Conditions of Wetlands in the Smyrna River Watershed, Delaware

Delaware Department of Natural Resources and Environmental Control

Delaware Wetlands

Purify Provide Protect

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EXECUTIVE SUMMARY

The Delaware Department of Natural Resources and Environmental Control's (DNREC) Wetland Monitoring and Assessment Program (WMAP) documented wetland acreage trends and determined the ambient condition of tidal and non-tidal wetlands in the Smyrna River watershed in 2014 and 2015. This was done with significant field assistance from the Partnership for the Delaware Estuary (PDE). The goals of this project were to: summarize recent gains, losses, and changes in wetland acreage; assess the condition of tidal and non-tidal wetlands throughout the watershed; identify prevalent wetland stressors; assess the value that non-tidal wetlands provide to the local landscape; and make watershed-specific management recommendations to different audiences, including scientists and land managers, decision makers, and landowners.

The Smyrna River watershed is located partially within Kent County and partially within New Castle County, where it encompasses 45,315 acres (71 square miles) of land within the Delaware Bay and Estuary Basin. The Smyrna River watershed consists of the Duck Creek, Smyrna River, and Cedar Swamp sub-watersheds, which were combined for this project and report. Approximately 27% of the land area of the watershed is covered by wetlands. Of these wetlands, 47% are tidal estuarine wetlands, 38% are non-tidal flats, 9% are non-tidal riverine wetlands, and 6% are non-tidal depressions.

We estimated historic (prior to 1992) and recent (1992 to 2007) wetland losses in the Smyrna River watershed based on historic hydric soil maps and recent statewide wetland mapping efforts. Our analysis indicated that by 1992, approximately 32% (5,576 acres) of the watershed's historic wetlands had been filled or lost, mostly due to conversion to other land uses such as agriculture or residential and commercial development. Between 1992 and 2007, the watershed lost another 52 acres of wetlands and gained approximately 149 acres. Most of the wetland acreage loss was due to conversion of non-tidal wetlands to agriculture or development. Most of the gained acreage was attributed to the creation of excavated ponds, which usually provide fewer ecosystem services than natural wetlands. Some wetlands also changed from 1992 to 2007; notably, about 21 acres of estuarine wetlands changed from having emergent vegetation to being unvegetated unconsolidated bottom (i.e. open water). Such changes represent losses of vegetated estuarine wetlands, likely due to erosion and sea level rise.

To assess wetland condition and identify stressors affecting wetland health, rapid assessments were conducted at random wetland sites throughout the watershed during the summers of 2014 and 2015. Wetland assessment sites were located on public and private property and were randomly selected utilizing a probabilistic sampling design with the assistance of the Environmental Protection Agency's (EPA) Ecological Monitoring and Assessment Program (EMAP). WMAP performed non-tidal wetland assessments in 2014 in 30 riverine wetlands, 32 flat wetlands, and 30 depression wetlands using the Delaware Rapid Assessment Procedure (DERAP) Version 6.0. Tidal wetland assessments were led by PDE in 2015 in 30 estuarine wetlands using the Mid-Atlantic Tidal Rapid Assessment Method (MidTRAM) Version 3.0.

Estuarine wetlands received a mean condition score of 80.9 ± 8.1 (median=83.3) out of a maximum possible score of 100.0, with scores ranging from 57.2 to 91.1. Riverine wetlands had a mean condition score of 63.2 ± 20.5 (median=67.0) out of a maximum possible score of 91.0, ranging widely from 20.0 to 91.0. Flat wetlands had a mean condition score of 78.2 ± 13.3 (median=79.5) out of a maximum possible score of 95.0, ranging widely from 32.0 to 95.0. Depression wetlands received a mean score of 61.3 ± 21.0 (median=69.0) out of a maximum

possible score of 82.0, ranging extremely from -2.0 to 80.0. Compared to seven other watersheds previously assessed in Delaware, the wetlands of the Smyrna River watershed were doing fairly well, with a relatively high percentage of wetlands being minimally stressed (47%). Despite this, 43% of wetlands in this watershed were still moderately stressed and 10% were severely stressed. A common wetland stressor was the presence of invasive plant species. Buffer disturbances were also common, particularly because of agriculture and development.

Wetland value was also evaluated in non-tidal wetlands because wetland value to the local area may be independent of wetland condition. Value-added assessments were conducted at non-tidal sites using Version 1.1 of the Value-Added Protocol, in conjunction with DERAP v.6.0. Most riverine wetlands were found to provide moderate value to the local area (40%), whereas most flat wetlands were rated as providing limited value (59%). Most depressions were also rated as providing limited value (43%).

Based on synthesis and analysis of all data collected for this report, we made several management recommendations to improve overall wetland condition and acreage by targeting specific issues in different wetland types. These recommendations were tailored to different audiences, including environmental scientists and land managers, decision makers, and landowners. We recommended that environmental scientists, researchers, and land managers work to: increase resiliency of tidal shorelines; maintain wetland buffers; control the extent and spread of invasive plant species; perform wetland monitoring, conservation, and restoration activities; and continue to increase citizen education and involvement through effective outreach. We also recommended that decision makers: improve the protection of non-tidal palustrine wetlands; update tidal estuarine wetland regulatory maps; develop incentives and legislation for maintaining tidal and non-tidal wetland buffers; and secure funding for wetland preservation. Finally, we suggested that landowners: strengthen tidal shorelines using environmentally-friendly methods (e.g., living shorelines); protect and maintain vegetated buffers around wetlands on their property; protect or restore wetlands on their property; and engage in best management practices for agricultural activities.

INTRODUCTION

Wetlands are unique, beautiful ecosystems that are intrinsically valuable and provide many important ecosystem services to communities. Wetlands can remove and retain disturbed sediments, pollutants, and nutrient runoff from non-point sources (e.g. agriculture, land clearing, and construction) from the water column before they enter our waterways, thereby improving the quality of drinking and swimming water. By retaining sediments, wetlands also help to control erosion. Wetlands minimize flooding by collecting and slowly releasing storm water that spills over channel banks, protecting infrastructure and property. They also sequester carbon, meaning that they help remove excess carbon dioxide from the atmosphere and store it in their plant biomass and soils. Additionally, wetlands are biologically-rich habitats and are home to many unique plant and animal species, some of which are threatened or endangered. They are critical resources for migrating shorebirds and wintering waterfowl, and serve as nurseries for commercial fish and shellfish species. Wetlands are also valuable sources of recreation (e.g. hunting, fishing, and birding) and livelihood (e.g. fishing, crabbing, fur-bearer trapping).

The ecosystem services that wetlands provide supply significant contributions to local economies in Delaware that together total more than $1 billion annually. For example, flood control benefits provided by Delaware wetlands are valued at $66 million annually, and wildlife activities conducted in these areas such as birding, fishing, and hunting generate approximately $386 million annually. Additionally, the state's wetlands provide an estimated $474 million annually in water quality benefits (Kauffman 2018).

Wetland acreage, condition, and variety are all crucial to the ability of wetlands to provide these beneficial services. If wetland acreage decreases, then there are fewer wetlands to perform ecosystem services to people and wildlife. Plus, if wetland acreage decreases, it becomes more difficult for wildlife to disperse and migrate among wetland habitats, as distances between wetlands may grow larger. Such reduced dispersal and migration can reduce genetic diversity and population sizes of wildlife species (Finlayson et al. 2017). Different wetland types typically perform certain functions better than others based on factors such as position in the landscape, vegetation type, and hydrological characteristics (Tiner 2003); therefore, a variety of wetland types ensure that all services that wetlands can offer are provided. Wetlands provide the greatest amount of services when they are in good condition.

Wetlands have a rich history across the region and their aesthetics have become a symbol of the Delaware coast. Unfortunately, many wetlands that remain are degraded from impacts of many stressors, and are therefore functioning below their potential. Mosquito ditches, agriculture, development, filling, and invasive species are all examples of common stressors that Delaware wetlands experience that can negatively affect their hydrology, biological community, and ability to perform beneficial functions. Many anthropogenic wetlands, such as storm water or agricultural ponds, cannot make up for the degradation of natural wetland function, because most of them are unvegetated and perform functions at lower levels than natural wetlands (Tiner et al. 2011).

While numerous wetlands have been degraded, many others have been lost completely; approximately half of all historic wetlands in Delaware have been lost since human settlement in the early 1700's. This decline in wetland acreage has continued in recent years; between 1992 and 2007, there was a substantial net loss of 3,126 acres of vegetated wetlands across the state. Acreage losses are particularly alarming for forested freshwater wetlands, which experienced the greatest losses of all wetland types between 1992 and 2007 (Tiner et al. 2011). These non-tidal wetland losses have largely occurred because of human impacts resulting from the lack of regulatory protection and enforcement. The State of Delaware regulates activities in tidal wetlands, but only in non-tidal wetlands that are 400 contiguous acres or more in size. Federal regulations do exist for non-tidal wetlands, but not for small wetlands <0.1 acres in size. Moreover, recent Supreme Court decisions (i.e. SWANCC and Rapanos/Carabell) have made federal wetland regulation more uncertain for isolated freshwater wetlands. Tidal wetlands in Delaware face different challenges. Although regulated by the state, most of the recent acreage losses of tidal wetlands have been caused by submergence instead of direct human impacts, indicating that sea level rise from climate change is bringing about their disappearance (Tiner et al. 2011). Acreage losses of tidal and non-tidal wetlands have led to losses of many beneficial functions, such as carbon sequestration, sediment retention, wildlife habitat, nutrient transformation, and shoreline stabilization (Tiner et al. 2011).

The State of Delaware is dedicated to preserving and improving wetlands through protection, restoration, education, and effective planning to ensure that they will continue to provide important services to the citizens of Delaware (DNREC 2015a). The State of Delaware Department of Natural Resources and Environmental Control (DNREC) works to support the Bayshore Initiative, which aims to protect and connect important coastal wildlife areas along the Delaware Bay and restore important areas that may have been degraded or destroyed (DNREC 2017a). Thus, DNREC examines changes in wetland acreage over time and monitors wetland condition and functional capacity to guide management and protection efforts.

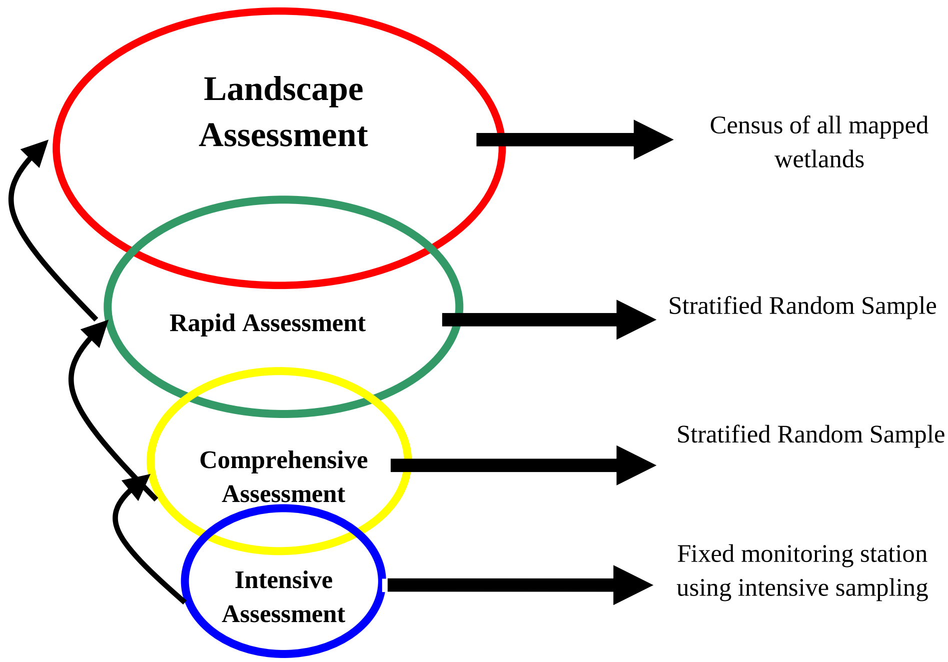


Figure 1. The four-tiered approach that is used to evaluate wetland condition across the Mid-Atlantic region.

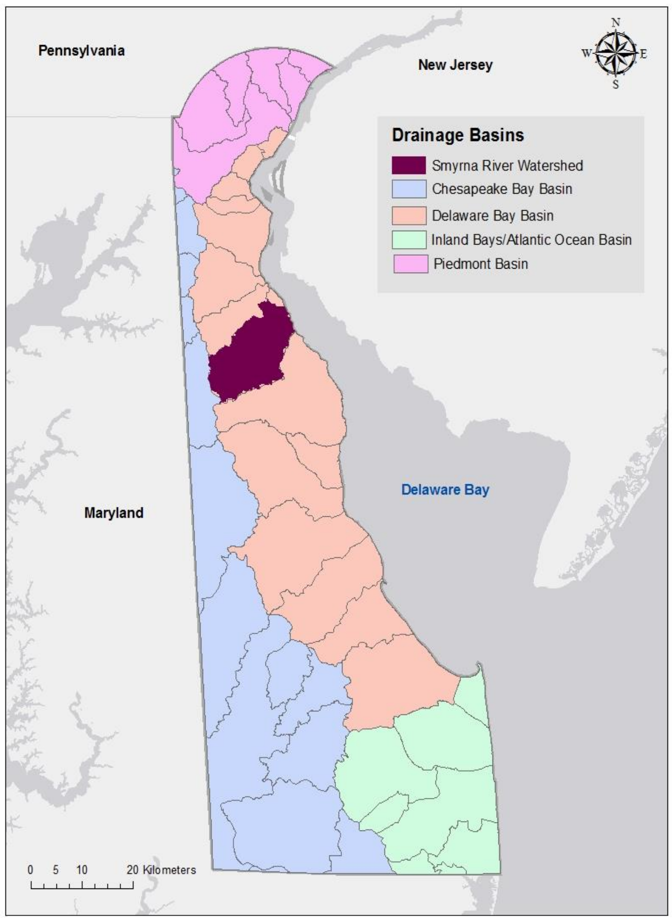
Since 1999, DNREC's Wetland Monitoring and Assessment Program (WMAP) has been developing scientifically robust methods to monitor and evaluate wetlands across the Mid-Atlantic region on a watershed basis using a 4-tiered approach that has been approved by the U.S. Environmental Protection Agency (EPA). WMAP evaluates wetland health (i.e. condition) by documenting the presence and severity of specific stressors that are degrading wetlands and preventing them from functioning at their full potential. Wetland assessments are conducted on 4 tiers, ranging from landscape-level to site-specific studies (Figure 1). The landscape level assessment (Tier 1) is the broadest and least detailed and is performed on desktop computers, while the rapid assessment (Tier 2), comprehensive assessment (Tier 3), and intensive assessment (Tier 4) are progressively more detailed and require active field monitoring. Of Tiers 2-4, rapid assessments require the least amount of work and shortest field days, while intensive assessments require the most intense field work, data collection, and analysis.

Once these assessments are complete, data are used to generate an overall watershed condition report that discusses trends in wetland acreage, identifies common stressors by wetland type, summarizes overall health of wetland types, and provides management recommendations based on these results. Information and recommendations provided by these reports can be used by watershed organizations, state planning and regulatory agencies, and other stakeholders to prioritize and improve wetland protection and restoration efforts. For example, protection efforts, such as through acquisition or easement, can be directed toward wetland types in good condition, and restoration efforts can target degraded wetland types to increase their functions and services. This particular report discusses wetland condition in the Smyrna River watershed in central Delaware.

Watershed Overview

The Smyrna River watershed is composed of three sub-watersheds, from southwest to northeast, respectively: Duck Creek, Smyrna River, and Cedar Swamp. All three sub-watersheds were assessed together as one watershed on the Hydrologic Unit Code (HUC) 10 scale. Thus, for the purpose of this report, all three sub-watersheds together will be referred to simply as the Smyrna River watershed. As a whole, the watershed encompasses approximately 45,315 acres (71 square miles) of land (Map 1).

The Smyrna River watershed is located partially within Kent County and partially within New Castle County. It is bordered by the Leipsic River watershed to the south, the Appoquinimink watershed to the north, the Chester/Choptank watershed to the west, and the Delaware Bay to the east. The headwaters of the Smyrna River



Map 1. Location of the Smyrna River watershed and the major drainage basins in Delaware. Watersheds at the Hydrologic Unit Code (HUC) 10 scale are outlined in gray.

begin in west-central Delaware, and the Smyrna River flows out into the Delaware Bay. Tributaries of the Smyrna River include the Massey Branch, Green Spring Branch, Paw Paw Branch, Providence Creek, Green Branch, Duck Creek, Mill Creek, Morris Branch, and Sawmill Branch. Lakes and ponds within the watershed include Duck Creek Pond, Wheatleys Pond, and Lake Como, all of which have dams.

Hydrogeomorphology

Prior to the last ice age, most of present day Delaware was covered by the ocean. However, as polar ice caps expanded, the sea level decreased, exposing more land. Massive amounts of sediment from the ancient Appalachians were carried down the large Delaware and Susquehanna Rivers and settled onto the coastal plains of Delmarva. Repeated continental glacier advances and retreats and subsequent melting of polar ice caps helped to shape the relative sea level and dictate stream formations that comprise current watersheds (DNREC 2005). However, the landscape is dynamic and continues to change through various processes, such as sea level rise. Ninety-seven percent of tidal wetlands in Delaware are predicted to be affected by a rise in sea level of 0.5m by 2100, as are 8% of non-tidal wetlands under the same scenario (DNREC 2012).

Today, the Delaware Bay and Estuary Basin, which includes the Smyrna River watershed, is contained within the Atlantic Coastal Plain Physiographic Province, just south of the Appalachian Piedmont Fall Zone. It is composed of two physiographic subdivisions: 1) the coastal lowland belt, which includes low elevation areas 0-5 ft above mean sea level on the eastern side of the basin, and 2) the inland plain, which includes areas of higher elevation (approximately 35 ft above mean sea level in Kent County, and 75 ft in New Castle County) on the western side of the basin (DNREC 2005). The Smyrna River watershed contains portions of all four hydrogeomorphic regions of the Basin; it is largely made up of well-drained uplands, but also includes poorly drained uplands in the northwestern part of the watershed, a small portion of inner coastal plain to the northeast, and beaches, tidal marshes, lagoons, and barrier islands on the eastern extent of the watershed (DNREC 2005).

The unconfined aquifer (water table) and several deeper confined aquifers throughout the Delaware Bay and Estuary Basin support the groundwater for the basin. The unconfined aquifer flows through gravelly sands and is refilled by precipitation in areas where permeable sediments allow water to infiltrate down to the aquifer. This ground-water is extremely important, as it is the only source of potable water in this region (DNREC 2005). It is estimated that the economic value of the treated public water supply in the Delaware Bay and Estuary Basin is $243 million annually. Water used for agricultural irrigation is valued at $6.5 million annually in Kent County, and at $0.6 million annually in New Castle County (Narvaez and Kauffman 2012). Runoff from impervious surfaces or agricultural land can affect the quality of this water. Wetlands, therefore, are extremely important in this region for drinking water and for irrigation because wetlands help clean and recharge ground-water.

According to the 2007 mapping effort from the Delaware Statewide Wetland Mapping Project (SWMP; State of Delaware 2007), the Smyrna River watershed had a total of 11,951 acres of wetlands. These wetlands can be further classified based on hydrogeomorphic (HGM) properties (i.e. landscape, landform, and water flow path) into the following wetland categories, which are the most common wetland types in Delaware: estuarine, riverine, flat, or depression. Estuarine wetlands are tidal wetlands that are located in areas where fresh and saltwater mix. Riverine wetlands are non-tidal wetlands that are located along floodplains of rivers and streams. Flat wetlands are non-tidal wetlands often found in headwater regions that are fed mainly by precipitation and that occur in areas with relatively flat landscapes and poor-draining soils. Depression wetlands are non-tidal wetlands that occur in areas of low elevation that tend to pool water (often seasonally) from groundwater, precipitation, and overland flow (Delaware Wetlands 2017). Throughout this report, the terms 'estuarine' and 'tidal' are used interchangeably, because estuarine wetlands are the

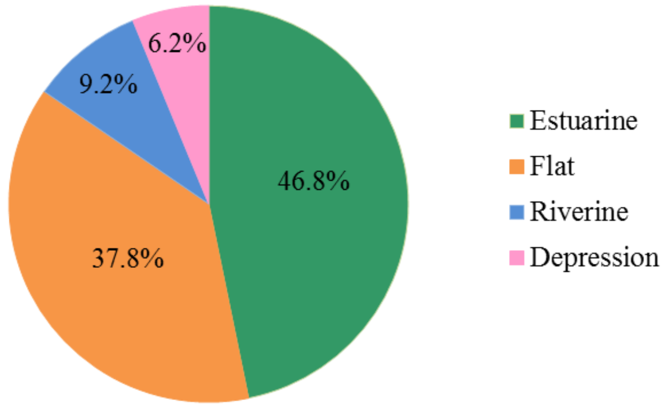
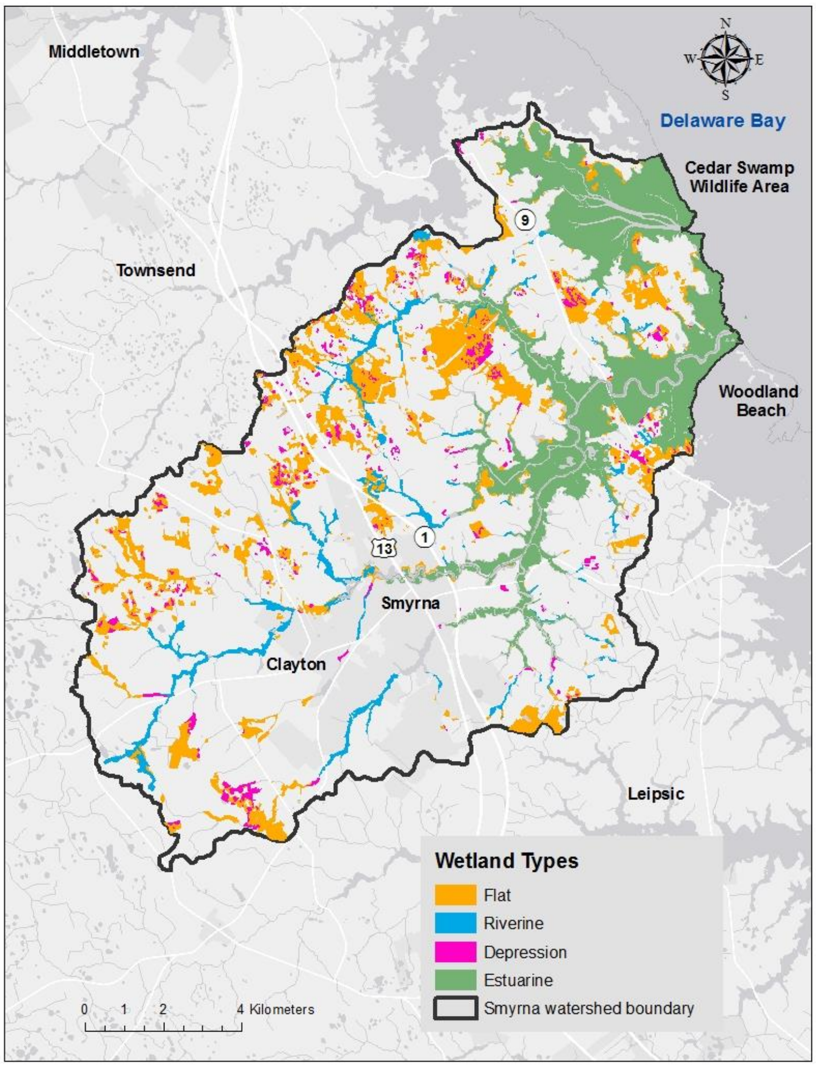


Figure 2. Proportions of hydrogeomorphic wetland types in the Smyrna River watershed.



Map 2. Hydrogeomorphic wetland types in the Smyrna River watershed based on 2007 SWMP data.

only tidal wetlands that were assessed in this watershed; flat, riverine, and depression wetlands are collectively referred to as 'non-tidal' in this report. Non-tidal wetlands are also referred to as 'palustrine' wetlands in this report, because palustrine is another term for freshwater wetlands.

In the Smyrna River watershed, more than half of wetlands were palustrine (6,354.3 acres; 53.2% of total). Of palustrine wetlands, the most common were flats (4,518 acres; 71.1% of palustrine), followed by riverine wetlands (1,098 acres; 17.3%) and depressions (739 acres; 11.6%). The other 46.8% of total wetlands were estuarine (5,596.7 acres; Figure 2). Estuarine wetlands were concentrated on the northeastern portion of the watershed, which is the part of the watershed that is the closest to the brackish waters of the Delaware Bay (Map 2). Riverine wetlands were located in small portions on the northeastern part of the watershed, but mostly in the center and southwestern parts of the watershed along parts of streams and rivers that were far enough inland to be freshwater systems. Flats were scattered across most of the watershed, though there were more in the northern half than the southern half. Depressions were also scattered across the watershed and were often located near flats (Map 2).

Land Use and Land Cover

Based on a comparison between 1997 and 2012 National Land Cover Datasets (NLCD), the Smyrna River watershed experienced a 4.8% increase in the amount of developed land in the 15-year time frame. Also notable was that land used for agriculture decreased by 8.0%, forested land decreased by 4.6%, and wetland coverage increased by 5.4% (Table 1). Comparison of the spatial datasets revealed that the decrease in agricultural land use was mainly caused by conversion of agricultural land to developed or transitional (i.e., in the process of being developed) land, which also explains the consequent increase in developed land. The reduction in forested land

Table 1. Land use/land cover (LULC) change in the Smyrna River watershed based on 1997 and 2012 National Land Cover Datasets (NLCD). Values are percentages.

Land Use	1997	2012	Change
Agriculture	54.3	46.3	-8.0
Wetlands	21.9	27.3	5.4*
Developed	11.3	16.1	4.8
Forest	9.5	4.9	-4.6
Rangeland	0.4	2.4	2.0
Water	1.6	2.2	0.6
Transitional	0.9	0.8	-0.1

*Positive change in wetland land cover was largely due to creation of excavated or impounded agricultural and residential ponds, *not* an increase in natural wetlands.

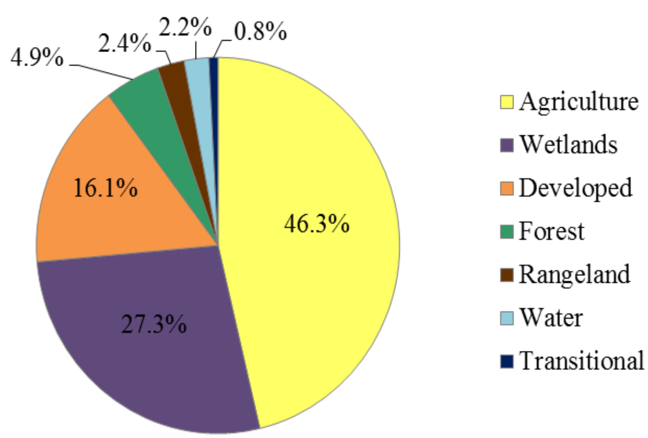
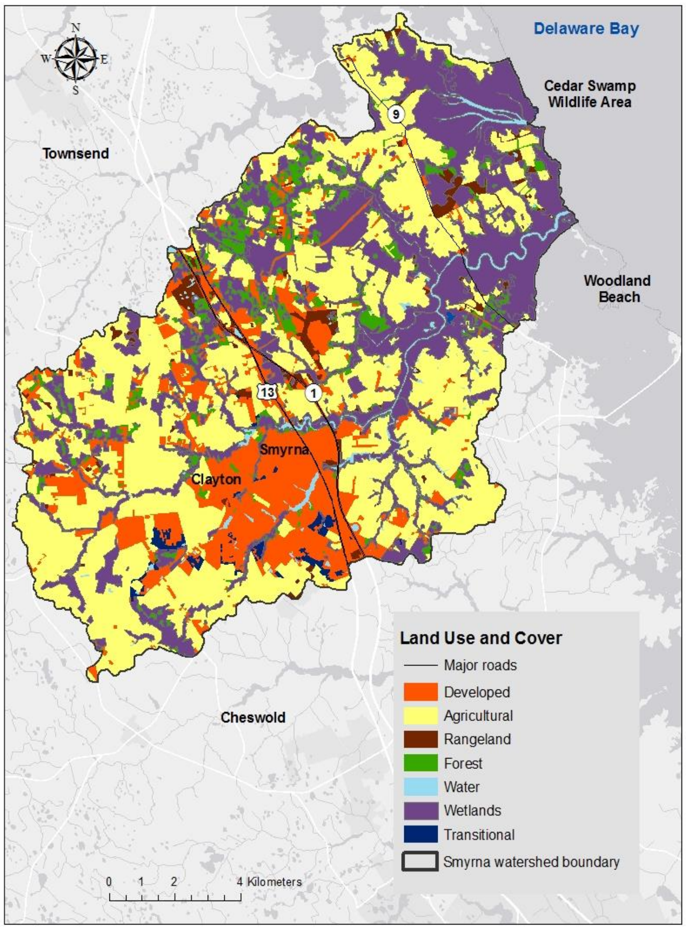


Figure 3 . LULC status in the Smyrna River watershed in 2012. Percentages shown are based on the 2012 NLCD.

was mainly because of the fact that some areas that were formerly classified as forests were recently reclassified as wetlands; many of these areas are still forested and are simply classified more accurately as forested wetlands, so the actual loss of forested land may be much smaller. Wetland coverage increased because of the creation of more excavated or impounded agricultural and residential ponds and because some areas that were formerly classified as forests were more recently reclassified as forested wetlands. Rangeland increased because small sections of agricultural land were converted to rangeland.

The most recent NLCD from 2012 showed that the Smyrna River watershed was dominated by agriculture (46.3%), followed by wetlands (27.3%). A significant amount of land was also developed (16.1%). Smaller portions of land were forested (4.9%), rangeland (2.4%), open surface water (2.2%), or transitional land that was cleared or filled in preparation for development (0.8%; Table 1, Figure 3).

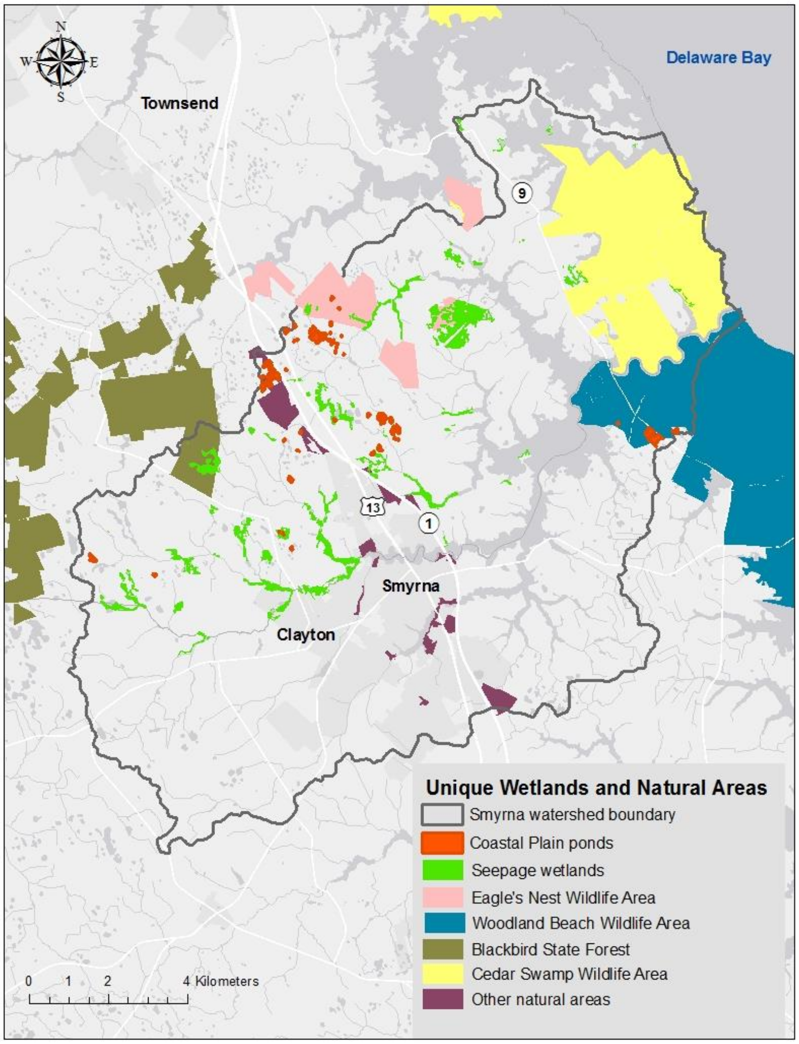


Map 3. LULC in the Smyrna River watershed in 2012 based on the 2012 NLCD.

As of 2012, wetlands occurred in more contiguous areas on the eastern side of the watershed, whereas they were more scattered in the central and western portions of the watershed. In the eastern side of the watershed, wetlands were mainly bordered by agricultural land, and in the central and western parts of the watershed, wetlands were usually bordered by agricultural land, developed land, or forest. Most of the developed land was concentrated in Clayton and Smyrna, but other sizable portions of developed land occurred just north or west of Smyrna and Clayton. Agricultural lands were scattered throughout the watershed and often occurred in relatively contiguous land areas. Most of the forested patches that remained were small and occurred in the northern half of the watershed. Surface water was mainly concentrated along the Smyrna River and in the Cedar Swamp Wildlife Area. There were small patches of rangeland in the central and northeastern parts of the watershed, and the small patches of transitional land occurred adjacent to areas that were already developed (Map 3).

Natural Areas and Unique Wetlands

There are several natural, state-owned areas in the Smyrna River watershed that contain wetlands. Woodland Beach Wildlife Area is split between the Smyrna River watershed and the Leipsic River watershed to the south. Cedar Swamp Wildlife Area lies mostly within the Smyrna River watershed, but smaller portions of it are within the Appoquinimink watershed just to the north. Portions of Eagle's Nest Wildlife Area and the Blackbird State Forest are along the northern boundary of the watershed (Map 4). Woodland Beach Wildlife Area and Cedar Swamp Wildlife Area are both managed by DNREC's Division of Fish and Wildlife, while the Blackbird State Forest is managed by the Delaware Forest Service. Other natural areas in the watershed include open space, town parks or trails, state historical sites, or small state impoundments. Most of the other natural areas are open space lands that are concentrated along Route 1 (Map 4). In 2007, all of these natural areas contained 53.4% of the watershed's estuarine wetlands and 18.9% of the watershed's palustrine wetlands (Table 2).



Map 4. Unique wetlands and natural areas in the Smyrna River watershed that are important for wildlife habitat and/or recreation opportunities.

Some parts of these state-owned natural areas contain unique types of wetlands. The Smyrna River watershed contains two kinds of unique palustrine wetlands, including Coastal Plain seasonal ponds and groundwater seepage wetlands. Coastal Plain seasonal ponds are relatively small depressions that are fed by groundwater and precipitation. They are usually flooded in the wet seasons of winter and spring, and are often dry on the surface in the summer and fall. Groundwater seepage wetlands, or groundwater seeps, are those that occur in areas on slopes where groundwater flows out onto the surface (DNREC 2015b, Delaware Wetlands 2017). As of 2007, there were approximately 1,078.7 acres of groundwater seeps and 124.6 acres of Coastal Plain seasonal ponds in this watershed. Nearly all of both unique wetland types were in the northern half of the watershed in New Castle County (Map 4). Of these unique wetlands, 18.3% of groundwater seeps and 36.7% of Coastal Plain ponds were within state-owned natural areas (Table 2), and were therefore less likely to be affected by human impacts.

Table 2. Amount of land in natural areas for different wetland types as of 2007, and the percentage of each wetland type in natural areas based on the total number of acres of each wetland type in the watershed. Palustrine wetland values include groundwater seepage and Coastal Plain pond wetlands.

Wetland Type	Amount in natural areas (acres)	Percentage of wetland type in natural areas
Estuarine	2,985.9	53.4
Palustrine	1,203.8	18.9
Groundwater seepage	197.9	18.3
Coastal Plain pond	45.7	36.7

Unique wetlands that are not within natural state-owned or open space areas are more susceptible to destruction or degradation from human impacts. Non-tidal wetlands in Delaware are only state-regulated if they are greater than 400 acres. This leaves most non-tidal wetlands, including groundwater seeps and Coastal Plain ponds, unregulated by the state. When wetlands are unregulated, they are far more likely to be destroyed or degraded by anthropogenic activity than if they were regulated. In the Smyrna River watershed, only 18.9% of palustrine wetlands were on state-owned or open space land in 2007 (Table 2), leaving over 80.0% of these wetlands largely unprotected and unregulated. Fortunately, tidal wetlands are regulated by the State of Delaware, meaning that they are far less likely to suffer adverse human impacts. Over half of the estuarine wetlands in this watershed were also state-owned, making them even less likely to suffer from human impacts (Table 2).

Wildlife Habitat and Outdoor Recreation

The Delaware Bay and Estuary Basin, including the Smyrna River watershed, is incredibly important for shorebirds and waterfowl, some of which are threatened or endangered. According to the 2015 Delaware Wildlife Action Plan (DNREC 2015b), many of the shorebird and waterfowl species that use this area as habitat are species of greatest conservation need (SGCN), including the red knot (*Calidris canutus*) and the American black duck (*Anas rubripes*). It is one of the key migration stopover areas for shorebirds as they stop and feed on horseshoe crab (*Limulidae polyphemus*) eggs before they continue to fly north to summer breeding grounds. Many species of waterfowl use the area for feeding grounds during the winter and during migration. Because of this, the Ramsar Convention, an intergovernmental treaty that provides the framework for the conservation and wise use of wetlands, recognizes the Delaware Bay Estuary as an International Wetland of Importance (Ramsar Convention 2014). The Delaware Bay Estuary is also a designated Site of Hemispheric Importance by the Western Hemisphere Shorebird Reserve Network (WHSRN; WHSRN 2009), indicating that the area is visited by 500,000 or more shorebirds a year, and accounts for more than 30 percent of the biogeographic population for certain species. Similarly, Delaware's Coastal Zone, which includes part of the Smyrna River watershed, is a designated Global Important Bird Area (IBA) by the National

Audubon Society because of the large seasonal congregations of waterbirds that occur there (National Audubon Society 2017).

The 2015 Delaware Wildlife Action Plan (DNREC 2015b) also highlights wetlands within the Smyrna River watershed as important habitats for many reptile and amphibian SGCN, such as the diamondback terrapin (*Malaclemys terrapin;* Figure 4) and the four-toed salamander (*Hemidactylium scutatum*). Many fish and insect SGCN use wetland habitats as well, including the mummichog (*Fundulus heteroclitus*) and the predaceous diving beetle (*Hoperius planatus*; DNREC 2015b). Unique wetlands can be particularly important for certain species of greatest conservation need (SGCN). Both groundwater seepage wetlands and Coastal Plain ponds are noted as being important for many rare plant and animal SGCN. They are also designated as habitats of conservation concern because they are threatened by factors such as human development, loss of buffers, fragmentation, draining, excess nutrients, and invasion by non-native plants (DNREC 2015b).

Figure 4. A juvenile diamondback terrapin. These turtles are a SGCN in Delaware and require estuarine wetlands for nesting and feeding.

Just as wetlands and the areas surrounding them can be important for wildlife, they can also provide many opportunities for outdoor recreation. Fishing, deer hunting, and waterfowl hunting are permitted in certain areas within Cedar Swamp and Woodland Beach Wildlife Areas, and there are several boat access ramps for boating and fishing activities in both areas. Blackbird State Forest contains many miles of trails for visitors to run, bike, hike, horseback-ride, and ski. Camping, picnicking, hunting, and catch-and-release fishing are also available at this state forest. Additionally, fishing and hunting are allowed at Eagle's Nest Wildlife Area. All four of these state areas provide abundant opportunities for wildlife viewing and related activities such as photography year-round. Within the town of Smyrna, public fishing is popular at Duck Creek Pond. In addition, fishing, swimming, picnicking, and boating are all available at Lake Como.

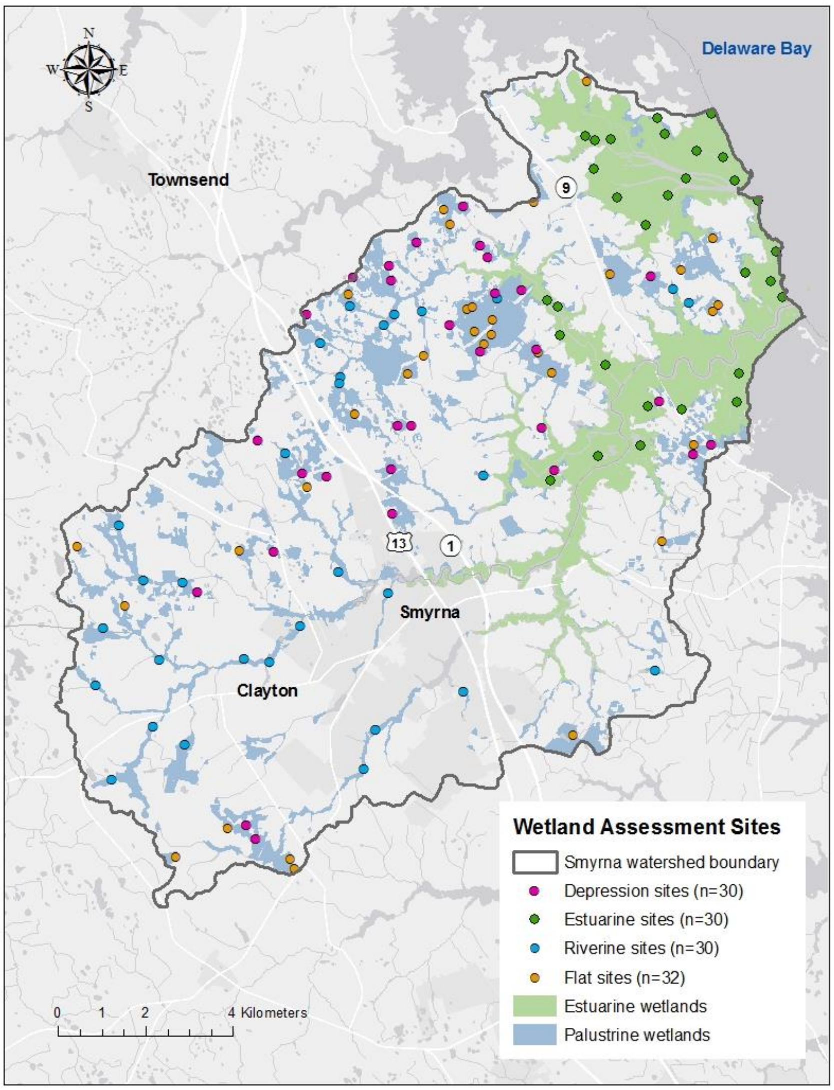
METHODS

Changes to Wetland Acreage

Historic wetland acreage in the Smyrna River watershed was estimated using a combination of current U.S. Department of Agriculture (USDA) soil maps and historic soil survey maps from 1915. These maps are based on soil indicators such as drainage class, landform, and water flow, and allow for classification of hydric soils. Hydric soils occurring in areas that are currently not classified as wetlands due to significant human impacts, either through urbanization, agriculture, land clearing, or hydrologic alterations, were assumed to be historic wetlands that have been lost prior to 1992. Current wetland acreage was calculated from maps created in 2007 as part of the most recent mapping effort by the Delaware Statewide Wetland Mapping Project (SWMP; State of Delaware 2007). Recent trends in wetland acreage were determined from SWMP spatial data, which classified mapped wetland polygons as 'lost', 'gained', or otherwise 'changed' from 1992 to 2007 (State of Delaware 2007 and Tiner et al. 2011).

Field Site Selection

The goal was to sample 30 tidal estuarine sites and 30 non-tidal palustrine sites in each common HGM class (riverine, flat, and depression). To accomplish this, the EPA's Ecological Monitoring and Assessment Program (EMAP) in Corvallis, Oregon assisted with selecting 210 potential sample sites in estuarine intertidal emergent wetlands and 540 potential sample sites in vegetated palustrine wetlands using a generalized random tessellation stratified design, which eliminates selection bias (Stevens and Olsen 1999, 2000). A target population was selected from all natural vegetated wetlands within the Smyrna River watershed from the 2007 National Wetland Inventory (NWI) maps (USFWS 2018). Study sites were randomly-selected points within mapped wetlands, with each point having an equal probability of being selected. Sites were considered and sampled in numeric order from lowest to highest as dictated by the EMAP design. Sites were only dropped from sampling in circumstances that prevented us from accessing the site or if the site was not actually in the target population (see 'Landowner Contact and Site Access' section below for details). In total, 30 estuarine sites, 30 riverine sites, 32 flat sites, and 30 depression sites were assessed in the field (Map 5). Statistical survey methods developed by EMAP were then used to extrapolate results from the sampled population of wetland sites to the whole population of wetlands throughout the watershed (see 'Data Analysis' section below for details).



Map 5. Locations of study sites by wetland type. Sites were selected using the EMAP sampling design.

Data Collection

Landowner Contact and Site Access

We obtained landowner permission prior to assessing all sites. We identified landowners using county tax records and mailed each landowner a postcard providing a brief description of the study goals, sampling techniques, and our contact information. They were encouraged to contact us with any questions or concerns regarding site access, data collection, and reporting. If a contact number was available, we followed the mailings with a phone call to discuss the site visit and secure permission. If permission was denied, the site was dropped and not visited. Sites were also dropped if a landowner could not be identified or if landowner contact information was unavailable. Sites were deemed inaccessible and were subsequently dropped if the site was unsafe to visit for any reason. Some sites that were selected using the EMAP design were determined upon visitation to be uplands rather than wetlands, and such sites were dropped. Wetlands that were not in the target sampling population (i.e., restoration sites or non-vegetated wetlands) were dropped if selected as sample sites because we were only sampling natural, vegetated wetlands.

Assessing Tidal Wetland Condition

Tidal wetland condition was evaluated using the MidTRAM v.3.0 protocol (Jacobs et al. 2010). MidTRAM consists of 14 scored metrics that represent the condition of the wetland buffer, hydrology, and habitat characteristics (Table 3). MidTRAM uses a combination of qualitative evaluation and quantitative sampling to record the presence and severity of stressors. Some of this is performed in the field during site visits, and some in the office using maps and digital orthophotos. We used MidTRAM v.3.0, with assistance from PDE, to complete assessments in 2015 at the first 30 random points from the EMAP design that were not dropped from analysis. Prior to field assessments, we produced site maps and calculated several buffer metrics (Table 3) using ArcMap GIS software (ESRI, Redlands, CA, USA). All metrics measured in the office were field-verified to confirm accuracy.

We navigated to the EMAP points with a handheld GPS unit and established an assessment area (AA) as a 50m radius circle (0.8 ha) centered on each random point (Figure 5). The AA buffer area was defined as a 250 m radius area around the AA (Figure 5). Any necessary adjustments to the AA shape or location were made according to the MidTRAM protocol (Jacobs et al. 2010).

Eight 1m^2 subplots were established along two perpendicular 100m transects that bisected the AA. These subplots were used to measure horizontal vegetative obstruction and soil bearing capacity (Table 3; Jacobs et al. 2010). Orientation, placement, and numbering of subplots, as well as any necessary adjustments to subplot locations, were done in accordance with the MidTRAM protocol (Figure 5; Jacobs et al. 2010). Assessment data collection was completed for all metrics within the AA and buffer via visual inspection during one field visit during the growing season (July 1-September 30) and was performed according to sampling methods described in the MidTRAM protocol (Jacobs et al. 2010).

Table 3. Metrics measured with the Mid-Atlantic Tidal Rapid Method (MidTRAM) Version 3.0.

Attribute Group	Metric Name	Description	Measured in AA or Buffer
Buffer/Landscape	Percent of AA Perimeter with 5 m Buffer	Percent of AA perimeter that has at least 5 m of natural or semi-natural condition land cover	Buffer
Buffer/Landscape	Average Buffer Width	The average buffer width surrounding the AA that is in natural or semi-natural condition	Buffer
Buffer/Landscape	Surrounding Development	Percent of developed land within 250 m from the edge of the AA	Buffer
Buffer/Landscape	250 m Landscape Condition	Condition of surrounding landscape based on vegetation, soil compaction, and human visitation within 250 m	Buffer
Buffer/Landscape	Barriers to Landward Migration	Percent of landward perimeter of marsh within 250 m with physical barriers preventing marsh migration inland	Buffer
Hydrology	Ditching & Draining	The presence and functionality of ditches in the AA	AA
Hydrology	Fill & Fragmentation	The presence of fill or marsh fragmentation from anthropogenic sources in the AA	AA
Hydrology	Diking/Restriction	The presence of dikes or other restrictions altering the natural hydrology of the wetland	AA and Buffer
Hydrology	Point Sources	The presence of localized sources of pollution	AA and Buffer
Habitat	Bearing Capacity	Soil resistance using a slide hammer	AA subplots
Habitat	Horizontal Vegetative Obstruction	The amount of visual obstruction due to vegetation	AA subplots
Habitat	Number of Plant Layers	Number of plant layers in AA based on plant height	AA
Habitat	Percent Co-dominant Invasive Species	Percent of co-dominant species that are invasive in the AA	AA
Habitat	Percent Invasive	Percent cover of invasive species in the AA	AA

After completing the field assessments, the field crew collectively assigned each site a Qualitative Disturbance Rating (QDR) from 1 (least disturbed) to 6 (most disturbed) using best professional judgements (category descriptions can be found in Appendix A). All quantitative

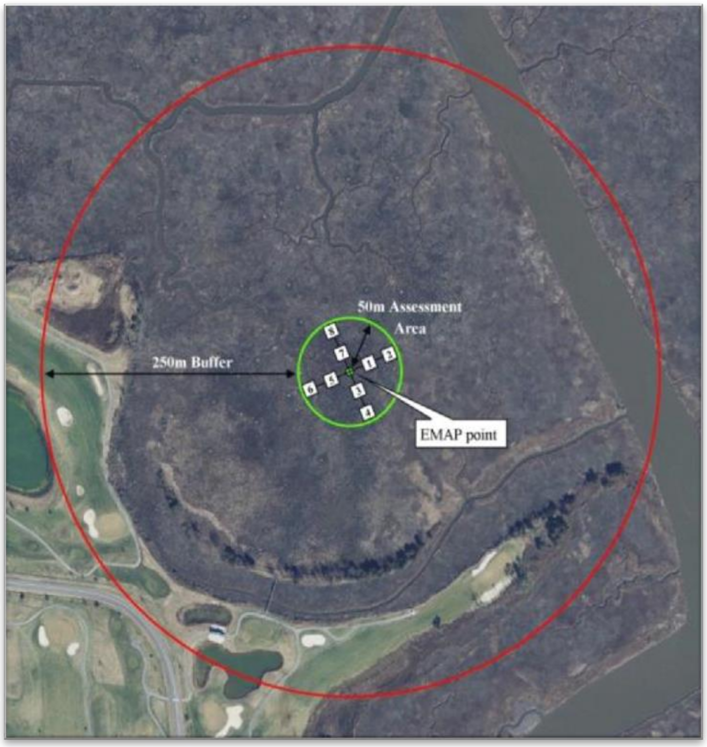


Figure 5. Standard assessment area (AA) in green, subplot locations, and buffer (red) used to collect data for the Mid-Atlantic Tidal Rapid Assessment Method (MidTRAM).

and qualitative metrics were rated as a 3, 6, 9, or 12 based on metric thresholds, where 3 was indicative of poorest metric condition and 12 was indicative of highest metric condition. A normalized final score was then computed using metric ratings, which provides a quantitative description of tidal wetland condition out of a total of 100 points (Jacobs et al. 2010). Statistical analysis of tidal wetland data was performed by WMAP using Microsoft Excel and R version 3.3.2.

Assessing Non-tidal Wetland Condition

WMAP used the Delaware Rapid Assessment Procedure (DERAP) v.6.0 to assess the condition of non-tidal, palustrine wetlands based on the presence and intensity of stressors related to habitat, hydrology, and buffer elements (Table 4; Jacobs 2010). DERAP was followed to complete assessments at 32 flat sites, 30 riverine, and 30 depression sites in the Smyrna River watershed in 2014. Prior to field assessments, we produced site maps and calculated several buffer metrics (Table 4) using ArcMap GIS software (ESRI, Redlands, CA, USA). All metrics measured in the office were field-verified to confirm accuracy.

We navigated to EMAP points in the field with a handheld GPS unit and established an AA as a 40m radius circle (0.5 ha) centered on each random point (Figure 6). Any necessary adjustments to the AA shape or location were made according to the DERAP protocol (Jacobs 2010). The entire AA was explored on foot and evidence of wetland habitat, hydrology, and buffer stressors (Table 4) were documented during one field visit during the growing season (June 1-September 30). Similar to MidTRAM, field investigators collectively assigned the wetland a Qualitative Disturbance Rating from 1 (least disturbed) to 6 (most disturbed; Appendix A) based on best professional judgements. Statistical analysis was performed using Microsoft Excel and R version 3.3.2.

Table 4. Metrics measured with the Delaware Rapid Assessment Procedure (DERAP) Version 6.0.

Attribute Group	Metric Name	Description	Measured in AA or Buffer
Habitat	Dominant Forest Age	Estimated age of forest cover class	AA
Habitat	Forest Harvesting within 50 Years	Presence and intensity of selective cutting or clear cutting within 50 years	AA
Habitat	Forest Management	Conversion to pine plantation or evidence of chemical defoliation	AA
Habitat	Vegetation Alteration	Mowing, farming, livestock grazing, or lands otherwise cleared and not recovering	AA
Habitat	Presence of Invasive Species	Presence and abundance of invasive plant cover	AA
Habitat	Excessive Herbivory	Evidence of herbivory or infestation by pine bark beetle, gypsy moth, deer, nutria, etc.	AA
Habitat	Increased Nutrients	Presence of dense algal mats or the abundance of plants indicative of increased nutrients	AA
Habitat	Roads	Non-elevated paths, elevated dirt or gravel roads, or paved roads	AA
Hydrology	Ditches (flats and depressions only)	Depth and abundance of ditches within and adjacent to the AA	AA and Buffer
Hydrology	Stream Alteration (riverine only)	Evidence of stream channelization or natural channel incision	AA
Hydrology	Weir/Dam/Roads	Man-made structures impeding the flow of water into or out of the wetland	AA and Buffer
Hydrology	Storm water Inputs and Point Sources	Evidence of run-off from intensive land use, point source inputs, or sedimentation	AA and Buffer
Hydrology	Filling and/or Excavation	Man-made fill material or the excavation of material	AA
Hydrology	Microtopography Alterations	Alterations to the natural soil surface by forestry operations, tire ruts, and soil subsidence	AA
Buffer	Development	Commercial or residential development and infrastructure	Buffer
Buffer	Roads	Dirt, gravel, or paved roads	Buffer
Buffer	Landfill/Waste Disposal	Re-occurring municipal or private waste disposal	Buffer
Buffer	Channelized Streams or Ditches	Channelized streams or ditches >0.6 m deep	Buffer
Buffer	Poultry or Livestock Operation	Poultry or livestock rearing operations	Buffer
Buffer	Forest Harvesting in Past 15 Years	Evidence of selective or clear cutting within past 15 years	Buffer
Buffer	Golf Course	Presence of a golf course	Buffer
Buffer	Row Crops, Nursery Plants, Orchards	Agricultural land cover, excluding forestry plantations	Buffer
Buffer	Mowed Area	Any re-occurring activity that inhibits natural succession	Buffer
Buffer	Sand/Gravel Operation	Presence of sand or gravel extraction operations	Buffer

Figure 6. Standard assessment area (green) and buffer (red) used to collect data for the Delaware Rapid Assessment Procedure (DERAP) v.6.0.

DERAP produces one overall wetland condition score for each wetland using a model based on the presence and intensity of various stressors (Appendix B, C; Jacobs 2010). Wetland stressors included in the DERAP model were selected using step-wise multiple regression and Akaike's Information Criteria (AIC) approach to develop the best model that correlated to Delaware Comprehensive Assessment Procedure (DECAP) data (i.e., more detailed assessment data) without over-fitting the model to this specific dataset (Jacobs et al. 2009). Coefficients, or stressor weights, associated with each stressor were assigned using multiple linear regression (Appendix C). This process allowed for effective screening and selection of stressor variables that best represent wetland condition for each HGM class. The DERAP Index of Wetland Condition (IWC) score is calculated by summing the stressor coefficients for each of the selected stressors that were present and subtracting the sum from the linear regression intercept for that HGM type:

$$\textbf{DERAP IWC}_{\textbf{FLATS}} = 95 - (\sum \text{stressor weights})$$
$$\textbf{DERAP IWC}_{\textbf{RIVERINE}} = 91 - (\sum \text{stressor weights})$$
$$\textbf{DERAP IWC}_{\textbf{DEPRESSION}} = 82 - (\sum \text{stressor weights})$$

As shown in these equations, the maximum condition score that flat wetlands can receive is a 95; for riverine wetlands, a 91; and for depression wetlands, an 82.

Example: Site D

Forested flat wetland with 25% of AA clear cut, 1-5% invasive plant cover, moderate ditching, and commercial development in the buffer:

DERAP condition score = 95 – (19+0+10+3)

DERAP condition score = 63

Assessing Non-tidal Wetland Value

The local values that wetlands provide may be independent of wetland condition and function (Rogerson and Jennette 2014). Thus, a value-added assessment protocol can provide additional information that, when used in conjunction with condition results from DERAP, can provide managers with a more complete picture for decision making purposes. We performed value-added assessments at non-tidal palustrine wetland sites in conjunction with the DERAP assessment using v.1.1 of the Value-Added Assessment Protocol (Rogerson and Jennette 2014). The purpose of this assessment was to evaluate the local ecological value that a wetland provides by assessing 7 value metrics (Table 5; Rogerson and Jennette 2014). Metric scores were tallied to produce a final score that ranged from 0 to 100. Initial categories and category thresholds for final scores are shown in Table 6; scoring will be updated as we gain more reference data. Statistical analysis was performed using Microsoft Excel and R version 3.3.2.

Table 5. Value metrics scored according to v.1.1 of the Value-Added Assessment Protocol.

Value Metric	Description
Uniqueness/Local Significance	Significance of wetland based on ecology and surrounding landscape
Wetland Size	Size of the wetland complex the site falls within
Habitat Availability	Percentage of unfragmented, natural landscape in AA and buffer
Delaware Ecological Network (DEN) Classification	Identification of ecologically important corridors and large blocks of natural areas
Habitat Structure and Complexity	Presence of various habitat features and plant layers important for species diversity and abundance
Flood Storage/Water Quality	Wetland ability to retain water and remove pollutants
Educational Value	Ability of wetland to provide education/recreation opportunities based on public accessibility and aesthetic qualities

Table 6. Categories and thresholds for value-added final scores from v.1.1 of the Value-Added Assessment Protocol.

Value Category	Value Score Range
Rich	≥ 45
Moderate	$< 45, \geq 30$
Limited	<30

Wetland Condition and Value Data Analysis

The EMAP sampling method is designed to allow inference about a whole population of resources from a random sample of those resources (Diaz-Ramos et al. 1996). Thus, we present our results from MidTRAM, DERAP, and Value Added assessments at both the site and population level. Site-level results are based solely from sites that we sampled in the field. We discuss site-level results by summarizing the range of scores that we found in sampled sites (e.g., habitat attribute scores ranged from 68 to 98). Population-level results are extrapolated from site-level results for each HGM subclass and represent the total area of each wetland class for the entire watershed. Population-level results have incorporated weights based on the EMAP probabilistic design. These are presented using weighted means and standard deviations (e.g., habitat for tidal wetlands averaged 87.0 ± 13.0), medians (e.g., the median score for tidal wetlands was 90.0), or percentages (e.g., 20.0% of riverine wetlands had channelization present).

Medians of final scores are presented in addition to means, as the final MidTRAM or DERAP scores of most wetland types were not normally distributed (Shapiro-Wilk normality test, α=0.05; estuarine: W=0.83, p<0.001; riverine: W=0.94, p=0.08; flat: W=0.87, p<0.001; depression: W=0.78, p<0.001). When data are not normally distributed, the median is a better descriptor of the central tendency of the data than the mean. Final value-added scores were all normally distributed (Shapiro-Wilk normality test, α=0.05; riverine: W=0.96, p=0.23; flat: W=0.97, p=0.49; depression: W=0.95, p=0.17). However, medians of final value-added scores are still presented in addition to means for consistency in data reporting throughout the document.

Sites in each HGM subclass were placed into 3 condition categories: Minimally Stressed, Moderately Stressed, or Severely Stressed (Table 7). Condition class breakpoints were determined by applying a percentile calculation to the QDRs and condition scores from sites in several watersheds that were assessed previously (Jacobs 2010, Jacobs et al. 2010). Minimally stressed sites are those with a condition score greater than the 25^{th} percentile of sites assigned a QDR of 1 or 2. Severely stressed sites are those with a condition score less than the 75^{th} percentile of sites assigned a QDR of 5 or 6. Moderately stressed sites are those that fall between. The condition breakpoints that we applied in the Smyrna River watershed are provided in Table 7.

Table 7. Condition categories and breakpoint values for tidal and non-tidal wetlands in the Smyrna River watershed as determined by wetland condition scores.

Wetland Type	Method	Minimally or Not Stressed	Moderately Stressed	Severely Stressed
Estuarine	MidTRAM	≥ 81	< 81 ≥ 63	< 63
Riverine	DERAP	≥ 85	< 85 ≥ 47	< 47
Flats	DERAP	≥ 88	< 88 ≥ 65	< 65
Depression	DERAP	≥ 73	< 73 ≥ 53	< 53

In accordance with EMAP design statistical procedures, we used a cumulative distribution function (CDF) to show wetland condition on the population level (Diaz-Ramos et al. 1996). A CDF is a visual tool that extrapolates assessment results from a sample to the entire watershed population. It can be interpreted by drawing a horizontal line anywhere on the graph and reading that as: 'z' proportion of the area of 'x wetland type' in the watershed falls above (or below) the score of 'w' for wetland condition. Points can be placed anywhere on the graph to determine the percent of the population that is within the selected conditions. For example, in Figure 7, approximately 55% of the wetland area scored 81 or above for wetland condition. A CDF also highlights cliffs or plateaus where either a large or small portion of wetlands are in similar condition. In the example (Figure 7), there is a condition cliff from 73 to 74, illustrating that a relatively large portion of the population had condition scores in this range.

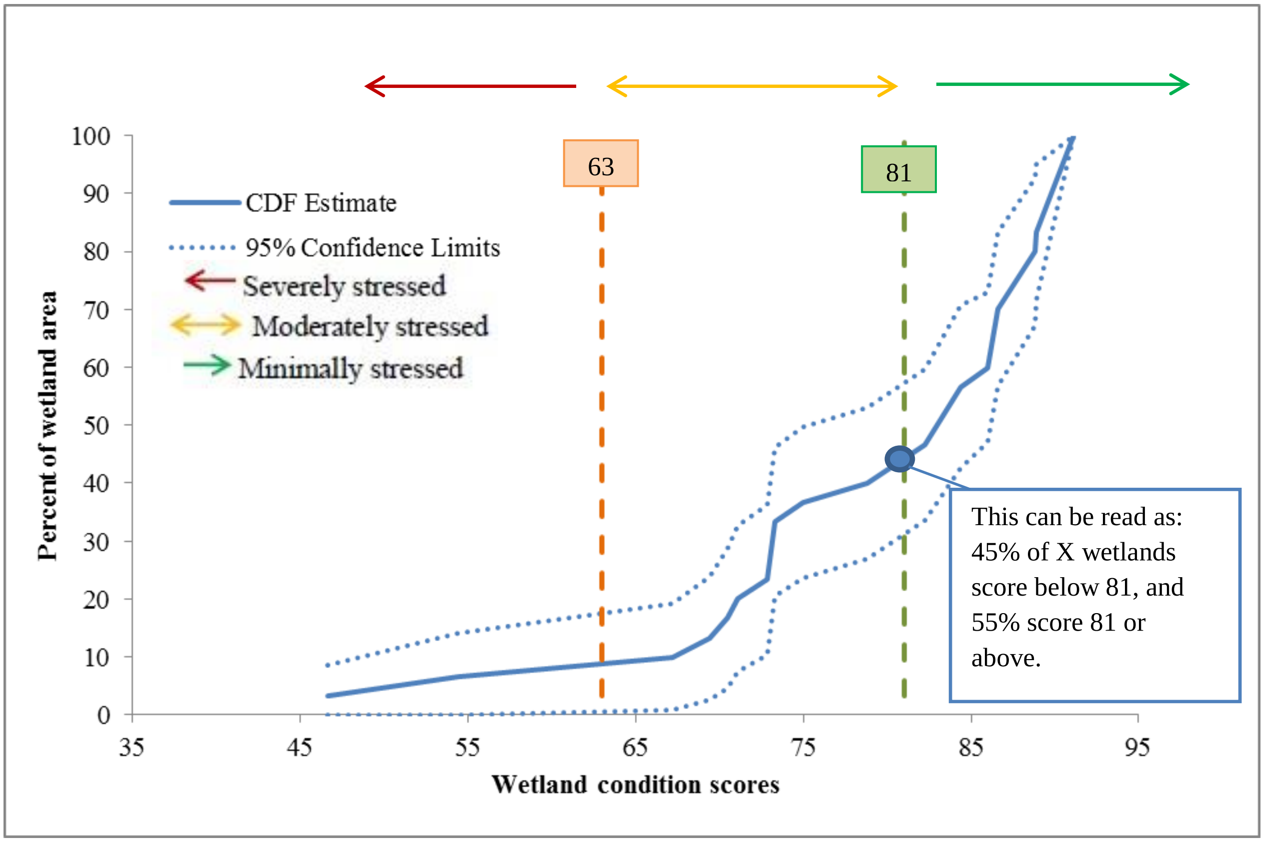


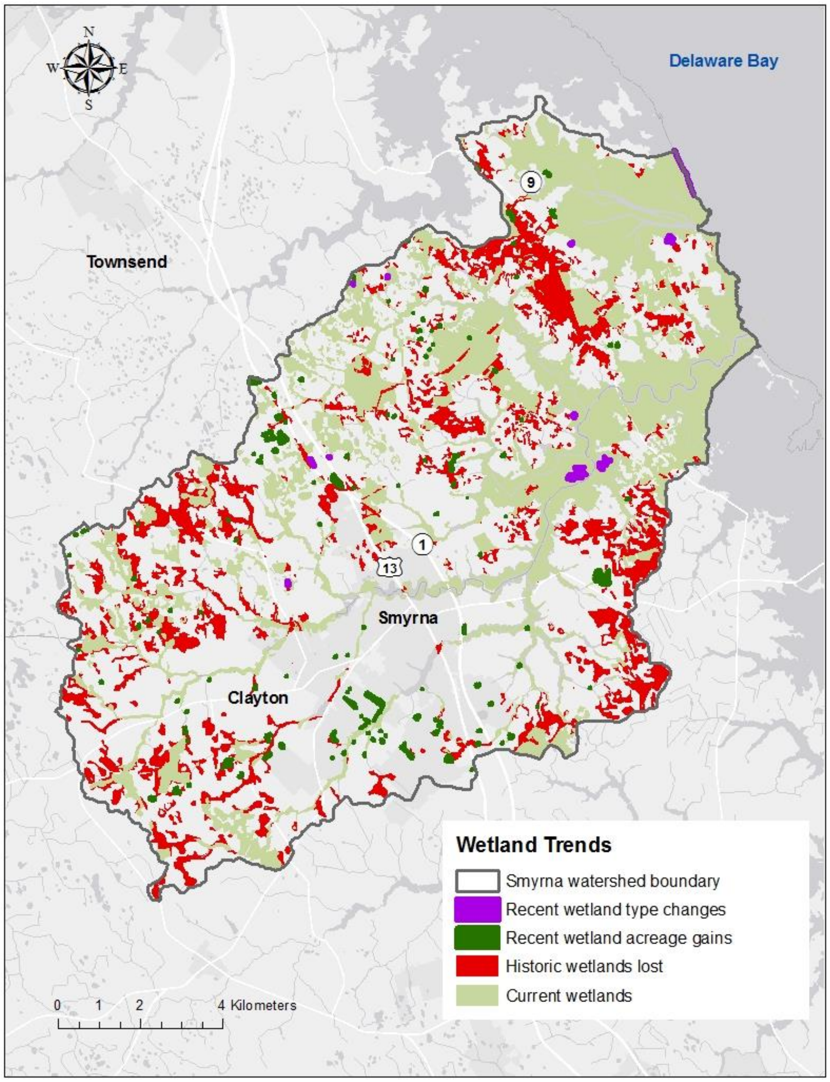
Figure 7. An example CDF showing wetland condition. The blue line is the population estimate, the dashed blue lines are 95% confidence intervals, and colored arrows show condition category ranges. The orange and green dashed lines show the numeric breakpoints between condition categories.

Wetland Health Report Card

Information reported here was used to create a wetland health report card based on the major stressors that were present in each wetland type. The report card provides a clear, concise summary of wetland health and management recommendations in the Smyrna River watershed for the general public. Letter grades (A-F) were assigned to each wetland type based on condition scores, with A being the highest grade for wetlands in the best health, and F being the lowest grade for wetlands in the worst health. It is easily accessible online (see pg. 54 for link). These grades were calculated by dividing average final MidTRAM (tidal) or DERAP (non-tidal) scores for each HGM type by the maximum possible MidTRAM or DERAP score for each type. The watershed as a whole was also assigned a letter grade, which was calculated by multiplying report card grades for each wetland type by the acreage proportion for each type in the watershed (i.e., weighting based on acreage), and then summing those values. Note that the letter grade scale used here was the same letter grade scale that was used for the Leipsic and Mispillion River watersheds, but has been updated and is therefore slightly different than the letter grade scale used previously.

RESULTS

Wetland Acreage



Map 6. Wetland trends over time in the Smyrna River watershed. Recent wetland type changes and wetland acreage gains are those that occurred between 1992 and 2007. Historic wetlands lost are all estimated losses that occurred over time up to 2007. Current wetlands include palustrine and estuarine wetlands as of 2007.

Prior to human settlement in the early 1700's, it is estimated that 17,579 acres of wetlands existed in the Smyrna River watershed. Approximately 5,576 acres were lost prior to 1992, while an additional 52 acres were lost between 1992 and 2007. This means that as of 2007, 32.0% of historic wetland acreage in this watershed was lost because of human impacts such as residential and commercial development, roads, and agriculture (Map 6).

The Smyrna River watershed gained 148.6 acres of wetlands and lost 52.2 acres between 1992 and 2007, resulting in a net gain of 96.4 acres (Table 8). However, most of the wetlands that were classified as gains in the SWMP dataset were attributed to excavated pond construction, and these ponds were not vegetated (130.8 acres; 88.1% of gained acreage; Table 8). The watershed did gain a small amount of palustrine scrub-shrub, forested, or emergent flat wetlands (7.2 acres; 4.8% of gained acreage) and depression wetlands (10.0 acres; 6.7% of gained acreage; Table 8). Flat and depression wetlands with emergent vegetation that were classified as gains were ponded areas within or near agricultural operations. Those that were scrub-shrub or forested were not ponded, were vegetated, but were bordered by or surrounded by agricultural fields, mowed areas, or roads. There were no acreage gains in riverine wetlands. Estuarine wetlands were classified as having a very small gain (0.6 acres; 0.04% of gained acreage; Table 8).

Most of the losses were of vegetated wetlands, mainly flats (36.9 acres; 70.7% of lost acreage) and depressions (5.9 acres; 11.3%; Table 8). There were no losses in natural riverine or estuarine wetland acreage. Some acreage was also lost from the disappearance of excavated or impounded agricultural ponds (9.4 acres; 18.0%; Table 8). The major causes for all losses were development or construction of roads, and agricultural activities.

Table 8. Acreage gains, losses, and changes in the Smyrna River watershed between 1992 and 2007. Values and categories are based on those in 2007 SWMP spatial datasets. Wetlands are listed by natural HGM type, with wetlands mapped as excavated or impounded listed separately. Flat, riverine, and depression wetlands are listed as subcategories under palustrine wetlands.

Wetland type	Gain (acres)	Loss from direct human impact (acres)	Change (acres)
Estuarine	0.6	0.0	24.6
Palustrine	17.2	42.8	3.2
Flat	7.2	36.9	0.4
Riverine	0.0	0.0	1.4
Depression	10.0	5.9	1.4
Excavated or Impounded	130.8	9.4	5.6
Total	**148.6**	**52.2**	**33.4**

A total of 33.4 acres of wetlands were classified as 'changed' in the Smyrna River watershed between 1992 and 2007 (Map 6, Table 8), meaning that their mapped wetland classification changed in that time period. Most changes to estuarine wetlands involved increased inundation, including one area along the Delaware Bay in Cedar Swamp Wildlife Area that changed from estuarine intertidal unconsolidated shoreline to estuarine subtidal unconsolidated bottom (2.5 acres), and two wetland areas along the Smyrna River just south of Woodland Beach Wildlife Area where emergent estuarine wetlands were converted to estuarine unconsolidated bottom habitat (20.8 acres). Another change that involved an increase in standing water was a change from an estuarine scrub-shrub wetland to an impounded estuarine area with unconsolidated bottom on the edge of an agricultural field (1.3 acres). Conversely, two areas on the edges of agricultural fields changed from impounded estuarine habitats with unconsolidated bottom to estuarine wetlands with emergent vegetation (5.6 acres; Table 8). Changes to palustrine wetlands (3.2 acres; Table 8) involved vegetation removal and habitat disturbance, where several small areas changed from palustrine forested wetlands to excavated ponds for residential storm water collection or for agricultural operations.

Landowner Contact and Site Access

A total of 122 wetland sites were sampled in the Smyrna River watershed. Of those 122 sites, 32.8% were on public land and 67.2% were on private land (Table 9). These within-watershed ownership percentages were somewhat similar to what is seen across the entire state; about 80% of Delaware's wetlands are privately owned, and about 20% are on public lands. When ownership was broken down by HGM type, over half of estuarine wetlands were on public property. Conversely, palustrine wetland types were mostly on private lands (Table 9).

A total of 35 estuarine sites were considered. Three sites were dropped because we were denied permission to access, and 2 sites were dropped because they were not part of the target wetland population, leaving 30 sites that were sampled (Figure 8). Of those 30 sites, 63.3% were on public lands, and 36.7% were on private lands (Table 9).

Table 9. Ownership of wetland condition sample sites (n=122).

HGM Type	Public (%)	Private (%)
All combined	32.8	67.2
Estuarine	63.3	36.7
Riverine	20.0	80.0
Flat	25.0	75.0
Depression	23.3	76.7

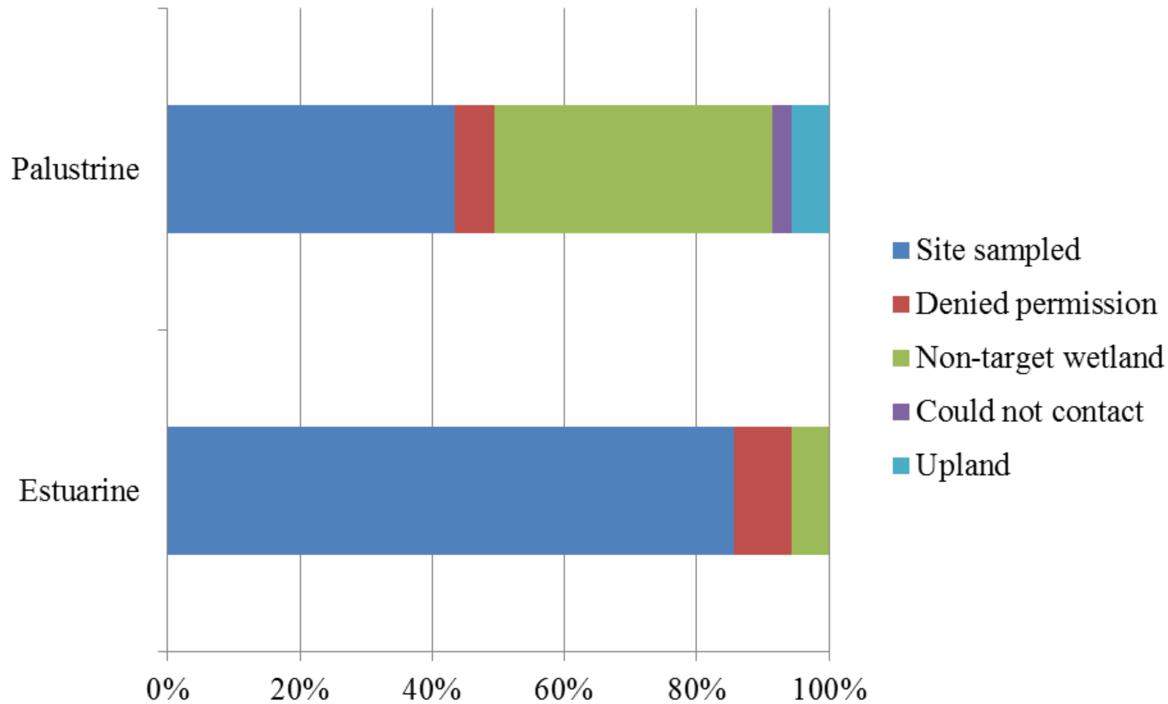


Figure 8. Sampling success for estuarine and palustrine wetlands. Shown are percentages of the total number of sites that we attempted to sample for each class (estuarine: n=35; palustrine: n=212).

A total of 212 palustrine sites were considered, and 120 of those sites were dropped and not sampled. Thirteen sites were dropped because we were denied permission to access them (6.1%), 89 sites were dropped because they were not in the target wetland population (42.0 %), 6 sites were dropped because we could not contact the landowner (2.8%), and 12 sites were dropped because they were found to be upland habitat instead of wetland (5.7%). Ninety-two palustrine sites were sampled in the field (43.4%; Figure 8). Of those 92 sites, 30 were depressions, 30 were riverine, and 32 were flats.

Wetland Condition and Value

Tidal estuarine wetlands

Tidal estuarine sites that were assessed (n=30 sites) in the Smyrna River watershed had final scores ranging from 57.2 to 91.1, with a mean score of 80.9 ± 8.1 (median=83.3) out of a maximum possible score of 100.0. The attribute that scored the highest overall was hydrology, followed by buffer and then habitat (Table 10). Most tidal estuarine wetlands were minimally stressed (66.7%), followed by moderately stressed (30.0%) and severely stressed (3.3%; Figure 9). Data for all sampled estuarine wetlands for all assessed metrics can be viewed in Appendix D.

Table 10. Means and standard deviations, medians, and ranges for overall MidTRAM condition scores, and for scores for each attribute type.

Attribute	Mean ± S.D.	Median	Range
Overall	80.9 ± 8.1	83.3	57.2-91.1
Buffer	80.4 ± 14.7	86.7	40.0-93.3
Hydrology	98.1 ± 5.2	100.0	75.0-100.0
Habitat	64.2 ± 12.7	66.7	40.0-80.0

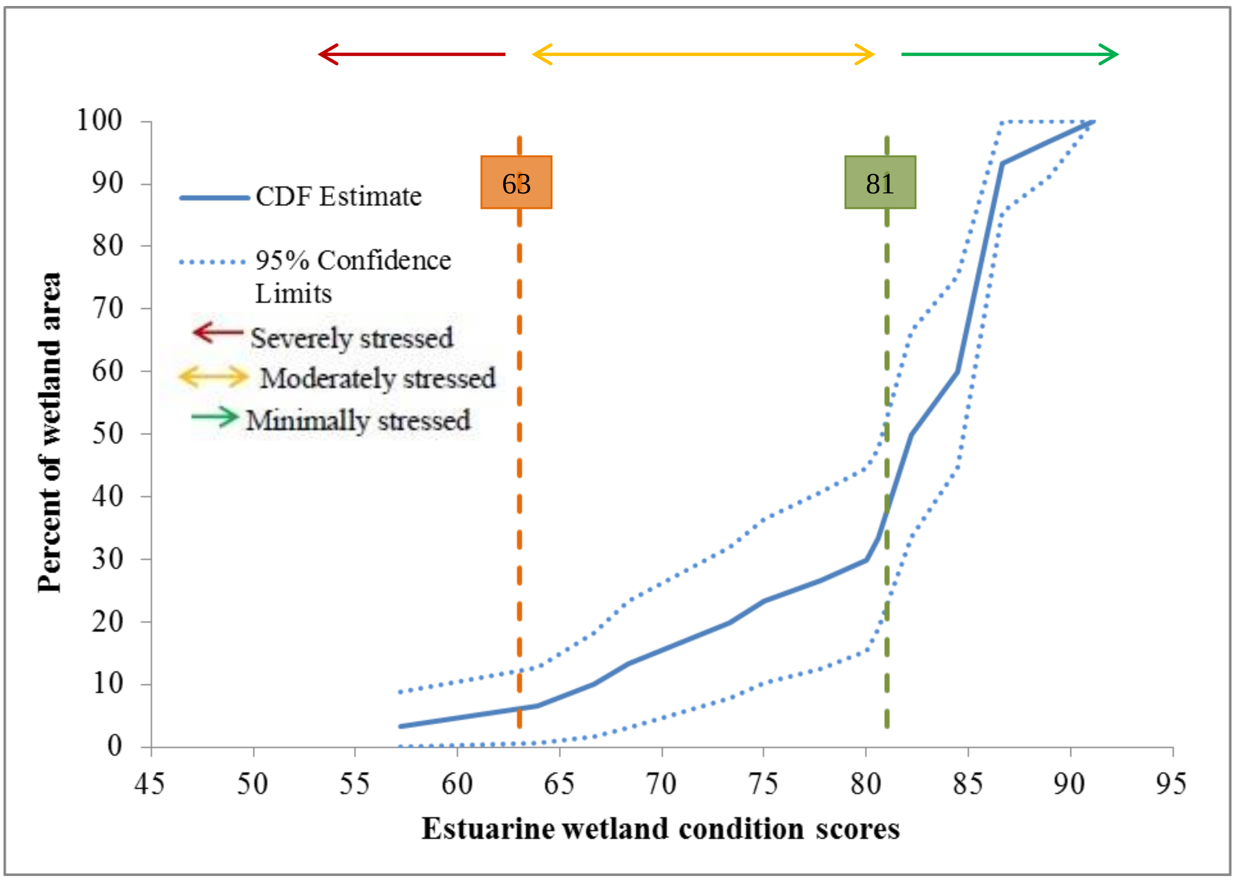


Figure 9. Cumulative distribution function (CDF) for tidal estuarine wetlands in the Smyrna River watershed. The solid blue line is the population estimate, the dashed blue lines are 95% confidence intervals, and colored arrows show condition category ranges. The orange and green dashed lines show the numeric breakpoints between condition categories.

Buffer attribute scores from sampled wetlands ranged from 40.0 to 93.3, with a mean score of 80.4 ± 14.7 (median=86.7; Table 10). The most common buffer stressors encountered in estuarine wetlands in this watershed were disturbance in the surrounding landscape (e.g. human visitation, compacted soils, or invasive plants) and barriers to landward migration (Table 11). All wetlands, even those that were minimally stressed, had some level of disturbance present in the surrounding landscape (Table 11). Half of the assessed wetlands (50.0%) had low levels of disturbance (i.e., dominated by native vegetation, had undisturbed soils, or had little to no evidence of human visitation), but the other half had intermediate to severe levels of disturbance (i.e., intermediate or dominant invasive plant cover, moderate or severe soil disturbance, or evidence of moderate to heavy human visitation). Of the 20.0% of wetlands that had barriers to landward migration (Table 11), most barriers were severe, causing 26-100% obstruction in potential areas for marsh migration. Estuarine wetlands scored relatively well on other buffer metrics.

Table 11. Stressors with the highest occurrence for each attribute category (buffer, hydrology, and habitat) in tidal estuarine wetlands in the Smyrna River watershed. Values shown are percentages of sites with stressors present for all estuarine wetlands combined (total), and for each condition category.

Stressor	% Total (n=30)	% Minimally stressed (n=20)	% Moderately stressed (n=9)	% Severely stressed (n=1)
Disturbance present in surrounding landscape	100.0	100.0	100.0	100.0
Invasive species present	100.0	100.0	100.0	100.0
Low marsh stability	96.7	100.0	88.9	100.0
Low vegetation thickness	63.3	60.0	66.7	100.0
Barriers to landward migration	20.0	10.0	33.3	100.0
Diking and tidal restriction present	10.0	0.0	22.2	100.0

Hydrology attribute scores from sampled wetlands ranged from 75.0 to 100.0, with a mean score of 98.1 ± 5.2 (median=100.0; Table 10). Estuarine wetlands scored the best overall in the hydrology attribute category compared with the buffer and habitat categories and suffered few impacts from hydrology stressors. The hydrology metric most commonly present was diking and tidal restriction. Minimally stressed wetlands had no diking or tidal restriction present, while moderately and severely stressed had increasing occurrence (Table 11). However, all restrictions were considered low in severity, even in severely stressed wetlands, and thus had minor impacts (Table 11). No wetlands had any ditching or draining. Similarly, no wetlands had any point source pollution. Most tidal wetlands (96.6%) had little to no fill or fragmentation.

Habitat attribute scores from sampled wetlands ranged from 40.0 to 80.0, with a mean score of 64.2 ± 12.7 (median=66.7; Table 10). This was the lowest overall of the three attribute categories for tidal wetlands. All sites had some invasive plant species present (Table 11), though most sites had fairly low percent cover (> 0%, but < 25%). Nearly three-quarters of estuarine wetlands (73.3%) had the invasive common reed (*Phragmites australis* ssp. *australis*), and 10.0% had the invasive narrow-leaf cattail (*Typha angustifolia*). Many wetlands (53.3%) also had invasive co-dominant species present, with an average of 18.9 % ± 22.8% coverage (median:

20.0%). Nearly all wetlands (96.7%) scored below a 12 for bearing capacity, meaning that they were below the highest possible score for marsh stability (Table 11). Most wetlands (66.7%) scored a 9 and were in the second-highest scoring bucket, but 30.0% scored either a 6 or 3, which was indicative of relatively poor marsh stability. Over half of estuarine wetlands scored below a 12 for horizontal vegetative obstruction (63.3%), meaning that they were below the highest possible score for vegetation thickness (Table 11). Some wetlands (33.3%) scored a 9 and were in the second-highest scoring bucket, but 30.0% scored either a 6 or 3, which was indicative of low vegetation thickness. In contrast, estuarine wetlands scored fairly high for number of plant layers, where nearly all wetlands had 2 to 5 layers.

Wetland value was not assessed for tidal estuarine wetlands because a protocol does not currently exist for evaluating estuarine wetland value.

Non-tidal riverine wetlands

Riverine wetlands in the Smyrna River watershed that were sampled (n=30) had final DERAP scores that ranged from 20.0 to 91.0, with a mean score of 63.2 ± 20.5 (median=67.0) out of a maximum possible score of 91.0. Most riverine wetlands were moderately stressed (60.0%), with smaller but equal proportions being minimally stressed (20.0%) and severely stressed (20.0%; Figure 10). Data for all sampled riverine wetlands for all assessed metrics can be viewed in Appendix E. The most prevalent stressors found in riverine wetlands were the

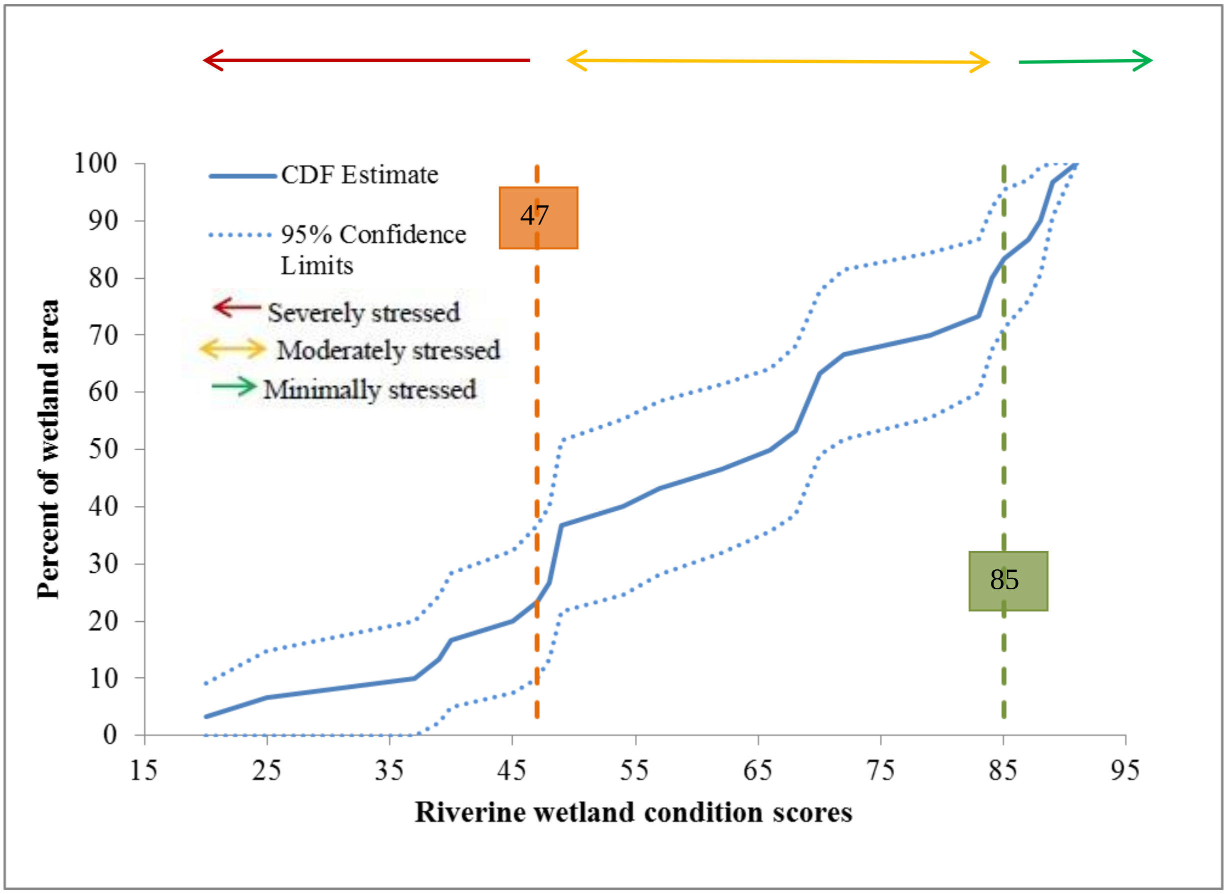


Figure 10. Cumulative distribution function (CDF) for non-tidal riverine wetlands in the Smyrna River watershed. The solid blue line is the population estimate, the dashed blue lines are 95% confidence intervals, and colored arrows show condition category ranges. The orange and green dashed lines show the numeric breakpoints between condition categories.

presence of invasive species for the habitat attribute category; stream alteration and presence of fill for the hydrology attribute category; and presence of development, channelized streams or ditches, and agricultural activities (i.e., row crops, nursery plants, or orchards) for the buffer attribute category (Table 12).

Table 12. Stressors with the highest occurrence for each attribute category (habitat, hydrology, and buffer) in non-tidal, riverine wetlands in the Smyrna River watershed. Values shown are percentages of sites with stressors present for all riverine wetlands combined (total), and for each condition category.

Stressor	% Total (n=30)	% Minimally stressed (n=6)	% Moderately stressed (n=18)	% Severely stressed (n=6)
Invasive species present	80.0	16.7	94.4	100.0
Agricultural activitiy in surrounding landscape	73.3	66.7	72.2	83.3
Stream alteration	46.7	0.0	44.4	100.0
Development in surrounding landscape	46.7	33.3	50.0	50.0
Channelized streams/ditches in buffer	40.0	0.0	38.9	83.3
Fill/excavation present	36.7	16.7	22.2	100.0

The most common of all of these stressors was the presence of invasive species. Eighty percent of riverine wetlands contained invasive species (Table 12), with 36.7% of wetlands being dominated by (≥50%) invasive cover. Although only 16.7% of minimally stressed wetlands had invasive species present, occurrence increased drastically in moderately and severely stressed wetlands (Table 12). Detected invasive species included Japanese stiltgrass (*Microstegium vimineum*), Japanese honeysuckle (*Lonicera japonica*), common reed (*P. australis*), European privet (*Ligustrum vulgare*), multiflora rose (*Rosa multiflora*), mile-a-minute (*Polygonum perfoliatum*), reed canary grass (*Phalaris arundinacea*), narrowleaf cattail (*T. angustifolia*), and orange daylily (*Hemerocallis fulva*). Riverine wetlands scored very well overall on other habitat metrics.

Stream alteration was a significant hydrologic issue in riverine wetlands (Table 12, Figure 11). The stressor was found in 46.7% of wetlands. No minimally stressed wetlands had any stream alteration, but occurrence increased from moderately to severely stressed wetlands (Table 12). Types of stream alteration that were seen included channelized streams that were not being maintained and were reverting back to natural morphology, spoil banks on one or both sides of the stream, and natural channel incision. Another significant hydrology stressor was fill or excavation, which was present in 36.7%

Figure 11. Stream channelization in a riverine wetland in the Smyrna River watershed.

of riverine wetlands. Some minimally stressed wetlands had fill or excavation present (16.7%), but the stressor was more commonly found in moderately and severely stressed wetlands (Table 12). Fill, when present, affected 1-75% of the AA, but never > 75% of the AA. Riverine wetlands scored fairly well on all other hydrology metrics.

Agriculture was very common in landscapes surrounding many riverine wetlands, occurring around 73.3% of wetlands. It was notable that 66.7% of minimally stressed wetlands were still very close to agricultural activities (Table 12). Many riverine wetlands also had residential or commercial/industrial development (46.7%) and channelized streams or ditches (40.0%) in the landscape surrounding them. The occurrence of both of these stressors tended to increase moving from minimally to severely stressed wetlands (Table 12). Other buffer stressors were not as prevalent as the ones described above, but were still found in many wetlands. For example, roads and mowed areas were found in the buffer areas in 30.0% of wetlands. All other buffer stressors were rare or entirely absent from riverine wetlands.

Riverine wetlands received an average value-added score of 38.2 ± 12.0 (median=35.5), with scores ranging from 21 to 64 on a 0 to 100 scale. This was the highest average out of all 3 palustrine HGM types. Most riverine wetlands were rated as providing moderate value-added (40.0%), followed by rich (33.3%), and limited (26.7%) value-added (Figure 12). Scores in most categories were highly variable. On average, riverine wetlands provided the most value in terms of flood storage and water quality, and in habitat structure and complexity. They also provided some value in wetland size, habitat availability, and DEN classification, while they provided low value for being unique or rare wetland types and for educational opportunities.

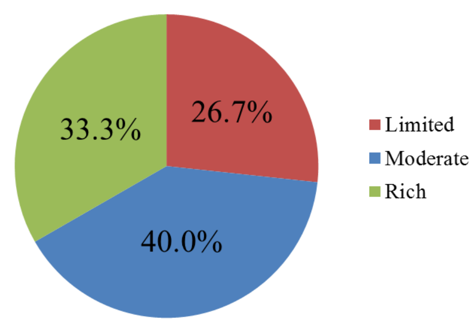


Figure 12. Percentage of riverine wetlands that scored in each of the three value-added categories (n=30 sites).

Non-tidal flat wetlands

Flat wetlands in the Smyrna River watershed that were sampled (n=32) had final DERAP scores that ranged from 32.0 to 95.0, with a mean score of 78.2 ± 13.3 (median=79.5) out of a maximum possible score of 95.0. Most flat wetlands were moderately stressed (56.3%), followed by minimally stressed (31.3%) and severely stressed (12.5%; Figure 13). Data for all sampled flat wetlands for all assessed metrics can be viewed in Appendix F. The most prevalent stressors in flat wetlands were invasive species from the habitat attribute category; ditching and fill from the hydrology attribute category; and agricultural activity, mowing, and presence of roads in the surrounding landscape for the buffer attribute category (Table 13).

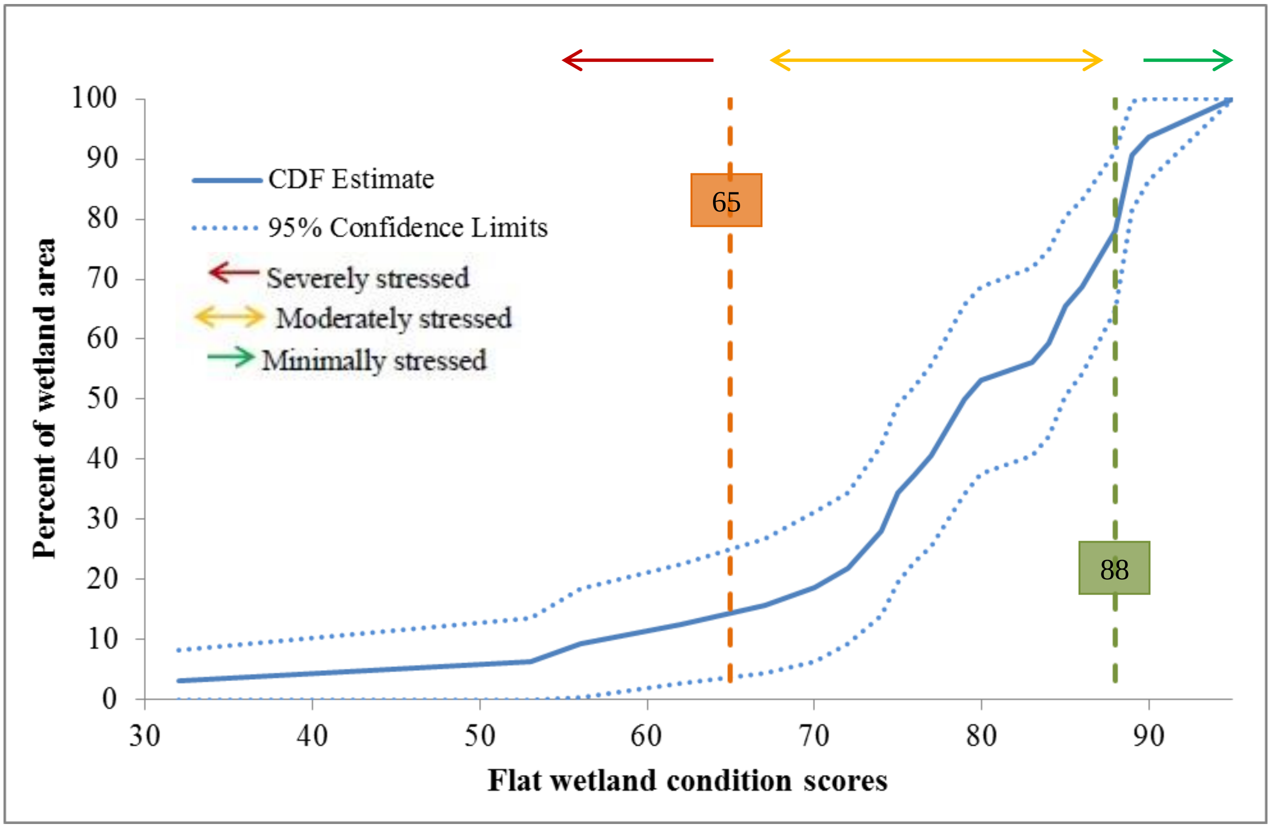


Figure 13. Cumulative distribution function (CDF) for non-tidal flat wetlands in the Smyrna River watershed. The solid blue line is the population estimate, the dashed blue lines are 95% confidence intervals, and colored arrows show condition category ranges. The orange and green dashed lines show the numeric breakpoints between condition categories.

Of those stressors, the most common was agriculture in the surrounding landscape, which was present for 53.1% of flats (Table 13). It was most commonly found around severely stressed wetlands (75.0%), but was still found around 50.0% of minimally and moderately stressed wetlands (Table 13). Another common buffer stressor was mowed areas in the surrounding landscape, as 40.6% of wetlands contained mowed areas in their buffers. However, wetlands showed an unusual pattern for this stressor, where moderately stressed wetlands had the highest occurrence rather than severely stressed wetlands (Table 13). Roads were present in the surrounding landscape of 34.4% of flats, and were most common for severely stressed wetlands (Table 13). Other buffer stressors were not as prevalent as the ones described above, but were still found in many wetlands. For example, channelized streams or ditches in buffers were found for 25% of wetlands, and 18.8% had some form of development in the surrounding landscape. All other buffer stressors were rare or entirely absent from flats.

Invasive species were present in 50.0% of flat wetlands and were the most common in severely stressed wetlands (Table 13). The extent of invasive coverage varied widely from < 1% to > 50%. The invasive species that were detected in these wetlands were the common reed (*P. australis*), Japanese stiltgrass (*M. vimineum*), Japanese honeysuckle (*L. japonica)*, multiflora rose (*R. multiflora*), reed canary grass (*P. arundinacea*), and English ivy (*Hedera helix*). Some flats also had selective tree cutting (15.6%) or roads (15.6%), while other habitat stressors were either rare or absent entirely.

Table 13. Stressors with the highest occurrence for each attribute category (habitat, hydrology, and buffer) in non-tidal, flat wetlands in the Smyrna River watershed. Values shown are percentages of sites with stressors present for all flat wetlands combined (total), and for each condition category.

Stressor	% Total (n=32)	% Minimally stressed (n=10)	% Moderately stressed (n=18)	% Severely stressed (n=4)
Agricultural activity in surrounding landscape	53.1	50.0	50.0	75.0
Invasive species present	50.0	40.0	50.0	75.0
Mowed areas in surrounding landscape	40.6	20.0	55.6	25.0
Ditching present	34.4	0.0	38.9	100.0
Roads present in surrounding landscape	34.4	10.0	44.4	50.0
Fill/excavation present	28.1	0.0	33.3	75.0

Hydrology was altered in flat wetlands mainly by ditching and fill, which were present in 34.4% and 28.1% of wetlands, respectively. These hydrology stressors were not present in minimally stressed wetlands, and were more common in severely stressed than in moderately stressed wetlands (Table 13). Most flats with fill had fill covering < 10% of the wetland (18.8% of flats), although some had 10-75% coverage (9.4%), and no flats had > 75% of fill covering the wetland. The majority of flats with ditching had only slight ditching (21.9% of flats), while fewer had moderate (6.3%) or severe (6.3%) ditching. Flats scored very well for all other hydrology metrics.

Flat wetlands in the Smyrna River watershed received an average value-added score of 29.3 ± 8.3 (median=28.0), with scores ranging from 13 to 46 on a 0 to 100 scale. Most flats were categorized as providing limited value-added (59.4%), followed by moderate (37.5%) and rich (3.1%) value-added (Figure 14). Scores in most categories were highly variable. On average, flats provided the most value in terms of habitat structure and complexity as well as habitat availability. They provided some value in wetland size and DEN classification, whereas they provided low value for flood storage or water quality, uniqueness or local significance, and education.

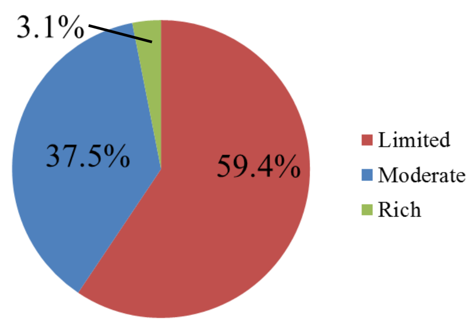


Figure 14. Percentage of flat wetlands that scored in each of the three value-added categories (n=32 sites).

Non-tidal depression wetlands

Depression wetlands in the Smyrna River watershed that were sampled (n=30) had final DERAP scores that ranged from -2.0 to 80.0, with a mean score of 61.3 ± 21.0 (median=69.0) out of a maximum possible score of 82.0. This was the lowest average DERAP score of all 3 HGM types. Most depression wetlands were moderately stressed (40.0%), followed by minimally stressed (33.3%) and severely stressed (26.7%; Figure 15). Data for all sampled depression wetlands for all assessed metrics can be viewed in Appendix G. The most prevalent stressors found in depressions were the presence of invasive species in the habitat attribute category; the presence of microtopographic alterations (Figure 16) and fill in the hydrology attribute category; and the presence of agriculture, development, and roads in the surrounding landscape in the buffer attribute category (Table 14).Of those stressors, the most common one was agricultural activity in the surrounding landscape, which was present for 50.0% of depressions (Table 14). Development and roads in the surrounding landscape were also common and were present for 40.0% and 43.3% of depressions, respectively. For all three of these buffer stressors, a surprising pattern emerged, where a higher occurrence of these stressors was seen in moderately stressed wetlands compared with severely stressed wetlands (Table 14). Some other buffer stressors were not as prevalent as the ones described above, but were still found in many

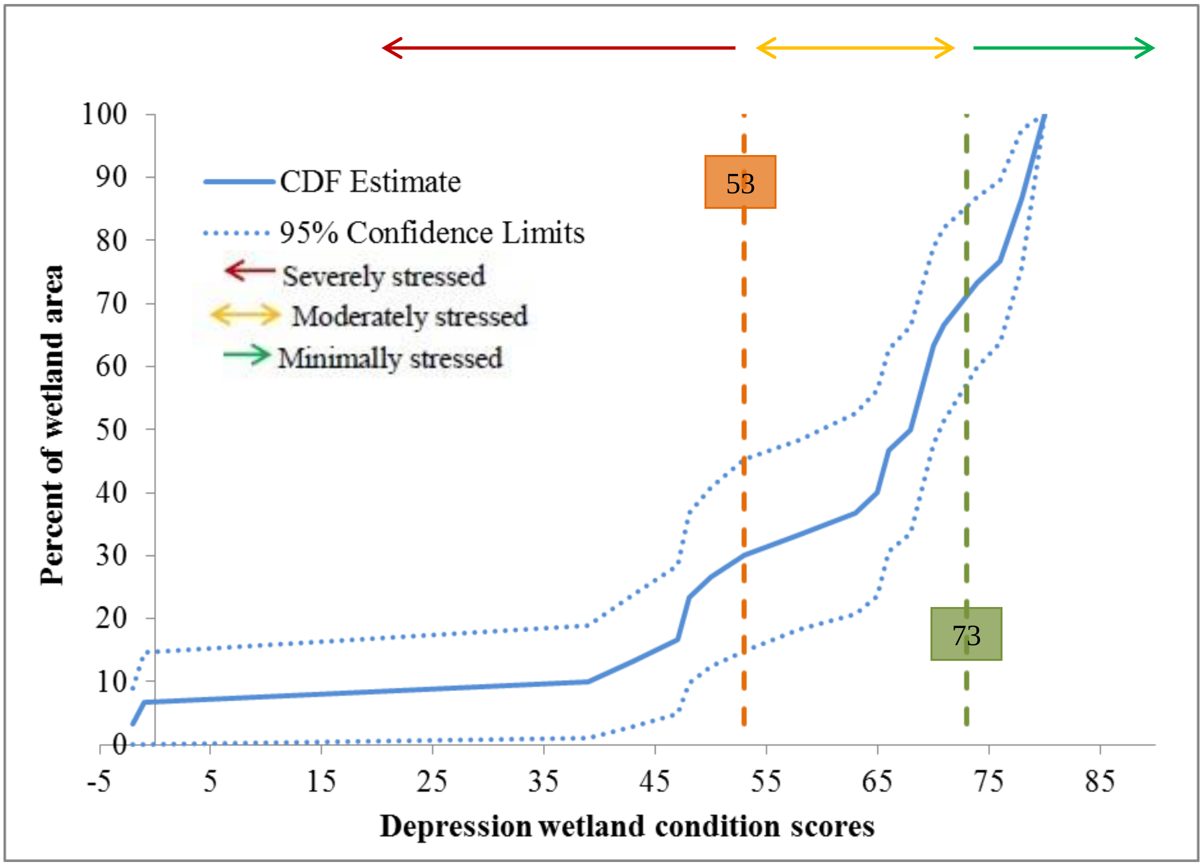


Figure 15. Cumulative distribution function (CDF) for non-tidal depression wetlands in the Smyrna River watershed. The solid blue line is the population estimate, the dashed blue lines are 95% confidence intervals, and colored arrows show condition category ranges. The orange and green dashed lines show the numeric breakpoints between condition categories.

wetlands. For instance, mowed areas were found in buffer areas for 33.3% of wetlands, and channelized streams or ditches were found in buffer areas for 16.7% of wetlands. All other buffer stressors were rare or entirely absent from depressions.

Invasive species were found in 36.7% of depressions. Species that were detected included reed canary grass (*P. arundinacea*), multiflora rose (*R. multiflora*), Japanese honeysuckle (*L. japonica*), common reed (*P. australis*), narrow-leaf cattail (*T. angustifolia*), and Japanese stiltgrass (*M. vimineum*). No invasive species were detected in any minimally stressed depressions, but occurrence increased sharply from moderately to severely stressed wetlands (Table 14). Nutrient indicator species, which are species that are associated with nutrient enrichment in depressions (Jacobs 2010), were found in some wetlands (20.0%), but were not as pervasive as invasive species. Nutrient indicator species that were detected were Japanese stiltgrass (*M. vimineum*), reed canary grass (*P. arundinacea*), common reed (*P. australis*), narrow-leaf cattail (*T. angustifolia*), lizard's tail (*Saururus cernuus*), and rice cutgrass (*Leersia oryzoides*). Depressions scored fairly well for all other habitat metrics.

Figure 16. Skidder tracks, common microtopographic alterations, in a depression in the Smyrna River watershed.

Fill was absent from minimally stressed wetlands, whereas occurrence increased from moderately to severely stressed wetlands (Table 14). Most depressions with fill had fill covering

Table 14. Stressors with the highest occurrence for each attribute category (habitat, hydrology, and buffer) in non-tidal, depression wetlands in the Smyrna River watershed. Values shown are percentages of sites with stressors present for all depression wetlands combined (total), and for each condition category.

Stressor	% Total (n=30)	% Minimally stressed (n=10)	% Moderately stressed (n=12)	% Severely stressed (n=8)
Agricultural activity in surrounding landscape	50.0	30.0	66.7	50.0
Roads present in surrounding landscape	43.3	0.0	66.7	62.5
Developed areas in surrounding landscape	40.0	0.0	66.7	50.0
Invasive species present	36.7	0.0	25.0	100.0
Microtopographic alterations present	30.0	50.0	16.7	25.0
Fill/excavation present	30.0	0.0	8.3	100.0

10-75% of the wetland (23.3% of depressions), while fewer had fill covering < 10% of the wetland (6.7%). The occurrence of microtopographic alterations showed an unusual pattern, where they were most common in minimally stressed wetlands (Table 14). Most depressions with microtopographic alterations (Figure 16) had alterations throughout 10-75% of the wetland (16.7% of depressions), while slightly fewer had alterations throughout < 10% of the wetland (13.3%). Such alterations were mainly in the form of skidder tracks. Although not as prevalent as microtopographic alterations or fill, some depressions had ditching (26.7%), though most ditching was slight. Depressions scored very well for all other hydrology metrics.

Depressions received an average value-added score of 34.0 ± 10.5 (median=33.0), with scores ranging from 17 to 55 on a 0 to 100 scale. Most depressions were rated as providing a limited amount of value-added (43.3%), closely followed by moderate (40.0%), and then rich value-added (16.7%; Figure 17). On average, depressions provided the most value in terms of habitat structure and complexity and habitat availability. They provided some value in terms of flood storage/water quality and DEN classification, and they provided low value for wetland size, uniqueness or local significance, and education.

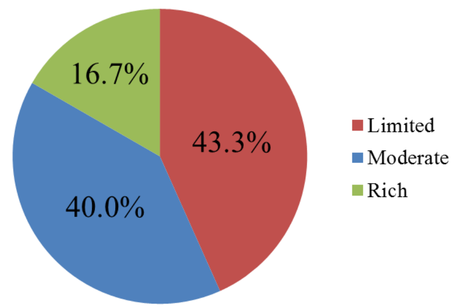


Figure 17. Percentage of depression wetlands that scored in each of the three value-added categories (n=30 sites).

Overall Condition and Watershed Comparison

We compared overall wetland condition in the Smyrna River watershed to 7 other previously assessed watersheds. To do this, we combined condition proportions (minimally, moderately, and severely stressed) for all major wetland types (estuarine, flat, riverine, and depression) weighted by the acreage of each type in each watershed (Figure 18). The highest proportion of wetlands in the Smyrna River watershed was minimally stressed (47%), followed by moderately stressed (43%) and severely stressed (10%). This wetland health breakdown was very similar to that of the Leipsic River and St. Jones River watersheds (Figure 18). Compared with other Delaware watersheds, the Smyrna River watershed was doing fairly well, with a relatively high percentage of wetlands being minimally stressed.

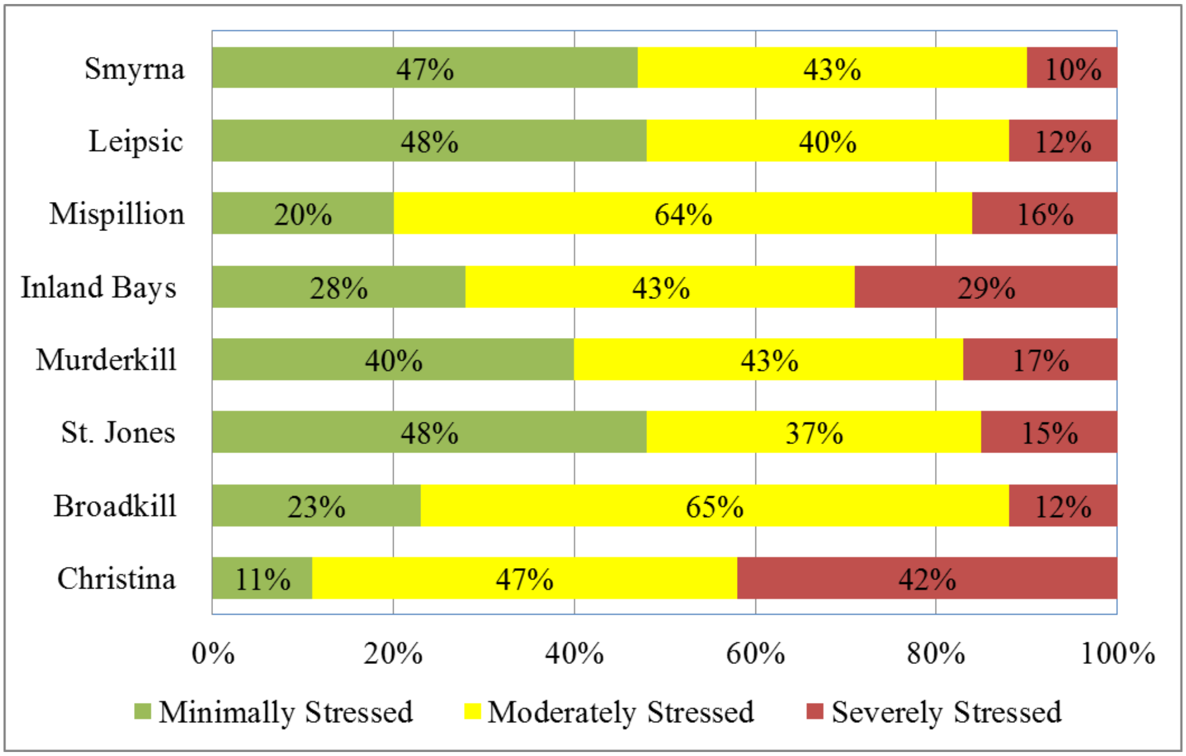


Figure 18. Comparison of overall condition categories for assessed watersheds throughout Delaware. Overall percentages shown are based on combined condition category percentages for all wetland types (estuarine, riverine, flat, and depression) that are weighted based on wetland type acreage for each watershed.

DISCUSSION

Acreage trends

The Smyrna River watershed experienced a net gain in wetland acreage between 1992 and 2007; however, more than 80% of wetland gains were not natural, vegetated wetlands, but were instead excavated, unvegetated ponds for agricultural or residential uses. Most of these ponds were classified as unconsolidated bottom, areas of which have less than 30% aerial vegetative cover (Federal Geographic Data Committee 2013). These ponds can be beneficial to some generalist species by providing habitat where natural wetlands are scarce (Brand and Snodgrass 2009; Tiner et al. 2011). However, such wetlands often do not provide the same functional value as natural wetlands, in part because they are largely unvegetated, small, and usually in a developed landscape. They may provide lower levels of certain functions, such as nutrient transformation, carbon sequestration, and sediment retention (Tiner 2003; Brand et al. 2010; Tiner et al. 2011; Howard et al. 2017). They may also provide wildlife habitat that is lower in quality than natural wetlands. For example, there is a lower abundance of chironomid insect genera in agricultural ponds surrounded by row crops and grazed grasslands compared with natural wetlands (Campbell et al. 2009), and tadpoles may suffer reduced survival or growth rates in agricultural ponds because of polluted runoff from agricultural land (Peltzer et al. 2008). Thus, although there was an acreage increase, gains in ecosystem services were likely much smaller than if acreage increases were attributable to gains in natural, vegetated wetlands. Palustrine and estuarine wetlands that changed from natural wetlands to agricultural or residential ponds likely experienced a relative decrease in ecosystem function for the same reason.

The Smyrna River watershed did gain some scrub-shrub and forested palustrine wetlands, though this only represented 11.6% of total gained acreage, a relatively small proportion. Also, a few small areas changed from unvegetated, impounded areas on the edges of agricultural fields to more natural, emergent estuarine wetlands, allowing for some minor wetland migration inland. All of these gained or changed wetlands were vegetated, which likely increased their chances of providing moderate to high function levels in services such as nutrient transformation, retention of sediments and pollutants, conservation of biodiversity, climate mitigation, and provision of wildlife habitat (Tiner 2003; Howard et al. 2017). However, all of these wetlands were either within, adjacent to, or very close to agricultural operations, mowed areas, or roads. Such stressors can dampen wetland condition through polluted runoff or reduced wetland habitat connectivity (Faulkner 2004; Brand et al. 2010), thereby reducing the ability of those wetlands to perform beneficial functions.

Wetland losses that occurred in vegetated flats and depressions were caused by development, road construction, or agricultural activities. Because these wetlands were lost completely, all functions that these wetlands performed were also lost entirely. These acreage losses were notably all caused by direct human impacts, indicating that the lack of non-tidal wetland regulation in the State of Delaware has resulted in the destruction of more non-tidal wetlands. These results aligned with trends seen statewide, as agriculture and residential development were the leading causes for losses of vegetated palustrine wetlands throughout all of Delaware (Tiner et al. 2011). Thus, increased protection, regulation and enforcement, and mitigation of non-tidal wetlands is necessary to prevent further acreage losses. Such regulations should encompass all palustrine wetlands, regardless of size. Although some palustrine wetlands tend to be small and isolated, these types of wetlands often have specific characteristics, such as hydroperiod, that are crucial to the survival and reproduction of amphibians (Babbitt 2005), making them just as important to protect as larger wetlands. Palustrine wetland losses also indicate that more education and outreach is needed for private landowners. By understanding the benefits that wetlands provide, landowners may be more willing to participate in voluntary conservation efforts.

There were no acreage losses of estuarine wetlands in this watershed due to direct human impacts between 1992 and 2007. This suggests that tidal wetland regulatory protection by the State of Delaware has been effective, and therefore needs to be maintained with proper enforcement and up-to-date regulatory maps. However, two estuarine emergent wetland areas along the Smyrna River became unconsolidated bottom, which resulted from increased inundation and led to loss of vegetated wetland habitat. Higher water levels may be attributed to sea level rise, as 97% of tidal wetlands in Delaware are predicted to be affected by a rise in sea level of 0.5m by 2100 (DNREC 2012). Although this only occurred in select areas in the Smyrna River watershed, such changes occurred on a larger scale just south in the Leipsic River watershed (Dorset et al. 2017), which may indicate that more wetland losses due to increased inundation could occur in the Smyrna River watershed in the near future. The installation of living shorelines at vulnerable areas may help combat this issue. Living shorelines can increase the resilience of tidal shorelines by promoting sediment accretion, marsh edge stabilization, or marsh edge seaward extension, thus potentially curbing further loss of tidal wetlands to erosion and sea level rise (SERC 2015). Allowing marshes to naturally migrate inland may also reduce the loss of estuarine wetlands to rising sea levels.

Tidal estuarine wetland condition

On average, estuarine wetlands had fairly intact hydrology. The lack of ditching and draining was very unusual for Delaware, as these stressors are very common in tidal wetlands in this state. Diking and tidal restrictions, though present in 10.0% of wetlands, were all considered small restrictions. This means that diking and tidal restrictions had a relatively low impact, even in severely stressed wetlands. Additionally, there was almost no fill detected in estuarine wetlands, and there were no point sources. Having intact hydrology is extremely important to the health and function of tidal wetlands. Hydrological characteristics play a major role in hydric soil formation, and they govern the types of plants and wildlife that can inhabit tidal marshes. Thus, they are crucial for proper ecosystem functioning. Natural hydrology can be incredibly difficult to recreate in wetland restoration projects, and it can also be difficult to evaluate if the restoration is successful (Zhao et al. 2016). It is therefore very important to preserve natural hydrology in estuarine wetlands in the Smyrna River watershed. Preservation of natural hydrology would ensure that healthy, minimally stressed wetlands continue to function well, while it would be easier and less costly to restore moderately or severely stressed wetlands if hydrology was already intact.

On the other hand, many estuarine wetlands had stressors within their buffers. These types of anthropogenic disturbances degrade wetland buffers, which are natural areas adjacent to wetlands that can provide wildlife habitat and process pollutants from nearby upland areas. For instance, all estuarine wetlands had some form of disturbance in the landscape surrounding them. Disturbances included non-native vegetation, human visitation, or soil disturbance. Some wetlands also had barriers to landward migration, meaning that physical, man-made barriers existed that would prevent wetlands from migrating inland as sea levels rise. If natural buffers are not present to convert to marsh as sea levels rise, wetlands will be pinched out. This will leave shorelines vulnerable to direct waves and storms, and tidal marsh plant and wildlife habitat will be lost. This data suggests that disturbances in wetland buffers should be minimized to ensure wetland health, even for those wetlands that were minimally stressed. Additionally, barriers to landward migration in wetland buffer areas should be reduced or removed wherever possible in order to try to maintain acreage of salt marshes as sea levels rise.

Estuarine wetlands received the lowest scores on average for habitat attributes, and were characterized by the presence of invasive species, low bearing capacity (i.e. marsh stability), and low horizontal vegetative obstruction (i.e. vegetation thickness). Many wetlands (66.7%) received the second highest possible score for marsh stability, suggesting only minor stress. However, 30.0% of wetlands scored poorly. This may indicate low or declining levels of below-ground biomass, because poor bearing capacity is often associated with low below-ground biomass (Twohig and Stolt 2011). It is difficult to say whether marshes are in a steady state or if marsh stability is declining because wetlands were only visited at a single point in time. However, it is still a concern because low or declining levels of below-ground biomass are often characteristics of deteriorating marshes. It is important to note that loss of below-ground organic matter often occurs before the loss of above-ground organic matter (Turner et al. 2004). However, in this case, many wetlands had moderate (33.3%) to poor (30.0%) vegetation thickness, which may indicate that above-ground biomass is also beginning to decline. Again, it is difficult to say whether marshes are in a steady state or if above-ground vegetation is steadily declining because wetlands were only visited at a single point in time. Monitoring should be conducted on estuarine wetlands in this watershed whenever possible to look for signs of marsh deterioration over time in order to address problems quickly if they arise.

Invasive plant species were detected in 100.0% of estuarine wetlands, meaning that there was a widespread problem, even among minimally stressed wetlands. Invasive species can rapidly displace the native species that characterize high-functioning wetlands and that provide vital habitat for wildlife, thus decreasing wetland condition. It is also incredibly difficult to eradicate many invasive plant species once they are established. Therefore, invasive species should be removed or controlled as soon as possible in landscapes surrounding wetlands so that they do not move into wetlands. These species should also be removed or controlled as soon as possible once found within wetlands to minimize damage to the native plant and wildlife community, and to prevent them from spreading to other nearby wetlands.

Over half (63.3%) of estuarine wetlands were publicly owned, meaning that they were on state-owned public lands and were shielded from many common direct human impacts. The other 36.7% were privately owned, leaving them more vulnerable; however, these privately owned tidal wetlands were still regulated by the state, shielding them from most direct human impacts. Estuarine wetlands in the Smyrna River watershed were in the best overall condition of the four major HGM wetland types, with most estuarine wetlands being minimally stressed (66.7%). This suggests that most efforts should be focused on preserving estuarine wetlands in the Smyrna River watershed because a high proportion of these wetlands were minimally stressed and were therefore functioning relatively well. If work is done to preserve wetlands in good condition, communities will continue to benefit from functions they provide, and money will not need to be spent on their restoration or the replacement of beneficial services in the future. Wetlands that were moderately (30.0%) or severely stressed (3.3%) would require restoration to ensure that they function at their highest potential.

Non-tidal palustrine wetland condition and value

Most palustrine wetlands were in fairly good condition in terms of habitat, with the exception of invasive species. Invasive plant species were detected in many palustrine wetlands of all 3 HGM types. As mentioned earlier, invasive species can rapidly displace the native species that characterize high-functioning wetlands and that provide vital habitat for wildlife, thus decreasing wetland condition. It is also incredibly difficult to eradicate many invasive plant species once they are established. Therefore, invasive species should be removed or controlled as soon as possible in landscapes surrounding wetlands so that they do not move into wetlands. These species should also be removed or controlled as soon as possible once found within wetlands to minimize damage to the native plant and wildlife community, and to prevent them from spreading to other nearby wetlands.

Stream alteration was a major hydrological issue in riverine wetlands. Spoil banks on the sides of streams that are created during stream alteration activities can prevent water from flowing over stream banks during rain and storm events. This disconnects the waterway from adjacent wetlands and diminishes flood storage capacity after storms, in effect disrupting wetland hydrology and causing more flooding downstream. When hydrology is disturbed in riverine wetlands, plant communities may change and diversity may decrease, which may further increase the prevalence of invasive species in riverine wetlands (Nilsson and Svedmark 2002).

Similar problems can occur in riverine wetland buffers when channelization or ditching is present that drain water away quickly, as was the case in the Smyrna River watershed. Fill and excavation were prevalent in all three palustrine wetland types. Ditching was common in flats, and microtopographic alterations were prevalent in depressions. All of these stressors can degrade natural wetland hydrology by increasing, decreasing, or altering the flow of water through wetlands. When hydrology is disturbed, soil moisture and groundwater levels may be reduced (Faulkner 2004). Such disturbances have the potential to affect wetland plant communities, which are adapted to live in certain hydrologic conditions. Therefore, restoration efforts should target these hydrological issues to reestablish natural functions. For example, restoration in this watershed could focus on reconnection of floodplain habitats or remeandering of channelized streams. Such techniques have been shown to increase presence of wildlife, flood frequency into the floodplain, aquatic vegetation, and natural sediment deposition (Roni et al. 2008).

Agricultural activities, development, roads, and mowed areas were present in the landscapes surrounding many palustrine wetlands. Such unnatural land uses surrounding palustrine wetlands indicate that buffer zones around these wetlands were degraded. Buffers are natural areas adjacent to wetlands that can provide wildlife habitat and help shield wetlands from indirect impacts. Runoff polluted with chemicals and excess nutrients from agricultural fields, development, roads, or mowed areas can enter wetlands directly if natural buffers do not separate wetlands from anthropogenic activities. Additionally, natural buffer areas surrounding wetlands can be just as important as wetlands, if not more so, to amphibians, many of which require forested habitats adjacent to wetlands for foraging, overwintering, and habitat corridors (Quesnelle et al. 2015; Finlayson et al. 2017). These data identify a clear need to conserve and improve buffers around non-tidal wetlands. Additionally, the prevalence of agriculture near wetlands highlights the importance of utilizing best management practices. Such responsible practices would dampen effects of indirect impacts by reducing harmful excess runoff of waste, nutrients, and chemicals (EPA 2003).

Seventy-five percent or more of wetlands in all 3 palustrine HGM classes were privately owned. With so many wetlands on private property, it is clear that state non-tidal wetland regulation and enforcement needs to be established to prevent further wetland degradation, particularly because palustrine wetland condition was reduced mainly by human impacts in this watershed. The high proportion of private ownership also highlights the need for more education and outreach for private landowners. By understanding the benefits that wetlands provide, landowners may be more willing to participate in conservation efforts.

Palustrine wetlands were overall more stressed than estuarine wetlands in the Smyrna River watershed. Most riverine wetlands were moderately stressed (60.0%), most flat wetlands were moderately stressed (56.3%), and most depression wetlands were moderately stressed (40.0%). This suggests that efforts should largely be focused on restoring palustrine wetlands in the Smyrna River watershed because a high proportion of these wetlands were negatively impacted and were therefore functioning below their full potential. It is easier and cheaper to restore wetlands that are moderately stressed compared with those that are severely stressed, so restoration activities should be conducted as soon as possible. Restoration projects should focus on reversing negative effects of common stressors found in non-tidal wetlands in this watershed. For example, invasive plant species should be targeted and controlled to allow for restoration of native plant communities. Minimally stressed wetlands should be preserved so that communities will continue to benefit from functions they provide, and money will not need to be spent on their restoration or the replacement of beneficial services in the future.

Although many non-tidal wetlands were not functioning at their highest potential, many moderately and severely stressed wetlands were still rated as providing moderate to rich value to the local landscape. This shows that in some ways even unhealthy wetlands can be very valuable to local communities and wildlife, which strengthens the case for conservation and restoration of wetlands, even those in poor or declining condition. Highlighting the specific local values that non-tidal wetlands provided in this watershed, such as habitat structure and complexity, can also make cases for increased protection of non-tidal wetlands more compelling. Value added data can also be used to inform wetland restoration and enhancement projects by focusing on improving value characteristics that were rated poorly in this watershed, such as education, to heighten their value to the local landscape.

MANAGEMENT RECOMMENDATIONS

Wetland acreage, condition, and value are all important to evaluate when considering the health of wetlands in a given watershed. Each component is related to the degree to which wetlands can perform beneficial functions and provide ecosystem services. Here, we synthesized information about wetland acreage trends, ambient wetland condition, and value-added characteristics to identify explicit conservation goals. We have developed management recommendations that identify specific actions that can be taken to accomplish the major goals that were outlined in the discussion (see ‘Discussion’ section above). Wetland conservation is most likely to be effective when many audiences with different backgrounds and interests are collaboratively involved, and when a variety of different approaches are used (Calhoun et al. 2014, 2017). Thus, a wide range of actions were tailored to several different audiences, including environmental scientists, researchers, and land managers, decision makers, and landowners, all of whom play an important role in protecting and restoring wetlands.

Environmental Scientists, Researchers, and Land Managers

1. **Increase resiliency of tidal shorelines by installing living shorelines at appropriate sites.** There were some losses of vegetated estuarine wetlands in this watershed due to increased inundation, and this trend is likely to continue. Installation of living shorelines can increase the resilience of tidal shorelines by promoting sediment accretion, marsh edge stabilization, or marsh edge seaward extension, thus potentially curbing any further loss of tidal wetlands to erosion and sea level rise (SERC 2015). Scientists should focus on identifying appropriate potential sites and securing funding to install living shorelines wherever possible to ensure that tidal wetlands are more resilient in the face of erosion and sea level rise. Post-installation monitoring of living shorelines is also important because it is necessary for adaptive management. It can also help scientists further improve designs to make them more effective in the future.

2. **Support vegetated buffers for tidal and non-tidal wetlands.** There is a clear need for establishment, improvement, or maintenance of natural, vegetated buffers around tidal and non-tidal wetlands in this watershed. Such work would help minimize indirect

impacts and ensure that wetlands can persist and function. Buffers of tidal and non-tidal wetlands can perform many important functions, such as trapping and filtering sediments and pollutants before they enter wetlands and providing critical habitat for many plant and animal SGCN. Additionally, maintaining buffers between tidal wetlands and upland communities can allow for landward marsh migration as sea levels continue to rise, ensuring that tidal wetlands could persist and provide ecosystem services in the future. Funding should be secured for improving buffers on currently protected lands, and for acquiring buffer land to extend riparian habitat corridors and connect more habitat hotspots.

3. **Continue to increase citizen education and involvement through effective outreach.** Nearly 70% of all sites that were sampled in the Smyrna River watershed were privately owned, and wetland loss and degradation was largely caused by human impacts, particularly in palustrine wetlands. By increasing wetland education to landowners and informing them about the benefits wetlands can provide, landowners may be more willing to take part in voluntary stewardship activities that can benefit wetlands around them, thereby decreasing wetland loss and degradation. To accomplish effective public outreach, it is incredibly important to create an active dialogue with landowners, to encourage active, hands-on participation in discussions and activities, and to create an understanding of how wetlands are relevant to the public (Calhoun et al. 2014, Varner 2014). For example, in order to address the goal of increased landowner wetland stewardship, DNREC's WMAP created a website called the Freshwater Wetland Toolbox in 2017 (see link on pg. 54). More outreach tools and programs should be created in order to address other specific public education goals. Such tools and programs should constantly be evaluated to gauge their effectiveness in addressing goals and to improve outreach efforts (Varner 2014).

4. **Control the extent and spread of non-native invasive plant species.** Each of the four HGM wetland classes assessed in the Smyrna River watershed was negatively affected by invasive species. To improve wetland health, the extent and spread of non-native invasive plant species needs to be controlled. DNREC has a Phragmites Control Program to help combat the spread of the invasive common reed, which has treated more than 20,000 acres throughout Delaware on private and public property since 1986 (DNREC 2017b). This program has the potential to continue to help improve wetland health on public land and private holdings greater than 5 acres. However, many other invasive species besides the common reed were prevalent in wetlands in this watershed, such as Japanese honeysuckle, narrow-leaf cattail, multiflora rose, Japanese stiltgrass, and reed canary grass. There is currently no program in place to control these invasive species. It would therefore be beneficial to expand invasive plant species control efforts to include more species besides just the common reed (see MidTRAM protocol for full list of Delaware invasive species; Jacobs et al. 2010). Education and awareness, such as efforts made by the Delaware Invasive Species Council (DISC 2018), is an important component of this by informing landowners about how to remove undesirables and only plant native species.

5. **Perform wetland monitoring, conservation, and restoration activities.** It is essential to monitor wetland condition in order to detect trends and stressors and address them as quickly as possible. In the Smyrna River watershed, tidal wetlands were found to have relatively poor vegetation thickness and marsh stability; monitoring would allow scientists to see if marshes remain stable or if they decline further and need attention. It is also important to support the Delaware Bayshore Initiative through conservation and restoration. Because most wetlands were minimally or moderately stressed in this watershed, a combination of preservation and restoration can greatly increase the overall health of these wetlands. When possible, environmental organizations can work to preserve or restore wetlands that are not currently protected through land acquisition or conservation easement. Projects should account for watershed-specific conditions. For example, the overall intact hydrology of estuarine wetlands should be kept in place, while the hydrologic stressors of palustrine wetlands should be addressed. In addition, value added results can strengthen cases for wetland conservation and restoration and inform wetland enhancement goals.

Decision Makers (State, County, and Local)

1. **Improve protection of non-tidal palustrine wetlands through state, county, and local programs.** Without increased protection, losses of non-tidal wetlands in the Smyrna River watershed will probably continue. Acreage losses will translate into losses of ecosystem services and values. These facts highlight the need for improved protection to fill the gaps left by recent Supreme Court decisions (i.e., SWANCC and Rapanos/Carabell) and to address the lack of state regulation. Conservation of palustrine wetlands will likely be most effective if state regulation is combined with smaller-scale efforts from local governments and organizations, stakeholders, and landowners. Such collaborative efforts can make everyone feel involved and informed, while successful solutions can be reached that simultaneously conserve wetlands and integrate interests of many parties (Calhoun et al. 2014, 2017). A state regulatory program in concert with county and local programs would reduce the ambiguity surrounding non-tidal wetland regulation and provide a comprehensive and clear means to protect these wetlands, both large and small, in the entire state. Local regulations can be incorporated into municipal and/or county code and homeowner associations to protect wetland areas of special significance.

2. **Update tidal wetland regulatory maps to further improve accuracy and efficiency of regulation.** Relatively few direct human impacts were detected within tidal wetlands in the Smyrna River watershed, and no recent acreage losses were attributed to human development, signifying that tidal wetland regulation by the State of Delaware has been effective in this watershed. Preservation of tidal wetlands is a key conservation goal in this watershed, so effective tidal wetland regulation needs to be maintained. Permit reviewers need accurate and current wetland maps to guide wetland permitting and ensure that wetlands are experiencing as few impacts as possible. Likewise, landowners and designers would benefit by using accurate maps for planning and design purposes. Currently, maps from 1988 are used for regulation of tidal wetlands within the state,

which must be verified in the field due to discrepancies. These maps are also difficult to read. Thus, these regulatory maps need to be updated.

3. **Develop incentives and legislation to establish, maintain, or improve natural wetland buffers.** The data presented in this report demonstrate a clear need for establishment, improvement, or maintenance of natural buffers around tidal and non-tidal wetlands. To further improve wetland condition, buffers need to be kept as wide as possible, development and agriculture within buffer areas needs to be prevented, and natural hydrology needs to be maintained. Barriers to landward migration of tidal wetlands should also be removed or prevented whenever possible. Incentive programs could attract landowner interest in maintaining natural buffers between tidal and non-tidal wetlands and human activity to reduce negative indirect impacts to wetlands, provide crucial wildlife habitat, and to allow for landward marsh migration in the face of sea level rise. Development of incentives or legislation, or continuation or improvement of any existing local legislation, for buffer setbacks would help to prevent further buffer degradation.

4. **Secure funding for wetland preservation.** Overall, 47% of wetlands were minimally stressed in the Smyrna River watershed, meaning that preservation can make a large impact in this watershed. Preservation of wetlands that are already healthy will ensure that they continue to provide beneficial ecosystem services in the future. Funding should be secured to continue and expand programs that already exist in Delaware that can help conserve wetlands, including the Open Space Program and the Delaware Forestland Preservation Program. New funding opportunities should also be explored.

Landowners

1. **Protect and maintain the buffers around wetlands.** Buffers are natural regions adjacent to wetlands that can help wetlands stay in good condition. Wetland buffers trap sediments and excess nutrients and filter pollutants before they reach wetlands. Buffers also slow storm water runoff from nearby impervious surfaces, such as roads. In this way, buffers can protect wetlands from some of the negative indirect impacts associated with roads, development, and agriculture that prevent wetlands from functioning at their fullest capacity. In the Smyrna River watershed, many palustrine wetlands were degraded from development, agricultural activities, or from channelization of streams or ditches in their surrounding landscapes. When buffers are degraded in this way, they do not perform ecosystem services to the same degree as when buffers are undisturbed. To maintain natural wetland buffers, avoid anthropogenic activities (e.g., development, stream channelization, ditching, agriculture, or mowing) adjacent to these buffers and within existing buffers.

2. **Strengthen tidal shorelines using environmentally-friendly methods.** Living shorelines, which are environmentally-friendly alternatives to ‘hardened shoreline’ structures such as bulkheads, seawalls, and riprap revetments (NOAA 2017), can be installed on properties to reduce impacts of erosion and sea level rise. They include natural materials such as coir logs, shell bags, and native vegetation to help gain

sediment, stabilize marsh edges, or extend marsh edges seaward. These designs can strengthen shorelines and protect properties while also providing valuable plant and wildlife habitat, unlike hardened shoreline structures (SERC 2015). Installation of living shorelines would help prevent more vegetated estuarine wetlands from being eroded or submerged under water in this watershed. More information about living shorelines and the process through which they are installed on properties is available on the Delaware Living Shorelines website (see link on pg.55)

3. **Preserve or restore wetlands that are on private property.** Over half of the wetlands in the Smyrna River watershed were located on privately-owned land. This means that in order to be truly effective in maintaining wetland acreage, function, and value, help is necessary from landowners. There are many ways that landowners can engage with the natural wetlands right in their backyards to ensure that they continue to perform beneficial ecosystem services. Planting native species and removing invasive species are two important actions that landowners can take, especially because many wetlands in the Smyrna River watershed were found to have invasive species present. They can also avoid mowing grasses and picking up downed logs and sticks within wetlands because those features provide important habitat for wildlife. In addition, leaving the hydrology intact (i.e., no draining or channelization of any kind) will help ensure that wetlands will remain healthy and fully functioning. Landowners can also choose to be part of a conservation easement, which can protect wetlands in their natural state from future development. WMAP's new Freshwater Wetland Toolbox website allows landowners to see if wetlands exist on their property, and to discover more ways in which they can benefit wetlands on their land (see link on pg.55).

4. **Utilize best management practices (BMPs) in agricultural operations.** In this watershed, agriculture was found near $\geq$ 50% of riverine, flat, and depression wetlands. Utilizing BMPs in agricultural operations can greatly reduce the amount of waste, sediment, chemical, and nutrient runoff from fields, thereby reducing the potential for indirect wetland impacts. Some examples of beneficial BMPs include use of cover crops, precision farming, crop rotation, tree planting, proper animal waste management, and avoidance of over-grazing (EPA 2003).

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APPENDIX A: QUALITATIVE DISTURBANCE RATING (QDR) CATEGORY DESCRIPTIONS

Qualitative Disturbance Rating: Assessors determine the level of disturbance in a wetland through observation of stressors and alterations to the vegetation, soils, hydrology in the wetland site, and the land use surrounding the site. Assessors should use best professional judgment (BPJ) to assign the site a numerical Qualitative Disturbance Rating (QDR) from least disturbed (1) to highly disturbed (6) based on the narrative criteria below. General description of the minimal disturbance, moderate disturbance and high disturbance categories are provided below.

Minimal Disturbance Category (QDR 1 or 2): Natural structure and biotic community maintained with only minimal alterations. Minimal disturbance sites have a characteristic native vegetative community unmodified water flow into and out of the site, undisturbed microtopographic relief, and are located in a landscape of natural vegetation (100 or 250 m buffer). Examples of minimal alterations include a small ditch that is not conveying water, low occurrence of invasive species, individual tree harvesting, and small areas of altered habitat in the surrounding landscape, which does not include hardened surfaces along the wetland/upland interface. Use BPJ to assign a QDR of 1 or 2.

Moderate Disturbance Category (QDR 3 or 4): Moderate changes in structure and/or the biotic community. Moderate disturbance sites maintain some components of minimal disturbance sites such as unaltered hydrology, undisturbed soils and microtopography, intact landscape, or characteristic native biotic community despite some structural or biotic alterations. Alterations in moderate disturbance sites may include one or two of the following: a large ditch or a dam either increasing or decreasing flooding, mowing, grazing, moderate stream channelization, moderate presence of invasive plants, forest harvesting, high impact land uses in the buffer, and hardened surfaces along the wetland/upland interface for less than half of the site. Use BPJ to assign a QDR of 3 or 4.

High Disturbance Category (QDR 5 or 6): Severe changes in structure and/or the biotic community. High disturbance sites have severely disturbed vegetative community, hydrology and/or soils as a result of ≥1 severe alterations or >2 moderate alterations. These disturbances lead to a decline in the wetland's ability to effectively function in the landscape. Examples of severe alterations include extensive ditching or stream channelization, recent clear cutting or conversion to an invasive vegetative community, hardened surfaces along the wetland/upland interfaces for most of the site, and roads, excessive fill, excavation or farming in the wetland. Use PBJ to assign a QDR of 5 or 6.

Appendix B: DERAP Stressor Codes and Definitions

Habitat Category (within 40m radius of sample point)	
Hfor50	Forest age 31-50 years
Hfor30	Forest age 16-30 years
Hfor15	Forest age 3-15 years
Hfor2	Forest age ≤2 years
Hcc10	<10% of AA clear cut within 50 years
Hcc50	11-50% of AA clear cut within 50 years
Hcc100	>50% of AA clear cut within 50 years
Hforsc	Selective cutting forestry
Hpine	Forest managed or converted to pine
Hchem	Forest chemical defoliation
Hmow	Mowing in AA
Hfarm	Farming activity in AA
Hgraz	Grazing in AA
Hnorecov	Cleared land not recovering
Hinv1	Invasive plants cover <1% of AA
Hinv5	Invasive plants cover 1-5% of AA
Hinv50	Invasive plants cover 6-50% of AA
Hinv100	Invasive plants cover >50% of AA
Hherb	Excessive Herbivory/Pinebark Beetle/Gypsy Moth
Halgae	Nutrients dense algal mats
Hnis50	Nutrient indicator plant species cover <50% of AA
Hnis100	Nutrient indicator plant species cover >50% of AA
Htrail	Non-elevated road
Hroad	Dirt or gravel elevated road in AA
Hpave	Paved road in AA
Hydrology Category (within 40m radius of sample point)	
Wditchs	Slight Ditching; 1-3 shallow ditches (<0.3m deep) in AA
Wditchm	Moderate Ditching; 3 shallow ditches in AA or 1 ditch >0.3m within 25m of edge of AA
Wditchx	Severe Ditching; >1 ditch 0.3-0.6 m deep or 1 ditch > 0.6m deep within AA
Wchannm	Channelized stream not maintained
Wchan1	Spoil bank on one or both sides of stream
Wchan2	Spoil bank on same side of stream as AA
Wincision	Natural stream channel incision
Wdamdec	Weir/Dam/Road decreasing site flooding
Wimp10	Weir/Dam/Road impounding water on <10% of AA
Wimp75	Weir/Dam/Road impounding water on 10-75% of AA
Wimp100	Weir/Dam/Road impounding water on >75% of AA
Wstorm	Stormwater inputs

Wpoint	Point source (non-stormwater)
Wsed	Excessive sedimentation on wetland surface
Hydrology Category (continued)	
Wfill10	Filling or excavation on <10% of AA
Wfill75	Filling or excavation on 10-75% of AA
Wfill100	Filling or excavation on >75% of AA
Wmic10	Microtopographic alterations on <10% of AA
Wmic75	Microtopographic alterations on 10-75% of AA
Wmic100	Microtopographic alterations on >75% of AA
Wsubsid	Soil subsidence or root exposure
Landscape/Buffer Category (within 100m radius outside site/AA)	
Ldevcom	Commercial or industrial development
Ldevres3	Residential development of >2 houses/acre
Ldevres2	Residential development of 1-2 houses/acre
Ldevres1	Residential development of <1 house/acre
Lrdgrav	Dirt or gravel road
Lrd2pav	2-lane paved road
Lrd4pav	≥4-lane paved road
Llndfil	Landfill or waste disposal
Lchan	Channelized streams or ditches >0.6m deep
Lag	Row crops, nursery plants, or orchards
Lagpoul	Poultry or livestock operation
Lfor	Forest harvesting within past 15 Years
Lgolf	Golf course
Lmow	Mowed area
Lmine	Sand or gravel mining operation

APPENDIX C: DERAP IWC STRESSORS AND WEIGHTS

Category/Stressor Name*	Code	Stressor Weights**		
**DERAP stressors excluded from this table are not in the rapid IWC calculation.*		Flats	Riverine	Depression
Habitat Category (within 40m radius site)				
Mowing in AA	Hmow	15	3	24
Farming activity in AA	Hfarm			
Grazing in AA	Hgraz			
Cleared land not recovering in AA	Hnorecov			
Forest age 16-30 years	Hfor16	5	4	2
≤10% of AA clear cut within 50 years	Hcc10			
Forest age 3-15 years	Hfor3	19	7	12
Forest age ≤2 years	Hfor2			
11-50% of AA clear cut within 50 years	Hcc50			
>50% of AA clear cut within 50 years	Hcc100			
Excessive Herbivory	Hherb	4	2	2
Invasive plants dominating	Hinvdom	2	20	7
Invasive plants not dominating	Hinvless	0	5	7
Chemical Defoliation	Hchem	5	9	1
Managed or Converted to Pine	Hpine			
Non-elevated road in AA	Htrail	2	2	2
Dirt or gravel elevated road in AA	Hroad			
Paved road in AA	Hpave			
Nutrient indicator species dominating AA	Hnutapp	10	12	10
Nutrients dense algal mats	Halgae			
Hydrology Category (within 40m radius site)				
Slight Ditching	Wditchs	10	0	5
Moderate Ditching	Wditchm		0	
Severe Ditching	Wditchx	17	0	
Channelized stream not maintained	Wchannm	0	13	0
Spoil bank on one or both sides of stream	Wchan1	0	31	0
Spoil bank on same side of stream as AA	Wchan2	0		0
Stream channel incision	Wincision	0	21	0
WeirDamRoad decreasing site flooding	Wdamdec	2	2	2
WeirDamRoad/Impounding <10%	Wimp10			
WeirDamRoad/Impounding 10-75%	Wimp75			
WeirDamRoad/Impounding >75%	Wimp100			
Stormwater Inputs	Wstorm	2	2	2
Point Source (non-stormwater)	Wpoint			
Excessive Sedimentation	Wsed			

Appendix C: DERAP IWC Stressors and Weights

Hydrology Category (continued)	Code	Flats	Riverine	Depression
Filling, excavation on <10% of AA	Wfill10	2	0	8
Filling, excavation on 10-75% of AA	Wfill75	16	11	2
Filling, excavation on >75% of AA	Wfill100			
Soil Subsidence/Root Exposure	Wsubsid	7	0	0
Microtopo alterations on <10% of AA	Wmic10			
Microtopo alteations on 10-75% of AA	Wmic75	16	11	2
Microtopo alterations on >75% of AA	Wmic100			
Buffer Category (100m radius around site)				
Development- commercial or industrial	Ldevcom			
Residential >2 houses/acre	Ldevres3			
Residential ≤2 houses/acre	Ldevres2	1 buffer stressor = 3	1 buffer stressor = 1	1 buffer stressor = 4
Residential <1 house/acre	Ldevres1			
Roads (buffer) mostly dirt or gravel	Lrdgrav			
Roads (buffer) mostly 2- lane paved	Lrd2pav			
Roads (buffer) mostly 4-lane paved	Lrd4pav			
Landfill/Waste Disposal	Llndfil	2 buffer stressors = 6	2 buffer stressors = 2	2 buffer stressors = 8
Channelized Streams/ditches >0.6m deep	Lchan			
Row crops, nursery plants, orchards	Lag			
Poultry or Livestock operation	Lagpoul			
Forest Harvesting Within Last 15 Years	Lfor	≥ 3 buffer stressors = 9	≥ 3 buffer stressors = 3	≥ 3 buffer stressors = 12
Golf Course	Lgolf			
Mowed Area	Lmow			
Sand/Gravel Operation	Lmine			
Intercept/Base Value		95	91	82
Flats IWCrapid= 95 -(∑weights(Habitat+Hydro+Buffer))				
Riverine IWCrapid= 91 -(∑weights(Habitat+Hydro+Buffer))				
Depression IWCrapid= 82 -(∑weights(Habitat+Hydro+Buffer))				

***Stressors with weights in boxes were combined during calibration analysis and are counted only once, even if more than one stressor is present.*

Appendix D-G are stored as a separate file and can be found online at Delaware Wetlands, Watershed Health Home, Smyrna River watershed. http://www.dnrec.delaware.gov/Admin/DelawareWetlands/Pages/WatershedHealth.aspx

This report and other watershed condition reports, assessment methods, scoring protocols, and wetland health report cards can be found on the Delaware Wetlands website:

Delaware Wetlands

Purify Provide Protect

http://de.gov/delawarewetlands

The Freshwater Wetland Toolbox can be found at the following link: de.gov/wetlandtoolbox

The Delaware Living Shorelines website can be found at the following link:
https://www.delawarelivingshorelines.org/