Condition of Wetlands in the Murderkill River Watershed

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EXECUTIVE SUMMARY

The Delaware Department of Natural Resources and Environmental Control (DE DNREC) assessed the condition of wetlands in the Murderkill River watershed in 2007-2008. The goal of this project was to determine the condition of both tidal and nontidal wetlands in the Murderkill River watershed, changes in wetland acreage, and identify the presence of wetland stressors. We will use wetland condition, stressor information and watershed wide trends to guide and improve future protection and restoration activities, education and effective planning to ensure the conservation Delaware's wetland resources.

Located in Kent County Delaware, the Murderkill watershed covers 28,000ha (69,000ac) within the Delaware Bay and Estuary Basin. The Murderkill River runs 13km (20mi) to meet the Delaware Bay at Bowers Beach. Flat wetlands, usually forested, form the headwaters of the Murderkill River in the western portion of the watershed. Riverine wetlands follow tributaries and streams until just west of Route 1, where expansive brackish to tidal wetlands run along the Murderkill River until it reaches the Delaware Bay. Pockets of depressions, including rare coastal plain ponds, are scattered throughout the watershed.

To assess the condition of wetlands and identify the prominent stressors affecting wetland health, we applied a rapid assessment method to random sites across the watershed to nontidal flat, riverine, and depressions, and to tidal wetlands on both private and public land. We used a probabilistic sampling design developed the EPA Ecological Monitoring and Assessment Program (EMAP) that allowed us to correct for site access and extrapolate sample results to represent the entire wetland population in the watershed.

We also evaluated changes in wetland acreage for major subclasses by comparing the 1994 state wetland inventory to historic wetland acreage based on hydric soils. Our comparison indicated 38% of the wetland acreage has been lost in the Murderkill River watershed since the time of settlement. The loss of nontidal wetlands has been the greatest overall, due to conversion to development and agriculture. Tidal wetland loss has occurred due to coastal development, particularly in Bowers Beach.

We completed rapid assessments on 30 flats, 31 riverine, 5 depressions and 50 tidal sites. Each assessment evaluated indicators of condition and wetland stressors related to plant community, hydrology and wetland buffers. We also collected data that are more comprehensive from a subsample of sites, including detailed vegetation measurements, soil characterizations, surveys of the bird community, and quantification of vegetative biomass.

Tidal wetlands were in fair condition with an average condition score of 76, ranging from 52 to 94. Hydrology, the presence and width of buffers, and the degree of adjacent upland shoreline hardening made the difference between the most and the least stressed tidal wetlands across the watershed. Using condition categories to separate the tidal wetland population, 34% were minimally/not stressed, 52% were moderately stressed, and 14% were severely stressed. Several stressors, such as fill material, invasive plants, extent of ditching, shoreline obstruction and development within the buffer, increased in occurrence with decreasing condition. Habitat indicators, such as soil resistance, plant fragments in the upper soil horizon, and presence of invasive species were among the lowest scoring components of the assessment.

Point count surveys of the avian community indicated that tidal sites with higher wetland condition scores had lower bird species richness values but were composed of primarily wetland specific species. Lower condition sites included more upland and generalist species. Vegetative biomass sampling indicated that tidal wetlands with greater condition scores had greater amounts of total below ground biomass and had a greater ratio of total above to total below ground biomass. Bearing capacity (soil resistance) was also positively related to several biomass quantities.

Much of the wetlands lost in the western portion of the watershed were headwater flats. Currently, flats make up 39% of the Murderkill River watershed's wetlands and serve as the headwaters for many nontidal coastal plain streams that are valued as key wildlife and state habitats. Among the 1,980ha of flats across the watershed 33% were minimally or not stressed, 57% were moderately stressed and 10% were considered severely stressed based on condition assessments. On the Index of Wetland Condition flats scores ranged from 48 to 94 and averaged 81. Disturbance by forestry activity was pervasive in flats in every condition category.

Riverine wetlands, or riparian wetlands, make up 26% of the watershed wetland population and serve an important role in water quality and storage and forming habitat corridors. The range of wetland condition stretched very widely, with pockets of wetlands in the mid 70's and 90, but also reaching down as low as 1. One quarter of the population was stressed mostly by channelization of streams which resulted in fill deposits and the encroachment of invasive plants. Residential development and agriculture in or adjacent to the wetland buffer also impacted riverine wetlands and was likely related to the high incidence of dumping in wetlands.

Based on the findings in this study we propose 9 management recommendations and need for data. One, improve the protection of headwater flat

wetlands by protecting them from landuse conversion and urging the use of sustainable practices for forestry harvesting. Two, improve the protection of nontidal wetlands by creating state legislation and supporting enforcement. Three improve nontidal wetland buffer regulations and codes to increase the natural protection of property and improve the quality of life for Delawareans. Four, update tidal wetland regulatory maps using 2007 wetland maps to increase effective permitting. Five, develop incentives to maintain natural buffers of tidal wetlands. Six, control the extent and spread of the non-native, invasive common reed (*Phragmites australis*) through state and federally funded DNREC programs. Seven, improve enforcement of wetland permitting and mitigation monitoring by cooperating with other regulatory branches and incorporating wetland assessment tools into the process. Eight, design a wetland restoration plan that includes the Murderkill River watershed. Finally, secure funding to implement a wetland restoration plan for the Murderkill River watershed to protect high condition wetlands and restore impacted wetlands to a higher level.

INTRODUCTION

Wetlands in the Murderkill River watershed provide many benefits to people, support natural processes, and provide habitats that are an integral part of the landscape. Wetlands transition between terrestrial and aquatic habitats and are one of the most productive ecosystems in the world. Wetlands minimize flooding from storms, control erosion, and improve water quality by removing nutrient runoff and pollutants from non-point sources. Wetlands remove and retain sediment loads from waters that can be elevated due to agricultural practices, land clearing, construction, and bank erosion before they enter tidal and nontidal waterways. They also have substantial cultural and economic value as a source of recreation (e.g. hunting, fishing, birding) and livelihood (e.g. fishing, crabbing, fur-bearer trapping). Tidal wetlands are biologically rich habitats and are a critical resource for migrating shorebirds and wintering waterfowl, and nurseries for commercial fish and shellfish species. Freshwater wetlands process and funnel ground and surface water into our waterways, providing wildlife habitat along the way.

Tidal emergent wetlands along the Murderkill River.

A riverine wetland in Killens Pond State Park.

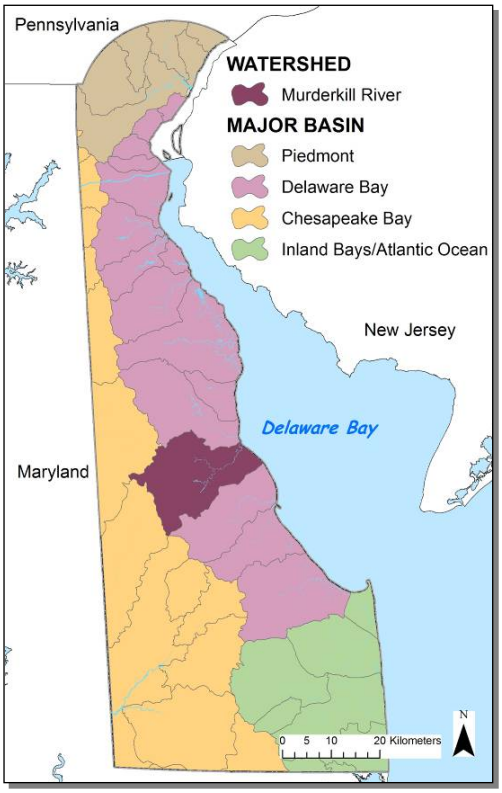
Wetlands have a rich history across the region and their aesthetics have become a symbol of the Mid-Atlantic Coast. The State of Delaware remains committed to improving wetlands through protection and restoration efforts, education, and effective planning to ensure that wetlands will continue to provide these services to the citizens of Delaware (DE DNREC 2008). In addition to assessing the change in wetland acreage over time, monitoring wetland condition is necessary to guide management and protection efforts. The Delaware Department of Natural Resources and Environmental Control (DE DNREC) has developed and implemented a wetland

assessment and monitoring program to evaluate the health of wetlands. Evaluating wetland health or condition, including the stressors that are degrading wetlands on a watershed scale, compiles useful information that watershed organizations, state planning and regulatory agencies, and other stakeholders can use to improve wetland restoration and protection efforts. Protection efforts can be directed towards wetlands in good condition, while allowing restoration efforts to target altered and degraded wetlands to increase functions and services. Wetland assessment information identifies specific stressors that are commonly altering wetlands, and can direct restoration projects and set priorities.

DNREC has developed scientifically valid methods to assess the condition of wetlands on a watershed scale. These methods are being used to generate an overall evaluation of the condition of wetlands in a watershed as well as to identify common stressors by wetland type. In this report, we review the changes in wetland acreage, summarize condition of tidal and freshwater wetlands, identify the common stressors degrading wetlands, and provide recommendations for improving the wetlands of the Murderkill River watershed.

A hardwood flat wetland in the Murderkill River watershed.

WATERSHED OVERVIEW



Map 1. Location of the Murderkill River watershed and the major basins of Delaware.

The Murderkill River Watershed in central Kent County, Delaware is one of 16 watersheds that comprise the Delaware Bay and Estuary Basin in the state (Map 1). The Murderkill watershed is bound by the St. Jones River watershed to the north, and the Mispillion River watershed to the south. It shares a western border with the Choptank and Marshyhope watersheds in the Chesapeake Bay Basin. The Murderkill River watershed covers 28,000ha (69,000ac) and has a varied landscape of development, agricultural production, state park land and other natural areas. The Murderkill River headwaters form near Felton and flow 13km (20mi) eastward to Bowers Beach where the mouth opens to the Delaware Bay. The lower half of the River is tidal.

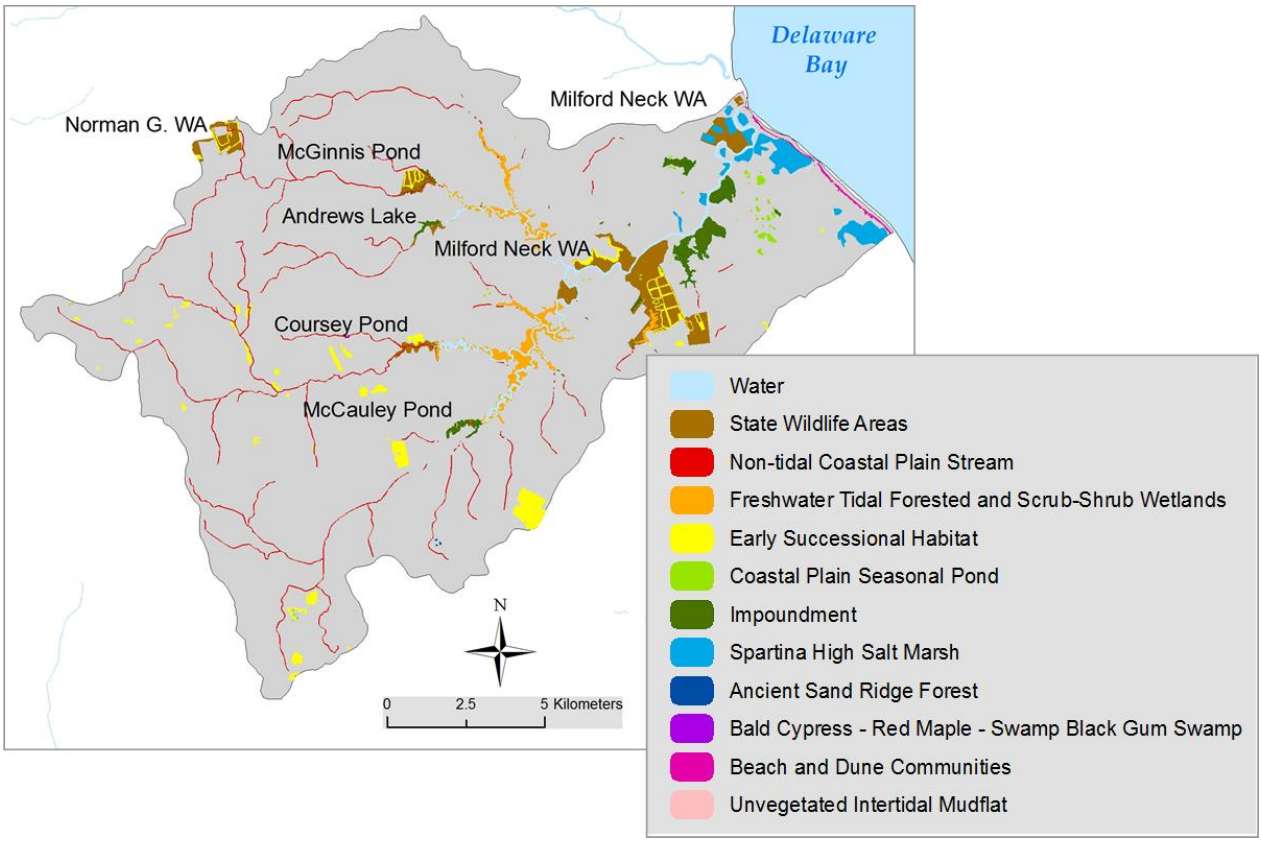
2.1 Geologic History

The Murderkill River watershed falls within the Atlantic Coastal Plain Physiographic Province south of the Appalachian Piedmont Fall Zone. The geologic formation of this area was due to a combination of glacier activity and sediment deposition and compaction. Most of present day Delaware was covered by ocean before the last ice age (DE DNREC 2005). Large amounts of sediments from the ancient Appalachians were carried down the Delaware River, Susquehanna River and others, and settled onto the coastal plain of Delmarva (DE DNREC 2005). These sediments compacted over time, lowering the land surface elevation.

2.2 Watershed Hydrogeomorphology

The Murderkill River watershed contains 3 of the 4 hydrogeomorphic regions, as defined by topography, geology, hydrogeology and soils that are found in the Delaware Bay and Estuary Basin: poorly-drained uplands, well-drained uplands, and beaches/tidal marshes/ lagoons/barrier islands (DE DNREC 2005). Portions along the western edge of the watershed as well on the southeastern side are poorly drained uplands and contain most of the headwater flat wetlands in the watershed. The middle of the watershed is mostly well-drained uplands where riverine

wetlands form on floodplains adjacent to natural streams and rivers. Tidal wetlands along with beaches, lagoons and barrier islands, are found in the eastern portion of the watershed which runs from 5 feet above mean sea level to mean sea level as you approach the Delaware Bay.



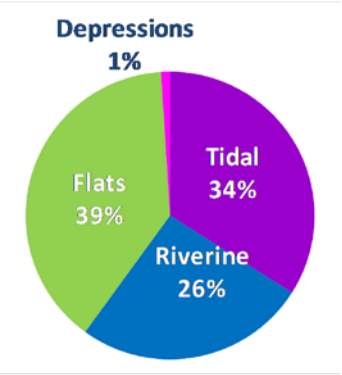
Map 2. Key habitats, wildlife areas and recreational ponds in the Murderkill River watershed, Delaware.

The Murderkill River watershed contains many key natural heritage and wildlife habitats such as coastal plain streams and ponds, impoundments, wetlands and beach dunes (Map 2). There are also several State ponds and lakes, and two Wildlife Areas: Milford Neck and a portion of Norman G. Wilder (Map 2).

The unconfined aquifer (water table) and several deeper confined aquifers, throughout the Delaware Bay and Estuary area, support the ground water for the basin and are the source of potable water in the Murderkill River watershed (DE DNREC 2005). The unconfined aquifer flows through gravelly sands and is recharged through precipitation in areas where permeable sediments allow water to infiltrate down to the aquifer. The water table aquifer is heavily drawn from for agricultural, industrial and municipal uses.

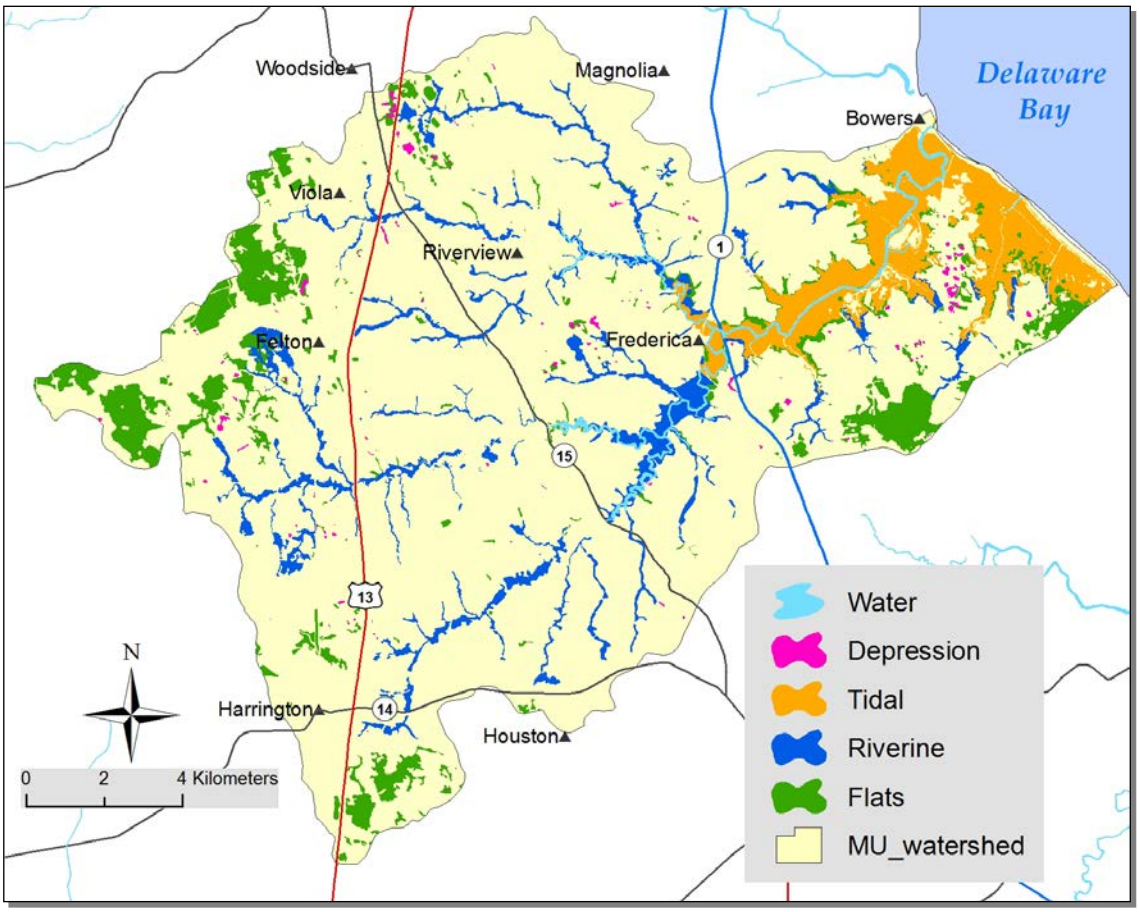
2.2 Wetlands

Wetlands make up 18% of the Murderkill River watershed (Figure 1). Tidal wetlands are most prevalent followed by flats and riverine wetlands (Figure 1).



Wetland Type	Hectares (Acres)	Proportion
Tidal or Brackish	1,718 (4,243)	34
Riverine	1,304 (3,221)	26
Freshwater Flats	1,980 (4,890)	39
Depressions	52 (127)	< 1
Total	**5,054 (12,482)**	**100**

Figure 1. Wetland proportions and acreage by wetland type for the Murderkill River watershed, Delaware.



Map 3. Distribution of tidal and nontidal wetland across the Murderkill River watershed, Delaware based on 2007 mapping.

Tidal wetlands associated with salt to brackish waters are found along the coast and upstream into rivers and tributaries, Nontidal freshwater wetlands such as riverine and flats dominate the western watershed, whereas tidal salt marshes

dominate the eastern portion of the watershed as the Murderkill River approaches the Delaware Bay (Map 3). Small pockets of freshwater depression wetlands are scattered around the watershed (Map 3). The Murderkill River watershed has 26ha (63ac) of unique and threatened wetland types. Coastal plain pond depressions, found mostly east of Frederica and Route 1, make up 97% of that acreage. One patch of Bald Cypress riverine located on the Spring Branch makes up the other 3%. Bald Cypress communities are particularly rare in Delaware where the tree species reaches its northern-most North American limits. Although these rare wetland habitats make up a small portion in the watershed, they are historically unique and valuable to plant, animal, and insect communities, as described in the Delaware Wildlife Action Plan (DE DNREC 2006).

The Ramsar Convention on Wetlands (www.ramsar.org) recognizes the wetlands of the Delaware Bay and Estuary as 'international wetlands of importance' because of their role in shorebird migration and waterfowl wintering habitat. In 1986, The Delaware Bay and Estuary was recognized as the first Western Hemisphere Shorebird Reserve site of Hemispheric Importance (WHSRN 2009). This is the highest rank recognized by the global organization and indicates that at least 500,000 shorebirds visit annually, or that at least 30% of the biogeographic population for a species is supported by the site.

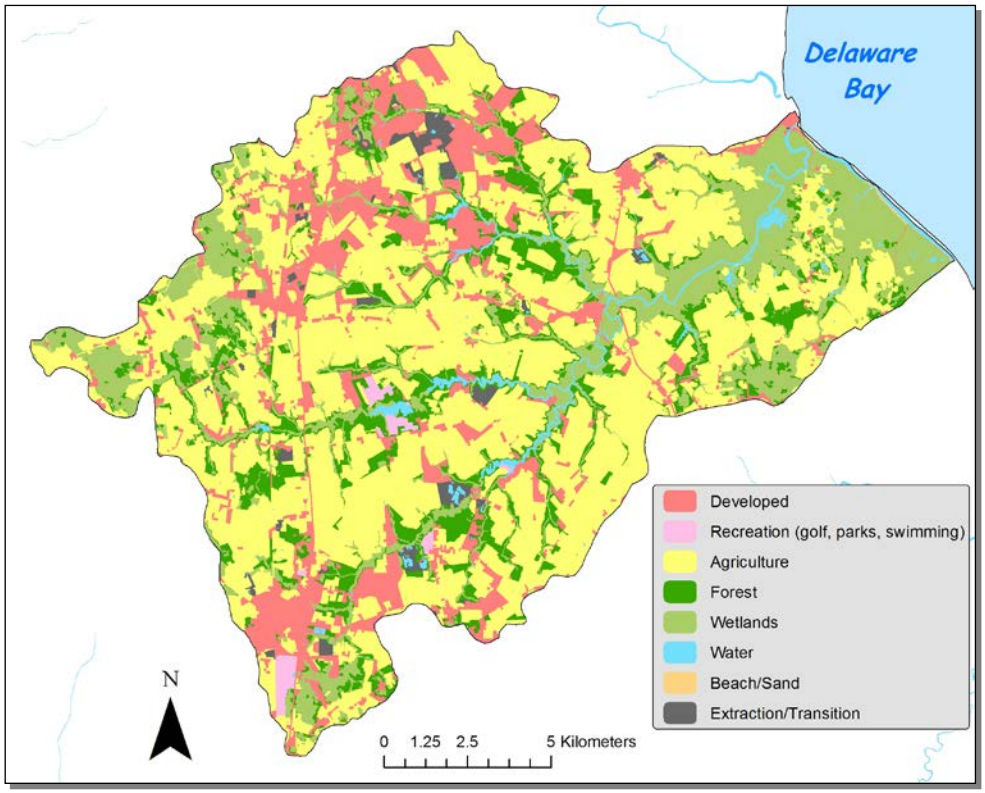
2.3 Land Use Changes and Wetland Issues

Based on 2007 National Land Cover Dataset (NLCD), 52% of the Murderkill watershed acreage is in agricultural land uses. Agriculture is a broad category that includes row crops, orchards, nurseries, confined feedlots, rangeland and farmsteads. Large tracts of agricultural land dominate the landscape across the watershed (Map 4). Concentrated areas of development are located in the watershed's northern portion between Woodside and Magnolia and in the south around Harrington. The dark gray extraction/ transitional areas are often areas in the early phase of being cleared and developed.

Using similar land use information from 1997 as a comparison, the land use types with the most change were agriculture and development (Table 1). The increase in development and extraction/ transitional is nearly identical to the decrease in agricultural, suggesting a conversion between the two land use types, similar to the neighboring St. Jones River watershed. In addition to the decrease in acreage, the average size of forest and wetland blocks have decreased over time, increasingly fragmented by road and project construction.

Land use affects the health of wetlands directly through conversion from wetland to other land use types and indirectly from adjacent activities associated

with different land use types. Common stressors to wetlands are alterations to the hydrology from drainage ditches, water quality issues related to nutrient and chemical runoff, and the disruption and compaction of soil layers. In the Murderkill River watershed, high nutrients, specifically nitrogen and phosphorus, and extremely low dissolved oxygen levels have been primary water quality concerns. The creation of residential developments will result in a large increase in impervious surfaces causing more storm water flashes and soil erosion, and reducing the groundwater recharge potential. Runoff from roads (e.g. oil, salt, gas) as well as lawn fertilizers and pesticides will affect water quality. Depending on if septic systems or central sewer is used, wastewater may also be a groundwater source of



Map 4. Land cover for the Murderkill River watershed in 2007 based on NLCD land use categories.

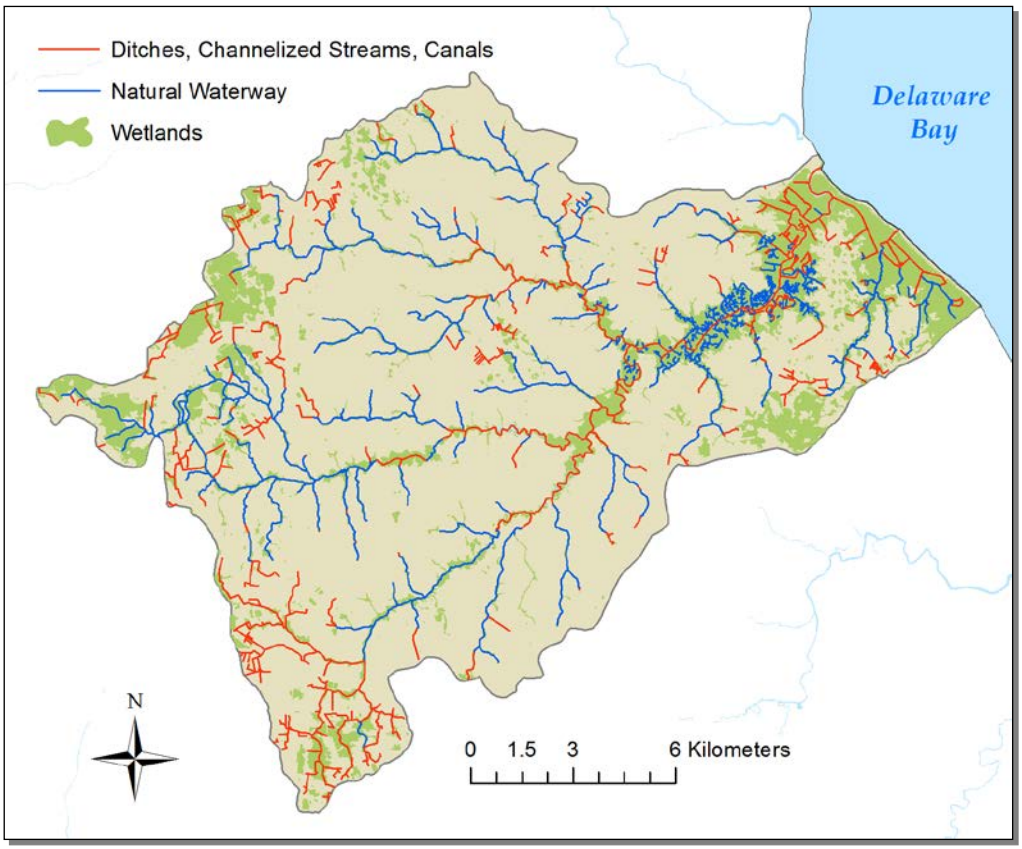
Table 1. Land use changes for the Murderkill River watershed between 1997 and 2007 based on NLCD.

Land Use Category	1997 (% area)	2007 (% area)	10-year % Change
Developed	11.9	15.5	+3.7
Recreation	0.6	0.7	+0.1
Agricultural	56.7	52.4	-4.3
Forest	11.6	10.8	-0.8
Wetlands (including forested wetlands)	17.0	16.9	-0.1
Water	1.5	1.9	+0.4
Sand/Beach	0.0	0.0	0.0
Extraction/Transitional	0.7	1.5	+0.8

nutrients. TMDLs were established by DNREC in 2001 for the Murderkill River and its tributaries to address nonpoint nutrient loading and low dissolved oxygen levels.

In 2007, the Murderkill River Study Group was formed between Kent County and the State of Delaware DNREC Division of Water Resources as a result of the County's appeal to the 2001 TMDL Regulation. The Kent County Regional Wastewater Treatment Facility, which is owned and operated by Kent County, is located on the Murderkill River and serves all of Kent County and portions of New Castle and Sussex County. The purpose of the group is to plan and implement a comprehensive monitoring effort to quantify the effect of tidal marshes and other natural resources on water quality of tidal portions of the Murderkill River.

Stream channelization and ditching for agriculture drainage, and mosquito control has been extensive in tidal and nontidal wetlands and has changed wetland hydrology, created a source of fill, and has altered natural wetland functions in the watershed (DE DNREC 2005). Half of the waterways across the watershed are ditched, channelized or are canals (Map 5). Also, the spread of invasive species such as *Phragmites australis* throughout fresh to brackish wetlands is also pervasive across the watershed. As natural hydrology patterns are altered by impoundments, dams, tidal restrictions and fill, *Phragmites* is able to aggressively out-compete native species and create large monotypic stands that provide poor habitat and food resources (DE DNREC 2005).



Map 5. Distribution of natural and artificial or altered waterways in the Murderkill River watershed.

Sea-level rise and the effects of climate change continue to be a concern for all coastal watersheds. Coastal development and the hardening of shorelines reduce the ability of wetlands to migrate upland with increasing sea level, restricting wetlands until they convert to open water. Shorelines without the protection of coastal wetlands are vulnerable to storm surges and erosion. As sea level rises, salt water will intrude further upstream into freshwater systems. Increased storm surges, changes in tidal amplitudes, more extreme precipitation and altered temperatures will also impact wetlands in the upcoming decades.

METHODS

We assessed the condition of tidal and nontidal wetlands in the Murderkill River Watershed. We used a probabilistic survey approach to assess wetlands on private and public lands within the watershed. For tidal wetlands, we used the Mid-Atlantic Tidal Rapid Assessment Method (MidTRAM; Jacobs et al. 2009a) and for nontidal wetlands we used the Delaware Rapid Assessment Protocol (DERAP, Jacobs 2007) to evaluate wetland condition and identify wetland stressors. We used comprehensive wetland data to validate our rapid methods.

3.1 Site Selection

EPA's Ecological Monitoring and Assessment Program (EMAP) in Corvallis, Oregon assisted with selecting 500 potential sample sites in estuarine intertidal emergent wetlands and 500 potential sample sites in nontidal wetlands using a generalized random tessellation stratified (GRTS) design (Stevens and Olsen 1999, 2000). The target population was mapped wetlands from the state wetland maps (State of Delaware 1994), which are based on 1992 aerial photography. Sampling sites were randomly chosen points within mapped wetlands, which give each point an equal probability of being selected and allows more than one point to fall in a wetland polygon. Sites were selected and sampled in numeric order as dictated by the EMAP design, lowest to highest. Sites were only excluded from sampling if permission for access was denied, if the site was of the wrong wetland classification, or if the site was upland. Our goal was to sample 50 tidal sites and 30 nontidal sites in each subclass (riverine, flats, and depression). For the nontidal sites, once we sampled 30 sites of one subclass we did not sample additional sites of that subclass but rather would continue to sites of the remaining subclasses in order of the EMAP selection.

3.2 Changes in Wetland Acreage

To accompany our assessment of wetland condition, we used state wetland maps to determine the distribution of wetlands across the Murderkill River watershed and where wetlands have been lost in recent decades and since Delaware settlement. We determined historic wetland acreage using U.S. Department of Agriculture Natural Resource Conservation Service soil maps. We identified hydric soil map units from soil survey data (which are based on soil indicators such as drainage class, landform, and water flow) as 'historic wetlands'. We added the historic wetland units to 1994 wetland units to create an estimated pre-settlement wetland layer. We used the 1994 SWMP layer to identify recent wetland distribution (State of Delaware 1994). We identified current wetlands using the most recent wetland inventory based on 2007 aerial photography (State of Delaware 2007). We determined changes in wetland acreage across the watershed by comparing the acreage of existing wetlands to both recent and historic wetlands.

Mention of wetland functions are based on estimates from landscape-level analysis using the USFWS NWIPlus (Tiner 2010).

3.3 Data Collection

3.3.1. Assessing Tidal Wetlands

3.3.1.a Rapid Sampling of Tidal Wetlands

We evaluated the condition of tidal wetlands using the MidTRAM. The MidTRAM was developed in 2007-2008 by adapting the New England Rapid Assessment Method (NERAM; Carullo et al. 2007) and the California Rapid Assessment Method (CRAM; Collins et al. 2008) to tidal wetlands in the MidAtlantic Region. MidTRAM consists of 15 scored metrics that represent the condition of the wetland buffer, hydrology, and habitat characteristics (Table 2). MidTRAM uses a combination of qualitative evaluation and quantitative sampling to record the presence and severity of stressors in the field or in the office using maps and digital orthophotos.

We completed the MidTRAM at the first 50 random points that we could access and that met our criteria of being of an estuarine intertidal emergent wetland. We established a site assessment area (AA) as a 50m radius circle centered on each random point (Figure 2). We defined the AA buffer area as a 250m radius area around the AA. If a 50m radius circle would go beyond the wetland into upland or open water, we moved the circle <50m or changed to a rectangle of equal area to have the entire AA within the wetland. The AA buffer could extend into upland or open water.

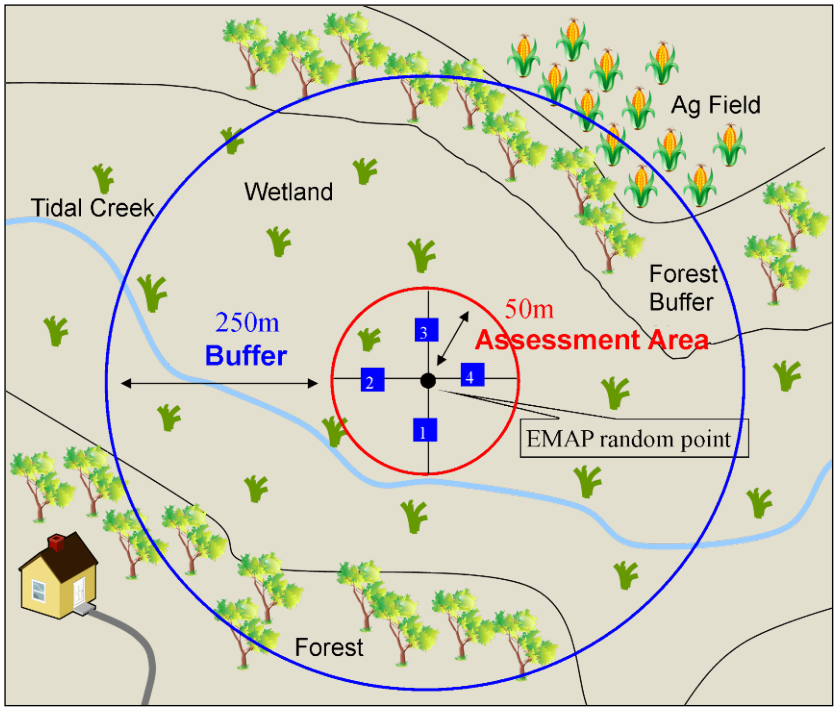


Figure 2. Assessment area and subplots used to collect data for the MidAtlantic Tidal Rapid Assessment Method.

For metrics measured within the AA (Table 2) we evaluated indicators throughout the entire AA with the exception of the soil profile, plant fragments, and soil bearing capacity. For these 3 metrics, we

established 4 1m² subplots within the AA along 2 100m transects that bisected the AA. We oriented one transect perpendicular to the nearest source of open water (>30m wide) and the other was perpendicular to the first. We placed each of the 4 subplots 25m from the center of the AA and numbered them clockwise starting with one towards the open water (Figure 2). If a subplot fell in a habitat type or patch that was not characteristic of the site (e.g. in a ditch) we moved it 1m along the transect.

We completed all metrics within the AA via visual inspection during the field visit, with the exception of soil bearing capacity and plant fragments. We measured soil bearing capacity using a slide hammer technique on a random spot in each subplot (Figure 2). To take the measurement, we raised the slide hammer and released 4 times to exert a consistent force on the soil surface. We subtracted the final depth below the marsh surface of the bottom of the slide hammer from the initial depth to get the change in depth due to the total force. We also measured plant fragments in each subplot by removing a 2cmx2cm piece of the soil from 2-4cm below the ground surface. We rinsed the sample to remove soil and measured the volume of the roots compressed in a plastic syringe to the nearest 0.1cm³. Each metric was scored a 3, 6, 9, or 12, except Plant Fragments which was on a 4, 8, 12 scale, based on the narrative or numeric criteria in the protocol.

Table 2. 14 Metrics comprising the MidAtlantic Tidal Rapid Assessment Method.

Attribute Group	*Metric Name*	*Description*	*Measured in AA or Buffer*	*Qualitative or Quantitative*
Buffer/Landscape	Percent of AA Perimeter with 5m-Buffer	Percent of AA perimeter that has at least 5m of natural or semi-natural condition land cover	Buffer	Quantitative Office
Buffer/Landscape	Average Buffer Width	The average buffer width surrounding the AA that is in natural or semi-natural condition	Buffer	Quantitative Office
Buffer/Landscape	Surrounding Development	Percent of developed land within 250m from the edge of the AA	Buffer	Quantitative Office/Field

Attribute Group	***Metric Name***	***Description***	***Measured in AA or Buffer***	***Qualitative or Quantitative***
Buffer/Landscape	Barriers to Landward Migration	Percent of landward perimeter of marsh within 250m that has physical barriers preventing marsh migration inland	Buffer	Quantitative Office/Field
Hydrology	Ditching & Draining	The presence and functionality of ditches in the AA	AA	Qualitative Field
Hydrology	Fill & Fragmentation	The presence of fill or marsh fragmentation from anthropogenic sources in the AA	AA	Qualitative Field
Hydrology	Diking/Restriction	The presence of dikes or other restrictions altering the natural hydrology of the wetland	AA and Buffer	Qualitative Field
Hydrology	Point Sources	The presence of localized sources of pollution	AA and Buffer	Qualitative Field
Habitat	Bearing Capacity	Soil resistance using a slide hammer	AA subplots	Quantitative Field
Habitat	Plant Fragments	Volume of plant fragments in the upper soil horizon	AA- subplots	Quantitative Field
Habitat	Vertical Biotic Structure	The interspersion and complexity of the vegetation community.	AA	Qualitative Field
Habitat	Number of Plant Layers	Number of plant layers in AA based on plant height	AA	Qualitative Field
Habitat	Percent Co-dominant Invasive Species	Percent of co-dominant species that are invasive in the AA	AA	Qualitative Field
Habitat	Percent Invasive	Percent cover of invasive species in AA	AA	Qualitative Field

We assessed buffer metrics (i.e. buffer width, surrounding development, percent of assessment area with a 5m buffer, and barriers to landward migration) in the office using ArcMap GIS software (ESRI, Redlands, CA, USA) and then verified visually in the field.

At the completion of the site visit and assessment, crew members gave each site a Qualitative Disturbance Rating (QDR) to rank the level of anthropogenic disturbance to the site's natural structure and biotic community. Descriptions of the disturbance ratings are provided in Appendix A. The average field time to sample each site was 2h. Metrics completed in the office took up to ½ hour to complete. Detailed instructions for using MidTRAM are provided in the protocol (Jacobs et al. 2009a).

We calculated attribute group scores by summing the metric scores and dividing by the total possible value. That value was adjusted to be on a 0-100 scale since each metric can only score a minimum of 3 or 4:

Attribute Group score = $((((\sum(\text{metric}_{1...n})/\text{MAX}_a)*100)-\text{floor}_x)/\text{ceiling}_x$

where $\text{metric}_{1...n}$=metric scores for the buffer, hydrology or habitat group, MAX_a=the maximum possible attribute group score, floor_x = the minimum calculated score for each group multiplied by 100 (e.g. 25, 25, 26.4), and ceiling_x=; 100-floor_x (e.g. 75, 75, 73.6). Final MidTRAM condition scores were calculated by averaging the 3 attribute group scores and ranged from 0-100:

MidTRAM condition score =
(Buffer Attribute Score + Hydrology Attribute Score + Habitat Attribute Score)/ 3

Example: Site B
Buffer group score= ((((9+9+6+12+3)/60)*100)-25)/(100-25)= 0.53*100=53
Hydrology group score= ((((12+9+6+12)/48)*100)-25)/(100-25)= 0.75*100=75
Habitat group score=((((3+3+6+12+9+12)/72)*100)-26.4)/(100-26.4)= 0.48*100=48

MidTRAM condition score = (53+75+48)/3 = 59

We used SAS (Version 9.1, Cary, NC. USA) and Excel for all of our statistical analyses with an alpha level of 0.10.

3.3.1.b Intensive Sampling in Tidal Wetlands

i. Marsh Birds

We performed point count surveys for marsh birds at 25 sites. We surveyed the first 7-10 random sites that we also sampled with the MidTRAM (7 in the

Inland Bays, 10 in the Murderkill and 8 in the St. Jones watershed). We analyzed the combined dataset with all three watersheds to increase sample size and statistical power. We surveyed the first 7-10 random sites in each watershed. We sampled sites once during each of two periods: May 5-15 and June 2-10 2008. We completed our surveys between 30 min before and 2h after sunrise (modified from Gibbs and Melvin 1993). We did not conduct surveys during precipitation, heavy fog, or wind speeds >12mph (Gibbs and Melvin 1993).

At each site, we recorded all species that were visually or audibly detected within 75m of our assessment point during a 5-minute passive survey when no calls were played, followed by a 6-minute callback survey. During the callback survey a portable CD player with a speaker was used to broadcast the calls of black rail (*Laterallus jamaicensis*), least bittern (*Ixobrychus exilis*), Virginia rail (*Rallus limicola*), king rail (*R. elegans*), clapper rail (*R. longirostris*), and American bittern (*Botaurus lentiginosus*). We played each species' call for one minute with a 30-second listening period in between.

We calculated an Index of Marsh Bird Community Integrity (IMBCI) based on DeLuca et al. (2004) and Pepper (2008). Following this technique, for every species detected during the point count surveys, we assigned a score based on their wetland specializations and compiled them to calculate a site score for each wetland. Wetlands with a richer diversity of wetland marsh birds scored a higher index value and indicated a healthy wetland ecosystem. For example, a wetland with an IMBCI score of 0 indicated that only generalist species were present whereas an IMBCI score of 12 indicated that several species detected had wetland specialist attributes.

The species scores were determined from 4 attribute values (L_s) listed below (values are listed in parentheses):

1. *Foraging habitat*. Primary foraging habitat. Scored as habitat generalist (1), marsh facultative (2.5) or marsh specialist (4).
2. *Nesting substrate*. Primary nesting location. Scored as non-marsh nesters (1), nesting in marsh vegetation (2.5) or marsh ground-nesters (4).
3. *Breeding range*. Restrictions for breeding habitat in North America. Scored as North America (1), North America only east of the Rocky Mountains (2), coastal North America (3), or North America east coast only (4).
4. *Conservation status*. Scored as low concern (1) moderate (2.5) or high (4) based on species' status according to state and federal wildlife agencies and scientific partnerships such as Partners in Flight.

Attribute values for each species were provided by DeLuca et al. (2004), Pepper (2008) or were determined using guides (National Geographic Society 1987)

and species literature (Burger 1996, McCrimmon et al. 2001, McGowan 2001, McNicholl et al. 2001, Nisbet 2002, Pierroti and Good 1994, Thompson et al. 1997). Calculations for the species' scores and wetland site scores (W_{IMBCI}) were calculated using the following formulas:

$$\mathbf{S_{IMBCI}} = \sum L_s \qquad W_{IMBCI} = [(\sum S_{IMBCI} / S_N) + MO_N] - 4$$

Where S_{IMBCI} was the score for each species, Ls represented each attribute score, S_N was the total number of species detected at the site and MO_N was the total number of obligate marsh species detected at the site as determined by the nesting and foraging requirements of the species. We subtracted 4 to ensure a scoring scale that begins with a zero and remains constant (DeLuca et al. 2004). The example below demonstrates the calculation of a wetland site score.

Example: Site A

Species	Foraging Habitat	Nesting Substrate	Breeding Range	Conservation Rank	Sum (S_{IMBCI})
Boat-tailed grackle	1	2.5	4	1.5	9
Clapper rail *	4	4	3	1	12
Glossy ibis	1	2	4	1	8
Red-winged blackbird	1	2.5	1	1	5.5
Seaside sparrow *	4	2.5	4	3	13.5
Willet *	4	4	4	2	14

* indicates a marsh obligate species

$$\mathbf{W_{IMBCI}} = [((\sum S_{IMBCI})/ S_N) + MO_N] - 4$$
$$= [((9+12+8+5.5+13.5+14)/6) + 3] -4$$
$$= 10.3 + 3 - 4$$
$$= 9.3$$

We used linear regressions between IMBCI values and species richness, MidTRAM condition scores, and attribute group scores to determine if a relationship existed between MidTRAM and the bird survey data.

ii. Vegetative Biomass

We collected vegetative above and below ground biomass samples from 30 sites across the Inland Bays (N=10), Murderkill (N=10) and St. Jones (N=10) watersheds. We sampled the first 10 random sites in each watershed that we had also sampled with the MidTRAM. We had also sampled most of the 30 sites for marsh birds. We collected biomass from subplots 1, 2 and 3 on August 21-26, 2008 and August 18-24, 2009. We sampled above ground biomass by clipping all vegetation within a 15.24cm radius circle randomly placed at the outside edge of the

subplot. We sorted the vegetation to separate live stems from dead. We collected below ground biomass by extracting sediment cores to 30cm below the marsh surface. We thoroughly rinsed the cores clean of any sediment, separated live from dead roots, and chilled the samples until we could dry them. We dried the samples (80-85°F) for approximately 72h until there was no additional weight loss detected with additional drying time. We weighed each sample to the nearest 0.01g (Turner et al. 2004).

We used averages of the 3 subplots at each site for all biomass comparisons and analyses. We used a nonparametric Spearman's ranking correlation to look for and measure the relationship between MidTRAM condition scores and total above ground (biomass), total below ground, above ground live, above ground dead, below ground live, below ground dead, above ground live:below ground live ratio, above ground dead:below ground dead ratio, and total above ground:total below ground ratio. We used regression to display the relationships between MidTRAM condition scores and total above ground (biomass), total below ground and total above:total below ground ratio.

3.3.2 Assessing Nontidal Wetlands

3.3.2.a Rapid Sampling in Nontidal Wetlands

We assessed the condition of nontidal wetlands in the Murderkill River watershed using the DERAP. DERAP collects data on the presence and intensity of stressors related to habitat, hydrology, and buffer features to assess the condition of wetlands by watershed. DERAP scores are calibrated to comprehensive wetland condition data collected using the Delaware Comprehensive Assessment Procedure.

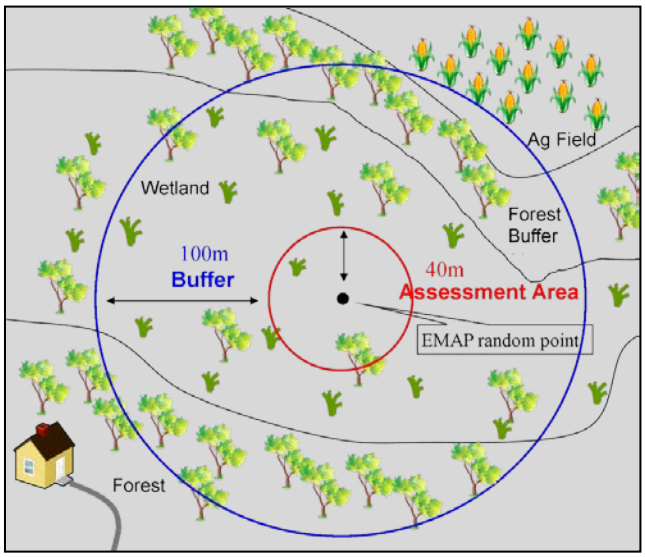


Figure 3. Assessment area and buffer used to collect data for nontidal rapid and comprehensive

We sampled 65 nontidal wetland sites in the Murderkill River watershed using DERAP (N_{FLAT}=30, N_{RIV}=30, N_{DEP}=5) in 2006. We established a 40m radius AA and 140m radius buffer around a random EMAP point (Figure 3). If the 40m radius circle extended beyond the wetland edge into upland or open water, we moved the AA <40m or changed to a rectangle of equal area in order to stay within the wetland. The stressors evaluated using the DERAP are provided in Table 3. A complete list of stressor names and abbreviations is in Appendix B. The DERAP takes a field crew of 2 people 30min to 2h to complete depending on field conditions. In 2009, we also sampled 12 restoration sites (11

Depression, 1 Flat) with DERAP to gain descriptive information on the condition of restored wetlands compared to natural sites.

Table 3. Stressors evaluated using the Delaware Rapid Assessment Procedure.

Habitat Stressors	Hydrology Stressors	Buffer Stressors
Mowing	Presence and depth of ditches	Development-commercial/industrial /residential
Farming activity	Ditching in floodplain	Waste water disposal method
Grazing	Channelized stream	Landfill
Forestry activity (time since last activity)	Channel incision	Channelized Streams or Ditches
Cleared land	Damming	Roads
Excessive Herbivory/ Pinebark Beetle /Gypsy Moth	Stormwater Inputs	Trails
Invasive species	Point Source	Row crops/Nursery
Chemical defoliation	Filling, Excavation	Orchard
Managed or converted to pine	Microtopography alterations	Poultry/Livestock Operation
Burned	Excessive sedimentation	Forest Harvesting within 15 Yrs
Trails	Soil Subsidence/Root Exposure	Slips/Docks
Roads		Boat moorings
Garbage/Isolated dumping		Golf course
Excessive nutrients		Mowing
		Sand/Gravel Operation

Scoring for the DERAP to produce one overall score of condition was developed through a process to calibrate the presence of stressors at a site to comprehensive wetland condition data using the DECAP Index of Wetland Condition (IWC). We developed the DECAP IWC using a process to screen hydrogeomorphic (HGM) variables specific to wetland subclass to select the strongest variables that would represent the condition of the primary wetland attributes of plant community, hydrology, and buffer (Jacobs et al. 2009b). The DERAP was then calibrated to the DECAP IWC using a data set of over 250 sites from the Nanticoke, Inland Bays, and Delaware Bay watersheds in Delaware (Sifneos et al. 2010).

We selected stressors using step-wise multiple regression and Akaike's information criteria (AIC) to develop the best model that correlated with comprehensive assessment data without over-fitting the model to this specific dataset. Coefficients or weights associated with each stressor were assigned using multiple linear regression (Appendix C). We calculated the DERAP IWC score by summing the stressor coefficients for each of the selected stressors that were present and subtracting the sum from the linear regression intercept. For flats

wetlands, 15 stressors were selected to be included in the DERAP IWC calculation; 7 habitat stressors, 5 hydrology and 3 landscape or buffer stressors (Appendix C). We selected 17 stressors for riverine wetlands including 7 habitat stressors, 10 hydrology stressors and 0 buffer stressors (Appendix C).

$$\text{DERAP IWC}_{\text{FLATS}} = 94.4 + (\sum \text{stressor weights})$$
$$\text{DERAP IWC}_{\text{RIVERINE}} = 90.4 + (\sum \text{stressor weights})$$

The DERAP stressor dataset from 30 flats, 30 riverine and 5 depression sites in the Murderkill watershed are provided in Appendix G, H, and K, respectively.

3.3.2.b Comprehensive Sampling in Nontidal Wetlands

We collected DECAP data from 6 flats, 6 riverine sites, and 2 depressions. Each site that was sampled with DECAP was also sampled with DERAP. We followed the Delaware Comprehensive Assessment Procedure as outlined in the protocol (Jacobs et al. 2008). These data will be combined with other DECAP data from sites throughout Delaware to continue to validate and calibrate the DERAP. Flats, riverine and depression DECAP data are provided in Appendix I, J and K, respectively. Due to our small sample size for depression wetlands, we were not able to report on the condition of the depression subclass for the Murderkill watershed.

3.4 Presenting Wetland Condition

We present our results at the site and population level. We discuss site level results by summarizing the range of scores that we found in sampled sites (e.g. Habitat attribute scores ranged from 68 to 98). Population level results are presented using weighted means and standard deviations (e.g. Habitat for tidal wetlands averaged 87±13) or weighted percentages (e.g. 20% of riverine wetlands had channelization present). Population level results have incorporated weights based on the probabilistic design and correct for any bias due to sample sites that could not be sampled and different rates of access on private and public lands to be able to extrapolate to the total area of wetland in the watershed. The cumulative

Condition Breakpoint Criteria –*calculated for each subclass (tidal, flats, riverine)*

Minimally or not stressed –. Sites with condition scores ≥25th percentile of the range for sites with a low disturbance QDR rating of 1 or 2.

Moderately stressed – Sites in between minimally and highly stressed.

Highly stressed –. Sites with condition scores ≤75th percentile of the range for sites with a high disturbance QDR rating of 5 or 6.

results represent the total area of the respective wetland subclass for the entire watershed.

Sites in each HGM subclass were placed into 3 condition categories (Minimally or not stressed, Moderately stressed or Severely stressed; Table 4). We determined breakpoints by applying a percentile calculation to the QDR's and condition scores from sites in several watersheds. For the tidal portion we used sites from the St. Jones, Murderkill, and Inland Bays watershed (N=136) combined for a larger, regional sample. We used the 25th percentile of MidTRAM scores for sites with a QDR of 1 or 2 to separate Minimally or not stressed from Moderately stressed. We used the 75th percentile of MidTRAM scores from sites with a QDR of 5 or 6 to separate Moderately stressed from Severely stressed. Based on the 3 watersheds combined, the condition breakpoints for tidal sites are provided in Table 4.

For the nontidal portion, we used assessment sites from the Nanticoke and Inland Bays watersheds (N=115) to determine condition breakpoints separately for flat and riverine wetlands. We used the 25th percentile of DERAP scores for sites with a QDR of 1 or 2 to separate Minimally or not stressed from Moderately stressed. We used the 75th percentile of DERAP scores from sites with a QDR of 5 or 6 to separate Moderately stressed from Severely stressed. Based on the 2 watersheds combined, the condition breakpoints for nontidal sites that we applied in the St. Jones watershed are provided in Table 4.

Table 4. Condition categories and breakpoint values for tidal, and nontidal flats and riverine wetlands in the St. Jones River watershed as determined by wetland condition scores.

Wetland Type	Method	Minimally or Not Stressed	Moderately Stressed	Severely stressed
Tidal	MIDTRAM	≥81	<81 and ≥ 63	<63
Nontidal Riverine	DERAP	≥85	<85 and ≥47	<47
Nontidal Flats	DERAP	≥88	<88 and ≥65	<65

We used a cumulative distribution function (CDF) to display wetland condition on the population level. A CDF extrapolates assessment results to the entire population and can be interpreted by drawing a horizontal line anywhere on the graph and reading that as: 'z' proportion of the area of tidal wetlands in the watershed falls above (or below) the score of 'w' for wetland condition. The advantage of these types of graphs is that they can be interpreted based on individual user goals, and break 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 4 roughly 40% of the wetland area scored above an 80 for wetland condition. A CDF also highlights clumps or platueas where either a large or small portion of wetlands are in similar condition. In the example, there is a condition plateau from 50 to approximately 75, illustrating that only a small portion of the population had condition scores in this range.

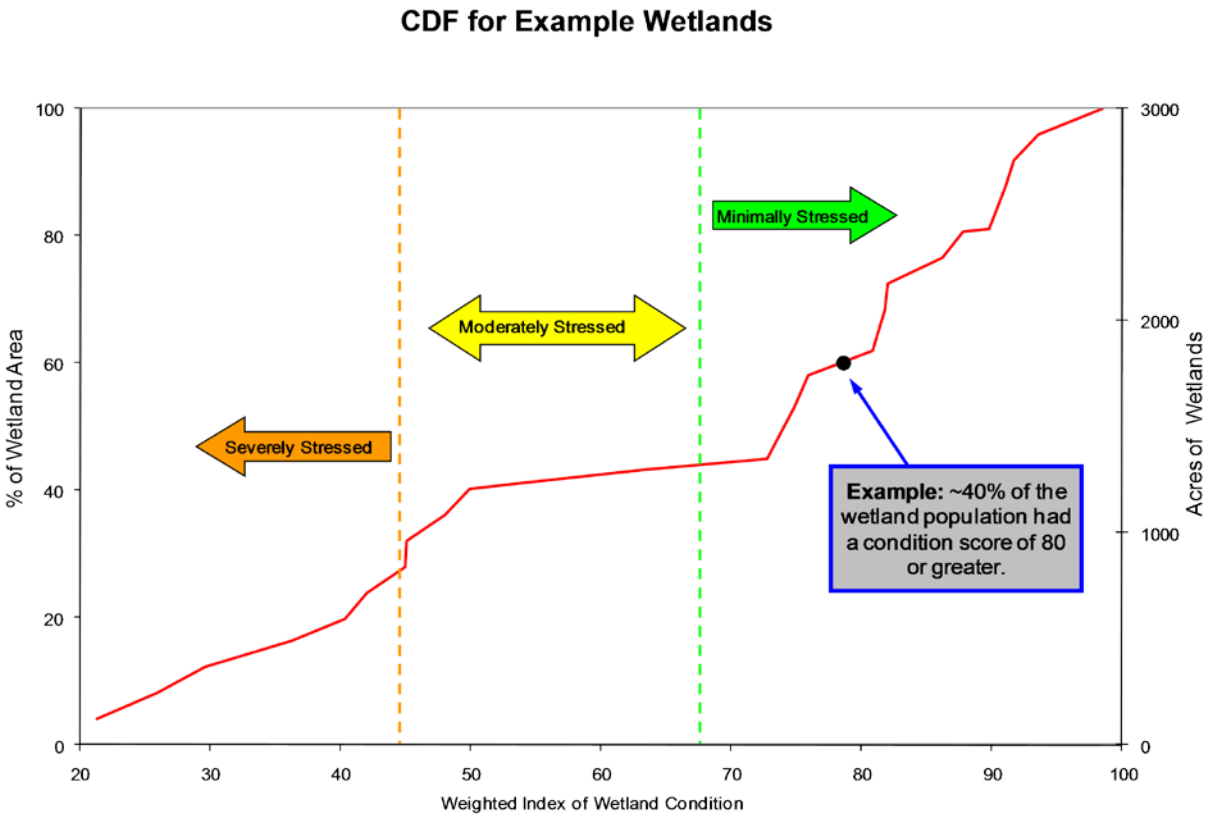
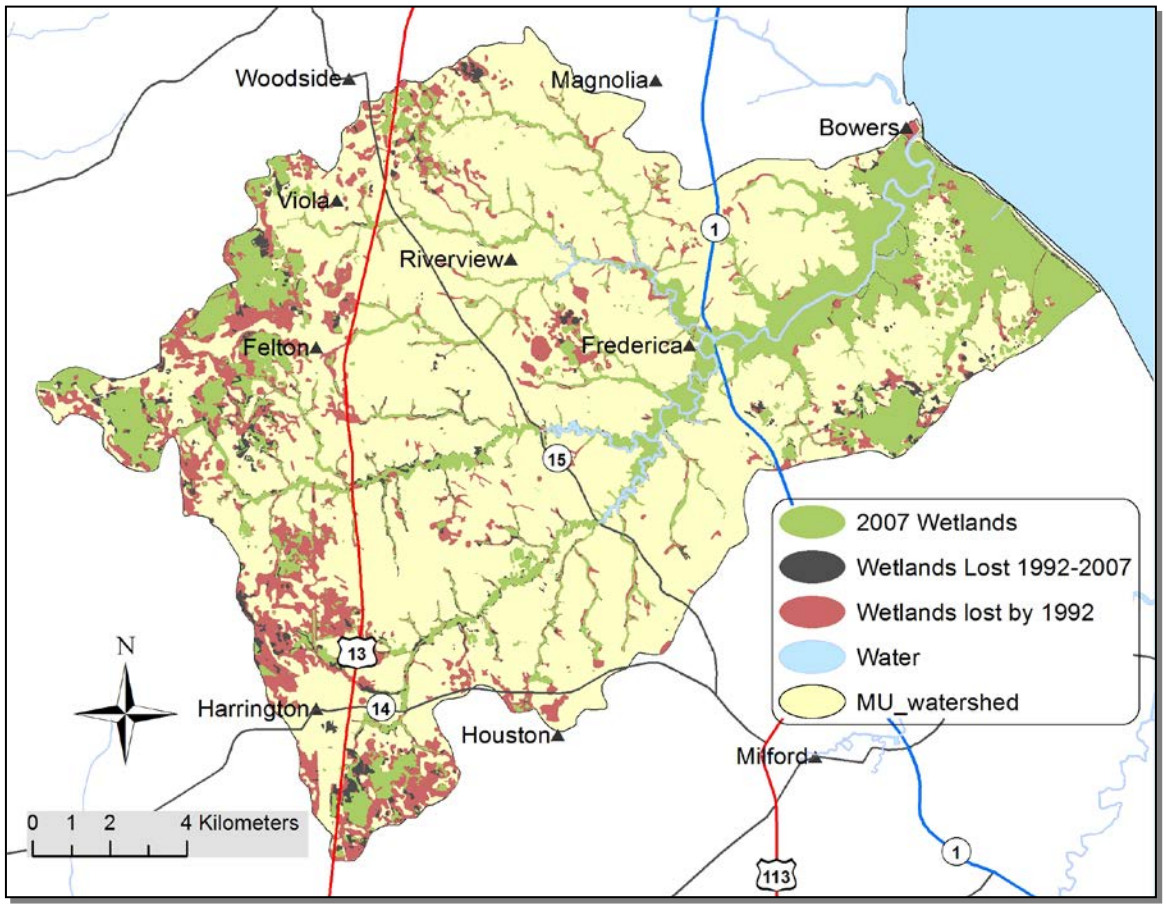


Figure 4. An example CDF showing wetland condition. The red line is the population estimate. The orange and green dashed lines show the breakpoints between condition categories.

RESULTS

4.1 Changes in Wetland Acreage

Our comparison of estimated historic wetlands to current wetlands indicated that 36% of wetland acreage was lost from the Murderkill River watershed between the time of settlement and 2007 (Map 6). Wetlands historically covered over 21,000 acres across the watershed. By 1992 wetlands had been reduced 38% to roughly 13,400 acres. From 1992 to 2007 wetland maps indicated a 2.6% gain in wetlands (359ac) to roughly 13,800 acres. This increase was largely (88%) due to the creation



Map 6. Past and present wetland coverage in the Murderkill River watershed, Delaware.

of ponds and fill borrow pits as well as the expansion of existing mapped wetlands resulting from refined mapping methods. Although acreage in this watershed technically increased, a statewide wetland trends analysis reported an overall loss in acreage and confirmed that the majority of gains were in low functioning stormwater ponds (Tiner et al. 2011). Freshwater forested wetlands continued to sustain the greatest losses, often in isolated and seasonally saturated wetland blocks that are more difficult to identify and protect.

The ratio of fresh to salt marshes has been shifting as well. Historically, the Murderkill watershed was 78% comprised of nontidal wetlands, 22% tidal. In 1992 that ratio was 58% nontidal to 42% tidal. By 2007 that ratio had rebounded slightly to 66% nontidal and 33% tidal. Nontidal wetland loss has been concentrated in the western portion of the watershed in headwater wetlands west of Route 13 (Map 6). Tidal wetlands were reduced historically and recently in Bowers Beach for coastal development.

As a result of recent changes in wetland acreage, the wetland functions potentially provided in the Murderkill watershed have been altered also. A recent landscape-level analysis of wetland function predicted that as a result of wetland losses between 1992 and 2007 in the Murderkill the potential for wetlands to perform nutrient transformation, sediment retention, surface water detention and serve as habitat for non-winged wildlife were reduced (Tiner 2011).

4.2 Landowner Contact and Site Access

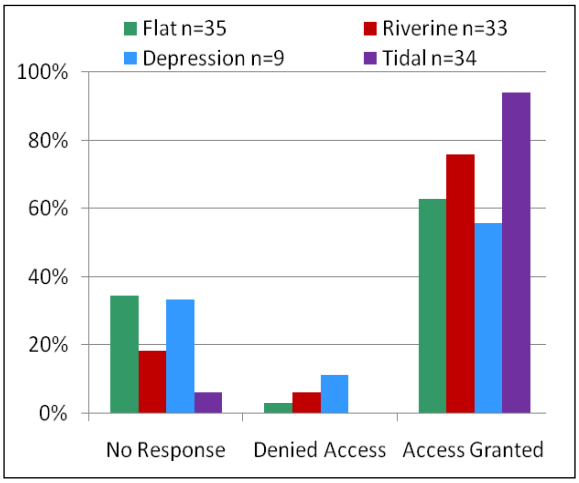


Figure 5. Success rates for privately owned wetland sites in the Murderkill River watershed Delaware in 2008 by wetland subclass.

We obtained landowner permission prior to accessing and sampling all sites. We identified landowners using county tax records and mailed a post card providing a brief description of our study goals, sampling techniques, and contact information. If a contact number was available, we followed the mailings with a phone call to discuss the site visit and secure permission.

Across all wetland types we had an 81% success rate for gaining access from landowners and a 95% success rate for privately owned sites once we made contact (Figure 5). The majority of our sampled sites were privately owned and some were public and owned by a conservation partner (Figure 6). We attempted to gain access to 43 flat sites of which only one was denied, and 12 others did not respond. Of the 30 flat sites sampled, 73% were privately owned, 1% was public, and 16% were owned by private conservation organizations. We considered 39 riverine sites, 2 of which denied access, and 6 did not respond. Of the 31 riverine sites that we sampled, 80% were privately owned and 19% were public. Depression wetlands made up a very low proportion of sites in the

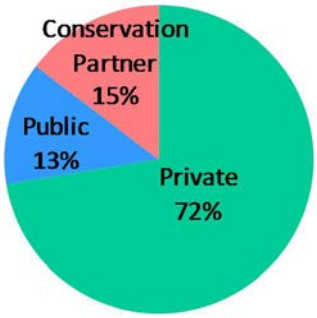


Figure 6. Ownership of sampled wetland sites in the Murderkill River watershed Delaware in 2008.

Murderkill watershed and only 9 were identified in the first 200 EMAP points. All 9 were privately owned, of which we sampled 5, 1 denied access and 3 did not respond. For tidal wetlands, we considered 52 sites and only 2 did not respond and the remainder all granted access. Of the 50 sites that we sampled, 64% were privately owned, 12% were public and 24% were owned by private conservation organizations.

4.3 Wetland Condition

4.3.1 Tidal Wetland Condition

Tidal wetlands provide coastal populations with more ecosystem services than any other habitat. They are highly fertile and productive, and are able to minimize flooding from storms, control erosion, and improve and maintain water quality by sequestering and storing excess nutrients, sediments and toxic chemicals.

Tidal wetlands in the Murderkill River watershed were in fair condition with an average condition score of 76.5±9 and ranged from 52 to 94. The top 4% of the tidal population scored >90 and were characterized as having intact hydrology, healthy and wide buffers, unaltered shorelines, and good soil stability. Conversely, wetlands scoring in the bottom 6% of the population had condition scores ≤60 with altered hydrology, small buffers due to development and hardened shorelines. Appendix D provides the raw values and scored metric data for tidal wetland sites.

The cumulative distribution function takes the sample population and extrapolates condition results onto the entire wetland population in the watershed. The cumulative distribution function for the tidal wetland population in the Murderkill showed a distribution skewed towards higher condition, with a minimum score of just 52 (Figure 7). Within the total range, there was an even distribution of condition above 70 but a smaller proportion of wetlands below 70, indicated by 2 small plateaus.

Overall, 34% of the tidal wetlands in the Murderkill River watershed were minimally or not stressed (Figure 8 *left*). Over half (52%) were moderately stressed and 14% were severely stressed (Figure 8 *left*). Minimally stressed wetlands averaged 5 stressors compared to 7 for moderately stressed and 10 for severely stressed wetlands.

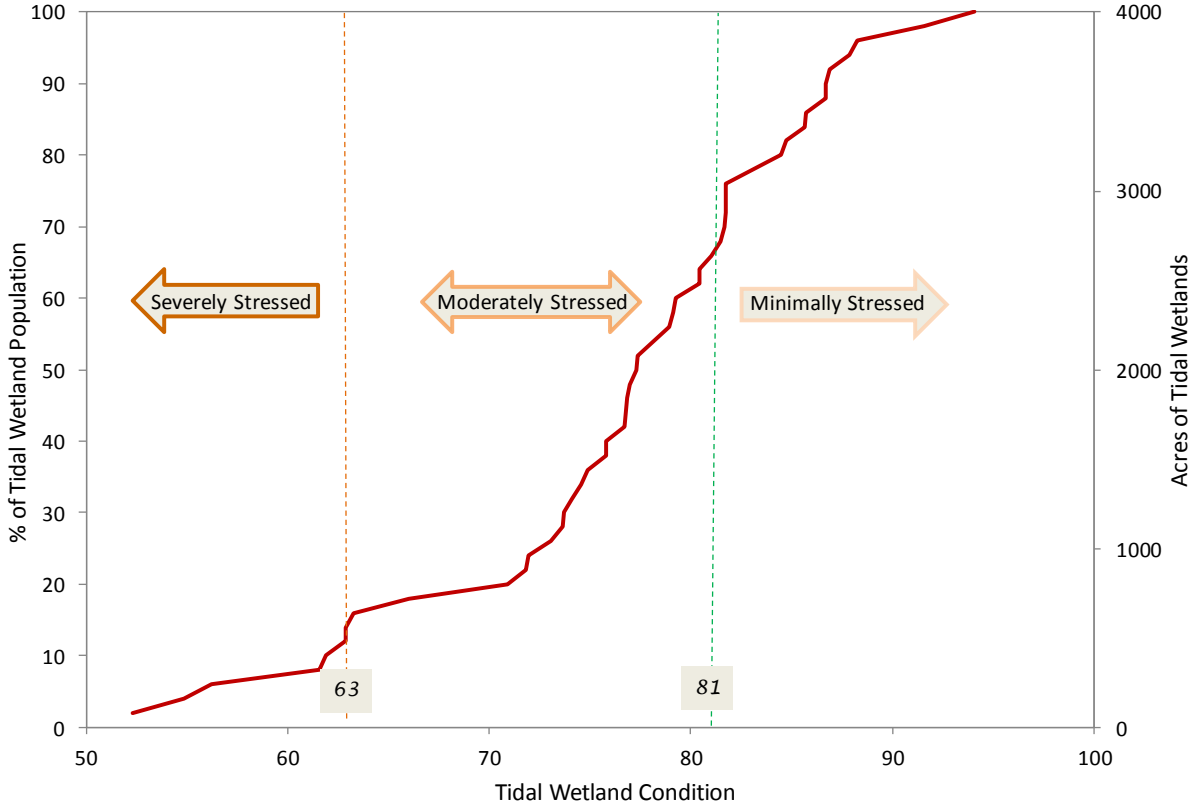


Figure 7. The Cumulative Distribution Function for tidal wetland condition based on the MidTRAM in the Murderkill River watershed, Delaware in 2008. The orange and green dashed lines designate the condition category breakpoints.

In addition to the number of stressors, the intensity of several stressors increased with decreasing condition category (Figure 8 *right*). Fill and invasive plants were less pervasive in minimally stressed sites, however, for the more stressed categories they were less prevalent in the assessment area here than observed in previously reported watersheds (St. Jones River and Inland Bays). The amount of shoreline obstructed by hardened surfaces such as roads or rip rap increased with decreasing condition. The proportion of wetlands with ditching doubled from the minimally to severely stressed categories. Mean bearing capacity and plant fragments were not responsive to condition categories.

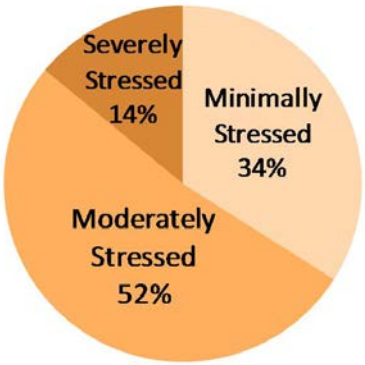


Figure 8. Tidal wetland condition proportions (*left*) and stressor prevalence (*right*) for the Murderkill River watershed, Delaware in 2008-2009.

Metric	Minimally Stressed n=17	Moderately Stressed n=26	Severely Stressed n=7
% Fill in AA	<1	1	6
% Cover by Invasive Plants in AA	2	12	11
Proportion of wetlands with ditching in the AA	41	65	86
% Development in 250m Buffer	<0.5	<1	6
% of buffer shoreline obstructed from marsh migration	6	11	27
Buffer Width (max=250m)	218	191	169
Bearing Capacity (cm)	4	4	3
Plant Fragments (cc)	14	13	12

After grouping the 14 metric scores into 3 wetland attribute group values for tidal wetlands, the three means were similar (Figure 9). The hydrology attribute group averaged the highest with 83±17 due to the low occurrence of point sources, tidal restrictions and fill. The Buffer group averaged 80±14 and reflected the presence of shoreline barriers, development, and soil and plant disturbances in the buffer. Habitat had the lowest average of 67±12 which was influenced by the presence of invasive plants and lower scores for bearing capacity and plant fragments.

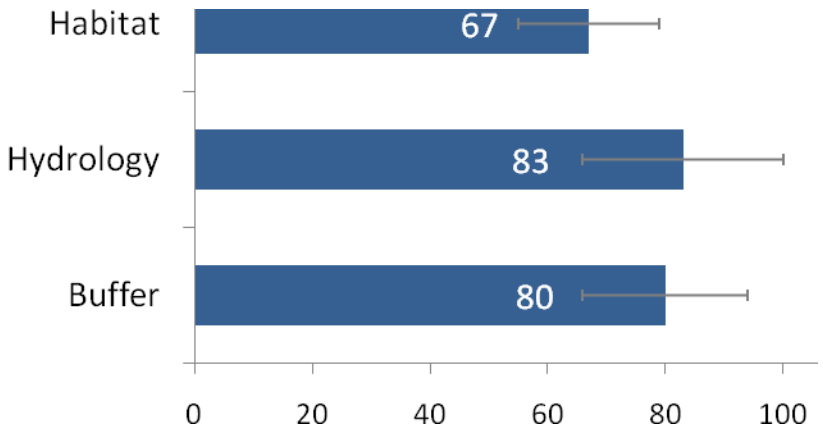


Figure 9. Mean attribute group values and standard deviations for tidal wetlands in the Murderkill River watershed, Delaware.

4.3.1.a Intensive Data

We compared MidTRAM condition scores to more intensive measures of the biotic community using marsh birds and vegetative biomass. MidTRAM was designed to give a basic wetland condition rating based on variables and metrics that are responsive to disturbance. Correlating MidTRAM data to more intensive measures of wetlands validates the assessment method and increases our confidence that it is able to distinguish and differentiate tidal wetlands based on changes in biological communities.

Breeding marsh bird surveys were relatively easy to perform, they represent a higher trophic level, and have been previously noted as indicators of marsh integrity (DeLuca et al. 2004, Banning et al. 2009, Conway 2008). Vegetative biomass is a comprehensive attribute of marsh systems that has been related to marsh condition (Turner et al. 2004) in regards to plant production, and marsh stability and accretion.

i. Marsh Bird Community

We recorded 19 bird species at 10 sites in the Murderkill River watershed in 2008. Clapper rails, marsh wrens, red-winged blackbirds, seaside sparrows and willets were the most frequently detected species. Site IMBCI scores (W_{IMBCI}) ranged from 4.1 to 9.4. Bird survey data for the 10 Murderkill sites are provided in Appendix E.

After combining marsh bird data from 25 tidal sites across 3 watersheds, we documented 37 bird species total. Clapper rails, red-winged blackbirds, and seaside sparrows were the most frequently detected species and site IMBCI values ranged from 3.3 to 13.2. Contrary to reference results, the site IMBCI values were not related to either attribute groups scores or the MidTRAM condition

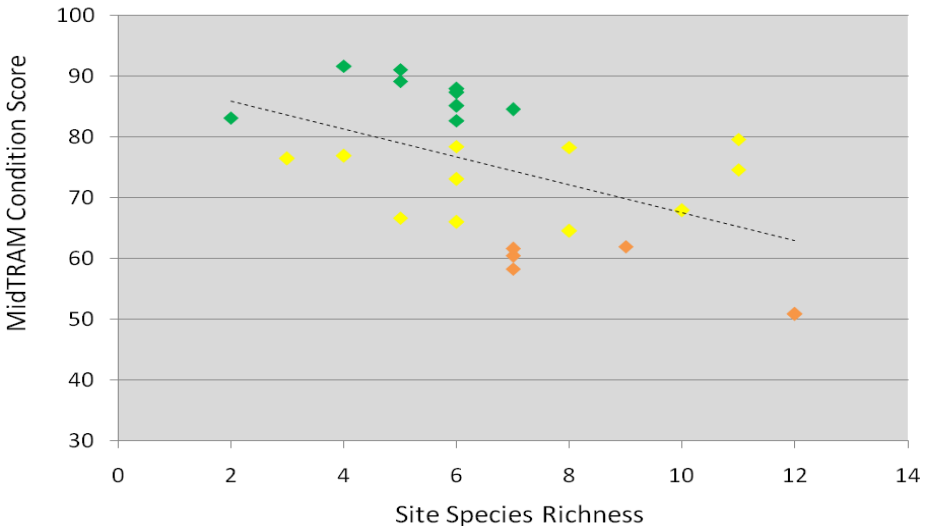


Figure 10. MidTRAM condition scores and overall bird species richness for tidal wetlands in the St. Jones River, Murderkill and Inland Bays watersheds, Delaware. Each site marker is colored by site condition category; green (minimally stressed), yellow (moderately stressed), and orange (severely stressed).

scores ($P \geq 0.13$). A regression of MidTRAM condition scores and IMBCI values colored by condition category showed weak separation.

However, species richness was related to MidTRAM scores, with species richness decreasing with increasing condition scores ($r^2=0.2461$, $P=0.0117$; Figure 10). We found that with increasing site condition scores the number of obligate marsh birds did not differ, but the number of more generalist or upland species decreased. A more thorough investigation of the relationship between rapid condition information and bird community integrity requires a larger sample size.

ii. Biomass

Our rapid condition scores were related to several biomass parameters. We found a positive relationship between MidTRAM condition scores and below ground live ($P=0.069$), below ground dead ($P=0.007$), and total below ground biomass ($P=0.005$) indicating that sites with greater amounts of below ground biomass also had higher condition scores (Table 5 and Figure 11 *left*).

Biomass	r^2	*P*	trend
Above Dead:Below Dead	0.38	0.002	-
Below Dead	0.32	0.007	+
Below Total	0.31	0.005	+
Above:Below	0.25	0.016	-
Below Live	0.15	0.069	+
Above Dead	0.13	0.089	-

Table 5. Correlation values between MidTRAM condition scores and biomass values for 22 tidal wetland sites in the St. Jones River, Murderkill River, and Inland Bays watersheds, Delaware.

We found a negative relationship between MidTRAM condition scores and above ground dead biomass ($P=0.089$) indicating that as condition scores increased, above ground dead biomass decreased. Also, total above to below ground biomass ratio ($P=0.016$), and above ground dead to below ground dead ratio ($P=0.002$) decreased with increasing condition scores which suggested that at sites with higher condition scores there is a greater proportion of below ground biomass compared to above ground biomass (Table 6 and Figure 11 *right*). This is consistent with the idea that stressed wetland plants place more energy in above ground biomass production rather than below ground (Turner et al. 2004). In a healthy system, plants should be able to produce ample root mass which accumulates as biomass.

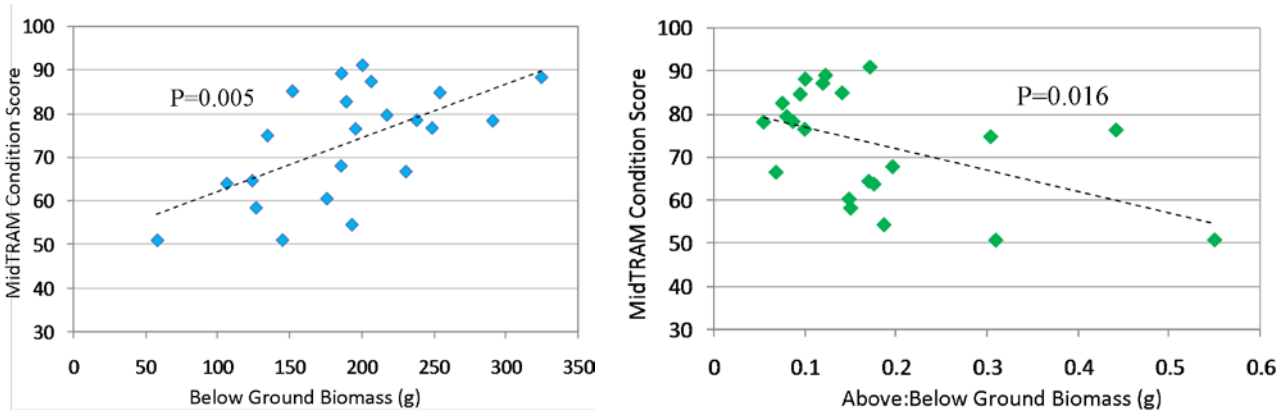


Figure 11. MidTRAM condition scores and total below ground biomass (*left*) and total above ground to total below ground biomass ratio (*right*) for 22 tidal wetland sites in the St. Jones River, Murderkill River and Inland Bays watersheds, Delaware in 2008.

We did not see a relationship between MidTRAM condition scores and above ground live biomass (P=0.380), above ground total (P=0.895), or above ground live:below ground live ratio (P=0.935).

We also found that bearing capacity was related to vegetative biomass in several ways. The strongest relationships were between bearing capacity and above ground live (r^2=0.54, P=0.001), above to below ground ratio (r^2=0.53, P=0.002), and the above live to above dead ratio (r^2=0.50, P=0.004). Strong relationships between bearing capacity and biomass have been important when re-evaluating and rescoring MidTRAM metrics. Vegetative biomass data for the 8 Murderkill River sites are provided in APPENDIX F.

4.3.2 Nontidal Wetland Condition

4.3.2.a Flats

Flat wetlands make up 39% of wetlands across the Murderkill River watershed, occurring in areas with low, gradual slopes. Flats are typically found on the periphery of the watershed in forested areas and are especially prevalent in the poorly drained western portion of the watershed (Map 3). Flats are valued for their ability to help store and slowly release water to prevent downstream flooding, to improve water quality by filtering precipitation and runoff from surrounding upland land uses, and by providing important wildlife habitat in large forested areas.

The cumulative distribution function of the Murderkill flats population is skewed towards higher condition, starting just below 50 and extending up into the 90's (Figure 12). Within the range of scores, there was an even distribution of condition across the population with no long plateaus. The sharp rise at the high end of the curve indicates that the top 10% of the population is in similar condition at 94.4 which is the maximum score for a flat wetland with no stressors present.

The top 10% of the population was characterized by intact hydrology, intact buffers, minimal invasive plants or microtopographic alterations, and no forestry activity within 30 years. The bottom 7% of the population scored ≤54 and was characterized by recent and extensive forestry, severe ditching in the AA, garbage/dumping, and substantial microtopographic alterations.

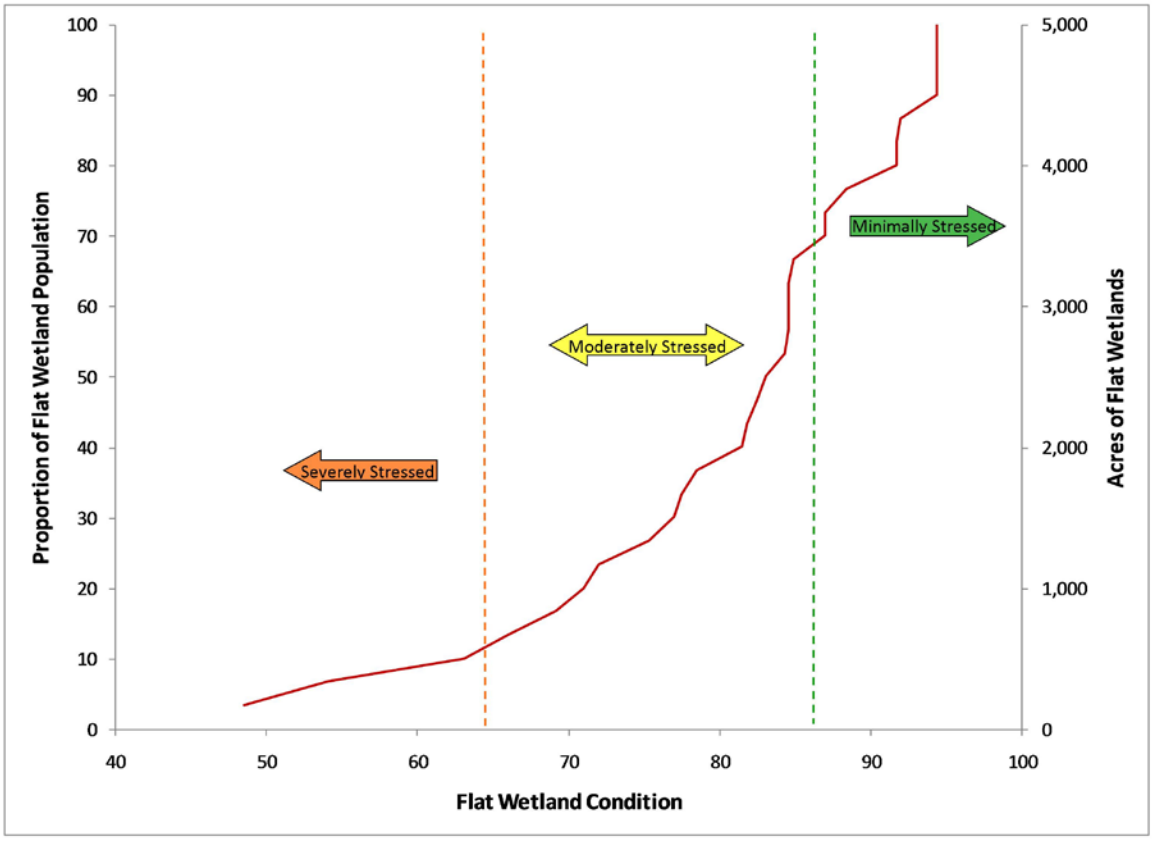
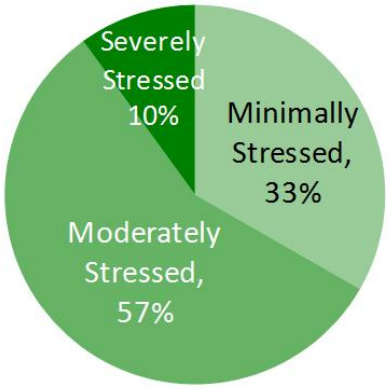


Figure 12. Cumulative Distribution Function for nontidal flat wetlands in the Murderkill River watershed, Delaware in 2007. The orange and green dashed lines signify condition category breakpoints dividing severely, moderately and minimally stressed portions of the flats wetland population.

Weighted rapid assessment condition scores for flats ranged narrowly from 48 to 94 and averaged 81±12. One third (33%) of flats were minimally or not stressed, 57% were moderately stressed, and 10% were severely stressed (Figure 13 *left*). The incidence of ditching in the AA increased sharply with decreasing condition (Figure 13 *right*). Some stressors were similarly prevalent for minimally and moderately stressed flats but were more common in severely stressed sites such as invasive plant coverage, and the presence of both fill/excavation and microtopographic alterations (Figure 13 *right*). Similarly, average tree basal area for the two less stressed condition categories were similar but was almost half for severely stressed flats (Figure 13 *right*). Forestry activity was present on all

condition levels but clear cutting increased with decreasing condition (Figure 13 *right*).



Stressor Name	Proportion with Stressor Present		
	Minimally Stressed N=10	Moderately Stressed N=17	Severely Stressed N=3
Invasive plants in the AA	30%	24%	67%
Ditches in the AA	0%	41%	100%
Tree Basal Area (m^2/ha)	78	79	43
Forest clear cutting	0%	18%	33%
Presence of both fill and mictrotopo alterations	30%	29%	67%

Figure 13. Condition proportions *(left)* and stressor occurrence *(right)* for the flat wetlands population in the Murderkill River watershed, Delaware in 2007.

In general, the most common habitat stressors were forestry activity, common hydrology stressors were fill and excavation and the effects of microtopographic alterations, and the most common buffer stressors were row crops in the wetland buffer. The rapid assessment stressor dataset from 30 flats sites in the Murderkill River watershed are provided in Appendix G. The comprehensive assessment raw indicator values and calculated variable scores from 6 flats sites are provided in Appendix I.

4.3.2.b Riverine

Riverine wetlands, also called riparian or floodplain wetlands, occur along downstream portions of rivers and streams and made up 26% of the Murderkill watershed's wetlands. They are valued for their water quality maintenance through sediment retention and nutrient uptake. They also provide storm water storage, either holding runoff water from upland areas or allowing overbank flood water storage. Riverine wetlands also provide rich habitat for fish, wildlife and plants and serve as an important landscape link between surface waters and upland habitats.

The cumulative distribution function for the Murderkill riverine wetlands showed a population in wide ranging condition, from near 0 up to 90 (Figure 14). Two sharp rises indicated where large portions were in similar condition, 16% at 74 and 39% at 90.4 which is the maximum a riverine wetland can score. The top 13% of riverine wetlands scored ≥90.4 and were characterized as having no forestry activity within 50 years, no invasive plants, and no habitat management (i.e. chemical defoliation, pine plantings, burning, trails, intact hydrology regimes, and no roads within 100m). Still, some of these high scoring wetlands had row crops and low density residential development in the buffer. In contrast, the lowest scoring riverine wetlands (≤28 for condition) had a history of forestry activity, invasive plants, channelized streams with spoil piles on both sides, and filling or

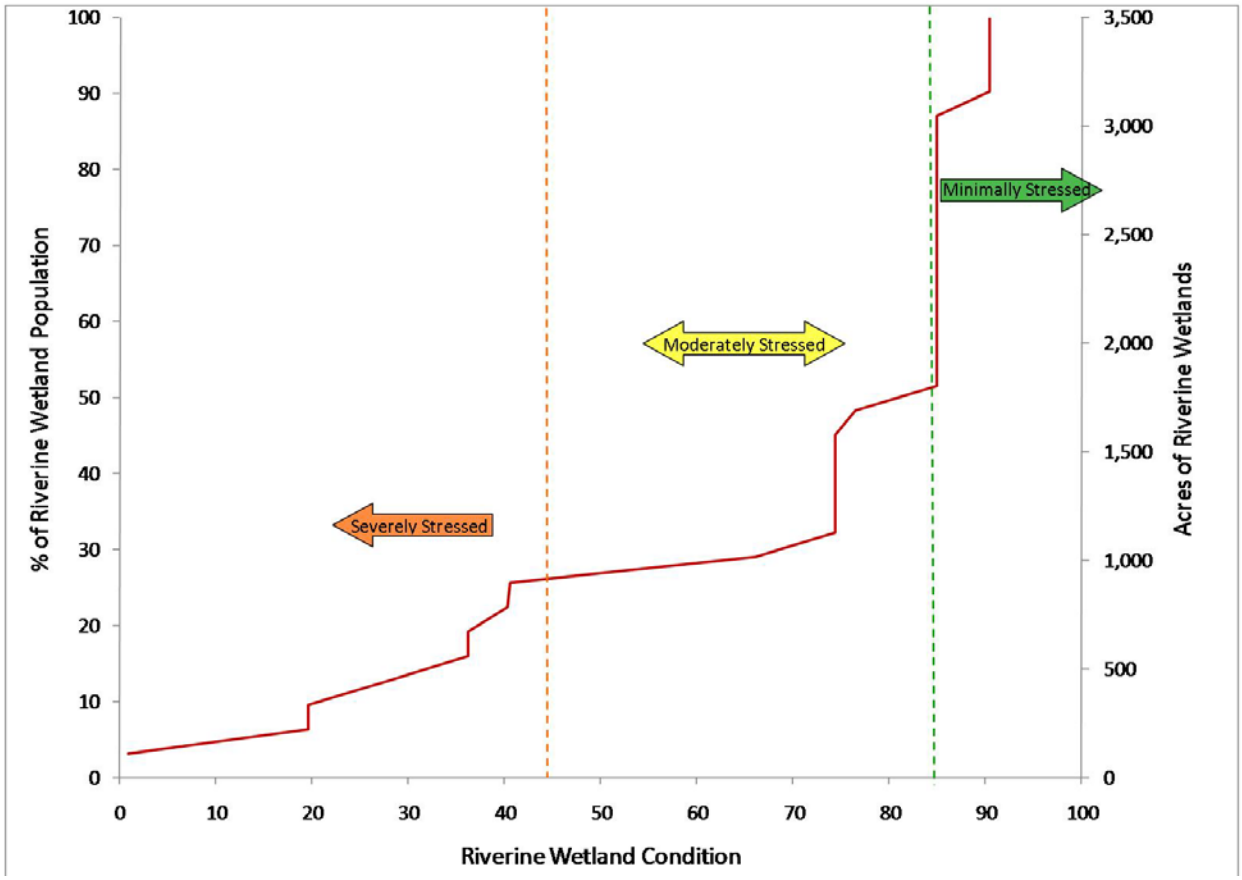
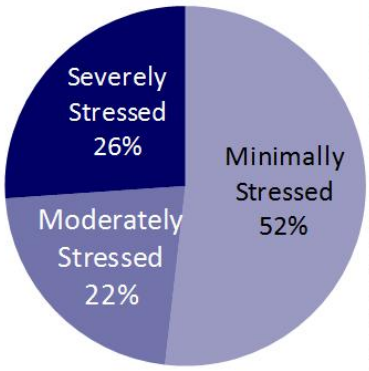


Figure 14. Cumulative Distribution Function for nontidal riverine wetland in the Murderkill River watershed, Delaware in 2007. The orange and green dashed lines signify the condition category breakpoints dividing severely, moderately and minimally stressed portions of the riverine wetland population.

soil disturbance in the AA.

The IWC scores for riverine wetlands ranged widely from 1 to 90 and averaged 68±26. Fifty-two percent of riverine wetlands in the Murderkill were minimally stressed, 22% were moderately stressed, and 26% were severely stressed (Figure 15 *left*). Using the condition categories to identify patterns, some stressors increased in occurrence with decreasing condition, some were prevalent throughout the population, and some were not responsive to condition category alone. Invasive



	Proportion with Stressor Present		
Stressor Name	Minimally Stressed N=16	Moderately Stressed N=7	Severely Stressed N=8
Invasive plants in the AA	75%	100%	100%
Channelized streams	0%	71%	100%
Fill in the AA	19%	14%	100%
Tree Basal Area (m^2/ha)	117	67	44
Residential development in the buffer	31%	57%	75%
Agriculture in the buffer	63%	100%	50%

Figure 15. Condition proportions *(left)* and stressor occurrence *(right)* for riverine wetlands in the Murderkill River watershed, Delaware in 2007.

plants in the AA were pervasive across the riverine wetland population, but average tree basal area decreased with decreasing condition categories, perhaps related to forestry (Figure 15 *right*). Channelized streams and residential development in the buffer increased incrementally with decreasing condition groups (Figure 15 *right*). The presence of agriculture in the 100m buffer varied but averaged at least 50%.

In general, the most common habitat stressors were the presence of invasive species (84% of population) and garbage or dumping (81%). Channelized streams (42%) and filling/excavation (39%) within the AA were common hydrology stressors. Common buffer stressors were the presence of agriculture (68%) as well as residential development (48%) and the roads related to these features. The rapid assessment stressor dataset from 31 riverine sites in the Murderkill River watershed are provided in Appendix H. The comprehensive assessment raw indicator values and calculated variable scores from 6 riverine sites are provided in Appendix J.

4.3.2.c Depressions

Depression wetlands occur throughout the watershed in low-lying areas and topographical depressions. They are fed by groundwater, rainfall or snow melt in the spring and winter and are often dry on the surface in the summer and fall. Although depressions make up only 1% of the Murderkill River wetland population they include rare habitats such as coastal plain ponds and provide critical seasonal habitat to many rare and threatened plants and animals. Depressions also collect and moderate storm water, cycle nutrients and improve water quality through sediment retention and nutrient uptake.

Our small sampling of depressions in the Murderkill River watershed did not allow us to report on the condition of the population. However, stressors found at both of the sampled depression sites included forestry activity within 30 years, garbage or dumping in the wetland, evidence of excavation or fill material, and agriculture in the buffer. The rapid and comprehensive assessment data from 2 depression sites are provided in Appendix K.

4.4 Overall Condition and Watershed Comparison

For an overall view of wetland condition in the Murderkill River watershed we combined the condition proportions for the major wetland types (tidal, flat, riverine and depression) based on the acreage of each type in the watershed (Figure 16).

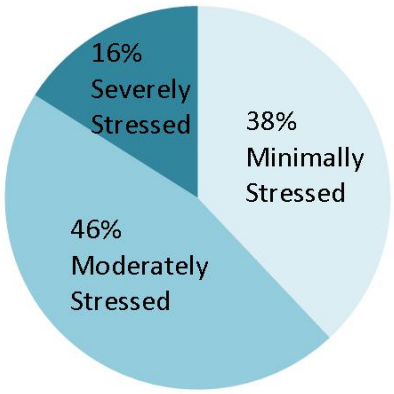


Figure 16. Combined condition of tidal, flat, riverine and depression wetlands in the Murderkill River watershed, Delaware in 2008-2009 based on the DERAP and MidTRAM.

A notable portion of Murderkill River wetlands were minimally or not stressed (Figure 16). Nearly equal weighted proportions of minimally stressed flats, riverine and tidal wetlands were represented here. The remaining 62% of wetlands have been moderately or severely stressed and are not functioning to their highest ability (Figure 16). Severely stressed flats and tidal wetlands influenced this proportion.

We compared the Murderkill River's overall condition proportions with 2 other recently assessed watersheds (Figure 17). The Murderkill River and St. Jones River watersheds had similar proportions of severely stressed wetlands. However, the Murderkill had a greater proportion of sites that were moderately stressed,

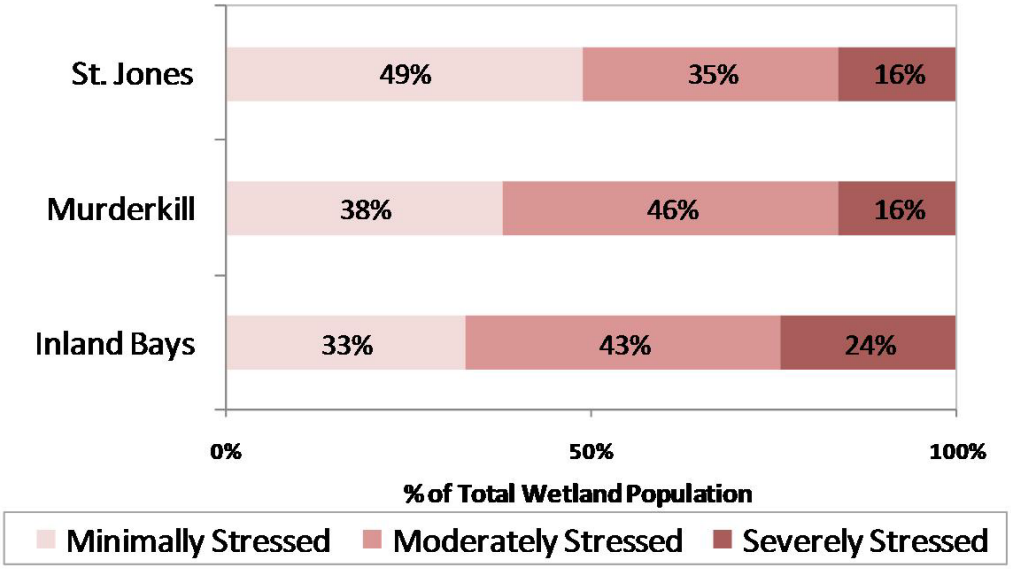


Figure 17. Comparison of wetland condition proportions in the St. Jones River, Murderkill River and Inland Bays watersheds, Delaware. Condition assessments were conducted 2005-2009.

similar to the Inland Bays. Even though the Murderkill and the St. Jones are adjacent watersheds with seemingly similar landcover and landuse, the St. Jones watershed had 11% more minimally stressed wetlands. Among the 3 watersheds, the Inland Bays had the largest proportion of severely stressed wetlands and lowest proportion of minimally stressed wetlands.

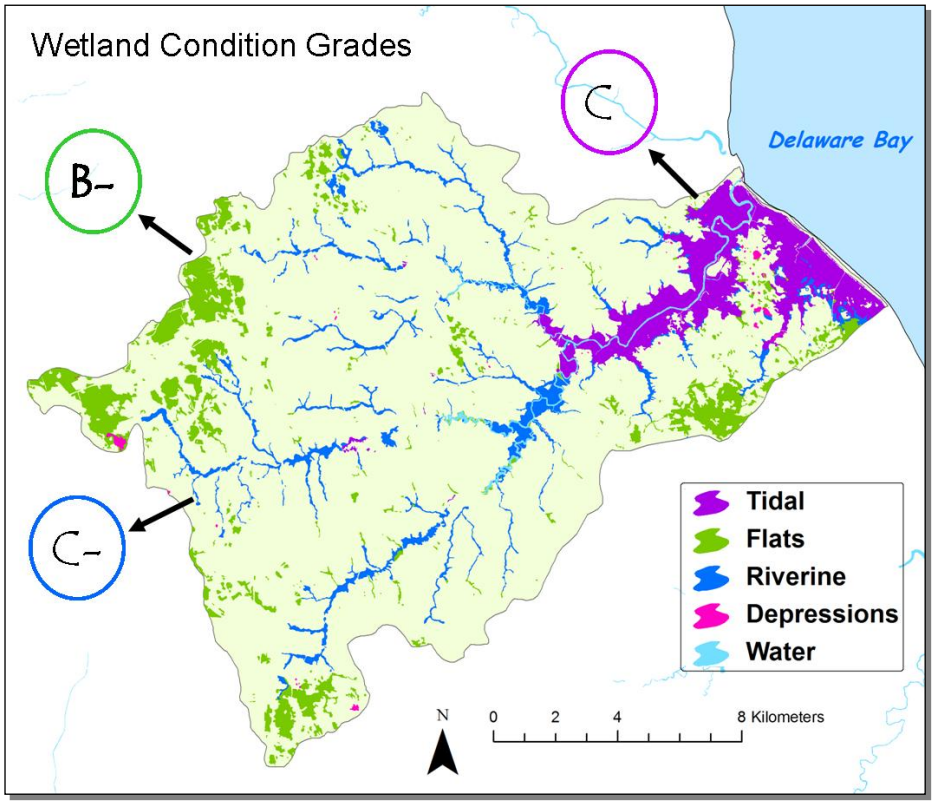
4.5 Wetland Grading and Summary

This report evaluated changes in wetland acreage between 1992 and 2007, the extent of wetlands by subclass as of 2007, and the condition of wetlands in the Murderkill River watershed as of 2008-2009. Stressors impacting wetland condition were determined for each of the major wetland types (tidal, riverine and flat). Wetland condition assessments alone were used to assign condition letter grades by wetland type (based on average DERAP scores; Map 7). Wetland mapping information combined with condition grades give a sense of where wetland loss has occurred and the condition of remaining wetlands.

As a result of tidal wetland impacts including undersized upland buffers, colonization of invasive plants (*Phragmites*) and hardened shorelines they received a condition grade of C (Map 7). Tidal wetlands are regulated through state wetland permitting in combination with the Army Corps of Engineers which prevents large

losses. Some losses still occurred, mostly in coastal communities by shoreline development or due to rising sea levels. In the Murderkill watershed, 44 acres of shoreline wetlands became shoreline open water between 1992 and 2007. Conversion of coastal wetlands to open water one topic being addressed as DNREC plans for adapting to sea level rise and climate change.

The B- grade for flats reflected impacts due to forestry activity, excavation and fill in the wetland, and having agriculture adjacent to or in the wetland buffer (Map 7; see Figure 13). Historically in Delaware and in the Murderkill, headwater forested flat wetland acreage has been greatly reduced by conversion to agriculture and development.



Map 7. Wetland condition grades for tidal, flats, and riverine wetlands in the Murderkill River watershed Delaware based on the subclass condition averages in 2008-2009.

Wetland loss patterns statewide indicated that substantial nontidal impacts have occurred in recent decades. In the Murderkill, 66% of the 57 acres of wetlands lost 1992-2007 were flats (37.5 acres). The majority of the remaining flats were moderately stressed.

Riverine wetland condition ranged so widely that although half of the population was classified as minimally stressed, wetlands in low condition brought the average condition grade down to a C- (Map 7). The prevalence of agriculture, residential development and roads in wetland buffers as well as invasive plants, garbage and channelized streams influenced this grade. Fourteen acres of riverine wetlands were converted to residential development in the Woodside/Magnolia/ Riverview area. One quarter (837 acres) of remaining riverine wetlands were severely stressed and functioning at sharply reduced levels.

MANAGEMENT RECOMMENDATIONS

Based on our study, we offer the following 9 recommendations to improve wetland management, identify additional data needs, and encourage informed and effective decisions concerning the future of wetland resources in the Murderkill River watershed.

1. **Improve the protection of flats**. Headwater flats incurred the most acreage loss recently through land use conversion which makes protecting those remaining more important. Our study found that 1/3 of remaining flats were in high condition and our priority is to make sure they don't become impacted. Protecting the top condition portion of the population will capitalize on their role in the watershed for improving water quality, providing important habitat and storing flood waters. Also, to ensure that moderate condition flats, which were mostly impacted by forestry activities, are being harvested using sustainable practices to allow them to regenerate to native forest communities. The Murderkill River watershed has a handful of pine plantations.

2. **Improve protection of nontidal wetlands**. Activities in nontidal wetlands are not regulated by the State of Delaware. Every additional wetland lost contributes to a reduction of water quality, wildlife habitat, and flood abatement services, and increases societal costs for providing man-made alternatives to these services. Improved protection for nontidal wetlands is needed to fill the gaps left by recent Supreme Court decisions (EPA 2008) and to provide a comprehensive and clear means to protect wetlands across the state. A state regulatory program would eliminate the ambiguity surrounding which wetlands are regulated and provide a comprehensive and clear means to protect wetlands in the entire state. Local regulations can be incorporated into home owner association, municipal and/or county code to protect wetland areas of special significance. Also, consider protecting high quality wetlands using fee simple acquisitions and conservation easements. We can encourage better protection at the state and local level by educating the public and decision makers on the importance of wetlands within the watershed.

3. **Improve nontidal wetland buffer regulations and codes**. By allowing generous wetland buffers between wetlands and upland activities and protecting riparian buffers, nontidal wetlands services including water quality improvement, wildlife habitat and flood water retention will be preserved. Kent County code[1] protects riparian buffers extending 100ft from

[1] http://www.ecode360.com/KE1751 November 2011

the mean high-water shoreline of a nontidal freshwater water body, lake or pond from buildings, structures, and impervious surfaces except for stairs, ramps, docks (200ft²) or fences (Article 11 § 187-78 B2). Under current wording, nontidal wetlands that extend >100ft from the shoreline are not protected. Establishing and enforcing wetland buffers that specifically start at the wetland edge would strengthen protection. Also, requiring wetland and riparian buffers to have forested vegetation would maximize nutrient removal from groundwater, surface water runoff and in-stream flow while also improving corridor habitat.

4. **Update tidal wetland regulatory maps**. In addition to improving the protection of nontidal wetlands, it is prudent to maximize the authority that already exists within DNREC. Tidal wetlands impacts are regulated by the State of Delaware and staff needs accurate and recent wetland maps to guide wetland permitting. Currently 1988 wetland maps are used, must be verified in person and are difficult to read. Evidence of recent coastal development and inundation of coastal wetlands due to sea level rise creates a greater need to adopt updated wetland maps as regulatory maps.

5. **Develop incentives to maintain natural buffers of tidal wetlands**. As sea level rise brings water levels higher and extreme storm events bring more flooding the importance of wetland buffers between water and upland is taking center stage. The need exists to inform Delawareans on the importance of allowing tidal wetlands to migrate inland unobstructed by roads, rip-rap and fill. In addition to awareness, an incentive program could attract an interest in maintaining natural buffers between wetlands and development.

6. **Control the extent and spread of the non-native, invasive common reed (*Phragmites australis)***. Invasive plants such as *Phragmites* are capable of spreading rapidly, outcompeting native species, reducing plant diversity in undisturbed areas, and reducing the success of other organisms by changing habitat structure and food availability. The DNREC Phragmites Control Program in the Division of Fish and Wildlife has treated more than 20,000 acres on private and public property since 1986. Without continued support from state funds and federal State Wildlife Grant funds Phragmites will degrade more wetlands. If invasive plants were not a stressor in tidal wetlands, 52% of tidal wetlands in the Murderkill watershed would be minimally stressed, up 18% from 34% and only 6% would be severely stressed.

7. **Improve enforcement of wetland permitting and mitigation monitoring**. Enforcing wetland impact criteria and following up with

mitigation monitoring is labor intensive and can be difficult to quantify. Delaware's DNREC is working together and with the ACOE to improve the effectiveness and efficiency of wetland permitting by incorporating the Delaware Rapid Assessment Procedure. Assessment scores will numerically and categorically document wetland impacts and mitigation improvement over time.

8. **Design a wetland restoration plan for the Delaware Bay Basin that includes the Murderkill River watershed**. This involves a science-based process that uses existing data to identify restoration and protection priority properties pertinent to forestry, agriculture, wetlands, restoration, soils, wildlife and botany branches of state, federal and non-profit organizations. The plan would lead to the implementation of restoration and conservation opportunities on private and public property across the Delaware Bay Basin and Murderkill River watershed. A basin-wide plan will combine resources, time, and manpower to plan for multiple watersheds. Roughly 5,700 acres of wetlands in the Murderkill were moderately stressed which identified a need for restoration before impacts reduce them to severely stressed. Severely stressed wetlands are likely more difficult and costly to restore.

9. **Secure funding to implement a wetland restoration plan for the Murderkill River watershed**. Find opportunities to protect and restore prioritized state and private properties through voluntary and incentive programs. The most proactive approach to conserving wetland resources is to protect wetlands in high condition that have not been impacted by significant stressors. Enhancement and restoration should be a priority in the watershed to reduce the impacts to the wetland resource and improve wetland function.

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APPENDIX A: Qualitative Disturbance Rating (QDR) Category Descriptions

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

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

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

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

APPENDIX B: Nontidal Rapid Assessment Stressor Codes and Definitions

Habitat Category (within 40m radius of sample point)	
Hmow	Mowing in AA
Hfarm	Farming activity in AA
Hgraz	Grazing in AA
Hfor50	No forestry activity within 50 years
Hfor30	Forestry activity 30-50 years ago
Hfor15	Forestry activity 15-30 years ago
Hfor2	Forestry within 15 years
Hforcc	Forestry Activity clear cut within 2 years
Hnorecov	Cleared land not recovering
Hfor10	Forest activity <10% of AA
Hherb	Excessive Herbivory/Pinebark Beetle/Gypsy Moth
Hinvdom	Invasive plants dominating AA
Hinvless	Invasives plants not dominating
Hchem	Chemical Defoliation
Hpine	Managed or Converted to Pine
Hburn	Burned (prescribed)
Htrail	Trails and Roads
Hgarb	Garbage/Isolated Dumping
Hnutapp	Nutrients direct application/runoff
Halgae	Nutrients dense algal mats
Hrdlog	Logging road in AA
Hrdgrav	Dirt or gravel road in AA
Hrdpav	Paved road in AA
Hydrology Category (within 40m radius of sample point)	
Wditchs	Slight Ditching; 1-3 shallow ditches (<.3m deep) in AA
Wditchm	Moderate Ditching; 3 shallow ditches (<.3m deep) in AA or 1
Wditchx	Severe Ditching; >1 ditch .3-.6 m deep or 1 ditch > .6m deep
Wditchfloodplain	Ditching in floodplain (not including main channel)
Wchannm	Channelized stream not maintained
Wchan1	Spoil bank only one side of stream
Wchan2	Spoil bank both sides of stream
Wincision	Stream channel incision
Wdamdec	WeirDamRoad decreasing site flooding
Wimp10	WeirDamRoad/Impounding water on <10% of AA
Wimp75	WeirDamRoad/Impounding water on 10-75% of AA
Wimp100	WeirDamRoad/Impounding water on >75% of AA
Wstorm	Stormwater Inputs
Wpoint	Point Source (non-stormwater)
Wfill10	Filling, excavation on <10% of AA

Wfill75	Filling, excavation on 10-75% of AA
Wfill100	Filling, excavation on >75% of AA
Wmic10	Microtopo alterations on <10% of AA
Wmic75	Microtopo alteations on 10-75% of AA
Wmic100	Microtopo alterations on >75% of AA
Wsedchan	Excessive Sedimentation in stream channel
Wsedwet	Excessive Sedimentation on wetland surface
Wsubsid	Soil Subsidence/Root Exposure
Wtidres	Tidal Restriction
Landscape/Buffer Category (within 100m radius outside site/AA)	
Ldevcom	Development- commercial or industrial
Ldevres3	Residential >2 houses/acre
Ldevres2	Residential ≤2 houses/acre
Ldevres1	Residential <1 house/2 acres
Lsew	Served by sewer
Lsept	Served by septic
Lrdgrav	Roads (buffer) mostly dirt or gravel
Lrd2pav	Roads (buffer) mostly 2- lane paved
Lrd4pav	Roads (buffer) mostly 4-lane paved
Llndfil	Landfill/Waste Disposal
Lchan	Channelized Streams or Ditches >0.6m deep
Lagrow	Row crops or nursery plants
Lagorch	Orchards
Lagpoul	Poultry or Livestock operation
Lfor	Forest Harvesting Within Last 15 Years
Ldock	Slips/Docks/Marina
Lmoor	Boat Moorings
Lgolf	Golf Course
Lmow	Mowed Area
Lmine	Sand/Gravel Operation

APPENDIX C: Nontidal Rapid Assessment IWC Stressors and Weights

Category/Stressor Name*	Abbreviation	Stressor Weights**	
**DERAP stressors excluded from this table are not in the rapid IWC calculation.*		Flats	Riverine
Habitat Category (within 40m radius site)			
Mowing in site	Hmow	-10.8	0
Forestry activity within 16-30 years	Hfor15	-7.4 if either present	-8.4 if any present
Forest activity <10% of site	Hfor10		
Forestry activity within 3-15 years	Hfor2	-20.7	
Clear cut within 2 years	Hforcc		
Excessive Herbivory/Pinebark Beetle/Gypsy	Hherb	-6.8	0
Invasive plants dominating site (>50% of site)	Hinvdom	0	-24.3
Invasives plants not dominating (<50% of site)	Hinvless	0	-5.5
Chemical Defoliation	Hchem	0	-30.6
Managed or Converted to Pine	Hpine	-6.1	0
Trails and Roads	Htrail	-2.4	0
Nutrients direct application/runoff	Hnutapp	-15.1	0
Hydrology Category (within 40m radius site)			
Ditching -slight	Wditchs	-9.5	0
Ditching -moderate	Wditchm	-10.2	0
Ditching -severe	Wditchx	-16.4	0
Channelized stream not maintained	Wchannm	0	-10.5
Spoil bank only one side of stream	Wchan1	0	-25.7
Spoil bank both sides of stream	Wchan2	0	-33.9
Stream channel incision	Wincision	0	-18.9
Impounding water on 10-75% of site	Wimp75	0	-16.9
Impounding water on >75% of site	Wimp100	0	
Filling, excavation on 10-75% of site	Wfill75	0	-12.5
Filing, excavation on >75% of site	Wfill100	0	
Microtopography altered on 10-75% of site	Wmic75	-15	-11
Microtopography altered on >75% of site	Wmic100		
Buffer Category (100m radius around site)			
Roads mostly dirt	Lrdgrav	-2.7	0
Roads mostly 2- lane paved	Lrd2pav		0
Roads mostly 4-lane paved	Lrd4pav		0
Forest Harvesting Within Last 15 Years	Lfor	-3.3	0
Mowed Area	Lmow	-8.9	0
Intercept/Base Value		94.4	90.4
Flats IWCrapid= 94.4 +(∑weights(Habitat+Hydro+Buffer)) **Riverine IWCrapid= 90.4 +(∑weights(Habitat+Hydro))**			

*** 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: Tidal Wetland Raw Data and Scored Metrics from MidTRAM for Murderkill River Sites *

Site Number (color coded by condition group)	QDR	H1: Ditching & Draining Score	(H2): % Cover of fill	H2: Fill & Fragmen-tation Score	H3: Diking & Restriction Score	H4: Point Source Score	(B1): % of AA with 5m buffer	B1:% of AA perimeter with 5m-Buffer Score	(B2): Average Buffer Width (m)	B2: Average Buffer Width Score	(B3): % develop-ment	B3: Surrounding Development Score	B4: 250m Landscape Condition Score
MU0047	1	12	0	12	12	12	100	12	250	12	0	12	9
MU0007	2	12	0	12	12	12	100	12	208	12	0	12	9
MU0013	2	6	0	12	12	12	100	12	250	12	0	12	12
MU0004	2	12	0	12	12	12	100	12	250	12	0	12	9
MU0012	3	12	0	12	12	12	100	12	135	9	0	12	9
MU0023	2	12	0	12	12	12	100	12	250	12	0	12	9
MU0039	2	9	0	12	9	12	100	12	249	12	0	12	9
MU0041	3	9	0	12	12	12	100	12	250	12	0	12	9
MU0043	2	12	0	12	6	12	100	12	217	12	0	12	9
MU0029	2	9	0	12	12	12	100	12	184	9	0	12	9
MU0005	2	9	0	12	12	12	100	12	192	12	0	12	9
MU0008	3	12	0	12	12	12	75	9	216	12	5	9	6
MU0025	2	6	0	12	12	12	100	12	205	12	0	12	9
MU0026	2	6	0	12	12	12	100	12	225	12	0	12	9
MU0028	3	12	0	12	12	12	100	12	205	12	0	12	9
MU0052	3	12	10	9	12	12	100	12	218	12	0	12	6
MU0031	3	12	0	12	12	12	100	12	207	12	0	12	6
MU0027	3	12	0	12	12	12	100	12	198	12	2	9	6
MU0020	4	9	0	12	12	12	100	12	250	12	0	12	6
MU0045	2	9	0	12	12	12	100	12	151	9	0	12	9
MU0049	3	6	0	12	12	12	100	12	250	12	0	12	9
MU0040	3	12	0	12	12	12	100	12	181	9	0	12	6
MU0042	3	6	5	9	12	12	100	12	246	12	0	12	9
MU0036	4	12	0	12	12	12	100	12	108	6	0	12	6

MU0046	3	3	0	12	12	12	100	12	218	12	0	12	6
MU0017	2	6	0	12	12	12	100	12	199	12	0	12	9
MU0014	3	3	0	12	12	12	100	12	175	9	0	12	6
MU0002	3	9	0	12	12	12	100	12	96	6	2	9	6
MU0033	3	6	0	12	12	12	100	12	203	12	0	12	9
MU0021	4	9	0	12	12	12	100	12	192	12	0	12	6
MU0016	4	12	0	12	12	12	100	12	230	12	0	12	6
MU0024	3	12	0	12	12	6	100	12	193	12	0	12	6
MU0022	3	6	1	9	12	12	100	12	183	9	0	12	9
MU0001	4	3	2	9	12	12	100	12	238	12	0	12	6
MU0032	5	12	0	12	12	12	100	12	168	9	6	6	6
MU0030	4	12	0	12	6	12	100	12	202	12	3	9	6
MU0019	3	6	1	9	12	12	100	12	224	12	0	12	6
MU0006	3	3	10	6	12	12	100	12	171	9	1	9	12
MU0044	4	12	0	12	9	12	100	12	202	12	0	12	6
MU0035	3	3	9	6	12	12	100	12	164	9	0	12	9
MU0051	4	9	0	12	12	12	95	9	156	9	0	12	6
MU0010	4	6	10	9	12	12	100	12	244	12	5	9	6
MU0048	5	12	0	12	9	12	100	12	133	9	2.5	6	6
MU0018	2	3	1	9	12	9	100	12	212	12	1	9	6
MU0034	5	6	0	12	3	12	100	12	93	6	3	9	6
MU0009	5	12	5	9	12	12	95	9	201	12	5	9	6
MU0003	5	3	3	6	6	12	90	9	219	12	0	12	6
MU0038	5	6	8	3	6	12	65	6	164	9	25	3	3
MU0037	4	3	17	6	6	12	100	12	136	9	4	9	9
MU0050	5	9	10	3	3	12	95	9	156	9	3	9	6

* Green columns indicate scored metric values; blue columns indicate raw variable values. Site numbers are colored by condition category, see Figure 8.

APPENDIX D continued laterally

Site Number (color coded by condition group)	QDR	(B5): % Obstructed Shoreline	B5: Barriers to Landward Migration Score	(HAB1): Avg Bear Cap (cm)	HAB1: Bearing Capacity Score	(HAB2:) Avg Plant Frag (cc)	HAB2: Plant Fragments Score	HAB3A: Vertical Biotic Structure Score	(HAB4): Number of Plant Layers	HAB4: Number of Plant Layers Score	(HAB5): % Co-dominant Invasive Plant Species	HAB5: % Co-Dominant Invasive Plant Species Score	(HAB 6): % Cover of Invasive Plants	HAB6: % Invasive Score
MU0047	1	0	12	3.69	9	18.75	12	12	2	9	0	12	0	12
MU0007	2	0	12	3.44	9	12.75	8	12	3	9	0	12	0	12
MU0013	2	0	12	2.63	9	12.00	8	12	3	9	0	12	0	12
MU0004	2	0	12	3.75	3	16.25	8	12	3	9	0	12	0	12
MU0012	3	0	12	2.88	9	10.25	4	12	4	12	14	12	3	9
MU0023	2	0	12	7.38	3	19.50	12	6	2	9	0	12	0	12
MU0039	2	0	12	2.00	9	21.25	12	9	3	9	0	12	1	12
MU0041	3	0	12	3.75	9	18.75	12	6	4	12	16	9	5	9
MU0043	2	6	9	2.38	9	14.00	8	12	4	12	0	12	0	12
MU0029	2	0	12	3.19	9	17.25	8	12	1	6	0	12	0	12
MU0005	2	0	12	3.19	9	4.75	4	12	1	6	0	12	0	12
MU0008	3	0	12	5.69	6	11.50	8	12	2	9	0	12	0	12
MU0025	2	0	12	2.88	9	8.50	4	9	2	9	0	12	0	12
MU0026	2	0	12	2.63	9	10.75	4	9	3	9	0	12	0	12
MU0028	3	0	12	5.19	3	7.50	4	12	2	9	20	9	20	9
MU0052	3	0	12	2.44	9	23.50	12	3	2	9	0	12	2	9
MU0031	3	92	3	3.63	9	17.50	12	9	2	9	0	12	3	9
MU0027	3	0	12	2.50	9	11.00	4	9	4	12	25	9	1	9
MU0020	4	0	12	2.13	9	3.75	4	12	4	12	27	9	30	6
MU0045	2	0	12	2.31	9	11.25	4	9	1	6	0	12	0	12
MU0049	3	0	12	6.63	3	22.50	12	6	2	9	0	12	2	9
MU0040	3	0	12	7.56	3	8.00	4	12	2	9	0	12	6	9
MU0042	3	0	12	4.38	6	11.00	4	12	3	9	0	12	0	12
MU0036	4	0	12	4.44	3	19.75	12	9	3	9	25	9	10	9

MU0046	3	0	12	4.38	6	13.75	8	9	3	9	0	12	0	12
MU0017	2	20	6	3.38	9	8.25	4	12	1	6	0	12	0	12
MU0014	3	0	12	2.19	9	12.00	8	9	3	9	0	12	0	12
MU0002	3	0	12	2.19	9	17.50	12	9	2	9	25	9	20	9
MU0033	3	0	12	4.19	6	13.50	8	6	1	6	0	12	0	9
MU0021	4	0	12	3.06	9	8.25	4	12	3	9	29	9	60	3
MU0016	4	0	12	4.56	3	10.25	4	9	4	12	38	6	30	6
MU0024	3	0	12	5.00	3	10.75	4	12	3	9	0	12	2	9
MU0022	3	0	12	2.06	9	5.00	4	9	4	12	18	9	7	9
MU0001	4	0	12	4.31	6	12.75	8	9	4	12	0	12	2	9
MU0032	5	0	12	7.69	3	22.75	12	12	2	9	40	6	30	6
MU0030	4	95	3	4.69	6	24.00	12	12	1	6	0	12	0	12
MU0019	3	0	12	4.50	6	12.75	8	12	3	9	40	6	10	9
MU0006	3	0	12	3.19	9	10.00	4	12	3	9	0	12	0	12
MU0044	4	55	3	3.75	3	10.50	4	12	2	9	14	12	25	9
MU0035	3	0	12	2.31	9	13.00	8	9	3	9	0	12	1	9
MU0051	4	16	6	3.88	3	20.00	12	6	2	9	0	12	1	9
MU0010	4	100	3	3.25	9	17.75	12	12	4	12	33	6	2	9
MU0048	5	0	12	3.00	3	14.50	8	12	1	6	100	3	90	3
MU0018	2	35	3	1.94	9	16.50	8	6	3	9	0	12	0	12
MU0034	5	3	9	3.50	9	16.00	8	9	5	12	25	9	10	9
MU0009	5	30	3	4.75	6	9.50	4	6	4	12	33	6	40	6
MU0003	5	0	12	4.69	6	10.50	4	9	4	12	13	12	8	9
MU0038	5	0	12	1.06	12	12.00	8	12	4	12	11	12	10	9
MU0037	4	55	3	2.94	9	8.00	4	12	2	9	25	9	2	9
MU0050	5	65	3	2.94	9	10.50	4	9	4	12	14	12	5	9

APPENDIX E: Bird Survey Data for Murderkill River Tidal Sites 2008

Bird Common Names	SIMBCI	MU0001	MU0002	MU0003	MU0004	MU0005	MU0006	MU0007	MU0008	MU0009	MU0010
American goldfinch	4	x									
barn swallow	4				x		x				x
blue jay	5	x									
clapper rail *	12	x	x	x		x	x			x	
common grackle	5	x								x	
common yellowthroat	7	x		x		x				x	
eastern kingbird	6	x								x	
marsh wren*	9.5			x	x			x	x	x	x
mourning dove	4	x									
red-bellied woodpecker	5	x									
red-winged blackbird	5.5	x	x	x	x	x	x	x	x	x	x
seaside sparrow*	13.5		x	x	x	x	x	x		x	x
song sparrow	4	x		x		x					
spotted sandpiper	5			x							
swamp sparrow*	9.5	x									
tree swallow	4		x			x	x				x
Virginia rail*	10				x			x			
willet*	14				x	x	x			x	x
yellow warbler	4									x	
Species Richness		**11**	**4**	**7**	**6**	**7**	**6**	**4**	**2**	**9**	**6**
WIMBCI		**4.09**	**6.75**	**7.07**	**9.42**	**7.57**	**7.83**	**8.63**	**4.5**	**8.5**	**7.42**

* Indicates and obligate marsh species

** An 'x' indicates the detection of the species (visually or audibly) within 75m of the assessment point.

APPENDIX F: Vegetative Biomass Data for Murderkill River Tidal Sites 2008

	MU0003	MU0006	MU0007	MU0010	MU0013	MU0019	MU0022	MU0030	MU0038	MU0047
Above Dead	6.66	7.23	6.82	4.25	15.38	3.86	25.42	6.86	5.20	6.68
Above Live	11.46	9.36	6.75	7.27	17.30	7.61	15.52	10.33	12.50	11.80
Above Total	18.12	16.59	13.57	11.52	32.68	11.47	40.94	17.19	17.70	18.48
Below Top Dead	71.07	105.73	79.77	92.44	161.35	72.73	46.89	81.09	112.94	66.46
Below Bottom Dead	65.24	50.75	57.03	84.33	130.10	67.95	73.50	41.43	95.29	55.22
Below Dead Total	136.31	156.48	136.80	176.77	291.45	140.68	120.39	122.52	208.23	121.68
Below Top Live	11.53	10.23	1.49	10.99	32.54	8.52	11.40	14.03	2.64	2.77
Below Bottom Live	1.61	5.77	0.66	0.59	0.81	1.18	2.70	3.44	1.66	1.13
Below Live Total	13.14	16.00	2.15	11.58	33.35	9.70	14.10	17.47	4.30	3.90
Below Top Total	82.60	115.96	81.26	103.43	193.89	81.25	58.29	95.12	115.58	69.23
Below Total	149.45	172.48	138.95	188.35	324.80	150.38	134.49	139.99	212.53	125.58
Above Live : Below Live	0.872	0.585	3.140	0.628	0.519	0.785	1.101	0.591	2.907	3.026
Above Dead : Below Dead	0.049	0.046	0.050	0.024	0.053	0.027	0.211	0.056	0.025	0.055
Above : Below	0.121	0.096	0.098	0.061	0.101	0.076	0.304	0.123	0.083	0.147

APPENDIX G: Nontidal Flat Wetland Rapid Assessment Stressors for Sites in the Murderkill River watershed in 2008

Stressor descriptions are listed in Appendix B (page 46). '1' indicates the stressor presence; '0' indicates stressor absence.

Habitat and Plant Community Stressors

Site #	QDR	TBA	Hmow	Hfarm	Hgraz	Hfor50	Hfor30	Hfor15	Hfor2	Hforcc	Hnorecov	Hfor10	Hherb	Hinvdom	Hinvless	Hchem	Hpine	Hburn	Htrail	Hgarb	Hnutapp	Halgae	Hrdlog	Hrdgrav	Hrdpav
MU0001	3	210	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
MU0002	3	90	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
MU0003	3	80	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
MU0005	5	20	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
MU0006	4	100	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0009	3	90	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
MU0010	3	80	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
MU0017	2	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
MU0018	2	130	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
MU0019	4	120	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0021	3	120	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
MU0023	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0025	3	105	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
MU0027	3	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
MU0028	4	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0030	4	100	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
MU0034	3	100	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0040	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0043	3	90	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
MU0050	2	100	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
MU0051	2	80	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
MU0053	4	110	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
MU0056	4	60	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0059	1	60	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0062	4	40	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
MU0066	4	110	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
MU0067	3	110	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
MU0078	3	50	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
MU0094	3	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
MU0097	4	90	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0

Appendix G continued

Hydrology Stressors

Site #	Wditchs	Wditchm	Wditchx	Wditchflood	Wimp10	Wimp75	Wimp100	Wstorm	Wpoint	Wfill10	Wfill75	Wfill100	Wmic10	Wmic75	Wmic100	Wsedchan	Wsedwet	Wsubsid	Wtidres
MU0001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0002	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0
MU0003	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
MU0005	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0
MU0006	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0009	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0
MU0010	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
MU0017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0018	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0
MU0019	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
MU0021	0	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
MU0023	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0025	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
MU0027	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0028	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
MU0030	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
MU0034	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0
MU0040	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0043	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
MU0050	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0051	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0053	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0
MU0056	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
MU0059	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0062	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0066	0	0	1	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
MU0067	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
MU0078	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0094	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
MU0097	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0

Appendix G continued

Buffer Stressors

Site #	Ldevcom	Ldevres3	Ldevres2	Ldevres1	Lsew	Lsept	Lgrav	Lrd2pav	Lrd4pav	Llndfil	Lchan	Lagrow	Lagorch	Lagpoul	Lfor	Ldock	Lgolf	Lmow	Lmine
MU0001	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
MU0002	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
MU0003	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
MU0005	0	0	0	1	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0
MU0006	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0
MU0009	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0010	0	0	0	1	0	1	0	1	0	0	1	0	0	0	1	0	0	0	0
MU0017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0018	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0019	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0021	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
MU0023	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
MU0025	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
MU0027	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0
MU0028	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	0	0	1	0
MU0030	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0034	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
MU0040	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0043	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0
MU0050	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
MU0051	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0053	0	0	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0
MU0056	1	0	0	0	0	0	1	0	1	0	0	1	0	0	1	0	0	0	0
MU0059	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0062	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
MU0066	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0
MU0067	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0078	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
MU0094	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
MU0097	0	0	0	1	0	1	0	1	0	1	0	1	0	0	0	0	0	0	0

APPENDIX H: Nontidal Riverine Wetland Rapid Assessment Stressors for Sites in the Murderkill River watershed in 2007-2008

Stressor descriptions are listed in Appendix B (page 46). '1' indicates the presence of that stressor, '0' indicates the absence.

Habitat and Plant Community Stressors

Site #	QDR	Basal Area	Hmov	Hfarm	Hgraz	Hfor50	Hfor30	Hfor15	Hfor2	Hforcc	Hnorecov	Hfor10	Hinvdom	Hinvless	Hchem	Hpine	Hburn	Hherb	Htrail	Hgarb	Hnutapp	Halgae	Hrdlog	Hrdgrav	Hrdpav
MU0008	2	140	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0014	3	136	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
MU0022	2	170	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
MU0026	3	110	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
MU0031	2	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0032	4	100	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
MU0041	2	140	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
MU0042	5	60	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0
MU0044	5	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
MU0057	2	100	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
MU0068	5	100	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
MU0072	3	70	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
MU0074	2	70	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
MU0080	2	100	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
MU0086	2	130	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
MU0088	2	90	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
MU0090	4	140	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
MU0095	1	150	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0100	2	110	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
MU0102	2	120	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
MU0105	3	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
MU0117	4	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	1	0	0	0	0	0
MU0121	5	60	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
MU0127	2	90	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
MU0136	1	40	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
MU0138	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
MU0141	5	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
MU0145	3	110	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0
MU0166	3	150	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
MU0176	4	130	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	1	0	0
MU0181	4	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0

Appendix H continued

Hydrology Stressors

Site #	Wditchs	Wditchm	Wditchx	Wditchflood	Wchannm	Wchan1	Wchan2	Wincision	Wimp10	Wimp75	Wimp100	Wstorm	Wpoint	Wfill10	Wfill75	Wfill100	Wmicro10	Wmicro75	Wmicro100	Wsedchan	Wsedwet	Wsubsid	Wtidres
MU0008	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0014	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
MU0022	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0026	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
MU0031	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0032	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0041	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0042	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
MU0044	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
MU0057	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0068	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
MU0072	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
MU0074	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0080	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0086	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0088	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0090	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
MU0095	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0102	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
MU0105	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0117	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0
MU0121	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0
MU0127	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
MU0136	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0138	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0141	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
MU0145	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MU0166	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
MU0176	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
MU0181	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0

Appendix H continued

Buffer Stressors

Site #	Ldevcom	Ldevres3	Ldevres2	Ldevres1	Lsew	Lsept	Lrdgrav	Lrd2pav	Lrd4pav	Llndfil	Lchan	Lagrow	Lagorch	Lagpoul	Lfor	Ldock	Lgolf	Lmow	Lmine	Lother
MU0008	0	0	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	
MU0014	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	
MU0022	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
MU0026	0	0	0	1	0	1	0	1	0	0	0	1	0	1	0	0	0	1	0	
MU0031	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
MU0032	0	1	0	0	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	
MU0041	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	SW pond
MU0042	0	0	0	1	1	0	0	1	0	0	1	1	0	0	1	0	0	0	0	
MU0044	0	1	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	
MU0057	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	
MU0068	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	
MU0072	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	
MU0074	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	
MU0080	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	
MU0086	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
MU0088	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	
MU0090	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	RR track
MU0095	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
MU0100	0	0	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	
MU0102	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	
MU0105	0	0	1	0	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	
MU0117	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	
MU0121	0	1	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	1	0	
MU0127	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	
MU0136	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	
MU0138	0	0	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0	
MU0141	0	1	0	0	1	0	0	1	0	0	1	1	0	0	0	0	0	0	0	
MU0145	0	1	0	0	1	0	0	1	0	1	0	1	0	0	1	0	0	0	0	RR track
MU0166	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	
MU0176	0	1	0	0	1	0	0	1	0	1	1	0	0	0	1	0	0	0	0	
MU0181	0	0	0	1	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	

APPENDIX I: Nontidal Flats Comprehensive Metric and Variable Data from Murderkill River watershed sites *

Site Number	MU0001	MU0002	MU0003	MU0006	MU0009	MU0025
QDR	3	3	3	4	3	3
% Affected by Ditching	40	50	35	13	60	45
Vdrain	0.60	0.50	0.65	0.87	0.40	0.55
Vdisturb	1.00	1.00	0.75	0.50	0.50	0.50
Tree Density (trees/ha)	520.00	173.00	146	306.70	226.70	120.00
Vtreeden	1.00	0.81	0.69	1.00	1.00	0.56
% FACU Trees >7.5cm dbh	8.00	14.00	9	2.00	39.00	10.00
Vtreespp	0.50	0.25	0.5	1.00	0.25	0.50
Tree Basal Area (m^2/ha)	41.36	24.6	10.2	12	15.2	9
Vtba	1.00	0.83	0.34	0.41	0.51	0.30
Vmicro	1.00	1.00	0.75	1.00	0.10	0.75
Vherb	0.75	0.75	0.75	0.75	0.75	0.50
% of Veg Plots with *Rubus*	33	0	33	33	33	100
Vrubus	0.75	1.00	0.75	0.75	0.75	0.25
Shrub Density (shrubs/ha)	80	10,054	6,000	1,347	8,654	6,240
Vshrubden	0.10	1.00	1.00	0.28	1.00	1.00
# of Shrub Species	1.00	2.00	9.00	3.00	6.00	9.00
Vshrubspp	0.25	0.50	1.00	0.75	1.00	1.00
% Fill in AA	0	<10%	0	0	<10%	0
Vfill	1.00	0.75	1.00	1.00	0.75	1.00
Volume LDW (m^3/ha)	-	-	-	-	-	-
Snag Density (snags/ha)	9.9	8.9	6.9	7.9	17.8	3.9
Vdeadwood	0.50	0.50	0.50	0.50	0.50	0.50
Buffer Tree Basal Area (m^2/ha)	41	13	19.6	10.3	25.8	14.7
Vbufferba	1.00	0.52	0.76	0.40	1.00	0.57
% High Impact Land Use	22	11	3	65	20	14
Vbuffuse200	0.83	0.95	1.00	0.33	0.77	0.92
% Buffer Impervious	1	0.5	0	3	0	0
Vbuff imperv200	0.97	0.98	1.00	0.91	1.00	1.00
% Buffer Road Cover	1	0.5	0	3	0	0
Vbuffroad200	0.94	0.97	1.00	0.83	1.00	1.00
Vfqai	0.32	0.89	0.93	0.45	1.00	0.89
Avg CoC	3.66	4.40	4.46	3.62	4.6	4.43
fqai'	33.95	44.00	44.6	36.20	46	43.8

*Shaded lines highlight calculated variable scores; unshaded lines denote raw values.
All sites were assessed in 2007 and scored with the Flats Variable Scoring Protocol version 2.0.

APPENDIX J: Nontidal Riverine Comprehensive Metric and Variable Data from Murderkill River watershed sites*

Site #	MU0057	MU0022	MU0031	MU0026	MU0014	MU0032
Qualitative Condition Ranking	2	2	2	3	3	4
Vveg history	1.00	1.00	1.00	0.75	0.50	1.00
FACU Tree IV	0.57	0.02	0.06	0.00	0.14	0.00
Vtreecomp	0.10	0.75	0.50	1.00	0.50	1.00
Tree Basal Area m²/ha	20.10	32.50	28.00	15.60	36.70	29.30
Vtba	0.48	0.77	0.67	0.37	0.87	0.70
Vmicrotopo	0.25	1.00	1.00	1.00	1.00	1.00
% Veg Plots with Rubus	33	0	0	0	66	66
Vrubus	1.00	1.00	1.00	1.00	0.50	0.50
Shrub Density (shrubs/ha)	4974	7801	3520	6014	2813	3227
Vshrubden	1.00	1.00	1.00	1.00	1.00	1.00
Buffer Tree Basal Area (m²/ha)	27.4	28.5	34.8	15.4	37.27	23.1
Vbufferba	0.77	0.80	0.97	0.43	1.00	0.65
% Buffer High Impact Land Use	15	0	0	75	40	85
Vbuffuse200	0.10	1.00	1.00	0.10	0.10	0.10
AA Floodplain Alterations	0	0	0	not effective	not effective	not effective
Vfloodplain	1.00	1.00	1.00	0.75	0.75	0.75
% Coverage Invasive Herbs	0.31	0.43	0.2	2.04	0.1	4.81
Vinvasive understory	0.75	0.75	0.75	0.50	0.75	0.25
% Channelization 500m from AA	0	0	0	10	0	40
Vchannel_out	1.00	1.00	1.00	0.75	1.00	0.50
Vinstream	1.00	0.60	0.60	0.60	0.60	0.60
Vhydroalt_out	0.50	1.00	0.50	0.10	0.50	0.10
Average CoC	4.54	4.88	4.47	4.45	4.56	4.43
FQAI'	43.9	47.62	43.12	42.89	44.24	41.76
Vfqai	0.89	1.00	0.84	0.83	0.91	0.77
Distance to Nearest Road (m)	290	400	170	30	200	0
Vdist_to_road	1.00	1.00	1.00	0.18	1.00	0.10

*Shaded lines highlight calculated variable scores; Unshaded lines denote raw values.
All sites were assessed in 2007 and scored with the Riverine Variable Scoring Protocol version 2.0.

APPENDIX K: Nontidal Depression Assessment Data from Murderkill River sites 2007-2008

Rapid assessment stressor checklist. Stressor definitions are listed in Appendix B. '1' indicates the presence of that stressor, '0' indicates the absence.

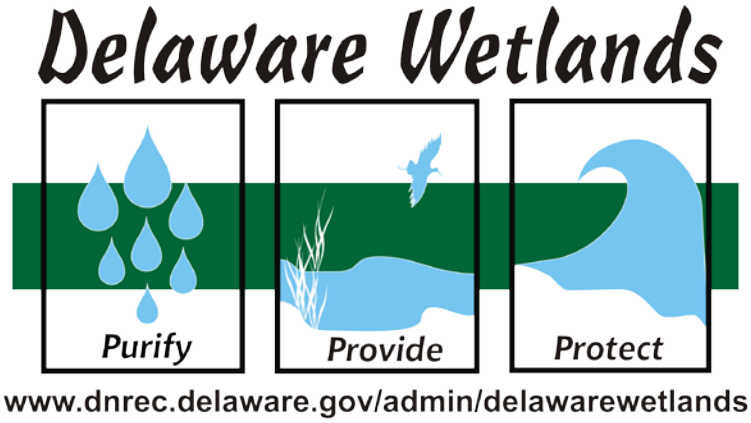
		Habitat Stressors (within 40m radius assessment area)																						
DEP Site #	QDR	Hmow	Hfarm	Hgraz	Hfor50	Hfor30	Hfor15	Hfor2	Hforselect	Hforcc	Hnorecov	Hfor10	Hherb	Hinvdom	Hinvless	Hchem	Hpine	Hburn	Htrail	Hgarb	Hnutapp	Haglage	Hrdlog	Hrdpav	Hrdgrav	Total Basal Area (trees/ha)
MU0039	3	0	0	0	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	65
MU0011	5	0	0	0	0	1	0	0	1	0	0	0	0	1	0	1	0	0	0	1	0	0	1	0	0	0

		Hydrology Stressors (within 40m radius assessment area)																	
DEP Site #	QDR	Wditchs	Wditchm	Wditchx	Wdamdec	Wimp10	Wimp75	Wimp100	Wstorm	Wpoint	Wfill10	Wfill75	Wfill100	Wmic10	Wmic75	Wmic100	Wsedwet	Wsubsid	Wtidres
MU0039	3	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0
MU0011	5	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0

		Landscape/ Buffer Stressors (within 100m radius from AA edge)																	
DEP Site #	QDR	Ldevcom	Ldevres3	Ldevres2	Ldevres1	Lsew	Lsept	Lrdgrav	Lrd2pav	Lrd4pav	Llndfil	Lchan	Lagrow	Lagorch	Lagpoul	Lfor	Ldock	Lgolf	Lmow	Lmine
MU0039	3	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
MU0011	5	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0

APPENDIX K Continued

Comprehensive assessment raw values (white lines) and variable scores (shaded lines) for Murderkill River watershed depression sites.

Site #	MU0011	MU0039
Qualitative Condition Ranking	5	3
Forest sapling density (sap/ha)	466	3226
Vsapden	1.00	0.23
Canopy tree density (trees/ha)	146.7	373.6
Vtreeden	0.52	1.00
Canopy tree basal area (m^2/ha)	7.32	25.36
Vtba	0.51	1.00
Shrub density (stems/ha)	0	19,814
Vshrubden	0.10	1.00
Shrub richness & composition	0 shrubs	5 spp & both indicator spp
Vshrubsp	0.10	1.00
Tree richness & composition	6 spp & both indicator spp	5 spp & both indicator spp
Vtreespp	1.00	1.00
% Native understory	93%	97%
Vnative	0.5	0.75
Hydrologic alterations	ditches, fill and ag	<10% fill
Vhydroalt	0.25	0.75
Buffer canopy tree basal area (m^2/ha)	22.02	31.66
Vbufferba	1.00	1.00
Distance from wetland to road (m)	360	400
Vdisttoroad	1.00	1.00
% Natural vegetation in 240m	50%	55%
Vnatland	0.63	0.69

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