preferred design approach and project goals/objectives.	
Construction	• Site managers responsible for riparian forest impacts should be present on site. • Limits of Disturbance (LODs) should be carefully drawn and managed. They should be kept as small as possible, and the construction sequence should be organized to prevent equipment from repeating trips over the same area many times. • Individual trees and swaths of trees to be protected should be flagged and marked. • Trees that are at risk of being impacted by construction activities should have additional protection measures applied. All trees within 5 feet of the LOD should be armored. • Rubber-tire construction vehicles should be used to minimize compaction. Ideally, those vehicles should be as small as possible. • Root trimming if impact from construction equipment is unavoidable. • Installation of water gators (bags of water attached to the tree that slowly drip down) and mulch application around the trees to keep underlying soil moist. • Implementation of ground protection practices to minimize rutting and compaction from construction and reinforce the organic content of the forest floodplain soils, which benefits native species. • Reuse downed or removed trees on-site. • Use planting plans that track survivability and post-construction vegetative management (including supplemental plantings and invasives control) as a tool to handle discrepancies, which allows for fine-tuning as the forest and vegetation re-establishes.	
Monitoring and Maintenance	• Set aside a minimum of 10% of total project costs for post-construction monitoring and maintenance. • Utilize performance-based contracting and warranty monitoring for plant survival and contractual requirements.	• Long-term monitoring of riparian benefits and total ecosystem benefits done by professionals/scientists with consideration of a pooled monitoring approach. • Local governments and funding agencies should allow for a percentage of funds to be allocated for post-construction monitoring and maintenance.

Table 1. Summary of best practices and programmatic and research recommendations		
General Best Practice	**Specific Best Practices**	**Programmatic and Research Recommendations**
	• Monitor beyond the LOD, and include a site's undisturbed areas, and adjacent upstream and downstream areas. • Develop clear monitoring metrics as a way of evaluating goals and the degree of project success. • Implement both a short and long-term vegetation management plan to maintain the post-restoration vegetation target for the banks and floodplain. • Maintain a designated maintenance trail on projects to allow practitioners to monitor and maintain constructed projects without contributing additional disturbance.	• Develop an agreed upon functional metric to define a healthy forest and regionally specific riparian monitoring protocols and forest quality indices. • Develop a training program to provide professional certification for vegetative community classification and condition assessments.

Introduction

The importance of forest buffers for stream health has been widely documented. Healthy riparian buffers in stream systems influence the degree of in-stream ecosystem services related to water quality, physical stream characteristics, and biological characteristics (Palmer et al., 2014; Mayer et al., 2022). Mayer et al. (2010) summarizes research on additional functions of riparian buffers, including stream temperature moderation, urban noise reduction, creation of critical habitat corridors for wildlife. There is existing comprehensive research that summarizes the importance of stream-riparian complexes, including the importance of stream restoration that extends beyond the channel (Wohl et al., 2021). Many of these riparian buffer benefits are acknowledged by and incorporated into state-level strategic planning and goal-setting documents, like the state of Maryland's 2020 – 2025 Forest Action Plan (MD DNR, 2020).

In 2003, Chesapeake Bay Program (CBP) partners set a goal to restore 900 miles of riparian forests in the watershed each year. This goal was renewed in the 2014 Chesapeake Bay Watershed Agreement (CBP, 2014), which was signed by all six Bay states and the District of Columbia. The agreement also calls for the conservation of existing buffers until at least 70 percent of riparian areas throughout the watershed are forested. With growing interest and implementation of stream restoration in the Chesapeake Bay Watershed, there is an increasing need for research about how to protect riparian buffers and minimize their impact during stream restoration construction.

The importance of forest and riparian vegetation protection during stream restoration is noted in the CBP stream restoration crediting protocols. The stream restoration expert panel developed crediting protocols (Schueler & Stack, 2014) that were approved in 2014 and since that time, states and municipalities within the Chesapeake Bay watershed have been implementing them to help meet their respective TMDL load reductions. It was outside the panel's charge to resolve the scientific debate over the prospects of functional uplift associated riparian cover. However, the panel did recognize that:

- Maintenance of riparian cover is a critical element in the ultimate success of any stream restoration project. Projects that involve extensive channel reconfiguration or remove existing riparian cover are likely to see less functional uplift, including nutrient removal, at least until the replanted areas achieve maturity (Orzetti et al., 2010).
- The research reinforces the notion that stream restoration should not be a stand-alone strategy for watersheds, and that coupling restoration projects with upland retrofits and other practices can help manage the multiple stressors that impact urban streams (Palmer et al., 2007).
- Some type of stream functional assessment needs to be an important part of both project design and post-project monitoring of individual restoration projects to provide better scientific understanding of the prospects for functional uplift over time.

The stream restoration expert panel recommendations include a qualifying condition that projects must demonstrate they 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. The panel also recommended that proposed stream restoration projects be developed through a functional assessment process, such as the stream functions pyramid (Harman et al., 2011) or functional equivalent.

Recent CBP technical work groups were convened and resulted in a series of recommendations to improve the stream restoration protocols previously approved in 2014. The groups that specifically expanded upon forest and riparian vegetation management as it relates to stream restoration include the outfall and gully stabilization work group (Bahr et al., 2019) and the Protocols 2 and 3 work group (Wood & Schueler, 2020). The outfall and gully stabilization work group (Bahr et al., 2019) noted that disturbance to trees should be minimized where possible to avoid unintended consequences. In addition, project documentation should indicate how future vegetation will be managed within the project limits to promote enhanced forest cover where appropriate, while allowing for vegetation management to ensure stability of the restored channel over time. The Protocols 2 and 3 work group (Wood & Schueler, 2020) expanded on the unintended consequences of stream restoration on riparian vegetation included in the original stream restoration expert panel report through a literature review and developed recommendations for best practices for floodplain restoration projects over the entire project life cycle.

Qualifying conditions for stream restoration Best Management Practices (BMPs) offer some protection for riparian vegetation but these conditions have not been consistently met. Because stream restoration and expanding forest buffers are a large component of state Watershed Implementation Plans (WIPs) and the 2014 Chesapeake Bay Agreement, it is imperative to better synergize efforts and investments to minimize negative trade-offs impacts/outcomes.

The Center for Watershed Protection, Inc. (CWP) worked collaboratively with the CBP and stakeholders to evaluate methods to reduce impacts of stream restoration projects on existing riparian ecology and forest buffers in Maryland, Pennsylvania, and Virginia. Although "restoration" has many different meanings, stream restoration in the context of this project is defined according to the Chesapeake Bay Program (CBP) stream restoration expert panel recommendations (Schueler & Stack, 2014) as "any natural channel design, regenerative stormwater conveyance, legacy sediment removal or other restoration project that meets the qualifying conditions for credits, including environmental limitations and stream functional improvements." This report was developed to support the "Scope of Work 3: Maintaining Forests in Stream Corridor Restoration and Sharing Lessons Learned" project identified in the 2020 Chesapeake Bay Trust-Technical Assistance - Chesapeake Bay Program Goals and Outcomes request for proposals. Results from final project report were used to inform development of a guidance document for local governments on the best practices to minimize unintended adverse outcomes to riparian forests and identify opportunities for coupling these practices to improve water quality and habitat improvements. The intention of the project is to help improve selection, permitting, and funding processes for stream restoration projects in the Chesapeake Bay watershed.

Methods

This project was guided by input from a Stakeholder Team (Table 2) consisting of members from the CBP Urban Stormwater, Stream Health, Wetlands, and Forestry Workgroups, the Water Quality and Maintain Healthy Watersheds Goal Implementation Teams, as well as representatives from EPA, the Army Corps of Engineers, Maryland Department of the Environment (MDE), Pennsylvania Department of Environmental Protection (PA DEP), Virginia Department of Environmental Quality (VA DEQ), and local government representatives. CWP coordinated closely with the Stakeholder Team over the course of the project to provide guidance, review progress, and discuss findings.

Table 2. Project stakeholder team	
Name	**Organization**
CBP Forestry Workgroup	
Sally Claggett	U.S. Forest Service
Rebecca Hanmer	U.S. Environmental Protection Agency (retired)
Anne Hairston-Strang	MD Forest Service
Judy Okay	Okay Consulting
Frank Rodgers	Cacapon Institute
CBP Wetlands Workgroup	
Denise Clearwater	MD Department of the Environment
Pam Mason	VA Institute of Marine Science
CBP Urban Stormwater Workgroup	
Norm Goulet	Northern VA Regional Commission
David Wood	Chesapeake Stormwater Network
CBP Water Quality Goal Implementation Team	
Suzanne Trevena	U.S. Environmental Protection Agency
Megan Fitzgerald	U.S. Environmental Protection Agency
CBP Maintain Healthy Watersheds Goal Implementation Team	
Renee Thompson	USGS - Chesapeake Bay Program
CBP Stream Health Workgroup	
Brock Reggi	VA Department of Environmental Quality
Chris Spaur	U.S. Army Corps of Engineers
State and Local Government Agencies and Jurisdictions	
Dave Goerman	PA Department of Environmental Protection
Christin Jolicoeur	Arlington County, VA
Sara Weglein	MD Department of Natural Resources
Elmer Weibley, CPESC	Washington County Soil Conservation District
Justin Williams	VA Department of Environmental Quality

Based on feedback from the Stakeholder Team and an informal, online survey of regulators, practitioners, and local governments in the Chesapeake Bay Watershed, CWP developed a Project Plan (Appendix A). The plan outlined the key documents to review and information to extract, individuals to be interviewed and interview questions, and potential focal areas and timeframe for detailed stream restoration evaluations. CWP also developed a quality assurance project plan (QAPP; Appendix B) that documents the planning, implementation, and assessment procedures of, and how specific quality assurance (QA) and quality control (QC) activities were applied during this project. The QAPP was developed in accordance with EPA's "Elements of a Quality Assurance

Project Plan for Collecting, Identifying and Evaluating Existing Scientific Data/Information" and aligns with the EPA Region 3 Quality Management Plan (QMP).

Following EPA approval of the QAPP, the key project tasks were completed, including:

- Policy and Document Review: Policy and guidance documents were reviewed to better understand the requirements of each state for protecting and mitigating damage to stream buffers associated with stream restoration projects. In addition, the requirements of three selected counties included as part of the case study analysis (see task description below) were evaluated.
- Interviews: Interviews were conducted of various stakeholders involved in stream restoration to better understand how the requirements identified from the review of regulatory and policy documents are (or are not) implemented in each jurisdiction and help to identify and refine best practices to minimize adverse impacts to riparian forests.
- Case Study Analysis: Ten stream restoration projects were selected to evaluate changes in riparian vegetation associated with stream restoration projects, including the level of post-construction riparian vegetation success. Changes in pollutant loads associated with any land cover modifications were also compared to pollutant load reductions from the stream restoration projects, to evaluate if there were any trade-offs due to project implementation.
- Webcasts: Three half-day state-focused webcasts (one each in PA, MD, and VA) were conducted in May 2022 to present the current project findings and discuss how to improve stream restoration practices to minimize impacts to habitat and maximize water quality benefits. The webcasts were intended for Bay partners, stream restoration practitioners, and local officials involved with stream restoration at the state and local level.

Specific methods for these tasks are further described in the sections below.

Policy and Document Review

CWP reviewed policy documents recommended from the Stakeholder Team and an online survey as outlined in the Project Plan. This included local forest conservation ordinances (in MD), Joint Wetlands and Waterways permits in PA, MD, and VA, codes and regulations for all three states as well as the local jurisdictions that were selected for further analysis, and technical guidance documents that accompany the relevant regulations. Additional sources of information were identified and reviewed as needed to support project objectives, including publications from USDA, USFWS, US EPA, USACE, and state program partners, and peer-reviewed journals. A total of 40 regulatory and 78 technical/guidance documents were reviewed to attempt to answer the questions defined in the scope of this project. The questions include:

- How are riparian areas and forests defined by various agencies and organizations and what definition should be applied to this study?
- What inventory requirements are in place and how are these inventories used in project planning?
- Are forest agencies engaged and how?
- How are existing forests addressed in project permits?
- What re-vegetation or other mitigation requirements are in place for impacts to streamside forests?
- What are the monitoring requirements and who is responsible for monitoring?
- Are best practices recommended to minimize impacts to riparian forests?

Documents and policies reviewed include the data source characterization required in the WQGIT-approved document, *Protocol for the Development, Review, and Approval of Loading and*

Effectiveness Estimates for Nutrient and Sediment Controls in the Chesapeake Bay Watershed Model (CBP, 2015) to help determine if a document was appropriate and how much influence each document should have on the final recommendations. The documents gathered for review were preferentially from peer-reviewed reports, and federal, state, and local agency sources. Refer to the QAPP (Appendix B) for additional information about the document acceptance criteria.

Interviews

A list of recommended individuals to interview was compiled in the Project Plan based on Stakeholder Team input and an online survey. Additional interviewees were identified from discussions with the three selected counties for stream restoration evaluation (Lancaster County, PA; Anne Arundel County, MD; and Fairfax County, VA). Interviewees were selected to provide a representative sample of state agency, practitioner and MS4 perspectives.

Interviews were conducted from December 21st, 2021, to January 13th, 2022, and were done via Zoom or Microsoft Teams to enable the project team to record the interviews for accuracy. Each interviewer was provided a list of standard questions that were developed to allow comparison across the different jurisdictions. The interviews also included the opportunity for relevant follow-up questions to be asked of the interviewees as needed. The list of interview questions developed cooperatively with the Stakeholder Team to address the project objectives are provided below. The questions are mostly open-ended since the goal of the interview was for the respondent to provide their experiences and expertise for their local jurisdiction regarding stream restoration implementation and impacts on forest resources.

Interview questions for <u>all individuals</u> include:

- What is your experience or involvement with stream restoration projects?
- In your experience, how are sites selected for stream restoration projects? Who identifies the sites?
- Is a riparian forest assessment done prior to restoration to determine forest health, and, if so, what indicators are used?
- How is tree and tree canopy protection deliberated during site selection, design, and installation? Are there scenarios when protecting trees, forest stability, and forest longevity are given priority over streambank reconstruction?
- Are there typical scenarios where entire buffers or mature trees are removed and why?
- When trees are removed during restoration, to what extent are riparian tree cover and structure restored after restoration? How quickly does this occur?
- What best practices are used to minimize impacts to riparian forests (this would include post-restoration maintenance)? To what extent are they implemented?

Interview questions <u>specific to stream restoration practitioners</u>:

- What are the decision processes for selecting the type of restoration?
- How are discrepancies between project design and implementation (such as expected vs. actual forest change) handled?
- What are the parameters for plants/rocks/woody debris used for restoration and where it is sourced? How are decisions regarding the use of "natural" materials and quality of materials made?
- What is done with the trees that are removed (e.g., are they sold? Are any used for restoration off-site or on-site?)?

- What post-construction monitoring is conducted and what is the purpose of the monitoring? Do monitoring requirements vary?
- Have you designed or managed projects that you deem successful? If so, what made them successful?
- Have you designed or managed projects that were less successful or unsuccessful? If so, what were some challenges or issues?

Interview questions specific to non-stream restoration practitioners:

- Are you aware of cases where there have been discrepancies between project design and implementation? If so, how were these discrepancies handled?
- In your experience, what sort of post-construction monitoring is conducted for stream restoration projects in your area?
- Are you aware or have you been involved with stream restoration projects that were successful? If so, what made them successful?
- Are you aware or have you been involved with stream restoration projects that were less successful or unsuccessful? If so, what were some challenges or issues?

The following additional questions for all individuals were sent to the interviewees in June 2022 for further clarification on some of the initial interview results:

- What regulations (federal, state, and local) do you typically follow for stream restoration projects? Are there any gaps that you know of in the regulations that result in the loss of forest cover? Which policies have "teeth", and which do not?
- From your experience, how involved are forest agencies in the stream restoration process? Indicate which agencies you work with and their role.
- What are the typical stream mitigation requirements and are they enforced?
- If you work in MD, do you follow the recommendation from the MD DNR policy document on stream restoration that a 10-year monitoring plan be implemented and conducted by an expert?
- What are the typical funding sources for stream restoration projects you've been involved with (grants, federal, state, in-kind, etc.)?
- What are the typical funding sources for monitoring and maintenance?

Case Study Analysis

Three counties (Lancaster County, PA; Anne Arundel County, MD, and Fairfax County, VA) were identified for the case study analysis to represent each of the three states, and a variety of physiographic regions and stream restoration design types. The counties were selected based on the availability of stream restoration projects, feedback from a Stakeholder Team survey, and available monitoring data. Each county provided a list of stream restoration projects that were considered representative of projects occurring in the county and for which GIS/CAD data, as-builts, permitting documents, design reports, and/or monitoring data were available. CWP ultimately selected ten of these projects for which sufficient data was able to be obtained

CWP used a combination of geospatial analysis, modeling, and document review to develop the case studies. To assess vegetation change at each study site, CWP used the currently available 2013/2014 1-m resolution land use data from the Chesapeake Conservancy[1], as well as NAIP imagery

[1] https://www.chesapeakeconservancy.org/conservation-innovation-center/high-resolution-data/land-use-data-project/

and leaf-off aerial imagery to delineate the land cover within the limit of disturbance (LOD) of each project site before and after restoration. To assist with this process, Peter Claggett from USGS provided a link to an online land use change viewer[2] that shows areas where change occurred between the 2013/2014 dataset and the forthcoming 2017/2018 land cover dataset. Because the pre-construction timeframe of the stream restoration projects did not always align with the timeframe of the 2013/2014 dataset, best professional judgement was used to determine the pre-construction land cover for some projects.

To quantify changes in pollutant loads, CWP used pollutant loading rates from the Chesapeake Assessment and Scenario Tool (CAST) for the Phase 6 land-river segment where each project is located. The loading rates were used with the quantified pre- and post-restoration land cover types to calculate the change in loads associated with land cover conversion due to project construction. The pollutant load reductions associated with each stream restoration project were calculated using the CBP stream restoration planning rate, as well as those calculated using the stream restoration crediting protocols (Schueler and Stack, 2014; Wood et al., 2021) when that information was included with the project data. The planning rate provides for a consistent stream restoration load reduction across all projects based on the pounds of nutrient and sediment reduction per foot of stream restoration project, whereas the load reductions reported for using the CBP crediting protocols are a more accurate estimate based on specific-site conditions and the restoration approach at each site.

CWP reviewed project information, including permitting documents and monitoring reports, to summarize regulatory requirements related to vegetation on the project sites, whether the requirements were met, and the level of post-construction riparian vegetation success. The Nationwide Permit 27 (NWP 27) applied to all but one of the case study projects. NWP 27 includes activities in waters of the United States associated with aquatic habitat restoration, enhancement, and establishment activities, provided those activities result in net increases in aquatic resource functions and services.

Webcasts

Webcasts were planned in coordination with the project's Stakeholder Team, who provided input on potential speakers, attendees, and discussion topics. Speakers that provided state agency perspectives included members from the Stakeholder Team that represented the PA Department of Environmental Protection (PA DEP), MD Department of the Environment (MDE), and VA Department of Environmental Quality (VA DEQ). Local government speakers represented the County in each state that was selected as a focal area for the project's recently completed case study analysis and included Lancaster County, PA, Anne Arundel County, MD, and Fairfax County, VA. These three counties were identified to represent each of the three states, and a variety of physiographic regions and stream restoration design types. The counties were selected based on the availability of stream restoration projects, feedback from a Stakeholder Team survey, and available monitoring data. Speakers providing the practitioner perspective were those identified that have implemented multiple stream restoration projects within the focus state of each webcast.

The agenda for each webcast was similar, with the state agency, local government, and practitioner presentations focused on the state in which each webcast was held and included the following:

- Welcome and Project Overview
- State Agency, Local Government, and Practitioner Presentations
- Presentation of Project Results

[2] Land Use Change Viewer (cicapps.org)

- Facilitated Discussion
- Wrap Up and Next Steps

Literature Review of Stream Restoration Impacts on Riparian Vegetation and Best Practices

Introduction

Stream restoration is extremely complex with numerous approaches due to the interaction of hydraulic, morphologic, physiochemical, biological, social, political, and other systems to varying degrees. This complexity is exemplified by the USDA NRCS Stream Restoration Design guidance document (USDA NRCS, 2007), Part 654 of the National Engineering Handbook, which is 714 pages in total. The USDA's more distilled "Guide for Stream Restoration" (Yochum, 2018) provides a more current overview as opposed to step-by-step guidance, but it is still over 100 pages in total. Even the "Natural Channel Design Review Checklist" (Harman & Starr, 2011) is nearly 100 pages. Given the complexity of stream restoration design, it is important to understand the impacts of restoration-related activities on riparian forest cover, and to accurately value associated tree trade-offs during project prioritization. This literature review includes a summary of potential riparian buffer impacts due to stream restoration, as well as a review of available guidance that includes best practices for minimizing impacts to riparian forests.

Temperature Impacts

There is increasing emphasis on the consideration of in-stream water temperatures as a metric of stream health, especially as it relates to measuring the success of stream restoration projects. In-stream water temperature is considered especially important in the context of climate change and urbanization (Mayer et al., 2010). According to a recent report from the Rising Watershed and Bay Temperatures CBP Science and Technical Advisory Committee (STAC), temperatures of both water and air have been increasing in the Chesapeake Bay Watershed for over 60 years; however, in-stream water temperatures are increasing faster than air temperatures, which is evidence of the influence of land use and other watershed-specific characteristics (Batiuk et al., 2022). Regulated thermal regimes in streams are important for a variety of reasons, including maintaining spawning habitat for fish, reducing algal growth, reducing populations of parasites that favor warmer temperatures, and regulating nutrient/carbon/oxygen dynamics, since temperature affects the dynamics of many gaseous and aqueous compounds (Batiuk et al., 2022; Mayer et al., 2010; Wilkerson et al., 2006).

The effects of stream restoration on stream-water temperature are still being researched, as well as the best approaches for reducing stream-water temperatures. Many consider decreased streamflow, widened channels, and reduced riparian cover to be the primary drivers of rising in-stream water temperatures (Batiuk et al., 2022; Justice et al., 2017; Wilkerson et al., 2006). These drivers were supported by the cumulative findings of the Rising Watershed and Bay Temperatures CBP STAC—summarized generally, riparian trees along narrower stream channels can provide shading (from the canopy cover) and cooling (from evapotranspiration), in addition to increasing the infiltration of stormwater runoff to the stream channel. One of the CBP STAC's reports identified infiltration as a process that may regulate the temperature of stormwater before it enters a stream (Brownson et al., 2022). This report also explains how certain types of BMPs, like tree planting and riparian buffers, decrease temperatures of treated stormwater, while other types of BMPs may have a heating effect on treated stormwater (Brownson et al., 2022). However, the evidence supporting these primary drivers does vary from study-to-study. For example, one of the CBP STAC's reports indicated that trends of increasing in-stream water temperatures were detected despite trends of increasing streamflow in portions of the Chesapeake Bay (Batiuk et al., 2022).

Each of these primary drivers—streamflow, channel width, and riparian cover—are typically impacted in some way by stream restoration projects. Generally, stream restoration projects aim to regulate streamflow, stabilize channels, reconnect to the floodplain and/or replace dying or at-risk trees. In many stream restoration projects, temporarily reduced riparian cover is an expected outcome. While the canopy is expected to expand over time as newly planted vegetation matures, temporary canopy reduction still impacts stream-water temperatures. Sudduth et al. (2011) and Violin et al. (2011) compared the functional uplift provided by four forest reference streams, four natural channel design (NCD)-restored streams, and four non-restored urban streams in the North Carolina Piedmont. The studies concluded that the heavy machinery used to reconfigure channels and banks led to significant losses of riparian canopy cover and corresponding increases in stream temperatures. These thermal impacts were a major factor in the lack of functional uplift observed in restored streams compared to non-restored, forested streams.

One of the recent reports from the Rising Watershed and Bay Temperatures CBP STAC[3] describes the importance of prioritizing the creation of thermal refugia in stream restoration design using a case study from a project in the District of Columbia (CBP STAC, 2022). This District-based project incorporated deeper channels for fish habitat and the preservation/planting of riparian trees to cool the stream-water; in current post-construction monitoring data, stream biota improvements have been observed. This case study supports the premise that stream restoration that considers and prioritizes the temperature impacts of riparian canopy and channel depth can offset thermal impacts typically associated with restoration (CBP STAC, 2022).

In contrast, other research considers groundwater interactions and microtopography to be the primary drivers of stream-water temperatures. Sentence with citation if possible. While microtopography can be considered as part of the stream restoration design, it can be difficult to mimic the complex microtopography found at natural sites. Stream-water temperature increases could be influenced by a variety of factors that are unrelated to riparian vegetation or stream restoration as well, including but not limited to climate change, industrial discharges, hydrologic regime modifications (including interactions with groundwater), land use/land cover, topography, and tidal influences (Batiuk et al., 2022).

Commented [LFM1]: Dave Goerman, you mentioned that you may have references for this during the webcast. If so, could you provide them so we can insert in the literature review?

Biologic, Habitat, & Water Quality Impacts

Streams provide critical habitat for many wildlife species, and healthy, native riparian vegetation is essential for maintaining that habitat. The species composition of riparian vegetation and the distribution/density of plants within the riparian buffer are two metrics that influence both the species and quantities of fish, insects, macroinvertebrates, and other wildlife that can be supported by a stream-riparian system. While there are a variety of assessment techniques to evaluate the quality of stream-riparian habitat, most involve biological monitoring. Macroinvertebrate assemblages are most widely used (Doll et al., 2016); however, fish assemblages (particularly cold-water fish) are also

[3] All 10 of the synthesis draft element reports produced by the Rising Watershed and Bay Temperatures CBP STAC can be found here: https://www.chesapeake.org/stac/events/day-1-rising-watershed-and-bay-water-temperatures-e2-80-94ecological-implications-and-management-responses-a-proactive-programmatic-cbp-stac-workshop/.

important indicators of habitat quality, especially in restored streams where canopy cover is temporarily reduced prior to regrowth.

When trees are removed for stream restoration projects, the critical habitat provided by their canopy and root systems is also removed. Although removed trees are typically replanted in-kind, the maturation of the restored vegetation can take many years. Recent work by Wood et al. (2021) and Kaushal et al. (2021) demonstrated that tree removal during stream restoration construction can trigger sub-surface fluxes of nutrients out of the riparian zone and into the stream and that there is an ecosystem recovery period following tree removal that lasts at least 5 years. These shifts in nutrient dynamics can also affect concentrations of both nutrients and organic carbon in groundwater (Kaushal et al., 2021).

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

It is difficult to develop a predictive relationship between metrics of stream-wetland habitat quality and indicators of biological success due to the inextricable influence of areas upland in the watershed (Doll et al., 2016; Stranko et al., 2011). Some studies have found either no evidence or very limited evidence that stream restoration projects in urban watersheds have the potential to improve habitat quality in a meaningful or reliable way, partially due to the influence of the contributing drainage area to the stream (Hilderbrand, 2020; Hilderbrand et al., 2015; Violin et al., 2011). However, it is clear that the removal of mature trees during restoration physically alters the available habitat in a stream-riparian system, and those physical alterations have coincidental effects on stream-water chemistry. Both of these restoration-related changes—physical and chemical—affect the biological uplift provided by a restored stream.

Inundation Impacts from Floodplain Reconnection

Stream restoration projects that enhance floodplain reconnection can impact existing upland riparian vegetation species. Flooding reduces upland tree species root growth which leads to decline, death, and decay over time (Coder, 1994). The severity of impact to the plant community is dependent on the tree's tolerance level to flooding, "the soil conditions present and the nature, timing and duration of the water level change" (Teskey & Hinckley, 1977). For example, Bald Cypress and Nuttall Oak trees "showed superior performance under frequent intermittent flooding regimes due to rapid recovery of gas exchange soon after soil was drained" (Anderson & Pezeshki, 1999). Similarly, Angelov et al. (1995) saw 95% of Swamp Tupelo and Sweetgum seedlings survive continuous root flooding for more than 2 years whereas Swamp Chestnut Oak and Cherry Bark Oak seedlings only survived 1 year of flooding. Hudson et al. (2015) recommends planting multiple primary successional species, excluding the American Sycamore, grown in gallon containers as the best choice for establishing productive trees in created forested wetlands.

Given the scarcity of fully functional floodplains in urbanized portions of the Chesapeake Bay watershed, stream restoration projects that include floodplain reconnection should represent a net gain of species diversity and the overall ecological health of the watershed (Budelis et al., 2020). Research conducted by Januschke et al. (2014) suggests that hydro-geomorphological restoration, or floodplain reconnection, results in different community assemblages. The above reasoning may justify why upland tree loss within this context may be seen as an acceptable or expected design objective for stream restorations that reconnect the stream to its floodplain. However, Budelis et al. (2020) found no clear evidence that floodplain reconnection altered functional composition and diversity in plant communities in a Maryland study that evaluated metrics of woody/tree and herbaceous plant communities using data from four stream restoration projects with varying project designs and watershed characteristics.

Best Practices for Minimizing Impacts to Riparian Forests

Federal, state, and local guidance documents were reviewed to identify best practices for accounting for forest health as part of stream restoration projects. All three states had technical guidance documents that detailed recommended practices for stream restoration and accompanying information on design techniques. The recommended best practices were reviewed and organized by the following categories corresponding to the various stages of the stream restoration process:

- Site Selection
- Establishing Goals and Objectives
- Design and Permitting
- Stakeholder Engagement
- Construction
- Monitoring and Maintenance

Error! Reference source not found. provides an overview of the guidance documents reviewed and which best practices they address.

Table 3. Guidance documents that incorporate best practices for minimizing riparian forest impacts.

Citation	Title	Jurisdiction	Description	Site Selection	Establishing Goals and Objectives	Design and Permitting	Stakeholder Engagement	Construction	Maintenance and Monitoring
Keystone Stream Team (2007)	Guidelines For Natural Stream Channel Design for Pennsylvania Waterways	PA	These guidelines will assist watershed organizations with the planning and implementation of stream restoration projects and professionals with stream restoration design, construction, and permitting in PA. The guidelines were developed by the Keystone Stream Team, an informal group comprised of government and environmental resource agencies, university researchers, sportsmen, citizen-based watershed groups, and private companies.				X	X	X
MD DNR (2015)	Principles and Protocols to Guide the Department of Natural Resources' Actions Regarding Stream Restoration Projects in Maryland	MD	MD DNR developed criteria to guide their actions to review, support, fund, and /or construct stream restoration projects in Maryland.			X		X	X
MD DNR (2018)	Regenerative Stream Conveyance Construction Guidance	MD	Presents guidance on the development and implementation of regenerative projects. Provides construction guidance to aid contractors' regenerative stream restoration efforts. Serves as common reference for various professionals in the field of water resources and watershed restoration.			X		X	X
MD DNR (2014)	River/Stream Management Strategy: Guiding Principles	MD	Outlines the "guiding principles" that provide a science-based perspective on rivers and streams intended to help MD DNR's Environmental Review Unit effectively evaluate and consistently formulate sound recommendations on						X

Table 3. Guidance documents that incorporate best practices for minimizing riparian forest impacts.

Citation	Title	Jurisdiction	Description	Site Selection	Establishing Goals and Objectives	Design and Permitting	Stakeholder Engagement	Construction	Maintenance and Monitoring
			proposed projects that could adversely affect the State's rivers and streams.						
MDE (n.d.)	MS4/Chesapeake Bay TMDL/Trust Fund Restoration Project Wetlands & Waterways Permit Package Checklist	MD	Details the permit package that must be submitted for stream restoration projects in nontidal areas.	X		X	X	X	
MDE (2022)	Guidance for Stream Restoration Based on Key Wildlife Habitats: Upper Coastal Plain Stream-Associated Wetlands	MD	Stream restoration guidance document developed by MDE to better ensure that restoration projects are designed to protect aquatic/wetland resources that may be present or dependent on the site while still allowing for projects which can receive credit toward nutrient and sediment reduction.	X	X	X		X	X
MW COG Berger et al. (2021)	Draft Recommended Stream Restoration Best Practices	DC, MD, VA	Details a set of practices for how local governments can best implement stream restoration projects, focusing on planning/design, siting and final project selection, public engagement, and construction/assessment/maintenance.	X	X	X	X	X	X
PA DEP (2022)	Pennsylvania Function-Based Aquatic Resource Compensation Protocol	PA	New guidance regarding compensatory mitigation for projects that must replace natural resources impacted during permitted projects	X	X	X	X		
US EPA Harman et al. (2012)	A Function-Based Framework for Stream Assessment & Restoration Projects	Nationwide	Provides a framework for approaching stream assessment and restoration from function-based perspective. The document is meant to help the restoration community understand the interrelationships and functional hierarchy that exists between stream	X	X				

Table 3. Guidance documents that incorporate best practices for minimizing riparian forest impacts.

Citation	Title	Jurisdiction	Description	Site Selection	Establishing Goals and Objectives	Design and Permitting	Stakeholder Engagement	Construction	Maintenance and Monitoring
			functions and other structural measures. Provides informal guidance and ideas on how standard operating procedures may incorporate stream functions into debit/credit determination methods, function-based assessments and performance standards.						
USACE USBR & ERDC (2016)	National Large Wood Manual—Assessment, Planning, Design, and Maintenance of Large Wood in Fluvial Ecosystems: Restoring Process, Function, and Structure	Nationwide	Provides a basic understanding of the role of wood in fluvial aquatic and riparian ecosystems. Explains how wood should be maintained, reintroduced, and managed while also evaluating the best policies behind restoring wood in rivers and streams. Provides resource manager and restoration practitioners with guidelines for the planning, design, placement, and maintenance of large wood in streams with a focus on ecosystem restoration.		X	X		X	
USDA FS Yochum (2018)	Guidance for Stream Restoration	Nationwide	Provides a guide for the available guidance via a series of short literature reviews on the topics of general methods of stream restoration, stream processes, restoration case studies, data compilations, preliminary assessments, and field data collection. Serves as a technical note to assist professionals in stream restoration projects.		X			X	
USDA FS	Chesapeake Bay Riparian Handbook: A Guide for	Chesapeak e Bay	Contains information on the functions, design, creation, and management of riparian forest buffers to be utilized by				X	X	

Table 3. Guidance documents that incorporate best practices for minimizing riparian forest impacts.									
Citation	**Title**	**Jurisdiction**	**Description**	**Site Selection**	**Establishing Goals and Objectives**	**Design and Permitting**	**Stakeholder Engagement**	**Construction**	**Maintenance and Monitoring**
Palone & Todd (1998)	Maintaining Riparian Forest Buffers		land managers and planners. The document is to be used by Delaware, Maryland, New York, Pennsylvania, Virginia, and West Virginia, all of which are in the Chesapeake Bay watershed, as well as Bay adjacent states. Uses a three-zone riparian buffer concept as the organizational guideline for buffer establishment.						
USDA NRCS (2007)	Stream Restoration Design (National Engineering Handbook 654)	Nationwide	Contains comprehensive guidance for the planning and designing of projects intended to improve streams and their functions. Provides engineering and ecological assessment tools used perform analyses and designs in the field of stream restoration that are representative of green techniques and structural approaches.		X	X	X	X	
USFWS Pollock et al. (2015)	The Beaver Restoration Guidebook: Working with Beaver to Restore Streams, Wetlands, and Floodplains	Nationwide	Contains an overview of the best available science for improving ecosystems using beavers to restore streams, floodplains, wetlands, and riparian ecosystems. Mainly covers beaver ecology and beaver restoration and management.		X				
VA DCR Baird & Wetmore (2003)	Riparian Buffers Modification & Mitigation Guidance Manual	VA	Provides assistance to local government staff for the implementation of buffer modification provisions of the Chesapeake Bay Preservation Area Designation and Management Regulations. The document is meant to be used with riparian landowners on buffer establishment, management, and			X	X		X

Table 3. Guidance documents that incorporate best practices for minimizing riparian forest impacts.									
Citation	**Title**	**Jurisdiction**	**Description**	**Site Selection**	**Establishing Goals and Objectives**	**Design and Permitting**	**Stakeholder Engagement**	**Construction**	**Maintenance and Monitoring**
			restoration issues. The manual is meant to improve buffer management strategies to help improve the water quality of the Chesapeake Bay and its tributaries.						
VA DCR (2004)	The Virginia Stream Restoration & Stabilization Best Management Practices Guide	VA	Provides information on the permitting issues, planning and design guidelines, costs, and individual best management practices for stream restoration. The guide is intended for use as technical resource in the constructing of stream channels and bank stabilization and restoration projects.	X		X			
VA DEQ (1992)	Virginia Erosion and Sediment Control Handbook	VA	Establishes new standards and guidelines for the control of soil erosion and sedimentation on land disturbing activities. It is intended to serve as a technical guide in the effort to meet the requirements dictated by the Virginia Erosion and Sediment Control law and the Virginia Erosion and Sediment Control Regulations (9VAC25-840). Additionally, the handbook contains specific guidance on the application of conservation practices.			X		X	

Key Findings and Recommendations

The results and lessons learned from each of the project tasks are summarized in separate documents included as appendices to this report:

- Policy/Document Review and Interview Results Technical Memorandum (Appendix C)
- Case Studies Summary (Appendix D)
- State Webcast Summary (Appendix E)

The key findings from these project tasks are summarized below and are organized by recommended best practice categories.

Site Selection

Site selection for stream restoration projects is typically done by either municipalities or planning-oriented organizations working in coordination with the municipalities. Stream restoration practitioners are often not involved in the planning, prioritization, or selection of sites, other than to provide comment on the applicability of a pre-identified site for restoration design and grant funding. Generally, sites are selected using one or a combination of the following methods: 1) opportunistic considerations, 2) watershed assessments conducted as part of a watershed planning initiative, or 3) mitigation banking efforts. In terms of mitigation banking projects, site selection is driven by the market and less through prioritization of a region/watershed.

Funding availability and landowner willingness were commonly identified as key parameters for site selection. Restoring lengths of stream that are significant at the landscape-scale is dependent on having agreement by multiple willing landowners. In some cases, a site is not necessarily the most optimal in relation to the rest of the watershed, but it is prioritized due to the likeliness that it will be implemented.

When considering site selection, upland stormwater controls were questioned during the webcasts as a potential alternative option to conducting stream restoration projects. Stream degradation is almost always the result of upland modification, particularly the development of urbanized areas and the increase of impervious surface cover. There are many older developed areas that have minimal or no stormwater management. Implementing enough stormwater controls at the watershed scale to be effective is challenging and depending on the watershed may not be feasible due to property ownership and enforcement concerns. Retrofitting older stormwater facilities can also be beneficial, but the area benefitted is often small and localized.

The difficulty with solely implementing upland stormwater controls is that that even if the stormwater flows are reduced, degradation to the stream systems has already occurred and will continue. Without addressing these causal factors, stream restoration projects will not be able to restore all the ecological stream functions (e.g., restoring biota) and can often fail over time. Considering that addressing impervious impacts from the watershed can take decades, many times it is prudent to "restore" certain functions of a stream that is rapidly eroding causing property damage and increased sediment and nutrient loadings to downstream waters. There is often a cost to not doing a stream project in terms of damage to infrastructure, threats to public safety and further loss of trees as streams continue to erode.

Table 4 contains identified best practices related to site selection for maintaining forests and riparian vegetation, and Table 5 contains programmatic and research recommendations related to site selection.

Table 4. Site Selection Best Practices
Follow a watershed-based approach for screening and prioritizing stream restoration projects that target restoration to areas in need instead of existing high-quality areas.
Evaluate options for combining stream restoration with stormwater, forestry and agricultural BMPs in the contributing watershed.

Table 5. Site Selection Programmatic and Research Recommendations
State agencies should develop guidance similar to Guidance for Stream Restoration Based on Key Wildlife Habitats: Upper Coastal Plain Stream-associated Wetlands (MDE, 2022) that defines "high-quality" existing areas that should be avoided.
Conduct a comprehensive review of the scientific and grey literature related to stream restoration and upland stormwater controls to determine if guidelines can be developed for conditions when one practice is recommended over the other or a combination of the practices is most effective. Many research studies are either underway or have recently been completed on this topic suggesting it may be good timing for synthesizing all the available findings. For example, Lammers et al. (2020) developed a set of recommendations for integrated planning of stormwater control measures and stream restoration to simultaneously achieve water quality and channel protection goals based on a modeling study. Dr. Tess Thompson is also currently conducting on a Chesapeake Bay Trust (CBT) funded modeling study, "Effectiveness of Stormwater Management Practices in Protecting Stream Channel Stability." In addition, CWP completed a monitoring study, "The Self-Recovery of Stream Channel Stability in Urban Watersheds due to BMP Implementation" (CWP, 2021) and was recently awarded additional funding from CBT to continue long-term monitoring of the study sites.

Establishing Goals and Objectives

Establishing achievable goals and objectives is one of the most important steps in a stream restoration project that determines not only the design, but the data collection effort and methodologies for assessments. The CBP stream restoration expert panel and subsequent work groups recommended that proposed stream restoration projects be developed through a functional assessment process, such as the Stream Functions Pyramid (Harman et al., 2012) or functional equivalent. However, many stream restoration projects state the goal of a project is to restore dimension, pattern, and profile, which correspond to standard operating procedures associated with the Clean Water Act Section 404 Program, instead of incorporating goals that provide some type of functional lift and better align with the fundamental objective of the CWP Section 404 regulatory program (Harman et al., 2012).

Stream restoration projects are also commonly implemented with the goal of obtaining nutrient and sediment load reductions for TMDL credit and do not consider CBP riparian buffer goals. The case study analysis found that the nutrient and sediment load reduction benefits of restoration significantly outweighed any negative water quality impacts from land use conversion due to the restoration (forest to wetlands or tree canopy over turf), further incentivizing their use for TMDL credit. However, this was not the intention of the CBP Stream Restoration Expert Panel and subsequent work groups, which contain a qualifying criterion that, "Stream restoration is intended to be a carefully designed intervention to improve the hydrologic, hydraulic, geomorphic, water quality, and ecological condition of degraded urban streams, and must not be implemented for the sole purpose of nutrient or sediment reduction" (Schueler and Stack, 2014; Wood et al., 2021)

Establishing appropriate goals and objectives is dependent on the definition of stream restoration, which varies among the states. For PA DEP, restoration addresses the underlying causes of resource degradation within the modern constraints and acceptable vegetative outcomes are driven by addressing the underlying cause of degradation. Targeting symptoms of degradation would not be considered restoration under this definition. PA DEP also recognizes that natural aquatic resources buried beneath legacy sediment are not exclusively forested and may provide substantial habitat and water quality benefits (Voli et al., 2009; Hilgartner et al., 2010; Merrits et al., 2011; Hartranft et al., 2011). MD DNR adopted guiding principles related to stream restoration in June 2015 that defines and reviews distinct criteria for various types of stream treatments (e.g., restoration, rehabilitation, engineering, reclamation, stabilization, and enhancement) and noted that not all projects should be considered stream restoration. Historic or predevelopment conditions for setting vegetation restoration goals do not play a major part in MDE's considerations, which instead evaluates projects based on the value of current conditions. In VA, the definition of stream restoration is the process of converting an unstable, altered, or degraded stream corridor, including adjacent areas and floodplains to its natural conditions.

Establishing goals and objectives should also consider potential effects on stream temperature due to the importance of riparian forest cover for cold water refugia. There is currently a STAC report under development on this topic. One problem is that many stream systems are driven by stormwater with limited groundwater-based flow. Microtopography is an important consideration and substantial groundwater connection is a driver of cooler stream temperature. This is inconsistent with findings from the STAC report but is dependent on multiple factors and can be a complicated modeling problem that requires further investigation.

Table 6 contains the identified best practices related to establishing goals and objectives for maintaining forests and riparian vegetation, and Table 7 contains programmatic and research recommendations related to establishing goals and objectives.

Table 6. Establishing Goals and Objectives Best Practices
Develop stream restoration projects through a functional assessment process, such as the Stream Functions Pyramid (Harman et al., 2012) or functional equivalent.
Review the project goals with all stakeholders to determine if forested riparian conditions are appropriate and achievable within the current, historic, and projected future conditions of a project site.

Table 7. Establishing Goals and Objectives Programmatic and Research Recommendations
Many current functional assessment methods have not yet been fully calibrated and standardized for floodplain restoration projects. The CBP Protocol 2 and 3 Workgroup (Wood and Schueler, 2020) identified a **research need to define and test new metrics that can effectively predict and rapidly measure the degree of functional uplift and/or functional losses achieved by floodplain restoration projects over short- and longer time frames. This method should incorporate functional assessment related to stream temperature**.

Table 7. Establishing Goals and Objectives Programmatic and Research Recommendations
The CBP Stream Restoration Expert Panel (Schueler and Stack, 2014) intended for stream restoration projects to be part of a holistic watershed approach that includes the riparian area. **State agencies should consider integrating CBP riparian buffer goals as part of the review process for stream restoration projects**.

Design and Permitting

The decision processes for the types of stream restoration vary widely among jurisdictions and practitioners. In some cases, a municipality, organization, or practitioner specializes in and only performs one type of restoration. There are some trends by state as well. For example, legacy sediment removal projects, which involve a high amount of disturbance and remove existing surface vegetation, appear to mainly be pursued in Pennsylvania and are typically avoided in Maryland and Virginia. The way in which practitioners described their decision-making process was also variable; however, most do not arrive at a new site with a preconceived preference for the type of restoration. They allow the assessment, site constraints, and goals to drive the selected method.

Regulations at the federal, state, and local levels impact the ways in which riparian forest cover is considered in stream restoration design as well. Some of these regulations are more specific and/or enforceable than others, especially at the county level. Practitioners in Virginia indicated that local regulations are typically the most specific and robust as a result of locally implemented Chesapeake Bay Preservation Ordinances administered through Virginia's Chesapeake Bay Act. However, local governments indicated there is a lack of state guidance on the topic, which would be a valuable resource as localities provide internal review of stream restoration projects. In Maryland, the Forest Conservation Act is enforced at the county level; however, practitioners described notable differences in the ease of implementation across counties in the state. This is partially due to the variation in counties' personnel resources for enforcement and partially due to the presence/absence of county-specific supplemental regulations. In addition, some counties exempt stream restoration projects from the regulations.

Most regulations at the federal and state level specify the need for required minimum vegetation cover and/or replating requirements in the form of a revegetation plan, as opposed to regulating the degree to which forests at project sites can be cleared. This does not mean that vegetation can be cleared haphazardly; rather, it permits flexibility in design approaches, like legacy sediment removal, which would otherwise be much more difficult to implement since it typically requires substantial vegetation clearing. While this is not technically considered a regulatory gap that permits the clearing of riparian vegetation, it does indicate the importance of adapting regulations to suit restoration needs.

In terms of pre-restoration riparian assessments, inventory of environmental features is necessary if a federal project permit is required. At the state and local level, pre-restoration assessments are typically not formally required, but are encouraged. Funding limitations are likely to necessitate a choice between conducting a full forest inventory or a survey of trees adjacent to the specific project area. At the minimum, riparian assessments are informal, may or may not be documented, and are conducted by professional judgment. When practitioners conduct more detailed assessments, factors like dead/at-risk trees, root coverage, bank stability, habitat, soil type, and invasive species presence may be considered.

In addition, states and local governments have forest agencies involved in stream restoration projects to highly variable degrees based on jurisdiction. In Maryland, local government offices who administer the Forest Conservation Act are generally regarded as a forest agency, and so is DNR's Forest Service, who typically works alongside those local government offices. However, this varies greatly by county and by project. Additionally, counties with Critical Areas tend to be heavily involved in the review of stream restoration projects. In Pennsylvania, forest agencies like the Department of Conservation and Natural Resources (DCNR) are not typically involved with stream restoration projects, and collaboration with non-local entities is typically limited to working with DEP and the ACOE on permitting. In Virginia, there are generally county-level Urban Forestry departments that are actively involved in stream restoration projects implemented by the counties. These Urban Forest Management groups within counties in Virginia typically:

1) Participate or are represented as a stakeholder during the design phase,
2) Provide regulatory inspections for tree and hazard inspection, including conducting formal plan reviews of tree inventories and tree protection/replacement plans,
3) Provide technical guidance and expertise to project managers and construction managers about forestry/arboriculture, including tree installation and maintenance.

As the degree of pre-restoration riparian assessments varies by state, practitioner, and project, so does the degree to which tree and canopy protection is considered. Many of the state and local ordinances reviewed include criteria for the retention of existing forest or tree resources over replacement or replanting. Multiple practitioners noted that if a site has an exceptionally high-quality forest stand and a project is likely to cause extensive tree loss, then that site is reconsidered altogether. The removal of entire buffers or mature trees is also typically avoided as much as possible. However, the removal of entire buffers was largely mentioned in association with legacy sediment removal, dam removal, and infrastructure protection projects, in which case it is accepted as part of the restoration process. For sites where tree impacts cannot be avoided, the protection or larger trees with good root structure or canopy cover are prioritized.

Floodplain restoration projects in a fully forested floodplain tend to be constructed if it is determined that minimal tree loss is possible. However, in cases where dry, upland species are occupying a stream terrace that has dried out over time, those trees wouldn't necessarily be targeted for removal, but their death as a result of stream restoration is sometimes considered an acceptable outcome.

One method to mitigate loss of streamside forests is to require replanting of buffers when impacts to the buffer are considered unavoidable. Replanting the buffers is required by the 404 permits, 401 certification requirements, and state permits after the restoration is complete. Some jurisdictions like Fairfax County experiment with different planting techniques to provide higher degrees of canopy coverage in shorter amounts of time. For mitigation bank projects, MD DNR's Interagency Review Team (IRT) for mitigation banking requires that impacts associated with waters of the U.S. are mitigated. There are also more specific mitigation requirements for impacts to wetlands. Especially in the case of TMDL projects, many practitioners indicated that their projects are designed to be self-mitigating, meaning that restoration-related impacts are offset by the restored resources. However, it can be a challenge to successfully replace lost forest and not all efforts are successful without additional post-construction maintenance, protection from herbivory, and establishment of water levels supportive of native tree species.

Pre-application meetings with federal and state permitting agencies help the applicant design a project that will minimize environmental impacts, including existing riparian resources, before a final design is committed to and a great deal of money is spent. This early feedback also helps to identify aspects of the proposed project that may affect permit approval and possible alternatives to streamline the approval process. Pre-application meetings can also apply to public outreach and education where they may help to reduce and/or address community concerns about the project.

Table 8 contains identified best practices related to design and permitting for maintaining forests and riparian vegetation, and Table 9 contains programmatic and research recommendations related to design and permitting.

Table 8. Design and Permitting Best Practices
Configure the restoration design to unique site conditions instead of the site to a specific type of practice.
Conduct a comparative analysis of different restoration approaches to evaluate the impacts of temporary construction landscaping relative to the creation of a long-term, sustainable system. This comparative analysis of restoration approaches should also consider the level of risk a client or landowner is willing to accept for both routine and restorative maintenance.
Rank on-site trees during the planning process based on factors such as tree health, location, size, value, bank proximity, root mass erosion status, and amount of shade cast.
Develop (and implement) planting plans that prioritize native species and consider impacts of invasive species.
Consider planting techniques to provide higher degrees of canopy coverage in shorter amounts of time.
Conduct pre-application meetings with state and federal permitting agencies.

Table 9. Design and Permitting Programmatic and Research Recommendations
State agencies should clearly define stream restoration and use consistent terminology for permit processing.
A comprehensive review of county-level regulations should be conducted to determine how well they incorporate state-level requirements such as the MD Forest Conservation Act, and the extent to which they include enforceability measures. State agencies should develop guidance documents to assist local governments with implementation of state-level requirements.
State agencies should encourage and coordinate collaboration between forest agencies and local governments to ensure they are involved with project design. Forest agency participation during the pre-application meetings should also be encouraged or required.
State agencies should develop checklists based on the best practices recommended in this report that can be used at the state and county level during stream restoration project review. This report summarizes information many valuable guidance documents and recommendations for best practices. Review checklists would provide a strategy by which these best practices are considered and implemented.

Stakeholder Engagement

Stakeholders include a range of individuals from internal and external groups. Internal stakeholders may include outreach managers, reviewers and permitting agencies, staff from various government departments and agencies, and elected officials. External stakeholders may include local residents and landowners near the site, community groups, non-profit organizations, others in the planning and design process, and schools.

Landowner engagement and public outreach/education are essential components of stream restoration projects and should be done early in the project process prior to the submission of permit applications to the state. Many community concerns are related to tree loss and Impacts to the terrestrial system in public areas where larger floodplain reconnection projects are proposed. It's important to understand what the public wants and then balance whether that is appropriate for the site or not within the regulatory requirements. It's also important that the community be involved in reviewing project documents and assisting with decision making.

Table 10 contains identified best practices related to stakeholder engagement for maintaining forests and riparian vegetation, and Table 11 contains programmatic and research recommendations related to stakeholder engagement.

Table 10. Stakeholder Engagement Best Practices
Conduct pre-restoration community engagement, including getting local stakeholders involved, communication about the project, setting expectations, and gathering consensus on the project's goals and objectives.
Coordinate with federal, state, and local governments, as well as practitioners, forest agencies, contractors, landowners, and local community stakeholders to **come to consensus on the preferred design approach and project goals/objectives**.

Table 11. Stakeholder Engagement Programmatic and Research Recommendations
State agencies and local governments should consider developing outreach materials to help the public and landowners better understand the stream restoration process. For example, an ArcGIS StoryMap highlighting what the agencies consider successful projects, the stages of stream restoration, and what the restoration site typically looks like during each stage would help to generate realistic expectations and better enable stakeholders to provide input.

Construction

Multiple practitioners described that their primary approach to handling discrepancies between design and implementation is to avoid discrepancies to begin with by conducting comprehensive planning. This was especially the case for discrepancies between expected and actual forest change, which would require a project change order and may also trigger permit violations. Other practitioners may devise a new design altogether and/or submit a change order. "Smaller" discrepancies, such as the plant palette/species list, may be modified during construction depending on hydrology—for example, shifting locations of specific plant species from areas with dry to wetter regimes based on post-construction conditions. Additionally, some practitioners rely on adaptive management, meaning that the discrepancies on-site "settle in" over time and resolve themselves. MDE has found discrepancies after or during implementation to be a violation of the permit and subject to enforcement action or through the permit modification process and has taken compliance actions for some projects.

In terms of woody debris, most practitioners prefer to source this from trees harvested on-site, or they will use trees harvested across the multiple sites that they are working on interchangeably. Trees harvested on-site are typically reused on-site for in-bed woody debris, stability or energy management structures, habitat creation, soil substrate integration, and/or mulch (for tree root protection or ground protection for construction access roads).

There are many available guidance documents that include information for best practices during stream restoration implementation. Some of the predominant best practices for maintaining forests and riparian vegetation during construction that were identified from the document review and interviews are summarized in Table 12 below.

Table 12. Construction Best Practices
Site managers responsible for riparian forest impacts should be present on site.
Limits of Disturbance (LODs) should be carefully drawn and managed. They should be kept as small as possible, and the construction sequence should be organized to prevent equipment from repeating trips over the same area many times.
Individual trees and swaths of trees to be protected should be flagged and marked.
Trees that are at risk of being impacted by construction activities should have additional protection measures applied. Some practitioners use bracing/wood posts around the trunks to prevent equipment damage, and others use a combination of foam and wood for protection. Sturdy metal cages may be installed around trees and shrubs on sites with large deer populations. All trees within 5 feet of the LOD should be armored.
Rubber-tire construction vehicles should be used to minimize compaction. Ideally, those vehicles should be as small as possible.
Roots should be trimmed if impact from construction equipment is unavoidable.
Water gators (bags of water attached to the tree that slowly drip down) should be installed, and mulch should be applied around the trees to keep underlying soil moist.
Ground protection practices should be implemented to minimize rutting and compaction from construction and reinforce the organic content of the forest floodplain soils, which benefits native species.
Trees that are downed or removed on-site should be reused on-site.
Planting plans that track survivability and post-construction vegetative management (including supplemental plantings and invasives control) should be used as tools to handle discrepancies, which allows for fine-tuning as the forest and vegetation re-establishes.

Monitoring and Maintenance

Monitoring and maintenance were noted as critical components of stream restoration projects that are often overlooked and vary among local governments. Post-construction monitoring is required for permitted projects, but policies and regulations do not always specifically mention forest resources.

Nationwide Permit 27 success criteria developed by the U.S. Army Corps of Engineers and the Chesapeake Bay Program Stream Restoration Expert Panel guidance are typically referenced in order to outline monitoring protocols that are required for different types of projects. In addition, there is a post-construction verification process for the pollutant reduction performance of individual stream restoration projects built to meet the Chesapeake Bay TMDL (Burch et al., 2019). At a minimum, most local governments conduct monitoring to meet NWP or state programmatic general permit requirements, with more comprehensive monitoring conducted at project sites of interest for research purposes.

Mitigation banking sites were described as requiring intensive monitoring, with performance-based credit release cycles after construction until performance standards are met, which is typically for 5 to 10 years. In addition, state monitoring requirements vary, with the MD FCA post-construction monitoring requirements considered by practitioners to be more stringent than the requirements in VA or PA.

Many practitioners reported conducting monitoring and maintenance for 5 years post-construction, corresponding to NWP permit requirements; however, it is variable amongst practitioners and jurisdictions. Monitoring is also conducted every 5 years to meet CBP stream restoration verification requirements, which includes visual inspections to eliminate projects that fail or no longer meet their restoration objectives and to reduce or eliminate their sediment and nutrient reduction credit. Local governments also monitor projects they implement in perpetuity, as required for MS4 permit compliance. While all these monitoring requirements are valuable, they are typically focused on stream stability as the biggest determinant of project success.

There is a policy document from MD DNR (MD DNR, 2015) that recommends having an expert (e.g., forester, arborist, or botanist) conduct up to 10 years of monitoring for forest or tree cover evaluation after stream restoration construction or be in conformance with the 1991 Forest Conservation Act. However, MD DNR indicated that they work within the guidelines of other regulatory frameworks, so the 10-year monitoring requirement is not always recommended. Even if more robust monitoring is recommended, it is not always accomplished with the lack of funding a highly limiting factor. More programmatic coordination would be necessary to make significant advances with longer-term monitoring requirements.

Monitoring and maintenance include post-construction vegetation management (site inspections, removal of invasives, installing permanent vegetation replacements). However, local governments use a variety of different methods to assess the riparian community, making it difficult to draw comparisons across sites. Some practitioners reported moving towards more of a function-based monitoring approach, where the metrics are designed to demonstrate that the restored stream is providing its designated functions (e.g., ecological uplift, stability). The Stream Function Pyramid Framework is an excellent reference that describes assessment methods for post construction monitoring of the stream channel and there are several methods to determine the health of the riparian forest which can be applied to the post construction period. However, there is a need for better over-arching guidance within the Bay watershed and requirements by regulatory agencies. For example, there isn't an agreed upon functional metric to define a healthy forest. Developing regionally specific riparian monitoring protocols and forest quality indices was suggested. With advances in technology, remote-sensing tools are also useful for broad scale monitoring to supplement on-the-ground investigations.

Funding was frequently mentioned as a limiting factor for extensive post-construction monitoring. The immediate costs of monitoring, maintenance, and management are a major factor in the lack of citizen support for stream restoration and complaints about projects, but the initial costs of design, coordination, and construction are typically so high that the maintenance should be a standard requirement. The monitoring and maintenance for projects constructed to meet MS4 compliance is strongly incentivized because it is necessary to maintain credits. However, there is a significant lack of funding for monitoring or maintenance of grant-funded projects. Municipal-funded projects typically include local funding for post-construction monitoring and maintenance, and mitigation banking projects are often required to have both short- and long-term monitoring and maintenance funds. A recommendation from discussion during the state webcasts was that municipalities set aside a minimum of 10% of project costs for monitoring and maintenance post-construction.

Incorporating maintenance into the project design and having it contracted is encouraged because landowners are unlikely to conduct maintenance themselves. One of the challenges identified was a lack of trained professionals that can conduct community classification and condition assessments. Performance-based contracting and warranty monitoring for plant survival and contractual requirements were noted as options to increase successful projects.

Invasive species management is also an important consideration. Stream restoration projects can open space for invasive encroachment, with invasive species growth common in the first 2 years post-construction. Many forested riparian areas will only persist in a healthy condition if actively managed. As carbon dioxide levels continue to rise, vines pose a potentially existential threat to deciduous forests in urban and suburban areas as they gradually convert to what is being called a "vine tangle." Development of invasive species control plans using appropriate methods are an important part of maintenance (hand pulling or cutting, mechanical controls, prescribed fire, grazing/goats, and/or chemical applications). Forest mitigation plans often required of stream restoration projects can eliminate invasives and plant native vegetation improving the ecological health of the riparian area.

Table 13 contains the identified best practices related to monitoring and maintenance for maintaining forests and riparian vegetation, and Table 14 contains programmatic and research recommendations related to monitoring and maintenance.

Table 13. Monitoring and Maintenance Best Practices
Set aside a minimum of 10% of total project costs for post-construction monitoring and maintenance.
Utilize performance-based contracting and warranty monitoring for plant survival and contractual requirements.
Monitor beyond the LOD, and include a site's undisturbed areas, and adjacent upstream and downstream areas.
Develop clear monitoring metrics as a way of evaluating goals and the degree of project success.
Implement both a short and long-term vegetation management plan to maintain the post-restoration vegetation target for the banks and floodplain that includes invasive species management, climate change impact management, deer predation protection, and other predation and pest control measures.

Table 13. Monitoring and Maintenance Best Practices
Maintain a designated maintenance trail on projects to allow practitioners to monitor and maintain constructed projects without contributing additional disturbance.

Table 14. Monitoring and Maintenance Programmatic and Research Recommendations
Long-term monitoring of riparian benefits and total ecosystem benefits should be done by professionals/scientists. The adoption of a pooled monitoring approach would work with researchers, practitioners, and the regulatory agencies to review monitoring needs to evaluate restored or enhanced stream functions.
With the high cost of stream restoration projects, **post-construction monitoring and maintenance is a small component that should be included as part of standard project expenses**. Local governments and funding agencies should allow for a percentage of funds to be allocated for post-construction monitoring and maintenance.
Develop an agreed upon functional metric to define a healthy forest and regionally specific riparian monitoring protocols and forest quality indices.
Develop a training program to provide professional certification for vegetative community classification and condition assessments.

Conclusion

Stream restoration and the protection and enhancement of the riparian cover is extremely complex with varying information and guidance in the scientific and grey literature. There is limited guidance about specific techniques for the protection of riparian cover in the CBP stream restoration expert panel report and work group documents. Guidance and regulations from state and local government is inconsistently implemented, and the experiences of practitioners and researchers have resulted in varying viewpoints of how forests and riparian areas should be considered as part of stream restoration projects. One viewpoint is that forest is important, and riparian areas should be managed to reflect current priorities for what is contemporary habitat, recognizing that some stream restoration sites and/or their riparian area are not severely degraded. An opposing viewpoint is that trees and riparian vegetation at project locations are often invasive and in low-quality habitat areas that should be restored through stream restoration project design that incorporates native plantings and habitat improvements. Still, other stream restoration project types, such as legacy sediment removal, are not designed to include a fully forested riparian area, but instead include a diverse mosaic of herbaceous plants, shrubs and water-loving trees that represent pre-development site conditions. State agencies, local governments, and practitioners all have their own opinions and approaches with regards to best practices, but there are no set standards in place across the Chesapeake Bay watershed.

The best practices recommended in this report include a compilation of the general best practices identified through proper site selection, establishment of goals and objectives, design and permitting, stakeholder engagement, construction practices, and monitoring and maintenance. These practices were identified through a comprehensive review of state, federal and local regulations, as well as the scientific and grey literature. In addition, programmatic and research recommendations are identified based on the needs and suggestions from the state, local government, and practitioner input received throughout the project.

References

Anderson, P. H., & S. R. Pezeshki. 1999. The Effects of Intermittent Flooding on Seedling of Three Forest Species. *Photosynthetica, 37*(4): 543 – 552. Retrieved from: https://www.srs.fs.usda.gov/pubs/ja/ja_anderson002.pdf

Bahr, R., Blair, A., Brown, T., Coffman, K., Cole, R., Harmon, T., Michelsen, E., … & N. Weinstein. 2019. Recommendations for Crediting Outfall and Gully Stabilization Projects in the Chesapeake Bay Watershed. Retrieved from: https://www.chesapeakebay.net/channel_files/37043/approval_draft_outfall_restoration_memo_070119.pdf.

Baird, A. R. T., & D. G. Wetmore. 2003. Riparian Buffers Modification & Mitigation Guidance Manual. Prepared for Virginia Department of Conservation and Natural Resources (VA DCR). Retrieved from: https://www.vbgov.com/government/departments/planning/boards-commissions-committees/Documents/CBPA/CBPA%20Applications/Riparian%20Buffers%20Modification%20and%20Mitigation%20Guidance%20Manual.pdf.

Batiuk, R., Jackson, N., Clune, J., Hinson, K., Karrh, R., Lane, M., Murphy, R., & R. Stewart. 2022. Synthesis Element 5: Past, Current, and Projected Changes in Watershed and Tidal Water Temperatures and Implications for Ecosystem Processes Influencing Stream, River, and Estuarine Health. Report prepared as part of "Rising Watershed and Bay Temperatures — Ecological Implications and Management Responses: A Proactive Programmatic CBP STAC Workshop." Retrieved from: https://www.chesapeake.org/stac/wp-content/uploads/2021/12/Element-5_Water-Temperatures-Trends-and-Effects-Synthesis-Paper-Final-10_16_2021.docx.pdf.

Berger, K., Howard, C., Bonnaffon, H., Trieu, P. & A. Maynard (Editors). 2021. Recommended Stream Restoration Best Practices: Voluntary Guidance for Stormwater Program Managers in the COG Region on Best Practices for Implementing Stream Restoration Projects. Metropolitan Washington Council of Governments. Retrieved from: https://www.mwcog.org/file.aspx?&A=pPPtNROzlX3kdoYpSwTo6sjlqSZiRz6ZfH9iY0%2BmJIY%3D.

Brownson, K., Schueler, T., Allen, A., Borsuk, F., Claggett, S., Dubin, M., Ehrhart, M., Faulkner, S., Hairston-Strang, A., Hanson, J., Okay, J., Ombalski, K., & L. Power. 2022. Synthesis Element 7/8: Impacts of BMPs and Habitat Restoration on Water Temperatures: Opportunities to Mitigate Rising Water Temperatures. Report prepared as part of "Rising Watershed and Bay Temperatures — Ecological Implications and Management Responses: A Proactive Programmatic CBP STAC Workshop." Retrieved from: https://www.chesapeake.org/stac/wp-content/uploads/2021/12/Element-7-8_Final-Draft_BMPSynthesis_10-15.docx.pdf.

Budelis, B., McDonald, L., Schreiner, S., & D. E. Strebel. 2020. An Evaluation of Forest Impacts Compared to Benefits Associated with Stream Restoration. Prepared by Versar, Inc. and ERG for Chesapeake Bay Trust Restoration Research Award Program. Retrieved from: https://cbtrust.org/wp-content/uploads/Award14833_RestoResearch2017_FinalReport_Versar.pdf.

Burch, J., Cox, S., Davis, S., Fellows, M., Hoverman, K., Law, N., Mumaw, K., Rauhofer, J., Schueler, T., & R. Starr. 2019. Recommended Methods to Verify Stream Restoration Practices Built for Pollutant Crediting in the Chesapeake Bay Watershed. Submitted by Restoration Group 1: Verification and Approved by the Urban Stormwater Work Group of the Chesapeake Bay Program. Retrieved from: https://www.chesapeakebay.net/documents/Approved-Verification-Memo-061819.pdf

Center for Watershed Protection (CWP). 2021. The Self-Recovery of Stream Channel Stability in Urban Watersheds due to BMP Implementation. Retrieved from: https://cbtrust.org/wp-content/uploads/Self_Recovery_of_Stream_Channel_Stability_Final_Draft_03-23-21.pdf

Chesapeake Bay Program (CBP) WQGIT. 2015. Protocol for the Development, Review, and Approval of Loading and Effectiveness Estimates for Nutrient and Sediment Controls in the Chesapeake Bay Watershed Model. U.S. Environmental Protection Agency, Chesapeake Bay Program, Annapolis, MD.

Chesapeake Bay Program (CBP). 2014. Chesapeake Bay Watershed Agreement (amended 2020). https://www.chesapeakebay.net/documents/FINAL_Ches_Bay_Watershed_Agreement.withsignatures-HIres.pdf.

Chesapeake Bay Program Rising Watershed and Bay Temperatures Scientific and Technical Advisory Committee (CBP STAC). 2022. Synthesis Element 1: Water Temperature Effects on Fisheries and Stream Health in Nontidal Waters. Report prepared as part of "Rising Watershed and Bay Temperatures — Ecological Implications and Management Responses: A Proactive Programmatic CBP STAC Workshop." Retrieved from: https://www.chesapeake.org/stac/wp-content/uploads/2022/01/ADDENDUM-EL1-WQS_final-1.pdf.

Coder, K. D. 1994. Flood Damage to Trees. University of Georgia Extension Forest Resources Publication FOR94-61.

Doll, B., Jennings, G., Spooner, J., Penrose, D., Usset, J., Blackwell, J., & M. Fernandez. 2016. Can Rapid Assessments Predict the Biotic Condition of Restored Streams? *Water, 8*(143). DOI: 10.3390/w8040143. Retrieved from: https://www.mdpi.com/2073-4441/8/4/143/pdf.

Harman, W. & R. Starr. 2011. Natural Channel Design Review Checklist. US Fish and Wildlife Service, Chesapeake Bay Field Office, Annapolis, MD and US Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Wetlands Division. Washington, D.C. EPA 843-B-12-005

Harman, W., Starr, R., Carter, M., Tweedy, K., Clemmons, M., Suggs, K., & C. Miller. 2012. A Function-Based Framework for Stream Assessment and Restoration Projects. US Environmental Protection Agency (US EPA), Office of Wetlands, Oceans, and Watersheds. Washington, DC. EPA 843-K-12-006. Retrieved from: https://www.spk.usace.army.mil/Portals/12/documents/regulatory/pdf/A_Function-Based_Framework.pdf.

Hartranft, J., Merritts, D., Walter, R., & M. Rahnis. 2011. The Big Spring Run Experiment: Policy, Geomorphology and Aquatic Ecosystems in the Big Spring Run Watershed, Lancaster County, PA. Franklin and Marshall University. Lancaster, PA. *Sustain: A Journal of Environmental and Sustainability Issues, 24*: 24 – 30. Retrieved from: http://louisville.edu/kiesd/sustain-magazine.

Hilderbrand, R. H. 2020. Determining Realistic Ecological Expectations in Urban Stream Restorations. Final Report to the Chesapeake Bay Trust: Award #15823. Retrieved from: https://cbtrust.org/wp-content/uploads/Hilderbrand-realistic-restoration-expectations-final-report.pdf.

Hilderbrand, R. H., Acord, J., Nuttle, T. J., & R. Ewing. 2015. Quantifying the Ecological Uplift and Effectiveness of Differing Stream Restoration Approaches in Maryland. Final Report to the Chesapeake Bay Trust: Award #13141. Retrieved from: https://cbtrust.org/wp-content/uploads/Hilderbrand-et-al_Quantifying-the-Ecological-Uplift.pdf.

Hilgartner, W., D. Merritts, R. Walter, and M. Rhanis. 2010. Pre-Settlement Habitat Stability and Post-Settlement Burial of a Tussock Sedge (Carex stricta) Wetland in a Maryland Piedmont River Valley. In: 95th Ecological Society of America Annual Meeting, Pittsburg, PA. August 1 – 6, 2010.

Hudson III, H. W., Wright, E., Atkinson, R. B. & J. E. Perry. 2015. Assessment of Woody Vegetation for Replacement of Ecological Functions in Created Forested Wetlands of the Piedmont Province of Virginia. 2014 Annual Report Submitted to Piedmont Wetlands Research Program.

Ilhardt, B. L., Verry, E. S., & B. J. Palik. 2000. Defining Riparian Areas. In: "Riparian Management in Forests of the Continental Eastern United States". Verry, E. S., Hornbeck, J. W., & C. A. Dollof (Editors). Lewis Publishers. New York, NY.

Januschke, K., Jahnig, S. C., Lorenz, A. W., & D. Hering. 2014. Mountain River Restoration Measures and Their Success(ion): Effects on River Morphology, Local Species Pool, and Functional Composition of Three Organism Groups. *Ecological Indicators, 38*: 243 – 255. Retrieved from: https://www.sciencedirect.com/science/article/abs/pii/S1470160X13004020.

Justice, C., White, S. M., McCullough, D. A., Graves, D. S., & M. R. Blanchard. 2017. Can Stream and Riparian Restoration Offset Climate Change Impacts to Salmon Populations? *Journal of Environmental Management, 188*, p. 212 – 227. DOI: https://doi.org/10.1016/j.jenvman.2016.12.005.

Kaushal, S. S., Wood, K. L., Vidon, P. G., & J. G. Galella. 2021. Tree Trade-Offs in Stream Restoration Projects: Impact on Riparian Groundwater Quality. A Report Submitted to the Chesapeake Bay Trust. Retrieved from: https://cbtrust.org/wp-content/uploads/Tree-Trade-off_University-of-Maryland-College-Park_Kaushal_final_report_032921.pdf.

Keystone Stream Team. 2007. Guidelines for Natural Stream Channel Design for Pennsylvania Waterways. Retrieved from: https://www.nrc.gov/docs/ML1430/ML14308A182.pdf.

Lammers R., Dell T., & B. Bledsoe. 2020. Integrating Stormwater Management and Stream Restoration Strategies for Greater Water Quality Benefits. *Journal of Environmental Quality*, *49*(3): 569 – 581. DOI: 10.1002/jeq2.20047. Retrieved from: https://acsess.onlinelibrary.wiley.com/doi/abs/10.1002/jeq2.20047.

Maryland Department of Natural Resources (MD DNR). 2020. 2020 – 2025 Forest Action Plan—Part II: Strategy. Retrieved from: https://dnr.maryland.gov/forests/Documents/Maryland-State-Strategy_wAON%202020FINALpages.pdf.

Maryland Department of Natural Resources (MD DNR). 2015. Principles and Protocols to Guide the Department of Natural Resources' Actions Regarding Stream Restoration Projects in Maryland. Policy Number: 2015:01. Retrieved from: https://dnr.maryland.gov/ccs/Documents/trustfund/StreamRestorationPolicy.pdf.

Maryland Department of Natural Resources (MD DNR). 2018. Regenerative Stream Conveyance Construction Guidance: First Edition. Retrieved from: https://dnr.maryland.gov/ccs/Documents/RSC_Training/RSC-Guidance.pdf.

Maryland Department of Natural Resources (MD DNR). 2014. River/Stream Management Strategy: Guiding Principles. Retrieved from: https://dnr.maryland.gov/streams/Publications/StreamRestorationPolicy2015.pdf.

Maryland Department of the Environment (MDE). n.d. MDE, MS4/Chesapeake Bay TMDL/Trust Fund Restoration Project Wetlands & Waterways Permit Package Checklist. Retrieved from: https://mde.maryland.gov/programs/water/WetlandsandWaterways/PermitsandApplications/Pages/nontidal_permits.aspx.

Maryland Department of the Environment (MDE). 2022. Guidance for Stream Restoration Based on Key Wildlife Habitats: Upper Coastal Plain Stream-Associated Wetlands. MDE. Baltimore, MD. 46 pp. Retrieved from: https://mde.maryland.gov/programs/water/WetlandsandWaterways/Pages/Stream-Wetland_NewGuidance.aspx

Mayer, P. M., Pennino, M. J., Newcomer-Johnson, T. A., & S. S. Kaushal. 2022. Long-Term Assessment of Floodplain Reconnection as a Stream Restoration Approach for Managing Nitrogen in Ground and Surface Waters. *Urban Ecosystems*. DOI: https://doi.org/10.1007/s11252-021-01199-z.

Mayer, P. M., Todd, A. H., Okay, J. A., & K. A. Dwire. 2010. Introduction to the Featured Collection on Riparian Ecosystems & Buffers. *Journal of the American Water Resources Association, 46*(2): p. 207 – 210. DOI: 10.1111/j.1752-1688.2010.00425.x.

Merritts, D., Walter, R., Rahnis, M., Hartranft, J., Cox, S., Gellis, A., Potter, N., … & S. Becker. 2011. Anthropocene Streams and Base Flow Controls from Historic Dams in the Unglaciated Mid-Atlantic Region, USA. *Philosophical Transactions of the Royal Society, 369*: 976 – 10093. Retrieved from: https://royalsocietypublishing.org/doi/abs/10.1098/rsta.2010.0335.

Orzetti, L., Jones, R., & R. Murphy. 2010. Stream Conditions in Piedmont Streams with Restored Riparian Buffers in the Chesapeake Bay Watershed. *Journal of American Water Resources Association, 46*(3): 473–485. Retrieved from: https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1752-1688.2009.00414.x.

Natural Resources Conservation Service and Wildlife Habitat Council (NRCS & WHC). 2007. Riparian Systems: Fish and Wildlife Habitat Management Leaflet. Number 45. Retrieved from: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_010137.pdf.

Palmer, M., Allan, J., Meyer, J., & E. Bernhardt. 2007. River Restoration in the Twenty-First Century: Data and Experiential Knowledge to Inform Future Efforts. *Restoration Ecology, 15*(3): 472 – 481. Retrieved from: https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1526-100X.2007.00243.x.

Palmer, M. A., Hondula, K. L., & B. J. Koch. 2014. Ecological Restoration of Streams and Rivers: Shifting Strategies and Shifting Goals. *Annual Review of Ecology, Evolution, and Systematics, 45*: p. 247–269. DOI: 10.1146/annurev-ecolsys-120213-091935.

Palone, R. S., & A. H. Todd (Editors). 1998. Chesapeake Bay Riparian Handbook: A Guide for Establishing and Maintaining Riparian Forest Buffers. United States Department of Agriculture Forest Service (USDA FS). NA-TP-02-97. Radnor, PA. Retrieved from: https://www.chesapeakebay.net/content/publications/cbp_13019.pdf.

Pennsylvania Department of Environmental Protection (PA DEP). 2022. Pennsylvania Function-Based Aquatic Resource Compensation Protocol. Document Number: 310-2137-001. Retrieved from: http://www.depgreenport.state.pa.us/elibrary/GetDocument?docId=4087720&DocName=01%20PENNSYLVANIA%20FUNCTION-BASED%20AQUATIC%20RESOURCE%20COMPENSATION%20PROTOCOL.PDF%20%20%3Cspan%20style%3D%22color%3Agreen%3B%22%3E%3C%2Fspan%3E%20%3Cspan%20style%3D%22color%3Ablue%3B%22%3E%3C%2Fspan%3E.

Pollock, M. M., Lewallen, G., Woodruff, K., Jordan, C. E., & J. M. Castro (Editors). 2015. The Beaver Restoration Guidebook: Working with Beaver to Restore Streams, Wetlands, and Floodplains. Version 1.02. United States Fish and Wildlife Service (USFWS). Portland, OR. 189 pp. Retrieved from: https://www.fws.gov/sites/default/files/documents/BRG%20v.1.0%20final%20reduced.pdf.

Schueler, T. and Stack, B. 2014. Recommendations of the Expert Panel to Define Removal Rates for Individual Stream Restoration Projects. Approved by the Water Quality Goal Implementation Team of the Chesapeake Bay Program September 8, 2014. https://www.chesapeakebay.net/documents/Stream_Panel_Report_Final_08282014_Appendices_A_G.pdf.

Selvakumar, A., O'Connor, T. P., & S. D. Struck. 2010. Role of Stream Restoration on Improving Benthic Macroinvertebrates and In-Stream Water Quality in an Urban Watershed: Case Study. *Journal of Environmental Engineering, 136*(1): p. 127 – 139. DOI: 10.1061/(ASCE)EE.1943-7870.0000116. Retrieved from: Research Gate.

Stranko, S. A., Hilderbrand, R. H., & M. A. Palmer. 2011. Comparing the Fish and Benthic Macroinvertebrate Diversity of Restored Urban Streams to Reference Streams. *Restoration Ecology, 20*(6): p. 747 – 755. DOI: 10.1111/j.1526-100X.2011.00824.x. Retrieved from: https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1526-100X.2011.00824.x.

Sudduth, E. B., Hassett, B. A., Cada, P., & E. S. Bernhardt. 2011. Testing the Field of Dreams Hypothesis: Functional Responses to Urbanization and Restoration in Stream Ecosystems. *Ecological Applications, 21*(6): p. 1972 – 1988. DOI: 10.1890/10-0653.1. Retrieved from: https://esajournals.onlinelibrary.wiley.com/doi/abs/10.1890/10-0653.1.

Teskey, R. O., & T. M. Hinckley. 1977. Impact of Water Level Changes on Woody Riparian and Wetland Communities. Vol. I: Plant and Soil Responses to Flooding. Published by the U.S. Fish and Wildlife Service. FWS/OBS-77/58.

United States Bureau of Reclamation and United States Army Engineer Research and Development Center (USBR & ERDC). 2016. National Large Wood Manual—Assessment, Planning, Design, and Maintenance of Large Wood in Fluvial Ecosystems: Restoring Process, Function, and Structure. 628 pp. Retrieved from: https://ewn.erdc.dren.mil/wp-content/uploads/2021/03/National_Large_Wood_Manual-USBR_USACE-January2016-FINAL2.pdf.

United States Department of Agriculture, Natural Resources Conservation Service (USDA NRCS). 2007. Stream Restoration Design Part 654 National Engineering Handbook. Retrieved from: https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17807.wba

Violin, C. R., Cada, P., Sudduth, E. B., Hassett, B. A., Penrose, D. L., & E. S. Berhardt. 2011. Effects of Urbanization and Urban Stream Restoration on the Physical and Biological Structure of Stream Ecosystems. *Ecological Applications, 21*(6): p. 1932 – 1949. DOI: 10.1890/10-1551.1. Retrieved from: https://esajournals.onlinelibrary.wiley.com/doi/abs/10.1890/10-1551.1.

Virginia Department of Conservation and Natural Resources (VA DCR). 2004. The Virginia Stream Restoration & Stabilization Best Management Practice Guide. Prepared with assistance from KCI Technologies, Inc. and the Center for Environmental Studies at Virginia Commonwealth University. Retrieved from: The Virginia Stream Restoration & Stabilization Best Management Practices Guide.

Virginia Department of Environmental Quality (VA DEQ). 1992. Virginia Erosion and Sediment Control Handbook. Retrieved from: https://www.deq.virginia.gov/water/stormwater/esc-handbook.

Voli, M., Merritts, D., Walter, R., Ohlson, E., Datin, D., Rahnis, M., Kratz, L., Deng, W., Hilgartner, W., & J. Hartfranft. 2009. Preliminary Reconstruction of a Pre-European Settlement Valley Bottom Wetland, Southeastern Pennsylvania. *Water Resources Impact, 11*: 11 – 13. Retrieved from: https://www.jstor.org/stable/wateresoimpa.11.5.0011.

Wilkerson, E., Hagan, J. M., Siegel, D., & A. A. Whitman. 2006. The Effectiveness of Different Buffer Widths for Protecting Headwater Stream Temperatures in Maine. *Forest Science, 52*(3): 221 – 231. Retrieved from: https://academic.oup.com/forestscience/article/52/3/221/4617648?login=true.

Wohl, E., Castro, J., Cluer, B., Merritts, D., Powers, P., Staab, B., & C. Thorne. 2021. Rediscovering, Reevaluating, and Restoring Lost River-Wetland Corridors. *Frontiers in Earth Science,* 9: 653623. DOI: 10.3389/feart.2021.653623. Retrieved from: https://www.frontiersin.org/articles/10.3389/feart.2021.653623/full.

Wood, D., and T. Schueler. 2020. Consensus Recommendations to Improve Protocols 2 and 3 for Defining Stream Restoration Pollutant Removal Credits. Approved by WQGIT October 26, 2020. Retrieved from: https://www.chesapeakebay.net/documents/FINAL_Approved_Group_4_Memo_10.27.20.pdf.

Wood, D., Schueler, T., and B. Stack. 2021. A Unified Guide for Crediting Stream and Floodplain Restoration Projects in the Chesapeake Bay Watershed. https://chesapeakestormwater.net/wp-content/uploads/dlm_uploads/2021/10/Unified-Stream-Restoration-Guide_FINAL_9.17.21.pdf

Yochum, S. E. 2018. Guidance for Stream Restoration. U.S. Department of Agriculture, Forest Service (USDA FS), National Stream & Aquatic Ecology Center. Technical Note TN-102.4. Fort Collins, CO. Retrieved from: https://www.fs.fed.us/biology/nsaec/assets/yochumusfs-nsaec-tn102-4guidancestreamrestoration.pdf.