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Narragansett Bay Sustainability Pilot

Phase I Report | March 20, 2012

INDUSTRIAL ECONOMICS, INCORPORATED

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SECTION 1 | INTRODUCTION

PROJECT BACKGROUND & OVERVIEW OF METHODS

This report describes the activities and results of Phase I of the Narragansett Bay Sustainability Pilot Project, a collaborative effort led by EPA's Office of Research and Development (ORD) and EPA Region 1. The project applies a system dynamics approach to addressing the problem of nutrient pollution in Narragansett Bay. The goal of the project is to develop an integrated assessment model that can help policymakers identify sustainable solutions to avoid, reduce, or manage the negative effects of nutrient pollution on the bay and its watershed.

Nutrient pollution threatens the environmental and economic viability of our nation's waters. It can cause algal blooms that deplete oxygen needed for fish and shellfish survival, smother vegetation, discolor and foul water, and produce toxins that are harmful to both humans and animals. There are two main nutrients that affect coastal waters: nitrogen and phosphorus. In Narragansett Bay, as in many coastal water bodies, nutrient pollution – primarily in the form of nitrogen – threatens a variety of social and economic activities, including recreational and commercial fishing, swimming, and tourism. Since nutrient pollution comes from a variety of sources and has a wide range of impacts, it is useful to understand the intricate linkages between the watershed's economic, social, and environmental systems.

EPA's ORD and Region I have identified nutrient pollution in coastal waters as a high-priority area in need of further research and urgent action. The Narragansett Bay watershed serves as an excellent location for piloting a new and innovative approach to addressing this issue. The watershed is an area of special and longstanding importance to New Englanders from an ecological, economic and recreational standpoint. The region has made significant water quality investments to resolve problems associated with nutrient loadings in the bay and its tributaries, and continues to work towards sustainable and integrated solutions. However, significant and complex nutrient-related problems remain.

Integrated assessment modeling is a relatively new policy tool at EPA. It applies a systems approach to decision-making by considering the three pillars of sustainability: economic prosperity, environmental protection, and social well-being. The goal of this methodology is to ensure that policy decisions are informed by a thorough understanding of the interdependencies and interactions within a system's economic, environmental and social spheres. Through integrated assessment modeling, policymakers and stakeholders can gain insight into the full suite of impacts of policy interventions, leading to more sustainable outcomes (U.S. EPA 2008).

The model being developed for the Narragansett Bay watershed uses a "triple value simulation" approach, allowing users to run a variety of different scenarios that simulate the impacts of specific interventions on the economic, environmental, and social sectors of the watershed. In addition, the collaborative process used to develop the model involved a wide range of stakeholders, and identified important environmental, economic and social indicators that might otherwise be overlooked or undervalued in the decision-making process.

Although developed independently, the Pilot Project applies a sustainability framework similar to the one outlined in the recently published National Academy of Sciences (NAS) Green Book (NAS 2011). It represents one of the first place- and programmatic-based pilot projects that EPA has developed as a concrete demonstration of how the Agency can use a systems approach to incorporate sustainability into its decision making.

PROJECT STATUS

Through intensive review of existing research, data gathering, and stakeholder outreach, the project team has developed an initial prototype of a triple-value simulation (3VS) model that is intended to provide a systems-level understanding of nitrogen pollution in the bay and facilitate exploration of an integrated strategy for addressing this issue through cost-effective, sustainable policy options.

The model being developed for Narragansett Bay (the Narragansett-3VS model) is a unique customization of the Millennium Institute's Threshold 21 (T21) model. The T21 model merges economic and biophysical variables into a single framework in order to simplify complex relationships in the economic, environmental and social spheres. By integrating knowledge from numerous studies of Narragansett Bay and similar watersheds into the T21 framework, the project team has created a unique tool to inform decision making in the bay.

Exhibit 1 depicts an overview of Phases I and II of the Narragansett Bay Sustainability Pilot Project. Phase I of the project began in May 2011 and addressed three main objectives:

1) **System Characterization:** To identify, through stakeholder outreach and review of the extensive body of existing research and studies, key environmental, economic, and social indicators and causal links for the watershed that could be incorporated into the Narragansett-3VS model to gauge the sustainability of policy interventions aimed at addressing nitrogen pollution in the bay;

2) **Sustainability Assessment and Modeling:** To develop an initial prototype of an integrated assessment model that demonstrates the effectiveness of a systems-level approach in assessing and developing policies for addressing the nitrogen management problem in the bay; and

3) **Strategy Development:** Identify the range of potential policy interventions and demonstrate how they can be incorporated into the Narragansett-3VS model. In addition, determine what next steps are necessary under Phase II to make the model an effective tool for local decision makers.

EXHIBIT 1.   NARRAGANSETT BAY SUSTAINABILITY PILOT PROJECT PHASES I & II

PHASE I						
2011						
MAY	JUNE	JULY	AUG	SEP	OCT	NOV
System Characterization						
		Sustainability Assessment & Modeling				
					Strategy Development	

PHASE II									
2012									
JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT
Continue systems research and model refinement									
						Stakeholder review and draft report			
								Finalized model and report	

A key element of Phase I of this project has been the stakeholder outreach effort, through which the project team compiled knowledge and data about the environmental, economic and societal conditions in the Narragansett Bay watershed. Through engaging stakeholders in Phase I, the project team also learned about the needs and priorities of those who live and work within the watershed. The team spoke directly with a wide range of stakeholders from government agencies (regional, state and local), NGOs, and industry, and performed an extensive literature review, which is discussed in greater detail in Section 3 of this report. The results of this outreach and research served as the basis for developing a prototype of the Narragansett-3VS model, which incorporates many, but not all, of the indicators that stakeholders identified as essential to characterizing the nitrogen issue in the bay.

While the prototype represents a functional systems-level model of the nitrogen issue in the bay, it contains a number of assumptions and limitations that need to be more fully explored and resolved before the model can provide credible outputs for exploring impacts of policy decisions concerning competing strategies for addressing the overall issue of nutrient pollution. Thus, in its current form the prototype of the Narragansett-3VS model is a work in progress that serves to demonstrate the potential of an integrated assessment modeling approach.

Phase II of the project will involve additional data collection and further refinement of the economic, environmental, and social relationships within the model, as well as quality assurance and uncertainty analyses of the model. The project team is currently working on establishing a "decision context" that will serve as a focal point for refining the Narragansett-3VS model prototype in Phase II and demonstrating how the model can be used to provide insights into the impacts and tradeoffs of alternative policy interventions across environmental, economic and social conditions in the watershed.

Provided that data are available, the 3VS model can be customized to address different geographic areas and a broad range of sustainability issues. The project team expects that this process will eventually be replicated for other locations in Region 1, as well as in other EPA Regions, that face complex environmental challenges.

REPORT ORGANIZATION

Section 2 of this report describes in further detail the systems approach employed to develop the Narragansett-3VS model. It defines the model's geographic scope, identifies the sources of nitrogen loadings in the bay, and discusses the Integrated Assessment Framework used to guide the model's development. Section 3 outlines the process of developing the Phase I prototype of the Narragnasett-3VS model, explaining the various indicators and their relationships to one another through causal linkages; the process of stakeholder engagement and data collection; the user interface for the prototype; and data gaps and limitations of the prototype. Section 4 provides an illustration of how the impacts of alternative conditions and policies can be explored through scenario testing. Lastly, Section 5 reviews the lessons learned from Phase I and discusses the anticipated schedule for Phase II of the pilot project.

There are three appendices included in this report, as well as five others that are available upon request. Appendix A provides detailed information on the data sources and processing steps used to estimate baseline nitrogen loading in the Phase I Narragansett-3VS model. Appendix B describes the environmental, economic, and social relationships and data sources that were used in the model. Appendix C provides an expanded version of the Phase I model schematic as well as an explanation of terms used in the model. Appendices D through H, available upon request, provide more in-depth information on model resources, policy interventions, stakeholder feedback, key model equations, and model simulations.

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SECTION 2 | SYSTEMS APPROACH TO NUTRIENT MANAGEMENT IN NARRAGANSETT BAY
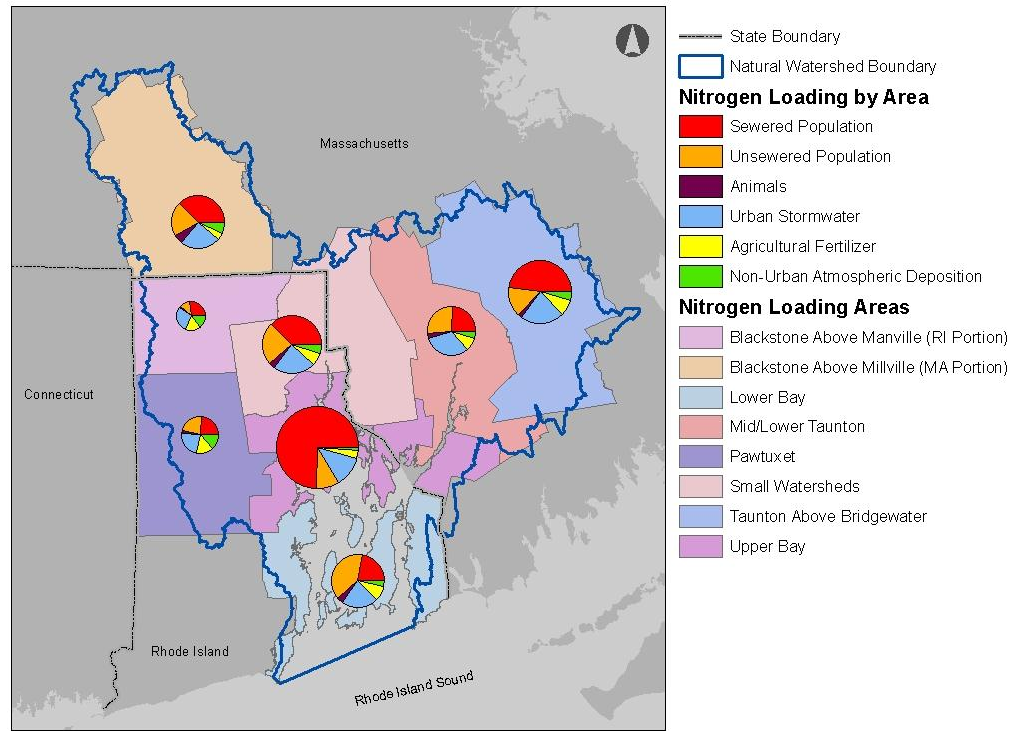
NITROGEN LOADING IN NARRAGANSETT BAY

Narragansett Bay is a 147-square-mile estuary that provides its watershed with a suite of valuable ecosystem services. A designated estuary of national significance, the bay provides value to the region by creating opportunities for tourism and recreation along its coastal habitat and by hosting hundreds of species that support commercial and recreational fin fishing and shell fishing (NEP 2011). As is the case in many U.S. waterways, human-caused nutrient pollution is degrading the bay and damaging its ecological and socioeconomic value. Although the bay is relatively well-mixed, compared to other estuaries, it has already experienced a number of impacts from nutrient pollution, including low dissolved oxygen, fish kills, eelgrass loss, and algal blooms (GNBWPC 2004). The fish kill that occurred during the summer of 2003 caused significant loss of marine life and widespread beach closures, triggering a watershed-wide initiative to address pollution in the bay. Along with human threats in the form of nutrient and bacterial pollution from wastewater, the projected effects of climate change, including altered wind and stratification patterns and increases in average water temperatures, threaten the bay's natural resilience and increase its vulnerability to the harmful effects of nutrient pollution.

Both nitrogen and phosphorus contribute to nutrient pollution in Narragansett Bay; phosphorus affects the water quality of the rivers that feed the bay, while nitrogen primarily affects the water quality of the bay itself. However, the Phase 1 prototype of the Narragansett-3VS model considers only the effects of nitrogen loadings on the bay.[1] Though nitrogen pollution in coastal ecosystems often originates from nonpoint sources, such as urban stormwater runoff, livestock, and agricultural fertilizer use, research into the sources of nitrogen pollution in the Narragansett Bay watershed has found that the largest share of nitrogen loadings comes from point sources, particularly wastewater treatment facilities (WWTFs) (Nixon et al. 2008). Exhibit 2 presents an estimate of the distribution of nitrogen loadings to the bay, by source category and by subregion, or nitrogen loading area, within the Narragansett Bay watershed (Vadeboncoeur et al. 2010). In Exhibit 2, the size of the pie charts corresponds to each loading area's relative contribution to total watershed loadings.[2]

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[1] Throughout this report, the term "nitrogen loadings" is used to refer to total nitrogen, which includes both inorganic and organic nitrogen.

[2] A detailed description of the methods and data sources used to estimate nitrogen loadings into Narragansett Bay by loading area and source category can be found in Appendix A.

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Source:
1. Environmental Systems Research Institute, Inc. (ESRI), Redlands, California, USA
2. Vadeboncoeur, A., Hamburg, S.P., and Pryor, D. 2010. "Modeled Nitrogen Loading to Narragansett Bay: 1850 to 2015." Estuaries and Coasts. 33:1113-1127.

Note: Nitrogen loading areas used for the Phase I prototype model are derived from a previous model of nitrogen loading in the watershed (Vadeboncoeur et al. 2010) and include all towns with at least 50 percent of their land area within each hydrologic basin. Thus, the outer boundaries for these loading areas differ from the boundary for the watershed (outlined in blue).

Federal and State regulatory agencies have mandated that the largest WWTFs in the watershed implement improved treatment to reduce nitrogen loadings substantially by 2014. However, population growth, economic development, and climate change are likely to increase both future nitrogen loadings to the bay and its vulnerability to the harmful effects of nitrogen pollution. It is therefore expected that additional policy interventions will be necessary to prevent further degradation of the bay's water quality.

While most of the bay is located in Rhode Island, about seven percent is located in Massachusetts, as is about 60 percent the watershed area. With the watershed spanning two states, evaluating and managing threats such as nitrogen pollution is particularly challenging. The impacts of impaired water quality in the bay, as well as the effects of any policies undertaken to reduce nitrogen pollution, are felt throughout the watershed. However, the costs and benefits of policies meant to improve the bay's water quality will likely not be distributed evenly across this area. As an example, the people bearing the cost of improved treatment at WWTFs upstream from the bay are not the same people who would enjoy the largest benefit from improved water quality in the bay. In order to support the broader goal of improving the

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sustainability of the region, it is crucial that policies aiming to address nitrogen pollution take into account the goals and considerations of all the key stakeholders within the watershed. Furthermore, policy evaluation must account for all benefits and costs – both direct and indirect – of each policy considered.

APPLICATION OF AN INTEGRATED ASSESSMENT FRAMEWORK

To address the complex challenges posed by nitrogen pollution in Narragansett Bay, the project team employed an integrated assessment approach to evaluate how potential policy approaches might impact the three pillars of sustainability: economic prosperity, environmental protection, and social well-being. This "triple-value" framework of economy, environment and society allows decision makers to evaluate policies not simply by how effectively they reduce nitrogen loadings, but also by how they contribute to the overall sustainability of the region. By taking a broad, systems-level view of the Narragansett Bay watershed, the triple-value framework ensures that the complexity of the system is recognized and that key watershed stakeholders and their goals are recognized. The triple-value framework is illustrated in Exhibit 3.

EXHIBIT 3.   **CONCEPTUAL TRIPLE-VALUE FRAMEWORK**

This framework recognizes the environment as an ecological resource base that provides materials and services to the economy and society. The economy sector transforms these inputs into desired goods, and the economic and social processes of creating and using these goods produce runoff, wastewater, and other stressors that can return to the environment, potentially imperiling its ability to provide future inputs (Fiksel et al., forthcoming). The Narragansett Bay Sustainability Project applies this framework through a triple-value simulation (3VS) model, designed to allow stakeholders and policymakers to think creatively

about how best to address the problem of nitrogen pollution in Narragansett Bay while maximizing sustainability in the region. The Narragansett-3VS model aims to facilitate discussion of a broad range of potential nitrogen management interventions – including stricter WWTF permits or low-impact development to manage stormwater runoff – by illustrating the effects of each intervention on important economic, environmental, and social indicators. Ultimately, the project team hopes that the Narragansett-3VS model will allow users to answer key questions, such as:

- What are the full costs and benefits (economic, social, and environmental) of reducing nitrogen loadings, including hidden or indirect consequences?

- How can nitrogen loading be reduced in the most cost-effective manner?

- What key factors (e.g., population growth, climate change impacts) are driving future changes in nitrogen loadings?

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SECTION 3 | DEVELOPMENT OF THE NARRAGANSETT TRIPLE-VALUE SIMULATION MODEL

SELECTION OF THE THRESHOLD 21 MODEL

To develop the Narragansett-3VS model, the project team worked with Millennium Institute (MI), a Washington, DC-based company that is skilled in the application of system dynamics modeling to complex decision making. The Phase I prototype is a customized version of MI's T21 model, a dynamic scenario analysis tool designed to support development of a comprehensive, integrated, and long-term roadmap for sustainable development. The T21 model has been widely adapted to examine the cross sector impacts of policy alternatives throughout the world. Perhaps most notably, MI customized T21 to serve as the underpinnings of the United Nations Environment Programs Green Economy Report. In addition, MI has applied T21 to several environmentally-based studies in the U.S., including a study of waste management policies in the State of Ohio.

Using an integrated assessment approach, the model prototype integrates three spheres – economy, environment, and society – into a single framework. The economy sphere contains major production sectors (agriculture, industry and services), which are characterized by production functions with inputs of resources, labor, capital, and technology. Specific issues, such as transportation, agriculture and renewable energy, are included in production sub-sectors.

The environment sphere tracks natural stocks within the system and perturbations from pollution created in the production processes. Through feedback loops, these impacts on the state of the system eventually influence production. The model estimates the consumption of natural resources – both renewable and non-renewable – and can estimate the impact of resource depletion on production and other factors. It also examines the effect of environmental degradation on other sectors. Specific issues addressed are fossil fuel use, forest depletion, land and water degradation, air and water pollution, and greenhouse gas emissions. This sphere can be expanded to take into account location-specific concerns, including the effects of nitrogen loadings.

The society sphere contains detailed population dynamics by sex and age; health and education; basic infrastructure; employment; and poverty levels and income distribution. Population determines the labor force over time, which shapes employment. Education and health, along with other factors, influence labor productivity. Employment and labor productivity affect the level of production from a given capital stock.

The Phase I prototype of the Narragansett-3VS model expands the T21 framework to include modules developed for the analysis of nitrogen loadings in the bay. Two key additions are the nitrogen loading module, which tracks nitrogen flows from multiple sources and by watershed area, and the environmental relationships module, which estimates the environmental impacts of nitrogen loadings (e.g., on chlorophyll *a*, water turbidity, beach visits, and fish landings).

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In addition to these new modules, selected variables were linked across sectors to integrate existing components of T21 with the new modules for nitrogen loadings and impacts. Specific linkages between nitrogen loadings and variables in the society and economy spheres include ties to population and GDP (both influencing, among other factors, water consumption and consequently nitrogen loadings). Additional linkages relate the environmental impacts of nitrogen loadings to the fisheries and services value added variables, both contained in the economy sphere. These customized elements of the model are further described in the discussion of the conceptual model below.

More complete documentation of the Phase I prototype of the Narragansett-3VS model is provided in Appendices A and B. Specifically, Appendix A details the data sources and methods used to estimate nitrogen loadings, while Appendix B includes information about the types and sources of demographic and economic data used in the model, the derivation of the environmental relationships for characterizing the effects of nitrogen loadings, and key equations in the model that define the interrelationships among social, economic, and environmental indicators.[3]

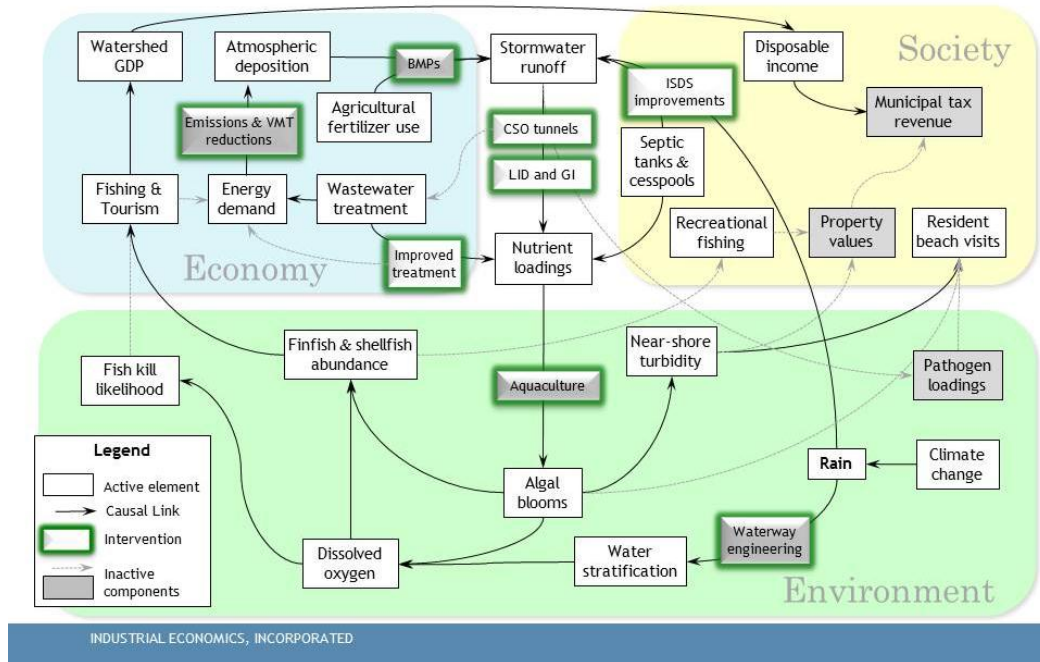## CONCEPTUAL MODEL FOR NITROGEN LOADING IN NARRAGANSETT BAY

As the project team collected the necessary data to build the Narragansett-3VS model, these data served to inform a series of iterations of a conceptual model showing the causal relationships linked to nitrogen loading in Narragansett Bay. The purpose of the causal relationship diagram is to tie scientific relationships to societal and economic outcomes. These linkages allow for the development of policy interventions based on desired outcomes, e.g. beach visits and fisheries production, in addition to the reduction of undesirable inputs, e.g., sewage effluent. A simplified version of the model schematic representing key scientific relationships is presented in Exhibit 4, using the triple-value framework of economy, society, and environment. A more complex version of the model schematic, along with a glossary and table of selected relationships, is presented in Appendix C. Relationships currently active in the Phase I prototype of the Narragansett-3VS model are represented by black lines. Relationships anticipated to be incorporated into future iterations of the model are represented by dotted, gray lines. Interventions are represented by green outlines and situated on the targeted causal relationship.

The main elements of the schematic can be grouped into loadings, environmental relationships, and impacts on economy and society. For loadings, the schematic highlights wastewater treatment effluent, agricultural fertilizer use, atmospheric deposition (both onto the watershed and directly into the bay), and septic tanks & cesspools. Loadings from several of these sources enter the bay through stormwater runoff. Groundwater can also carry nitrogen from septic tanks & cesspools to the bay.

The key environmental relationships in the Narragansett-3VS model schematic start with nitrogen loadings that lead to algal blooms. Unlike watershed nitrogen loading estimates, which are characterized by source and location within the watershed, environmental relationships in the current model prototype are represented as bay-wide estimates, due to the lack of data for disaggregating scientific relationships into geographic or hydrodynamic components of the bay. In many cases, key relationships in the model are derived from scientific literature that captures bay-wide impacts, such as the impact of total nitrogen loading on fin fish landings.

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[3] Appendix G, which is available upon request, contains a full list of all of the equations used in the model.

EXHIBIT 4.   SELECTED, SIMPLIFIED CAUSAL RELATIONSHIPS FOR NITROGEN LOADING IN NARRAGANSETT BAY.

As shown in this schematic, algal blooms have three direct effects that are active in the prototype. Algal blooms lead to decreased levels of dissolved oxygen through decomposition, increased finfish and shellfish abundance by increasing their food supply, and increased turbidity within the water column. In addition, algal blooms, particularly *Ulva* (sea lettuce), are thought to decrease beach visits by making beaches aesthetically, physically and olfactorily less appealing. Some algal blooms are harmful to human health as well as to the environment, producing potent chemical toxins, "red tides," and sudden increases in the mortality of fish and other marine life. While this type of harmful algal bloom is now uncommon in Narragansett Bay, it is a real threat in many other coastal systems.

The model schematic also attempts to capture one of the key second-order environmental relationships involving algal blooms. If algal blooms coincide with stratification, which is enhanced by rainfall, then dissolved oxygen levels decrease. As dissolved oxygen decreases, the likelihood of a fish kill increases and finfish and shellfish abundance decreases. Likewise, the increased near shore turbidity decreases beach visits. Near shore turbidity also retards the growth of submerged aquatic vegetation, such as eel grass, by preventing light penetration. The reduction in eel grass can increase juvenile fish predation, lowering fish populations. For the model prototype, this relationship is not directly estimated, but is implicitly incorporated into the relationship between nitrogen loading and finfish landings.

Environmental effects shown in the model schematic tie into sectors of the economy and society that interact closely with the bay. Finfish and shellfish abundance is directly related to commercial and recreational fishing. Along with abundance, fish kill frequency may influence tourism and the broader marine economy.

Environmental and societal sectors that are closely tied to the bay support the larger watershed economy and society. Fishing and tourism are shown in the model schematic to support watershed GDP, which translates into societal disposable income. Fishing and tourism also lead to energy demand, which ties back into nitrogen loading. Although not reflected in the current prototype, watershed property values support municipal tax revenues, which in turn support a broad range of societal aims.

The system dynamics approach can help identify sustainable solutions by promoting inquiry throughout the causal chain to find sustainable options. Interventions traditionally focus on reducing nitrogen use in the watershed, e.g. agricultural best management practices and vehicle miles travelled reductions, or on intercepting and removing nitrogen before it reaches the bay, e.g. CSO tunnels, WWTFs, and low impact development. Examining the environmental relationships involving nitrogen once it reaches the bay can demonstrate the potential impacts of less traditional interventions. For example, increased shellfish aquaculture in the bay might reduce the standing stock of algae, thus reducing blooms that may contribute to hypoxia and beach closures. Likewise, the extent and magnitude of hypoxia increases as the water column becomes more stratified. Therefore, interventions aimed at decreasing stratification through waterway engineering could help reduce hypoxia. Additional opportunities for policy interventions at different points in the environmental causal chain are likely to be identified as Agency staff and stakeholders explore the model prototype and it continues to be revised.

STAKEHOLDER ENGAGEMENT AND DATA COLLECTION

Stakeholder engagement was a central element of Phase I of the project for three reasons: (1) the project team needed input from stakeholders in order to ensure that the model reflected their priorities and concerns; (2) the interdisciplinary nature of the model required data and input from a variety of experts and stakeholders; and (3) due to scientific uncertainty and conflicting policy opinions surrounding the issue of nitrogen pollution in the bay, it was necessary to incorporate multiple viewpoints into the model. As a result, the project team solicited input and feedback from key stakeholders and experts throughout Phase I, contacting nearly 80 individuals from federal, state, and local government; local and regional academic and research institutions; and a variety of NGOs.[4]

Two formal stakeholder meetings were held: a project briefing on July 27, 2011 in Narragansett, RI, and a workshop on October 12, 2011 in Woonsocket, RI. The purpose of the first meeting was to provide an overview of the project, identify potential data sources, and learn about relevant research and other initiatives throughout the watershed. At the second meeting, EPA presented the current prototype of the model and then received feedback from stakeholders on a variety of topics, including information needs and gaps, pressures, opportunities, and desires.[5] To complement the information received from stakeholders, the project team conducted a detailed review of existing research on the ecological, economic, and social indicators for the Narragansett Bay watershed.[6]

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[4] Appendix D, which is available upon request, provides a complete list of these contacts.
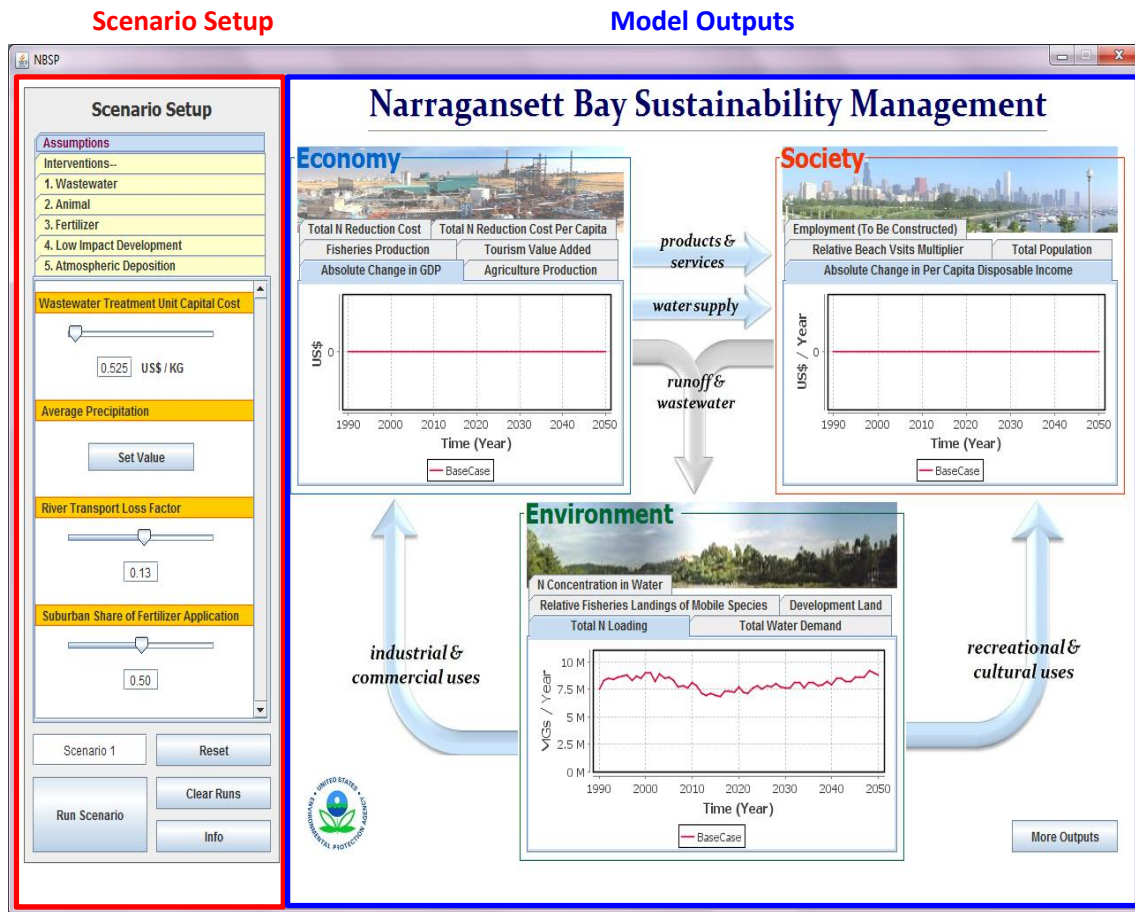
[5] Attendee lists and notes from the two stakeholder meetings are presented in Appendix F, which is available upon request.

[6] The complete list of resources consulted in Phase I is presented in Appendix D, which is available upon request.

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INTERFACE FOR PHASE I PROTOTYPE

In order to make the Phase I prototype of the Narragansett-3VS model a useful scenario testing tool, the project team designed it to work with a user-friendly interface. The interface, developed by the Ohio State University Center for Resilience, provides a menu of options for defining scenarios based on alternative model inputs, including policy alternatives. The interface consists of two panels: Scenario Setup and Model Outputs (see Exhibit 5).

EXHIBIT 5.   SCENARIO SETUP AND MODEL OUTPUTS FOR THE PHASE I PROTOTYPE MODEL

SCENARIO SETUP

In the Scenario Setup section of the interface, users can select scenarios by defining simulation assumptions, choosing intervention options, and defining corresponding parameters. The intervention options in the Phase I prototype are derived from the conceptual model (explained above) and include:

- Wastewater (reductions in nitrogen loading from WWTFs and independent sewage disposal systems (ISDS))

- Animal (reductions in nitrogen loading from livestock waste)

- Fertilizer (reductions in nitrogen loading from fertilizers)

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- Low Impact Development (LID) (reductions in nitrogen loading from increased use of LID techniques)

- Atmospheric Deposition (reductions in nitrogen loading from atmospheric deposition)

These intervention options are described in further detail in Section 4 of the report. Exhibit 6 summarizes the variables associated with the intervention options as well as baseline assumptions that can be adjusted through the user interface. These variables, values, and ranges will continue to be refined through future model development in Phase II of this pilot project. They are presented here to illustrate the model's potential to simulate the combined impacts of multiple policy interventions on the economy, environment, and society.

EXHIBIT 6.   SUMMARY OF ASSUMPTIONS AND INTERVENTIONS OPTIONS IN THE PHASE I PROTOTYPE MODEL

	VARIABLE	RANGE	UNIT
Assumptions	Average Precipitation	715 – 850	MM / Year
	River Transport Loss factor (for Upper Watersheds)	0 – 0.25	Unitless
	Suburban share of Total Fertilizer Application (Suburban and Agricultural)	0 – 100	Unitless
	Heavy Rainfall Increase (Annual amount if modeled 2 week period of heavy rainfall were year-long)	0-5,000	MM / Year
	Heavy Rainfall Start Year	2012-2051	Year
Interventions	*Wastewater*		
	WWTF Loading Reduction Factor by 2050	0 – 1	Unitless
	WWTF Nitrogen Removal Capital Unit Cost	0 – 100	US$ / Kg-N *Year
	ISDS Phase-Out/Upgrade Factor (proportion of ISDS units improved)	0 – 1	Unitless
	ISDS Phase-Out Capital Annual Unit Cost Per Household	1,000 – 2,000	US$/Year
	Animal (Livestock)		
	Animal (Livestock) Waste Loading Reduction Factor by 2050	0 – 1	Unitless
	Animal (Livestock) Waste Loading Reduction Unit Cost	0 – 100	US$/Kg-N*Year
	Fertilizer (Agricultural)		
	Nitrogen (Agricultural) Fertilizer Reduction Factor by 2050	0 – 1	Unitless
	(Agricultural) Fertilizer Reduction Unit Cost	0 – 100	US$/Kg-N*Year
	Low Impact Development		
	Low Impact Development Starting Year	2011 – 2051	Year
	Low Impact Development Implementation Factor	0 – 1	Unitless
	Atmospheric Deposition		
	N Atmospheric Deposition Reduction Factor by 2050	0 – 1	Unitless
	Atmospheric Deposition Reduction Unit Cost	0 – 100	US$/Kg-N*Year

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An assumption or an intervention option can be set up by using either a slider control or a table input. A slider control allows users to select from a range of values by moving a slider. A table input allows users to define a function by entering a list of numbers labeled as "inputs" (usually the year in which a parameter value is expected to change) and "outputs" (different parameter values, e.g., average rainfall).

MODEL OUTPUTS

Users can view the results of a simulation in the model outputs panel of the interface. Following the 3VS framework, key economic, social, and environmental indicators appear on the main page of the interface. Users can see graphs of the outputs of the simulations and overlay different simulations on the graphs to compare effects. The impact on additional indicators can be seen by selecting the "more outputs" box on the lower right of the model outputs frame.

DATA GAPS AND LIMITATIONS IN THE PHASE I PROTOTYPE MODEL

The Phase I prototype of the Narragansett-3VS model seeks to demonstrate the effectiveness of system dynamics and integrated assessment modeling for use in addressing watershed-wide environmental management issues, as well as the ability of integrated assessment modeling to aid policymakers in general. In characterizing the nitrogen pollution issue in Narragansett Bay for the Phase I prototype, the project team encountered a number of data limitations and real-world uncertainties that required simplifying assumptions or temporarily omitting key relationships from the model to produce a working prototype within the time allotted for this phase of the project. In Phase II, the project team will focus on specific questions facing policymakers, which will guide the effort to refine the model. This section describes broad categories of assumptions and limitations inherent in the Phase I modeling effort and how they can be addressed in future versions of the model.

- For the Phase I prototype of the model, nitrogen loadings are disaggregated by loadings area (as described in Section 2 of this report); however, environmental impacts are currently presented on a bay-wide basis. Since the ecological response of the bay to nitrogen loading is a function of localized factors, the ability to distinguish between the effects of nitrogen on the Lower Bay and the Upper Bay and its tributaries may enhance the model's performance in estimating impacts of nitrogen on certain environmental indicators. Determining the proper level of geographic specificity for disaggregating environmental impacts in the bay and developing approaches for accomplishing this are priorities for Phase II of this project.

- Ongoing scientific debate over current conditions in the bay and environmental impacts of changing nitrogen loadings and other factors made it difficult to incorporate certain relationships and policy interventions into the Phase I prototype of the model. (See the model schematic in Exhibit 4 for an illustration of model elements that have and have not been included in the prototype.) The prototype currently handles this obstacle either by omitting the disputed relationships pending further research, or by allowing the user to choose values for parameters that drive these relationships.

- Many environmental indicators for the bay are represented in the model as though nitrogen concentration is the primary driver in their variability. However, only a portion of the variability for these indicators (sometimes as low as 10 percent) is driven by

nitrogen concentration (e.g. turbidity is driven by total suspended solids, colored dissolved organic matter, and several other factors). As the Narragansett-3VS model is refined during Phase II of the project, it will be important to address the other variables influencing environmental indicators and remove some of the simplifying assumptions made during Phase I.

- The Phase I prototype incorporates many of the primary benefits and costs of nitrogen reduction policies, but does not include several substantial ancillary benefits or unintended negative impacts of these interventions. For example, improved CSO tunnels not only help reduce nitrogen loadings, they also have a substantial effect on pathogen loadings, which is an additional benefit. Increased energy usage associated with advanced wastewater treatment technologies is an example of unintended negative impacts that can also occur. Incorporating ancillary benefits and consequences in future iterations of the model to provide policymakers with a complete picture of the interrelationships in the watershed system is a priority for Phase II.

SECTION 4 | INTERVENTION SCENARIOS AND OUTPUTS

This section provides a description of how the Phase 1 prototype of the Narragansett-3VS model can be used to examine the impacts of alternative policy interventions and potential future changes in rainfall on key economic, social, and environmental indicators. Two examples of scenario testing are presented here.[7] In each example, a test scenario is compared to a base scenario, which assumes the continuation of current trends (e.g., population growth) and agreed-upon future actions (e.g., nitrogen loading limitations for wastewater treatment facilities (WWTFs), with full compliance required by 2014).

The first test scenario models a collection of six interventions that reduce nitrogen loading. It is important to note that this scenario represents a very broad set of interventions that are not necessarily reflective of any combination of policies currently being considered in the watershed. However, it demonstrates the Phase I prototype's ability to combine the impacts of multiple interventions and show the directional changes in key indicators associated with the resulting nitrogen reductions. The second test scenario models an increase in extreme precipitation events, which could be associated with climate change. This scenario demonstrates the prototype's ability to show impacts of short-term events.

ILLUSTRATION OF NITROGEN REDUCTION INTERVENTION SCENARIO

The nitrogen reduction intervention scenario assumes that the following six interventions are gradually implemented between 2010 and 2050:[8]

1) Reduction in WWTF loadings by an additional 50 percent beyond the already agreed-upon baseline reductions achieved by 2014.

2) Phase-out or upgrade of 50 percent of the non-sewered population using "problem" ISDS (i.e., those located within two kilometers of the bay). Note that each ISDS phase-out/upgrade is assumed to take 10 years.

3) Reduction in loadings from atmospheric deposition (both direct to the bay and indirect via non-urban lands in the watershed) by 50 percent beyond baseline levels.

4) Reduction in loadings from animals (livestock) by 50 percent beyond baseline levels.

5) Reduction in loadings from agricultural fertilizer use by 50 percent beyond baseline levels.

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[7] Additional scenario testing examples are presented in Appendix H, which is available upon request.

[8] For more information about baseline nitrogen loadings from WWTFs, ISDS, atmospheric deposition, animals, and fertilizer, please see Appendix A. Appendix E, which is available upon request, provides additional information on policy interventions associated with each loadings source.
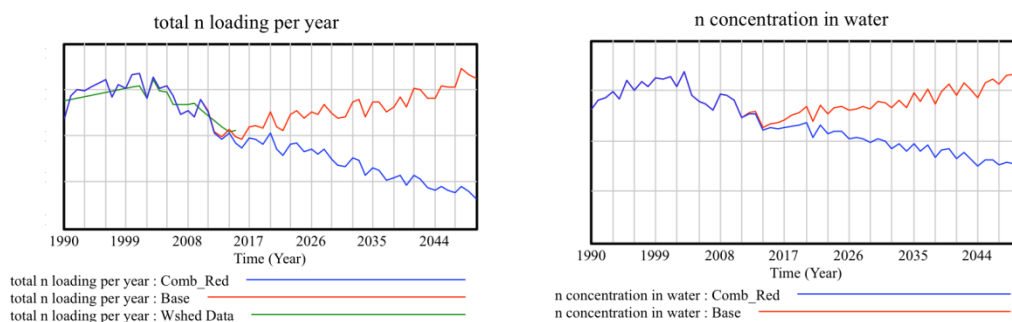
6) Implementation of low-impact development on 50 percent of new developments, beginning in 2015.

NITROGEN LOADING TRENDS

As illustrated in Exhibits 7A and 7B, the base scenario total nitrogen loadings in the Narragansett Bay watershed show a sharp decline between 2002 and 2014, mainly due to agreed-upon reductions in nitrogen from WWTFs. However, after 2014, nitrogen loadings are projected to increase through the end of the simulation in 2050, driven primarily by projected population growth expansion of urban developments, and increased use of fertilizer. Other factors, such as those resulting from climate change, are recognized as potentially important drivers of future nitrogen loadings.

The gradual implementation through 2050 of the nitrogen reduction interventions selected for the scenario (labeled "Comb_Red" in Exhibits 7A and 7B) reverses this upward trend, cutting total loadings relative to the base scenario.

EXHIBITS 7A AND 7B. NITROGEN REDUCTION INTERVENTIONS SCENARIO OUTPUTS - TOTAL NITROGEN LOADINGS PER YEAR AND NITROGEN CONCENTRATION IN WATER
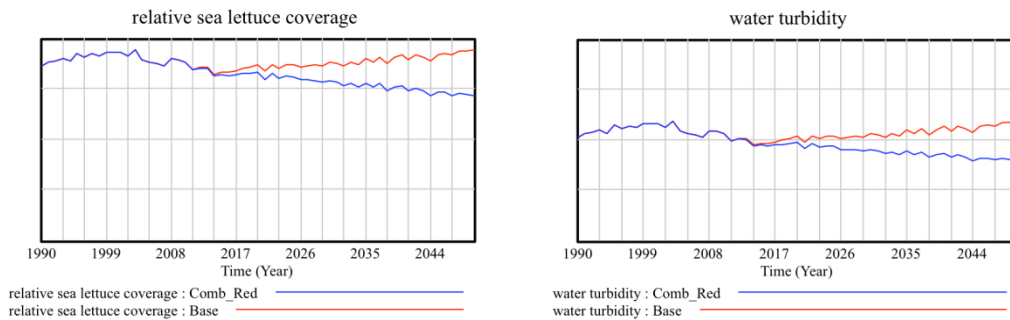

Note: The green line in Exhibit 7A represents historical loadings data used to calibrate the model.

ENVIRONMENTAL INDICATORS

Changes in nitrogen loadings and the resulting concentration in the bay lead directly to impacts on environmental indicators for the watershed. Despite variability due to seasonality and precipitation, the Phase I prototype projects that all environmental indicators in the model will deteriorate in the future if no actions are taken beyond achievement of the revised WWTF permit standards in 2014. However, under the "Comb_Red" scenario, improvements occur across all environmental indicators. Exhibits 8A and 8B show the directional change of relative sea lettuce coverage and water turbidity, two key environmental indicators reflected in the Phase I prototype.

EXHIBITS 8A AND 8B. NITROGEN REDUCTION INTERVENTIONS SCENARIO OUPUTS - RELATIVE SEA LETTUCE COVERAGE AND WATER TURBIDITY

SOCIOECONOMIC INDICATORS

In addition to the changes in environmental indicators, the results of the simulation suggest potential impacts of nitrogen loadings reduction on the local society and economy. Exhibits 9A and 9B show that under the base scenario, the projected nitrogen increase in the Narragansett Bay watershed starting after 2014 is expected to reduce beach visits and fish landings. However, under the "Comb_Red" scenario, the projected decreases in beach visits and fish landings are reversed.

EXHIBITS 9A AND 9B. NITROGEN REDUCTION INTERVENTIONS SCENARIO OUPUTS - FISHERIES PRODUCTION, BEACH VISITS
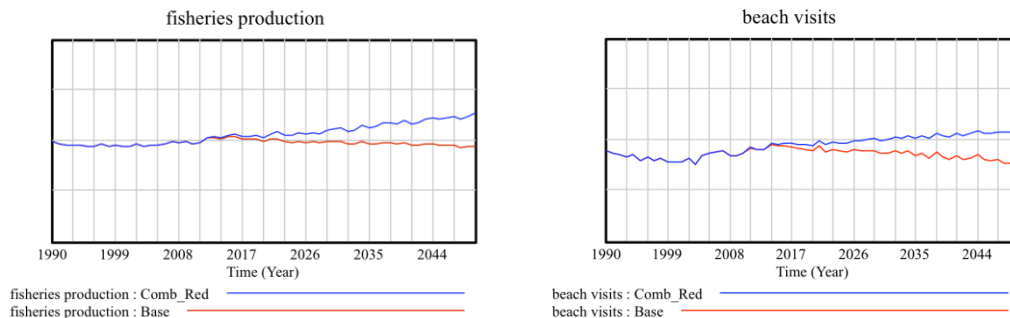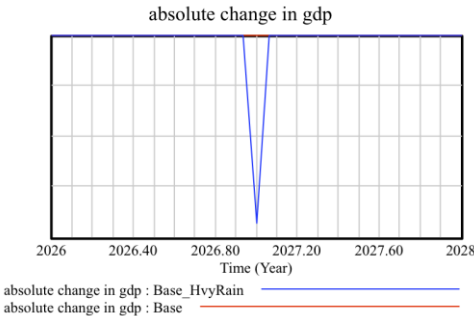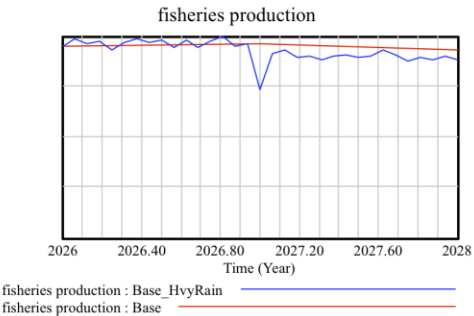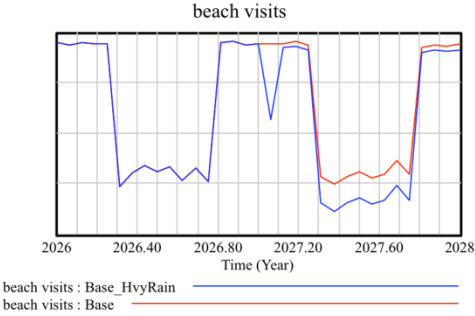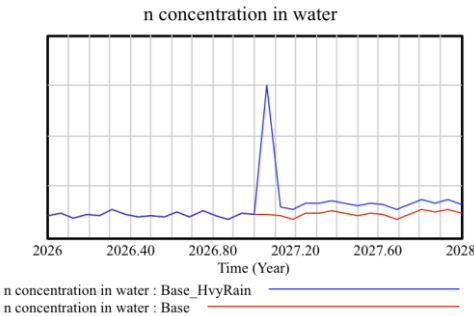

ILLUSTRATION OF SHORT-TERM HEAVY PRECIPITATION SCENARIO

To assess the implications of potential short-term heavy precipitation events, which may become more frequent over time due to climate change, an additional scenario ("Base_HvyRain") simulates a storm event that produces approximately 6 inches of rain over a two-week period. This kind of scenario can be used to examine the resilience of the system as a whole – and of particular nitrogen reduction policies – to short-term disruptions, such as extreme weather events.

As shown in Exhibits 10A through 10D, the scenario of short-term heavy precipitation is expected to produce a sudden spike in nitrogen concentration in the bay. The resulting water turbidity leads to a reduction in beach visits. Similarly, fish landings decline during the period of heavy rainfall.

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n concentration in water

beach visits

fisheries production

absolute change in gdp

IEc

In the first phase of the Narragansett Bay Sustainability Pilot, the project team applied a systems approach to develop a working prototype of an integrated assessment model and demonstrated its potential to support sustainable nutrient management strategies for the Narragansett Bay watershed. Further refinement of the Narragansett-3VS model in Phase II will allow it to provide a more holistic view of the nitrogen pollution problem in Narragansett Bay, shedding light on the key relationships, feedback loops and synergies within the system and supporting the development of policies that contribute to the sustainability of the region. Ultimately, the goal of this pilot project is that the model will become a valuable decision-making tool, and will help demonstrate the effectiveness of a systems modeling approach to addressing complex environmental issues. This section of the report reviews lessons learned from Phase I about potential applications of the Narragansett-3VS model for policymakers and identifies next steps to be completed in Phase II.

LESSONS LEARNED FROM PHASE I

Although the Phase I prototype does not yet represent a complete system dynamics model of the Narragansett Bay nutrient pollution problem, the scenarios illustrated offer the following insights about how the Narragansett-3VS model can be used to guide policymakers:

- *The model can be used to evaluate the effectiveness of combinations of proposed policy interventions.* Through defining scenarios consisting of multiple policy interventions, the model can be used to evaluate the relative effectiveness of varying combinations of interventions. It can also be used to explore the marginal reductions that can be achieved by individual interventions.

- *The model can be used to evaluate how policies affect both long-term trends in environmental conditions and the watershed's resilience to short-term events*. The sustainability of the bay depends on both the long-term trends of key parameters (e.g., nitrogen concentration, water turbidity) and the resilience of the system to short-term perturbations (e.g., extreme rainfall). As the two scenarios described in Section 4 demonstrate, the Narragansett-3VS model is capable of simulating effects over a range of timeframes.

- *The model can be used to help guide more detailed modeling efforts.* Because the Narragansett-3VS model considers the entire Narragansett Bay watershed system, it provides a broad assessment of impacts. Specialized models can provide more fine-grained analysis of economic, social, or environmental impacts. For example, if the Narragansett-3VS model suggests that a particular policy approach might have a positive impact on net GDP, a focused economic model could evaluate which particular regions and economic sectors might realize the greatest gains.

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NEXT STEPS

The purpose of the Phase I prototype of the Narragansett-3VS model is to provide a preliminary representation of the watershed system with respect to nitrogen pollution. The Phase I prototype represents an important first step in characterizing many of the relevant components of the watershed system and demonstrating the capacity of the model to assist in decision making.

To address current limitations in the Phase I prototype of the Narragansett-3VS model, the project team intends to continue soliciting feedback from stakeholders, scientists, and policy experts. The stakeholder workshop on October 12, 2011 yielded important recommendations on how to improve the Phase I prototype and requires follow up from the project team. Additional input from local and regional economic and planning experts is also needed to help guide future development of the model and make it an effective decision-making tool.

Given the complexity of the nitrogen management issue in the Narragansett Bay watershed, it is essential that the project team continue to take advantage of lessons learned by other regions facing similar issues. Current modeling efforts by other watershed initiatives, such as the Chesapeake Bay Program and the Delaware Estuary Program, represent opportunities for collaboration that could greatly enhance the model's effectiveness and overall value.

Having demonstrated the model's basic capabilities in Phase I, the project team will focus its efforts in Phase II on refining the model to address specific policy questions concerning the sustainable management of the Narragansett Bay watershed. An important additional task will be defining the model's target users and audience, which are likely to include staff from regional, state, and local agencies, including policymakers, planners, and scientists; NGOs; academics; and other experts. The project team also intends to explore various options for providing access to the final version of the model, including through a web-based interface.

The project team's anticipated schedule for Phase II, summarized in Exhibit 1, is as follows:

- January to July 2012 - Continue systems research and model refinement

- July to August 2012 - Stakeholder review of refined model and draft project report

- September to October 2012 - Finalize model and project report

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