Preparing for Tomorrow’s High Tide

Sea Level Rise Vulnerability Assessment for the State of Delaware

July 2012
Other Documents in the
Preparing for Tomorrow’s High Tide Series

A Progress Report of the
Delaware Sea Level Rise Advisory Committee
(November 2011)

A Mapping Appendix to the
Delaware Sea Level Rise Vulnerability Assessment
(July 2012)
Preparing for Tomorrow’s High Tide

Sea Level Rise
Vulnerability Assessment for the State of Delaware

Prepared for the Delaware Sea Level Rise Advisory Committee by the Delaware Coastal Programs of the Department of Natural Resources and Environmental Control
About This Document

This Vulnerability Assessment was developed by members of Delaware’s Sea Level Rise Advisory Committee and by staff of the Delaware Coastal Programs section of the Department of Natural Resources and Environmental Control. It contains background information about sea level rise, methods used to determine vulnerability and a comprehensive accounting of the extent and impacts that sea level rise will have on 79 resources in the state. The information contained within this document and its appendices will be used by the Delaware Sea Level Rise Advisory Committee and other stakeholders to guide development of sea level rise adaptation strategies.

Users of this document should carefully read the introductory materials and methods to understand the assumptions and trade-offs that have been made in order to describe and depict vulnerability information at a statewide scale. The Delaware Coastal Programs makes no warranty and promotes no other use of this document other than as a preliminary planning tool.

This project was funded by the Delaware Department of Natural Resources and Environmental Control, in part, through a grant from the Delaware Coastal Programs with funding from the Office of Ocean and Coastal Resource Management, National Oceanic and Atmospheric Administrations, under award number NA11NOS4190109.

Further information about this document and the Delaware Sea Level Rise Advisory Committee can be found online at http://de.gov/slradvisorycommittee/ and at the address below:

Delaware Coastal Programs
5 East Reed Street, Suite 201
Dover, DE 19901
(302) 739-9283
Delaware Coastal Programs Project Staff

**Delaware Coastal Programs Management**
- Sarah Cooksey - Program Administrator
- David Carter - Program Manager II

**Natural Resources Workgroup**
- Tricia Arndt - Environmental Scientist III
- Kelly Valencik - Planner I

**Society & Economy Workgroup**
- Susan Love - Planner IV

**Public Safety & Infrastructure Workgroup**
- Dr. Robert Scarborough - Environmental Scientist IV
- Mark Wolanski - Environmental Scientist

**Map Design and Document Compilation**
- Carl Yetter - Environmental Engineer III
## Contents

### Sections

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXECUTIVE SUMMARY</td>
<td>viii</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>DELAWARE'S SEA LEVEL RISE ADVISORY COMMITTEE</td>
<td>3</td>
</tr>
<tr>
<td>PLANNING FOR SEA LEVEL RISE</td>
<td>4</td>
</tr>
<tr>
<td>EFFECTS OF SEA LEVEL RISE</td>
<td>5</td>
</tr>
<tr>
<td>SALT LINE</td>
<td>5</td>
</tr>
<tr>
<td>RATES AND CAUSES OF SEA LEVEL RISE</td>
<td>7</td>
</tr>
<tr>
<td>FUTURE RATES OF SEA LEVEL RISE</td>
<td>8</td>
</tr>
<tr>
<td>VISUALIZING SEA LEVEL RISE</td>
<td>9</td>
</tr>
<tr>
<td>MEAN HIGHER HIGH WATER (MHHW)</td>
<td>9</td>
</tr>
<tr>
<td>VULNERABILITY ASSESSMENT METHODS</td>
<td>12</td>
</tr>
<tr>
<td>IDENTIFICATION OF RESOURCES OF CONCERN</td>
<td>13</td>
</tr>
<tr>
<td>DATA COLLECTION</td>
<td>14</td>
</tr>
<tr>
<td>EXPOSURE ASSESSMENT</td>
<td>14</td>
</tr>
<tr>
<td>IMPACT ASSESSMENT</td>
<td>15</td>
</tr>
<tr>
<td>PUBLIC ENGAGEMENT</td>
<td>15</td>
</tr>
<tr>
<td>RISK ASSESSMENT</td>
<td>16</td>
</tr>
<tr>
<td>VULNERABILITY ASSESSMENT FINDINGS</td>
<td>18</td>
</tr>
<tr>
<td>HOW TO USE THE EXPOSURE TABLES</td>
<td>19</td>
</tr>
<tr>
<td>RESULTS OF RESOURCE RISK ASSESSMENT</td>
<td>20</td>
</tr>
<tr>
<td>NATURAL RESOURCES</td>
<td>22</td>
</tr>
<tr>
<td>ASSESSING EXPOSURE OF NATURAL RESOURCES</td>
<td>23</td>
</tr>
<tr>
<td>ASSESSING VULNERABILITY OF NATURAL RESOURCES</td>
<td>24</td>
</tr>
<tr>
<td>DETAILED RESOURCE ASSESSMENTS</td>
<td>28</td>
</tr>
<tr>
<td>WATER RESOURCES</td>
<td>28</td>
</tr>
<tr>
<td>GROUNDWATER</td>
<td>31</td>
</tr>
<tr>
<td>WETLANDS</td>
<td>33</td>
</tr>
<tr>
<td>Tidal Wetlands</td>
<td>33</td>
</tr>
<tr>
<td>Saltwater Tidal Wetlands</td>
<td>34</td>
</tr>
<tr>
<td>Freshwater Tidal Wetlands</td>
<td>35</td>
</tr>
<tr>
<td>Non-tidal Freshwater Wetlands</td>
<td>39</td>
</tr>
<tr>
<td>IMPOUNDMENTS</td>
<td>42</td>
</tr>
<tr>
<td>BEACHES AND DUNES</td>
<td>44</td>
</tr>
<tr>
<td>UPLAND FOREST</td>
<td>47</td>
</tr>
<tr>
<td>FLORA AND FAUNA</td>
<td>50</td>
</tr>
<tr>
<td>HABITATS OF CONSERVATION CONCERN</td>
<td>50</td>
</tr>
<tr>
<td>NATIVE VEGETATION</td>
<td>51</td>
</tr>
<tr>
<td>NATIVE FAUNA</td>
<td>52</td>
</tr>
<tr>
<td>NATURAL RESOURCE CONSERVATION LANDS</td>
<td>54</td>
</tr>
<tr>
<td>PROTECTED LANDS STATEWIDE</td>
<td>54</td>
</tr>
<tr>
<td>NATURE PRESERVES</td>
<td>55</td>
</tr>
<tr>
<td>NATIONAL WILDLIFE REFUGES</td>
<td>57</td>
</tr>
<tr>
<td>AGRICULTURE</td>
<td>61</td>
</tr>
<tr>
<td>HIGHLY PRODUCTIVE SOILS</td>
<td>61</td>
</tr>
<tr>
<td>PRESERVATION DISTRICTS AND CONSERVATION EASEMENTS</td>
<td>63</td>
</tr>
<tr>
<td>SOCIETY &amp; ECONOMY</td>
<td>66</td>
</tr>
<tr>
<td>ASSESSING EXPOSURE OF SOCIETY &amp; ECONOMY RESOURCES</td>
<td>67</td>
</tr>
<tr>
<td>ASSESSING VULNERABILITY OF SOCIETY &amp; ECONOMY RESOURCES</td>
<td>67</td>
</tr>
</tbody>
</table>
Contents

Table of Tables

Table 1 - Risk Assessment Scores, Basis and Recommended Action ..........................................................16
Table 2 - Total Acreage of Uplands and Wetlands Exposed to Sea Level Rise ............................................19
Table 3 - Undeveloped Recharge Areas .......................................................................................................31
Table 4 - Wellhead Protection Areas ...........................................................................................................32
Table 5 - Tidal Wetlands ...............................................................................................................................34
Table 6 - Freshwater Tidal Wetlands ............................................................................................................35
Table 7 - Mixed Broadleaf Freshwater Tidal Marsh .......................................................................................36
Table 8 - Freshwater Tidal Forested and Shrub Wetlands ............................................................................36
Table 9 - Non-Tidal Emergent Wetlands .......................................................................................................39
Table 10 - Non-Tidal Forested Wetlands .......................................................................................................40
Table 11 - Non-Tidal Shrub Wetlands ...........................................................................................................40
Table 12 - Impoundments .............................................................................................................................43
Table 13 - Inter-dunal Wetlands .....................................................................................................................45
Table 14 - Total Upland Forest .......................................................................................................................47
Table 15 - Deciduous Forest .........................................................................................................................48
Table 16 - Evergreen Forest ..........................................................................................................................48
Table 17 - Mixed Forest .................................................................................................................................48
Table 18 - Habitats of Conservation Concern (HCC) ....................................................................................50
Table 19 - Flora that may be affected by sea level rise and associated habitat type .....................................52
Table 20 - Protected Lands (2009) .................................................................................................................54
Table 21 - Nature Preserves (2009) ...............................................................................................................56
Table 22 - USFWS Property ..........................................................................................................................57
Table 23 - Highly Productive Soils ................................................................................................................62
Table 24 - Agricultural Land Preservation Districts .......................................................................................63
Table 25 - Agricultural Land Conservation Easements ................................................................................64
Table 26 - Number of Commercial Addresses .............................................................................................73
Table 27 - Number of Business Licenses within the Sea Level Rise Scenario Areas ......................................74
Table 28 - Coastal Zone Heavy Industrial Acreage Exposed to Sea Level Rise ............................................76
Table 29 - Number of Factories (as represented by Toxic Release Inventory sites) .....................................77
Table 30 - Residential Addresses affected by sea level rise .......................................................................79
Table 31 - Number of Residential Multi-Unit Addresses Exposed to Sea Level Rise ....................................79
Table 32 - Number of Residential Manufactured Home Addresses Exposed to Sea Level Rise .....................80
Table 33 - State Strategy Level 3 Areas Inundated by Sea Level Rise ............................................................82
Table 34 - Acres of Actively Farmed Land Exposed to Sea Level Rise ...........................................................84
Table 35 - Acres of Confined Animal Feeding Operations Exposed to Sea Level Rise ..................................84
Table 36 - Acres of Farmsteads and Related Buildings Exposed to Sea Level Rise ......................................85
Table 37 - Acres of Delaware State Parks Exposed to Sea Level Rise ...........................................................87
Table 38 - Number of State Historic Sites Exposed to Sea Level Rise ...........................................................89
Table 39 - Number of National Register Sites Exposed to Sea Level Rise ..................................................89
Table 40 - Miles of Dams & Levees Exposed to Sea level Rise ....................................................................104
Table 41 - Number of Fire & Rescue Stations Exposed to Sea Level Rise .....................................................106
Table 42 - Number of Ambulance & Paramedic Stations (EMS) Exposed to Sea Level Rise .......................106
Table 43 - Number of Police Stations Exposed to Sea Level Rise ................................................................107
Table 44 - Number of Emergency Operation Centers Exposed to Sea Level Rise ...............................................107
Table 45 - Miles of Evacuation Routes Exposed to Sea Level Rise ........................................................................109
Table 46 - Miles of DART Bus Routes Exposed to Sea Level Rise .................................................................110
Table 47 - Number of DART Bus Stops Exposed to Sea Level Rise ...............................................................111
Table 48 - Number of Navigation Aids Exposed to Sea Level Rise ..............................................................112
Table 49 - Acres of the Diamond State Port Corporation Property Exposed to Sea Level Rise .....................114
Table 50 - Acres of Port Operations and Supporting Activity Exposed to Sea Level Rise .............................114
Table 51 - Miles of Railroad Lines Exposed to Sea Level Rise ........................................................................116
Table 52 - Number of Ramps and Piers Exposed to Sea Level Rise ..............................................................117
Table 53 - Miles of Roads & Bridges Exposed to Sea Level Rise .......................................................................119
Table 54 - Number of Septic Systems Exposed to Sea Level Rise ..............................................................121
Table 55 - Miles of Pipeline Exposed to Sea Level Rise .................................................................................123
Table 56 - Number of Public Pumping Stations Exposed to Sea Level Rise ................................................125
Table 57 - Number of Public Spray Irrigation fields Exposed to Sea Level Rise .............................................125
Table 58 - Number of Public Treatment/Collection Facilities Exposed to Sea Level Rise ............................126
Table 59 - Number of Domestic Wells Exposed to Sea Level Rise .................................................................128
Table 60 - Number of Industrial Wells Exposed to Sea Level Rise ...................................................................128
Table 61 - Number of Irrigation Wells Exposed to Sea Level Rise ..............................................................128
Table 62 - Number of Public Wells Exposed to Sea Level Rise .........................................................................129
Table 63 - Number of Adult Care Facilities Exposed to Sea Level Rise ..........................................................130
Table 64 - Number of Child Care Facilities Exposed to sea level Rise .........................................................131
Table 65 - Number of Cemeteries Exposed to Sea Level Rise .........................................................................132
Table 66 - Number of Private Schools Exposed to Sea Level Rise ...............................................................133
Table 67 - Number of Public Schools Exposed to Sea Level Rise ....................................................................133
Table 68 - Number of Brownfield Sites Exposed to Sea Level Rise .............................................................135
Table 69 - Number of Landfills Exposed to Sea Level Rise ..........................................................................137
Table 70 - Acres of Landfills Exposed to Sea Level Rise ...............................................................................137
Table 71 - Number of salvage Yards Exposed to Sea Level Rise .....................................................................137
Table 72 - Acres of SIRS Sites Exposed to Sea Level Rise .............................................................................140
Table 73 - Number of SIRS Sites Exposed to Sea Level Rise ..........................................................................140
Table 74 - Number of UST Facilities Exposed to Sea Level Rise .....................................................................142
Table 75 - Number of LUST Sites Exposed to Sea Level Rise .......................................................................142

Table of Figures and Maps

Figure 1 - Shoreline erosion (Woods Hole Group Consulting, Inc.) .................................................................6
Figure 2 - Mean Sea Level Trend - Lewes, DE (NOAA, 2012) .......................................................................7
Figure 3 - Sea Level Rise Scenarios Recommended by DNREC’s Technical Workgroup ............................8
Figure 4 - Differences in high tide heights ....................................................................................................10
Figure 5 - Storage tanks exposed to inundation ..........................................................................................14

Map 1 - Delaware Coastal Zone Industrial Area ..........................................................................................75
Executive Summary

As a coastal state, Delaware’s economy and quality of life have historically been linked to its shores, its vast expanses of protected tidal wetlands, and its fertile farm fields. Because of its location, low average elevation, and dependence on the coast, Delaware is particularly vulnerable to the effects of rising sea levels including loss of low-lying land and structures, saltwater intrusion into ground and surface waters, and increased coastal flooding from storm events.

Today, sea level rise is rarely, if ever, considered by governments, organizations, and individuals as they make decisions about where to develop, how to build, or what to preserve. However, changes in sea levels could impact the longevity, safety, and return-on-investment of projects that have long planning horizons or long life-spans. Accounting for changes in sea level that may be expected to occur over the lifetime of these projects will help lead to informed decisions for public and private investments by minimizing risk and potential for damage. Planning for the long-term effects of sea level rise may also help us better prepare in the short-term for flooding from coastal storms.

Delaware’s Sea Level Rise Advisory Committee

Delaware’s Sea Level Rise Advisory Committee (SLRAC) was established by invitation of Collin O’Mara, Secretary of the Department of Natural Resources and Environmental Control (DNREC), to help the state plan for sea level rise. The committee is composed of members from a wide variety of interest groups including state agencies, local governments, citizen organizations, business organizations, and environmental organizations. The goal of the Sea Level Rise Advisory Committee is to assess Delaware’s vulnerability to current and future inundation problems that may be exacerbated by sea level rise and to develop a set of recommendations for state agencies, local governments, businesses, and citizens to enable them to adapt programs, policies, business practices and make informed decisions.

The committee’s work has been split into two phases, a vulnerability assessment phase and an adaptation planning phase. This document is the culmination of the vulnerability assessment phase, during which the committee provided expert opinions to analyze and assess potential impacts of sea level rise to 79 statewide resources, ranging from roads to wetlands to tourism. This vulnerability assessment will be used as the basis for the next phase, adaptation planning. During the adaptation planning phase, the Advisory Committee will identify ways that government, businesses, and citizens can adapt their policies and business practices to reduce the impact of sea level rise on our state’s citizens, economy, and natural resources. The final report of the Sea Level Rise Advisory Committee will contain recommendations to help governments, businesses and citizens prepare for sea level rise.
Results of the Sea Level Rise Vulnerability Assessment

Delaware’s sea level rise vulnerability assessment demonstrates that inundation from sea level rise will occur in all three of Delaware’s counties, affecting a range of resources. Although the direct impacts from sea level rise inundation will be felt primarily in areas near tidal waters, every Delawarean is likely to be affected by sea level rise whether through increased costs of maintaining public infrastructure, decreased tax base, loss of recreational opportunities and wildlife habitat, or loss of community character.

Statewide, between 8% and 11% of the state’s land area (including wetlands) could be inundated by a sea level rise of 0.5 meters to 1.5 meters, respectively. Within those potentially inundated areas lie transportation and port infrastructure, historic fishing villages, resort towns, agricultural fields, wastewater treatment facilities and vast stretches of wetlands and wildlife habitat of hemispheric importance.
Executive Summary

Based upon the information in this vulnerability assessment, the Sea Level Rise Advisory Committee ranked each resource according to the potential impacts that could result from sea level rise and their relative statewide importance. Based upon this ranking, 16 resources emerged as being of high concern statewide:

**Beaches and Dunes:** Delaware’s coastline is an important ecological resource—providing habitat for a variety of plants, animals, insects, migratory birds, and a multitude of other terrestrial and aquatic wildlife. Shorelines naturally shift and retreat in response to wind, waves, tides, storms and rising seas. However, natural shoreline processes are interrupted by people’s desire to live and recreate near the shore. Delaware’s 381 miles of shoreline, including 24 miles that front the Atlantic Ocean, provides economic benefits from tourism, coveted high-value space for commercial and residential development, and many forms of recreation, including boating, fishing, and beach-going. When combined with wind-driven waves, sea level rise can exacerbate shoreline erosion that damages dune habitat and leaves infrastructure along the coastline vulnerable to storm damage. Beach replenishment has been the predominant means to offset sand loss and protect structures to which the state has contributed considerable funding. Due to the economic value, natural resource value and significant state investment in sand replenishment, this resource was ranked as a high concern.

**Coastal Impoundments:** Coastal impoundments are vital resources that serve to provide important breeding, migration, and wintering habitat for a variety of birds, serve as nurseries for fish, help to control mosquitoes, and provide important recreational opportunities. Impoundments in each county are at risk from sea level rise. A sea level rise of 0.5 meters would result in the potential inundation of 81% of the state’s acreage of impounded wetlands. Up to 99% of all the state’s acreage of impounded wetlands could be inundated at both 1.0 and 1.5 meters of sea level rise. The impacts will be relatively local; however the areas that are affected show high levels of inundation and complete loss of function. Since the majority of the resource within the state may be affected, this resource was ranked as a high concern.

**Dams, Dikes & Levees:** Between 39% and 78% of the state’s 50 miles of dams, dikes and levees could be inundated by sea level rise by 2100. The highest concentration of potential impact is focused in Kent County, whose dikes primarily protect wildlife areas. The majority of the dikes in New Castle County protect people, property, and, in one case, a contaminated site. These structures were built to provide a certain level of containment or protection. If a breach or structural failure were to occur, the resultant flooding could affect a large area inland of the structure. Due to these considerations, inundation of dams, dikes, and levees in the state was ranked as a high concern.

**Evacuation Routes:** Between 1% and 6% of the state’s evacuation routes are within an area that could be inundated by sea level rise by 2100. Interstates and arterial roads tend to serve as the major evacuation routes for emergencies; substantial reliance on a single mode of transportation for evacuations may endanger many people if the highway infrastructure is made inaccessible because of sea level rise. All three counties experience exposure but the highest concentration is found in Sussex County. Because evacuations rely on automobile transportation and because flooded roadways can prevent or slow evacuation by car, inundation of evacuation routes was ranked as a high concern.
**Freshwater Tidal Wetlands:** Freshwater tidal wetlands occur at the upper reaches of estuaries where the water is no longer salty, but is still influenced by the rise and fall of the ocean tides. These wetlands are home to unique plant and animal communities and are known for their high species diversity. Sea level rise, over time, may introduce salinity to freshwater areas, replacing freshwater tidal marshes with brackish marshes or open water, which in turn will cause major shifts in species composition. For freshwater tidal marshes affected by sea level rise, a wetland system may still exist with increased salinity, but its unique habitat value will be lost. Sea level rise could impact between 84% and 98% of the total freshwater tidal wetland acreage statewide by the year 2100. Because of the unique habitats contained within freshwater tidal wetlands and because the majority of the resource within the state could be affected, this resource was ranked as a high concern.

**Future Development Areas:** Between 3% and 7% of land designated as future development areas by Delaware’s Strategies for State Policies and Spending are within an area that could be inundated by sea level rise by 2100. These areas are typically rural or suburban in nature and are adjacent to the actively growing zones of Delaware’s municipalities. Four-fifths of these potentially inundated areas are located in Sussex County and could be developed to meet the future demand for residential and commercial development in and around the resort areas. Careful consideration must be given to determine whether directing new development to potential inundation areas will place citizens and infrastructure at risk in the future and whether creating new building restrictions will impact citizens’ freedom of choice and the regional economy. Due to the significant potential effects for development in Sussex County coupled with the potential need for state funding of infrastructure repairs and legal concerns, sea level rise within future development areas was ranked as a high concern.

**Habitats of Conservation Concern:** The Delaware Wildlife Action Plan, the framework for conserving the state’s native wildlife, identified 27 Habitats of Conservation Concern (HCC). These habitats are rare, have special significance in Delaware, are particularly sensitive to disturbance, and/or have a high diversity of rare plants. Of these 27 unique habitat types, 15 were determined to be vulnerable to sea level rise and were analyzed to determine the extent of possible exposure. Between 55% and 65% of the total acreage of the 15 HCCs analyzed could be inundated by sea level rise by 2100. Because these exceptional habitat types often harbor rare plant and animal species and are sensitive to environmental stresses, including sea level rise, this resource was ranked as a high concern.

A driver navigates across a flooded road during a nor’easter in October 2009.
Executive Summary

Heavy Industrial Areas: Between 16% and 25% of the acreage of heavy industrial lands in the coastal area (as permitted by Delaware’s Coastal Zone Act) are within an area that could be inundated by sea level rise by 2100; the majority of these areas are in New Castle County. While the inundation model shows that inundation risk to the facility buildings themselves is low, many associated structures like docks, piers, and lagoons could be affected. Because these facilities are a large economic driver for the state, reduced operational capacity could impact both the economies of the towns surrounding these facilities and the state’s economy as a whole. If the lands currently zoned for heavy industry become unsuitable for industrial operations, retaining these businesses within the state could prove difficult due to lack of suitable industrially zoned land and the difficulties of rezoning land to industrial uses. Due to the significant potential statewide effects resulting from sea level rise, heavy industrial areas were ranked as a high concern.

Port of Wilmington: Between 36% and 73% of the Port of Wilmington’s property is within an area that could be inundated by sea level rise by 2100. The port is based in northern New Castle County; however, the economic value to Delaware and the entire Northeast Region makes exposure to sea level rise a state and regional issue. Due to these considerations, inundation of the Port of Wilmington was ranked as a high concern.

Protected Lands Statewide: Protected lands encompass a variety of lands owned by state, local and municipal governments, conservation groups and individuals. These lands include state wildlife areas, state parks, state forests, boat ramps, nature preserves, historical sites, national wildlife refuges, municipal parks, open space, and recreational facilities and public and private conservation easements. Collectively, these properties represent a variety of habitat types and extensive opportunities for outdoor recreation. Statewide, between 37% and 44% of protected lands statewide are exposed to sea level rise under the three scenarios. Because these lands represent a significant investment to protect natural habitats and recreational use and because sea level rise could impact their intended use, protected lands were ranked as a high concern.

Roads & Bridges: Between 1% and 5% of the state’s roads and bridges are within an area that could be inundated by sea level rise by 2100. Inundation of an individual segment of road could cause regional transportation disruptions, particularly if no alternative routes are available. The highest concentration of roadway exposure to sea level rise was found in Sussex County; however, potential exposure was found throughout the state. Due to the potential regional impacts, inundation of roads and bridges from sea level rise was ranked as a high concern.

Railroad Lines: Between 2% and 6% of the state’s railroad lines are within an area that could be inundated by sea level rise by 2100. The highest concentration of impact is focused in New Castle County. Even with smaller amounts of exposure in Kent and Sussex Counties, it should be noted that if a single rail line segment becomes inundated, the entire functionality of the line could be lost. This may impact industries served by rail such as power plants and the Delaware City refinery. Passenger travel is also a concern; disruptions and possible restrictions to the Amtrak rail line could impact travel throughout the northeast corridor. Because disruption of rail service in Delaware could have impacts throughout the state and region, inundation of railroad lines as a result of sea level rise was ranked as a high concern.
Tidal Wetlands: Tidal wetlands are among the most productive ecosystems in the world and provide habitat, food and breeding grounds for many species of plants and animals. Delaware’s tidal wetlands are an intricate part of the local, regional, national, and international ecosystems. Tidal wetlands act as sponges by soaking up floodwaters and buffering storm impacts and also act as filters by trapping sediments and removing contaminants. The potential impacts to tidal wetlands as a result of sea level rise are striking in their extensiveness, affecting the vast majority of tidal wetlands in all three counties. The exposure assessment found that 97% of the state’s tidal wetlands may be impacted at the 0.5 meter scenario, and 99% at both the 1.0 and 1.5 meter scenarios. Since the majority of the resource within the state may be affected, impacts to tidal wetlands as a result of sea level rise was ranked as a high concern.

Tourism and Coastal Recreation: Tourism and coastal recreation are important components of Delaware’s economy and quality of life. Significant portions of Delaware’s resort areas, coastal historic sites, and natural resources could be inundated or significantly altered by sea level rise. Of specific concern is the maintenance of Delaware’s beaches, which are currently replenished on a routine basis with federal and state funding. Accelerated rates of sea level rise may necessitate larger or more frequent beach replenishment projects to preserve recreational beach uses. Due to the potential for revenue losses statewide, coupled with the potential increased funding needs for maintenance or repair of tourist destinations, sea level rise impacts to tourism and coastal recreation was ranked as a high concern.

U.S. Fish and Wildlife Service Refuges: Prime Hook National Wildlife Refuge (NWR) is located in Sussex County near the town of Milton. Bombay Hook NWR is located in Kent County near the towns of Smyrna and Dover. Area residents and tourists use the refuges for passive outdoor recreation activities such as birding, wildlife watching, and photography, as well as for hunting and fishing. Refuge wetlands provide habitat for overwintering and migrating waterfowl and shorebirds, wading birds, secretive marsh birds and wetland passerines. Reduction or loss of wetland habitats within the protected boundaries of the refuges can impact populations of these species. Species may be forced to redistribute if refuge wetlands no longer meet their needs, and may relocate in wetlands that are not afforded the same protection and management that is provided by the NWR designation. Between 85% and 95% of refuge acreage could be inundated under the three scenarios. While the impacts are localized, the acreage affected (21,354 to 24,120 acres) represents a significant loss of protected habitat and was ranked as a high concern.

Wells: Residents and businesses in Kent and Sussex Counties rely on groundwater resources for drinking, irrigation and industrial purposes. Operation of wells that extract groundwater can be compromised by inundation from sea level rise, and the quality of groundwater can be compromised by saltwater intrusion resulting from sea level rise. Statewide, between 3% and 7% of domestic wells, 3% and 7% of industrial wells, 1% and 2% of irrigation wells, and 2% and 10% of public wells are within an area that could be inundated by sea level rise by 2100. Potential exposure of wells to sea level rise is focused along the coast; however, reduction in availability of groundwater in the coastal areas may increase demand on inland public wells. Because access to clean water is a necessity and because demand on inland wells may increase, sea level rise impacts to wells was ranked as a high concern.

The Sea Level Rise Advisory Committee will use the results of the Vulnerability Assessment to inform and focus efforts during the next phase of their work, the development of adaptation options.
Executive Summary

Use of this Document

This document and its appendices provides an exhaustive accounting of resources vulnerable to sea level rise of up to 1.5 meters in Delaware. It includes background information, a description of the process used to assess vulnerability, exposure assessment tables, and risk assessments for 79 resources. A comprehensive set of vulnerability maps and information on how to use them is also included as the Mapping Appendix. The vulnerabilities and risk assessment described in this document should be considered as a starting point for more detailed localized or resource-based assessments and as a starting point for prioritizing adaptation strategies.

This document is the first of its kind to provide detailed estimates of numbers or acres of resources at risk from sea level rise at a state level. It represents a significant accomplishment and positions the state well to develop and implement specific adaptation strategies for resources most important to Delaware’s continued sense of community, economic well-being, and natural resource diversity.

Homes and wildlife habitat at Broadkill Beach, along the Delaware Bay.
Introduction
Introduction

Delaware’s Sea Level Rise Advisory Committee

Delaware’s Sea Level Rise Advisory Committee was formed to help the state plan for sea level rise, a coastal issue that could affect a wide range of quality of life and economic issues from infrastructure sustainability to crop yields to wildlife habitat. The committee was established by invitation of Collin O’Mara, Secretary of the Department of Natural Resources and Environmental Control (DNREC), to investigate Delaware’s vulnerability to sea level rise and to provide recommendations about how to best prepare for higher sea levels. The committee is composed of members from a wide variety of interest groups including state agencies, local governments, citizen organizations, business organizations, and environmental organizations.

The Sea Level Rise Advisory Committee held their inaugural meeting in November 2010 and has met thirteen times between November 2010 and May 2012. Three workgroups were formed in February 2011 to allow in-depth discussions of priority sea level rise issues: Natural Resources; Society & Economy and Public Safety and Infrastructure.

The committee’s work was split into two phases, a Vulnerability Assessment Phase and an Adaptation Planning Phase. This document is the culmination of the Vulnerability Assessment Phase, during which the committee provided expert opinions to analyze and assess potential impacts of sea level rise to 79 statewide resources, from roads to wetlands to tourism. The vulnerability assessment will be used as the basis for the next phase, adaptation. During the Adaptation Planning Phase, the Advisory Committee will identify ways that government, businesses, and citizens can adapt their policies and business practices to reduce the impact of sea level rise on our state’s citizens, economy, and natural resources. The final report of the Sea Level Rise Advisory Committee will contain recommendations to help governments, businesses and citizens prepare for sea level rise.

It is the intent of the Sea Level Rise Advisory Committee to provide information and guidance to help people make informed decisions when considering activities and investments in areas that may be at risk from the effects of sea level rise; it will not oversee implementation of adaptation measures. Any recommended adaptation action that would require a change in legislation or regulations will go through the normal legislative and public processes.

Sea Level Rise Advisory Committee Member Agencies

| Delaware Association of Realtors | Delaware Office of the Governor |
| Delaware Department of Agriculture | Delaware Office of Management and Budget |
| Delaware Department of Health and Social Services | Delaware State Chamber of Commerce |
| Delaware Department of Natural Resources and Environmental Control | Home Builders Association of Delaware |
| Delaware Department of Safety and Homeland Security | Kent County |
| Delaware Department of Transportation | League of Women Voters of Delaware |
| Delaware Economic Development Office | New Castle County |
| Delaware Farm Bureau | Positive Growth Alliance |
| Delaware Insurance Commissioner’s Office | Sussex County |
| Delaware League of Local Governments | The Nature Conservancy |
| Delaware Legislature | Tidewater Utilities, Inc. |
| Delaware Nature Society | University of Delaware |
Planning for Sea Level Rise

Delaware is a coastal state; its economy and quality of life have historically been linked to its shores, its vast expanses of protected tidal wetlands, and its fertile farm fields. Because of its location, low average elevation, and dependence on the coast, Delaware is particularly vulnerable to the effects of rising sea levels including loss of low-lying land and structures; saltwater intrusion into ground and surface waters; and increased coastal flooding from storm events.

Today, sea level rise is rarely, if ever, considered by governments, organizations, and individuals as they make decisions about where to develop, how to build, or what to preserve. However, changes in sea levels could impact the longevity, safety, and return-on-investment of projects that have long planning horizons or long life-spans. Accounting for changes in sea level that may be expected to occur over the lifetime of these projects will help lead to informed decisions for public and private investments by minimizing risk and potential for damage. For example, expensive retrofits or replacements of roads and buildings could be avoided by building structures that are specifically designed to withstand a certain rise in sea level. Funding and resources for shoreline stabilization, wetland restoration, and infrastructure improvements could be planned and in-place before emergency measures are necessary. Thoughtful, proactive planning for sea level rise may help Delaware’s economy and natural resources continue to flourish even with the new long-term challenges sea level rise brings.

Planning for the long-term effects of sea level rise may also help the state better prepare in the short-term for periodic flooding from coastal storms. Storm surges of between two and four feet frequently occur along the Delaware Bay and Atlantic coast from tropical storms and nor’easters. Delaware’s largest storm on record, a nor’easter that occurred in 1962, caused a storm surge of 4.5 feet (1.4 meters) in Lewes; a nor’easter that occurred on Mother’s Day in 2008 produced a storm surge of 4.0 feet (1.2 meters) in Bowers Beach. These storm surges are comparable to the sea level rise expected by 2100; any actions taken to reduce the effects of sea level rise in the future will also have the added benefit of increased protection from storm surge flooding now.

The goal of the Sea Level Rise Advisory Committee is to assess Delaware’s vulnerability to current and future inundation problems that may be exacerbated by sea level rise and to develop a set of recommendations for state agencies, local governments, businesses, and citizens to enable them to adapt programs, policies, business practices and make informed decisions.
Introduction

Effects of Sea Level Rise

Sea level rise is just one of the factors that contribute to changes in the coastal landscape over time. Other factors such as storms, erosion, and sediment accretion act in concert with changes in sea level to shape the size and makeup of our sandy shorelines, wetlands, and river channels. However, as the rates of sea level rise accelerate, sea level rise may increasingly become the driving force in coastal changes. Accelerated rates of sea level rise could cause inundation of low-lying land, saltwater intrusion into groundwater and streams, and increased extent and severity of storm flooding.

Inundation of low-lying land and structures can occur when the sea level rises faster than natural forces can build up land or where shoreline protection structures are not constructed. This can cause dry land to become flooded and can cause wetlands to convert into open water (CCSP, 2009). Structures, including homes, roads, and utilities that have been built in low-lying areas can become difficult to access, suffer structural instability or become unusable. This vulnerability assessment focuses primarily on these inundation effects in Delaware.

Saltwater intrusion of groundwater and streams can also occur as sea levels increase. In rivers and streams, sea level rise may cause the "salt line" to move inland, changing the types of vegetation in and around the stream, and impacting the quality of fish spawning areas. It also may affect intake structures for drinking water and industry. In certain areas, water from the ocean and bay may turn groundwater supplies salty, affecting water used for drinking and irrigation (United States Environmental Protection Agency & Delaware River Basin Commission, 1986). The data and information necessary to assess the potential for saltwater intrusion issues from sea level rise in Delaware is not currently available, however, throughout this document, potential impacts are discussed, and data gaps are highlighted.

Salt Line

The salt line is the location where a stream or river is no longer considered to be salty (contains less than 250 milligrams per liter of chloride). The salt line fluctuates each year depending upon tidal inputs and freshwater inflows from rain and dam releases. In the Delaware River, the salt line is currently a mile south of the Delaware Memorial Bridge, but has reached as far as 2 miles north of the Ben Franklin Bridge in Philadelphia in severe drought years.
As sea level rises, flooding from coastal storm events may become more widespread. As sea levels increase, so do the storm surge heights generated by a given storm. An increased storm surge height, combined with resulting coastal erosion and loss of tidal wetlands that provide natural flood protection may result in increased flood depths in already flood-prone areas. It may also cause flooding in areas further inland that have not previously been flood-prone. Flooding from storm surges can cut off evacuation routes and cause significant damage to homes and infrastructure.

While increased storm surge heights and flooding is a very important consideration for understanding the potential range of effects caused by sea level rise, modeling specific storm surge impacts statewide is a complicated and resource-intense undertaking that was outside of the scope of this assessment. However, the general effects of increased storm surge heights with regard to resources of concern are discussed throughout this document.

Figure 1 maps shoreline retreat in the Bombay Hook area of Delaware Bay. This map demonstrates historic shoreline loss along the shoreline of Bombay Hook Delaware and was constructed using shoreline maps for 1883 and 1969 published by the National Ocean Service, and a digitized shoreline from a US Geological Survey aerial photograph taken in 2007. Rates of shoreline retreat at this location between 1883 to 2007 range from 2 to 5 meters per year. Between 1969 and 2007, the rate was 5 to 10 meters per year, among the highest rate for the wetland coast of Delaware Bay. A combination of storm-wave erosion and relative sea level rise are responsible for landward migration of the shoreline over time (CCSP, 2009).

---

1Storm surge is an abnormal rise of water generated by a storm. A useful description of storm surge can be found on NOAA's website http://www.nhc.noaa.gov/surge/
Introduction

Rates and Causes of Sea Level Rise

Sea level trends are recorded by tide stations, which measure the height of water referenced to a stable point on land with a known elevation (benchmark). Tide stations are primarily installed for navigational purposes and their data are used to make tide predictions. Long term data sets from these tide stations have also been used to understand local and global sea level trends (IPCC, 2001). Globally, sea level rises for two primary reasons: expansion of saltwater as it warms and loss of ice on land. As the ocean absorbs solar radiation in excess of what it emits, the water warms. When water warms, it expands and causes the average level of the water to rise. In addition, as the Earth becomes warmer, land-based glaciers and ice-caps melt and slide into the sea. This melt-water and ice empties into oceans and causes the average level of the water to rise. In combination, these two forces constitute the eustatic (or global) rate of sea level rise. The eustatic sea level rate during the twentieth century, as determined by tide gauge measurements, was about 0.07 inches per year (or about 7 inches over 100 years) (IPCC, 2001).

Tide gauges indicate that the change in the local mean sea level (LMSL) in Delaware is greater than the eustatic sea level rate. The rate of change recorded at the tide gauge in Lewes is 0.13 inches per year (or 13 inches over 100 years), as compared to eustatic rate of 0.07 inches per year. This difference is due to the vertical movement of the Earth’s crust, which is causing the land in Delaware to slowly sink. Tide gauges record this combined motion of the land and the sea. Figure 2 shows the local mean sea level trend from the tide gage at Lewes from 1919 to 2011. Other tide gauges throughout the Mid-Atlantic show similar trends.

While it cannot be proven with certainty, climatologists have predicted that the rate of sea level rise occurring today will likely become greater in the decades to come (IPCC, 2001) The extent of the increase will depend on a number of factors including future emissions of greenhouse gases (especially carbon dioxide), the rate at which the temperature of the ocean increases and the rate at which ice is lost from land-based glaciers.

![Figure 2 - Mean Sea Level Trend - Lewes, DE (NOAA, 2012)](image)

2The eustatic sea level rate is a technical term for the worldwide change of sea level elevation with time

3Local Mean Sea Level (LMSL) is a term that describes the height of the ocean relative to land, measured hourly by a tide gauge and averaged over a nineteen year period known as the National Tidal Datum Epoch.
Future Rates of Sea Level Rise

In 2009, the DNREC formed a Sea Level Rise Technical Workgroup to provide the Department with planning scenarios for sea level rise to the year 2100. This workgroup, composed of scientists from the University of Delaware, Delaware Geological Survey, Center for the Inland Bays, Partnership for the Delaware Estuary and DNREC, reviewed historical data for local sea level rise and reviewed the findings of international and national sea level rise expert panels. Based on this information, the Sea Level Rise Technical Workgroup recommended three planning scenarios for sea level rise to 2100. The conclusions of the workgroup were then reviewed by national experts\(^5\) and used by DNREC in the development of an internal policy that directed it to plan for sea level rise (DNREC Sea Level Rise Technical Workgroup, 2009).

The Technical Workgroup chose to recommend a range of scenarios to DNREC because it is not possible to precisely predict future rates of sea level rise (DNREC Sea Level Rise Technical Workgroup, 2009). The three scenarios can be used as a planning tool to determine a range of potential outcomes and options. The Technical Workgroup’s low scenario was a sea level rise of 0.5 meters (1.6 feet) between now and the year 2100. This scenario is slightly higher than the current rate of sea level rise in Delaware and is partially based on low estimates for future global warming. The high scenario was a sea level rise of 1.5 meters (4.9 feet) between now and the year 2100. This scenario is based on higher estimates of future global warming. The intermediate scenario was 1.0 meter (3.3 feet) between now and the year 2100, and is based on moderate estimates of future global warming. Figure 3 contains a graph of the three scenarios, which can be used to estimate a range of sea level rise scenarios between now and 2100. The upward curvature of the lines indicates that the rates increase with time. The straight, or “stable,” line is included for reference; it shows the sea level that would occur if today’s rate of sea level rise continued into the future, rather than accelerating.

These three scenarios were provided to the Sea Level Rise Advisory Committee by DNREC and have been used throughout the vulnerability assessment to understand the potential range of impacts that sea level rise may have for the state. Evaluation and endorsement of these recommended sea level rise scenarios was outside of the purview of the Advisory Committee.

It is important to note that scientists are continually working to increase their knowledge about sea level rise and to provide better predictions of future sea levels. As new data and information become available, the planning scenarios (and associated maps) will be revised in order to reevaluate potential impacts.

\(^4\)Tide gauge information is available from the National Oceanic and Atmospheric Administration: http://tidesandcurrents.noaa.gov/sltrends/sltrends.shtml.

\(^5\)The scenarios were reviewed by S. Jeffress Williams, Coastal Marine Geologist at the US Geological Survey Woods Hole Science Center and Jim Titus, US Environmental Protection Agency.
Introduction

Visualizing Sea Level Rise

It is difficult to reliably model how shorelines and coastal areas will change and reshape due to the combined forces of accelerated rates of sea level rise, coastal erosion, storm surges and human activities (dredging, shoreline protection), particularly at a statewide scale. However, bathtub inundation models, which assume a static shoreline, can be useful in identifying low-lying coastal areas that could be subject to inundation in the future.

Using high resolution elevation data, a bathtub model of the state was created. The bathtub model floods all land below a certain elevation, unless there is a structure that would block tidal flow (like dikes and dams). Based upon this model, a series of maps was developed to show what the recommended sea level rise scenarios would look like on the ground at mean higher-high water (see text box). Maps were created for mean higher-high water (MHHW), MHHW + 0.5 meters, MHHW + 1.0 meter and MHHW + 1.5 meters.

Mean Higher High Water (MHHW)

These sea level rise scenario maps depict potential future sea levels at mean higher-high water; a term that describes an average height of water at high tide. In Delaware, there are two high tides per day. Of those, one rises slightly higher than the other (the same is true of low tides). Mean higher-high water is calculated by taking the average of the higher of the two high tides each day, observed over a nineteen year period (the National Tidal Datum Epoch).

The maps are available online as an interactive viewer at http://de.gov/slrmap.aspx. A complete description of the process used to develop the maps is available in the Mapping Appendix document.

There are many other terms used to describe water levels at various tides (e.g. mean high tide, ordinary high water mark); in this document any time the term “high tide” is used, it is referring to mean higher-high water.

These maps show the level of high tide in Bowers Beach, Delaware under three different planning scenarios, which were developed using local data coupled with scenarios generated by several federal agencies.
A useful reference that briefly describes water level recording devices and tidal datums is available online from the Southeast Atlantic Coastal and Ocean Observing System (SEACOOS): http://seacoos.org/Data\%20Access\%20and\%20Mapping/water_level_product_desc

Figure 4 - Differences in high tide heights.

Bowers Beach at high tide with 3.3 feet of sea level rise
Bowers Beach at high tide with 4.9 feet of sea level rise

*A useful reference that briefly describes water level recording devices and tidal datums is available online from the Southeast Atlantic Coastal and Ocean Observing System (SEACOOS): http://seacoos.org/Data%20Access%20and%20Mapping/water_level_product_desc*
Vulnerability Assessment Methods
Vulnerability Assessment Methods

Vulnerability assessments are conducted as a way to understand the effects of a hazardous event, whether the event is an attack by a computer hacker, a tornado or in this case – sea level rise. Vulnerability assessments identify locations and extent of impacts and often prioritize the importance of these impacts. This process can then lead to changes that may limit the negative effects should the event occur.

Completion of a statewide vulnerability assessment for sea level rise was the first major task of the Sea Level Rise Advisory Committee and represents a significant achievement. Delaware is the first state to comprehensively assess specific resource vulnerability to sea level rise at a statewide level. This document provides detailed information about what resources will be impacted, where those impacts will occur and what the likely secondary social, environmental, and economic effects will be. Because the vulnerability assessment has a very large scope and covers a large geographic area, it should be considered a screening tool for determining the need for more detailed vulnerability assessments and for development of sea level rise adaptation strategies.

The Vulnerability Assessment was developed in five stages, described in detail below:

1. Identification of Resources of Concern
2. Data Collection
3. Exposure Assessment
4. Impact Assessment
5. Risk Assessment

Additionally, a series of Public Engagement Sessions was held to inform the public of the Committee's activity and as a cross-check on the issues.

Identification of Resources of Concern

Each workgroup met several times to identify issues that would result from sea level rise and to identify specific resources of concern to them. The definition of resource in this case is broad, including items from historic sites to industrially zoned land to roads to special wildlife habitats. As a result of these discussions, the three workgroups identified 140 resources that could be mapped and quantified for use in the vulnerability assessment.

House raised above coastal flood zone in Slaughter Beach, Delaware.
Data Collection

In order to conduct an in-depth vulnerability assessment, geographic datasets are necessary. Geographic datasets are a special type of dataset that contains information so that it can be placed on a map. Delaware Coastal Programs staff spent considerable time and effort compiling geographic datasets that could be utilized with the sea level rise scenario maps to determine the location and numbers of resources at risk from sea level rise. Datasets like roads, railways and public safety facilities were relatively easy to obtain as they are maintained and routinely updated by a state or county agency. Many datasets were out of date or lacked appropriate documentation as to when the data was collected or how it was collected (metadata). A few datasets were unable to be used for this assessment due to privacy or homeland security concerns (electrical substations for example). In many other cases, the desired data did not exist or was so out of date that it could not be used.

Of 140 datasets identified as necessary to understand impacts to resources, 79 were obtained and analyzed as a part of this vulnerability assessment. In all cases, existing data was used for this assessment. Creating, improving or updating geographic datasets generated by disparate entities was outside of the scope of this assessment. However, throughout this document, all data sources are cited and any issues with the data are explained. Additional information about this is available in the Mapping Appendix.

Exposure Assessment

After the data was collected, an exposure assessment for each resource was conducted using ArcGIS. Locations of resources of concern were “overlaid” with the three sea level rise scenarios; any resource within the sea level rise scenarios was counted as “exposed.” Figure 4 shows how this was done using storage tanks as an example. The pink dots represent locations of storage tanks; the yellow areas indicate areas that could be inundated at the 1.0 meter sea level rise scenario. Any pink dot within the yellow area would be counted as exposed at 1.0 meter. Results are reported in an Exposure Table and summarized for each scenario and for each county (see Table 2 and text box description of how to use the exposure tables below). Maps were also developed for each resource that depict the geographic extent of inundation under each scenario at a statewide level (see Mapping Appendix for complete description of how statewide maps were developed and how to interpret them).

The exposure tables and maps are an indication of the extent and severity of inundation for a specific resource. However, a resource that is “exposed” to sea level rise may or may not be impacted. The impact of this exposure depends upon a number of factors including whether a building is elevated or flood-proofed; the type of materials utilized in construction; or use of protective structures. For example, a home that is within a mapped sea level rise area (and therefore “exposed”) but is raised on pilings may not suffer any structural damage from increased water levels. Conversely, there are also instances where resources may be affected but are not included in the exposure table. For example, structures which are not inundated but are surrounded by inundation areas become “islands” and may no longer function as intended because of access issues.

Figure 5 - Storage tanks exposed to inundation.
**Vulnerability Assessment Methods**

**Impact Assessment**

Using the information obtained in the exposure assessment, committee members provided input about the potential direct impacts that could result from the inundation of resources as well as the secondary economic, environmental, and social impacts that could result.

**Direct impacts include**
- Loss of land and wetlands from inundation
- Loss of buildings and infrastructure from inundation
- Decreased usability of structures due to flooded access roads and supporting infrastructure
- Increased structural damage from repetitive storm damages

**Secondary impacts include**
- Loss of jobs and revenue streams
- Loss of community or sense of place
- Contaminant releases from industrial sites or storage tanks
- Loss of habitat from increased erosion
- Increased need for government services or intervention

Because this assessment was conducted at a statewide scale, all “exposed” resources were assumed to be impacted. Vulnerability assessments can be conducted in the future that focus in on a geographic area or specific resource; limiting the scope of a vulnerability assessment allows for more site specific conditions to be considered. This statewide vulnerability assessment should be considered a screening tool to determine where more focused studies should be conducted.

Information for each resource compiled in a standardized format and reviewed by workgroup members and Delaware Coastal Programs staff. The individual assessments (including exposure tables) are included in the remaining chapters of this document.

**Public Engagement**

A series of five public engagement sessions was held in November 2011 to share preliminary results of the exposure and impact assessments with Delawareans and to obtain feedback about the findings and work of the committee. Additional information about public engagement strategies can be found in Appendix E.
Risk Assessment

The final step of the vulnerability assessment was a risk assessment exercise that considered the combined consequences of the sea level rise exposure and impacts documented for each resource. Using standardized questions, workgroups ranked each resource according to the statewide magnitude of potential impacts. The magnitude of impact was determined using three primary factors: the geographic scope of exposure, the geographic scope of impacts and the functionality of the resource.

In considering geographic scope of exposure, the workgroups used the vulnerability assessment maps to determine where inundation would occur. For geographic scope of impacts, the workgroups considered where direct or secondary impacts would occur. Would impacts be felt by citizens statewide, or in a limited area? Would exposure cause economic impacts to one neighborhood, or would it cause impacts statewide? For example, although the exposure of heavy industrial areas was limited primarily to New Castle County, the economic impacts of exposure could be felt statewide through loss of job opportunities and revenues.

In considering functionality, the workgroups determined whether a resource could continue to meet its intended purpose when exposed to sea level rise. For example, an evacuation route functions to allow safe travel in emergency situations; a manufacturing facility functions to produce goods and provide jobs; a wetland functions to provide wildlife habitat and to attenuate storm flooding.

As a result of this discussion, each resource was ranked as a High, Moderate, Low, or Minimal Concern. In general, resources of high concern are those that if inundated, no longer meet their intended use and this loss of function would have statewide implications. Resources of low concern are those that, if inundated, would likely continue to function with modifications and whose impacts are generally of localized concern. Resources ranked as a high and moderate concern will likely become the starting point for adaptation strategy development in Delaware.

This risk assessment was subjective in nature; workgroup members used the information available to them to make a reasonable assessment of the risk to the state for inundation of each resource. The risk assessment will inform Phase II (adaptation) of the SLRAC’s work. Adaptation strategies for many of the resources ranked as high and moderate concern will be discussed and developed, however, that does not preclude the development of strategies for resources that were ranked as lower concern at this time.

Table 1 - Risk Assessment Scores, Basis and Recommended Action

<table>
<thead>
<tr>
<th>Score</th>
<th>Impact</th>
<th>Geographic Scope</th>
<th>Recommended Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Concern</td>
<td>Resource does not function or meet its intended use</td>
<td>And/or Statewide</td>
<td>Develop adaptation strategies</td>
</tr>
<tr>
<td>Moderate Concern</td>
<td>Major loss of function or some failure of intended use</td>
<td>And/or County-level</td>
<td>Evaluate further and develop adaptation strategies if necessary</td>
</tr>
<tr>
<td>Low Concern</td>
<td>Resource functions with modifications</td>
<td>And/or Localized</td>
<td>Monitor and re-asses in future years</td>
</tr>
<tr>
<td>Minimal Concern</td>
<td>minor or no impact to function</td>
<td>And/or Isolated</td>
<td>Re-asses in future years</td>
</tr>
</tbody>
</table>
Vulnerability Assessment Findings
Vulnerability Assessment Findings

This vulnerability assessment demonstrates that inundation from sea level rise will occur in all three of Delaware's counties, affecting a range of resources. Although the direct impacts from sea level rise inundation will be felt in areas near tidal waters, every Delaworean is likely to be affected whether through increased costs of maintaining public infrastructure, decreased tax base, loss of recreational opportunities, or loss of community character.

Table 2 - Total Acreage of Uplands and Wetlands Exposed to Sea Level Rise

<table>
<thead>
<tr>
<th>Count</th>
<th>Total Acres</th>
<th>Acres Inundated by SLR Scenarios</th>
<th>Percent of Total Inundated by SLR Scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0.5 m</td>
<td>1.0 m</td>
</tr>
<tr>
<td>State</td>
<td>1,385,495</td>
<td>110,497</td>
<td>133,531</td>
</tr>
<tr>
<td>New Castle</td>
<td>278,754</td>
<td>25,179</td>
<td>29,916</td>
</tr>
<tr>
<td>Kent</td>
<td>510,428</td>
<td>50,095</td>
<td>57,784</td>
</tr>
<tr>
<td>Sussex</td>
<td>596,314</td>
<td>35,223</td>
<td>45,831</td>
</tr>
</tbody>
</table>

Source: USGS and Delaware Geologic Survey, State Outline (Area), 2007-04-01

Statewide, between 8% and 11% of the state's land area (including wetlands) could be inundated by sea level rise of 0.5 to 1.5 meters. Table 2 shows potential inundation by acreage and percent of land area for the state as a whole and for each county. The county with the lowest percentage of land area at risk is Sussex County, where between 6% and 9% of the land area could be inundated by sea level rise. This may be a surprising result to many, and emphasizes the statewide nature of the sea level rise issue.

The nature of resources at risk varies between counties. The vast majority of the land area that could be inundated within Kent County is tidal wetlands, although the surrounding uplands and communities would also be affected. Wetlands are also affected in southern New Castle County, but in the northern parts of the County, several urban residential and commercial areas are at risk, as are transportation corridors, including the Port of Wilmington. In Sussex County, low lying resort communities along the Atlantic Ocean, Delaware Bay, and Inland Bays are within potential inundation areas, as are tidal wetlands in the Inland Bays and Delaware Bay areas.

How to Use the Exposure Tables

Exposure tables are provided throughout this document to help the reader understand the number or acreage of a resource that could be inundated by 0.5, 1.0 or 1.5 meters of sea level rise and to help the reader understand where those potential impacts occur. Maps are also provided in the Mapping Appendix to assist the reader to visualize the geographic extent of potential inundation.

The “Total Acres” column in Table 2 represents that total area of the state or county. The “Acres Inundated” columns report the number of acres of land that fall within the three sea level rise scenarios. These numbers are reported cumulatively. For example, 151,528 acres of land statewide would be inundated at 1.5 meters of sea level rise; this includes the 133,531 acres of land inundated at 1.0 meter.

The Percent of Total Inundated columns provide an additional way to understand the extent of inundation. The percent is calculated by dividing the Acres Inundated by the Total Acres. Because the Acres Inundated column is reported cumulatively, the Percent Inundated column is also cumulative.
Results of Resource Risk Assessment

As outlined above, the SLRAC workgroups conducted an exercise to determine the relative level of concern for impacts to each resource assessed. The results are below and are detailed further in the following chapters.

High Concern - A high concern resource is generally a resource where inundation would cause it to no longer function as designed and/or could cause impacts statewide, whether directly to the resource itself or indirectly through disruptions in jobs or revenue streams. Additional research and development of adaptation strategies for high concern resources is strongly recommended.

The following resources were ranked as high concern by SLRAC workgroups:

<table>
<thead>
<tr>
<th>Heavy Industrial Areas</th>
<th>US Fish &amp; Wildlife Property</th>
<th>Port of Wilmington</th>
</tr>
</thead>
<tbody>
<tr>
<td>Future Development Areas</td>
<td>Railroad Lines</td>
<td>Tourism and Coastal Recreation</td>
</tr>
<tr>
<td>Roads and Bridges</td>
<td>Tidal and Freshwater Tidal Wetlands</td>
<td>Beaches and Dunes</td>
</tr>
<tr>
<td>Evacuation Routes</td>
<td>Coastal Impoundments</td>
<td>Dams, Dikes &amp; Levees</td>
</tr>
<tr>
<td>Habitats of Conservation Concern</td>
<td>Wells</td>
<td>Protected Lands Statewide</td>
</tr>
</tbody>
</table>

Moderate Concern - A moderate concern resource is generally one in which there is some impact or loss of function and/or the geographic extent of the impact is less than statewide. Further evaluation and development of adaptation strategies for moderate concern resources is recommended.

The following resources were ranked as moderate concern by SLRAC workgroups:

<table>
<thead>
<tr>
<th>Residential Areas</th>
<th>Landfills, Nature Preserves</th>
<th>Septic Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricultural Land Conservation Easements</td>
<td>Wastewater Facilities</td>
<td></td>
</tr>
</tbody>
</table>

Low Concern - A low concern resource is generally one in which the impacts to the resource itself would not be significant or the impact would be isolated to several small geographic regions. A ranking of low concern does not necessarily mean that a resource is not important or that impacts from sea level rise will not be felt, rather that the impacts would not be of statewide concern. Low concern resources should be monitored and reassessed in subsequent planning activities.

<table>
<thead>
<tr>
<th>Businesses and Commercial Areas</th>
<th>Brownfield Sites</th>
<th>Agriculture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salvage Yards</td>
<td>Historic and Cultural Resources</td>
<td>Underground Storage Tank Sites</td>
</tr>
<tr>
<td>Factories</td>
<td>Contaminated Sites</td>
<td>Non-tidal Wetlands</td>
</tr>
<tr>
<td>Commodity Pipelines</td>
<td>Highly Productive Agricultural Soils</td>
<td>Agricultural Land Preservation Districts</td>
</tr>
</tbody>
</table>

Minimal Concern - A resource of minimal concern is generally one in which the geographic scope is isolated and/or would have minor to no loss of function. Minimal concern resources should be reassessed in subsequent planning activities.

<table>
<thead>
<tr>
<th>Upland Forest</th>
<th>Bus Routes and Bus Stops</th>
<th>Adult and Child Care Facilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergency Services</td>
<td>Cemeteries</td>
<td>Navigation Aids</td>
</tr>
<tr>
<td>Schools</td>
<td>Boat Ramps and Piers</td>
<td>Leaking Underground Storage Tank Sites</td>
</tr>
</tbody>
</table>

No Exposure - The following resources were analyzed and were found to have no exposure to sea level rise of up to 1.5 meters.

<table>
<thead>
<tr>
<th>Correctional Facilities</th>
<th>Public Safety Access Points</th>
<th>Airports</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell Towers</td>
<td>Hospitals</td>
<td></td>
</tr>
</tbody>
</table>