2020 Red Lion Watershed

Delaware Department of Natural Resources and Environmental Control

Delaware Wetlands
Purify Provide Protect

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EXECUTIVE SUMMARY

The Delaware Department of Natural Resources and Environmental Control's (DNREC) Wetland Monitoring and Assessment Program (WMAP) documented wetland acreage trends and determined the ambient condition of tidal and non-tidal wetlands in the Red Lion watershed in 2017. This was done with field assistance from the Partnership for the Delaware Estuary (PDE). The goals of this project were to: summarize acreage gains, losses, and changes across the Red Lion watershed based on the most current state wetland maps; assess the condition of tidal and non-tidal wetlands throughout the watershed; identify prevalent wetland stressors; assess the value that non-tidal wetlands provide to the local landscape; and make watershed-specific management recommendations to different audiences, including scientists, land managers, decision makers, and landowners.

The Red Lion watershed is located within New Castle County, where it encompasses 46,283 acres (72 square miles) of land within the Delaware Bay and Estuary Basin. It is composed of 5 sub-watersheds at the HUC12 level, including C&D Canal East, Dragon Creek, Red Lion Creek, Army Creek, and Broad Dike Canal, which were combined for this project and report. Approximately 16% of the land area of the watershed was covered by wetlands. Of these wetlands, 50.5% were tidal estuarine wetlands, 4.4% were tidal palustrine wetlands, 24.9% were non-tidal flats, 13.7% were non-tidal riverine wetlands, and 6.5% were non-tidal depressions.

We estimated historic (prior to 1992) and more recent (1992 to 2007) wetland losses in the Red Lion watershed based on historic hydric soil maps and the most current (2007) statewide wetland mapping resources. Our analysis indicated that by 1992, approximately 1,375 acres of the watershed's historic wetlands had been filled or lost, mostly due to conversion to other land uses such as residential and commercial development. Between 1992 and 2007, the watershed lost another 45 acres of wetlands and gained approximately 179 acres, resulting in a net gain of 134 acres between those years. Most of the wetland acreage loss was due to conversion of non-tidal wetlands to development, such as housing developments or highways. Most of the gained acreage was attributed to the creation of ponds, usually in the form of storm water retention ponds, which do not resemble natural wetlands and generally provide fewer ecosystem services than natural wetlands. Other wetlands changed wetland type from 1992 to 2007. Some of these changes resulted in a shift from vegetated to non-vegetated wetlands, and vice versa.

To assess wetland condition and identify stressors affecting wetland health, rapid assessments were conducted at wetland sites throughout the watershed during the summer of 2017. Wetland assessment sites were located on public and private property and were randomly selected utilizing a probabilistic sampling design with the assistance of the Environmental Protection Agency's (EPA) Ecological Monitoring and Assessment Program (EMAP). With field assistance from the Partnership for the Delaware Estuary (PDE), WMAP performed non-tidal wetland assessments in 33 riverine wetlands, 31 flat wetlands, and 22 depression wetlands using the Delaware Rapid Assessment Procedure (DERAP) Version 6.0. Tidal wetland assessments were conducted in 30 tidal wetlands (i.e., estuarine or tidal palustrine) using the Mid-Atlantic Tidal Rapid Assessment Method (MidTRAM) Version 4.1.

Tidal wetlands received a mean condition score of 61.1 ± 15.2 (median=59.6) out of a maximum possible score of 100.0, with scores ranging broadly from 35.6 to 86.7. Flat wetlands had a mean condition score of 76.7 ± 11.6 (median=79.0) out of a maximum possible score of 95.0, ranging from 55.0 to 92.0. Riverine wetlands had a mean condition score of 75.0 ± 12.5 (median=83.0) out of a maximum possible score of 91.0, ranging widely from 46.0 to 90.0. Depression wetlands received a mean score of 51.6 ± 15.4 (median=52.0) out of a maximum possible score of 82.0, ranging widely from 23.0 to 78.0. Compared with 9 other watersheds previously assessed in Delaware, the wetlands of the Red Lion watershed scored relatively poorly. The greatest proportion of wetlands in the Red Lion watershed were severely stressed (43%), while 36% were moderately stressed and 21% were minimally stressed. A common wetland stressor was the presence of

invasive plant species. Buffer disturbances were also common, particularly because of adjacent agriculture, roads, and development.

Wetland value was also evaluated in non-tidal wetlands because wetland value to the local area may be independent of wetland condition. Value-added assessments were conducted at non-tidal sites using Version 1.1 of the Value-Added Protocol, in conjunction with DERAP v.6.0. Most flat wetlands were found to provide limited value to the local area (58%) because of factors such as small wetland size and low education potential, whereas the highest proportions of riverine and depression wetlands were rated as providing moderate value (36% and 50%, respectively). Habitat availability and habitat structure and complexity were common features that non-tidal wetlands possessed that provided value to the local landscape.

Based on analysis and synthesis 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: maintain adequate wetland buffers, control the extent and spread of invasive plant species, perform wetland monitoring, conservation, and restoration activities, and continue to increase citizen education and involvement through effective outreach. We also recommended that decision makers: improve the protection of non-tidal palustrine wetlands, update tidal wetland regulatory maps, develop incentives and legislation for maintaining tidal and non-tidal wetland buffers, and secure funding for wetland preservation. Finally, we suggested that landowners: protect and maintain vegetated buffers around wetlands on their property, protect or restore wetlands on their property, and engage in best management practices in agricultural and urban settings.

INTRODUCTION

Wetlands are unique, beautiful ecosystems that are intrinsically valuable and provide many important ecosystem services to communities. Wetlands can remove and retain disturbed sediments, pollutants, and nutrient runoff from non-point sources (e.g. agriculture, land clearing, and construction) from the water column before they enter our waterways, thereby improving the quality of drinking and swimming water. By retaining sediments, wetlands also help to control erosion. Wetlands minimize flooding by collecting and slowly releasing storm water that spills over channel banks, protecting infrastructure and property. They also sequester carbon, meaning that they help remove excess carbon dioxide from the atmosphere and store it in their plant biomass and soils to potentially reduce the effects of climate change. 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 most commercial fish and shellfish species in Delaware. Wetlands are also valuable sources of recreation (e.g. hunting, fishing, kayaking, and birding) and livelihood (e.g. fishing, crabbing, and fur-bearer trapping).

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

Wetland acreage, condition, and diversity are all crucial to the ability of wetlands to provide these beneficial services. If wetland acreage decreases, then there are fewer wetlands to perform ecosystem services to people and wildlife. Engineered solutions that are designed to replace some wetland ecosystem services, such as water treatment facilities, can be very costly to construct and maintain. Additionally, if wetland acreage decreases, it becomes more difficult for wildlife to disperse and migrate among wetland habitats, as distances between wetlands may grow larger. Such reduced dispersal and migration can reduce genetic diversity and population sizes of wildlife species (Finlayson et al. 2017). Different wetland types typically perform certain functions better than others based on factors such as position in the landscape, vegetation type, and hydrological characteristics (Tiner 2003); therefore, a variety of wetland types ensure that all services that wetlands can offer are provided. Wetlands provide the greatest amount of services when they are in good condition. Wetlands that have been impacted by removal of buffer habitat, altered hydrologically by ditching, or have been severed by a road, for example, will function at a lower capacity.

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 by the impacts of many direct and indirect stressors, and are therefore functioning below their potential. Mosquito ditches, adjacent agriculture and development, filling, and invasive species are all examples of common stressors that Delaware wetlands experience that can negatively affect their hydrology, biological community, and ability to perform beneficial functions. Many anthropogenic wetlands, such as storm water or agricultural ponds, cannot make up for the degradation of natural wetland function. This is because most created wetlands are non-vegetated and do not resemble natural wetlands, and they perform many functions at lower levels than natural wetlands (Woodcock et al. 2010, Tiner et al. 2011, Rooney et al. 2015).

While a portion of wetlands have been degraded, many others have been lost completely; approximately half of all historic wetlands in Delaware have been lost since human settlement in the early 1700's. This decline in wetland acreage has continued in recent years; between 1992 and 2007, there was a substantial net loss of 3,126 acres of vegetated wetlands across the state. Acreage losses are particularly alarming for forested freshwater wetlands, which experienced the greatest losses of all wetland types between 1992 and 2007 (Tiner et al. 2011). These non-tidal wetland losses have largely occurred because of direct human impacts, many of which are likely the result of the lack of regulatory protection and enforcement. The State of Delaware regulates activities in tidal wetlands, but only in non-tidal wetlands that are 400 contiguous acres or more in size. Federal regulations do exist for non-tidal wetlands, but not for small wetlands <0.1 acres in size. A lack of stringent enforcement presence on the ground leaves room for unpermitted losses. Moreover, very recent changes to the definitions of the Waters of the U. S. (WOTUS) have lessened federal regulations for small or geographically isolated freshwater wetlands.

Tidal wetlands in Delaware face many different challenges. Although regulated by the state, most of the recent acreage losses of tidal wetlands have been caused by subsidence and submergence, highlighting the impacts of sea level rise from climate change. Acreage losses of tidal and non-tidal wetlands have led to the reduction of many beneficial functions, such as carbon sequestration, sediment retention, wildlife habitat, nutrient transformation, and shoreline stabilization (Tiner et al. 2011).

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

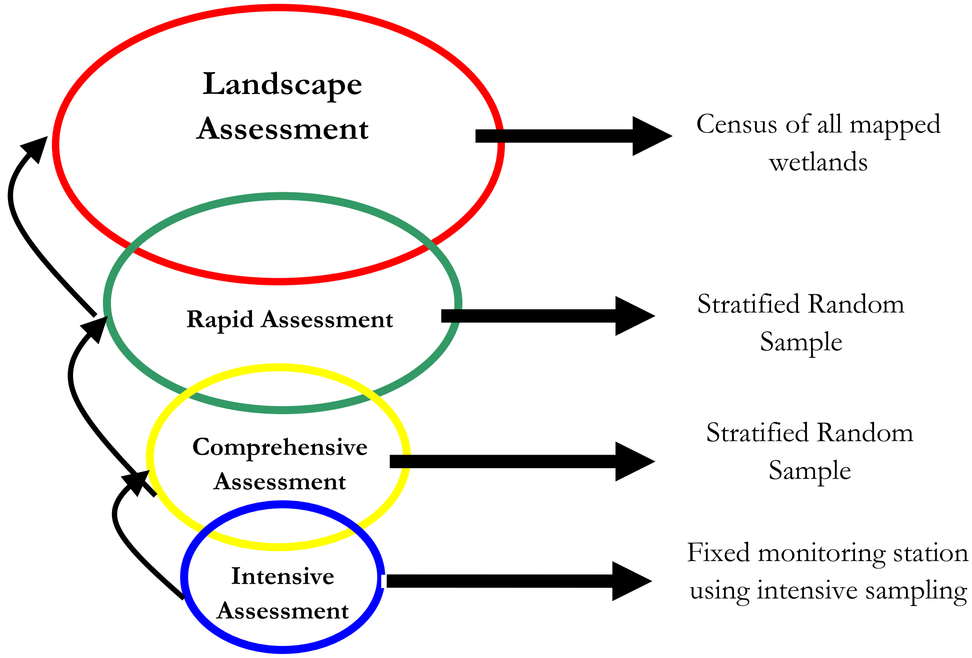


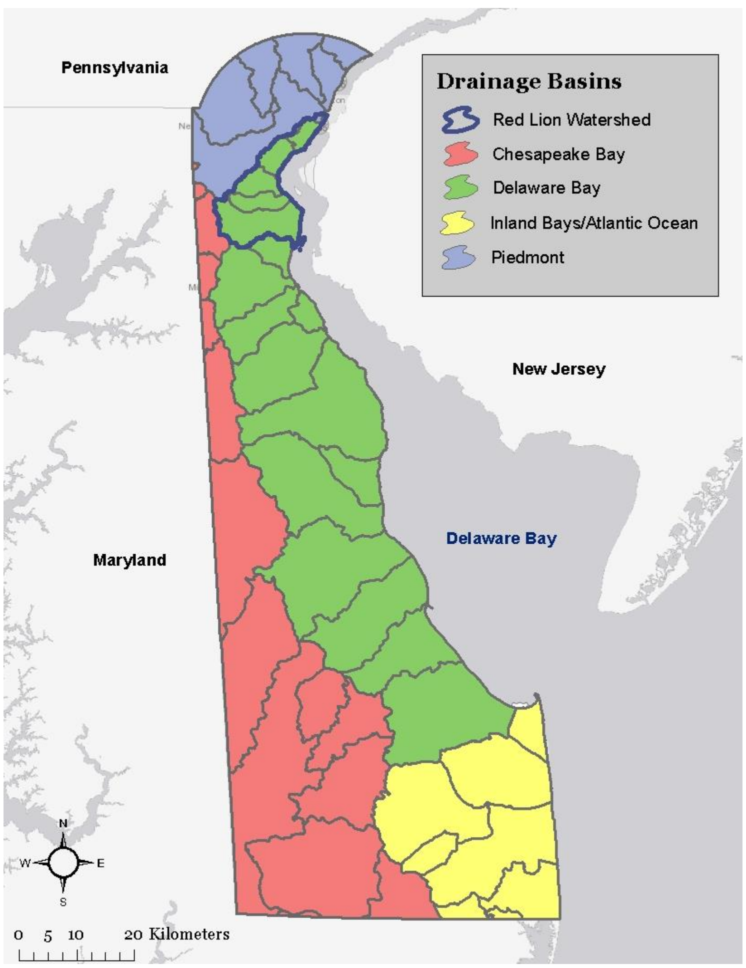
Figure 1. The four-tiered approach that is used to evaluate wetland condition across the Mid-Atlantic region.

Delaware's Approach

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

State wetland maps that are created for Delaware for desktop analyses include the two most common types of wetland classification: the Cowardin system (FGDC 2013), which is the main classification used by the U.S. Fish and Wildlife Service's National Wetlands Inventory (USFWS 2020), and the LLWW, or hydrogeomorphic (HGM) system, which describes landscape position, landform type, waterbody type, and water flow path (USFWS 2014). WMAP considers both classification systems when performing desktop and field assessments. The Cowardin system is used for random selection of assessment points, splitting wetlands into estuarine, tidal palustrine, and non-tidal palustrine wetland types (see "Field Site Selection" in Methods section below). The LLWW system is then used in the field to differentiate among the most common non-tidal palustrine wetland types in Delaware based on hydrogeomorphic characteristics, which are flat, riverine, and depression wetlands.

Once these assessments are complete, data are used to generate an overall watershed condition report that discusses trends in wetland acreage, identifies common stressors by wetland type, summarizes overall health of wetland types, and provides management recommendations based on these results. Information and recommendations provided by these reports can be used by watershed organizations, state planning and regulatory agencies, and other stakeholders to prioritize and improve wetland protection and restoration efforts. For example, protection efforts, such as through acquisition or easement, can be directed toward wetland types in good condition, and restoration efforts can target degraded wetland types to increase their functions and services. This report discusses wetland acreage trends and wetland condition in the Red Lion watershed in northern Delaware and is based on landscape (Tier 1) and rapid (Tier 2) assessment data.



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

Watershed Overview

The Red Lion Creek watershed, hereafter referred to as the Red Lion watershed, is a watershed at the HUC10 scale that drains into the Delaware Bay (Map 1). The watershed encompasses 46,283 acres (72 square miles) of land in New Castle County, and is composed of 5 sub-watersheds at the HUC12 level: C&D Canal East, Dragon Creek, Red Lion Creek, Army Creek, and Broad Dike Canal. Directly east of the watershed is the Delaware River, while to the west, the watershed is bordered by the Elk River watershed. The neighboring watershed to the south is the Appoquinimink River watershed, and to the north is the Christina River watershed. Major populated areas included in the watershed are Delaware City, New Castle, Red Lion, and part of Bear.

In the southern part of the watershed, the man-made C&D Canal spans about 14 miles, and connects the Delaware River and the Chesapeake Bay. It was originally constructed to create a much shorter route to ship goods between Wilmington and Baltimore. Dragon Creek is just north of the canal, and drains into the Delaware River. Moving northward, Red Lion Creek runs west to east and drains into the Delaware Bay. It is fed by several tributaries, including Doll Run and Pigeon Run. Similarly, Army Creek, which is north of Red Lion Creek, flows into the Delaware Bay. The Broad Dike is a man-made canal at the northeastern-most tip of the watershed and is one of several dikes in northern Delaware that was created for community flood protection. Dragon Creek, Red Lion Creek, and Army Creek all have tide gates at their mouths that allow water to drain to the Delaware River, but do not allow tidal influx from the Delaware River. The Broad Dike was originally constructed to only allow water to flow out to the Delaware River; however, in 1995, as part of a wetland restoration plan, a water control structure was installed to allow tidal exchange with the Delaware River.

Lums Pond is the largest pond in the watershed, which was created by damming the St. Georges Creek in the early 1800's. The watershed also contains 2 large impoundments near the C&D Canal, which are the Lang impoundment of Augustine Wildlife Management Area and the Thousand Acre Marsh impoundment. Both impoundments provide important habitat for waterfowl and shorebirds.

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 that we know today is dynamic and continues to change through various processes, such as sea level rise. In the past 50 years, sea level rise along the Mid-Atlantic coast of the U.S. has been accelerating (Boon 2012). 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).

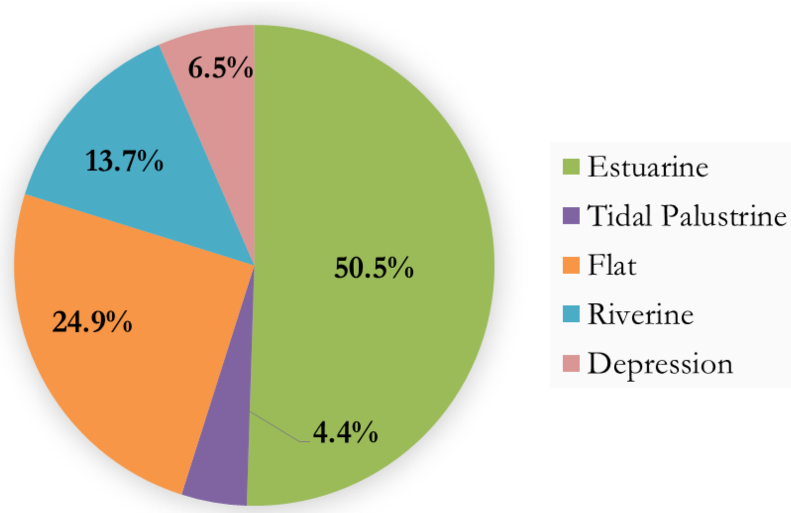
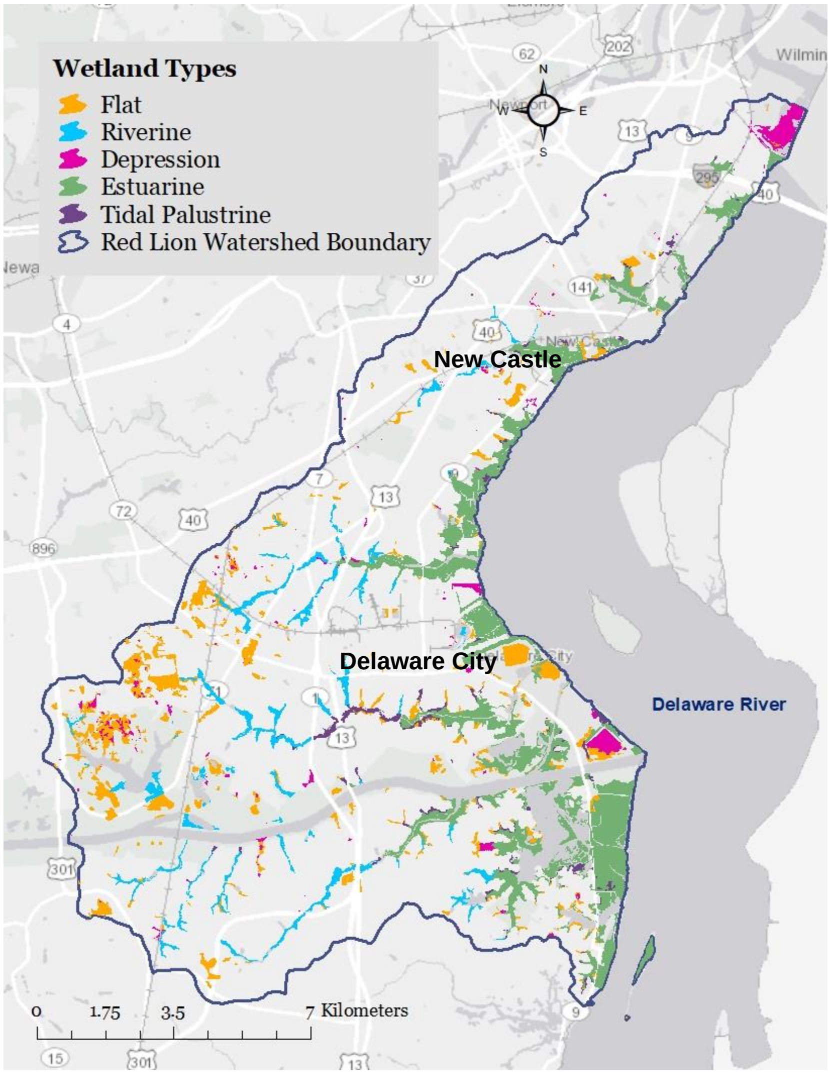


Figure 2. Proportions of wetland types in the Red Lion watershed based on 2007 SWMP maps. Proportions are based on acreage of vegetated wetlands only (non-vegetated wetlands not included).

Today, the Delaware Bay and Estuary Basin, which includes the Red Lion watershed, is contained within the Atlantic Coastal Plain Physiographic Province, just south of the Appalachian Piedmont Fall Zone. It is composed of two physiographic subdivisions: 1) the coastal lowland belt, which includes low elevation areas 0-5 ft above mean sea level on the eastern side of the basin, and 2) the inland plain, which includes areas of higher elevation (approximately 35 ft above mean sea level in Kent County, and 75 ft in New Castle County) on the western side of the basin (DNREC 2005). The Red Lion watershed is composed of three hydrogeomorphic regions, including inner coastal plain, well-drained uplands, and beaches, tidal marshes, lagoons, and barrier islands. The beach and marsh region is located along the eastern part of the watershed adjacent to the Delaware River. Most of the rest of the watershed is made up of inner coastal plain, with only small patches of well-drained uplands (DNREC 2005).

According to the 2007 Delaware Statewide Wetland Mapping Project (SWMP) mapping effort, the Red Lion watershed had a total of 9,943 acres of wetlands, including both vegetated and non-vegetated mapped wetlands. Of those, 7,029 acres of wetlands were vegetated. Delaware's wetland condition assessments are conducted only on vegetated wetland types, so those were the focus of the assessments and this report.



Map 2. Major vegetated wetland types in the Red Lion watershed based on 2007 SWMP data.

However, both vegetated and non-vegetated wetland types are discussed in acreage trends (see 'Wetland Acreage' section in Results).

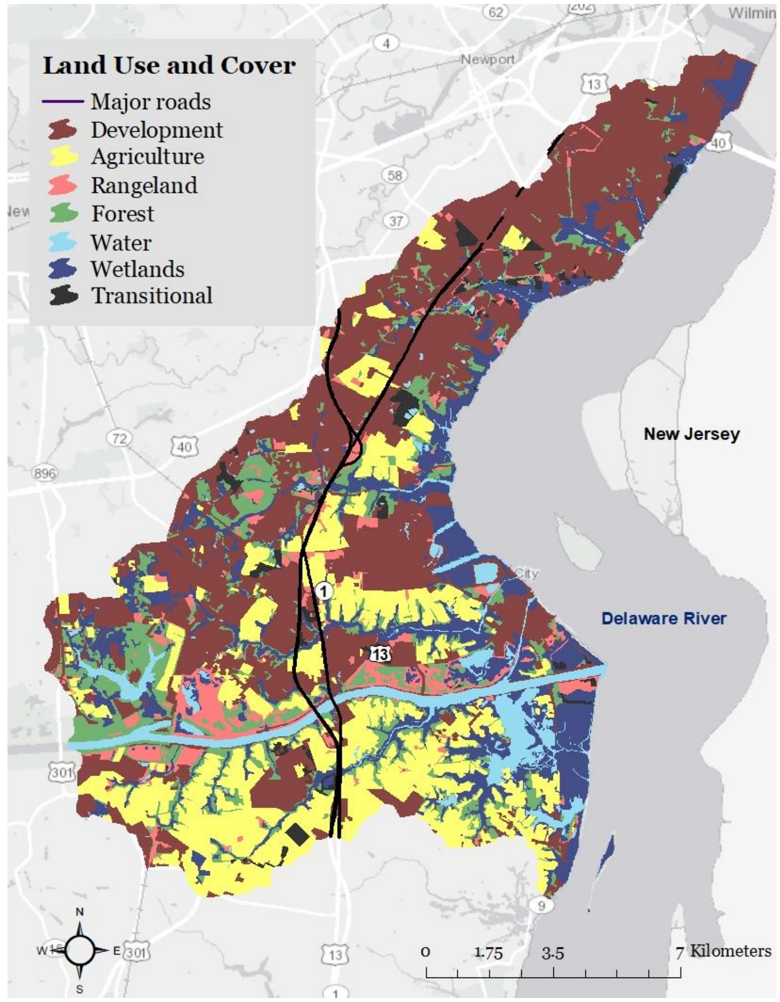
The Red Lion watershed had several different major types of vegetated wetlands, including estuarine, tidal palustrine, flat, riverine, and depression. Estuarine wetlands are tidal wetlands that are in areas where fresh and saltwater mix, and tidal palustrine wetlands are wetlands that are close enough to the ocean to be influenced by tides, but far enough inland to have fresh water (i.e., tidal freshwater). Riverine wetlands are non-tidal wetlands that are located along floodplains of rivers and streams. Flat wetlands are non-tidal wetlands often found in headwater regions that are fed mainly by precipitation and that occur in areas with relatively flat landscapes and poor-draining soils. Depression wetlands are non-tidal wetlands that occur in areas of low elevation that tend to pool water (often seasonally) from groundwater, precipitation, and overland flow.

Out of the vegetated wetlands, 50.5% (3,542 acres) were estuarine, 4.4% (307 acres) were tidal palustrine, 24.9% (1,744 acres) were flat, 13.7% (964 acres) were riverine, and 6.5% (455 acres) were depression (Figure 2). Estuarine wetlands were concentrated on the eastern portion of the watershed close to the tidal influence of the Delaware River. Tidal palustrine wetlands were on the inland borders of estuarine wetlands or between estuarine and riverine wetlands along waterbodies. Flats were scattered throughout the watershed, but were the most concentrated in the western part of the watershed in headwater areas. Depressions were scattered throughout the watershed, and riverine wetlands were along waterways in the center and southern parts of the watershed (Map 2). Aquatic bed wetlands are not shown because there were very few (17 acres) and they were not part of the target population for wetland assessments.

Land Use and Land Cover

The most recent land cover dataset for Delaware is from 2012 and is based on the 2012 National Land Cover Dataset (NLCD). The land cover dataset showed that the Red Lion watershed was dominated by development (40.0%), followed by agriculture (21.1%), wetlands (15.8%), and forest (11.1%). Smaller portions of land were water (6.1%), rangeland (4.1%), or transitional land that was cleared, likely for future development (1.8%; Table 1). As of 2012, the watershed was dominated by agriculture below the C&D Canal, while it was dominated by development above the canal. Much of the forest land was concentrated in Lums Pond State Park in the southwest part of the watershed above the canal. Other forest patches occurred along the C&D Canal and in the central portion of the watershed. The largest wetland blocks occurred on the eastern half of the watershed adjacent to the Delaware River, while other smaller patches occurred along rivers and creeks and within forest patches throughout the watershed. Transitional land was scattered throughout the watershed, and rangeland occurred either along the northern banks of the canal or in scattered patches above the canal. Dredge spoil areas from the C&D Canal were scattered along the canal and were included in various land use categories, such as transitional or rangeland.

Based on a comparison between 1997 and 2012 Delaware land use and land cover datasets, the Red Lion watershed experienced a 7.3% increase in the amount of developed land in the 15-year time frame. Also notable was that land used for agriculture decreased by 6.6%, forested land decreased by 1.3%, and wetland coverage increased by 5.2% (Table 1). The increase in development largely explained the decline in agricultural, forest, transitional, and rangeland. Some transitional land also became agricultural land or rangeland. Aside from development, forest declined because some became transitional land that was waiting to be developed. The increase in wetland acreage was partially explained by the excavation of storm water ponds near developments, as was the small increase in water acreage. Water acreage also increased because of wetland erosion and sea level rise along the coast of the Delaware River.



Map 3. LULC in the Red Lion watershed based on the 2012 Delaware state land use and land cover data.

Table 1. Land use/land cover (LULC) change in the Red Lion watershed based on 1997 and 2012 Delaware datasets. Values are percentages.

Land Use	1997	2012	Change
Development	32.7	40.0	7.3
Agriculture	27.7	21.1	-6.6
Rangeland	5.3	4.1	-1.2
Forest	12.4	11.1	-1.3
Water	5.6	6.1	0.5
Wetland	10.6	15.8	5.2
Transitional	5.7	1.8	-3.9

However, some of the changes were artifacts of mapping methods, meaning that some land areas were more accurately reclassified from 1997 to 2012. For example, wetland acreage appeared to increase largely because areas that were incorrectly classified as upland forest or water in 1997 were correctly reclassified as forested wetlands or marshes, respectively, in 2012. Increases in natural wetland land cover were therefore much smaller than 5.2%. This also means that some of the apparent forest decline was simply because of land reclassification to wetlands in mapping. Similarly, some of the decline in transitional land was explained by reclassification to wetlands or water, especially in manipulated areas with berms along the coastline of the Delaware River. Some wetlands were reclassified as water, and some rangeland was reclassified as forest or wetland. In summary, actual changes are smaller than shown in Table 1.

Surface and Ground Water

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

The State of Delaware is required by the U. S. Environmental Protection Agency (EPA) to develop a list of impaired waters under Section 303(d) of the Clean Water Act. Impaired waters are defined as waters that are not meeting clean water criteria even when current existing pollution control strategies are enacted. DNREC performs water quality monitoring throughout the state on a regular basis, allowing them to identify waterbodies that are not meeting water quality standards. States are required to create total maximum daily loads (TMDLs) for certain pollutants of impaired waterbodies, which set limits on the amount of those pollutants that can be discharged into those waterbodies in order for water quality standards to be met.

Several waterbodies within the Red Lion watershed are considered impaired under Section 303(d). The Red Lion Creek, Army Creek, Dragon Run Creek, and C&D Canal East, and their tributaries, have been identified as having high levels of pollutants such as harmful bacteria or excess nitrogen or phosphorus from non-point sources. TMDLs were established for Red Lion Creek, Army Creek, and Dragon Run Creek in 2006 and for C&D Canal East in 2012 (DNREC 2006, n.d.-c). Once TMDLs are developed for impaired waterbodies, the next step is typically to create pollution control strategies (PCSs), which describe specific actions that can be taken to achieve water quality goals. In Delaware, PCSs are often made by collaboration between DNREC and Tributary Action Teams. Tributary Action Teams are specific to each impaired waterbody and include a variety of stakeholders, allowing a diverse group of public participants to play a role in the development of PCSs. Presently, no Tributary Action Team has been formed for the Red Lion Creek, Army Creek, Dragon Run Creek, or C&D Canal East, and there are no published PCSs specific to any of these waterbodies (DNREC n.d.-b). However, New Castle county, which contains these waterbodies, has a National Pollutant Discharge Elimination System (NPDES) permit. The NPDES permit requires regular water monitoring and adherence to stormwater management plans (DNREC n.d.-c).

A recent report from University of Delaware staff that analyzed surface water quality trends from 1999-2014 in New Castle County found that dissolved oxygen (DO), phosphorus, nitrogen, bacteria, and total suspended solids (TSS) levels were decreasing or remaining constant in some of these waterbodies, while they were increasing in others. Army Creek remained constant for DO and had improved phosphorus levels, but worsened in terms of nitrogen, bacteria, and TSS. Red Lion Creek showed increased levels of DO and lower nitrogen and remained constant for phosphorus, bacteria, and TSS. DO and TSS improved in Dragon Run Creek, while nitrogen, phosphorus, and bacteria remained constant. The C&D Canal showed increased DO, decreased nitrogen and phosphorus, and constant levels of bacteria and TSS (Table 2; Kauffman 2016).

These data show that despite a trend toward improving overall water quality in several waterbodies in the Red Lion watershed, some parameters have only stayed constant, while others are worsening. Wetlands can play an important role in the quality of surface waters, as they can filter and process many pollutants. Wetland health, type, and acreage are all important factors that determine the extent to which they can benefit water quality. Therefore, the results of this report may have important implications for further improving surface water quality in the Red Lion watershed.

Table 2. Water quality trends from 1999-2014 in water bodies within the Red Lion watershed. This table is modified from Table 4 within Kauffman (2016).

Waterbody	DO	Bacteria	N	P	TSS
Army Creek	Constant	Worsening	Worsening	Improving	Worsening
Red Lion Creek	Improving	Constant	Improving	Constant	Constant
Dragon Run Creek	Improving	Constant	Constant	Constant	Improving
C&D Canal	Improving	Constant	Improving	Improving	Constant

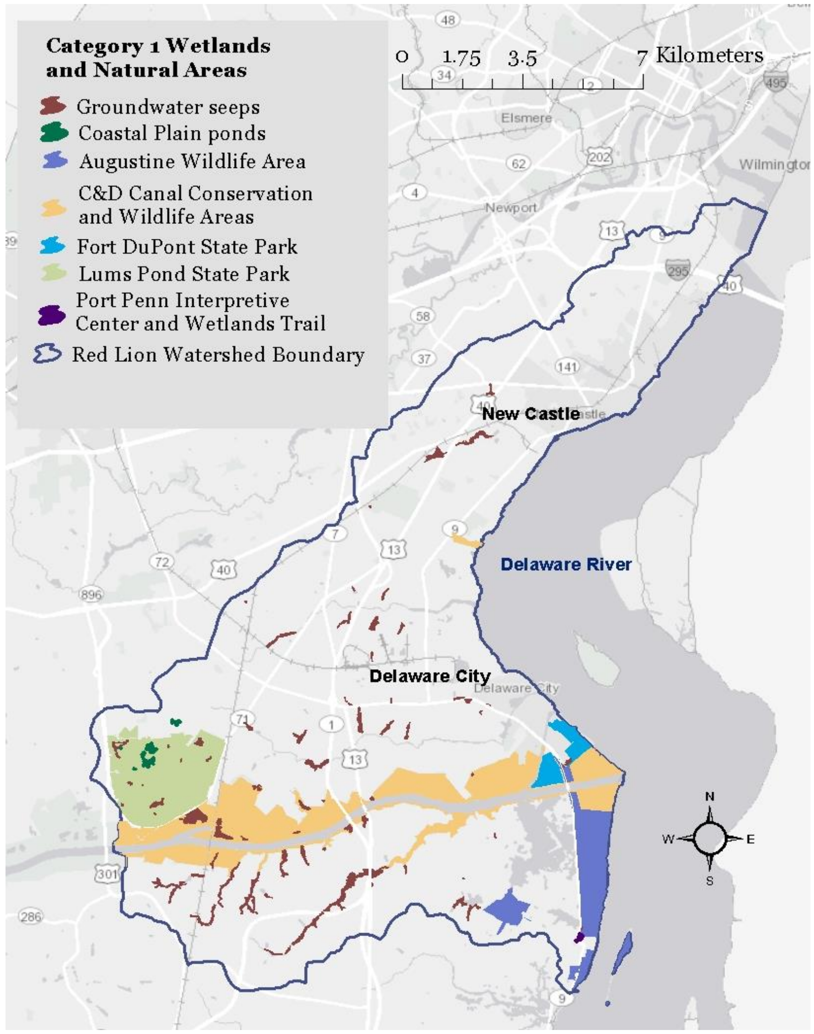
Key
- ● (green) Improving
- — (blue line) Constant
- ● (red) Worsening

Natural Areas and Category 1 Wetlands

There are several natural, state-owned areas in the Red Lion watershed that contain wetlands. Augustine Wildlife Area is partially located on the southeastern side of the watershed, with other tracts in the Appoquinimink River watershed to the south. Adjacent to a tract of Augustine Wildlife Area lies the Port Penn Interpretive Center and Wetlands Trial. Lums Pond State Park is on the southwestern side of the watershed. The C&D Canal Conservation Area and C&D Canal Wildlife Area run across the entire southern part of the watershed along the C& D Canal. Fort DuPont State Park is along the C& D Canal and the Delaware River to the southeast (Map 4). Augustine Wildlife Area, the C&D Canal Conservation and Wildlife Areas, and a small part of Fort DuPont State Park are managed by the Delaware Division of Fish and Wildlife, while most of Fort DuPont State Park, Lums Pond, and the Port Penn Interpretive Center and Wetlands Trail are managed by Delaware State Parks. In 2007, all these state-owned natural areas combined contained 1,295.2 acres (36.6%) of the watershed's estuarine wetlands, 54.7 acres (17.8%) of tidal palustrine wetlands, and 895.2 acres (28.3%) of non-tidal palustrine wetlands (Table 3).

The Red Lion watershed contains some Category 1 wetlands, which are rare, unique, freshwater wetland types in Delaware. The types of Category 1 wetlands found in this watershed are Coastal Plain ponds and groundwater seepage wetlands. Coastal Plain ponds are relatively small, circular or oval-shaped depressions that are fed by groundwater and precipitation. They are usually flooded in the wet seasons of winter and spring and are often dry on the surface in the summer and fall. Groundwater seepage wetlands, or groundwater seeps, are those that occur in areas on slopes where groundwater flows out onto the surface. According to 2007 SWMP maps, there were approximately 537.5 acres of groundwater seeps and 15.8 acres of Coastal Plain seasonal ponds in this watershed. Coastal Plain ponds were in the southwestern part of the watershed in Lums Pond State Park, while seeps were more scattered (Map 4). Of these unique wetlands, 154.4 acres (28.7%) of groundwater seeps and 15.8 acres (100%) of Coastal Plain ponds were within state-owned natural areas (Table 3).

Wetlands that are not within natural, protected areas are more susceptible to destruction or degradation from human impacts. Non-tidal wetlands in Delaware are only state regulated if they are greater than 400 contiguous acres. This leaves most non-tidal wetlands, including Category 1 wetlands like groundwater seeps and Coastal Plain ponds, unregulated by the state. When wetlands are unregulated, they are far more likely to be destroyed or degraded by anthropogenic activity than if a permit were required for their impacts. Non-tidal wetlands on state-owned lands are less likely to be affected by human impacts, so the 28.3% of non-tidal wetlands that are heavily concentrated in Lums Pond State Park are relatively safe. However, the other 71.7% of non-tidal wetlands that are not on natural, state-owned lands are much more vulnerable. Fortunately, the State of Delaware does have the jurisdiction to regulate activities in tidal wetlands, meaning that they are far less likely to suffer adverse human impacts. A little over one third (35.1%) of the tidal wetlands in this watershed were state-owned, making the likelihood of them being impacted by human alterations even less (Table 3).



Map 4. Category 1 wetlands and state-owned natural areas in the Red Lion watershed.

Table 3. Acres of wetlands in natural, state-owned areas as of 2007, and the percentage of each wetland type in these state areas based on the total number of acres of each wetland type in the watershed. Tidal wetland values combine estuarine and tidal palustrine.

Wetland Type	Acres	Percentage
Tidal	1,349.9	35.1
Non-tidal	895.2	28.3
Groundwater seep	154.4	28.7
Coastal Plain pond	15.8	100

Wildlife Habitat and Outdoor Recreation

The Delaware Bay and Estuary Basin, including the Red Lion 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), several of the shorebird, waterfowl, and marsh bird species that use this area as habitat are species of greatest conservation need (SGCN), including the red knot (*Calidris canutus*), the American black duck (*Anas rubripes*), and the clapper rail (*Rallus crepitans*). It is one of the key migration stopover areas for shorebirds as they rest and feed on horseshoe crab (*Limulus polyphemus*; Figure 3) eggs before they continue to fly north to summer breeding grounds in the Arctic. Many species of waterfowl use the area for feeding grounds during the winter and during migration. Because of this, the Ramsar Convention, an intergovernmental treaty that provides the framework for the conservation and wise use of wetlands, recognizes the Delaware Bay Estuary as an International Wetland of Importance (Ramsar Convention 1992). The Delaware Bay Estuary is also a designated Site of Hemispheric Importance by the Western Hemisphere Shorebird Reserve Network (WHSRN; WHSRN 2019), indicating that the area is visited by 500,000 or more shorebirds a year, and accounts for more than 30 percent of the biogeographic population for certain species. Similarly, Delaware's Coastal Zone, which includes part of the Red Lion 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 n.d.).

Figure 3. Horseshoe crabs along a sandy shoreline in Delaware.

The 2015 Delaware Wildlife Action Plan (DNREC 2015b) also highlights wetlands within the Red Lion watershed as important habitats for many reptile and amphibian SGCN, such as the spotted turtle (*Clemmys guttata*) and the four-toed salamander (*Hemidactylium scutatum*). Many fish and insect SGCN use wetland habitats as well, including the American eel (*Anguilla rostrata*) and the rare skipper (*Problema bulenta*; DNREC 2015b). Unique wetlands, such as Category 1 wetlands, can be particularly important for certain SGCN. Both groundwater seepage wetlands and Coastal Plain ponds, which are unique wetland types found within the Red Lion watershed, 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), and remain unregulated at the state level.

Just as wetlands and the areas surrounding them can be important for wildlife, they can also provide many opportunities for outdoor recreation. People can enjoy a variety of wetland-related activities at Lums Pond State Park, including hiking or biking near wetlands, fishing, boating, and wildlife viewing. At Augustine State Wildlife Area, visitors can boat, fish, bird watch, and hunt waterfowl. The C&D Canal Conservation and Wildlife Areas offer fishing and boating, and also have 15 miles of trails along the canal for walking, biking, and horseback riding with wetland views. Fort DuPont State Park has a boat ramp for boating and fishing. Delawareans can enjoy and learn about wetlands at the Port Penn Interpretive Center and Wetlands Trail. Runners, walkers, and bikers can also view many wetlands while exercising along the Jack A. Markell Trail.

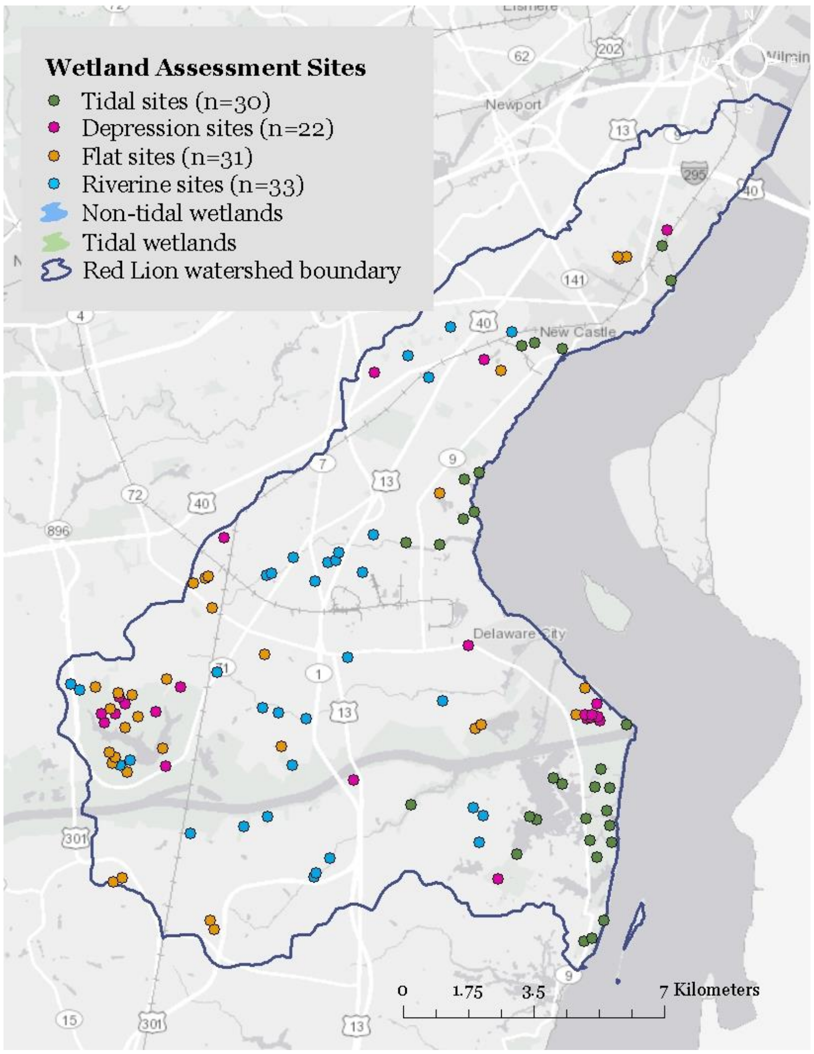
METHODS

Changes to Wetland Acreage

Historic wetland acreage in the Red Lion watershed was estimated using a combination of 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 SWMP (State of Delaware 2007). More recent trends in wetland acreage were determined from SWMP spatial data, which classified mapped wetland polygons as ‘lost’, ‘gained’, or otherwise ‘changed’ from 1992 to 2007 (State of Delaware 2007 and Tiner et al. 2011). Both vegetated and non-vegetated wetlands were included in this desktop analysis. Vegetated wetlands were those classified as being dominated by forest, scrub-shrub, emergent, or aquatic bed vegetation. Non-vegetated wetlands were those classified as having little to no vegetation, including unconsolidated bottom or shore.

Field Site Selection

Our goal was to sample 30 tidal sites and 30 non-tidal sites in each common HGM class (riverine, flat, and depression) for a total of 120 sites. To accomplish this, the EPA’s Ecological Monitoring and Assessment Program (EMAP) in Corvallis, Oregon selected a target population from all natural vegetated wetlands within the Red Lion watershed from the 2007 National Wetland Inventory (NWI) maps (USFWS 2020). EMAP selected 210 potential sample sites in estuarine emergent wetlands, 120 potential sample sites in palustrine tidal emergent wetlands, and 570 potential sample sites in vegetated non-tidal palustrine wetlands using a generalized random tessellation stratified design. This design eliminates selection bias (Stevens and Olsen 1999, 2000). Study sites were randomly-selected points within mapped wetlands, with each point having an equal probability of being selected. We only considered sample sites from the estuarine and non-tidal palustrine sample pools because tidal palustrine wetlands were not our initial focus. However, nearly half of the sites that we assessed that were mapped as estuarine turned out to be tidal palustrine upon field



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

visitation. Fortunately, MidTRAM v.4.1(see '*Assessing Tidal Wetland Condition'* below) allowed us to assess both estuarine and tidal palustrine wetlands, so hereafter we report these wetland types together as 'tidal wetlands.' Non-vegetated wetlands were not included in the sample population and were not assessed because Delaware's wetland condition assessment protocols are only designed to assess natural, vegetated wetlands.

Once the full list of potential sample sites was created, 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). Several sites were sampled as reference sites early in the summer in order to gain a better understanding of the full range of wetland condition in the watershed. In total, 30 tidal, 31 flat, 33 riverine, and 22 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 'Wetland Condition and Value Data Analysis' section below for details). Reference sites were excluded from statistical analyses.

Data Collection

Landowner Contact and Site Access

We obtained landowner permission prior to assessing all sites. We identified landowners using county tax records and mailed each landowner a postcard providing a brief description of the study goals, sampling techniques, and our contact information. They were encouraged to contact us with any questions or concerns regarding site access, data collection, and reporting. If a contact number was available, we followed the mailings with a phone call to discuss the site visit and secure permission. If permission was denied, the site was dropped and not visited. Sites were also dropped if a landowner could not be identified or if landowner contact information was unavailable. Reasonable efforts were made to reach all points, but sites were deemed inaccessible and were subsequently dropped if the site was unsafe to visit for any reason (e.g. severe terrain, deep water, infestation with poisonous plants). Some sites that were selected using the EMAP design were determined upon visitation to be uplands or open water rather than vegetated wetlands, and such sites were dropped because they were not in the target sampling population.

Assessing Tidal Wetland Condition

Tidal wetland condition was evaluated using MidTRAM v.4.1 protocol (Rogerson and Haaf 2017). MidTRAM was updated to v.4.1 to include accurate assessment of tidal palustrine wetlands, as it was previously only appropriate for estuarine wetlands. MidTRAM consists of 13 scored metrics that represent the condition of the wetland buffer, hydrology, and habitat characteristics (Table 4). 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. With assistance from PDE, we used MidTRAM v.4.1 to complete assessments in 2017 at 30 tidal sites. Prior to field assessments, we produced site maps and calculated several buffer metrics (Table 4) using ArcMap GIS software (ESRI, Redlands, CA, USA). All metrics measured in the office were field-verified to confirm accuracy.

We navigated to 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. The AA buffer area was defined 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 (Rogerson and Haaf 2017).

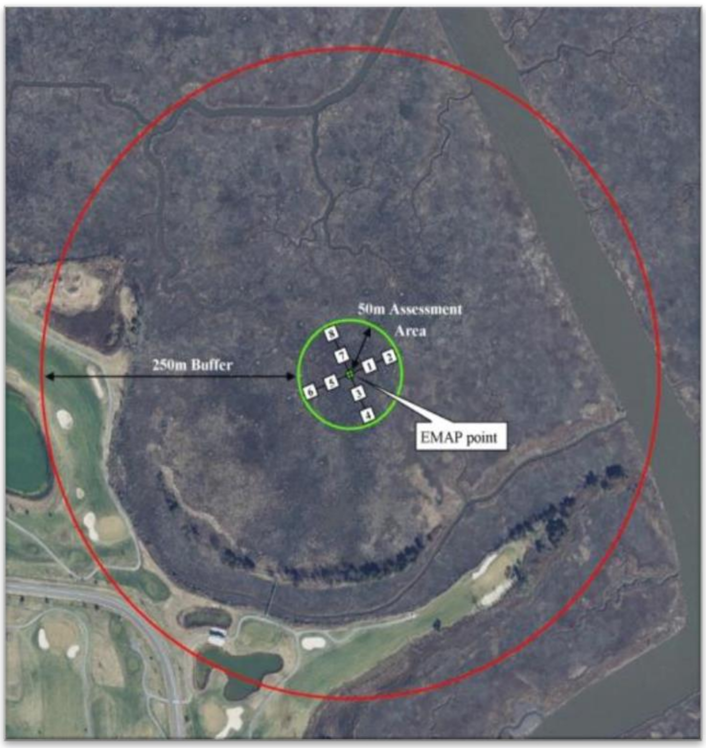


Figure 4. Standard assessment area (AA) in green, subplot locations, and buffer (red) used to collect data for the Mid-Atlantic Tidal Rapid Assessment Method (MidTRAM).

Eight 1m^2 subplots were established along two perpendicular 100m transects that bisected the AA. These subplots were used to measure horizontal vegetative obstruction and soil bearing capacity (Table 4). 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). 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 (Rogerson and Haaf 2017).

After completing the field assessments, the field crew collectively assigned each site a Qualitative Disturbance Rating (QDR) from 1 (least disturbed) to 6 (most disturbed) using best professional judgements (category descriptions can be found in Appendix A). All quantitative and qualitative metrics were rated as a 3, 6, 9, or 12 based on metric thresholds, where 3 was indicative of poorest metric condition and 12 was indicative of highest metric condition. A normalized final score was then computed using metric ratings, which provides a quantitative description of tidal wetland condition out of a total of 100 points (Rogerson and Haaf 2017). Statistical analysis of tidal wetland data was performed by WMAP using Microsoft Excel and R version 3.3.2.

Table 4. Metrics measured with the Mid-Atlantic Tidal Rapid Method (MidTRAM) Version 4.1.

Attribute Group	Metric Name	Description	Measured in AA or Buffer
Buffer/Landscape	Percent of AA Perimeter with 10m-Buffer	Percent of AA perimeter that has at least 5m of natural or semi-natural condition land cover that is at least 10m in width	Buffer
Buffer/Landscape	Contiguous Natural Land Use	Percent of the buffer area that is contiguous between the AA and 250m buffer edge and in a natural or semi-natural state	Buffer
Buffer/Landscape	Surrounding Altered and High Impact Land Use	Percent of the buffer area that is an altered or high impact land use	Buffer
Buffer/Landscape	250m Landscape Condition	Landscape condition within 250m surrounding the AA based on the nativeness of vegetation, disturbance to substrate and extent of human visitation	Buffer
Buffer/Landscape	Barriers to Landward Migration	Percent of landward perimeter of wetland within 250m that has physical barriers preventing wetland migration inland	Buffer
Hydrology	Ditching and Excavation (OMWM) or Point Sources	The presence of ditches or OMWM in the AA of estuarine wetlands, or the presence of point sources in tidal palustrine wetlands	AA
Hydrology	Fill	The presence of fill or wetland fragmentation from anthropogenic sources in the AA	AA
Hydrology	Diking and Tidal Restriction	The presence of dikes or other tidal flow restrictions	AA and Buffer
Habitat	Bearing Capacity	Soil resistance using a slide hammer	AA subplots
Habitat	Horizontal Vegetative Obstruction	Visual horizontal obstruction by vegetation at 0.25-1.25m heights measured in 0.25 intervals with a cover board	AA subplots
Habitat	Number of Plant Layers	Number of plant layers in the AA based on plant height	AA
Habitat	Species Richness	Count of plant species found in the AA	AA
Habitat	Percent Invasive	Percent cover of invasive species in the AA	AA

Assessing Non-tidal Wetland Condition

The WMAP used the Delaware Rapid Assessment Procedure (DERAP) v.6.0 to assess the condition of non-tidal palustrine wetlands based on the presence and intensity of stressors related to habitat, hydrology, and buffer elements (Table 5; Jacobs 2010). DERAP was followed to collect data at 31 flat sites, 33 riverine sites, and 22 depression sites in the Red Lion watershed in 2017 with the assistance of PDE staff. Prior to field assessments, we produced site maps and calculated several buffer metrics (Table 5) 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 (green) and buffer (red) used to collect data for the Delaware Rapid Assessment Procedure (DERAP) v.6.0.

We navigated to the 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 5) were documented during one field visit during the growing season (June 1- September 30). Similar to MidTRAM, field investigators collectively assigned the wetland a Qualitative Disturbance Rating from 1 (least disturbed) to 6 (most disturbed; Appendix A) based on best professional judgements. Statistical analysis was performed using Microsoft Excel and R version 3.3.2.

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. Tier 3, more detailed assessment data) without over-fitting the model to a specific dataset (Jacobs et al. 2009). Coefficients, or stressor weights, associated with each stressor were assigned using multiple linear regression (Appendix C). This process allowed for effective screening and selection of stressor variables that best represent wetland condition for each HGM class. The DERAP Index of Wetland Condition (IWC) score is calculated by summing the stressor coefficients for each of the selected stressors that were present and subtracting the sum from the linear regression intercept for that HGM type:

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

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

Example: Site D

Forested flat wetland with 25% of AA clear cut (weight 19), 1-5% invasive plant cover (weight 0), moderate ditching (weight 10), and commercial development in the buffer (weight 3):

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

DERAP condition score = 63

Table 5. 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 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	Depth and abundance of ditches within and adjacent to the AA (flats and depressions only)	AA and Buffer
Hydrology	Stream Alteration	Evidence of stream channelization or natural channel incision (riverine only)	AA
Hydrology	Weir/Dam/Roads	Man-made structures impeding 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 or Waste Disposal	Reoccurring municipal or private waste disposal	Buffer
Buffer	Channelized Streams or Ditches	Channelized streams or ditches >0.6m deep	Buffer
Buffer	Poultry or Livestock Operation	Poultry or livestock rearing operations	Buffer
Buffer	Forest Harvesting within 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, or Orchards	Agricultural land cover, excluding forestry plantations	Buffer
Buffer	Mowed Area	Any reoccurring activity that inhibits natural succession	Buffer
Buffer	Sand/Gravel Operation	Presence of sand or gravel extraction operations	Buffer

Assessing Non-tidal Wetland Value

The local values that wetlands provide may be independent of wetland condition and function (Rogerson and Jennette 2014). Thus, a value-added assessment protocol can provide additional information that, when used in conjunction with condition results from DERAP, can provide managers with a more complete picture for decision making purposes. We performed value-added assessments at non-tidal palustrine wetland sites in conjunction with the DERAP assessment using v.1.1 of the Value-Added Assessment Protocol (Rogerson and Jennette 2014). The purpose of this assessment was to evaluate the local ecological value that a wetland provides to the local landscape by assessing 7 value metrics (Table 6). Metric scores were tallied to produce a final score that ranged from 0 to 100. Categories and category thresholds for final scores are shown in Table 7. Statistical analysis was performed using Microsoft Excel and R version 3.3.2. This protocol was designed for non-tidal wetlands only and was therefore not used for tidal wetlands.

Table 6. Value metrics scored according to v.1.1 of the Value-Added Assessment Protocol.

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

Table 7. 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 and Value Data Analysis

The EMAP sampling method is designed to allow inference about a whole population of resources from a random sample of those resources. In accordance with EMAP design statistical procedures, we used a cumulative distribution function (CDF) to show wetland condition on the population level (Diaz-Ramos et al. 1996). A CDF is a visual tool that extrapolates assessment results from a sample to the entire watershed population. It can be interpreted by drawing a horizontal line anywhere on the graph and reading that as: 'z' proportion of the area of 'x wetland type' in the watershed falls above (or below) the score of 'w' for wetland condition. Points can be placed anywhere on the graph to determine the percent of the population that is within the selected conditions. For example, in Figure 6, approximately 55% of the wetland area scored above 81 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, there is a condition cliff around 73 and 74, illustrating that a relatively large proportion of the population had condition scores in this range. In contrast, the plateau from about 67 and below indicates that a small proportion of the wetland population scored in this range.

Medians of MidTRAM or DERAP final scores are presented in addition to means, as the final scores of flat and riverine wetlands were not normally distributed (Shapiro-Wilk normality test, $\alpha=0.05$; tidal: $W=0.94$, $p=0.08$; flat: $W=0.93$, $p=0.04$; riverine: $W=0.85$, $p<0.01$; depression: $W=0.97$, $p=0.61$). Depression final value-added scores were also not normally distributed (Shapiro-Wilk normality test, $\alpha=0.05$; flat: $W=0.98$, $p=0.74$; riverine: $W=0.94$, $p=0.05$; depression: $W=0.80$, $p<0.01$). When data are not normally distributed, the median is a better descriptor of the central tendency of the data than the mean.

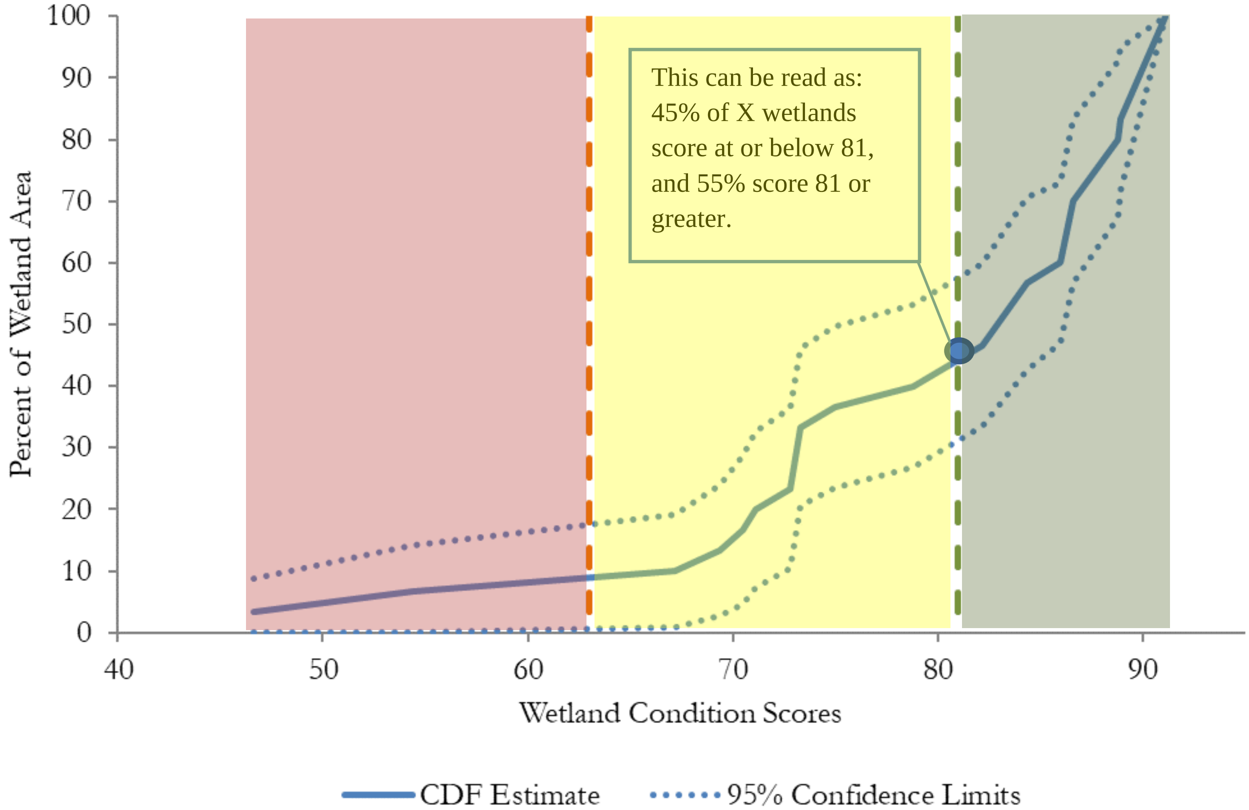


Figure 6. An example CDF showing wetland condition. The solid blue line is the population estimate and the dashed blue lines are 95% confidence intervals. Colored blocks show condition category ranges, where red is severely stressed, yellow is moderately stressed, and green is minimally stressed. The orange and green dashed lines show the numeric breakpoints between condition categories.

Sites in each HGM subclass were placed into 3 condition categories: Minimally Stressed, Moderately Stressed, or Severely Stressed (Table 8). Condition class breakpoints were determined by applying a percentile calculation to the QDRs and condition scores from sites in several watersheds that were assessed previously (Jacobs 2010, Rogerson and Haaf 2017). Minimally stressed sites are those with a condition score greater than the 25^{th} percentile of sites assigned a QDR of 1 or 2. Severely stressed sites are those with a condition score less than the 75^{th} percentile of sites assigned a QDR of 5 or 6. Moderately stressed sites are those that fall in between. The condition breakpoints that we applied in the Red Lion watershed are provided in Table 8.

Table 8. Condition categories and breakpoint values for tidal and non-tidal wetlands in the Red Lion watershed as determined by wetland condition scores, where 'x' denotes a condition score in each listed inequality.

Wetland Type	Method	Minimally Stressed	Moderately Stressed	Severely Stressed
Tidal	MidTRAM	$x \geq 81$	$81 > x \geq 63$	$x < 63$
Flat	DERAP	$x \geq 88$	$88 > x \geq 65$	$x < 65$
Riverine	DERAP	$x \geq 85$	$85 > x \geq 47$	$x < 47$
Depression	DERAP	$x \geq 73$	$73 > x \geq 53$	$x < 53$

Wetland Health Report Card

Information reported here was used to create a wetland health report card that provides a clear, concise summary of wetland health and management recommendations in the Red Lion watershed for the general public. The watershed report card is easily accessible online (see pg. 56 for link). In the report card, wetland health was portrayed in a symbolic and colorful manner to make the data clear and understandable for the general public. This involved converting wetland health scores from this report into letter grades, symbols, and color-coded health categories.

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. These overall grades were calculated by dividing average final MidTRAM (tidal) or DERAP (non-tidal) scores for each HGM type by the maximum possible MidTRAM or DERAP score for each type. Tidal wetlands received a D-; flat wetlands, a B-; riverine wetlands, a B-; and depressions wetlands, a D. The whole watershed was assigned a letter grade of D+, which was calculated by multiplying overall 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. All report card grades are listed in Table 9, and the letter grade scale used can be seen in Appendix D.

Table 9. Report card grades by wetland type and overall watershed. Grades are listed as final overall grades for each type, as well as by attribute category.

HGM Type	Overall Grade	Habitat Grade	Hydrology Grade	Buffer Grade
Tidal	D-	D-	A	F
Flat	B-	A	C	C
Riverine	B-	B	A	D
Depression	D	D	B+	C
Overall watershed	D+	.	.	.

The habitat and hydrology attribute categories for each non-tidal wetland type were also given letter grades by dividing total stressor sums for each category by the total possible stressor category sum, and then converting it to a 0 to 100 scale. Letter grades were assigned to non-tidal buffers by averaging the buffer stressor tally for each wetland type (i.e., the number of buffer stressors rather than stressor weights) and comparing that average to a grading scale that was designed specifically for non-tidal buffers (see Appendix D). Tidal stressors were already on a 0 to 100 scale, so letter grades were simply based on the overall averages for each attribute category. To make the report cards more effective as visual aids, attribute categories (i.e. habitat, hydrology, and buffer) were color-coded based on letter grades, where each color represented a qualitative health category ranging from excellent to very poor (see Appendix D). The symbols that were used in the report card for habitat, hydrology, and buffer were all used in the results section of this report as well to provide a clearer link between this report and the report card. A key to the symbols and their meanings are shown in Table 10.

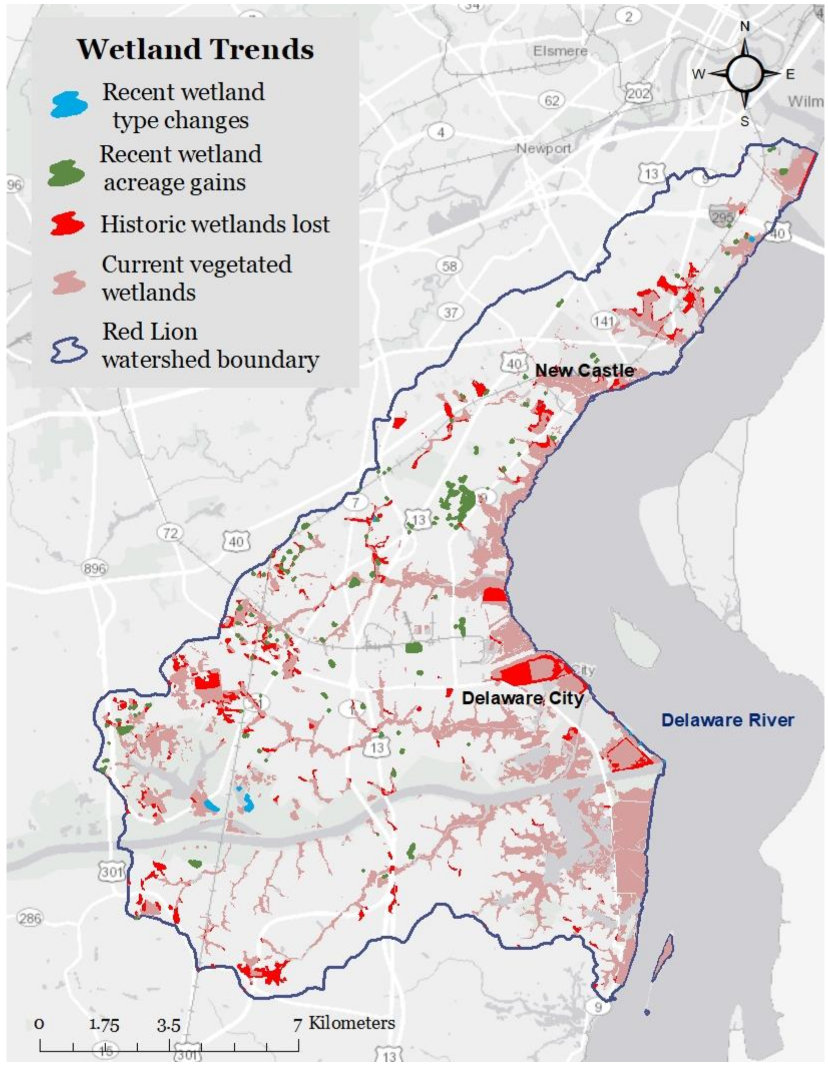
Table 10. Symbols and their meanings for each attribute category.

Category	Symbol
Habitat	
Hydrology	
Buffer	

Wetland Acreage

The Red Lion watershed contained an estimated 11,362.5 acres of wetlands prior to human settlement in the early 1700's. Approximately 1,375.4 acres were lost or destroyed prior to 1992, while an additional 44.6 acres were lost between 1992 and 2007. Altogether, this indicates that about 12.5% of historic wetland acreage has been lost in this watershed up to 2007. These wetland losses were due mainly to human development scattered throughout the watershed (Map 6, Table 11).

Most wetlands that were lost between 1992 and 2007 were destroyed because of development (42.7 acres), such as housing developments or highways. Many of the wetlands that were lost were vegetated non-tidal flats (20.3 acres) or non-vegetated ponds (14.7 acres). Others were non-tidal riverine wetlands (6.1 acres) or tidal palustrine wetlands (1.6 acres; see example in Figure 7). No depressions or estuarine wetlands were lost during that time period. Some non-vegetated ponds were also lost to transitional land that was in the process of being converted to some form of development (1.9 acres; Map 6, Table 11).



Map 6. Wetland trends over time in the Red Lion watershed. Recent wetland types changes and wetland acreage gains are those that occurred between 1992 and 2007. Historic wetlands lost are all estimated losses that occurred over time up to 2007. Current wetlands include all vegetated wetlands as of 2007.

In the same time frame, the Red Lion watershed gained 178.6 acres of wetlands, meaning that the watershed experienced a net gain of 134.1 acres of wetlands (Table 11). Wetlands were created in developed areas (8.5 acres), on agricultural lands (80.2 acres), on rangeland (38.7 acres), on forested land (14.5 acres), and on transitional land (36.7 acres). Despite the net acreage gain, functional gain was probably very limited because a high proportion of the new wetlands (157.9 acres; 88.4% of gained acreage) were non-vegetated retention ponds with unconsolidated bottom. Others gained wetlands were ponds with aquatic bed habitat (16.8 acres; 9.4% of gained acreage). A very small proportion (3.9 acres; 2.2% of gained acreage) of gained wetlands were classified as depressions with emergent vegetation. All those depressions appeared severely degraded in aerial imagery, did not resemble natural depression wetlands, and lacked natural buffers. Depressions were either within stormwater retention ponds in developed areas with very low water levels or were within sediment extraction operations.

Table 11. Wetland acreage gains, losses, and changes in the Red Lion watershed between 1992 and 2007. Values and categories are based on those in 2007 SWMP spatial datasets. Natural, vegetated wetlands are listed by type. Ponds include mapped areas that were classified as unconsolidated bottom or aquatic bed habitats and that visually resembled ponds in aerial imagery.

Wetland Type	Gain (acres)	Loss (acres)	Change (acres)
Estuarine	0	0	0.1
Palustrine Tidal	0	1.6	0
Flat	0	20.3	0.9
Riverine	0	6.1	1.4
Depression	2.8	0	6.9
Ponds (Non-vegetated or aquatic bed)	175.8	16.6	9.0
Total	178.6	44.6	18.3

Figure 7. An example of a wetland loss between 1992 and 2007. In 1992, there was a forested wetland present, outlined in green (left). By 2007, the wetland was lost to development (right).

A total of 18.3 acres were classified as 'changed' in the Red Lion watershed between 1992 and 2007 (Map 6, Table 10). Such areas changed from one wetland type to another in that time period. Many of these changes resulted in a loss of vegetated wetlands as wetlands were converted to open water habitats. For example, 6.9 acres of wetlands that were non-tidal depressions in 1992 became unconsolidated bottom habitat in 2007. Some flat (0.9 acres) and riverine wetlands (1.4 acres) were converted to non-vegetated retention ponds. Additionally, a small amount of estuarine wetlands (0.1 acres) along the coast of the Delaware Bay were converted to open water, meaning that they were likely lost because of erosion or sea level rise.

Other changes resulted in small gains in vegetated wetlands. One area (1.0 acre) that was unconsolidated bottom habitat in 1992 became a vegetated tidal palustrine wetland by 2007. Similarly, another area (8.0 acres) that was unconsolidated bottom changed to a vegetated flat wetland.

Landowner Contact and Site Access

In total, 286 non-tidal sites were considered, where 193 sites were dropped (67.4%) and 93 sites were assessed (32.6%). Seven of the 93 sites that were assessed were reference sites; data was collected there, but reference sites were dropped from condition analyses. Many non-tidal sites were dropped because we were denied landowner permission to access them (21.3%), or because they were not wetlands (22.4%). Other sites were dropped after being deemed inaccessible (13.6%) either because of unsafe conditions or because the landowner could not be contacted. Some visited sites were also dropped because they were not target wetlands for our assessment (10.1%). A total of 53 tidal sites were considered. Over half (56.6%) of those sites were assessed in the field. Most of the sites that were dropped were non-target wetlands (17.0%). Other tidal sites were dropped because they were inaccessible (15.1%), we were denied permission to access (9.4%), or they were not wetlands (1.9%; Figure 8).

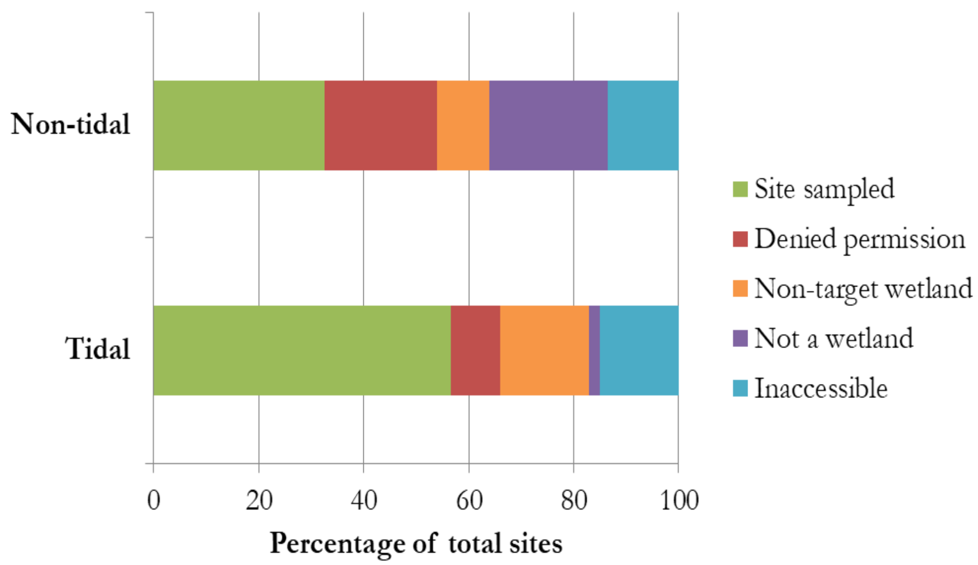


Figure 8. Sampling success for non-tidal and tidal wetlands in the Red Lion watershed. Shown are percentages of the total number of sites that we attempted to sample for each class (non-tidal: n=286; tidal: n=53).

A total of 116 wetland sites were assessed and analyzed in the Red Lion watershed. The majority of these sites were privately owned (56.0%). Ownership percentages varied greatly by wetland type. Tidal wetlands were evenly split, as half were privately owned, and half publicly owned. Flat wetland ownership was very similar to overall wetland ownership, where 45.2% were publicly owned, and 54.8% were privately owned. Private ownership was dominant among riverine wetlands (84.8% private), whereas public ownership was dominant among depressions (77.3% public; Table 12).

Table 12. Ownership of wetland sites that were assessed and analyzed in the Red Lion watershed (does not include reference sites).

Wetland Type	Public (%)	Private (%)
All combined	44.0	56.0
Tidal	50.0	50.0
Flat	45.2	54.8
Riverine	15.2	84.8
Depression	77.3	22.7

Wetland Condition and Value

Tidal wetlands

The sampled tidal wetlands in the Red Lion watershed (n=30) were tidal palustrine marsh (56.7%), high estuarine marsh (40.0%), or low estuarine marsh (3.3%). Plant species that were commonly found within estuarine wetlands were saltmarsh cordgrass (*Spartina alterniflora*), big saltmarsh cordgrass (*Spartina cynosuroides*), European reed (*Phragmites australis australis*, hereafter *P.australis*), narrow-leaf cattail (*Typha angustifolia*), Walter's barnyard grass (*Echinochloa walteri*), and various smartweeds (*Persicaria spp.*). In tidal palustrine wetlands, some of the most widespread plant species included European reed (*P. australis australis*), various smartweeds (*Persicaria spp.*), Walter's barnyard grass (*E. walteri*), narrow-leaf cattail (*T. angustifolia*), arrow arum (*Peltandra virginica*), and broadleaf arrowhead (*Sagittaria latifolia*).

Most estuarine wetlands were severely stressed (63.3%), followed by minimally stressed (20.0%) and moderately stressed (16.7%; Figure 9). On average, tidal wetlands in this watershed scored 61.1 ± 15.2 total out of 100 possible points (median=59.6), with scores ranging from 35.6 to 86.7. In terms of attribute categories, estuarine wetlands scored the highest on average for hydrology, and much lower for buffer and habitat. A wide range of overall scores was observed for habitat, hydrology, and buffer (Table 13). Minimally stressed tidal wetlands frequently contained invasive species, had low species richness and few plant layers, had low marsh stability, and had poor surrounding landscape condition and limited contiguous natural buffer. Moderately stressed tidal wetlands were characterized by the same main stressors, but also by fill in the wetland and by disturbed 10m buffer, high-impact land uses in the surrounding landscape, and barriers to landward migration in

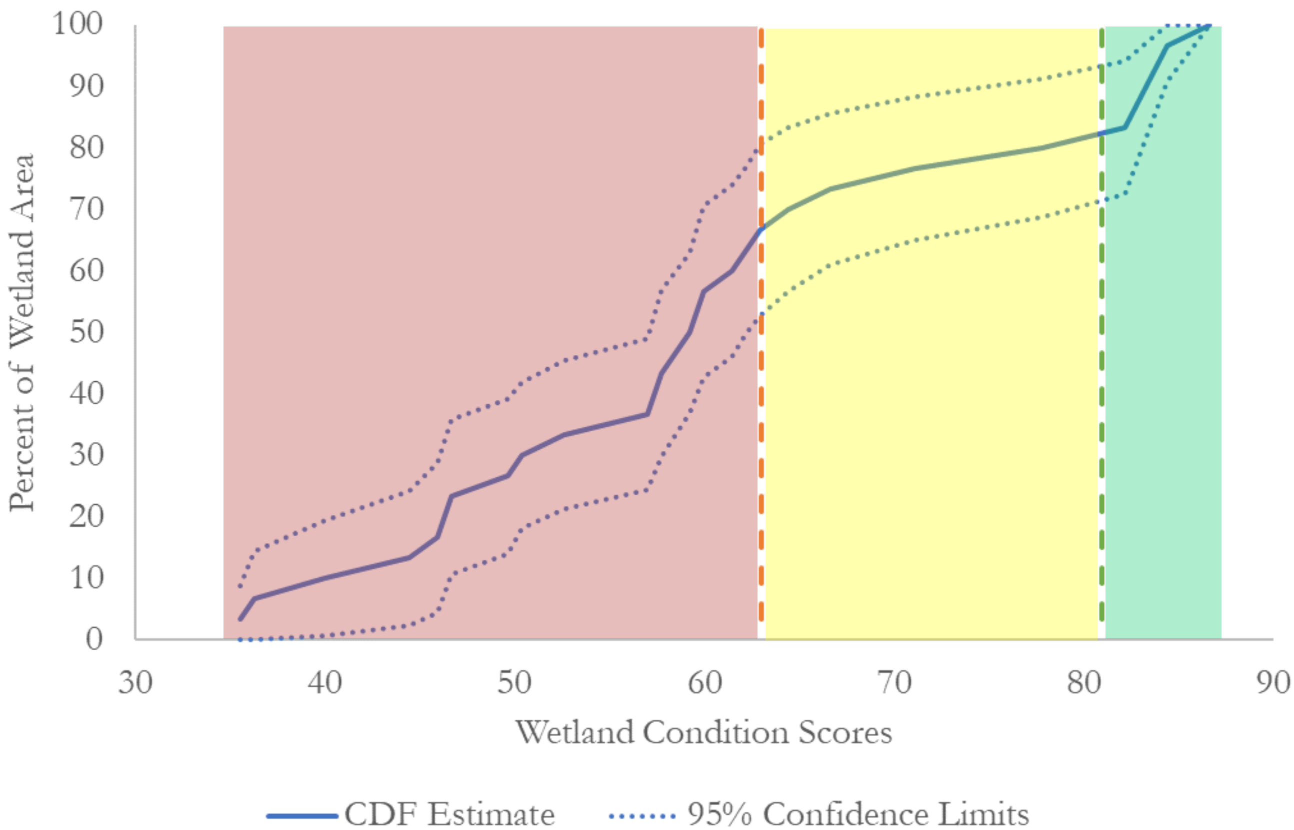


Figure 9. Cumulative distribution function (CDF) for tidal wetlands in the Red Lion watershed. The solid blue line is the population estimate and the dashed blue lines are 95% confidence intervals. Colored blocks show condition category ranges, where red is severely stressed, yellow is moderately stressed, and green is minimally stressed. The orange and green dashed lines show the numeric breakpoints between condition categories.

Table 13. Shown are the summary statistics of all tidal wetlands overall (denoted by all 3 attribute symbols), and of each attribute category (denoted by singular attribute symbols; see Table 10 for symbol meanings).

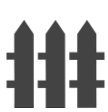
Category	Mean ± S.D.	Median	Range
	61.1 ± 15.2	59.6	35.6-86.7
	57.1 ± 16.7	60.0	26.7-86.7
	82.6 ± 22.0	94.4	22.2-100
	43.6 ± 27.6	40.0	6.7-93.3

the surrounding landscape. Severely stressed wetlands were further impaired by tidal restrictions (Table 13). Data for all sampled tidal wetlands for all assessed metrics can be viewed in Appendix E.

Tidal wetlands scored poorly in terms of habitat in this watershed, where habitat attribute scores ranged from 26.7 to 86.7 and averaged 57.1 ± 16.7 (median=60.0; Table 13). Nearly all wetlands contained invasive species (Table 14), and of those wetlands with invasive species, 51.7% had ≤ 25% invasive cover, 13.8% had 26-50% invasive cover, and 34.5% had >50% invasive cover. The most common invasive species included the European reed (*P. australis australis*) and narrow-leaf cattail (*T. angustifolia*). Another common habitat stressor was low species richness, where 90.0% of wetlands had fewer than 6 species present. Tidal wetlands also often had few plant layers, with 86.7% of wetlands having fewer than 4 plant layers; although, 70.0% of wetlands received the second highest possible score of 9, suggesting only minor stress. Many tidal wetlands had low bearing capacity, or marsh stability, with 83.3% scoring below the highest rating of 12 (Table 14). Many wetlands (33.3%) received the second highest possible score (i.e. score of 9) for marsh stability, suggesting only minor stress. However, 50.0% of wetlands scored poorly (i.e., score of 6 or 3). The only habitat metric that tidal wetlands did not score poorly for was horizontal vegetative obstruction, as 83.3% of wetlands received the highest possible score.

Hydrology attributes of estuarine wetlands scored the highest of all attribute categories, ranging widely from 22.2 to 100 and averaging 82.6 ± 22.0 (median=94.4; Table 13). A third (33.3%) of wetlands had some form of diking or tidal restriction in the form of properly sized dikes or berms. Roughly a quarter (26.7%) of tidal wetlands contained fill (Table 14). Ditching or excavation was present in 30.8% of estuarine wetlands, and point sources were apparent in 23.5% of tidal freshwater wetlands.

Table 14. Listed are the most common stressors (>20% occurrence) in tidal wetlands (see Table 8 for symbol category meanings). Also shown are the occurrence of stressors in each condition category (%min = % minimally stressed; %mod = % moderately stressed; %sev = % severely stressed).

Category	Stressor	% Total (n=30)	% Min (n=6)	% Mod (n=5)	% Sev (n=19)
	Invasive species	96.7	100	100	94.7
	Low species richness	90.0	100	80.0	89.5
	Few plant layers	86.7	100	80.0	84.2
	Low marsh stability	83.3	100	80.0	78.9
	Tidal restrictions	33.3	0.0	0.0	52.6
	Fill material in wetland	26.7	0.0	20.0	36.8
	Poor condition of surrounding landscape	100	100	100	100
	Limited contiguous natural buffer	90.0	50.0	100	100
	Disturbed 10m buffer	80.0	0.0	100	100
	High-impact land uses in buffer	76.7	0.0	100	94.7
	Barriers to Landward Migration	50.0	0.0	20.0	73.7

Tidal wetlands scored most poorly in the buffer category. Buffer attribute scores from sampled wetlands ranged widely from 6.7 to 93.3, with a mean score of 43.6 ± 27.6 (median=40.0; Table 13). Poor condition of the surrounding landscape, resulting from disturbance, was the most prevalent buffer stressor for tidal wetlands, as all wetlands had some form of impact, such as non-native vegetation, soil compaction, human visitation, and/or discharge from polluted sources. The majority of tidal wetlands also suffered from limited contiguous natural buffer, as 90.0% of wetlands did not have a completely natural, contiguous 250m buffer. Similarly, most tidal wetlands (80.0%) did not have a complete natural buffer zone around them that was at least 10 meters wide. The presence of high-impact land uses in the buffer was also a common stressor, with 76.7% of tidal wetlands having at least some unnatural or high-impact land use in the landscape surrounding them (Table 14). Examples of such land use include residential roads, golf courses, agriculture, and development. Half (50.0%) of tidal wetlands had some type of barrier to landward migration in their surrounding landscape.

Non-tidal flat wetlands

Sampled flat wetlands in the Red Lion watershed (n=31; Figure 10) all had mineral soils. More than half (61.3%) were in what are considered old growth forests in Delaware, with tree age estimated to be > 50 years old; all other were forested, but tree age was < 50 years old. Flats had final DERAP scores that ranged from 55.0 to 92.0, with a mean score of 76.7 ± 11.6 (median=79.0) out of a maximum possible score of 95.0. The highest proportion of flats was moderately stressed (51.6%), followed by minimally stressed (25.8%) and severely stressed (22.6%; Figure 11). Minimally stressed flats often contained invasive species and had many buffer disturbances, including agriculture, development, roads, and mowing. In addition to those stressors, moderately and severely stressed wetlands also commonly suffered from roads, ditching, and microtopographic alterations within wetlands (Table 15). Data for all sampled flat wetlands for all assessed metrics can be viewed in Appendix F.

Figure 10. A flat wetland in the Red Lion watershed covered in the invasive plant mile-a-minute.

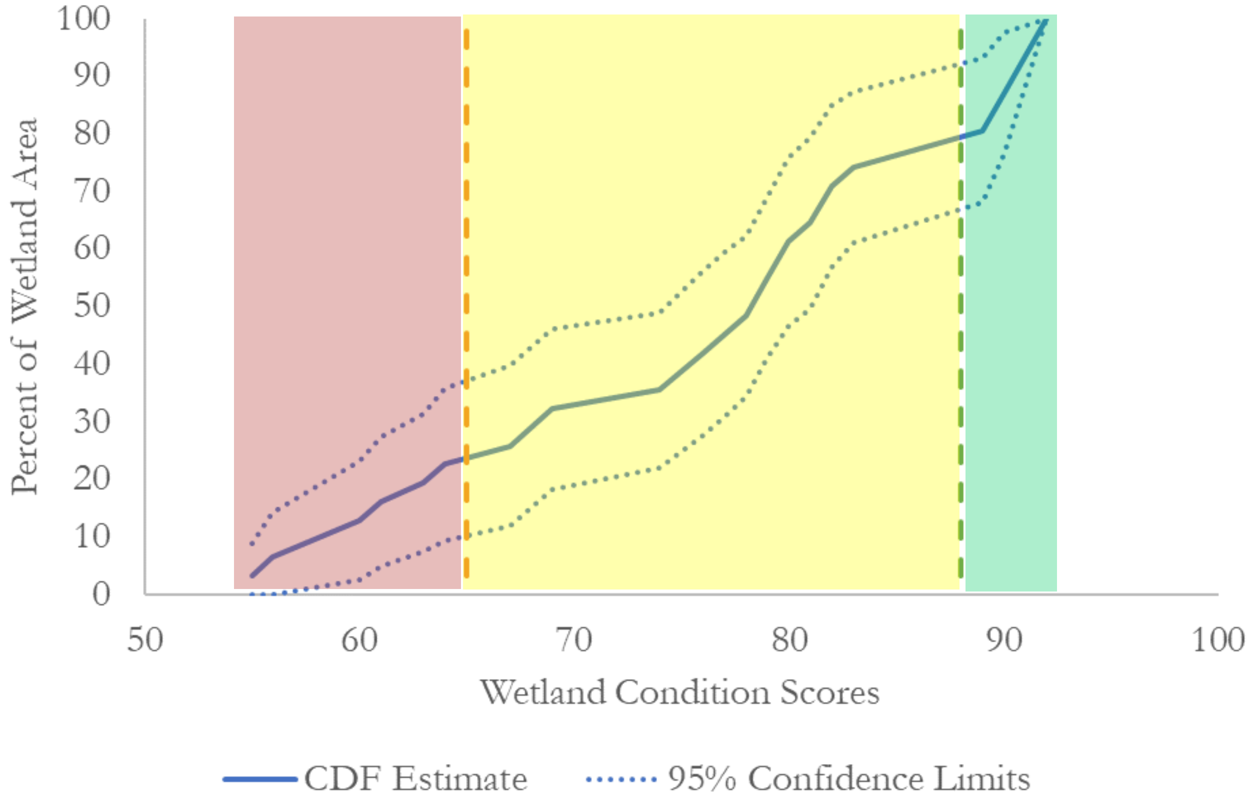


Figure 11. Cumulative distribution function (CDF) for non-tidal flat wetlands in the Red Lion watershed. The solid blue line is the population estimate and the dashed blue lines are 95% confidence intervals. Colored blocks show condition category ranges, where red is severely stressed, yellow is moderately stressed, and green is minimally stressed. The orange and green dashed lines show the numeric breakpoints between condition categories.

Invasive plants were found in 80.6% of flats, making it the most widespread issue in flat wetlands, and by far the worst habitat stressor. Species that were detected were multiflora rose (*Rosa multiflora*), Oriental bittersweet (*Celastrus orbiculatus*), reed canary grass (*Phalaris arundinacea*), mile-a-minute (*Persicaria perfoliate;* Figure 10), and wineberry (*Rubus phoenicolasius*). Of the flats that had invasive plants, most (52.0%) had 6-50% cover, followed by > 50% cover (20.0%), < 1% cover (16.0%), and 1-5% cover (12.0%). Roads were also common habitat stressors, as they were present in 25.8% of flats (Table 15). Of the wetlands that contained roads, most had non-elevated logging, dirt, or ATV roads (62.5%), while others had elevated dirt or gravel roads (12.5%), paved roads (12.5%), or both elevated and paved roads (12.5%). All other habitat stressors, including forest harvesting or management, vegetation alteration, excessive herbivory, and dense algal mats, had relatively low occurrence in flat wetlands in this watershed (i.e., <10% occurrence).

Ditches were the most common hydrology stressors in flat wetlands, and were found in 51.6% of flats. Of the wetlands with ditches, 56.3% were considered slight, 25.0% moderate, and 18.7% severe in terms of depth, frequency, and conveyance of water. Microtopographic alterations, such as skidder tracks, were also predominant stressors, and were present in 35.5% of flats (Table 15). Of these wetlands, most had < 10% cover of microtopographic alterations (54.5%), and the rest had 10-75% cover (45.5%). Fill was present in 19.4% of flats, representing a somewhat common hydrology stressor. Fifty percent of flats with fill had <10% cover of fill, while the other 50.0% had 10-75% cover. All other hydrology stressors, including weirs, dams, or roads, stormwater inputs, and point sources, had relatively low occurrence in flat wetlands in this watershed (i.e. <10% occurrence).

Table 15. Listed are the most common stressors (>20% occurrence) in flat wetlands (see Table 10 for symbol category meanings). Also shown are the occurrence of stressors in each condition category (%min = % minimally stressed; %mod = % moderately stressed; %sev = % severely stressed).

Category	Stressor	% Total (n=31)	% Min (n=8)	% Mod (n=16)	% Sev (n=7)
	Invasive species	80.6	62.5	81.3	100
	Roads	25.8	0.0	31.3	42.9
	Ditching	51.6	0.0	62.5	85.7
	Microtopographic alterations	35.5	0.0	43.8	57.1
	Development in surrounding landscape	45.2	37.5	50.0	42.9
	Roads in surrounding landscape	35.5	50.0	31.3	28.6
	Agriculture in surrounding landscape	32.3	25.0	18.8	71.4
	Mowing in surrounding landscape	29.0	25.0	25.0	42.9

Development was the most widespread buffer stressor in the landscape surrounding flat wetlands. It was found around 45.2% of flats, and of those wetlands, 71.4% were surrounded by residential development, and 28.6% were surrounded by commercial or industrial development. Roads were the next most common buffer stressors, and were in the landscape surrounding 35.5% of flats. Of those wetlands, 63.6% had 2-lane roads, and 36.4% had dirt or gravel roads. Other prevalent buffer stressors were agriculture and mowing, which was in the landscape surrounding 32.3% and 29.0% of flats, respectively (Table 15). Stream channelization was somewhat common, as it was detected around 19.4% of flat wetlands. All other buffer stressors, including landfill or waste disposal, poultry or livestock operations, recent forest harvesting, golf courses, and sand or gravel operations, had relatively low occurrence in flat wetlands in this watershed (i.e., <10% occurrence).

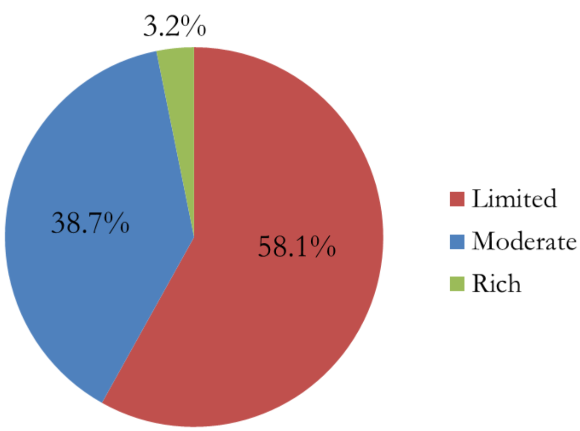


Figure 12. Proportion of flat wetlands in each value added category.

Most flat wetlands were rated as providing limited value (58.1%), followed by moderate (38.7%) and rich value (3.2%; Figure 12). Scores ranged from 13 to 47 out of a maximum possible score of 100, and on average scored 27.3 ± 8.9 (median=27.0). Overall, flats provided the most added value in terms of habitat availability. They also provided some value, though relatively less, in habitat structure and complexity, and being within the DEN (i.e., within ecologically important corridors). Flat wetlands provided low value for uniqueness or local significance, wetland size, flood storage and water quality, and education potential.

Non-tidal riverine wetlands

Figure 13. A riverine wetland in the Red Lion watershed.

Riverine wetlands in the Red Lion watershed (Figure 13) that were sampled (n=33) were all classified as being along first or second order upper perennial streams. Most (87.9%) were in old growth forests, with average tree age estimated to be >50 years old. Riverine wetlands had final DERAP scores that ranged widely from 46.0 to 90.0, with a mean score of 75.0 ± 12.5 (median=83.0) out of a maximum possible score of 91.0. The highest proportion of these wetlands was moderately stressed (75.8%), followed by minimally stressed (21.2%), leaving a small proportion severely stressed (3.0%; Figure 14). Minimally and moderately stressed riverine wetlands often contained invasive species and had many buffer disturbances, including development, agriculture, roads, and mowing. Severely stressed wetlands were characterized by some of these stressors as well, though interestingly, severely stressed wetlands lacked agriculture and mowing in their buffers (Table 16). Data for all sampled riverine wetlands for all assessed metrics can be viewed in Appendix G.

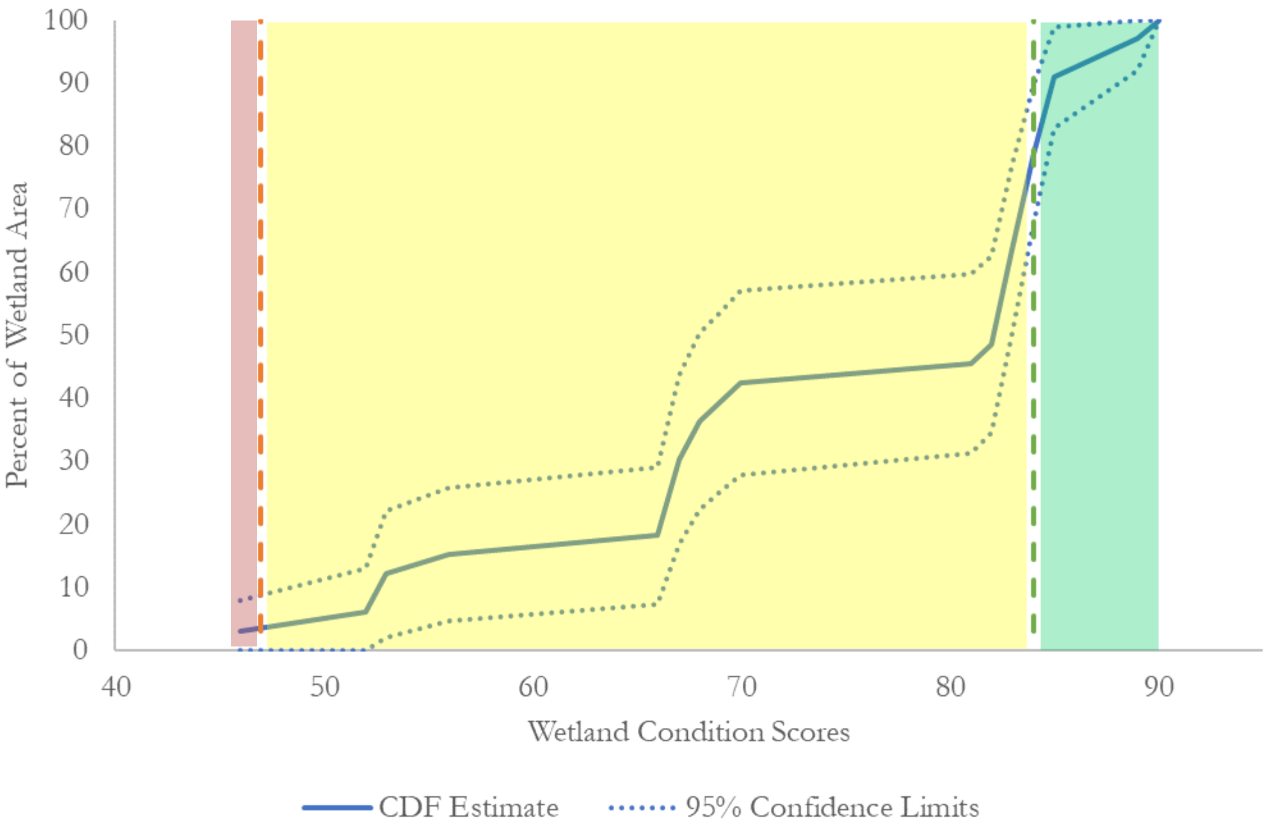


Figure 14. Cumulative distribution function (CDF) for non-tidal riverine wetlands in the Red Lion watershed. The solid blue line is the population estimate and the dashed blue lines are 95% confidence intervals. Colored blocks show condition category ranges, where red is severely stressed, yellow is moderately stressed, and green is minimally stressed. The orange and green dashed lines show the numeric breakpoints between condition categories.

Table 16. Listed are the most common stressors (>20% occurrence) in riverine wetlands (see Table 10 for symbol category meanings). Also shown are the occurrence of stressors in each condition category (%min = % minimally stressed; %mod = % moderately stressed; %sev = % severely stressed).

Category	Stressor	% Total (n=33)	% Min (n=7)	% Mod (n=25)	% Sev (n=1)
	Invasive species	90.9	57.1	100	100
	Roads in surrounding landscape	63.6	14.3	76.0	100
	Development in surrounding landscape	54.5	14.3	64.0	100
	Agriculture in surrounding landscape	42.4	57.1	40.0	0.0
	Mowing in surrounding landscape	33.3	42.9	32.0	0.0

The presence of invasive plant species was the most common stressor for this wetland type, which was found in 90.9% of riverine wetlands (Table 16). Invasive species that were detected were Japanese stiltgrass (*M. vimineum*), Japanese honeysuckle (*L. japonica*), European reed (*P. australis australis*), multiflora rose (*R. multiflora*), reed canary grass (*P. arundinacea*), Oriental bittersweet (*C. orbiculatus*), mile-a-minute (*P. perfoliata*), privet (*Ligustrum spp.*), and garlic mustard (*Alliaria petiolata*). Of the riverine wetlands that had invasive plants, most (46.7%) had 6-50% cover, followed by > 50% cover (33.3%), 1-5% cover (16.7%), and <1 % (3.3%). Roads were present within 12.1% of wetlands, representing a much less pervasive habitat stressor for riverine wetlands. Forest harvesting or management, vegetation alteration, excessive herbivory, and dense algal mats were not present in any riverine wetlands.

Fortunately, hydrology stressors were relatively uncommon, and none had an overall occurrence above 20% (Table 16). Stream alteration was found in 12.1% of riverine wetlands, and of those wetlands, 75.0% had spoil banks and 25.0% had natural incision. Some wetlands (12.1%) had storm water inputs. Few had fill or excavation (6.1%), with half of those wetlands having <10% cover of fill, and half having 10-75% cover. Microtopographic alterations were infrequent (6.1%), with those wetlands having alterations either having <10% cover of alterations (50.0%), or having soil subsidence and root exposure (50.0%). Only 3.0% of riverine wetlands had weirs, dams, or roads that were affecting water movement, and in those wetlands, such structures were only impounding the water in <10% of the wetland. Very few wetlands (3.0%) had point sources or excessive sedimentation.

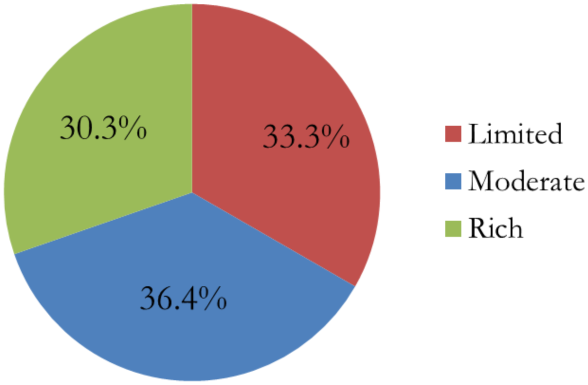


Figure 15. Proportion of riverine wetlands in each value added category.

On the other hand, many riverine wetlands had buffer stressors in the landscapes surrounding them. Roads were the most common buffer stressor, and were detected around 63.6% of wetlands. Of those wetlands, 61.9% were surrounded by 2-lane roads, 19.1% by dirt or gravel roads, and 19.0% by 4-lane roads. The next most common buffer stressor was development, as it was found around 54.5% of riverine wetlands. Out of those, 66.7% were surrounded by residential development, 22.2% by commercial or industrial development, and 11.1% by both residential and commercial development. Agriculture and mowing were frequently found in the landscapes surrounding riverine wetlands, being around 42.4% and 33.3% of wetlands, respectively (Table 16). A rarer buffer stressor was stream channelization, which was found around 9.1% of wetlands. Rarer still was landfill or waste disposal, which was only found in areas around 3.0% of wetlands. Poultry or livestock operations, recent forest harvesting, golf courses, and sand or gravel operations were absent in landscapes surrounding riverine wetlands.

Riverine wetlands had a range of value-added scores from 20 to 59, with an average final score of 37.8 ± 11.8 (median=37.0). Proportions in each value category were close to being evenly split (Figure 15). Overall, riverine wetlands provided the most value in terms of habitat structure and complexity, flood storage and water quality, and habitat availability. They also provided some value by being within the DEN (i.e., within ecologically important corridors), while they provided low value for uniqueness or local significance, wetland size, and for education potential.

Non-tidal depression wetlands

Figure 16. A forested depression wetland in the Red Lion watershed.

Most of the non-tidal depression wetlands in the Red Lion watershed (Figure 16) that were assessed (n=22) had mineral soils (95.5%), with fewer having organic soils (4.5%). Some (27.3%) were in older growth forests, with tree age estimated to be >50 years old, while others were in younger forest between 31 and 50 years old (31.8%), or 16-30 years old (13.6%). Other depressions (27.3%) were not forested at all. Depression wetlands had final DERAP scores that ranged from 23.0 to 78.0, with a mean score of 51.6 ± 15.4 (median=52.0) out of a maximum possible score of 82.0. The highest proportion of these wetlands was severely stressed (50.0%), followed by moderately stressed (40.9%) and minimally stressed (9.1%; Figure 17). Minimally stressed depressions frequently contained invasive species and had development and agriculture in their surrounding landscapes. Moderately and severely stressed depressions suffered from similar stressors but were also characterized by the presence of nutrient indicator plant species, impaired hydrology from weirs, dams, or roads within wetlands, and roads in the surrounding landscape (Table 17). Data for all sampled depression wetlands for all assessed metrics can be viewed in Appendix H.

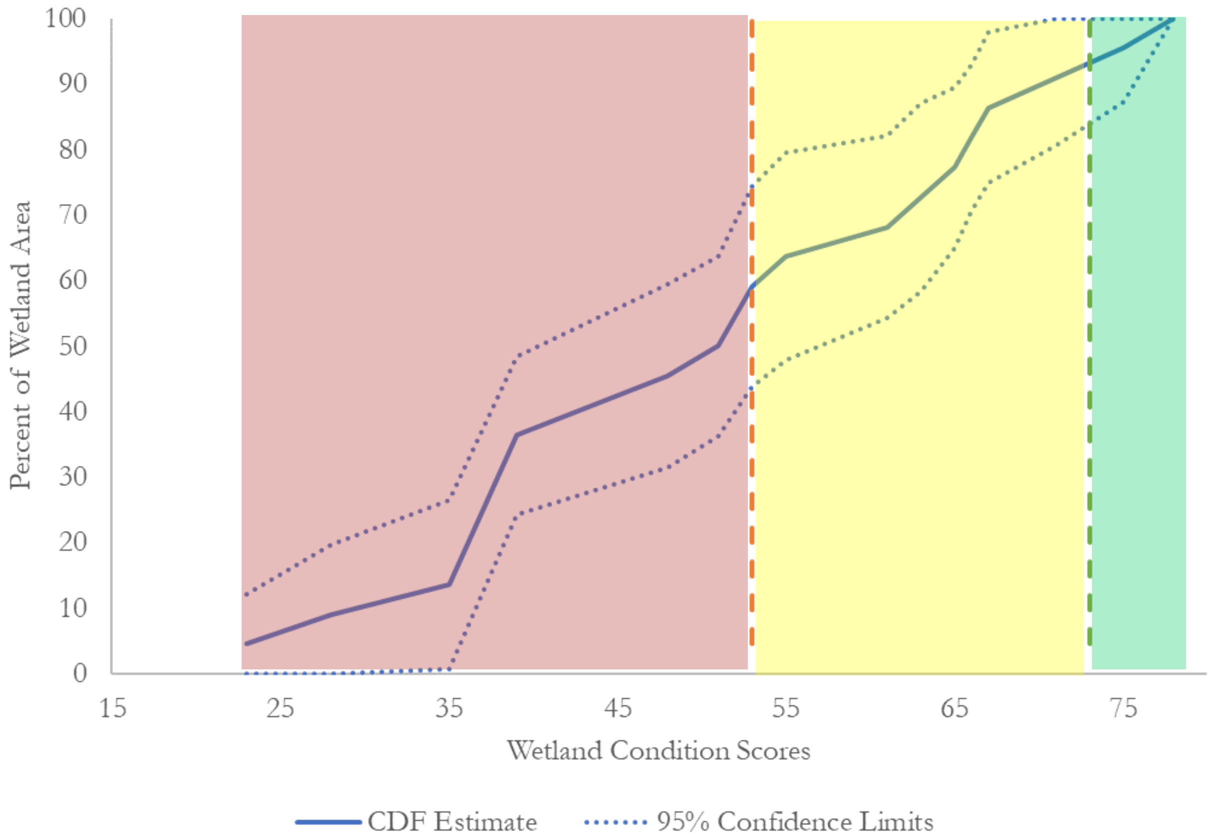
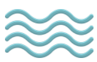


Figure 17. Cumulative distribution function (CDF) for non-tidal depression wetlands in the Red Lion watershed. The solid blue line is the population estimate and the dashed blue lines are 95% confidence intervals. Colored blocks show condition category ranges, where red is severely stressed, yellow is moderately stressed, and green is minimally stressed. The orange and green dashed lines show the numeric breakpoints between condition categories.

Nearly all depressions in this watershed had invasive species, making this the most widespread stressor in this wetland type. Of the depressions with invasive species, 52.4% had >50% cover, 19.0% had 6-50% cover, 19.0% had <1% cover, and 9.6% had 1-5% cover. The species that were detected were Japanese stiltgrass (*M. vimineum*), Japenese honeysuckle (*L. japonica*), European reed (*P. australis australis*), multiflora rose (*R. multiflora*), mile-a-minute (*P. perfoliata*), Oriental bittersweet (*C. orbiculatus*), garlic mustard (*A. petiolata*), and autumn olive (*Elaeagnus umbellata*). Another common habitat stressor in depression wetlands was the presence of nutrient indicator species, which were found in 68.2% of depressions (Table 17). Out of those depressions, 66.7% had nutrient indicator species covering >50% of the wetland, while 33.3% had them covering <50% of the wetland. All other habitat stressors were rare or entirely absent. Elevated roads were found in only 4.5% of depressions, and forest harvesting or management, vegetation alteration, dense algal mats, and excessive herbivory were not seen.

Table 17. Listed are the most common stressors (>20% occurrence) in depression wetlands (see Table 10 for symbol category meanings). Also shown are the occurrence of stressors in each condition category (%min = % minimally stressed; %mod = % moderately stressed; %sev = % severely stressed).

Category	Stressor	% Total (n=22)	% Min (n=2)	% Mod (n=9)	% Sev (n=11)
	Invasive species	95.5	50.0	100	100
	Nutrient indicator species	68.2	0.0	44.4	100
	Weir/dam/road	40.9	0.0	11.1	72.7
	Roads in surrounding landscape	40.9	0.0	66.7	27.3
	Development in surrounding landscape	36.4	100	55.6	27.3
	Agriculture in surrounding landscape	22.7	100	33.3	18.2

Weirs, dams, or roads were the most widespread hydrology stressors in depression wetlands, being found in 40.9% of them (Table 17). Of those wetlands, 88.9% were experiencing reduced flooding because of such structures, while the other 11.1% had water impounding over 10-75% of the wetland area due to the structures. Fill or excavation was found in some depressions (18.2%), as was ditching (9.1%) and storm water inputs (9.1%). All other hydrology stressors, including point sources, excessive sedimentation, and microtopographic alterations, were absent from depressions in this watershed.

Much like flats and riverine wetlands, roads, development, and agriculture in the surrounding landscape were the most common buffer stressors for depressions. Roads were found around 40.9% of depressions, of and those wetlands, 77.8% were surrounded by 2-lane roads, and 22.2% had dirt or gravel roads around them. Development was present in landscapes around 36.4% of depressions. Out of those wetlands, 50.0% has residential development around them, 25.0% had commercial or industrial development, and 25% had other kinds of development, including wastewater treatment facilities and nature centers. Agriculture was found in the buffer regions around 22.7% of depressions (Table 17). Mowing was only found around 13.6% of depressions, and some depressions (13.6%) had buffer stressors nearby that were not listed in the protocol, including berms and parking lots. Very few depressions (4.5%) had landfill or waste disposal or stream channelization in their buffer

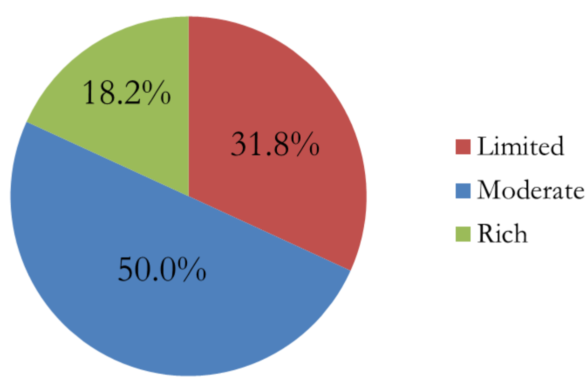


Figure 18. Proportion of depression wetlands in each value added category.

zones. Poultry or livestock operations, recent forest harvesting, golf courses, and gravel operations were not found in landscapes surrounding depression wetlands.

Most depression wetlands were rated as providing moderate value to the local landscape (50.0%), and others were rated as providing limited (31.8%) or rich value (18.2%; Figure 18). Depressions had a total average value-added score of 35.8 ± 15.1, with scores ranging from 19 to 68 (median=31.0). Overall, these wetlands provided high value in terms of habitat availability. They also provided some value by being within the DEN (i.e., within ecologically important corridors), habitat structure and complexity, wetland size, flood storage and water quality, and education potential. Depressions overall provided little value in terms of uniqueness or local significance.

Overall Condition and Watershed Comparison

We compared overall wetland condition in the Red Lion watershed to 9 other watersheds that we previously assessed. To do this, we combined condition proportions (minimally, moderately, and severely stressed) for all major assessed wetland types (tidal, flat, riverine, and depression) weighted by the acreage of each type in each watershed. Overall, the highest proportion of wetlands in the Red Lion watershed were severely stressed (43%), followed by moderately stressed (36%) and minimally stressed (21%). This wetland health breakdown was notable because it was the highest proportion of severely stressed wetlands recorded to date. The Red Lion watershed was the most similar to the Christina River and Inland Bays watersheds in terms of condition category breakdown (Figure 19).

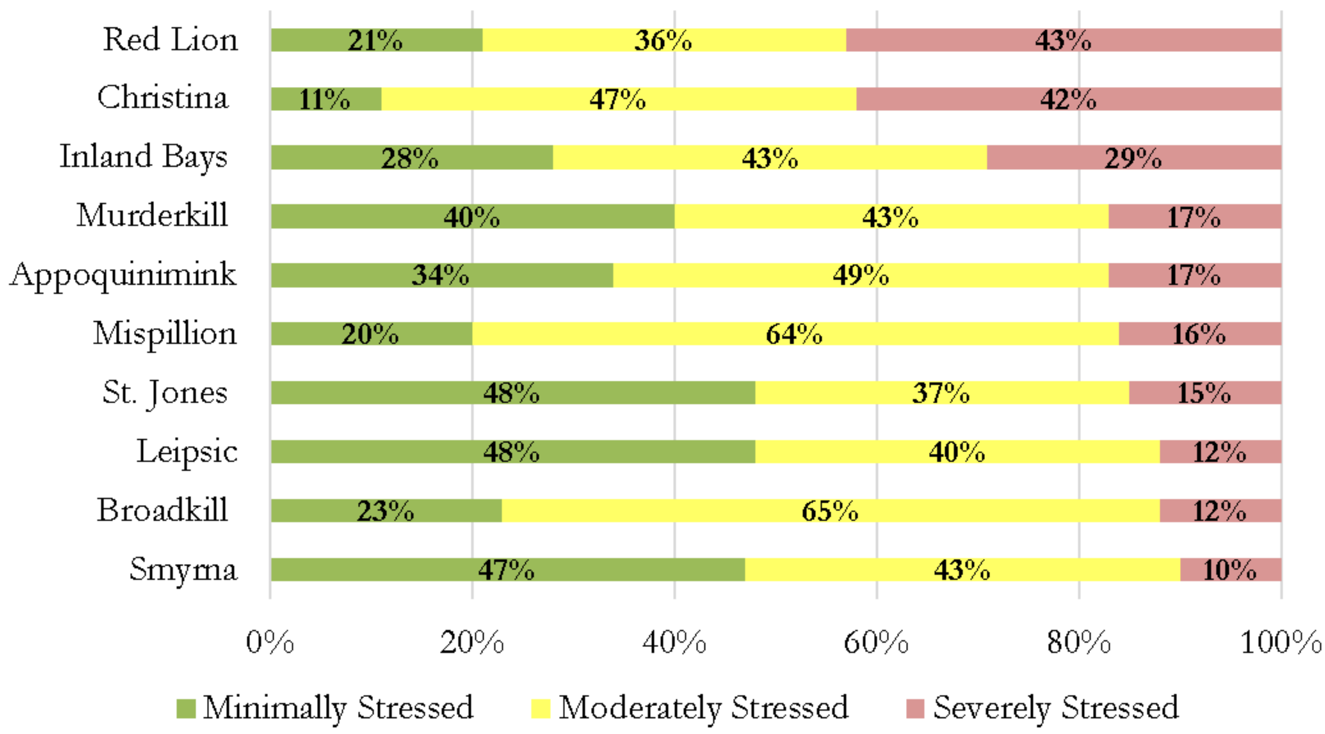


Figure 19. Comparison of overall condition categories for assessed watersheds throughout Delaware. Overall percentages shown are based on combined condition category percentages for all assessed wetland types (tidal/estuarine, flat, riverine, and depression) that are weighted based on wetland type acreage for each watershed.

DISCUSSION

Acreage trends

The Red Lion watershed experienced a net gain in wetland acreage between 1992 and 2007; however, nearly all 178.6 acres of gained wetland acreage (97.8%) was not natural, vegetated wetlands, but was instead non-vegetated ponds for residential or commercial uses (see example in Figure 20). These ponds usually had little to no natural buffer area around them, making them very vulnerable to indirect impacts such as polluted runoff. Most of these ponds were classified as unconsolidated bottom, areas of which have less than 30% aerial vegetative cover (FGDC 2013).

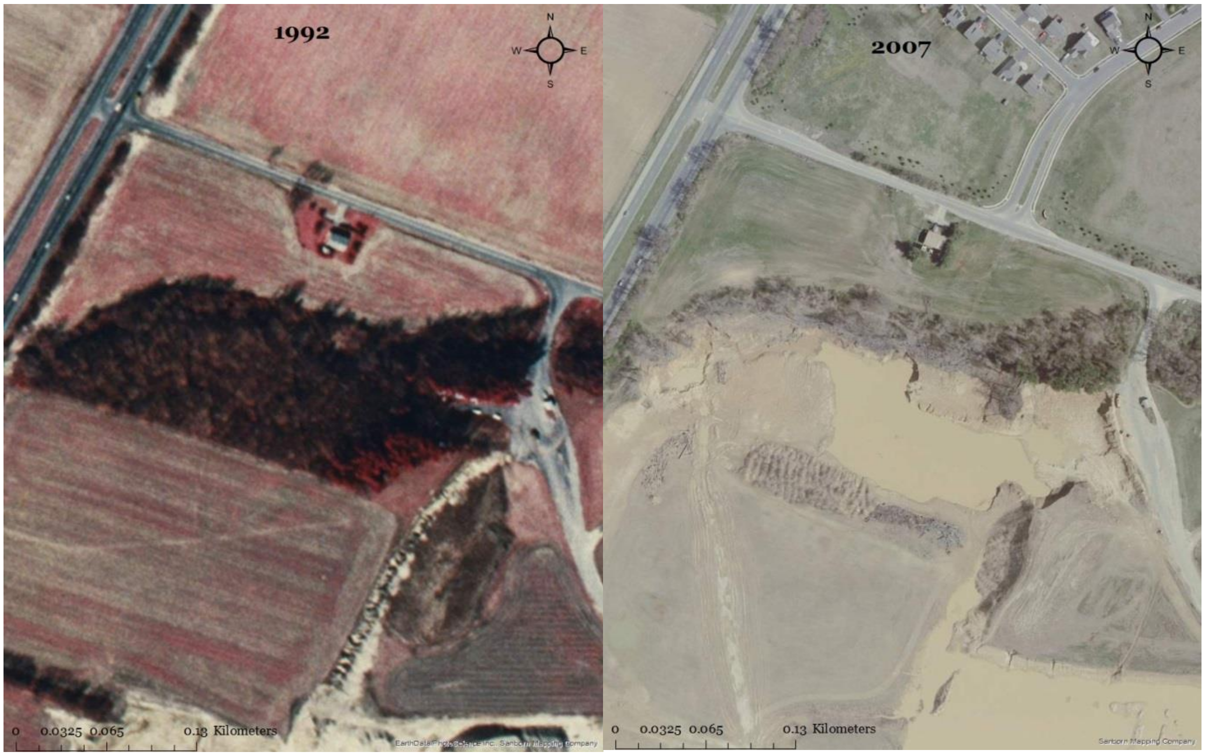


Figure 20. An example of a gained non-vegetated pond between 1992 and 2007. In 1992, there was a patch of upland forest surrounded by agriculture (left). By 2007, there were constructed non-vegetated ponds in place of the upland forest (right).

These ponds can be beneficial to some generalist species by providing habitat where natural wetlands are scarce (Brand and Snodgrass 2009; Tiner et al. 2011). However, such wetlands most often do not provide the same functional value as natural wetlands, in part because they are largely non-vegetated, usually occur in a developed landscape, and may be disconnected from groundwater because of liners. They may provide lower levels of certain functions, such as nutrient transformation, carbon sequestration, and sediment retention (Tiner 2003; Brand et al. 2010; Tiner et al. 2011; Howard et al. 2017). Storm water retention ponds have been shown to support fewer wetland-dependent plant and bird species compared with natural wetlands; this may in part be a result of their physical dissimilarities with natural wetlands, including steeper slopes and different and less variable hydroperiods (Rooney et al. 2015). Storm water ponds may also have different water chemistry, organic matter, and invertebrate communities compared with natural wetlands (Woodcock et al. 2010). Thus, created ponds do not resemble natural wetlands and do not replace natural wetland functions. Non-tidal palustrine wetlands that changed from natural wetlands to excavated ponds experienced a relative decrease in ecosystem function for this same reason.

The Red Lion watershed also gained a small amount of non-tidal palustrine wetlands that were classified as depressions, though this only represented a mere 2.2% of total gained acreage. These gained wetlands were somewhat vegetated with emergent plants, which likely increased their chances of providing moderate to high function levels in services such as nutrient transformation, retention of sediments and pollutants, conservation of biodiversity, climate mitigation, and provision of wildlife habitat (Tiner 2003; Howard et al. 2017). However, none of these wetlands resembled natural depressions in aerial imagery, and all of them were partially bordered or entirely surrounded by housing developments, commercial industry, or mining operations. Such stressors can reduce wetland condition through polluted runoff or reduced wetland habitat connectivity (Faulkner 2004; Brand et al. 2010), thereby reducing the ability of those wetlands to perform beneficial functions fully.

Wetland losses that occurred in non-tidal palustrine wetlands and non-vegetated or aquatic bed ponds were caused by direct destruction due to building of housing developments or highways, or transitional land being prepared for future development. Most of the wetlands lost were natural non-tidal palustrine wetlands. Because these wetlands were lost completely, all functions that these wetlands performed were also lost entirely. This indicates that the lack of non-tidal wetland regulation in the State of Delaware, along with weak or inconsistent federal regulation and relaxed county requirements, have resulted in the continued destruction of non-tidal wetlands. These results aligned closely with trends seen statewide, as agriculture and residential development were the leading causes for losses of vegetated palustrine wetlands throughout all of Delaware (Tiner et al. 2011).

Therefore, increased protection, regulation, enforcement, and mitigation in non-tidal wetlands are necessary to prevent further acreage losses. Stricter regulations should prevent as much non-tidal wetland loss as possible. Where impacts are permitted, mitigation requirements should be strongly enforced, and effort should be made to replace wetland types and functions lost. Regulations should encompass all non-tidal palustrine wetlands, regardless of size. Although some palustrine wetlands tend to be small and geographically isolated, these types of wetlands often have specific characteristics, such as hydroperiod, that are crucial to the survival and reproduction of amphibians (Babbitt 2005), making them just as important to protect as larger wetlands. These geographically isolated wetlands are also important for base stream flow and for sediment retention and can in some cases perform such functions better than other wetland types (Cohen et al. 2016). It is possible that some losses were permitted losses that were mitigated in some way.

Non-tidal wetland losses also indicate that more education and outreach is needed for private landowners. In 2007, most unregulated non-tidal palustrine wetlands were under private ownership (unpublished). By understanding the benefits that wetlands provide, landowners may be more willing to participate in voluntary conservation efforts. This idea is supported by results from a recent survey conducted in Delaware that showed that landowner perception of wetlands became more positive once landowners were presented with facts about wetlands (DNREC and OpinionWorks 2017).

Very little tidal wetland acreage in this watershed was lost due to direct human impacts between 1992 and 2007. This suggests that tidal wetland regulatory protection by the State of Delaware has largely been effective in maintaining acreage, and therefore needs to be maintained with proper enforcement and up-to-date regulatory maps. Only a very small area along the coast of the Delaware Bay that used to be estuarine emergent wetlands became unconsolidated bottom, which resulted from increased inundation and led to loss of vegetated wetland habitat. This suggests that erosion and sea level rise were not strong drivers of change in tidal wetlands in the Red Lion watershed between 1992 and 2007. However, acreage changes in tidal wetlands should be closely monitored in this watershed in the future, as sea levels are projected to continue to rise. As many 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), so more tidal wetlands could be converted to open water in the near future in this watershed. As this occurs it will become even more critical that shorelines and other land bordering current tidal marshes remain soft and unobstructed to allow tidal wetlands to migrate inland and survive.

Tidal wetland condition

Fill and tidal restrictions (e.g., berms or dikes) were hydrology stressors that were detected in tidal wetlands in the Red Lion watershed. Tidal restrictions can impair tidal marsh function and condition by causing elevation loss, reducing flooding and drainage, altering soil chemistry, and changing plant communities (Portnoy 1999, Mora and Burdick 2013). In addition, some estuarine wetlands were ditched, while some tidal palustrine wetlands suffered from point sources. Ditches can degrade tidal wetlands through some of the same mechanisms as tidal restriction by reducing the amount of water on the marsh surface. When tidal marsh soils are less waterlogged, aerobic metabolism of microbes increases, which subsequently increases decomposition rates. If organic material decomposes more quickly, marshes could lose elevation. Point sources can introduce toxic contaminants, sediments, and excess nutrients to wetlands, which can harm plants and wildlife and degrade water quality.

Although some hydrology stressors were found, tidal wetlands in the Red Lion watershed scored relatively well in terms of hydrology. Having fairly intact hydrology is extremely important to the health and function of tidal wetlands. Hydrological characteristics play a major role in hydric soil formation, and they govern the types of plants and wildlife that can inhabit tidal marshes. Thus, they are crucial for proper ecosystem functioning. Natural hydrology can be incredibly difficult to recreate in wetland restoration projects, and it can also be difficult to evaluate if restoration is successful (Zhao et al. 2016). It is therefore very important to preserve natural hydrology in tidal wetlands in the Red Lion watershed. Preservation of natural hydrology would ensure that healthy, minimally stressed wetlands continue to function well, and it would be easier and less costly to restore moderately or severely stressed wetlands if hydrology was already intact.

On the other hand, many tidal wetlands had buffer stressors present within the landscapes surrounding them. These types of anthropogenic disturbances degrade wetland buffers, which are natural areas adjacent to wetlands that can provide wildlife habitat and process pollutants from nearby upland areas before they enter the wetland. For instance, all tidal wetlands had some form of disturbance in the landscape surrounding them. Disturbances included non-native vegetation, human visitation, or soil disturbance. Many tidal wetlands also suffered from limited contiguous natural buffer or lack of complete 10m of natural buffer. These buffer stressors can negatively affect wildlife like amphibians and reptiles by destroying, fragmenting, or degrading terrestrial habitat around wetlands. Reptiles and amphibians require the terrestrial landscape around wetlands just as much as the wetlands themselves for shelter, foraging, and overwintering (Semlitsch and Bodie 2003). Additionally, runoff polluted with chemicals and excess nutrients from agricultural fields, development, and roads can enter wetlands directly if natural buffers do not separate wetlands from anthropogenic activities.

Figure 21. Example of a tidal wetland in the Red Lion watershed, outlined in pink, that has development as a barrier to landward migration.

Half of tidal wetlands also had barriers to landward migration, such as roads, development, berms, or walls (Figure 21), suggesting that many wetlands will be unable to migrate inland as sea levels rise. If natural buffers are not present to allow conversion to marsh as sea levels rise, wetlands will continue to shrink and drown, and coastal protection benefits will be lost. Where barriers are absent, marshes have been shown to be able to migrate inland slowly, converting coastal forest into marsh habitat (Brinson et al. 1995, Donnelly and Bertness 2001). In such cases, marsh habitats persist and continue to offer flood and storm protection as well as crucial wildlife habitat. Land adjacent to tidal wetlands should therefore be kept natural and unstructured wherever possible in order to try to maintain acreage of these marshes in the face of sea level rise. Collectively, these data suggest that disturbances in tidal wetland buffers should be minimized to ensure tidal wetland health and maintain acreage.

Tidal wetlands received the lowest ratings on average for habitat attributes, and were characterized by the presence of invasive species, low bearing capacity (i.e. marsh stability), low species richness, and few plant layers. Low marsh stability may indicate poor or declining levels of below-ground biomass, because poor bearing capacity is often associated with reduced below-ground biomass (Twohig and Stolt 2011). It is difficult to say whether marshes are in a steady state or if marsh stability is declining further because wetlands were only visited at a single point in time. However, it is still a concern because low or declining levels of below-ground biomass are often characteristics of deteriorating marshes. Tidal marshes also had high invasive species cover, particularly by *P. australis* and *T. angustifolia*. In many wetlands, high invasive cover likely caused low species richness and few plant layers. As invasive species take over wetlands, plant diversity tends to decrease, as does the variety of plant sizes and structures. Wetland condition assessments by DNREC and other regional environmental organizations should continue to be conducted to detect overall shifts and changes over time in this watershed.

Invasive plant species were detected in nearly all tidal wetlands, meaning that there was a widespread problem, even among minimally stressed wetlands. Invasive species can rapidly displace the native species that characterize high-functioning wetlands and that provide vital habitat for wildlife, thus decreasing wetland condition. It is also incredibly difficult to eradicate many invasive plant species once they are established. Oftentimes, invasive plants such as *P. australis* are able to colonize after disturbances, especially when natural hydrology has been impacted. As noted above, some tidal wetlands did contain hydrology stressors, which could make those wetlands even more susceptible to invasion and expansion. Therefore, these species should be removed or controlled as soon as possible once found within wetlands to minimize damage to native plant and wildlife communities, and to prevent them from spreading to other nearby wetlands. Invasive species should also be removed or controlled as soon as possible in landscapes surrounding wetlands so that they do not move into wetlands.

Half of tidal wetlands were publicly owned, meaning that they were on state-owned public lands and were thus shielded from many common direct human impacts. However, the other half were privately owned, leaving them more vulnerable to direct impacts despite state and federal regulation. Both public and private tidal wetlands can still experience indirect impacts from their surroundings. The highest proportion of tidal wetlands in the Red Lion watershed were severely stressed (63.3%), which suggests that a large effort should be focused on rehabilitating existing tidal wetlands in this watershed to ensure that they function at their highest potential. Wetland preservation should also be a priority, as 20.0% of tidal wetlands were minimally stressed. If work is done to preserve wetlands in good condition, communities will continue to benefit from functions they provide, and funds for the restoration or the replacement of beneficial services in the future will be saved.

Non-tidal palustrine wetland condition and value

The presence of invasive plant species was the most common habitat stressor in non-tidal palustrine wetlands in the Red Lion watershed. As mentioned earlier, invasive species can rapidly displace the native species that characterize high-functioning wetlands and that provide vital habitat for wildlife, thus decreasing wetland condition. It is also incredibly difficult to eradicate many invasive plant species once they are established. Therefore, invasive species should be removed or controlled as soon as possible both within and adjacent to wetlands.

Some flat wetlands also had roads degrading their habitat. Though most of the roads detected were non-elevated, they do still have potential to alter site hydrology, plant growth, or animal use or movement. Many depressions contained nutrient indicator plant species, and frequently, such species were dominating wetlands. The prevalence of this habitat stressor suggests that a high proportion of depressions were experiencing high levels of nutrient inputs, which can alter natural plant communities and water quality. Whenever possible, care should be taken not to construct any more roads or paths through non-tidal wetlands in this watershed. Additionally, a variety of best management practices (BMP's) should be utilized throughout the watershed in agricultural, residential, and industrial operations in order to reduce the amount of non-point source pollution to non-tidal palustrine wetlands.

Figure 22. Example of a non-tidal flat wetland complex in the Red Lion watershed that is surrounded by development and roads. Green lines outline 2007 SWMP wetlands. Imagery is from 2007.

Non-tidal palustrine wetlands were in good or fair condition for hydrology, with the exception of some ditching and microtopographic alterations in flats, and weirs, dams, or roads in some depressions. All of these stressors can degrade natural wetland hydrology by increasing, decreasing, or altering the flow of water through wetlands. When hydrology is disturbed, soil moisture and groundwater levels may be reduced (Faulkner 2004). Such disturbances have the potential to affect wetland plant communities, which are adapted to live in certain hydrologic conditions. Therefore, rehabilitation efforts in flats and depressions should target these hydrological issues to reestablish natural functions. Riverine wetlands were in the best hydrological condition, as hydrology stressors were relatively rare. Wetland preservation efforts in this watershed should aim to keep natural hydrology of non-tidal riverine wetlands intact.

Agricultural activities, development, and roads were present in the landscapes surrounding many non-tidal palustrine wetlands of all 3 types (see example in Figure 22). Mowed areas were also present around numerous flats and riverine wetlands. Such unnatural land uses adjacent to non-tidal palustrine wetlands indicated that buffer zones around these wetlands were degraded. Buffers are natural areas adjacent to wetlands that can provide wildlife habitat and help shield wetlands from indirect impacts. Runoff polluted with chemicals and excess nutrients from agricultural fields, development, roads, or mowed areas can enter wetlands directly if natural buffers do not separate wetlands from anthropogenic activities. Additionally, natural buffer areas surrounding wetlands can be just as important as wetlands, if not more so, to amphibians and reptiles, many of which require forested habitats adjacent to wetlands for foraging, overwintering, and habitat corridors for movement among wetlands (Semlitsch and Bodie 2003; Quesnelle et al. 2015; Finlayson et al. 2017). These data identify a clear need to conserve and improve buffers around non-tidal wetlands. Additionally, the prevalence of agriculture and development near wetlands highlights the importance of utilizing best management practices. Such responsible practices would dampen effects of indirect impacts by reducing harmful runoff of waste, excess nutrients, and chemicals (EPA 2003, 2005).

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

Efforts should largely be focused on rehabilitating non-tidal palustrine wetlands in the Red Lion watershed because a high proportion of these wetlands, particularly depressions, were characterized as severely stressed. Projects should pay special attention to common stressors that were detected in this watershed. For example, invasive plant species should be targeted and controlled to allow for restoration of native plant communities, and surrounding buffer habitat should be conserved and improved. Rehabilitation efforts should not just be performed on severely stressed wetlands, but on moderately stressed wetlands, too. This watershed had a high proportion of moderately stressed wetlands, and it is easier and cheaper to restore wetlands that are moderately stressed compared with those that are severely stressed or destroyed. Rehabilitation activities should therefore be conducted as soon as possible. Wetland preservation should always be conducted whenever possible as well. If intact wetlands are preserved, communities will continue to benefit from functions they provide, and money will not need to be spent on their restoration or the replacement of beneficial services in the future. Preserved wetlands that are protected will also have a much lower likelihood of being destroyed, and a higher likelihood of being rehabilitated.

Highlighting the specific local values that non-tidal wetlands provided in this watershed, such as habitat availability and habitat structure and complexity, makes the case for increased protection of non-tidal palustrine wetlands more compelling. Value added data can also be used to inform wetland restoration and enhancement projects by focusing on improving value characteristics that were rated poorly in this watershed, such as wetland size, to heighten their value to the local landscape. Moreover, many moderately and severely stressed non-tidal palustrine wetlands were still rated as providing moderate to rich value to the local landscape. This shows that in some ways even unhealthy wetlands can be very valuable to local communities and wildlife, which strengthens the case for conservation and restoration of wetlands, even those in poor or declining condition.

The Watershed Approach: Beyond Wetlands

The State of Delaware aims to protect and improve its water resources by following a watershed-based approach, meaning that data is often analyzed and recommendations are often made on a watershed scale. This is the case not only for wetlands, but also for surface water quality. Through the Surface Water Quality Monitoring Program, DNREC has identified several waterbodies as impaired in the Red Lion watershed because of high levels of harmful bacteria or excess nitrogen or phosphorus from non-point sources. Impaired waterbodies include the Red Lion Creek, Army Creek, Dragon Run Creek, and C&D Canal East (DNREC n.d.-d). Despite some recent improvements in water quality parameters over time, other parameters have remained the same or worsened (Kauffman 2016). Not only is surface water quality impaired, but as described in this report, the Red Lion watershed has a high proportion of degraded tidal and non-tidal wetlands. It is clear that additional measures need to be taken to improve the condition of water resources in the Red Lion watershed as a whole. Therefore, environmental agencies should better coordinate their watershed-based efforts to further improve the condition of all water resources within the Red Lion watershed.

MANAGEMENT RECOMMENDATIONS

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

Environmental Scientists, Researchers, and Land Managers

1. **Support vegetated buffers for tidal and non-tidal wetlands.** There is a clear need to establish, improve, and maintain adequate natural, vegetated buffers around tidal and non-tidal wetlands in this watershed. Such work would help minimize indirect impacts and ensure that wetlands can persist and function. Currently, New Castle County, which contains the Red Lion watershed, requires 100ft buffers around tidal wetlands and 50ft buffers around non-tidal wetlands. Buffer width around non-tidal wetlands should increase to at least 75ft, and all buffer regulations should be more strongly and regularly enforced. Funding should be secured for improving buffers on currently protected lands, and for acquiring buffer land to extend riparian habitat corridors and connect more habitat hotspots.

2. **Continue to increase citizen education and involvement through effective outreach.** Over half of all sites that were sampled in the Red Lion watershed were privately owned, and wetland loss and degradation were largely caused by human impacts. By increasing wetland education to landowners and informing them about the benefits wetlands can provide, landowners may be more willing to take part in voluntary stewardship activities that can benefit wetlands around them, thereby decreasing wetland loss and degradation. To accomplish effective public outreach, it is incredibly important to identify your audience, create an active dialogue with landowners, to encourage active, hands-on participation in discussions and activities, and to create an understanding of how wetlands are relevant to the public (Calhoun et al. 2014, Varner 2014). For example, in order to address the goal of increased landowner wetland stewardship, DNREC's WMAP created a website called the Freshwater Wetland Toolbox in 2017 that allows landowners to look up their property and locate wetlands, highlighting ways to care for backyard wetlands (see link on pg. 56). More outreach tools and programs should be created in order to address other specific public education goals. Such tools and programs should constantly be evaluated to gauge their effectiveness in addressing goals and to improve outreach efforts (Varner 2014).

3. **Control the extent and spread of non-native invasive plant species.** All assessed wetland classes in the Red Lion watershed were negatively affected by invasive species. To improve wetland health, the extent and spread of non-native invasive plant species needs to be controlled. DNREC has a Phragmites Control Program to help combat the spread of the invasive European reed, which has treated more than 20,000 acres throughout Delaware on private and public property since 1986 (DNREC n.d.-e). This program has the potential to continue to help improve wetland health on public land and private holdings greater than 5 acres. However, many other invasive species besides the European reed were prevalent in wetlands in this watershed, such as Japanese honeysuckle, narrow-leaf cattail, multiflora rose, Japanese stiltgrass, and reed canary grass. There is currently no program in place to control these invasive species.

It would therefore be beneficial to expand invasive plant species control efforts to include more species besides just the European reed (see MidTRAM protocol for full list of Delaware invasive species; Rogerson and Haaf 2017). Education and awareness, such as efforts made by the Delaware Invasive Species Council (DISC 2020), is an important component of this by informing landowners about how to identify and remove undesirables and only plant native species.

4. **Perform wetland monitoring, conservation, and restoration activities.** It is essential to monitor wetland condition in order to detect common stressors and address them as quickly as possible. In the Red Lion watershed, tidal wetlands were found to have relatively poor marsh stability, low species richness, and few plant layers; monitoring would allow scientists to see if marshes remain stable or if they decline further and need attention. Because most wetlands were moderately or severely stressed in this watershed, a combination of rehabilitation and preservation 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. This would help curb wetland acreage losses in this watershed while also protecting their health. Projects should account for watershed-specific conditions. For example, the overall intact hydrology of estuarine and riverine wetlands should be kept in place, while the buffer stressors of all wetland types should be addressed. In addition, value added results can strengthen cases for wetland conservation and restoration and inform wetland enhancement goals. Care should be taken when restoring wetlands to have them resemble natural, vegetated wetlands as closely as possible. Professionals can use landscape-level screening tools such as the Delaware Watershed Resources Registry (WRR) to help locate highly suitable areas for wetland restoration and preservation (WRR 2017). Such activities would be consistent with the goals of the Delaware Bayshore Initiative (DNREC n.d.-a).

5. **Improve coordination of watershed-based efforts both within and among agencies, and municipalities.** It has been demonstrated from thorough data collection that tidal and non-tidal wetlands, as well as many waterbodies, within the Red Lion watershed are degraded. To best improve water quality in this watershed, state and local environmental agencies and municipalities should better coordinate efforts. Water resources should not be assessed and reported independently of one another but should rather be viewed as parts of the whole watershed. Improved coordination could help maximize funding opportunities, reduce any redundancy of data collection efforts, and make clearer management recommendations.

Decision Makers (State, County, and Local)

1. **Improve regulatory protection of non-tidal palustrine wetlands through state, county, and local programs.** Without increased regulatory protection, loss of non-tidal wetlands in the Red Lion watershed will probably continue, especially because all losses in this watershed were because of direct human impacts. Acreage losses will translate into loss of ecosystem services and values. Degradation of non-tidal wetlands from anthropogenic stressors, such as those commonly found in the Red Lion watershed (e.g. ditching or impounding water), will likely also continue without increased protection. These facts highlight the need for improved protection to fill the gaps left by very recent changes to the definitions of the Waters of the U. S. (WOTUS) and to address the lack of state regulation. Conservation of non-tidal palustrine wetlands will likely be most effective if state regulation is combined with smaller-scale efforts from counties, local governments and organizations, stakeholders, and landowners. Such collaborative efforts can make everyone feel involved and informed, while successful solutions can be reached that simultaneously conserve wetlands and integrate interests of many parties (Calhoun et al. 2014, 2017). A state regulatory program in concert with county and local programs would reduce the ambiguity surrounding non-tidal wetland regulation and provide a comprehensive and clear means to

protect these wetlands in the entire state. Regulations should aim to protect palustrine wetlands of all sizes and should include geographically isolated wetlands. Local regulations can be incorporated into municipal and/or county code and homeowner associations to protect wetland areas of special significance. In addition, the development of incentives programs could attract landowner interest in conserving wetlands and the beneficial ecosystem services that they provide. Where impacts are permitted, mitigation requirements should be strongly enforced, and effort should be made to replace wetland types and functions lost.

2. **Update tidal wetland regulatory maps to further improve accuracy and efficiency of regulation.** Direct human impacts were relatively uncommon within tidal wetlands in the Red Lion watershed, and very few acreage losses were attributed to human development, signifying that tidal wetland regulation by the State of Delaware has been fairly effective in this watershed and should 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 purposes. Currently, maps from 1988 are used for regulation of tidal wetlands within the state. These maps are outdated, difficult to read, and must be verified in the field due to discrepancies. Coastal wetlands are going through rapid changes today as a result of sea level rise and intensified coastal storms. Thus, regulatory maps need to be updated to ensure that human impacts to tidal wetlands remain minimal.

3. **Develop incentives and legislation to establish, maintain, or improve natural wetland buffers.** The data presented in this report demonstrate a clear need for establishment, improvement, or maintenance of natural buffers around tidal and non-tidal wetlands. To further improve wetland condition, buffers need to be kept as wide as possible, and development, agriculture, and roads within buffer areas needs to be prevented. Incentive programs could attract landowner interest in maintaining natural buffers between tidal and non-tidal wetlands and human activity to reduce negative indirect impacts to wetlands, provide crucial wildlife habitat, and to allow for landward marsh migration in the face of sea level rise. Development of incentives or legislation or improvements to any existing local legislation for buffer setbacks would help to prevent further buffer degradation or destruction. Additionally, municipalities and developers should be encouraged to use best management practices (BMPs) to reduce indirect impacts to wetlands from nonpoint source pollution. Aside from maintaining natural buffers, BMPs could include preserving open space in urban areas, using permeable paving materials, rebuilding in areas that were previously constructed, and enacting slope restrictions for building to discourage erosion (EPA 2005).

4. **Secure funding for wetland restoration and preservation.** Overall, 43% of wetlands were severely stressed and 36% of wetlands were moderately stressed in the Red Lion watershed, meaning that restoration can make a large impact on improving wetland health in this watershed. Specifically, efforts should focus on rehabilitation, or the restoration of lost features and functions within existing wetlands. Although a fairly low proportion of wetlands were minimally stressed in this watershed, it is always important to prioritize wetland preservation as well. Preservation of wetlands that are already healthy will ensure that they continue to provide beneficial ecosystem services in the future, while preservation of less healthy wetlands can reduce the likelihood of further degradation and increase the likelihood that rehabilitation actions will occur. Funding should be secured to continue and expand programs that already exist in Delaware that can help conserve wetlands, including the Delaware Open Space Program (DNREC n.d.-f) and the Delaware Forestland Preservation Program (DE DDA n.d.). New funding opportunities should also be explored. If new wetlands are created, care should be taken to replace the same type of wetland and to replicate natural features and processes as much as possible. Note that storm water wetlands and ponds are not functional substitutes for natural wetlands.

<u>Landowners</u>

1. **Protect and maintain the buffers around wetlands.** Buffers are natural, vegetated areas 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. Buffers are also vital for the survival of wetland wildlife, including many species of reptiles and amphibians. In the Red Lion watershed, wetland buffers were degraded or entirely absent due to development, agricultural activities, roads, or mowing. 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. Buffers can also be maintained by planting native plant species between open spaces and waterways.

2. **Preserve or restore wetlands that are on private property.** Over half of the wetlands in the Red Lion watershed were located on privately-owned land. This means that landowners play an important role in maintaining wetland acreage and function. There are many ways that landowners can engage with the natural wetlands right in their backyards whether they have a small property or own a large area. For large landholdings, one of the best ways to do so is to protect or restore wetlands through conservation easements, which can be accomplished through programs such as the Agricultural Conservation Easement Program (ACEP; NRCS n.d.) or the Delaware Forestland Preservation Program (DE DDA n.d.). Easements can protect wetlands in their natural state from future development for a number of years or permanently. One potential resource to identify other wetland preservation or restoration options for New Castle County, which includes the Red Lion watershed, is the Wetlands Work website by the Chesapeake Bay Program (CBP 2020). For smaller property owners, planting native species and removing invasive species are two other important actions, especially because many wetlands in the Red Lion watershed were found to have invasive species present. They can also avoid mowing grasses and picking up downed logs and branches within wetlands because those features provide important habitat for wildlife. In addition, leaving the hydrology intact by allowing waterways to flow naturally without being dug out or straightened and by not adding ditches or trenches to drain wet areas will help ensure that wetlands will remain healthy and fully functioning. WMAP's 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.56).

3. **Utilize best management practices (BMPs) in agricultural operations and in urban and suburban settings.** In this watershed, agriculture, development, and roads were found near many non-tidal palustrine wetlands, and many depressions contained nutrient indicator species, suggesting that indirect effects on wetlands were occurring from surrounding land use. Utilizing BMPs in agricultural operations can greatly reduce the amount of waste, sediments, chemicals, and nutrient runoff from fields, thereby reducing the potential for indirect wetland impacts from non-point source pollution. Some examples of beneficial BMPs include use of cover crops, precision farming, exclusion of animals from waterways, crop rotation, tree planting, proper animal waste management, and avoidance of over-grazing (EPA 2003). Similarly, BMPs can also be used in urban and suburban settings to limit effects of non-point source pollution. These include practices such as washing cars on grass, properly disposing of pet waste and chemicals, and minimizing use of fertilizers and pesticides on lawns (EPA 2005). DNREC's Non-

Point Source Program provides some funding opportunities to help landowners and other public or private entities reduce non-point source pollution (DNREC n.d.-g).

Literature Cited

Babbitt, K. J. 2005. The relative importance of wetland size and hydroperiod for amphibians in southern New Hampshire, USA. Wetlands Ecology and Management: 13, 269-279.

Boon, J.D. 2012. Evidence of Sea Level Acceleration at U.S. and Canadian Tide Stations, Atlantic Coast, North America. Journal of Coastal Research, 28: 1437-1445.

Brand, A.B., and J.W. Snodgrass. 2009. Value of Artificial Habitats for Amphibian Reproduction in Altered Landscapes. Conservation Biology, 24: 295-301.

Brand, A.B., J.W. Snodgrass, M.T. Gallagher, R.E. Casey, and R. Van Meter. 2010. Lethal and Sublethal Effects of Embryonic and Larval Exposure of *Hyla versicolor* to Stormwater Pond Sediments. Archives of Environmental Contamination and Toxicology, 58: 325-331.

Brinson, M. M., Christian, R. R., and L. K. Blum. 1995. Multiple States in the Sea-Level Induced Transition From Terrestrial Forest to Estuary. Estuaries, 18: 648-659.

Calhoun, A. J. K., Jansujwicz, J. S., Bell, K. P., and M. L. Hunter, Jr. 2014. Improving management of small natural features on private lands by negotiating the science-policy boundary for Maine vernal pools. PNAS, 111: 11002-11006.

Calhoun, A. J. K., Mushet, D. M., Bell, K. P., Boix, D., Fitzsimons, J. A., and F. Isselin-Nondedeu. 2017. Temporary wetlands: challenges and solutions to conserving a ‘disappearing’ ecosystem. Biological Conservation, 211: 3-11.

CBP. 2020. Wetlands Work: New Castle, Delaware. Chesapeake Bay Program. < https://www.wetlandswork.org/programs-planners/new-castle-delaware>. Accessed 25 June 2020.

Cohen, M. J., Creed, I. F., Alexander, L., Basu, N. B., Calhoun, A. J. K., Craft, C., D’Amico, E., DeKeyser, E., Fowler, L., Golden, H. E., Jawitz, J. W., Kalla, P., Kirkman, L. K., Lane, C. R., Lang, M., Leibowitz, S. G., Lewis, D. B., Marton, J., McLaughlin, D. L., Mushet, D. M., Raanan-Kiperwas, H., Rains, M. C., Smith, L., and S. C. Walls. 2016. Do geographically isolated wetlands influence landscape functions? PNAS, 113: 1978-1986.

DE DDA. n.d. Conservation Programs. Delaware Department of Agriculture. <https://agriculture.delaware.gov/forest-service/forest-conservation-programs/>. Accessed 25 June 2020.

Diaz-Ramos, S., D.L. Stevens Jr., and A.R. Olsen. 1996. EMAP Statistical Methods Manual. Environmental Monitoring and Assessment Program, U.S. Environmental Protection Agency, Corvallis, OR. 13p.

DISC. 2020. Delaware Invasive Species Council. Delaware Department of Agriculture, Dover, DE. < http://delawareinvasives.net/blog1/>. Accessed 27 January 2020.

DNREC. 2005. Delaware Bay and Estuary Assessment Report. Delaware Department of Natural Resources and Environmental Control, Dover, DE. 156p.

DNREC. 2006. Total Maximum Daily Loads (TMDLs) Analysis for the Watersheds of Army Creek, Red Lion Creek, and Dragon Run Creek, Delaware. Delaware Department of Natural Resources and Environmental Control, Watershed Assessment Section, Dover, DE. 126p.

DNREC. 2012. Preparing for Tomorrow's High Tide: Sea Level Rise Vulnerability Assessment for the State of Delaware. Delaware Coastal Programs, Department of Natural Resources and Environmental Control, Dover, DE. 210p.

DNREC. 2015a. Delaware Wetland Management Plan. Delaware Department of Natural Resources and Environmental Control, Dover, DE. 22p.

DNREC. 2015b. The Delaware Wildlife Action Plan 2015-2025. Division of Fish and Wildlife, Delaware Department of Natural Resources and Environmental Control, Dover, DE. 135p.

DNREC. n.d.-a. Delaware Bayshore Initiative. Delaware Department of Natural Resources and Environmental Control. <http://www.dnrec.delaware.gov/pages/delaware-bayshore.aspx>. Accessed 27 February 2020.

DNREC. n.d.-b. Pollution Control Strategies and Tributary Action Teams. Delaware Department of Natural Resources and Environmental Control. <http://www.dnrec.delaware.gov/swc/wa/pages/pollutioncontrolstrategiesandtributaryactionteams.aspx>. Accessed 19 May 2020.

DNREC. n.d.-c. Municipal Separate Storm Sewer Systems. Delaware Department of Natural Resources and Environmental Control. < https://dnrec.alpha.delaware.gov/water/surface-water/npdes/municipal-storm-sewers/>. Accessed 19 May 2020.

DNREC. n.d.-d. Total Maximum Daily Loads (TMDLs). Delaware Department of Natural Resources and Environmental Control. < http://www.dnrec.delaware.gov/swc/wa/Pages/WatershedAssessmentTMDLs.aspx>. Accessed 24 March 2020.

DNREC. n.d.-e. Delaware Phragmites Control Cost-Share Program. Delaware Department of Natural Resources and Environmental Control. <http://www.dnrec.delaware.gov/fw/dplap/services/Pages/DelawarePhragmitesControl.aspx>. Accessed 27 February 2020.

DNREC. n.d.-f. Delaware Open Space Program. Delaware Department of Natural Resources and Environmental Control. < https://dnrec.alpha.delaware.gov/parks/open-space/>. Accessed 25 June 2020.

DNREC. n.d.-g. Non-Point Source Program Funding. Delaware Department of Natural Resources and Environmental Control. < https://dnrec.alpha.delaware.gov/environmental-finance/non-point-source-funding/>. Accessed 25 June 2020.

DNREC and OpinionWorks. 2017. State of Delaware Wetlands Survey Final Report. Delaware Department of Natural Resources and Environmental Control, Dover, DE and OpinionWorks LLC, Annapolis, MD. 166p.

Donnelly, J. P., and M. D. Bertness. 2001. Rapid shoreward encroachment of salt marsh cordgrass in response to accelerated sea-level rise. PNAS, 98: 14218-14223.

EPA. 2003. National Management Measures to Control Nonpoint Source Pollution from Agriculture. U. S. Environmental Protection Agency, Office of Water, Washington, D.C. 302p.

EPA 2005. National Management Measures to Control Nonpoint Source Pollution from Urban Areas. U. S. Environmental Protection Agency, Office of Water, Washington, D.C. 518p.

ESRI. ArcMap v.10.3.1. Redlands, CA, USA.

Faulkner, S. 2004. Urbanization impacts on the structure and function of forested wetlands. Urban Ecosystems, 7: 89-106.

FGDC. 2013. Classification of wetlands and deepwater habitats of the United States. FGDC-STD-004-2013. Second Edition. Adapted from Cowardin et al. 1979. Wetlands Subcommittee, Federal Geographic Data Committee and U.S. Fish and Wildlife Service, Washington, DC. 86p.

Finlayson, C. M., Everard, M., Irvine, K., McInnes, R. J., Middleton, B. A., van Dam, A. A., and N. C. Davidson. 2017. The Wetland Book. Springer Science + Business Media. Springer, Dordrecht. 2044p.

Howard, J., A. Sutton-Grier, D. Herr, J. Kleypas, E. Landis, E. Mcleod, E. Pidgeon, and S. Simpson. 2017. Clarifying the role of coastal and marine systems in climate mitigation. Frontiers in Ecology and the Environment, 15: 42-50.

Jacobs, A. D., Whigham, D. F., Fillis, D., Rehm, E., and A. Howard. 2009. Delaware Comprehensive Assessment Procedure Version 5.2. Delaware Department of Natural Resources and Environmental Control, Dover, DE. 72p.

Jacobs, A.D. 2010. Delaware Rapid Assessment Procedure Version 6.0. Delaware Department of Natural Resources and Environmental Control, Dover, DE. 36p.

Kauffman, G. J. 2016. Stream Water Quality Trends in New Castle County, Delaware (1999-2014). University of Delaware and Water Resources Agency, Newark, DE. 14p.

Kauffman, G. J. 2018. Socioeconomic Value of Delaware Wetlands. University of Delaware, Water Resources Center, and Institute for Public Administration, Newark, DE. 32p.

Mora, J. W. and D. M. Burdick. 2013. The impact of man-made earthen barriers on the physical structure of New England tidal marshes (USA). Wetlands Ecology and Management, 21: 387-398.

Narvaez, M.C. and G. Kauffman. 2012. Economic Benefits and Jobs Provided by Delaware Watersheds. Institute for Public Administration and University of Delaware, Newark, DE. 77p.

National Audubon Society. n.d. Important Bird Areas: Delaware. <https://www.audubon.org/important-bird-areas/state/delaware>. Accessed 21 February 2020.

NRCS. n.d. 2014 Farm Bill—Agricultural Conservation Easement Program—NRCS. Natural Resources Conservation Service (NRCS), U.S. Department of Agriculture (USDA). <https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/programs/easements/acep/?cid=stelprdb1242695>. Accessed 16 January 2020.

Portnoy, J. W. 1999. Salt Marsh Diking and Restoration: Biogeochemical Implications of Altered Wetland Hydrology. Environmental Management, 24: 111-120.

Quesnelle, P. E., Lindsay, K. E., and L. Fahrig. 2015. Relative effects of landscape-scale wetland amount and landscape matrix quality on wetland vertebrates: a meta-analysis. Ecological Applications, 25: 812-825.

Ramsar Convention. 1992. Ramsar Sites Information Service: Delaware Bay Estuary. The Convention on Wetlands of International Importance. < https://rsis.ramsar.org/ris/559>. Accessed 3 April 2020.

Rogerson, A. and L. Haaf. 2017. Mid-Atlantic Tidal Wetland Rapid Assessment Method Version 4.1. Delaware Department of Natural Resources and Environmental Control, Dover, DE and Partnership for the Delaware Estuary, Wilmington, DE. 45p.

Rogerson, A. and M. Jennette. 2014. Guidance for Rating Wetland Values in Delaware. Delaware Department of Natural Resources and Environmental Control, Dover, DE. 21p.

Rooney, R. C., Foote, L., Krogman, N., Pattison, J. K., Wilson, M. J., and S. E. Bayley. 2015. Replacing natural wetlands with stormwater management facilities: biophysical and perceived social values. Water Research, 73: 17-28.

Semlitsch, R. D. and J. R. Bodie. 2003. Biological Criteria for Buffer Zones around Wetlands and Riparian Habitats for Amphibians and Reptiles. Conservation Biology, 17: 1219-1228.

Stevens, D.L. Jr. and A.R. Olson. 1999. Spatially restricted surveys over time for aquatic resources. Journal of Agricultural, Biological, and Environmental Statistics, 4:415-428.

Stevens, D.L. Jr. and A.R. Olsen. 2000. Spatially-restricted random sampling designs for design-based and model-based estimation. Accuracy 2000: Proceedings of the 4th International symposium on spatial accuracy assessment in natural resources and environmental sciences: 609-616. Delft University Press, Delft, The Netherlands.

Tiner, R.W. 2003. Correlating Enhanced National Wetlands Inventory Data with Wetland Functions for Watershed Assessments: A Rationale for Northeastern U.S. Wetlands. National Wetlands Inventory Program, Northeast Region, U.S. Fish and Wildlife Service, Hadley, MA. 26p.

Tiner, R.W., M.A. Biddle, A.D. Jacobs, A.B. Rogerson, and K.G. McGuckin. 2011. Delaware Wetlands: Status and Changes from 1992 to 2007. Cooperative National Wetlands Inventory Publication. U.S. Fish and Wildlife Service, Northeast Region, Hadley, MA and the Delaware Department of Natural Resources and Environmental Control, Dover, DE. 40p.

Twohig, T.M. and M.H. Stolt. 2011. Soils-Based Rapid Assessment for Quantifying Changes in Salt Marsh Condition as a Result of Hydrologic Alteration. Wetlands, 31: 955-963.

USFWS. 2014. Dichotomous Keys and Mapping Codes for Wetland Landscape Position, Landform, Water Flow Path, and Waterbody Type Descriptors: Version 3.0. U.S. Fish and Wildlife Service, National Wetlands Inventory Project, Hadley, MA. 65p.

USFWS. 2020. National Wetlands Inventory. U. S. Fish and Wildlife Service. <http://www.fws.gov/wetlands/>. Accessed 25 March 2020.

Varner, J. 2014. Scientific Outreach: Toward Effective Public Engagement with Biological Science. BioScience, 64: 333-340.

WHSRN. 2019. WHSRN List of Sites. Western Hemisphere Shorebird Reserve Network. < https://www.whsrn.org/delaware-bay>. Accessed 21 February 2020.

Woodcock, T. S., Monaghan, M. C., and K. E. Alexander. 2010. Ecosystem Characteristics and Summer Secondary Production in Stormwater Ponds and Reference Wetlands. Wetlands, 30: 461-474.

WRR 2017. Delaware Registry. Watershed Resources Registry. < https://watershedresourcesregistry.org/states/delaware.html>. Accessed 20 March 2020.

Zhao, Q., Bai, J., Huang, L., Gu, B., Lu, Q., and Z. Gao. 2016. A review of methodologies and success indicators for coastal wetland restoration. Ecological Indicators, 60: 442-452.

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 $\geq$1 severe alterations or >2 moderate alterations. These disturbances lead to a decline in the wetland's ability to effectively function in the landscape. Examples of severe alterations include extensive ditching or stream channelization, recent clear cutting or conversion to an invasive vegetative community, hardened surfaces along the wetland/upland interfaces for most of the site, and roads, excessive fill, excavation or farming in the wetland. Use PBJ to assign a QDR of 5 or 6.

Appendix B: DERAP Stressor Codes and Definitions

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

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

Appendix C: DERAP IWC Stressors and Weights

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

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	1 buffer stressor = 3 2 buffer stressors = 6 ≥ 3 buffer stressors = 9	1 buffer stressor = 1 2 buffer stressors = 2 ≥ 3 buffer stressors = 3	1 buffer stressor = 4 2 buffer stressors = 8 ≥ 3 buffer stressors = 12
Residential >2 houses/acre	Ldevres3			
Residential ≤2 houses/acre	Ldevres2			
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			
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			
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: Report Card Grading Scales

The following is the letter grade scale used in wetland health report cards for overall watershed grades, overall wetland type grades, and habitat and hydrology grades within wetland types (left), and the letter grade scale used for buffer grades within wetland types (right):

Score Range	Letter Grade
97-100	A+
93-96	A
90-92	A-
87-89	B+
83-86	B
80-82	B-
77-79	C+
73-76	C
70-72	C-
67-69	D+
63-66	D
60-62	D-
0-59	F

Average Stressor Tally Range	Letter Grade
0 - 0.60	A
0.61 - 1.20	B
1.21 - 1.80	C
1.81 - 2.40	D
2.41 - 3.00	F

Once letter grades are determined, wetland types as well as their attribute categories (habitat, hydrology, and buffer) are color-coded and placed on a qualitative wetland health scale shown below. This color-coded wetland health scale is designed to make public interpretation of wetland health as clear as possible.

Letter Grade	Wetland Health Scale
A+, A, A-	Excellent
B+, B, B-	Good
C+, C, C-	Fair
D+, D, D-	Poor
F	Very Poor

Appendix E-H are stored as a separate file and can be found online at Delaware Wetlands, Watershed Health Home, Red Lion watershed (here).

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

Data collected for this report are publicly available for viewing and downloading for both tidal and non-tidal wetlands.

Other helpful resources described in this report include the Freshwater Wetland Toolbox and the Delaware Watershed Resources Registry.