Natural Resources

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Assessing Exposure of Natural Resources

The Natural Resources Workgroup was composed of members of the Sea Level Rise Advisory Committee and additional subject matter experts. A list of those who participated in this workgroup is available in Appendix C. The workgroup met six times between February 2011 and March 2012 to identify, assess, and rank issues related to environmental impacts from sea level rise.

Resources Considered

Specific resources that the Natural Resources Workgroup was concerned with included:

- Water resources (such as salinity changes and groundwater effects)
- Wetlands
- Beaches and dunes
- Upland forest
- Flora and fauna
- Protected lands
- Agricultural resources such as soils and protected lands

Assessing Exposure

As described in the introductory section, Delaware Coastal Programs staff worked with Workgroup and Committee members to collect data and information about each resource that the workgroup wished to assess. Based upon available data, tables were generated in ArcGIS that described the exposure of each resource to sea level rise under each of the three scenarios. Maps depicting location and density of this exposure were also generated in ArcGIS. Workgroup members filled out resource assessment templates based upon their own expertise and in collaboration with their colleagues. All of this information was compiled together into a comprehensive assessment for each resource, which were reviewed and edited by workgroup members. Full text of each one of these assessments follows.

Data and Information Gaps

This vulnerability assessment relied on existing data and information to complete a state level screening of resources at risk to sea level rise. In some cases, data and information that would have provided a better picture of the resource impacts of sea level rise was not available at a scale that would be useful for analysis of sea level rise. However, this did not impede our ability to understand the range of potential impacts from sea level rise and make recommendations for future studies that would help improve our understanding of specific impacts. Two resources in particular, Salinity Changes and Groundwater Effects, were difficult to assess given the unknowns about the complex hydrological and hydrogeological interactions involved. The potential impacts are discussed within the natural resources chapter however; there is not enough data to compare the level of concern about sea level rise impacts relative to the other resources.

[1]Beaches and Agricultural resources were also identified by the Society and Economy Workgroup as a concern but were evaluated from a different perspective. Whereas this workgroup was more focused on ecological significance of the resources, the Society and Economy Workgroup review of beaches concentrated more on tourism and recreational uses. For agriculture, the workgroup reviewed total acreage and types of agriculture for economic and cultural impacts.

Salinity Changes: The influence of sea level rise on salinity levels in rivers and streams depends on the increase in tidal prism and the increase in estuary surface area (its width), assuming the tide range remains unchanged. The mean depth of the estuary will increase with sea level rise only if sedimentation does not keep pace with the vertical space created. The extent to which the tide range changes with sea level rise (if at all) depends on the modified depth and width of the estuary, which is difficult to predict given the number of variables involved. For this reason it is problematic to forecast how the salinity of estuarine waters will change with sea level rise, independent of other factors such as climatic changes in freshwater runoff and human influences on the geometry of the basin.

Groundwater Effects: Rising sea levels could increase the salinity of groundwater tables in shallow coastal aquifers. As rising water levels submerge low-lying sections of land, portions of the aquifer could become saline. Aquifers recharged by fresh water regions of the Delaware River may become saline in the future as well, if salt water pushes further up the waterway. The inundation scenarios used to assess resources affected by sea level rise are ill-suited to provide a meaningful assessment of potential groundwater impacts. Hydraulic interactions between sea level, aquifers, precipitation, streams, and other surface waters are too complex to draw conclusions based on just the increase in water level assumed in the three scenarios.

Assessing Vulnerability of Natural Resources

As discussed in the Introduction, once the resource assessments were completed and maps were available, the Natural Resources Workgroup conducted an exercise to assess the vulnerability of the state to the effects of sea level rise for each resource. Using standardized questions, the workgroup considered the two primary factors: the geographic scope of impacts and whether the resource could continue to "function." For geographic scope, the workgroup considered both the discrete locations of impacts themselves and the extent to which impacts may be felt outside of those locations. For example, loss of lands protected for wildlife habitat not only affects the species that live there but may also reduce ecotourism opportunities and generated revenue. As a result of this discussion, each resource (with the exception of Salinity Changes and Groundwater Effects discussed above) was ranked as a high concern, moderate concern, or low concern. Resources ranked as high and moderate concerns will likely become the starting point for adaptation strategy development in Delaware.

High Concern Resources

Based upon the risk assessment conducted by the workgroup, the following resources are of the highest concern: tidal wetlands, freshwater tidal wetlands, coastal impoundments, habitats of conservation concern, protected lands statewide, U.S. Department of Fish and Wildlife property, and beaches and dunes. A high concern resource is generally a resource where inundation would cause it to no longer provide its typical functions, values, benefits and/or could cause impacts statewide. Additional research and development of adaptation strategies for high concern resources is recommended.

[1]The tidal prism is the volume of water that moves into and out of the estuary during a tidal cycle

[2]The tide range is the vertical difference between the high tide and the low tide

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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 by sea level rise, this resource 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 wetlands 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.

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.

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.

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.

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.

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.

Moderate Concern Resources

Based upon the risk assessment conducted by the workgroup, Nature Preserves and Agricultural Land Conservation Easements were categorized as having moderate concern. Resources are considered to be of moderate concern if there is some impact or loss of function and/or if the geographic extent of the impact is less than statewide.

Nature Preserves: Nature preserves are relatively undisturbed protected lands, free from development pressure and thereby provide exceptional habitat for various species of flora and fauna. These lands are unique and often fragile environments that represent some of Delaware's most important natural habitats. The percentage of affected acreage of dedicated nature preserves ranges from 34% to 43% under the three scenarios. The impact to the resource appears to be fairly local in scale; however, the habitat value of those sites may be exceptional. As a result of these factors, impacts to nature preserves from sea level rise were ranked as a moderate concern.

Agricultural Land Conservation Easements: The Delaware Department of Agriculture has a land preservation program that uses two strategies to preserve farmland, agricultural preservation districts (ranked low concern and discussed below) and agricultural conservation easements. Conservation easements provide permanent protection from development for agricultural activities. Statewide, 13% to 17% of the land in conservation easements may be exposed to rising water. The exposure is localized with a concentration in Kent County. Conservation easements are considered to be an important tool to preserve farming operations and to prevent development and infrastructure in vulnerable areas. Due to these considerations, impacts to conservation easements were ranked as a moderate concern.

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Low Concern Resources

Based upon the risk assessment conducted by the workgroup, the following resources were considered to be of lower concern at this time: Non-tidal Wetlands, Highly Productive Soils, Agricultural Land Preservation Districts, and Upland Forest. 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 the impacts will not be significant in nature and/or will be isolated to several small geographic regions. Low concern resources should continue to be monitored and re-assessed in subsequent planning activities.

Non-tidal Wetlands: Non-tidal freshwater wetlands are floodplains of natural stream channels, ditched modifications and extensions of natural streams, and isolated systems. These wetlands represent a large proportion of the forested area in Delaware and are too wet to build upon or farm without substantial draining or filling. These wetlands are classified as emergent, shrub or forested systems. When all three types are combined, 8% to 12% of the total non-tidal wetland acreage throughout the state is potentially affected under the inundation scenarios. Under the right conditions these wetlands may become tidal, thereby maintaining some of their former functions. This conversion will however, affect the uniqueness of the non-tidal wetland habitat. Given the relatively limited acreage affected, impacts to non-tidal wetlands from sea level rise were considered a low concern at this time.

Highly Productive Soils: This resource includes soil types considered to be prime farmland and farmland of statewide importance. Prime farmland is land whose soils have the best combination of physical and chemical characteristics for the production of crops. Farmland of statewide importance includes those soils that are nearly prime farmland and that produce high yields of crops when treated and managed according to acceptable farming methods. Land classified as having highly productive soils includes some areas that are not currently used for agriculture. Statewide, impacts to highly productive soils are limited, with 2% to 4% of the highly productive soils potentially exposed under the three scenarios. Localized impacts may be significant but would not negatively affect the state as a whole. As such, impacts to highly productive soils were ranked as a low concern at this time.

Agricultural Land Preservation Districts: The Delaware Department of Agriculture has a land preservation program that uses two strategies to preserve farmland, agricultural preservation districts and agricultural conservation easements. An agricultural preservation district is a voluntary agreement to use land only for agricultural purposes for at least a ten year period. There is no guarantee that the property will remain agricultural land once the 10 years expires but there is the possibility of permanent protection under the conservation easement program. Approximately 8% to 11% of acreage within Delaware's agricultural land preservation districts will be exposed to sea level rise. Because the acres affected is not a large percentage of the acres within the preservation districts program statewide, this resource was ranked as a low concern at this time.

Upland Forest: The level of exposure to upland forest resources is fairly limited. The combined impacts from the three upland forest types—deciduous, evergreen and mixed forest— range from 2% to 6% for the state as a whole under the range of inundation scenarios. Reductions in upland forest will negatively affect biodiversity and wildlife habitat, including that for migratory bird species. However, given the relatively limited acreage affected, impacts to upland forest from sea level rise were considered a low concern at this time.

Detailed Resource Assessments

The following sub-chapters contain a detailed exposure assessment for each resource and a description of the likely economic, social and environmental impacts that could result. As discussed in the introduction to this document, an exposure assessment describes how much of a particular resource is within each one of the three sea level rise scenarios. The potential effects to each resource are described within the text, along with the caveats of the analysis and data. These assessments are being used as the baseline data and information to formulate an adaptation strategy for the state, while recognizing the limitations of this method for site specific planning.

Water Resources

This section of the vulnerability assessment focuses on two primary concerns related to sea level rise with respect to water resources: the effects of changes in salinity within the Delaware Estuary and Inland Bays and the impacts to groundwater from salt water inundation. Neither issue is easily addressed as there are many unknowns. In order to evaluate the potential impact from sea level rise more information is needed, including an evaluation of the potential for intrusion of saltwater further into the Delaware River and Inland Bays and a detailed evaluation of the freshwater heads in coastal aquifers to identify potential changes in the salt content in coastal aquifers.

Salinity Changes

The salinity regime of a waterbody determines not only human uses, such as drinking water or agricultural irrigation, but also regulates habitat suitability for aquatic plants and animals. It also impacts certain aspects of water quality and flow dynamics.

Estuaries of coastal Delaware receive fresh water from rivers and saline water from the coastal ocean. In general, the salinity of estuarine waters reflects a balance between the freshwater discharge volume and the tidal prism volume. For example, fresh water enters the Delaware River and Bay estuary primarily through the Delaware, Schuylkill, and Brandywine/Christina river tributaries. Salt water is driven into the bay between Cape May and Cape Henlopen at its mouth by a combination of tidal currents and non-tidal density-driven flow. Fresh water is less dense than salt water, so freshwater runoff tends to flow over the salt water transported landward from the mouth. These waters mix with tidal energy, a process that leads to a transition from salt water at the bay mouth to fresh water in the upper estuary.

At any point along an estuary, salinity levels vary as a result of tides, storms events, and seasonal cycles in precipitation and evaporation. Over a long period of time, processes that alter the freshwater discharge or tidal prism influence the steepness of the along-estuary salinity gradient and the mean salinity of the estuary as a whole. Such a change could result from changes in weather and climate patterns and oceanographic phenomena, among other factors.

The landward limit of salt in surface water, also known as the salt line, is based on established drinking water standards of 250 milligrams per liter chloride concentration. The Delaware River and Basin Commission uses the seven day average location of the salt line to define the upper bounds of salinity intrusion in the Delaware Estuary. The salt line varies daily in response to tides, seasonally and in response to freshwater inputs—rainfall, streamflow, and reservoir releases—but is typically between Wilmington, Delaware and Philadelphia, Pennsylvania.

Exposure to Sea Level Rise: With rising mean sea level, an estuary will widen through erosion or submergence of its coasts, particularly in low-lying areas. The influence of sea level rise on salinity depends on the unit increase in tidal prism with unit increase in estuary surface area, assuming the tide range remains unchanged. The mean depth of the estuary will increase with sea level rise only if sedimentation does not keep pace with the vertical space created. The extent to which the tide range changes with sea level rise (if at all) depends on the modified depth and width of the estuary, which is difficult to predict given the number of variables involved. For this reason it is problematic to forecast how the salinity of estuarine waters will change with sea level rise independent of other factors such as climatic changes in freshwater runoff and human influences on the geometry of the basin.

Changes in salinity and sedimentation patterns from sea level rise could be a stressor to aquatic life, and will be most harmful for organisms that cannot easily migrate in response to changes like oyster beds. It should be noted that estuarine settings naturally experience a wide range of salinity, so organisms that inhabit these environments are generally well-adapted to this variability.

Potential Economic Impact: Drinking water reliability in Delaware is highly dependent on surface water withdrawal in New Castle County (the rest of the state utilizes groundwater for drinking water). An increase in salinity near drinking water intake pipes could affect the quality and reliability of drinking water for thousands of citizens. If augmentation of drinking water infrastructure is necessary to mitigate increased salinity, associated costs may be substantial.

Additionally, changes in salinity could cause changes in habitat for species that have commercial and recreational value. Industrial facilities dependent upon freshwater withdrawals may also be affected to varying degrees by salinity changes. Increased salt content in process water may affect some operations; require alternate sources of freshwater, or other economic hardship. Economic impacts to industrial facilities from sea level rise are covered in more detail in the Society & Economy chapter of this assessment.

Potential Social Impact: Changes to habitats for species with commercial or recreational value as a result of saltwater intrusion could result in impacts to local communities with historic and economic ties to those resources. Industries or municipalities that rely on fresh water for industrial processes or drinking water may be adversely affected by salt water intrusion, which in turn could lead to reduced production, fewer jobs, and resultant community impacts.

Potential Environmental Impact: Sea level rise could potentially increase the tidal prism volume of estuaries in Delaware, increasing the mean salinity of the estuaries, and causing salt to migrate landward into what is currently tidal fresh water. The combination of higher water levels and increased salinity could impact tidal wetlands by increasing the frequency of inundation and the salinity of tidal waters.

Increased salinity may impact plants and animals sensitive to changes in salt content. Sessile species such as shellfish are most vulnerable to these changes. Over time, shellfish beds may shift inland, but that requires time and appropriate bottom substrate in the new location. An additional concern specific to the Eastern oyster (Crassostrea virginica) is the correlation between increased salinity and disease prevalence. Oysters are primarily a mesohaline species whose population is limited at higher salinities by major predators (oyster drills and starfish). Although not harmful to humans, two parasitic diseases, MSX and Dermo, are extremely lethal to Delaware's native oyster population. These diseases thrive in warmer, higher salinity environments. Since MSX was introduced, it has become a second factor killing oysters at salinities above 15 ppt. The disease Dermo is less prevalent in the Delaware Bay but still a concern. Increased prevalence and infection occur in waters with salinity concentrations between 12-15 parts per thousand (Virginia Institute of Marine Science, 2012).

Changes in salinity will also affect fish species like American shad, river herring, and striped bass which live in salt water but return to freshwater rivers to spawn. These recreationally important species would be negatively affected by decreased tidal freshwater acreage that could be caused by rising sea levels and saltwater intrusion. A decrease in suitable freshwater habitat would likely result in a decrease in spawning areas and a decrease in juvenile foraging areas, leading to population declines.

Another important anadromous species is the Atlantic sturgeon, a state and federally endangered species. The spawning grounds are unknown; however, less tidal freshwater acreage reduces the potential area for spawning and early larval stage. Additionally, juvenile foraging area will be reduced and likely reduce the production capacity of the system.

Alternately, increased salt content might make the bay more suitable for other coastal species that prefer a higher salinity.

Additional Information: The Delaware Division of Fish and Wildlife have identified the Marcus Hook anchorage and Chester Island areas as potential spawning grounds at the edge of the salt to fresh transition zone based on the presence of adult male Atlantic sturgeon in May and early June. This area is currently being targeted by an ongoing Delaware State University study of sturgeon. Increased salinity could be devastating to these areas (if they are in fact used as spawning grounds or early larval staging area).

The Delaware River Basin Commission (DRBC) is the agency responsible for managing flows in the Basin. Managing releases of water from upstream dams and regulating the allocation of water is the primary tool for managing salinity levels, and the salt line is one target that the DRBC uses in its management efforts.

Extensive information on Delaware Bay oyster populations and climate change impacts can be found in Appendix O. Oysters in Delaware Bay – Climate Change of the report titled, Climate Change and the Delaware Estuary: Three Case Studies in Vulnerability Assessment and Adaptation Planning (Kreeger, et al., 2010).

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Groundwater

Delaware's groundwater is one of its most important natural resources. It is essential for meeting the needs of all segments of our society and for maintaining economic growth and agriculture. At this time, all water used for public and domestic supply and more than 98% of water used for irrigation south of the Chesapeake and Delaware Canal is groundwater. North of the canal, approximately 70% of public water supplies are obtained from four surface-water sources (creeks) and 30% from ground-water resources (Delaware Geologic Survey).

Exposure to Sea Level Rise: Rising sea levels could increase the salinity of rivers, bays, and the groundwater tables in the state. Shallow coastal aquifers are particularly vulnerable. As rising water levels submerge low-lying sections of land, portions of the aquifer could become saline. Aquifers recharged by fresh water regions of the Delaware River may become saline in the future as well, if salt water pushes further up the waterway.

The inundation scenarios used to assess resources affected by sea level rise are ill suited to provide a meaningful assessment of potential groundwater impacts. Hydraulic interactions between sea level, aquifers, precipitation, streams, and other surface waters are too complex to draw conclusions based on just the increase in water level assumed in the three scenarios. However, a data layer available that is related to potential groundwater impacts from rising sea levels is the Undeveloped Recharge Areas layer. A groundwater recharge area is a region where water from precipitation is transmitted through the soil layers to an aquifer. Developed parcels and impervious surface prohibit effective recharge so for the purpose of this assessment, only the undeveloped recharge areas were analyzed. This data layer was generated using impervious surface data in conjunction with the recharge areas layer to identify undeveloped areas that would infiltrate precipitation. Statewide, the percentage of undeveloped recharge areas that could be inundated by sea level rise ranges from 2% to 4% (Table 3).

Table 3 - Undeveloped Recharge Areas

County	Total Acres	Acres Inundated			Percent of Total Inundated		
		0.5 m	1.0 m	1.5 m	0.5 m	1.0 m	1.5 m
State	396,107	7,788	12,682	17,358	2%	3%	4%
New Castle	16,658	31	35	40	< 1%	< 1%	< 1%
Kent	150,483	1,098	2,288	3,746	1%	2%	2%
Sussex	228,967	6,659	10,359	13,572	3%	5%	6%

Sources: DNREC, Recharge Areas, 2010-10-27, Office of State Planning Coordination, 2007 Impervious Surface Data, 2008 05 18

Table 4 - Wellhead Protection Areas

County	Total Acres	Acres			Percent of Total Inundated		
		0.5 m	1.0 m	1.5 m	0.5 m	1.0 m	1.5 m
State	29,224	270	613	987	1%	2%	3%
New Castle	12,977	43	133	175	<1%	1%	1%
Kent	6,684	104	159	228	2%	2%	3%
Sussex	9,563	123	321	585	1%	3%	6%

Source: DNREC, Statewide Wellhead Protection Areas 2009, 2009-09-29

A wellhead is the physical structure of a well above ground. Wellhead data analyzed for this assessment is for public water supply sources. Private wells and irrigation wells were not analyzed because the data is not available for public use. Areas surrounding public water supplies are designated as wellhead protection areas and regulated by DNREC to control land use activities that may prove detrimental to the groundwater resource.

Statewide, 1% - 3% of the total acreage of wellhead protection areas could be inundated by sea level rise. The highest level of potential impact is in Sussex County where up to 6% of the public wellhead protection areas could be inundated by sea level rise (Table 4).

Potential Economic Impact: Saltwater intrusion to groundwater resources could affect the reliability of drinking water for hundreds of thousands of people. If augmentation of drinking water infrastructure is necessary as a result of sea level rise, associated costs may be substantial. Further, the negative economic effects of salt-contaminated groundwater can extend far beyond the costs of remediation or replacement. Many farms and neighboring communities depend on groundwater withdraws for farm operations and domestic water consumption. Salt-contaminated groundwater can discourage new businesses or residents from locating in a community. Existing businesses reliant on groundwater may be forced to move to an area with access to an uncontaminated water supply.

Potential Social Impact: Delawareans rely extensively on groundwater withdrawals for all water used for public and domestic supply. Any disruption to a society's supply of fresh, potable water has far reaching impacts. The effects would result in disruptions to daily life, public health concerns, agricultural production issues, and consequences to industrial facilities that rely on fresh water for processing. If a groundwater supply is contaminated by salt water from rising seas, there will be a pressing need to locate a clean freshwater supply, inform the public, and determine a long-term solution. Once a water supply is contaminated, replacement is often the most reasonable alternative and the costs of siting new wells, treating existing supplies, or providing bottled water are high.

Potential Environmental Impact: Impacts to aquifers similar to the potential stresses of sea level rise already occur during times of severe drought. Many shallow aquifer systems along the Atlantic coast are in direct hydraulic connection with streams and other surface waters that are often sources of recharge to the underlying ground-water system.

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The USGS summarizes the impacts of sea level rise on aquifers

Perhaps most fundamentally, a landward movement of seawater would push saltwater zones in coastal aquifers landward and upward, which could accelerate rates of saltwater intrusion into aquifers already experiencing saltwater contamination. Rising sea levels also might cause upstream migration of saltwater in coastal estuaries, inundation of low-lying areas including wetlands and marshes, and submergence of coastal aquifers. In some areas, sea level rise would erode beaches and bluffs, leading to shoreline retreat, narrowing of aquifers, and diminished areas of aquifer recharge. Sea level rise also might cause increases in coastal ground-water levels, because of the overall rise in the position of the freshwater-saltwater interface.

Although sea level rise could increase saltwater intrusion into coastal surface and groundwaters, landward saltwater movement also will depend in part on changes in precipitation, runoff, and recharge that may occur within coastal watersheds. For example, increased freshwater runoff could counterbalance the landward movement of saltwater. Moreover, should saltwater intrusion into coastal aquifers occur in response to sea-level rise, it is likely that some aquifers may require hundreds to thousands of years to re-equilibrate to changes in sea level, such as has occurred in parts of the Northern Atlantic Coastal Plain aquifer system where freshwater-saltwater interfaces appear to be still responding to sea-level increases that began at the end of the last ice age. (Barlow, 2003)

Wetlands

For the purpose of this assessment, wetlands are broken into the categories tidal wetlands, non-tidal wetlands, and man-made impounded wetlands. The impact tables for tidal wetlands are further broken down by impacts to saltwater tidal wetlands and impacts to freshwater tidal wetlands; however the discussion of economic, social and environmental impacts refer to all tidal wetlands. Similarly the impact tables for non-tidal wetlands are sub-categorized by emergent, shrub, and forested wetlands, but the discussion of impacts addresses impacts from non-tidal wetlands combined.

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. Without these tidal wetlands, populations of migratory birds and fish would be impacted, thus shifting traditional patterns and altering ecosystems elsewhere. As a result, it can be said that while the primary users of the tidal wetlands are Delaware residents and visitors, the existence and the continued health of our tidal wetlands are important to communities throughout the United States.

Additionally, both saltwater and freshwater tidal wetlands sequester more carbon than any other habitat type in the Delaware Estuary (Kreeger, et al., 2010). Carbon sequestration is important to combating climate change—an issue of international importance.

Many different human and non-human communities use tidal wetlands and derive significant benefits from them. Human users of tidal wetlands are primarily Delaware residents and visitors. Groups of human users can be split into two categories- those who knowingly and directly benefit from being physically present in the tidal wetlands, and those who indirectly and perhaps unknowingly benefit from the existence of the tidal wetlands.

Tidal wetlands act as sponges, soaking up floodwaters and buffering storm impacts. This function provides a

valuable service to coastal communities.

Tidal wetlands also act as a sink for nutrients and pollutants to help maintain water quality. Freshwater tidal wetlands in particular are also a first line of defense for capturing contaminants flowing from urban lands to the estuary. The nutrient storage and sequestration function of saltmarshes is of particular importance to Delaware's Inland Bays and tributaries to the Delaware Bay which suffer from excess nutrient pollution. Tidal wetlands remove excess nitrogen entering the estuaries from both non-point sources and direct deposition from the atmosphere.

Saltwater Tidal Wetlands

Saltwater tidal wetlands are low flat marshlands inundated by salt water. These tidal wetlands form a continuous fringe around the Delaware Bay and Inland Bays. While it is possible that some saltwater wetlands will migrate landward and upward in response to sea level rise, due to the limitations of the bathtub model used for this assessment, the exposure values discussed below do not take into consideration natural processes of erosion, accretion and landward migration

Exposure to Sea Level Rise: Saltwater tidal wetlands are extremely vulnerable to sea level rise, as indicated by the figures in the Table 5 (and depicted on maps in the Mapping Appendix). However, the extent to which a given tidal wetland is vulnerable to sea level rise depends on several factors: the burial rate of organic and inorganic sedimentary matter; the rate of regional land subsidence relative to the rate of sea level rise; and the degree to which coastal development, topography, and other factors limit the landward migration of marshes.

Tidal wetlands grow vertically through accretion. They do this by capturing sediment brought in by the tides and by maintaining high plant production above ground and slow decomposition rates below ground. By accumulating dead plant matter and inorganic sediment, established marshes generally accrete at rate sufficient to keep pace with sea level rise. However, accelerating rates of sea level rise are likely to alter wetland accretion dynamics in some areas and the potential impact on accretion rates depends on interplay between the biotic and physical factors involved. The rate of sea level rise is critical, and we can expect many of our tidal wetlands to drown under the higher sea level rise scenarios (Kirwan, Guntenspergen et al. 2010).

Table 5 - Tidal Wetlands

County	Total Acres of Wetlands	Total Acres Inundated			Percent of Total Acres Inundated		
		0.5 m	1.0 m	1.5 m	0.5 m	1.0 m	1.5 m
State	73,408	71,172	72,956	73,141	97%	99%	99%
New Castle	16,113	14,614	15,755	15,877	91%	98%	99%
Kent	36,205	35,609	36,152	36,191	98%	99%	99%
Sussex	21,090	20,949	21,048	21,073	99%	99%	99%

Source: DNREC, Delaware Wetlands SWMP 20100901, unpublished

Tidal wetland acreage during periods of rising sea level is also determined by the capacity of marshes to migrate landward and upward (transgress) over adjacent uplands. The rate of marsh migration under a given rate of sea level rise is determined primarily by the slope of adjacent lands and their management. Rates of marsh migration are lower where the slopes of adjacent lands are higher (Carey, 1996). Migration can be stalled by naturally steep slopes or land management activities that raise the elevation of adjacent lands or harden the upland wetland boundary. This will stall the migration of wetlands until sea levels rise enough to push marshes past the obstructions. Where obstructions include (or are protecting) infrastructure like roads, communities will likely be inclined to prevent this process for as long as possible. Under conditions of rapidly rising sea levels, landward wetland migration is likely to be the primary process by which wetlands maintain their acreage and function, if such migration is possible (CCSP, 2009).

A recent report, Delaware Wetlands: Status and Changes from 1992-2007, identified a loss of 579.5 acres of tidal wetlands, attributing 83% of the loss to conversion to open water. However, a portion of this acreage lost was offset by gains elsewhere resulting in a net loss of 238 acres (Tiner, Biddle, Jacobs, Rogerson, & McGuckin, 2011). These trends are expected to continue and likely increase with climate change impacts, including sea level rise. Sea level rise will interact with various other stressors to push many wetlands past their sustainable threshold (Kreeger, et al., 2010).

Freshwater Tidal Wetlands

Freshwater tidal wetlands occur at the upper reaches of estuaries where the water level is influenced by the rise and fall of the ocean tides, but is beyond the salt line. Freshwater tidal wetlands were not mapped separately but the acres inundated were included within the broader category of tidal wetlands (Maps 1-3 in the Mapping Appendix). However, because freshwater tidal wetlands are ecologically important and known for high species diversity, they are addressed separately here. The tables below represent freshwater tidal wetlands combined (Table 6) as well as separated into two types: mixed broadleaf (Table 7) and forested and shrub (Table 8). This data was provided by the Delaware Natural Heritage Program and was obtained through both field verification and interpretation of aerial and satellite photographs.

Exposure to Sea Level Rise: Freshwater tidal wetlands are very vulnerable to sea level rise, as indicated by the results of the exposure assessment in Tables 6-8. The extent to which a given freshwater tidal wetland is vulnerable to sea level rise depends on the factors noted above for salt marshes. Additionally, the degree to which sea level rise increases the salinity of tide water is another factor, because salinity limits the types of flora that colonize the marshes.

Table 6 - Freshwater Tidal Wetlands

County	Total Acres of Tidal Marsh	Total Acres Inundated			Percent of Total Acres Inundated		
		0.5 m	1.0 m	1.5 m	0.5 m	1.0 m	1.5 m
State	11,052	9,264	10,638	10,828	84%	96%	98%
New Castle	3,368	2,351	3,202	3,306	70%	95%	98%
Kent	1,749	1,286	1,681	1,714	74%	96%	98%
Sussex	5,934	5,628	5,755	5,806	95%	97%	98%

Source: DNREC - Natural Heritage Program, Habitats of Conservation Concern (2011), unpublished

Table 7 - Mixed Broadleaf Freshwater Tidal Marsh

County	Total Acres of Tidal Marsh	Total Acres Inundated			Percent of Total Acres Inundated		
		0.5 m	1.0 m	1.5 m	0.5 m	1.0 m	1.5 m
State	5,933	4,683	5,797	5,887	79%	98%	99%
New Castle	3,143	2,195	3,011	3,099	70%	96%	99%
Kent	298	1	298	298	< 1%	99%	99%
Sussex	2,491	2,487	2,489	2,489	99%	99%	99%

Source: DNREC - Natural Heritage Program, Habitats of Conservation Concern (2011), unpublished

Freshwater tidal wetlands are expected to grow vertically to keep pace with accelerating rates of sea level rise in most areas, but only if they are not exposed to salt water.

Due to possible increases in salinity associated with sea level rise (and possibly other system alterations) at least some transitional brackish and freshwater tidal wetlands are expected to be exposed to increasing salinity. As salinity increases in freshwater tidal wetlands, freshwater-adapted species die, and salt-tolerant species may or may not replace them. Some new research is finding that sometimes there is insufficient time for belowground processes to shift and the soils become toxic to most vegetation due to redox changes (Carey, 1996).

Table 8 - Freshwater Tidal Forested and Shrub Wetlands

County	Total Acres of Wetlands	Total Acres Inundated			Percent of Total Acres Inundated		
		0.5 m	1.0 m	1.5 m	0.5 m	1.0 m	1.5 m
State	5,119	4,581	4,841	4,941	89%	95%	97%
New Castle	225	156	191	207	69%	85%	92%
Kent	1,451	1,285	1,383	1,416	89%	95%	98%
Sussex	3,443	3,141	3,266	3,317	91%	95%	96%

Source: DNREC - Natural Heritage Program, Habitats of Conservation Concern (2011), unpublished

Freshwater wetland acreage during periods of rising sea level is also determined by the capacity of these wetlands to migrate over adjacent uplands. In more landward areas upriver, it may be possible for some freshwater tidal marshes to 'out run' sea level rise by migrating inland, but this depends on the rate of change and the capacity to move into inland areas. Rates of migration are lower where the slopes are adjacent lands are higher, and migration can be stalled by natural steep slopes or land management activities that raise the elevation of adjacent lands or harden the upland wetland boundary. This will stall the migration of wetlands until sea levels rise enough to push wetlands past the obstructions. According to several studies, landward migration of freshwater tidal marshes in Delaware is very unlikely since many of these coastal areas are developed or 'hardened.' (Kirwan & Guntenspergen, 2010) Where obstructions to migration include or protect important infrastructure like roads and structures, taking action to allow migration is complicated and may be unlikely.

Because of the relative rarity of these wetlands in Delaware and their high natural capital value (described below), preventing inundation or change due to sea level rise is especially important.

Potential Economic Impact: While no specific economic data is available for economic production from tidal wetlands in Delaware, an assessment of the economic value of the state of New Jersey's natural resources determined that tidal wetlands provided $6,269 per acre per year in total goods and services to residents and visitors (State of New Jersey, 2007). These estimates can be reasonably applied to tidal wetlands in Delaware.

Natural Resources

Loss of associated ecosystem services: Associated ecosystem services include water filtration, carbon sequestration, flood protection, and habitat critical to fisheries and shellfisheries. According to an assessment by the Water Resources Agency of the University of Delaware in 2011, saltwater tidal wetlands provide an average of $7,235 per acre in ecosystem services (Kauffman, Homsey, Chatterson, McVey, & Mack, 2011). Losing 97% of Delaware's saltwater tidal wetlands, the most conservative number, would result in the loss of over $500 million of ecosystem services per year. The same study valued freshwater tidal wetlands at an average of $13,621 per acre in ecosystem services. Losing 79% of Delaware's mixed broadleaf freshwater tidal marsh, and 89% of Delaware's freshwater tidal forested and shrub wetlands (the most conservative estimate) would result in the loss of over $125 million of ecosystem services per year. This analysis does not account for many secondary economic or climate impacts. For example, the loss of more than 70,000 acres of tidal wetlands would result in a large pulse of carbon dioxide due to respiration of outwelled peat, thereby contributing a positive feedback for greenhouse gas emission.

Loss of tourism/recreation: According to the same study, the estimated economic value associated with fishing, hunting, and wildlife watching along coastal Delaware is $134 million annually. This value is derived from estimates of trip related expenditures including food and lodging, transportation, and hunting, fishing, and wildlife watching equipment (Kauffman, Homsey, Chatterson, McVey, & Mack, 2011). Given the important role of tidal wetlands in fish production and natural habitats in coastal Delaware and the unique habitat niche filled by freshwater tidal wetlands, it is likely that a large portion of this value can be attributed at least in part to tidal wetlands.

Loss of jobs: While there are no specific estimates regarding what would happen to commercial fishing operations if 97% of Delaware's saltwater tidal wetlands, 79% of Delaware's mixed broadleaf freshwater tidal wetlands and 89% of Delaware's freshwater tidal forested and shrub wetlands were inundated, it is likely that this industry would suffer some type of decline. It is estimated that anywhere from 85%-95% of our recreationally and commercially important coastal fisheries rely on tidal wetlands as a place to shelter and grow their young (Department of Natural Resources and Environmental Control, 2011).

Loss of flood protection: Though it was mentioned above during the discussion of ecosystem services, the importance of flood protection to coastal communities cannot be overstated. Without wetlands to attenuate flooding effects from storms, damage to homes, businesses and infrastructure would likely increase significantly. Coastal tidal wetlands are especially important for absorbing or dissipating storm surge effects.

Potential Social Impact: Losing significant acreage of tidal wetlands would result in quality of life impacts, including the loss of income for commercial fishers; loss of hunting and fishing opportunities; and increased flooding for coastal communities. These losses, combined with increased flooding, could affect the social fabric and sustainability of Delaware's coastal communities.

Potential Environmental Impact: The inundation of saltwater tidal wetlands could create major environmental changes including:

- Shifts in community species composition (including loss of rare plants)
- Changes to extent of wetland areas
- Changes to the ratio of shoreline edge to marsh area
- Changes to the rate of channel scour
- Increase in storm surge susceptibility
- Reduction in fisheries production
- Reduction in water quality

The impact of sea level rise and resulting salinity changes on freshwater tidal wetlands could create major changes to these areas. In a recent estuary-wide study, wetlands experts expressed a high concern about the following changes to freshwater tidal wetlands as a result of sea level rise and resulting salinity changes:

- Shifts in community species composition
- Saltwater intrusion to freshwater habitats
- Changes in habitat support
- Ability for wetlands to migrate landward
- Change to extent of wetland areas
- Increase in storm surge susceptibility
- Increased seaward edge erosion
- Increased salt exposure/stress/event

(Kreeger, et al., 2010)

As sea levels rise and wetlands migrate inland where they are able, there will be shifts in species composition and habitat types. Within salt marshes, low-marsh species will replace mid- and high-marsh species. Similarly, salt marshes will replace brackish marshes.

Sea level rise over time changes the salinity of freshwater tidal wetlands in Delaware. Salinity changes will replace freshwater tidal wetlands with brackish wetlands or open water, which will cause major shifts in species composition. In addition to their vulnerability to salinity, freshwater tidal wetlands are threatened by the physical effects of rising sea level, such as erosion of seaward edges. Some freshwater tidal wetlands may convert to brackish wetlands, possibly dominated by invasive species that thrive under more frequent disturbance regimes (Kreeger, et al., 2010).

Natural Resources

Non-tidal Freshwater Wetlands

Non-tidal freshwater wetlands (also known as palustrine wetlands) in Delaware are mostly held in private ownership with the majority of the total acreage located in Kent County and Sussex County. GIS mapping indicates that there are approximately 163,000 total acres of non-tidal freshwater wetland in Delaware, of which 86% is forested. These wetlands exist as floodplains of natural stream channels, as ditched modifications and extensions of natural streams, and as isolated systems. Non-tidal freshwater wetlands represent a large proportion of the forested area in Delaware and are too wet to build upon or farm without substantial draining or filling.

Historically, non-tidal freshwater wetlands have been used for lumber production. Until the passage of laws pertaining to the handling of rubbish and other garbage in the mid-twentieth century, these wetlands were frequently used as "dumps." With the exception of some hunting and naturalist activity, usage by people is light. Habitat quality and species diversity varies and all three subcategories discussed here are used by a variety of wildlife.

Exposure to Sea Level Rise: The tables below summarize the results of the sea level rise exposure assessment for non-tidal freshwater wetlands. Results are divided into three categories: non-tidal emergent wetlands (Table 9), non-tidal forested wetlands (Table 10), and non-tidal shrub wetlands (Table 11). Inundated acreage determinations are based on data generated by the DNREC. All computer-generated numbers are rounded to two significant figures to avoid the presentation of numbers that are unrealistically precise thus slight disagreements exist between the state total and the sum of the county totals. Corresponding maps are located in the Mapping Appendix.

Table 9 - Non-Tidal Emergent Wetlands

County	Total Acres of Emergent Wetlands	Total Acres Inundated			Percent of Total Acres Inundated		
		0.5 m	1.0 m	1.5 m	0.5 m	1.0 m	1.5 m
State	8,873	2,236	2,950	3,140	25%	33%	35%
New Castle	2,602	635	761	818	24%	29%	31%
Kent	2,178	253	695	742	12%	32%	34%
Sussex	4,093	1,348	1,494	1,580	33%	37%	39%

Source: DNREC, De_Wetlands_20100901_PD6, 2010-09-01

Potential Economic Impact: A loss of non-tidal freshwater wetlands may result in increases in flooding and/or increased expenditure of funds for stormwater projects to prevent flooding. As the acreage of these wetlands declines, the delivery of nutrients and suspended sediments to downstream waters is expected to increase. This could lead to detrimental economic and environmental outcomes including decreased water quality, increased cost of pollutant removal and disruptions to fish and waterfowl populations.

Table 10 - Non-Tidal Forested Wetlands

County	Total Acres of Forested Wetlands	Total Acres Inundated			Percent of Total Acres Inundated		
		0.5 m	1.0 m	1.5 m	0.5 m	1.0 m	1.5 m
State	140,891	8,192	10,828	12,605	6%	8%	9%
New Castle	12,614	607	851	998	5%	7%	8%
Kent	53,878	2,403	3,623	4,383	4%	7%	8%
Sussex	74,399	5,181	6,354	7,224	7%	9%	10%

Source: DNREC, De_Wetlands_20100901_PD6, 2010-09-01

Potential Social Impact: The flood controlling function of these non-tidal freshwater wetlands has societal value. Intrinsic value such as catchment basin-like topography, flow-impeding roughness of the ground surface and the seasonal transpiration of the trees, shrubs, and herbaceous plants allow stormwater to be retained, with some being recharged to groundwater and the remainder being discharged relatively slowly downstream or to the atmosphere by evapotranspiration. These functions result in water quality and water quantity benefits.

Table 11 - Non-Tidal Shrub Wetlands

County	Total Acres of Shrub Wetlands	Total Acres Inundated			Percent of Total Acres Inundated		
		0.5 m	1.0 m	1.5 m	0.5 m	1.0 m	1.5 m
State	13,178	2,446	2,886	3,104	19%	22%	24%
New Castle	973	325	429	463	33%	44%	48%
Kent	2,624	868	1,090	1,167	33%	42%	44%
Sussex	9,581	1,253	1,367	1,474	13%	14%	15%

Source: DNREC, De_Wetlands_20100901_PD6, 2010-09-01

Flooding, whatever its cause, results in social impacts as well as economic loss. With regard to the loss of non-tidal freshwater wetlands to sea level rise, social impacts are closely intertwined with environmental impact. The loss of wetlands and associated changes in ecological character of an area may occur so slowly as to be indiscernible to anyone other than a trained ecologist. History suggests that gradual and subtle losses are unlikely to elicit much concern on the part of the general public.

Finally, these highly complex ecosystems serve as important wildlife habitat to a wide variety of species. In addition, waterfowl hunting, bird watching, and nature photography are popular activities in and around non-tidal wetlands. Therefore loss of recreational opportunities could also be considered a social impact.

Natural Resources

Potential Environmental Impact: As water moves downstream, wetlands improve its quality by functioning as a purifying filter. Nutrients are used by the vegetation while suspended sediments settle, elevating the floodplain and thereby somewhat offsetting the coinciding sea level rise. Such retention of nutrients and sediments by wetlands of any kind reduces the quantities delivered downstream. Fisheries and migratory waterfowl populations have been disrupted by environmental conditions resulting from these pollutants including low dissolved oxygen, loss of seagrass, and blooms of undesirable algae.

The retention capacity of wetlands serves to reduce the quantity of stormwater flow carried by a stream bed. This can reduce the failure of stream banks, which leads to detrimental outcomes including the loss of riparian trees that shade the water, the elimination of pools as fish habitat due to filling with silt, sand and gravel, and the widening and shallowing of the stream channel such that summer water temperature becomes too high to support many plants and animals.

The shrinking of habitat will result in a decrease in environmental carrying capacity, cascading to a reduction in abundance at the species level and diversity at the community level. Many such impacts may be “silent” and go unnoticed by the general public.

Additional impacts are listed below:

- Alteration of species diversity (locally)
- Alteration of species diversity (landscape)
- Alteration of species composition
- Alteration of habitat structure
- Conversion of one habitat type to another
- Conversion to tidal wetlands
- Conversion to open water
- Salinization of aquifers
- Alteration of flood water retention
- Alteration of nutrient dynamics
- Alteration of sediment transport
- Alteration of land subsidence rate
- Alteration of wetland accretion rate
- Increased stress on forested communities result disease outbreaks
- Alteration of invasive community dynamics
- Introduction of and susceptibility to pathogens and parasites
- Alteration of woodlands to emergent shrub, forb, or grass species
- Shift to more salt tolerant species
- Altered susceptibility to wildfire
- Local extirpation of rare/endangered flora and fauna
- Increased human pressure on remaining land base

(Tiner R. W., 1985)

Additional Information: Many non-tidal freshwater wetlands are not regulated and can be filled or altered without permits. Because of this, losses due to sea level rise will likely be obscured by losses due to other types of human activity such as agriculture and development.

It should be noted that the exposure assessment estimates do not take into account the generation of new palustrine wetlands that can be expected to develop in some places as the water rises and the uplands retreat.

An in-depth evaluation of current landscape use and ownership within and around vulnerable wetlands may provide useful information to guide adaptation recommendations. This information coupled with current land use and zoning regulations and various sea level rise scenarios could be used to make predictions about future losses and gains in acreage and functions.

Impoundments

Coastal impoundments are man-made structures that primarily serve to provide important breeding, migration, and wintering habitat for a variety of birds. They also serve as nurseries for fish and help control mosquito populations. In addition, they provide important recreational opportunities such as bird-watching and fishing. Alongside these uses, impoundments also provide flood control for many coastal communities, roadways, and agriculture resources. The coastal impoundments have a variety of owners and management objectives which causes landscape-scale management to be a complex problem, especially in the face of sea level rise. The largest owners of impounded wetlands are the U.S. Fish & Wildlife Service, the DNREC Division of Fish and Wildlife and the city of New Castle. The U.S. Fish & Wildlife Service owns and maintains impoundments at Bombay Hook and Prime Hook National Wildlife Refuges that were created to provide habitat for waterfowl. The DNREC Division of Fish & Wildlife owns and operates several impoundments throughout the state that were created to provide habitat for waterfowl, migratory shorebirds, and to control mosquito populations. The City of New Castle owns and maintains several impoundments that were created to provide flood and storm water control for the city.

Wetland loss, whether the wetlands are natural or managed, will have dramatic consequences for wildlife populations. Therefore, management of impounded wetlands needs to be conducted in the short term to maximize the services they perform annually but also must be conducted in the long term to ensure they will be available for, and provide utility to, sea level rise adaptation. An impoundment management plan that addresses the interconnectedness of impoundments and their surrounding habitats in an adaptive way and within the context of sea level rise will help to ensure wetland habitat is available over the long term.

Natural Resources

Exposure to Sea Level Rise: Breaching of freshwater or brackish impoundments threaten the flora and fauna within these habitats. Increasing the duration of tidal flow and salinity concentration raises the potential of permanent inundation and vegetation dieback, which could result in impoundments converting into a permanent open water body. A sea level rise of 0.5 meters could result in inundation of 81% of the state's impoundments. At 1.0 and 1.5 meters of sea level rise, 99% of all impoundments could be affected (Table 12 and maps in the Mapping Appendix).

Table 12 - Impoundments

County	Total Impoundment Acres	Total Acres Inundated			Percent of Total Acres Inundated		
		0.5 m	1.0 m	1.5 m	0.5 m	1.0 m	1.5 m
State	12,236	9,961	12,107	12,176	81%	99%	99%
New Castle	2,882	2,007	2,870	2,876	70%	99%	99%
Kent	2,950	1,800	2,935	2,946	61%	99%	99%
Sussex	6,403	6,154	6,302	6,354	96%	98%	99%

Source: Delaware Coastal Programs, Impoundments (2010), unpublished.

Potential Economic Impact: The economic impact is unclear. Potential losses may come indirectly as a result of reduced ecotourism and associated dollars spent on lodging, food and equipment. No economic data specific to impoundments has been generated.

Potential Social Impact: Coastal impoundments provide important breeding, migration, and wintering habitat for a variety of birds. They serve as nurseries for fish and help to control mosquito populations. In addition, they provide important recreational opportunities. Loss of impoundments could result in loss of historic and cultural connections to such activities as waterfowl hunting, trapping, and bird watching.

Potential Environmental Impact: These freshwater, brackish, and tidal impoundments fill a void in the distribution of wetlands along the coast, as human activities have resulted in a loss of freshwater and brackish wetlands. The habitat that is provided by the impoundments has become a core component of the distribution of available habitat in the Mid-Atlantic for migratory waterfowl, shorebirds, wading, and ground birds. The loss of these areas could result in a large scale shift in the distribution of birds within Delaware and the Delmarva Peninsula.

Additional Information: Detailed information on types of habitat loss may be available from data collected from each affected impoundment.

Beaches and Dunes

The coastline of Delaware is a vital economic and environmental resource. Its 24 miles of Atlantic Ocean shoreline and 357 miles of river and bay shoreline provide economic benefits from tourism, high-value space for commercial and residential development, and recreational opportunities including boating, fishing, and beach-going. Delaware's shoreline is also an important ecological resource—providing habitat for a variety of plants, animals, insects, and migratory birds.

The assessment below focuses on the ecological impacts of sea level rise to beaches and dunes. Impacts to beaches and coastal communities resulting from these impacts are also addressed within the Tourism section of the Society and Economy chapter of this document.

Operating in tandem with the Sea Level Rise Advisory Committee is another state committee focused on the communities of Delaware's Bay Beaches. The Delaware Bay Beach Work Group (also known as the Simpson Bushweller Committee) has provided the Governor with 14 short-term recommendations to help alleviate flooding and erosion problems in these areas. The Delaware Bay Beach Work Group will also provide recommendations for addressing the long term issues threatening these coastal communities including storms, rising sea levels, subsidence, beach erosion, and flooding. These recommendations will assist the State in developing a sustainable long-term strategy, including new approaches to financing restoration work (Delaware Bay Beach Work Group, 2011). This document will refer readers to their work considering these at-risk coastal communities.

Exposure to Sea Level Rise: Typically, Delaware's beaches include a berm and dune system. The berm and dune system naturally transgress or migrates landward, but infrastructure built on areas along the coast block that process. Instead, material is eroded and carried offshore. This decreases beach width and berm height, thus eliminating or damaging the dune systems, exposing coastal properties to storm damage.

Sea level rise has the potential to exacerbate the damaging effects of coastal storms by increasing the severity of flooding in coastal communities. When combined with wind-driven waves, sea level rise can cause shoreline erosion that leaves roads, boardwalks, hotels, and houses along the coastline vulnerable to storm damage.

There is no data table presented here to quantify acreage impacts to beaches. Because beaches erode and accrete naturally on a short term basis and public beaches are augmented with periodic sand replenishment projects, it may not be apparent that sea level rise is affecting beaches. Often the impacts are more obvious on the bay/wetland side of barrier beaches because without replenishment projects, as the water rises, more land is lost. The degree to which a beach would be affected by sea level rise is difficult to ascertain given the dynamic nature of the habitat. Dramatic changes can be seen annually between winter and summer beach profiles and the natural landward migration of the beach and dune habitat. Periodic beach re-nourishment efforts in developed coastal areas continually reshape the coastline.

Natural Resources

Inter-dunal wetlands are a unique coastal dune habitat type at risk from sea level rise. These small wetlands are found only among maritime dunes along the Atlantic Coast. Despite their proximity to the ocean, their seasonal flooding is driven by groundwater and precipitation. As dynamic as many other beach and dune habitats, these swales are periodically created or destroyed by major storms. Some types are wholly herbaceous vegetation, while others are dominated by shrubs. More than 20 types of rare plants are found in these wetlands. There are 72 acres of this habitat type in Sussex County, Delaware, mostly on protected state parkland. A small percentage would be affected at the 0.5 m scenario but the 1.0 m and 1.5 m scenarios indicate a more drastic impact of 81% and 94% respectively (Table 13). Impacts from predicted sea level rise, made worse by disturbance of normal coastal processes, could be substantial. Note that although inter-dunal wetlands are part of a very dynamic coastal ecosystem, their recovery from disturbance – including sea level rise – is believed to be fairly slow because a thin layer of peat must develop on the sand to establish the plant community. Note: the economic, social, and environmental impacts discussion below refers to the broader category of Beaches and Dunes, not just inter-dunal wetlands.

Table 13 - Inter-dunal Wetlands

County	Total Acres	Total Acres Inundated			Percent of Total Acres Inundated		
		0.5 m	1.0 m	1.5 m	0.5 m	1.0 m	1.5 m
State	72	3	58	68	5%	81%	94%
New Castle	0	0	0	0	0%	0%	0%
Kent	0	0	0	0	0%	0%	0%
Sussex	72	3	58	68	5%	81%	94%

Source: DNREC-Natural Heritage Program, Habitats of Conservation Concern (2011), unpublished

Potential Economic Impact: Based on 2008 statistics from the Delaware Tourism office, the tourism industry was the 5th largest employment sector in the state accounting for 8.3% of Delaware's total employment. The industry brought in approximately $408 million in state and local taxes and fees that year. It was estimated that 16% of total trips involved beach recreation (DEDO, 2008). Delaware's bay beaches and Atlantic coast beaches also provide ecotourism opportunities. A 2006 National Survey found that 395,000 Delaware residents and nonresidents fished, hunted, or watched wildlife in the state. Of the total number of participants, 159,000 fished, 30,000 hunted, and 285,000 participated in wildlife-watching activities, which included observing, feeding, and photographing wildlife (US DOI-FWS and US DOC-Census Bureau, 2006).

The most recent beach replenishment effort in 2011-2012 along the Atlantic coast beaches (Rehoboth, Dewey, Bethany, South Bethany and Fenwick) cost approximately $38 million. This particular sand nourishment project was paid for with federal disaster relief funding. However, the initial project was funded under the typical 35% local and 65% Federal cost share.

Along the Delaware Bay coast during the same time period, beach nourishment occurred using a truck hauling method. The bay beaches replenished were Kitts Hummock with 7,000 cubic yards of sand coasting $111,230, Bowers Beach with 13,000 cubic yards of sand costing $206,570 and South Bowers Beach with 2,000 cubic yards of sand costing $31,780. Unlike the Atlantic Ocean projects, these projects were funded exclusively with state funds.

Potential Social Impact: Coastal communities are intertwined with rising sea levels. The social fabric of these coastal towns is based around fishery activities, marina activities, and tourism. As long as these critical social factors are not affected by sea level rise, then these communities will be able to survive. However, the potential loss of beach access, and the loss of beach resort infrastructure may have impacts on their social structure. Further, as sea levels continue to rise, residents in some coastal communities may experience property damage, interrupted services, and access issues which will negatively affect their quality of life.

Potential Environmental Impact: Coastal habitats are adapted to the dynamic conditions of shifting sands, strong winds, and salt spray unique to the narrow zone along the Atlantic Ocean and Delaware Bay. They range from the beach – covered and exposed by the twice-daily tides – to the first grassy dunes and overwashes, to a complex of shrub-dominated back dunes.

These habitats have declined significantly in extent and quality during historical times primarily because of residential development and associated infrastructure, particularly artificial shoreline hardening, jetties, and groins. In recent decades, this decline has greatly slowed on the Atlantic Coast, where most remaining habitats are on public land. Losses continue along the shorelines of the Delaware Bay and Inland Bays. All of these habitats are subjected to on-going impacts from recreational activities, and Delaware Bay beaches in particular are occasionally impacted by oil spills. The long term prospect for beaches and dunes is potentially poor given predicted sea level rise, even though these disturbance-dependent habitats might be expected to accommodate sea level rise reasonably well by migrating inland. However, onshore and offshore coastal processes that would facilitate such a shift, especially sand transport, may have already been irreversibly compromised by the issues noted above.

Efforts to stabilize dunes may also further disrupt these processes in the future, despite their seeming benefits at present. Beach replenishment is a potential solution to the loss of natural sand transport, but costs are very high and nearshore habitats that serve as a sand source may be adversely impacted (DNREC-Div. of Fish and Wildlife, 2006).

Natural Resources

Upland Forest

Forests offer a wide variety of outdoor recreational activities such as hiking, jogging, biking, horseback riding, camping and hunting. They provide wildlife habitat for a variety of species and provide air quality benefits. They also provide direct economic benefits to the state through timber production.

Approximately one-third of Delaware is forested, according to the 2010 Delaware Forest Resource Assessment generated by the Delaware Forest Service. Of this, 97% is classified as potential commercial timberland and could provide benefits to the timber industry (foresters, loggers, and mills-saw timber, pulpwood, veneer, and pilings). Forests are also valuable for wildlife habitat, recreation, soil protection, water quality and quantity as well as aesthetics (Delaware Forest Service, 2010).

Exposure to Sea Level Rise: Three upland forest types were analyzed for exposure to sea level rise under the three scenarios: evergreen forest, deciduous forest, and mixed forest. However, the map (see Maps 13-15) and the discussion of impacts refers to the impact of all upland forest types combined.

The level of exposure to upland forest resources is fairly limited. The combined exposure to the three forest types represented here range from 2% to 6% of the total upland forested acreage in the state under the range of inundation scenarios (see Table 14 - 17).

Table 14 - Total Upland Forest

County	Total Forested Acres	Total Acres Inundated			Percent of Total Acres Inundated		
		0.5 m	1.0 m	1.5 m	0.5 m	1.0 m	1.5 m
State	177,590	4,236	7,890	11,090	2%	4%	6%
New Castle	41,305	833	1,371	1,857	2%	3%	4%
Kent	35,366	1,060	2,321	3,404	3%	7%	10%
Sussex	100,919	2,344	4,197	5,830	2%	4%	6%

Potential Economic Impact: Forests provide a wide range of social and economic benefits from timber products to recreation to aesthetics. The markets for timber products are a significant sector of our state's economy. While there is no current, statistically-valid data on the contribution of the forest products industry to Delaware, it is certainly a significant component. In 2002, more than 2,600 people were employed in the forest products manufacturing industry in Delaware. Most of these jobs were located in secondary wood processing industries. Sixty-three establishments in Delaware produce a variety of products including furniture, custom millwork, cabinets, and other wood products. Approximately 4,800 acres are harvested annually–2,400 acres by clear-cut, 1,500 acres by selection harvests, and 900 acres of pine thinning (pulpwood). The Delaware Forest Service estimates that these harvests generate at least $4 million of income for landowners annually. Furthermore, urban forests also contribute jobs to Delaware's economy. The number of tree-care companies is growing as Delaware continues to urbanize. There are now 81 certified arborists in Delaware. Nursery farms generate an estimated $47 million in sales annually (Delaware Forest Service, 2010).

Maintaining and growing these markets is vital not only to Delaware's economy but also to sustain the forest land base; owners need to generate sufficient income from their forests to retain their forests. Furthermore, it is important to develop new markets, such as wood energy, to maintain a robust and diverse forest products economy so it is not overly dependent on a single market. Public investment in forests, forest markets, and forest research is also necessary to ensure a sustainable land base and the best information is available to landowners and decision-makers. Addressing all of these issues is necessary to help ensure that Delaware's forests will continue to meet society's needs in the future.

Table 15 - Deciduous Forest

County	Total Deciduous Acres	Total Acres Inundated			Percent of Total Acres Inundated		
		0.5 m	1.0 m	1.5 m	0.5 m	1.0 m	1.5 m
State	58,625	1,250	2,427	3,383	2%	4%	6%
New Castle	38,219	744	1,205	1,641	2%	3%	4%
Kent	16,000	445	1,098	1,549	3%	7%	10%
Sussex	4,406	61	123	194	1%	3%	4%

Source: Delaware Geographic Data Committee, 2007 Delaware Land Use and Land Cover, 2008-05-19

Table 16 - Evergreen Forest

County	Total Evergreen Acres	Total Acres Inundated			Percent of Total Acres Inundated		
		0.5 m	1.0 m	1.5 m	0.5 m	1.0 m	1.5 m
State	29,190	612	1,290	1,833	2%	4%	6%
New Castle	656	5	9	14	1%	1%	2%
Kent	2,366	145	326	485	6%	14%	21%
Sussex	26,168	463	955	1,334	2%	4%	5%

Source: Delaware Geographic Data Committee, 2007 Delaware Land Use and Land Cover, 2008-05-19

Table 17 - Mixed Forest

County	Total Mixed Forest Acres	Total Acres Inundated			Percent of Total Acres Inundated		
		0.5 m	1.0 m	1.5 m	0.5 m	1.0 m	1.5 m
State	89,775	2,374	4,173	5,874	3%	5%	7%
New Castle	2,430	84	157	202	3%	6%	8%
Kent	17,000	470	897	1,370	3%	5%	8%
Sussex	70,345	1,820	3,119	4,302	3%	4%	6%

Source: Delaware Geographic Data Committee, 2007 Delaware Land Use and Land Cover, 2008-05-19

Natural Resources

Potential Social Impact: Forests offer a wide array of outdoor recreation activities. Losses from sea level rise could reduce opportunities for hiking, jogging, biking, horseback riding, camping, hunting, and wildlife observation whether on private or publicly owned lands.

Potential Environmental Impact: Delaware has a large variety of forest communities in a relatively small geographic area. Delaware's bottomland forest species (oak, gum, cypress) may be particularly impacted by sea level rise. However, some of the rarer forests such as the Inland Dune Ridge Forest found in the Nanticoke River area, the Southern New England Red Maple Seepage Swamp found in the Piedmont, and the North Atlantic Coastal Oak-Holly Forest found in the Nanticoke and Choptank River watersheds could potentially be impacted. The loss of these unique forest communities will negatively impact biodiversity, buffering capacity, and wildlife habitat including migratory bird species.

While there is considerable research needed, several potential issues relating to forests and habitat include:

- Migration of maritime forests/riparian areas inland
- Shifts in species range (migration)
- Changes in species composition and/or disappearance of species
- Increases in invasive/nuisance species and disease
- Loss of rare plant species

Additionally, there is need to establish baseline risk assessment for species and habitats and to consider methods to move low-lying riparian forest buffers inland with any rise in sea level to ensure that these buffers are not lost. It is important that these baseline risk assessments account for possible changes from sea level rise in the future.

Flora and Fauna

Habitats of Conservation Concern

The Delaware Wildlife Action Plan, the framework for conserving the state's native wildlife, identifies 27 unique 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 habitat types, 15 were determined to be vulnerable to sea level rise and were analyzed to determine the extent of possible exposure.

Exposure to Sea Level Rise: Fifteen of the 27 Habitats of Conservation Concern (HCC) identified in the Delaware Wildlife Action Plan will be exposed to sea level rise. Under the 1.5 m scenario for sea level rise, approximately half of all HCC's will be inundated and potentially lost (Table 18 and maps in the mapping appendix). The analysis indicates that habitats in Kent and New Castle Counties have a higher level or exposure than those in Sussex County.

Of those HCC's that are exposed to sea level rise, seven types (each a unique type of wetland) could experience inundation of more than 90%. However, it is unknown if, how, and where HCC's and other wetland habitats might migrate to as water levels rise.

Table 18 - Habitats of Conservation Concern (HCC)

County	Total HCC Acres	Total Acres Inundated			Percent of Total Acres Inundated		
		0.5 m	1.0 m	1.5 m	0.5 m	1.0 m	1.5 m
State	31,340	17,088	19,470	20,342	55%	62%	65%
New Castle	3,945	2,480	3,334	3,441	63%	85%	87%
Kent	7,039	5,911	6,460	6,555	84%	92%	93%
Sussex	20,357	8,698	9,676	10,346	43%	48%	51%

Source: DNREC - Natural Heritage Program, Habitats of conservation Concern (2011), unpublished

Potential Economic Impact: The impact of sea level rise on HCC's and their associated wetlands is enormous. Delaware, being a coastal state, relies heavily on its coastal wetlands for part of its economy. There are many ways that coastal wetlands benefit the state. For example, coastal wetlands are extremely important for providing flood protection to houses, roads and other infrastructure from storm surges resulting from hurricanes and nor'easters. They efficiently sequester nutrients and trap sediments to improve water quality. Finally, they provide spawning and nursery habitat for many of our economically important commercial fisheries including the blue crab.

Potential Social Impact: The high intrinsic value of coastal wetlands and their predicted loss from sea level rise will undoubtedly have impacts on society. A substantial loss of habitats of conservation concern is an indicator of overall coastal wetland loss. We have become accustomed, even complacent, about the benefits of our coastal wetlands and the protections to infrastructure, health and the economy they provide. Once those protections are removed, the citizens of Delaware may have to think differently about a variety of issues from how they will get around in the state to where they will find clean water.

Potential Environmental Impact: Intrusion of saltwater into freshwater is an important environmental impact of losing coastal HCC's and their associated wetlands from sea level rise. As waters push further inland, hydraulic pressure at the land/water interface will increase. That pressure will cause saline surface water to move inland underground, salinizing shallow freshwater aquifers. This interaction between saline surface water and fresh and saline groundwater would potentially lead to saltwater contamination of freshwater resources. This interaction is an area that needs further investigation to fully quantify the threats posed to freshwater resources. Other sections (salinity changes, groundwater, freshwater tidal wetlands, and non-tidal freshwater wetlands) within this assessment also identify saltwater intrusion as a pertinent issue.

Additional Information: The amount of each habitat type needs to be monitored with aerial imagery set. These maps can then be updated with each aerial imagery set in order to see whether they are decreasing or increasing. More research needs to be conducted on the resource use of the animals and whether there is a trend of their populations following the trends of the habitat or whether they are adapting to other habitats.

Native Vegetation

Native vegetation discussed within this section includes rare, uncommon, and common species that occur in upland, tidal, and non-tidal habitats near or adjacent to the coast. Specifically, the following Delaware Wildlife Action Plan habitats are considered: beach and dune (overwash, foredune, grassland, inter-dunal wetland, shrubland, forests & woodlands); freshwater tidal (shorelines & mudflats, herbaceous, shrub, forested); peat wetlands (acidic fens); submerged aquatic beds (fresh and brackish); brackish tidal wetlands (herbaceous and shrub); tidal salt water wetlands (salt panne, high wetland, low wetland).

Exposure to Sea Level Rise: An analysis of the flora of Delaware, focusing on the habitats mentioned above (Table 19), found that a total of 631 native species of plants that typically occur within these habitats have the potential to be affected by sea level rise. This figure includes 172 that are state rare and uncommon (11% of the overall state native flora), 7 that are globally rare, and one that is listed as threatened by the U.S. Fish and Wildlife Service. In addition, 22 species that are at the northern limit of their natural geographic distribution and 9 species that are at their southern limit could be potentially affected by sea level rise. If these edge-of-range species, (the majority of which are freshwater species) were to become extirpated, then critical genotypes of the species will become extinct and the genetic diversity of the species will be degraded. Results specific to certain habitat types can be found in the spreadsheet below.

Potential Economic Impact: Unknown.

Potential Social Impact: Unknown.

Potential Environmental Impact: See discussion above.

Table 19 - Flora that may be affected by sea level rise and associated habitat type

DELAWARE WILDLIFE ACTION PLAN HABITAT	Total Taxa	S1	S1.1	S2	S3	Total Rare & Uncommon	% of overall flora	G1, G2, G3	U.S.F.W.S Listed	Northern Limit	Southern Limit
BEACH AND DUNE HABITATS (Overwash, Foredune, Grassland, Interdunal Wetland, Shrubland, Forests & Woodlands)	218	14	3	18	25	57	26	2	1	6	1
FRESH WATER TIDAL (Shorelines & Mudflats, Herbaceous, Shrub, Forested)	170	16	3	15	7	41	24	4	0	6	4
PEAT WETLANDS (Acidic Fens)	122	4	2	21	15	40	33	1	0	5	2
SUBMERGED AQUATIC BEDS (Fresh & Brackish)	35	5	0	3	5	13	37	0	0	0	2
BRACKISH TIDAL WETLANDS (Herbaceous and Shrub)	54	6	3	3	4	13	24	0	0	4	0
TIDAL SALT WATER WETLANDS (Salt Panne, High Marsh, Low Marsh)	32	3	0	2	3	8	25	0	0	1	0
TOTALS	**631**	**48**	**11**	**62**	**59**	**172**	**28**	**7**	**1**	**22**	**9**

Conservation Status Ranks- S1: Extremely rare and of conservation concern; typically 5 or fewer extant occurrences or populations in the state; or only a few remaining individuals; may be especially vulnerable to extirpation. S1.1: To date, only a single extant occurrence or population of this species is known to exist in the state. S2: Very rare and of conservation concern; typically between 6 and 20 known occurrences or populations; may be susceptible to becoming extirpated. S3: Uncommon not of conservation concern; typically 21 to 50 known occurrences or populations. Global Status Ranks-G1: Critically imperiled globally because of extreme rarity (5 or fewer occurrences) or because of some factor(s) making it especially vulnerable. G2: Imperiled globally because of rarity (6-20 occurrences) because of some factor(s) making it especially vulnerable. G3: Either very rare or local throughout its range (21 to 100 occurrences), or found locally in a restricted range, or because of some other factor making it vulnerable to extinction throughout its range.

Native Fauna

Sea level rise impacts to Delaware's fish and wildlife species is a complex issue. Species have evolved to become dependent on habitats and habitat conditions over the millennia. As sea level rises, those habitats could be degraded or lost at a rate faster than species are able to adapt. Indeed, some of the species that are dependent on our coastal resources may already be experiencing population declines due to sea level rise. In particular, spartina high salt marsh (a habitat of conservation concern) harbors black rails, one of the rarest bird species both within the state as well as along the Atlantic coast. Black rail populations have declined by as much as 85% over the last twenty years and there is real concern for this species and its vulnerability to sea level rise. Greater than 99% of its habitat is predicted to be lost under the most conservative sea level rise scenario of 0.5 m by the 2100. This is just one of many examples of species that might be lost in the very near future.

Natural Resources

Exposure to Sea Level Rise: Approximately 20% of the state's native fauna is considered rare and uncommon. Of the rare and uncommon species, 54% could be impacted at the 1.5 m sea level rise scenario which represents 11% of the entire state fauna. In addition, there are species that are currently considered common that may become rare or extirpated as a result of habitat changes from sea level rise. Therefore, 11% of the fauna is a conservative estimate of what could be impacted by sea level rise as this number only accounts for those species currently identified as rare and uncommon. Animals do have the ability to move and adapt with changing conditions and the bathtub inundation model used for this assessment does not take into account habitat that may be created or replaced. Regardless, sea level rise is anticipated to have significant impacts to our fauna. The level to which species populations will decline or become extirpated requires species-specific vulnerability assessments.

Potential Economic Impact: According to a report by the U.S. Fish and Wildlife Service, approximately one out of every three Americans over the age of 16 participates in wildlife watching. This has significant economic impact for Delaware where wildlife watching generates $131 million in retail sales, $77 million in salaries, wages, and business-owner income, and $19.5 million in state and local tax revenue. It also creates 1,975 jobs within the state (Leonard, 2008). While these are state-wide figures, the economic impact from sea level rise would be significant considering that the habitats within the Delaware Bay coastal area are highly vulnerable to sea level rise and are a significant natural resource due to the extent and completeness of its ecological system.

Potential Social Impact: Sea level rise has the potential to result in significant social impacts as a result of wildlife population declines. Although not well understood, there is the possibility that the loss of species that help to control pest or pathogens associated with pests might increase disease transmission. Combined with a warming climate, more pests and pathogens that were once restricted to warmer tropical climates might become established in Delaware (Logan, Regniere, & Powell, 2003). Sea level rise may also impact harvested fish and wildlife to the extent that recreational or commercial hunting and fishing opportunities are no longer available. Finally, many people simply enjoy wildlife viewing. There may be physical and emotional consequences for individuals if opportunities to be outdoors and enjoy nature are limited. The loss of the salt marsh environment in Delaware, the most extensive natural system in the state, may have a negative impact on people and communities who can no longer utilize the habitat for flood attenuation, recreational or commercial purposes.

Potential Environmental Impact: The loss of just one species could be a significant environmental impact that has far reaching consequences. In most cases, it is unknown exactly what a species contributes to the environment around it or what ecological services it may provide. One example is control of pests and pathogens. However, there is also species inter-dependence. The loss of a nectar plant may extirpate a moth that then reduces food for another species and so on. If it were not for horseshoe crabs, red knots and other shorebirds may not find the food they need during a critical period of their life cycle.

Natural Resource Conservation Lands

This section of the assessment focuses on protected lands of conservation and recreational value. The first heading, Protected Lands Statewide, considers lands protected for various purposes and by various agencies. Of this broader category, two sub-heading of protected lands are discussed, Nature Preserves and National Wildlife Refuges. Nature Preserves are discussed because of the unique habitat types and significant ecological of these areas. The National Wildlife Refuges within the state, Bombay Hook and Prime Hook, are also of significant ecological value and represent a large portion of protected land in Delaware.

Protected Lands Statewide

Protected lands statewide are lands that are protected from development by a variety of different organizations and through a variety of different measures. They include state-owned properties such as wildlife areas, state parks, state forests, boat ramps, nature preserves, and historical sites. Protected lands also includes two federally-owned wildlife refuges, Bombay Hook and Prime Hook. Municipal land holdings such as municipal parks, open space, and recreational facilities are also included. Privately-owned land with a permanent and legally binding conservation easement are also included. These easements prohibit future development and in some cases, limit the use of the land to specific purposes (like wildlife habitat) and are "held" by either a state or local government or private conservation organization. Collectively, these properties represent a variety of habitat types and extensive opportunities for outdoor recreation.

Exposure to Sea Level Rise: Sea level rise will bring changes to many of the places and amenities that people visit and enjoy in Delaware. Parks, natural areas and wildlife areas may lose ground to inundation and erosional forces, and wildlife populations may relocate or shrink as a result of changing habitats. Statewide, 37% to 44% of the state's permanently protected land could be inundated by sea level rise under the three planning scenarios (Table 20 Protected Lands (2009)). Geographically, these areas are concentrated in areas adjacent to the Delaware Bay in Kent and Sussex Counties (Maps in Mapping Appendix). Impacts resulting from sea level rise to these lands could affect the tourism industry and recreational opportunities in the first state.

Table 20 - Protected Lands (2009)

County	Total Acres	Total Acres Inundated			Percent of Total Acres Inundated		
		0.5 m	1.0 m	1.5 m	0.5 m	1.0 m	1.5 m
State	168,384	61,989	70,003	74,653	37%	42%	44%
New Castle	45,553	11,407	12,681	13,428	25%	28%	29%
Kent	54,399	30,289	34,336	36,388	56%	63%	67%
Sussex	68,433	20,294	22,986	24,837	30%	34%	36%

Source: DNREC- Parks and Recreation, Outdoor Recreation Inventory (2009), unpublished

Natural Resources

Potential Economic Impact: Outdoor recreation opportunities in Delaware are a large component of the tourism industry, as well as a way of life for Delaware residents. A 2006 national survey of wildlife recreation found that 395,000 people who live in or visited Delaware fished, hunted, or watched wildlife in the state. Of the total number, 159,000 people fished, 30,000 people hunted and 285,000 participated in wildlife-watching activities, which includes observing, feeding, and photographing wildlife (US DOI-FWS and US DOC-Census Bureau, 2006). During this time period, state residents and non-residents spent $299 million on wildlife recreation in Delaware. Of that total, trip-related expenditures were $75 million and equipment purchases totaled $204 million. The remaining $20 million was spent on licenses, contributions, land ownership, and leasing, and other items (Caudill & Henderson, 2005). Inundation of the habitats within protected areas in the state may lead to a reduction in opportunities for fishing, hunting and wildlife-watching and a loss of the associated economic benefit of these activities.

Potential Social Impact: The social fabric of many of Delaware's small coastal towns is based upon fishing, boating, hunting, and other outdoor recreational activities. Reductions in the availability of these amenities as a result of sea level rise may affect tourism levels and local business revenues, leading to loss of business services and sense of community.

Potential Environmental Impact: The environmental impact is difficult to quantify as the lands discussed in this section represent various habitat types statewide. Reduction or loss of habitat within the protected lands can impact populations of the species that inhabit them. Wildlife may be forced to redistribute if habitats within the protected areas no longer meet their needs and may relocate to areas that are not afforded the same protection and management. Species that are unable to relocate may experience population decline.

Additional information about environmental impacts specific to nature preserves and national wildlife refuges are discussed in the following sections.

Nature Preserves

Nature preserves are relatively undisturbed protected lands, free from development pressure that thereby provide exceptional habitat for various species of flora and fauna. The designation of nature preserve is the highest level of land protection afforded by the State of Delaware. These lands are unique and often fragile environments that represent some of Delaware's most important natural habitats. There are currently 28 dedicated nature preserves composed of 65 tracts of both public and private land and water. The total acreage of nature preserves in the state is 4,774 acres.

Exposure to Sea Level Rise: Between 34% and 43% of the total acreage of natural preserves within the state could be inundated by sea level rise of up to 1.5 meters (Table 21). The level of exposure varies based on location and types of habitats within each nature preserve. Within New Castle County, there are four nature preserves that could lose up to half of their area as a result of inundation of up to 1.5 meters of sea level rise. One, Pea Patch Island, could be completed inundated by 1.5 meters of sea level rise. Kent County's Murderkill River Nature Preserve and Mispillion Harbor.

Reserve could also be completely inundated with up to 1.5 meters of sea level rise. In Sussex County, there are eight preserves that could be impacted, one that is approximately 50% inundated (Nanticoke River Nature Preserve) and one that is marginally affected (Doe Bridge Nature Preserve). The percent of each nature preserve that could be subject to sea level rise is presented graphically in the Mapping Appendix.

Table 21 - Nature Preserves (2009)

County	Total Acres	Total Acres Inundated			Percent of Total Acres Inundated		
		0.5 m	1.0 m	1.5 m	0.5 m	1.0 m	1.5 m
State	4,774	1,633	1,874	2,031	34%	39%	43%
New Castle	1,626	414	482	512	25%	30%	32%
Kent	476	197	204	206	41%	43%	43%
Sussex	2,673	1,022	1,188	1,313	38%	44%	49%

Source: DNREC Division of Parks and Recreation, Nature Preserves (2009), unpublished

Potential Economic Impact: The potential economic impact from inundation of nature preserves is unclear. Potential economic losses may come indirectly as a result of reduced ecotourism and associated dollars spent on lodging, food, etc. No economic data specific to nature preserves is available.

Potential Social Impact: Loss of nature preserves as a result of sea level rise would deprive residents and visitors of access to these sites of ecological significance resulting in potential “quality of life” type social impacts and fewer passive recreation opportunities. It is essential that people retain the opportunities to maintain close contact with thriving ecological communities and environmental systems and to benefit from the scientific, educational, esthetic, recreational, and cultural values they possess. The benefit to the public is to have permanently protected unspoiled natural areas to enjoy.

Potential Environmental Impact: As stated above, nature preserves are unique and often fragile environments that represent some of Delaware’s most important natural habitats. Sites selected for dedication as a nature preserve often have an outstanding vegetation community and habitat, species rarity, outstanding geological features or outstanding archaeological features. The environmental impact resulting from sea level rise is difficult to quantify as the preserves represent various habitat types statewide. In general, reduction or loss of unique habitats within the protected boundaries of the preserves can impact wildlife populations and plant communities. If habitats within the preserves no longer meet their needs, wildlife may relocate, sometimes to areas that do not afford the same protection and management that is provided by the nature preserve designation.

Additional Information: Detailed information on types of habitat loss may be available from data collected from each affected preserve. This data is likely available from the Natural Areas Program or may be captured under other land use data layers.

National Wildlife 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 visitors use the refuges for passive outdoor recreation activities such as birding, wildlife watching, and photography, as well as for consumptive wildlife uses such as hunting and fishing. In 2004, 63% of visitors to Prime Hook NWR were residents of Delaware; the remainder were visitors to the state. The vast majority of those visitors were there for non-consumptive (passive) outdoor recreation. Classes and school groups from area schools and colleges also use the refuges for environmental education programs.

Exposure to Sea Level Rise: The sea level rise inundation maps show that between 85-95% of the total acreage of NWRs in Delaware could be inundated by sea level rise (Table 22 USFWS Property). Up to 94% of the over 16,000 acres of marsh, forest and agricultural fields at Bombay Hook NWR could be inundated by sea level rise of 1.5 meters. Up to 98% of the habitats and land at Prime Hook NWR could be inundated by sea level rise of 1.5 meters.

Table 22 - USFWS Property

County	Total Acres of USFWS Property	Total Acres Inundated			Percent of Total Acres Inundated		
		0.5 m	1.0 m	1.5 m	0.5 m	1.0 m	1.5 m
State	25,266	21,354	23,478	24,120	85%	93%	95%
New Castle	0	0	0	0	0%	0%	0%
Kent	16,137	13,010	14,769	15,152	81%	92%	94%
Sussex	9,129	8,344	8,709	8,969	91%	95%	98%

Source: DNREC- Parks and Recreation, Outdoor Recreation Inventory (2009), unpublished.

In addition to the results of the inundation maps that serve as the basis for this vulnerability assessment, the sea level rise risk for Bombay Hook NWR and Prime Hook NWR have been analyzed using the Sea Level Affecting Marshes Model (SLAMM). SLAMM analysis has limitations which are discussed in more detail within each specific SLAMM report (Scarborough, 2009). However, the results provide further indication of the magnitude of threat facing the two National Wildlife Refuges in Delaware and demonstrate the potential associated land cover changes.

For Prime Hook NWR, a SLAMM analysis was conducted by the Delaware Coastal Programs, utilizing SLAMM version 5 combined with more accurate elevation data than was typically relied upon for that version of the model (Scarborough, 2009). The model was applied utilizing inputs representing a range of possible future scenarios. It is anticipated that the reality could fall anywhere within these predicted outcomes. For example, under the 0.5 meter sea level rise scenario, if the model assumes that salt marsh accretion keeps pace with current sea level rise rates, and that there is full tidal influence along the coast, then the refuge is predicted to lose more than half of its marsh, and the amount of open water and tidal mudflat (combined) will more than quadruple. If the model assumes that salt marsh accretion will increase to 5.0 mm/year, keeping pace with sea level rise as salt marshes often can, then the reduction of marsh acreage is small and conversion to open water and tidal mud flat are not as pronounced. In both cases, more than half of the upland is predicted to be lost. The primary difference is whether or not the remaining areas are maintained in some form of wetland cover, or are converted to open water. Under each sea level rise and marsh accretion scenario, if the model assumes that coastal dunes will instead be maintained, these predictions do not change appreciably. Results for additional scenarios, such as increased rates of sea level rise, can be found in (Scarborough, 2009).

For Bombay Hook NWR, this effort was conducted in 2010 by a contracting firm on behalf of the USFWS Washington Office (Clough & Larson, 2010). Input values (e.g., elevation, sea level rise, accretion, erosion) were based on the available local or regional estimates. Under this analysis, Bombay Hook is predicted to lose more than three quarters of its regularly flooded (salt) marsh in scenarios higher than 1.0 meter. This model predicted that saltmarsh will increase with sea level rise scenarios less than 1.0 meter due to the conversion of irregularly flooded marshes. The refuge is predicted to lose between 23% and 62% of its upland, and between 15% and 97% of its irregularly flooded marsh across all scenarios. Maps of model results seem to predict that the refuge is fairly resilient to rates of eustatic sea level below 1.0 meter by 2100. However, there are concerns regarding the accuracy of the elevation data covering the refuge (Clough & Larson, 2010). New elevation data obtained during spring 2011 may allow for a new, more accurate, SLAMM analysis of Bombay Hook NWR.

Potential Economic Impact: Refuge management activities and influences contributing to the economy of the surrounding communities include Refuge purchases of goods and services within the local community, Refuge personnel salary spending, revenues generated by Refuge Revenue Sharing, and spending in the local community by Refuge visitors. The effects of sea level rise on Delaware's National Wildlife Refuges could have significant indirect economic impacts to the communities near the refuge, and thus to the state, from loss of recreational opportunities, and therefore loss of economic activity generated by recreation on Refuges. Potentially, changes in Refuge habitats could lead to changes in management that would alter other economic activities of the Refuges, but this cannot be estimated. For both Refuges, the "Banking on Nature" reports provide information on the economic input of the Refuge to the surrounding economy (Caudill & Henderson, 2005). This report examines expenditures by people visiting Refuges, and also calculates the "final demand" associated with each Refuge. Final demand is defined as the total spending by final consumers on all goods, in a given region, attributable to refuge visitation. Final demand includes spending by people who earn income from refuge visitors' activities as well as spending by refuge visitors themselves.

Natural Resources

According to “Banking on Nature,” the total visitor recreation expenditures for Bombay Hook NWR in 2004 were $3,166,800, with non-residents accounting for $3,009,800 (95 percent of total expenditures). Expenditures on non-consumptive activities accounted for 99 % of the total with hunting accounting for one percent. Total final demand was $4,316,600. This is the total monetary value of economic activity generated in the 2-county area by refuge visitor spending. In turn, this final demand generated 37 jobs (both full-time and part-time) with total job income of $1,387,400. Total tax revenue generated (county, state, and federal) amounted to $855,000.

At Prime Hook NWR, “Banking on Nature” reports that visitor recreation expenditures in 2004 were $1,043,600 with non-residents accounting for $795,000, or 76%, of the total Refuge visitor recreational expenditures. Dollars spent by non-consumptive users totaled $771,900, fishing expenditures accounted for $222,100, or 21% of the total, and hunting expenditures totaled $49,700, or 5% of total recreation expenditures. The final demand was calculated as $1,456,000. This amount reflects the total monetary value of economic activity generated in the three counties of Delaware by Prime Hook NWR visitor spending. In turn, the final demand generated 13 jobs (both full-time and part-time) with a total job income of $419,400. Total tax revenue generated (county, state, and federal) amounted to $291,000.

At Prime Hook NWR, the Regional Economic Impacts of Current Management for the Refuge were also estimated using the “Impacts Analysis for Planning” (IMPLAN) regional input-output modeling system (Koontz, 2010), providing an updated refuge-specific report. Refuge management activities directly related to Refuge operations generate an estimated $2.7 million in local output, 25 jobs, and $742,000 in labor income in the local economy. Including direct, indirect, and induced effects, Refuge activities are estimated to generate total economic impacts of $3.9 million in local output, 33 jobs, and $1.1 million in labor income.

More specifically, non-consumptive uses (such as birding and general refuge visits) directly related to Refuge operations are estimated to generate $2.1 million in local output, 21.3 jobs, and $602,700 in labor income in the local economy. Including direct, indirect, and induced effects, non-consumptive uses are estimated to generate total economic impacts of $3.1 million in local output, 29.3 jobs and $875,000 in labor income. Fishing activities directly related to Refuge operations are estimated to generate $180,4000 in local output, 1.8 jobs, and $50,400 in labor income in the local economy. Including direct, indirect, and induced effects, fishing activities are estimate to generate total economic impacts of $252,500 in local output, 2.1 jobs, and $72,100 in labor income.

Overall hunting activities directly related to Refuge operations are estimated to generate $73,500 in local output, 0.6 jobs, and $21,000 in labor income in the local economy. Including direct, indirect, and induced effects, overall Refuge hunting activities are estimated to generate total economic impacts of $103,600 in local output, 0.9 jobs, and $30,100 in labor income. A further breakdown of hunting activities on the Refuge, including direct, indirect, and induced effects, reveals that big game hunting on the Refuge would generate total economic impacts of $45,500 in local output, 0.4 jobs, and $13,00 in labor income. Waterfowl hunting on the Refuge is estimated to generate total economic impacts of $60,000 in local output, 0.5 jobs, and $16,600 in labor income. Small game hunting on the Refuge would generate total economic impacts of $2,000 in local output, 0.02 jobs, and $500 in labor income.

Impacts from sea level rise would likely result in a conversion of large areas of Refuges to different habitat types, and/or open water. The Refuges will still provide wildlife habitat, even if the nature of that habitat has changed, so, it is possible that outdoor recreation opportunities would remain. However, it is reasonable to expect that the quality or accessibility would be reduced, resulting in economic impacts for the nearby area.

Potential Social Impact: Social impacts will stem from the loss of recreational opportunities, as well as from the loss of quality wildlife habitat. As described above, recreation at the Refuges provides significant and measurable economic benefit to the local economy by encouraging tourism from outside Delaware. The loss of such benefits will have considerable societal impact. Area residents, in particular, will suffer from the loss of a treasured natural area. Residents who use the Refuges for convenient source of recreation and a place to relax in the outdoors will be deprived of those opportunities, as access to the Refuges is likely to decrease following inundation. Regardless of how frequently they may visit, the mere presence of highly regarded National Wildlife Refuges in the area can be a sense of pride for some residents.

Far more difficult to quantify, but worth noting, is the loss of ecosystem services provided by the habitats, particularly the wetlands, that comprise both Refuges. These impacts are discussed in more detail under the assessment for each habitat resource (e.g., tidal emergent wetlands, forested wetlands). In summary, healthy wetlands provide a measure of flood protection by absorbing run-off from uplands as well as storm surge from the Delaware Bay. Healthy wetlands also improve water quality in areas downstream. The coastal wetlands of the Refuges, which are likely first to be inundated, provide important nursery habitat for fish species that are an important component of the local seafood economy. Indirect society impacts of inundation of the Refuges include loss or degradation of these important ecosystem services provided by Refuge lands.

Potential Environmental Impact: National Wildlife Refuges are an incredibly important environmental resource in Delaware, and sea level rise is anticipated to have many significant environmental consequences. Both NWRs were established primarily for migratory birds, due to their position within the Atlantic flyway. Birds in various guilds concentrate at both Refuges at different stages of their life history. For example, both Refuges are important for migrating and overwintering waterfowl in the fall and winter, and for migrating shorebirds in the spring and late summer. Refuge wetlands also provide habitat for wading birds, secretive marsh birds, wetland passerines, and other landbirds. Reduction or loss of wetland habitats within the protected boundaries of the Refuges can impact populations of these species. They may be forced to redistribute if Refuge wetlands no longer meet their needs, and relocate in wetlands that are not afforded the same protection and management that is provided by the NWR designation.

Natural Resources

Further details about the environmental consequences of the reduction or loss of specific habitat types found on the Refuges, especially wetlands, can be found elsewhere in this vulnerability assessment.

Agriculture

Agricultural land used in Delaware ranges from local crop and vegetable farms to large poultry producers and food processors. Support businesses, such as grain, fertilizer, and irrigation supply businesses, also fall in the agricultural use category. Many groups throughout Delaware benefit from the strength of the agricultural economy. State and local government agencies use funds generated by agricultural taxes to support other programs. This section discusses the potential impact from sea level rise on highly productive soils, agricultural preservation districts and conservation easements. The Society and Economy section of this document includes additional information about agricultural impacts.

Highly Productive Soils

The category of highly productive soils includes prime farmland and farmland of statewide importance. Prime farmland is land which has the best combination of physical and chemical characteristics for the production of crops. It has the soil quality, growing season, and moisture supply needed to economically produce sustained high yields of crops when treated and managed, including water management, according to current farming methods. Prime farmland does not include publicly owned lands for which there is an adopted policy preventing agricultural use (NRCS). Farmland of statewide importance is land other than prime farmland which has a good combination of physical and chemical characteristics for the production of crops. Farmlands of statewide importance include those that are nearly prime farmland and that produce high yields of crops when treated and managed according to acceptable farming methods. It does not include publicly owned lands for which there is an adopted policy preventing agricultural use (NRCS).

Exposure to Sea Level Rise: According to the inundation maps, exposure of highly productive soils to sea level rise are low, with only 2% to 4% of the highly productive soils potentially exposed under the three scenarios (Table 23 and maps in Mapping Appendix). An additional consideration is that highly productive soils data only considers the soil type; it does not consider whether or not the land area is used for agriculture. Localized impacts from sea level rise may be significant but would not likely negatively affect the state as a whole.

Table 23 - Highly Productive Soils

County	Total Acres of Highly Productive Soils	Total Acres Inundated			Percent of Total Acres Inundated		
		0.5 m	1.0 m	1.5 m	0.5 m	1.0 m	1.5 m
State	693,128	12,564	22,699	32,361	2%	3%	4%
New Castle	147,779	2,538	4,366	5,934	2%	3%	4%
Kent	279,976	4,111	7,969	11,865	2%	3%	4%
Sussex	265,373	5,916	10,364	14,562	2%	4%	5%

Source: Delaware Coastal Programs, Prime Farmland (2011) and Farmland of Statewide Importance, unpublished

Potential Economic Impact: Prime farmland and farmland of statewide importance are the areas of Delaware where the highest crop production rates could occur (if the soils are in agricultural production). These soils are the state's economic drivers for agriculture; in 2009, net farm income was estimated at $193 million (Awokuse, Ilvento, & Johnston, 2010). Inundation of highly productive soils could render them unsuitable for agricultural purposes and decrease farming income to individuals and throughout the state, however, the percentage of highly productive soils potentially impacted is low and not all of these soils are in agricultural production. In addition to inundation, saltwater intrusion as a result of sea level rise could impact agricultural activities in general by decreasing crop yield, completely eliminating the capability of growing certain crops, and impacting the health of domestic livestock.

Potential Social Impact: Many communities in Delaware developed due to relative proximity to prime farmland. The potential loss of productive agricultural fields and resulting losses in employment may cause farmers and farm workers to relocate to areas not affected by sea level rise, causing losses to the local agricultural heritage of a community.

Potential Environmental Impact: Agriculture in Delaware often relies on irrigation which may be impacted by the intrusion of seawater pushing further up into fresh water stream and rivers. In coastal areas, the increased water withdrawal, combined with sea level rise, may increase saltwater intrusion into the groundwater or aquifers. Additionally, in agricultural locations near the coast, the seaward boundary for agriculture often is the point where saltwater penetrates inland far enough to prevent crops from growing (IPCC, 2007). As sea level rises, this boundary could move farther inland causing increased amounts of farmland to become too salty for traditional crop cultivation. Once seawater has invaded to a distance beyond that is tolerable, restoration of water quality in the invaded zone is generally an expensive or ineffective proposition. (Bear, Cheng, Sorek, Ouazar, & Herrera, 1999). Concerning prime farmland and farmland of state-wide importance, these soil types will lose their high production characteristics as salinity increases. The land may still allow for cultivation however, crop yields will begin to diminish well before inundation occurs.

Natural Resources

Preservation Districts and Conservation Easements

The Delaware Department of Agriculture implements a preservation program that uses two strategies to preserve farmland, agricultural preservation districts and agricultural conservation easements. A district is a voluntary agreement to use land only for agricultural purposes for at least a ten year period. Land must yield a minimum farm income, satisfy a scoring system standard, and undergo a review and approval process. Almost any size farm anywhere in the state can qualify. Permitted agricultural uses include but are not limited to: crop production, herd animal and poultry operations, horse operations, forest production, non-commercial hunting, trapping and fishing, and agricultural eco-tourism operations, as well as farm markets and roadside stands. In order to permanently preserve farmland, the development rights are purchased from landowners and a permanent agricultural conservation easement is placed on the land. Land must first be in an agricultural preservation district before the owner can apply to sell the development rights.

Exposure to Sea Level Rise: Approximately 8% -11% of acreage within Delaware's agricultural land preservation districts will be exposed to sea level rise (Table 24 and maps in the Mapping Appendix). The largest percentage of impact will be felt in New Castle County where 14% -16% of district farmland will be inundated under the 3 scenarios. Kent County has a similar range of 11% -16% of the total acreage impacted; however this percentage represents the largest acreage of impact within any of the counties. Impacts in Sussex County, where development has largely replaced farmland in coastal areas, range from 2% - 4% of the total district farmland.

Table 24 - Agricultural Land Preservation Districts

County	Total Acres of Land Preservation	Total Acres Inundated			Percent of Total Acres Inundated		
		0.5 m	1.0 m	1.5 m	0.5 m	1.0 m	1.5 m
State	55,907	4,307	5,281	6,218	8%	9%	11%
New Castle	6,264	847	940	1,028	14%	15%	16%
Kent	26,676	2,995	3,656	4,287	11%	14%	16%
Sussex	22,967	464	685	904	2%	3%	4%

Source: Del. Dept. of Agriculture, State Ag Easements, 2010-09-17

Approximately 13% - 17% of acreage of Delaware's agricultural land conservation easements could be exposed to sea level rise under the 3 scenarios (Table 25 and maps in the Mapping Appendix). Again, the largest percentage impact will be felt in New Castle County where 25% - 31% of preserved farmland within the county will be inundated. Kent County has a range of 14% - 19% of the total area impacted; however, this percentage represents the largest acreage of impact within the three counties. Impacts in Sussex County, where development has largely replaced farmland in coastal areas, range from 5% - 8% of the total farmland under conservation easement.

Table 25 - Agricultural Land Conservation Easements

County	Total Acres of Land Conservation	Total Acres Inundated			Percent of Total Acres Inundated		
		0.5 m	1.0 m	1.5 m	0.5 m	1.0 m	1.5 m
State	94,401	11,826	13,864	15,920	13%	15%	17%
New Castle	11,693	2,950	3,317	3,652	25%	28%	31%
Kent	52,139	7,334	8,532	9,687	14%	16%	19%
Sussex	30,569	1,542	2,015	2,582	5%	7%	8%

Source: Del. Dept. of Agriculture, State Ag Districts, 2010-09-17

Potential Economic Impact: As mentioned in the previous section, net farm income for Delaware was estimated at $193 million in 2009 (Awokuse, Ilvento, & Johnston, 2010). Agriculture is a major driver of the state's economy. However, it is difficult to gauge the specific impacts to farms in the preservation program from sea level rise with the general information available for this assessment.

Potential Social Impact: Many communities in Delaware developed due to relative proximity to prime farmland. The potential loss of productive agricultural fields and resulting losses in employment may cause farmers and farm workers to relocate to areas not affected by sea level rise, causing losses to the local agricultural heritage of a community.

Potential Environmental Impact: Agriculture in Delaware often relies on irrigation which may be impacted by the intrusion of seawater pushing further up into fresh water stream and rivers. In coastal areas, the increased water withdrawal, combined with sea level rise, may increase saltwater intrusion into the groundwater or aquifers. Additionally, in agricultural locations near the coast, the seaward boundary for agriculture often is the point where saltwater penetrates inland far enough to prevent crops from growing (IPCC, 2007). As sea level rises, this boundary could move farther inland causing increased amounts of farmland to become too salty for traditional crop cultivation. Once seawater has invaded to a distance beyond that is tolerable, restoration of water quality in the invaded zone is generally an expensive or ineffective proposition (Bear, Cheng, Sorek, Ouazar, & Herrera, 1999). Concerning prime farmland and farmland of state-wide importance, these soil types will lose their high production characteristics as salinity increases. The land may still allow for cultivation however, crop yields will begin to diminish well before inundation occurs.

Additional environmental impacts may come from the loss of open space and actively farmed acreage which could result in habitat losses, decreases in water quality and increased erosion.