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ASSESSING CUMULATIVE LOSS OF WETLAND FUNCTIONS IN THE NANTICOKE RIVER WATERSHED USING ENHANCED NATIONAL WETLANDS INVENTORY DATA

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Abstract: The coterminous U.S. has lost more than 50% of its wetlands since colonial times. Today, wetlands are highly valued for many functions including temporary storage of surface water, streamflow maintenance, nutrient transformation, sediment retention, shoreline stabilization, and provision of fish and wildlife habitat. Government agencies and other organizations are actively developing plans to help protect, conserve, and restore wetlands in watersheds. The U.S. Fish and Wildlife Service's National Wetlands Inventory Program (NWI) has produced wetland maps, digital geospatial data, and wetland trends data to aid these and other conservation efforts. Most recently, the NWI has developed procedures to expand the amount of information contained within its digital databases to characterize wetlands better. It has also developed techniques to use these data to predict wetland functions at the watershed level. Working with the states of Delaware and Maryland, the NWI applied these techniques to the Nanticoke River watershed to aid those states in developing a watershed-wide wetland conservation strategy. Wetland databases for pre-settlement and contemporary conditions were prepared. An assessment of wetland functions was conducted for both time periods and comparisons made. Before European settlement, the Nanticoke watershed had an estimated 93,000 ha of wetlands covering 45% of the watershed. By 1998, the wetland area had been reduced to 62% of its original extent. Sea-level rise and wetland conversion to farmland were the principal causes of wetland loss. From the functional standpoint, the watershed lost over 60% of its original capacity for streamflow maintenance and over 35% for four other functions (surface-water detention, nutrient transformation, sediment and particulate retention, and provision of other wildlife habitat). This study demonstrated the value of enhanced NWI data and its use for providing watershed-level information on wetland functions and for assessing the cumulative impacts to wetlands. It provides natural resource managers and planners with a tool that can be applied consistently to watersheds and large geographic areas to show the extent of wetland change and its projected effect on wetland functions.

Key Words: cumulative wetland impacts, historic wetlands, Nanticoke River watershed, National Wetlands Inventory, wetland classification, wetland functional assessment, wetland trends

INTRODUCTION

Many investigators have reported significant losses of wetlands in the United States (e.g., Frayer et al. 1983, Tiner and Finn 1986, Dahl and Johnson 1991, Hefner et al. 1994, Tiner et al. 1994, Dahl 2000). These reports address wetland trends in terms of area lost or area gained but do not address the significance of the loss in functional terms. In the past decade, there has been considerable interest in wetland functional assessment at both the site-specific and landscape or watershed levels. The latter assessments require the use of geospatial data and geographic information technology (GIS). Several states in the Northeast with interest in landscape-level analysis have cooperated with the U.S. Fish and Wildlife Service (FWS) in producing watershed-level assessments of wetland functions. Among the areas evaluated were watersheds associated with Maine's Casco Bay, New York City's water supply system, the Nanticoke River of Maryland and Delaware, and Maryland's Coastal Bays plus Pennsylvania's Coastal Zone (Tiner et al. 1999, 2000, 2001, 2002, 2004, Tiner and DeAlessio 2002, Tiner and Stewart 2004). To accomplish this work, the FWS's Northeast Region developed a technique to prepare preliminary assessments of wetland functions for watersheds and large geographic areas (Tiner 2002). The technique requires enhancing digital National Wetlands Inventory (NWI) data by adding descriptors for landscape position, landform, water flow path, and waterbody type (LLWW) to the NWI digital database and then applying correlations between wetland characteristics and functions to identify wetlands of potential significance for various functions. When applied to different-era datasets for wetlands in the same watershed, this assessment approach provides a perspective on the magnitude of the losses from a functional standpoint.

The states of Maryland and Delaware are working cooperatively to develop a watershed-based strategy for wetland conservation and restoration for the Nanticoke River watershed. They contacted the FWS for assistance in conducting watershed-level assessments of wetlands, first for the present era and then for the pre-settlement period. The purpose of the investigation was to produce an inventory and analysis of historic wetlands and their functions for the Nanticoke River watershed and to compare these findings to present-day conditions. The specific objectives were 1) to produce a map showing the general extent of wetlands prior to European colonization, 2) to prepare a preliminary functional assessment of pre-settlement wetlands, 3) to create a consistent database of contemporary wetlands for the entire watershed from existing enhanced NWI data, 4) to prepare a preliminary wetland functional assessment for the present-day watershed, and 5) to compare the changes in wetland extent and functions based on the pre-settlement and contemporary wetland assessments. This paper generally describes the assessment method and demonstrates its use for predicting the cumulative effect of historic wetland losses on wetland functions for the Nanticoke River watershed.

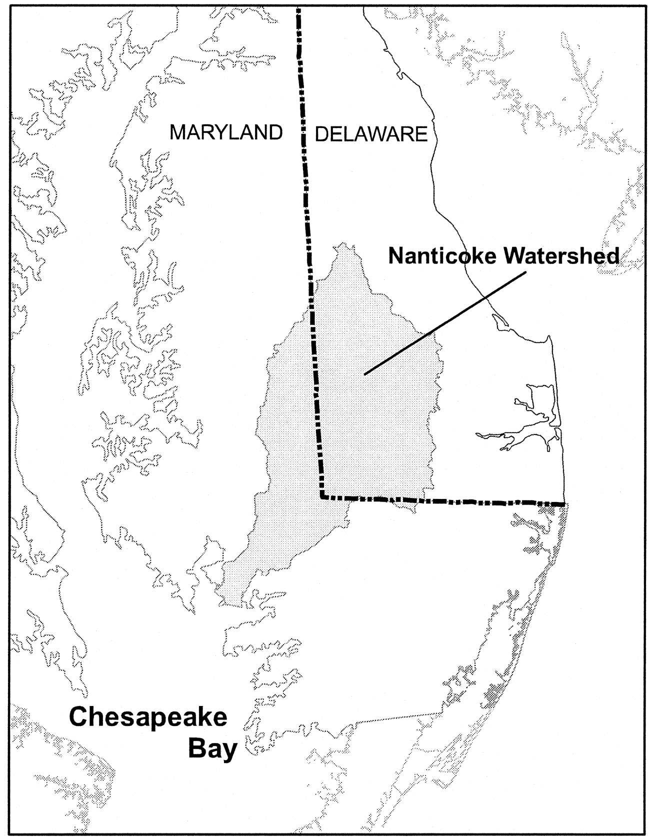

Figure 1. Locus map showing the Nanticoke River watershed on the Delmarva Peninsula.

Study Area

The study area is the Nanticoke River watershed, a tributary of the Chesapeake Bay, beginning in western Delaware on the Delmarva Peninsula and flowing in a southwesterly direction into Chesapeake Bay (Figure 1). This watershed is roughly 2,070-km^2 in size and includes about 25% of the state of Delaware. Major tributaries include five in Delaware (Broad Creek, Deep Creek, Gravelly Branch, Gum Branch, and Marshyhope Creek) and four in Maryland (Marshyhope Creek, Rewastico Creek, Quantico Creek, and Wetipquin Creek).

METHODS

Pre-settlement Wetland Inventory

Reconstructing the distribution of historic wetlands requires using varied sources of information and making certain assumptions. Regardless of the procedures employed, the outcome is an approximation and not an exact replication of pre-settlement conditions. For this study, the distribution and extent of pre-settlement wetlands were derived from two sources: 1) soil survey data from the U.S.D.A. Natural Resource Conservation Service (NRCS) and the Delaware Department of Natural Resources and Environmental Control (DNREC) based on 1:15,840 to 1:20,000 soil maps and 2) U.S. Geological Survey orthophotomaps (1:24,000). The former source was the primary source, and most historic wetlands were identified from this material, since urban development was minor compared to agricultural impacts. The orthophotomaps were used to locate ''lost'' estuarine wetlands that are now shallow water.

Hydric soil map units from soil survey data were identified as historic wetlands. A digital database of hydric soil map units was created for the Nanticoke watershed from existing digital soil survey data and from soil map unit data in published soil surveys. Two counties had digital soils data available: Dorchester (SSURGO data from NRCS based on Brewer et al. 1998) and Sussex (from DNREC). For other counties (Caroline, Wicomico, and Kent), hydric soil digital data were created by scanning individual soil survey maps from county soil survey reports (Matthews 1964, Hall 1970, Matthews and Ireland 1971, respectively).

Scanning was done at 300 dots per inch (dpi) and saved as TIFF images. The black color band (all line-work) was selected in each image and copied to form a composite image (mosaic) for the county. Mosaics were georeferenced in ArcGIS 8.0 using the georeferencing extension, with a 1:24,000 digital raster graphics (DRG) serving as the base. These mosaics were then converted to georeferenced GRIDS and then to linear coverages, which were converted to polygonal coverages and finally to shapes. The shapes were edited and hydric soil map units labeled using the georeferencing image to code ID in the background in ArcGIS 8.3.

The soil-based historic wetland data were compared with existing NWI data to identify possible large wetland complexes (typically forested wetlands) that were not recorded as historic wetlands based on soils mapping (e.g., likely hydric inclusions in larger nonhydric soil units). Due to alignment issues caused by merging data sources, a 5-ha threshold was established for identifying significant omissions. These larger NWI wetlands were added to the historic data base. The presumption was that if the area is a large forested wetland today, it was likely a forested wetland at the time of European settlement.

Estuarine wetlands have migrated landward and upriver due to sea-level rise over the past 500 years, while others have become permanently inundated. Consequently, the pre-settlement estuarine-riverine break had to be relocated further downriver than its current location, and ''lost'' estuarine wetlands had to be added to the database. For the former, the presence of soils recognized as submerged uplands and the appearance of salt-stressed forests were used to establish this break at the mouth of the Baron Creek. Understandably, this is a conservative demarcation, as it is likely that freshwater forested wetlands also occurred downstream along the edges of estuarine wetlands. The Honga and Sunken series (submerged ''uplands,'' now brackish tidal wetlands) both represent former lowland forests (likely palustrine forested wetlands or wet flatwoods similar to those occurring today on Othello and Elkton soils) that became estuarine wetlands with rising sea level over the past few hundred years. The former is an organic soil (Terric Sulfihemists) with more than 40 cm of organic matter, whereas the latter is a mucky silt loam soil (Typic Ochraquults) with a surface layer of only 5–20 cm of organic matter (Brewer et al. 1998). The Sunken series is typified by salt-stressed (dying or dead) stands of loblolly pine (*Pinus taeda* L.) and some areas have become salt/brackish marshes. While both series represent former forest, for purposes of this study, only the Sunken series was identified as pre-settlement freshwater forested wetlands. Given the thickness of its organic horizon, the Honga series most likely became estuarine wetland more than 300 years ago (e.g., wood found in the organic and mineral horizons was carbon-dated at less than 700 years before present; Brewer et al. 1998). Pone soils were designated as temporarily flooded-tidal forested wetlands where contiguous with tidal marsh soils; in other places, they were designated as nontidal temporarily flooded forested wetlands. Muck soils and contiguous soils that are now estuarine wetlands were also identified as historic tidal forested wetlands. Elsewhere, muck soil map units were regarded as non-tidal forested wetlands. The Nanticoke series and the tidal marsh map units from the soil surveys were considered pre-settlement freshwater tidal marshes. The pre-colonial limits of estuarine and freshwater tidal reaches represent approximate boundaries, mainly used to indicate a significant ecological and hydrologic change in this watershed over time. It is further recognized that the upstream limit of tidal influence was probably downstream from its current location, but approximating this limit was not possible.

To identify ''lost'' estuarine wetlands due to sea-level rise over the past few hundred years, U.S. Geological Survey 1:24,000 orthophotomaps (Deal Island 1972, Mardela Springs 1982, Nanticoke 1983, and Wetipquin 1983) were consulted. The 2-m depth shown on these maps represents a convenient approximation of the lower limit of the intertidal zone 600 years ago; recorded depths within this boundary are mostly listed as 1 m below mean low water. Given a spring tide range of 0.8 to 0.9 m for the Nanticoke River (http://co-ops.nos.noaa.gov/tide_pred.html) and a near constant rate of sea-level rise of 1.4 mm/yr in Chesapeake Bay over the past 6,000 years (Curtis Larsen, U.S. Geological Survey, pers. comm.; Larsen 1998), these shallow water areas were predicted to be estuarine wetlands (probably some combination of tidal marshes and flats) around 1400 AD.

Impounded sections of rivers (i.e., artificial instream ponds and lakes) shown on the soil surveys were classified as forested wetlands similar to contiguous wetlands above and below the impoundment. Some minor area of open water was probably included in the wetland area estimate following this interpretation.

After pre-settlement wetlands were identified, they were classified according to NWI types (Cowardin et al. 1979). All inland wetlands were classified as palustrine forested wetlands, recognizing that periodic wildfires would have created a succession of types from emergent wetlands through shrub swamps to forested wetlands, much like we observe today after timber harvest. According to the 1920s soil surveys, most of the soils were forested in their original state (e.g., Wicomico County was ''practically'' all forest until ''reclaimed for agricultural purposes;'' Snyder and Gillett 1925). Water regimes were based on hydrology data for soil map units published in the soil survey reports.

The condition of the historic landscape is therefore much simplified. No attempt was made to separate forested wetlands into different types at the subclass level according to Cowardin et al. (1979) or to account for the effect of increased sedimentation on estuarine wetlands following conversion of forests to agricultural land, since these patterns were impossible to predict.

1998 Wetland Inventory

The distribution, extent, and classification of present-day wetlands were based on NWI mapping. NWI data for the Nanticoke watershed were recently updated using spring 1998–1:40,000 black and white photography (see Tiner et al. 2001, 2000 for details). Wetlands were classified according to the FWS's official wetland classification system (Cowardin et al. 1979).

Enhanced Wetland Classification

The NWI database was expanded to include descriptors for landscape position, landform, water flow path, and waterbody types (LLWW descriptors). They were applied to all wetlands and deepwater habitats in the NWI digital database by merging NWI data with online U.S. Geological Survey topographic maps (digital raster graphics), consulting aerial photography where necessary, and interpreting dichotomous keys to the descriptors (Tiner 2003a; Table 1). Enhanced classification was applied to both the pre-settlement and 1998 wetlands.

Preliminary Assessment of Wetland Functions

This study employed a landscape-level wetland assessment approach called ''Watershed-based Preliminary Assessment of Wetland Functions'' (W-PAWF). W-PAWF applies general knowledge about wetlands and their functions to produce a watershed profile highlighting wetlands of potential significance for numerous functions. The method was developed to predict wetland functions for large geographic areas, particularly watersheds, from NWI data. To do this, two steps must be undertaken: 1) the digital NWI database must be expanded by adding LLWW descriptors, and 2) correlations between wetland characteristics in the database and wetland functions must be developed. Many wetland functions are related to physical properties, while others are dependent on a combination of biological and physical characteristics. For example, floodplain and depressional wetlands temporarily store surface water, whereas slope wetlands do not; wetlands that are sources of streams are vital for streamflow maintenance; marshes provide habitat for waterfowl and waterbirds.

In W-PAWF, ten wetland functions are evaluated: 1) surface-water detention, 2) streamflow maintenance, 3) nutrient transformation, 4) sediment and other particulate retention, 5) coastal storm-surge detention (for tidal regions only), 6) shoreline stabilization, 7) provision of fish and shellfish habitat, 8) provision of waterfowl and waterbird habitat, 9) provision of other wildlife habitat, and 10) conservation of biodiversity (e.g., rare or uncommon wetland types in the watershed based on NWI mapping or photointerpretable wetland types of regional significance for biodiversity). The rationale for correlating wetland characteristics with these functions for the Northeast is described in Tiner (2003b). Correlations are based on a review of the literature and application of best professional judgment from many wetland biologists and resource specialists in the Northeast.

After the digital databases for pre-settlement and contemporary wetlands were constructed (including LLWW descriptors), analyses were performed to produce a preliminary assessment of wetland functions for the watershed for each era. Correlations between wetland functions and characteristics were applied to the enhanced NWI database to identify wetlands that may be performing each function at significant levels. The conservation of biodiversity function was not evaluated for the pre-settlement era since source data were limited.

After running the analyses, a series of maps were generated by ArcView 3.x to highlight wetlands that may perform these functions at high or other significant levels. Area summaries for each function were generated from Microsoft's Access program. The targeted wetlands were predicted to perform a given function at a significant level presumably important to the watershed's ability to provide that function. ''Significance'' is a relative term and is used in this analysis to identify wetlands that are likely to perform a given function at a level above that of wetlands not designated.

Function Comparison: Pre-settlement vs. 1998

To assess the impact of cumulative loss of wetlands on specific functions, one can simply examine the change in area of functionally significant wetlands. This was done, but the area difference alone may not adequately convey the cumulative impact on wetland functions. To address the latter, a simple weighting scale for wetlands of potential significance for each function was devised. A ''high'' potential was given

Table 1. Simplified keys for classifying wetlands by landscape position, landform, and water flow path. (Adapted from Tiner 2003a)

Landscape Position

1. Wetland borders a river, stream, in-stream pond, lake, reservoir, estuary, or ocean 2
1. Wetland does not border one of these waterbodies; it is completely surrounded by upland or borders a pond surrounded by upland . . . . Terrene
2. Wetland lies along an ocean shore and is subject to tidal flooding . . . . Marine
2. Wetland does not lie along an ocean shore 3
3. Wetland lies along an estuary (salt to brackish tidal waters) and is subject to tidal flooding . . . . Estuarine
3. Wetland does not lie along an estuary or if so, it is not subject to tidal flooding 4
4. Wetland lies along a lake or reservoir or within its basin . . . . Lentic
4. Wetland lies along a river, stream, or in-stream pond, or borders an estuarine wetland 5
5. Wetland is the source of a river or stream and this watercourse does not extend through the wetland . . . . Terrene
5. River or stream flows through the wetland, or wetland borders an estuarine wetland 6
6. Wetland is periodically flooded by river or stream . . . . Lotic[1]
6. Wetland is not periodically flooded by the river or stream or by tides (episodic flooding may occur) . . . . Terrene

Landform

1. Wetland occurs on a slope >2% . . . . Slope
1. Wetland does not occur on a slope >2% 2
2. Wetland forms an island completely surrounded by water . . . . Island
2. Wetland does not form an island 3
3. Wetland occurs in the shallow water zone of a permanent non-tidal waterbody, the intertidal zone of an estuary with unrestricted tidal flow, or the regularly flooded (daily tidal inundation) zone of freshwater tidal wetlands . . . . Fringe
3. Wetland does not occur in these waters or intertidal zones with unrestricted tidal flow 4
4. Wetland occurs in a portion of an estuary with restricted tidal flow due to tide gates, undersized culverts, dikes, or similar obstructions . . . . Basin
4. Wetland does not occur in such location 5
5. Wetland forms a non-vegetated bank or is within the banks of a river or stream . . . . Fringe
5. Wetland is not a non-vegetated riverbank or streambank or within the banks 6
6. Wetland occurs on an active alluvial plain . . . . Floodplain*
6. Wetland does not occur on an active floodplain 7
7. Wetland occurs on a broad interstream divide (including headwater positions) associated with coastal or glaciolacustrine plains or similar plains . . . . Interfluve*
7. Wetland does not occur on such a landform 8
8. Wetland occurs in a distinct depression . . . . Basin
8. Wetland occurs on a nearly level landform . . . . Flat

Water Flow Path[2]

1. Wetland is typically surrounded by upland (non-hydric soil); receives precipitation and runoff from adjacent areas with no apparent outflow . . . . Isolated**
1. Wetland is not geographically isolated 2
2. Wetland is a sink receiving water from a river, stream, or other surface-water source, and lacking surface-water outflow . . . . Inflow
2. Wetland is not a sink; surface water flows through or out of the wetland 3
3. Wetland is subjected to tidal flooding . . . . Bidirectional-Tidal
3. Wetland is not tidally influenced 4
4. Water flows out of the wetland, but does not flow into this wetland from another source . . . . Outflow
4. Water flows in and out of the wetland 5
5. Water flows through the wetland, often coming from upstream or uphill sources (typically wetlands along rivers and streams) . . . . Throughflow
5. Wetland is along a lake or reservoir and its water levels are subjected to the rise and fall of this waterbody . . Bidirectional-Nontidal

[1] Lotic wetlands are separated into river and stream sections (based on watercourse width at map scale of 1:24,000 – polygon = Lotic River vs. linear = Lotic Stream) and then divided into one of five gradients: 1) high (e.g., shallow mountain streams on steep slopes), 2) middle (e.g., streams with moderate slopes), 3) low (e.g., mainstem rivers with considerable floodplain development), 4) intermittent (subject to periodic flows), and 5) tidal (hydrology under influence of the tides).

[2] Surface-water connections are emphasized because they are more readily identified than groundwater linkages.

* Basin and Flat sub-landforms can be identified within these landforms when desirable.

** Wetland is geographically isolated; hydrological relationship to other wetlands and watercourses may be more complex than can be determined by simple visual assessment of surface-water conditions.

a weight of 2, while a ''moderate'' potential and other potentially significant wetlands (i.e., shading for fish habitat and wood duck habitat) were assigned a weight of 1. By multiplying the wetland area listed as high, moderate, or other potential by the weighting factor, a total number of functional units was calculated for each function at pre-settlement and 1998. This allowed comparison between pre-settlement functional capacity (total functional units for time one) and the 1998 capacity (total functional units for time two) and could demonstrate a percent loss of pre-settlement function. This provides an interesting perspective on the current conditions from a functional capacity standpoint and may give a better sense of the relative magnitude of the functional loss than change in wetland area alone.

RESULTS

The wetland database created for this project allowed production of wetland maps and statistics on wetland extent and predicted functions for two time periods (pre-settlement and 1998). Two sets of watershed-scale maps (1:110,000) were produced to profile the Nanticoke's wetlands—one set showing estimated pre-settlement conditions and predicted wetlands of significance for nine functions (excluding conservation of biodiversity) and the other set showing 1998 conditions and predicted wetlands of significance for ten functions. These maps are multi-colored and too detailed to present in this paper; they display wetlands by NWI types, landscape position, landform, water flow path, and potential significance for each of ten functions. An example of a reduced version is presented as Figure 2; examples of similar maps for the Maryland portion of the watershed can be viewed on the web at: http://wetlands.fws.gov/Pubs_Reports/Md_Watershed/Md_watershed.htm.

Wetland Extent Comparison

Trends by Generalized NWI Types. There have been significant changes in wetland and aquatic resources since pre-settlement times (Figure 3). Prior to European settlement, an estimated 93,125 ha of wetlands may have existed in the Nanticoke watershed (Table 2). Ninety percent of the predicted wetland area was represented by palustrine (freshwater) wetlands, mostly nontidal (79,537.5 ha). Most (88.5%) of the wetlands were forested, with the rest being classified as emergent (10.3% as estuarine and 1.2% as palustrine). The actual extent of palustrine emergent wetlands was undoubtedly greater than estimated due to fire impacts, but there were no data to predict this effect. The estimates also do not include any predicted area of palustrine scrub-shrub wetlands for similar reasons.

By 1998, the Nanticoke's wetland area had fallen to 57,492 ha (about 62% of the pre-settlement total). Eighty-eight percent was palustrine wetland, with forested and scrub-shrub wetlands accounting for over 46,000 ha. This figure includes many wetlands in post-harvest succession. Estuarine wetlands accounted for nearly 12% of the watershed's wetland area. Irregularly flooded emergent wetlands predominated, occupying over 6,000 ha (about 93% of the Nanticoke's estuarine wetlands; Table 3). Although Table 2 shows a tremendous increase in palustrine non-tidal emergent wetland area, the huge difference is an artifact, related more to the detailed wetland mapping in 1998 vs. generalized pre-settlement data. Much emergent wetland area in 1998 resulted from timber harvest operations converting forested wetland to emergent wetland and with some increase in emergent wetland also due to pond construction. Table 3 gives a more detailed accounting of present-day wetlands by NWI types.

Trends by LLWW Types. At pre-settlement, an estimated 2,809 wetlands occupied over 93,000 ha of the watershed (Table 4). Seventy-eight percent of the wetland area was represented by terrene wetlands, while lotic wetlands comprised 12% of the area; estuarine wetlands made up 10%. About 77% of the wetlands were interfluve types. Fringe wetlands constituted 11% and floodplain wetlands about 10% of the wetland area. From the water flow perspective, 73% of the wetland area experienced outflow, 15% bidirectional-tidal flow, 7% throughflow, and 5% was isolated (completely surrounded by nonwetland).

By 1998, the Nanticoke's wetland area had been reduced by 39%, while the number of wetlands (excluding ponds) increased 1.75 times to 4,920 due largely to fragmentation by roads and agricultural fields. The ratio of wetland types comprising the Nanticoke's wetlands changed slightly with the significant decrease in wetland area. Terrene wetlands now represent about 72% of the wetland area (excluding ponds), while estuarine wetlands comprise 16% and lotic wetlands 12%. Lentic wetlands created from dammed rivers or streams or by excavating and diking terrene wetlands occupy only 0.2% of the area. From the landform standpoint, interfluve wetlands account for 71% of the wetland area, followed by fringe wetlands (17%) and floodplain wetlands (11%). Other wetland landforms now represent less than 2% of the area (flats− 1.1%; basins −0.5%, and islands −0.2%). Outflow wetlands remain the predominant water-flow-path type, totaling 38,539 ha (68% of the wetland area). Bidirectional-tidal wetlands are second-ranked with 10,434 ha (18% of the wetland area), followed by throughflow wetlands with 5,917 ha (10%). Isolated wetlands amount to 2,029 ha (4%) and bidirectional-

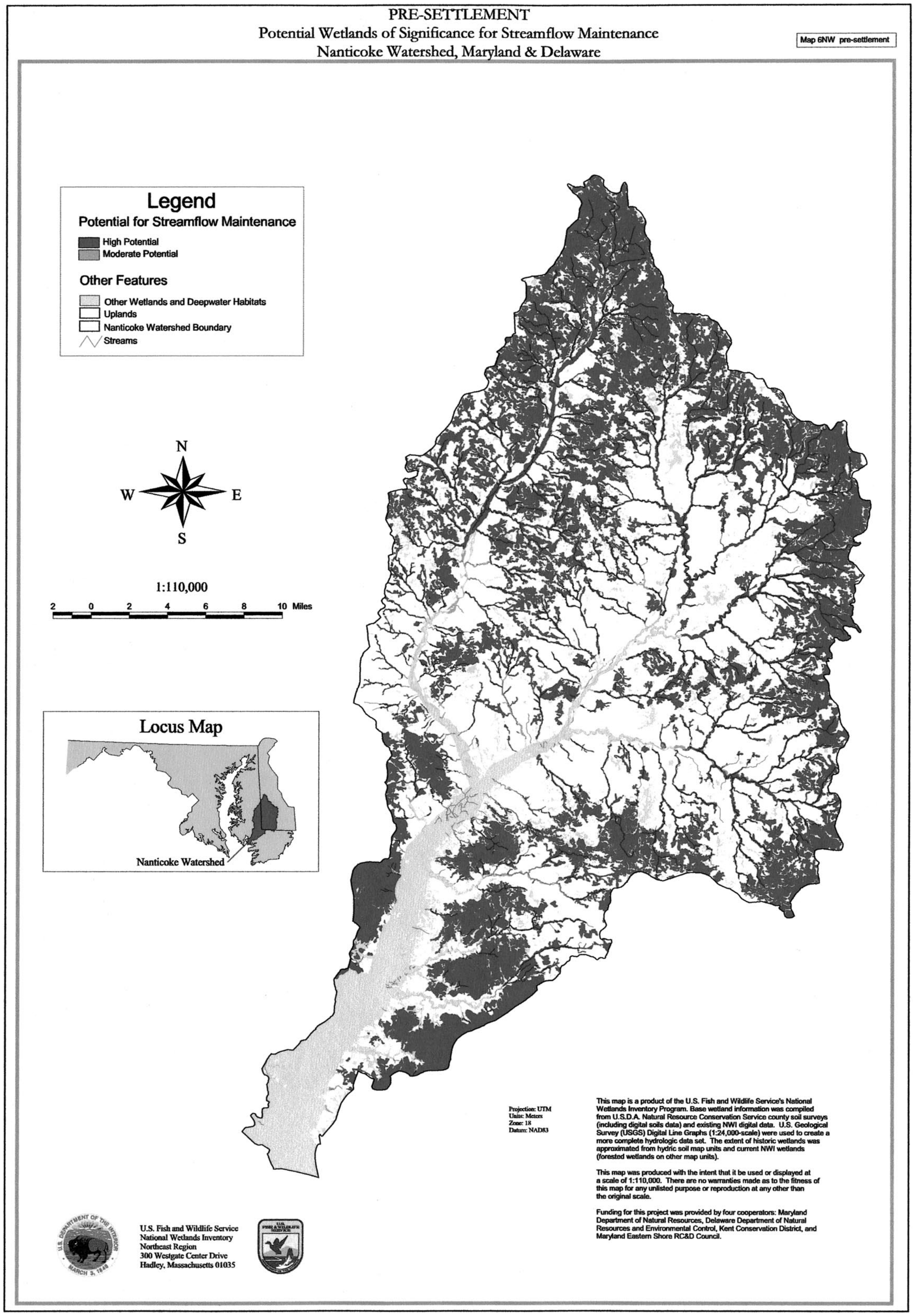

Figure 2. Example of published thematic map (reduced in size and black & white copy of color map) highlighting pre-settlement wetlands of potential significance for streamflow maintenance. Black areas represent wetlands with high potential for contributing significantly to stream flow. (Tiner and Bergquist 2003)

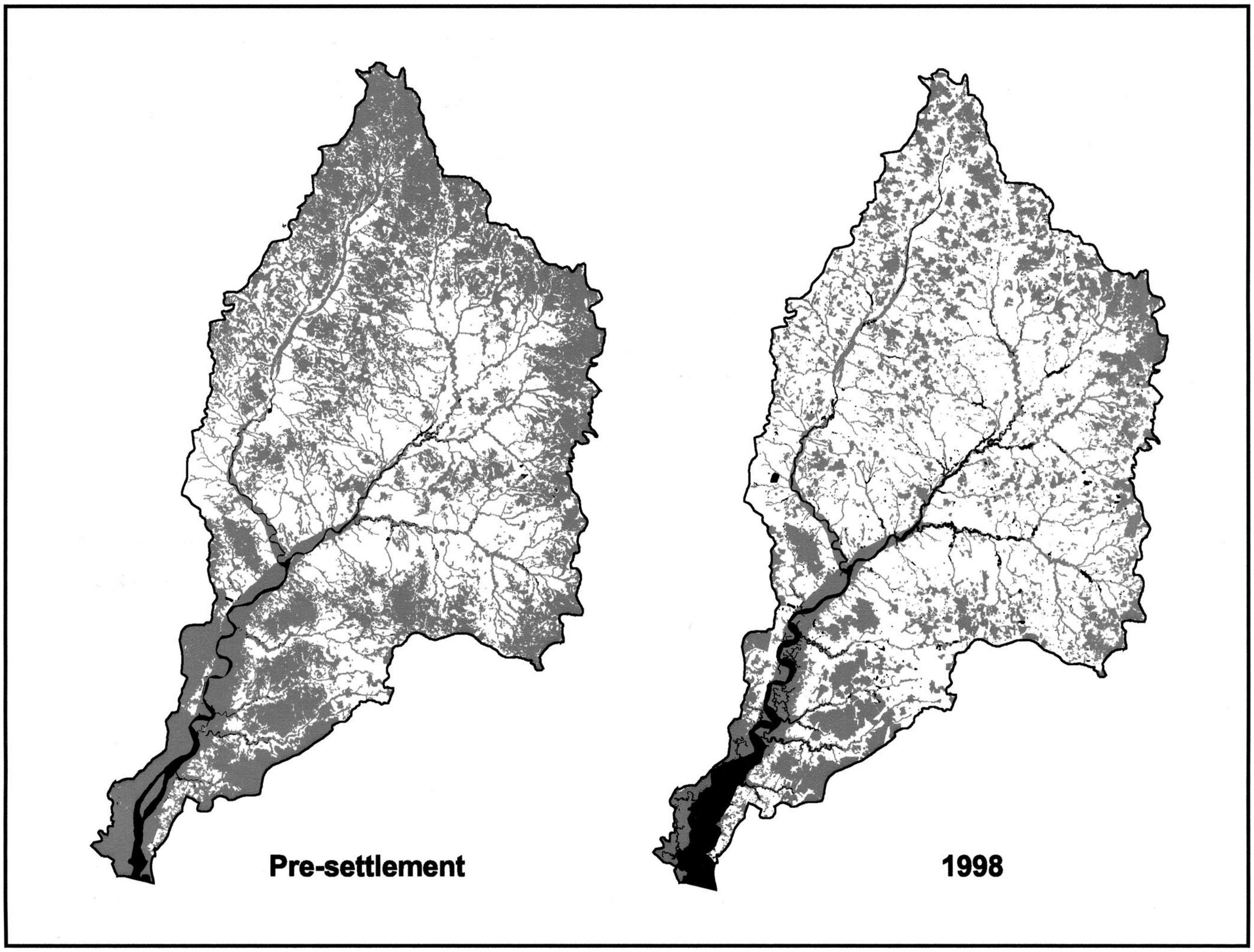

Figure 3. Nanticoke River watershed's wetlands and deepwater habitats at pre-settlement and in 1998. Black areas are deepwater habitats; gray areas are wetlands (including ponds).

nontidal wetlands associated with impoundments total only 105 ha (0.2%).

Since pre-settlement, terrene wetlands experienced the greatest loss, decreasing by nearly 44%, with terrene interfluve wetlands being most adversely affected. Habitat fragmentation was significant, with the mean size of interfluve wetlands dropping to a third of their original size (i.e., from 33.8 ha at pre-settlement to 10.6 ha in 1998). By 1998, the mean size of the most abundant wetlands—terrene outflow wetlands—had decreased from 175 ha to 18 ha, while their number increased nearly 6-fold (from 380 to 2120). Only 63% of the pre-settlement lotic wetland area remained in 1998; lotic river wetlands experienced the greatest loss (−70%) from about 4,100 ha to roughly 1,200 ha. The area of estuarine wetlands dropped by an estimated 4%, and lentic wetlands became established in river impoundments and diked former terrene wetlands. Ponds were created from both wetlands and uplands. The proportion of wetland area represented by different landforms changed slightly, with a drop in interfluve wetlands (77 to 71%) and an increase in fringe and floodplain types (11 to 17% and 10 to11%, respectively). The percent of outflow wetland area fell from 73 to 68%, whereas the percent represented by throughflow and bidirectional-tidal flow rose from 7 to 10% and 15 to 18%, respectively.

Causes of Wetland Trends

Both natural processes and human activities were responsible for the predicted wetland losses. The chief natural process was sea-level rise, which affected both estuarine and palustrine wetlands. Most of the estuarine wetlands lost became shallow estuarine water due to increased erosion and submergence. This hydrologic change also moved the salt wedge further upstream and inland converting many areas of freshwater wet-

Table 2. Historic trends in the Nanticoke's wetland area (in hectares) by generalized NWI types: pre-settlement vs. 1998. (Note: 1998 data are more detailed than presented here – see Table 3; 1998 types have been aggregated for comparison with pre-settlement types; totals may be slightly different than sum of numbers duo to round-off procedures.)

Wetland Type	Pre-settlement Area (% of Wetlands)	1998 Area (% of Wetlands)	Net Area Change (% of Pre-settlement)
Estuarine Intertidal	9,569.6 (10.3)	6,849.4 (11.9)	−2,720.2 (−28.4%)
Palustrine Emergent			
Tidal	1,091.7 (1.2)	273.2* (0.5)	−818.5 (−75.0%)
Nontidal	25.7 (<0.1)	2,169.3 (3.7)	+2,143.6 (+8341%)**
Total	1,117.4 (1.2)	2,442.5 (4.2)	+1,325.1 (+118.6%)
Palustrine Forested			
Tidal	2,926.4 (3.1)	3,307.9*** (5.8)	+381.5 (+13.0%)
Nontidal	79,511.8 (85.4)	42,975.5*** (74.8)	−36,536.3 (−46.0%)
Total	82,438.2 (88.5)	46,283.4 (80.5)	−36,154.8 (−43.9%)
Other Palustrine			
Farmed	-0-	1,428.3 (2.5)	+1,428.3 (NA%)
Ponds	-0-	488.0 (0.8)	+488.0 (NA%)
Total	-0-	1,916.3 (3.3)	+1,916.3 (NA%)
Grand Total	93,125.2	57,491.6	−35,633.6 (−38.3%)

* Includes 153.3 ha of riverine tidal wetlands, mostly marshes.
** This increase is an artifact, since the pre-settlement extent of non-tidal emergents could not be accurately established.
*** Includes scrub-shrub wetlands and mixed communities where forested or scrub-shrub wetland was the dominant class.

lands (lotic river wetlands) to estuarine wetlands in the lower portion of the watershed. This process continues today, as witnessed by stumps and dead trees in estuarine marshes and dying or salt-stressed trees in neighboring landward areas. Rising sea level undoubtedly had the effect of extending tidal influence upstream, thereby changing the hydrology of former nontidal wetlands to a freshwater tidal regime. With European settlement and subsequent population growth, drainage and conversion of much palustrine forested wetland to farmland took place for more than 200 years. In 1998, over 1,400 ha were classified as farmed wetlands, while the bulk of the drained wetlands were converted to non-wetland agricultural fields. Farming is the predominant land use in the watershed today. Many of the remaining palustrine wetlands are fragmented by roads and cropland. Human activities also resulted in the creation of about 500 ha of ponds built in both wetlands and uplands.

Trends by Wetland Function

Two comparisons of changes in functions were made, one showing changes in wetland area providing functions at significant levels (Table 5) and the other depicting changes in functional units (Table 6). From an area standpoint, substantial losses of wetlands providing all functions ranged from an over 50% area loss in wetlands important for sediment retention to a 23% loss of wetlands stabilizing shorelines and those storing coastal storm surge. More than 30% of the wetland area rated as significant for performing half of the wetland functions evaluated was lost. Wetlands that served as sources of streams (headwater wetlands) were most negatively impacted; 87% of the pre-settlement wetland area predicted as having high potential for this function was altered. Ditching of terrene interfluve wetlands either effectively drained many of these headwater wetlands, converting them to cropland (upland), or diminished the duration of their seasonal wetness (reducing their contribution to streamflow).

When functional units were evaluated, the change in the watershed's ''functional capacity'' may be better realized (Table 6). For most of the wetland functions evaluated, the Nanticoke watershed is predicted to be operating at 50 to 77% of its original capacity. The streamflow maintenance function supported by wetlands is operating at only 36% of its original capacity; this has undoubtedly had significant adverse impacts on aquatic biota. The watershed's capacity for providing six other functions decreased by more than 28% (i.e., surface-water detention, nutrient transformation, sediment and other particulate retention, fish and shellfish habitat, waterfowl and waterbird habitat, and other wildlife habitat). The two remaining func-

Table 3. Wetlands in the Nanticoke watershed in 1998 classified by NWI wetland type to the class level (Cowardin et al. 1979).

NWI Wetland Type	Area (ha)
Estuarine Wetlands	
Emergent (Regularly Flooded)	259.2 (96.9 = oligohaline)
Emergent (Irregularly Flooded)	6,203.8 (2,469.7 = oligohaline)
Scrub-Shrub (Irregularly Flooded)	56.4 (34.5 = oligohaline)
Forested (Irregularly Flooded)	97.6
Unconsolidated Shore (Irregularly Exposed)	15.7
Unconsolidated Shore (Regularly Flooded)	216.7 (111.1 = oligohaline)
Total	6,849.4 (2,712.2 = oligohaline)
Palustrine Wetlands (nontidal, except where noted)	
Aquatic Bed	0.3
Emergent	590.2 (3.4 = Emergent/Forested)
Emergent (Tidal)	119.9
Mixed Emergent/Scrub-Shrub (Deciduous)	1,260.6
Mixed Emergent/Scrub-Shrub (Evergreen)	318.1
Farmed	1,428.3
Needle-leaved Deciduous Forested	32.3
Evergreen Forested	3,350.0 (27.2 = Atlantic White Cedar)
Evergreen Forested (Tidal)	43.7
Scrub-Shrub/Emergent	1,032.6
Broad-leaved Deciduous Forested	15,587.9 (76.0 = w/Bald Cypress)
Broad-leaved Deciduous Forested (Tidal)	2,902.8 (10.5 = w/Bald Cypress)
Mixed Forested	12,228.6
Mixed Forested (Tidal)	231.8
Deciduous Forested/Emergent	166.1 (9.5 = tidal)
Forested/Scrub-Shrub and Forested/Scrub-Shrub	5,665.0 (43.5 = tidal)
Deciduous Scrub-Shrub	856.5
Evergreen Scrub-Shrub	2,475.9
Mixed Scrub-Shrub	1,633.5
Scrub-Shrub (Tidal)	76.7
Unconsolidated Bottom/Vegetated	16.4 (14.1 = w/Bald Cypress)
Unconsolidated Bottom	468.4
Unconsolidated Shore	3.2
Total	50,488.8
Riverine Wetlands	
Emergent (Tidal)	134.4
Unconsolidated Shore (Tidal)	18.9
Total	153.3
GRAND TOTAL	57,491.5

tions (shoreline stabilization and coastal storm-surge detention) lost nearly one-quarter of their pre-settlement capacity. No function experienced an increase in capacity.

DISCUSSION

Extensive wetlands have always been recognized on the Delmarva Peninsula. Interpretation of the 1920s soil survey data predicted that the percent of the county represented by wetlands ranged from 32% for Caroline County to a high of 75% for Dorchester County (Table 7). The latter county had extensive tidal wetlands bordering Chesapeake Bay and much flatwood soil area (e.g., Elkton series). The extent of potential wetlands in the five-county area was roughly 50%. For the Nanticoke River watershed, pre-settlement wetlands were estimated to occupy 44% of the watershed. This figure is consistent with the five-county wetland total for the 1920s, especially considering that the Nanticoke watershed did not have as high a percent of tidal wetlands as the five-county area (13% vs. 21% of the wetlands). Today, only 28% of the watershed is wetland.

Table 4. Historic trends in the Nanticoke's wetland area (in hectares) by landscape position, landform, and water flow path: pre-settlement (YR 1400) vs. 1998. Codes for water flow path: BT = bidirectional-tidal; TH = throughflow; BI = bidirectional-nontidal; IS = isolated; OU = outflow. Number of wetlands is approximate due to GIS processing.

Landscape	Landform	Water Flow Path	1400 #	1400 Area (ha)	1998 #	1998 Area (ha)	% Change in Area
Estuarine	Fringe*	BT	83	9,228.2	143	9,062.6	−1.8
	Island	BT	1	341.3	2	100.6	−70.5
	Total		84	9,569.5	145	9,163.2	−4.2
Lentic	Basin	BI	—	—	26	44.4	+
	Flat	BI	—	—	8	8.7	+
	Fringe	BI	—	—	14	50.0	+
	Island	BI	—	—	4	2.0	+
	Total		0	0	52	105.1	+
Lotic River	Floodplain	BT	102	2,907.3	151	957.2	−67.1
		TH	10	66.5	6	11.3	−83.0
	Fringe	BT	105	1,091.7	104	248.7	−77.2
		TH	2	25.7	—	—	—
	Island	BT	—	—	1	0.1	+
	Total		219	4,091.2	262	1,217.3	−70.2
Lotic Stream	Basin	TH	12	29.6	52	142.4	+381.1
	Flat	TH	13	68.2	95	315.6	+362.8
	Floodplain	TH	130	6,670.6	385	5,018.6	−24.8
		BT	2	19.1	25	56.2	+194.2
	Fringe	TH	—	—	29	99.5	+
		BT	—	—	13	8.5	+
	Total		157	6,787.5	599	5,640.8	−16.9
Terrene	Basin	IS	—	—	7	6.0	+
		OU	79	330.2	14	101.7	−69.2
	Flat	IS	—	—	10	33.5	+
		OU	162	1,047.9	47	292.1	−72.1
		TH	—	—	1	0.4	+
	Fringe	OU	—	—	1	0.4	+
	Interfluve	IS	1723	4,616.2	1551	1,989.2	−56.9
		OU	380	66,655.3	2120	38,144.3	−42.8
		TH	5	27.2	111	329.2	+1110.3
	Total		2,349	72,676.8	3,862	40,896.8	−43.7
Grand Total			2,809	93,125.0	4,920	57,023.2**	−38.8

* Includes tidal freshwater wetlands contiguous with estuarine wetlands and along estuarine waters.
** Excludes ponds.

General Limitations of the Study

Historic wetland data compiled from contemporary soil surveys have obvious limitations. Translating this information to historic wetland extent for the Nanticoke required making certain assumptions: 1) hydric soil mapping units represent a reasonable approximation of historic wetlands, 2) areas of the Sunken series were freshwater forested wetlands at pre-settlement, 3) areas of typical freshwater wetland soils that are now mapped as estuarine wetlands were also freshwater forested wetlands at pre-settlement, 4) areas of Honga series were estuarine wetlands at this time, although they were forested wetlands at least 700 years ago (Brewer et al. 1998), and 5) areas within non-hydric soil map units that were mapped as forested wetlands in 1998 by NWI represent hydric inclusions that were forested wetlands at pre-settlement.

The 1998 database should adequately reflect current conditions due to strengthened federal and state regulations in the 1980s and 1990s. One must, however, recognize the limitations of any wetland mapping effort derived mainly through photointerpretation techniques (Tiner 1997, 1999). Photo quality, scale, and environmental conditions at the time of acquisition are

Table 5. Comparison of preliminary functional assessment results for Nanticoke wetlands at pre-settlement versus 1998. Area (in hectares) and percentage of the wetland area total are given for each function. Total wetland area for 1998 (57,543.2 ha) includes 520 ha of ponds.

Function	Potential Significance	Pre-settlement Area (% of total area)	1998 Area (% of total)	% Change in Area
Surface-water Detention	High	20,380.5 (21.9)	15,870.7 (27.6)	−22.1
	Moderate	70,814.5 (76.0)	39,847.7 (69.2)	−43.7
	Total	91,195.0 (97.9)	55,718.4 (96.8)	−38.9
Streamflow Maintenance	High	72,971.2 (78.4)	9,586.2 (16.7)	−86.9
	Moderate	546.4 (0.6)	33,332.4 (57.9)	+600.0
	Total	73,517.6 (79.0)	42,918.6 (74.6)	−41.6
Nutrient Transformation	High	39,009.7 (41.9)	14,476.2 (25.2)	−62.9
	Moderate	54,115.5 (58.1)	40,864.3 (71.0)	−24.5
	Total	93,125.2 (100.0)	55,340.5 (96.2)	−40.6
Retention of Sediments and Other Particulates	High	20,380.1 (21.9)	15,627.2 (27.2)	−23.3
	Moderate	20,365.2 (21.9)	1,920.1 (3.3)	−90.6
	Total	40,745.3 (43.8)	17,547.3 (30.5)	−56.9
Shoreline Stabilization	High	20,448.2 (22.0)	15,798.1 (27.5)	−22.7
	Moderate	-0-	0.4 (−)	+negligible
	Total	20,448.2 (22.0)	15,798.5 (27.5)	−22.7
Coastal Storm-surge Detention	High	13,587.7 (14.6)	10,415.1 (18.1)	−23.3
Fish/Shellfish Habitat	High	10,670.0 (11.5)	7,133.4 (12.4)	−33.1
	Moderate	-0-	572.3 (1.0)	+significant
	Shading*	6,787.6 (7.3)	5,349.1 (9.3)	−21.2
	Total	17,457.6 (18.8)	13,054.8 (22.7)	−25.2
Waterfowl/Waterbird Habitat	High	10,686.9 (11.5)	7,337.0 (12.8)	−31.3
	Moderate	-0-	486.4 (0.8)	+significant
	Wood Duck	8,025.7 (8.6)	5,453.0 (9.5)	−32.1
	Total	18,712.6 (20.1)	13,276.4 (23.1)	−29.1
Other Wildlife Habitat	High	90,559.4 (97.2)	52,648.5 (91.5)	−41.9
	Moderate	2,565.8 (2.8)	2,699.1 (4.7)	+5.2
	Total	93,125.2 (100.0)	55,347.6 (96.2)	−40.6

Table 6. Predicted change in the Nanticoke watershed's capacity to perform nine wetland functions from pre-settlement to 1998. Functional units were derived from predictive values for each time period by applying a weighting scheme (2 for high; 1 for moderate; and 1 for other significant features, e.g., stream shading). The conservation of biodiversity function was not compared since original data lacked sufficient detail for such comparison.

Function	Pre-settlement Functional Units	1998 Functional Units	Predicted % of Original Capacity Left	Predicted % Change in Functional Capacity
Surface-water detention	111,575.5	71,589.1	64.2	−35.8
Streamflow Maintenance	146,488.8	52,504.8	35.8	−64.2
Nutrient Transformation	132,134.9	69,816.7	52.8	−47.2
Sediment and Other Particulate Retention	61,125.4	33,174.5	54.3	−45.7
Shoreline Stabilization	40,896.4	31,596.6	77.3	−22.7
Coastal Storm-surge Detention	27,175.4	20,830.2	76.7	−23.3
Fish and Shellfish Habitat	28,127.6	20,188.2	71.8	−28.2
Waterfowl and Waterbird Habitat	29,399.5	20,613.4	70.1	−29.9
Other Wildlife Habitat	183,684.6	107,996.1	58.8	−41.2

Table 7. Area (in heactares) of wetland soil mapping units in each county falling within the Nanticoke River watershed based on 1920s soil surveys (Dunn et al. 1920, Snyder et al. 1924, Snyder and Gillett 1925, Snyder et al. 1926, and Winant and Bacon 1929). Statistics are for entire county; percent of county represented by each mapping unit is given in parentheses.

Wetland	County				
Mapping Unit	Caroline Area (%)	Dorchester Area (%)	Wicomico Area (%)	Kent Area (%)	Sussex Area (%)
Elkton	13,215 (16.6)	73,743 (49.4)	26,896 (27.4)	32,233 (21.0)	41,172 (16.8)
Plummer	933 (1.1)	-0-	-0-	-0-	-0-
Portsmouth	6,193 (7.5)	544 (0.4)	10,105 (10.3)	15,728 (10.2)	28,295 (11.7)
St. Johns	-0-	-0-	2,539 (2.6)	-0-	389 (0.1)
Coastal Beach	-0-	-0-	-0-	285 (0.2)	1,710 (0.7)
Meadow	4,172 (3.0)	2,047 (1.4)	1,788 (1.8)	3,346 (2.2)	1,373 (0.6)
Swamp	-0-	-0-	2,747 (2.8)	4,327 (2.8)	10,701 (4.4)
Tidal Marsh	1,788 (2.2)	35,679 (23.9)	6,141 (6.3)	18,449 (12.0)	14,225 (5.8)
Total	26,321 (31.8)	112,013 (75.1)	50,216 (51.2)	74,468 (48.4)	97,865 (40.1)

major limiting factors. Moreover, drier-end wetlands, such as seasonally saturated and temporarily flooded palustrine wetlands, are often difficult to separate from non-wetlands on-the-ground, thereby complicating their detection through photointerpretation.

It is important to re-emphasize that this type of functional assessment is a preliminary one based on wetland characteristics interpreted through remote sensing and using the best professional judgment of numerous wetland specialists. Wetlands believed to be providing potentially high or other significant levels of performance for a particular function were highlighted. No attempt was made to produce a more qualitative ranking for each function or for each wetland based on multiple functions, as this would require more input from others and more data, well beyond the scope of this study. Field checking of seasonally flooded and seasonally flooded/saturated emergent wetlands should be done to determine if they are marshes or wet meadows. If the former, they will likely have high potential as both fish and shellfish habitat and waterfowl habitat rather than the moderate rating given in this analysis.

The functional assessment used (W-PAWF) does not consider the condition of the adjacent upland (e.g., level of disturbance) or the actual water quality of the associated waterbody, which may be regarded as important metrics for assessing the health of individual wetlands (not part of this study). Collection and analysis of some of these data were done in related studies (Tiner et al. 2000, 2001, Tiner 2004) and were not part of the present study.

Appropriate Use of this Type of Analysis

Keeping in mind the limitations mentioned above, this analysis is a first-cut or initial screening of the watershed's wetlands and an assessment of the potential impact of cumulative losses on wetland functions. It highlights wetlands that may have a significant potential to perform each of ten functions. While the analysis provides perspective on the ability of the watershed's wetlands to perform these functions, it does not evaluate differences among wetlands of similar type and function. The latter information is often important for making decisions about wetland acquisition and designating certain wetlands as more worthy of preservation versus others with the same categorization. Such information can be collected through field investigations and/or by consulting agencies having specific expertise in a subject area.

The analysis for the Nanticoke watershed is a watershed-based wetland characterization and a historical assessment of changes in wetland extent and function. It can serve as an initial screening for prioritization of wetlands for acquisition, restoration, or strengthened protection, as an educational tool for improving the public's understanding of wetland functions and trends, and as a baseline assessment of how wetlands and functions have changed since pre-settlement. For more than two decades, NWI maps have been used by local governments in compiling natural resource inventories. Now, by enhancing NWI data and using it for wetland functional assessment, local planners have a valuable tool for preparing ecologically based municipal master plans (Honachefsky 1999).

CONCLUSIONS

Wetlands in the Nanticoke River watershed have undergone significant changes since pre-settlement. Prior to European colonization, about 45% of the watershed (roughly 93,000 ha) was wetland, with extensive headwater wetlands supporting streamflow. By 1998, about 57,000 ha of wetlands (62% of the original area) remained and much of this area has been ditched, excavated, or impounded. Conversion of wetlands to agricultural lands was the predominant cause of freshwater wetland change; sea-level rise was the main agent of estuarine wetland change.

Cumulative wetland losses have led to significant reductions of many wetland functions. Since colonial times, it was estimated that the Nanticoke watershed lost over 60% of its predicted capacity for streamflow maintenance and over one-third of its capacity for four other functions: surface-water detention, nutrient transformation, sediment and other particulate retention, and provision of other wildlife habitat. No function experienced an increase in capacity.

The findings of this study provide an overview of the predicted changes in wetland extent and function for the Nanticoke River watershed since European settlement. The comparison of changes in wetland function watershed-wide should be considered approximate due to the nature of this type of analysis. As with any remotely-sensed analysis, field checking should be conducted to validate the interpretations regarding functions of individual wetlands, since this type of assessment is a coarse-filter approach. Despite these limitations, the assessment serves as a foundation for understanding the extent to which wetlands have changed in general form and function, and as such, it provides a valuable tool for resource planning. It should be used with other tools to help devise a watershed-wide strategy for wetland conservation and restoration.

This pilot study demonstrated that it is possible to produce historic assessments of wetlands and functions through analysis of existing information and enhancement of NWI data. Depending on the nature of wetland development and the information available, many assumptions have to be made. Nonetheless, this approach provides a consistent method for evaluating wetland status and trends from a functional perspective while helping increase our understanding of how much historic wetland losses have impacted a watershed's ability to perform numerous functions.

The NWI Program in the Northeast plans to add LLWW descriptors to the NWI digital database as maps are updated. This will increase the value of the NWI database and facilitate its use for preparing preliminary watershed assessments of wetland functions throughout the region. This type of assessment will also be incorporated into localized wetland trends studies to demonstrate how wetland losses are impacting specific functions. There is also interest in this applying these procedures to other regions. Such work will require review of the wetland function-characteristic correlations; minor modifications will undoubtedly be needed to address regional differences in fish and wildlife habitat.

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