# Valuing Wetland Ecosystem Services: A Case Study of Delaware

*Healthy wetlands perform a range of functions of value to humans. While the importance of healthy wetlands may be clear to wetlands scientists, communicating this in a way that is meaningful to decisionmakers and the general public is essential for gaining public and political support for wetlands conservation and restoration programs. Our analysis links wetland functions to ecosystem services—the contribution that wetland functions make to the well-being of human populations—and uses economic valuation to express the value of healthy wetlands in monetary terms readily understood by decisionmakers and the general public.*

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Wetland science generally focuses on describing the functions that wetlands perform in support of healthy ecosystems. These functions include surface water detention, streamflow maintenance, nutrient retention and transformation, coastal storm surge protection, shoreline stabilization, sediment retention, provision of habitat, biodiversity conservation, and carbon sequestration.[1] In order to communicate the importance of these functions to the general public, ecologists are increasingly collaborating with economists to translate ecosystem functions into ecosystem services and to use economic valuation methods to measure the contribution of ecosystem services to human well-being in monetary terms, sometimes referred to as an "ecosystem services approach" to valuation. The distinction between ecosystem functions and ecosystem services is grounded in the explicit connection between ecosystem services and their value to humans.

Mitsch et al. (2009) identify the following five key categories of wetland ecosystem services.

- Climate Stability: Wetlands are particularly important ecosystems with respect to storing carbon, accounting for around 30% of all organic carbon storage on the planet. Wetlands are important ecosystems for sequestering carbon from the atmosphere and storing that carbon in plants, detritus, and soils. Humans benefit from this service in the form of decreased damages associated with climate change to human health, crops, and coastal environments.
- Water Quality Improvement: Wetlands can change water chemistry, removing pollutants, such as nitrogen and phosphorus, and increase water clarity. Multiple benefits of water quality improvements to humans include drinking water supply, improved conditions for fishing and other water-based recreation, and aesthetic values.
- Flood Mitigation: Wetlands act as sponges, capturing overflow from flooded rivers and streams. The development of floodplains into land uses, such as agriculture and residential and commercial development, has resulted in costly flood events due to the decreased capability of the landscape to absorb excess water. As with coastal protection, reducing the risk of flooding may be valued in terms of reduced damages, or associated increased property values.
- Coastal Protection: Recent studies on tsunami and hurricane events have demonstrated the importance of coastal wetlands in attenuating coastal storm surges. By reducing storm-related surges along the coast, wetlands may decrease the extent of damage associated with flooding to infrastructure, villages, cities, and agriculture.
- Wildlife Protection: Wetlands are important for providing habitat for species, for example, for breeding, nesting, or feeding. Due to the diversity of species (waterfowl, other birds, fish, shellfish, reptiles, and amphibians) that rely on wetlands to support life functions, these ecosystems are also important in preserving biodiversity. The ways in which wildlife contributes to human well-being are manifold: as food sources; for recreational opportunities (wildlife-viewing, hunting, fishing); and cultural importance. These values may be associated with individual species or with the biodiversity protected by these habitats, in general.[2]

The objective of our analysis is to value the ecosystem services provided by Delaware's wetlands, focusing on the above five key service categories, in order to provide a deeper understanding of the economic benefits expected to result from efficient and effective conservation and management of the state's wetland resources.

## CONTEXT

Wetlands cover approximately 25% of the state of Delaware.[3] Wetland ecosystems throughout the state are threatened by expanding development associated with the growing population. Decreased quality and quantity of wetlands compromise their ability to provide valuable ecosystem services.

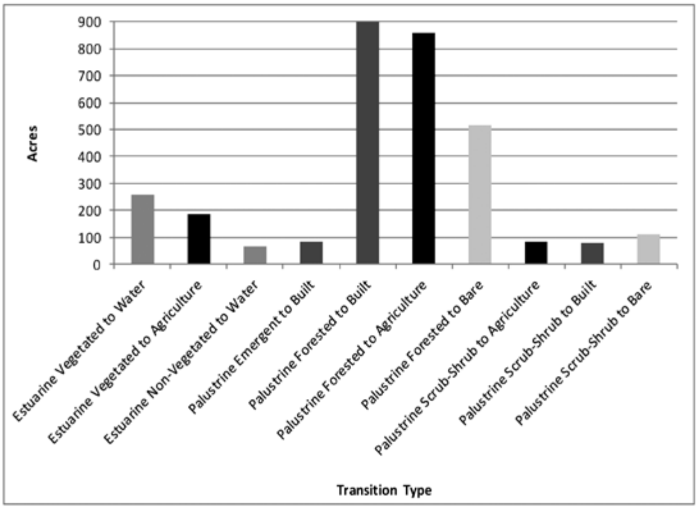

Figure 1: Forecast Wetland Transitions in Delaware: 2007-2022.

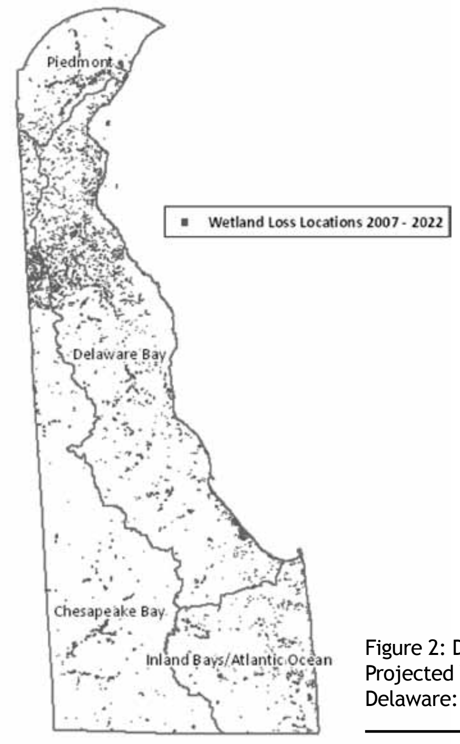

Figure 2: Distribution of Projected Wetland Losses in Delaware: 2007-2022.

In order to evaluate ecosystem service trade offs associated with potential future wetland losses in Delaware, we compare the services provided by wetlands under two scenarios: (1) the current baseline scenario reflecting the existing distribution of wetlands across the state; and (2) a hypothetical future scenario assuming wetland decline continues across the state over the next 15 years following similar trends of the past 15 years. The Delaware Department of Natural Resources and Environmental Control (DNREC) provided geographic information systems (GIS) data describing wetland decline by wetland type between 1992 and 2007. We used these data to develop our future scenario, employing Idrisi Taiga software to project continued wetland loss through 2022 based on the rate, location, and nature of the losses since 1992. Figure 1 describes the resulting forecast of wetland losses according to the land use expected to replace them, i.e., wetland transitions, and Figure 2 maps the projected wetlands losses within the four principle drainages in the state: Chesapeake Bay, Delaware Bay, Inland Bays, and Piedmont.

The change in wetland area between the baseline and future scenarios represent a 1.2% decline in wetlands across the state (3,132 acres of wetland loss) between 2007 and 2022. The difference in values provided by wetland ecosystem services between our two scenarios therefore reflects conversion of 1.2% of Delaware wetlands to other land use categories, primarily development and agriculture.

## Framework

Ecosystem service valuation approaches often involve transferring value estimates from existing literature to develop average, per-acre values for given services by ecosystem type. This might be thought of as a "schedule-based" approach to quantifying ecosystem service values. While relatively simple to execute, this approach fails to recognize fundamental ecological and economic concepts, for example:

- Site-specific differences in ecosystems of a given type. For example, the level at which particular wetlands perform ecosystem functions depends on the condition, size, and situation of a given wetland within the broader landscape.
- Site-specific difference in socioeconomic context. For example, a wetland that provides flood protection for a city may be much more valuable than a wetland that provides equivalent flood protection but to a relatively uninhabited area.
- The net change in services. Losses in a given service associated with a land use change are not necessarily absolute. For example, where wetlands are replaced by agriculture, there is a reduction in the carbon storage capacity of the transition area but not a complete loss.

Our analysis captures these factors by relying on site-specific models describing trade offs in the delivery, geographic distribution, and economic values of ecosystem services due to a specific future wetland decline scenario in Delaware. Specifically, we apply the Natural Capital Project's Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) tool to quantify changes in carbon sequestration, water purification, flood protection, and biodiversity associated with the projected wetland losses.

The InVEST tool was developed by ecologists and economists at The Natural Capital Project, a collaboration of the Woods Institute for the Environment at Stanford University, The Nature Conservancy, the World Wildlife Fund, and the Institute on the Environment at the University of Minnesota (http://www.naturalcapitalproject.org/home04.html). InVEST is an analytic framework comprising service-specific tools rooted in ecology, hydrology, biochemistry, and economics. It incorporates well-established methods to first quantify (in biophysical terms) and then value (in economic terms) a suite of ecosystem services. Where data and resources are available to support implementation, the InVEST approach to valuing ecosystem services is superior to a schedule-based transfer for multiple reasons. First, the spatially explicit models are able to account for interactions with the surrounding landscape in determining the value of services provided. In other words, the value of a given wetland in buffering against flooding is dependent on the position of that wetland within the broader landscape, e.g., elevation, surrounding vegetation types, and density, as well as the proximity of infrastructure vulnerable to damage from flooding. Second, our analysis values the net change in services associated with projected wetland decline. For example, where wetlands are converted to agriculture, the model quantifies the *difference* in services, such as carbon storage, provided by the landscape rather than assuming a total loss in carbon storage due to the lost wetland. Quantifying the net change as opposed to an absolute value of services provides more meaningful estimates to inform policy design and evaluation.

Our analysis provides information on both biophysical and economic endpoints. In some cases, a biophysical change may provide more meaningful information to land managers than economic values of services. In addition, not all services are equally amenable to monetization. Our analysis only emphasizes monetization for individual service categories insofar as there exist data and methods consistent with established economic principles to do so. Consequently, we do not report a monetized estimate of changes in the quantity and quality of wildlife habitat associated with the projected wetland losses. This summary, therefore, does not present the results of the wildlife habitat analysis, which were provided as a series of maps describing habitat areas anticipated to experience additional degradation due to wetland losses. Figure 3 summarizes the biophysical and economic endpoints quantified in our analysis for each service category.

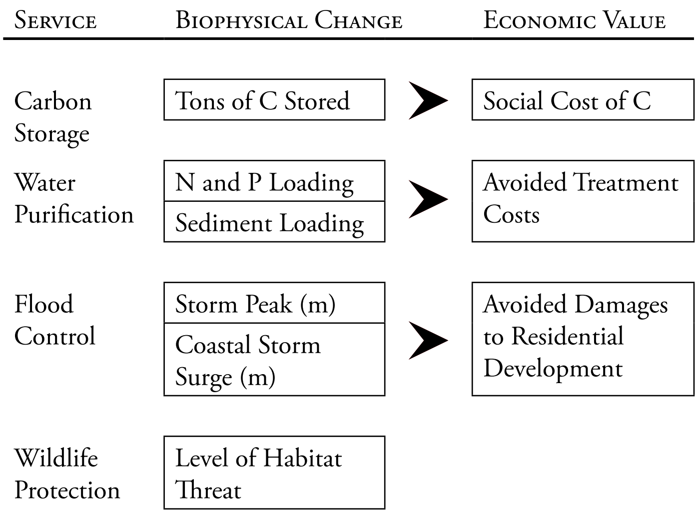

Figure 3: Biophysical and economic endpoints associated with the services evaluated.

## RESULTS

We estimate an annualized loss of approximately $2.4 million in the value of the ecosystem services analyzed due to projected wetland decline in Delaware. Figure 4 summarizes the results of our analysis by service evaluated. The following section then interprets our findings.

### *Carbon Storage Analysis*

Wetlands contribute to climate regulation by storing carbon in biomass, e.g., vegetation and soils. Wetland soils are particularly efficient at storing carbon, and forested wetlands support substantial storage capacity in trees. Where wetlands are degraded or replaced by other land uses, such as residential and commercial development, the stored carbon is released into the atmosphere as greenhouses gases, which contribute to climate change.

The purpose of the carbon model in InVEST is to quantify and value the carbon storage capacity of a landscape by applying information on carbon pools for various land use types, and the social costs of carbon in the atmosphere. By extension, we can apply the model to estimate the change in storage capacity associated with a change in the landscape: in this case, the decline in wetlands between our baseline and future scenarios.

We relied on existing literature to describe average carbon storage capacity by land use type. To quantify the economic value of the change in carbon storage, we apply an estimate of the social cost of carbon in the atmosphere. In other words, the value of a megagram (Mg) of carbon sequestered is equivalent to the avoided damage generated by that Mg of carbon if it were released into the atmosphere. Of note, significant uncertainty surrounds the estimate of the social cost of carbon. For this analysis, we apply an estimate of $118 per Mg (2010 dollars) for the social cost of carbon reflecting the median value from existing studies as summarized in Tol (2009). This estimate reflects the marginal economic effects of carbon dioxide ($CO_2$) emissions and derives from multiple studies researching the welfare effects of climate change in terms of crop damage, coastal protection costs, land value changes, and human health effects.[4]

### *Water Purification Analysis*

Wetlands can alter water chemistry by impeding flow from developed land and filtering out nutrients and sediment, thereby improving the quality of water downstream of the wetland. Purifying stormwater runoff in this manner can provide increased water clarity, as well as improved conditions for municipal drinking water supply and recreational activities, such as boating and fishing.

Our analysis applies InVEST models to forecast the effect of our future wetland loss scenario on mitigating nonpoint source pollution in terms of three water quality parameters: nitrogen; phosphorus; and sediment concentrations. The linked models combine water yield, nutrient loading, and filtration information to calculate the amount of nutrients and sediment retained and exported to waterways across a given landscape. We apply three linked InVEST models for this analysis, and each is subject to significant data requirements. Much of the data employed in these linked models were provided by environmental monitoring efforts in Delaware. We supplemented these data with information derived from the scientific literature.

- Water yield model: This model calculates annual average runoff as a function of precipitation and evapotranspiration.

| SERVICE CATEGORY | BIOPHYSICAL CHANGE ASSOCIATED WITH WETLAND LOSSES | NATURE OF ECONOMIC VALUE | PRESENT VALUE 2007-2022 | ANNUALIZED VALUE |
|---|---|---|---|---|
| Carbon Storage | • 194,417 metric tons of carbon storage lost | Social cost of carbon in the atmosphere (based on damages associated with climate change) | $19,900,000 | $1,590,000 |
| Water Purification | • 1.2% increase in nitrogen delivered to waterways<br>• 0.9% increase in phosphorus delivered to waterways<br>• 1.3% increase in sediment delivered to waterways | Municipal water treatment costs | $9,670,000 | $770,000 |
| Inland Flood Control* | • Increased flood heights, variable within the case study watershed (see Appendix A) | Damages to flooded residences along Red Clay Creek*<br>Range is due to assumptions regarding number of homes affected and height of homes above ground level | $720 - $21,200* | $57 - $1,690* |
| Coastal Storm Protection | • Increased flood heights, variable across landscape (see Appendix A) | Damages to flooded residences<br>Range is due to assumptions regarding number of homes affected and height of homes above ground level | $47,600 - $301,000 | $3,790 - $23,900 |

- Notes: The present value and annualized value calculations apply a 3% real discount rate.
- *Results are statewide values for all service categories except inland flood control, which represents the results of a case study of a single watershed.

Figure 4: Summary of Results (2010 Dollars).

- Retention model: The nutrient and sediment retention models combine the water yield output with a statewide digital elevation model to determine how the water flows across the landscape. The models then incorporate data on land use-specific nutrient and sediment loading rates and vegetation filtering capacities to determine the extent to which the nutrients and sediment are filtered by the vegetation downslope. Ultimately, the model describes the fraction of nutrients or sediments delivered to the waterways.
- Valuation model: This model employs information on per-unit costs of water treatment in Delaware to determine the equivalent value of the wetlands in filtering pollutants.

The degraded water quality is valued in terms of increased treatment costs. We apply recent cost estimates for nitrogen removal calculated by the DNREC of $85 per pound (approximately $188/kilogram in 2010 dollars). This represents the cost of removing nitrogen by connecting an on-site wastewater treatment and disposal system to sewer districts.[5] Based on our estimates of added phosphorus and sediment loading and relative costs of treating each, the total added cost of treatment is dominated by the costs of additional nitrogen treatment.

### *Inland Flood Control Analysis*

A key service provided by wetland ecosystems stems from their ability to store excess water and mitigate flooding from storm events. Wetlands adjacent to rivers and streams intercept runoff, buffering inland properties from increased river heights due to periods of high rainfall. Our analysis applies the InVEST storm peak model to evaluate how the presence of wetlands affects flood area and height associated with a 25-year, 24-hour rainfall event. Due to issues of model development and data availability, this analysis contains results for a case study of the Red Clay Creek Watershed, rather than results for the entire state. We quantify the economic costs of wetland loss in terms of increased property damages. The model considers only one type of potential flooding by focusing on properties within floodplains of streams and rivers. In fact, additional flooding potential may be associated with, for example, "ponding" of stormwater in inland areas.

The GIS model generates a hydrograph for a select watershed applying information on the landscape characteristics to estimate the time it takes for stormwater runoff to reach the watershed outlet. Specifically, the model incorporates information on level of rainfall, i.e., storm depth, as well as land use-specific soil and vegetation characteristics, surface roughness (affecting the velocity of the runoff), and slope. We also incorporate assumptions regarding the capacity of wetlands to store the runoff as it travels across the landscape, i.e., wetland depth. In other words, as water falls on the landscape, runoff travels downslope to the watershed outlet. The amount and timing of water reaching the outlet is a function of the capacity of the landscape to slow or store the water.

In order to estimate the contribution of wetlands in mitigating flood extent and level, we first run the model according to our 2007 baseline scenario. We then reran the model for our 2022 wetland loss scenario. The difference in flood height and extent between the two scenarios represents the change in flood characteristics due to the forecast continued wetland loss over the next 15 years.

We quantify the potential economic damages associated with the changes in flood height and extent in terms of damages to residential development. This requires assumptions regarding how many houses are affected, and the height of the houses off the ground, i.e., the height at which flood levels no longer infiltrate houses. For the Red Clay Creek Watershed, we apply specific spatial information developed by New Castle County on the existing residential structures within the 100-year floodplain. At the low end, we assume the affected houses are limited to the existing residences overlapping the incrementally flooded area. At the high end, we assume full build-out of these areas within the time frame of the analysis.

To value the potential damages to houses due to incremental flooding, we use data from the Federal Emergency Management Agency (FEMA) National Flood Insurance Program (NFIP) on total damages associated with various flood levels in a 2,000-square-foot home to estimate a functional relationship between flood height and total damages per house.

### *Coastal Storm Protection Analysis*

Coastal wetlands likewise protect coastal regions by attenuating storm surges. At the time of our analysis, the InVEST tool did not yet incorporate a coastal storm surge model. We therefore developed a simplified GIS model to simulate potential increases in storm surge associated with loss of coastal wetlands. The analysis relied on maps of flooded areas due to sea-level rise scenarios as a proxy for coastal flooding following a storm event. We then approximated the extent to which coastal wetlands attenuate storm surge applying an estimate from a recent study of wetland attenuation rates along the Louisiana coastline. The marginal storm surge attenuation rate associated with wetlands along the Louisiana coast was estimated to be one meter per 13 kilometers.[6] We estimated the economic value of this service in the same manner as described above for the inland flood-control service: in terms of avoided damage to residential structures that occur within the incrementally flooded areas.

## Interpreting the Results

The results of this analysis should not be interpreted as a total value of 3,132 wetland acres in Delaware, nor should an average per-acre value of wetlands be inferred from this estimate. The values for each service category are also the net of the values for these services provided by the substitute land use. For example, where wetlands are replaced by agricultural land use, there is a reduction in the carbon storage capacity of the land, but not a total loss. Thus, the results do not reflect the total value of the lost wetland in storing carbon. Our results are also based on site-specific factors, such as the locations of houses subject to potential increased flooding.

The value may be considered a lower bound estimate of the ecosystem service losses associated with the projected wetland losses. The current results do not include the value of all ecosystem services, though it does include ecosystem services known to be important, and for one service, inland flood control, it only contains values for a case study, rather than the entire state. The impacts reflect decreases in the value of ecosystem services due to our 1.2% wetland loss scenario. Should the rate of wetland loss increase, or extend beyond the 15-year time frame of the analysis, these ecosystem service losses would increase. In addition, these values reflect only those service categories described above and do not account for other categories of ecosystem service for which data or model limitations prevented reliable valuation, for example, recreation, commercial fishing, and aesthetic or cultural values. Finally, our results for one category of services, inland flooding, reflect only a single case study and do not reflect the full value of this service associated with wetlands across the state.

Our results indicate that losses of wetland ecosystem services within the time frame of this analysis would likely be in the millions of dollars annually across the state. If wetland loss trends continue, this value would most likely increase over time as wetland ecosystems grow increasingly scarce. ■

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Endnotes

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