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Application of Ecological and Economic Models of the Impacts of Sea-Level Rise to the Delaware Estuary

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INTRODUCTION

Accelerated rates of sea level rise over the next century have the potential to dramatically affect wetland habitats. Potential impacts of sea level rise include loss of habitats to open water through submergence and erosion in coastal areas, migration of wetlands where coastal elevations and private property protection efforts allow, and increased salinity in estuarine systems. Such changes in the physical environment will in turn affect the diverse ecological services provided by coastal habitats. Forecasting such changes in the physical environment and in the related ecological services will allow government agencies and other organizations to better allocate resources to adapt, potentially either preventing or mitigating these events.

This report describes a new approach to climate adaptation planning that draws from the assessment of natural resource damages associated with oil spills and other episodic events. Efficient adaptation to climate change requires knowledge of the potential impacts as well as the costs and effects that would be obtained by specific actions. As such, our analytic framework couples the wetland change modeling in SLAMM (Sea Level Affecting Marshes Model) with traditional damage assessment methods via habitat equivalency analysis (HEA). Rather than estimating an inherent value to the services (e.g., natural capital approach), we estimate gains and losses in the ecological service flows provided by coastal habitats as well as the type and size of projects necessary to maintain current wetland services. Potentially, these projects can be either restoration of degraded habitats or preventative measures taken to avoid future loss.

By combining a marsh migration model with a habitat equivalency model, we have developed a framework for identifying and valuing the cost of efforts to address potential changes in wetlands habitats. The combined framework first estimates habitat change over time resulting from increased sea level rise. SLAMM is a spatial model that calculates rates of inundation, erosion, and saturation based on site-specific parameters, providing an output of habitat area by wetland class on a decadal scale in the area of interest. The output from SLAMM drives a HEA model that calculates the change in ecological services by habitat type over time and identifies the size and cost of projects that provide suitable compensation for any net loss in ecological services.

In this report, we present our methodology and the results of our investigation into potential changes in wetland habitats and associated ecological services under an increased sea level rise scenario for the Delaware Estuary. The change in services results either from increased periodic inundation and changes in salinity, which alters the habitat type, or from complete inundation and conversion to open water. We perform SLAMM modeling using available site-specific parameters, calculate loss on a decadal time scale, and use those losses as the basis for the habitat equivalency model. The HEA model calculates the compensatory restoration necessary to restore those services, using primary productivity as a metric to compare habitat types.

The remainder of this report is divided into three sections. Section 2 describes the analytic methods. Section 3 details the results of the SLAMM and HEA models by watershed region, based on the site-specific parameters provided in the appendices. This section includes tabular decadal summaries of habitat change, and tables of HEA results by watershed for specific response/restoration scenarios. The final section discusses the implications of the model results, reviews suggested next steps, and discusses limitations of the current data sets. The appendices to this report provides detailed maps by subsite as well as model parameters for each subsite.

METHODS

Our process for estimating the economic impacts of habitat loss due to sea level rise consists of two models: SLAMM (Sea Level Affecting Marshes Model) and HEA (Habitat Equivalency Analysis). SLAMM calculates habitat change over time resulting from increases in sea level. HEA uses the output from SLAMM to calculate changes in ecological services by habitat type and scale restoration projects to provide appropriate compensation for any loss in services. In this section, we provide an overview of the models.

OVERVIEW OF MODELS

SLAMM

Using NWI and elevation data, SLAMM simulates the dominant processes involved in wetland conversions and shoreline modification during long-term sea level rise. SLAMM offsets the impacts of sea level rise by simulating sedimentation and accretion based on user-identified accretion rates. Modeled saturation of upland soils allows migration of coastal wetlands. The model also estimates potential second order effects of erosion and exposure to wave action from storms.

Initial development of SLAMM occurred in the 1980s.[1] The current version of the model, SLAMM 6 categorizes the detailed NWI wetlands classifications into 23 separate wetland classes (e.g., swamp, scrub shrub, regularly flooded marsh)[2]. The spatial model uses these classes in conjunction with sea level rise rates, elevation data, accretion rates, tidal datums, erosion rates, and other inputs to estimate the transition of each class over time. The output from SLAMM is a spreadsheet of acres lost/gained by class and year.[3] The information is also available spatially and can be mapped using GIS software.

The user identifies appropriate values for key parameters within SLAMM, in order to make the model more accurate on local scales. Tidal data (extent of high tides, inter annual variation in tides) for the area of interest are determined from local tide gauge data. Estimates of accretion rates by marsh type are necessary to set baseline conditions. The model provides a set of accelerated sea level rise scenarios for the user, either IPCC 2000 scenarios[4], Titus and Narayanan (1995)[5] or a specific increase by 2100 (*e.g.*, 1.0

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[1] Park, R.A., T.V. Armentano, and C.L. Cloonan. 1986. Predicting the Effects of Sea Level Rise on Coastal Wetlands. In *Effects of Changes inStratospheric Ozone and Global Climate, Vol. 4: Sea Level Rise*, edited by J.G. Titus, 129-152. Washington, D.C.: U.S. EnvironmentalProtection Agency.

[2] For the purposes of this report, we categorize salt and brackish marsh areas into "regularly" and "irregularly" flooded marsh. These are the categories SLAMM uses. Regularly flooded marsh refers to NWI code E2EM with a tidal regime of M or N (if specified). Irregularly flooded marsh refers to NWI code E2EM with a tidal regime of P.

[3] The user may select different time steps for the analysis (*e.g.*, 25-year steps).

[4] Intergovernmental Panel on Climate Change. 2000. "IPCC Special Report on Emissions Scenarios." Available electronically at http://www.grida.no/publications/other/ipcc_sr.

meters). The user also identifies rates of fetch-based erosion and frequency of washover events; these values have greater relevance in more open-ocean areas.

Various government and non-profit groups are currently using this model to characterize potential impacts of accelerated sea level rise on coastal ecosystems. The U.S. FWS is applying SLAMM to all of its coastal refuges, in order to prioritize response actions. Various stakeholders such as the Nature Conservancy, who own large tracts of vulnerable land, and the National Wildlife Foundation are also currently engaged in this work. Recent research by Craft *et al*. (2009)[6] used SLAMM to forecast the effects of marsh inundation on tidal marsh ecosystem services at selected sites along the Georgia coast. This work tied together model outputs with field research on ecosystem services such as plant biomass and potential denitrification.

HEA

Habitat equivalency analysis is a method to determine compensation for injuries to natural resources.[7] We quantify injuries based on loss of ecological service flows. Exhibit 1 demonstrates the loss of the ecological services provided by a habitat resulting from habitat inundation. The total lost services are the area on the graph between the baseline and the ecological services curve. In the context of responding to an event such as an oil spill, the goal of HEA is to provide an equivalent magnitude of ecological services to those lost through restoration projects that enhance similar ecological services in a nearby area. With HEA, we do not measure an intrinsic economic value to habitats, but rather estimate the costs associated with replacing lost ecological services, accounting for differences in timing.[8] For the application of HEA in response to the continuous impacts of sea level rise, we can examine the effort necessary to either prevent the service loss as well as restoration activities after the loss starts to occur.

For a restoration project, we scale the project such that the increase in services over time provided by the project is equivalent to the "Lost Services" area in Exhibit 1. In contrast to natural resource damage assessment, we also have the opportunity to consider "avoided costs" if ecological services are not lost, due to the implementation of preventative measures. We could then compare the cost of those preventative measures to the costs necessary to restore habitat in the future under various sea level rise scenarios (using HEA to ensure no net loss of ecological services).

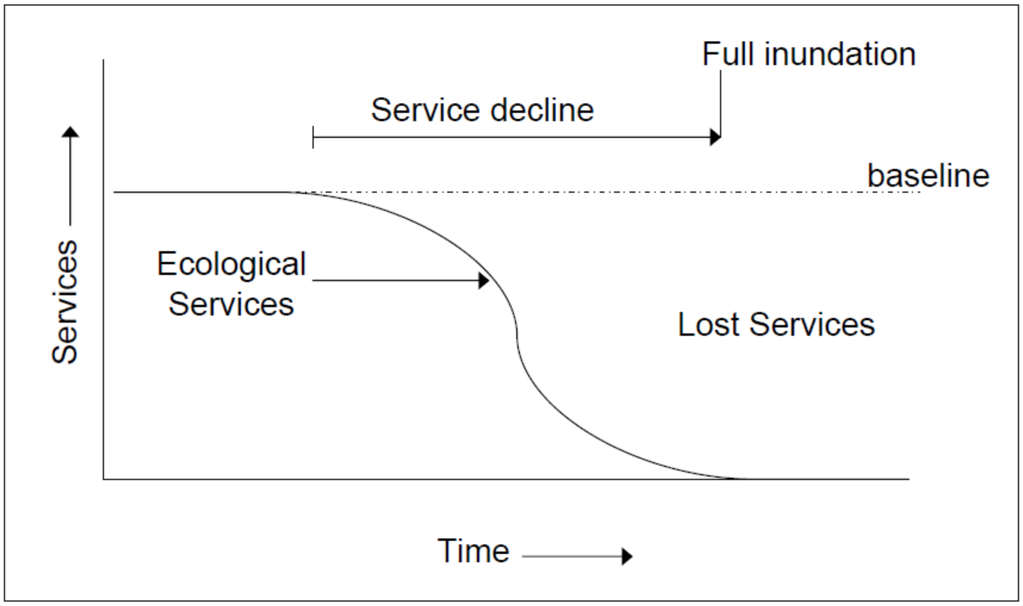
[5] Titus, J. and V. Narayanan. 1995. The Probability of Sea Level Rise. U.S. EPA Office of Policy, Planning, and Evaluation. EPA230-R-95-008.

[6] Craft, C., J. Clough, J. Ehman, S. Joye, R. Park, S. Pennings, H. Guo, and M. Machmuller. 2009. Forecasting the effects of accelerated sea-level rise on tidal marsh ecosystem services. *Frontiers in Ecology and the Environment*. Vol. 7, pp 73-78.

[7] NOAA and U.S. FWS use HEA for damage determination resulting from injuries to natural resources, as described under OPA and CERCLA. NOAA websites provide detailed descriptions of this method and guidance on its implementation. Two suggested sites are http://www.darrp.noaa.gov/library/pdf/heaoverv.pdf and http://www.csc.noaa.gov/coastal/economics/habitatequ.htm.

[8] We can contrast this methodology with more direct economic evaluations of ecological services, as might be provided by natural capital valuation.

EXHIBIT 1. HEA EXAMPLE: EFFECT OF HABITAT INUNDATION ON ECOLOGICAL SERVICES



With HEA under NRDA assumptions, we calculate appropriate compensation for lost services in one location and time through restoration of similar ecological services in nearby areas, taking into account differences in timing through the use of discounting.[9] Ecological services for each area of interest are defined in terms of "service-acre years", with one fully-functioning acre providing one service acre-year annually. These values are then discounted (increasing in the past and decreasing in the future) to create the net present value. The present value of the services are described as "discounted service acre-years" or DSAYs.

[9] NOAA provides four basic requirements necessary for appropriate implementation of HEA:

- the primary services lost are biological (as opposed to human-use services)
- there exists a means of quantifying the level of lost services due to the injury and the level of services gained by the compensatory restoration
- an estimate of recovery rates is available (i.e., natural recovery if applicable and restoration recovery)
- suitable restoration sites exist (e.g., same habitat type as injured area, close by, likely to succeed).

(Source: http://www.csc.noaa.gov/coastal/economics/habitatequ.htm)

Comparing Ecological Services

To understand the impacts of changes in habitat types due to sea level rise, we first identify a common scale for comparing those habitats. For example, every acre of regularly flooded marsh that is "lost" may become a different habitat, which has its own ecological value. We address this issue through identification of ecological metrics, which allow the determination of the relative value of habitat types. In habitat equivalency analysis, we generally calculate loss either in terms of acres degraded or in terms of specific resources (e.g., turtles, birds, oysters) injured or killed. Our modeling of changes in habitat due to sea level rise (using the SLAMM model) will estimate acres lost during specific time periods; therefore, metrics that could readily be translated to area of land lost, and that could also reasonably be adjusted to account for condition of the affected area, are most appropriate. As sea level rise could result in complete inundation of a habitat and conversion to a different habitat type, metrics that are representative of the habitat as a whole are also desirable.

PRIMARY PRODUCTIVITY

Primary productivity covers plant, bacterial, and algal productivity. Our review of the literature indicated significant information on marsh productivity in the vicinity of the Delaware Estuary. In addition, literature documents productivity measurements for a variety of other coastal habitats in this area (e.g. mud flats, subtidal regions, oyster reefs). Average productivity values are readily available for different wetland types, and site-specific data can be substituted when available.

In HEA, productivity is a common metric for comparing different habitats. In many cases, sufficient areas of an injured habitat type are not available for restoration or enhancement. Therefore, compensatory restoration may occur through creation of a similar habitat type in the same geographic region. In these cases, services that are present and significant in multiple habitat types are very useful.

As a metric, primary productivity is particularly relevant as it both directly quantifies basic food web support and indirectly quantifies the structural provision of many habitats. Structural provision relates to the refuge, shelter, and nesting/spawning habitat provided to various species by a given habitat. While some habitats have much higher secondary productivity relative to *in situ* primary productivity (i.e. oyster reefs), these habitats rely on primary productivity exported from other habitats as part of their food web support.

In our previous research, we identified primary productivity as the metric most applicable to this modeling approach, given the extent of data and the key role that primary production has in defining the services provided by many habitats.[10] This report also provided detail on additional metrics that could be applied for the analysis such as carbon

[10] IEc, April 2009, Application of Ecological and Economic Models of the Impacts of Sea-Level Rise to the Delaware Estuary (New Jersey). Report to EPA.

sequestration, water quality, and threatened and endangered species. For this report, we use primary productivity as the common scale for comparing gains and losses in habitat types.

We developed estimates of primary productivity for seven wetland/open water habitats: regularly and irregularly flooded marsh, tidal fresh marsh, scrub-shrub/transitional marsh, tidal marsh, tidal open water, and tidal flats (Exhibit 2). To designate primary productivity values for the different habitat areas, we first collected values from the literature, looking for aboveground and belowground primary productivity of vegetation in the marsh habitats, benthic microalgae values, and primary productivity values for tidal flats and open water areas. We sought values measured within or close to the Delaware Estuary. Specifically, we only factored in values specific to the Delaware Estuary or the Chesapeake Bay estuary. Then we used a methodology employed by Peterson *et al*. (2008) to find the value of primary productivity available for consumption.[11] We chose to evaluate habitats based on primary productivity available for consumption, because this is a more accurate representation of services provided than primary productivity alone. For instance, tidal flats may have a lower primary productivity value than wetlands, but a higher proportion is readily available for consumption. Finally, to be consistent with Peterson *et al*., our final productivity values are in ash-free dry weight.[12]

To develop productivity values for each of the vegetated wetland habitats, we estimated and combined values for productivity of vegetation and of benthic microalgae. To find macrophyte productivity, we first combined values found in the literature, keeping aboveground and belowground productivity separate, to find average values for *Spartina*-dominated, regularly flooded marsh; *Phragmites*-dominated, irregularly flooded marsh; *Spartina*-dominated, irregularly flooded marsh; *Phragmites*-dominated freshwater marsh, and freshwater marsh dominated by desirable marsh species (e.g., *Typha* spp., *Peltandra*, *Zizania aquatica*). Then for averages for aboveground and belowground productivity of regularly flooded marsh, we used the values for *Spartina*-dominated regularly flooded marsh. For irregularly flooded marsh, we combined the averages for *Spartina*-dominated and *Phragmites*-dominated marsh. For freshwater marsh, we combined the averages for *Phragmites*-dominated marsh and marsh dominated by desirable marsh species. We treated scrub-shrub and tidal swamp areas similarly, determining annual primary productivity estimates (not standing biomass) for the prevalent species. Using percentages found by Peterson *et al*. for conversion to organic matter that is available for consumption (roughly 19.9 percent of aboveground and 0.5 percent of belowground productivity), we calculated total vegetative productivity that is available for consumption in each of the wetland habitats. We then added to each figure the value for

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[11] The conversion methodology used by Peterson assumes that herbivores consume 10% of aboveground productivity at a conversion efficiency of 10 percent, of which 20 percent returns to the food web as animal detritus for consumption by detritivores. Based on his analysis, we further assume that ninety percent of aboveground productivity directly enters the detrital pathway and is converted into fungi at an efficiency of 55 percent, of which a third is consumed by detritivores and two thirds is first converted to bacteria at 10 percent efficiency, and then consumed by detritivores. The assumption for belowground productivity is that crabs and geese excavate five percent and the bacteria convert the remainder at 10% efficiency for consumption by detritivores.

[12] To be consistent with the methodology of Peterson *et al*. (2008), we converted figures into ash-free dry weight, if they were not already in this form. We assumed that 12.4 percent of aboveground dry weight and 18.4 percent of belowground dry weight is ash.

primary productivity of microalgae reported by Peterson *et al*., assuming that 100 percent of microalgae production is available for consumption.[13]

EXHIBIT 2. AVAILABLE PRIMARY PRODUCTIVITY FOR CONSUMPTION BY HABITAT TYPE

HABITAT TYPE	DOMINANT VEGETATION		PRIMARY PRODUCTIVITY (g AFDW/m^2)			
			ABOVE-GROUND	BELOW-GROUND	MICROALGAE	TOTAL
Regularly Flooded Marsh	*Spartina* **spp.**	Total	1,068	3,866	202	
		Available for Consumption	213	19	202	434
Irregularly Flooded Marsh	*Spartina* **spp. and** *Phragmites* **spp.**	Total	1,613	4,692	202	
		Available for Consumption	322	23	202	547
Tidal Fresh Marsh	**various**	Total	1,501	4,469	202	
		Available for Consumption	299	22	202	524
Scrub-Shrub Marsh	*Spartina patens*	Total	1,099	3,754	202	
		Available for Consumption	219	19	202	440
Tidal Swamps	**various**	Total	1,077	4,032	202	
		Available for Consumption	215	20	202	437
Tidal Flats	**n/a**	Total	--	--	300	
		Available for Consumption	--	--	300	300
Tidal Open Water	**n/a**	Total	--	--	268	
		Available for Consumption	--	--	268	268

For the productivity of tidal flats and unvegetated open water, we used values from Chesapeake Bay and Massachusetts estuaries, because we could not find values specific to the vicinity of the Delaware Estuary. The value for these areas consists only of benthic microalgae primary productivity.

Once an ecological service is defined and quantified for each habitat type (i.e., primary productivity), the metric can be used as a common scale for comparing habitat types. While the DSAYs for each habitat type cannot be added directly, they can be added together if they are first converted to a common scale. We can perform this conversion by using a ratio of relative productivity. For example, in order to present all DSAY values in the common units of "regularly flooded marsh DSAYs", we can multiply each habitat's DSAY value by the ratio of (specified habitat primary productivity)/(regularly flooded marsh primary productivity). At this point, the "regularly flooded marsh DSAYs" can be

[13] This benthic microalgae value was specific to salt or brackish marshes, but we assumed the same value for freshwater marsh as well.

summed for each habitat type to encompass the impact to multiple habitats on a single scale.

Restoration Scaling

We scale restoration projects to provide ecological services (or DSAYs) equal to those lost through direct injury or other degradation. This scaling results in a "no net loss" scenario for ecological services, whether the injured habitat is degraded or lost completely. In the case of potential future loss, as noted above, this could be either prevention of those future losses or restoration/ enhancement projects conducted at any point over the timeframe of interest.

While the presence of suitable restoration sites is critical for traditional HEA applications, these sites may be different habitat types from the injured habitat. HEA accepts the use of conversion factors to equate dissimilar habitats, based on shared services determined by functional or structural characteristics. HEA guidance suggests basing the relative values of the habitat types on measured or modeled attributes of the habitats. In general, implementation of HEA relies on the use of a single metric to measure services, with applicability to both the injured and restored habitats.[14]

DESCRIPTION OF HEA DEVELOPMENT

To develop a habitat equivalency analysis relevant throughout the study area, we identified and evaluated appropriate parameters within the estuary. This includes description of the impacts of sea level rise in terms of injury to (and creation of) habitat types, and identification and characterization of potential restoration projects. In this section, we also provide detailed descriptions of the mechanics of the analysis.

For the purposes of the estuary-wide evaluation, we have evaluated habitat changes only for the tidal wetland and open water habitats: regularly flooded marsh, irregularly flooded marsh, tidal freshwater marsh, scrub shrub/transitional, and swamp as well as tidal flats and open water. We provide two options for response, for the purposes of estimating the ecological benefits of a compensatory restoration project (or alternatively, of the benefit provided by pre-emptive response prior to marsh loss): a major salt marsh restoration project and a marsh edge improvement project. As representative projects, we consider major brackish/salt marsh restoration projects (which would include fill removal, regrading, creation of tidal creeks, and revegetation) and living shoreline-type projects.

For the major brackish/salt marsh restoration, our estimate of maximum service for these areas is 85 percent, which represents the necessary level of desired vegetation, under New Jersey mitigation requirements. We base restoration costs for the HEA on estimates for recent and future projects in the area of interest. In particular, estimates for two wetland restoration projects in southern New Jersey are both near $200,000 per acre for construction costs.[15] We calculate the cost in the year of recovery using the 30-yr average

[14] Dunford, R.W., T.C. Ginn, and W.H. Desvousges. 2004. The use of habitat equivalency analysis in natural resource damage assessments. *Ecological Economics*. Vol. 48, pp 49-70.

[15] Estimates are from U.S. Army Corps of Engineers/NOAA for Woodbridge Creek and from State of New Jersey for proposed salt marsh restoration at Mad Horse Creek.

annual increase from the Construction Cost Index for Philadelphia[16], and then discount it to 2010 using the selected discount rate.

For the preventative project, we reviewed available literature on "living shorelines" projects in the mid-Atlantic, primarily in Chesapeake Bay. Details of our findings are in Appendix A. We base restoration costs on the average project size (450 linear feet); average marsh enhanced or created (0.23 acres); and average cost ($250 per linear foot), as reported for over 250 projects in Maryland.[17] This results in a final cost of approximately $491,000 per acre. The living shorelines project both increases current service levels and creates new marsh, corresponding to a roughly 50 percent average increase in service for the affected areas.

To perform the analysis for each of the subsites, we developed a database mode. The model incorporates the habitat acreage output from SLAMM directly into the database structure. The user can then enter the comparison metric values and process the HEA. The model produces estimates of the DSAY losses as well as the acres of compensatory restoration required, based on user-defined inputs regarding the restoration project.

Application of SLAMM/HEA to the Delaware Estuary

Our investigation covers the tidal portion of the Delaware Estuary, from Cape May in New Jersey and Cape Henlopen in Delaware to Trenton, New Jersey. We divided the estuary into 27 subsites to allow for differentiation in site parameters and to meet data size restrictions within the SLAMM model. Exhibit 3 depicts the relationship of the subsites, watershed regions, and overall estuary.

Processing the SLAMM analysis requires numerous data inputs. For the Delaware Estuary as a whole, we used the following general parameters/inputs:

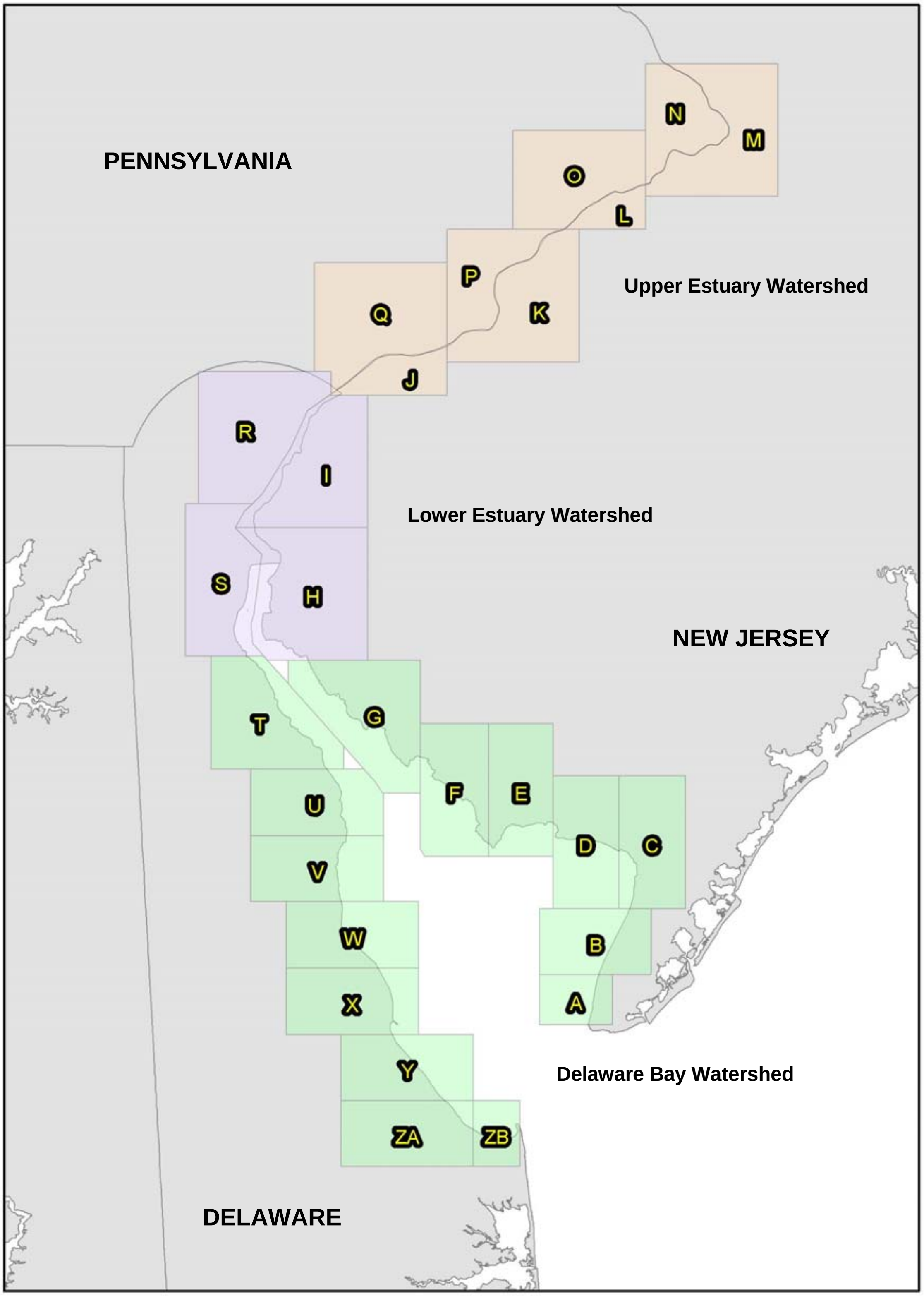
- Sea level rise scenario of 1.0 meter rise by 2100 fit to the IPCC A1B curve;
- Initial elevation conditions defined by most recent available 10-meter resolution digital elevation maps acquired from the USGS National Map Seamless Server[18];
- Initial wetland types defined by most recent available National Wetlands Inventory maps obtained from the U.S. FWS data manager; and

[16] *Engineering News Record* publishes the Construction Cost Index, which corresponds to the annual nominal increase in construction costs. The 30-year average for Philadelphia, PA from 1979-2008 is 4.52 percent.

[17] Project size and marsh acreage are from Bhaskaran Subramanian, Johann Martinez, Audra Luscher, and David Wilson, "Living Shorelines Projects in Maryland in the Past 20 Years," Management, Policy, Science, and Engineering of Nonstructural Erosion Control in the Chesapeake Bay: Proceedings of the 2006 Living Shoreline Summit, December 2006. Costs are from multiple sources; see Appendix C.

[18] http://seamless.usgs.gov/ accessed March 31, 2010.

EXHIBIT 3. WATERSHED AND SUBSITE DIVISIONS FOR DELAWARE ESTUARY



- Non-wetland habitats delineated as developed or un-developed based upon impervious surface layers available from Delaware, Pennsylvania, and New Jersey.[19] SLAMM interprets any land with more than 25 percent impervious cover as developed.

Further discussion of the SLAMM parameter development is included in Appendix B. Detailed subsite parameters are in Appendix C.

HEA INPUTS

In Exhibit 4, we present the HEA parameters used to define the mapped habitats from SLAMM. We included a lowered service level (75 percent of full services) as an average description of baseline habitat quality across the entire estuary.

EXHIBIT 4. HEA INPUT PARAMETERS: CURRENT HABITATS

HEA INPUT PARAMETER	INPUT VALUE	INPUT SOURCE
Annual Primary Productivity for Consumption (g/m^2)		See IEc (2009) for literature review and calculations.
Regularly Flooded Marsh	434	
Irregularly Flooded Marsh	547	
Tidal Freshwater Marsh	524	
Swamp	437	
Scrub Shrub/Transitional Marsh	440	
Open Water	268	
Tidal Flats	300	
Baseline Year	2010	User Input
Discount Rate	3%	NOAA HEA guidelines
Baseline Service Level	75%	Expert Judgment

The HEA also requires the description of potential compensatory restoration projects. We run two options for restoration: a full marsh restoration project and a living shorelines habitat protection/enhancement project. The salt marsh habitat restoration in our calculations is based on restoration of a degraded former marsh area, corresponding to a roughly 75 percent increase in service.[20] The living shorelines project both increases current service levels and creates new marsh, corresponding to a roughly 50 percent average increase in service for the affected areas.

Exhibit 5 provides a summary of the parameters used for the restoration options. Appendix A provides additional details on the data sources and findings.

[19] Data sets include: "2007 Impervious Surface Data" published in 2008 by the State of Delaware, Office of Management and Budget; "Impervious surface area for Southeast Pennsylvania, 2000," published in 2003 by Penn State University, Dept. of Meteorology; and Land Use/Land Cover data published in 2002 by the New Jersey Department of Planning, Office of Information Resources Management, Bureau of Geographic Information Systems.

[20] Maximum service for restoration projects is generally not equal to 100 percent for HEA. Based on literature reviews of restored habitats, created habitat is generally less productive, less diverse, and less robust than "natural" habitats over the time scale of relevance.

RESULTS

WETLAND CHANGE: SLAMM

In Exhibit 6 to 8, we present initial, intermediate, and final results (2010, 2050, and 2100), produced by SLAMM, for habitat type over time. We divided the results by the major watersheds within the Delaware Estuary as well as by the state boundaries to facilitate regional planning. According to SLAMM projections, as sea level rises, increasing inundation leads to inward migration of the regularly flooded marshes. Over the entire estuary, the model anticipates an increase of over 75,000 acres of regularly flooded marshes. In contrast, the estuary would loss over 120,000 acres of the more productive irregularly flooded marsh. The other marsh categories are also subject to notable changes. SLAMM predicts a gain in over 100,000 acres of tidal flats and tidal open water, a loss of nearly 44,000 acres of dryland, and loss of approximately 18,700 acre of scrub-shrub habitat.

EXHIBIT 5. HEA INPUT PARAMETERS: RESTORATION OPTIONS

HEA INPUT PARAMETER	INPUT VALUE	INPUT SOURCE
PREVENTATIVE RESTORATION OPTION (LIVING SHORELINES)		
Initial Service Level of Restoration Area	50%	User Input (Default)
Final Service Level of Restoration Area	100%	User Input (Default)
Year Recovery Begins	2020	User Input
Recovery Period	3	User Input (Default)
Annual Primary Productivity of Restoration Area (g/m^2)	500	User Input (Default – representative of three marsh types)
COMPLETE RESTORATION OPTION		
Initial Service Level of Restoration Area	10%	User Input (Default)
Final Service Level of Restoration Area	85%	User Input (Default)
Year Recovery Begins	2050	User Input
Recovery Period	15	User Input (Default)
Annual Primary Productivity of Restoration Area (g/m^2)	500	User Input (Default – representative of three marsh types)

The pattern of marsh loss varies within the three watersheds. As shown, the upper estuary would have a net gain in marsh area (over 5,600 acres) and a loss of approximately 2,000 acres of scrub-shrub/swamp and 3,700 acres of undeveloped dryland. Due to its location near the upper limit of the tidal range of the Delaware River as well as significant development, tidal wetlands overall are limited in the watershed region. We do note that SLAMM does not take into account any changes to the amplitude of the tidal range. In contrast, the Delaware Bay would experience significantly greater loss of marsh area (over 46,000 acres loss), minimal change in scrub-shrub/swamp, and significant loss of beach and undeveloped dryland (over 26,000 acres combined).

In contrast to previous analyses for selected sites in the estuary, we now model inundation of, or migration of wetland across, current undeveloped dry land, identified based on percent impervious cover. So, the overall wetland area (as sum of open water plus wetland areas) now changes; however, the sum of overall wetland areas plus undeveloped dry land remains constant. At the bottom of Exhibits 6 through 8 we group the habitats into general wetland type (marsh, open water, scrub-shrub/swamp, and other). For these categories, we see a large increase in open water and tidal flat areas in the lower estuary and Delaware Bay watershed regions, along with a decrease in undeveloped dry land. Changes in the upper estuary are more limited, although there is a large decrease in the undeveloped dry land, indicating significant areas of inundation.

EXHIBIT 6. ACREAGE CHANGE OVER TIME BY WETLAND CATEGORY FOR UPPER ESTUARY

	MARSH				OPEN WATER/TIDAL FLATS			SCRUB-SHRUB/ SWAMP		OTHER	
	Regularly Flooded Marsh	Irregularly Flooded Marsh	Tidal Freshwater Marsh	Non-Tidal Freshwater Marsh	Tidal Flats	Tidal Open Water	Non-Tidal Open Water	Tidal Scrub Shrub/ Transitional	Scrub Shrub/ Forested Swamp	Beach	Undeveloped Dryland
UPPER ESTUARY: PENNSYLVANIA SIDE TOTAL ACREAGE BY HABITAT TYPE											
2010	0	16	380	1,175	48	12,255	4,187	117	5,154	249	102,760
2050	305	62	383	1,198	22	12,683	3,821	106	5,200	246	102,316
2100	1,028	125	381	1,208	0	12,933	3,656	161	5,038	185	101,627
Net Change	1,028	109	1	33	-48	677	-532	44	-115	-64	-1,134
% of Initial	n/a	663%	0%	3%	-100%	6%	-13%	38%	-2%	-26%	-1%
UPPER ESTUARY: NEW JERSEY SIDE TOTAL ACREAGE BY HABITAT TYPE											
2010	5	58	2,801	1,345	389	12,922	1,985	202	11,633	607	65,987
2050	785	577	2,831	1,564	201	13,537	1,575	271	11,134	601	64,859
2100	2,944	1,442	2,701	1,590	1	14,122	1,365	448	9,486	431	63,404
Net Change	2,939	1,384	-100	245	-388	1,200	-620	246	-2,147	-176	-2,583
% of Initial	58,201 %	2,396%	-4%	18%	-100%	9%	-31%	121%	-18%	-29%	-4%
TOTAL ACREAGE CHANGE IN 2100 BY GENERAL WETLAND CATEGORY IN THE UPPER ESTUARY											
	Marsh				**Open Water/Tidal Flats**			**Scrub-Shrub/Swamp**		**Other**	
Pennsylvania	1,171				98			-71		-1,197	
New Jersey	4,468				192			-1,902		-2,758	

EXHIBIT 7. ACREAGE CHANGE OVER TIME BY WETLAND CATEGORY FOR LOWER ESTUARY

	MARSH				OPEN WATER/TIDAL FLATS			SCRUB-SHRUB/ SWAMP		OTHER	
	Regularly Flooded Marsh	Irregularly Flooded Marsh	Tidal Freshwater Marsh	Non-Tidal Freshwater Marsh	Tidal Flats	Tidal Open Water	Non-Tidal Open Water	Tidal Scrub Shrub/ Transitional	Scrub Shrub/ Forested Swamp	Beach	Undeveloped Dryland
LOWER ESTUARY: DELAWARE SIDE TOTAL ACREAGE BY HABITAT TYPE											
2010	1,218	6,893	1,623	1,038	176	21,704	1,241	89	2,297	229	71,291
2050	7,115	2,525	1,698	1,162	212	21,910	1,214	353	2,056	213	69,341
2100	5,584	554	1,654	1,167	4,919	22,854	1,170	300	1,586	183	67,830
Net Change	4,366	-6,340	31	129	4,743	1,149	-71	211	-711	-46	-3,461
% of Initial	358%	-92%	2%	12%	2,690%	5%	-6%	238%	-31%	-20%	-5%
LOWER ESTUARY: NEW JERSEY SIDE TOTAL ACREAGE BY HABITAT TYPE											
2010	2,612	16,312	3,928	4,042	829	28,466	2,064	136	18,960	89	65,983
2050	19,277	4,379	4,789	4,239	698	29,700	1,269	1,199	18,131	89	59,651
2100	14,529	1,894	5,176	4,366	12,804	31,712	1,092	936	15,500	89	55,324
Net Change	11,917	-14,418	1,248	324	11,975	3,246	-971	799	-3,460	-1	-10,659
% of Initial	456%	-88%	32%	8%	1,445%	11%	-47%	587%	-18%	-1%	-16%

TOTAL ACREAGE CHANGE IN 2100 BY GENERAL WETLAND CATEGORY IN THE LOWER ESTUARY

	Marsh	Open Water/Tidal Flats	Scrub-Shrub/Swamp	Other
Delaware	-1,814	5,821	-500	-3,507
New Jersey	-930	14,250	-2,661	-10,659

EXHIBIT 8. ACREAGE CHANGE OVER TIME BY WETLAND CATEGORY FOR DELAWARE BAY

	MARSH				OPEN WATER/TIDAL FLATS			SCRUB-SHRUB/ SWAMP		OTHER	
	Regularly Flooded Marsh	Irregularly Flooded Marsh	Tidal Freshwater Marsh	Non-Tidal Freshwater Marsh	Tidal Flats	Tidal Open Water	Non-Tidal Open Water	Tidal Scrub Shrub/ Transitional	Scrub Shrub/ Forested Swamp	Beach	Undeveloped Dryland
DELAWARE BAY: NEW JERSEY SIDE TOTAL ACREAGE BY HABITAT TYPE											
2010	6,420	50,890	573	1,120	692	149,066	2,516	1,109	40,983	651	69,223
2050	42,947	18,446	577	1,121	649	150,235	2,082	631	38,791	427	67,336
2100	29,831	2,993	551	942	31,765	154,921	1,842	1,262	33,822	182	65,132
Net Change	23,411	-47,897	-22	-179	31,073	5,855	-674	154	-7,160	-469	-4,091
% of Initial	365%	-94%	-4%	-16%	4,491%	4%	-27%	14%	-17%	-72%	-6%
TOTAL ACREAGE CHANGE IN 2100 BY GENERAL WETLAND CATEGORY IN DELAWARE BAY											
	Marsh				**Open Water/Tidal Flats**			**Scrub-Shrub/ Swamp**		**Other**	
New Jersey	-24,688				36,254			-7,007		-4,560	

HEA RESULTS

In Exhibits 9 and 10, we present the HEA model results for tidal emergent wetlands, scrub shrub/transitional wetlands, tidal swamps, tidal flats, and tidal open water (DSAYs by type in Exhibit 9, overall results in Exhibit 10). The results in Exhibit 10 present both acres of compensatory restoration (for each alternative) and the predicted costs of compensatory restoration, both discounted to the present. We combine the net habitat change to examine the cumulative impacts and overall loss. As shown, the wetland areas transition from the more productive irregularly flooded marshes to wetland types that are moderately less productive according to the available literature. Given that the upper estuary watershed has no net loss in the wetland categories evaluated in the HEA, we do not carry the analysis of that area through to Exhibit 10. The largest losses in the upper estuary occur in the scrub/shrub and swamp areas, which we do not evaluate in the current HEA.

EXHIBIT 9. DISCOUNTED SERVICE ACRE-YEARS USING 3 PERCENT DISCOUNT RATE

		Regularly Flooded Marsh	Irregularly Flooded Marsh	Transitional / Scrub Shrub	Swamp	Tidal Flat	Tidal Fresh Marsh	Open Water
Upper Estuary	Pennsylvania	3,961	512	-923	472	-430	35	5,754
	New Jersey	9,425	6,030	-188	-8,865	-2,994	120	7,098
Lower Estuary	Delaware	50,241	-59,866	2,476	-3,979	1,686	838	2,560
	New Jersey	139,565	-154,735	9,650	-11,597	1,280	9,713	13,531
Delaware Bay	Delaware	418,895	-513,908	19,449	-60,194	3,129	6,037	33,315
	New Jersey	335,206	-451,528	-10,958	-38,292	8,645	6	13,515
TOTAL		957,293	-1,173,497	19,506	-122,455	11,316	16,749	75,774

Note: HEA outputs are in Discounted Service Acre Years (DSAYs). DSAYs are the sum of the annual ecological service loss/gain for the period of concern (2010-2100), with each year's service discounted to present day. These service levels are specific to each habitat type (*i.e.*, they have not been normalized).

We consider two different scenarios within the HEA. The first presumes a near-term (2020) project that results in preservation of wetlands (i.e., a living shorelines type project). The second, a full marsh restoration beginning in 2050, demonstrates the effect of completing a restoration project further in the future, when marsh loss has already occurred. This represents replacement responses rather than prevention.

As shown in Exhibit 10, the analysis estimates the total restoration acreage would range between 45,000 and 109,000 acres for the restoration, depending upon whether the projects undertaken are preventative in nature (such as the living shoreline approach) or complete restoration after loss. The corresponding estimates of the cost of restoration ranges between approximately $26 and $39 billion. Consequently, the timing of the adaptation effort has a significant impact on the total cost.

EXHIBIT 10. COMPARATIVE ADAPTATION REQUIREMENTS BASED UPON 3 PERCENT DISCOUNT RATE

REGION	STATE	DISCOUNTED SERVICE ACRE YEAR LOSS[1]	DISCOUNTED CONSUMABLE PRIMARY PRODUCTIVITY LOSS (THOUSAND KG)	COMPENSATORY RESTORATION ACREAGE	ESTIMATED COST OF RESTORATION (MILLION $2010)
Preventative Restoration Option (Living Shorelines): 2020					
Lower Estuary	Delaware	-22,950	-2,461	1,832	$ 1,041
	New Jersey	-36,384	-3,902	2,904	$ 1,650
Delaware Bay	Delaware	-239,686	-25,704	19,128	$ 10,869
	New Jersey	-269,223	-28,871	21,485	$ 12,208
TOTAL		-568,243	-60,938	45,348	$ 25,767
Complete Restoration Option: 2050					
Lower Estuary	Delaware	-22,950	-2,461	4,422	$ 1,589
	New Jersey	-36,384	-3,902	7,010	$ 2,519
Delaware Bay	Delaware	-239,686	-25,704	46,178	$ 16,594
	New Jersey	-269,223	-28,871	51,869	$ 18,639
TOTAL		-568,243	-60,938	109,478	$ 39,341

1. DSAYs in this table are normalized in terms of relative DSAYs of regularly flooded marsh in order to sum them across habitat types. The conversion uses the primary productivity of each habitat relative to regularly flooded marsh.

DISCUSSION

CONCLUSIONS

Our application of SLAMM and HEA to Delaware Bay demonstrates the potential for a scalable framework to evaluate ecological changes due to sea level rise. Through this approach, ecosystem managers can quantify the potential ecological impacts of sea level rise and inform the corresponding measures that might be taken (e.g., preventative versus restorative methods) to promote adaptation and work to achieve no net loss of ecological services.

With SLAMM, we demonstrate that we can undertake large-scale analyses at a ten-meter resolution, a finer scale than undertaken in other investigations. While we recommend further fine-tuning of the model parameters and inputs (*e.g.* LIDAR data, undeveloped land cover data), the model provides useful planning-level information to demonstrate the likely effects of increased rates of sea level rise on wetland habitat types.

We also show that concepts from natural resource damage assessment (habitat equivalency) are applicable to losses due to sea level rise. The HEA model provides a powerful tool for comparing ecological services among different habitat types and across time. With this tool, ecosystem managers can evaluate areas that will most benefit from measures to prevent loss and those that may best be left to adapt naturally. In particular, as shown in Exhibit 10, managers can use this methodology to determine the cost of preservation and determine the optimal timing for adaptation.

As shown in the results, SLAMM estimates that a significant area of undeveloped dry land would be inundated by sea level rise and therefore may be converted to wetland habitat. The question remains, however, whether those lands are or will remain undeveloped and whether property owners will allow the wetland conversion to occur. As such, further development and property protection efforts in this region could further increase the net wetland acreage loss in the estuary.

NEXT STEPS

While the current model produces valuable results for the Delaware Bay, from our initial work we have identified various areas that could benefit from additional effort. The currently available data also limit the potential scenarios, which should be considered when using the results of this project.

Wetland Migration Modeling

To improve the predictive capacity of wetland migration modeling, the following research efforts would be beneficial:

- **Data Inputs**: The available DEM and NWI data are outdated and do not reflect the current state of the estuary. Bare-earth LiDAR and updated wetlands layers would greatly enhance the baseline of the analysis and lend greater weight to differentiation among habitat types in the model.
- **Designation of Undeveloped Lands**: Depending upon the topography, SLAMM allows wetlands to migrate onto adjacent undeveloped property. Although the wetland migration is a prospective modeling, the delineation of undeveloped land is a static sample based upon current impervious surface cover. If further coastal development occurs along the estuary, less land may be available for wetland migration and additional acreage losses could occur. As such, in future analyses, we recommend applying information from other modeling efforts that examine existing property values to assess locations where property owners would be economically positioned to protect their property (and therefore potentially block wetlands).[21] The lands identified by this modeling effort could be applied in SLAMM as the “Developed” lands unlikely to be available for wetland migration. Similarly, future shore protection may detrimentally affect adjacent wetland areas, which is not be considered in the current model.
- **Accretion**: For SLAMM, our previous sensitivity analyses indicate that the accretion rate is one of the largest drivers of variability.[22] We have refined these

[21] Neumann, J.E., et al, 2010 (submitted), “Assessing sea-level rise impacts: a GIS-based framework and application to coastal New Jersey”, Coastal Management.

[22] While other parameters also affect the results, there is far less potential for variability in many of them (e.g. historical rate of sea level rise, which is a directly measured value).

values further in this version through additional literature research and discussion with local experts. As additional surface elevation table data become available for the Delaware Estuary, these values can be refined further. Additionally, the recently released SLAMM 6 also includes an algorithm that can compute variable accretion rates as a function of elevation, distance to river or tidal channel, and a salinity factor.

- **Salt-wedge modeling**: Further parameter development for fresh and salt water flows in the Delaware Estuary. The current version of SLAMM provides a considerably enhanced salt wedge/estuary model as compared to previous versions. The module considers the effect of increasing salinity in an estuarine system as a driver for habitat change, as well as simple inundation. Development of parameters for the Delaware Estuary relevant to this module will allow for additional delineation of changes in habitat types.
- **Sediment Supply**: Predictions on future sediment supply are outside the scope of the current model; however, fluctuations in sediment supply can greatly affect the ability of marshes to adapt to rising sea levels. The model currently presumes a continuation of the current sediment inputs. In the event of future decreases in sediment supply, a likely effect of changes in development patterns, the model would overestimate the ability of marshes to adapt in place to sea level rise.
- **Hydrodynamics**: Increasing sea level may greatly affect the hydrodynamics of the estuary, particularly one that narrows as dramatically as the Delaware River does in its upper estuary reaches. A particular issue for the Delaware River is the impact of channel dredging and/or deepening on its hydrodynamic features. Specifically, channel deepening may increase the already significant tidal amplitude in the upper estuary reaches.

Equivalency Analysis

For the HEA model, we recommend the following research:

- **Potential Restoration Projects**: The characterization of future restoration projects are large drivers of the results of the HEA. Additional research and discussion with local stakeholders on these issues is important. For characterization of potential restoration projects, potential future research could include working with local experts to identify preservation (e.g. preventive maintenance) methods and their expected efficiency, and then working with engineering cost experts to evaluate costs.
- **Relative Ecological Service Metrics**: Further work could include support for primary research on other potential metrics, as well as literature surveys of current primary research in ecological services (i.e., the considerable efforts underway to calculate carbon sequestration capacities of various habitat types, values that are unfortunately not yet available). Other ecological services may better represent the priorities of different resource managers; the current structure of the HEA allows

for ready substitution of new services or of a more basic relative ranking scheme for habitats.

- **Baseline Condition Data**: Spatial datasets to represent existing habitat condition (e.g., baseline ecological services) would also improve the responsiveness of the HEA to local conditions, and would allow application of detailed condition information over a larger area. We envision integrating spatial condition data with the spatial analysis conducted in SLAMM to more accurately predict ecosystem responses.

APPENDIX A | SUMMARY OF LIVING SHORELINES LITERATURE REVIEW

DEFINITION OF "LIVING SHORELINE"

"Living Shoreline" is a more natural method of erosion and habitat protection approach that allows natural processes to occur rather than hardening or armoring the shoreline. Previously termed "soft" or "nonstructural shoreline stabilization alternatives" in the 1980s, today's "living shoreline" approaches encompass not only erosion control but also minimize critical habitat impacts and disruption to coastal processes.[1]

"Living shorelines is a concept based on an understanding and appreciation of the dynamic and inherent ecological value that our natural shorelines provide. Living shoreline projects apply these natural principles in the design and construction of shorelines in order to enhance habitat and maintain shoreline processes."[2] This definition has four important aspects: dynamic, function, habitat, and processes.[3] "Living shorelines" strategies manage shoreline erosion while also preserving and improving valuable ecosystem services, such as providing habitat for terrestrial and aquatic species and maintaining water quality.[4] Structural or "hard" shoreline stabilization alternatives previously used as erosion control tended to cause permanent destruction of marshes, sandy beaches and forested buffers.

SUITABLE AREAS FOR "LIVING SHORELINE"

"Living shoreline" techniques are most easily implemented in low energy wave environments. "Living shore" solutions for environments within medium and high energy environments are more difficult and become a balancing act between maintaining enough protection, while, at the same time, providing viable habitat and continuation of natural water exchange processes.

[1] Jefferson Patterson Park & Museum, "Shore Erosion Control: Living Shorelines and Other Approaches," Accessed on 3/15/2010 at: http://www.jefpat.org/Living%20Shorelines/lsmainpage.htm

[2] Smith, Kevin, "Integrating Habitat and Shoreline Dynamics into Living Shoreline Applications," Management, Policy, Science, and Engineering of Nonstructural Erosion Control in the Chesapeake Bay: Proceedings of the 2006 Living Shoreline Summit, December 2006.

[3] Smith, Kevin, "Integrating Habitat and Shoreline Dynamics into Living Shoreline Applications," Management, Policy, Science, and Engineering of Nonstructural Erosion Control in the Chesapeake Bay: Proceedings of the 2006 Living Shoreline Summit, December 2006.

[4] Duhring, Karen, "Overview of Living Shoreline Design Options for Erosion Protection on Tidal Shorelines," Management, Policy, Science, and Engineering of Nonstructural Erosion Control in the Chesapeake Bay: Proceedings of the 2006 Living Shoreline Summit, December 2006.

Determining if a living shoreline is the appropriate erosion control method must be made on a site by site basis. In general, deciding if a living shoreline approach is appropriate depends on a combination of:

- **Landscape setting:** salinity range and freshwater influence, shoreline orientation – lots of sunlight and infrequent storm exposure, surrounding land and water uses are compatible.
- **Erosion condition:** gradual landward retreat, minor bank erosion, only minor groundwater flow, easier when erosion is caused by upland runoff, rather than tide and waves.
- **Wave Climate:** low to moderate wave energy, regular high times not reaching upland bank, few boat wakes.
- **Gradual Slope:** bank heights less than 30 feet, bank slope not vertical, wide and flat intertidal areas, wide and shallow subaqueous areas.
- **Existing Buffers:** riparian buffers, tidal marsh, sand beach, sand dunes.

The less favorable the conditions are for implementing a non-structural "living shoreline" technique, the more likely a hybrid or combination of "living shoreline" and structural approach is necessary.

EXAMPLES OF PROJECTS WHERE "LIVING SHORELINE" ARE CURRENTLY USED

- **Riparian Vegetation Management:** enhance the density or species of bank vegetation.[5] Many "living shoreline" projects include an effort to increase vegetation on banks by planting or replanting to enhance natural slope stabilization.
- **Beach Nourishment and Dune Restoration:** addition of sand to a beach to raise its elevation and increase its width to enable to better buffer from wave action. Dune restoration reshapes and stabilizes a due with appropriate plants usually after beach nourishment event.
- **Tidal Marsh enhancement:** includes adding new marsh plants to barren or sparsely vegetated marsh areas. Many "living shoreline" marsh projects include planting or replanting native marsh plants to increase natural anchoring properties.
- **Tidal Marsh creation:** Non-vegetated intertidal areas converted to a tidal marsh by planting on the existing substrate. Need wide gradual slopes from the upland bank to tidal waters.
- **Bank Grading:** Physically altering slope. A dense cover of deeply rooted vegetation on the graded banks act as a buffer for upland runoff and groundwater seepage. Re-grading a steep or near vertical slope to a gently graded slope will dissipate wave energy along the shallow slope.

[5] Duhring, Karen, "Overview of Living Shoreline Design Options for Erosion Protection on Tidal Shorelines," Management, Policy, Science, and Engineering of Nonstructural Erosion Control in the Chesapeake Bay: Proceedings of the 2006 Living Shoreline Summit, December 2006.

- **Fiber Logs:** Biodegradable logs are staked in place to temporarily contain sand and reduce wave action at planted marsh sites. The Delaware Estuary Living Shoreline Initiative used coconut-fiber logs and mats as well as ribbed mussels that attach to the fibers of the logs.[6]
- **Marsh Toe revetment (hybrid):** structure placed at eroding edge of existing tidal marsh. Known as marsh edge stabilization, typically constructed with quarry stone.
- **Marsh sill (hybrid):** low stone structure, similar to marsh toe revetment, but used where no existing marsh is present.
- **Marsh with groins (hybrid):** using short stone groins to support a planted marsh, structures are placed perpendicular rather than parallel to the shoreline.
- **Offshore breakwater system (hybrid):** strategically positioned offshore structures that create a stable beach profile with embayments. Works in medium to high energy sand beaches, banks, and bluffs.

Choosing the stabilization method that is effective as well as least intrusive is the objective of living shorelines. Non-structural methods such as riparian vegetation can be applied to many low energy shorelines and can and should be applied to re-graded banks and dunes. Hybrid methods, mentioned above, must be minimally disruptive to the tidal exchange and sediment transport processes to be considered effective.

COSTS OF "LIVING SHORELINES"

The costs of a living shoreline depend on what method of stabilization is employed. It is obviously cheaper if the shore in question has only had marsh grasses planted on it and has not be re-graded or had any structural work done. Therefore, it is hard to estimate the cost of the average living shoreline. Instead, we offer the costs of different types of living shoreline and hybrid erosion control alternatives.

One paper estimates that high energy areas requiring large amounts of rock would cost approximately $500 per linear foot (2006 dollars), with prices varying drastically on the actual site conditions.[7] The same paper estimated that for low energy alternatives, living shorelines requiring less rock than traditional armor would be approximately $50-200 per linear foot (2006 dollars), depending on site condition.[8] A more recent 2009 presentation estimates that low energy non-structural projects such as beach nourishment and planted marsh cost in the range of $50 to $100 per foot (2009 dollars); Medium energy hybrid projects such as a marsh sill cost between $150 to $500 per foot (2009 dollars); high

[6] Partnership for the Delaware Estuary, "Living Shorelines" website, 2010. Accessed on March 15, 2010 at: http://www.delawareestuary.org/science_projects_living_shoreline.asp

[7] Davis, Jana and Audra Luscher, "Incentives to Promote Living Shoreline Techniques in the Chesapeake Bay," Management, Policy, Science, and Engineering of Nonstructural Erosion Control in the Chesapeake Bay: Proceedings of the 2006 Living Shoreline Summit, December 2006.

[8] Davis, Jana and Audra Luscher, "Incentives to Promote Living Shoreline Techniques in the Chesapeake Bay," Management, Policy, Science, and Engineering of Nonstructural Erosion Control in the Chesapeake Bay: Proceedings of the 2006 Living Shoreline Summit, December 2006.

energy structural projects such as revetment and bulkhead cost between $500 to $1,200 per foot (2009 dollars).[9]

EXHIBIT A-1. COSTS ASSOCIATED WITH LIVING SHORELINES

TECHNIQUE	UNITS	COST RANGE ($/UNIT)	COST INSTALLED ($/UNIT)
PLANTS			
Smooth Cordgrass	Linear foot	$1.00 – 2.00/ft	2.50 – 4.50/ft
Saltmeadow Cordgrass	Linear foot	$0.60 – 1.60/ft	1.30 – 3.50/ft
Sea Oats	Linear foot	$0.60 – 1.60/ft	1.30 – 3.50/ft
Panic Grass	Linear foot	$0.60 – 1.60/ft	1.30 – 3.50/ft
SOFT, NON-STRUCTURAL STABLIZATION			
Straw Blanket	yd^2	$0.29/$yd^2$	
Coconut Straw Blend	yd^2	$0.52/$yd^2$	
Coconut fiber	yd^2	$0.65/$yd^2$	
Non-woven geotextiles	yd^2	$0.70 – 1.35/$yd^2$	
"Snow" fencing	100 feet	$45.00	
Coir Log	10' lengths	$57.25	
GeoTextile Tube 15' circumference 22' circumference 30' circumference	Linear foot	$115 - 175 $175 - 225 $140 - 200	
OFFSHORE/NEAR SHORE BREAKWATERS (STRUCTURAL)			
Oyster Shell	Loose Shell (yd^{3}) Bag	$50-60 $5 ($30 for bag w/ spat)	
Concrete Bags	Bag	$4 – 6 (~$12-16/lf)	
Limestone Rock	Linear Foot	$125 - 200	
Reef Balls	Linear Foot	$44 Installed (~$36-38 w/volunteers)	
Reef Blk	Linear foot	$150 installed	
Wave Attenuation Device	Linear foot	$180 - 250	
Rip Rap	Yd^3	18-35/yd^3	

[9] Duhring, Karen, "Shoreline Stabilization with Envrionmentally Friendly Methods," PowerPoint Presentation, March 20, 2009. Accessed on March 18, 2010 at: http://www.vwrrc.vt.edu/vwmc/March2009Conference/presentations/2_KDuhring.pdf

TECHNIQUE	UNITS	COST RANGE ($/UNIT)	COST INSTALLED ($/UNIT)
BULKHEAD, SEAWALL, REVETMENT		COSTS BASED ON 4-8 FOOT HEIGHT	
Vinyl	Linear Foot	$125 - 200	
Vinyl w/toe protection	Linear Foot	$210 - 285	
Wooden	Linear foot	$115 - 180	
Wooden w/toe protection	Linear foot	$200 – 265	
Concrete	Linear foot	$500 – 1,000	
Sheetpile	Linear foot	$700 – 1,200	
Revetment	Cubic yard (Yd^3)	$25 – 45 ($120 – 180/lf installed)	

"LIVING SHORELINE" PROTECTION

We estimate an average length of shoreline protection projects of approximately 450 linear feet per project. Using the number of shoreline protection projects in Maryland in the past 20 years, 258 projects, and the total project length, 117,208 linear feet.[10] The total area of tidal wetland habitat saved in Maryland was estimated to be 200,309 square feet of tidal wetland habitat and creation of 2,376,570 square feet. Therefore, we estimate an average of approximately 775 square feet of tidal wetland saved per project and an average of approximately 9,210 square feet of tidal wetland created per project.

[10] Bhaskaran Subramanian, Johann Martinez, Audra Luscher, and David Wilson, "Living Shorelines Projects in Maryland in the Past 20 Years," Management, Policy, Science, and Engineering of Nonstructural Erosion Control in the Chesapeake Bay: Proceedings of the 2006 Living Shoreline Summit, December 2006.

APPENDIX B | REVIEW OF SLAMM AND HEA PARAMETER DEVELOPMENT

SLAMM

In the first step, we incorporate the NWI and elevation data into the model. National Wetlands Inventory data are available from U.S. FWS through their data manager. We couple these data with the National Elevation Data for New Jersey, Delaware, and Pennsylvania. SLAMM then processes information on the dates of the NWI and elevation data to resolve differences in the vintage of the data and produce a consistent baseline (*i.e.*, habitat present in 2010). These datasets provide a 10-meter resolution for our analysis.

We also ensure that all datasets are set to the same relative baseline. SLAMM's internal datum is mean tide level (MTL). As a result, the model requires a correction factor to adjust the NED data, which USGS provides using a vertical datum of NAVD88.[1] To develop this correction factor, we first identify the NED elevations at 10-meter intervals along the shoreline of the study area. We then use NOAA's VDatum tool to transform the NED elevations from NAVD88 to MTL.[2] At each point, we develop a correction value by taking the difference between MTL and NED elevation. Finally, we average these correction values across the study site.

To develop tide ranges, we employ a similar procedure, only we use the VDatum tool to convert the NED elevations along the shoreline to Mean Higher High Water (MHHW) and Mean Lower Low Water (MLLW). We then average the differences between these datums across the study site. Based on discussions with SLAMM's developer, we assume the inland and ocean tide ranges are the same.[3] The current version of SLAMM also requires Mean High Water Spring (MHWS) relative to MTL. We were unable to obtain subsite-specific values for MHWS, and instead, used MHHW. We discussed the MHWS parameter with personnel at NOAA Center for Operational Oceanographic Products and Services (CO-OPS), who recommended MHHW, as this would be a close

[1] For more information on tidal and vertical datums, see http://vdatum.noaa.gov/docs/datumtutorial.html.

[2] VDatum is a free software tool developed jointly by NOAA's National Geodetic Survey (NGS), Office of Coast Survey (OCS), and Center for Operational Oceanographic Products and Services (CO-OPS). VDatum is designed to vertically transform geospatial data among a variety of tidal, orthometric and ellipsoidal vertical datums - allowing users to convert their data from different horizontal/vertical references into a common system and enabling the fusion of diverse geospatial data in desired reference levels. NOAA. 2009. "Welcome to VDatum." Available at: http://vdatum.noaa.gov/.

[3] Clough, Jonathon, Personal Communication, January 5, 2009.

approximation to MHWS, though perhaps a slight underestimation.[4] Again, we employ a similar approach to estimate MHHW relative to MTL, by calculating the difference between the datums at 10-meter intervals, and then averaging the results across the study site.

We use rates for marsh accretion based on literature values summarized in Reed *et al*. (2008) for marsh sites in Delaware Bay. [5] The report identifies separate rates for freshwater, brackish, and salt marshes.[6] We conducted additional literature searches for accretion information and have discussed the proposed values with members of the Partnership for the Delaware Estuary's Climate Workgroup. The values for historic trend in sea level rise are from NOAA CO-OPS, which tracks historic tide gauge data and provides estimates of eustatic sea level rise for long-term gauges throughout U.S. tidal waters. We selected the nearest gauge for each subsite.[7] Values for each subsite are in Appendix C.

Due to the large size of the spatial data sets and internal processing limits of the model, we divided the watersheds into subsites and excised data significantly inland from the shore (areas that had limited wetland information). We rejoin the subsites for our watershed analysis and for the maps presented in the bodies of the text. The individual subsite maps and detailed input parameters are shown in Appendix C. Further detail on the parameters used in SLAMM is available online.[8]

HEA

The HEA model requires a series of area-specific parameters. The HEA values used for the estuary are shown in Exhibits 4 and 5 in the main body; further descriptions of these parameters are below:

- **Habitat Acreage**: Output from SLAMM.
- **Timing of Habitat Change**: Output from SLAMM.

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[4] According to personnel at CO-OPS, NOAA no longer provides measurements for MHWS, due to poor definition and limited applicability of the parameter. Definitions state that it is the average of the high tides around the full and new moon, but do not specify if this means, for instance, high tide on the days of the full or new moon, or the few days surrounding them. The developer for SLAMM concurred that the parameter is no longer particularly relevant and that the substitution of MHHW for MHWS would have limited impact on the model. We included MHWS in our sensitivity analysis to verify this.

[5] Reed, D.J., D.A. Bishara, D.R. Cahoon, J. Donnelly, M. Kearney, A.S. Kolker, L.L. Leonard, R.A. Orson, and J.C. Stevenson. 2008. Site-Specific Scenarios for Wetlands Accretion as Sea Level Rises in the Mid-Atlantic Region. Section 2.1 in: Background Documents Supporting Climate Change Science Program Synthesis and Assessment Product 4.1, J.G. Titus and E.M. Strange (eds.). EPA 430R07004. U.S. EPA, Washington, DC. The document is available electronically at http://www.epa.gov/climatechange/effects/downloads/section2_1.pdf.

6 As with other literature, we map brackish marsh to irregularly flooded marsh and salt marsh to regularly flooded marsh.

[7] CO-OPS estimates the mean sea level trend for Reedy Point, Delaware based on monthly mean sea level data from 1956 to 2006, equivalent to a rise of 1.14 feet in 100 years. Similarly, the mean sea level trend for Philadelphia is based on monthly mean sea level data from 1900 to 2006, equivalent to a rise of 0.92 feet in 100 years. Rates are available at http://co-ops.nos.noaa.gov/sltrends/sltrends.shtml.

[8] Further documentation on SLAMM is available from http://www.warrenpinnacle.com/prof/SLAMM/index.html.

- **Discount Rate**: For natural resource damage assessment, three percent is the standard accepted value, serving as a proxy for the social rate of time preference.[9] However, in other applications for valuing costs and benefits, federal guidelines suggest different discount rates. Seven percent is the standard discount rate for government valuation of external social benefits.[10] For this analysis, we use only the three percent rate. The primary impact of using a seven percent rate would emphasize the impact of near-term changes.

- **Baseline Ecological Service Level**: Either an estimated value for an area ("best professional judgment"), or a site-specific input (e.g. summary information from local natural organization).

- **Final Ecological Service Level**: For lost habitat areas, we estimate a final ecological service level of zero, since the habitat no longer exists. For new habitat types created through migration or inundation, we assume the habitat reaches the local baseline level after a transition period.

- **Transitional Ecological Service Levels**: As inundation or migration creates new habitat types, those habitats go from zero to full ecological service over a transition period (10 years). In calculating cumulative primary productivity change, we account for the fact that, in the time surrounding marsh type transition as identified by SLAMM, service level will be lower, as the vegetation associated with the prior marsh type wanes and vegetation associated with the new marsh type replaces it.[11] For those acres that were added, we reduce the service level by half for the ten years following an increase in a given habitat type. For those acres that are lost, we also reduce the service level by half for the ten years prior to an acreage loss for a given habitat type.

- **Type of Potential Restoration Projects**: The type of potential restoration project refers to the habitat restored by the restoration project as well as the extent of ecological service improvement provided by the project.

- **Relative Ecological Values**: Relative ecological values of different habitat types, in order to compare the losses and gains between habitat types, have been incorporated in the model based on a literature search. At this time, we base relative habitat value on the selected metric of primary productivity. In order to compare between vegetated and non-vegetated areas (*i.e.* marsh versus tidal flat), a scaling factor that represents incorporation of primary productivity into the trophic relay is included, using ratios developed by Peterson *et al*. (2008).

[9] NOAA (National Oceanic and Atmospheric Administration). 1999. *Discounting and the Treatment of Uncertainty in Natural Resource Damage Assessment: Technical Paper 99-1*. Silver Spring, MD.

[10] OMB Circular No. A-94, Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs.

[11] Marsh transition is triggered in SLAMM by changes in elevation and salinity. Vegetation changes lag behind changes in elevation and salinity. This concept is frequently applied to increases in ecological service for ecological restoration projects (e.g. McCay and Rowe, 2003, discussed below.) We have additionally applied a gradual decrease to account for the expected decline in ecological service due to inundation.

HEA CALCULATIONS

To compute losses and gains in ecological service on an annual basis, we use the acreage output from SLAMM, grouped by habitat class. As shown in Exhibit B-1, to focus the analysis on key wetland categories, we combine these classes into 14 categories for our post-SLAMM evaluations. Using a discount factor of three percent (based on the social rate of time preference), we scale annualized losses and gains, relative to a baseline ecological service for an area, to a common year and sum them to estimate the net loss or gain in services, expressed as Discounted Service Acre Years (DSAYs).

EXHIBIT B-1. SLAMM CODES AND CLASS NAMES AS WELL AS IEc EVALUATION CATEGORIES

SLAMM CODE	SLAMM CLASS NAME	CATEGORY FOR EVALUATION
1	DevDryLand	Developed Dry Land
2	UndDryland	Undeveloped Dry Land
3	Swamp	Swamp
4	CypressSwamp	Swamp
5	InlandFreshMrsh	Inland Fresh Marsh
6	TidalFreshMarsh	Tidal Fresh Marsh
7	Scrub Shrub/ Transitional Marsh	Scrub Shrub/Transitional
8	Regularly Flooded Marsh	Regularly Flooded Marsh
9	Mangrove	Scrub Shrub/Transitional
10	Estuarine Beach	Beach
11	TidalFlat	Tidal Flat
12	Ocean Beach	Beach
13	Ocean Flat	Tidal Flat
14	Rocky Intertidal	Beach
15	Inland Open Water	Inland Open Water
16	Riverine Tidal Open Water	Tidal Open Water
17	Estuarine Open Water	Tidal Open Water
18	Tidal Creek	Tidal Open Water
19	Open Ocean	Tidal Open Water
20	Irregularly Flooded Marsh	Irregularly Flooded Marsh
21	Not used (formerly Tall Spartina)	Not present in study area
22	Inland Shore	Beach
23	Tidal Swamp	Tidal Swamp
24	Blank	Not present in study area
25	Vegetated Tidal Flat	Not present in study area
26	Backshore	Not present in study area

In our model of habitat transition due to sea level rise, there are three components to the ecological services over time. The first is the initial habitat – each cell of a given habitat category provides a set quantity of ecological services. When the category of the cell changes due to sea level rise, the ecological service for that habitat category drops to zero for the specified area. The second component corresponds to the new habitat category that occurs in a given cell. In this case, an increase in ecological services occurs for that habitat category. These two transitions either go from baseline to zero (habitat loss), or zero to baseline (habitat gain). The losses and gains from the transitions occur indefinitely, albeit discounted.[12] The final component to the ecological services model is the ecological service associated with habitat restoration. This provides an additional compensatory uplift, moving a degraded habitat (low baseline) to a higher level of service. We scale the potential future restoration projects to provide the amount of ecological service that compensates for a computed net loss. A cost estimate for the future project serves as an estimate of the cost to replace the lost services.

Exhibit B-2 demonstrates an example of the HEA calculations. In this hypothetical example, sea level rise converts one acre of brackish marsh to one acre of salt marsh (via inundation) in 2050.[13] Ecological services for the brackish marsh decrease in the decade prior to inundation. In the created salt marsh, ecological services increase in the decade following transition. The total comparative value is the sum of the annual discounted service changes: DSAYs, or discounted service acre years, for the specific marsh category, and discounted primary productivity for comparison between habitat categories. The overall model tracks these values by acre for each transition in each category.

[12] Due to discounting, changes more than fifty years in the future have minimal impact. With a three percent discount rate, an acre lost in 50 years is equivalent to 0.23 acres lost today. Similarly, an acre lost in 100 years is equivalent to 0.05 acres today with a three percent discount rate. Therefore, due to the impact of discounting, incremental changes are seldom considered beyond 100 years.

[13] The purpose of this example is to show the effects of discounting, the service changes related to habitat transition, and the use of a comparative metric (primary productivity). Brackish marsh does not necessarily transition to salt marsh, and further transitions may occur.

EXHIBIT B-2. SAMPLE HEA CALCULATION (CONVERSION OF BRACKISH TO SALT MARSH)

INPUTS:			
INITIAL HABITAT:	Brackish Marsh	BASELINE ECOLOGICAL SERVICE:	75 percent
REPLACEMENT HABITAT:	Salt Marsh	SERVICE TRANSITION TIME:	10
TIME STEP OF HABITAT CHANGE:	2050	DISCOUNT RATE:	3 percent

ANNUAL CALCULATIONS:

	Brackish Marsh Service Level	Discounted Change in Brackish Marsh Service Level	Discounted Change in Brackish Marsh Primary Productivity (kg)	Salt Marsh Service Level	Discounted Change in Salt Marsh Service Level	Discounted Change in Salt Marsh Primary Productivity (kg)
2010	75.0%	0.0%	0.0	0.0%	0.0%	0.0
2011	75.0%	0.0%	0.0	0.0%	0.0%	0.0
2012	75.0%	0.0%	0.0	0.0%	0.0%	0.0
...	...	...	...	...	...	...
2038	75.0%	0.0%	0.0	0.0%	0.0%	0.0
2039	75.0%	0.0%	0.0	0.0%	0.0%	0.0
2040	37.5%	-15.0%	-338.7	0.0%	0.0%	0.0
2041	37.5%	-14.6%	-328.8	0.0%	0.0%	0.0
2042	37.5%	-14.1%	-319.3	0.0%	0.0%	0.0
2043	37.5%	-13.7%	-310.0	0.0%	0.0%	0.0
2044	37.5%	-13.3%	-300.9	0.0%	0.0%	0.0
2045	37.5%	-12.9%	-292.2	0.0%	0.0%	0.0
2046	37.5%	-12.6%	-283.7	0.0%	0.0%	0.0
2047	37.5%	-12.2%	-275.4	0.0%	0.0%	0.0
2048	37.5%	-11.8%	-267.4	0.0%	0.0%	0.0
2049	37.5%	-11.5%	-259.6	0.0%	0.0%	0.0
2050	0.0%	-22.3%	-504.1	37.5%	+11.2%	+183.4
2051	0.0%	-21.7%	-489.4	37.5%	+10.8%	+178.0
2052	0.0%	-21.0%	-475.1	37.5%	+10.5%	+172.9
2053	0.0%	-20.4%	-461.3	37.5%	+10.2%	+167.8
2054	0.0%	-19.8%	-447.9	37.5%	+9.9%	+162.9
2055	0.0%	-19.3%	-434.8	37.5%	+9.6%	+158.2
2056	0.0%	-18.7%	-422.1	37.5%	+9.3%	+153.6
2057	0.0%	-18.1%	-409.9	37.5%	+9.1%	+149.1
2058	0.0%	-17.6%	-397.9	37.5%	+8.8%	+144.8
2059	0.0%	-17.1%	-386.3	37.5%	+8.6%	+140.5
2060	0.0%	-16.6%	-375.1	75.0%	+16.6%	+272.9
2061	0.0%	-16.1%	-364.1	75.0%	+16.1%	+265.0
2062	0.0%	-15.7%	-353.5	75.0%	+15.7%	+257.2
...	...	...	...	...	...	...
2098	0.0%	-5.4%	-122.0	75.0%	+5.4%	+88.8
2099	0.0%	-5.2%	-118.4	75.0%	+5.2%	+86.2
2100	0.0%	-5.1%	-115.0	75.0%	+5.1%	+83.7
		-7.28	-16,449.5		+4.99	+8,192.1
For one acre:		Total DSAYs	Total PP Change		Total DSAYs	Total PP Change

APPENDIX C | SLAMM PARAMETERS AND MAPS BY SUBSITE

EXHIBIT C-1. SLAMM PARAMETERS BY SUBSITE FOR DELAWARE ESTUARY

PARAMETER	SUBSITE								
	A	B	C	D	E	F	G	H	I
NWI Photo Date (YYYY)	1997	1995	1995	1995	2000	2002	2002	2000	2000
DEM Date (YYYY)	2001	2001	2001	2001	2001	2001	2001	2001	2001
Direction Offshore [n,s,e,w]	West	West	West	South	South	West	West	West	West
Historic Trend (mm/yr)	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
MTL-NAVD88 (m)	0.124	0.123	0.136	0.123	0.1	0.079	0.059	0.026	-0.017
GT Great Diurnal Tide Range (m)	1.69	1.835	1.925	1.941	1.921	1.976	1.964	1.913	1.842
Salt Elev. (m above MTL)	0.887	0.959	1	1.008	1	1.026	1.019	0.991	0.952
Marsh Erosion (horz. m /yr)	0.5	0.5	0.5	1.5	9.1	1.5	5.2	1.3	1.3
Swamp Erosion (horz. m /yr)	1	1	1	1	1	1	1	1	1
T.Flat Erosion (horz. m /yr)	0.5	0.5	0.5	1.5	9.1	1.5	5.2	1.3	1.3
Reg. Flood Marsh Accr (mm/yr)	4.4	3.6	3.6	3.6	4.6	4.5	4.5	4.3	4.3
Irreg. Flood Marsh Accr (mm/yr)	4.4	3.6	3.6	3.6	4.6	4.5	4.5	4.3	4.3
Tidal Fresh Marsh Accr (mm/yr)	10	10	10	10	10	10	10	10	10
Beach Sed. Rate (mm/yr)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Freq. Overwash (years)	25	25	25	25	25	25	25	25	25
Use Elev Pre-processor [True,False]	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
Max Width Overwash (m)	500	500	500	500	500	500	500	500	500
Beach to Ocean Overwash (m)	30	30	30	30	30	30	30	30	30
Dryland to Beach Overwash (m)	30	30	30	30	30	30	30	30	30
Estuary to Beach Overwash (m)	60	60	60	60	60	60	60	60	60
Marsh Pct Loss Overwash (%)	50%	50%	50%	50%	50%	50%	50%	50%	50%
Mang. Pct. Loss Overwash (%)	25%	25%	25%	25%	25%	25%	25%	25%	25%

PARAMETER	SUBSITE								
	J	K	L	M	N	O	P	Q	R
NWI Photo Date (YYYY)	2002	2002	1972	2002	1975	1981	1989	1989	1999
DEM Date (YYYY)	2001	2000	2000	2000	2000	2000	2000	2001	2000
Direction Offshore [n,s,e,w]	North	West	North	West	East	South	East	South	East
Historic Trend (mm/yr)	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
MTL-NAVD88 (m)	-0.02	-0.057	-0.113	-0.132	-0.129	-0.112	-0.049	-0.021	-0.017
GT Great Diurnal Tide Range (m)	1.87	2.054	2.275	2.549	2.568	2.27	2.034	1.862	1.82
Salt Elev. (m above MTL)	0.966	1.057	1.162	1.3	1.31	1.159	1.048	0.962	0.942
Marsh Erosion (horz. m /yr)	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Swamp Erosion (horz. m /yr)	1	1	1	1	1	1	1	1	1
T.Flat Erosion (horz. m /yr)	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Reg. Flood Marsh Accr (mm/yr)	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
Irreg. Flood Marsh Accr (mm/yr)	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
Tidal Fresh Marsh Accr (mm/yr)	10	10	10	10	10	10	10	10	10
Beach Sed. Rate (mm/yr)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Freq. Overwash (years)	25	25	25	25	25	25	25	25	25
Use Elev Pre-processor [True,False]	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
Max Width Overwash (m)	500	500	500	500	500	500	500	500	500
Beach to Ocean Overwash (m)	30	30	30	30	30	30	30	30	30
Dryland to Beach Overwash (m)	30	30	30	30	30	30	30	30	30
Estuary to Beach Overwash (m)	60	60	60	60	60	60	60	60	60
Marsh Pct Loss Overwash (%)	50%	50%	50%	50%	50%	50%	50%	50%	50%
Mang. Pct. Loss Overwash (%)	25%	25%	25%	25%	25%	25%	25%	25%	25%
PARAMETER	SUBSITE								
	S	T	U	V	W	X	Y	ZA	ZB
NWI Photo Date (YYYY)	1999	1999	1981	1981	1982	1981	1981	1981	1981
DEM Date (YYYY)	2000	2000	1998	1997	1998	1998	1998	1998	1998
Direction Offshore [n,s,e,w]	East	East	East	East	East	East	East	North	North
Historic Trend (mm/yr)	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
MTL-NAVD88 (m)	0.021	0.05	0.07	0.077	0.078	0.088	0.101	0.113	0.121
GT Great Diurnal Tide Range (m)	1.849	1.928	1.868	1.813	1.75	1.644	1.566	1.489	1.439
Salt Elev. (m above MTL)	0.958	1.001	0.972	0.946	0.915	0.862	0.823	0.784	0.757
Marsh Erosion (horz. m /yr)	1.3	5.2	5.2	5.2	1.5	1.5	0.5	0.5	0.5
Swamp Erosion (horz. m /yr)	1	1	1	1	1	1	1	1	1
T.Flat Erosion (horz. m /yr)	1.3	5.2	5.2	5.2	1.5	1.5	0.5	0.5	0.5
Reg. Flood Marsh Accr (mm/yr)	4.3	4.5	4.5	4.5	4.6	4.6	3.6	3.6	4.4
Irreg. Flood Marsh Accr (mm/yr)	4.3	4.5	4.5	4.5	4.6	4.6	3.6	3.6	4.4
Tidal Fresh Marsh Accr (mm/yr)	10	10	10	10	10	10	10	10	10
Beach Sed. Rate (mm/yr)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Freq. Overwash (years)	25	25	25	25	25	25	25	25	25
Use Elev Pre-processor [True,False]	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
Max Width Overwash (m)	500	500	500	500	500	500	500	500	500
Beach to Ocean Overwash (m)	30	30	30	30	30	30	30	30	30
Dryland to Beach Overwash (m)	30	30	30	30	30	30	30	30	30
Estuary to Beach Overwash (m)	60	60	60	60	60	60	60	60	60
Marsh Pct Loss Overwash (%)	50%	50%	50%	50%	50%	50%	50%	50%	50%
Mang. Pct. Loss Overwash (%)	25%	25%	25%	25%	25%	25%	25%	25%	25%

EXHIBIT C-2. SUBSITES M AND N: INITIAL, 2050, 2100

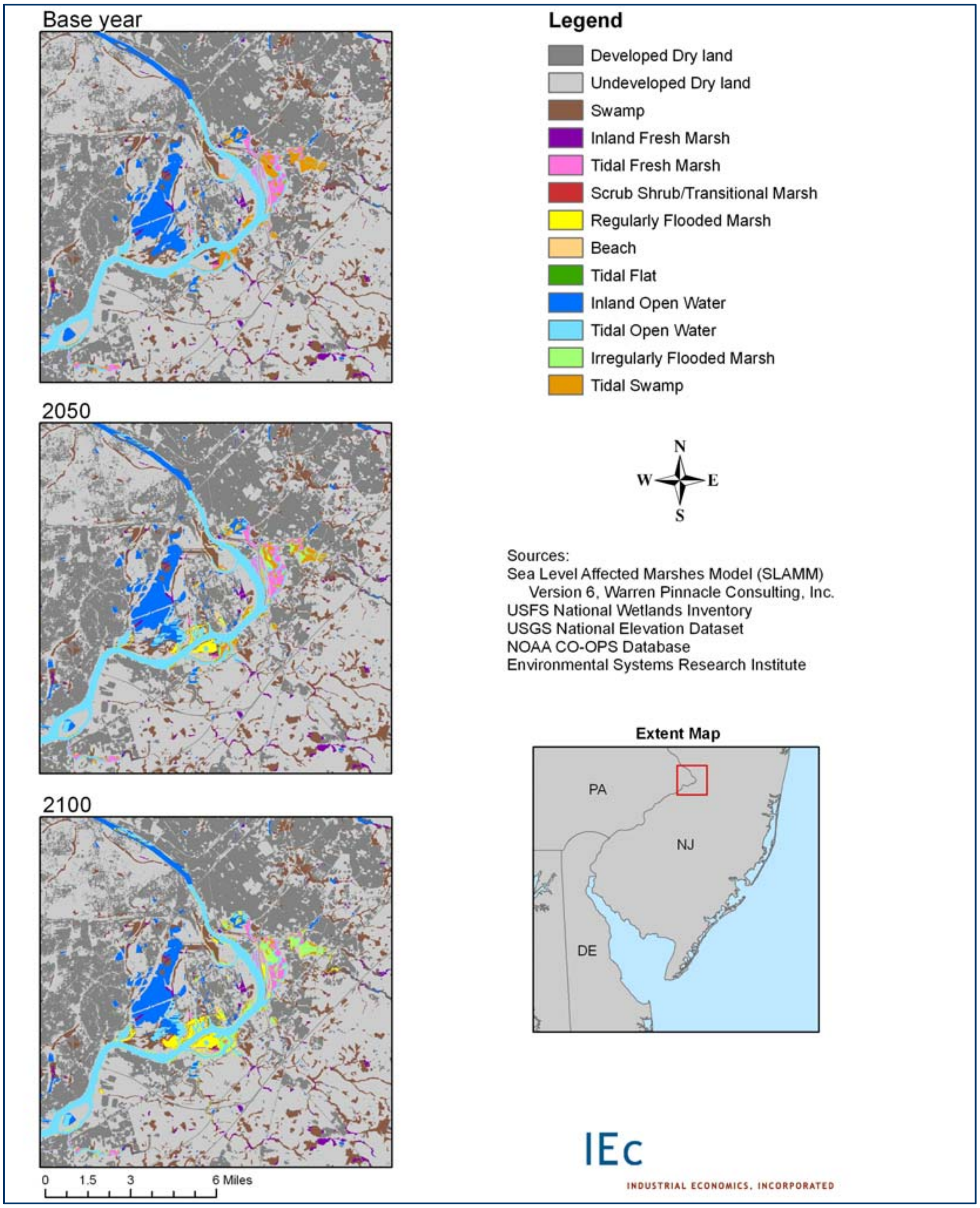

EXHIBIT C-3. SUBSITES O AND L: INITIAL, 2050, 2100

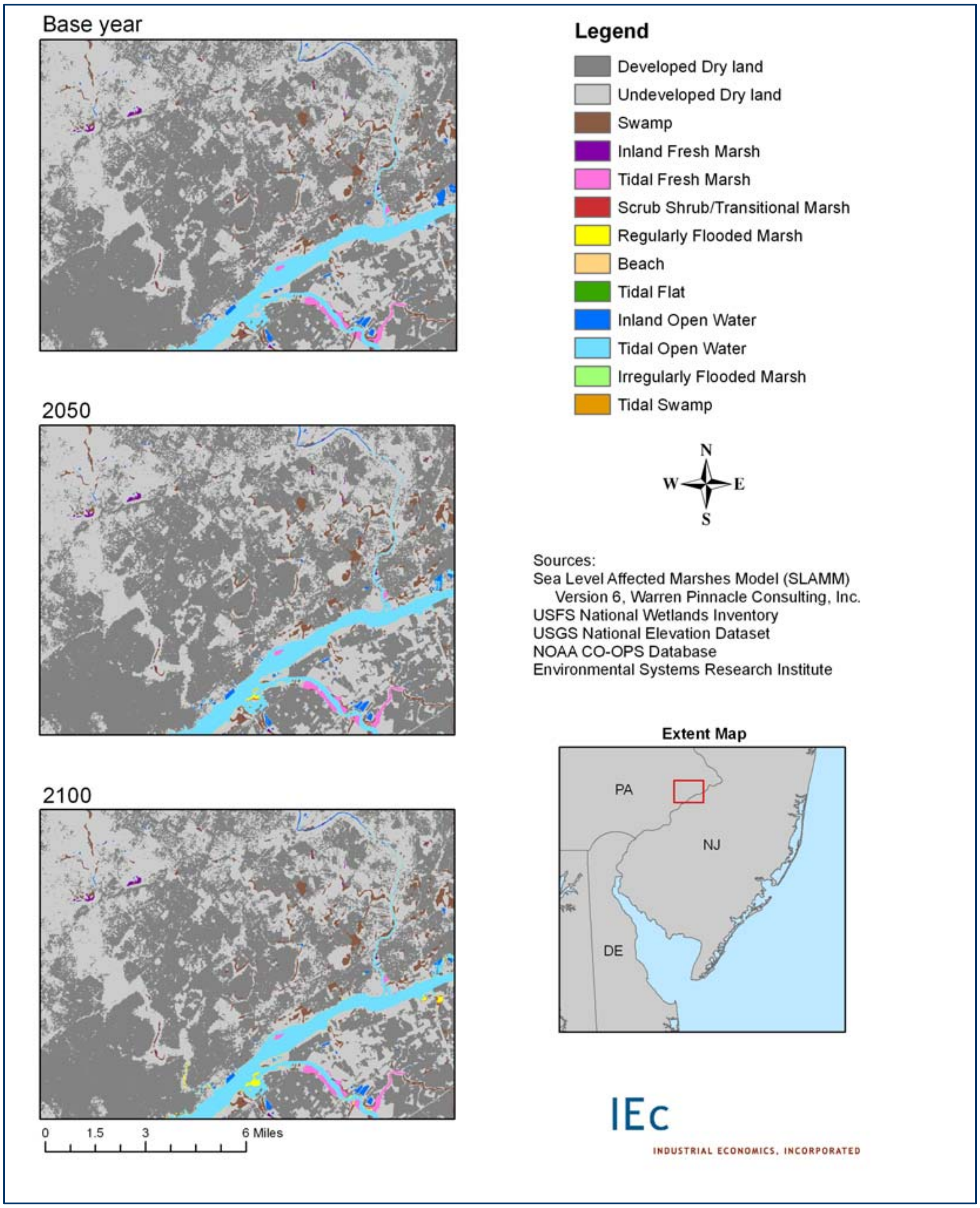

EXHIBIT C-4. SUBSITES P AND K: INITIAL, 2050, 2100

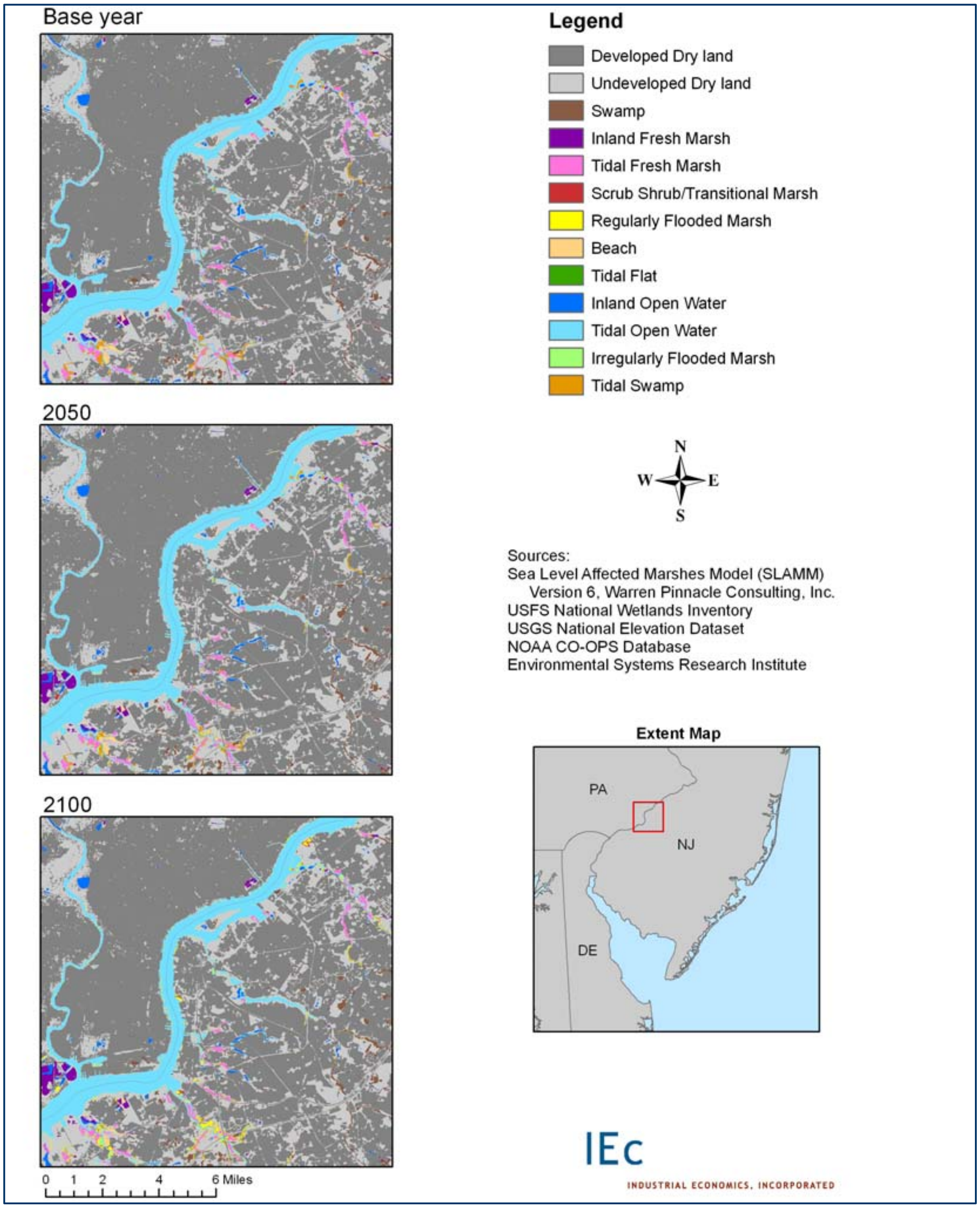

EXHIBIT C-5. SUBSITES Q AND J: INITIAL, 2050, 2100

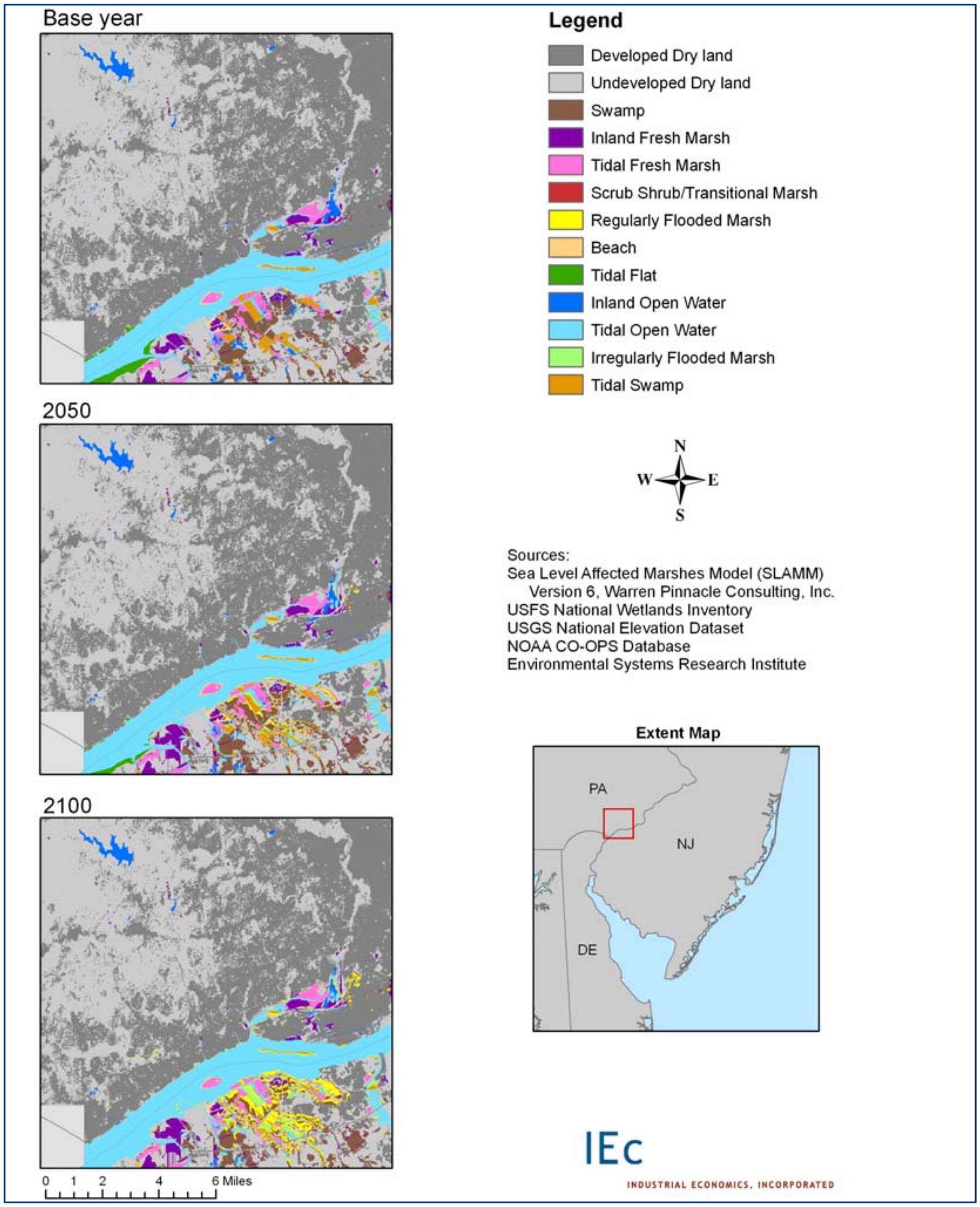

EXHIBIT C-6. SUBSITES R AND I: INITIAL, 2050, 2100

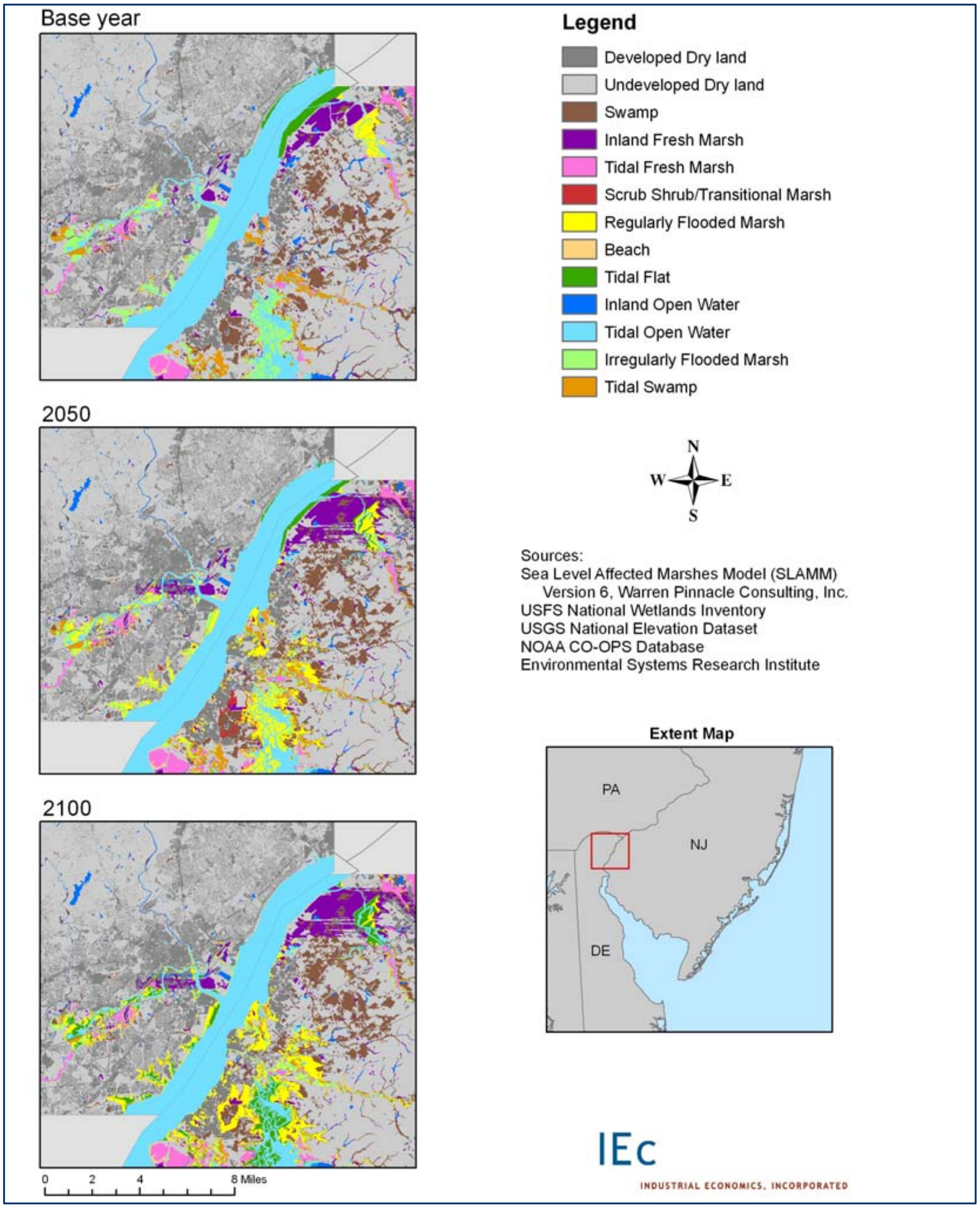

EXHIBIT C-7. SUBSITES S AND H: INITIAL, 2050, 2100

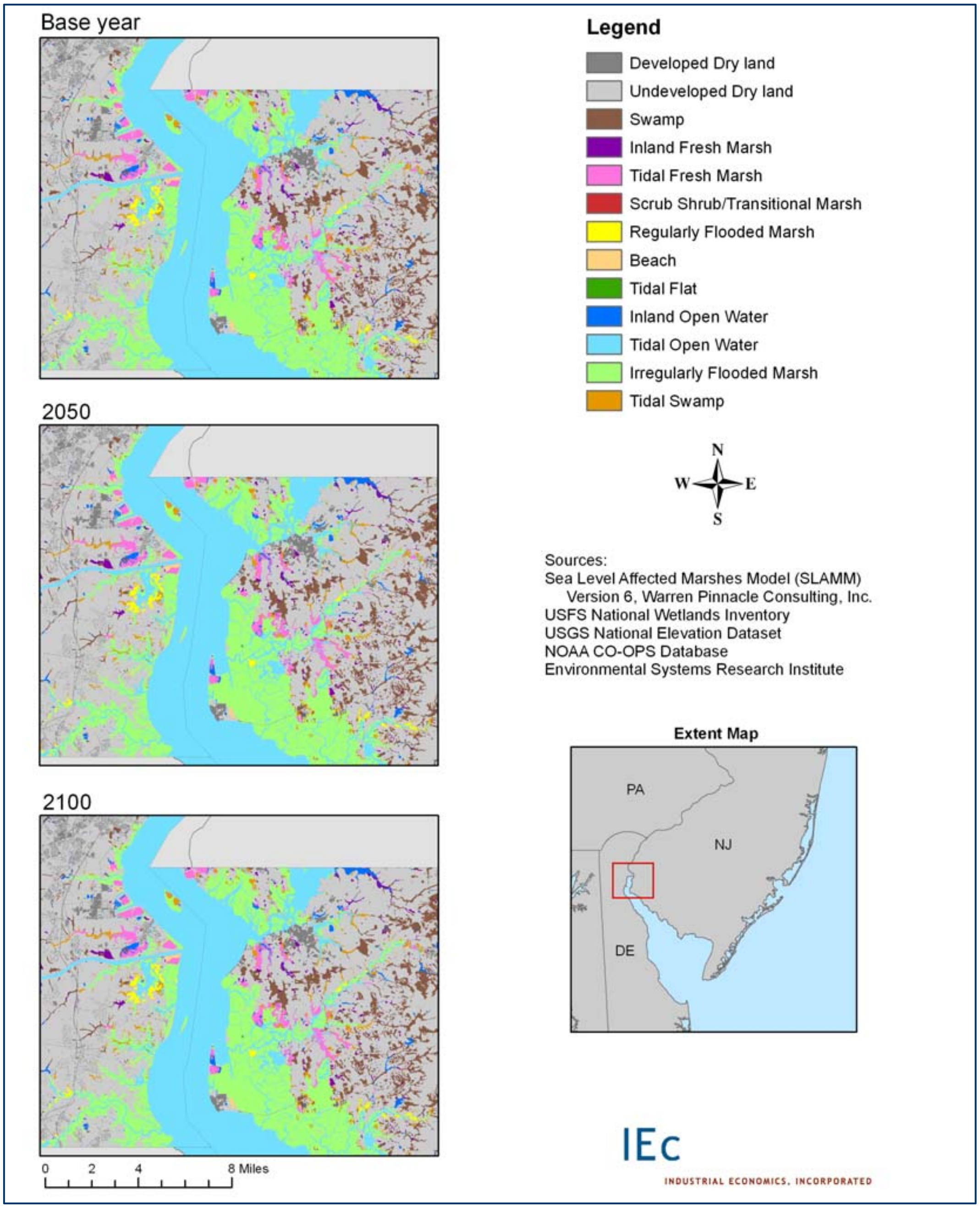

EXHIBIT C-8. SUBSITES T AND G: INITIAL, 2050, 2100

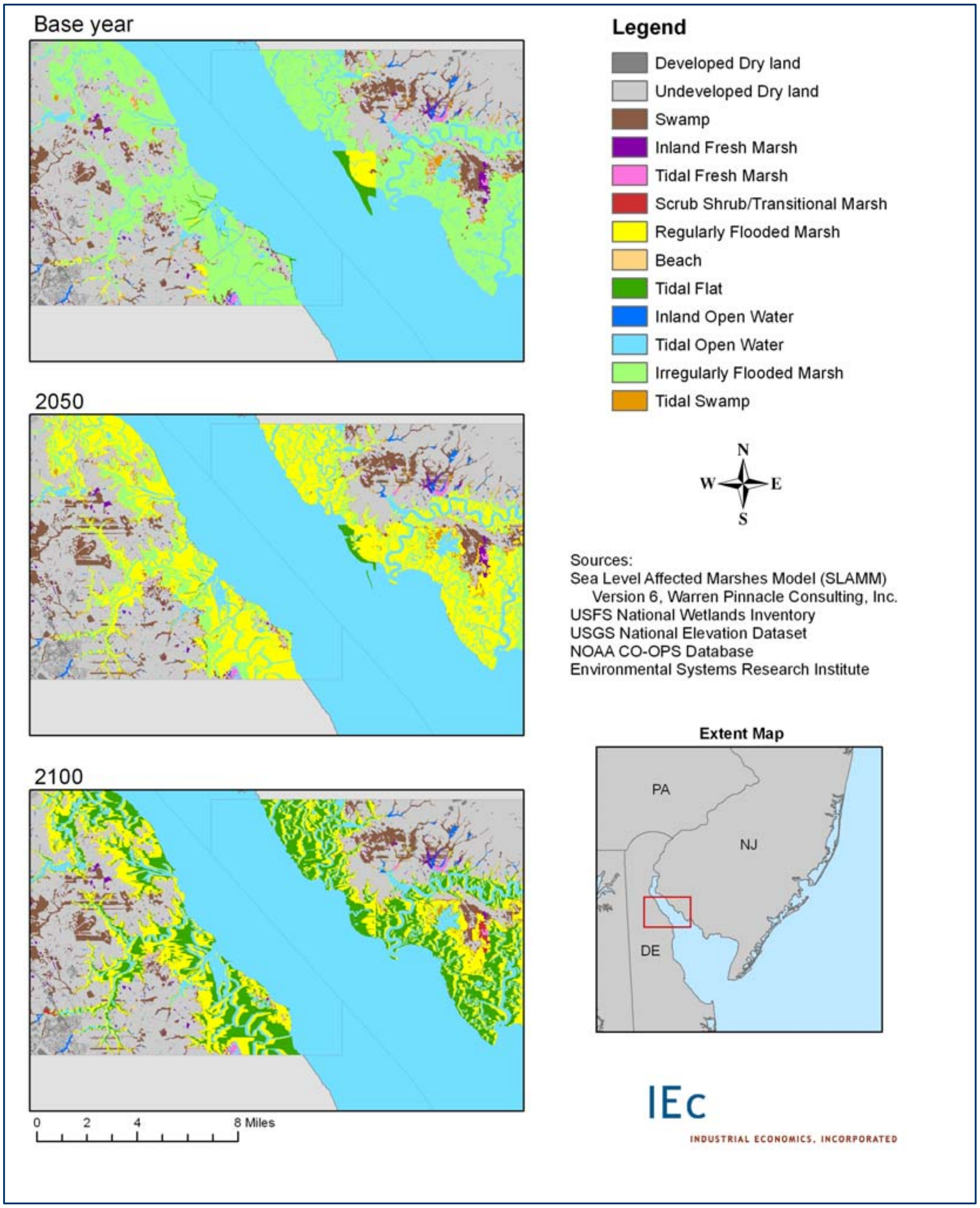

EXHIBIT C-9. SUBSITES F AND E: INITIAL, 2050, 2100

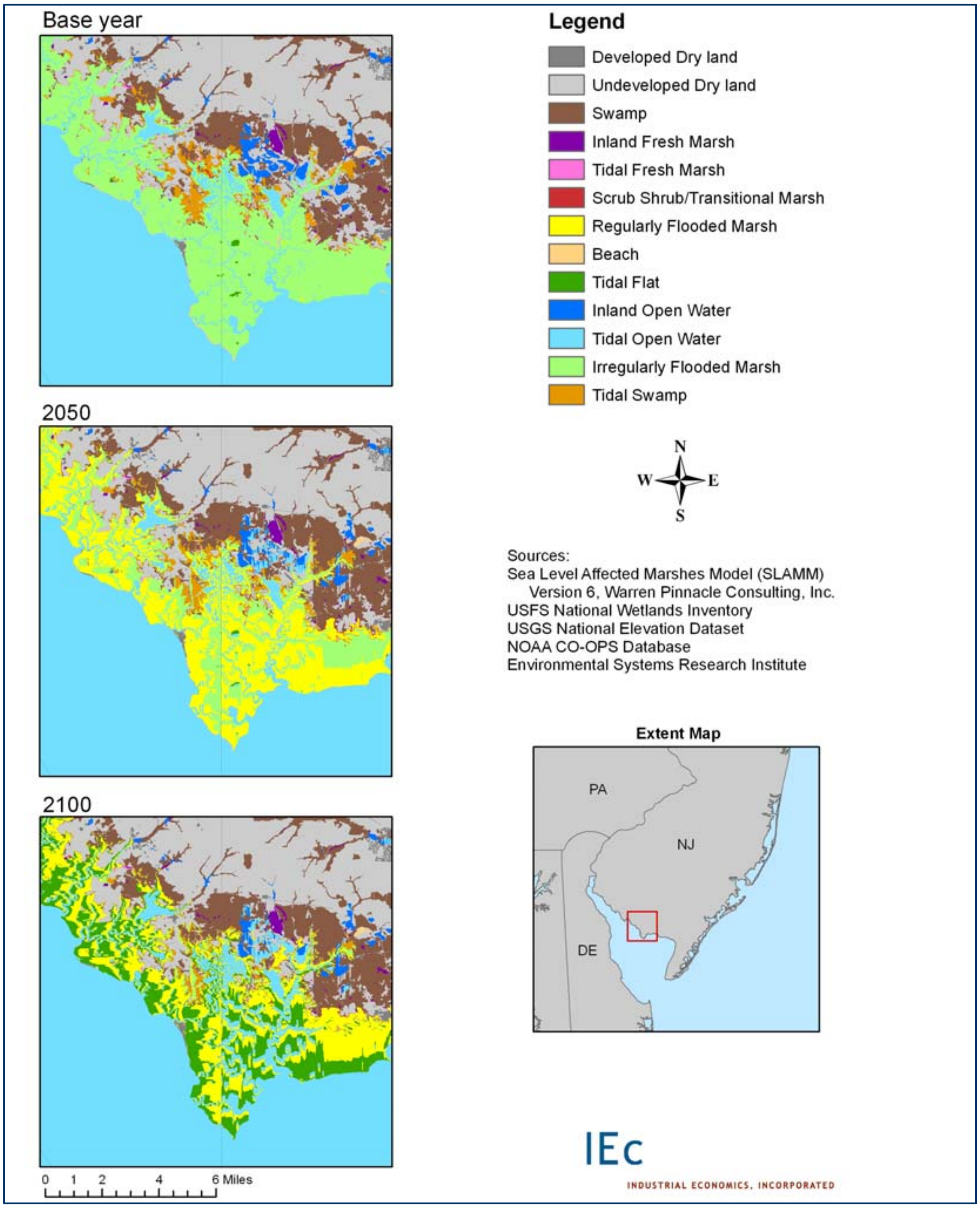

EXHIBIT C-10. SUBSITES U AND V: INITIAL, 2050, 2100

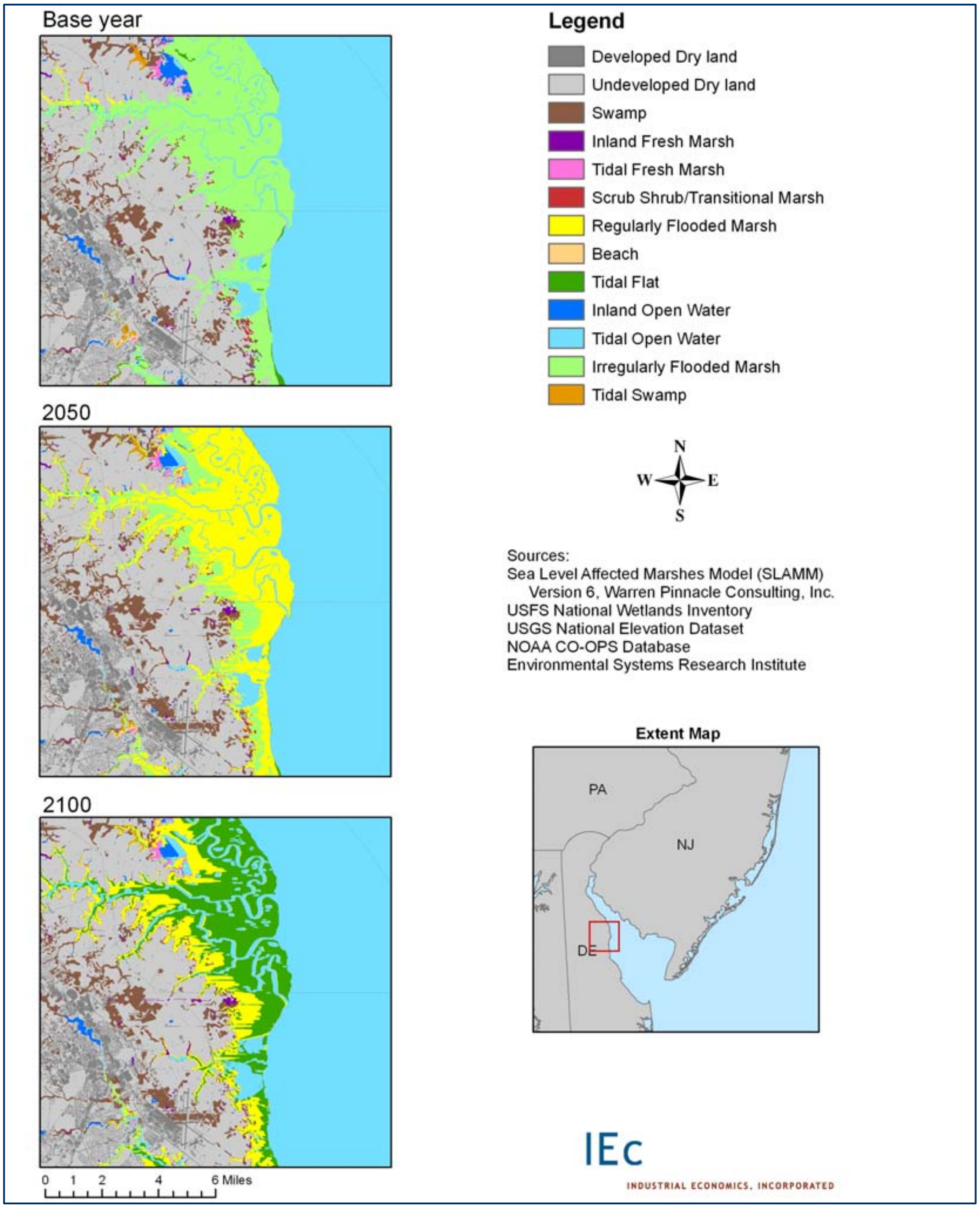

EXHIBIT C-11. SUBSITES D AND C: INITIAL, 2050, 2100

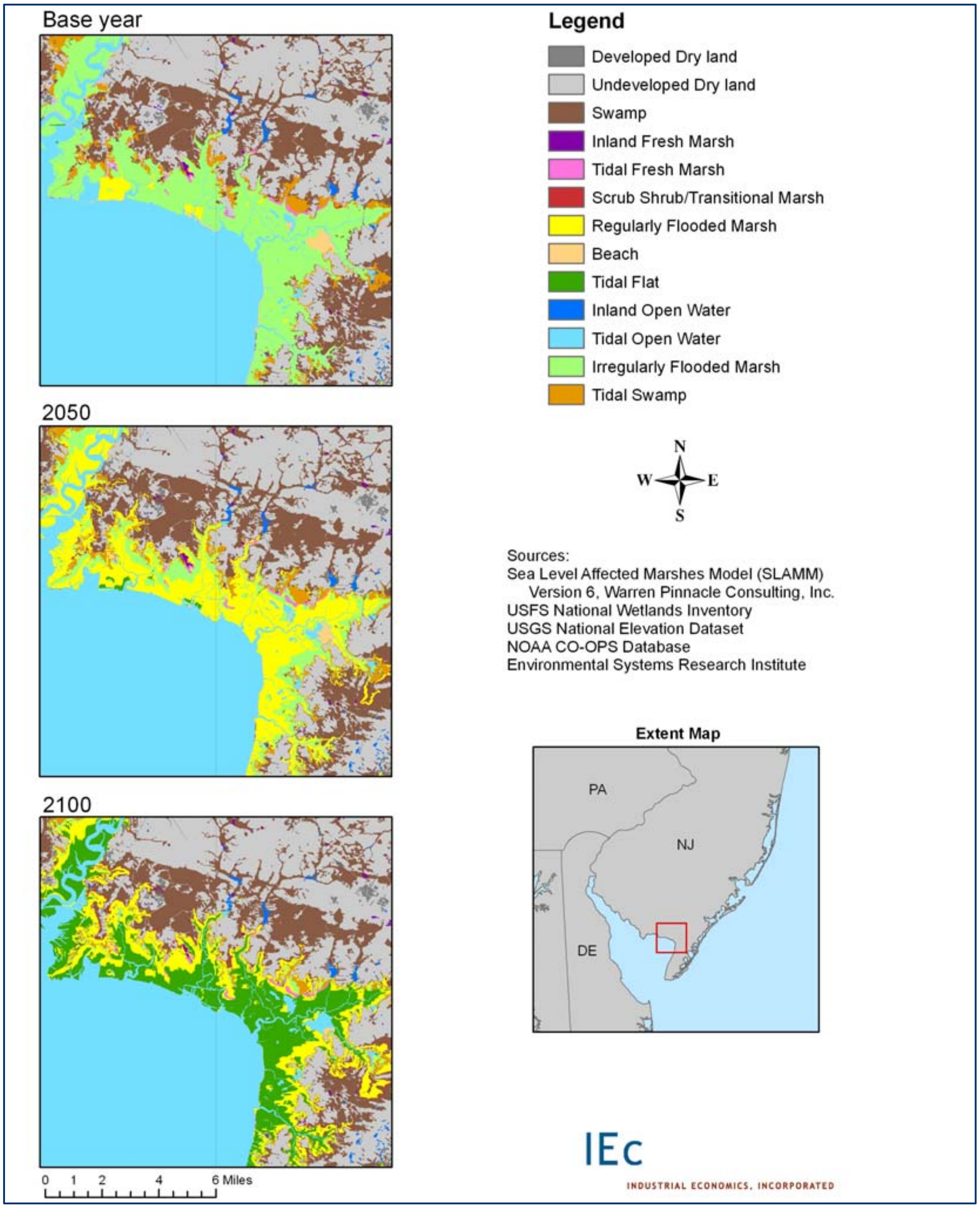

EXHIBIT C-12. SUBSITES W AND X: INITIAL, 2050, 2100

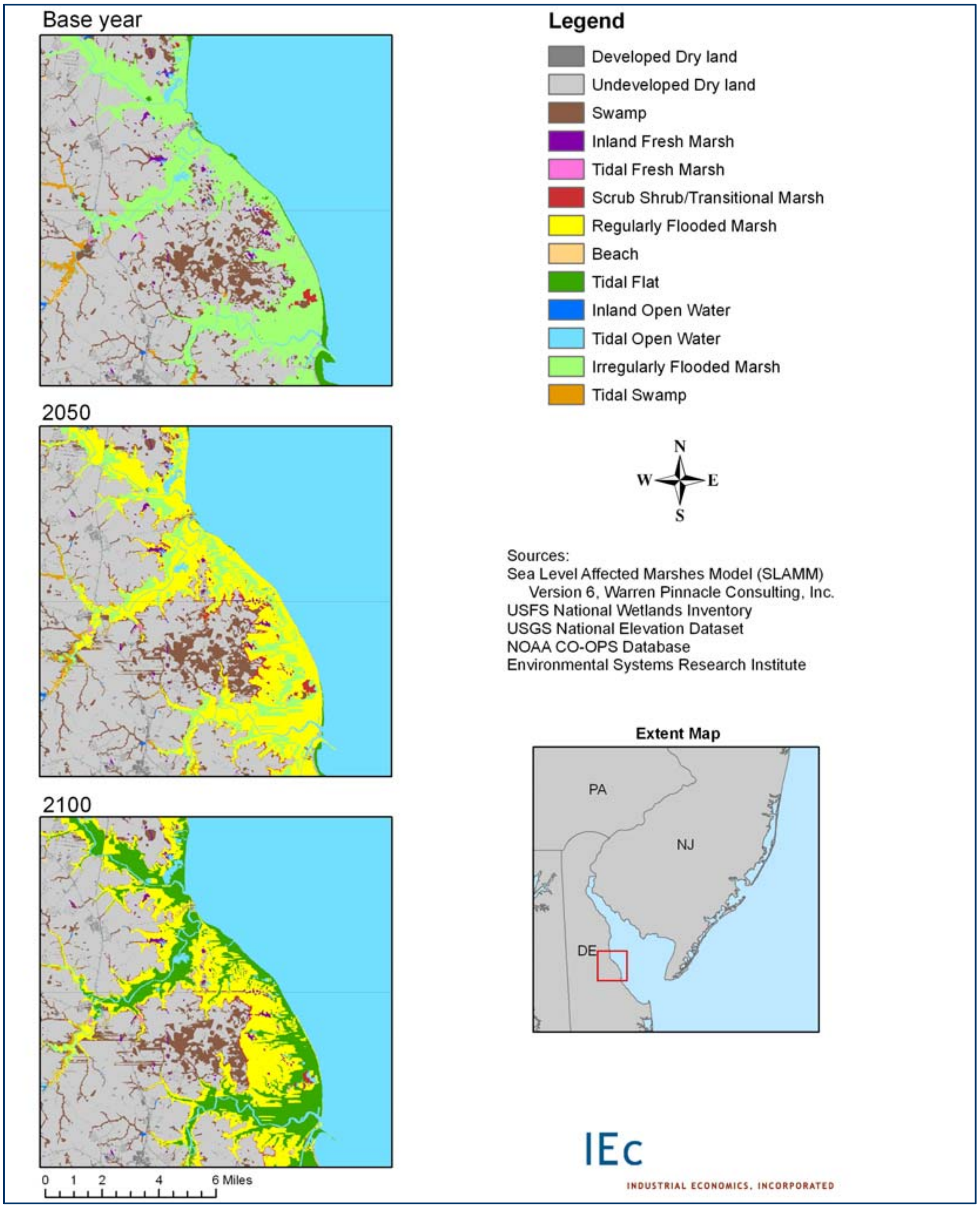

EXHIBIT C-13. SUBSITES A AND B: INITIAL, 2050, 2100

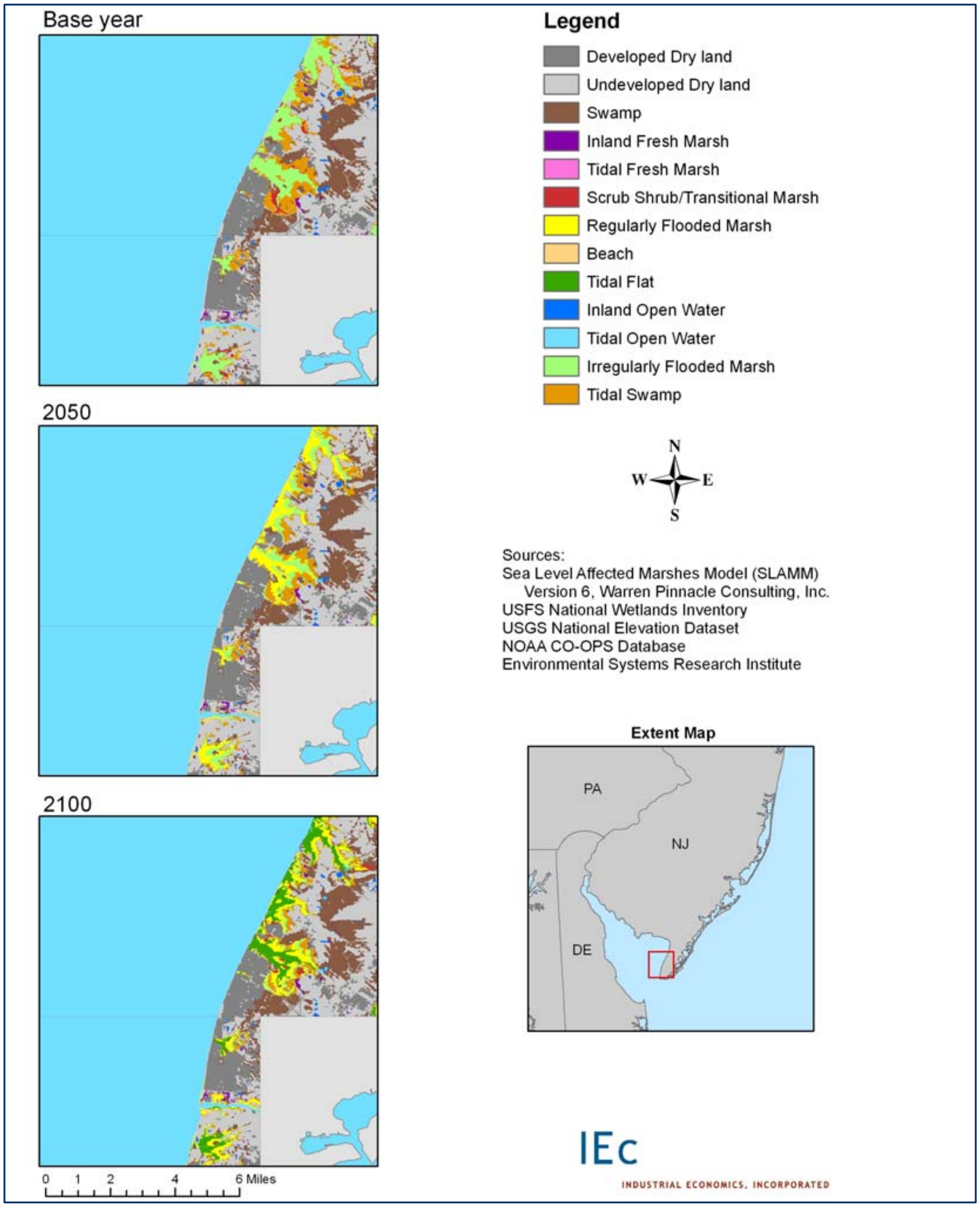

EXHIBIT C-14. SUBSITES Y, ZA AND ZB: INITIAL, 2050, 2100