Conditions of Wetlands in the Leipsic River Watershed, Delaware

Delaware Department of Natural Resources and Environmental Control

Delaware Wetlands

Purify Provide Protect

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CONTENTS

FIGURES

MAPS

TABLES

EXECUTIVE SUMMARY

The Delaware Department of Natural Resources and Environmental Control (DNREC) documented wetland acreage trends and determined the ambient condition of tidal and non-tidal wetlands in the Leipsic and Little Creek River Watersheds (here on referred to as Leipsic River watershed) in 2013. The goal of this project was to summarize recent gains, losses, and changes in wetland acreage, assess the condition of tidal and non-tidal wetlands throughout the watershed, and identify prevalent wetland stressors. Based on findings, we made watershed-specific management recommendations to improve wetland conservation measures. We also aimed to educate the public on watershed stewardship and the importance of wetland conservation for public health and well-being.

The Leipsic River watershed is located in central-eastern Kent County where it encompasses 128 square miles (78,000 ac) of the Delaware Bay and Estuary Basin. The Leipsic River watershed consists of the Little Creek and Leipsic River sub-watersheds, which were combined for this project and report. The Leipsic River originates in Kenton and flows approximately 19 miles eastward through Bombay Hook National Wildlife Refuge. Little Creek (also known as Little River) flows for approximately 8 miles through the town of Little Creek. Both water bodies flow into the Delaware Bay. Approximately 40% of the watershed (32,000ac) is covered by wetlands, including tidal estuarine wetlands (72%) and non-tidal flat (19%), riverine (7%), and depression wetlands (2%).

We estimated historic (prior to 1992) and recent (1992 to 2007) wetland losses in the Leipsic River watershed based on historic hydric soil maps and recent statewide wetland mapping efforts. Our analysis indicated that by 1992, approximately 21% (8,493 acres) of the watershed's historic wetlands had been filled or lost, mostly due to conversion to other land uses, including agricultural land and residential and commercial development. Between 1992 and 2007, the watershed lost another 60 acres of wetlands and gained approximately 251 acres of wetlands. 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 a borrow pit (i.e., where sediment has been dug out for use at a different site, and water may subsequently fill the pit left behind) and many smaller excavated storm water ponds, all of which provide fewer ecosystem services than natural wetlands.

Some wetlands also changed from 1992 to 2007. Five acres of non-tidal wetlands changed from natural wetlands to excavated agricultural or residential ponds, which likely reduced the functional value of these wetlands. Tidal wetlands experienced greater change, with 647 acres of emergent vegetated wetlands shifting mostly to aquatic bed, intertidal unconsolidated shore, or subtidal unconsolidated bottom habitat. These changes indicate an overall decline in vegetative cover and changes in hydrologic regime and wildlife habitat. Many of these changes occurred along the coastline adjacent to the Delaware Bay, suggesting that erosion and sea level rise are converting vegetated wetlands into largely unvegetated unconsolidated bottom and shore (i.e., open water).

To assess wetland condition and identify stressors affecting wetland health, we conducted rapid assessments at random wetland sites throughout the watershed during the summer of 2013. Wetland assessments were performed in 30 tidal wetlands using the Mid-Atlantic Tidal Rapid Assessment Method (MidTRAM) Version 3.0. In addition, 30 freshwater riverine wetlands, 29 flat wetlands, and 39 depression wetlands were visited and assessed using the Delaware Rapid Assessment Procedure (DERAP) Version 6.0. Wetland assessment sites were located on public and private property and randomly selected utilizing a probabilistic sampling design with the assistance of the Environmental Protection Agency's (EPA) Ecological Monitoring and Assessment Program (EMAP).

Estuarine wetlands received a median condition score of 84.4 out of a maximum possible score of 100.0, with scores ranging from 46.6 to 91.1. Flat wetlands had a median condition score of 70.0 out of a maximum possible score of 95.0, ranging from 32.0 to 95.0. Riverine wetlands had a median condition score of 72.0 out of a maximum possible score of 91.0, ranging widely from 2.0 to 90.0. Depression wetlands received a median score of 55.0 out of a maximum possible score of 82.0, ranging from -1.0 to 80.0. Compared to six other watersheds previously assessed in Delaware, the wetlands of the Leipsic River watershed were doing fairly well, with a relatively high percentage of wetlands being minimally stressed (48.0%). Despite this, 40.0% of wetlands in this watershed were still moderately stressed and 12.0% were severely stressed. Some common wetland stressors were invasive plant species and buffer disturbances, such as adjacent development.

Wetland value was also evaluated in non-tidal wetlands because wetland value to the local area may be independent of wetland condition. The Leipsic River watershed was the first watershed where value-added assessments were conducted; as such, scores presented here are considered pilot scores, and scoring methods will be further refined as more watersheds are evaluated in the future. 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 non-tidal wetlands were found to provide moderate value to the local area (46.7%), and contributed the highest amounts of value in terms of habitat structure and complexity and habitat availability.

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, and secure funding for wetland preservation and restoration. We also recommended that decision makers improve the protection of non-tidal palustrine wetlands, update tidal estuarine wetland regulatory maps, and develop incentives for maintaining tidal and non-tidal wetland buffers. 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, and protect or restore wetlands on their property.

INTRODUCTION

Wetlands are unique, beautiful ecosystems that are intrinsically valuable and provide many important ecosystem services to communities. Disturbed sediments, pollutants, and nutrient runoff from non-point sources such as agriculture, land clearing, and construction, can be removed and retained from the water column by wetlands 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. For example, it is estimated that flood control benefits to property owners provided by Delaware watersheds and the wetlands within them are valued between $42 and $105 million annually, and wildlife activities conducted in these areas such as birding, fishing, and hunting generate approximately $303 million annually (Narvaez and Kauffman 2012). Coastal wetlands in Delaware provide approximately $19.3 million in wages to hundreds of workers through associated jobs, and generate millions of dollars every year from commercial fisheries (Narvaez and Kauffman 2012).

Wetland acreage and condition are both crucial to the ability of wetlands to provide these beneficial services. For example, if a wetland was large in size but was degraded, its ability to perform ecosystem services would be reduced even though it was a large wetland. Conversely, if a wetland was small in size but was in excellent condition, it would perform services well, but would only be able to provide them to a very limited number of plants, animals, and communities. Wetlands provide the greatest amount of services when they are in good condition and exist in large, contiguous blocks.

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 experiencing many stressors, and are therefore functioning below their potential. Mosquito ditches, agriculture, development, filling, and invasive species are all examples of some of the stressors that Delaware wetlands experience that can negatively affect their hydrology, biological community, and ability to perform beneficial functions. Additionally, approximately half of all historic wetlands in Delaware have been lost over time. 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 palustrine wetlands, which experienced the greatest losses of all wetland types between 1992 and 2007 (Tiner et al. 2011). These losses highlight the need for greater protection of freshwater, non-tidal wetlands, as the State of Delaware only regulates activities in tidal wetlands and non-tidal wetlands that are 400 contiguous acres or more in size.

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). Thus, the State of Delaware Department of Natural Resources and Environmental Control (DNREC) examines changes in wetland acreage over time and monitors wetland condition and functional capacity to guide management and protection efforts. 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). The program evaluates wetland health, or 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, and data collection and analysis.

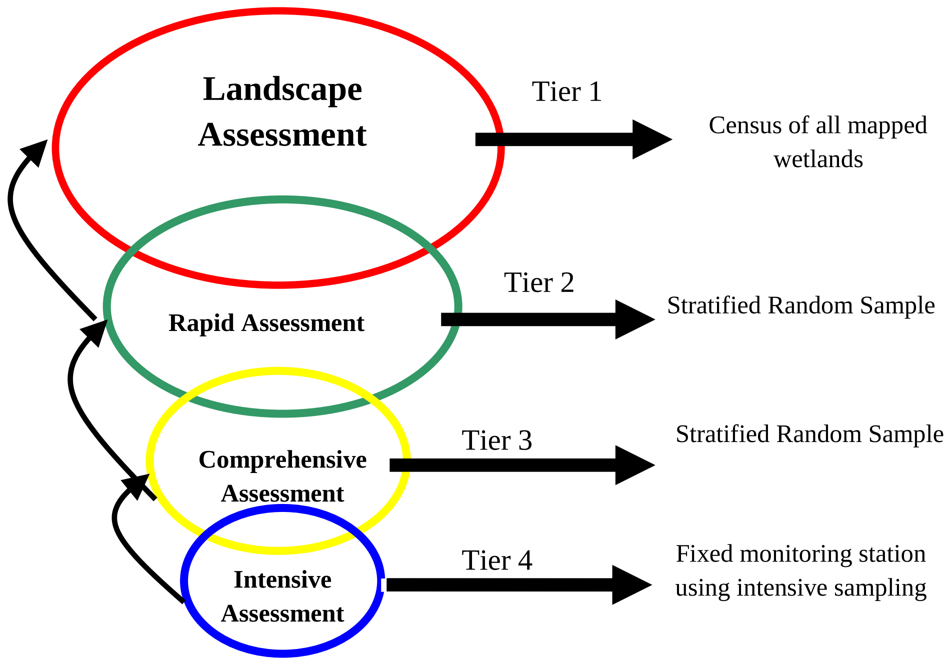
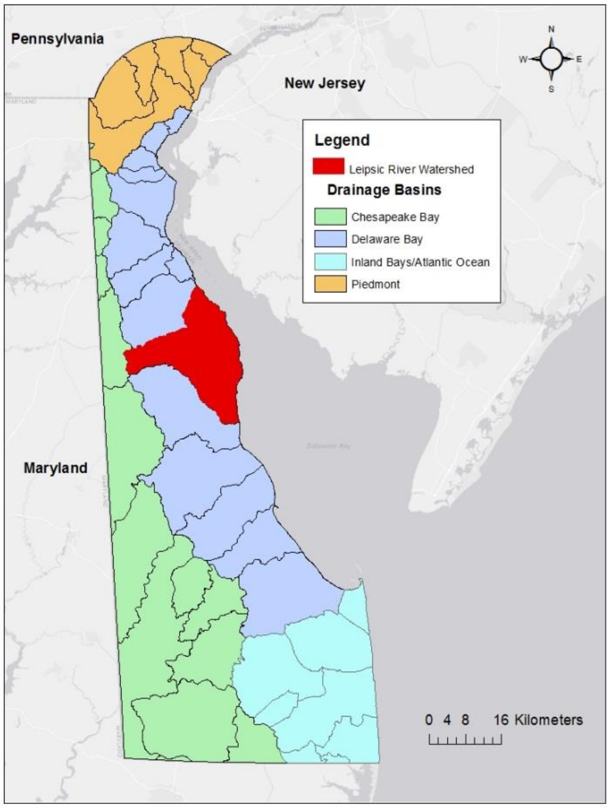


Figure 1. The four-tiered approach that is used to evaluate wetland condition across the Mid-Atlantic region.

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 easements, can be directed toward wetland types in good condition, and restoration efforts can target degraded wetland types to increase their functions and services.



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

Watershed Overview

The Leipsic River watershed is comprised of two sub-watersheds: the Leipsic River watershed, and the Little Creek watershed. Both sub-watersheds were assessed together as one watershed by DNREC, so for the purpose of this report, Leipsic River and Little Creek sub-watersheds together will hereafter be referred to as simply the Leipsic River watershed. As a whole, the watershed encompasses 128 square miles of land (78,000 acres; Map 1).

The Leipsic River is located in Kent County within the Delaware Bay and Estuary Basin. It is bordered by the St. Jones watershed to the south, the Chester River watershed to the west, the Smyrna River watershed to the north, and the Delaware Bay to the east. At one time, the Leipsic River was actually considered a tributary of the Smyrna River, but it was cut off from the Smyrna River in 1682 when the Thoroughfare Canal was constructed (DelDOT a). Now, the Leipsic River is divided into an upper and lower segment by a dam at Garrison’s Lake, which was installed in the 1800’s to supply water power for grain mills (DelDOT b). The lower segment is tidal and runs for approximately 13.6 miles from the Garrison’s Lake dam out into the Delaware Bay. The upper, non-tidal segment runs for approximately 5.8 miles from the headwaters of the Leipsic River in Kenton into Garrison’s Lake. Water from Massey’s Millpond feeds into Garrison’s Lake through the Pinks Branch. Duck Creek converges with the lower segment of the Leipsic River in Bombay Hook National Wildlife Refuge. Little Creek, also known as Little River, runs for approximately 8 miles, through the town of Little Creek and east of Dover out to the Delaware Bay. The Pipe Elm and Morgan Branches feed into the Little River.

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 through 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 Leipsic 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) on the western side of the basin (DNREC 2005). The Leipsic River watershed is within two of the four hydrogeomorphic regions of the Basin, including well-drained uplands on the western extent, and beaches, tidal marshes, lagoons, and barrier islands on the eastern extent (DNREC 2005).

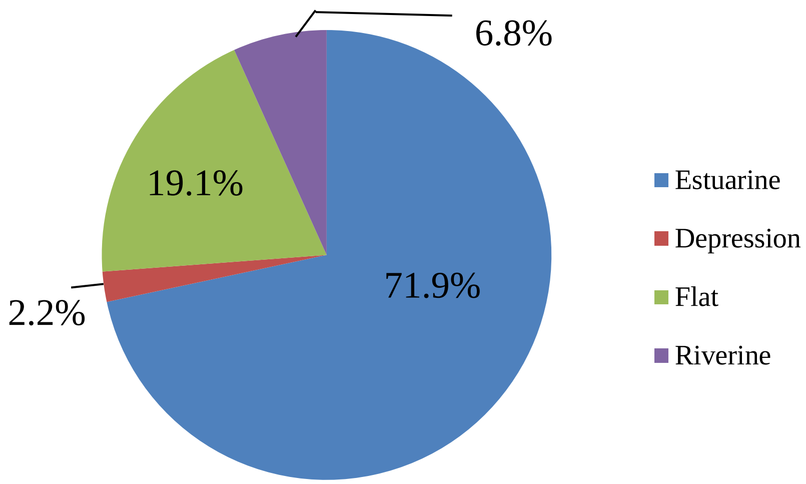
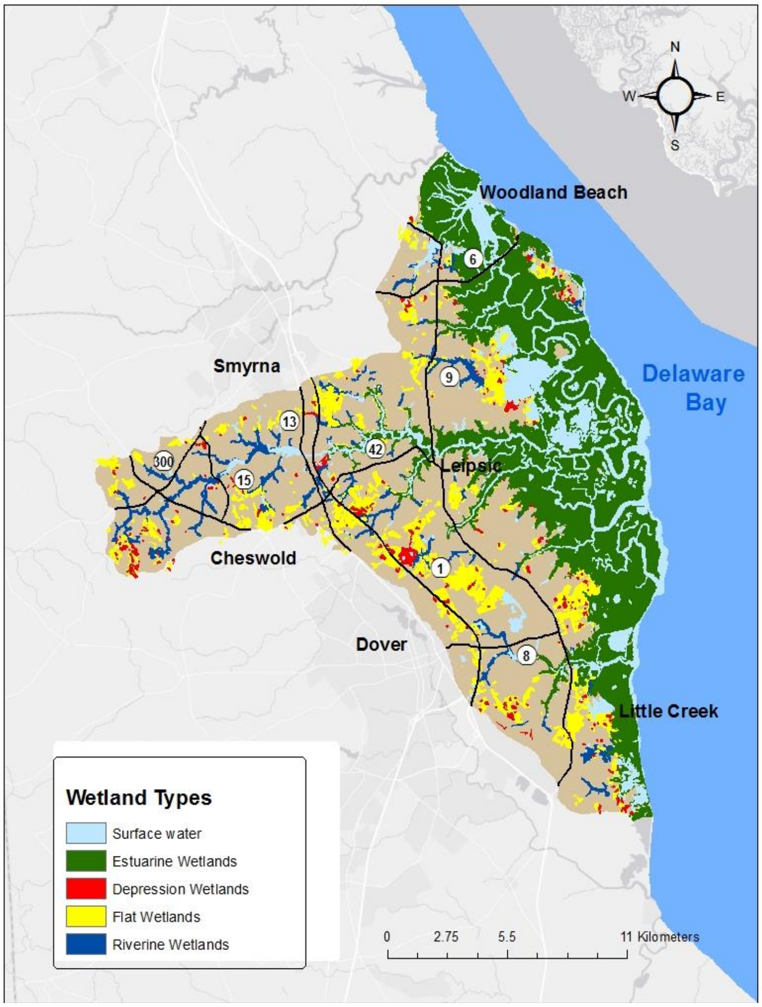


Figure 2. Proportions of hydrogeomorphic wetland types in the Leipsic River watershed.

According to the 2007 mapping effort from the Delaware Statewide Wetland Mapping Project (SWMP; State of Delaware 2007), the Leipsic River watershed has a total of 31,917 acres of wetlands, which can be categorized into different classes based on hydrogeomorphic (HGM) properties, such as landscape, landform, and water flow path. Most wetlands in this watershed are classified as estuarine (71.9%), totaling 22,962 acres, followed by flats (19.1%; Figure 2), totaling 6,088 acres. Only 2,160 acres (6.8%) of the wetlands are riverine, and only 707 acres (2.2%), are depression. Throughout this report, the terms 'estuarine' and 'tidal' are used interchangeably. Flat, riverine, and depression wetlands are collectively referred to as palustrine (i.e., freshwater, non-tidal) wetlands, and in this report, the terms 'palustrine' and 'non-tidal' are used interchangeably.



Map 2. Hydrogeomorphic wetland types and surface water in the Leipsic River watershed based on 2007 SWMP data.

Estuarine wetlands are heavily concentrated on the eastern side of the watershed because the eastern side is influenced by the tidal action of the Delaware Bay. Flat wetlands are scattered throughout the watershed, with some adjacent to estuarine wetlands and some occurring in low-lying headwater regions. Riverine wetlands are along river and stream bodies, and depression wetlands occur throughout the watershed, often adjacent to or surrounded by flat wetlands (Map 2).

The unconfined aquifer (water table) and several deeper confined aquifers throughout the Delaware Bay and Estuary Basin support the ground-water 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). Wetlands, therefore, are extremely important in this region for drinking water because wetlands help clean and recharge ground-water. It is estimated that the economic value of the treated public water supply in the Delaware Bay and Estuary Basin is $243 million annually (Narvaez and Kauffman 2012). Water is also used for agricultural irrigation in Kent County and is valued at an estimated $6.5 million annually (Narvaez and Kauffman 2012). Runoff from impervious surfaces or agricultural land can affect the quality of this water.

Land Use and Land Cover

Based on a comparison between 1997 and 2012 National Land Cover Datasets (NLCD), the Leipsic River watershed experienced a 3.0% increase in the amount of developed land in the 15-year time frame (Table 1). Land used for agriculture decreased by 4.7%, forested land decreased by 3.6%, land covered with water increased by 1.7%, and wetland acreage increased by 2.8% (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. The reduction in forested land was because of both the increase in developed land and the fact that some areas that were formerly classified as forests were recently reclassified as wetlands. Most development was concentrated along Route 13 and Route 1, with some also occurring by Route 15. Wetland acreage increased because of the creation of storm water retention ponds associated with many developments and because some areas that were formerly classified as forests were more recently reclassified as wetlands. The amount of land covered by water increased because of conversion of some shoreline to open water and because of an increase in surface water in some tidal wetland areas.

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

Land Use	1997 Land Use	2012 Land Use	'97-'12 Change
Developed	8.5	11.5	3
Agriculture	41.6	36.9	-4.7
Forest	6.1	2.5	-3.6
Water	6.1	7.8	1.7
Wetland	37.1	39.9	2.8

The more recent 2012 NLCD shows that the Leipsic River watershed is currently dominated by wetlands (40%), followed closely by agricultural land (37%; Figure 3), which is used for livestock and poultry, and for growing crops such as corn, soybeans, and wheat. Some land is also used for development (12%) or is covered with water (8%), and small fractions of land are forested (2.5%), beach or sand (<1%), or transitional (i.e., in the process of being converted to use for development; <1%; Figure 3).

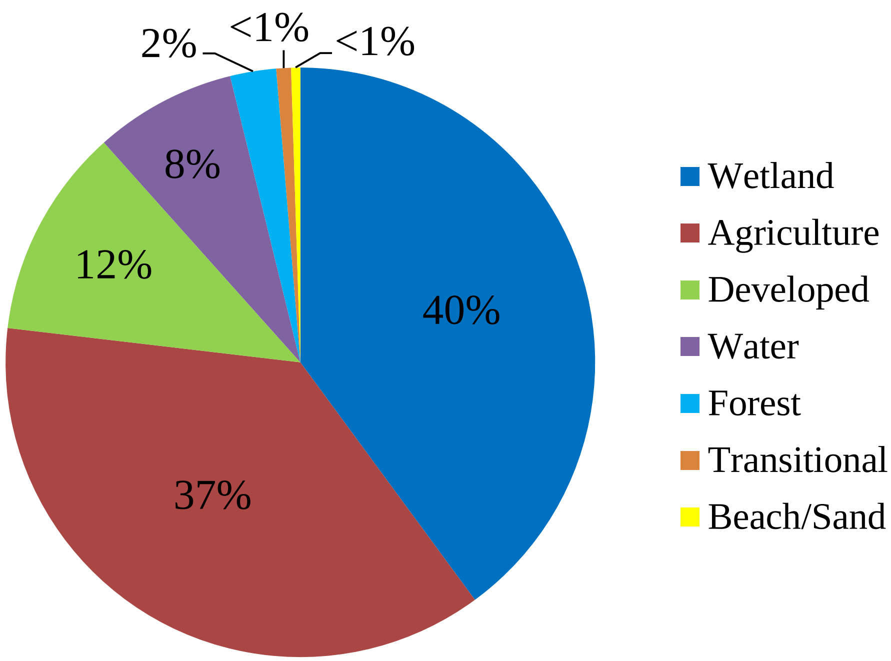
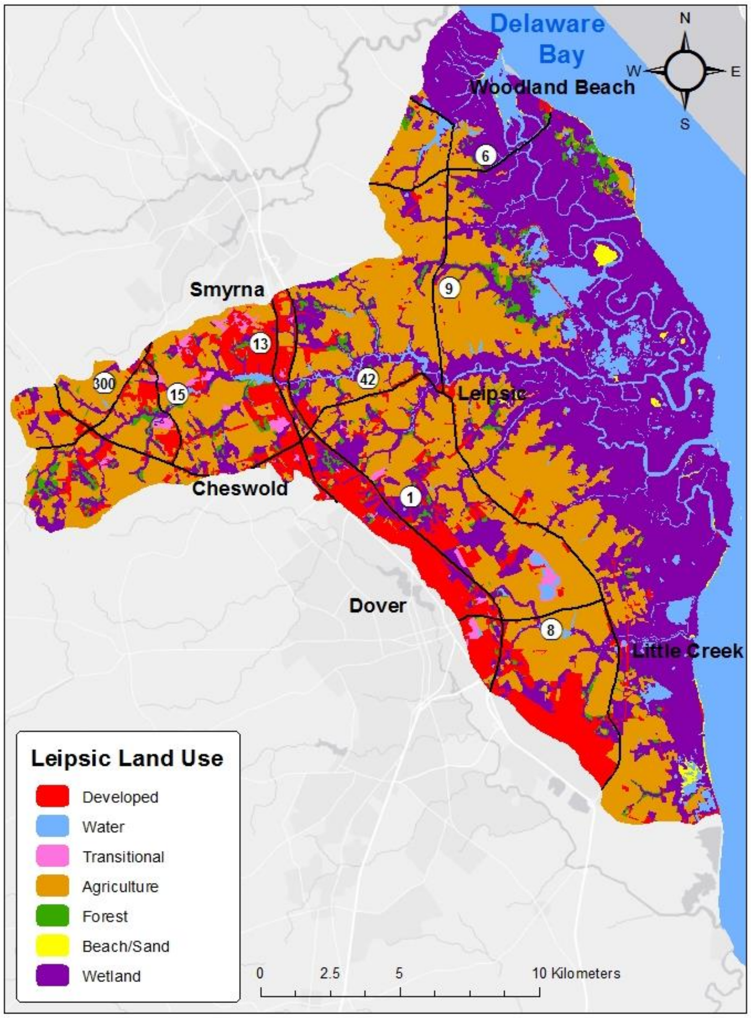


Figure 3. LULC status in the Leipsic River watershed in 2012. Percentages shown are based on the 2012 NLCD.

Most of the wetland areas are on the eastern side of the Leipsic River watershed adjacent to the open water of the Delaware Bay, with some smaller patches of wetlands scattered throughout the watershed. To the west, these wetlands are bordered primarily by agricultural land, which occur in the western extent of the watershed (Map 3). A large strip of developed land runs northwest to southeast down the watershed, beginning just south of Dover Downs along Route 13 and continuing down through the center of the Dover Airforce Base. Some smaller patches of developed land are scattered throughout the watershed, though most development occurs on the western half (Map 3). The open surface water is concentrated on the eastern side of the watershed in the wetland areas, with some water bodies extending west, including the Leipsic River. There are small patches of forested and transitional land scattered throughout the watershed, while the small beach/sand areas are along the shoreline of the Delaware Bay or within the tidal wetlands (Map 3).

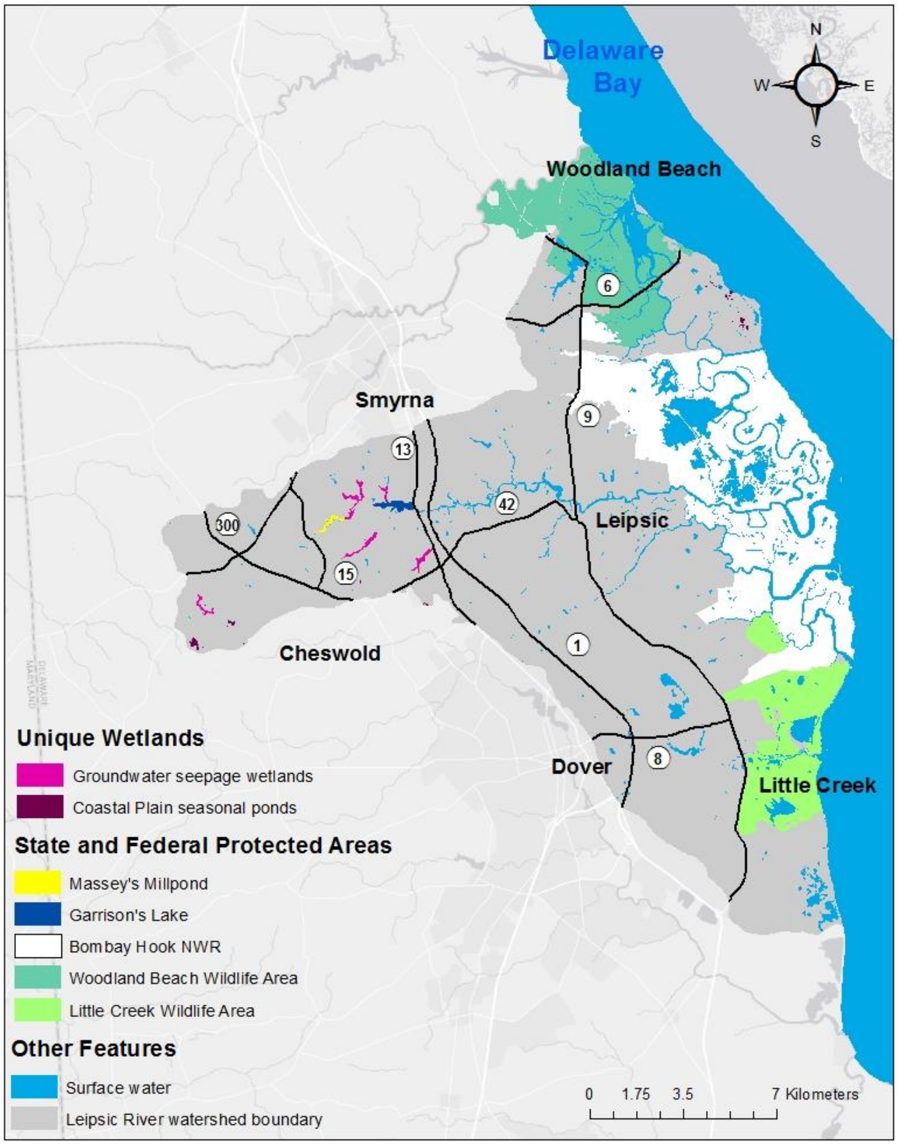


Map 3. LULC in the Leipsic River watershed in 2012 based on the 2012 NLCD.

It is likely that land use and landcover will continue to change. As mentioned above, sea level rise is predicted to affect wetland landcover, particularly tidal wetlands, with 97% of tidal wetlands in Delaware predicted to be affected by a rise in sea level of 0.5m by 2100 (DNREC 2012). Since most of the wetlands in the Leipsic River watershed are estuarine (Figure 2), it is highly likely that wetland landcover in this watershed will be altered over time. Sea level rise will probably affect beach and sand areas as well because they are located along the shoreline with the tidal wetlands. The proportion of land used for development may continue to increase, which would likely contribute to a further decrease in agricultural land, forests, and wetlands.

Wildlife Habitat and Outdoor Recreation

The Delaware Bay and Estuary Basin, including the Leipsic 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 spp.*) 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



Map 4. State and federal protected areas, and unique wetlands, in the Leipsic River watershed that are important for wildlife habitat and/or recreation opportunities.

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 a large portion of the Leipsic 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 2016).

The 2015 Delaware Wildlife Action Plan (DNREC 2015b) also highlights wetlands within the Leipsic River watershed as important habitats for many reptile and amphibian SGCN, such as the diamond-backed terrapin (*Malaclemys terrapin*) 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 SGCN, and the Leipsic River watershed contains two kinds of these wetlands. There are 64.5 acres of Coastal Plain seasonal ponds, some of which are located on the far western side of the watershed, and some of which are on the eastern side near Bombay Hook NWR and Woodland Beach (Map 4). There are also 178.0 acres of groundwater seepage wetlands, all of which are on the western side of the watershed, and some of which are adjacent to Massey's Millpond and Garrison's Lake (Map 4). Both of these unique wetland types 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). None of these unique wetlands are within protected area boundaries in this watershed (Map 4).

The Leipsic River watershed contains several protected wildlife areas that serve as important habitat for many resting, feeding, and breeding wildlife species, including the SGCN listed above (Map 4). Bombay Hook National Wildlife Refuge (NWR) is owned and operated by the U.S. Fish and Wildlife Service (USFWS). It contains a large region of unfragmented tidal salt marsh and four freshwater impoundments. The water levels in these impoundments are controlled seasonally with water control structures to create shorebird feeding habitat in the spring and waterfowl feeding habitat in the fall and winter.

Delaware Division of Fish and Wildlife, part of DNREC, owns and manages Little Creek Wildlife Area, Woodland Beach Wildlife Area, Garrison's Lake, and Massey's Millpond. Little Creek Wildlife Area, similar to Bombay Hook, contains tidal salt marsh and three managed freshwater impoundments. Woodland Beach Wildlife Area, located just north of Bombay Hook, contains tidal salt marsh and several small freshwater impoundments. About two-thirds of this wildlife area lies within the northernmost part of the watershed, with part of the area extending outside of the watershed (Map 4). Garrison's Lake is dammed on its eastern side, making it a freshwater impoundment cut off from the tidal portion of the Leipsic River. Massey's Millpond is also a freshwater impoundment with a dam on its eastern side.

There are many opportunities for outdoor recreation within these protected areas of the Leipsic River watershed. At Bombay Hook NWR, the public can enjoy birding and wildlife viewing year round, and deer, waterfowl, turkey, and small game hunting on a seasonal basis. Bombay Hook also offers a variety of environmental education programs. Seasonal deer, waterfowl, turkey, and small game hunting is popular at Little Creek Wildlife Area and Woodland Beach Wildlife Area, and fishing from shore, canoes, and small boats is popular at Garrison's Lake and Massey's Millpond. Birding and wildlife viewing can be enjoyed year round at all of these state-owned protected areas as well. Many of these recreation activities and associated costs (i.e., lodging, food, transportation, and equipment) contribute significantly to the local economy. For example, approximately $20.2 million is made annually from costs associated with outdoor recreation activities at Bombay Hook NWR (Narvaez and Kauffman 2012).

METHODS

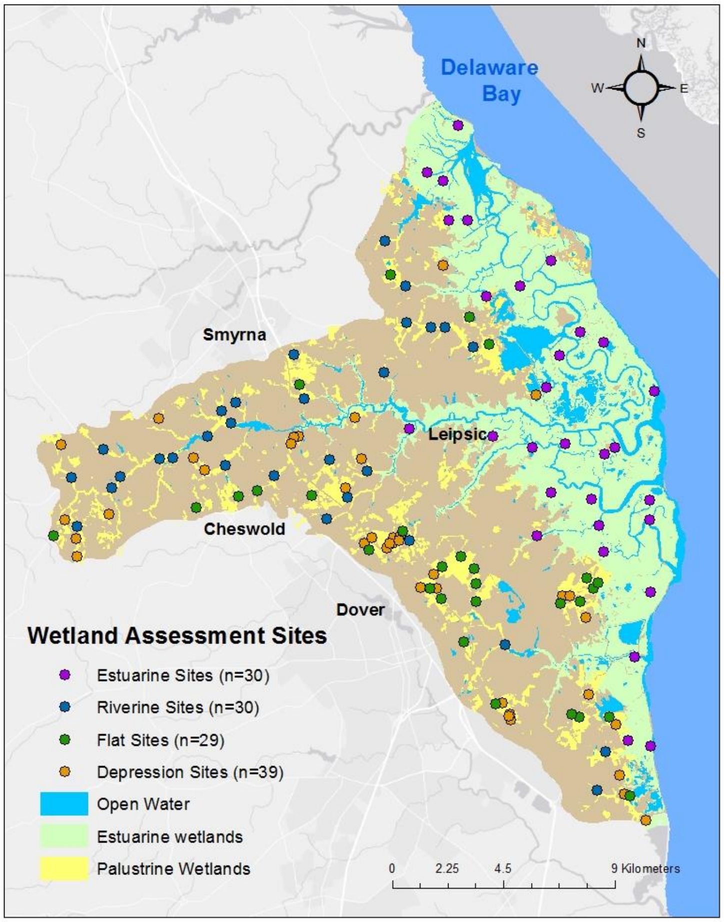
Changes to Wetland Acreage

Historic wetland acreage in the Leipsic 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 data which classified changed wetlands 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 250 potential sample sites in estuarine intertidal emergent wetlands and 750 potential sample sites in vegetated palustrine wetlands (250 for each HGM class) 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 Leipsic River watershed from the 2007 National Wetland Inventory (NWI) maps. 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, 29 flat sites, and 39 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

<u>Landowner Contact and Site Access</u>

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 to not be wetlands upon field visits, and such sites were dropped. Similarly, some sites that were identified and selected by the EMAP design as being a certain HGM class were determined to be a different HGM class upon field visits, and those sites were either dropped or changed in our database and sampled. 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.

<u>Assessing Tidal Wetland Condition</u>

We evaluated the condition of tidal wetlands using the MidTRAM v3.0 protocol (Jacobs et al. 2010). MidTRAM consists of 14 scored metrics that represent the condition of the wetland buffer, hydrology, and habitat characteristics (Table 2). 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.

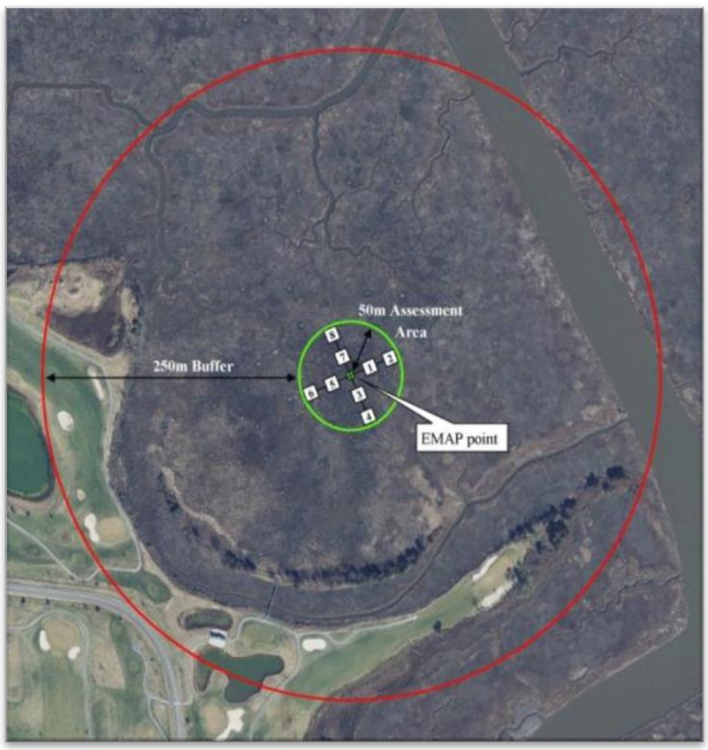


Figure 4. Standard assessment area (AA), subplot locations, and buffer used to collect data for the Mid-Atlantic Tidal Rapid Assessment Method (MidTRAM).

MidTRAM was used to complete assessments 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 2) 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 4). We defined the AA buffer area as a 250 m radius area around the AA (Figure 4). Any necessary adjustments to the AA shape or location were made according to the MidTRAM protocol (Jacobs et al. 2010).

Eight 1 m^2 subplots were established along two perpendicular 100 m transects that bisected the AA. These subplots were used to measure horizontal vegetative obstruction and soil bearing capacity (Table 2). Orientation, placement, and numbering of subplots, as well as any necessary adjustments to subplot locations, were done in accordance with the MidTRAM protocol (Figure 4; 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).

Additionally, marsh bird surveys were conducted between July 1-September 30 in 2013 and 2014 at 29 of 30 sites. This was done to measure community integrity in order to further determine if rapid assessment methods (i.e., MidTRAM) are reflective of intensive wetland condition measures. MidTRAM wetland condition scores were found to be significantly correlated with Index of Marsh Bird Community Integrity (IMBCI) scores, supporting the idea that MidTRAM scores are reflective of true wetland condition ($p<0.005$; $r^2=0.27$; Jennette 2014). Detailed methods, statistical results, and discussion of marsh bird surveys are not covered in this report, but can be found online (see pg. 58 for website link).

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). A normalized final score was then computed, which provides a quantitative description of tidal wetland condition out of a total of 100 points. Statistical analysis was performed using Microsoft Excel and R version 3.3.2.

Table 2. 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

Assessing Non-tidal Wetland Condition

Rapid Sampling in Non-tidal Wetlands

The Delaware Rapid Assessment Procedure (DERAP) v.6.0 was used 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 3; Jacobs 2010). DERAP was followed to complete assessments at 29 flat sites, 30 riverine, and 39 depression sites in the Leipsic River watershed in 2013. 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.

Figure 5. Standard assessment area and buffer used to collect data for the Delaware Rapid Assessment Procedure (DERAP).

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 5). 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 3) were documented during one field visit during the growing season (July 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. Note that some stressors only apply to certain non-tidal wetland types (i.e., ditches are only assessed for flats and depressions, and stream alteration is only assessed for riverine wetlands; Table 3). Statistical analysis was performed using Microsoft Excel and R version 3.3.2.

Table 3. 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

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. 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

Value Added Assessments in Non-tidal Wetlands

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 some non-tidal 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 value that a wetland provides by assessing 7 value metrics (Table 4; for details on scoring metrics, see protocol; Rogerson and Jennette 2014).

Value added pilot assessments were performed at 17 riverine sites, 14 flat sites, and 29 depression sites. This was a pilot for the method, as the Leipsic River watershed was the first watershed for which we conducted value added assessments. 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 5; scoring will be updated as we gain more reference data. We presented results only on the site level; value added scores were not extrapolated to the whole wetland population. Statistical analysis was performed using Microsoft Excel and R version 3.3.2.

Table 4. 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
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 5. 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, ≥30
Limited	<30

Wetland Condition 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 and DERAP 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, and correct for any bias due to sample sites that could not be sampled and different rates of access on private and public lands. These are presented using weighted means and standard deviations (e.g., habitat for tidal wetlands averaged 87 ± 13), medians (e.g., the median score for tidal wetlands was 90), or percentages (e.g., 20% of riverine wetlands had channelization present).

Sites in each HGM subclass were placed into 3 condition categories: Minimally Stressed, Moderately Stressed, or Severely Stressed (Table 6). 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. Non-tidal regional datasets includes DERAP data from St. Jones, Murderkill, Inland Bays, and Nanticoke watersheds (n = 160). Minimally stressed sites are those with a condition score greater than the 25th percentile of sites assigned a QDR of 1 or 2. Severely stressed sites are those with a condition score less than the 75th 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 Leipsic River watershed are provided in Table 6.

Table 6. Condition categories and breakpoint values for tidal and non-tidal wetlands in the Leipsic 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 and 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 6, 35% of the wetland area scored 80 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 6), there is a small condition plateau from 57 to 65, illustrating that only a small portion of the population had condition scores in this range.

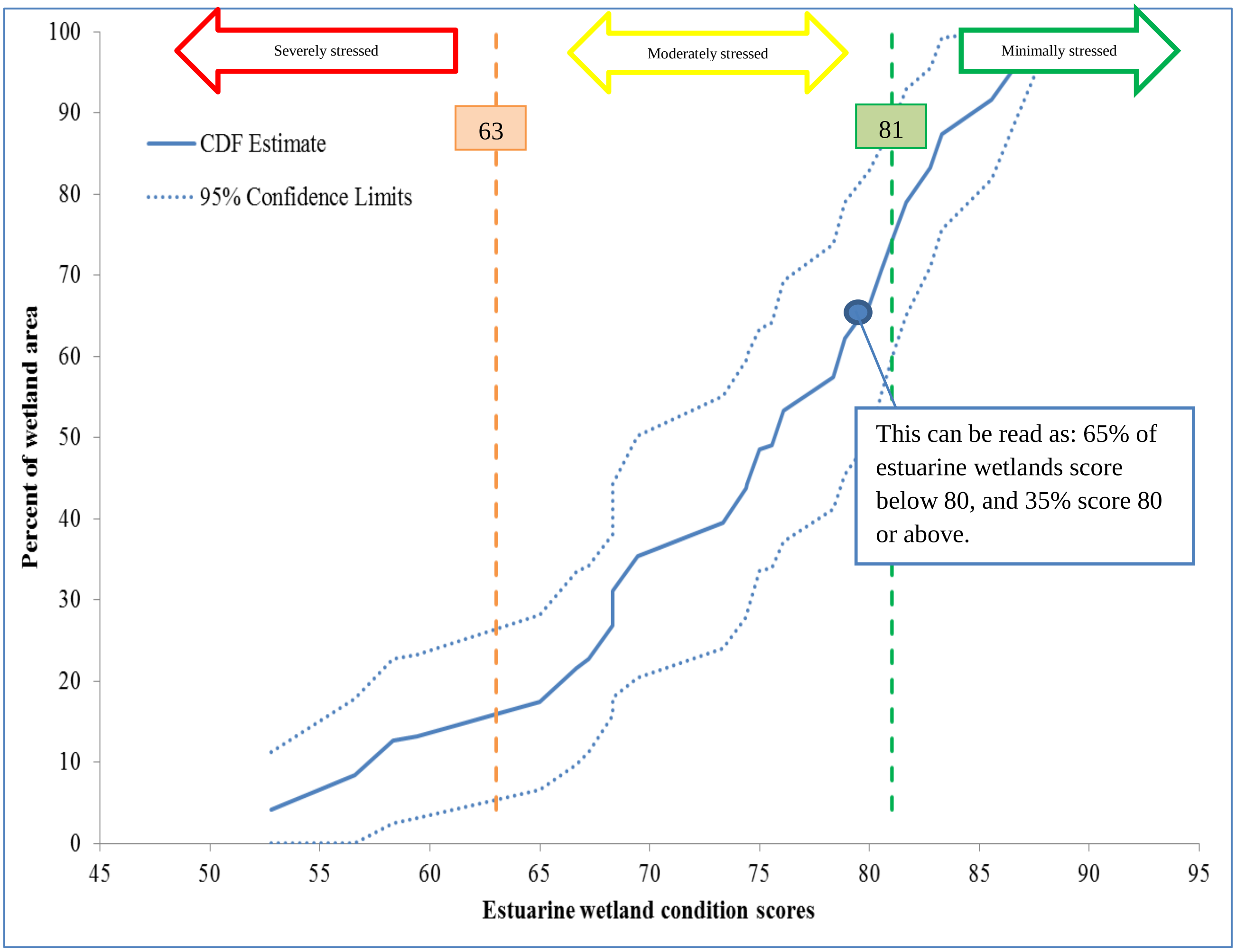


Figure 6. An example CDF showing wetland condition. The blue line is the population estimate and the dashed blue lines are 95% confidence intervals. The orange and green dashed lines show the breakpoints between condition categories.

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 Leipsic 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. 58 for link). These grades are 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 Mispillion River watershed, but has been updated and is therefore slightly different than the letter grade scale used for all other previously assessed watersheds besides Mispillion.

RESULTS

Wetland Acreage

Trends: gains, losses, and changes

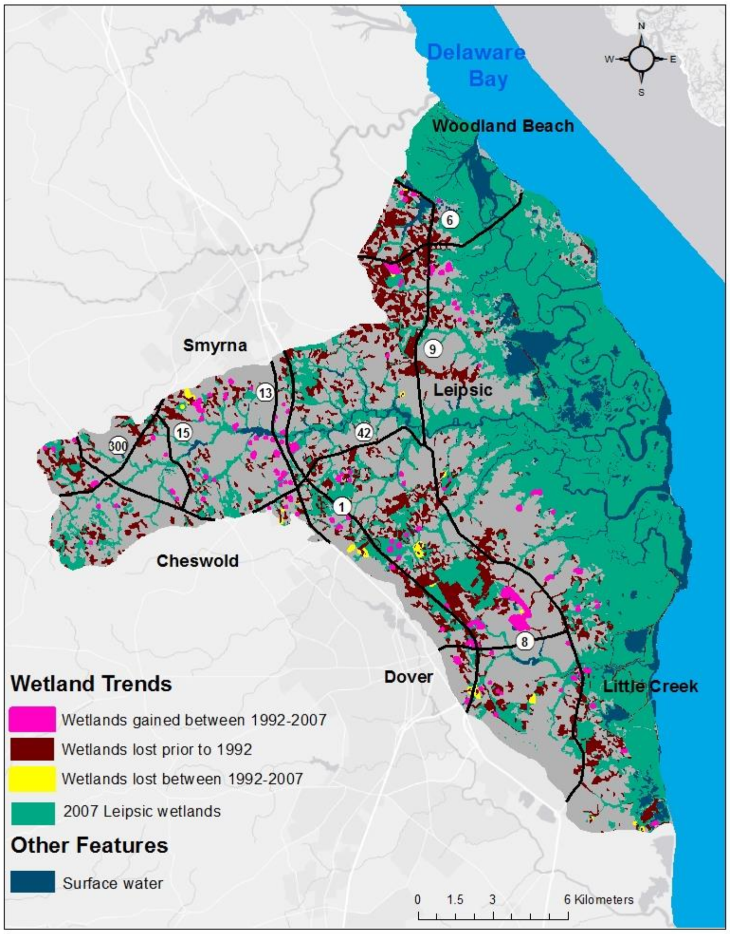
Wetlands covered an estimated 40,470 acres of the Leipsic River watershed prior to human settlement of the area. Approximately 8,493 acres of this historic total were lost prior to 1992, and an additional 60 acres were lost between 1992 and 2007. This means that as of 2007, 21.1% of historic wetland acreage was lost because of human impacts such as residential and commercial development, roads, and agriculture (Map 6).

Table 7. Trends in wetland acreage from 1992 and 2007. Values and categories are based on those in 2007 SWMP spatial datasets. Flat, riverine, and depression wetlands are presented as sub-categories here because they are all palustrine wetlands. Estuarine values are shown in blue, and palustrine values are shown in green.

Wetland type	Gain (acres)	Loss from human impacts (acres)	Change (acres)
Estuarine	3.1	0.0	647.2
Palustrine	25.5	53.2	5.0
Flat	12.9	34.4	0.5
Riverine	3.1	13.4	2.7
Depression	9.5	5.4	1.8

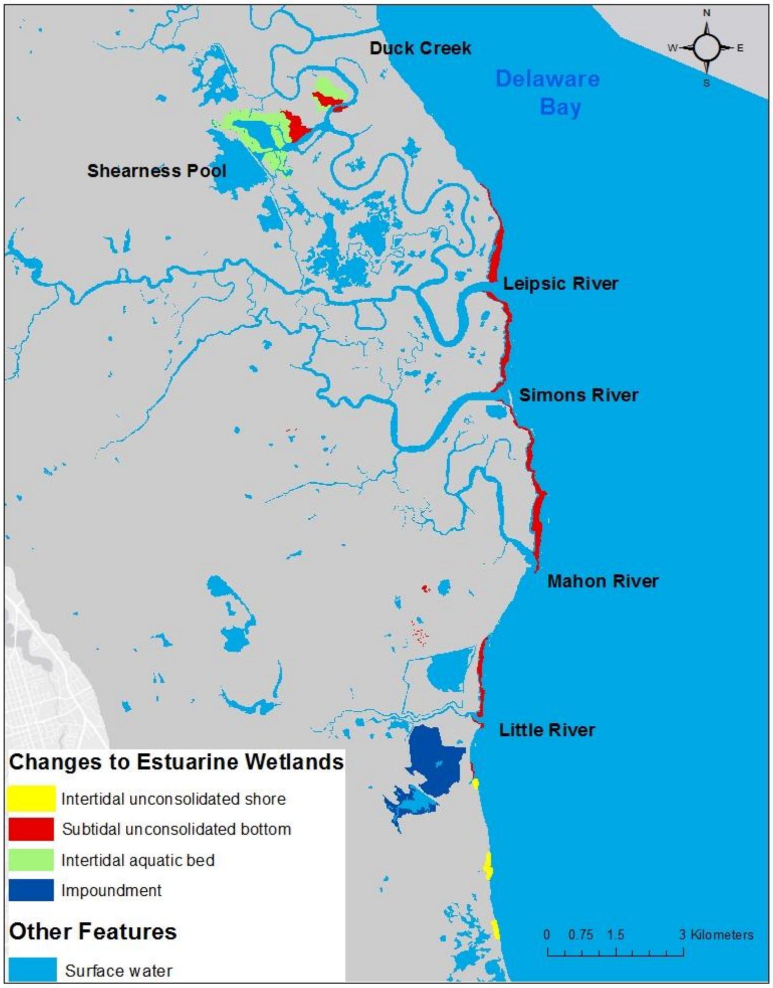
The Leipsic River watershed gained 250.7 acres of wetlands and lost 60.0 acres of wetlands between 1992 and 2007, resulting in a net gain of 190.7 acres of wetlands. However, only 28.6 of the acres that were gained were vegetated wetlands. Most of the gained acreage was attributed to the creation of a borrow pit and many smaller storm water ponds. Most of the wetland acreage that was lost was vegetated palustrine wetlands, while smaller losses were due to the conversion of excavated ponds to developed, agricultural, or barren land. This is very similar to the trend reported statewide, where palustrine forested wetlands across the state of Delaware experienced the greatest losses of all wetland types between 1992 and 2007, and most acreage gain was due to the creation of ponds (Tiner et al. 2011).

Estuarine wetlands in the Leipsic River watershed gained 3.1 acres between 1992 and 2007 from agricultural land. These new estuarine wetlands were all vegetated with intertidal emergent vegetation, were scattered throughout the watershed, and were partially bordered by other estuarine wetlands and by agricultural land. Palustrine wetlands in general gained 25.5 acres between 1992 and 2007. Depression wetlands gained 9.5 acres from agricultural and barren land in scattered, small patches. The new depressions were partially bordered by agricultural fields, small patches of trees, roads, houses, ponds, or other wetlands. Flats gained 12.9 acres from agricultural and barren land in small, scattered patches, and they were near or adjacent to roads, houses, agricultural ponds, agricultural land, thin rows of trees, or forest. Riverine wetlands gained 3.1 acres from agricultural and barren lands, also in small, scattered patches. One new riverine wetland was near Garrisons Lake and was bordered by forest and agricultural land; the other was bordered by flat wetlands. All of these freshwater wetlands that were gained were vegetated either with emergent, scrub-shrub, or forest vegetation.



Map 6. Wetland trends over time in the Leipsic River watershed.

Palustrine wetlands lost 53.2 acres between 1992 and 2007, meaning that palustrine wetlands experienced a net loss of 27.7 acres in this time period. Flat wetlands experienced the greatest impact, as they lost 34.4 acres to development, agriculture, and gravel pits. Flats that were lost were scattered throughout the watershed in small patches, and all flats that were lost were forest or scrub-shrub habitats. Riverine wetlands lost 13.4 acres to development in small patches in the southern portion of the watershed, and these wetlands were all vegetated forest habitats. Depressions lost 5.4 acres to development and agriculture. These wetlands were scattered in small patches throughout the watershed and had all been vegetated emergent or forest habitats. These results align with the statewide report, which identified that agricultural and residential development are the leading causes for loss of vegetated palustrine wetlands (Tiner et al. 2011).



Map 7. Changes that occurred to estuarine wetlands between 1992 and 2007. Only impoundments identified as a 'change' in the SWMP data are highlighted in dark blue.

Although no estuarine wetlands were categorized as 'losses' in the SWMP dataset between 1992 and 2007, 'changes' were identified on approximately 1,032 acres of emergent, vegetated tidal wetlands in this time period (Map 7, Table 8). Wetlands that changed to intertidal unconsolidated shore (7.2 acres) or to subtidal unconsolidated bottom (352.9 acres) were mostly small, thin areas along the shoreline (Map 7, Table 8). Changes from emergent vegetation to subtidal unconsolidated bottom also occurred adjacent to areas that changed to aquatic bed habitat in Bombay Hook NWR. Such changes occurred in smaller areas further south as well in the Little Creek Wildlife Area, largely due to ditch excavation (Map 7). Wetlands that changed to intertidal aquatic bed habitat were concentrated in Bombay Hook NWR, just northeast of the Shearness Pool impoundment near the scenic driving road (Map 7). Two large areas (318.1 acres

Table 8. Types of changes that occurred in vegetated, emergent estuarine wetlands identified by the 2007 SWMP spatial dataset. Ecological impacts of each type of change are summarized.

Change	Acres	Ecological and societal impacts
Intertidal unconsolidated shore	7.2	decreased vegetative cover; increased flooding; decreased habitat for tidal wetland species; decreased coastal protection
Subtidal unconsolidated bottom	352.9	decreased vegetative cover; increased flooding; decreased habitat for tidal wetland species; decreased coastal protection
Intertidal aquatic bed	286.3	shift in vegetative community to submergent or floating plants; increased flooding; decreased habitat for tidal wetland species; decreased coastal protection
Excavated palustrine unconsolidated bottom	0.8	decreased vegetative cover; increased flooding; decreased habitat for tidal wetland species; decreased coastal protection
Impoundment	384.6	managed by DNREC Divison of Fish and Wildlife; change seasonally to create different habitats for migratory shorebirds and waterfowl

and 66.5 acres) within Little Creek Wildlife Area that were identified as changing habitats by the SWMP mapping effort are actually impoundments that are managed by DNREC Division of Fish and Wildlife (Map 7). These areas are constantly changing because they contain water control structures that allow for seasonal control of water levels, causing changes in vegetative cover that create different habitats for migrating shorebirds and waterfowl. Discounting these impoundment areas, changes occurred to 647.2 acres of estuarine wetlands.

Changes to palustrine wetlands were also identified but occurred in much smaller numbers (not shown on map because of small sizes). There were 2.7 acres of riverine wetlands that became a single dammed or impounded agricultural pond near the inland reach of estuarine wetlands in the south-central portion of the watershed. There were also 1.8 acres of depressions that became either dammed or impounded agricultural ponds or excavated residential ponds in 2 small, scattered patches, and 0.5 acres of flats that became either excavated residential ponds or excavated agricultural ponds in 2 small, scattered patches.

Implications of acreage trends

Although the Leipsic River watershed experienced a net gain of 190.7 acres of wetlands between 1992 and 2007, looking at this number alone may be misleading. As mentioned above, most of the acreage gains were due to creation of a borrow pit and many smaller storm water ponds. These ponds can be beneficial to some generalist species by providing habitat in upland areas (Brand and Snodgrass 2009; Tiner et al. 2011). However, although these water bodies are technically considered wetlands, they do not provide the same functional value as natural wetlands. In fact, they may provide lower levels of certain functions, such as nutrient transformation, wildlife habitat, carbon sequestration, and sediment retention (Tiner 2003; Brand et al. 2010; Tiner et al. 2011). Thus, although there was an acreage increase, gains in ecosystem services were much smaller than if acreage increases were attributable to gains in natural, vegetated wetlands. Palustrine wetlands that changed from natural wetlands to agricultural or residential ponds likely experienced a relative decrease in ecosystem function for the same reason.

Many of the estuarine or palustrine wetlands that were gained were adjacent to or near agricultural fields, houses, and roads, which have the potential to negatively affect these wetlands and the wildlife that rely on them through pollution runoff or reduced wetland habitat connectivity (Faulkner 2004; Brand et al. 2010). Those that are partially or completely bordered by trees or other wetlands may not suffer these adverse secondary effects. All of the gained estuarine and palustrine wetlands were vegetated, which may increase their chances of providing moderate to high function levels in services such as nutrient transformation, retention of sediments and pollutants, shoreline stabilization, conservation of biodiversity, climate mitigation, and provision of wildlife habitat (Tiner 2003; Howard et al. 2017). However, all palustrine losses were vegetated wetlands, so functions that vegetated wetlands can provide were lost in these areas. No estuarine wetlands were categorized as 'losses', showing that no coastal development occurred in tidal wetlands between 1992 and 2007. This suggests that tidal wetland regulatory protection from direct human impacts by the State of Delaware has been effective in this watershed.

Hundreds of acres of estuarine wetlands that began with emergent, persistent vegetation experienced changes from 1992 to 2007 (Map 7, Table 8). Emergent estuarine wetlands are defined as areas that have 30% or more aerial coverage of emergent plants, such as saltmarsh cordgrass (*Spartina alterniflora*) and saltmeadow cordgrass (*Spartina patens*; Federal Geographic Data Committee 2013). Several hundred acres of these estuarine emergent wetlands became aquatic bed habitat (286.3 acres), which is defined as having submergent plants or plants that float on the surface of the water covering 30% or more of the area (Federal Geographic Data Committee 2013). Aquatic beds are often composed of algal beds or submerged aquatic vegetation such as eelgrass (*Zostera marina*) or widgeon grass (*Ruppia maritima*). Several hundred more acres of estuarine emergent wetlands became either intertidal unconsolidated shore (7.2 acres) or subtidal unconsolidated bottom (352.9 acres; Table 8). Unconsolidated bottom includes areas that have less than 30% areal vegetative cover and at least 25% aerial cover of sediment particles that are smaller than stones, and unconsolidated shore includes areas that have less than 30% aerial vegetative cover except pioneer plants and less than 75% aerial sediment cover of boulders, stones, or bedrock (Federal Geographic Data Committee 2013).

Although categorized as ‘changes’ by the 2007 SWMP spatial dataset, these changes are essentially losses of vegetated tidal wetlands that will likely have negative impacts both for ecosystems and for society (Table 8). These changes reflect an increase in the amount of flooding and either a shift in the vegetative community (aquatic beds) or a decrease in vegetative cover (unconsolidated bottom and shore). Loss of emergent vegetation means that these areas will be much less effective at protecting coastal communities and infrastructure, because tidal wetland vegetation helps to dissipate wave energy (Möller et al. 2014). Additionally, it signifies a decrease in available habitat for tidal marsh obligate species, such as saltmeadow cordgrass, northern sea lavender (*Limonium nashii*), saltmarsh sparrows, and clapper rails. Changes likely also affects carbon sequestration capabilities of these areas, because vegetation in tidal wetlands stores carbon in biomass, and their roots help trap sediments that become part of the carbon-rich soil (Howard et al. 2017).

It is evident that conversion to intertidal unconsolidated shore and a large proportion of the conversion to subtidal unconsolidated bottom occurred on the shoreline adjacent to the Delaware Bay (Map 7), suggesting that erosion and sea level rise caused the loss of hundreds of acres of emergent vegetated wetlands. This is not surprising, 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).

Landowner Contact and Site Access

A total of 128 wetland sites were sampled in the Leipsic River watershed. Of those sites, 53.1% were privately-owned, and 46.9% were publicly-owned (Table 9). These within-watershed ownership percentages were not reflective of what is seen across the entire state; statewide, about 80% of Delaware's wetlands are privately owned, and about 20% are public lands. Thirty-three estuarine wetland sites were considered to achieve a sample of 30 estuarine sites; 3 sites were dropped and not sampled because we were denied permission to access the land, the site was inaccessible, or the landowner's contact information was unavailable (Figure 7). Of the 30 sites sampled, 7 were privately-owned (23.3%) and 23 were publicly-owned (76.7%; Table 9).

Table 9. Ownership of wetland sample sites. Percentages are based only on sites that were actually sampled (i.e., only sites that we visited and collected data from).

HGM type	Public (%)	Private (%)
All combined	46.9	53.1
Estuarine	76.7	23.3
Depression	51.3	48.7
Flat	51.7	48.3
Riverine	10.0	90.0

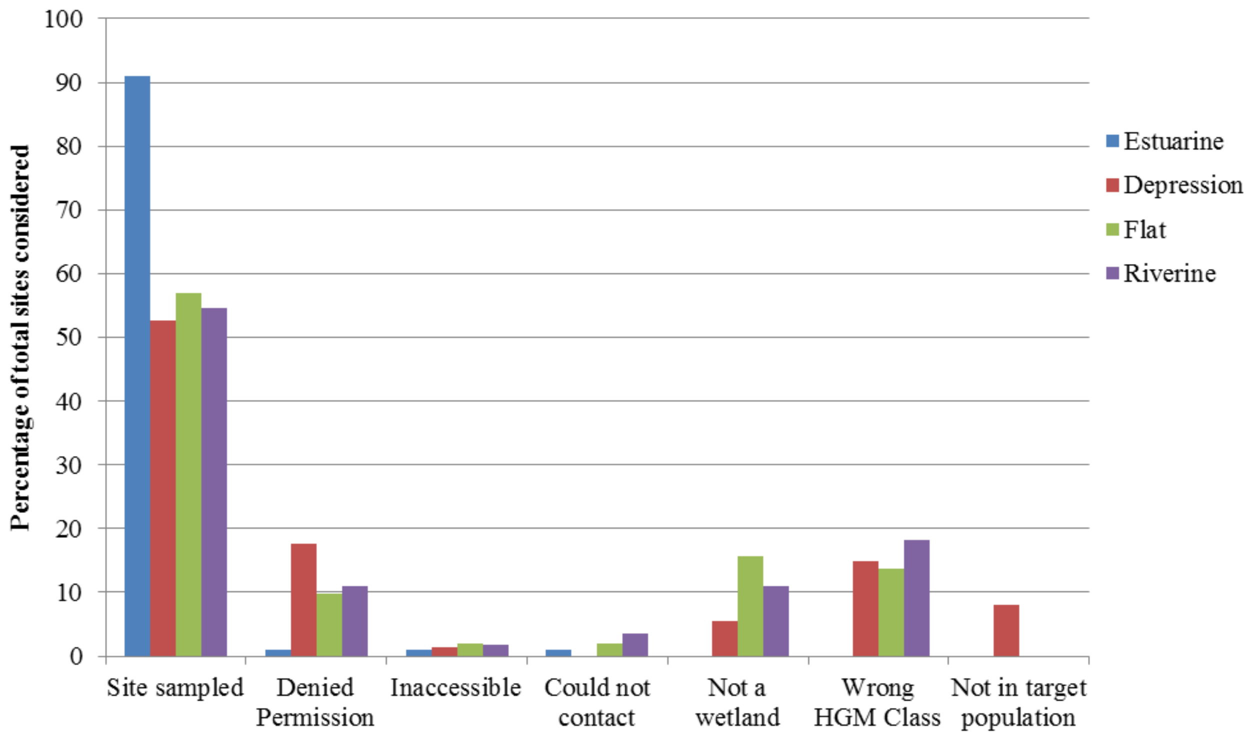


Figure 7. Sampling success for all 4 HGM wetland classes. Shown are percentages of the total number of sites considered, i.e. the total number of sites that we attempted to sample for each HGM class.

Seventy-four depression sites were considered to achieve a sample size of 39; 35 depression sites were dropped because we were denied permission, the site was not a wetland, the site was the wrong HGM class, or the site was a created wetland and was therefore not part of the target population (Figure 7). Of the 39 depression sites sampled, 19 were on private land (48.7%) and 20 were on public land (51.3%; Table 9). Twenty-nine flat wetland sites were sampled out of 51 total flat sites considered; 22 sites were dropped because we were denied permission, the site was not a wetland, we could not access the site, we could not contact the landowner, or the site was the wrong HGM type (Figure 7). Of the 29 flat sites, 15 were on public land (51.7%) and 14 were on private land (48.3%; Table 9). Fifty-five riverine wetland sites were considered to yield 30 sample sites; 25 sites were dropped because we were denied permission to access the site, the site was not a wetland, the site was the wrong HGM type, we could not access the site, or we could not contact the landowner (Figure 7). Out of the 30 riverine sites sampled, 27 were privately-owned (90.0%) and 3 were publicly-owned (10.0%; Table 9).

Wetland Condition

Tidal estuarine wetlands

Tidal estuarine wetlands in the Leipsic River watershed (n=30) that were sampled had final MidTRAM scores ranging from 46.6 to 91.1, with a median score of 84.4 (the median was a better descriptor of the central tendency of the data, as the overall dataset was not normally distributed; Shapiro-Wilk normality test: W=0.86, p<0.001; Table 10). The majority of tidal wetlands were minimally stressed (60.0%; Figure 8) and had intact hydrology, wide buffers with minimal disturbance and few barriers to landward migration, low invasive plant cover, and a fairly high number of plant layers. In contrast, only a small portion of tidal wetlands were severely stressed (6.7%; Figure 8). Severely stressed wetlands were characterized by buffers that were highly disturbed and had adjacent development and barriers to landward migration. Severely stressed wetlands also had habitat stressors such as high invasive plant cover and low marsh platform stability (i.e., poor bearing capacity).

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

Attribute	Mean±SD	Median	Range
Overall	80.0 ± 11.1	84.4	46.6-91.1
Buffer	79.8 ± 19.1	86.7	26.7-100
Hydrology	91.7 ± 12.4	100	66.7-100
Habitat	68.7 ± 9.5	70	46.7-86.7

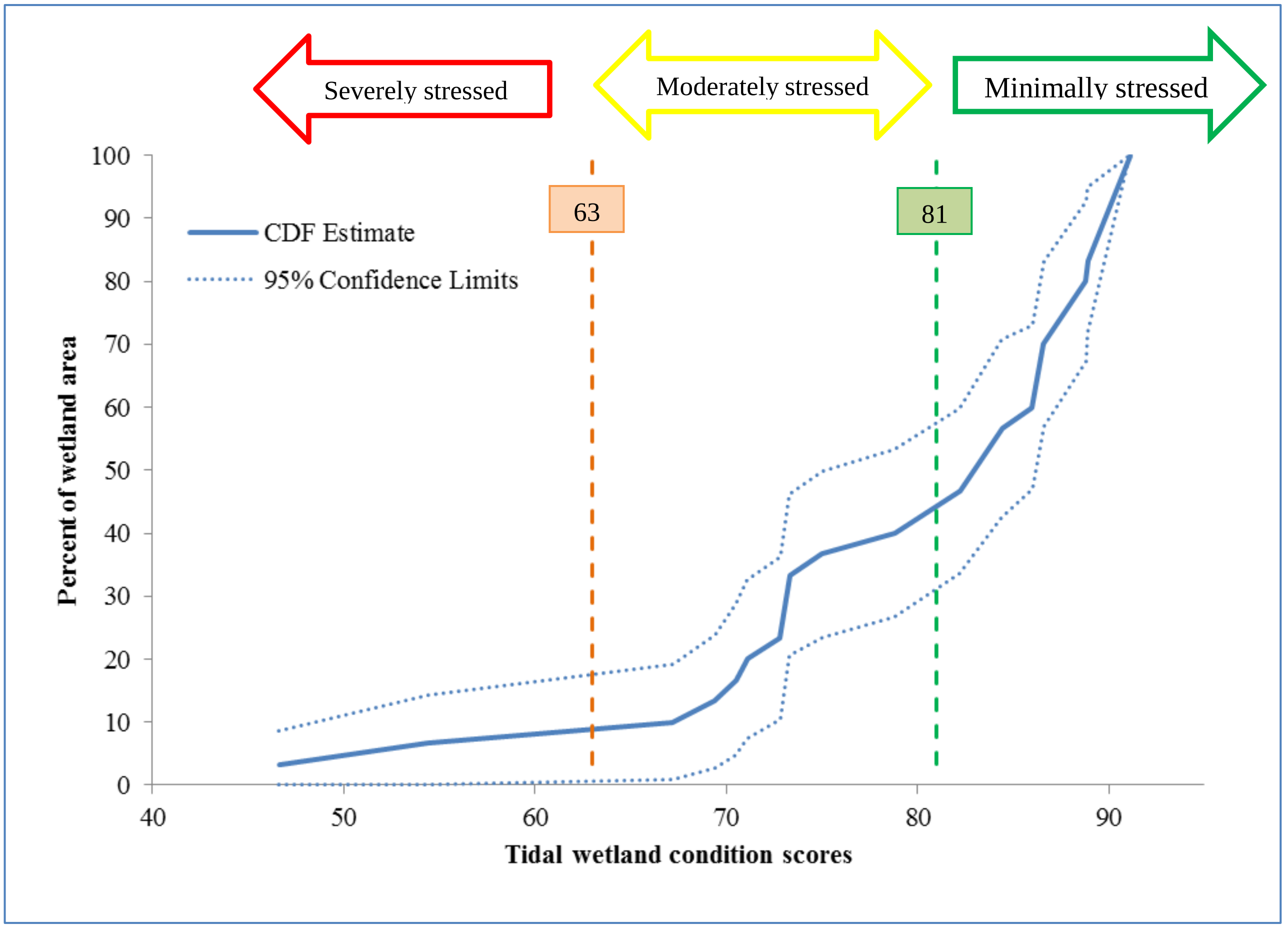


Figure 8. Cumulative distribution function (CDF) for tidal estuarine wetlands in the Leipsic River watershed. The blue line is the population estimate and the dashed blue lines are 95% confidence intervals. The orange and green dashed lines show the breakpoints between condition categories.

Buffer attribute scores from sampled wetlands ranged widely from 26.7 to 100, with a median score of 86.7 (Table 10). This attribute showed the largest range of all 3 attribute categories. Tidal wetlands that were minimally stressed had wide buffers with few disturbances. Severely stressed tidal wetlands had narrow buffers comparatively, but were wide enough to score highly on buffer width metrics. However, surrounding landscape condition was poor, containing significant human disturbance, development, and barriers to landward migration.

Hydrology attribute scores from sampled wetlands ranged from 66.7 to 100, with a median score of 100.0 (Table 10). Tidal wetlands scored the best on average in the hydrology attribute category compared with the buffer and habitat categories. Minimally stressed tidal wetlands had very little draining and ditching, no fill, no diking or tidal restriction, and no point sources of pollution. Severely stressed wetlands surprisingly had no ditching and draining and had fairly low levels of diking, tidal restriction, and point source pollution, but they did have some impacts from fill. The low level of ditching in tidal wetlands is unusual in Delaware, and contributed largely to the relatively intact hydrology of tidal wetlands in this watershed.

Table 11. Common stressors in tidal, estuarine wetlands in the Leipsic 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=18)	% Moderately stressed (n=10)	% Severely stressed (n=2)
Barriers to landward migration	23.3	5.6	40.0	100.0
Development in surrounding landscape	26.7	11.1	40.0	100.0
Disturbance in surrounding landscape condition	93.3	88.9	100.0	100.0
Fill	13.3	0.0	30.0	50.0
Ditching/draining	26.7	11.1	60.0	0.0
Declining marsh stability	96.7	94.4	100.0	100.0
Invasive species present	60.0	44.4	80.0	100.0

Habitat attribute scores from sampled wetlands ranged from 46.7 to 86.7, with a median score of 70.0 (Table 10). This was the lowest on average of the three attribute categories for tidal wetlands. Wetlands that were minimally stressed had low invasive plant occurrence, high diversity of plant layers, and thick horizontal vegetative obstruction. However, these wetlands scored more poorly for bearing capacity compared with the other habitat metrics, though still better than moderately and severely stressed wetlands. Severely stressed wetlands, surprisingly, had thick vegetation cover and high diversity of plant layers, but had higher levels of invasive plant cover and scored more poorly for bearing capacity. The overall poor bearing capacity suggests that the marsh platform, even in minimally stressed wetlands, is not as stable as it could be (Figure 9). This could indicate that these tidal wetlands have low levels of below-ground biomass, because poor bearing capacity is often associated with low below-ground biomass (Twohig and Stolt 2011). 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); thus, although wetlands scored relatively well on metrics related to above-ground biomass (i.e., horizontal vegetative obstruction and number of plant layers), the fact that they scored relatively low on bearing capacity may indicate that many tidal wetlands are in the process of deteriorating to some extent. Common invasive plant species found in tidal wetlands in the watershed included the common reed (*Phragmites australis*) and the narrowleaf cattail (*Typha angustifolia*).

Figure 9. DNREC scientists measure bearing capacity, an indicator of marsh stability, in a tidal marsh using a slide hammer during a site assessment.

Table 11 highlights 2 or 3 stressors from each attribute category that were affecting tidal wetlands: barriers to landward migration, development, and landscape condition from the buffer category; fill and ditching/draining from the hydrology category; and bearing capacity and invasive plant cover from the habitat category. Note that in the case of ditching and draining, moderately stressed wetlands actually scored lower than severely stressed wetlands on average. For all other stressors listed, scores decline moving from minimally stressed to severely stressed. Raw data values and metric scores for all sampled tidal wetland sites can be found in Appendix D.

Non-tidal riverine wetlands

Riverine wetlands in the Leipsic River watershed that were sampled (n=30) had final DERAP scores that ranged widely from 2 to 90, with a median score of 72.0 (the median was a better reflection of the central tendency of the dataset, as the data were not normally distributed; Shapiro-Wilk normality test: W=0.82, p<0.001). Most riverine wetlands were moderately stressed (66.7%), followed by minimally stressed (23.3%) and severely stressed (10.0%; Figure 10). Table 12 highlights the most common stressors seen in riverine wetlands for each category: invasive species presence from the habitat category; stream alteration and fill or excavation from the hydrology category; and row crops/nursery plants/orchards in the surrounding landscape,

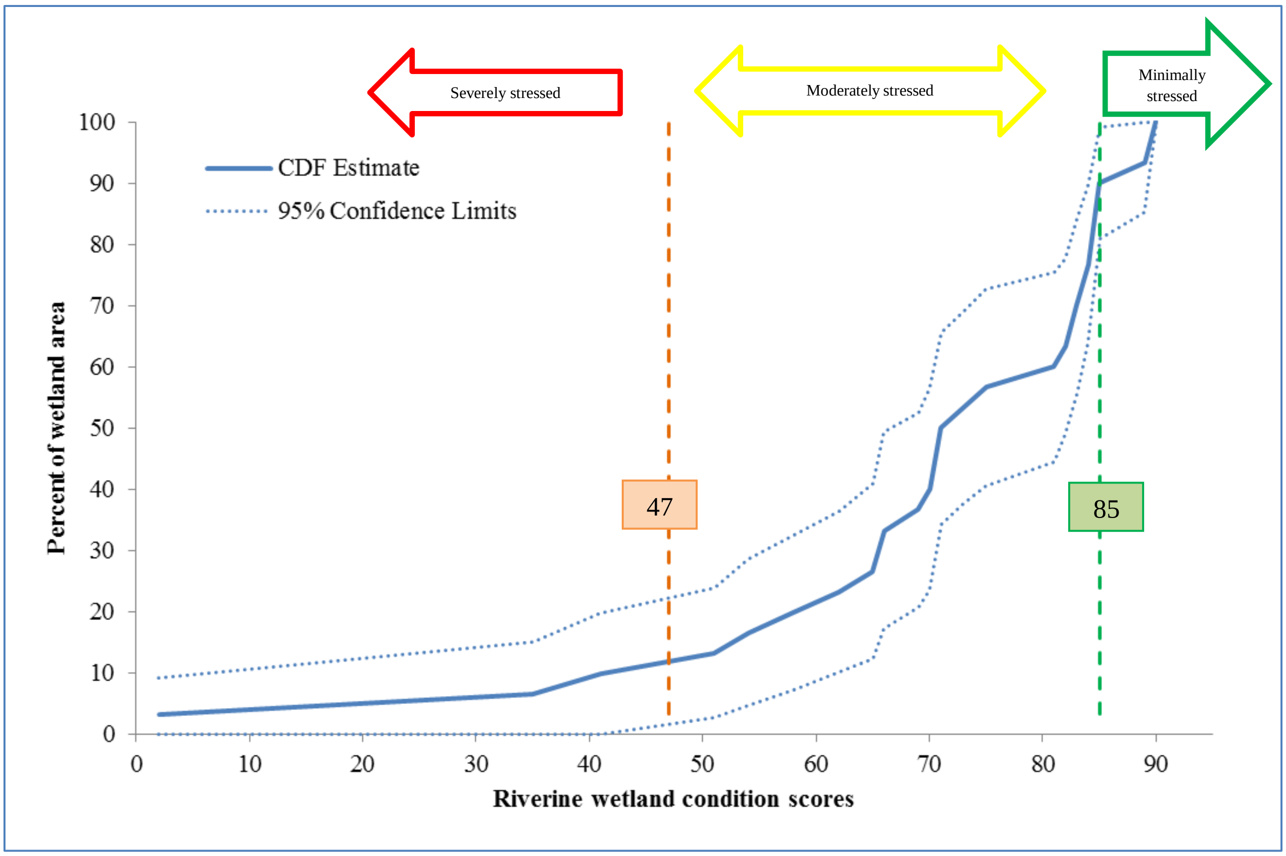


Figure 10. Cumulative distribution function (CDF) for non-tidal riverine wetlands in the Leipsic River watershed. The blue line is the population estimate and the dashed blue lines are 95% confidence intervals. The orange and green dashed lines show the breakpoints between condition categories.

channelized streams/ditches in the buffer, and development in the surrounding landscape from the buffer category. In most cases, the occurrence of major stressors increased moving from minimally stressed to severely stressed. Data for all sampled riverine wetlands for all assessed metrics can be viewed in Appendix G.

Figure 11. Ditching and stream channelization were common stressors found in riverine wetland buffer regions in this watershed.

One of the most pervasive stressors in riverine wetlands was the presence of invasive plant species, where even 71.4% of minimally stressed wetlands had invasive species present (Table 12). This is concerning because invasive species are often able to spread quickly, displacing native species in the process. Some of the invasive species that were present were Japanese stiltgrass (*Microstegium vimineum*), Japanese honeysuckle (*Lonicera japonica*), common reed (*Phragmites australis*), privet (*Ligustrum spp.*), multiflora rose (*Rosa multiflora*), Japanese knotweed (*Polygonum cuspidatum*), Japanese barberry (*Berberis thunbergii*), and stinging nettle (*Urtica dioica subsp. dioica*).

Stream alteration and fill were major hydrological issues in riverine wetlands. Spoil banks on the sides of streams that are created from stream alteration activities can prevent water from flowing over stream banks during rain and storm events. This disconnects the waterway from adjacent wetlands, in effect disrupting wetland hydrology. Fill and excavation can similarly alter wetland hydrology. When hydrology is disturbed in riverine wetlands, plant communities may change and diversity may decrease, which may further increase the prevalence of invasive

Table 12. Common stressors in non-tidal, riverine wetlands in the Leipsic 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=7)	% Moderately stressed (n=20)	% Severely stressed (n=3)
Invasive species present	86.7	71.4	90.0	100.0
Stream alteration	36.7	0.0	40.0	100.0
Fill or excavation	36.7	14.3	35.0	100.0
Row crops/nursery plants/orchards in surrounding landscape	70.0	100.0	65.0	33.3
Channelized streams/ditches in buffer	50.0	0.0	60.0	100.0
Development in surrounding landscape	40.0	0.0	50.0	66.7

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 (Figure 11).

Development and row crops, nursery planting, and orchard activities occurred in landscapes surrounding many riverine wetlands (Table 12), which can lead to many indirect wetland impacts by degrading wetland buffers. Runoff polluted with chemicals and excess nutrients from roads, fields, or lawns can enter wetlands from these nearby areas, which indeed occurred in the Leipsic River watershed, as storm water inputs and point sources were identified as a stressor to riverine wetlands (not shown in Table 12). Development, row crop, nursery, and orchard activities also have the potential to introduce more invasive species into adjacent wetlands. The occurrence of these unnatural land uses surrounding riverine wetlands indicates that buffer zones around these wetlands are degraded. Buffers are natural areas adjacent to wetlands that can provide wildlife habitat and process pollutants from nearby upland areas, often by separating wetlands from human activity. If anthropogenic activities are occurring in the area surrounding the wetland, the area adjacent to the wetland can no longer function as a beneficial buffer.

Non-tidal flat wetlands

Flat wetlands in the Leipsic River watershed that were sampled (n=29) had final DERAP scores that ranged from 32 to 95, with a median score of 70.0 (the median was a better reflection of the central tendency of the dataset, as the data were skewed and nearly non-normal; Shapiro-Wilk normality test: W=0.93, p=0.05). Most flats were moderately stressed (55.2%), followed by severely stressed (31.0%), and minimally stressed (13.8%; Figure 12). The most common stressors seen in flat wetlands for each category were presence of invasive plant species and clear or selective cutting forestry practices for the habitat category; fill or excavation and ditching for the hydrology category; and channelized streams or ditches and development for the buffer category (Table 13). In most cases, stressor prevalence increased moving from minimally stressed to severely stressed (Table 13). Data for all sampled flat wetlands for all assessed metrics can be viewed in Appendix F.

Similar to what was observed in riverine wetlands, the presence of invasive plant species was the most common stressor in flat wetlands. Invasive species were present in three-quarters of sampled wetlands (Table 13). Invasive species detected in flat wetlands included honeysuckle, reed canary grass (*Phalaris arundinacea*), common reed, Japanese stilt grass, multiflora rose, and barnyard grass (*Echinochloa crus-galli*). Many wetlands also experienced impacts from clear or selective cutting (Figure 13). These practices can lead to problems such as soil nutrient loss and acidification of nearby stream water (Dahlgren and Driscoll 1994) and altered faunal communities (Summerville and Crist 2002). Although tree harvesting is renewable, the impacts to the plant communities and site hydrology can be long-lasting.

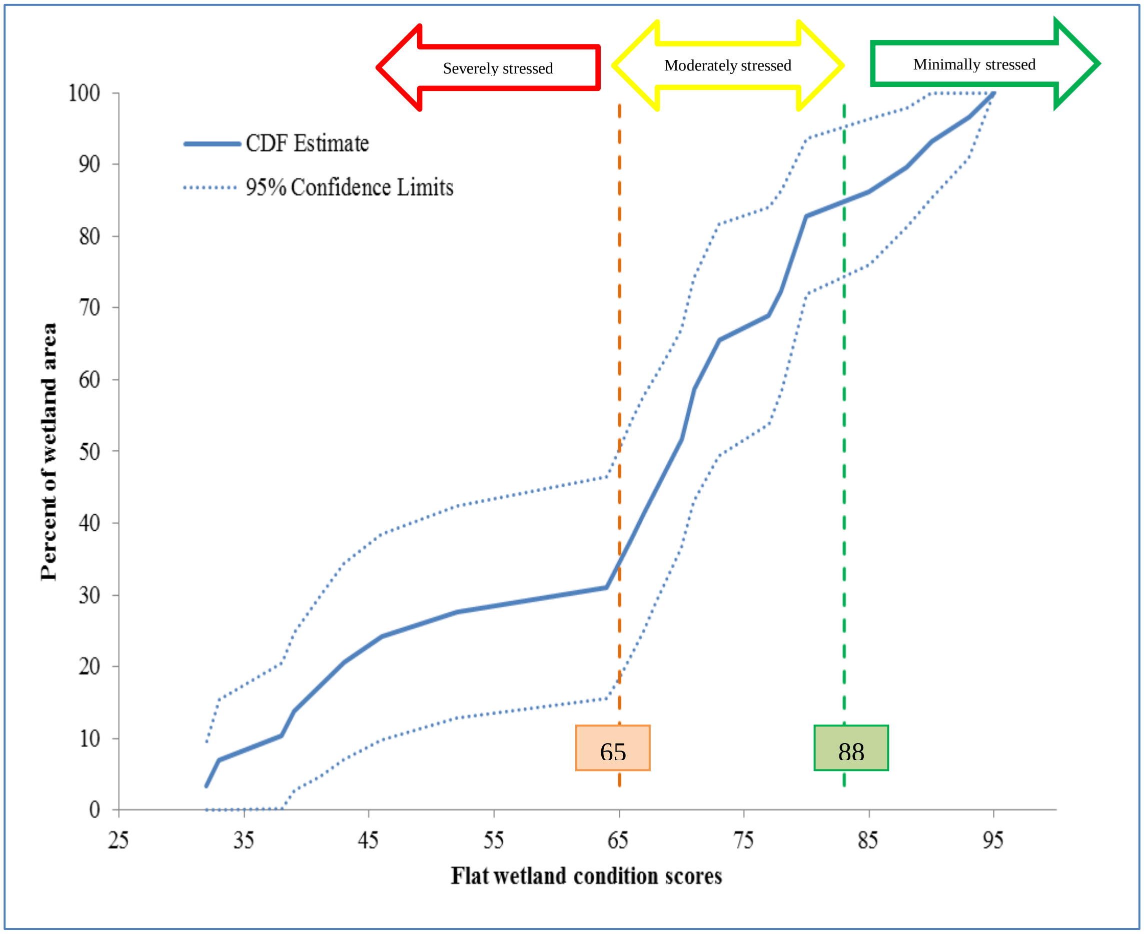


Figure 12. Cumulative distribution function (CDF) for non-tidal flat wetlands in the Leipsic River watershed. The blue line is the population estimate and the dashed blue lines are 95% confidence intervals. The orange and green dashed lines show the breakpoints between condition categories.

Table 13. Common stressors in non-tidal, flat wetlands in the Leipsic 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=29)	% Minimally stressed (n=4)	% Moderately stressed (n=16)	% Severely stressed (n=9)
Invasive species present	75.9	75.0	68.8	88.9
Clear or selective cutting	44.8	0.0	31.3	88.9
Fill or excavation	65.5	0.0	62.5	100.0
Ditching	51.7	0.0	43.8	77.8
Channelized streams or ditches in buffer	44.8	0.0	43.8	66.7
Development in surrounding landscape	37.9	0.0	31.3	66.7

Flat wetlands experienced hydrological stress from filling or excavation and ditching within assessment areas, and channelization of streams and ditches within buffers.
When hydrology is disturbed, soil moisture and groundwater levels may be reduced (Faulkner 2004). Such disturbance has the potential to affect flat wetland plant communities, which are adapted to live in certain hydrologic conditions.

Figure 13. Clear or selective cutting, as evidenced by downed, clean-cut trees and skidder tracks, were common stressors in flat wetlands of this watershed.

The landscape surrounding many flat wetlands was developed, which, as previously discussed, can introduce polluted runoff into wetlands. It indicates that the buffer area is degraded, because if anthropogenic development is occurring in the areas surrounding wetlands, the areas adjacent to wetlands can no longer function as a beneficial buffer.

Non-tidal depression wetlands

Depression wetlands in the Leipsic River watershed that were sampled (n=39) had final DERAP scores that ranged from -1 to 80, with a median score of 55.0 (the median was a better reflection of the central tendency of the dataset, as the data were not normally distributed; Shapiro-Wilk normality test: W=0.93, p=0.01). Most depression wetlands were either severely stressed (46.2%) or moderately stressed (46.2%), and relatively few were minimally stressed (7.7%; Figure 14).

The most common stressors found in depression wetlands were nutrient-dense algal mats or nutrient indicator plant species (Figure 15), invasive plant species (Figure 16), and young forest age (less than 50 years) for the habitat category; microtopographic alterations and ditching for the hydrology category; and roads and/or development for the buffer category (Table 14). Data for all sampled depression wetlands for all assessed metrics can be viewed in Appendix E.

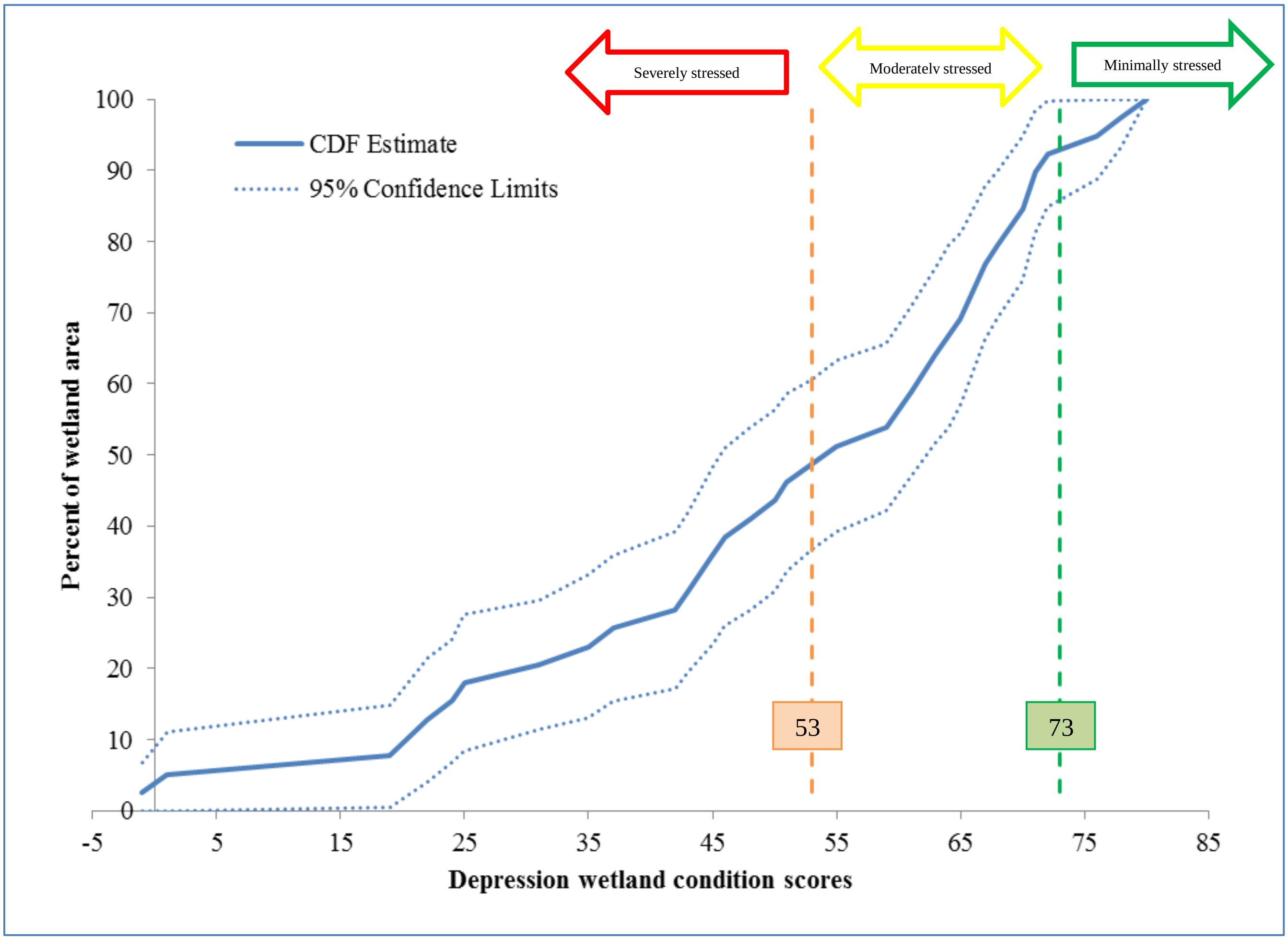


Figure 14. Cumulative distribution function (CDF) for non-tidal depression wetlands in the Leipsic River watershed. The blue line is the population estimate and the dashed blue lines are 95% confidence intervals. The orange and green dashed lines show the breakpoints between condition categories.

Table 14. Common stressors in non-tidal, depression wetlands in the Leipsic 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=39)	% Minimally stressed (n=3)	% Moderately stressed (n=18)	% Severely stressed (n=18)
Invasive species present	76.9	0.0	66.7	100.0
Young forest age	74.4	33.3	66.7	88.9
Nutrient dense algal mats/nutrient indicator plants	56.4	0.0	55.6	66.7
Microtopographic alterations	56.4	33.3	44.4	72.2
Ditching	33.3	0.0	5.6	66.7
Roads and/or development in surrounding landscape	61.5	0.0	61.1	72.2

As observed in other palustrine wetlands, the most pervasive stressor in depression wetlands was the presence of invasive plant species (Table 14). Invasive species documented in depression wetlands include burdock species (*Arctium spp.*), barnyard grass, Japanese honeysuckle, common reed, reed canary grass, narrow-leaf cattail, wineberry (*Rubus phoenicolasius*), multiflora rose, purple loosestrife (*Lythrum salicaria*), Japanese stilt grass, and giant foxtail (*Setaria faberi*). Many of these invasives were also part of another common stressor, nutrient indicator species (Table 14), including narrow-leaf cattail, common reed, reed canary grass, Japanese stilt grass, barnyard grass, and burdock species. Other nutrient indicator species found were seedboxes (*Ludwigia spp.*), knotweeds (*Polygonum spp.*), smooth rush (*Juncus effusus*), broadleaf cattail (*Typha latifolia*), river birch (*Betula nigra*), and black willow (*Salix nigra*). Nutrient indicator species signify sustained nutrient enrichment of an area, such as from runoff from agricultural fields and developments. This nutrient enrichment often contributes to reduced plant diversity and loss of rare and unique plant species (Bedford et al. 1999). Young forest age was another common habitat stressor (Table 14). This can be a problem because invasive species tend to occur in greater densities in younger forests compared with more mature forests (Flory and Clay 2006).

Figure 15. An algal mat in a depression wetland in the Leipsic River watershed.

Figure 16. Japanese stiltgrass was a common invasive species in non-tidal wetlands in the Leipsic River watershed.

Microtopographic alterations, such as those from skidder tracks and tire ruts, were a common hydrologic stressor in depression wetlands (Table 14). Natural microtopography, including natural heterogeneity in the soil surface such as hummocks and hollows, is usually associated with greater species diversity and species abundance in freshwater wetlands (Vivian-Smith 1997). When microtopography is altered, that means the natural soil surface has been changed, and so the manner in which water will flow or pool over the land in the wetland will also change. This could have negative implications for species that rely on natural microtopography in the wetland, particularly if the overall amount of microtopography is diminished. Ditching was also a common hydrologic stressor (Table 14), which can reduce soil moisture and groundwater levels (Faulkner 2004).

Roads and development were common in the landscape surrounding depression wetlands. Roads are a source of runoff that can transport water polluted with chemicals and nutrients from developments and roads to nearby ecosystems, including wetlands. When roads and developments are present in the area adjacent to wetlands, there is less functional buffer habitat adjacent to the wetland to help filter these pollutants before they reach wetlands. Roads and development also fragment habitat, which may disrupt hydrology and allow invasive species to intrude.

Overall Condition and Watershed Comparison

We compared overall wetland condition in the Leipsic River watershed to 6 other previously assessed watersheds. To do this, we combined condition proportions (minimally stressed, moderately stressed, and severely stressed) for all major wetland types (estuarine, flat, riverine, and depression) weighted by the acreage of each type in each watershed (Figure 17).

Most wetlands in the Leipsic river watershed were minimally stressed (48%), followed by moderately stressed (40%) and severely stressed (12%). This wetland health breakdown was very similar to that of the St. Jones and Murderkill watersheds (Figure 17). Compared with other Delaware watersheds, the Leipsic River watershed was doing fairly well, with a relatively high percentage of wetlands being minimally stressed. Minimally stressed wetlands can be the focus of protection efforts because they are already functioning at a high capacity. Thus, there is a strong need for preservation in the Leipsic River watershed to keep these minimally stressed wetlands intact and functional. There was also a high proportion of moderately stressed wetlands in this watershed. Moderately stressed wetlands can be the focus of attainable restoration efforts because although they are not currently functioning at their full potential, targeted restoration efforts may restore this functionality. It is easier to improve wetland condition when wetlands are moderately stressed compared with when they are severely stressed because there are fewer stressors to consider in restoration planning. It is therefore essential to focus restoration efforts on moderately stressed wetlands as soon as possible before they degrade further.

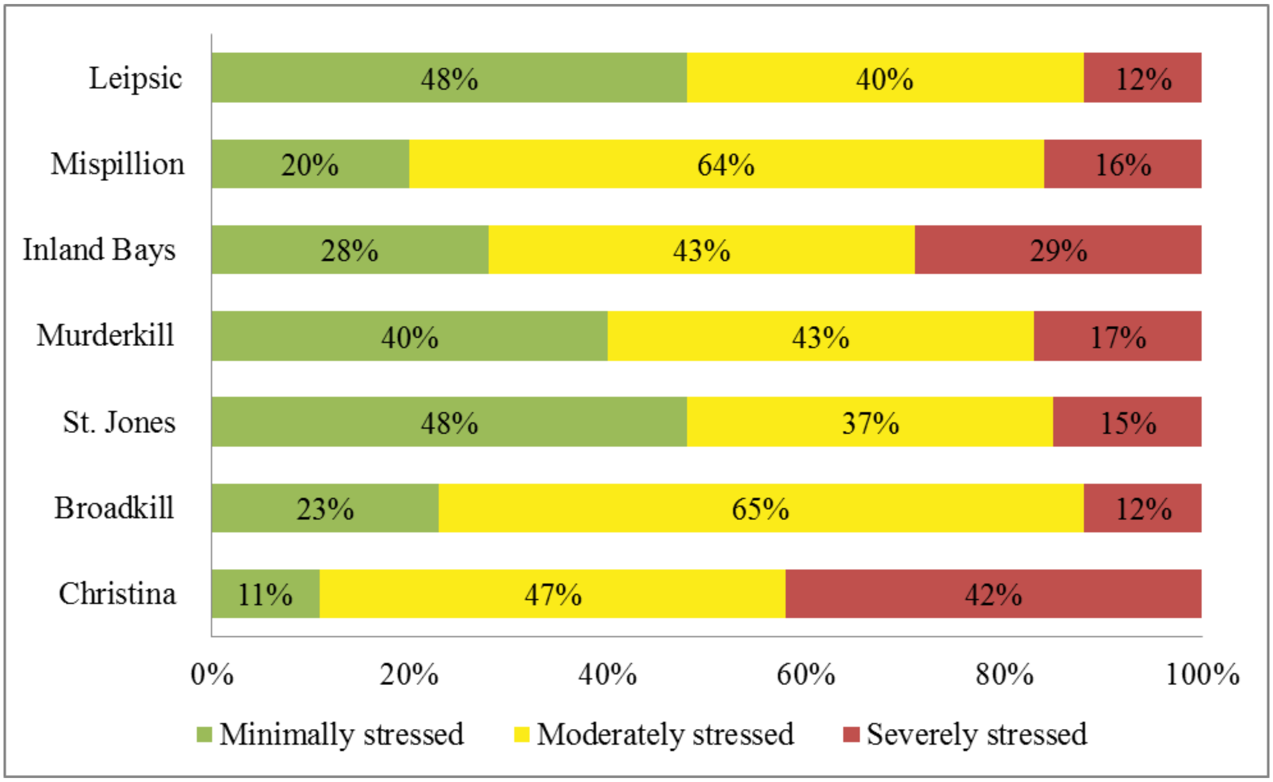


Figure 17. Comparison of overall condition categories for assessed watersheds throughout Delaware. Overall percentages shown are based on combined condition category percentages for all wetland types (estuarine, riverine, flat, and depression) that are weighted based on wetland type acreage for each watershed.

Value Added

Most sampled non-tidal wetlands were moderate in terms of value added (46.8%), followed by limited (38.7%), and then rich (14.5%; Figure 18). Final value added pilot scores for 62 non-tidal sites (19 riverine sites, 14 flat, 29 depression) ranged from 18 to 63 on a scale from 0 to 100, with an average score of 35.1 ± 10.7 (moderate value added; Table 15).

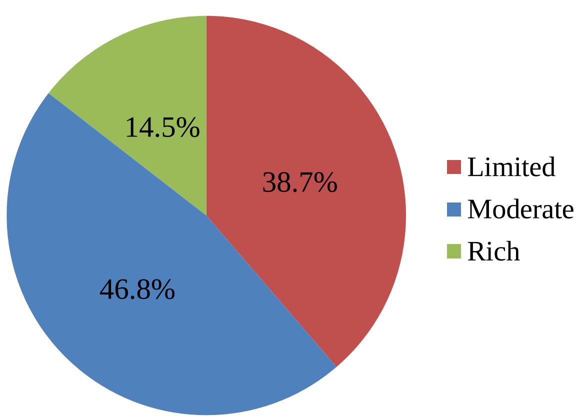


Figure 18. Percentage of sampled non-tidal, palustrine wetlands that scored in each of the three value added categories (n=62 sites).

Non-tidal wetlands in this watershed provided the most value in habitat structure and complexity. Specifically, they provided microtopographic relief, surface water for amphibians and macroinvertebrates, coarse woody debris, large downed wood, and herbaceous, shrub, and tree plant layers (Table 15). Such complexity in wetland habitat can be important for species abundance and diversity, flood control benefits, and storage of water (Rogerson and Jennette 2014). Non-tidal wetlands also provided value in terms of habitat availability; on average, 66.8% ± 24.6% of the buffer area around wetlands was unfragmented (Table 15), providing contiguous wildlife habitat and allowing for wildlife dispersal. Riverine wetlands provided additional value in terms of flood storage and water quality (Table 15); these wetlands were adjacent to surface waters and had high potential for surface water detention, and moderate or high potential for sediment detention attributes.

On average, non-tidal wetlands in the Leipsic watershed provided some value in wetland size, which is related to a wetlands' ability to store water and provide habitat. However, wetland size was highly variable, indicating that some wetlands were fairly large and some were small (Table 15). Non-tidal wetlands were also somewhat valuable as part of the Delaware Ecological Network (DEN) Classification, where many assessment areas were located either partially or entirely within core areas. Core areas are important because they are designated as large tracts of high-quality areas for plants and wildlife. These scores, however, were highly variable, indicating that wetlands did not consistently score high for this metric (Table 15).

Table 15. Mean scores for each value added metric and their implications to the local area. Mean raw data values are only shown for two metrics because metric scores were based on raw numerical values for only those two metrics. The mean overall final score is also shown. See protocol for scoring details (Rogerson and Jennette 2014).

Metric	Max. possible category score	Mean score ± S.D.	Mean raw data value ± S.D.	Value implications
Uniqueness/Local significance	30	2.3 ± 5.1	--	low value; very few non-tidal wetlands considered ecologically unique, locally rare, or restored/enhanced/established
Wetland size	10	5.1 ± 2.6	86.7ha ± 86.8ha	some value, but highly variable; size important for the degree to which wetlands can store water and provide habitat
Habitat availability	10	5.8 ± 2.3	66.8% ± 24.6%	relatively high value; many wetlands had ≥60% to <80% of buffer as natural and unfragmented
DEN Classification	14	4.9 ± 4.1	--	some value, but highly variable; AA's often located partially or entirely in core areas (i.e., designated areas that are large tracts of high-quality plant and wildlife habitat)
Habitat structure and complexity	19	11.2 ± 3.4	--	relatively high value; provided microtopographic relief, surface water for amphibians and macroinvertebrates, coarse woody debris, large downed wood, and several plant layers
Flood storage/water quality	12	5.1 ± 3.3	--	riverine value high for surface water detention and sediment detention; low value for flats and depressions
Education	5	0.5 ± 1.0	--	low value; very few wetlands located on public property with public access
Final score	**100**	**35.1 ± 10.7**	**--**	**moderate value added**

Non-tidal wetlands in this watershed were not easily accessible to the public (i.e. not on public property, little to no parking available, and no nearby trail system); thus, they scored low on the educational value metric. Very few non-tidal wetlands were classified as ecologically unique, enhanced, or locally rare (Table 15), so wetlands also scored low on the uniqueness/local significance metric.

It is again important to note that this was the first time that the value added assessment was used, making this a pilot study. The relatively small range of final scores (18 to 63) on a 0 to

100 scale suggests that protocol refinements might be necessary to further increase the accuracy and usefulness of the assessment.

DISCUSSION

Tidal estuarine wetlands

Estuarine wetlands were in the best overall condition of the four major HGM wetland types, with most estuarine wetlands being minimally stressed (60.0%). This suggests that most efforts should be focused on preserving estuarine wetlands in the Leipsic 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 replacement of beneficial services in the future.

However, hundreds of acres of vegetated emergent estuarine wetlands changed to aquatic bed, unconsolidated bottom, or unconsolidated shore between 1992 and 2007, which represents an overall large decline in vegetated, emergent estuarine wetland acreage and conversion to open water, likely because of erosion and sea level rise along the coast. These results suggest that direct human impacts (i.e., agriculture and development) were not causing recent acreage losses of estuarine wetlands in this watershed, and that losses were instead caused by more natural forces. Similarly, most stressors within estuarine wetlands were not from direct human disturbances; estuarine wetlands had very little hydrological impact from ditching, tidal restriction, and point sources. Most human disturbance to estuarine wetlands occurred in areas adjacent to wetlands; regions adjacent to estuarine wetlands experienced impacts from barriers to landward migration, development, and poor landscape condition, essentially degrading wetland buffers and potentially causing indirect impacts to wetlands.

Although a bulk of effort should be focused on preservation, some habitat improvements to existing wetlands can help to reduce wetland loss and maintain or increase wetland condition. To try to curb tidal wetland losses to erosion and sea level rise, efforts should be focused on making estuarine wetlands more resilient using methods such as living shorelines. Sea levels are projected to continue to increase, especially in the Mid-Atlantic region (DNREC 2012), so action is necessary to prevent more tidal wetlands from being converted to open water. Living shorelines have the potential to curb losses of vegetated estuarine wetlands and allow shorelines to recover quickly after storm events, which would ensure that tidal wetlands would continue to protect coastal development and wildlife habitat and provide important ecosystem services.

In order to maintain or increase wetland condition, efforts should also be directed at preserving intact buffer regions or restoring disturbed buffer regions. Buffers can help protect wetlands by trapping sediments and excess nutrients and filtering pollutants before they reach wetlands, improving the water quality within wetlands and maintaining the filtering function of wetlands. Buffers also slow storm water runoff from nearby impervious surfaces. In this way, buffers can protect wetlands from some negative wetland impacts associated with nearby roads and residential or commercial development. Additionally, if buffers are preserved or restored, tidal wetlands will be able to migrate inland as sea levels rise through conversion of buffer habitat to marsh. This will ensure that tidal wetlands can continue to protect coastal development and infrastructure from flooding while also providing wildlife habitat.

Additional stressors affecting estuarine wetlands were low marsh stability and presence of invasive plant species. Invasive plant species should be targeted and controlled to allow for preservation of native plant communities. Native plant growth may help address the issue of low marsh stability, because marsh stability is often associated with below-ground biomass (Twohig and Stolt 2011). Living shorelines may also help address low marsh stability by promoting plant growth and sediment accretion.

Non-tidal palustrine wetlands

Palustrine wetlands were overall more stressed than estuarine wetlands in the Leipsic River watershed. Most riverine wetlands were moderately stressed (66.7%); most flat wetlands were moderately stressed (55.2%); and most depression wetlands were either moderately (46.2%) or severely (46.2%) stressed. Most wetland losses in this watershed were vegetated palustrine wetlands, and these areas were lost largely due to conversion to agriculture and development. Many common stressors within palustrine wetlands were from direct human disturbances, including microtopographic alterations, fill or excavation, ditching, stream alteration, or clear or selective cutting. Buffer regions were also degraded because of human activities, including row crops/nursery plants/orchards, ditching or stream channelization, and development. All 3 non-tidal wetland types suffered from presence of invasive plant species as well.

Collectively, these data suggest that human impacts were the main factor reducing palustrine wetland acreage and condition in this watershed. Because palustrine wetland losses were caused mostly by direct human impacts rather than by natural forces (i.e., conversion to development and agriculture), efforts need to be focused on increased protection of non-tidal wetlands. Once wetlands are protected, management efforts should be focused largely on restoration because the majority of these wetlands were moderately stressed, and are therefore currently functioning below their full potential. It is easier and cheaper to restore wetlands that are moderately stressed compared with wetlands that are severely stressed, so restoration projects should be implemented 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.

Restoration projects should include buffer regions because many palustrine wetland buffers were degraded from nearby human activities. Just as with tidal wetland buffers, non-tidal wetland buffers can trap excess sediments and nutrients and filter pollutants before they enter wetlands, and they can slow storm water runoff. Thus, buffers protect the wetlands they surround and are a critical component of wetland health.

Non-tidal wetland value

Evaluation of condition assessments and acreage trends provide necessary information to target preservation and restoration efforts, but in the face of limited funds, time, or staff, conservation priorities may need to be further refined. Value added assessments can potentially be used to do that by adding more information, where wetlands that provide the most local value to wildlife and society may be first priority conservation targets. It is also useful to be aware of how wetlands are valuable within their local landscape in order to maintain high-value characteristics in restoration efforts. For example, palustrine wetlands in the Leipsic River watershed provided fairly high value in terms of habitat structure and complexity and habitat availability, and riverine wetlands provided high value in flood storage and water quality. Because these were identified as characteristics of high value in this watershed, it may be important to pay particular attention to these characteristics when working on restoration or preservation projects. Highlighting these local values that non-tidal wetlands provide can also make cases for increased protection of non-tidal wetlands more compelling. Additionally, by collecting more data and using it to further improve the value-added protocol, we will continue to gather more accurate and useful information that can be used to more effectively inform conservation efforts.

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 report on health and identify conservation goals. We listed 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). Actions were tailored to specific 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.** 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 further loss of tidal wetlands to erosion and sea level rise. Living shorelines also promote growth of submerged aquatic vegetation and promote abundance or diversity of waterbirds, blue crabs, many nearshore fish species, and benthic invertebrates, unlike traditional hardened shoreline structures (SERC 2015). Because many living shoreline designs promote sediment accretion and plant growth, living shorelines can also potentially help further stabilize the marsh platform, which may begin to address the overall poor bearing capacity (i.e., marsh stability) of tidal wetlands in the Leipsic River watershed. 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.** Work should focus on establishing or maintaining (depending on buffer condition) natural, vegetated buffers for wetlands to minimize indirect impacts and ensure that wetlands can persist and function.

Buffers can continue to perform important functions including trapping and filtering sediments and pollutants before they enter wetlands, protecting coastal communities from flooding and storms, and providing critical habitat for many plant and animal SGCN. Buffers ensure that tidal wetlands could continue to be valuable resources for climate mitigation by acting as carbon sinks as well (Howard et al. 2017). In estuarine wetlands, maintaining buffers between tidal wetlands and upland communities can also allow for landward marsh migration as sea levels continue to rise. Funding should be secured for working with buffers on currently protected lands, and for acquiring buffer land that is not currently protected so that it can be preserved or restored.

3. **Continue to increase citizen education and involvement through effective outreach.** Over half of all sites that were sampled in the Leipsic River watershed were privately owned (53.1%), and many sites were dropped from this study because access to the sites was denied by landowners. By increasing wetland education to landowners and informing them about the benefits wetlands can provide, landowners may be more willing to participate in wetland studies that can benefit wetlands around them. Landowners may also be more willing to take part in voluntary stewardship activities toward wetland conservation or restoration if they are more aware of what wetlands are, how they can benefit landowners, and what specific actions they can take to conserve or enhance wetlands on their property. A website called the Freshwater Wetland Toolbox (see link on pg. 58) was created by DNREC in early 2017 to address this goal and communicate with landowners, and we encourage the development and use of similar materials as well as other education and outreach tools and programs.

4. **Control the extent and spread of non-native invasive plant species.** Each of the four HGM wetland classes assessed in the Leipsic 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 common reed, which has treated more than 20,000 acres throughout Delaware on private and public property since 1986 (DNREC 2017a). This program has the potential 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, including 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 is an important component of this, which can be accomplished by informing landowners about removing undesirables and only planting native species.

5. **Support the Delaware Bayshore Initiative by securing funding for wetland conservation and restoration.** One of the main goals of the Delaware Bayshore Initiative is to protect and connect important coastal wildlife areas along the Delaware Bay coast and restore important areas that may have been degraded or destroyed (DNREC 2017b). 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.

Decision Makers (State, County, and Local)

1. **Improve protection of non-tidal palustrine wetlands through state, county, and local programs.** Activities in most non-tidal wetlands are not regulated by the State of Delaware, so without increased protection, losses of non-tidal wetlands in the Leipsic River watershed may continue. Acreage losses will translate into losses of ecosystem services and values such as reductions in water quality improvement, flood storage, and wildlife habitat availability. Sustained losses could also translate into declines in Coastal Plain seasonal ponds and groundwater seepage wetland habitats in this watershed, which are home to many unique plant and animal species and are habitats of conservation concern (DNREC 2015b). Together, 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 provide a comprehensive and clear means to protect wetlands across the state. 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 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 estuarine wetland regulatory maps to improve accuracy and efficiency.** Relatively few direct human impacts were detected within tidal wetlands in the Leipsic 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. Evidence of recent inundation of tidal wetlands due to sea level rise and erosion in the Leipsic River watershed creates an even greater need to adopt updated wetland regulatory maps, as tidal wetland areas will likely continue to change over time.

3. **Develop incentives to maintain natural buffers of *tidal* wetlands.** In order for tidal wetlands to continue to protect upland areas (i.e., properties and infrastructure), they need to be able to migrate landward as sea levels rise, unobstructed by barriers such as roads, rip-rap, bulkheads, and other human development. Tidal wetlands, if unobstructed, could migrate into intact buffer habitat, such that as sea levels rise, buffer habitat would convert to tidal wetland habitat. Incentive programs could attract landowner interest in maintaining these natural buffers between wetlands and development to allow for

landward marsh migration in the face of sea level rise. If natural upland buffers are not present to convert to marsh as sea levels rise, water will instead flood upland development and infrastructure, and tidal marsh plant and wildlife habitat will be lost.

4. **Develop incentives to maintain natural buffers of *non-tidal* wetlands.** When buffers are degraded, they do not perform ecosystem services, such as water quality control, to the same degree as when buffers are undisturbed. To further improve wetland condition, buffers need to be kept as wide as possible, development and agriculture adjacent to buffers needs to be prevented, and natural hydrology needs to be maintained. An incentives program could attract an interest in maintaining natural buffers between wetlands and development or agriculture to reduce negative indirect impacts to wetlands.

<u>Landowners</u>

1. **Protect and maintain the buffers around your 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 Leipsic River watershed, many palustrine wetlands were degraded from adjacent development, agricultural activities, or from channelization of streams or ditches. 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 accrete 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).

3. **Preserve or restore wetlands that are on your land.** Over half of the wetlands in the Leipsic River watershed are located on privately-owned land. This means that in order to be truly effective in maintaining wetland acreage and function, we need help from private landowners. Wetlands provide people with many ecosystem services, such as flood control, water quality maintenance, and provision of commercial fish and shellfish habitat. There are many ways that landowners can engage with the natural wetlands right in their backyards to ensure that they continue to perform these beneficial services. Planting native species and removing invasive species are two important actions that landowners can take, especially because many wetlands in the Leipsic 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. Our 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. 58).

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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 (<.3m deep) in AA
Wditchm	Moderate Ditching; 3 shallow ditches in AA or 1 ditch >.3m within
Wditchx	Severe Ditching; >1 ditch .3-.6 m deep or 1 ditch > .6m deep within
Wchannm	Channelized stream not maintained
Wchan1	Spoil bank only one side of stream
Wchan2	Spoil bank both sides of stream
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 Wfill100	Filling or excavation on 10-75% of AA 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 only one side of stream	Wchan1	0	31	0
Spoil bank both sides of stream	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, Leipsic 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