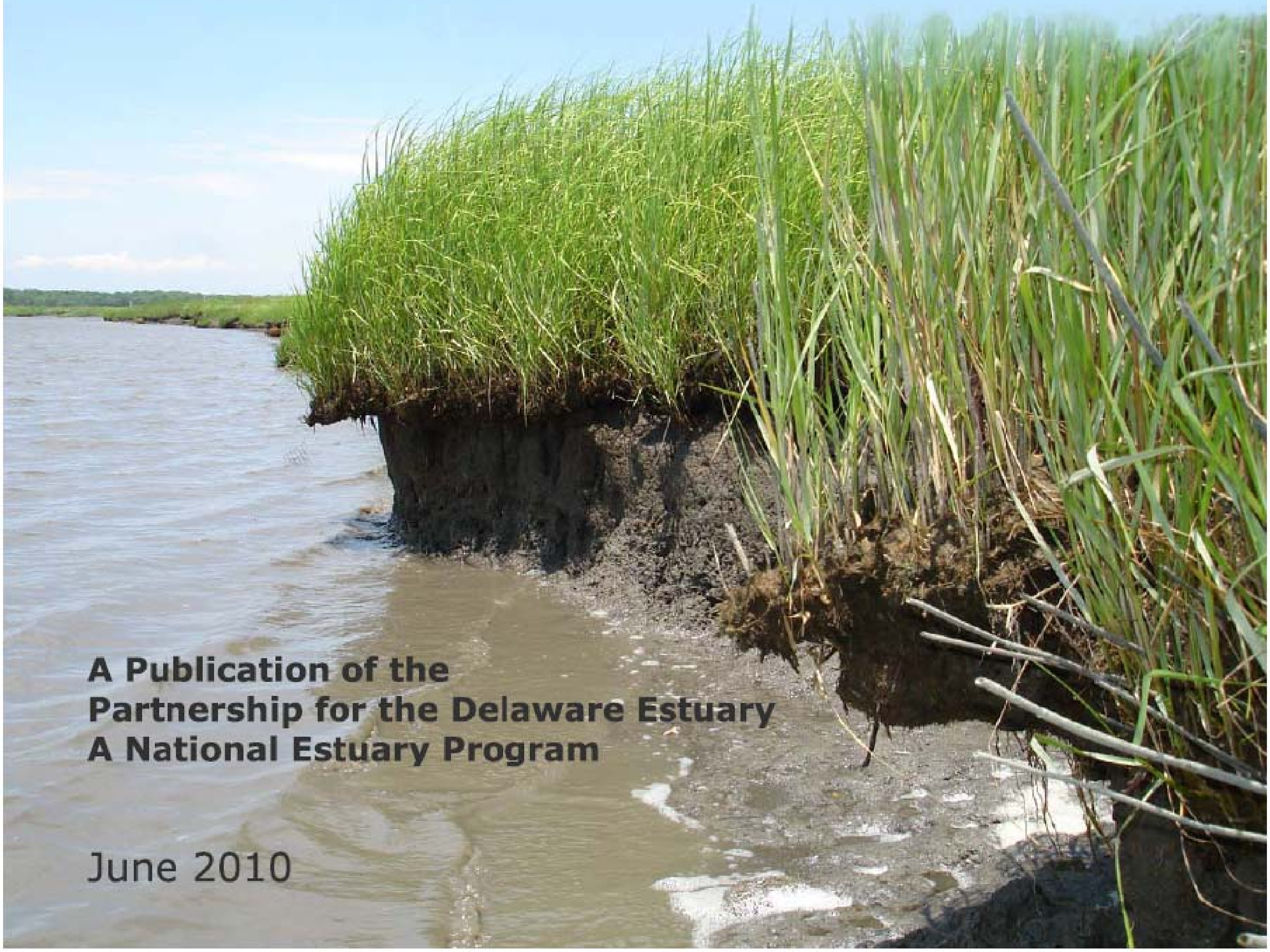
Climate Change and the Delaware Estuary

Executive Summary



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Established in 1996, the Partnership for the Delaware Estuary is a non-profit organization based in Wilmington, Delaware. The Partnership manages the Delaware Estuary Program, one of 28 estuaries recognized by the U.S. Congress for its national significance under the Clean Water Act. PDE is the only tri-state, multi-agency National Estuary Program in the country. In collaboration with a broad spectrum of governmental agencies, non-profit corporations, businesses, and citizens, the Partnership works to implement the Delaware Estuary's Comprehensive Conservation Management Plan to restore and protect the natural and economic resources of the Delaware Estuary and its tributaries.

Executive Summary

The Delaware Estuary watershed and its natural resources will face a variety of challenges with climate change. Due to the many unique features of the Estuary, some aspects of changing climate may not be as severe here as in nearby watersheds and estuaries, whereas other changes may be more important. Since 2008, the Partnership for the Delaware Estuary has engaged experts from throughout the region to conduct an assessment of the vulnerabilities and adaptation options for three key resources of the Delaware Estuary: tidal wetlands, drinking water, and bivalve shellfish. These provide three case studies – a habitat case study, a human/water use case study, and a living resource case study – for looking at climate change impacts and how best to adapt to them here in the Delaware Estuary. These case studies represent the very first step in an adaptation planning process, the goal of which is to ensure the resiliency of this vast and valuable system as climate changes.

This image from the US Geological Survey, Dept. of the Interior depicts the Delaware Estuary from above with land areas in shades of green and open water in blue.

How Will Climate Change in the Delaware Estuary?

To answer this question, the Partnership enlisted the help of a predictions team led by Dr. Raymond Najjar from The Pennsylvania State University. This prediction team's work confirmed that climate models like those used by the Intergovernmental Panel on Climate Change (IPCC) are relatively good predictors of key elements of past climate in the Delaware Estuary region. The details of this work can be found in Chapter 2 and the appendices referenced there. Climate change resulting from two greenhouse gas emissions scenarios was investigated. The median projections of the 14 climate models for the end of this century are as follows:

- Temperatures will rise between 2 and 4 degrees Celsius, with substantially more warming in summer than in winter, resulting in more extreme heat days.
- Precipitation will increase by 7-9%, with substantially more increase in winter months, and 5-8 more days of heavy precipitation annually.
- The growing season will increase substantially (by 15-30 days annually) and the number of frost days will decrease substantially (by 20-40 days annually).
- Sea-level will rise by between .5 meters and 1.5 meters (or more).
- Sea-level rise will result in larger tidal volumes that bring more salt water up the estuary, and some of that salinity increase could be offset by increases in precipitation, at least during cooler months.

For temperature, precipitation and growing season metrics, the ranges of these predicted changes represent the difference between the high and low emission scenarios used in prediction models. The difference between the high and low ends of these predictions may not seem like much – for example, between 2 and 4 degrees Celsius of temperature increase. But the consequences to human populations and natural resources are expected to be dramatic between these two temperature outcomes. A one-degree rise is capable of causing local extinction or extirpation of some plants and animals, but a four-degree rise is likely to lead to mass extinction (Yohe et al., IPCC, 2007). These differences emphasize the importance of taking aggressive action to reduce greenhouse gas emissions as soon as possible.

However, for the next quarter century, predictions indicate that the Delaware Estuary (like the rest of the world) is locked into a climate change trajectory dictated by levels of greenhouse gasses already released. Even if all carbon dioxide emissions were stopped today, climate change will continue on this trajectory for many years. Therefore, in the short-term, the region will have to adapt to the forecast climate conditions.

How Will Climate Change Effect the Resources of the Delaware Estuary?

Assessing the effects of climate change on the vast and varied resources of the Delaware Estuary is a huge effort, and one that can only be accomplished over time, and with a tremendous commitment of resources. The three case studies examined here represent a small fraction of the effects that climate change will have on our region and broader society, including people and property. But they offer insights into how natural resources can be impacted by climate change, and how we can begin assessing those impacts and our options for adapting to minimize them. These case studies provide valuable information about the vulnerability of a select set of key resources, and changes that will impact them the most, based on the best available information and expert opinion.

More than 15 million people get their drinking water from the Delaware Basin.

An expert team led by Dr. David Velinsky of the Academy of Natural Sciences assessed five different elements of climate change for their impacts on two different types of tidal wetlands. For a full explanation of results, see Chapter 3 and the appendices referenced there. In summary, results indicate that tidal wetlands are most vulnerable to three of the elements assessed: increases rates in sea-level rise, salinity, and precipitation and storms. The top single concern to experts in our region is the effect of sea-level rise on Brackish/Saltwater Wetlands. These wetlands run a high risk of "drowning" as sea-levels rise in the Lower Estuary. On the other hand, freshwater tidal wetlands are thought to be highly vulnerable to all three of those elements, and especially to salinity effects. With plant communities that cannot tolerate high salinity levels and few areas left to migrate inland because of the built environment, the narrow fringe of freshwater wetlands remaining in the Delaware Estuary faces a combination of threats.

To assess climate change impacts on drinking water resources (specifically, surface water) a team of experts led by Paula Conolly of the Philadelphia Water Department examined impacts of potentially changing physical conditions in the Delaware Basin on drinking water. For a full explanation of results, see Chapter 4 and the appendices referenced there. Important concerns identified by the workgroup as ideal candidates for future study include potential damage to, and inundation of, drinking water infrastructure through flooding, sea-level rise, and storm surge. Drinking water treatment plants, pumping stations, and other infrastructure are located close to water resources and in the direct path of flooding and storm surges. Degraded source water quality is also of concern to drinking water experts. With potentially heavier precipitation and continued development of the watershed, runoff will increasingly contribute to both flooding and decreased water quality. Salinity intrusion exacerbated by sea-level rise and storm surge, and power outages and customer supply issues which could be influenced by increased flooding and storm surge are also major concerns for drinking water supplies.

Bivalve shellfish play a unique role as both a living resource to protect in the Delaware Estuary, and a source of habitat and water quality protection for the Delaware Estuary. The effects of five elements of climate change on bivalves in the Delaware Estuary were assessed by a team of shellfish experts led by Dr. Danielle Kreeger of the Partnership for the Delaware Estuary. For a full explanation of results, see Chapter 5 and the appendices referenced there. Overall, concern for freshwater mussels emerged as greatest among shellfish experts, based on vulnerability to the effects of storms, temperature, and precipitation. The life history of freshwater mussels makes them not only directly vulnerable to these effects, but also indirectly vulnerable through impacts to the fish hosts required to complete their life cycle, and impacts to the conditions the streams that serve as their habitat. The effect of sea-level and salinity on both freshwater tidal bivalves and saltwater bivalves, like oysters, is also a major concern. For oysters, sea-level rise and salinity combined with temperature increases will likely contribute to more virulent diseases that can take a great toll on oyster populations. Freshwater tidal bivalves cannot tolerate salinity, so sea-level and salinity increases would force their populations into smaller areas.

Planting oyster in the Bay for the Delaware Bay Oyster Restoration Project has demonstrated a $40 to $1 return on investment of federal dollars based on dockside value.

For all three case studies, the top concerns among experts are the vulnerabilities of key resources to sea-level rise and salinity changes, and flooding and precipitation effects. Whereas, many estuaries around the world are concerned with sea-level rise, the vulnerability to salinity rise in the Delaware Estuary is somewhat unique, and especially notable because this system has the world's largest freshwater tidal prism.

What Are the Options for Making Key Resources More Resilient to Climate Changes?

Anticipating all of the options available to us to adapt to climate change, now and in the future, is impossible. However, the case studies provide us with a basic grasp of the most feasible and effective options available to us in the short term for protecting some key resources.

Allowing for landward migration was identified by tidal wetland experts as the most promising adaptation tactic for tidal wetlands. For a full explanation of results, see Chapter 3 and the appendices referenced there. For some tidal wetlands this can be facilitated by protecting the natural buffers along side wetlands and instituting structure setbacks so that wetlands can make their way into those areas as sea-level rises. For areas where structures, roads, or other improvements are in the way of wetland migration, their removal (a type of strategic retreat) may be the best adaptation option. Experts also identified the installation of living shorelines as a promising adaptation tactic in places where they can be effective at stemming erosion. In addition, managing water flows was identified as a potentially important tactic for maintaining salinity balance by insuring adequate freshwater flows into the system. Determining where each of these tactics is appropriate will require development of a geospatial framework that integrates LIDAR, land use, and monitoring data.

Installations of "living shorelines" like these on the Maurice River, NJ can help prevent erosion of wetlands.

Drinking water experts selected one regional-level priority and one utility-level priority adaptation option for each major drinking water vulnerability identified. The options selected were identified by the workgroup as the most important actions needed now to address the vulnerabilities. Adaptations selected generally do not require extensive climate change modeling; they minimize current threats to drinking water supplies to provide a "cushion" for physical changes expected as a result of climate change, or they aim to improve current knowledge of conditions in the Basin order to facilitate future projections. To address potential degraded source water quality, forest protection in the Upper Delaware Basin was identified is the single most important action needed on a regional level. Improving monitoring of priority parameters, such as UV254, chlorides, turbidity, and other concerns for drinking water is the most critical utility level adaptation identified. With respect to the potential for increased spills and accidents, ensuring continued support for tools that facilitate region-wide communication during emergencies, such as the Delaware Valley Early Warning System, is key. Modernizing emergency response protocols is also essential at a utility level. For a full explanation of results, see Chapter 4 and the appendices referenced there.

The top three adaptation options identified by shellfish experts for assisting bivalve shellfish to adapt to climate change are direct restoration efforts: plant shell to restore oyster beds, propagate all bivalves and seed new reefs/beds, and restore forested areas along streams for freshwater mussels. Through these activities, populations of bivalves can be restored and strengthened to be more resilient to climate change. However, two more challenging adaptation tactics were also identified as imperative for bivalves. One of these is managing water flow to minimize the effects of flooding on freshwater mussels and salinity on oysters and freshwater tidal bivalves. The other is maintaining water quality for all bivalves. Both will require the concerted efforts of government agencies, conservation organizations, and local communities to be successful. For a full explanation of bivalve shellfish adaptation options assessment results, see Chapter 5 and the appendices referenced there.

Sampling teams look for freshwater mussels in headwater streams in Pennsylvania.

For all three case studies, the protection and/or restoration of buffers (of various types) and the management of water flows were identified by experts as critical actions for climate change adaptation. It's also important to note the two-way connection between adaptation options for bivalve shellfish and tidal wetlands and improving water quality and system resiliency. Maintaining water quality and system resiliency is important for sustaining tidal wetlands and bivalve shellfish – ***and vice versa***. Bivalve shellfish and tidal wetlands also play an important role in improving water quality and system resiliency, making investment in these resources extremely important.

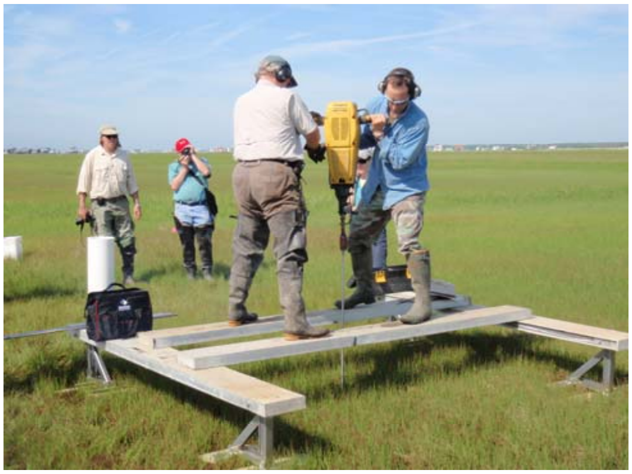
What Actions Are Recommended to Protect Key Resources?

The three case studies provide valuable insights into the actions we can take today and in the near future to help key resources adapt to climate change in the Delaware Estuary. A complete set of recommended actions is provided in each case study chapter; following is a synthesis that takes into account some of the key points and commonalities between case studies.

Take immediate action to protect buffers, plant shell, and protect drinking water infrastructure.

- Protect known forested streamside areas and undeveloped wetland buffer migration areas to benefit water quality and allow tidal wetlands to migrate.
- Continue/reinvigorate shell planting on existing beds for oyster restoration.
- Evaluate placement of new drinking water infrastructure with respect for potential exacerbated flooding.

Develop and fund a climate monitoring program for tidal wetlands, bivalve shellfish and drinking water quality. Indicators are needed to track both impairments (and possibly benefits) that result from climate change, such as the presence of oysters in intertidal areas. Scientific analyses should be directly relevant for managers. It should help to bolster our understanding of the benefits (a.k.a., ecosystem services) of these habitats and species to watershed health as well as the consequences of watershed management on these habitats and species. This information is crucial to carrying out each of the following recommendations, and to developing the more detailed projections and adaptations that will be required to ensure the resiliency of the Delaware Estuary to climate change. More monitoring at a utility level and regional level to detect trends in important parameters for drinking water, such as UV254, chlorides and turbidity, is a good example of a specific monitoring need.



Surface elevation tables like this one recently installed in neighboring Barnegat Bay, NJ can be used to monitor changing marsh conditions over time.

Develop watershed and estuarine hydrodynamic models to fill information gaps about the combined effects of key climate change drivers. Across all three case studies, vulnerability to sea-level rise and the need for flow management were common concerns. To better predict the effects of sea-level on local resources (and interacting with precipitation, flooding, and salinity) and to manage freshwater flows, improved information and modeling of flows in the watershed is greatly needed. This information is also critical for evaluating the combined effects of climate change with other major initiatives and events that could impact the Estuary, such as channel deepening, Marcellus gas drilling, and oil spills.

Develop a geospatial framework to identify priority tidal wetland areas to restore and protect, including:

- Vulnerable areas of tidal wetlands that could benefit from restoration or adaptation to increase or enhance the acreage that is sustainable. For example, living shorelines can be installed to slow erosion and stem marsh loss at seaward edges, and sediment budgets and hydrology can be engineered to help marshes build themselves up. These tactics help tidal wetlands maintain their elevation and health in relation to rising sea-levels.
- Lands in the buffer zone landward of current tidal marshes that have suitable elevation, slope and other traits can be managed to facilitate tidal marsh expansion into these areas. For example, tactics like strategic retreat, setbacks or conservation easements can be used to ensure unimpeded marsh migration.

Assess stream and shoreline conditions to identify priority bivalve populations for restoration, including:

- High quality areas for augmentation, where the current population is below the system's carrying capacity and can be augmented through hatchery propagation and outplanting of seed, relocation of gravid broodstock, and restoration or protection of forests along streams.
- Promising areas for reintroduction that currently are not colonized, where bivalves can be (re)introduced and supported through hatchery propagation and outplanting of seed, relocation of gravid broodstock, and restoration or protection of forested areas along streams.

Educate the broader resource management community about key Delaware Estuary resources, including:

- The importance of tidal wetlands and bivalves for watershed health and the effects of water quality and quantity on them.
- The importance of using green infrastructure to address local issues, build community amenities, and add to overall Basin resiliency in the face of climate change.

Rain gardens like this one planted with the help of volunteers in New Castle County, DE are one example of "green infrastructure."

Identify special protection or management areas based on key ecosystem goods and services furnished. Quantify the ecosystem goods and services furnished by key resources like wetlands, bivalves, and forests (for drinking water) in different locations and prioritize areas having the greatest natural capital. This does not apply to the main oyster beds in Delaware Bay, which are already carefully protected and managed.

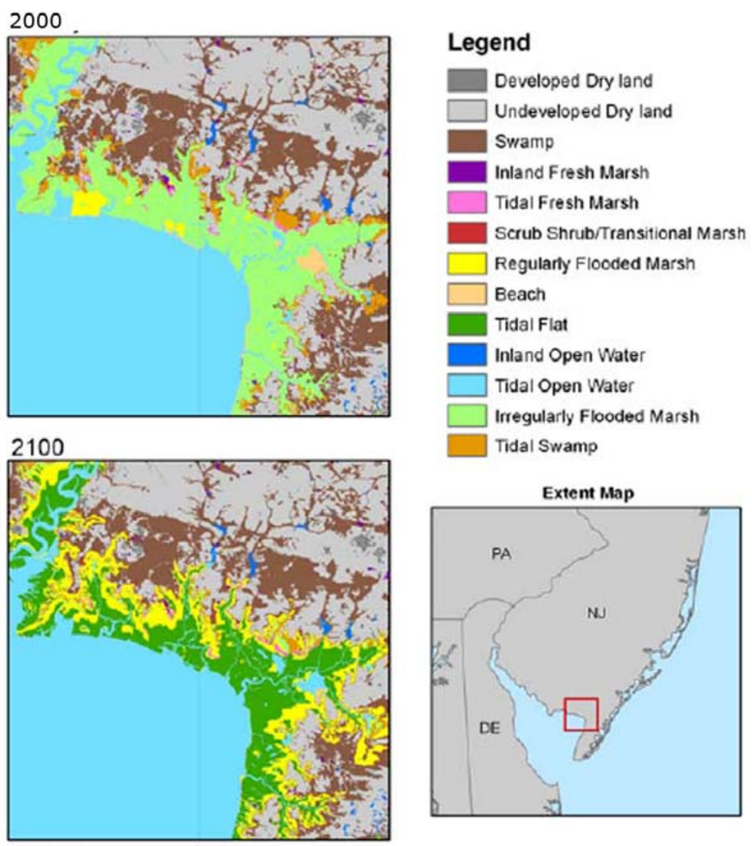
Consider policy changes needed to facilitate climate change adaptation. The following were identified through the three case studies, but there are likely others:

- Policies that focus on restoring to past conditions without taking into consideration future needs/conditions may not result in the best investment of public funds. Restoring certain plant communities or places may not be sustainable, nor the best use of funds.
- Some of the best future restoration opportunities for oysters lie within waters that are "closed" to oysters due to public health concerns.
- Permitting requirements for wetlands can prevent (or severely thwart) living shorelines from being used to prevent marsh erosion.
- Policies that prevent the interstate transfer of species can prevent mussels from being reintroduced to streams where they have been extirpated.
- Policies that acknowledge the direct value of forests to drinking water supply protection and that protect drinking water supplies from salinity intrusion are largely lacking.
- Policies and plans that guide the development of infrastructure should take changing conditions into account.

What Happens If We Don't Take Action?

Adaptation to climate change will happen, whether we take action or not. By taking action, we can choose to adapt in a way that protects our most valued resources. By not taking action, we are risking the likelihood of losing or damaging some of our most valuable resources (as indicated by vulnerability assessment results for each case study). To help inform decisions about what resources to protect, and at what cost, it's useful to consider "natural capital values" that measure the benefits provided by natural resources.

A team of experts led by Priscilla Cole, Science & Policy Fellow at the Partnership for the Delaware Estuary, was formed to assess the natural capital values associated with case study resources. There are many components of the natural capital values of these resources, including provisioning services (e.g., the value of oysters for food), regulating services (e.g., the value of forests for water filtration), cultural services (e.g., the value of mussels for jewelry), and supporting services (e.g., the value of wetlands for primary production). Calculating comprehensive values for all of these services is very complex, and beyond the scope of the case studies. However, some assessment of natural capital value was completed for each of the case studies to illustrate these values and their potential uses.



Industrial Economics used SLAMM model 6 to estimate wetland changes from climate change in 2100. This map series shows a loss of brackish marshes with conversions to salt marsh and mud flats by 2100.

For tidal wetlands, this included a rigorous assessment of the loss of primary production value of tidal wetlands due to climate change. This work was completed by Industrial Economics (IEc) and is presented in more detail in Chapter 3.7.2. IEc used modeling to predict tidal wetland changes due to sea-level rise and found that 40,000 hectares of tidal wetlands would be lost across the whole Estuary by 2100, with a primary production service loss of 60 million kilograms over the century. Tidal wetlands provide a host of natural capital values, including flood protection, support for fisheries and shellfisheries, sequestering carbon, helping to maintain water quality, and others. A more complete inventory of these values is provided in Table 3.8. According to the report Valuing New Jersey's Natural Capital project completed in 2007, wetlands have the highest combined natural capital value of any land/habitat type assessed.

For drinking water, a more rudimentary assessment was used to illustrate natural capital values associated with source water protection. This illustration is included as a feature box in Chapter 4. The hypothetical scenario it presents shows how even a relatively small amount of damage to drinking water infrastructure (1%) due to climate change could lead to significant supply shortages if demand grows at the same rate as population (2.5 million by 2050). It also illustrates how employing conservation BMPs to reduce demand and fill the shortage would be less expensive than the cost of filling the supply deficit with bottled water for only 2 days.

According to the NJ Natural Capital project completed in 2007, forests have the highest natural capital value for water quality protection of any land/habitat type assessed.

For bivalve shellfish, the natural capital values of different bivalve shellfish are compared and contrasted in Appendix Q. While only oysters boast value as a food and ecotourism resource, marsh mussels and freshwater mussels both share the oyster's other values, including shoreline stabilization and bio-filtration – two extremely valuable assets for water quality and watershed resiliency. The natural capital team estimates that the 4 billion adult Elliptio freshwater mussels in the Delaware Estuary currently filter 758 million kilograms of total suspended solids from streams annually. With a hypothetical 15% population decrease by 2050 due to climate change that filtering capacity would be reduced by 114 million kilograms. For perspective, total suspended solids are regulated in New Jersey with targets of 20-40 milligrams per litre.

Natural capital values can provide a very helpful tool for illustrating the value of resource protection, as shown here. With more rigorous assessment and better information, they can also guide decisions about where to invest in resource protection for the greatest benefit.

What's Next?

This report concludes the Partnership for the Delaware Estuary's pilot study under the EPA Climate Ready Estuaries Program, but **implementing the recommendations of this report is our highest priority "next step"**.

As previously noted, the case studies presented here are just a start to climate adaptation planning for the Delaware Estuary. A great deal of additional work is needed not just to fully understand and plan for impacts to the three resources assessed here, but also to assess climate impacts and adaptation options for the myriad other resources in the Delaware Estuary <u>not</u> addressed here. For example, experts on the drinking water workgroup acknowledged that their assessment does not adequately address groundwater, a critical source of drinking water for millions of people in the Delaware Estuary region. Given the potential threat of salt-water intrusion into groundwater supplies and relatively little information encountered by the drinking water workgroup about the impacts of climate change on our groundwater resources, this is an important area for investigation. Similarly, while the wetlands workgroup considered removal of structural impoundments (such as dikes, levees, weirs) as potential adaptation tactics, they did not assess the vulnerabilities of existing structures themselves. Given the hundreds, possibly thousands, of these structures throughout the Delaware Estuary, that some of these structures are not regularly inspected or maintained, and that they protect quite a bit of our built and natural environment, this is also an important area for investigation. These are just two examples of important resources that were outside the scope of this study, but for which vulnerability assessment and adaptation planning is clearly needed. **Working with our partners to recognize and seize opportunities for adaptation planning to address *other* important Delaware Estuary resources is also an important "next step."**

Many wetlands in the Estuary are squeezed up against impoundments and other structures, leaving no place for them to migrate if rising sea-levels push in.

One of the most common threads across the case studies, and the experts who worked on them, is the need for more research and monitoring in order to better understand climate change impacts, and their effects on our natural resources and systems here in the Delaware Estuary. The lack of hard data on this is reflected in the survey methods employed by the case studies presented here, reliant largely on expert opinion. This provides some critical initial guidance, but leaves us with much more work to be done even for the three cases presented here. For rigorous adaptation planning that can be confidently used as the basis for making tough decisions about policies and investments, better data and information is needed. This is crucial to every aspect of adaptation planning, from improving predictions to implementing adaptation tactics. **Continuing to improve our knowledge base on climate change through research and monitoring is an ongoing "next step."**

Another common thread across the case studies is the need for education – especially of resource managers and decision-makers, but for all stakeholders in the region as well. The information gathered from these case studies is a great resource for helping people to make the connection between global climate change, and impacts on resources here in the Delaware Estuary. **We encourage our partners to use it for this purpose, and will do so ourselves as another ongoing "next step."**

Climate change will have a profound effect on our society that will go well beyond the resources examined here. As people and property become increasingly impacted, prioritizing resources will become increasingly challenging, and essential. So it's important that we begin taking the actions we can today for our most important resources, using the best available information.