Wetlands and Wetland Restoration

Recommendations of the Wetland Expert Panel for the incorporation of wetland best management practices (BMPs) and land uses in the Phase 6 Chesapeake Bay Watershed Model

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First draft released for CBP partnership review: 11/22/2016
Approved by Wetland Workgroup: TBD
Approved by Watershed Technical Workgroup: TBD
Approved by Habitat GIT: TBD
Approved by Water Quality GIT: TBD

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Executive Summary

Table of Contents

Executive Summary i

Chapter 1. Charge and membership of the expert panel 1

- Additional context for the expert panel 3
- Literature Cited 4

Chapter 2. Definitions of terms used in the report 5

- Defining wetland best management practices for the Phase 6 modeling tools 6

Chapter 3. Background on wetlands and wetland BMPs in the Chesapeake Bay Watershed 10

- Overview of wetland BMPs currently implemented in the watershed 10
- Background on the Phase 6 Watershed Model 11

Chapter 4. Review of available science – Non-Tidal wetland effects on water quality: an updated landscape perspective 13

- Advancing a conceptual model to explain how wetland water quality and habitat benefits vary across space and time 13
  - The Importance of Physiographic Setting 17
- Advances in understanding how hydrogeologic setting influences wetlands nutrient dynamics 27
  - Nitrogen—transport and removal from groundwater and surface water 27
  - Phosphorus—fate, transport, and removal from groundwater and surface water 29
  - Sediment—fate, transport, and removal from surface water 31
- Advanced understanding of human impacts, especially due to changes in timing, rate, and chemistry of sources waters 31
- Remote sensing capabilities and advances in spatial modeling provide enhanced understanding of near-surface processes in relation to physiographic setting 32
- Summary 33
- Literature Cited 34

Chapter 5. Recommendations for Wetlands as land-use and BMPs in Phase 6 Watershed Model 44

- Overview 44
- Wetland land uses in the Phase 6 CBWM 45
  - Mapping the recommended land uses 45

Justification for wetlands land uses ... 46
Justification for wetland nutrient and sediment loading rates the same as forest ... 47
Justification for natural and restored nutrient and sediment retention efficiencies based on hydrogeologic and landscape setting ... 49
Wetland BMPs ... 49
Review of existing Phase 5.3.2 wetland restoration BMP ... 49
Recommended effectiveness estimates for wetland restoration (re-establishment) in Phase 6 ... 52
Summary of findings, recommendations, key uncertainties, and future research needs ... 58
Recommendations for wetland creation (establishment), wetland enhancement and wetland rehabilitation ... 60
Literature Cited ... 61
Chapter 6. Accountability Mechanisms ... 63
Chapter 7. Unintended consequences and qualifying conditions of wetland BMPs ... 66
Chapter 8. Future research and management needs ... 68

List of Tables

Table 1. Wetlands Expert Panel membership and other participants. ... 3
Table 2. Proposed categories for wetland BMPs in the Chesapeake Bay Program's Phase 6 Chesapeake Bay Watershed Model. ... 7
Table 3. Descriptions of wetland activities that are not counted towards TMDL progress. ... 9
Table 4. Acres of wetland restoration reported by jurisdictions in annual progress runs. ... 11
Table 5. Restoring wetlands on agricultural lands, cumulative acreage by state (2010-2014). ... 11
Table 6. Area of non-tidal wetlands and general description of wetland types in major Physiographic Provinces of the Chesapeake Bay watershed. ... 26
Table 7. Land use classes and relative loading rates for nontidal wetlands in the Phase 6 Watershed Model. ... 45
Table 8. TN and TP removal efficiencies for wetlands by geomorphic province (Simpson and Weammert, 2009). ... 51
Table 9. Summary of wetland TN, TP and Sediment reductions from literature review. The mean retention efficiencies reported for all natural sites (i.e., not constructed sites) are the

recommended retention efficiencies for the Phase 6 Watershed Model, to replace the current Phase 5.3.2 values ... 53
Table 10. Wetland forms and distributions across the Chesapeake Bay Watershed, by physiographic province and geomorphic setting ... 55
Table 11. Likelihood of Hydrologic Contact with Non-Point Source Contaminated Waters ... 56
Table 12. Summary of relative retention efficiencies and upland acres treated by each acre of wetland by wetland type and physiographic subregion. ... 58
Table 13. Summary of recommended load reductions. ... 60

List of Figures

Figure 1. Conceptual diagram of Phase 5.3.2 Watershed Model and related modeling tools. ... 12
Figure 2. Physiographic regions in the Chesapeake Bay Watershed. ... 16
Figure 3. Topography and shallow fracture systems determine groundwater movement in the aquifers of the Appalachian Plateaus. Water infiltrates weathered bedrock and moves mostly through near-surface fractures; some water moves in a steplike fashion vertically along deeper fractures and horizontally through fractured sandstone or coal beds. Because of the absence of deep groundwater circulation and regional flow systems, saline water is at shallow depths. ... 18
Figure 4. Depiction of sloping, floodplain, and riparian wetlands across the Appalachian Plateau. Depressional wetlands, while not depicted in this conceptual diagram, can occur in this landscape, especially where glacial moraine deposits exist. ... 19
Figure 5. Thick wedges of colluvium on the lower flanks of ridges store large quantities of water that subsequently move into aquifers in the valleys. The colluvium commonly contains perched bodies of groundwater that are separated from the main water table by clay confining units. ... 20
Figure 6. Thick wedges of colluvium on the lower flanks of ridges store large quantities of water that subsequently move into aquifers in the valleys. The colluvium commonly contains perched bodies of groundwater that are separated from the main water table by clay confining units. ... 22

Figure 7. Conceptual model of Coastal Plain shallow groundwater conditions. Alternating and inclined layers of unconsolidated deltaic and estuarine deposits across a flat terrain results in a complex, nested groundwater system. 23
Figure 8. Conceptual model of bottom-land hardwood forest floodplain, which occur frequently in the Coastal Plain lowlands. 24
Figure 9. Literature review data points for wetland nutrient removal efficiency based on the wetland area as a proportion of the watershed. Curves indicate non-linear regression fit to data values, with 95% confidence limits. (STAC 2008). 50
Figure 10. Wetland BMP Reporting Matrix 65

Appendix A Literature review for nutrients and sediment
Appendix B Literature review for habitat and other impacts of wetland BMPs
Appendix C Technical Appendix for Scenario Builder
Appendix D Compilation of panel meeting minutes
Appendix E Glossary
Appendix F Conformity of report with BMP Protocol

List of acronyms used in this report

AgWG	Agriculture Workgroup
BMP(s)	Best Management Practice(s)
CBP	Chesapeake Bay Program
CBPO	Chesapeake Bay Program Office
CWP	Center for Watershed Protection
CBWM	Chesapeake Bay Watershed Model
GIT	Goal Implementation Team
HGIT	Habitat Goal Implementation Team
HGM	Hydrogeomorphic
N	Nitrogen
NRCS	Natural Resources Conservation Service (USDA)
NWI	National Wetlands Inventory
P	Phosphorus
SPARROW	SPAtially Referenced Regressions On Watershed Attributes
STAC	Scientific and Technical Advisory Committee (CBP)
TMDL	Total Maximum Daily Load
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USDA-NRCS	U.S. Department of Agriculture, Natural Resource Conservation Service

USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
WEP	Wetlands Expert Panel
WIP(s)	Watershed Implementation Plan(s)
WQGIT	Water Quality Goal Implementation Team
WTWG	Watershed Technical Workgroup

Chapter 1. Charge and membership of the expert panel

With the signing of the Chesapeake Watershed Agreement in 2014, Chesapeake Bay Program (CBP) partners committed to the following outcome for wetlands: 85,000 acres of created or reestablished wetlands, and 150,000 additional acres of enhanced wetlands by 2025. Additionally, partners committed to protect 225,000 acres of wetlands under the Protected Lands Outcome that seeks to protect a total of two million acres of valuable lands by 2025, relative to a 2010 base year. The 2014 wetland goals revise a long-standing commitment by Bay partners to wetland restoration, enhancement and preservation as indicated by wetland goals in previous Bay Agreements.

The current Phase 5.3.2 Chesapeake Bay Watershed Model (CBWM) does not recognize the additional water quality benefits that wetlands provide compared to upland forests; nor does the model recognize that wetland function depends on landscape *and* condition. These issues were first addressed in a 2007 Scientific and Technical Advisory Committee (STAC) workshop (STAC, 2008), that evaluated the nutrient and sediment processing efficiencies of wetlands, but the limited literature search and data used at the time was inadequate to recommend substantive changes to the way wetlands are modeled by the partnership (credited as forest). A STAC workshop held in March 2012 by the Maintaining Healthy Watershed Goal Implementation Team (GIT) included identification and mapping of new land use classes, one of which is "other wetlands" (STAC, 2012). This recommendation in the workshop report also states, "The potential value of identifying additional new land use classes that also demonstrate a greater functional capacity for retaining nutrients and sediments should be evaluated." A second recommendation from this workshop indicated that loading rates associated with the new land use classes should be estimated based on spatially explicit landscape attributes that include directional connectivity, multi-direction flow fields, and flow path analysis (STAC, 2012).

Given these priority needs, the Habitat Goal Implementation Team's Wetlands Workgroup recommended that a Wetlands Expert Panel (WEP) be convened to (1) review and make recommendations to refine the existing wetland restoration best management practice (BMP) definitions and load reductions represented in the Phase 5.3.2 Chesapeake Bay Watershed Model (CBWM), and; (2) make recommendations to define wetlands as a separate land use classification as part of the CBWM Phase 6.0 update, applicable to all land uses. The panel, which convened in Fall 2014, operates under the Scope of Work described below in addition to the Water Quality Goal Implementation Team's *Protocol for the Development, Review, and Approval of Loading and Effectiveness Estimates for Nutrient and Sediment Controls in the Chesapeake Bay Watershed Model*. Appendix F summarizes locations in the report where elements of the BMP Protocol and Scope of Work are addressed.

- Wetland Restoration BMP: The expert panel will review the current wetland restoration BMP definition and efficiencies in the model and evaluate recent research on nitrogen, phosphorus, and sediment retention rates of wetlands to determine how they may be improved and/or refined. For example, the expert panel will review all new science and research regarding wetland enhancement and rehabilitation that has

been performed since the 2007 STAC wetlands workshop. The panel will determine whether the science supports development of wetland enhancement/rehabilitation BMP efficiencies for nitrogen, phosphorus, and sediment retention; if so, the panel will provide recommendations for the appropriate efficiencies for wetland enhancement/rehabilitation as a BMP.
- Review the current CBWM assumptions to simulate the impact of wetland restoration BMPs to agricultural land uses and recommend how practice(s) should be represented in the CBWM version 5.3.2 and make recommendations for Phase 6.
- Provide a definition, describe the geographic boundary, and determine any qualifying conditions needed prior to receiving nutrient and/or sediment pollutant load reductions.
- Define the proper units that local governments will report practice implementation to the State to incorporate into the CBWM.
- Recommend procedures for reporting, tracking and verifying any recommended wetland upgrade credits over time.
- Critically analyze any unintended consequence associated with the credit and any potential for double or over-counting of the credit

In addition to review of the wetland BMP, the expert panel was asked to evaluate and make recommendations for including wetlands as a land use classification in the Phase 6 CBWM update. This assessment was limited to determine: 1) if there is sufficient evidence to support a wetland land use different from the forested land use based on loading rates in the CBWM; and 2) what categories for wetland land uses could be supported by the literature (e.g., floodplain, emergent, high marsh, low marsh, tidal, etc.). Currently, the loading rate for wetlands is the same as the forest land use in the CBWM. The panel was tasked to seek guidance from the Land Use Workgroup, Watershed Technical Workgroup, Agricultural Workgroup, and other Chesapeake Bay partners, as needed, in its assessment of the data. The panel was instructed to provide these recommendations to the CBPO's Water Quality GIT for inclusion in the 2017 midpoint assessment of the modeling tools.

The panel members and other participants engaged during the panel's deliberation are outlined in Table 1 below. The panel was facilitated by the Center for Watershed Protection (CWP) from its launch until February 2015 and was transitioned to Virginia Tech for the remainder of their work beginning in May 2015. The panel wishes to acknowledge Neely Law and the CWP for the extensive groundwork they provided to the panel and their continued willingness to provide input after they were no longer coordinating the panel. Tetra Tech provided contractual support to the panel, primarily in the form of literature reviews described in this report, as well as assistance in preparation of the report documentation.

Table 1. Wetlands Expert Panel membership and other participants.

Name	Role (post-CWP)	Organization
Erin McLaughlin	Panel member	Maryland Department of Natural Resources (MD DNR), Wetland Work Group Co-Chair
Steve Strano	Panel member	Natural Resource Conservation Service (NRCS)
Judy Denver	Panel member	U.S. Geological Survey (USGS)
Ken Staver	Panel member	Wye Research and Education Center
Kathy Boomer	Panel member	The Nature Conservancy
Pam Mason	Co-Chair	Virginia Institute of Marine Science
Dave Davis	Panel member	Virginia Department of Environmental Quality (VA DEQ)
Jeff Hartranft	Panel member	Pennsylvania Department of Environmental Protection (PA DEP)
Ralph Spagnolo	Co-Chair	USEPA Region 3
Jeff Thompson	Panel member	Maryland Department of Environment (MDE)
Tom Uybarreta	Panel member	USEPA Region 3
Quentin Stubbs	Panel member	USGS, CBPO
Rob Brooks	Panel member	Pennsylvania State University
Dr. Jarrod Miller	Panel member	University of Maryland (UMD) Extension
Michelle Henicheck	Panel member	VA DEQ
Denise Clearwater	Panel member	MDE
Panel support		
Jeremy Hanson	Panel Coordinator	Virginia Tech, CBPO
Jennifer Greiner	HGIT Coordinator	US Fish and Wildlife Service (USFWS), CBPO
Hannah Martin	Support	Chesapeake Research Consortium (CRC), CBPO
Kyle Runion	Support	CRC, CBPO
Aileen Molloy	Support	Tetra Tech
Jeff Sweeney	CBPO Modeling and WTWG rep	USEPA CBPO
David Wood	CBPO Modeling rep	CRC, CBPO
Peter Claggett	GIS Support	USGS, CBPO
Brian Benham	VA Tech Project Director	Virginia Tech
Additional panel guest participants: Ken Murin (PA DEP), Kristen Saacke-Blunk (Chesapeake Bay Agricultural Workgroup former Co-Chair), Anne Wakeford (West Virginia Department of Natural Resources) Previous participants who contributed previously and are no longer active (post-CWP): Brian Needelman (UMD), Tom Jordan (Smithsonian Environmental Research Center), and Robert Kratochvil (UMD) Other individuals the panel wishes to acknowledge for providing valuable input or services to the panel: Neely Law (Center for Watershed Protection), Bill Stack (Center for Watershed Protection),		

The panel met 17 times over the course of more than 24 months, including two face-to-face meetings in the Annapolis area.

Additional context for the expert panel

Wetland restoration is an important BMP within the state Watershed Implementation Plans (WIPs), which call for approximately 83,000 acres of implementation within the Bay watershed. The Chesapeake Bay Program currently defines the agricultural wetland restoration best management practice (BMP) as:

Reestablishment (restore)—Manipulation of the physical, chemical, or biological characteristics of a site with the goal of returning natural/historic functions to a former wetland. Results in a gain in wetland acres.

Establishment (create)—Manipulation of the physical, chemical, or biological characteristics present to develop a wetland that did not previously exist on an upland or deepwater site.

Results in a gain in wetland acres.

The literature search for this practice focuses only the water quality benefits that restored and natural wetlands provide and literature on the wildlife and mitigation wetlands are not considered.

A more broad-based definition is provided by the CBPO when wetland area or drainage area is unreported:

> Agricultural wetland restoration activities reestablish the natural hydraulic condition in a field that existed before the installation of subsurface or surface drainage. Projects can include restoration, creation and enhancement acreage. Restored wetlands can be any wetland classification including forested, scrub-shrub or emergent marsh.

There are other issues related to landuse/landcover in the Bay and watershed models that complicate credit for wetlands. Currently in the Phase 5.3.2 CBWM, wetlands are simulated the same as forests. Many suggest that the enhanced denitrification potential from saturated wetland soils support an approach wherein the wetland land use receives a higher credit compared to the forested land use.

Literature Cited

STAC (Scientific and Technical Advisory Committee). 2008. *Quantifying the Role of Wetlands in Achieving Nutrient and Sediment Reductions in Chesapeake Bay*. Publication 08-006. Annapolis, MD.

STAC. 2012. The role of natural landscape features in the fate and transport of nutrients and sediment. STAC Report 12-04. Edgewater, MD. http://www.chesapeake.org/pubs/293_2012.pdf

Chapter 2. Definitions of terms used in the report

There are many terms associated with wetlands that often have specific technical, scientific or regulatory meanings. To reduce confusion it must be emphasized that this panel report and any unique definitions described herein apply in contexts relevant to the Chesapeake Bay Program and associated efforts of its partners, e.g., as related to tracking/reporting purposes for annual BMP progress reporting toward Chesapeake Bay Total Maximum Daily Load (TMDL) targets. This section is not a comprehensive glossary, as many terms and concepts (e.g., hydric soils, wetland hydrology, etc.) are used in this report in a context generally consistent with widely accepted or established definitions (i.e., national guidance or manuals from the USACE, USEPA, USFWS, USDA-NRCS or other government or academic entities). A glossary is provided for the reader as Appendix E. Definitions provided in this section are only applicable to this report and its subsequent incorporation with the Chesapeake Bay Program partnership modeling tools and other partnership efforts to track progress toward outcomes and targets under the Watershed Agreement or the Chesapeake Bay TMDL.

Effectiveness estimate refers to the estimated pollutant reduction for a BMP as defined by an expert panel or the Chesapeake Bay Program partnership. The reduction for a BMP is often described as a percent (%) reduction that is applied to specific land use(s) or source of loads in the CBP partnership modeling tools; when expressed as a percent reduction, the effectiveness estimate is often referred to as an **efficiency**. An effectiveness estimate can also be defined in other ways, such as an absolute load reduction (e.g., in pounds (lbs) or pounds per unit area of the given pollutant).

Existing wetlands or **natural wetlands**. For the purposes of this report these terms are used to refer to wetlands that are currently present as wetlands in the landscape or were present in land use data used for calibration of the Phase 6 CBWM.

Former wetland or **historic wetland**. For purposes of this report, a former wetland is a site where available evidence suggests that a functional wetland previously existed.

Degraded wetland. The term "degraded" is subjective. Assessment methods can be used to determine whether a particular resource is degraded, based on the chosen threshold(s). Best professional judgment may also be used to identify degraded resources in situations where appropriate assessment methods are not available. For purposes of this report, "degraded wetland" refers to a wetland area that does not meet one or more threshold(s) set by the entity assessing the wetland (likely a state agent). The assessment may not be limited to water quality. Specific thresholds or assessment methods are outside the scope of this panel and will be set based on the applicable local, state or federal guidance or regulations.

There are some BMPs already approved by the CBP partnership that can be confused with wetland practices described by this panel. These other CBP-approved BMPs are not within the purview of this panel's recommendations as they have already been reviewed and approved by the CBP partnership:

- **Constructed stormwater wetlands or wet ponds** – if engineered and designed for stormwater purposes, should be reported under the existing CBP-approved urban BMP, Wet Ponds and Wetlands. Or, in an agriculture context, constructed wetland structures that treat or capture barnyard runoff as part of a treatment train may be eligible under the future recommendations of the ongoing panel for agriculture stormwater structures.

- **Riparian tree plantings** – follow the definitions and protocols for the riparian forest buffer BMPs. For qualifying projects, the total reduction combines the land use change from the previous land use to forest, and also applies a percent effectiveness value to the upland area.

- **Living shoreline projects** – follow the definitions and protocols for the shoreline management BMP. For qualifying projects, the reduction is calculated based on the four protocols defined by the Shoreline Management panel.

- **Regenerative Stormwater Conveyances** (RSC's) – dry channel RSC projects can be reported using the existing stream restoration BMP (Protocol 4 – Dry Channel RSC as a retrofit). The TN, TP and TSS reductions for Protocol 4 are calculated using the adjustor curves developed by the retrofits BMP panel.

- **Urban Stream restoration** – any natural channel design, regenerative stormwater conveyance (wet-channel), legacy sediment removal or other restoration project that meets the qualifying conditions set by the Stream Restoration Expert Panel (2014). The Stream Restoration Expert Panel defined three protocols that can be used to determine the nutrient and sediment load reduction for a qualifying stream restoration project: Protocol 1 – Prevented Sediment; Protocol 2 – Instream Denitrification, and; Protocol 3 – Floodplain Reconnections. Protocol 3 may be particularly relevant for wetland projects that include connection of the wetland to the waterway creating the opportunity for treatment of water delivered from the upstream watershed via stream flooding. Care must be taken to avoid double counting.

Defining wetland best management practices for the Phase 6 modeling tools

There is a wide range of actions and practices that can be implemented to restore, create, enhance or rehabilitate wetlands in the Chesapeake Bay watershed. The Wetlands Expert Panel was asked to define BMPs for the Phase 6 Chesapeake Bay Watershed Model that the jurisdictions will then be able to report in their annual progress run submissions. The panel discussed various wetland practices and categories of practices to develop a scheme that allows for a relatively simple approach to report and credit wetland BMPs in Phase 6. After much discussion it is clear that there will always be some ambiguous projects that may be labeled as different things by different practitioners, so the panel strove to provide guidance that will allow the jurisdictions and CBP to better understand when a project should be reported as restoration-reestablishment, creation, enhancement, or rehabilitation for CBP purposes. While it is impossible for the panel to pre-emptively clarify every ambiguous project that may arise in the future, the panel's recommendations will hopefully reduce confusion and simplify the reporting process.

Some practices closely related to wetland restoration, particularly restoration of floodplain wetlands, may be eligible for BMP credit under the CBP-approved protocols for Stream Restoration.[1] The reporting entity should work closely with their jurisdictional agency to consider other crediting protocols in conjunction with the recommendation from this panel. It is possible that crediting protocols from the wetland expert panel recommendations are combined with other crediting protocols to account for reductions from floodplain restorations. However, careful consideration of the protocols to avoid double counting reduction estimates is the responsibility of jurisdictional and reporting entities.

Table 2 is a guide to the four categories of wetland BMPs considered by the Wetlands Expert Panel for incorporation into the Chesapeake Bay Program (CBP) partnership's Phase 6 Chesapeake Bay Watershed Model (CBWM) for annual progress runs. The table also provides information as to how each category will be tracked towards Watershed Agreement outcomes in addition to the annual progress runs for TMDL purposes. **The examples in the right-hand column are not intended to be comprehensive – nor limiting or restrictive – as some projects or practices could count under a different category depending on the design, site location, or other specific factors of the project. The table is intended to help clarify how a type of practice is most likely to be categorized under the Panel's Phase 6 BMP definitions.** The categories in Table 2 are not presented in any particular order or hierarchy.

Table 2. Proposed categories for wetland BMPs in the Chesapeake Bay Program's Phase 6 Chesapeake Bay Watershed Model.

Proposed BMP Category	Proposed CBP Definition (for Phase 6 CBWM)	CBP will count the BMP acres as...	Practice and Project Examples
Restoration	Re-establish The manipulation of the physical, chemical, or biological characteristics of a site with the goal of returning natural/historic functions to a former wetland.	Acreage gain *(toward Watershed Agreement outcome of 85,000 acre wetland gain and in Phase 6 annual progress runs)*	Restore hydrology to prior-converted agricultural land (cropland or pasture); re-establishing needed vegetation on cropland with wetland hydrology; native wetland meadow planting; elevate subsided marsh and re-vegetate; ditch plugging on cropland; Legacy Sediment Removal NRCS Practice 657

[1] I.e., floodplain reconnection, legacy sediment removal, and other types of restoration projects that interact with the stream channel (e.g., wetland bench/active floodplain, Rosgen, Natural Channel Design)

Proposed BMP Category	Proposed CBP Definition (for Phase 6 CBWM)	CBP will count the BMP acres as...	Practice and Project Examples
Creation	Establish (or Create) The manipulation of the physical, chemical, or biological characteristics present to develop a wetland that did not previously exist at a site.	Acreage gain *(toward Watershed Agreement outcome of 85,000 acre wetland gain and in Phase 6 progress runs)*	Modifications to shallow waters or uplands to create new wetlands. Placement of fill material or excavation of upland to establish proper elevations for tidal wetland; Hydrologic measures such as impoundment, water diversion and/or excavation of upland to establish nontidal wetlands NRCS Practice 658
Enhancement	Enhance The manipulation of the physical, chemical, or biological characteristics of a wetland to heighten, intensify, or improve a specific function(s).	Function gain *(toward 150,000 acre outcome and Phase 6 annual progress runs)*	Flood seasonal wetland for waterfowl benefit; regulate flow velocity for increased nutrient uptake; NRCS Practice 659
Rehabilitation	Rehabilitate The manipulation of the physical, chemical, or biological characteristics of a site with the goal of repairing natural/historic functions to a degraded wetland.	Function gain *(toward 150,000 acre outcome and Phase 6 annual progress runs)*	Restore flow to degraded wetland; ditch plugging in a forested wetland area; moist soil management*; invasive species removal, floodplain reconnection May include some NRCS Code 657 practices. *Moist soil management should only be counted if there are predominantly native wetland plants; and site can sustain itself as wetland without active management, meaning whether water control structure is operated or not.

There are other wetland activities that occur in the watershed to preserve wetlands, or for regulatory purposes of compensatory mitigation. These types of activities are wholly outside the scope of this expert panel and are not reported for annual progress submissions toward TMDL targets. The types of voluntary restoration, creation, or enhancement of wetlands as summarized in Table 2 should not be confused with wetland preservation or regulatory wetland mitigation. For clarification purposes to benefit the reader, Table 3 provides basic descriptions of these activities. Wetland preservation may not be a BMP for purposes of annual progress reporting, but it is still a vital activity that is part of the protection goal in the 2014 Chesapeake Bay Watershed Agreement. Compensatory wetland mitigation is not part of tracking and reporting toward

TMDL progress or Watershed Agreement outcomes, but it is also important for protecting wetland resources in the region.

Table 3. Descriptions of wetland activities that are not counted towards TMDL progress.

Activity	Basic description	CBP will count the BMP acres as...	Examples, if applicable
Preservation	Protect (or Preserve) Acquisition of land or easements of at least 30 years' duration	Neither acreage nor function *(will track toward protection goal)*	Non-mitigation acquisitions; easements of 30+ years duration
Compensatory mitigation	Not applicable for CBP Watershed Agreement and Chesapeake Bay TMDL purposes. 33CFR Part 332 (2008) defines compensatory mitigation as "the restoration (re-establishment or rehabilitation), establishment (creation), enhancement, and/or in certain circumstances preservation of aquatic resources for the purposes of offsetting unavoidable adverse impacts which remain after all appropriate and practicable avoidance and minimization has been achieved."	Not applicable for CBP purposes. Compensatory mitigation projects are not reportable or creditable for Chesapeake Bay TMDL purposes.	Not applicable for CBP purposes

Chapter 3. Background on wetlands and wetland BMPs in the Chesapeake Bay Watershed

The critical role of wetlands in the Chesapeake Bay ecosystem was recognized in the 1987 Chesapeake Bay Agreement, the 1989 Chesapeake Bay Wetlands Policy, Directive 97-2, Wetlands Protection and Restoration Goals, the Chesapeake 2000 Agreement, and the 2014 Chesapeake Watershed Agreement.

Scientific studies of wetland function provide increasingly powerful evidence of the efficiency of wetlands in filtering surface-water runoff and shallow groundwater. In the Chesapeake Bay watershed, the retention of nutrients and sediment by wetlands contributes to ambient and downstream water quality improvements. Wetlands reduce flooding and erosion in non-tidal areas by trapping and slowly releasing surface water. In coastal areas, wetlands help buffer the shoreline from damaging erosive forces. Wetlands also provide essential habitat for a wide variety of plant, fish and wildlife species.

While wetlands represent a relatively small portion of the total watershed, they are an essential component of the Chesapeake Bay ecosystem for the reasons stated above. Efforts are underway to more accurately map wetlands throughout the full 64,000 square mile watershed, but it has been estimated there are approximately 900,000 acres of nontidal wetlands in the watershed (Tiner, 1987).[2] Nontidal wetlands represent about 86% of the total wetlands in the Bay region, while tidal wetlands account for approximately another 282,291 acres as of 2010, according to the CBP.[3]

Overview of wetland BMPs currently implemented in the watershed

A wide range of federal, state, local, academic, extension and nonprofit partners are engaged in efforts to restore, enhance and protect wetlands throughout the watershed. These efforts include headwater restorations, stream corridor riparian restoration, and floodplain reconnections. Restoring degraded wetlands also is important to enhancing wetland function. For example, a common wetland restoration practice is returning hydrology to ditched areas that are currently forested. Upon restoration of hydrology and soil saturation denitrification is expected to increase thereby functioning as a BMP reducing nitrogen load in the watershed. Since these projects often restore hydrology and possibly the wetland footprint, they are often given the name wetland rehabilitation and occasionally given credit. Common types of projects include floodplain reconnection (through various methods – breaching spoil berms, bringing up the stream bed); and ditch plugs in forested wetlands to restore “natural” groundwater table/reduce the effects of the ditch on the water table, among others.

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[2] This is an estimate based on acreage of inland wetlands, excluding freshwater ponds, in Tiner 1987 (Tiner, R.L. 1987. *Mid-Atlantic Wetlands: A Disappearing Natural Treasure*. U.S. Fish and Wildlife Service and U.S. Environmental Protection Agency). Acres of wetlands in the Phase 6 CBWM may be different as it will include NWI and other more recent data from the jurisdictions.

[3] http://www.chesapeakebay.net/indicators/indicator/tidal_wetlands_abundance

Under the Phase 5.3.2 definition for the wetland restoration BMP, most of the acres reported in annual progress runs are associated with U.S. Department of Agriculture (USDA)-NRCS cost-share practices. There are many other funding sources and implementing partners, however, and partners continue to improve their data collection efforts to more fully account for all wetland-related BMP implementation in the region. Available implementation data from the jurisdictions' most recent annual BMP progress reports is summarized in Table 4 below. Table 5 summarizes cumulative wetland restoration by state as reported to the CBP from 2010 to 2014.

Table 4. Acres of wetland restoration reported by jurisdictions in annual progress runs.

	1985 Calibration	2009	2010 Progress	2011 Progress	2012 Progress	2013 Progress	2014 Progress	2015 Progress
DE	0	287	439	588	2,694	2,697	2,699	2,717
MD	0	7,716	8,249	8,614	9,037	9,260	9,284	9,729
NY	0	5,214	5,578	6,217	6,217	6,278	6,307	6,320
PA	77	3,002	3,874	3,875	3,875	3,857	3,858	3,985
VA	0	213	213	411	420	420	452	452
WV	0	203	203	203	203	203	208	220
Total	77	16,617	18,538	19,890	22,428	22,715	22,808	23,423

Note: Reported under Phase 5.3.2 definition for the BMP, in acres.
Source: BayTAS Summary BMPs report, February 2016.

Table 5. Restoring wetlands on agricultural lands, cumulative acreage by state (2010-2014).

State	Acres
Maryland	1,568
Pennsylvania	874
Virginia	239
West Virginia	5
New York	1,093
Delaware	2,412

Source: CBP indicators: http://www.chesapeakebay.net/indicators/indicator/restoring_wetlands, Accessed 2/9/2016, last updated 7/8/2015

All data summarized in Table 4 and Table 5 reflect established, rehabilitated, or re-established wetlands on agricultural lands reported to date for BMP credit. These wetlands are considered functional and of benefit since they provide increased wetland habitat, among other services. Although partners report information for wetlands establishment or re-establishment on urban lands, these data are not included in Table 5 because a myriad of project proponents complicates consistent and accurate data collection across the Bay region and some projects (such as urban stormwater ponds) are established for the sole purpose of stormwater capture and are of limited habitat value. Since rehabilitation does not have a credit efficiency assigned in the CBP modeling tools, rehabilitation records included in the above table are incomplete as not all projects have been reported for credit.

Background on the Phase 6 Watershed Model

At the time of this report, the Phase 6 Chesapeake Bay Watershed Model is undergoing development and beta calibrations. The final calibration will occur in 2017. The Water Quality and Sediment Transport Model (aka the estuarine model) will simulate tidal wetlands given the dominance of their direct interactions with the tidal water column over their interactions with runoff from upland areas. Nontidal wetlands will be simulated as two new land uses[4] in the Phase 6 Watershed Model based on the recommendations described in this report (see Chapter 5), which were previously discussed and approved by the CBP partnership in the fall of 2015.

Figure 1 below illustrates how various components of the Phase 5.3.2 modeling structure are related. Though specific aspects of data inputs, Scenario Builder, the Watershed Model, and the Estuarine Model will be updated for Phase 6 based on cumulative partnership feedback and recommendations, the overall structure and data flow will remain similar.

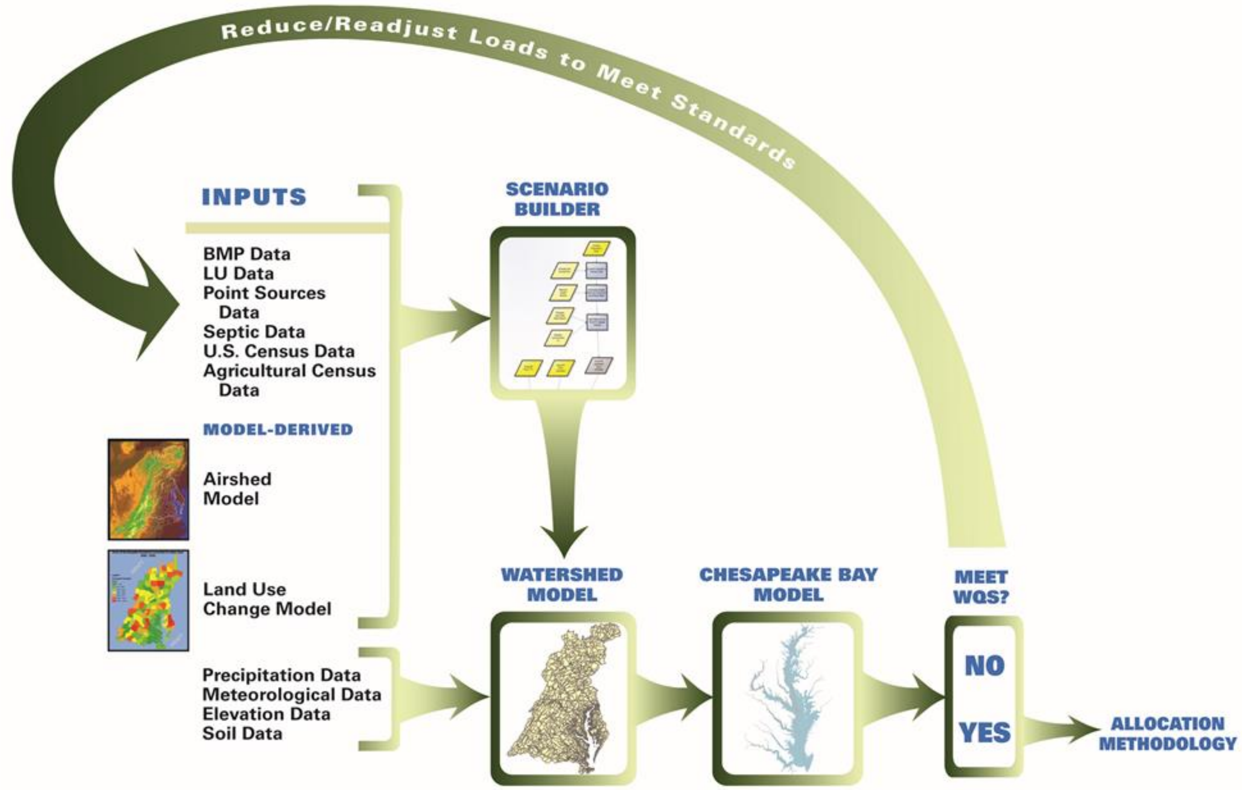

Figure 1. Conceptual diagram of Phase 5.3.2 Watershed Model and related modeling tools.

[4] The two wetland land uses are Nontidal – Floodplain and Nontidal – Other (Non-Floodplain). Or simply, Floodplain and Other.

Chapter 4. Review of available science – Non-Tidal wetland effects on water quality: an updated landscape perspective

Advancing a conceptual model to explain how wetland water quality and habitat benefits vary across space and time.

Predicting water quality and habitat benefits of wetlands across regional scales requires a systematic understanding of how hydrogeologic factors and watershed position combine to influence wetland form and function (Bedford, 1999). Hydrogeologic frameworks emphasize the importance of climate, surface relief and slope, thickness and permeability of soils, and the geochemical and hydraulic properties of underlying geologic materials (Winter, 1988, 1992). Stream classifications describe systematic changes and hydrologic interactions along the river corridor, from headwater reaches and associated wetlands to delta ecosystems (e.g., Brinson, 1993a; Church, 2002; Rosgen, 1994; Vannote et al., 1980). Hydrogeomorphic (HGM) frameworks combine these conceptual models to describe how wetland hydrodynamics and hydrologically-influenced geochemical variables vary across space and time (Brinson, 1993b; Brooks et al., 2014; Euliss et al., 2004); thus when the HGM framework is presented in the context of a physiographic setting, it provides a compelling basis to capture variability in wetland function and to predict water quality benefits of different wetland types within a region. Accordingly, the panel combined these frameworks to describe how biogeochemical processes affecting transport and delivery of excess nutrients and sediment might vary in wetlands across the Chesapeake Bay watershed. Results build on the work of Lowrance et al. (1997) by emphasizing linkages between wetland function and watershed position, given physiographic setting.

The hydrogeologic setting controls ground- and surface-water interactions and the role of wetlands as nutrient and sediment sinks, sources, and transformers (Winter, 1999). In upland areas, depth to bedrock, soil infiltration capacity, and topographic relief strongly influence the amount of runoff and the rate at which it is delivered to waterways versus infiltration to the shallow groundwater system. Shallow bedrock and steep terrain typical of mountainous ridge and valley regions result in rapid runoff rates, narrow stream/river corridors, and wetlands development primarily in valley bottoms. Steep upland land surfaces can cause erosion and transport of sediment and phosphorus to streams. In contrast, deep, unconsolidated sedimentary deposits across flat terrains, such as those defining much of the Coastal Plain, allow development of broad, expansive wetlands along entire stream networks. The relative influence of surface runoff versus infiltration controls the quantity and rate at which contaminants of concern are delivered to down-gradient wetlands. In addition, the physio-chemical structure of a contaminant strongly influences delivery mechanisms. For example, while phosphorus and sediments are transported primarily through overland processes, nitrogen primarily enters streams in the form of nitrate dissolved in groundwater.

Where productive shallow groundwater systems develop, the potential for wetlands to capture excess nitrate depends on the thickness of the surficial aquifer above a confining layer (e.g., fine-grain, clay stratum, consolidated hardpan, or capstone bedrock) and the resulting hydrologic connectivity with wetland soils. This stratigraphy determines the potential for nitrate-enriched groundwater to flow through reduced, organic-rich wetland sediments ideal for denitrification or to bypass these reactive zones (Hill et al., 2004; Vidon and Hill, 2004a, 2006). Phosphorus retention depends on physical factors affecting erosion and deposition as well as hydrochemical conditions affecting phosphorus chemistry. Flat open areas typical of valley bottoms and bottom lands slow flow velocities and allow sedimentation. Steep relief enhances erosion and transport of sediment and phosphorus to streams, especially where sandy loam soils occur.

Consideration of watershed position can further expand the basis for evaluating how wetland function varies across space and time (Brinson, 1993a). Stream classifications describe variation in hydrobiological function in positions along a stream network, recognizing systematic changes as headwater streams converge ultimately to form large-order rivers (e.g., Brinson, 1993a; Church, 2002; Rosgen, 1994; Vannote et al., 1980). Most describe the 'riverine landscape' to include the open water channel zone, headwater wetlands, and adjacent riparian or floodplain zones. In less disturbed systems, the relative importance of overland flow, groundwater contributions, and surface water inundation changes systematically along this up-stream to downstream continuum:

- Upland areas include the majority of a watershed and are defined as where stream channels connect directly to hillslopes and where sediment mobilized on upland slopes moves directly into the stream channel at the slope base (Church, 2002). In these areas, headwater wetlands, including many depressional, sloping, and riparian wetlands, provide important nutrient, sediment and carbon sinks (Church, 2002; Cohen et al., 2016). Uplands are groundwater recharge areas where soils and surficial sediments are permeable.
- Upland valley regions refer to portions of the stream network that function primarily as transfer zones (Church, 2002). These low-order streams tend to have the greatest capacity to transport sediments downstream (i.e., stream power; Bagnold, 1966) thus often limiting in-stream biota (Church, 2002). These reaches also have the greatest frequency of adjacent sloping wetlands where advective groundwater flow controls water table position and the delivery of nutrients (Devito et al., 1999).
- The main valley forming the "backbone" of the drainage system accumulates alluvial materials along the channel and within adjacent floodplains due to much lower gradients (Church, 2002). Here, "sediment recruitment and onward transfer become purely consequences of erosion of the streambed and banks", with the former dominating further upstream and depositional processes becoming increasingly important downstream toward the distal end of stream networks (Church, 2002).

Combining the underlying principles of hydrogeology and stream classification, Brooks et al. (2011) refined a hydrogeomorphic (HGM) classification of wetlands (Brinson, 1993b) for the

Mid-Atlantic Region (MAR), including the entire Chesapeake Bay watershed. The model broadly includes flats, depressions, and slope wetlands; lacustrine fringe, riverine floodplains, and tidal and non-tidal fringe wetlands. Importantly, the authors recognized distinct patterns in the distribution and hydrologic characteristics of wetlands across major physiographic provinces of the region (e.g., Ator et al., 2005; Cole and Brooks, 2000), including the Appalachian Plateau, Appalachian Ridge and Valley, Piedmont and Coastal Plain (see Figure 2). Each of the major wetland classes described below can occur in the different physiographic provinces, but the distribution and predominant geochemical controls vary across that space. Wetlands are most common in the relatively flat Coastal Plain followed by the Piedmont, and occur less frequently in the other physiographic provinces (See Box 1, Table 6). While information presented herein provides a generalized framework to better account wetland water quality functions within a TMDL framework, it is critical to recognize that the water quality services provided by an individual wetland strongly depends on hydrologic connectivity with sources of excess nutrients and sediment.

Flats develop where a combination of flat topography and slow infiltration results in precipitation accumulation at the surface. Accordingly, short-term weather patterns including evapotranspiration, primarily influence water table dynamics. In the Chesapeake Bay watershed, flats tend to occur on Coastal Plain interfluves (higher ground between two watercourses in the same drainage system) (Brinson, 1993b). They are particularly common along the central topographic high of the Delmarva Peninsula between the Chesapeake Bay watershed and the Delaware Bay and Atlantic Ocean drainages in the poorly drained soils of the Outer Coastal Plain. While flats sustain denitrifying conditions, these wetland sediments often do not intercept nitrate-enriched groundwater (Denver et al., 2014) or capture large quantities of surface overland flow because of their location along watershed drainage divides and small contributing areas. However, interception may occur where drainages drop down into flats at lower topographical positions within the watershed.

Depressional wetlands occur in topographic hollows and are controlled mainly by precipitation runoff, evapotranspiration, and also local interflow. Typically, these small wetlands lack surface water inlets or outlets. They form in areas up-gradient of headwater reaches and thus can provide important areas of focused groundwater recharge. The small contributing areas often limit external supply of nutrients (Craft and Casey, 2000), however, because of their high ratio of perimeter to surface area and their frequent distribution across the landscape, depressional wetlands initially intercept surface runoff, thus providing important deposition areas (Cohen et al., 2016). Where these wetlands are located in agricultural fields, they can intercept and denitrify nitrate in or potentially entering groundwater (Denver et al, 2014). Areas with prior-converted cropland and hydric soils that are former depressional wetlands also can be areas of denitrification when soils are saturated. Further, low surface connectivity reduces exports to mitigate impacts on downstream waters, and retention rates are relatively high (Craft and Casey, 2000). Low pH (4 to 5.5) due to the predominant influence of precipitation, limits production and decomposition especially during wet seasons. Within the Chesapeake Bay watershed, depressional wetlands include the Delmarva Bays of the Outer Coastal Plain and ridge top wetlands of the Appalachian Ridge and Valley.

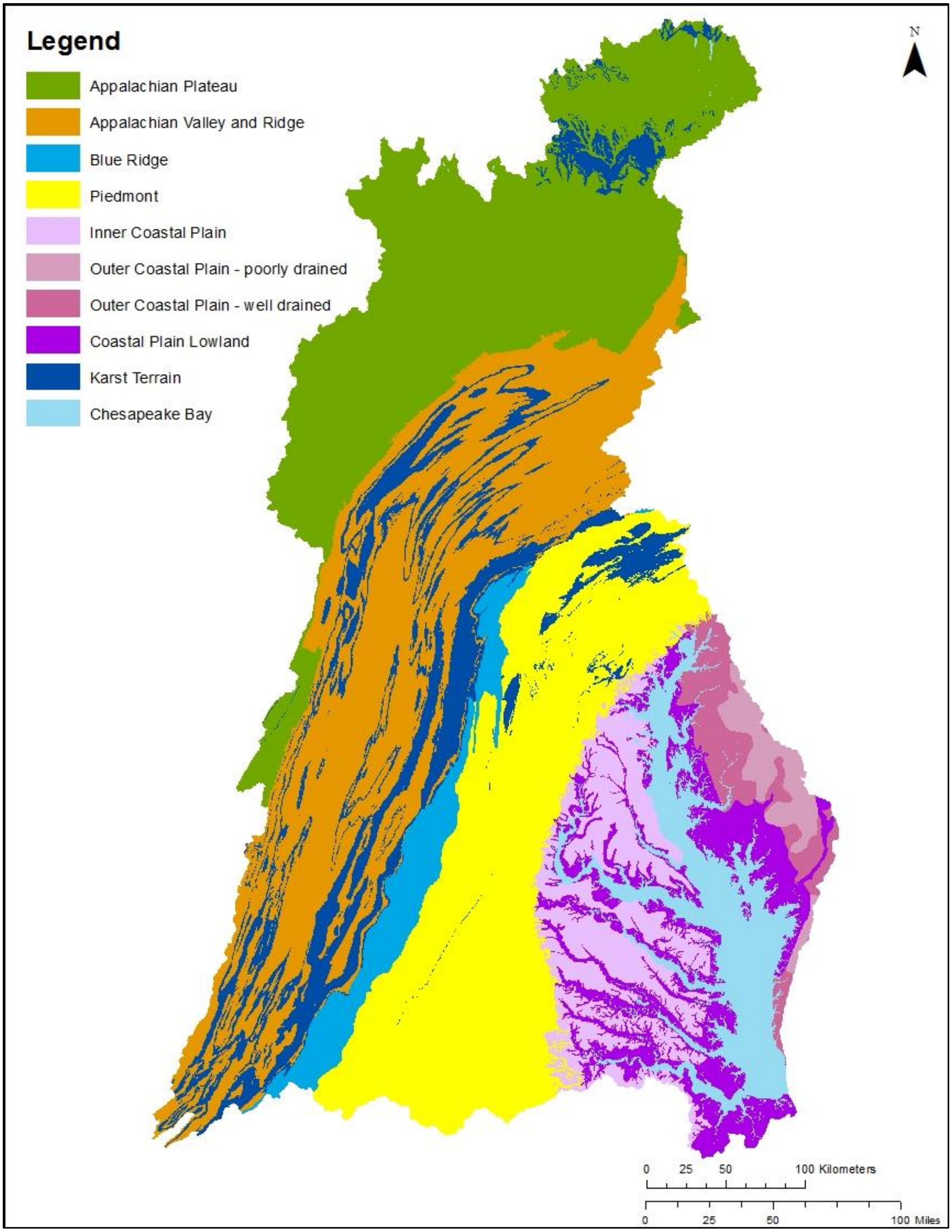

Figure 2. Physiographic regions in the Chesapeake Bay Watershed.

Map generated by Quentin Stubbs, USGS.

Sloping wetlands, including riparian corridors, often occur in association with headwater reaches where geologic discontinuities or breaks in topographic slope result in groundwater discharge to the land surface. As a result, the water table remains near the land surface (within 10 cm), and the plant rooting zone effectively is permanently saturated (Almendinger and Leete, 1998). Groundwater flow tends to occur in one direction, in relation to topographic gradients. Although saturated conditions retard decomposition and often result in the development of organic-rich peat soils, supplies of oxic, nitrate-rich groundwater and generally neutral pH create biogeochemically active areas especially conducive to removing excess nitrogen (Gu et al., 2008; Hill and Cardaci, 2004; Schipper et al., 1993; Vidon and Hill, 2004b). These wetlands have the highest reported denitrification rates, although sub-oxic conditions also can enhance phosphorus availability and exacerbate downstream eutrophication, especially where human impacts have altered water chemistry (Boomer and Bedford, 2008; Dupas et al., 2015; Lucassen et al., 2004; Smolders et al., 2010; Verhoeven et al., 2008). Where surficial aquifer thickness is significantly greater than the depth of associated anoxic wetland sediments, contaminated groundwater can bypass sloping wetlands and limit natural filter treatment (Bohlke and Denver, 1995; Puckett, 2004; Tesoriero et al., 2009).

Riverine floodplains occur adjacent to waterways where overbank storm flow provides the dominant water source (Brinson, 1993b). These surface-water driven systems generally have more variable water level fluctuations related to season and storm events compared to other wetland types, and also greater external supplies of nutrients. As a result nutrient availability, primary production, and decomposition rates are higher, especially where forested wetlands establish stabilizing root systems. In addition, groundwater inflows from the local contributing area sustain water quality functions similar to sloping wetlands.

The Importance of Physiographic Setting

The form and distribution of wetlands strongly depend on climate and physiographic setting. Defining characteristics including topographic relief and geology strongly influence the relative importance of runoff vs infiltration, where near-surface groundwater and surface water interactions support wetland development, and also the evolution of land use history. Together, these factors influence the distribution of different wetland types and the potential delivery of excess nutrients and sediment to these wetland systems. The Chesapeake Bay watershed can be divided into five major physiographic regions with additional sub-classes to summarize key characteristics that predominantly influence the form and function of wetlands throughout each sub-region (see Figure 2). The distribution of wetlands varies widely across the physiographic regions.

The Appalachian Plateau extends across the most remote areas from the Bay, including the New York portion of the Bay watershed, across more than half of western Pennsylvania, and through the westernmost areas of Maryland and Virginia. The region is characterized by overlaying, consolidated sandstone and carbonate sedimentary rocks that are flat-lying to gently folded, but highly fractured, especially in more weathered units closer to the land surface (Figure 3; modified from Trappe Jr. and Horn, 1997). In the unglaciated subregions, which includes much of the Appalachian Plateau in the Bay watershed, the region includes highly dissected waterways with adjacent slopes covered by thin accumulations of regolith; therefore, most precipitation runs to streams and only a small portion infiltrates to the groundwater system (Trappe Jr. and Horn, 1997). About 5% of the land area is wetlands, most of which are in floodplains in wide valleys and topographic lows formed upstream of erosion resistant bedrock stream contacts (Figure 4; modified from Fretwell et al., 1996). Depression and sloping wetlands also occur where permeable, water-bearing strata outcrop dissected valley walls to sustain groundwater fed springs (Figure 4; modified from Fretwell et al., 1996). In the glaciated regions of northern Pennsylvania and New York, depressional wetlands occur in association with glacial moraine deposits (Fretwell et al., 1996). The average dissolved solids concentration is 230 milligrams per liter with a median pH of 7.3. Contaminated waters, notably from coal mining, generally are acidified and have higher concentrations of iron, manganese, sulfate, and dissolved solids (Trappe Jr. and Horn, 1997), all of which can strongly influence nutrient biogeochemistry. Limited development and agriculture in the region reduces the risk of contamination by excess nutrients and sediment.

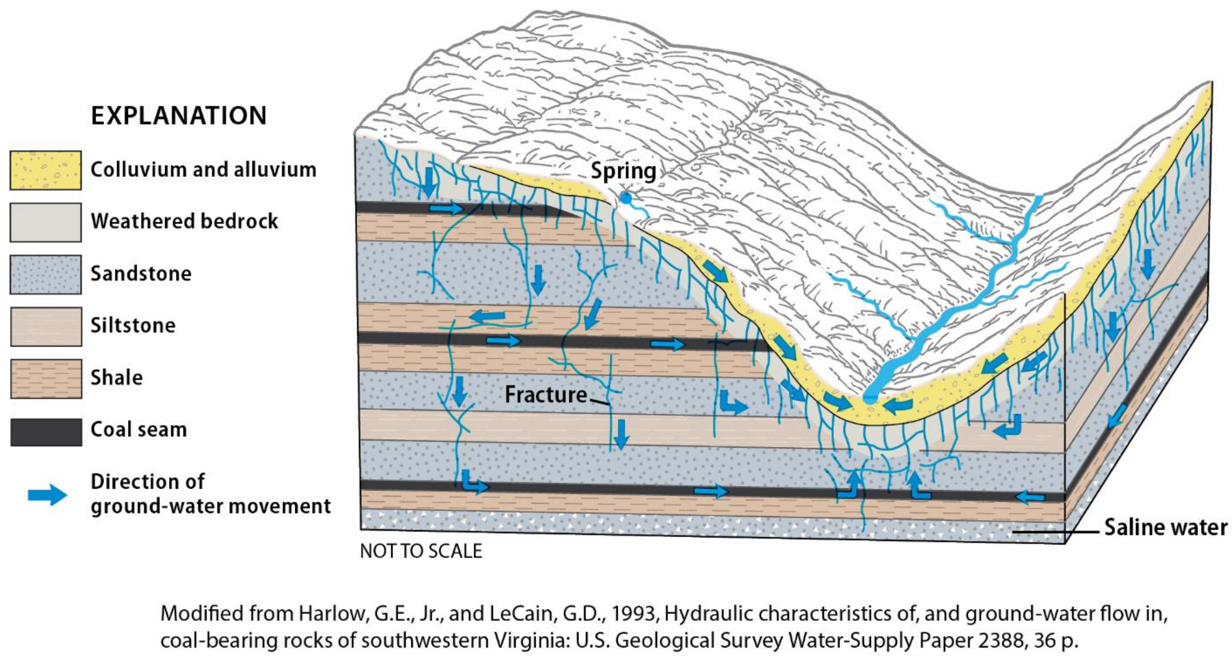

Figure 3. Topography and shallow fracture systems determine groundwater movement in the aquifers of the Appalachian Plateaus. Water infiltrates weathered bedrock and moves mostly through near-surface fractures; some water moves in a steplike fashion vertically along deeper fractures and horizontally through fractured sandstone or coal beds. Because of the absence of deep groundwater circulation and regional flow systems, saline water is at shallow depths. Modified from Trappe Jr. and Horn, 1997.

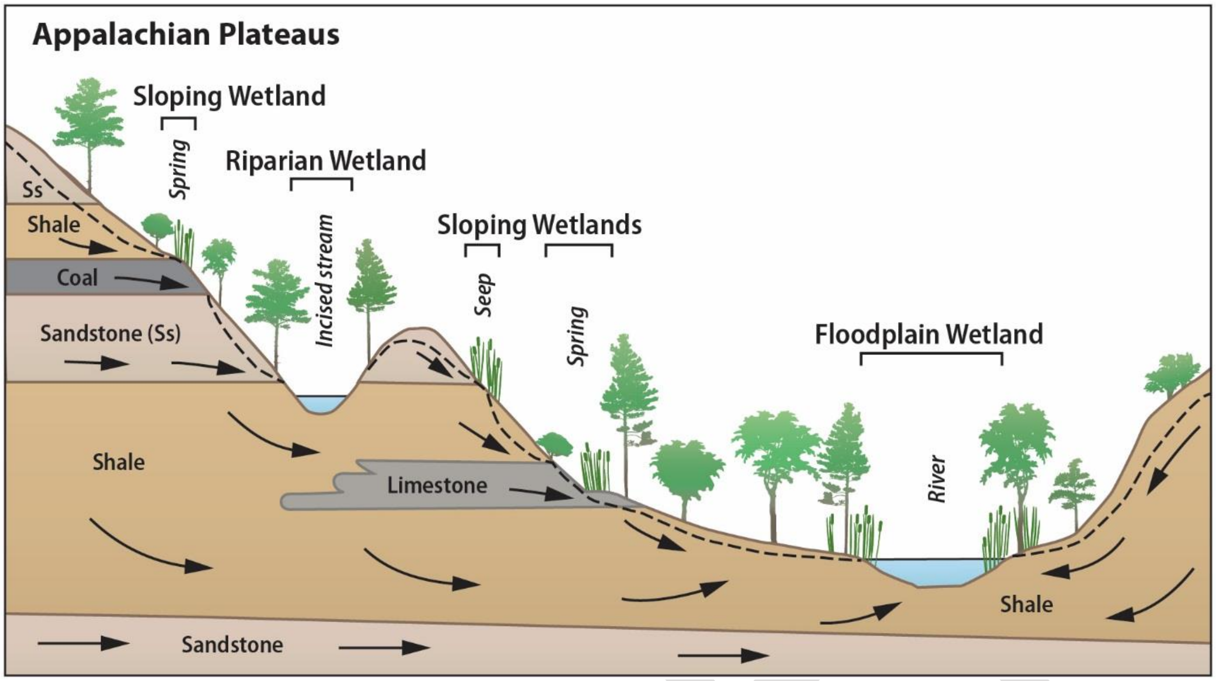

Figure 4. Depiction of sloping, floodplain, and riparian wetlands across the Appalachian Plateau. Depressional wetlands, while not depicted in this conceptual diagram, can occur in this landscape, especially where glacial moraine deposits exist.
Modified from Fretwell et al., 1996.

The **Appalachian Ridge and Valley** province is defined by alternating, distinctly linear valleys and ridges that trend southwest from northern New Jersey to northern Georgia and Alabama. This includes areas of central Pennsylvania, Maryland and Virginia in the Chesapeake Bay region. Similar to the Appalachian Plateau, bedrock consists mostly of sandstone, shale, and carbonate, with some locally important coal-bearing units (Trappe Jr. and Horn, 1997). The stratum underlying the region's distinct topography, however, are highly deformed and folded and also more fractured (Trappe Jr. and Horn, 1997). In addition to the steep terrain, valley floor bottoms tend to have deeper accumulations of regolith. Groundwater generally flows through ever-larger, subsurface conduits, until discharging at springs (Figure 5, modified from Trappe Jr. and Horn, 1997). Three types of springs occur within the region (Trappe Jr. and Horn, 1997), including 1) contact springs where a water-bearing unit and underlying aquitard emerge at the land surface; 2) impermeable rock springs fed by fractures, joints or bedding planes in rocks; and 3) tubular springs that from where solution channels emerge. The latter are common in carbonate-rich, karst regions, described below in more detail. Wetlands cover less than three% of the land in this region. Water chemistry also is similar to resources across the Appalachian Plateau, although more variable and slightly more dilute: the average dissolved-solids concentration is 115 mg/L and median pH is 7.4. Contaminated sources of water are generally from mining in the ridge areas; in the valleys, especially in areas underlain by carbonate rocks (see karst section), high nitrate concentrations from agricultural sources are common.

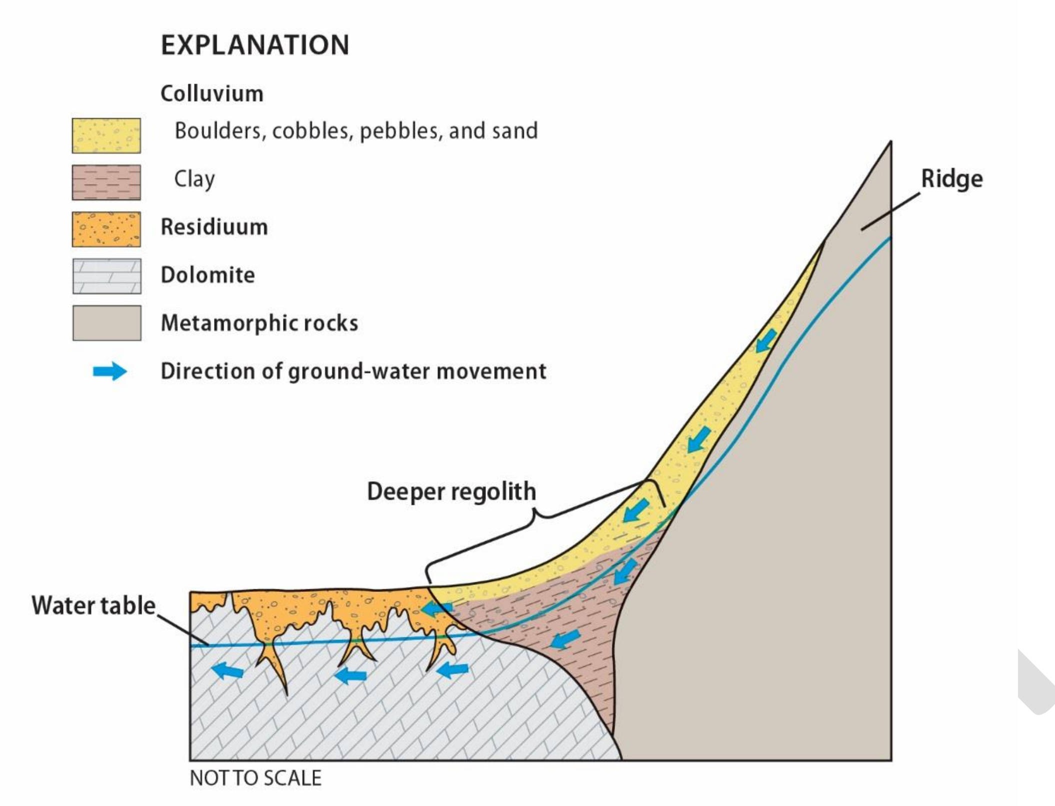

Figure 5. Thick wedges of colluvium on the lower flanks of ridges store large quantities of water that subsequently move into aquifers in the valleys. The colluvium commonly contains perched bodies of groundwater that are separated from the main water table by clay confining units. Trappe Jr. and Horn, 1997, Modified from Nutter, L.J., 1974a, Hydrogeology of Antietam Creek Basin: U.S. Geological Survey Journal of Research, v. 2, p. †249-252.

The **Blue Ridge Province** is characterized by its surrounding steep, mountainous slopes and numerous streams that feed into a broad valley with heavy rolling terrain, and deeply incised, fast flowing streams (Trappe Jr. and Horn, 1997). Underlying bedrock consists of highly faulted, folded, and fractured crystalline and siliciclastic bedrock (Denver et al., 2010). As a result, the groundwater system is unique to the sedimentary aquifers typical of other physiographic provinces in the region (LeGrand, 1988). Deep groundwater moves mainly through bedrock fractures. A mix of unconsolidated materials, which varies greatly in thickness, composition, and grain size, lays over top, resulting in highly variable hydraulic properties. The regolith is more permeable than the bedrock (Trappe Jr. and Horn, 1997), and groundwater flow generally is constrained to the unconfined aquifer. Flowpaths are relatively short, from recharge areas in uplands to local streams and springs; baseflow contributes more than 50% of annual stream discharge (Denver et al., 2010). Wetlands occupy less than 1% of the region.

The **Piedmont** has similar geology to the adjacent Blue Ridge Province, but is distinguished by its low, gently rolling hills and moderate relief. To the east, the Fall Line demarcates where deeply weathered igneous and metamorphic rocks often exposed in the Piedmont are covered by unconsolidated sediments characteristic of the Coastal Plain. With its hilly terrain and shallow upland soils (less than 1 m thick) with slow infiltration rates, the Piedmont is predominantly an erosive environment (Markewich et al., 1990). Groundwater occurs in unconfined conditions, in the bedrock fractures or in the overlying mantle of weathered regolith (Johnston, 1964). For more than 200 years, extensive forest clearing, agriculture, and milling operations have contributed significantly to the naturally deep valley floor deposits (Lowrance et al., 1997; Walter and Merritts, 2008). As a result of natural and anthropogenic processes, the river-scape is entrenched or channelized through legacy sediments more than other regions in the Chesapeake Bay watershed (Donovan et al., 2015). Baseflow supplied by the unconfined aquifer ranges between 50 and 75% of watershed discharge (Lowrance et al., 1997). Wetlands typically are small and spring-fed, associated with slope changes in riparian or bedrock fracture zones (Fretwell et al., 1996). Where connected and functioning, floodplain wetlands also provide significant nutrient and sediment trapping capacities (Schenk et al., 2013, Hupp et al., 2013). Overall, wetlands cover about 4% of the land area. Dissolved solids concentrations in natural waters of the Piedmont average 120 mg/L with a median pH of 6.7.

Carbonate deposits (karst terrain) in the Appalachian Plateau, Ridge and Valley, and Piedmont Provinces provide unique karst features that influence regional hydrology and the distribution of wetlands. Chemical dissolution of the bedrock creates a network of tunnels, caves, and related features that significantly increase groundwater transmissivity (Figure 6, modified from Trappe Jr. and Horn, 1997). Rapid groundwater drainage limits extensive wetland development (Fretwell et al., 1996). Limestone outcrops, however, discharge calcium-bicarbonate rich waters that create unique groundwater fed wetland habitats and also uniquely influence wetland water chemistry. Ancient sink holes associated with subterranean karst network support depressional wetlands that typically are not directly connected by surface water flows to regional water ways, but may be connected in through spring discharge in other areas.

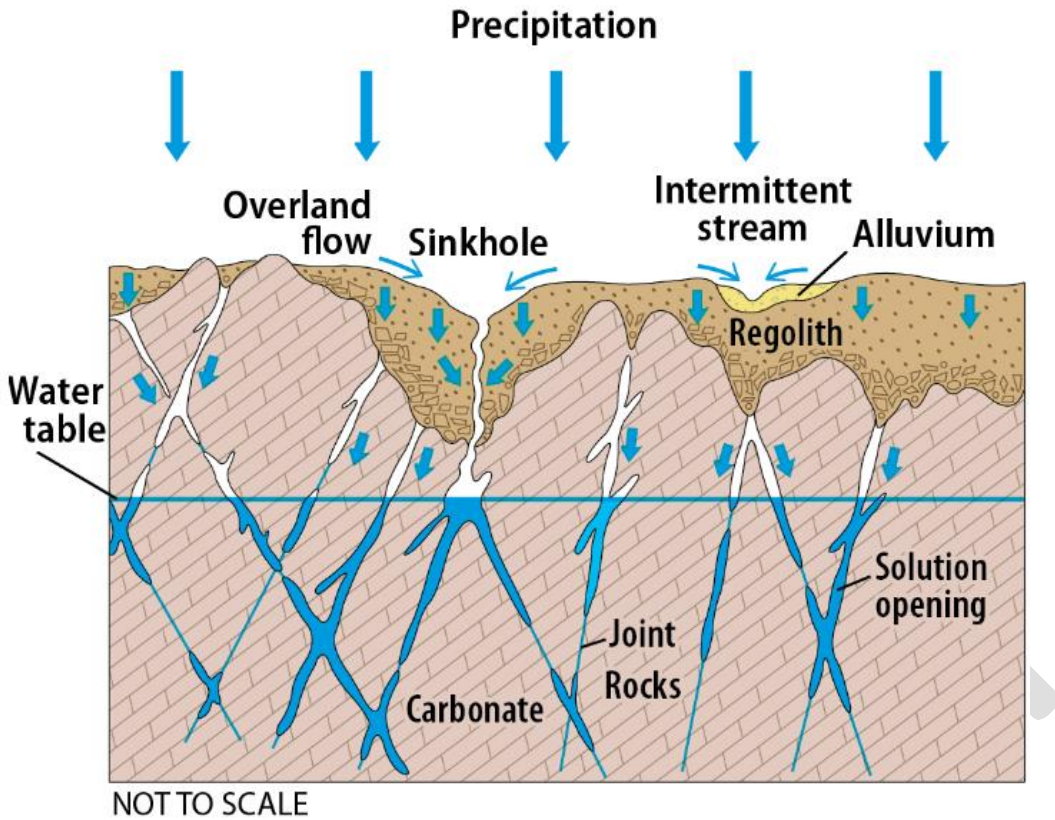

Figure 6. Thick wedges of colluvium on the lower flanks of ridges store large quantities of water that subsequently move into aquifers in the valleys. The colluvium commonly contains perched bodies of groundwater that are separated from the main water table by clay confining units.
Trappe Jr. and Horn, 1997, Modified from Nutter, L.J, 1973, Hydrogeology of the carbonate rocks, Frederick and Hagerstown Valleys: Maryland Geological Survey Report of Investigations 9, 70.

The **Coastal Plain** describes the broad wedge of unconsolidated sediments that occurs along the Atlantic Ocean coastline (See Figure 7). Within the Chesapeake Bay watershed, the Coastal Plain deposits extend from the land surface, at the Piedmont Fall Line, on the Chesapeake Bay's western shore, to a depth of more than 8,000 feet closer to the Atlantic coastline (Debrewer et al., 2007). The region can be divided into three sub-areas with distinctly different trends in wetland distributions and functions. The Inner Coastal Plain includes areas west of the Chesapeake Bay characterized by gently rolling hills and incised streams. This area has the lowest percentage of wetlands (5%) compared to other Coastal Plain subregions. On the Eastern Shore, the Outer Coastal Plain includes poorly drained divides and well-drained regions (wetlands cover about 15% of the land area). In interior areas depressional wetlands and expansive flats form on poorly drained soils along watershed divides. In these areas, wetlands occupy 34% of the land area. In well drained inland areas between the inland poorly drained soils and the Coastal Lowlands, narrow bands of palustrine wetlands occupy less than five% of the land area but provide riparian and floodplain functions. The Coastal Plain lowlands include low-lying areas on both sides of Chesapeake Bay that occur generally within 25 feet of sea level. Here, the flat terrain and shallow regional water-table depth results in broad, unconstrained channels and expansive backwater areas (e.g., slacks or bottom-bottomland hardwood forests). These riverscapes are characterized by continuous inundation mainly driven by seasonal conditions rather than storm events, and limited directional flow (Brooks et al., 2014). Precipitation, runoff from upland areas, and groundwater from local and regional aquifer discharge also can contribute significantly to bottomland wetland water budgets (Fretwell et al., 1996). Despite slow advective flow, bottomland wetlands provide important nutrient and sediment sinks (Noe and Hupp, 2005) (See Figure 8). Similar to the Piedmont and Great Valley regions, the Coastal Plain has sustained intensive development and agricultural land use, and contamination by excess nutrients and sediments occurs frequently. Importantly, despite that the Coastal Plain occupies less than 10% of the Bay watershed, this region supports the greatest expanse, nearly 40%, of all wetlands in the region (Tiner, 1994). Tidal wetlands occur almost exclusively within the Coastal Plain and constitute more than half of all wetlands in the region. Remaining tidal wetlands occur predominantly along the shoreline of the Lower Eastern Shore. It is estimated that between 45 and 65% of non-tidal wetlands have been drained and converted, mostly for agriculture (Clearwater et al., 2000).

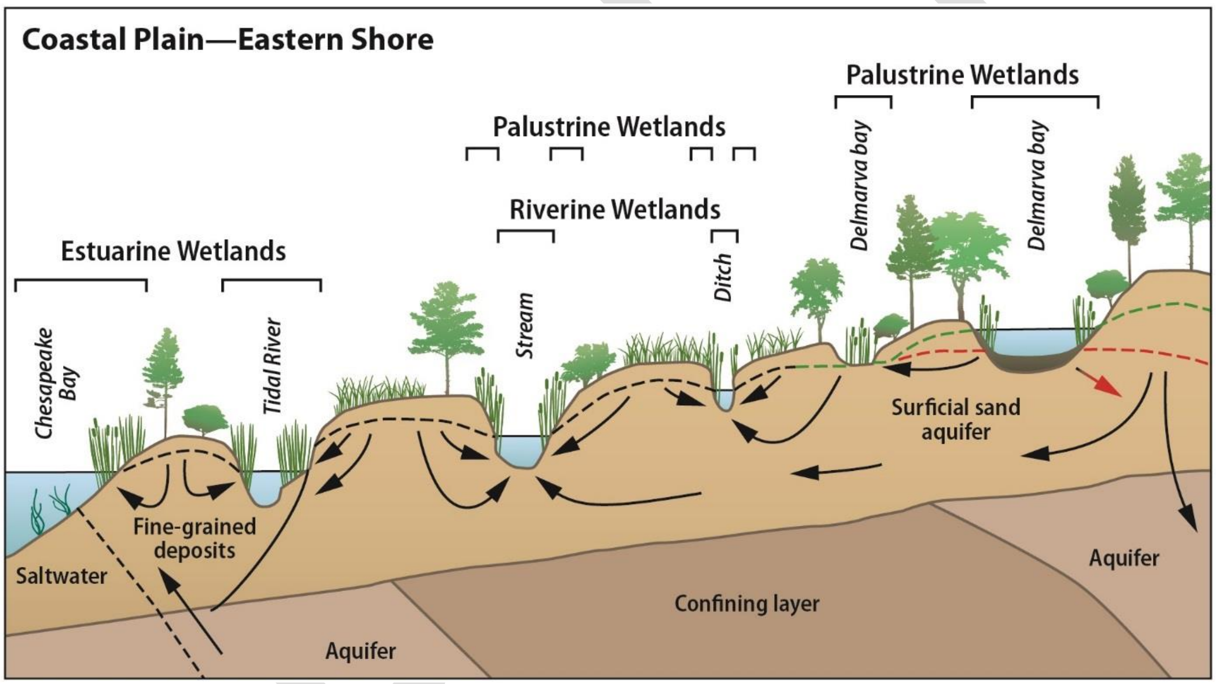

Figure 7. Conceptual model of Coastal Plain shallow groundwater conditions. Alternating and inclined layers of unconsolidated deltaic and estuarine deposits across a flat terrain results in a complex, nested groundwater system.
Modified from Fretwell et al., 1996.

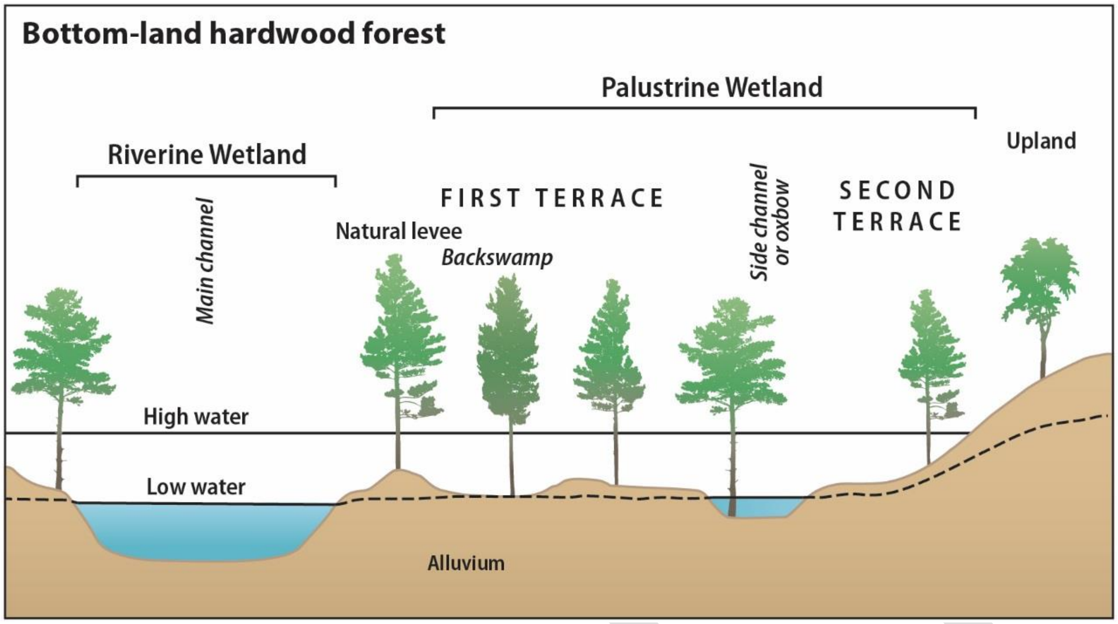

Figure 8. Conceptual model of bottom-land hardwood forest floodplain, which occur frequently in the Coastal Plain lowlands.
Modified from Fretwell et al., 1996.

Box 1 – Acres of wetland land uses in the Phase 6 CBWM beta calibrations

This Box provides a summary of the current acreages of Phase 6 wetland land uses, based on the physiographic regions described here in Chapter 4. Chapter 5 reviews the land uses for nontidal wetlands that were accepted by the CBP partnership in 2015. The acreages in this chapter are from the latest beta version of the CBWM, and are thus subject to change based on CBP partnership decisions and review outside the purview of this panel. It is useful, however, to see the latest land use acres; the latest estimates have been used in this chapter to give the reader an approximation of wetland prevalence in each physiographic region.

An overall goal of considering wetlands as Phase 6 land uses was to evaluate wetland functions across the Bay watershed's landscape. Mapped wetlands in were classified as either "Tidal", "Floodplain", or "Other". Tidal wetlands were identified as estuarine and tidal wetlands (using Cowardin et al 1979, e.g., system, subsystem, class, water regime, etc.) within two meter elevation above sea level, as identified from the 10 meter National Elevation Dataset (USGS). For non-tidal wetlands, floodplain wetlands were classified by creating and overlaying a floodplain mask over NWI polygons. Any polygons that intersected the floodplain mask were classified as "Floodplain", while the remaining wetland polygons were classified as "Other" wetlands. The floodplain mask was derived from combining FEMA flood hazard layers with a SSURGO layer created by querying polygons according to attributes linked to floodplain conditions. The "Other" wetland class primarily consisted of isolated depressional wetlands, sloping, riparian wetlands, and flats. Many of the NWI-mapped wetlands are classified as palustrine, providing limited information about hydrologic function and setting. Because sloping and depressional wetlands and flats cannot be distinguished from NWI data, these were grouped as "Other" for the Phase 6 land uses.

The physiographic province of each mapped wetland was determined by intersection with the USGS physiographic map (Brakebill and Kelley 2000; see Figure 2) created by sub-dividing physiographic province according to hydrogeomorphologic conditions and wetland characteristics. The seven major physiographic provinces included the Appalachian Plateau, the Appalachian Ridge and Valley, the Blue Ridge, Piedmont, Coastal Plain, and the Karst Terrain. With respect to the major provinces, non-tidal wetlands consume 70% of land cover in the Coastal Plain province. Whereas, non-tidal wetlands account for less than or equal to 3% of land cover in each of the remaining physiographic provinces, which are dominated by either riverine wetlands located in topographic slopes or isolated, upland depressions. With respect to acreage, the Coastal Plain floodplain wetlands were dominated by Coastal lowlands that accounted for 60% of the floodplains. On the other hand, the Coastal Plain's "Other" wetlands were more evenly distributed with the Coastal Plain lowlands accounting for 36% (187,977 acres), the Outer Coastal Plain, poorly drained uplands accounting for 35% (182,249 acres) and the Outer Coastal Plain, well drained uplands accounting for 21% (108,302 acres). With respect to the acreage of floodplain and "Other" wetlands in non-Coastal Plain provinces, the Appalachian Plateau (11, 112 acres) and the Piedmont (57,391) provinces had the highest acreage of "Other" wetlands, and the inverse was applied to the Floodplain with the Piedmont accounting for 227,317 acres and Appalachian Plateau accounting for 82,041 acres. When comparing the ratios of floodplain wetlands to other wetlands, the "Floodplain" wetlands accounted for 4 times more spatial area (acreage) than "Other" wetlands in the Piedmont, and the Karst Terrain –Piedmont and Appalachian Ridge and Valley provinces. The "Other" wetlands accounted for almost 6 times more acreage than floodplain wetlands in the Outer Coastal Plains poorly drained uplands followed by well drained wetlands with a 2:1 other: floodplain ratio.

Table 6. Area of non-tidal wetlands and general description of wetland types in major Physiographic Provinces of the Chesapeake Bay watershed.

Physiographic Province	Total Other Wetland acreage[1] (mean size)	Total Floodplain Wetland acreage[1] (mean size)	Combined, nontidal wetland area as % of total province area	Description[2]
Appalachian Plateau	110,112 (2.5)	82,041 (1.8)	2	Diverse wetland types including wet thickets, shrub bogs, seasonally flooded wet meadows and marshes
Appalachian Ridge and Valley	12,408 (1.2)	36,472 (1.3)	1	Wetlands uncommon; located in topographic slopes and depressions
Blue Ridge	2,024 (1.2)	4,870 (1.3)	<1	
Piedmont (inc. Piedmont Crystalline and Mesozoic Lowlands)	57,391 (1.4 to 2.6)	227,317 (2.1 to 2.3)	3	Mostly isolated palustrine and riverine wetlands in floodplains and upland depressional swamps
Coastal Plain				Wetlands located in riparian areas and floodplains, and in upland depressions divides and broad flat areas between along drainage divides
Inner Coastal Plain	45,930 (1.9)	87,569 (2.05)	5	Most wetlands located in riparian areas of stream valleys
Outer Coastal Plain, poorly drained uplands	182,249 (7.7)	32,831 (3.8)	34	Wetlands common in depressions and flats near drainage divides and along low-gradient, poorly incised streams, most of which have been channelized
Outer Coastal Plain, well-drained uplands	108,302 (6.6)	51,396 (3.7)	15	Wetlands generally associated with riparian zones of natural stream channels
Coastal Plain lowlands	187,977 (6.1)	262,190 (3.8)	16	Non-tidal wetlands located in broad swamps and riparian zones
Karst Terrain				
Appalachian Plateau	7,555 (2.6)	4,400 (1.6)	3	
Appalachian Ridge and Valley	5,102 (0.7)	18,844 (1.3)	1	
Piedmont	772 (1.1)	2,859 (1.5)	1	

[1] From Stubbs, written communication, 7/22/2016

[2]From Brooks et al. 2011; Shedlock et al. 1999; (input from Strano MD document)

Advances in understanding how hydrogeologic setting influences wetlands nutrient dynamics

Nitrogen—transport and removal from groundwater and surface water

Our understanding of landscape controls on nitrogen (N) transport and transformations has increased substantially over the past decade. Agricultural fields are a major source of nitrogen in many parts of the watershed (Ator et al., 2011). In the Mid-Atlantic region, approximately 15% of applied fertilizer and manure leaches to the shallow aquifer (Puckett et al., 2011). The most significant shallow aquifer contamination occurs in irrigated, well drained soils (e.g., carbonate-rich, karst terrain or the well-drained Outer Coastal Plain) where as much as 30% of applied nitrogen has been shown to leach into groundwater (Bohlke and Denver, 1995; Puckett et al., 2011). Once delivered to the aquifer, nitrate often remains in that form, with limited biogeochemical transformation, due to high dissolved-oxygen levels and/or lack of carbon substrate which limits microbial denitrifier populations (Parkin and Meisinger, 1989; Yeomans et al., 1992). Nitrate removal via denitrification does not occur until the contaminated groundwater intersects carbon-rich soils, typically in wetlands (Carlyle and Hill, 2001; Duval and Hill, 2007; Green et al., 2008; Hill and Cardaci, 2004; Koretsky et al., 2007). The conversion of dissolved nitrate to inert nitrogen gas via denitrification is the only long-term and continuous mechanism by which excess biologically available N is converted to inert dinitrogen (N2) gas (Boyer et al., 2006). The distribution of wetlands, therefore likely provides an important control on nitrogen transport and stream water quality (Alexander et al., 2007; Curie et al., 2007; Oehler et al., 2009).

The effectiveness of nitrogen removal via wetlands is dependent on the connectivity between wetlands and nitrogen sources (Goldman and Needleman, 2015; USEPA, 2015). The relative importance of stream baseflow contributed from groundwater versus stormflow generated by overland runoff affects the timing and form of N delivery to regional waterways. Where surface runoff dominates contributions to streams, such as in steep rocky terrains of the Appalachian Ridge and Valley Region, most N is in organic or ammonia forms and concentrations are generally low. As groundwater contributions to total stream flow increase, such as in the flat, unconsolidated Coastal Plain, nitrate typically becomes the dominant source of N. Most nitrate is formed in the soil zone and infiltrates to groundwater through the unsaturated zone.

Nitrate from groundwater is the source of, on average, about half of the nitrogen in surface waters (inclusive of nonpoint and point sources) in the Chesapeake Bay watershed. Contributions of nitrate from groundwater at individual gaging stations ranges between 17 to 80% (Bachman et al., 1998). The variability is due to differences in nitrogen application and hydrogeologic setting that affect the physical transport of water and nutrients and the geochemical conditions that are encountered along surface and subsurface flowpaths. In general, Bay-wide areas with carbonate and crystalline rock aquifers have higher median nitrate concentrations in groundwater and streams than in areas with siliciclastic rocks (Ator and Ferrari, 1997). In the Coastal Plain, areas with thick sandy aquifer sediments have higher nitrate concentrations than in areas with thinner sequences of sandy sediments at the land surface (Ator et al., 2000). Areas with higher concentrations of nitrate in streams are directly correlated to higher inputs, even considering the potential for nitrate reduction by riparian and other wetlands.

Surface- and ground-water nitrogen may potentially be intercepted, especially where nitrate enriched waters intersect reduced, organic-rich substrates and enhance removal via denitrification. Important denitrification zones include headwater depression and sloping wetlands, riparian wetlands, and at the upland-wetland interface of floodplains bordering streams and rivers and poorly drained areas including shorelines of lakes, ponds, and the Chesapeake Bay. These settings commonly occur where near-surface ground- and/or surface-water interactions combined with finer-textured sediments slow water flow, resulting in saturated substrates that reduce decomposition rates and provide organic matter conducive to denitrifying conditions. While denitrification primarily occurs in carbon-rich wetland environments, this redox-sensitive process also occurs in older, less oxygenated groundwater of shallow aquifers in buried organic-rich estuarine deposits, near the boundary layers of overlying geologic stratums, or in contaminant plumes from landfills and other contaminant sources which provide carbon substrate to the denitrifying bacteria (Smedley and Edmunds, 2002). Denitrification in the shallow aquifer may account for as much as 10% of TN loss in groundwater, or 1 to 2% of the total N load (Puckett et al., 1999).

For water that is already in streams, overbank flooding of stormwater into floodplains has been shown to trap particulate N, absorb ammonia, and reduce nitrate in water that infiltrates through the organic-rich sediments (Noe, 2013). Several studies of flow-through wetlands (including restored wetlands) show significant reductions in N from wetland inlets to outlets (Woltemade and Woodward, 2008; Seldomridge and Prestegaard, 2014; Kalin et al., 2013; Jordan et al., 2003). Nitrogen uptake was found to increase with longer residence time and warmer water temperature. Noe and Hupp (2005) noted retention of nitrogen in the floodplain where it is connected to streams in the Coastal Plain, but the disconnection of the river to the floodplain by channelization at one site resulted in very limited retention. Coastal Plain floodplains typically trap a large proportion of their annual river load of N, similar to the proportion of river load that is particulate N (Hoos and McMahon, 2009; Noe and Hupp, 2009).

Riparian-zone denitrification in slope wetlands is most effective where aquifer sediments are very thin in alluvial valleys and the discharging groundwater mostly passes through near-stream reducing conditions. This denitrification can occur in near-stream wetland sediments and the hyporheic zone (Pucket, 2004; Puckett et al., 2008; Ator and Denver, 2015). These conditions are common in the Coastal Plain on the Western Shore of the Chesapeake Bay and near the fall-line in the northern part of the Eastern Shore (Krantz and Powars, 2000; Ator et al., 2005). Models developed by Weller et al. (2011) indicated a potential high nitrate removal relative to upland inputs in this area, although groundwater data were not collected to verify upland nitrate concentrations. They can also exist in the Ridge and Valley provinces where water-bearing geologic units emerge at the land surface or where topographic slope changes between the valley walls and alluvial sediments (Winter et al., 1998).

Where the surficial aquifer is thick and groundwater flows along deeper flowpaths, much of the discharging groundwater can bypass reducing conditions in the near-stream riparian zone leading to limited potential for denitrification and elevated concentrations of nitrate in water discharging to a stream (Puckett, 2004; Böhlke and Denver, 1995; Baker, et al., 2001). This setting occurs in areas of the Piedmont with thick weathered bedrock sediments at the land surface and in parts of the Coastal Plain with a thick surficial aquifer, as is common on the Eastern Shore (Bachman et al., 1998; Ator and Denver, 2015). It also occurs in carbonate areas where most water in streams originates in springs that are fed by solution channels in the underlying carbonate rocks (Bachman et al., 1998). The widespread distribution of high nitrate concentrations in streams indicates that settings resulting in groundwater bypassing reducing conditions in near-stream areas are common in parts of the Chesapeake Bay region.

The potential for nitrogen removal by wetlands is highly variable and dependent on numerous factors, many of which are difficult to determine without local studies of particular areas. It is important to consider all types of available information and to include local hydrogeology for nitrate transport. Data sources that only look at the land surface are not adequate to determine subsurface processes, but are critical for understanding inputs and potential hydraulic flow paths from upland source areas to discharge areas in streams and rivers.

Phosphorus—fate, transport, and removal from groundwater and surface water

The highly dynamic and complicated pathways that regulate downstream phosphorus (P) delivery continue to challenge our ability to predict P fluxes in relation to landscape setting and management practices. Because dissolved P concentrations originating from arable upland areas generally are low or below detection in groundwater (Denver et al., 2014; Lindsey et al, 2014), storm-based sediment transport and floodplain deposition have been considered the primary mechanisms controlling delivery of excess phosphorus to downstream aquatic habitat (Kröger et al., 2012). Increasing evidence of P-saturated soils and potential for increasing P bioavailablity, however, have raised concerns about the role of wetlands for P management (Sharpley et al., 2014). While organic-rich, wetland soils can provide critically important ecosystem storage compartments for long-term P storage (Bridgham et al., 2001; Dunne et al., 2007; Reddy et al., 1999), anoxic conditions can also contribute to downstream eutrophication (House, 2003; Smolders et al., 1995). The following provides a brief overview of how different wetland types may influence P-availability throughout the Chesapeake Bay watershed, recognizing that these natural filter processes are strongly influenced by local topography and water chemistry along a stream network.

At the watershed-scale, hillslope processes strongly influence P transport and storage: 50 to 90% of P is tied up in recalcitrant forms, and physical processes including erosion, sediment transport and deposition, and burial are considered the primary mechanisms regulating P availability across the landscape. Approximately 80% of annual river loads of P are attached to sediment (Hupp et al., 2009). Vegetated wetlands provide important deposition zones. As flood waters inundate vegetated floodplains, reduced flow velocity allows sedimentation (Zedler, 2003).

Within or across variation in the frequency, magnitude, duration, and timing of flooding, regulate P storage and export. Prolonged flooding reduces decomposition rates and increases accumulation of organic matter (Gambrell and Patrick, 1978; Mitsch and Gosselink, 2000), thus providing a long-term storage pool (Dunne et al., 2007). Conversely, water table drawdown and soil aeration more typical of floodplain wetlands enhances decomposition, organic matter mineralization, and P release (Venterink et al., 2001). Importantly, P dynamics vary across individual sites; for example, soil P mineralization varies laterally across Chesapeake floodplains associated with gradients or water flux, nutrient inputs, soil texture, and soil pH (Noe et al., 2013).

The interaction of natural waters and organic-rich substrates creates a unique biogeochemical environment that strongly influences soil P dynamics depending on pH and redox conditions (Reddy et al., 1999). In acidic, mineral wetland soils, more typical of flats and intermittently inundated floodplains, P sorption is closely related to hydrogen ion activity, organic matter content, and subsequent effects on amorphous (non-crystalline) aluminum and iron dynamics (Axt and Walbridge, 1999; Richardson, 1985). Under circumneutral pH conditions, redox conditions play a more prominent role than pH-controls in regulating P availability (Carlyle and Hill, 2001; Lamers et al., 2002; Lucassen et al., 2005; Smolders et al., 2010). In particular, the redox-sensitive iron-bound P-pools are highly dynamic and affected by short-term hydrologic condition and subsequent effects on water chemistry (Hous,e 2003; Richardson, 1985; Walbridge and Struthers, 1993). Under aerobic drawdown conditions or with oxygenated water supplies, iron-oxides rapidly precipitate with P sorbing to the mineral surfaces (Patrick and Khalid, 1974). For example, in areas of the Outer Coastal Plain, naturally high phosphorus and iron concentrations occur in groundwater associated with reduced, estuarine deposits; in wetlands where the groundwater emerges at the land surface, exposure to the atmosphere enhances iron mineral precipitation and P co-precipitation, thus reducing P availability (Bricker et al., 2003). More typically, however, reduced wetland soils dissolve iron materials and enhance P availability (Reddy et al., 1999) and even can result in eutrophication, especially where nitrate- or sulfate-contaminated waters further enhance iron-P dissolution (Lucassen et al., 2004; Smolders and Roelofs, 1993; Smolders et al., 2006, 2010). In alkaline, reduced environments, likely to occur where calcium-bicarbonate rich water discharge, co-precipitation with calcium minerals can limit phosphorus availability (Moore and Reddy, 1994). Alkaline conditions (pH greater than 9 with calcium concentrations greater than 100 mg/L) limit P solubility by enhancing calcium-P precipitation (Diaz et al., 1994; Plant and House, 2002).

Although soils have a high capacity to sorb phosphorus, the filtration process can be overloaded, resulting in groundwater P contamination (Lory, 1999). For example, sandy soils commonly formed across the Outer Coastal Plain provide limited mineral sorption sites. In addition, rapid infiltration and groundwater recharge in areas with karst geology, shallow, fractured bedrock, or where soils have a high proportion of macropores (e.g., openings formed by organism burrowing or root growth and decay may short-circuit opportunities for P removal by wetland biogeochemical processes (Harvey and Nuttle, 1995). Although these processes can elevate phosphorus concentrations in stream baseflow, impacts to surface water quality are relatively small when compared to the quantity of sediment sorbed P delivered by surface water (Denver et al., 2010). Importantly, although sediment deposition can continue to provide additional sorption capacity, it is important to recognize that soils have a finite P sorption capacity which ultimately limits wetland retention capacity (Dunne et al., 2006). Further, over longer timeframes, sedimentation and concurrent P deposition will shift downstream with floodplain aggredation.

Sediment—fate, transport, and removal from surface water

Sediment transport and deposition processes related to wetlands play an important role in regulating downstream water clarity and water quality. The relatively flat terrain of all wetland types compared to the surrounding watershed results in significant sediment deposition at the upland-wetland edge. For any given wetland, the importance of this function depends largely on the form of the wetland (e.g., size, slope, soil conditions) and also the size of the local contributing area, as well as land management practices within that area (Burkart et al., 2004; Tomer et al., 2015; Wilkinson et al., 2009). Where runoff is distributed via sheet or rill flow (i.e., not channelized), sloping, riparian wetlands along low order streams provide especially important sites for sediment retention, removing 80 to 90% of the gross erosion occurring on adjacent uplands (Brinson, 1993a; Lowrance et al., 1997; Tomer et al., 2003; Whigham et al., 1988). The edge-of-wetland benefit also has been documented as a critical consideration to headwater (e.g., depressional) wetlands management (Cohen et al., 2016), although retention rates are more variable, perhaps due to typically small (<100 km2) contributing areas and potential for more direct impacts from anthropogenic disturbance (Craft and Casey, 2000). Upland-wetland edges of floodplains also provide important sediment deposition zones (McClain et al., 2003).

In addition to edge-of-wetland function, floodplain wetlands are widely recognized for the ability to capture sediment during flood events, specifically where overbank flow rates are slowed and surface water interacts with floodplain vegetation (Whigham et al., 1988). Floodplains along lower reaches of a river system provide key opportunities to capture nutrient-laden fine clay particles (Craft and Casey, 2000). For example, sediment deposition measurements in Coastal Plain floodplains indicated that these wetlands can capture 100% of associated annual river loads (Noe and Hupp, 2009). In contrast to the edge-of-wetland benefit, however, flood deposition occurs infrequently, only during high-magnitude storm events (Alexander et al., 2015).

Although this report focuses on the benefits of non-tidal wetlands to water quality, specifically by reducing excess nutrient and sediment loads, the panel also recognizes that watershed-derived sediments strongly influence coastal wetland aggradation. Indeed, the supply of external sediments maybe critical to coastal wetland evolution with sea level rise (Bruland, 2008).

Advanced understanding of human impacts, especially due to changes in timing, rate, and chemistry of sources waters

Human alterations influence wetland water quality and habitat functions largely through effects on hydroperiod and water chemistry (Bedford and Preston, 1988). Resulting changes in the distribution of HGM types within a regional watershed or across physiographic provinces of the Chesapeake Bay undoubtedly has altered cumulative wetland functions and benefits significantly (Bedford, 1996; Brooks et al., 2014). For example, most streams and rivers in poorly drained areas of the Delmarva Peninsula have been channelized and, in many areas, drainage ditch construction extended entire stream networks by thousands of miles. As a result, many flats and depressional wetlands were drained to form what are referred to as prior-converted croplands. Ditching lowered the water table, allowing former wetlands to be farmed and developed. However, the ditching also short-circuited the natural groundwater and surface flowpaths, resulting in less contact time with, or even complete bypass of, natural wetlands and marshes where processing of nutrients and trapping of sediments occurs (Bricker et al., 2003). In the Piedmont, the long history of intensive agriculture and timber harvest caused extensive watershed erosion, which resulted in burial of many floodplain wetlands and the formation of incised streams with highly erodible streambanks that provide major sources of sediment to downstream locations (Donovan et al., 2015). The steep relief and limited extent of navigable waterways historically limited human impacts to wetlands in the Appalachian Ridge and Valley Region and also the Appalachian Plateau. Wetland loss occurred mainly along river main stems, where development often occurs within river floodplains. Across the Bay watershed, expanding impervious surface area, channelization, and general watershed hardening has increased surface water runoff and reduced groundwater recharge, resulting in more significant flooding, altered hydroperiods and shifts in sediment loads throughout entire river corridors (Brooks and Wardrop, 2014; Hupp et al., 2013; Strayer et al., 2003). Compared to physical alterations imposed by human land use, less attention has been focused upon effects of shifting water chemistry. For example, increased nitrate loads ultimately can enhance P availability, especially where pyrite-rich geologic deposits can influence near-surface iron-sulfate-phosphorus chemistry (Smolders et al., 2010). While past human impacts to wetlands provide key opportunities for targeted wetland restoration, related human impacts or needs may also pose limitations in some cases, such as the need to keep certain agricultural lands in production.

Remote sensing capabilities and advances in spatial modeling provide enhanced understanding of near-surface processes in relation to physiographic setting

Remote sensing capabilities and advances in spatial modeling in recent years have provided a better understanding of near-surface processes with respect to the potential for nutrient processing by wetlands. High resolution elevation data made available through LiDAR has been especially important to understanding surface flow and potential areas of interception and infiltration of water containing nutrients in extremely flat areas commonly associated with wetlands. This type of data will be especially useful for understanding phosphorus as most phosphorus transport takes place over the land surface. For nitrogen, there is still a need to include subsurface transport pathways as that is the main pathway for nitrogen transport. Combining LiDAR –derived elevation data with data on aquifer configuration can be used to understand potential subsurface flow pathways.

There has been limited research on the efficiency of wetlands to treat nonpoint source nutrients, such as from agriculture, within the Chesapeake Bay watershed (Goldman and Needleman, 2015). The ratio of wetland to watershed area has been used as a surrogate for hydrologic retention time (Simpson and Weammert, 2009), but this approach does not consider site-specific conditions that affect N removal and only weakly fits the data used to develop the model (Goldman and Needleman, 2015). New regional models that include a broader suite of factors that may influence nutrient transport and transformation are needed. Monitoring targeted to supply needed data for model development will be important to the success of improved models.

Regional differences in surface and subsurface processes affecting nitrogen transport in the environment, including wetland interception, have been generally defined in the Chesapeake Bay watershed in the context of explanation of processes in different hydrogeomorphic or hydrogeologic settings. The Chesapeake Bay watershed was divided into simplified hydrogeomorphic regions by Bachman, et al. (1998). These regions work well for understanding general processes in the hard-rock regions above the Fall-Line. In the Coastal Plain, however, further work has refined understanding, especially with respect to subsurface processing of nitrogen (Ator et al, 2005; Krantz and Powars, 2000). Digital datasets are available to incorporate these interpretations on a regional basis for use with other pertinent data sets such as digital elevation models, soil characteristics, and land use and wetland maps.

Summary

The panel recognizes that the role of wetlands in regulating regional water quality trends depends on hydrologic connectivity between source or contamination areas and downstream regional waterways. Accordingly, the panel recommends evaluating wetland function based on the likelihood of groundwater and/or surface water influence, given watershed position and physiographic setting. Depressional and sloping wetlands and wetland flats in headwater areas likely have the strongest capacity to intercept shallow, contaminated groundwater. Floodplains also provide additional capacity by enhancing sedimentation during storm events. The physiographic setting strongly influences the distribution of wetlands within a region and also the extent to which humans have altered the hydrogeologic setting.

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Chapter 5. Recommendations for Wetlands as land-use and BMPs in Phase 6 Watershed Model

Overview

The Wetlands Expert Panel convened to provide recommendations on how wetlands should be represented and evaluated in the CBP Phase 6 Watershed Model. Based on their cumulative understanding and best professional judgment of the wetland literature and wetland restoration, including past reports and recommendations presented to the CBP, the following overarching conclusions and recommendations are detailed herein:

- Wetlands provide significant and unique water quality benefits to regional water supplies compared to other land use/land cover classes, specifically by reducing excess nutrients and sediment, and therefore should be considered explicitly in the Phase 6 watershed model.
- Similar to unmanaged forests, undisturbed, natural wetlands are unlikely to generate excess nutrient and sediment loads. Few studies, however, report wetlands as sole contributions because these unique landscape features tend to occur as transition zones between upland and aquatic habitats. As such, the panel recommends that the Phase 6 model set wetland loading rates equal to forest loading rates.
- There is strong evidence demonstrating that wetlands naturally filter ground- and surface waters but that effectiveness varies widely based on hydrologic connectivity to up-gradient 'contaminant' sources and to down-gradient regional waterways, and on wetland condition. Quantifying wetland water quality benefits accordingly, however, remains challenging based on available information. To address this need, the panel proposed a simple model to predict the potential for different types of natural, undisturbed or restored wetlands to intercept, transform, and reduce excess nutrient and sediment loads, given physiographic setting and watershed position.

Key findings and considerations in the panel's recommendations include the following:

- The hydrogeologic setting, including geology, topography, land use, and climate conditions, together with position in the watershed influence the hydroperiod (i.e., timing, duration, magnitude, and frequency of flooding as well as the rate of water table change) and the relative importance of ground- and surface-water sources. Resulting hydrologic fluxes control the potential for wetlands to intercept and treat contaminated waters.
- Connectivity to contaminant sources strongly influences water quality benefits. If up-gradient sources are lacking or contaminated waters by-pass a wetland (e.g., through concentrated flow channels or deep groundwater), limited retention will occur.
- In addition to hydrologic fluxes, natural and anthropogenic influences on water quality affect nutrient fluxes and wetland retention capacities. In particular, effects on pH, redox, as well as carbon availability strongly influence N and P transformations in wetlands;

human land and water management often artificially influences these environmental controls significantly.

Wetland land uses in the Phase 6 CBWM

The expert panel and wetland workgroup arrived at a set of recommended land uses and relative loading rates for existing wetlands in the Phase 6 CBWM as shown in Table 7. The WQGIT accepted the recommended land uses on September 14, 2015. The accepted land uses will represent natural nontidal wetlands within the Phase 6 CBWM, and do not represent recommended efficiencies or reductions associated with any wetland best management practices (BMPs) such as restoration, creation or enhancement; these BMP reductions are described in the next section of this chapter.

Table 7. Land use classes and relative loading rates for nontidal wetlands in the Phase 6 Watershed Model.

Wetland land uses for Phase 6 Watershed Model	Relative Loading Rate (TN)	Relative Loading Rate (TP)	Relative Loading Rate (Sediment)
Floodplain Wetland	100% Forest	100% Forest	100% Forest
Other Wetland (non-floodplain)	100% Forest	100% Forest	100% Forest

The two recommended land uses and their relative loading rates were supported by the Wetlands Workgroup following their August 28th conference call, with one dissention from Pennsylvania. As noted at that time, Pennsylvania supports establishing wetlands as a land use, which would provide a means to apply the new wetlands enhancement BMP, but they dissented given concerns about the inaccuracy of current NWI data for their state and the inconsistency of the NWI data across the jurisdictions. The panel and workgroup understood that there is opportunity to adjust the data inputs during the 2016 review period, and hopefully that will allow for improvements to the mapped wetland land uses in Pennsylvania or other jurisdictions, but they also understand that changes past the October 2016 calibration cannot be guaranteed by the Modeling Workgroup. The Wetland Expert Panel and Wetland Workgroup strongly recommend that if updated and/or improved wetland mapping data is available before the final calibration date, the Modeling Workgroup and CBPO Modeling Team will make it a priority to update these data in the modeling tools. At the time this report was developed for release in Fall 2016, Pennsylvania is still in the process of developing an improved dataset for wetlands to be used in the final Phase 6 CBWM calibration. With the addition of wetlands as an explicit set of land uses, updating wetland data layers will also be a higher priority for partnership resources.

Mapping the recommended land uses

Despite its limitations, the National Wetlands Inventory (NWI) provides an appropriately scaled and comprehensive map of wetland resources throughout the entire Chesapeake Bay Watershed. The database, which includes information on wetland type and setting, can be integrated with other information sources to describe wetland function and then combined with the proposed land uses for the Phase 6 CBWM almost seamlessly. Targeted NWI wetland classes will include non-tidal palustrine, lacustrine, and riverine wetland systems, which will be queried according to the NWI attributes in accordance with the Cowardin et al. (1979) wetland classification system. To summarize wetland water quality functions, wetland class acres will be subdivided into two proposed land use classes: floodplain and other (non-floodplain). Floodplain wetlands will include riverine wetlands and also NWI mapped wetlands that intersect the FEMA Flood Hazard Layer and SSURGO hydric soils layer along NHD mapped waterways. Remaining palustrine wetlands, including flats, depressional wetlands, and sloping wetlands, will be combined into the "other" class. Although the WEP recognized that these wetlands represent very unique systems, the panel agreed that in the absence of additional information, variation in wetland water quality benefits could be captured based on variation of local contributing area (i.e., treatment acres). In limited areas, NWIPlus provides additional information potentially useful to providing a more comprehensive assessment of wetland function, including vegetation type, hydrology, and hydrogeomorphic setting. When completed for the entire Bay watershed, the expanded database structure potentially could provide a more satisfying model to predict water quality benefits.

Justification for wetlands land uses

The recommendation to add wetlands as their own land use classification has been suggested by others in the past (e.g., STAC, 2012), due to the understanding that they perform natural functions that benefit water quality. Recently, however, it has been suggested that wetlands could potentially be captured in the Phase 6 Watershed Model without an explicit set of land uses. If this occurred and wetlands are not included as Phase 6 land uses, they will continue to be lumped with Forest or other land uses similarly to how they are in the Phase 5.3.2 and earlier versions of the Watershed Model. This would limit the recommendations by an expert panel to evaluate how to apply wetlands BMPs, such as wetland enhancement, based on landscape position (a larger driver of BMP efficiency). While wetland BMPs could still potentially be reported on non-wetland land uses, such an approach would ignore an explicit accounting of the water quality functions performed by approximately 900,000 acres[5] of nontidal wetlands in the Chesapeake Bay watershed. CBP partnership efforts to incorporate the habitat benefits of wetlands into planning tools or management actions would also benefit from explicit land uses in the modeling tools. Currently the partnership relies on BMP implementation data for its wetland indicators and these efforts could be enhanced for nontidal wetlands with these new land uses. The panel and workgroup agreed that establishing wetlands as a set of Phase 6 land use classes will provide a better basis for the reporting and crediting of wetlands BMPs and also improve the modeling tools by explicitly simulating the presence and function of natural nontidal wetlands. While the loading rate is unchanged, establishing a unique land use for wetland allows for future refinement and potential for crediting sediment and nutrient reductions from natural wetlands.

The accepted wetland land uses satisfy all of the Land Use Workgroup's criteria for establishing new Phase 6 land uses:

[5] This is an estimate based on acreage of inland wetlands, excluding freshwater ponds, in Tiner (1987). The actual acres in the beta and final Phase 6 CBWM will differ from this figure and are subject to change until the final calibration.

(1) They can be mapped, albeit imperfectly as conveyed by Pennsylvania. Establishing the land use, however, could incentivize partners and stakeholders to improve available wetland data. Without wetland land uses there is less incentive to improve wetland data in the context of CBP partnership modeling inputs.

(2) They have a unique contribution to the landscape. Wetlands play an important role between the "edge of field" and the "edge of stream" pollutant loads that has not been explicitly captured in previous versions of the modeling tools. While the land-to-water factors in the Phase 6 Watershed Model are understood to implicitly capture the effect of existing wetlands in the landscape through the model calibration, the partnership may wish to apply a distinct factor in the model to account for the retention and treatment effects of existing wetlands. Their inclusion as land uses will be a basis for potentially simulating their contribution in the future. Though the Panel was unable to make a recommendation for a distinct loading rate or retention factor for existing wetlands at this time due to a dearth of science on wetland load contributions, it is recommended that future research using SPARROW or other tools be used to inform the partnership in the future.

(3) They will have unique BMPs applied to them. Though this panel is unable to make recommendations for wetland enhancement and wetland rehabilitation at this time beyond a temporary value, pending investigation by a future panel, these functional gain BMPs are anticipated to only be eligible for reporting on wetland land use acres. The recommended wetland restoration and wetland creation BMPs will also be simulated as a land use change BMP where the previous land use is converted to the wetland land use, with additional treatment of upland acres by the restored/created wetland. Without wetland land uses the crediting and application of these BMPs would become much more complicated for the expert panel, jurisdictions, and the public.

The panel and workgroup support classifying the wetland acres according to their landscape position (i.e. Floodplain and Other) over alternatives (e.g., by type of vegetative cover) because it is more reflective of expected water quality function in terms of nutrient transformation and sediment retention. As detailed in Chapter 4, the proposed framework presented herein attempts to describe how landscape position and hydrogeologic setting influence water quality benefits provided by an existing or a restored wetland.

Justification for wetland nutrient and sediment loading rates the same as forest

It is difficult to assign unique nutrient and sediment loading rates to wetlands because few studies evaluate loading rates separately from surrounding land uses. Indeed, wetlands provide important transition zones between upland and aquatic habitats. The panel agreed, therefore, that assigning loading rates similarly to those of other land uses would not reflect the multitude of studies that support the conceptual model that a wetland's water quality functions depend on the hydrogeologic setting and the nutrient/sediment load delivered to that wetland. Some limited loading rate data are summarized in this section, but due to the inherent nature of wetlands, the panel did not find it appropriate to establish a unique base loading rate. Instead, efforts were focused on how best to estimate the additional water quality benefits that wetland's provide compared to forests.

To date, it has been challenging to develop a comprehensive description of how wetland water quality functions vary in relation to landscape setting and climate condition. Individual field studies are not coordinated to facilitate integrated meta-analyses that would improve understanding of how function varies across space and time. Published reports often do not provide enough information describing location, and research methods vary widely. To address this challenge and advance future assessments as reported herein, future research could be coordinated to tie more explicitly to modeling tools that are developed to predict wetland water quality benefits (e.g., SPARROW, described below).

A literature review conducted for the panel by Tetra Tech found only two studies that attempted to define loading rates for wetland areas, neither of which were located in the Chesapeake Bay region. Baker et al. (2014) evaluated Barnegat Bay-Little Egg Harbor HUC14 watersheds and determined the export concentration for forest and wetlands combined was 1.17 mg/L for TN and 0.021 mg/L for TP. Similarly, Dodd et al. (1992) created nutrient budgets for the Albemarle-Pamlico Sound area; forest and wetlands were again considered as having the same loading rate, which Dodd et al. determined to be 2.08 lbs/ac/yr for TN and 0.12 lbs/ac/yr for TP. Neither study separated the loading from forest and wetland areas into distinct categories. No other studies were identified that provided a loading rate for wetlands as a uniform land use. However, the panel has concern that the literature review may have omitted pertinent research, e.g., some forest loading rates available in the literature may have been wetlands but were not identified as wetlands in the abstract or other fields.

One study by Harrison et al. (2011) calculated the surface water and groundwater concentrations of TN and TP within wetlands, however, the export rates were not calculated. The wetlands, located near Baltimore, MD, were two restored relic oxbow wetlands in an urban area and two reference forested floodplain wetlands. Across the restored oxbow wetlands, the groundwater concentrations for TN and TP, respectively, were 0.72 mg/l and 11.5 µg/L. The average at the forested floodplain wetlands were 0.37 mg/L and 114.7 µg/L for TN and TP, respectively. Surface water nutrient concentrations measured within the oxbow wetlands averaged 0.6 mg/L for TN and 24 µg/L for TP. A study of natural depressional wetlands in the Choptank watershed found that nitrogen concentrations in groundwater were generally less than 0.1 mg/L N beneath the depressional wetlands as well as their surrounding wooded upland areas (Denver et al., 2014). Natural groundwater on the Delmarva Peninsula is generally found to be 0.4 mg/L as N, which is primarily defined by investigation of forested areas that also contain wetlands (Hamilton et al., 1993).

The panel and workgroup agreed it is most reasonable to keep wetland loading rates equivalent to the Phase 6 Forest land use, which is the most comparable land use with assigned loading rates similar to the few loading rates reported for wetlands. The Phase 6 loading rate for forest land use was set using SPARROW models inclusive of all forested land use area in the Bay watershed. In contrast to forests, however, the panel recognized that wetlands provide important transitional zones and act as nutrients sinks and/or transformers; therefore the panel concluded it is inappropriate to further refine wetland specific loading rates. Instead, the panel focused their efforts on characterizing how wetland nutrient and sediment retention efficiencies vary based on where a wetland occurs in the landscape.

Justification for natural and restored nutrient and sediment retention efficiencies based on hydrogeologic and landscape setting

Given the importance of landscape position to wetland water quality function, the panel explored the potential to develop spatially-explicit retention efficiencies for existing wetlands. The literature review reaffirmed previous meta-analyses that reported wide variation in wetland nutrient and sediment retention efficiencies, but the meta-analysis did not provide enough information to describe variation in efficiencies related to landscape position. The panel therefore developed a conceptual model, based on these studies and current understanding of wetland hydrology, to summarize where different types of wetlands occur throughout the Chesapeake Bay watershed and to evaluate the likelihood of providing targeted water quality benefits accordingly. The resulting framework is intended to provide a basis for integrating future wetland studies and advancing our capacity to characterize wetland water quality benefits.

Wetland BMPs

Review of existing Phase 5.3.2 wetland restoration BMP

The CBP Scientific and Technical Advisory Committee (STAC) and the Mid-Atlantic Water Program have previously attempted to evaluate the effectiveness of wetlands as a BMP. During the April 2007 STAC workshop on quantifying the role of wetlands in achieving nutrient and sediment reductions, a first order kinetic equation was proposed to describe the exponential decline of nutrient and sediment over time related to detention time of runoff in a wetland. The kinetic equation was originally developed by Dr. Tom Jordan from the Smithsonian Environmental Research Center (SERC) and provided in both STAC (2008) and Simpson & Weammert (2009). The Mid-Atlantic Water Program (Simpson and Weammert, 2009) was tasked with defining BMPs and determining effectiveness estimates that are representative of the overall Bay watershed.

Data have shown that longer water residence and retention times improve the nutrient removal efficiency of wetlands (Simpson and Weammert, 2009). The kinetic equation assumes that wetland retention time is proportional to the ratio of the area of wetland to the area of the watershed, see Figure 9. A first order kinetic equation was used to relate the rate of removal to the concentration, thus providing a practical way to express efficiency as a percentage of the inflow pollutant removed by the wetland.

The first order kinetic equation was developed to represent the cumulative removal efficiency of all restored wetlands in a land segment, based on the following assumptions:

- removal is an exponential function of retention time;

- retention time is proportional to the proportion of the watershed that is wetland; and
- there is zero removal when there is no wetland in the watershed.

Nonlinear regression was used to parameterize the model based on the removal data in the literature. This yielded the equation:

Removal = $1 - e^{-k(\text{area})}$

Where:

- Removal: proportion of contaminant removed by the wetland
- Area: proportion of the watershed area that is wetlands
- k: fitted parameter, based on reported retention efficiencies
    - TN, k=7.90, 95% confidence limits [4.56, 11.2]
    - TP, k=16.4, 95% confidence limits [8.74, 24.0].

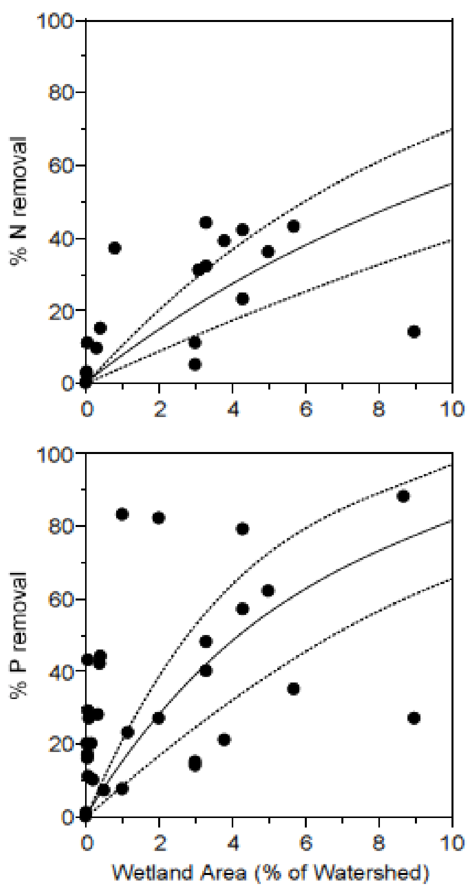

Figure 9. Literature review data points for wetland nutrient removal efficiency based on the wetland area as a proportion of the watershed. Curves indicate non-linear regression fit to data values, with 95% confidence limits. (STAC 2008).

The kinetic equation was developed for wetlands as a BMP (wetlands restoration) in Phase 5.3.2 model scenarios. To use the equation, the ratio of wetland area to watershed area must be defined for each BMP reported by a jurisdiction for a particular land-river segment. If this information was not reported, alternative calculations specific to physiographic regions were developed (Simpson and Weammert, 2009). The alternative calculations assumed wetlands to be 1, 2, and 4% of the watersheds in the Appalachian, Piedmont and Valley, and Coastal Plain geomorphic provinces, respectively. The resulting TN and TP removal efficiencies are described in Table 8.

Table 8. TN and TP removal efficiencies for wetlands by geomorphic province (Simpson and Weammert, 2009).

Geomorphic Province	TN Removal Efficiency	TP Removal Efficiency	TSS Removal Efficiency
Appalachian	7%	12%	4%
Piedmont and Valley	14%	26%	8%
Coastal Plain	25%	50%	15%
Default, if HGM unknown	16.75%	32.18%	9.82%

One of the shortcomings of the kinetic equation is that it cannot account for wetlands that are sources of nutrients. Negative removal values (nutrient export) cannot be derived from this equation. During the literature review for development of the equation, any wetlands where only negative removal values were observed were removed from the calculations. When negative removal occurred in particular years, but not on the average, Simpson and Weammert used the average removal percentage in fitting their simple model. In cases where only negative removal was observed the observation was omitted, i.e. for one negative TP removal for one wetland studied by Kovacic et al (2000) and negative TN removal by one of the wetlands studied by Koskiaho et al (2003).

Due to the lack of data, the relationship between total suspended sediment and wetland area was not determined. A uniform 15% removal was approved, based on the average annual removal rates that were available in the literature, plus a margin of safety. This 15% removal was then applied to the region with the highest removal rates (Coastal Plain) and adjusted proportionally to the TP removal for the other two HGM regions.

The kinetic equation is unable to account for variations in wetland age, seasonal variation, spatial and temporal variability of flow, landscape position, or type of wetland. These factors will affect the residence time and loadings to a wetland. For example, Craft and Schubauer-Berigan found that floodplain wetlands removed 3 times the nutrients of depressional wetlands on an areal basis (in Simpson and Weammert, 2009). Nicholas and Higgins found that phosphorus removal declined significantly after about 4 years (in Simpson and Weammert, 2009). Declining phosphorus removal rates over time also are not accounted for in the kinetic equation.

The BMP Assessment recommended future refinements to account for seasonal variability, nutrient discharge, hydraulic loading rate, wetland aging, and potential for dissolved P discharge during anaerobic conditions from wetlands with high phosphorus content (Simpson and Weammert, 2009).

Recommended effectiveness estimates for wetland restoration (re-establishment) in Phase 6

Nontidal wetland re-establishment for Phase 6 Watershed Model

Based on currently available information, the wetlands expert panel recommends assigning wetland retention capacity based on a combination of factors reflecting 1) the efficiency of wetlands to sequester nutrients and sediment given wetland type (floodplain or other); and 2) the likelihood that contaminated waters will intersect wetlands as biogeochemically active transition zones based on physiographic setting and watershed position. The approach is intended to parallel previous modeling studies, including Jordan et al (as part of Simpson and Weammert 2009), that demonstrate the utility of a simple exponential decay model to tracking contaminant transport:

$$\frac{C}{C_0} = \exp^{-rt}$$

where C is the remaining concentration, C_0 is the initial concentration, *r* is the removal/reaction rate, and *t* is the travel time (e.g., Heinen, 2006). Importantly, previous applications explicitly recognize that both *r* and *t* vary across time and space. Given available information and the scope of the Bay-wide watershed modeling effort, the conceptual underpinning of the decay model was adapted as described below, and acknowledging the following:

- Decomposition or sequestration rates reflect effects of key environmental conditions that drive retention processes and underlie measured retention efficiencies (e.g., soil C and water availability, water chemistry, and temperature).
- The amount of excess nutrient and sediment (i.e., original contaminant concentration) depends on the expanse and intensity of source acres (e.g., croplands or developed lands) in the watershed or local contributing areas and the likelihood that contaminated or enriched waters intersect wetlands of a specific type.
- Time is considered as a unit factor (e.g., one year)

Wetland nutrient and sediment retention efficiencies are proportional to reaction rates

The importance of landscape setting to regulating natural filter functions, and also the importance of wetlands as a BMP to meet Bay watershed goals first led the panel to strongly recommend mapping wetland land cover explicitly in the Watershed model. The panel subsequently endeavored to develop nutrient and sediment retention efficiencies specific to physiographic province and watershed position. The results of a literature review are summarized in Table 9.

Table 9. Summary of wetland TN, TP and Sediment reductions from literature review. The mean retention efficiencies reported for all natural sites (i.e., not constructed sites) are the recommended retention efficiencies for the Phase 6 Watershed Model, to replace the current Phase 5.3.2 values

Wetland Type	Vegetation Type	TN % Reduction Mean Range Median (# of studies)	TP % Reduction	TSS % Reduction
Headwater/ Depressional	ALL	33% -8-97 34% (9)	25% -15-94 10% (13)	28% -30-75% 37% (6)
Floodplain	ALL	44% -8-94 38% (24)	37% -41-100 29% (24)	32% -15-95 14% (7)
All except constructed	Forest, mixed and unknown	47% -8-97 59% (16)	45% -47-100 43% (44)	37% -15-95 32% (8)
All except constructed	Emergent	39% -8-89 36% (20)	31% -15-100 30% (20)	25% -30-75 27% (7)
All	All	40% -8.4-97 36% (48)	40% -54-100 38% (95)	44% -30-98 50% (19)
Chesapeake Bay Only	All	22% -8-89 10% (10)	20% -41-81 17% (10)	24% -15-68 21% (8)
All except constructed	**ALL**	**42% -8-97 39% (36)**	**40% -47-100 41% (64)**	**31% -30-95 27% (15)**

The range of retention efficiencies reported in the literature highlighted the importance of wetlands as natural filters but also revealed the large variability in water quality functions at different locations (Table 9; see also Appendix A). Although the panel recognized the importance of landscape setting, hydrology, soils, and vegetation, published studies often lacked information needed for inter-comparisons, including adequate descriptions of study site settings or field methods. Ultimately, limited information from the updated literature review precluded the panel from assigning wetland retention efficiencies based on wetland type, physiographic setting, or watershed position. Given these limitations, the panel concluded that, currently, the mean reductions for all reported natural wetland studies (i.e. not including constructed wetlands) provide the most reliable estimates of retention efficiency.

The panel determined that the mean value for all wetlands, exclusive of constructed wetlands (see Box 2), offered the most reasonable estimate for nitrogen, phosphorus and sediment reduction efficiencies associated with treatment of upslope acres for re-established wetlands. These are the recommended effectiveness values for wetland re-establishment in the Phase 6 Watershed Model, to replace the current Phase 5.3.2 values described in the previous section. Additional factors described below attempt to capture effects of physiographic setting as described by Simpson and Weammert (2009) and in Chapter 4 of this report, for Phase 5 and Phase 6 of the CBWM, respectively.

Initial excess contaminant loads are a function of hydrologic connectivity and land management

For this report, several conceptual frameworks developed to predict how wetland function varies in relation to landscape position were combined to predict wetland water quality benefits based on hydrologic connectivity and wetland condition. These frameworks included Winter's (1999) treatise on surface- and ground-water as a single resource, Brinson's (1993) river corridor hypothesis, and Brook's et al. (2014) hydrogeomorphic classification of Mid-Atlantic wetlands. Accordingly, the distribution of major wetland types, including depressional and sloping wetlands, wetland flats, and floodplain wetlands were considered in relation to watershed position and physiographic province.

To more fully capture the variability in wetland forms and functions across the Chesapeake Bay Watershed, the number of physiographic provinces was expanded from those used in the Phase 5.3.2 CBWM. The Coastal Plain was divided into three different sub-regions reflecting differences in surface soil permeability and depth to the confining layer of the shallow, unconfined aquifer. In addition, areas dominated by carbonate (karst) bedrock were identified and combined into one class due to their commonly unique hydrologic functions in contrast to the parent physiographic province. Across all provinces, the distribution of different wetland types, according to the HGM classification for the Mid-Atlantic (Brooks et al., 2014), were

Box 2 – Constructed Wetlands

Wetlands constructed specifically, and singularly, for water quality treatment purposes of a defined source. These constructed wetlands are generally of simple hydrology, limited inflow and outflow, and typically vegetated with herbaceous plants only, specifically monocultures of species known for high rates of pollutant uptake, such as cattails (*Typha* spp.) and common reed (*Phragmites*). Thus, constructed wetland studies provide limited information to evaluate or characterize natural wetland water quality functions. Constructed wetlands offer limited habitat value that may be additionally comprised by heavy metals and other toxicants in the effluent waters, are not generally considered wetlands for regulatory purposes; for example, these systems are not considered as restored or created acres in wetland status and trends assessments. The panel determined that the load reduction values from these wetlands should not be incorporated into the recommended efficiencies for wetland restoration in the Phase 6 model.

summarized with respect to watershed position (i.e., headwaters to valley bottom or base level) and water source (see Table 10). Results provided a basis to evaluate how likely natural waters contaminated by nonpoint source pollution are hydrologically connected to wetlands that can provide natural filter functions.

Table 10. Wetland forms and distributions across the Chesapeake Bay Watershed, by physiographic province and geomorphic setting. For the Phase 6 Watershed Model, flats, depressional wetlands and sloping wetlands were combined into a single 'other' class because of the limited information available to differentially map these unique wetland types. In this 'other' class, shallow groundwater dynamics primarily drive biogeochemical processes, whereas surface water acts as an important driver in floodplain wetlands.

Physiographic Province	Other Wetlands			Floodplain Wetlands
	Flats	Depressional Wetlands	Sloping Wetlands	
Appalachian Plateau		Moraine depressions	Aquifer outcrops Small tributary Riparia	Valley floors, above bedrock outcrops
Appalachian Ridge & Valley		Aquifer outcrops Fractured rock springs	Small tributary Riparia Slope breaks	Medium to large waterways
Blue Ridge		Ridgetops	Fractured bedrock outcrops Riparia	Tributary confluences Medium to large waterways
Piedmont			Fractured bedrock outcrops Riparia	Eroded stream/river terraces
Inner Coastal Plain			Small streams, floodplain edges	Small to large waterways
Outer Coastal Plain - Poorly drained uplands	Watershed divides	Watershed divides	Small (natural and artificial)tributary Riparia	Small to large waterways
Outer Coastal Plain - Well drained uplands			Small tributary Riparia	Small to large waterways
Coastal Plain Lowlands	Watershed divides		Small (natural and artificial) tributary Riparia	Bottom lands
Karst terrain Appalachian Plateau Appalachian Ridge & Valley Piedmont		Tubular springs	Outcrops, slope breaks, springs	

The summary of wetland types in each of the Bay watershed's physiographic provinces provided a basis to evaluate wetland water quality benefits. For each wetland type, the panel used regional water resources information to evaluate the potential for contaminated source waters to intersect organic-rich, anoxic wetland soils (see Chapter 4). Predominant wetland source waters and their potential for contamination were primary considerations. Results are presented in Table 11. Wetlands supplied by shallow surficial groundwater highly susceptible to contamination from agriculture or development, were ranked high (H). For example, Inner Coastal Plain, sloping, riparian wetlands draining watersheds with extensive agriculture and development were ranked high (H). In contrast, wetlands supplied by groundwater discharge from forested recharge areas (e.g., depressional wetlands across the Appalachian Plateau) or naturally protected, confined aquifers (e.g., sloping, spring-fed wetlands in the Appalachian Ridge and Valley province) were ranked low (L). Wetlands where contaminated waters are likely to by-pass the natural biogeochemical reactors also were ranked low (e.g., sloping, riparian wetlands in the Outer Coastal Plain well-drained uplands). Wetlands with mixed potentials were evaluated as medium potential (M). For example, the Piedmont has a long history of intensive agriculture, and although shallow, surficial groundwater primarily sustains streamflow, deeply incised streams through legacy sediment deposits often limit interactions between contaminated waters and wetland soils.

Table 11. Likelihood of Hydrologic Contact with Non-Point Source Contaminated Waters

Physiographic Province	Other Wetlands			Floodplain Wetlands
	Flats	Depressional Wetlands	Sloping Wetlands	
Appalachian Plateau		L – variability in hydrologic settings & predominant forest cover	L – confined aquifer discharge not likely contaminated	L - predominant forest cover and greater likelihood of hyporheic exchange rather than wetland discharge
Appalachian Ridge & Valley		L – small contributing area; predominant forest cover	L – confined aquifer discharge not likely contaminated; predominant forest cover	L - predominant forest cover and greater likelihood of hyporheic exchange rather than wetland discharge
Blue Ridge		L – small contributing area; predominant forest cover	H - Surficial aquifer and heavy human impacts	M – Incised, more infrequent events; potential deep aquifer by-pass
Piedmont			M - Surficial aquifer and heavy human impacts	M – Incised, more infrequent events; potential deep aquifer by-pass
Inner Coastal Plain			H - Surficial aquifer and heavy human impacts	H – well connected, more frequently flooded

Physiographic Province	Other Wetlands			Floodplain Wetlands
	Flats	Depressional Wetlands	Sloping Wetlands	
Outer Coastal Plain - Poorly drained uplands	L – small contributing area; flat hydraulic gradient predominant forest cover	L – small contributing area; flat hydraulic gradient predominant forest cover	M – Small contributing area, but surficial aquifer important and heavily influenced by human impacts	M – well connected, frequently flooded but potentially limited exchange due to flat hydraulic gradients
Outer Coastal Plain - - Well drained uplands			L – Deep aquifers with strong potential to bypass contaminated waters	H – well connected, more frequently flooded
Coastal Plain Lowlands	L – small contributing area; flat hydraulic gradient predominant forest cover		H – well connected, more frequently flooded	M – well connected, frequently flooded but potentially limited exchange due to flat hydraulic gradients
Karst terrain* Appalachian Plateau Appalachian Ridge & Valley Blue Ridge & Valley		H – Strong potential for contaminated discharge.	M – Strong potential for contaminated discharge, but potential for rapid flow-through & short contact time	L/M – see floodplain descriptions above, respectively

H – high potential; M – moderate or variable; and L – low potential for hydrologic connectivity with up-gradient sources of excess nutrients and sediments.

To account for wetland services within the CBWM, the qualitative assessment was translated to a quantitative matrix that can be used to estimate annual retention rates (Table 12). Variation in the potential for delivery of contaminated waters were modeled by adjusting the representative number of upland acres treated by a given wetland type, thus roughly representing variation in initial source loads. Acreages were assigned based on reported local contributing areas for wetland restorations in Maryland (Erin McLaughlin, pers. communication) and on the relative expected water quality benefits compared to other wetland types in different locations. The average local contributing area per acre of restored wetland (2:1 upland-to-wetland ratio) was used as a midpoint for wetlands considered to have moderate potential to reduce excess nutrient and sediment loads. For wetlands with low potential to intercept contaminated or enriched waters, a 1:1 upland-to-wetland acre ratio was assigned. Wetlands with the strongest potential to mitigate water quality impacts from expansive areas of agriculture and development, such as sloping riparian wetlands in the Inner Coastal Plain, were assigned a 4:1 upland-to-wetland acre ratio. Because floodplains provide capacity to reduce nutrients and sediment overbank flooding as well as by treating diffuse groundwater and surface water discharge treated acre ratios were assigned 1.5 times that of ‘other’ wetlands for the same physiographic region. While there is evidence that suggests connected floodplains provide much greater benefits (Noe and Hupp

2009), the Panel assigned this conservatively smaller ratio to reflect that floodplain benefits occur during storm events of varying intensity. In all cases the ratios fall within a reasonable range of 1-to-1 at the low end and 6-to-1 at the high end. All proposed retention efficiencies upland-to-wetland acre ratios were rounded to the nearest whole number. It is expected that the information describing treated acres or delivered loads will improve as our understanding of wetland function and landscape modeling advances.

Table 12. Summary of proposed retention efficiencies and upland acres treated by each acre of wetland by wetland type and physiographic subregion.

	Retention Efficiency			Upland Acres Treated	
Physiographic Subregion	**TN**	**TP**	**TSS**	**Other Wetlands**	**Floodplain Wetlands**
Appalachian Plateau	42	40	31	1	2
Appalachian Ridge and Valley	42	40	31	1	2
Blue Ridge	42	40	31	2	3
Piedmont	42	40	31	2	3
Inner Coastal Plain	42	40	31	4	6
Outer Coastal Plain- Poorly Drained	42	40	31	1	2
Outer Coastal Plain- Well Drained	42	40	31	2	3
Coastal Plain Lowland	42	40	31	2	3
Karst Terrain	42	40	31	2	3

Summary of Findings, Recommendations, Key Uncertainties, and Future Research Needs

The expert panel recognizes that wetland nutrient and sediment retention capacity depends on the hydrologic flux (be it ground- or surface-waters or both) through a wetland system (USEPA, 2015). The relative importance of ground- and surface-waters has major implications to retention potential. For example, wetlands sustained by nitrate-enriched groundwater have greater TN removal capacity than unexposed wetlands or wetlands where enriched groundwater can bypass the organic-rich wetland soils needed for denitrification (e.g., Vidon & Hill, 2006; Devito et al., 1999). Surface water dominated systems have greater potential to trap sediment and nutrients, especially during flood events (e.g., Noe and Hupp, 2009). Biogeochemical processes are also related to the dominant vegetative community of the wetland, which reflects the underlying wetland hydroperiod and hydrochemistry. Overall, studies support consideration of a wetland classification scheme that creates the opportunity for attribution of different load reduction values by landscape and hydrogeologic position.

For the Phase 6 CBWM, the Wetland Expert Panel recommends its framework to capture variation in wetland water quality benefits due to differences in hydrogeomorphic settings across the physiographic provinces of the Chesapeake Bay Watershed. Results are intended to parallel Jordan's meta-analysis and resulting kinetic equation relating nutrient and sediment reductions to retention time (see Figure 9), but also to explicitly recognize the importance of location. The updated literature review developed by the panel and Tetra Tech further revealed wide variation in nutrient and sediment retention but limited information to evaluate how performance varies across different landscape gradients (i.e., based on hydrogeomorphic setting and wetland type). Given the wide range of uncertainty in the collective understanding of wetland water quality functions, the Panel recommends using the average reported retention efficiencies for all wetland types (42%, 40% and 31% for TN, TP and TSS, respectively), which fall within the range of values used for the Phase 5.3.2 CBWM. The Panel also recognizes that wetland water quality benefits reflect the nature of wetlands to occur as transitional zones between human dominated uplands and downstream aquatic habitats. Nutrient and sediment retention capacity depends on hydrologic connectivity to upland sources. Accordingly, the Panel also proposed using upland-wetland treatment acreage ratios to reflect expected field conditions in terms of hydrologic connectivity, based on general knowledge of hydrogeomorphic settings and land use history in different physiographic provinces of the Chesapeake Bay watershed. The panel is confident that the recommended framework, which emphasizes the importance of location, represents a positive step towards a more accurate representation of the water quality benefits for wetland restoration in the Phase 6 CBP partnership modeling tools.

Future efforts to describe the role of wetlands and wetland BMPs should focus on refining our understanding of how wetland retention efficiencies vary across space and also in relation to short-term and seasonal weather conditions. Results will help understand impacts to wetland ecosystem functions from shifting climatic conditions. In addition to coordinating field studies to validate our current conceptual understanding, additional modeling efforts may reveal patterns in retention efficiencies. For example, future panels may leverage the SPARROW model to explore and extrapolate wetland water quality benefits throughout a region. In fact, the current panel attempted to apply SPARROW in this manner, but capacity was not available in time for this report. Discussions with USGS staff to develop SPARROW runs in the near future are proceeding Because these analyses will occur outside the timeframe for this expert panel review, the CBP partnership is encouraged to continue coordinating with USGS and the Wetland Workgroup, perhaps to form a small task force to work with USGS staff in developing the application of SPARROW and interpreting results. Ultimately, the Chesapeake Bay Program should commit to refining a field-scaled accounting framework, based on developing understanding of how wetland ecosystem functions vary by location and condition, to track the benefits and gains attributable to existing and restored wetlands.

Wetland restoration (re-establishment) in tidal areas

In the Phase 6 model, tidal wetlands will be simulated in the estuarine model, not the Watershed Model. This means there are no tidal wetland land use acres to which a tidal wetland restoration BMP can be applied. Given this context and the protocols developed by the Shoreline Management Expert panel already approved, this panel reviewed that effort for relevance to the charge to develop wetland BMPs. Specifically, the panel considered Protocols 2, 3 and 4 as defined by that expert panel.

- Protocol 2: Denitrification
- Protocol 3: Sedimentation

- Protocol 4: Marsh Redfield Ratio

The panel concluded that the Shoreline Management Panel's Protocols 2-4 adequately characterize the relevant nutrient and sediment processes of tidal wetlands and tidal wetland restoration. It was noted that no new literature has been published since 2015 that would affect or change the load reductions recommended by the Shoreline Management panel. It is recommended that these protocols be used as a load reduction effectiveness estimate for tidal wetland restoration BMP in the Phase 6 modeling tools. The overall load reduction is summarized in Table 13 below. While the existing Shoreline Management BMP can be used for reporting wetland restoration in tidal areas in the Phase 6 CBWM, the partnership should consider how it can efficiently track the acres of tidal wetland restoration reported as Shoreline Management for annual progress runs towards the Watershed Agreement outcome for an 85,000 acre wetland gain.

Table 13. Summary of recommended load reductions.

Shoreline Management Protocol		TN	TP	Sediment
Protocol 2 – Denitrification	Acres of re-vegetation	85	NA	NA
Protocol 3 - Sedimentation	Acres of re-vegetation	NA	5.289	6,959
Protocol 4 – Marsh Redfield Ratio	Acres of re-vegetation	6.83	0.3	NA
Tidal wetland restoration		91.83 lbs/ac	5.589 lbs/ac	6,959 lbs/ac

Recommendations for wetland creation (establishment), wetland enhancement and wetland rehabilitation

This panel was unable to determine a recommended benefit for these BMPs in the time available but strongly encourages the partnership to quickly convene another expert panel to evaluate the effectiveness of these categories of wetland BMPs. The suggested definitions in Chapter 2 and the framework for these BMPs are already provided as a starting point for the future expert panel, which should be convened as a high priority under the WQGIT's BMP Protocol. Unlike wetland restoration and wetland creation, the enhancement and rehabilitation BMPs represent gains in function only, not gains in acres. As such, these BMPs would likely be credited as effectiveness estimates applied to nontidal wetland land use acres in the Phase 6 modeling tools and not represented as a land use change. The Wetland Creation BMP, similar to Wetland Restoration, would be expected to be a land use change plus treatment to upland acres. However, the effectiveness estimate applied to the upland acres for Wetland Creation should not be assumed to be equal to the estimate provided by this panel for Wetland Restoration.

If the future panel is instructed to consider these BMPs for application to tidal areas, the recommended protocols for the tidal BMPs would likely need to reflect the fact that there are no land use acres for tidal wetlands as they are simulated through the Estuarine Model, not the Watershed Model.

Following approval of this report and the wetland restoration BMPs, the Wetland Workgroup and Habitat GIT should work with the Water Quality GIT to promptly form an ad hoc group to craft the charge and scope for a new expert panel to evaluate the effectiveness wetland enhancement and wetland rehabilitation BMPs to reduce nitrogen, phosphorus and sediment loads. The future panel should build and clarify on the recommended definitions of this panel, but is asked to maintain the broader category definitions described in Table 2 of Chapter 2.

The future panel may consider using the same distinction for the BMPs according to physiographic region (Coastal Plain, Piedmont, etc.) and land use (Floodplain and Other), or it may decide that an alternate approach is appropriate for the functional gain BMPs or Wetland Creation.

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Chapter 6. Accountability Mechanisms

Wetland restoration practices must be accounted for and verified for credit toward Chesapeake Bay water quality goals. The Panel recommends the following reporting and verification protocols for wetland restoration projects consistent with existing CBP wetland BMP verification guidance:

1. Initial verification – The installing agency must confirm that the proposed practice was installed to design specifications, is hydrologically stable and vegetatively stable, and all erosion and sediment control measures have been removed.

   All jurisdictions have or will have verification protocols for reporting wetlands BMPs. Protocols were based on Chesapeake Bay Program (CBP) guidance. The addition of wetland enhancement/rehabilitation as BMPs will require additional guidance from CBP on the practices which would be included under the new wetland enhancement/rehabilitation BMP. Outreach to practitioners will be necessary to ensure that additional qualifying practices are reported. In addition, CBP will have to ensure that reporting databases contain appropriate fields to receive data on the new BMP, distinct from other wetland BMPs.

2. Recordkeeping – The installing agency must keep records of all wetland restoration projects.

3. Reporting and duration of credit – Once a year, the NEIEN coordinator for each state will compile this information and submit it to Chesapeake Bay Program.

4. Tracking
   a. The following 8 fields are requested from the state contacts every year:
      i. Field 1: County
      ii. Field 2: HUC-10
      iii. Field 3: Is the project on Federal Land?
      iv. Field 4: Prior landuse
      v. Field 5: Wetland drainage area (acres)
      vi. Field 6: Project Partners
      vii. Field 7: Completion date
      viii. Field 8: Gains in acres (by wetland type: non-tidal emergent, non-tidal shrub, non-tidal forested, non-tidal other, tidal)
         1. Gains – Reestablishment (i.e. Wetland Restoration – See Table 2)
         2. Gains – Establishment (i.e. Wetland Creation – See Table 2)
         3. Functional gains – Enhancement (i.e. Wetland Enhancement – See Table 2)
         4. Functional gains – Rehabilitation (i.e. Wetland Rehabilitation – See Table 2)

5. Protection – Long-term (i.e. applied toward Watershed Agreement protection outcome – See Table 3)
6. Protection – Short-term (i.e. applied toward Watershed Agreement protection outcome – See Table 3)

b. NEIEN has been updated for Phase 6 to reflect the four categories of wetland BMPs that are now available as defined by this panel and future panel(s). It will accept and distinguish Wetland Restoration and Wetland Creation as acreage gains and; Wetland Enhancement and Wetland Rehabilitation as functional gains. State databases must also be updated to accommodate the enhancement and rehabilitation entries.

5. Ongoing verification – Verification is required to ensure that the wetland restoration projects are performing as designed. The installing agency should confirm that the project was built according to plans (as-built survey was completed). Monitoring of vegetation, hydrology, and soil should be completed for the first three - five years of the project. Native vegetation species cover, invasive species, and wetland indicator status should be recorded. Invasive species should be managed early to prevent further invasion. Hydrology or indicators of hydrology should be recorded, as well as indicators of hydric soils (per the Army Corps of Engineers Wetland Delineation Manual and Regional Supplements). After 5 years, annual observations are recommended to document the continued success of the project. However, if on-site observations are not possible, other methods can be used as a proxy. The Chesapeake Bay Program BMP Verification guidance states the following:

> Onsite monitoring within the three years following construction is recommended. For any long-term monitoring, use of aerial imagery for remote observations is highly recommended for verification of wetland BMPs; remote observations can indicate encroachment of agricultural activities, clearing, and tree removal. Any issues or concerns with projects implemented on private lands are typically reported by the landowner to the installing agency and addressed as needed.

Wetland restoration and construction projects are reported to CBP either as stormwater BMP's or Ag BMP's/Voluntary restoration. The flow chart shown in Figure 10 was developed to help practitioners and agency personnel determine how to correctly report wetland acres. Wetland restoration practices that would receive the recommended Phase 6 BMP efficiency values described in this report would fall under the Tidal and Non-Tidal portions of Figure 10; though as noted in the diagram there are other practices (e.g., shoreline management) that are covered through other BMPs as defined by the CBP.

Existing BMP verification guidance for wetlands is available online as part of the CBP's adopted BMP Verification Framework at:
http://www.chesapeakebay.net/about/programs/bmp/verification_guidance

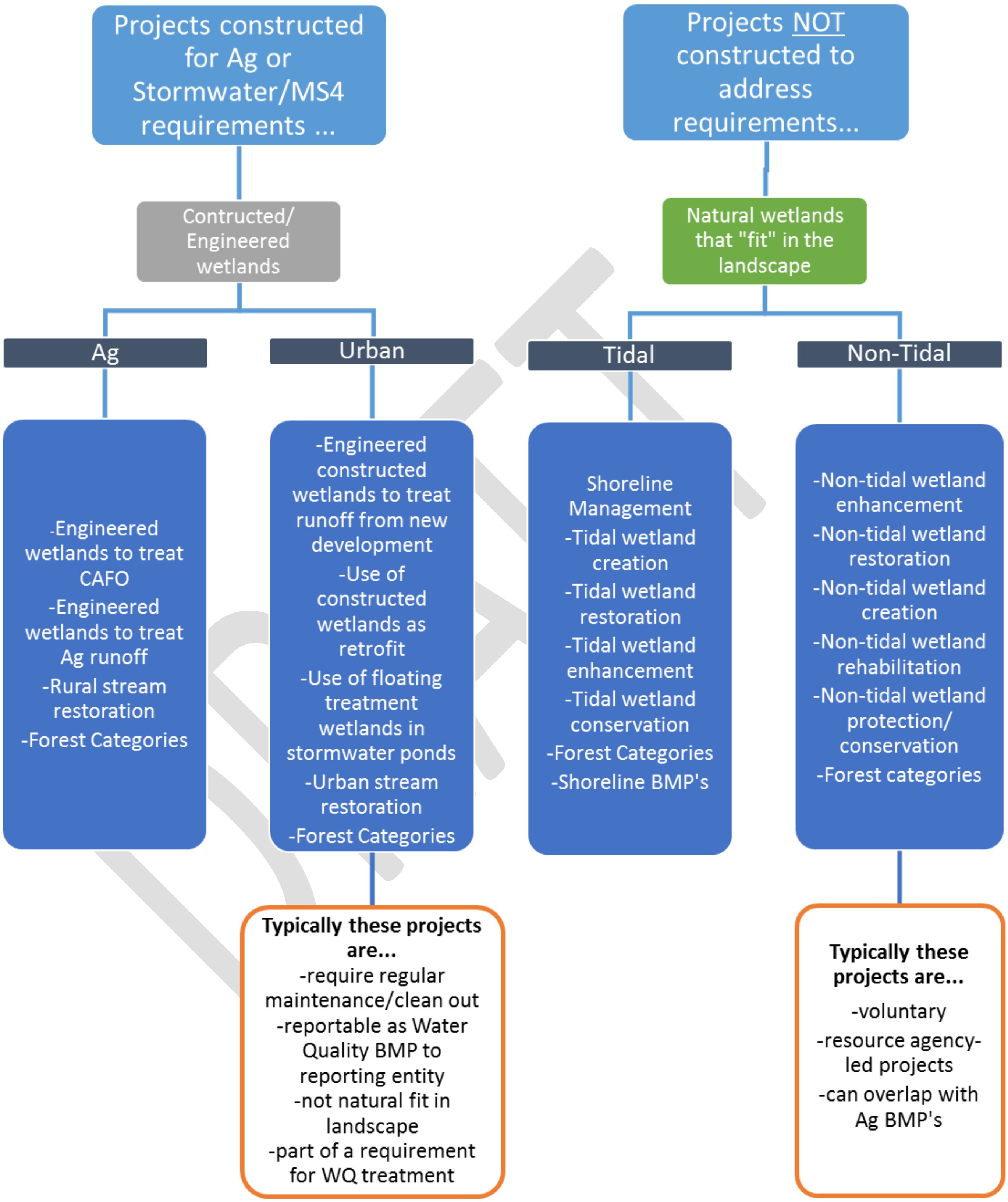

Figure 10. Wetland BMP Reporting Matrix

Chapter 7. Unintended consequences and qualifying conditions of wetland BMPs

There are numerous benefits associated with tidal and non-tidal wetlands aside from their potential to reduce nutrient and sediment pollution, including vital habitats for waterfowl, fish, other animals, and plants; flood control, water storage, storm abatement, and aquifer recharge; carbon sequestration; and reduction of toxic pollutants (see Appendix B for more information). For these and other reasons, implementing wetland enhancement, restoration, and creation as a BMP in the Chesapeake watershed will provide many benefits, especially in urban and agricultural areas, among others. The panel believes that these practices are critical to meeting the Chesapeake Bay's water quality 2025 goals under both the Chesapeake Bay TMDL and the 2014 Watershed Agreement. However, it is the intention of the panel that wetland BMP projects only earn nutrient and sediment reductions if they are implemented at appropriate sites which do not damage existing ecological conditions. For instance, the panel believes BMPs should not compromise existing high quality habitat resources. The panel does not recommend the conversion or alteration of high quality wetlands for the purposes of nitrogen, phosphorus or sediment load reductions. The panel recognizes that improvements to water quality or other functions may not be zero-sum and can mutually benefit one another, but this requires careful planning and implementation by multiple stakeholders at the local, state and federal levels.

Changing the functions and/or values of existing high quality wetland systems and high quality non-wetland ecosystems that already provide denitrification and phosphorous or sediment trapping should not be pursued. Also, important ecosystems such as rare and endangered species habitat, older growth forests, unique ecotones (i.e. Delmarva Bays, Magnolia bogs, critical fish spawning areas, among others) should not be priorities for wetland practices solely for the nutrient and sediment reductions recommended by this panel for use in the Phase 6 suite of modeling tools. This list is not all inclusive of every important ecosystem of the Chesapeake Bay; however, project prioritization, selection and implementation should include the assessment of the project area to make sure these types of systems are not negatively impacted. It is understood that each project should be assessed based on federal, state, and local regulatory requirements, according to best professional judgments in the field, and supported by benchmarks presented in state and federal guidance documents. While this minimizes the risk of implementing extraneous wetland BMPs that could potentially harm habitat or other functions at the expense of nutrients and sediment, the panel wants to emphasize that practitioners, permit reviewers, and other stakeholders should not take these safeguards for granted. Jessop et al (2015) found that designing wetlands to focus on nutrient reduction may come at the expense of biodiversity, which reinforces the panel's consensus that practitioners should prioritize wetland functions based on local site and watershed context. For instance, practitioners should be aware of wetland types that are classified as key wildlife habitats in State Wildlife Action Plans, and follow recommendations for preserving or enhancing these areas for wildlife purposes.

Implementation of the practices described in this report for the purposes of nutrient and sediment load reductions should be performed in or adjacent to areas that have relatively high potential to export these pollutants. If the site is a relatively healthy wetland or forested area, or if it already provides valuable habitat to native flora and fauna then alternate sites should be prioritized to reduce the potential for unintended negative consequences. Furthermore, it is recommended that each project that may require a permit to work in "waters of the US" or "waters of a state" and may want to pursue a pre-application meeting to discuss project specific information with the Federal and state regulatory agencies. This will allow for a more efficient regulatory review of the proposed project.

Appendix B summarizes some studies related to ancillary benefits and potential negative impacts of wetlands, though it is not a comprehensive or exhaustive literature review since that would take much more time and effort than available to this expert panel. With that in mind, the literature review reinforces the notion that on average the benefits of wetlands far outweigh the potentially negative impacts and that the negative impacts can be avoided through proper site selection as encouraged by the panel in this section.

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Chapter 8. Future research and management needs

The work of the panel was focused on three differing services of wetlands: 1) what, if any, are the nutrient and sediment loads contributed by wetlands to receiving waters (landuse/landcover), 2) what, if any, reductions in loads are achieved by wetlands adjacent to parcels of land with known pollutant loads (efficiencies), and 3) what, if any, load reductions can be achieved by implementation of wetland Best Management Practices (BMPs).

The literature is largely silent on the contribution of wetlands as sources for nutrients and sediment, though numerous studies exist showing differences between nutrient and sediment inputs compared to outputs. Since the scientific literature and existing Bay models have not focused on wetlands as a unique landcover with regard to nutrient loading, this information is sparse. The historic paradigm still largely held in scientific circles is that wetlands are sinks – at least most wetlands, most of the time, for most pollutants.

The literature on wetland efficiencies is more robust and there is a large body of work on wetlands as BMPs. However, much of the research has focused on constructed wetlands for water treatment. These wetlands are generally of simple hydrology, limited inflow and outflow, and typically vegetated with herbaceous plants only, specifically monocultures of species known for high rates of pollutant uptake, such as cattails (*Typha* spp.) and common reed (*Phragmites*). These constructed wetlands are not accounted for in wetland status and trends as new wetland acreage. The panel determined that the load reduction values from these wetlands should not be incorporated into the recommended efficiencies for use in the Phase 6 model. While there are fewer studies on the role of natural wetlands and even fewer on restored, enhanced, or created habitat wetlands in the reduction of nutrients and sediments, the values from these studies were used for the panel recommendations. A more expansive literature search than conducted for this report may identify additional useful studies on nutrient dynamics in natural wetlands, which could refine efficiencies in future models.

Given the state of the science, the panel seeks to advance research efforts on the role of existing and created/restored wetlands on nutrient and sediment loads to the Bay.

First: Studies that investigate the question of wetlands as sources or sinks, or both, would improve the accuracy of the landuse loading values in the Chesapeake Bay Watershed model and potentially provide a different loading rate from forest in future model versions. It is likely that we will learn much from the inclusion of wetlands as a landuse/landcover class in the watershed model. The lessons learned should be used to help direct future research on this aspect of wetlands and water quality.

Second: Investigations are needed to determine the efficiencies of various types of wetlands in different Chesapeake Bay physiographic regions to intercept and reduce the nutrient and sediment inputs from other land uses via surface or subsurface flow.

The SPARROW model offers the possibility to assess the overall role and magnitude of impact that existing wetlands have at the watershed scale. Such an analysis would help address these first two research needs and serve as an informative next step towards understanding the effect of wetlands as sources, sinks, or both across the Chesapeake Bay region, as well as providing a comparison with forest land. The Wetland Workgroup is encouraged to take lead on such an effort in coordination with USGS staff that work with the SPARROW tool.

Third: The load reductions of various BMP practices are dependent not only on the practice (restoration, creation, enhancement, rehabilitation) but other attributes such as landscape position, hydrology, vegetative community, etc. To accurately attribute load reductions to the various practices for purposes of giving credit to specific project(s), we need additional research to determine load reductions for the various practices and attributes. Specific recommendations to address these needs include the following:

1. Define specific restoration/conservation objectives related to wetland function to provide a basis for prioritization;
2. Map "shuffle zones," where near surface- and groundwater interactions create an organic-rich biogeochemical hotspot;
3. Overlay knowledge of mineralogy and/or groundwater quality to predict nutrient storage, transport, and transformations;
4. Identify subsurface features that influence groundwater flow patterns;
5. Combine information to map restoration efforts, including estimates of water quality and habitat benefits.

As has been discussed in the report, and this chapter, the scientific understanding of particular wetland BMP practices and project elements is sometimes limited, as is our understanding of wetland nutrient and sediment contributions (and demands in the face of climate change). Management of water quality improvement efforts that incorporate wetlands will need to be adaptive. That is, as the understanding of wetlands as source, sink or both - based on landscape position, hydrology, soils and vegetation - improves, appropriate changes to water quality models and habitat priorities and practice should be modified accordingly.