Literature Review for Development of Maryland Wetland Monitoring Strategy: Background Information on Maryland's Wetland Types

Prepared for the Maryland Department of the Environment
Wetland and Waterways Program

by
Kathryn C. Haering and John M. Galbraith
Department of Crop and Soil Environmental Sciences
Virginia Tech
and
Denise Clearwater
Wetlands and Waterways Program
Maryland Department of the Environment

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Introduction and definitions

Wetlands in Maryland

This report was prepared in support of the Maryland Department of the Environment (MDE) effort to develop a wetland monitoring strategy. It includes information on the types of wetlands in Maryland and the functions and services that they may provide.

The Maryland Wetland Conservation Plan (2003) briefly summarizes wetland properties as follows:

> "Wetlands may be permanently flooded by shallow water, permanently saturated by groundwater, or periodically inundated or saturated for varying periods during the growing season in most years. Many wetlands are the periodically flooded lands that occur between uplands and salt or fresh water bodies (i.e., lakes, rivers, streams and estuaries). Other wetlands may be isolated in areas with seasonally high water tables that are surrounded by upland or occur on slopes where they are associated with groundwater seepage areas or drainageways. Wetlands are important natural resources providing numerous values to society, including fish and wildlife habitat, flood protection, erosion control and water quality preservation. Wetlands comprise a range of environments within interior and coastal regions of Maryland."

Approximately one tenth of Maryland's land area is composed of wetlands. More than half the state's wetlands are nontidal and tidal freshwater wetlands, while the rest are tidal estuarine wetlands (Clearwater et al., 2000). In Maryland, tidal wetlands occur on the Coastal Plain around the Chesapeake Bay and its associated tidal rivers, and behind the Atlantic barrier islands (Darmody and Foss, 1979; McCormick and Somes, 1982; Tiner and Burke, 1995). Nontidal wetlands can be found in every physiographic province in Maryland, but are most common in the Coastal Plain province (Tiner and Burke, 1995).

Wetlands in the State of Maryland are protected under the following federal and state regulations:

- U.S. Clean Water Act, Section 404
- Maryland Nontidal Wetlands Protection Act (COMAR 26.23)
- Maryland Tidal Wetlands Act (COMAR 26.24)
- Maryland Waterway and 100-Year Floodplain Construction Regulations (COMAR 26.17.04)

Although many wetlands provide water quality improvement functions, and are valued for this service, wetlands have limits to their capacity for filtering pollutants. Wetlands can thus be negatively impacted by water quality problems throughout Maryland. Control of point sources of water pollution such as industrial effluents and municipal wastewater treatment plants is improving, but urban and agricultural runoff continues to affect water quality in many of the state's waterways. Improved techniques for storm water discharge treatment, riparian habitat management and employment of best management practices on farmland and managed forests, may further enhance water quality in wetland and associated waterways (Tiner and Burke, 1995).

Wetland definitions

The federal definition of wetlands is "Those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas." (Environmental Laboratory, 1987) Specific wetland indicators include:

- hydrology which results in water levels in or above the surface during some part of the growing season
- hydrophytic vegetation
- hydric soils

Specifically, the Code of Maryland Regulations (COMAR) defines *tidal wetlands* as[1]:

> "All State and private tidal wetlands, marshes, submerged aquatic vegetation, lands, and open water affected by the daily and periodic rise and fall of the tide within the Chesapeake Bay and its tributaries, the coastal bays adjacent to Maryland's coastal barrier islands, and the Atlantic Ocean to a distance of 3 miles offshore of the low water mark. "

A *non-tidal wetland* is defined by COMAR as[2]:

> "(a) an area that is inundated or saturated by surface water or ground water at a frequency and duration sufficient to support, and that under normal circumstances does support, a prevalence of vegetation typically adapted for life in saturated soil conditions, commonly known as hydrophytic vegetation;
> (b) is determined according to the Federal Manual[3];
> (c) does not include tidal wetlands regulated under Natural Resources Article, Title 9, Annotated Code of Maryland. "

Wetland hydrology

Hydrology is the dominant factor controlling wetland formation, size, persistence, and function (Carter, 1996; Mitch and Gosselink, 2000). Hydrologic processes in a specific wetland are affected by water source and movement pattern, geology, geomorphic position and many other factors, but the hydrologic characteristic common to all wetlands is a sufficient and continuing supply of water (Carter, 1996; Environmental Laboratory, 1987).

Input of water into wetlands can come from direct precipitation, stream flow, overbank flow from streams and rivers, surface runoff, groundwater, and/or tides. Water leaves

[1] http://www.dsd.state.md.us/comar/getfile.aspx?file=26.24.01.02.htm
[2] http://www.dsd.state.md.us/comar/getfile.aspx?file=26.23.01.01.htm
[3] *Federal Manual for Identifying and Delineating Jurisdictional Wetlands*

wetlands through evapotranspiration, groundwater infiltration, and/or surface and subsurface return flow after flooding and tidal inundation (Brinson, 1993; Carter, 1996). As a result, the direction of water flow in a wetland can be one or more of the following:

- Vertical: up and down (for example, precipitation and evapotranspiration).
- Unidirectional or horizontal: one way across surface or subsurface (for example, surface runoff).
- Bidirectional: back and forth horizontal across surface or subsurface (for example, tidal flooding and return).

Wetland hydrology is also influenced by the *hydroperiod* or the pattern of water table fluctuation within a wetland (Vasilas et al., 2005). In many tidal wetlands, hydroperiod is diurnal since it is controlled by tidal movement. In non-tidal wetlands, hydroperiod is often seasonal.

Hydrophytic vegetation

Hydrophytic plants are species which can tolerate prolonged inundation or soil saturation during the growing season (Environmental Laboratory, 1987; US Army Corps of Engineers, 2008). Hydrophytic plants are classified as obligate, facultative wetland, or facultative. Obligate plants almost always occur in wetlands. Facultative wetland plants usually occur in wetlands but sometimes occur in uplands. Facultative plants have an equal probability of occurring in either wetland or upland conditions. Some upland plant species occasionally occur in wetlands, but are not wetland indicators.

Hydric soils

Hydric soils are defined as: "Soils that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part (USDA-NRCS, 2006b). Hydric soils may be identified by hydric soil indicators, which are morphological features that result from anaerobic conditions, including iron and manganese reduction, translocation, and accumulation , sulfate reduction, and/or organic matter accumulation, and others. However, a soil that meets the definition of a hydric soil is hydric whether or not it exhibits indicators, provided it meets the National Technical Committee for Hydric Soils (NTCHS) hydric soil technical standard.[4]

Hydric soils can be either mineral, organic, or (Histosols), or mineral with an organic surface layer (histic epipedon). Histosols can be loosely defined as soils in which the upper 80 cm contains 12 to 18% organic carbon (approximately 20-30% organic matter). A histic epipedon can be broadly defined as a 20 to 40 cm layer at or near the surface of a mineral soil that contains 12 to 18% organic carbon depending on clay content.   For more precise definitions of mineral and organic soils, see Soil Survey Staff (2006).

Wetland functions and services

Wetland *functions* are the physical, chemical, and biological processes that take place in and around a wetland (Marble, 1992; Novitzki et al., 1996). The functions performed by

[4] NRCS Hydric Soils Technical Note 11 ftp://ftp-fc.sc.egov.usda.gov/NSSC/Hydric_Soils/note11.pdf

individual wetlands vary by wetland type, size, location, degree of disturbance, soil and vegetation type, and so forth, but almost all wetland functions can be classified as either *hydrologic*, *biogeochemical*, or *habitat provision* (USEPA, 1998). Some examples of these functions are defined in Smith et al. (1995), Carter (1996), Shafer and Yozzo (1998), and Bleil (2004):

- *Hydrologic functions*: floodwater storage, stormwater retention and rainfall capture, delayed peak discharge of floodwater, wave and storm tide buffering, floodwater buffering, ground-water recharge and discharge, alteration of weather through modifications of temperature, precipitation, transpiration and evaporation, maintenance of water balance in estuaries, maintenance of stream base flow.
- *Biogeochemical functions*: nutrient cycling, removal of sediment, nutrients, trace metals, carbon sequestration, and particulate and dissolved organic matter from surface water and groundwater.
- *Habitat* provision functions: habitat for plants and animals that are adapted to hydric soils, vegetation or aquatic habitat, feeding area, nursery and/or reproduction area for fish, amphibians, birds, and mammals, maintenance of biodiversity by providing habitat for diverse and endangered species.

Statutory wetland functions listed in the Maryland Nontidal Wetlands Protection Act and regulations[5] include:

- Attenuation of flood waters and storm waters;
- Reduction of pollutant loadings, including excess nutrients, sediments, and toxics.
- Providing habitat and breeding grounds for plants and wildlife, including fish, game, and nongame birds and mammals, as well as threatened and endangered species and species in need of conservation.
- Shoreline stabilization and erosion control..
- Timber production.

Additional functions assessed by the Maryland Department of the Environment (MDE) in nontidal wetlands include groundwater discharge for maintaining base flow and groundwater recharge.

The Maryland (Tidal) Wetlands and Riparian Rights Act and regulations[6] suggest that certain values associated with tidal wetlands to be considered during review of proposed activities to the degree that they will:

- "Destroy or adversely affect the value of tidal wetlands as a source of nutrients to finfish, crustaceans mollusks, or wildlife of significant economic value;

[5] Environment Article Title 5, Subtitle 5-901through 5-911, Annotated Code of Maryland, and COMAR 26.23; specifically http://www.dsd.state.md.us/comar/getfile.aspx?file=26.23.01.01.htm
[6] Environment Article Title 16, Annotated Code of Maryland, and COMAR 26.24; specifically http://www.dsd.state.md.us/comar/getfile.aspx?file=26.24.02.03.htm

- Affect potential habitat areas such as historic spawning and nursery grounds for anadromous and semianadromous fisheries species and shallow water areas suitable to support populations of submerged aquatic vegetation;
- Eliminate or substantially reduce marine commerce, recreation, and aesthetic enjoyment;
- Affect the natural ability of tidal wetlands to reduce flood damage and adversely affect the public health and welfare; and
- Substantially reduce the capacity if tidal wetlands to trap sediment, and result in increased silting of channel and harbor areas to to the detriment of free navigation."

Ecosystem *services* are defined by Constanza et al. (1997) as "the benefits human populations derive, directly or indirectly, from ecosystem functions". The specific human and cultural services provided by wetlands that are evaluated by MDE are:

- Providing recreational opportunities such as hiking and wildlife viewing, and/or being adjacent to areas used for recreational water sports.
- Providing harvestable natural resources such as timber, fish, or furbearing mammals and/or being adjacent to recreational or commercial fishing areas.
- Providing environmental educational opportunities.
- Providing aesthetic (scenic) qualities.
- Representing a rare ecotype within the watershed.
- Having historic significance.

Wetland *condition* has been described by Fennessy et al. (2004) as "the extent to which a given site departs from full ecological integrity (if at all). Condition can be defined as the relative ability of a wetland to support and maintain its complexity and capacity for self-organization with respect to species composition, physico-chemical characteristics and functional processes as compared to wetlands of a similar class without human alterations." However, wetlands in good condition do not necessarily provide wetland services. For example, unaltered wetlands often have very little opportunity to improve water quality because the input of nutrients and/or other pollutants into an undisturbed wetland is usually quite low.

Wetland classification systems of Maryland

Maryland Coastal Wetland system

The Coastal system classifies tidal wetlands by salinity, range of tidal inundation, vegetation type, and plant community (MDE Wetlands and Waterways Program, 2008). It is the oldest wetland classification system currently used in Maryland. Background information for the Coastal System is available in McCormick and Somes (1982). This system only covers tidal wetlands, and although maps are available, they date from 1972.

U.S. Fish and Wildlife Service System

The U.S. Fish and Wildlife Service (USFWS) system was first outlined in Cowardin et al. (1979) and is used in the National Wetlands Inventory (NWI) maps (USFWS, 2002), and classifies both wetlands and deepwater habitats. The highest level of classification is by ecological system: Marine, Estuarine, Riverine, Lacustrine, or Palustrine. All systems except the Palustrine include both wetlands and deepwater habitats. The systems are further divided into ecological subsystem, and then into classes. Classes are based on either vegetation or substrate type (for areas with <30% vegetative cover). Further classification for wetland areas is usually based on dominant vegetation, and then modifiers describing hydroperiod, water chemistry, soil type (organic or mineral), and extent of human disturbance re applied.

The USFWS system has probably the most commonly used wetland classification in the U.S., and wetland maps and GIS layers using this system are widely available. Since the USFWS system is used to classify wetlands based on aerial photos for National Wetlands Inventory (NWI) maps, many of its classes and subclasses are based on type of vegetation and other features that are visible at that level of detail (Brinson, 1993). However, the USFWS system does not include all wetland characteristics that are important in functional evaluation. NWI has recently expanded its mapping efforts to add functional modifiers but these are not yet available on a statewide scale.

Hydrogeomorphic system

The hydrogeomorphic (HGM) system of wetland classification was first proposed by Brinson (1993), and was expanded into a functional assessment method by Smith et al. (1995).

HGM classification is based on three abiotic components which influence wetland function (Brinson, 1993; Smith et al., 1995):

1. Geomorphic setting: the landform and landscape position of wetland.
2. Water source: where the water in the wetland came from directly before it entered the wetland.
3. Hydrodynamics: the energy level of the water coming into the wetland and the direction of water flow in the wetland.

The premise behind HGM is that wetlands with similar geomorphology, water source, and hydrodynamics will also have similar functions (Brinson, 1993; Smith et al., 1995).

There are seven wetland hydrogeomorphic classes in HGM (Smith et al., 1995):

- Depressions
- Slope
- Riverine
- Organic soil flats
- Mineral soil flats
- Estuarine fringe
- Lacustrine fringe

The HGM system includes the landscape surrounding the wetland since this affects both structure and function of the wetland. Although the HGM system does not take biotic factors such as vegetation into account, the abiotic components of the classification greatly influence the structure of corresponding regional plant communities. Hydroperiod is not included in the HGM class model, although it affects many wetland functions and should be addressed at the regional subclass level if necessary [Vasilas et al., 2008; Brooks et al., (in prep.)].

Key Wildlife Habitat System

The Maryland Department of Natural Resources classifies several wetland types under its Key Wildlife Habitat system (Maryland Department of Natural Resources, 2005). In Maryland's Wildlife Diversity Conservation Plan, Key Wildlife Habitats are used to identify habitats used by species of Greatest Conservation Need (GCN). Ten wetland wildlife habitat types are identified under this system:

- Floodplain forests
- Upland depressional swamps
- Carolina Bays
- Vernal pools
- Forested seepage wetlands
- Bog and fen wetland complexes
- Nontidal shrub wetlands
- Tidal shrub wetlands
- Nontidal emergent wetlands
- Tidal marshes

Maryland's draft wetland classification

Draft regional subclasses for Maryland's wetlands have been outlined by the Maryland Department of the Environment (MDE) Wetlands and Waterways Program (2008), and are summarized in Table 1. The draft classification is modified from the HGM classification system, with some subclasses including more than one HGM class based on landscape position. For example, the Riparian Headwater class includes slope and depression wetlands that are associated with the floodplain. This subclass is also used in Pennsylvania (Cole et al., 1997; Cole et al., 2008). Maryland's draft classification also includes hydroperiod, which is not a component of the HGM system. The classification system can also be cross referenced with the wetland portion of the Key Wildlife Habitat system used by the Maryland Department of Natural Resources (2005).

Table 1. Draft regional subclasses for Maryland's wetlands (adapted from MDE Wetlands and Waterways Program, 2008).

Maryland Wetland Class	**HGM Class**	**Brief Description**	**Hydrology: 1) source 2) hydrodynamics 3) hydroperiod**	**Key Wildlife Habitat**
Tidal Freshwater	Fringe	0 – 0.5 ppt salinity	1) Overbank flow from channel 2)Bidirectional, horizontal, vertical 3)Diurnal	Tidal Shrub Wetlands Tidal Marshes Floodplain Forest
Tidal Estuarine	Fringe	> 0.5 ppt salinity	1) Overbank flow from channel 2)Bidirectional, horizontal, vertical 3)Diurnal	
Nontidal Riparian Headwater Complex	Riverine, Slope, Depressions	Riparian zone of waterway, floodplain, and transitional upland fringe. ≤ 3rd order mosaic of low/high gradient streams, depressions, toe-slopes	1) Overbank, groundwater, surface runoff 2) Bidirectional, horizontal, vertical 3) Variable	Floodplain Forest Nontidal Shrub Wetland Nontidal Emergent Wetland Forested Seepage Wetland Bogs and Fens Vernal Pools
Non-tidal Riparian Mainstem Complex	Riverine	Riparian zone of waterway, floodplain, and transitional upland fringe. > 3rd order mosaic of low/high gradient streams, depressions, toe-slopes	1) Overbank, groundwater, surface runoff 2) Bidirectional, horizontal, vertical 3) Variable	Floodplain Forest Nontidal Shrub Wetland Nontidal Emergent Wetland Vernal Pools
Seasonal Flat (mineral soil) • **Connected** • **Isolated**	Mineral Flats	Broad, flat areas with poor drainage	1) Precipitation, groundwater, overbank 2) Vertical 3) Temporarily to semi-permanently flooded	
Peatland • **Connected** • **Isolated**	Organic Flats, Depressions	Broad, flat areas or depressions with sustained saturation and deep peat	1) Precipitation, groundwater 2) Vertical 3) Saturated, semi-permanently flooded	Bogs and Fens
Isolated Depressional	Depressions	Topographic low area lacking hydrologic connection to riparian tidal waters	1) Precipitation, Groundwater, surface run-off 2) Vertical 3) Temporarily, seasonally, to semipermanently flooded	Upland Depressional Swamps Vernal Pools Carolina Bays
Isolated Seepage Slope	Slope	Discharge area lacking observable surface connection to riparian or tidal waters	1) Groundwater 2) Unidirectional, horizontal 3) Saturated most or all of the year	Nontidal Shrub Wetlands Nontidal Emergent Wetlands
Constructed or Incidental	Any class	May become any of above classes after wetland matures	Any of above sources	Can include many types.

Tidal fringe wetlands

Overview

A tidal fringe wetland is an area of land that is periodically flooded with tidal waters[7]. Tidal wetlands are divided by many researchers into two zones: "low marsh," flooded on a daily basis, and "high marsh," flooded during extreme high tides, although this is a somewhat simplistic model (Mitsch and Gosselink, 2000, Rabenhorst, 2001). Tidal wetlands can be saline, brackish, or fresh[8], depending on their distance from the ocean and/or freshwater rivers, and sometimes on the weather and the season (Tiner and Burke, 1995). The hydroperiod is diurnal, although this may be modified by the degree of tidal influence (Kroes et al., 2007).

In Maryland, tidal wetlands are found along the Chesapeake Bay and its tidal rivers and behind Atlantic barrier islands. They are most common on the lower Eastern Shore: approximately 2/3 of the tidal fringe wetlands in Maryland are located in the Pocomoke, Nanticoke, and Choptank River basins (McCormick and Somes, 1982; Clearwater, 2000). Most of the organic soils in Maryland are found in tidal fringe wetlands, but soils may be organic, mineral, or mineral with a histic epipedon.

In the USFWS system (Cowardin et al., 1979) tidal wetlands with more than 0.5 ppt salinity are classified as in the intertidal subclass of the estuarine system or the tidal subclass of the riverine system, while tidal wetlands with 0.5 ppt salinity or less are considered to be freshwater, and fall under several classes of the palustrine system. In the HGM system, all tidal wetlands are classified as *estuarine fringe* wetlands.

The geormorphology, water source, and hydrodynamics of estuarine fringe wetlands have been described by Smith et al. (1995). Tidal fringe wetlands are located along coasts and estuaries, often intergrading landward with riverine wetlands. According to Smith et al. (1995), "The interface between the tidal fringe and riverine classes is where bidirectional flows from tides dominate over unidirectional ones controlled by floodplain slope of riverine wetlands." Topography sometimes limits formation of riverine wetlands adjacent to tidal wetlands, and tidal wetlands transition directly into uplands

Water sources are tidal currents, sometimes wind-driven, with some groundwater discharge and precipitation as well. In tidal freshwater wetlands, river flow can be an important contributor (Kroes et al., 2007). Water loss is through tidal exchange, overland

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[7] From Code of Federal Regulations 33 CFR 328.3: "The term tidal waters means those waters that rise and fall in a predictable and measurable rhythm or cycle due to the gravitational pulls of the moon and sun. Tidal waters end where the rise and fall of the water surface can no longer be practically measured in a predictable rhythm due to masking by hydrologic, wind, or other effects."

[8] There are several different descriptive scales for salinity levels, although all agree that freshwater areas have salinity of <0.5 ppt. The salinity scale used by Tiner (1995) and other researchers divides the estuaries of Maryland into polyhaline: 18-30 ppt salinity; mesohaline areas: 5-18 ppt salinity, oligohaline: 5-0.5 ppt salinity; and fresh: <0.5 ppt salinity.

flow to creek channels, and evapotranspiration. Tidal fringe wetlands are frequently flooded, and seldom dry, and tend to accumulate organic matter if isolated from daily flooding and shore erosion.

In Maryland's draft wetland classification (MDE Wetlands and Waterways Program, 2008) tidal fringe wetlands are classified as either tidal estuarine or tidal freshwater depending on salinity level (Table 1).

Functions

Shafer and Yozzo (1998) and Carter (1996) have outlined the following typical functions for tidal fringe wetlands.

1. Hydrologic and biogeochemical functions:
    - Tidal surge attenuation, including reduction of storm surges and prevention of shore erosion.
    - Deposition and retention of both inorganic and organic sediment, which maintains surface height that may have been lost through sea level rise or erosion.
    - Nutrient and organic carbon import and export, which allows maintenance of water quality and provides nutrients to sustain the plant community. May discharge nutrients seasonally.
    - Estuarine water balance, including buffering of freshwater inputs from stream flow, groundwater discharge, precipitation, and so forth allowing maintenance of estuary water chemistry.

2. Habitat functions:
    - Preservation of characteristic plant community. This is important because of shore, which aids in shoreline stabilization and nutrient and carbon cycling (as noted above).
    - Habitat for resident fish and macrocrustaceans; providing food, areas for spawning, and a refuge from predators.
    - Use by transient fish and macrocrustaceans as nursery areas, food sources, and a refuge from predators.
    - Habitat for prey for fish and macrocrustaceans.
    - Habitat for resident and transient birds, and for reptiles, amphibians, and mammals.

Two biogeochemical functions not mentioned specifically above are nitrogen removal and carbon sequestration. Both tidal freshwater and tidal estuarine wetland ecosystems are capable of removing and either sequestering or denitrifying N from adjacent waters, thus improving water quality (Craft, 2007; Craft et al., 2009; Hopfensperger et al., 2009). The N removal rate as well as the potential nitrification rate is generally higher in freshwater wetlands. Organic wetland soils are also capable of storing much more carbon than most mineral upland soils. Mineral soils tend to reach a carbon saturation level where carbon sequestration becomes equal to carbon decomposition rate, but C storage in organic marsh soils is often cumulative (Hussein et al., 2004). Rabenhorst (1995) estimates that accreting tidal wetlands are capable of sequestering 0.05 to 0.5 kg C/m^2/yr to offset greenhouse gas production. Denitrification processes in wetlands also produce the greenhouse gas N_2O, which will reduce net carbon removal (Jordan et al., 2007).

Vulnerabilities

Sea level rise

In the past, tidal fringe wetlands were ditched, drained, filled, cleared, and/or used as dumping grounds. They are now protected against deliberate disturbance by legislation but they are facing another threat in the form of rising sea levels. Although many tidal wetlands in Maryland formed as a direct result of coastal submergence as a results of rising sea levels after the last period of glaciation (Darmody and Foss, 1979), the rate of sea level rise has accelerated in the past two decades because of global warming caused by the burning of fossil fuels (CSSP, 2009). Land subsidence also occurs in areas that where groundwater withdrawals for or drinking or irrigation supply exceed groundwater recharge rates.

Tidal fringe wetlands accrete material at the surface through several processes, including tidal sedimentation, storm sedimentation, peat accumulation from wetland vegetation, and fluvial sediment supply (this last is particularly important in freshwater tidal marshes). They lose surface height through compaction, tidal sediment export, organic matter decomposition and subsidence (Reed et al., 2008; FitzGerald et al., 2009). Tidal wetlands can only survive if they accumulate material at a rate equivalent to compaction, export, decomposition and sea level rise. In the past, marsh surfaces have generally been able to keep up with sea level rise (often by migrating inland, if possible) but the recent rapid increases in sea level may mean that many of these wetlands will not be able to sustain surface levels, and will "drown" or be transformed into mud flats (Brinson et al., 1995a; Cahoon et al., 2009; FitzGerald et al., 2009).

Reed et al. (2008) modeled marsh loss in the Mid-Atlantic based on three scenarios of sea level rise and other factors resulting from climate change. The results are summarized below:

- *Back barrier lagoon marshes along the Atlantic shore:* These wetlands accrete primarily through storm sedimentation and overwash. Since climate change is expected to likely result in stronger coastal storms (because of increasing ocean surface temperatures), these marshes will likely survive if the rate of sea level rise does not increase over present levels, although they may suffer severe erosion losses.
- *Chesapeake Bay tidal wetlands (excepting the Lower Eastern Shore):* This area includes freshwater wetlands as well as saline and brackish wetlands. A primary accretion process common to all these wetlands is peat accumulation, and this is expected to increase to an extent as sea level increases. Freshwater tidal marshes dominantly accrete through peat accumulation and this is expected to continue even at the highest estimates of sea level increase. In addition to this, climactic changes will likely result in heavier rainfall events, increasing fluvial sediment inputs to these marshes, and storm sedimentation in some estuarine marshes.

- *The Lower Eastern Shore:* Many estuarine tidal wetlands on the eastern shore of Maryland between the Chester River and the Pocomoke River are already being lost through sea level rise, including many marshes in Blackwater National Wildlife Refuge. The other estuarine/brackish marshes in this area are threatened even at current sea levels, and will likely be lost if the rate of sea level rise increases. Freshwater tidal wetlands in the area are expected to sustain themselves, and possibly even expand upstream. [Kroes et al. (2007) notes that this upstream expansion will likely come at the expense of freshwater nontidal wetlands.]

Despite Reed et al.'s (2008) optimistic projection for freshwater tidal marshes, sea level rise is thought by other researchers to be causing increasing salinity in upstream areas of tidal rivers, resulting in the conversion of tidal forested freshwater wetlands to brackish marshes (Brinson et al., 1995a; Harrison et al., 2004, Kroes et al., 2007; Baldwin et al., 2007). A model by Craft et al (2009) which simulates the effect of sea level rise on the Georgia coast, predicts that tidal marshes on the low and high ends of the salinity range will be the most affected by sea level rise. Salt marshes along the oceans will be unable to accrete sediments at a rate which will prevent inundation, and freshwater tidal marshes will be affected by the intrusion of saline water and will be converted to brackish marshes.

Other vulnerabilities

Other threats currently facing tidal wetlands include (Chambers et al., 1999; Stevenson et al., 2000; Rice et al., 2000; Wilson et al., 2007; Stevenson et al., 2007):

- Loss of sediment for accretion, or loss of marsh area, resulting from urbanization, river channeling, and/or dredging.
- Subsidence due to groundwater withdrawals from underlying aquifers.
- Hardened shoreline structures which prevent marshes from moving inward as sea level rises.
- Foraging by exotic animal species such as nutria (*Myocastor coypus*). Nutria eat the roots of marsh plants which results in the obliteration of large areas of vegetation and subsequent soil erosion. Although nutria have been eradicated in Blackwater National Wildlife Refuge in Dorchester County where they were destroying several hundred acres of marsh per year, they can still be found in other areas of Maryland's Eastern Shore
- "Sudden marsh dieback." This is a phenomenon that has recently occurred in several locations on the Atlantic coast, including Blackwater National Wildlife Refuge.

Invasion by *Phragmites australis* has often thought to be a threat to tidal marshes because *Phragmites* is an aggressive colonizer that may form a monoculture and forces out native plant species (Wilson et al., 2007). It also alters marsh hydrology, which may decrease populations of fish and other estuarine wildlife (Meyerson et al., 2000). *Phragmites*, however, produces large amounts of litter and roots which can increase marsh substrate level. This provides increased marsh stability (Rooth and Stevenson, 2000; Meyerson et al., 2007). *Phragmites* is also a very efficient nutrient cycler.

Tidal wetland soils

Hydric soils indicators for Mid-Atlantic tidal wetlands are most commonly those that show accumulation of organic matter, iron reduction, or, for estuarine wetlands, sulfate reduction (USDA-NRCS, 2006a; USDA-NRCS, 2006b). The most commonly-used indicators in low-marsh areas are A1 (Histosols), A2 (Histic Epipedon), A3 (Black Histic), A4 (Hydrogen Sulfide), S4 (Sandy Gleyed Matrix), and F2 (Loamy Gleyed Matrix). Other possible indicators in high-marsh areas are: S5 (Sandy Redox) and F3 (Depleted Matrix).

Tidal fringe wetlands: Estuarine

Maryland's draft wetland classification (MDE Wetlands and Waterways Program, 2008) classifies all tidally influenced wetlands with a salinity of >0.5 ppt as *tidal estuarine*. Darmody and Foss (1979) divided Maryland's tidal estuarine marshes into three physiographic types:

- Coastal: formed as tidal sediments collect in barrier island back bays. These marshes typically have a very well developed drainage network of tidal creeks.
- Estuarine: formed along the Bay and its tidal rivers as silt is deposited in tidally influenced river meanders and bays. The soils of these marshes tend to have a very low bearing capacity. The tidal creek network in estuarine marshes is generally not as extensive as those in coastal marshes.
- Submerged uplands: formed due to inundation because of rising sea level. These are located primarily in Dorchester and Somerset Counties. These marshes are usually quite large, and tend to lack the wide tidal creek drainage network typical of estuarine marshes. Soils are characterized by peat accumulation over a submerged upland soil, so bearing capacity is quite high.

In their late 1970's reconnaissance survey, Darmody and Foss (1979) estimated that Submerged Upland marshes were the most extensive, making up about 54% of the total non-freshwater tidal wetlands in Maryland. Coastal marshes were about 8% of the total marsh area, and estuarine marshes were about 38% of the total. It is likely that these proportions may have changed as more upland area has been submerged. Stevenson et al. (2000) estimated that 50% of the tidal wetlands in Blackwater National Wildlife Refuge had been converted to open water during the 20th century.

As previously stated, researchers often divide tidal wetlands into low marsh (flooded daily) and high marsh (flooded irregularly) zones. The terms low marsh and high marsh are useful for describing hydrology, but in areas around the Chesapeake Bay, which has a relatively low tidal range, there is often not a clear cut demarcation between these areas. Instead, there is a continuum between areas which flood daily (for example, tidal creeks and adjacent portions of the marsh), and areas which are rarely flooded. The "low marsh" is often limited to tidal creeks and directly adjacent areas (Haering et al., 1989; Rabenhorst, 2001).

The source of most of the water in tidal marshes is the associated tidal creek network. Water also enters through precipitation and sometimes as groundwater, and leaves the marsh via tidal flushing and evapotranspiration. The low marsh receives inputs of brackish water through tidal flushing, and water movement is bidirectional (Rabenhorst, 2001). The high marsh tends to have stagnant pore water, except during spring tides, and subsurface flow is controlled by plant water uptake and evapotranspiration (Dacey and Howes, 1984; Odum, 1988). The boundary between marsh and upland is affected by fresh groundwater (Hemond and Fifield, 1982).

Estuarine marsh soils typically have a low redox potential because they are saturated with brackish or saline water. They are also high in organic matter because the saturated conditions slow decomposition rates. Thus they are an ideal environment for the reduction of the sulfate in brackish water to sulfide. If an iron source is present, sulfide will precipitate as iron sulfide minerals such as pyrite (Haering et al., 1989; Rabenhorst, 2001).

Marshes at the high salinity ranges generally have a lower diversity of vegetation, because fewer plants are adapted to a very saline environment (Wilson et al., 2007), although species diversity is not necessarily linear with salinity. Sharpe and Baldwin (2009) found that oligohaline (0.5–5 ppt salinity) marshes along the Nanticoke River had as many or more plant species than adjacent freshwater marshes. Lower salinity marshes can be often by identified by the presence of *Spartina cynosuroides* (big cord grass), *Pontederia cordata* (pickerel weed), *Leersia oryzoides* (rice cutgrass) *Peltandra virginica* (arrow arum), *Typha sp.* (cattail), and other species, including *Phragmites*, that are adapted to the transition zone between saline and fresh water (Darmody and Foss, 1979; Tiner and Burke, 1995, Sharpe and Baldwin, 2009).

Wetlands in areas with a large tidal range tend to have definite zones of vegetation delineating the low and high marsh areas, but zones of vegetation along the Chesapeake Bay, where the tidal range is <1m, are less pronounced (Rabenhorst, 2001). In more saline areas in Maryland., the low marsh is often characterized by large stands of *Spartina alterniflora* or smooth cordgrass (McCormick and Somes, 1982; Tiner and Burke, 1995), while the high marsh may contain more species, including *Spartina patens* (salt meadow cordgrass), *Juncus roemerianus* (black needlerush), and *Scirpus olneyi* (Olney three-square) and others. Darmody and Foss (1979) found that submerged upland marshes were identifiable by widespread, stands of *Juncus roemerianus* with some *Scirpus olneyi* in the brackish areas, and *Spartina patens* in the more saline areas. This was also observed by Tiner and Burke (1995), although he did not correlate it with soil properties. Odum (1988) noted that low marsh areas directly adjacent to tidal creeks tend to have higher primary productivity than high marsh areas because of increased nutrient exchange and lower sulfide concentrations.

The upland edge of the marsh generally contains the highest diversity of species, possibly because of the influence of fresh surface water or groundwater (Hemond and Fifield, 1984), and sometimes intergrades into upland forest. In Maryland, small areas of brackish woodland with *Pinus taeda* (loblolly pine) are often found along some mesohaline (5-18 ppt salinity) tidal creeks and rivers, and along the edges of the high marsh (Tiner and Burke, 1995; Harrison et al., 2004), but these communities may be relicts of sea level rise, and thus short lived.

Tidal fringe wetlands: Freshwater

Maryland's draft wetland classification (MDE Wetlands and Waterways Program, 2008) classifies all tidally influenced wetlands with a salinity of <0.5 ppt as *tidal freshwater*. Tidal freshwater wetlands form under the following conditions (Mitsch and Gosselink, 2000):

- Enough rainfall or river flow to maintain average salinity at <0.5 ppt.
- Relatively flat gradient from the ocean to inland.
- A tidal range that is high enough to move water upstream in estuaries and river channels.

In Maryland, tidal freshwater wetlands are primarily located in the river basins of the Upper Eastern and Western Shores and in the Patuxent and Middle Potomac watersheds, although some are also found along the upper reaches of the Nanticoke, Pocomoke, and Choptank river basins (Tiner and Burke, 1995). The soils form from a combination of mineral deposition of silts and clays from alluvial sediment and organic matter accumulation from wetland vegetation (Rabenhorst, 2001). They often have a low bearing capacity, and if they are located in areas of high sediment deposition, they may be mineral, rather than organic, soils.

The demarcation between tidal estuarine and tidal freshwater wetlands is actually a gradient, since salinity in the adjacent estuary or tidal river varies with season, river flow levels and amount of freshwater runoff (McCormick and Somes, 1982; Tiner and Burke, 1995). Cowardin et al. (1979) define the limit of wetlands associated with the Estuarine Systems as "upstream and landward to where ocean-derived salts measure less than 0.5 ppt during the period of average annual low flow." Baldwin et al. (2007) found that tidal wetlands along the Nanticoke River that met the criteria for classification as freshwater had higher salinity (up to 7 ppt) during droughts, and that this affected plant species distribution. They suggested that a more accurate name for these wetlands might be "salt-pulsed."

Freshwater tidal wetlands have a low marsh and high marsh zone defined by frequency of tidal inundation, but the border line between these two zones is typically not as apparent as that in estuarine tidal wetlands (Odum, 1988; Baldwin, 2004). Tidal forested wetlands are often located behind the high marsh. The elevation of the forested wetland may be lower than that of the high marsh, because sediment tends to be trapped and accumulate in the high marsh area (Barendregt et al., 2006). The vegetation in emergent and scrub-shrub tidal freshwater wetlands tends to be more diverse than that of most tidal estuarine wetland areas, particularly in the high marsh area (Baldwin, 2004). Low marsh areas are often dominated by *Nuphar luteum* (spatterdock.) and *Peltandra virginica*, while high marsh areas contain many more species. Detailed surveys can be found in McCormick and Somes, 1982; Tiner and Burke, 1995; and Pasternack et al., 2000.

Forested tidal freshwater wetlands tend to be located at the upper ends of the estuarine rivers, often bordering on nontidal forested wetlands (McCormick and Somes, 1982). The most predominant type of forested tidal freshwater wetlands in Maryland have been identified by McCormick and Somes (1982) and Harrison et al. (2004) as *Acer rubrum* (red maple) and *Fraxinus sp*. (ash) forest. *Taxodium distichum* (bald cypress) forests, which are similar in all properties except dominant hardwood type, are usually associated with the Pocomoke River watershed in Somerset and Worchester Counties. Healthy tidal forested wetlands are located at or above mean high water in the adjacent estuary or river, and often have a "hummock-hollow" microtopography, with trees growing on the elevated hummocks. In Maryland, the surface of *Taxodium distichum* dominated wetlands is typically at the mean high water mark, while the surfaces of *Acer rubrum-Fraxinus sp*. forests are generally located above the mean high water level (Day et al., 2007).

Odum (1988) has written an extensive review on the comparative ecology of tidal freshwater and tidal estuarine marshes that is summarized in Table 2 below. Note that he chose to compare freshwater wetlands to polyhaline estuarine wetlands. Oligohaline estuarine wetlands will likely have vegetation and soil properties that may be more similar to those of freshwater wetlands (Darmody and Foss, 1979; Tiner and Burke, 1995, Sharpe and Baldwin, 2009).

Table 2. Comparison of properties of tidal freshwater and polyhaline tidal estuarine wetlands (adapted and condensed from Odum, 1988, and Craft et al., 2009).

	Tidal Freshwater	**Tidal estuarine**
Location	Head of estuary, above oligohaline zone	Mid and lower estuary
Salinity	<0.5 ppt annual average	18-35 ppt annual average
Streambank and stream channel morphology	Low gradient, little undercutting, low sinuosity	Steeper gradient, undercutting, moderate to high sinuosity
Location relative to intertidal zone	Entire intertidal zone	Upper two thirds of intertidal zone (the lower third is mud flats)
Accretion rate	Higher than estuarine marshes because of lower decomposition rate	Generally lower than that of freshwater marshes
Soils	Silt/clay, high organic matter, lower peat/root content	Sandier, lower organic matter with higher peat and root content
Soil chemistry	Low in dissolved sulfur, with very few reduced sulfur/iron compounds. High in dissolved and particulate organic carbon	High in dissolved sulfur and in reduced sulfur/iron compounds. Moderate to low in dissolved and particulate organic carbon
Subsurface hydrology	Similar to estuarine wetlands, with more contributions from upland groundwater	Inflow: from tidal creeks, vertical infiltration from tidal water and precipitation, upland groundwater. Outflow: through creek banks and evapotranspiration.
Plant species diversity	High	Low; tend to be dominated by single species
Net primary productivity*	Difficult to estimate an average for freshwater marshes because of vegetative diversity, although freshwater/brackish (0-20 ppt salinity) marshes along the Georgia coast produced more aboveground biomass than did polyhaline marshes	
Decomposition rate of vascular plants	Rapid in intertidal zone, slow to moderate in high marsh zone	Slow to moderate
Invertebrate diversity (excepting insects)	Low	High
Reptile and amphibian diversity	High	Low
Fur-bearing mammals diversity and density	High species diversity; high density	Low to moderate species diversity; moderate density
Waterfowl diversity and density	High species diversity; high (but variable) density	Moderate species diversity; moderate density

*Primary productivity is the rate at which new plant biomass is formed by photosynthesis. Gross primary productivity equals the rate of energy fixed by photosynthetic production of biomass; net primary productivity is gross primary productivity minus energy expended by the respiration rate.

Nontidal wetlands

Overview

Nontidal wetlands are situated in every physiographic province in Maryland. The Coastal Plain province contains the largest acreage of nontidal wetlands (Tiner and Burke, 1995). Under the USFWS system (Cowardin et al., 1979), almost all of these nontidal wetlands would have been classified as Palustrine, with modifiers based on type of vegetation (forested, scrub-shrub, or emergent).

As stated in Table 1, the MDE Wetlands and Waterways Program (2008) has proposed a draft classification for Maryland's wetlands. Nontidal classes in this system are:

- **Nontidal riparian headwater**: These are wetlands associated with the riparian zone of waterways, floodplains, and transitional upland fringes of smaller (1^{st} to 3^{rd} order) streams. Most of these wetlands would be in the HGM riverine class, although some depressions and slope wetlands that are hydrologically connected to smaller order streams are also included.
- **Nontidal riparian mainstem**: These are wetlands associated with the riparian zone of waterway, floodplain, and transitional upland fringe of larger (> 3^{rd} order) streams. These would also be largely classified as riverine under the HGM system, although, again, some depressions and slope wetlands associated with larger order streams or rivers would be included.
- **Seasonal flat wetlands** (both isolated[9] and connected): These wetlands are broad, flat areas with poor drainage, either seasonally or semi-permanently flooded, and would be classified under HGM as mineral flats.
- **Peatlands** (both isolated and connected): These are broad, flat areas or depressions with sustained saturation and a thick organic layer located in all physiographic provinces except the Upper Coastal Plain. Specifically, these are described as "nontidal wetlands characterized by a sphagnous mat, organic soils, or accumulated peat, and soils saturated to the surface throughout the year with minimal fluctuations in water level" (MDE Wetlands and Waterways Program, 2008). They would be classified as organic flats or depressions under the HGM system.
- **Isolated depressions**: These are topographic low areas where water collects but does not drain externally by overland flow except during peak runoff episodes. They do not have a hydrologic connection to riparian or tidal waters. They are classified as HGM depression wetlands.
- **Isolated seepage slopes**: These are discharge area lacking evidence of channelized surface flow to riparian or tidal waters, and would be classified as HGM slope wetlands.
- **Constructed/incidental wetlands** – These are wetlands that have been created or maintained as a result of human activity. These can fall under any HGM class, including lacustrine fringe for wetlands that surround man-made reservoirs.

[9] Isolated means "not hydrologically connected by surface or subsurface flow to streams, tidal or nontidal wetlands, or tidal waters". (MDE Wetland and Waterways program, 2008)

> Some examples are mitigation wetlands that have not achieved full functioning, drainage ditches, human-made channels and canals, stormwater retention basins, mining pits, wetlands resulting from altered drainage patterns or impoundments as a result of highway and other construction, and so forth.

In most cases, the vegetation of nontidal wetlands is far more diverse than that of tidal estuarine wetlands. In Maryland, this diversity is emphasized because the climate varies so greatly from east to west, by aspect, and with elevation. Thus, it is difficult to generalize about typical vegetation in Maryland's nontidal wetland types. For a detailed survey of vegetation by wetland type and location, see Tiner and Burke (1995).

Vulnerabilities

While specific vulnerabilities will be discussed by wetland type (for example, the threat that stream channelization poses to riparian wetlands), all types of nontidal wetlands are vulnerable to human disturbance and other stressors. The list of possible stressors is long, and includes nearby development, road-building, nutrient pollution from point and non-point sources, acid rain, logging, drainage of adjacent areas, salinization, erosion, and urbanization or other increases in impervious surfaces (Moore et al., 1997; Ehrenfeld et al., 2003; Maryland Department of Natural Resources, 2005; Franklin et al., 2009). Fire, beaver activity, and other natural processes may also affect wetland function. Disturbance need not originate in areas in or adjacent to the wetlands: anything that changes hydrology, soils or vegetation can disrupt wetland functions. For example, the increase in impervious surfaces ensuing from urbanization usually decreases flood delay from surface storage of storm water and groundwater recharge, while increasing local temperature, runoff, upland and stream bank erosion, flooding, pollution, and sedimentation. Wetlands affected by urbanization often have rapid large changes in water levels and tend to be drier than unaltered wetlands (Ehrenfeld et al., 2003).

As in tidal wetlands, invasive plant, insect, and animal species can also disrupt natural functions, as can deer overpopulation and subsequent loss of vegetation (Maryland Department of Natural Resources, 2005). Decreased precipitation and increased temperatures resulting from climate change affects all nontidal wetlands. Wetlands where the primary source of water is precipitation are particularly vulnerable to warmer, drier climates (Moore et al., 1997; Winter, 2000), whereas nontidal wetlands where the primary source of water is groundwater are less likely to be affected by climate change. In Maryland, certain non-tidal wetlands have been designated by the state as having significant plant or wildlife value[10]. These include

a. Wetlands with the following unusual or unique community types:
    i. *Bogs:* Nontidal wetlands characterized by organic soils, accumulated peat, and soils saturated to the surface throughout the year with minimal fluctuation in water level.
    ii. *Areas with at least 20% of the following species:* Bald cypress (*Taxodium distichum*), Atlantic white cedar (*Chamaecyparis thyoides*), red spruce (*Picea rubens*), balsam fir (*Abies balsamea)*, or American larch (*Larix*

[10] http://www.dsd.state.md.us/comar/getfile.aspx?file=26.23.01.01.htm

laricina). Some examples of these are coniferous swamp forests in Garrett County, and bald cypress and Atlantic white cedar swamps on the Eastern Shore.

iii. *Delmarva bays.*

b. Wetlands with water discharge that maintains minimum stream base flow important for maintaining plant and wildlife species;
c. Wetlands with threatened or endangered species, or species in need of conservation;
d. Wetlands adjacent to Class III or Class IV waters defined in COMAR 26.08.02.08 (generally trout waters and public water supply)
e. Wetlands of Special State Concern (see below).
f. Wetlands that support vernal pools.

Selected wetlands have been classified as *Nontidal Wetlands of Special State Concern*, and require increased buffer areas (100 feet, as compared to 25 feet for other nontidal wetlands) and other best management practices. Nontidal Wetlands of Special State Concern are defined by the Code of Maryland Regulations as:

- wetlands that provide habitat or ecologically important buffers for the habitat of plant or animal species:
    1. Listed as endangered or threatened by the U.S. Fish and Wildlife Service, or
    2. Listed as endangered or threatened, or species listed as in need of conservation by the Maryland Department of Natural Resources, or
    3. Considered to be a candidate for listing by the U.S. Fish and Wildlife Service, or considered to be locally unusual or rare by the Maryland Department of Natural Resources,
- Are unique natural areas or contain ecologically unusual natural communities.

Nontidal wetland soils

Thiesing et al. (2004) has listed hydric soils indicators for Mid-Atlantic nontidal wetlands by HGM class and USDA-NRCS (U.S. Department of Agriculture Natural Resources Conservation Service) land resource regions and major land resource areas (USDA-NRCS, 2006a; USDA-NRCS, 2006b). Wetland soils are variable within each HGM class, but there is consistency in the distribution of hydric soil indicators among the different classes. Table 3 summarizes their work and indicates the approximate physiographic province in Maryland for each USDA-NRCS region/area. Further information on Mid-Atlantic hydric soils and redoximorphic features can be found in Mid-Atlantic Hydric Soils Committee (2004), and detailed criteria for hydric soils can be found in USDA-NRCS (2006b)

Table 3. Hydrogeomorphic (HGM) classes and common hydric soil indicators in Maryland non-tidal wetlands (adapted from data in Thiesing et al., 2004).

Wetland HGM Class	Approximate Maryland Physiographic Province	Common Hydric Soil Indicators	USDA Land Resource Regions and Major Land Resource Areas
Riverine	Allegheny Plateau	S5 (Sandy Redox), S7 (Dark Surface), F3 (Depleted Matrix), F12 (Iron-Manganese Masses)	N; 127
Riverine	Ridge & Valley, Piedmont, Upper Coastal Plain	S5 (Sandy Redox), S7 (Dark Surface), S9 (Thin Dark Surface), F3 (Depleted Matrix)	S; 147, 130A, 148, 149A
Riverine	Lower Coastal Plain	S5 (Sandy Redox), S7 (Dark Surface), S9 (Thin Dark Surface), F3 (Depleted Matrix), F12 (Iron-Manganese Masses)	T; 153C, 153D
Mineral Flats	Allegheny Plateau	A3 (Black Histic), A10 (2 cm Muck), A11 (Depleted Below Dark Surface), S5 (Sandy Redox), S7 (Dark Surface), F3 (Depleted Matrix), F6 (Redox Dark Surface)	N; 127
Mineral Flats	Ridge & Valley, Piedmont, Upper Coastal Plain	A3 (Black Histic), A11 (Depleted Below Dark Surface), S5 (Sandy Redox), S7 (Dark Surface), S9 (Thin Dark Surface), F3 (Depleted Matrix), F6 (Redox Dark Surface)	S; 147, 130A, 148, 149A
Mineral Flats	Lower Coastal Plain	A3 (Black Histic), A9 (1 cm Muck), A11 (Depleted Below Dark Surface), S5 (Sandy Redox), S7 (Dark Surface), S9 (Thin Dark Surface), F3 (Depleted Matrix), F6 (Redox Dark Surface)	T; 153C, 153D
Organic Flats	Upper Coastal Plain, Lower Coastal Plain	A3 (Black Histic)	S & T; 147, 130A, 148, 149A, 153C, 153D
Depressions	Allegheny Plateau	A10 (2 cm Muck), S5 (Sandy Redox), S7 (Dark Surface), F3 (Depleted Matrix), F6 (Redox Dark Surface), F8 (Redox Depressions)	N; 127
Depressions	Ridge & Valley, Piedmont, Upper Coastal Plain	S5 (Sandy Redox), S7 (Dark Surface), F3 (Depleted Matrix), F6 (Redox Dark Surface), F8 (Redox Depressions)	S; 147, 130A, 148, 149A
Depressions	Lower Coastal Plain	A9 (1 cm Muck), S5 (Sandy Redox), F3 (Depleted Matrix), F6 (Redox Dark Surface), F8 (Redox Depressions)	T; 153C, 153D
Slope	Allegheny Plateau	A11 (Depleted Below Dark Surface), S1 (Sandy Mucky Mineral), S5 (Sandy Redox), S7 (Dark Surface), F3 (Depleted Matrix), F6 (Redox Dark Surface)	N; 127
Slope	Ridge & Valley, Piedmont, Upper Coastal Plain, Lower Coastal Plain	A11 (Depleted Below Dark Surface), S1 (Sandy Mucky Mineral), S5 (Sandy Redox), S7 (Dark Surface), S9 (Thin Dark Surface), F3 (Depleted Matrix), F6 (Redox Dark Surface)	S & T; 147, 130A, 148, 149A, 153C, 153D

Isolated wetlands

The MDE Wetlands and Waterways Program (2008) has defined an *isolated wetland* as a "nontidal wetland not hydrologically connected by surface or subsurface flow to streams, tidal or nontidal wetlands, or tidal waters." These can include depressions, flats, and seepage slopes. Tiner (2003) suggests that more accurate terminology would be "geographically isolated wetlands" or "wetlands surrounded by upland," since many apparently isolated wetlands are hydrologically connected to other wetlands or to streams and rivers via groundwater, and/or are often ecologically connected to surrounding areas;

Whigham and Jordan (2003) have said that "isolation is a term that is not very useful from an ecosystem perspective." Isolated wetlands perform many functions that are associated with non-insolated wetlands: flood buffering, surface water storage, biogeochemical transformations, nutrient storage and transformation habitat, and so forth, and provide habitat for many U.S. endangered or at-risk plant and animal species (Leibowitz, 2003; Comer et al., 2005).

United States Supreme Court decisions in 2001 (Solid Waste Agency of Northern Cook County v. U.S. Army Corps of Engineers[11]) and 2006 (Rapanos v. United States[12]) have exempted many isolated wetlands from protection under the Clean Water Act, primarily because of a strict interpretation of connection to navigable waters. The Clean Water Restoration Act (S.B. 787)[13], which would reinstate many of these protections, is currently under consideration by Congress. The State of Maryland independently regulates isolated wetlands under State statute and regulation.

Riparian wetlands

Overview

Riparian corridors may be the most intricate and diverse terrestrial ecosystems because of their position as the interface between aquatic and upland systems (Naiman et al., 1993; Naiman and Decamps, 1997). Riparian wetlands are located along stream and river mainstem channels from bank to floodplain, and in the headwater area where channels tend to be less pronounced or absent. Along headwater streams, the actual riparian zone is generally smaller and/or less well defined than it is along larger streams and rivers (Richardson and Danehy, 2007).

Riparian wetlands are often forested (Brinson, 1995b; Mitsch and Gosselink, 2000), although some have emergent or scrub-shrub vegetation. One of the most common types of riparian wetlands in Maryland is floodplain forest (Maryland Department of the Natural Resources, 2005). Extensive stands of these seasonally flooded wetlands are located on the floodplains and natural levees of the Coastal Plain rivers, where they intergrade into tidal freshwater wetlands at the freshwater/oligohaline boundary. They

[11] http://www.epa.gov/owow/wetlands/pdf/2001supremecourt.pdf
[12] http://www.supremecourtus.gov/opinions/05pdf/04-1034.pdf
[13] http://thomas.loc.gov/cgi-bin/query/z?c111:S.+787:

are also commonly found along the Potomac River and its tributaries in the Piedmont and Ridge and Valley provinces, and, to a lesser extent, in the Allegheny Plateau.

Many riparian headwater and mainstem wetlands are classified as riverine under the HGM system. The exception would be slopes and depression wetlands that are in or connected to the floodplain of the river or stream system, although some of these are classified as riverine in regional HGM subclasses (Cole and Brooks, 2000a; Bleil, 2004; Lin, 2006). The depressions associated with the riparian headwater zone tend to form at either the bottom of a slope or around a seep that eventually enters a channel. They can be identified by their bowl shape. Associated slope wetlands may also form at the foot of a slope, but do not have closed contour lines (Hough and Cole, 2009). Depressions such as vernal pools also form in the floodplain of riparian mainstem areas and these also function as part of the riparian ecosystem (Smith and Klimas, 2002; Bleil, 2004; Lin, 2006). The hydrodynamics of both riparian headwaters and mainstem wetlands is a combination of bidirectional (to and from channel), horizontal, and vertical flow (MDE Wetlands and Waterways Program, 2008).

Functions

Brinson (1995b) has outlined typical hydrological, geochemical, and habitat functions for riverine wetlands (Tables 4a, 4b, 4c).

Table 4a. Hydrologic functions of riverine wetlands (collated and condensed from Brinson, 1995b).

Hydrologic Function	Description
Dynamic Surface Water Storage	**Definition:** Capacity of a wetland to detain moving water from overbank flow for a short duration when flow is out of the channel. (floodwater detention) **Effects Onsite:** Replenishes soil moisture; import/export of sediments, nutrients, contaminants and plant propagules; provides access for aquatic organisms. **Effects Offsite:** Reduces downstream peak discharge; delays downstream delivery of peak discharges; improves water quality.
Long-Term Surface Water Storage	**Definition:** Capacity of a wetland to temporarily store surface water for long durations. **Effects Onsite:** Replenishes soil moisture; removes sediments, nutrients, and contaminants; detains water for chemical transformations; maintains vegetative composition; maintains habitat; influences soil characteristics. **Effects Offsite:** Improves water quality; maintains base flow; maintains seasonal flow distribution; lowers the annual water yield; recharges groundwater.
Energy Dissipation	**Definition:** Allocation of the energy of water to other forms as it moves through, into, or out of the wetland as a result of roughness and/or obstructions. **Effects Onsite:** Increases deposition of suspended material; increases chemical transformations and processing due to longer residence time. **Effects Offsite:** Reduces downstream peak discharge; delays delivery of peak discharges; improves water quality; reduces erosion of shorelines and floodplains.
Subsurface Storage of Water	**Definition:** Availability of water storage beneath the wetland surface. **Effects Onsite:** Short- and long-term water storage; influences biogeochemical processes in the soil; retains water for establishment and maintenance of biotic communities. **Effects Offsite**: Recharges groundwater; maintains base flow; maintains seasonal flow distribution.
Moderation of Groundwater Flow or Discharge	**Definition**: Capacity for wetland to moderate the rate of groundwater flow or discharge from upgradient sources. **Effects Onsite:** Prolonged wetness/saturated soil conditions; extended growing season; moderate soil temperatures. **Effects Offsite:** Maintains groundwater storage, base flow, seasonal flow regimes, and surface water temperature.

Table 4b. Biogeochemical functions of riverine wetlands (collated and condensed from Brinson, 1995b, with some added notes in brackets).

Biogeochemical Function	Description
Nutrient Cycling	**Definition:** Abiotic and biotic processes that convert nutrients and other elements from one form to another. **Effects Onsite:** Gains through import processes and losses through hydraulic export, efflux to the atmosphere, and long-term retention in persistent biomass and sediments. **Effects Offsite:** Reduces the level of nutrient loading offsite *[Note: This, and retention of particulates, would also add to carbon sequestration. However, the denitrification process in wetlands also produces the greenhouse gas N_2O (Jordan et al., 2007)].*
Removal of Imported Elements and Compounds	**Definition:** The removal of imported nutrients, contaminants, and other elements and compounds. **Effects Onsite:** Nutrients and contaminants in surface or ground water that come in contact with sediments are either removed from a site or rendered noncontaminating because they are broken down into biogeochemically inactive forms. Effects Offsite: Chemical constituents removed and concentrated in wetlands, regardless of source, reduce downstream loading. *[see note above regarding denitrification]*
Retention of Particulates	**Definition:** Deposition and retention of inorganic and organic particulates from the water column, primarily through physical processes. **Effects Onsite:** Contributes nutrients and organic matter, increases surface elevation and changes topography. **Effects Offsite:** Reduces stream sediment and woody debris. *[See note above regarding carbon sequestration.]*
Organic Carbon Export	**Definition:** Export of dissolved and particulate organic carbon from a wetland by leaching, flushing, and displacement, and erosion. **Effects Onsite**: Removes organic matter, possibly mobilizes chelated metals. **Effects Offsite:** Provides support for aquatic food webs downstream.

Table 4c. Habitat functions of riverine wetlands (collated and condensed from Brinson, 1995b).

Habitat Function	Description
Maintain Characteristic Plant Communities	**Definition:** Maintaining species composition and physical characteristics of living plant. **Effects Onsite:** Photosynthesis of energy**.** Provides seeds. Provides habitat for animals, including both long- and short-term habitat for resident or migratory animals. Creates microclimatic conditions that support plants and animals, and roughness that reduces velocity of floodwaters. Provides organic matter for soil development and soil-related nutrient cycling processes. **Effects Offsite:** Source of propagules for nearby ecosystems. Provides habitat and food for migratory and cover for transient animals. Provides migratory pathways, enhances species diversity and ecosystem stability. Supports primary and secondary production in associated aquatic habitats, as well as providing material for habitat in these ecosystems.
Maintain Characteristic Plant Detrital Biomass	**Definition:** The production, accumulation and dispersal of dead plant biomass of all sizes – either from onsite or upslope – including standing and fallen woody debris. **Effects Onsite:** Provides primary resources for supporting detrital-based food chains. Provides important resting, feeding, hiding, and nesting sites for animals. Provides surface roughness and particulate detention and retention. Adds organic matter to soil **Effects Offsite**: Source of dissolved and particulate organic matter and nutrients for downstream ecosystems. Reduces downstream peak discharges and delayed downstream delivery of peak discharges. Contributes to downstream water quality through particulate retention and detention.
Maintain Vegetation Structure of Animal Habitat	**Definition:** The capacity of a wetland to support animal populations and guilds by providing heterogeneous habitats. (*Vegetation structure* refers to dimensional complexity and not to species composition. Communities possessing greater structural complexity are often more diverse.) **Effects Onsite:** Provides potential feeding, resting, and nesting sites, regulates and moderates fluctuations in temperature, provides habitat heterogeneity to support a diverse assemblage of organisms. Affects all ecosystem processes. **Effects Offsite:** Provides habitat heterogeneity to landscape, provides habitat for wide-ranging and migratory animals, provides a corridor for gene flow between separated populations, and allows progeny to exploit new areas.
Maintain Animal Interspersion and Connectivity	**Definition:** The capacity of a wetland to permit aquatic organisms to enter and leave the wetland via channels, overbank flow, or aquifers and the capacity of a wetland to permit access of terrestrial or aerial organisms to contiguous areas of food and cover. **Effects Onsite:** Provides habitat diversity. Contributes to secondary production, and provides access to and from wetland for reproduction, feeding, rearing, and cover. Contributes to completion of life cycles and dispersal between habitats. **Effects Offsite:** Provides corridors for wide-ranging or migratory species. Provides conduits for dispersal of plants and animals to other areas.
Maintain Distribution and Abundance of Invertebrates	**Definition:** The capacity of a wetland to maintain characteristic density and spatial distribution of invertebrates. **Effects Onsite:** Provides food to predators, aerates soil, decomposes debris, increases organic matter availability for microbes, and disperses seeds within site. **Effects Offsite:** Provides food (energy) for wide-ranging carnivores/insectivores, etc. Transports seeds and propagules for germination elsewhere.
Maintain Distribution and Abundance of Vertebrates	**Definition:** The capacity of a wetland to maintain characteristic density and spatial distribution of vertebrates that utilize wetlands for food, cover, rest, and reproduction. **Effects Onsite:** Disperses seeds throughout site, pollinates flowers (bats), aerates soil and woody debris with tunnels, and alters hydroperiod and light regime (beavers). **Effects Offsite:** Disperses seeds between sites, pollinates flowers (bats), provides food for predators, alters hydroperiod, light regime, and downstream flows (beavers).

Vulnerabilities

Stream channelization, damming, levee building, and other flood control measures are major threats to the effective functioning of riparian wetlands (Ehrenfeld et al., 2003; Franklin et al., 2009). Flood control structures particularly affect riparian mainstem ecosystems which are dependent on the natural riparian flooding and drying cycle (Johnson, 2002). Artificial drainage and changing watershed land use patterns such as increasing agriculture, logging, or urbanization also inhibit and reduce the number of riparian wetland functions. For example, Baker et al. (2007) studied nutrient filtering in riparian buffer zones which included wetlands in 503 watersheds of the Chesapeake Bay drainage area. They found that nutrient filtering capacity was limited both by the proximity of agricultural land to stream channels and the presence of large acreages of cropland within a watershed. Large cropland areas produced higher nutrient runoff concentration than the riparian area was able to buffer. Decades of urban runoff have resulted in the downcutting of stream channels, reducing the frequency of overbank flooding into riparian wetlands. New flood control structures and impoundments are now only rarely authorized in wetlands.

Surveys of wetland history and extent in the Nanticoke River Watershed (Tiner and Berquist, 2003; Tiner, 2005) show that 38% of all pre-colonial wetlands were lost (destroyed, channelized or drained) by 1998. As a result, Tiner (2005) estimated that the Nanticoke watershed lost 60% of its ability to maintain stream flow, and over one-third of its ability to detain surface water, transform nutrients, retain sediment and provide wildlife habitats. Whigham et al. (2007) found that riverine wetlands, specifically, had low scores for many hydrologic and biogeochemical functions. Habitat functional capacity was not as degraded, apparently because vegetation was still growing in areas with altered hydrology.

Riparian headwater wetlands

Riparian headwater wetlands are wetlands that are hydrologically connected to streams of a third order or less. They can include floodplain forests, scrub-shrub wetlands, emergent wetlands, forested seepage (slope) wetlands, bogs and fen complexes, and vernal pools[14] (Smith et al., 1995; MDE Wetlands and Waterways Program, 2008). Riparian headwater wetlands are located in all of Maryland's physiographic provinces, thus vegetation is quite diverse (Maryland Department of Natural Resources, 2005).

The water source for riparian headwater depressions is primarily groundwater, while water sources for some associated slope wetlands include both groundwater and surface runoff. Surface water from precipitation and occasional overbank flooding are important sources of water for other headwater floodplain wetlands (Brinson, 1995b; Cole et al., 1997; Cole and Brooks, 2000a; MDE Wetlands and Waterways Program, 2008; Hough and Cole, 2009). Riparian headwater wetlands lose water by flow to the channel (either

[14] Vernal pools are defined by the Maryland Department of Natural Resources (2005) as small depressions with no surface outlet that typically fill in the fall and winter and dry up in the summer. However, the term vernal pool originally referred to seasonally flooded wetlands in a Mediterranean climate – for example, on the West Coast of the U.S. (Mitsch and Gosselink, 2000).

surface or subsurface), evapotranspiration, and some infiltration to groundwater (Smith et al., 1995). These tend to be outflow wetlands (Tiner and Berquist, 2003; Bleil, 2004) because water leaves but does not enter by means of surface flow.

Headwaters are the areas where water originates in a stream channel network, and are composed of interconnected terrestrial, wetland, and aquatic systems that support downstream areas with sediment, water, nutrients, and organic materials. The topographic components of a headwater system are outlined by Gomi et al. (2002) as:

1. The associated hill slopes.
2. “Zero-order basins”: depressions which may be either wet or dry.
3. Ephemeral or “transitional” channels that emerge from the basins.
4. First and second order stream channels (They note that third-order streams may be included in the headwater system if they receive material from surrounding slopes rather than solely from the channel).

Materials transported by processes in headwater zones proceed from adjacent slopes to stream channels, thus the slopes are an integral part of the headwater ecosystem. Headwater areas tend to be zones where some organic and mineral material accumulates and some is transported downstream and deposited in the channel or floodplain. Wardrop and Brooks (1988) found that headwater floodplains and depressions had a higher mineral sedimentation rate than mainstem floodplain wetlands, while headwater depressions had higher rates of organic matter accumulation than either headwater or mainstem floodplains.

It is difficult to separate ecological processes in headwater wetlands from those in associated uplands and streams because they are interconnected. Some general ecologic characteristics of headwater areas are (Richardson and Danehy, 2007):

- High ratio of stream edge to surface.
- High inputs of organic matter from surrounding vegetation, particularly in areas with a closed forest canopy.
- Low light input, moderation in temperature, groundwater input and high air moisture, especially in closed canopy areas. This microclimate may provide habitat for certain species of plants and animals that cannot survive elsewhere.
- Few to no fish because of periodic low flows, thus reduced predation from both fish and animals that prey on fish.
- Small habitats that are vulnerable to disturbance.
- Generally low flows even during storms, resulting in less habitat disruption. Large input of organic matter in forested headwaters (food source) and larger particles of organic matter than downstream areas.
- Source of organic matter, water filtration, and nursery/spawning areas.

Havens et al. (2006) noted that headwater wetlands are important in maintaining water quality in downstream ecosystems because they have a high capacity for processing potential pollutants such as inorganic nitrogen.

Since headwater channels are usually small, have low flows in summer, and are located in thickly forested areas, the extent of headwater streams is often underestimated (Naiman and Decamps, 1997; Richardson and Danehy, 2007). Brooks et al. (2009) estimated that headwater streams and their related floodplains, wetlands and uplands occupied approximately 65-75% of the drainage basin for associated rivers in the eastern U.S. Thus headwater areas have a major effect on the entire watershed, particularly on "buffer" functions, which are more effective in smaller catchment areas (Naiman and Decamps, 1997).

Rheinhardt et al. (1999) thought it was likely that only 1% of the headwater ecosystems in the inner Coastal Plain of North Carolina were undamaged, mostly because of stream channelization and draining and filling of floodplains for agricultural purposes. Many agricultural areas now drain directly into channelized headwater streams. Thus the natural wetland and floodplain buffer areas that protect against non-point source pollution in riparian areas have been destroyed or bypassed, resulting in eutrophication in downstream rivers and estuaries.

Riparian mainstem wetlands

Riparian mainstem wetlands are defined as wetlands that are hydrologically connected to fourth order or larger streams or rivers. They can include floodplain forests, scrub-shrub wetlands, emergent wetlands, and vernal pools. The water source for riparian mainstem wetlands is primarily some form of surface water (overbank or overland), but subsurface flow between stream and wetland, and groundwater inputs are also possible water sources (Smith et al., 1995; MDE Wetlands and Waterways Program, 2008). Like headwater wetlands, mainstem wetlands lose water by surface or subsurface flow to the channel through evapotranspiration, and possibly some seepage to groundwater (Smith et al., 1995).

Healthy floodplain ecosystems require a hydrologic connection to the adjacent stream or river, provided by surface and groundwater flow, including overbank flooding (Tockner and Schiemer, 1997). Flooding allows exchange of nutrients, organic matter, biota, and sediment between the floodplain and the river, and increases productivity levels in both (Johnson et al., 1995). Flooding also controls the hydrology in floodplain wetlands (Cole and Brooks, 2000a).

Tiner and Berquist (2003) and Bleil (2004) characterized riparian floodplain wetlands in the Nanticoke River watershed as having two kinds of hydrology:

- Bidirectional flow: input through overbank flooding; output through soil drainage.
- Through-flow: input from overbank flooding; output through an outlet channel.

Both Bleil (2004) and Lin (2006) noted that depressional wetlands in the floodplain tended to export materials downstream because of overbank flooding, and had functional capabilities that were similar to wetlands in the HGM riverine class.

In Cole and Brooks' (2002a, 2002b) studies in the Ridge and Valley province of Pennsylvania, mainstem floodplain wetlands were the driest wetlands associated with the riparian zone, with the possible exception of associated depressions (Bleil, 2004). Most of the Pennsylvania mainstem wetlands rarely had standing water, and although they were flooded during the spring, or after storm events, they were generally dry for months in the summer and fall, with water levels below the root zone. This hydroperiod permits some species that are adapted to upland soils to become established. Johnson (2002) also noted that the periodic flooding and drying characteristic of the floodplain ecosystem allowed more diversity of vegetation than that found in permanently saturated areas.

Franklin et al. (2009) found that the largest cause of disturbance in floodplain wetlands in western Tennessee was channelization and levee construction, which altered subsurface hydrology and diminished the ability of the wetland to remove pollutants and export organic carbon. Floodplains are also particularly vulnerable to being converted to agriculture since they are nearly level and possess very productive soils.

Seasonal flats

Overview

Flats are broad wetlands with nearly level relief (Rheinhardt et al., 2002; Whigham and Jordan, 2003; MDE Wetlands and Waterways Programs, 2008; Jordan et al., 2007). Because of the lack of relief, lateral drainage is poor, and some may lack channelized surface flow except after unusual events. When precipitation occurs, temporary ponding may develop, the water does not run off the area rapidly, and hydric soil conditions develop. Flats often have poor vertical drainage because of the presence of slowly permeable or impermeable subsoil horizons. Degree of soil wetness depends on how impermeable the associated subsoil layers are (Bleil, 2004), as well as on topography and connection to channelized flow paths from ditches. Flats usually have no to very little surface flooding (Whigham and Jordan, 2003), but spring ponding is not unusual. Flats with high levels of soil saturation may actually be very large depressions (Tiner and Berquist, 2003; Smith and Klimas, 2002).

There are two HGM classes for flats: mineral and organic (Smith et al., 1995), depending on the type of soil they contain. In Maryland's draft wetland classification system, organic flats are included with organic depressions in the "peatlands" class, while mineral flats are termed "seasonal flats." Seasonal flats can be found in every physiographic province in Maryland, but they are most common in the Coastal Plain, where they occur on interfluve areas, riparian headwaters, and floodplain and hillslope terraces (Tiner and Berquist, 2003; Bleil, 2004; MDE Wetlands and Waterways Program, 2008). They are saturated in winter and early spring, but water levels drop during the summer (Tiner and Berquist, 2003).

Flats may be either isolated or non-isolated. Tiner (2005) describes isolated wetlands, including flats, as those where the wetlands is "surrounded by upland (non-hydric soil); receives precipitation and runoff from adjacent areas with no apparent outflow." This is as opposed to throughflow wetlands, where waterways or other wetlands are located above and below the wetland (i.e. flats that are part of the riparian mainstem complex and others); inflow wetlands, which have no aboveground outlet, but where water enters from a stream or other wetland, or outflow wetlands with water leaving by waterway or slope (i.e. riparian headwaters). Mineral flats can contain ephemeral low order streams as well as ditches, and may be conduits of sheet flow runoff between uplands and streams. The main water source is precipitation, rather than surface or groundwater flow (Smith et al., 1995; Rheinhardt et al., 2002; MDE Wetlands and Waterways Program, 2008), so the prevailing hydrodynamics are vertical: inputs from precipitation and water loss from evaporation and seepage. Groundwater movement may influence flat hydrology if the flat is surrounded by uplands of higher elevation (Bleil, 2004; North Carolina Division of Forest Resources, 2006).

Examples of mineral flats ecosystems are wet pine flats, wet hardwood flats, non-riverine swamp forest and mixed pine-hardwood flats (North Carolina Division of Forest Resources, 2006). Both upland and wetland pine flats developed originally as a result of fires which burned the understory every few years, retarding the natural tendency towards hardwood succession (Rheinhardt et al., 2002). Organic soils and fine-textured mineral soils are both wetter than the sandy soils that support non-hydrophytic pines, so these areas tended not to burn. As a result, wet hardwood flats developed on areas with poorly-drained fine-textured mineral soil. Mineral flats are often characterized by micro-depressions or ridge/swale topography, and may include larger depressions (Smith and Klimas, 2002).

Functions

Functions of flats have been summarized by Havens et al. (2001); Rheinhardt et al. (2002) and Smith and Klimas (2002):

- Maintenance of characteristic hydrology, which is important in maintaining biogeochemical and habitat functions.
- Capture and storage of precipitation.
- Maintenance of characteristic flora and fauna. Flats provide an important connection between floodplains and upland areas. This allows animals to find shelter during floods, and also helps maintain ecosystem diversity by preventing habitat isolation.
- Nutrient/elemental cycling. Since hydrology is controlled by precipitation, nutrient levels are usually low. This, coupled with the low depth and velocity of flooding levels and the characteristic microtopography, provides an ideal environment for nutrient cycling as nutrients are released during litter decomposition or, particularly, after fires. However, since flat receive little surface runoff, they likely do not contribute as much to downstream water quality improvement as other types of wetlands.
- Export of dissolved organic compounds via surface water (for non-isolated flats only), although the rate of export may be very low compared to other wetland types.

Non-isolated flats associated with headwater areas and mainstem floodplains perform more hydrologic and geochemical functions (such as surface water detention, streamflow maintenance, sediment retention, nutrient export, and so forth). However, all seasonally flooded and wetter areas have high potential for nutrient cycling, particularly the removal of nitrate from groundwater via denitrification (Tiner and Berquist, 2003). [Note that denitrification produces N_2O, a greenhouse gas (Jordan et al., 2007)]. Draining of disturbance of isolated flats would likely result in nutrient release to groundwater and surface water (Whigham and Jordan, 2003).

Vulnerabilities

Human practices which affect flat functions are artificial drainage, water impoundments, soil excavation or fill within the flat, channelization, and nearby agricultural or urban development, including road building near or within the flat (Havens et al., 2001; Bleil, 2004; Whigham et al., 2007; Jordan et al., 2007). Many flats in the watershed have been artificially drained for use as pine plantations and other forestry (Whigham et al., 2007; Jordan et al., 2007). Pine flats, which depend on periodic fires, have been lost because of the institution of fire controls (Rheinhardt et al., 2002.)

Peatlands

Overview

Peatlands are "broad, flat areas or depressions with sustained saturation and deep peat" (MDE Wetlands and Waterways Program, 2008). They include bog and fen ecosystems. Nearly all of the wetlands in Maryland that are commonly termed "bogs" are not true bogs because they are all supported by groundwater (Maryland Department of Natural Resources, 2005). Both bogs and fens have organic soils, but bogs are *ombrotrophic*, meaning that they receiving water input almost exclusively from precipitation. Thus they are acidic, and are vegetated with mosses and other vegetation that is adapted to acidic conditions. Fens are *mineratrophic*: they receive water input from groundwater (Mitsch and Gosselink, 2000). The formation of any kind of peatland requires a relatively constant water input that is greater than the evapotranspiration rate and a rate of organic matter accumulation that is greater than the decomposition rate.

Peatlands are classified as either organic flats, depressions, or seepage slopes under the HGM system (Richardson and Brinson, 2003; MDE Wetlands and Waterways Program, 2008). Types of peatlands in Maryland include (Sipple and Klockner, 1984; Maryland Department of Natural Resources, 2005; Fleming et al., 2006):

- High elevation bog wetland complexes (Appalachian bogs): Although these are not common, they are the most abundant of all Maryland's bog/fen habitats, and are primarily found in Garrett County. These are often, but not always, found on seepage slopes and along streams. These are typically not true bogs because they receive input from groundwater; one exception is The Glades in Garret County[15].
- Coastal Plain bogs: The remnants of these rare wetlands are mostly located in the Magothy River watershed in or near Anne Arundel County. Like true bogs, they have deep peat layers, and are vegetated with Sphagnum mosses along with other types of shrub and emergent vegetation (including some rare species). They are

[15] http://www.nature.org/wherewework/northamerica/states/maryland/preserves/art4783.html

usually located on steams, ponds, and along seepage slopes. These are typically not true bogs because they receive input from groundwater.

- Piedmont bogs: These rare wetlands occur in similar locations to Coastal Plain bogs, but tend to support different plant species groups. These are typically not true bogs because they receive input from groundwater.
- Sea level fens: These extremely rare wetlands are saturated seepage wetlands that are found where groundwater discharges at the bottom of a slope along the edge estuarine bays. Few of these remain, and those that do are threatened by rising sea levels.

Some Delmarva Bays may contain organic soils, although organic surface layers are not as common in Delmarva Bays as they are in the same type of landform in North and South Carolina (Sharitz, 2003). In a survey of Delmarva Bays in Maryland and southern Delaware, Stolt and Rabenhorst (1987a) found that more than 20% of soils in wooded bays were Histosols or had histic epipedons.

Other types of peatlands in Maryland may include those listed by the North Carolina Division of Forest Resources (2006) as organic wet pine flats, white cedar forests with organic soils, nonriverine swamp forests and pocosins. True pocosins are not found in Maryland (Richardson, 2003; Tiner, 2003), but it's likely that some examples of these other types are found on the Coastal Plain.

Peatlands may be either connected or isolated by surface flow, although "surface isolated" peatlands are always connected ecologically or via groundwater to the surrounding ecology and hydrologic system. Connected peatlands can have discernible inlets or outlets or can be connected by unchannelized currents (Brinson, 1993), and include those on seepage slopes, in riparian headwaters, or along streams or ponds. Isolated peatlands would be those with groundwater input/output only, such as those in closed depressions and possibly some on interfluves (Richardson, 2003). The hydrodynamics of depression and flat peatlands are dominantly vertical, while those of seepage slope peatlands are dominated by horizontal unidirectional water flow (Smith et al., 1995; MDE Wetlands and Waterways Program, 2008).

Functions

Brinson (1993) defines some specific functions of peatlands as:

- Storage of surface runoff and groundwater,
- Primary production and organic matter export (in mineratrophic peatlands), and
- Unique habitat for plants and other biota.

Organic soils may hold several hundred percent of their weight in water, making peatlands an important ecological sponge for storage of runoff and reservoir of soil water. Peatlands sequester carbon at a higher rate than mineral soils (Hussein et al., 2004), and thus also serve as a source of dissolved organic carbon for downstream wetlands and ecosystems. Because peatland areas in Maryland are relatively small, their most important function after carbon sequestration is likely to be plant and animal habitat, especially for rare and endangered species that are specifically adapted to these ecosystems (Warren et al., 2004; Maryland Department of Natural Resources, 2005).

Vulnerabilities

Peatland ecosystems are obviously vulnerable to anything that alters hydrology such as soil or plant removal, fire, drainage, lake construction, and urbanization or other development. They are particularly susceptible to rising temperatures resulting from climate change, since this speeds organic matter decomposition rates (Moore et al., 1997). Other threats include shrub and tree invasion, which may occur as a result of fire controls; nutrient or pollutant runoff; and invasive species such as *Phragmites* (Maryland Department of Natural Resources, 2005). Many plants found in peatlands require a specific (often acidic) pH range for survival, and are thus vulnerable to human activities that promote calcium and salts in runoff such as urbanization, road construction and salting for ice prevention.

Isolated depressions

Overview

Isolated depressions are closed contour areas which have no aboveground connection to riparian or tidal waters. Water sources are precipitation and/or groundwater discharge, with occasional surface water inputs. Water loss pathways are evapotranspiration and/or infiltration. Therefore hydrodynamics are dominantly vertical and seasonal (Brinson, 1993; Smith et al., 1995; Tiner and Berquist, 2003; Whigham and Jordan, 2003; Vasilas et al., 2008). The soil in depressions may be either organic, mineral, or a mineral soil with a histic epipedon. Depressions with organic soils would be classified as "peatlands" under Maryland's draft wetland classification (MDE Wetlands and Waterways Program, 2008).

Specific types of isolated depressions in Maryland include (MDE Wetlands and Waterways Program, 2008; Maryland Department of Natural Resources, 2005; Stolt and Rabenhorst, 1987a; Tiner, 2003):

- Delmarva Bays: located on the Delmarva Peninsula, primarily Caroline and Queen Anne's County
- Vernal pools: found in every physiographic province, but most common on the Coastal Plain.
- Upland depressional swamps: found in the Piedmont and Coastal Plain[16].

Delmarva Bays are Carolina Bays that are located on the Delmarva Peninsula. A Delmarva Bay is defined in the Code of Maryland Regulations[17] as "a nontidal wetland characterized by an elliptical or oval shape and centripetal drainage, usually bordered by a distinct rim, that is (a) Located in a depression with seasonal surface water that is

[16] Note: Fleming et al. (2006) restricts upland depressional swamps in Virginia to the Piedmont. Occurrences in the Coastal Plain appear to be classified as "Coastal Plain Depressions", although this category may include some vernal pools as well.
[17] http://www.dsd.state.md.us/comar/getfile.aspx?file=26.23.01.01.htm

absent in summer; (b) Generally located on the Delmarva Peninsula; and (c) Thinly forested or unforested with abundant herbaceous vegetation that may be apparent only after surface water recedes in the summer."

Stolt and Rabenhorst (1987b) estimated that there are between 1500 and 2500 Delmarva Bays on the northern part of the peninsula, most of which have been altered or damaged by drainage or conversion to agricultural fields. Delmarva Bays are elliptically shaped, and typically (but not always) have sandy soil around the rim. Many Delmarva Bays were likely formed by wind erosion and may be sandy or silty with low clay content. They may have either emergent, scrub-shrub or forest vegetation (or a combination), and a range of hydrologic conditions from permanently saturated to seasonally dry (Sharitz, 2003). They provide habitat support for numerous species of amphibians, and habitat for many species of rare vascular plants, along with other diverse flora and fauna (Sipple and Klockner, 1984; Sharitz and Gibbons, 1982; Tiner, 2003). They also function as groundwater recharge and discharge areas, add to base flow via groundwater, and possibly serve to remove nitrate from groundwater (Tiner, 2003; Sharitz, 2003).

The Code of Maryland Regulations[18] defines a vernal pool as "a nontidal wetland in a confined depression that has surface water for at least 2 consecutive months during the growing season, and: (a) Is free of adult fish populations; (b) Provides habitat for amphibians; and (c) Lacks abundant herbaceous vegetation. Vernal pools are saturated in fall, winter, and spring, but often dry completely during the summer (Tiner, 2003; Maryland Department of Natural Resources, 2005). Like Delmarva Bays, they are important habitats for amphibians. Some vernal pools are found on headwater and floodplain wetlands, but isolated vernal pools are not connected to a riparian system. Vernal pools and Delmarva Bays are combined in the category of "seasonal pools" by Brown and Jung (2005). Seasonal pools are defined as small, shallow, isolated wetlands that periodically dry out completely. This can happen every summer, or may occur during droughts only. They sustain populations of animal species that are adapted to seasonally dry environments. Since they do not contain fish, they are ecologically important to species which are vulnerable to fish predation. Several species of salamanders and frogs require seasonal pools in order to reproduce; as does the fairy shrimp, a crustacean in the order Anostraca (Brown and Jung, 2005).

Upland depression swamps are seasonally flooded, forested wetlands found in both the Coastal Plain and in the Piedmont, where they are commonly found in Triassic basins. They typically have a perched water table resulting from impermeable or slowly permeable soil layers or bedrock. Water comes primarily from precipitation and surface runoff. As a result, they are usually flooded during spring and drier during summer and fall. Some of these wetlands contain rare ecological communities such as Atlantic white cedar swamps, and all provide plant and wildlife habitat. Most upland depressional swamps have been disturbed by human activities, and only a small number remain intact (North Carolina Division of Forest Resources, 2006; Maryland Department of Natural Resources, 2005; Fleming et al., 2006).

[18] http://www.dsd.state.md.us/comar/getfile.aspx?file=26.23.01.01.htm

Functions

Functions for isolated depressions in both the Mid-Atlantic region and other parts of the U.S. have been outlined by Tiner (2003), Whigham and Jordan (2003), Sharitz (2003); Havens et al. (2003); Bleil (2004), Lin (2006), and Gilbert et al. (2006) as:

- Storing water.
- Mitigation of flooding via surface runoff because of water storage.
- Recharging groundwater.
- Retaining particulates and sediment.
- Removing, converting, and sequestering dissolved substances, particularly nitrate.
- Maintaining plant communities (including rare and endangered species).
- Providing faunal habitat for both obligate and facultative species (particularly important for amphibians because they often require areas with fluctuating water levels.)
- Carbon sequestration.

Sharitz (2003) felt the most important function of Delmarva Bays and similar depressions was as a habitat for varied and rare plants and animals, especially those that are adapted to a seasonal hydroperiod

Vulnerabilities

Since isolated depressions are often small, they are easy to drain for agriculture, forestry, or other development (Tiner, 2003; Sharitz, 2003; Havens et al., 2003; Brown and Jung, 2005; Maryland Department of Natural Resources, 2005). Because of their shape, they have often been used as dumping grounds, stormwater detention ponds, or as the recipients of drainage from agricultural fields. Since isolated depressions have no riparian input or outflow, the water stored in them is likely to be lost through evapotranspiration or deep percolation. In such wetlands that have been drained and farmed, there is potential for leaching of fertilizer inputs to the groundwater. Increased groundwater withdrawals can permanently alter hydrology of depressions, even those that are protected, and may result in colonization by upland species, or by invasive plants.

Bleil (2004) found that depression wetlands in the Nanticoke River watershed were negatively affected by a number of human activities. Faunal habitat for amphibians and reptiles was degraded because of a lack of woody debris caused by logging. Nearby construction of roads and ditches changed both hydrological and habitat functions. Farm fields and ditches located either in or at the edge of the depression resulted in nutrient loading or sedimentation, and forestry or grazing within the depression changed plant species plant species composition, evapotranspiration levels, and hydroperiod.

Isolated seepage slopes

Overview

Slope wetlands, also known as seepage slopes, occur where groundwater is discharged at the surface of the land (Brinson, 1993: Smith et al., 1995). This usually happens on a slope where the groundwater level intersects the land surface, often above an impermeable layer of soil or rock. Seepage slopes can occur on nearly level areas, and can be distinguished from depressions because they lack closed contour lines and have an outlet. The water source is primarily groundwater, with input from surface flow from surrounding upland areas and precipitation. Hydrodynamics are unidirectional and downslope. Slope wetlands lose water by subsurface and surface flow from the wetland after it becomes saturated, and from evapotranspiration.

Brinson (1993) described two typical situations for slope wetlands: sideslope seeps where groundwater meets the land surface or slope base seepage where groundwater wells up to meet the slope break. In the central Appalachians of Pennsylvania, slope wetlands are divided into similar subclasses: stratigraphic seepage wetlands, located on sideslopes in the middle of the slope gradient, and toeslope wetlands, located at the bottom of the slope gradient (Cole et al., 2008).

Isolated seepage slopes are those that are not connected with surface waters, which excludes the slope wetlands found in riparian headwater and mainstem areas. Vasilas et al. (2008) noted that slope wetlands formed on sideslopes in the Piedmont province are often the source of first order streams, while toeslope wetlands generally do not have a direct surface water connection to streams. Fens often form on seepage slopes, but under Maryland's draft classification, these are classified under peatlands (MDE Wetlands and Waterways Program, 2008).

Seepage slope wetlands occur in all the physiographic provinces of Maryland (Maryland Department of Natural Resources, 2005), although they have not been widely studied. In Maryland, most are forested wetlands, although some contain patches of emergent and scrub-shrub vegetation. Magnolia "bogs" are a type of mineral seepage slope wetlands found along the fall line in Maryland and the northern part of Virginia (Simmons and Strong, 2003; Maryland Department of Natural Resources, 2005). They are acidic seeps which are found on gravel terraces where groundwater moves through the aquifer over an impermeable clay layer. They generally have forest/shrub vegetation with a few patches of emergents, and can contain rare or uncommon species.

Slope wetlands are generally small, although the ultimate size depends on the amount of groundwater discharge (Brinson, 1993). Groundwater chemistry determines the level of nutrients supplied to the wetland and also the pH.

According to Brinson (1993), slope wetlands supplied by shallow perched groundwater aquifers often become dry during the summer because of water uptake by surrounding vegetation. Vasilas et al. (2008) found that Piedmont slope wetlands in Maryland, Delaware and Pennsylvania that formed on sideslopes tended to be permanently saturated, while those formed on toeslopes often experienced periods of seasonal dryness. Areas with emergent vegetation tended to be the most saturated. Cole and Brooks (2000a) found that slope wetlands in the Ridge and Valley province of Pennsylvania were seldom inundated, and that subsurface water levels were within the root zone for about half the year. Tufford et al. (2008) discovered that flow within some South Carolina slope wetlands continued even during times of drought.

Functions

Functions of slope wetlands have been discussed by Brinson (1993); Whigham and Jordan (2003), Vasilas et al. (2005), Fleming et al. (2006); Vasilas et al. (2008) and Tufford et al. (2008), and are summarized below:

- Surface and shallow subsurface water storage: Although Whigham and Jordan (2003) state that slope wetlands are capable of storing very little surface water compared to other wetland types, this is likely only true for sideslope wetlands. Water tends to pond at toeslope wetlands during periods of seasonal saturation (Vasilas et al., 2008)
- Nutrient cycling and removal of sediment and pollutants from groundwater: including considerable amounts of nitrate. Slope wetlands may remove particulates and dissolved compounds from surface runoff if flow rates are not too fast.
- Organic carbon export and carbon sequestration: If groundwater supplies nutrients, then primary productivity and subsequent organic matter accumulation will be high (Brinson, 1993).
- Support a diversity of wetland plant communities, including some rare species.
- Provide surface moisture during seasonal dry times.
- Provide habitat for fauna, especially aquatic and semi-aquatic species (Tufford et al., 2008).
- Maintain ecosystem diversity.

Vulnerabilities

Seepage slope wetlands have similar vulnerabilities to other types of nontidal wetlands. Because they are typically small and often located within forested upland areas where they are hidden by closed canopy cover, many remain unmapped. They are thus sometimes not recognized as wetlands, and are vulnerable to logging, grazing, and both urban and agricultural development (Maryland Department of Natural Resources, 2005; Fleming et al., 2006). Seepage wetlands are also in danger from any process that alters groundwater hydrology such as aquifer drawdown, or nearby pond or drainage structure construction, and wetland drainage may result in nutrient pollution downstream (Whigham and Jordan, 2003).

Excess nutrients and other pollutants originating from groundwater and surface water contamination can alter biogeochemical processes and species composition within the wetland (Maryland Department of Natural Resources, 2005; Fleming et al., 2006). If nearby areas are cleared or developed, wetland functioning may be damaged by sedimentation. Because the water source in seepage slope wetlands is primarily groundwater, however, they are thought to be less likely to be affected by climate change than wetlands which rely on surface water (Winter, 2000).

Altered, constructed, or incidental wetlands

Altered, constructed, and incidental wetlands are defined in Maryland's draft wetland classification system as "wetlands actively managed or established by human activity," which have "disturbed conditions that are not comparable to natural reference wetlands, and have increased or decreased functional performance and benefits as a result of human actions." Wetlands in this class that evolve to become comparable to natural reference wetlands can then be reassigned to the appropriate class.

This class specifically includes:

- Wetlands that are constructed solely to improve water quality (for example, stormwater or sediment ponds).
- Mitigation or restored wetlands that have not matured.

This class specifically excludes:

- Wetlands where humans deliberately attempt to replicate a natural activity (for example, tree removal to imitate the effects of periodic fires).

Wetlands in this class can also be members of any of the HGM classes. Regional subclasses proposed by Brooks et al. (in prep.) that cover similar wetlands classify these wetlands under the appropriate HGM class. Borrow pits, farm ponds and some mitigation sites are classified as depressions/ human impounded or excavated. Wetlands associated with reservoirs are classified as lacustrine fringe/artificially flooded. Mill ponds and large non-depressional farm ponds are classified as riverine/human impounded. Waterfowl impoundments are classified as estuarine/impounded.

Unlike other examples given above, mitigation wetlands are deliberately constructed in an attempt to replace the full suite of functions in a comparable natural wetland that has been damaged or destroyed as a result of human activity. Wetland mitigation involves either wetland *creation*, where non-tidal wetlands are constructed on upland areas; wetland *restoration*, where wetland conditions are reinstated in former wetland areas; or wetland *enhancement*, where additional work is done to help improve wetland functioning, for example, re-planting wetland vegetation in formerly farmed wetlands (Walbeck and Clearwater, 1998).

Most wetland sites constructed for mitigation in Maryland are successful and appear to have appropriate trajectory for replacing intended functional services (MDE Wetland and Waterways Program, 2008). In 2007, the success of 92 mitigation sites was evaluated using a scoring method that evaluated vegetation, soils, hydrology, and function. Seventy-three of these sites, which covered 95% of the total acreage evaluated, were deemed to be successful. Sites that failed had a variety of problems. The most common issue was inability to establish the correct hydrology: the sites were either too wet or too dry. Other issues involved vegetation failure, low soil organic matter levels, and stony surface soils.

List of references

Baker, M.E., D.E. Weller, and T.E. Jordan. 2007. Improved methods for quantifying potential nutrient interception by riparian buffers. Landscape Ecology 21:1327–1345.

Baldwin, A.H. 2004. Restoring complex vegetation in urban settings: The case of tidal freshwater marshes. Urban Ecosystems 7:125-137.

Baldwin, A.H. 2007. Vegetation and seed bank studies of salt-pulsed swamps of the Nanticoke River, Chesapeake Bay. p. 139–160. *In* W. H. Conner, et al. (ed.) Ecology of tidal freshwater forested wetlands of the southeastern United States. Springer Netherlands.

Barendregt, A., D.F. Whigham, P. Meire, A.H. Baldwin, and S.V. Damme. 2006 Wetlands in the tidal freshwater zone. p. 117-148. *In* R. Bobbink et al. (ed.) Wetlands: Functioning, biodiversity conservation, and restoration. Springer, Berlin Heidelberg.

Bleil, D. 2004. Wetland profile for the Nanticoke River watershed. Final report for Wetland Program Development Grant CD-98337701, EPA Region III. Maryland Department of Natural Resources, Annapolis, MD.

Brinson, M.M. 1993. A hydrogeomorphic classification for wetlands. Technical Report WRP-DE-4. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Brinson, M.M., R.R. Christian, and L.K. Blum. 1995a. Multiple states in the sea-level induced transition from terrestrial forest to estuary. Estuaries and Coasts 18:648-659.

Brinson, M.M., F.R. Haner, L.C. Lee, W.L. Nutter, R.D. Rheinhardt, R.D. Smith, and D. Whigham. 1995b. A guidebook for application of hydrogeomorphic assessment to riverine wetlands. Technical Report WRP-DE-11. U.S. Army Engineers, Waterways Experiment Station, Vicksburg, MS.

Brooks, R., M. McKenney-Easterling, M. Brinson, R. Rheinhardt, K. Havens, D. O'Brien, J. Bishop, J. Rubbo, B. Armstrong, and J. Hite. 2009. A Stream–Wetland–Riparian (SWR) index for assessing condition of aquatic ecosystems in small watersheds along the Atlantic slope of the eastern U.S. Environmental Monitoring and Assessment 150:101-117.

Brooks, R.P., M.M. Brinson, K.J. Havens, C.S. Hershner, R.D. Rheinhardt, D.H. Wardrop, D.F. Whigham, A.D. Jacobs, and J.M. Rubbo. (in prep.). Proposed hydrogeomorphic classification for wetlands of the Mid-Atlantic region, USA. Funded through U.S. EPA agreement R-82868401 in support of the Atlantic Slope Consortium. Available on-line at: http://www.asc.psu.edu/public/pubs/Articles/HGMmidAtlClass_ASCversion.pdf

Brown, L.J., and R.E. Jung. 2005. An introduction to Mid-Atlantic seasonal pools. EPA/903/B-05/001. U.S. Environmental Protection Agency Office of Research and Development, Fort Meade, MD.

Cahoon, D.R., D.J. Reed, A.S. Kolker, M.M. Brinson, J.C. Stevenson, S. Riggs, R. Christian, E. Reyes, C. Voss, and D. Kunz. 2009. Coastal wetland sustainability. p. 191-239. *In*: Coastal sensitivity to sea-level rise: A focus on the Mid-Atlantic region. A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. J.G. Titus (coordinating lead author), K.E. Anderson, D.R. Cahoon, D.B. Gesch, S.K. Gill, B.T. Gutierrez, E.R. Thieler, and S.J. Williams (lead authors). U.S. Environmental Protection Agency, Washington, DC.

Carter, Virginia. 1996. Technical aspects of wetlands: Wetland hydrology, water quality, and associated functions. *In* National Water Summary on Wetland Resources. USGS Water Supply Paper 2425. U.S. Geological Survey, Reston, VA.

Chambers, R.M., L.A. Meyerson, and K. Saltonstall. 1999. Expansion of *Phragmites australis* into tidal wetlands of North America. Aquatic Botany 64:261-273.

Clearwater, D., P. Turgeon, C. Noble, and J. LaBranche. 2000. An overview of wetlands and water resources of Maryland. Report prepared for Maryland Wetland Conservation Plan Work Group. Maryland Department of the Environment, Baltimore, MD. Available on-line at:
http://www.mde.state.md.us/assets/document/wetlandswaterways/h2Oresources.pdf

Cole, C.A., R.P. Brooks, and D.H. Wardrop. 1997. Wetland hydrology as a function of hydrogeomorphic (HGM) subclass. Wetlands 17:456–467.

Cole, C.A., and R.P. Brooks. 2000a. Patterns of wetland hydrology in the Ridge and Valley Province, Pennsylvania, USA. Wetlands 20:438-447.

Cole, C.A., and R.P. Brooks. 2000b. A comparison of the hydrologic characteristics of natural and created mainstem floodplain wetlands in Pennsylvania. Ecological Engineering 14:221-231.

Cole, C.A., C.P. Cirmo, D.H. Wardrop, R.P. Brooks, and J. Peterson-Smith. 2008. Transferability of an HGM wetland classification scheme to a longitudinal gradient of the central Appalachian Mountains: initial hydrological results. Wetlands 28:439-449.

Comer, P., K. Goodin, A. Tomaino, G. Hammerson, G. Kittel, S. Menard, C. Nordman, M. Pyne, M. Reid, L. Sneddon, and K. Snow. 2005. Biodiversity values of geographically isolated wetlands in the United States. NatureServe, Arlington, VA. Available on-line at: http://www.natureserve.org/publications/isolatedwetlands.jsp.

Constanza, R., R. d'Arge, R. deGroot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. O'Neill, J. Paruelo, R. G. Raskin, P. Sutton, and M. v. d. Belt. 1997. The value of the world's ecosystem services and natural capital. Nature 387:253-260.

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. FWS/OBS-79/31. Office of Biological Services, U.S. Department of the Interior Fish and Wildlife Service. Washington, DC.

Craft, C. 2007. Freshwater input structures soil properties, vertical accretion, and nutrient accumulation of Georgia and U.S. tidal marshes. Limnology and Oceanography 52:1220-1230.

Craft, C., J. Clough, J. Ehman, S. Joye, R. Park, S. Pennings, H.Y. Guo, and M. Machmuller. 2009. Forecasting the effects of accelerated sea-level rise on tidal marsh ecosystem services. Frontiers in Ecology and the Environment 7:73-78.

CSSP. 2009. Coastal sensitivity to sea-level rise: A focus on the Mid-Atlantic region. A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. James G. Titus (Coordinating lead author), K. Eric Anderson, Donald R. Cahoon, Dean B. Gesch, Stephen K. Gill, Benjamin T. Gutierrez, E. Robert Thieler, and S. Jeffress Williams (Lead authors). U.S. Environmental Protection Agency, Washington, DC.

Dacey, J.W.H., and B.L. Howes. 1984. Water uptake by roots controls water table movement and sediment oxidation in short *Spartina* marsh. Science 224: 487-489.

Darmody, R.G., and J.E. Foss. 1979. Soil-landscape relationships of the tidal marshes of Maryland. Soil Science Society of America Journal 43:534-541.

Ehrenfeld, J.G., H.B. Cutway, R.H. IV, and E. Stander. 2003. Hydrologic description of forested wetlands in northeastern New Jersey, USA - an urban/suburban region. Wetlands 23:685-700.

Environmental Laboratory. 1987. Corps of Engineers Wetlands Delineation Manual. Technical Report Y-87-1. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. Available at: http://el.erdc.usace.army.mil/wetlands/pdfs/wlman87.pdf

Fennessy, M. S., A. D. Jacobs, and M. E. Kentula. 2004. Review of rapid methods for assessing wetland condition. EPA/600/R-04/009. U.S. Environmental Protection Agency. Washington, DC.

FitzGerald, D.M., M.S. Fenster, B.A. Argow, and I.V. Buynevich. 2009. Coastal impacts due to sea-level rise. Annual Review of Earth and Planetary Sciences 36:601-647.

Fleming, G.P., P.P. Coulling, K.D. Patterson, and K. Taverna. 2006. The natural communities of Virginia: classification of ecological community groups. Second approximation. Version 2.2. Virginia Department of Conservation and Recreation, Division of Natural Heritage, Richmond, VA. Available on-line at: http://www.dcr.virginia.gov/natural_heritage/ncintro.shtml.

Franklin, S.B., J.A. Kupfer, R. Pezeshki, R. Gentry, and R.D. Smith. 2009. Efficacy of the hydrogeomorphic model (HGM): A case study from western Tennessee. Ecological Indicators 9:267-283.

Gilbert, M.C., P.M. Whited, J. Ellis J. Clairain, and R.D. Smith. 2006. A regional guidebook for applying the hydrogeomorphic approach to assessing wetland functions of prairie potholes. ERDC/EL TR-06-5. U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Gomi, T., R.C. Sidle, and J.S. Richardson. 2002. Understanding processes and downstream linkages of headwater systems. BioScience 52:905-916.

Haering, K.C., M.C. Rabenhorst, and D.S. Fanning. 1989. Sulfur speciation in some Chesapeake Bay tidal marsh soils. Soil Science Society of America Journal 53:500-505.

Harrison, J.W., P.Stango III, and M.C. Aguirre. 2004. Forested tidal wetland communities of Maryland's Eastern Shore: Identification, assessment and monitoring. Prepared for the U.S. Environmental Protection Agency Clean Water Act 1998 State Wetlands Protection Development Grant Program. Maryland Natural Heritage Program, Maryland Department of Natural Resources, Annapolis, MD.

Havens, Kirk J., Cary Coppock, David Stanhope, Rebecca Thomas, and Gene Silberhorn. 2001. A draft regional guidebook for applying the hydrogeomorphic approach to wet hardwood flats on mineral soils in the Coastal Plain of Virginia. Final report to the U.S. Environmental Protection Agency. Center for Coastal Resources Management, Virginia Institute of Marine Science, Gloucester Point, VA.

Havens, Kirk J., David O'Brien, David Stanhope, Kory Angstadt, Dan Schatt, Donna Marie Bilkovic, and Carl Hershner. 2006. Intermediate development of a forested headwater wetland HGM model for wetlands management in Virginia. Final report to the U.S. Environmental Protection Agency. Center for Coastal Resources Management, Virginia Institute of Marine Science, Gloucester Point, VA.

Havens, Kirk J., David O'Brien, David Stanhope, Rebecca Thomas, and Gene Silberhorn. 2003. Initiating the development of a draft woody depressional wetland HGM model for the Coastal Plain of Virginia. Final report to the U.S. Environmental Protection Agency. Center for Coastal Resources Management, Virginia Institute of Marine Science, Gloucester Point, VA.

Hemond, H.F., and J.L. Fifield. 1982. Subsurface flow in salt marsh peat: A model and field study. Limnology and Oceanography 27:126-236.

Hopfensperger, K.N., S.S. Kaushal, S.E.G. Findlay, and J.C. Cornwell. 2009. Influence of plant communities on denitrification in a tidal freshwater marsh of the Potomac River, United States. Journal of Environmental Quality 38:618-626.

Hough, Z., and C.A. Cole. 2009. Aboveground decomposition dynamics in riparian depression and slope wetlands of central Pennsylvania. Aquatic Ecology 43:335-349.

Hussein, A.H., M.C. Rabenhorst, and M.L. Tucker. 2004. Modeling of carbon sequestration in coastal marsh soils. Soil Science Society of America Journal 68:1786-1795.

Johnson, B.L., W.B. Richardson, and T.J. Naimo. 1995. Past, present, and future concepts in large river ecology. BioScience 45:134-141.

Johnson, W.C. 2002. Riparian vegetation diversity along regulated rivers: contribution of novel and relict habitats. Freshwater Biology 47:749–759.

Jordan, T.E., M.P. Andrews, R.P. Szuch, D. F.Whigham, D.E. Weller, and A.D. Jacobs. 2007. Comparing functional assessments of wetlands to measurements of soil characteristics and nitrogen processing. Wetlands 27:479–497.

Kroes, D.E., C.R. Hupp, and G.B. Noe. 2007. Sediment, nutrient, and vegetation trends along the tidal, forested Pocomoke River, Maryland. p. 113–137, *In* W. H. Conner, et al. (ed.) Ecology of tidal freshwater forested wetlands of the southeastern United States. Springer Netherlands.

Leibowitz, S.G. 2003. Isolated wetlands and their functions: an ecological perspective. Wetlands 23:517–531

Lin, J.P. 2006. A regional guidebook for applying the hydrogeomorphic approach to assessing wetland functions of depressional wetlands in the Upper Des Plaines River Basin. ERDC/EL TR-06-4. U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Marble, A.D. 1992. A guide to wetland functional design. Lewis Publishers, Boca Raton, FL.

Maryland Department of Natural Resources. 2005. Key wildlife habitats and their conservation. Chapter 4. Maryland Wildlife Diversity Conservation Plan. Maryland Department of Natural Resources, Annapolis, MD. Available on-line at: http://www.dnr.state.md.us/wildlife/divplan_wdcp.asp.

McCormick, J., and H.A. Somes Jr. 1982. The coastal wetlands of Maryland. Prepared for the Maryland Department of Natural Resources Coastal Zone Management Program. J. McCormick and Associates, Inc., Chevy Chase, MD.

Maryland Department of the Environment. 2003. Maryland State Wetland Conservation Plan. 174 pp.

MDE Wetlands and Waterways Program. 2008. Maryland wetland monitoring strategy: Background and discussions, years 1-3. Maryland Department of the Environment and Maryland Department of Natural Resources, Baltimore, MD, and Annapolis, MD.

MDE Wetlands and Waterways Program. 2007. Effectiveness of Maryland compensatory mitigation program. Final report to the U.S. Environmental Protection Agency. Maryland Department of the Environment, Baltimore, MD. Available on-line at: http://www.mde.state.md.us/Programs/WaterPrograms/Wetlands_Waterways/about_wetlands/mitigation_report.asp

Meyerson, L.A., K. Saltonstall, R.M. Chambers. 2009. *Phragmites australis* in eastern North America: a historical and ecological perspective. p. 57-82. *In* B.R. Silliman, et al. (ed.) Salt marshes under global siege. University of California Press, Berkeley, CA.

Mid-Atlantic Hydric Soils Committee. 2004. A guide to hydric soils in the Mid-Atlantic Region. Version 1.0. L.M. Vasilas and B.L. Vasilas (ed.) U.S. Department of Agriculture Natural Resources Conservation Service, Morgantown, WV. Available on-line at: http://www.epa.gov/reg3esd1/wetlands/hydric.htm

Mitsch, W.J., and J.G. Gosselink. 2000. Wetlands. 3rd edition. John Wiley and Sons, New York.

Moore, M.V., M.L. Pace, J.R. Mather, P.S. Murdoch, R.W. Howarth, C.L. Folt, C.Y. Chen, H.F. Hemond, P.A. Flebbe, and C.T. Driscoll. 1997. Potential effects of climate change on freshwater ecosystems of the New England/Mid-Atlantic region. Hydrological Processes 11:925-947.

Naiman, R.J., H. Decamps, and M. Pollock. 1993. The role of riparian corridors in maintaining regional biodiversity. Ecological Applications 3:209-212.

Naiman, R.J., and H. Decamps. 1997. The ecology of interfaces: Riparian zones. Annual Review of Ecology and Systematics 28:621-658.

North Carolina Division of Forest Resources. 2006. Appendix 11: Seven common types of forested wetlands, p. 237-238. *In* North Carolina forestry best management practices manual. Publication number FM-08-01. North Carolina Division of Forest Resources Raleigh, NC.

Novitzki, R.P., R. Daniel Smith, and J.D. Fretwell. 1996. Restoration, creation, and recovery of wetlands: Wetland functions, values and assessment. *In* National Water Summary on Wetland Resources. USGS Water Supply Paper 2425. . U.S. Geological Survey, Reston, VA.

Odum, W.E. 1988. Comparative ecology of tidal freshwater and salt marshes. Annual Review of Ecology and Systematics 19:147-176.

Pasternack, G.B., W.B. Hilgartner, and G.S. Brush. 2000. Biogeomorphology of an upper Chesapeake Bay river-mouth tidal freshwater marsh. Wetlands 20:520-537.

Rabenhorst, M.C. 1995. Carbon storage in tidal marsh soils. p. 93–103. *In* R. Lal, et al. (ed.) Soils and global change. CRC Press, Boca Raton, FL.

Rabenhorst, M.C. 2001. Soils of tidal and fringing wetlands. p. 301-316. *In* J. L. Richardson and M. J. Vepraskas (ed.) Wetland soils: Genesis, hydrology, landscapes, and classification. Lewis Publishers, Chelsea, MI.

Reed, D.J., D.A. Bishara, D.R. Cahoon, J. Donnelly, M. Kearney, A.S. Kolker, L.L. Leonard, R.A. Orson, and J.C. Stevenson. 2008. Site-specific scenarios for wetlands accretion as sea level rises in the Mid-Atlantic region. Section 2.1. *In* J.G. Titus and E.M. Strange (ed.) Background Documents Supporting Climate Change Science Program Synthesis and Assessment Product 4.1. EPA 430R07004. U.S. Environmental Protection Agency, Washington, DC.

Rheinhardt, R.D., M.C. Rheinhardt, M.M. Brinson, and J. Karl E. Faser. 1999. Application of reference data for assessing and restoring headwater ecosystems. Restoration Ecology 7:241-251.

Rheinhardt, R.D., M.C. Rheinhardt, and M.M. Brinson. 2002. A regional guidebook for applying the hydrogeomorphic approach to assessing wetland functions of wet pine flats on mineral soils in the Atlantic and Gulf Coastal Plains. ERDC/EL TR-02-9. U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Rice, D., J. Rooth, and J. Court Stevenson. 2000. Colonization and expansion of *Phragmites australis* in upper Chesapeake Bay tidal marshes. Wetlands 20:280-299.

Richardson, J.L., and M.M. Brinson. 2001. Wetland soils and the hydrogeomorphic classification of wetlands. p. 209-227. *In* J. L. Richardson and M. J. Vepraskas (ed.) Wetland soils, genesis, hydrology, landscapes, and classification. Lewis Publishers, Chelsea, MI.

Richardson, C.J. 2003. Pocosins: Hydrologically isolated or integrated wetlands on the landscape. Wetlands 23:563-576.

Richardson, J.S., and R.J. Danehy. 2007. A synthesis of the ecology of headwater streams and their riparian zones in temperate forests. Forest Science 53:131-147.

J.E. Rooth, J.E., and J.C. Stevenson. 2000. Sediment deposition patterns in *Phragmites australis* communities: Implications for coastal areas threatened by rising sea-level. Wetlands Ecology and Management 8: 173–183.

Shafer, D.J., and D.J. Yozzo. 1998. National guidebook for application of hydrogeomorphic assessment to tidal fringe wetlands. Technical Report WRP-DE-16. U.S. Army Corps of Engineers Waterways Experiment Station Vicksburg, MS.

Sharitz, R.R., and J. Whitfield Gibbons. 1982. The ecology of southeastern shrub bogs (pocosins) and Carolina Bays: A community profile. FWS/OBS-82-04. U.S. Fish and Wildlife Service, Division of Biological Services, Washington, DC.

Sharitz, R.R. 2003. Carolina Bay wetlands: Unique habitats of the Southeastern United States. Wetlands 23:550–562.

Sharpe, P.J., and A.H. Baldwin. 2009. Patterns of wetland plant species richness across estuarine gradients of Chesapeake Bay. Wetlands 29:225–235.

Simmons, R., and M. Strong. 2003. Fall Line magnolia bogs of the Mid-Atlantic region. Marilandica 11:19-20.

Sipple, W.S., and W.A. Klockner. 1984. Uncommon wetlands in the coastal plain of Maryland p. 111-138. *In* A. W. Norden, et al. (ed.). Threatened and endangered plants and animals of Maryland: proceedings of a symposium held September 3-4, 1981 at Towson State University, Towson, Maryland. Maryland Department of Natural Resources, Annapolis, MD.

Smith, R.D., and C.V. Klimas. 2002. A regional guidebook for applying the hydrogeomorphic approach to assessing wetland functions of selected regional wetland subclasses, Yazoo Basin, Lower Mississippi River Alluvial Valley. ERDC/EL TR-02-4. U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Soil Survey Staff. 2006. Keys to Soil Taxonomy, 10th edition. U.S. Department of Agriculture Natural Resources Conservation Service, Washington, DC. Available on-line at: ftp://ftp-fc.sc.egov.usda.gov/NSSC/Soil_Taxonomy/keys/keys.pdf

Stevenson, J.C., J.E. Rooth, K.L. Sundberg, and M.S. Kearney. 2000. The health and long term stability of natural and restored marshes in Chesapeake Bay. p. 709-735. *In* M. P. Weinstein and D. A. Kreeger (ed.) Concepts and controversies in tidal marsh ecology. Springer Netherlands.

Stolt, M.H., and M.C. Rabenhorst. 1987a. Carolina Bays on the Eastern Shore of Maryland: I. Soil characterization and classification. Soil Science Society of America Journal 51:394-398.

Stolt, M.H., and M.C. Rabenhorst. 1987b. Carolina Bays on the Eastern Shore of Maryland: II. Distribution and origin. Soil Science Society of America Journal 51:399-405.

Thiesing, Mary Ann, Lenore M. Vasilas, and Erin Patrick. 2004. Mid-Atlantic wetland landscapes and hydric soil indicators. p. 71-76 *In* Mid-Atlantic Hydric Soils Committee. 2004. A guide to hydric soils in the Mid-Atlantic Region. Version 1.0. L.M. Vasilas and B.L. Vasilas (ed.) U.S. Department of Agriculture Natural Resources Conservation Service, Morgantown, WV. Available on-line at: http://www.epa.gov/reg3esd1/wetlands/hydric.htm

Tiner, R.W., and D.G. Burke. 1995. Wetlands of Maryland. U.S. Fish and Wildlife Service, Ecological Services, Region 5, Hadley, MA and Maryland Department of Natural Resources, Annapolis, MD.

Tiner, R.W. 2003. Geographically isolated wetlands of the United States. Wetlands 23:494–516.

Tiner, R.W., and H.C. Berquist. 2003. Historical analysis of wetlands and their functions for the Nanticoke River watershed: A comparison between pre-settlement and 1998 conditions. NWI Technical Report, National Wetlands Inventory (NWI) Program U.S. Fish and Wildlife Service, Hadley, MA.

Tiner, R.W. 2005. Assessing cumulative loss of wetland functions in the Nanticoke River watershed using enhanced National Wetlands Inventory data. Wetlands 25:405–419.

Tockner, K., and F. Schiemer. 1997. Ecological aspects of the restoration strategy for a river-floodplain system on the Danube River in Austria. Global Ecology and Biogeography Letters 6:321-329.

Tufford, D.L., S.H. Bennett, N. Brunswig, and J.B. Nelson. 2008. Conservation values of seepage slope wetlands on the US southeast Coastal Plain (abstract). Annual Meeting of the International Congress for Conservation Biology, July 13-18, Chattanooga, TN. Society for Conservation Biology, Washington, DC.

US Army Corps of Engineers. 2008. Interim Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Atlantic and Gulf Coastal Plain Region. ERDC/EL TR-08-30. U.S. Army Engineer Research and Development Center, Vicksburg, MS 39180-6199. Available on-line at: http://el.erdc.usace.army.mil/elpubs/pdf/trel08-30.pdf

USDA-NRCS. 2006a. Land resource regions and major land resource areas of the United States, the Caribbean, and the Pacific Basin. U.S. Department of Agriculture Handbook 296. U.S. Department of Agriculture Natural Resources Conservation Service. Available at: http://soils.usda.gov/survey/geography/mlra/

USDA-NRCS. 2006b. Field indicators of hydric soils in the United States, Version 6.0. G.W. Hurt and L.M. Vasilas (ed.) U.S. Department of Agriculture Natural Resources Conservation Service and the National Technical Committee for Hydric Soils. Available at: ftp://ftp-fc.sc.egov.usda.gov/NSSC/Hydric_Soils/FieldIndicators_v6_0.pdf

USEPA. 1998. Wetland biological assessments and HGM functional assessment. EPA843-F-98-001f. U.S. Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Washington, DC.

USFWS. 2002. National Wetlands Inventory: A strategy for the 21st century. U.S. Department of the Interior Fish and Wildlife Service, Washington, DC.

Vasilas, B., A. Whelchel, and L. Vasilas. 2005. The hydrogeomorphic approach to functional assessment for Piedmont slope wetlands. *In* Managing Watersheds for Human and Natural Impacts: Engineering, Ecological, and Economic Challenges. Proceedings of the 2005 Watershed Management Conference. 19-22 Jul 2005, Williamsburg, VA. American Society of Civil Engineers, Reston, VA.

Vasilas, Bruce, Jeffry Fuhrmann, Jacob Bowman, William Ritter, and Anastacia Chirnside. 2008. Monitoring and assessing the nutrient status and overall health of freshwater wetlands. Final report to Maryland Department of the Environment, Baltimore, MD.

Walbeck, D. and D. Clearwater. 1998. Maryland nontidal wetland mitigation guidance. Maryland Department of the Environment, Wetlands and Waterways Program, Baltimore, MD.

Wardrop, D.H., and R.P. Brooks. 1998. The occurrence and impact of sedimentation in central Pennsylvania wetlands. Environmental Monitoring and Assessment 51:119-130.

Warren, R.J., J.D. Pittillo, and I.M. Rossell. 2004. Vascular flora of a Southern Appalachian fen and floodplain complex. Castanea 69:116-124.

Whigham, D.F., and T.E. Jordan. 2003. Isolated wetlands and water quality. Wetlands 23:541–549.

Whigham, D.F., A.D. Jacobs, D.E. Weller, T.E. Jordan, M.E. Kentula, S.F. Jensen, and D.L. Stevens. 2007. Combining HGM and EMAP procedure to assess wetlands at the watershed scale - Status of flats and non-tidal riverine wetlands in the Nanticoke River watershed, Delaware and Maryland (USA). Wetlands 27:462–478.

Wilson, M.D., B.D. Watts, and D.F. Brinker. 2007. Status review of Chesapeake Bay marsh lands and breeding marsh birds. Waterbirds 30:22-137.

Winter, T.C. 2000. The vulnerability of wetlands to climate change: a hydrologic landscape perspective. Journal of the American Water Resources Association 36:305-311.