

Chapter 2

Hydrogeomorphic (HGM) Classification, Inventory, and Reference Wetlands

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Abstract Classifying wetlands is useful for describing and managing their natural variability. The hydrogeomorphic (HGM) approach, which covers classification, reference, and functional assessment aspects, has proven to be helpful in classifying wetlands as to their position in the landscape, their source of water, and the flow of that water. In this chapter, we review the origins and characteristics of freshwater wetlands for ecoregions of the Mid-Atlantic region (MAR), which are dominated by riverine types. Inventories of wetlands in the MAR are dated, so we discuss what is known with regard to status and trends, and potential solutions. We discuss the value of establishing a reference set to assist with classification, assessment, and mitigation of wetlands, and describe the set of reference wetlands compiled for Pennsylvania by Riparia. Preliminary results from a regional condition assessment of wetlands in the MAR are provided.

2.1 Classification

We classify things, habitats included, because we need a way to systematically organize the data or information we have collected into a conceptual framework that is useful to us. A natural resource inventory can be described as a list of observable

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or measurable physical, chemical, and biological features. These inventory “snapshots” from a narrow window of space and time were used to group types of streams into categories defined by specific objectives (Naiman et al. 2005). Similarly, if we wish to develop a representation of the land cover and land use for a geographic area, spectral signatures from satellite imagery can be grouped to represent forest, field, or urban lands. We can group wetland plants into families and genera to populate a botanical classification system, or into functional groups, or guilds if we prefer to focus on their ecological traits. In each case, classification provides a way to organize an array of things into logical groupings.

2.1.1 Classification in the Hydrogeomorphic Approach

Recent evidence indicates utility in classifying wetlands as to their position in the landscape, their source of water, and the flow of that water. These concepts are the basis of the hydrogeomorphic (HGM) approach, and were adopted for national implementation in permit evaluations and watershed planning by the U.S. Army Corps of Engineers (Brinson 1993; Smith et al. 1995). The HGM classification system recognizes seven major classes, which can be further divided into subclasses. From a national perspective, HGM classes consist of **Riverine, Depression, Slope, Fringe (Lacustrine and Estuarine), and Flats (Organic and Mineral)**. *Bolded* terms in this chapter refer to HGM classes and subclasses in Table 2.1, a wetland classification system for the Mid-Atlantic region (MAR) (Brooks et al. 2011).

The same inherent variability in ecological characteristics that defines ecological function and instills societal value for wetlands has hindered their classification and protection. The classification system of Cowardin et al. (1979) that describes vegetation and hydroperiod, neglects differences in morphometry and landscape position. Classification by HGM harnesses this additional wetland variability, and when integrated with Cowardin et al. (1979), provides a framework to characterize observed differences in wetland structure and function. Wetland functions are closely tied to HGM class, and thus, wetlands in the same HGM class should have similar structure and functions. We have found this to be true for most measured variables (Brooks 2004).

Through an understanding of the distribution of HGM subclasses within a watershed and their relative condition, one can begin to assess how wetlands potentially contribute to watershed health. A change in HGM subclass distribution should signal an alteration of function within the watershed (Bedford 1996; Cole et al. 1997; Wardrop et al. 2007). Because of the tight coupling of function to wetland type, a change in the distribution of wetland type may be the first sign of a significant loss of function. Thus, the distribution of wetland type provides a logical and scientifically based first step of wetland and watershed protection.

Table 2.1 Key to tidal and nontidal hydrogeomorphic (HGM) wetland types in the Mid-Atlantic region of the US classes and subclasses are in *bold*. Please read footnote before using this wetland classification system^a

1. Wetland found along tidal fringe of a marine ecosystem (ocean, beach, rocky shore)	2
1. Wetland not associated with marine ecosystem	3
2. Continuously submerged littoral zone	Marine subtidal (MF1)
2. Alternately flooded and exposed to air	Marine intertidal (MF2)
3. Wetland associated with shallow estuarine ecosystem (mixture of saline and freshwater)	4
3. Wetland not associated with shallow estuarine ecosystem	7
4. Wetland not impounded	5
4. Wetland impounded	Estuarine impounded (EFh)
5. Wetland continuously submerged	Estuarine subtidal (EF1)
5. Wetland alternately flooded and exposed to air	6
6. Wetland regularly or irregularly flooded by semidiurnal, storm, or spring tides	Estuarine lunar intertidal (EF2l)
6. Wetland flooding induced by wind	Estuarine wind intertidal (EF2w)
7. Wetland associated with freshwater stream or river	8
7. Wetland not associated with freshwater stream or river	11
8. Wetland associated with permanent flowing water from surface sources	9
8. Wetland dominated by ground water or intermittent flows	10
9. Wetland associated with low gradient tidal creek (see Estuarine types 3)	
9. Wetland associated with low gradient and low velocities, within a well-developed floodplain (typically >3 rd order)	Riverine lower perennial (R2)
9. Wetland part of a mosaic dominated by floodplain features (former channels, depressions) that may include slope wetlands supported by ground water (see Slope 17)	Riverine floodplain complex (R2c)
9. Wetland associated with high gradient and high velocities with relatively straight channel, with or without a floodplain (typically 1 st - 3 rd order)	Riverine upper perennial (R3)
10. Wetland part of a mosaic of small streams, depressions, and slope wetlands generally supported by ground water	Riverine headwater complex (R3c)
10. Wetland associated with intermittent hydroperiod	Riverine intermittent (R4)
Note: For any riverine type that is impounded, distinguish between:	
Wetland impounded by beaver activity	Riverine...beaver impounded (R...b)
Wetland impounded by human activity	Riverine...human impounded (R...h)
11. Wetland fringing on a lake or reservoir	12
11. Wetland not fringing on lake or reservoir	14
12. Wetland inundation controlled by relatively natural hydroperiod	13
13. Wetland inundation is permanent with minor fluctuations (year round)	Lacustrine permanently flooded (LFH)
13. Wetland inundation is semipermanent (growing season)	Lacustrine semipermanently flooded (LFF)
13. Wetland inundation is intermittent (substrate exposed often)	Lacustrine intermittently flooded (LFJ)
12. Wetland inundation controlled by dam releases	Lacustrine artificially flooded (LFK)
14. Wetland water source dominated by precipitation and vertical fluctuations of the water table due to low topographic relief	15
14. Wetland differs from above	16
15. Wetland substrate is primarily of mineral origin	Flat mineral soil (FLn)
15. Wetland substrate is primarily of organic origin	Flat organic soil (FLg)

(continued)

Table 2.1 (continued)

16. Wetland water source is primarily ground water and has unidirectional and horizontal flows	17
16. Wetland forms a depression	18
17. Water source for wetland derived from structural geologic discontinuities resulting in discharge of groundwater from distinct point(s) on slope	Stratigraphic slope (SLs)
17. Water source for wetland accumulates at toe-of-slope before discharging	Topographic slope (SLt)
Note: For any slope type, distinguish between: Wetland substrate is primarily of mineral origin ... slope mineral soil (SL...n) Wetland substrate is primarily of organic origin ... slope organic soil (SL...g)	
18. Wetland with frequent surface connections conveying channelized flow	Depression perennial (DFH)
18. Wetland with infrequent surface water connections conveying channelized flow	Depression seasonal (DFC)
18. Wetland with no surface outlet, often perched above water table	Depression temporary (DFA)
Note: For any depression type that is impounded or excavated distinguish between: Wetland is impounded by human activities ... Depression...human impounded (DPh) Wetland is excavated by human activities ... Depression...human excavated (DPx) Wetland is impounded by beaver activities ... Depression...beaver impounded (DPb)	

Modified from Brooks et al. (2011)

"No classification system can capture effectively all of the inherent variability in natural systems, nor can it provide a foolproof determination given the different experiences of users. This wetland classification system for the Mid-Atlantic region is designed to distinguish among major wetland types with recognizable differences. It also purports to serve both the needs of the regulatory community where certainty is preferred, and the science community that grapples with variability in ecological systems. Given that dual function, it is critical that users consider the landscape and hydrologic contexts of each wetland. How large an area is being classified? A river channel and the associated floodplain on both sides of the channel, or just the wetland associated with a property on the upland edge of a floodplain. Context really matters, and should be carefully and succinctly documented. When seeking to classify a particular wetland, the most fundamental question the user must ask is, "How was the wetland formed?," which can be stated as, "What is the origin of the wetland?." If this question is thoughtfully answered and described in a brief narrative, then the actual label assigned to the wetland matters less, because the user will have considered where and how the wetland fits in a given landscape and hydrologic setting. Obviously, this is more relevant for regions where wetlands do not form the dominant matrix of a landscape (e.g., coastal salt marshes, bottomland hardwood forests)

For example, is it a depression that is isolated during drier times of the year, but located in a floodplain setting? Or is it isolated from all riverine influences, and receiving a combination of ground-water and precipitation? Clearly, these wetlands are distinctively different in many of their attributes and functions, but they could have the same morphometric dimensions. Either wetland also could have some characteristics of yet another type, warranting a dual label (e.g., depression/slope) just as NWI mapping recognizes mixed vegetation classes (e.g., forested/scrub-shrub, FO/SS). Thus, it is important to recognize these distinctive elements and document the reasons for labeling the wetland as a specific type. This is especially important when addressing wetlands that occur along a broad hydrologic gradient and when a group of microhabitats occur in a cluster. Thoughtful selection of classes supported by careful documentation will make any classification system more consistent among users

2.1.2 Wetland Hydrogeomorphic Syntypes and Holotypes

Borrowing nomenclature from biological systematics, we suggest that investigators proposing local or regional classification systems provide locations of representative examples of wetlands that typify each major HGM subclass (i.e., syntypes). In addition, a single site that is the archetypical member of the subclass should also be designated as a HGM holotype, displaying characteristics that best define a specific type of wetland for that region. Given that these are not species, but habitats, and that they are subject to fairly rapid changes from climatic and disturbance forces, having a single representative may not be desirable. Thus, we suggest listing several examples—syntypes—that are relatively homogeneous in structure and function when compared to other wetland subclasses, but that display the inherent, natural variability within the designated subclass.

Toward that goal, we recommend listing locations for sites on publicly accessible lands and providing representative photographs for a few examples of wetland subclasses. On the following website, there is an accumulation of images and associated data to be archived over time (<http://www.riparia.psu.edu/MARbook>). We envision that this growing database of wetland syntypes will become a useful service primarily for educational and training purposes for those seeking to learn and recognize the diversity of wetland types they occur in the MAR. Procedures for submitting exemplar wetlands are being considered at this time by the Society of Wetland Scientists (<http://www.sws.org>; Brooks and Tyrna 2012).

2.1.3 Origins and Landscape Settings of Freshwater Wetlands in the Mid-Atlantic Region

In this section, the influence of the regions' physiographic provinces or ecoregions (Fig. 2.1) on the origins and locations of wetland types and their abundance are described. Riverine types are described first, followed by the other major wetland types, contrasting their occurrence across an ecoregional gradient from the Atlantic coast to the Ohio River valley.

2.1.3.1 Riverine Wetlands

As stated in Chap. 1 of this book, the majority of freshwater wetlands in the MAR are **riverine** types, associated with streams and their floodplains. These include wetlands in-stream, occurring as narrow terraces or vegetated islands within the banks of the defined channel. Most, however, are found in the adjacent floodplain along with other features derived from the dynamics of the stream over time (Fig. 2.2). Riverine wetlands are described for each of the major physiographic regions in the MAR.

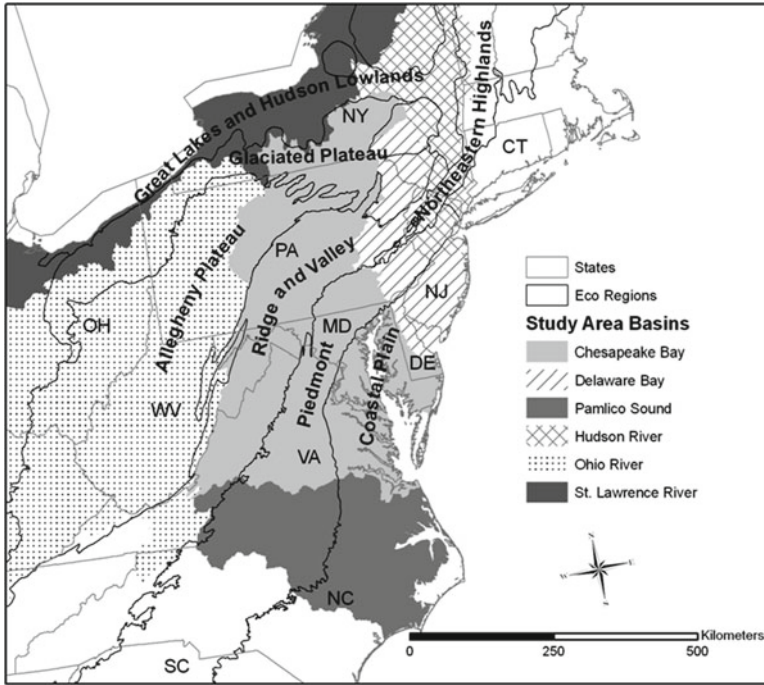


Fig. 2.1 Extended study area of the Mid-Atlantic region (MAR) showing boundaries of states, ecoregions, and major river basins

Coastal Plain

The Appalachian Mountains, the dominant geophysical features of the MAR, began rising to their peak elevations about 250 million years ago when the ancestral African continental plate collided with the eastern edge of the North American plate during the Alleghenian Orogeny (Slatick 2003), and have been eroding ever since. Rivers, at times interacting with glaciers, have carried these sediments southeastward to form the current Atlantic coastal plains, and westward to the wide floodplains of the Ohio River's valleys.

The coastlines that exist today along the Atlantic Slope are a product of the interplay of those southeast-flowing rivers and their bedload, changing sea elevations of the Atlantic Ocean, and variable rates of land subsidence and rebound. Along the coast, barrier islands contain coastal bays and drowned river mouths become estuaries, both rimmed with salt marshes and other wetland types. One does not generally encounter freshwater wetlands until locating reaches where the seaward freshwater flows of the rivers confront the incoming marine tides. At these zones of hydrologic tension, freshwater tidal and brackish marshes occur, referred to as **estuarine lunar or wind intertidal wetlands** in Brooks et al. (2011). Refer to overviews such as

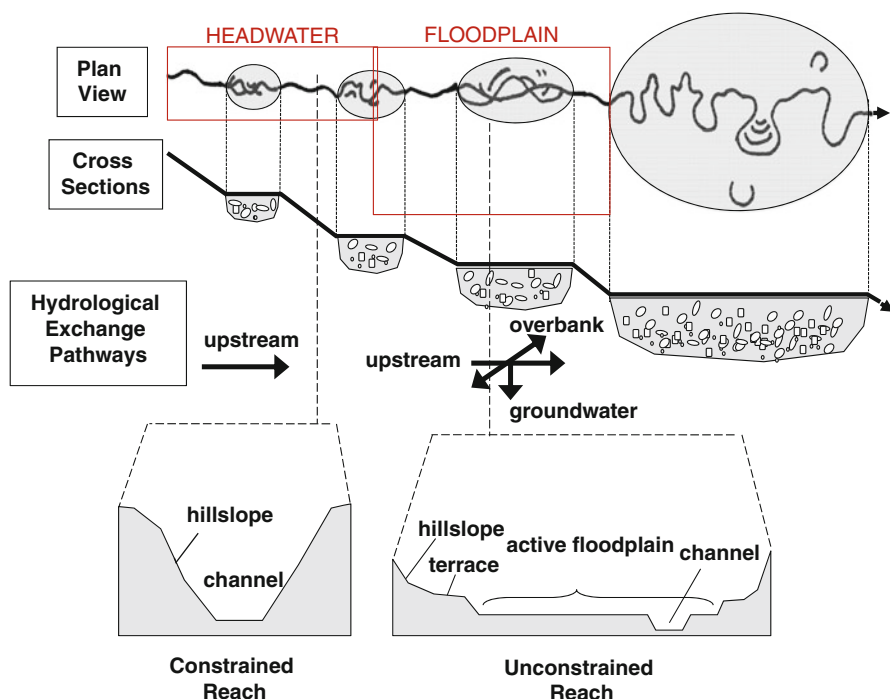


Fig. 2.2 Conceptualization of a riverine corridor derived over time by an active river channel interacting with the adjacent floodplain and uplands. Shown from headwater to mouth are alternating sequences of constrained and unconstrained floodplain reaches with predominant hydrological exchange pathways indicated for longitudinal (*horizontal arrows*), lateral (*oblique arrow*), and vertical (*vertical arrow*) dimensions (graphic by S. Yetter, modified from Ward et al. 2002)

Barendregt et al. 2009 or Perillo et al. 2009 for descriptions of these wetlands, as they are not discussed in this book.

The streams of the MAR's Coastal Plain flow across relatively flat landscapes formed of unconsolidated sands, silts, and clays. Elevations average 200 m above sea level (asl), but are much lower along the rivers and their floodplains. The sinuosity of these mature sections of rivers is high because of the numerous meanders formed over time across these weakly dissected alluvial soils (U.S. Forest Service 2010). Remnant channels become crescent-shaped oxbows that often support hydrophytic vegetation. Springs and other groundwater discharges erupt laterally along the edge of the floodplain and then mingle with surface water flows in a variety of ways, to produce **riverine floodplain complexes** (Brooks et al. 2011).

Floodwater dynamics, overbank flooding and subsequent floodplain deposition, and erosion from surface flow patterns, along with remnant meander scars and levees, produce distinct surface topographic and soil variations that then affect conditions for wetland formation. Biotic factors, such as beavers excavating bank dens

or toppled trees, further modify the hydrologic conditions by affecting the conveyance of flood flows between the river and the bordering floodplain.

In areas where regional water tables are at or near the surface for extended periods of time, soils are saturated sufficiently to support vegetation indicative of **flats**.

Piedmont

A distinct and historically relevant line of cataracts or areas of steep gradient divide the more inland Piedmont ecoregion from the Coastal Plain. Many of the major cities of the region, such as Philadelphia, Baltimore, and Richmond, began where mills powered by hydraulic energy were established along this geologic feature, the “fall line.”

Before European colonization, communities of indigenous peoples took advantage of the abundant resources found in these zones. These river rapids initially formed impediments to upstream navigation by colonizing Europeans, and thus, served as settlement and economic kernels from which these cities grew.

The riverine ecosystems of the MAR Piedmont exist on a mature, dissected peneplain interspersed with hilly and rolling terrain. Dendritic patterns are more common here than in the Ridge and Valley, where the predictable northeast-to-southwest orientation of both valleys and ridges tend to produce trellis drainage patterns. Bedrock is overlain by residuum on the ridges and hills, colluvium on the slopes, and alluvial materials in the valleys. Thus, the rivers wind through areas of soils and bedrock of varying resistances to erosion producing elevational ranges from 25 to 500 m (U.S. Forest Service 2010).

Wetlands of the Piedmont occur primarily along the riparian corridors. Headwater streams receive base flow from springs occurring at the break in slopes where hill-sides meet flood plains. If the floodplains are wide enough, **topographic slope** and **riverine headwater complexes** are formed. In more narrow stream valleys, wetlands form linear strips within the channel or along the riparian banks creating a **riverine upper perennial subclass**. In active beaver habitats, dams maintained in place for years or decades can greatly enlarge these riverine wetlands. In the later successional stages of beaver habitat development, large patches of emergent hydrophytes form marshes or shrub wetlands on the fine sediments accumulating behind the dams; these are designated as **riverine beaver-impounded**.

Ridge and Valley

The Ridge and Valley Ecoregion is where the tortuous geology of the Appalachians is most apparent. The orogenic folding rearranged the horizontal bedding planes of sedimentary sandstone, siltstone, shale, carbonate rock, and coal into a myriad of angles from the original horizontal planes to completely vertical and even overturned strata. When coupled with fracturing and solution openings formed in carbonate rock the effects on groundwater storage and pathways, and on surface water

drainage patterns are astonishing. Predicting the occurrences of wetlands on ridge tops, along hillslopes, and within the floodplains is challenging. Many of the headwater wetlands are small, and can be quite cryptic beneath the dominant forest canopies. Elevation ranges from 200 to 600 m (U.S. Forest Service 2010). Approaches for inventorying these types of wetlands are detailed later in this chapter in Sect. 2.

Wetland formation in the Ridge and Valley is similar to that in the Piedmont, and likewise, open-water or deep-water lakes are uncommon unless excavated ponds or dams have been built. These man-made impoundments often alter the dynamics of existing streams or rivers. Some headwater streams have steep gradients if they descend directly from the ridges to the valley bottoms, allowing few wetlands to form. However, tributary confluences often are sufficiently broad to form **riverine upper perennial** or **headwater complexes**. **Stratigraphic slopes** frequently form a distinct band along a topographic contour where the underlying geologic strata are less permeable than the strata above, leading to an expression of groundwater as a seep or spring. For example, a sandstone layer atop one of siltstone or shale may force groundwater to discharge at the surface where those two layers meet, forming a spring or slope wetland. Such contact zones can serve as indicators of wetland occurrence (e.g., McLaughlin 1999; Herz 2005).

Some ridge tops may have a saddle, providing landscape locations where wetlands can form. If flows are slow, and soils remain saturated, moss or sedge peat can accumulate and bogs or fens may develop (e.g., **depression perennial**, or **...beaver-impounded; riverine headwater complex**). Beaver can more easily dam the streams in these locations, and further enlarge wetland extent.

As tributary streams reach the broad valleys of this ecoregion, floodplains can be much wider, spanning hundreds of meters, providing larger areas for wetland formation; **riverine lower perennial, depression perennial or seasonal**. Rivers form meanders in the flatter valleys, but are often constrained on one or both sides by a ridge. The linearity of the ridges produces the trellis patterns common to the lower reaches of these watersheds. Steep riparian banks can form either where the river erodes into the base of ridges, or on the outer curve of meanders. These habitats are used extensively by nesting belted kingfishers and bank swallows, and by resting wood turtles. Point bars, or shallow, gently sloping areas of sediment deposition, form on the inner curve of meanders, where the river's kinetic energy is low. These flatter areas are more conducive for germinating annual hydrophytes and aquatic shrubs. Shorebirds, such as the spotted sandpiper, will frequent bare soils, whereas basking amphibians and turtles benefit from vegetated bars.

Two major factors can alter the typical pattern of heterogeneous wetland formation on broad floodplains. Karst landscapes form in carbonate valleys, where streams alternately flow aboveground, then belowground (i.e., sinking), entering solution channels, or sinkholes. The other factor is the centuries of human activities, including farming, transportation corridors, and urban development, that have altered natural river flow patterns through channelization, ditching, riparian bank hardening, and changes in soil infiltration rates. These valleys have been farmed extensively, removing most of the woody vegetation and influence hydrologic patterns. Today,

either agriculture continues to dominate the valley bottoms, or urban development is expanding, with subsequent increases in impervious surfaces and stormwater runoff. In combination, these factors reduce the presence and extent of all types of wetlands in this region.

Allegheny Plateau: Unglaciaded

The unglaciaded Allegheny Plateau consists of a mature, dissected plateau, producing relatively narrow valleys, and hence, narrow floodplains. Elevation generally ranges from 200 to 400 m asl, with a few areas exceeding 600 m. As in much of the Appalachians, bedrock composed primarily of sandstone, siltstone, and shale is overlain by residuum on the ridges and hilltops, colluvium on the slopes, and either or both alluvium and Pleistocene lacustrine materials in the valleys (U.S. Forest Service 2010). The geologic strata, however, tend to remain more horizontal and much less folded than similar beds in the Ridge and Valley. Limestone and dolomite are less prominent than in the Ridge and Valley, whereas coal beds are more common, but vary in depth from the surface. Soils tend to be fine-grained, and are commonly acidic. The high acidity is a result of the parent bedrock material, high rates of wet and dry acid deposition from coal-fired power plants, and in isolated pockets, acid mine drainage produced during past coal mining activities.

As the region's name suggests, the upper elevations form broad, level, or gently undulating terrain. Where local water tables occur near to the surface, extensive wetlands, often forested, can form. Headwater streams intermingle with small, seasonal depressions and topographic slopes, which can produce a highly interspersed mixture of wetland and upland patches (e.g., **riverine headwater complexes; depressions seasonal and temporary**).

Dendritic stream networks have eroded the plateau producing, in some areas, steep, narrow valleys as can be found in central and western West Virginia and western Pennsylvania. Wetlands are linear in these valleys (e.g., **riverine upper perennial**), often further pinched by roads built to gain access into and through this steep, dissected terrain. Lower-lying areas are typically flooded more frequently than in the Ridge and Valley, creating a diversity of habitats with different hydrologic regimes, soils conditions, and plant communities (e.g., riverine lower perennial and floodplain complex). These floodplain forests are temporarily flooded during seasonal high water and periodic flood events, but during much of the growing season the groundwater may be well below the surface.

Allegheny Plateau: Glaciaded

The glaciaded portion of the Allegheny Plateau also consists of a mature, dissected plateau, but with rounded hills, ridges, and broad valleys. Elevation ranges from 200 to 300 m asl. Glacial features include valley scour, ground moraines, kames, eskers, and kettled outwash plains. Thin Pleistocene till and stratified drift cover many

upland bedrock surfaces. Lower slopes are covered by colluvium. Glacial outwash, recent alluvium, and glacial lacustrine materials cover valley floors. Bedrock beneath the drift consists of shale, siltstone, sandstone, conglomerate, and coal (U.S. Forest Service 2010).

Not all soils are of glacial origin, with residual materials occurring in place upon weathered bedrock on the hills, and colluvium transported by water and ice to the lower slopes. Soils are highly variable, but tend to be more coarse-grained.

The stream networks display more amorphous patterns, having had much less time to develop (thousands vs. millions of years). Streams are underlain primarily by thick coarse sand and gravel in glacial outwash. Small natural lakes and wetlands (either bogs or marshes) are features of this glaciated landscape. Those derived from orphaned ice blocks of the receding glacier tend to form deeper kettle holes, whereas shallower depressions, typically forming emergent marshes or fens, have varied origins. The density of wetlands is much higher in both the northwestern and northeastern glaciated portions of the MAR (i.e., Pennsylvania) than any of the other ecoregions; 19% and 26% of land area, respectively (Tiner 1987). Whereas wetland patches of any type exceeding 10–20 ha are quite uncommon in the Piedmont and Ridge and Valley ecoregions, it is not uncommon to find wetlands >50–100 ha in area in the glaciated regions.

2.1.3.2 Other Wetland Types

The greatest density of **lacustrine (or fringing)** wetlands occurs along the natural and hydrologically altered lakes and ponds in the glaciated ecoregions of northeastern and northwestern Pennsylvania, northern New Jersey, and southern New York. The more acidic soils of the Pocono Plateau support classic bogs, dominated by *Sphagnum* mosses, ericaceous shrubs (e.g., leather leaf, bog rosemary), and black and red spruce, that one finds in New England, the Adirondacks, or the boreal regions of Canada. In the northwestern corner of the MAR, calcareous soils support sedges. The wetland-dependent evergreen species of the Poconos are less common in this ecoregion, where alders, dogwoods, and a diversity of grass-like and forbs that favor alkaline soils predominate.

Flats occur where water sources are dominated by precipitation and vertical fluctuations of the water table (Brinson 1993). They typically occur in regions of low topographic relief, such as the Coastal Plain, particularly on the outer coastal plain of Delaware, Maryland, Virginia, and North Carolina, and North Carolina. They are represented by pocosins, which tend to have soils with high amounts of organic matter. Other types of flats may have soils containing predominately mineral sediments derived from extensive outwash plains of rivers. There are other ecoregions of the MAR with landscapes that are relatively flat topographically, including parts of the Allegheny Plateau, and the glaciated regions (Fig. 2.1), but hydrologic regimes in these locales are based on a mix of surface flows and soils saturated with groundwater that are more like other wetland types than the characteristic flats. Thus, these

wetlands have been classified as a mixture of shallow depressions, low gradient slopes, and riverine floodplains, rather than flats.

We have identified two major types of **slope** wetlands (Stein et al. 2004; Brooks et al. 2011). **Topographic slopes** are those located at the toe of a hillslope where the volume of groundwater discharge is sufficient to support a wetland. **Stratigraphic slopes** are those typically located farther upslope, but they are also found on valley floors, where bedrock contacts form a permeability contrast which allows a discharge of sufficient groundwater to support a wetland. Slopes have unidirectional flow occurring either in braided channels, or across a broader surface. These flows often contain a mix of deeper groundwater, interflow, and surface runoff from precipitation events. They tend to be smaller in area than most other wetlands found in the MAR. Similar to flats, slopes can be further differentiated by dominant soil type, mineral vs. organic.

Wetland **depressions** can vary in area, depth, and permanence of water. They are formed through a variety of geophysical processes. Isolated depressions, by definition, have no surface water connections to other waterbodies. Small (typically <1 ha), isolated depressions are often referred to as temporary, seasonal, or vernal pools. This type is noted for its importance as habitat for breeding amphibians (Calhoun and deMaynadier 2007). Larger depressions can occur anywhere in the landscape where a low-lying area collects and stores water in a shallow or deep, bowl-shaped feature. Those found in the uppermost reaches of watersheds can collect water and release it to headwater streams whenever the outlet elevation is exceeded. Bogs and fens, many of which formed when ice blocks cleaved from retreating glaciers melted in place, occur predominantly in the northern and mountainous portions of the region. Other depressions form in floodplain or valley bottom settings where they may have both inlets and outlets, allowing greater connectivity with the stream or river network. Water levels are maintained by layers of impervious soils that perch the water or by a water table that is high enough to keep the soil saturated. Areas scoured by past flowing water (e.g., oxbows) or wind (e.g., Carolina Bays) forces also form wetland depressions. Dams or excavations, whether created by beaver or humans, can produce either open-water or vegetated depressions, familiarly known as farm ponds, reservoirs, and lakes.

2.2 Inventory

2.2.1 *Innovative Approaches to Wetlands Inventory*

The MAR was one of the first geographic areas of the United States to produce National Wetlands Inventory quadrangle maps, status and trends reports (e.g., Tiner 1987). Consequently, the aerial photographs on which those original NWI data were based are now over 30 years old. Western Pennsylvania's NWI maps and the subsequent digital data are based on black and white imagery at 1:80,000 scale from the late 1970s and early 1980s. High priority areas of Pennsylvania have received more recent attention. The Delaware River and Lake Erie coastal zones were

recently updated with high-resolution imagery (i.e., 2004 NAIP CIR 1 m resolution, 2003–2006 PAMAP True Color 0.3 m resolution, 2005 DVRPC 0.3 m resolution; Pennsylvania Department of Environmental Protection 2011). Despite the recent availability of statewide lidar and digital orthophotographs (<1 m resolution; <http://www.pasda.psu.edu>), there is no definitive plan to produce a new wetlands inventory for Pennsylvania wetlands away from the two coasts.

Each state has approached their inventories of wetlands in different ways, and independent efforts by agencies, research scientists, conservation organizations, and consultants have produced a set of fragments for which no central repository exists. Inventory efforts around the United States are working on the leading edge of advancing technology to “find” wetlands that may be small in size, hidden under forest canopies, or seasonally wet (e.g., Maxa and Bolstad 2009). So, the wetlands inventory collective for the region consists of mixed media and varied chronology sources that are not universally compatible or accessible. Based on Tiner’s (1987) report of total wetland acreage for both inland and coastal wetlands in the region, based on sampling the original NWI aerial photography, the proportion of wetlands by state was Virginia (46%), Pennsylvania (22%), Maryland (19%), Delaware (9%), and West Virginia (4%), for a total of about 800,000 ha.

As Wardrop et al. (2007) and others have shown, the NWI data for the MAR can underestimate the abundance of inland wetlands by almost 50%. In part, this is because many wetlands in the region are small in size, and others are obscured by forest canopies. Thus, finer resolution aerial imagery is not necessarily the only solution. A variety of predictive techniques have been explored to further identify and delineate wetlands. For example, McLaughlin (1999) combined aspects of geomorphology (e.g., faults, contacts) and topography (e.g., changes in slope) to predict likelihood of wetland occurrence in the Ridge and Valley.

Herz (2005) combined GIS-based spatial modeling with field validation to predict locations of groundwater discharges along streams in central Pennsylvania as a means to locate small wetlands dependent upon springs and seeps. She found that three factors, concave curvature of the landscape, underlying geologic structure and composition, and hydric soils, used individually or collectively could predict discharge locations for 60–70% of the sampled field sites. Use of higher resolution topographic data, from lidar could enhance the predictions.

Both of these studies demonstrated the importance of understanding landform and landscape setting to enhance inventories for small, groundwater-supported wetlands.

2.2.2 The Future of Wetlands Inventory in the Mid-Atlantic Region

Given this patchwork quilt of available imagery and interpreted geospatial data for wetlands in the MAR, it is doubtful that a consistent, region-wide wetlands inventory will be sustainably produced. Funding for a comprehensive inventory, by the NWI or other entity, is probably prohibitively expensive. The likelihood that a region-wide

product could be produced at predictable intervals (e.g., 5, 10, or 20 years) is low. Yet, the MAR urgently needs to develop an approach that efficiently and periodically produces wetland inventories. We suggest, therefore, that a wetlands inventory for the MAR be built around acceptance of a continuous process, where verified changes to the NWI base layer (or whatever layer is deemed to be the best for each state) be made as they become available. Each state would most likely maintain its own database. For example, wetlands delineated for permit submittals could be routinely provided in digital form to the designated office. Similarly, intensive inventories created for a single watershed or river basin using advanced technologies (e.g., lidar coupled with low-altitude, multispectral photographs) could be submitted. Whenever possible, these individual efforts should follow FGDC Wetlands Mapping Standard (FGDC 2009) (<http://www.fgdc.gov/standards/projects/FGDC-standards-projects/wetlands-mapping>). Whatever is used, however, should be properly documented with appropriate metadata and be served from publicly accessible, web-based databases. At a minimum, a technically proficient, two-person team could provide this service for a state for a reasonable investment. This inventory team could be based within an existing resource agency, an organization, a university, or a private firm, as long as the funding sources and mechanisms were sustainable, and access was assured.

With this approach, we might not gain a uniform dataset acquired during a narrow window of time that would reflect the entire region, but we would have a continuously updated database that could provide the best available inventory data for a geographic area of interest. Since most decision-making involving changes in land use takes place at spatial scales that are relevant to a small watershed, municipality, or county, we would be assured that the most recent wetlands inventory data would be available for those users. Areas of high priority due to intense development pressures or identified as desirable for protection might receive more frequent attention, but all regions would likely be updated more often than if we wait for a single, region-wide effort.

2.2.3 Status and Trends

Overall, in 2009, there were an estimated 44.6 million ha of wetlands in the conterminous United States, with 95% being freshwater types (Dahl 2011). The average year for imagery used was 2009. During the study period, 2004–2009, there was slight decline in area overall, in contrast to the previous report which showed a slight gain (Dahl 2006). Most of these losses and gains can be attributed to land use trends, successional changes, and variations in effectiveness of regulatory and non-regulatory programs. Regardless of the causes of these variations, it appears that during the past decade, we are beginning to meet the goals emerging from the National Wetlands Policy Forum of no net losses and long-term gains (National Wetlands Policy Forum 1988). This seminal meeting held in 1987 was convened by the Conservation Foundation at USEPA's request, and set the stage for concerted

Table 2.2 Wetlands losses by state for the Mid-Atlantic region (includes inland and coastal types; data from Dahl 1990; modified from Mitsch and Gosselink 2007)

State	Original estimated area (ha)	National wetlands inventory (ha)	Change (%)
	Circa 1780	Mid-1980s	
Delaware	194,000	90,000	−54
Maryland	668,000	178,000	−73
New Jersey	607,000	370,000	−39
New York	1,037,000	415,000	−60
North Carolina	4,488,000	2,300,000	−44
Pennsylvania	456,000	202,000	−56
Virginia	748,000	435,000	−42
West Virginia	54,000	380,000	−31
Mid-Atlantic region	8,252,000	4,370,000	−47

political, scientific, and grassroots efforts to stem the losses of wetlands that occurred since European settlement, and to begin to offset those losses with gains.

Because NWI’s most recent analyses of losses and gains were conducted for the entire nation, the trends for individual states or regions are not available. The most recent report for the MAR providing state data comes from Dahl’s (1990) estimates of losses from the colonial period of the 1780s through the mid-1980s (Table 2.2). Since that time, losses in area have declined nationally and regionally, primarily due to strong regulatory programs at both federal and state levels, and significant non-regulatory programs that provide incentives to private landowners to protect and conserve their wetlands.

2.3 Reference Wetlands

2.3.1 Concepts of Reference Wetlands

The use of reference sites has become increasingly more common as scientists and resource managers search for reasonable and scientifically based methods to measure and describe the inherent variability in natural aquatic systems (e.g., Hughes et al. 1986; Kentula et al. 1992). We use the term reference wetlands to connote naturally occurring sites composed of wetland, stream, and riparian components that span a gradient of anthropogenic/human disturbance. Although reference sites often represent areas of minimal human disturbance (i.e., reference standards in HGM parlance; Smith et al. 1995), in many instances it is more useful to represent a range of environmental conditions across a landscape (Karr and Chu 1999; Brooks et al. 2006).

The primary reasons to include reference sites in regional assessments and restoration efforts are the need to compare impacted or degraded sites to a least-impaired set of attributes or benchmarks. These benchmarks can represent a starting point in

time for trend analyses (e.g., long-term successional studies or impact analysis on a group of wetlands). Reference sites can also serve as alternatives to standard experimental controls, which are seldom available in large-scale field studies. The primary criterion for selecting reference sites involves choosing sites that represent ideal, relatively natural conditions represented by the least disturbed sites available, which is common for stream assessments (Karr and Chu 1999). Sites can be chosen to represent the best attainable conditions for a particular region even though they may not be pristine (Smith et al. 1995). This approach has been adopted in the MAR by several states, in part, because there has been an intentional process to use common approaches and methods.

Sites within the reference set can span several gradients. They should include, at a minimum, the common types of wetlands found within a region, and the range of conditions from relatively pristine (ecologically intact) to severely disturbed sites (degraded ecological integrity and functions). This will provide the data necessary to assess and rank the condition for the full range of sites that are being assessed (Brooks et al. 2004).

Given limited human and financial resources, creating a pool of reference wetlands that satisfies multiple objectives is desirable. Investigators and managers must decide jointly upon the acceptable level of analytical compromise they can tolerate vs. the advantages of shared data and resources. Most studies will benefit from some overlap among sets of reference sites. Using reference wetlands from a wide variety of vegetation types, disturbance regimes, and landscape positions allows for characterization of this variability. Once established, reference wetlands can be used to set the standard by which mitigation and management projects (restoration, creation, or enhancement) can be judged.

Since the early 1990s, universities, agencies, and organizations throughout the MAR have assembled a growing set of reference wetlands. Other wetlands have been studied by numerous investigators, but here we distinguish wetlands purposefully established as a set and monitored to provide condition assessments and/or comparative data for mitigation projects. From 1993 to 2003, the Penn State Cooperative Wetlands Center (now Riparia) established a set of 222 reference wetlands for Pennsylvania (Table 2.3, Fig. 2.3). They were chosen based on three criteria; accessibility for multiple years, commonly impacted types, and random selections. The following protocol was used to standardize the selection procedure. Candidate sites were selected at random from a regional pool of sites developed from US Geological Survey topographic maps, NWI maps, and Natural Resource Conservation Survey soil surveys. Potential wetlands of the desired type (e.g., public land, vegetation type, size class, degree of disturbance) occurring in 1 km × 1 km blocks (UTM grid) on NWI maps in the vicinity of the target population were numbered and placed in a pool of potential sites. To obtain an adequate distribution geographically, several potential sites from each of 5 to 10 topographic maps within an ecoregion were chosen. Each was checked during a site visit, and if permanent access from landowners was available, the site was selected for the reference set. Wetlands in the reference set used for the Upper Juniata Watershed study (about one-third of the total) were selected using USEPA's generalize random-tessellation

Table 2.3 Summary of reference wetlands sampled in Pennsylvania, 1993–2003 (*n*=222) by ecoregion and HGM subclass

	Glaciated plateau	Piedmont	Glaciated poconos	Allegheny plateau	Ridge and valley	Total
Lacustrine permanently flooded (fringing)	0	1	1	5	10	17
Riverine upper perennial	2	2	2	7	52	65
Riverine beaver-impounded	0	0	1	3	7	11
Depression, seasonal or temporary (isolated)	0	0	2	0	15	17
Riverine lower perennial and floodplain complex	3	3	4	9	24	43
Riverine headwater complex or depression perennial	0	0	8	2	16	26
Slope	3	3	6	12	19	43
Total	8	9	24	38	143	222

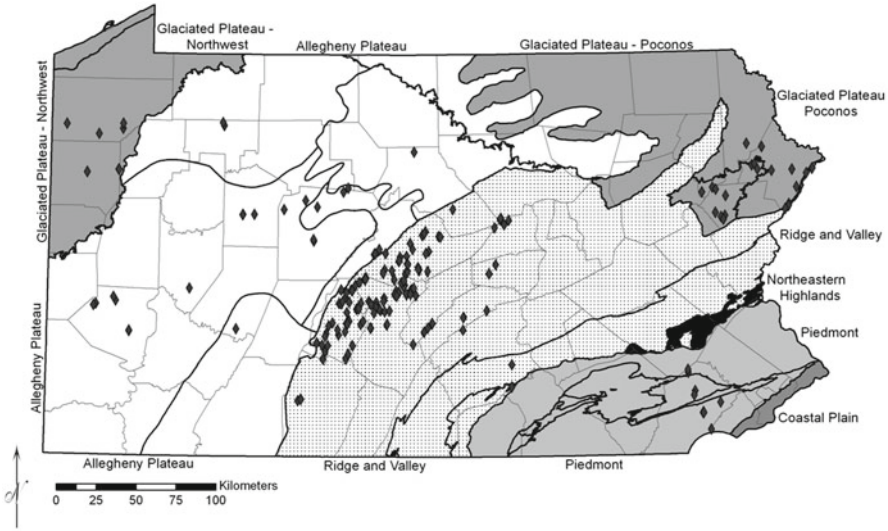


Fig. 2.3 Distribution of reference wetlands by ecoregion in Pennsylvania, as established from 1993 to 2003 by Riparia at the Pennsylvania State University

stratified (GRTS) design (Stevens and Olsen 2004), which assures a spatially well-balanced sample. A full listing of sites, their location and characteristics appears in Brooks 2004, Table 2, and at <http://www.riparia.psu.edu/MARbook>.

When bounding reference wetlands, it will be necessary to truncate wetland complexes and mix types, particularly in long, linear, riverine systems. Riparia selected sites in the range of about 0.25–3.0 ha, with most being about 0.4 ha.

Sampling is typically conducted along the hydrologic gradient. This approach has been used elsewhere in the MAR, but is not universally applied.

Reference collections need not be restricted by state borders. For example, to increase the number of reference wetlands in the Glaciated Plateau of Pennsylvania, we arranged to share data with the Ohio Environmental Protection Agency for adjoining ecoregions along our common border with Ohio (J. Mack, pers. comm.). These types of collaborative arrangements among states can help efficiently generate regional sets of reference wetlands for use by multiple groups.

2.3.2 Recommended Steps for Establishing a Regional Set of Reference Wetlands

Based on our experience, the following steps for establishing a regional set of reference wetlands are recommended (Brooks et al. 1996, 2002). It is assumed that one of the primary uses of the reference set will be to classify wetlands and develop functional models using the HGM approach, but that other needs will be met by the same set.

1. Identify the need and goals for establishing reference wetlands in a specific ecoregion or set of ecoregions that are similar.
2. Choose a multi-organizational regional assessment team with the necessary expertise to assess the types of wetlands in the given region.
3. Assessment team core members must commit to repeated meetings and field visits to establish the reference set. Auxiliary team members can come and go as needed and as available to expand the realm of expertise.
4. Ideally, the assessment team should range from 5 to 10 members (minimum of 3, maximum of 12). This will provide sufficient expertise while still allowing the group to develop as a cohesive unit. Presumably, all or a portion of the assessment team will be involved in aspects of characterizing (modeling subclasses for HGM approach) the reference set.
5. The assessment team should be provided the Corps HGM documents as a starting point (e.g., Brinson 1993, Smith et al. 1995, regional HGM models).
6. The assessment team members should conduct a series of 1-day seminars on HGM concepts, classification, and functions for potential stakeholders in the region. This will explain the rationale and methodology for establishing reference wetlands, as well as introduce potential users to the HGM approach.
7. It is useful to discuss potential regional changes in the national HGM classification system for the region of concern and conduct several field visits to multiple types of wetlands until the assessment team consistently recognizes and agrees upon classification of most sites.
8. At some point, it will be necessary to determine whether all or only some HGM subclasses will be considered. Wetland types to be investigated can be prioritized by potential threats, relative abundance, or available expertise.

9. We recommend that the assessment team identify a pool of wetlands at least 2–3 times the desired number of reference sites targeted for detailed characterization to account for access problems. To ensure adequate spatial coverage to facilitate post-monitoring analyses, we suggest organizers review and consider use of the GRTS approach to survey design, as utilized in USEPA's National Aquatic Resource Surveys (Stevens and Olsen 2004) (http://www.epa.gov/nheerl/arm/designing/design_intro.htm).
10. Further cautionary notes regarding selection of reference wetlands:
 - (a) Consider all needs for reference sites, not just for HGM functional assessment.
 - (b) One cannot always examine a statistically valid sample for each wetland type or HGM subclass; our rule of thumb is to use three wetlands as the absolute minimum per subclass, 30–50 is probably a maximum, and 8–12 begins to cover the variability in a subclass; Smith et al. (1995) suggest a minimum of 20.
 - (c) Sites can be chosen based on proportions of NWI types, or types of special concern.
 - (d) Sites should have long-term accessibility, which suggests public ownership, yet the reference set must cover subclass variability, including disturbance, which probably will require that some sites be on private lands subject to typical land use and management activities.
 - (e) A subset of the total reference set should meet the requirement of long-term accessibility; this subset should consist of representative/typical wetlands.
 - (f) Once selected from the pool, secure written permission that acknowledges the probable sampling protocol and access procedures.

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