IEc

Narragansett Bay Sustainability Pilot

APPENDICES

Phase I Report | March 20, 2012

INDUSTRIAL ECONOMICS, INCORPORATED

TABLE OF CONTENTS

APPENDIX A. NITROGEN LOADINGS SOURCES

APPENDIX B. ENVIRONMENTAL, SOCIAL AND ECONOMIC RELATIONSHIPS AND DATA SOURCES

APPENDIX C. EXPANDED PHASE I PROTOTYPE MODEL SCHEMATIC, EXPLANATION OF TERMS AND SELECTED RELATIONSHIPS

APPENDIX A | NITROGEN LOADINGS SOURCES

In Appendix A, we discuss the data sources and processing steps used to estimate baseline nitrogen loadings into Narragansett Bay for the Phase I prototype of the Narragansett-3VS model.

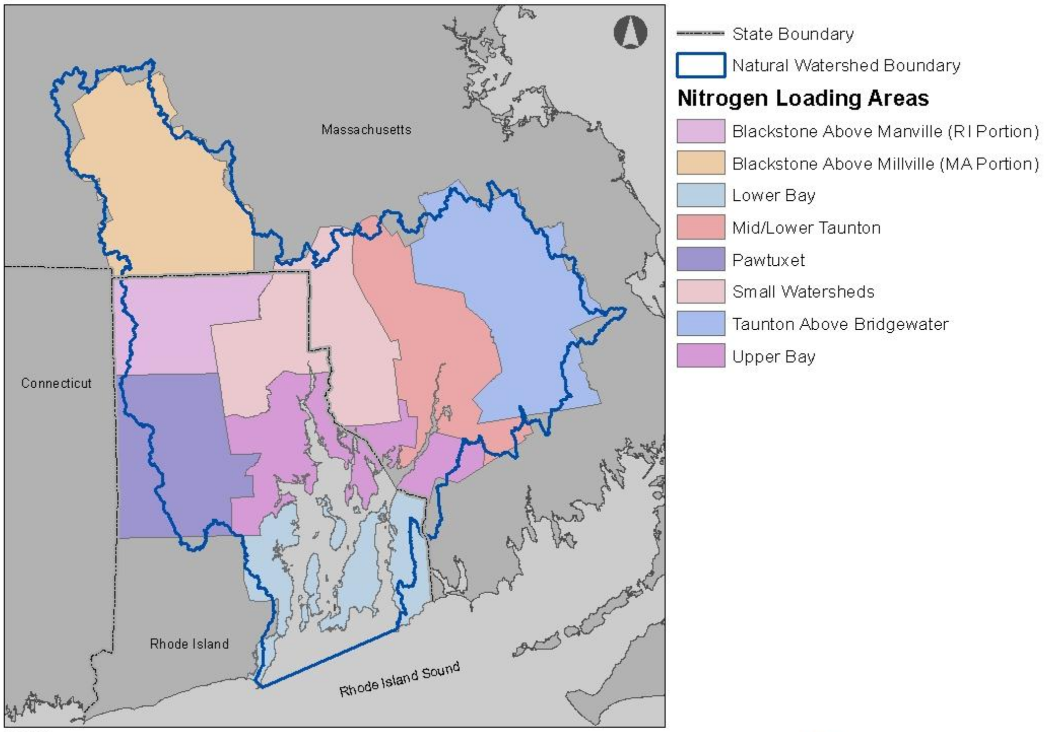
PRIMARY SOURCE DOCUMENT

To estimate nitrogen loadings in the Narragansett Bay watershed, we relied primarily on a model developed by Matthew Vadeboncoeur, Steven Hamburg, and Donald Pryor. The authors developed this model for a 2010 study examining historic trends in nitrogen loadings to Narragansett Bay (Vadeboncoeur et al. 2010). This model includes estimated nitrogen loadings to the Bay from six sources:

1) <u>Atmospheric deposition directly to the bay</u> – the portion of atmospheric nitrogen accumulation—both wet and dry—that is deposited directly into the Bay.
2) <u>Atmospheric deposition via the watershed</u> – the portion of atmospheric nitrogen accumulation—both wet and dry—that is deposited to the watershed and reaches the Bay through surface or groundwater transport.
3) <u>Fertilizer</u> – nitrogen from excess fertilizer applied to agricultural or suburban land that reaches the Bay through surface or groundwater transport.
4) <u>Agricultural livestock</u> – nitrogen from livestock waste that reaches the Bay through surface or groundwater transport.
5) <u>Sewered population</u> – nitrogen from human waste that persists in wastewater treatment facility (WWTF) effluent discharged directly into the Bay or into rivers in the watershed.
6) <u>Non-sewered population</u> – nitrogen from human waste that passes through individual sewage disposal systems (ISDS) like septic tanks or cesspools and reaches the Bay through surface or groundwater transport.

The authors divided the Narragansett Bay region into eight nitrogen loading areas to illustrate how the contribution of different loading sources varies by region. To facilitate data collection, the authors defined each nitrogen loading area to include all towns with at least 50 percent of their land within the specific hydrologic basin. These nitrogen loading areas, displayed in Exhibit A-1, are (from left to right) Blackstone Above Millville (the MA portion of the Blackstone watershed), Blackstone Above Manville (the RI portion of the Blackstone watershed), Pawtuxet, Small Watersheds (including the Woonasquatucket River watershed and the Ten Mile River watershed), Upper Bay, Lower Bay, Mid/Lower Taunton, and Taunton Above Bridgewater.

EXHIBIT A-1. MUNICIPAL BOUNDARIES CORRESPONDING TO NITROGEN LOADING AREAS USED TO MODEL NITROGEN LOADING



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.

We chose the Vadeboncoeur et al. model as the basis for the nitrogen loadings inputs for the Phase I prototype for the following reasons:

1) *Simplicity and transparency*: Because the model does not require complex simulations, we were able to access all of the data sources and parameters used by the authors and modify them to account for more recent and precise data.

2) *Consistency with observed data*: In their 2010 study, the authors compared modeled loadings estimates to observed data in 2003-2004, both for the overall watershed level and for each individual nitrogen loading area. They found that all observed loadings estimates fit within the range of their "low" and "high" estimates and generally corresponded closely to their "mid" estimates, which formed the basis of our model.

3) *Straightforward integration with system dynamics model*: Because the Narragansett-3VS model linearly applies set parameters to input data, such as population and land use, we were able to add a nitrogen loadings module to the prototype that built off of variables contained in other modules already in the model (such as the population and land modules).

DATA PROCESSING STEPS

Because the Vadeboncoeur et al. model estimated loadings only through 2000 (with projected estimates for 2015), we collected and processed additional data in order to develop baseline loadings trends through 2010. In addition, information gained from research into different loadings sources and the effectiveness of potential policy interventions allowed us to augment the loadings model and simulate the environmental impacts of specific policies.

UPDATED WASTEWATER TREATMENT FACILITY DATA

The Vadeboncoeur et al. model calculates sewered population nitrogen loadings by applying a constant parameter of 3.3 kg of nitrogen per person per year to the population in each nitrogen loading area connected to the sewer system. To improve the precision of the model's sewered population loading estimates, we examined the 30 WWTFs discharging into the Bay (both directly and indirectly via rivers) and obtained facility-specific estimates of both total annual nitrogen discharges and population served, which we used to develop annual per-capita loading parameters for each facility. In addition to developing baseline annual per-capita loading parameters, we developed parameters reflecting compliance with revised NPDES permits (with full compliance expected in 2014, where applicable). Exhibit A-2 lists the 30 WWTFs in the Narragansett Bay watershed, together with the nitrogen loading area where each facility is located and the share of total 2010 sewered population loadings attributable to each facility. Exhibit A-3 presents the baseline and post-compliance loading parameters we used to estimate sewered population loadings in the Narragansett Bay watershed more precisely.

To account for the fact that some WWTFs discharge into rivers several miles upstream from the Bay, we added a river transport loss factor to all WWTFs in the Blackstone Above Manville, Blackstone Above Millville, and Taunton Above Bridgewater nitrogen loading areas. We reduced total nitrogen loadings from each of these WWTFs by 13 percent, the same parameter used in the Vadeboncoeur et al. model to account for surface water nitrogen loss from the non-sewered population. Because there is not a consensus in the academic literature on how to model nutrient loss in river transport, we designed the user interface for the Phase I prototype so that this variable can be adjusted within a range from 0 to 25 percent.

EXHIBIT A-2. WASTEWATER TREATMENT FACILITIES (WWTFS) IN THE NARRAGANSETT BAY WATERSHED.

WWTF	NITROGEN LOADING AREA	PERCENT OF 2010 SEWERED POPULATION LOADINGS*
Rhode Island Facilities		
Bristol	Upper Bay	2.6%
Bucklin	Small Watersheds	6.6%
Burrillville	Blackstone Above Manville	0.2%
Cranston	Upper Bay	4.1%
East Greenwich	Upper Bay	0.1%
East Providence	Upper Bay	3.1%
Fields Point	Upper Bay	23.9%
Jamestown	Lower Bay	0.1%
Newport	Lower Bay	5.0%
Quonset	Lower Bay	0.3%
Smithfield	Small Watersheds	0.4%
Warren	Upper Bay	1.2%
Warwick	Pawtuxet	1.0%
West Warwick	Pawtuxet	1.8%
Woonsocket	Blackstone Above Manville	2.1%
Massachusetts Facilities		
Attleboro	Small Watersheds	3.1%
Bridgewater	Taunton Above Bridgewater	2.0%
Brockton	Taunton Above Bridgewater	14.1%
Douglas	Blackstone Above Millville	0.1%
Fall River	Upper Bay	12.3%
Hopedale	Blackstone Above Millville	0.0%
Mansfield	Mid/Lower Taunton	0.6%
Middleborough	Taunton Above Bridgewater	0.4%
North Attleborough	Small Watersheds	1.2%
Northbridge	Blackstone Above Millville	0.2%
Somerset	Mid/Lower Taunton	1.5%
Taunton	Mid/Lower Taunton	2.9%
Upton	Blackstone Above Millville	0.1%
Uxbridge	Blackstone Above Millville	0.4%
Worcester/UBWPAD**	Blackstone Above Millville	8.2%

Notes:
* Percentages do not sum to 100.0% due to rounding.
** Upper Blackstone Water Pollution Abatement District

EXHIBIT A-3. ANNUAL PER-CAPITA SEWERED POPULATION NITROGEN LOADING PARAMETERS BY FACILITY

WWTF	PER-CAPITA LOADING PARAMETERS (KG/PERSON/YEAR)	
	BASELINE LOADING	LOADING ASSUMING COMPLIANCE WITH REVISED PERMITS (2014)
Rhode Island Facilities		
Bristol	5.47[a,c]	no change
Bucklin	2.00[a,d]	1.33
Burrillville	1.27[a,d]	0.97
Cranston	1.94[a,d]	1.89
East Greenwich	1.77[a,d]	2.21
East Providence	2.38[a,d]	1.14
Fields Point	4.13[a,d]	1.51
Jamestown	2.35[a,c]	no change
Newport	4.69[a,e]	no change
Quonset	2.10[a,e]	no change
Smithfield	1.24[a,d]	1.49
Warren	5.50[a,d]	1.55
Warwick	1.34[a,d]	no change
West Warwick	2.20[a,d]	1.92
Woonsocket	1.65[a,d]	0.74
Massachusetts Facilities		
Attleboro	2.60[b,f]	no change
Bridgewater	3.30[b,g]	no change
Brockton	4.65[b,c]	no change
Douglas	2.32[b,f]	no change
Fall River	4.86[b,c]	no change
Hopedale	0.32[b,f]	no change
Mansfield	3.30[b,g]	no change
Middleborough	3.30[b,g]	no change
North Attleborough	3.99[b,f]	no change
Northbridge	1.30[b,f]	no change
Somerset	4.14[b,c]	no change
Taunton	3.30[b,g]	no change
Upton	3.61[b,f]	no change
Uxbridge	8.47[b,f]	no change
Worcester/UBWPAD**	2.80[b,h]	1.24

EXHIBIT A-3. ANNUAL PER-CAPITA SEWERED POPULATION NITROGEN LOADING PARAMETERS BY FACILITY (*continued*)

Notes:

* Where available, we used total annual nitrogen loadings data by facility to calculate per-capita loadings parameters. For some facilities, we estimated total nitrogen loadings by multiplying effluent nitrogen concentration by average annual flow.

** Upper Blackstone Water Pollution Abatement District.

Sources:

a. Population served by each WWTF obtained from RIDEM Office of Water Resources 2008.
b. Population served by each WWTF obtained from EPA 2008.
c. Annual nitrogen loadings derived from Nixon et al. 2008.
d. Annual nitrogen loadings derived from Liberti 2010.
e. Annual nitrogen loadings derived from Nixon et al. 2005.
f. Annual nitrogen loadings derived from Stearns & Wheler and CDM 2008.
g. Annual nitrogen loadings provided by Vadeboncoeur et al. 2010 (default per-capita loadings parameter).
h. Annual nitrogen loadings derived from Walsh 2011.

URBAN STORMWATER LOADINGS

Because nitrogen reduction interventions often target stormwater runoff from developed land, we created a new loadings category: urban stormwater. For this category, we combined the urban portion of loadings from atmospheric deposition via watershed and the suburban portion of fertilizer loadings. Although the Vadeboncoeur et al. model separates atmospheric deposition via watershed into urban, agricultural, and forested portions, it does not distinguish between agricultural and suburban fertilizer use. In the absence of reliable data on suburban fertilizer use in the region, we assumed that 50 percent of all loadings from fertilizer are attributable to suburban fertilizer application and designed the user interface of the prototype so that this assumption can be adjusted across the full range of 0 to 100 percent.

Having created the urban stormwater category, we then accounted for the nitrogen removed by the Narragansett Bay Commission's (NBC) Fields Point Combined Sewer Overflow (CSO) tunnel in the Upper Bay nitrogen loading area, which came online in November 2008. According to an NBC presentation given in June 2011, the CSO tunnel removed approximately 68,000 pounds (31,000 kg) of nitrogen between November 2008 and March 2011 (Comeau 2011). Assuming a constant rate of nitrogen removal, we estimated an annual nitrogen removal rate of approximately 28,000 pounds (13,000 kg) per year for the CSO tunnel. Beginning in 2008, we reduced urban stormwater loadings accordingly.

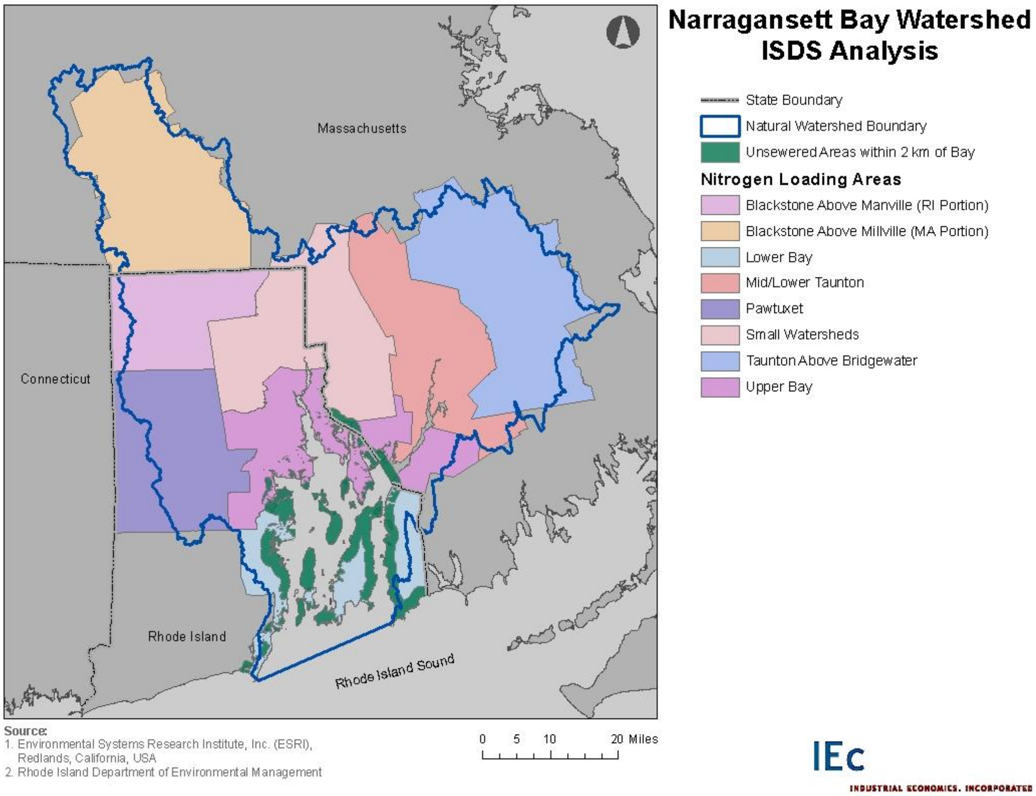
REVISED NON-SEWERED POPULATION LOADINGS

The Vadeboncoeur et al. model assumes that average per-capita nitrogen loadings from the non-sewered population (1.5 kg/person/year) are lower than average per-capita loadings from the sewered population in the Narragansett Bay watershed (3.3 kg/person/year), due to nitrogen filtration expected to take place during groundwater transport. From our communications with stakeholders, we learned that non-sewered population loadings in the watershed are highly variable. Although the majority of the population in the watershed connected to ISDS may have relatively low per-capita nitrogen loadings, a group of "problem" ISDS actually have much higher nitrogen loadings, due to poorly maintained systems, proximity to the bay, and poor groundwater filtration, among other factors.

Research into groundwater transport in Narragansett Bay has identified the densely populated one- to two-kilometer wide zone immediately adjacent to the Bay as “the direct discharge zone” (Gold and Nowicki 2008), where poorly drained soils and a relatively shallow depth to groundwater minimize opportunities for filtration and uptake of nitrogen. We therefore defined ISDS located within two kilometers of the Bay as “problem” ISDS due to the likelihood that these systems would contribute a greater amount of nitrogen than systems located further from the Bay. In the nitrogen loading model, we used the default Vadeboncoeur non-sewered per capita loadings (1.5 kg/person/year) only outside of the “direct discharge zone.” For ISDS within this zone, we did not apply the Vadeboncoeur et al. model’s loss factors for groundwater filtration and uptake, resulting in a per-capita loadings parameter of 4.2 kg/person/year.

We used ArcGIS to determine the portion of each nitrogen loading area’s non-sewered population using “problem” ISDS. We first obtained GIS map data of the sewered areas in Rhode Island from the Rhode Island Department of Environmental Management (RIDEM). We then drew a two-kilometer buffer around the Bay and removed the sewered areas, creating a map layer showing the areas where all residents would be assumed to employ “problem” ISDS (see Exhibit A-4). Finally, we used U.S. Census Block Group Data (ESRI 2004), to calculate the percent of each nitrogen loading area’s population that potentially uses “problem” ISDS. Multiplying these values by the population in each nitrogen loading area yielded the total number of people in each area using “problem” ISDS. Exhibit A-5 presents the total nitrogen loading area populations used in the model, together with the breakdown of the non-sewered population into “problem” and “non-problem” ISDS categories.

EXHIBIT A-4. POTENTIAL “PROBLEM” ISDS AREAS WITHIN NITROGEN LOADING AREAS OF THE BAY.



Source:
1. Environmental Systems Research Institute, Inc. (ESRI), Redlands, California, USA
2. Rhode Island Department of Environmental Management

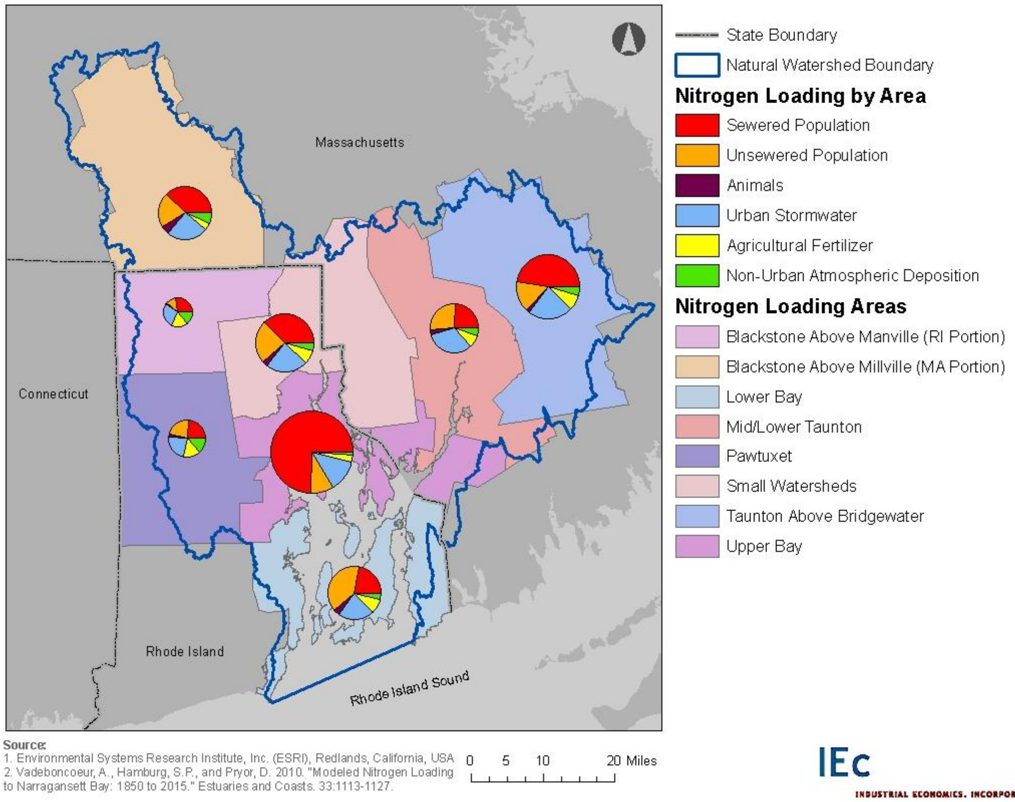
EXHIBIT A-5. NON-SEWERED POPULATION IN NARRAGANSETT BAY NITROGEN LOADING AREAS

NITROGEN LOADING AREA	TOTAL POPULATION (2000)	NON-SEWERED POPULATION (2000)		
		POTENTIAL “PROBLEM”	“NON-PROBLEM”	TOTAL
Blackstone Above Manville (RI Portion)	79,586	0	19,171	19,171
Blackstone Above Millville (MA Portion)	315,863	0	100,944	100,944
Lower Bay	128,120	79,856	1,682	81,537
Pawtuxet	118,522	0	61,325	61,325
Small Watersheds	336,888	1,271	154,009	155,280
Taunton Above Bridgewater	270,869	0	117,451	117,451
Mid/Lower Taunton	163,041	0	114,926	114,926
Upper Bay	523,228	29,098	45,974	75,072
Total	**1,936,117**	**110,224**	**615,483**	**725,708**

NITROGEN LOADINGS ESTIMATES

Using the Vadeboncoeur et al. model and applying the data processing steps described in the previous section, we estimated total baseline nitrogen loadings for 2000-2015, which served as inputs to the Phase I prototype. Exhibit A-6 presents the map of the Narragansett Bay watershed with pie charts representing nitrogen loadings. Note that the sizes of the pies in each nitrogen loading area correspond to that area's share of total nitrogen loadings for the Bay. Exhibit A-7 summarizes our estimates of 2011 loadings by nitrogen loading area and source category.

EXHIBIT A-6. ESTIMATED 2011 NITROGEN LOADINGS TO NARRAGANSETT BAY BY NITROGEN LOADING AREA AND SOURCE CATEGORY



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.

EXHIBIT A-7. ESTIMATED NITROGEN LOADINGS IN THE NARRAGANSETT BAY WATERSHED IN 2011, BY NITROGEN LOADING AREA AND SOURCE CATEGORY

NITROGEN LOADING AREA	ANNUAL NITROGEN LOADINGS (THOUSAND KG)							
						ATMOSPHERIC DEPOSITION		
	SEWERED POPULATION	NON-SEWERED POPULATION	ANIMALS (LIVESTOCK)	URBAN STORMWATER	AGRICULTURAL FERTILIZER	VIA WATERSHED (NON-URBAN)	DIRECT TO BAY*	TOTAL
Blackstone Above Manville (RI Portion)	73	31	5	76	48	38	0	271
Blackstone Above Millville (MA Portion)	312	183	46	220	37	59	0	858
Lower Bay	196	350	33	197	82	31	0	889
Pawtuxet	102	99	10	100	63	59	0	433
Small Watersheds	398	253	34	251	78	50	0	1,065
Taunton Above Bridgewater	599	192	27	284	100	58	0	1,260
Mid/Lower Taunton	180	198	25	236	61	37	0	737
Upper Bay	1,558	192	16	253	63	23	0	2,106
Total	**3,419**	**1,499**	**195**	**1,617**	**533**	**356**	**276**	**7,893**

Note:
* Loadings in this category are not divided by nitrogen loading area because they are deposited directly from the atmosphere to Narragansett Bay.

REFERENCES

Comeau, Christine. 2011. “Evaluating the Narragansett Bay Commission CSO Abatement Project.” Narragansett Bay Commission. June 16.

Liberti, Angelo. 2010. “CHRP/Managers Meeting: December 9, 2010.” Coastal Hypoxia Research Program. December 9.

Nixon, S., Buckley, B.A., Granger, S.L., Harris, L.A., Oczkowski, A.J., Fulweiler, R.W., and Cole, L.W. 2008. “Nitrogen and Phosphorous Inputs to Narragansett Bay: Past, Present, and Future.” In *Science of Ecosystem-Based Management: Narragansett Bay in the 21st Century*, ed. A. Desbonnet, and B.A. Costa-Pierce, 101–175. New York: Springer.

Nixon, S., Buckley, B.A., Granger, S.L., Harris, L.A., Oczkowski, A.J., Cole, L.W., and Fulweiler, R.W. 2005. *Anthropogenic Nutrient Inputs to Narragansett Bay. A Twenty-Five Year Perspective*. A report to the Narragansett Bay Commission and Rhode Island Sea Grant.

Gold, Arthur, and Barbara Nowicki. "Groundwater Nitrogen Transport along Narragansett Bay." *Science for Ecosystem-Based Management*. Eds. Alan Desbonnet and Barry Costa-Pierce. New York: Springer, 2008. 67-100.

Rhode Island Department of Environmental Management (RIDEM), Office of Water Resources. 2008. *Board of Certification of Operators of Wastewater Treatment Facilities: Wastewater Treatment Facilities/Locations and Officials in Charge*. Available at http://www.dem.ri.gov/programs/benviron/water/permits/wtf/ potwops.htm. Accessed September 22, 2011.

Stearns & Wheler and CDM. 2008. *Engineering Feasibility & Cost Analyses of Nitrogen Reduction from Selected POTWs in Massachusetts*. Prepared for Massachusetts Department of Environmental Protection.

U.S. Environmental Protection Agency (EPA). 2008. Clean Watersheds Needs Survey. Detail Reports: Population Receiving Treatment (Centralized and Decentralized), Massachusetts. Available at http://iaspub.epa.gov/apex/cwns2008/f?p=115:1:1260148549645119. Accessed September 22, 2011.

Vadeboncoeur, A., Hamburg, S.P., and Pryor, D. 2010. “Modeled Nitrogen Loading to Narragansett Bay: 1850 to 2015.” *Estuaries and Coasts*. 33:1113-1127.

Walsh, Tom. 2011. “Progress in Sustainably Achieving Low Nutrient Levels.” *A Day on the Upper Bay: Current Monitoring, Research, Source Reduction Progress & Future Challenges*. Narragansett Bay Commission. Johnson & Wales University: Culinary Archives & Museum. June 16.

APPENDIX B | ENVIRONMENTAL, SOCIAL AND ECONOMIC RELATIONSHIPS AND DATA SOURCES

Appendix B describes the environmental, economic, and social relationships and data sources that were used to create the Phase I prototype of the model. It includes two sections. The first section explains the derivation of the environmental relationships used in the model to show the effects of nitrogen loading on ecological indicators and several related economic and social indicators. The second section provides information about the types and sources of demographic and economic data used in the model to characterize the Narragansett Bay watershed in the context of the nitrogen loading issue.

DERIVATION OF ENVIRONMENTAL RELATIONSHIPS

This section of Appendix B presents the results of our efforts to compile data on the effects of nitrogen loading on environmental indicators, as well as on related economic and social indicators such as commercial fishing and beach visits. Developing relationships between nitrogen loadings and these indicators for Narragansett Bay is an essential step in customizing the T21 model for this project. To accomplish this, we reviewed existing literature and contacted a number of local scientists who have conducted studies of the environmental conditions in the Bay. As noted throughout this section, there is a great deal of uncertainty concerning the relationship between nitrogen loading and Bay conditions. The relationships presented here represent the project team's initial work to develop the Phase I prototype. As such, the relationships are currently expressed on a Bay-wide basis; there is no geographic specificity incorporated into the prototype in terms of the effects of nitrogen loading. We anticipate that refining these relationships, including exploring the potential to geographically disaggregate the Bay for purposes of estimating nitrogen loadings, will be a major focus for Phase II of this project. This will likely involve reviewing additional literature and convening groups of experts to debate the alternative ways of modeling the effects of nitrogen on the Bay.

The relationships outlined here have been incorporated into the prototype and serve as the basis for estimating outcomes caused by baseline nitrogen loadings and changes in loadings over time.

EFFECT OF NITROGEN LOADING ON MICROALGAE (MEASURED AS CHLOROPHYLL *A*)

Summer: Chlorophyll *a* = 57.5 * (N concentration in water) ^2.09
Winter: Chlorophyll *a* = 10.3 * (N concentration in water) ^1.275
Units: Nitrogen concentration (g / m^3), Chlorophyll *A* concentration (µg / L)
Source: Dettmann et al. (2005)
Assumptions: Relationship based on regression analysis of
data from Narragansett Bay.
Limitations: Chlorophyll *a* abundance is a function of nitrogen as well as light, turbidity, temperature, and other variables.

EFFECT OF NITROGEN LOADING ON RELATIVE SEA LETTUCE (ULVA) ABUNDACE

Method: To derive relative ulva abundance, this method uses ulva growth rate. Ulva growth is dependent on nitrogen, among other influences. Baseline conditions are estimated at 4-9 mg N / m^3.

- Relative percentage growth of ulva per day is equal to: *((Log(N) * 9 + 16.685) - 0.02938) / 0.02938*
- It is assumed that relative percentage growth of ulva is equal to relative percentage cover of ulva.

- Relative percentage cover of ulva is equal to: *0.08 * { [Log(N) * 9 + 16.685] - 0.02938 } / 0.02938 + 0.08*

Units: Nitrogen (g N / m^3).
Source: ASA calculations from Teichberg et al. (2010)
Assumptions: Ulva growth is only a function of nitrogen. Relative percentage growth of ulva is equal to relative percentage cover of ulva. Baseline ulva coverage is 8 percent.
Limitations: The relationship is an approximation. Other influences are light, hydrodynamics, temperature, and grazing.

THE RELATIONSHIP AMONG MICROALGAE (CHLOROPHYLL A), STRATIFICATION, AND DISSOLVED OXYGEN (DO)

This relationship is presented in the model as two functions. The relative DO is estimated by the table function presented in Exhibit B-1. The relative stratification is estimated, largely illustratively as a function of chlorophyll *a* in the equation below. The combined effect on DO is estimated by multiplying the results of these equations.

Effect Of Micro Algae (Chlorophyll *A*) On Dissolved Oxygen (Do) (Hypoxia)

EXHIBIT B-1. TABLE FUNCTION SHOWING RELATIVE DO AS A FUNCTION OF RELATIVE CHLOROPHYLL *A*.

RELATIVE CHLOROPHYLL A	RELATIVE DISSOLVED OXYGEN
1	1 (Average saturation ~ 7.2 mg/L)
2	0.65 (Hypoxia at 4.8 mg/L)
3	0.31 (Acute hypoxia at 2.3 mg/L)

Units: Dimensionless (Dmnl).
Source: ASA estimated relationship based on benchmarks of 4.8 mg/L (hypoxia) and 2.3 mg/L (acute) for average concentration of 7.2 mg/L.
Assumptions: DO depends only on nitrogen and stratification.
Limitations: This represents a rough approximation of the relationship between estimated DO and chlorophyll *a*. There is no identified source to illustrate relative changes in chlorophyll *a* and relative DO, in part because DO also depends on wind, temperature, tidal mixing, rain, and freshwater input.

Relative Stratification

*Relative stratification = 1 + (1/10 * (relative rainfall + relative temperature) - (1/10 * (relative waterway engineering + relative wind))*
Units: Dmnl.
Source: ASA and IEc estimated based on perceived influence of factors on stratification.
Assumptions: These variables control stratification.
Limitations: There are no numerical figures to support the qualitative assumptions. These are meant to be illustrative.

EFFECT OF MICRO ALGAE (CHLOROPHYLL A) ON WATER TURBIDITY

$$\textit{Water turbidity} = 1(\ \textit{NTUs} / \textit{TSS (mg/L)} * (\textit{chlorophyll } a + 6.32) / 2.52$$

Units: Water Turbidity (NTU), chlorophyll *a* (µg/l).

Source: Linear relationship from Moore et al. (1997).

Assumptions: Chlorophyll *a* is the only factor for water turbidity.

Limitations: Colored dissolved organic matter and total suspended solids account for approximately 80 percent of variability in turbidity with chlorophyll *a* accounting for the remaining 20 percent.

Effect Of Water Turbidity On Beach Visits

EXHIBIT B-2. TABLE FUNCTION SHOWING BEACH VISITS AS A FUNCTION OF WATER TURBIDITY

TURBIDITY	RELATIVE BEACH VISITS MULTIPLIER
0	1
2	1
3	0.9
11	0.2

Units: Turbidity (NTU), Multiplier (Dmnl)

Source: Smith and Davies-Colley (1992).

Assumptions: Estimated relationship using turbidity values based upon swimming suitability: 1=eminently suitable, 2=suitable, 3=marginally suitable, and >8-11 totally unsuitable. People's preferences for water clarity for salt and freshwater are the same. Water clarity affects Narragansett Bay beach visitors.

Limitations: This is an understudied area. The relative beach visits multiplier is intended only as an approximation. These values can be adjusted by users of the model and are expected to be refined in Phase II of the project.

Effect Of Hypoxia On Fish Kills

EXHIBIT B-3. TABLE FUNCTION SHOWING MULTIPLIER OF PROBABILITY OF A FISH KILL AS A FUNCTION OF RELATIVE DO

RELATIVE DISSOLVED OXYGEN	FISH KILL PROBABILITY
1	0
0.65	0
0.31	0.05
0.2	0.1
0.1	0.2

Units: Dmnl.
Source: IEc and ASA estimated relationship based on conversation with Marilyn Ten Brink (USEPA/AED) suggesting including low probabilities of fish kills into the model.
Assumption: Fish probability of death is an approximation based on hypoxic cutoffs. These values can be adjusted by users of the model and are expected to be refined in Phase II of the project.
Limitations: Relative DO thresholds and probability of fish impacts are approximations. Other factors influence fish kills, such as wind, tides, fish age, and others.

RELATIVE EELGRASS ABUNDANCE

This relationship is modeled as a function of water turbidity and relative sea lettuce abundance. Each of these factors is given equal weight.

Effect Of Water Turbidity On Eelgrass

EXHIBIT B-4. TABLE FUNCTION SHOWING RELATIVE EELGRASS AS A FUNCTION OF RELATIVE WATER TURBIDITY.

RELATIVE WATER TURBIDITY	RELATIVE EELGRASS
1	1
1.4	0.75

Units: Dmnl.
Source: ASA estimated relationship based on loss of eelgrass with increasing turbidity (Moore et al., 1997; Longstaff, 1999; Nielsen et al., 2002). USEPA AED's Jim Latimer concurred that this is the key relationship.
Assumption: Water turbidity and sea lettuce are the only influences on eelgrass. Other factors that influence eelgrass include superficial epiphytes, hydrodynamics, light limitation, temperature, and nutrients.
Limitations: Small percentage, likely 10-20 percent, of eelgrass variability is attributable to turbidity.

Effect Of Sea Lettuce On Eelgrass

EXHIBIT B-5. TABLE FUNCTION SHOWING RELATIVE EELGRASS AS A FUNCTION OF RELATIVE MACROALGAE

RELATIVE SEA LETTUCE	RELATIVE EELGRASS
1	1
2	0.75
3	0.65
5	0.5

Units: Dmnl.
Source: ASA estimated algal bloom table based on increasing turbidity resulting in loss of eelgrass (Moore et al., 1997; Longstaff, 1999; Nielsen et al. 2002) . However, "It appears that there is no simple relationship between nutrient loading and the outcome of competition between phytoplankton and macroalgae in the field" (Nixon et al. 2001).
Assumption: Sea lettuce and water turbidity are the only influences on eelgrass. Other factors influencing eelgrass include superficial epiphytes, hydrodynamics, light limitation, temperature, and nutrients.
Limitations: Small percentage, likely 10-20 percent, of eel grass variability is attributable to sea lettuce.

NITROGEN LOSSES IN THE BAY

*Nitrogen loss = .3 * Nitrogen stock*
Units: kg N/year
Source: Ed Dettmann, personal correspondence.
Assumption: Nitrogen loss is a simple function of nitrogen stock.
Limitation: Nitrogen loss occurs through sedimentation, denitrification and other nitrogen process that vary throughout the bay in space and time. This relationship is a general approximation that is believed to be appropriate for the level of accuracy demanded by this model prototype.

EFFECT OF NITROGEN LOADING ON SOFT-SHELL CLAM AND QUAHOG GROWTH RATE (PROXIES FOR BENTHIC ABUNDANCE)

Method: Soft-shell clam and quahog growth depends on nutrients stimulating chlorophyll *a*, which they consume. For the model, this relationship is simplified to nitrogen loadings influencing soft-shell clam and quahog growth. The model works best with relative rather than absolute growth rates, so increasing the growth rate 100% would in effect double the population.
Growth rate of soft-shell clams:
$\text{Growth Rate (mm wk}^{-1}) = 0.22 \ln (N) + 1.16$
Growth rate of quahogs:
$\text{Growth Rate (mm wk}^{-1}) = 0.19 \ln (N) - 0.99$
Next, the relative change in growth is assumed to indicate the change in population, e.g., double growth equals double population.

Growth rate of soft-shell clams:

Soft-shell clam percent relative change = [(0.22 ln (N) + 1.16) – 1.06] / 1.06

Growth rate of quahogs:

Quahog percent relative change= [0.19 ln (N) – 0.99) – 0.93] / 0.93

Source: ASA calculations from Weiss et al. (2002).

Assumptions: Population size is directly related to growth rate. Narragansett Bay behaves in a similar fashion to Cape Cod salt ponds, where the relationships where derived. Nitrogen, mediated through chlorophyll *a*, is the only factor on growth rate.

Limitations: The Narragansett Bay relationships may differ from those in Cape Cod salt ponds because populations are influenced by reproduction, predation, growth rate, mortality, harvesting and other environmental factors that may vary by location.

FISHERIES LANDINGS (PROXY FOR FISH ABUNDANCE)

Relationship between N loadings and fisheries landings of mobile species in estuaries and semi-enclosed seas:

$$f = 2.83 + 0.99 \times \exp\left\{-0.5\left[\frac{x - 4.08}{0.45}\right]^2\right\}$$

where x is the log N loadings in log$_{10}$kg km^{-2} yr^{-1}. To normalize this relationship as a relative change from present conditions, divide by the estimated average present day log N loading of 3.58 log kg N km^{-2} yr^{-1}.

$$f = \frac{\left[2.83 + 0.99 \times exp\left\{-0.5\left[\frac{x - 4.08}{0.45}\right]^2\right\}\right] - 3.58}{3.58}$$

Units: Nitrogen (g N /m^3).

Source: ASA calculations from Breitburg et al. (2009).

Assumption: Nitrogen loadings directly correspond to fish landings. Fish landings relate directly to fish population. Fishing effort over time is consistent.

Limitations: Fish populations do not track one to one with fish landings.

SOCIAL AND ECONOMIC DATA SOURCES

Exhibit B-6 presents each of the demographic and economic variables used in the model along with their sources. Much of the demographic and economic data used in the model comes from the National Oceanic and Atmospheric Administration’s (NOAA) Spatial Trends in Coastal Socioeconomics (STICS) database. This database, maintained by NOAA's National Ocean Service Special Projects Office, provides data for EPA’s National Estuary Program watersheds, including the Narragansett Bay watershed. Data are available for 42 demographic variables for every five years from 1970 to 2040.

EXHIBIT B-6. LIST OF VARIABLES AND SOURCES

VARIABLE	SOURCES	GEOGRAPHIC AREA
SOCIAL SECTOR		
Total population	NOAA STICS Database	Watershed
Total employment	NOAA STICS Database	Watershed
Labor force	NOAA STICS Database	Watershed
Number of households	NOAA STICS Database	Watershed
Average adult literacy rate	U.S. Census	Rhode Island
Total fertility rate	World Bank, World Development Indicators	US
Average life expectancy	World Bank, World Development Indicators	US
ECONOMIC SECTOR		
Disposable income	BEA, US Regional Economic Information System	Rhode Island
Real GDP	BEA, US Regional Economic Information System	Rhode Island
Agriculture production	BEA, US Regional Economic Information System	Rhode Island
Industry production	BEA, US Regional Economic Information System	Rhode Island
Services production	BEA, US Regional Economic Information System	Rhode Island
Crop and livestock production	BEA, US Regional Economic Information System	Rhode Island
Forestry and fisheries production	BEA, US Regional Economic Information System	Rhode Island
Fish landings	RIDEM SAFIS Dealer Reports; Commercial Fisheries Research Foundation	Watershed
GDP deflator	World Bank, World Development Indicators	US
Tourism value added	NOAA Coastal County Snapshots Tool	Watershed
Number of beach visits per year	Colt, Tyrrell, and Lee, 2000	Watershed
ENVIRONMENTAL SECTOR		
LAND		
Settlement (developed) Land	Vadeboncoeur, Pryor and Hamburg, 2010	Watershed
Agriculture land	Vadeboncoeur, Pryor and Hamburg, 2010	Watershed
Forest	Vadeboncoeur, Pryor and Hamburg, 2010	Watershed
WATER		
Total water demand	U.S. Geological Survey	Rhode Island
Domestic and municipal water demand	U.S. Geological Survey	Rhode Island
Industry water demand	U.S. Geological Survey	Rhode Island
Agriculture water demand	U.S. Geological Survey	Rhode Island
ENERGY		
Total energy consumption	Energy Information Administration	Rhode Island
Energy demand oil	Energy Information Administration	Rhode Island
Energy demand gas	Energy Information Administration	Rhode Island
Energy demand coal	Energy Information Administration	Rhode Island
Energy demand renewables	Energy Information Administration	Rhode Island
Electricity imports	Energy Information Administration	Rhode Island

Where watershed-level data from the STICS database were not available, the model relied on state-level data for Rhode Island and country-level data from various sources, including the U.S. Census and the World Bank. The main source for the model's economic data is the Regional Economic Information System from the Bureau of Economic Analysis (BEA), which provides state-level data on income, employment, GDP and sectoral value-added. To estimate values for the watershed, these data were transformed to per-capita values and scaled by the population living within the watershed (both Massachusetts and Rhode Island portions of the watershed).

The fisheries production data, which is an important indicator in the model, is estimated using landing data (pounds of finfish and shellfish caught in the Bay in 2010 and the corresponding dollar values) obtained from the Atlantic Coastal Cooperative Statistics Program's Standard Atlantic Fisheries Information System (SAFIS) Dealer Reports and John Scotti, a Cornell University professor conducting research with the Commercial Fisheries Research Foundation.

Tourism and recreation data for the watershed come from NOAA's Coastal County Snapshots tool. The tool estimates "ocean-related" goods and services attributed to tourism and recreation in 2008 for each county located in the Bay's watershed. This tool does not distinguish Bay-related from overall ocean-related goods and services, and it omits the contributions of the self-employed, such as commercial fishermen. However, these data allow for the representation of the tourism and recreation sector in the initial prototype of the model.

In the environmental sector, data on the amount of forest, agricultural and settlement land in the watershed are provided by an earlier model developed by Vadeboncoeur, Pryor, and Hamburg (2010). Water consumption by domestic, agricultural and industrial sectors are derived from the U.S. Geological Survey and energy consumption by source (oil, gas, coal, renewables and electricity) are derived from the U.S. Department of Energy's Energy Information Administration. These data were collected at the Rhode Island state level and calibrated to obtain the watershed estimates (for both Massachusetts and Rhode Island portions of the watershed) based on the per-capita values.

REFERENCES

EFFECTS OF NITROGEN LOADING ON ENVIRONMENTAL INDICATORS

Bintz, J., Nixon, S., Buckley, B., and Granger, S. 2003. Impacts of temperature and nutrients on coastal lagoon plant communities. Estuaries 26: 765-776.

Breitburg, D.L. et al. 2009. Hypoxia, Nitrogen, an Fisheries: Integrating Effects Across Local and Global Landscapes. Annual Review of Marine Science 1: 329-349.

Deacutis, C.F and Ribb R.C. 2002. Ballast Water and Introduced Species: Management Options for Narragansett Bay and Rhode Island. A Report Prepared to fulfill the requirements of Chapter 46-17.3 of the Rhode Island General Laws Related to Ballast Water. Narragansett Bay Estuary Program, R.I. Department of Environmental Management.

Deacutis, C.F., D. Murray, W. Prell, E. Saarman, L. Korhun. 2006. Hypoxia in the Upper Half of Narragansett Bay, RI, During August 2001 and 2002. Northeastern Naturalist Vol 13 , pp. 173-198.

Dettman, E.H. 2011. Personal Correspondence. September 28, 2011.

Dettman , E.H., et al. 2005. Load Response Relationships for Nitrogen and Chlorophyll A in Coastal Embayments. In *3rd International Nitrogen Conference: Contributed Papers, Eds.* Zhaoliang Zhu, Katsu Minami and Guangxi Xing. Science Press: Beijing, pp. 531-538.

Freeman, A.S. and JE Byers. 2006. Divergent induced responses to an invasive predator in marine mussel populations. Science 313: 831-833.

Keser, M.J., T Swenarton, JM Vozarik, and JF Foertch. 2003. Decline in eel grass (Zostera marina L.) in Long Island Sound near Millstone Point, Connecticut (USA) unrelated to thermal input. Journal of Sea Research 49: 22-26.

Latimer, J. 2011. Personal Correspondence. October 4, 2011.

Longstaff, B.J. and Dennison, W.C. 1999. Seagrass survival during pulsed turbidity events: the effects of light deprivation on the seagrasses *Halodule pinifolia* and *Halophilia ovalis*. Aquatic Botany, vol. 65, pp. 105-221.

Melrose, D.C., Oviatt, C.A., and Berman, M.S. 2007. Hypoxic Events in Narragansett Bay, Rhode Island, during the Summer of 2001. Estuaries and Coasts, vol. 30, no. 1, pp. 47-53.

Moore, K.A., R.L. Wetzel, R.J. Orth. 1997. Seasonal pulses of turbidity and their relations to eelgrass (Zostera marina L.) survival in an estuary. Journal of Experimental Marine Biology and Ecology. Vol 215, pp. 115-134.

Neilsen, S.L., Sand-Jensen, K., Borum, J., and Geertz-Hansen, O. 2002. Depth colonization of eelgrass (*Zostera marina*) and Macroalgae as determined by water transparency in Danish coastal waters. Estuaries, Vol 25, No. 5, pp. 1025-1032.

Nixon, S., Buckley, B., Granger, S., Bintz, J. 2001. Responses of very shallow marine ecosystems to nutrient enrichment. Human and Ecological Risk Assessment, Vol. 7, No. 5. pp. 1457-1481.

Smith and Davies-Colley. 1992. Perception of water clarity and color in terms of suitability for recreational use. Journal of Environmental Management, 36: pp. 226-235.

Teichberg et al. 2010. Eutrophication and macroalgal blooms in temperate and tropical coastal waters: nutrient enrichment experiments with Ulva spp. Global Change Biology. Vol 16, pp. 2624–2637.

United States Environmental Protection Agency. 1998. Climate change and Rhode Island. US EPA, Washington, DC.

Weiss et al. 2002. The effect of nitrogen loading on the growth rates of quahogs (Mercenaria mercenaria) and soft-shell clams (Mya arenaria) through changes in food supply. Aquaculture Vol. 211, pp. 275–289.

DEMOGRAPHIC AND ECONOMIC SOURCES

American FactFinder. U.S. Census Bureau. Web. 4 Nov. 2011. http://factfinder.census.gov/home/saff/main.html?_lang=en.

Coastal County Snapshots: NOAA Coastal Services Center. National Oceanic and Atmospheric Administration. Web. 4 Nov. 2011. http://www.csc.noaa.gov/digitalcoast/tools/snapshots/index.html.

Colt, Ames, Timothy Tyrrell, and Virginia Lee. Narragansett Bay Summit 2000: White Paper. "Marine Recreation and Tourism in Narragansett Bay: Critical Values and Concerns" Working paper.11 April.

NOAA's Spatial Trends in Coastal Socioeconomics (STICS). National Oceanic and Atmospheric Administration. Web. 4 Nov. 2011. http://coastalsocioeconomics.noaa.gov/.

Regional Economic Information System. U.S. Department of Commerce, Bureau of Economic Analysis. Web. 4 Nov. 2011. http://www.bea.gov/regional/.

Scotti, John, Emerson Hasboruck, and Jacqueline Stent. *The Rhode Island Commercial Fishing Industry: Development of Profile.* Commercial Fisheries Research Foundation. Web. 4 Nov. 2011. http://www.cfrfoundation.org/research-programs/development-of-aprofile/the-rhode-island-commercial-fishing-industry-development-of-a-profile.

Standard Atlantic Fisheries Information System (SAFIS). Atlantic Coastal Cooperative Statistics Program. Web. 4 Nov. 2011. http://www.accsp.org/safis.htm.

U.S. Energy Information Administration. U.S. Department of Energy. Web. 4 Nov. 2011. http://www.eia.gov/state/state-energy-profiles.cfm?sid=RI.

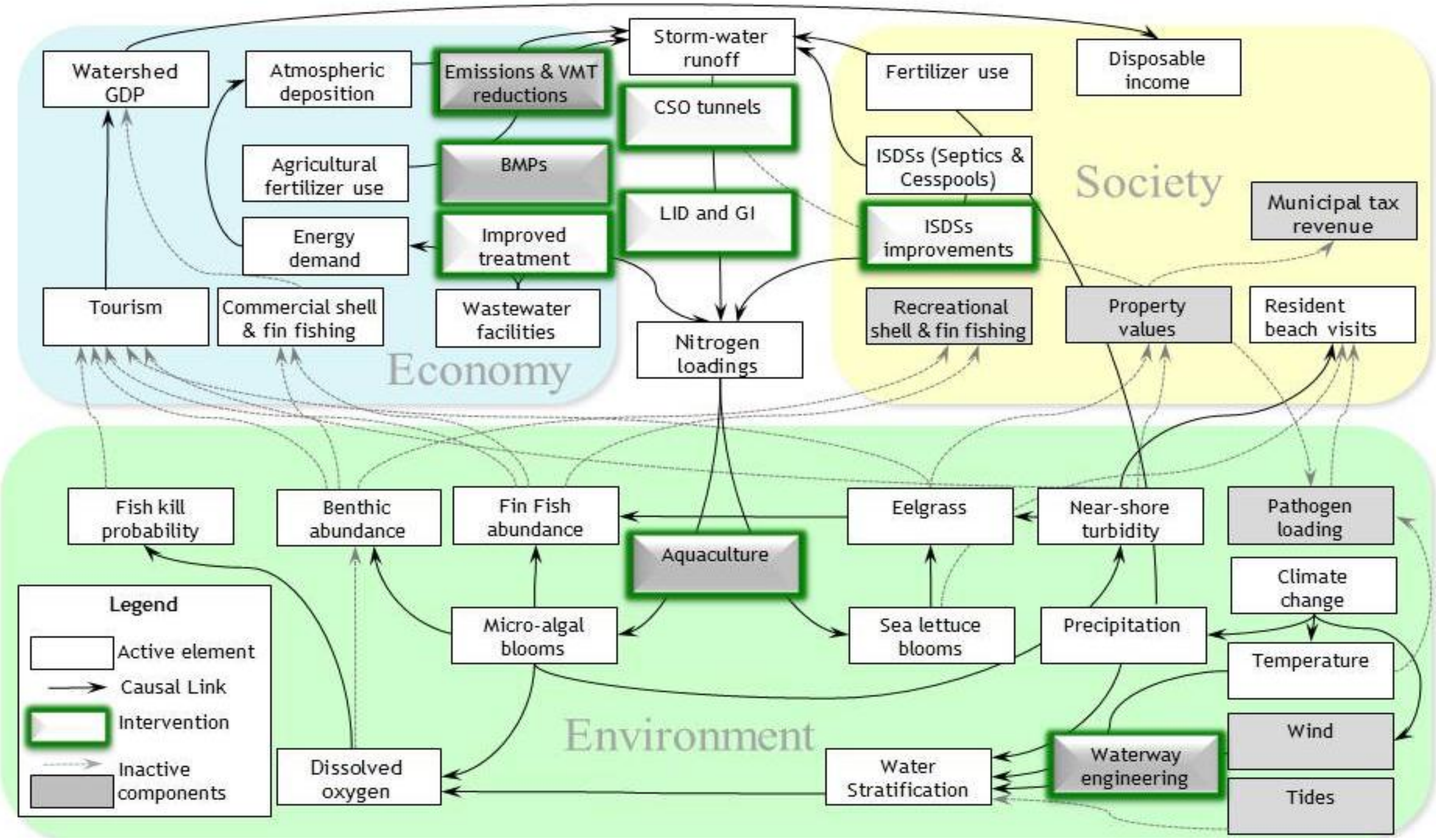
Vadeboncoeur, A., Hamburg, S.P., and Pryor, D. 2010. “Modeled Nitrogen Loading to Narragansett Bay: 1850 to 2015.” *Estuaries and Coasts*. 33:1113-1127.

Water Use in the United States. U.S. Geological Survey. Web. 4 Nov. 2011. http://water.usgs.gov/watuse.

World DataBank: World Development Indicators (WDI) & Global Development Finance (GDF). World Bank. Web. 4 Nov. 2011. <http://databank.worldbank.org/ddp/home.do?Step=12&id=4&CNO=2>.

APPENDIX C | EXPANDED PHASE I PROTOTYPE MODEL SCHEMATIC, EXPLANATION OF TERMS AND SELECTED ENVIRONMENTAL RELATIONSHIPS

EXPANDED PHASE I PROTOTYPE MODEL SCHEMATIC



EXPLANATION OF TERMS

ECONOMY

Agriculture - The amount of nitrogen runoff from agricultural practices.

Atmospheric deposition – Nitrogen that is deposited into the watershed and Bay from the atmosphere as both wet and dry deposition.

Commercial shell & fin fishing - The dollar value of commercial shell and fin fishing in the Bay.

Energy use - The amount of anthropogenic energy use within the watershed.

Stormwater runoff - The amount of nitrogen contained in stormwater, which includes contributions from atmospheric deposition, agriculture, septic tanks & cesspools, and fertilizer.

Tourism - The share of the service sector in the T21 model that is attributed to tourism.

Watershed GDP - The share of GDP that occurs in the watershed.

Wastewater treatment facilities - Facilities that remove solids, contaminants, pathogens, and nutrients from wastewater before discharging to the Bay.

SOCIETY

Disposable income - A component of the T21 model that relates GDP to income after taxes.

Fertilizer use - The nitrogen from fertilizer used in the watershed that flows to the Bay.

Municipal tax revenue - The local tax revenue for cities and towns.

Property values - The property values of residences in the watershed.

Recreational shell & fin fishing - The value of the recreational shell & fin fishing in the Bay.

Resident beach visits - The estimated number of visits by watershed residents to Bay beaches.

ISDSs (septics & cesspools) - The amount of nitrogen from septic systems & cesspools that flows into the Bay.

ENVIRONMENT

Benthic abundance - The relative amount of bottom dwelling life based on quahogs and soft-shell clams.

Climate change - Long term shifts in temperature, wind, and precipitation patterns over time.

Dissolved oxygen - The relative amount of dissolved oxygen in the Bay.

Eelgrass - The relative size of eelgrass (*Zostera marina*) beds.

Fin fish abundance - The relative amount of finfish within the Bay based on fisheries landings.

Fish kill probability - The probability of a fish kill occurring for differing levels of dissolved oxygen.

Micro-algal blooms - The blooms of single celled algae, measured as chlorophyll *a*.

Near-shore turbidity - The clarity or transparency of micro-algal blooms on waters close to land.

Nitrogen loadings - The total amount of nitrogen entering Narragansett Bay from atmospheric deposition, agriculture, wastewater treatment facilities, fertilizers, and septic tanks & cesspools.

Pathogen loading - The relative amount of infectious agents in the Bay.

Precipitation - The annual amount atmospheric water entering the watershed (e.g. rain, snow, hail, sleet).

Sea lettuce blooms - The relative amount of Sea lettuce (*Ulva*) areal coverage, as a proxy for macro-algae blooms.

Stratification - The relative amount of vertical mixing in the Bay.

Temperature - The annual average temperature (both air and water) in the watershed.
Tides - The size of the daily tides, which works to reduce stratification.
Wind - The relative annual wind strength in the watershed.

INTERVENTIONS

BMPs - Best management practices aimed at reducing nitrogen runoff from agriculture to the Bay.
CSO tunnels - Combined sewage overflow tunnels that collect stormwater during intense precipitation events and allow for the treatment of stormwater runoff, which would otherwise enter the Bay.
Emissions & VMT reductions- Reductions in nitrogen emissions and vehicle miles traveled.
Improved treatment - Improvements in wastewater treatment facilities which increase their efficiency, therefore reducing the quantity of nitrogen released to the Bay.
Increased aquaculture - Increased aquaculture of shellfish which reduce standing stocks of micro-algae therefore reducing nitrogen concentrations in the Bay.
ISDSs improvements - Individual sewage disposal systems (ISDS) improvements to reduce nitrogen runoff to the Bay.
LID and GI - Low impact development and green infrastructure to reduce nitrogen loading into the Bay.
Waterway engineering - The relative amount of activities such as dredging that physically alter the bay floor and therefore circulation patterns in the bay which may reduce stratification.

SELECTED ENVIRONMENTAL RELATIONSHIPS

<table>
<tr><th>SELECTED ENVIRONMENTAL INDICATOR</th><th colspan="2">DESCRIPTION AND RELATIONSHIP</th><th>SOURCES</th></tr>
<tr><td>Micro-algal Blooms</td><td colspan="2">Relationship based on season and nitrogen concentration derived from nitrogen loadings:
Summer: Chlorophyll a = 57.5 * (N concentration in water) ^2.09
Winter: Chlorophyll a = 10.3 * (N concentration in water) ^1.275</td><td>Dettmann et al. (2005)</td></tr>
<tr><td>Sea lettuce (*Ulva)* Blooms</td><td colspan="2">Relationship based on change in relative nitrogen concentration derived from nitrogen loadings:
Relative percentage cover of ulva = 0.08 * { [Log(N) * 9 + 16.685] - 0.02938 } / 0.02938 + 0.08</td><td>ASA calculations from Teichberg et al. (2010)</td></tr>
<tr><td>Relative Fin Fish Abundance</td><td colspan="2">Relationship based on bay wide nitrogen concentration derived from nitrogen loadings:
Relative fin fish abundance = ([2.83+0.99 × exp{ 〖-0.5 [(x-4.08)/0.45]〗 ^2 }]-3.58)/3.58</td><td>ASA calculations from Breitburg et al. (2009).</td></tr>
<tr><td rowspan="5">Dissolved Oxygen</td><td colspan="2">Step function based on relative micro-algal blooms and scaled by water stratification:</td><td rowspan="5">ASA estimated relationship based on benchmarks of 4.8 mg/L (hypoxia) and 2.3 mg/L (acute) for 7.2 mg/L (average concentration).</td></tr>
<tr><td>Relative Micro-algae</td><td>Relative dissolved oxygen</td></tr>
<tr><td>1</td><td>1</td></tr>
<tr><td>2</td><td>0.65</td></tr>
<tr><td>3</td><td>0.31</td></tr>
<tr><td>Relative Stratification</td><td colspan="2">Illustrative relationship of relative stratification with inputs of rainfall, temperature, waterway engineering, and wind:
Relative stratification = 1 + (1/10 * (relative rainfall + relative temperature) - (1/10 * (relative waterway engineering + relative wind))</td><td>ASA and IEc estimated based on perceived influence of factors on stratification.</td></tr>
<tr><td rowspan="6">Beach Visits</td><td colspan="2">Relationship of beach visits and turbidity using a step function based on turbidity units:</td><td rowspan="6">ASA estimated relationship based on Smith and Davies-Colley (1992).</td></tr>
<tr><td>Turbidity</td><td>Relative beach visits multiplier</td></tr>
<tr><td>0</td><td>1</td></tr>
<tr><td>2</td><td>2</td></tr>
<tr><td>3</td><td>0.9</td></tr>
<tr><td>11</td><td>0.2</td></tr>
<tr><td rowspan="4">Eel Grass</td><td colspan="2">Relationship of relative eelgrass and nearshore turbidity using a step function based on relative turbidity</td><td rowspan="4">ASA estimated relationship based on loss of eelgrass with increasing turbidity (Moore et al., 1997; Longstaff, 1999; Nielsen et al., 2002).</td></tr>
<tr><td>Relative water turbidity</td><td>Relative eelgrass</td></tr>
<tr><td>1</td><td>1</td></tr>
<tr><td>1.4</td><td>0.75</td></tr>
</table>