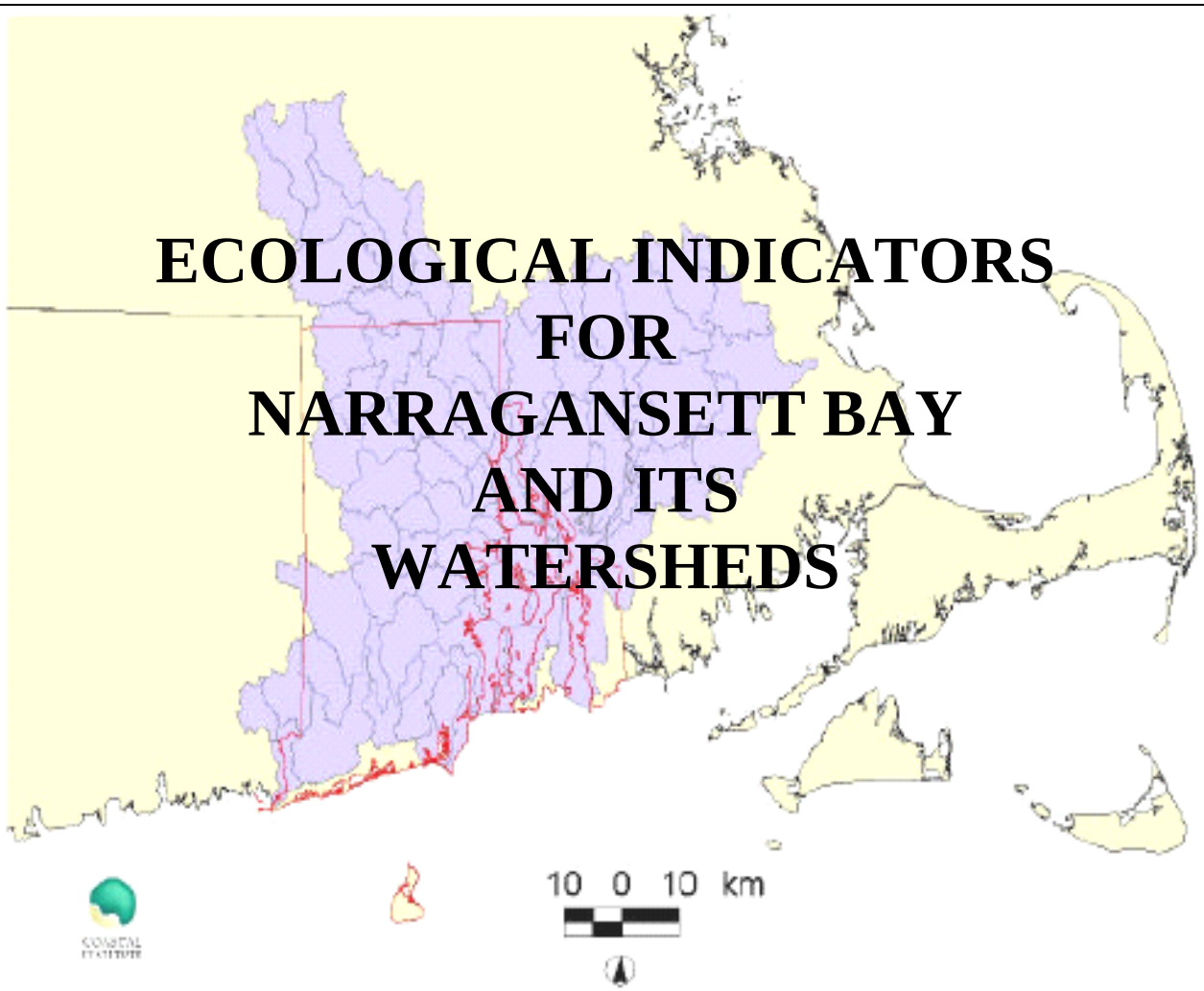

ECOLOGICAL INDICATORS FOR NARRAGANSETT BAY AND ITS WATERSHEDS

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The Partnership for Narragansett Bay

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ECOLOGICAL INDICATORS FOR NARRAGANSETT BAY AND ITS WATERSHEDS

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ECOLOGICAL INDICATORS FOR NARRAGANSETT BAY AND ITS WATERSHEDS

1.0 INTRODUCTION

This paper presents a core suite of ecological indicators designed for use in assessing the overall state of Narragansett Bay (Bay) and its watersheds (are conditions good or bad from an ecological perspective?) and tracking important environmental trends (are conditions getting better or worse over time?). These indicators were developed based on a review of existing literature, including an assessment of what is being done for other National Estuary Programs around the country and input from regional scientists and regulators gained through a two-day indicators workshop held in February 2003. The indicators were developed for the Partnership for Narragansett Bay (PNB) as part of a larger project intended to improve planning and decision-making regarding the Bay and its watersheds.

The ecological indicators presented herein do not represent all the environmental variables that might be monitored within the Bay and its watersheds. Rather, they represent a recommended core set of parameters that should be measured over time to support a long-term resource management and decision-making process. These core indicators will help in evaluating and communicating information about the state of the Bay and its watersheds and will facilitate a more coordinated approach to long-term monitoring. Without an effective monitoring system of key indicator measurements, there is no way of knowing whether various plans, policies and management activities are having their desired effects.

In many cases there are existing programs that currently measure some of the recommended core indicators. In other cases, parameters are being measured but only on a very limited basis (in time or space) and/or are not being measured at all in any kind of systematic way.

Ultimately, the ecological indicators identified in this report should be viewed as a starting point rather than as an end point. These indicators should be tested and refined as appropriate over time to create an effective environmental monitoring system that provides

accurate information about the status of the ecosystems that comprise the Bay and its watersheds that is useful to scientists, regulators, decision-makers, and the public.

The term "framework" as used herein refers to a basic organizational structure for categorizing and identifying appropriate indicators. The term is not meant to infer a management or institutional framework for implementation of an environmental monitoring program. All references to Narragansett Bay, or Bay, in this report refer to the physical limits of the waters of the Bay such that all Bay indicators are for in-water attributes. The term watersheds, as used in this report refers to all lands that drain into the Bay and coastal Rhode Island beginning at the immediate shoreline of the Bay or ocean and moving upstream.

2.0 FEBRUARY 5-6, 2003 WORKSHOP

To assist in identifying appropriate core ecological indicators for Narragansett Bay and its watersheds, the PNB sponsored a two-day workshop of regional scientists and policy makers on February 5-6, 2003. The workshop was designed to build on two previous workshops on environmental monitoring and ecological indicators sponsored by PNB in 2001 (see www.ci.uri.edu/projects/mon_ind for more details). The workshop involved approximately 40 individuals from the regional area (RI and MA) as well as a few experts from outside the area that could offer an independent and objective perspective to the discussions. Individuals were invited who are familiar with Narragansett Bay and its watersheds, ongoing monitoring programs, and various ecological studies and data sets relevant to the selection of appropriate ecological indicators. Appendix A provides more details on the workshop including a list of attendees.

Workshop attendees were provided background materials and a draft framework for identifying core ecological indicators in advance of the workshop. At the workshop attendees discussed and refined the framework and identified specific data sets that might be used to support the indicators, as well as data gaps. Workshop attendees focused on addressing the following key question:

> ***What do we need to measure to say something about the ecological status and trends of the Bay and its watersheds***?

In addressing this question, workshop attendees noted that there are two important considerations: (1) understanding how the system functions and how various factors are linked; and (2) identifying appropriate reference conditions as a benchmarks against which current conditions can be compared. Workshop attendees also pointed to the need for clearly articulated goals and objectives for the system that would dictate the need for specific performance indicators.

The recommended ecological indicators presented in Section 4 below incorporate the input received during the February 5-6, 2003 workshop. The original draft framework has been

modified and indicators have been categorized according to the level of currently available information. The framework has also been expanded to distinguish between indicators focused on Bay environs, those applicable to watershed areas, and those that should be tracked in both the Bay and its watersheds.

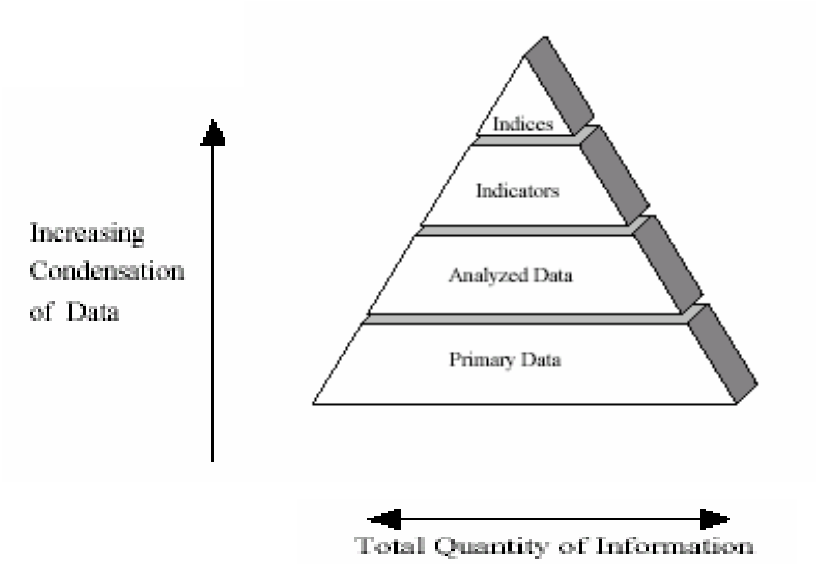
3.0 ECOLOGICAL INDICATORS

There has been considerable research, as well as practical applications, regarding ecological indicators throughout the country, particularly over the past several years. This includes several large-scale national level initiatives as well as many regional and landscape level efforts undertaken by a variety of governmental and non-governmental organizations. The first step in developing a set of ecological indicators for Narragansett Bay and its watersheds was to review these existing models and identify an overall framework applicable to Narragansett Bay and its watersheds. Some of the literature and programs reviewed included:

- *Ecological Indicators for the Nation*, National Research Council (NRC), 2000;
- *The State of the Nation's Ecosystems*, the Heinz Center, 2002;
- *The Role of Biological Indicators in a State Water Quality Management Process*, Yoder, 1998;
- *Conceptual Framework for the Development of Long-term Monitoring Protocols at Cape Cod National Seashore*, Roman and Barrett, 1999;
- USEPA, Office of Research and Development , Environmental Monitoring and Assessment Program (EMAP) and Science to Achieve Results (STAR);
- Mid-Atlantic Integrated Assessment (MAIA)
- Estuarine and Great Lakes (EaGLe) Research Program, including the Great Lakes Environmental Indicators Project, Atlantic Coast Environmental Indicators Consortium, and the Pacific Estuarine Ecosystem Research Consortium;
- U.S. EPA Environmental Indicators Initiative;
- The Chesapeake Bay Program (CBP) indicators;
- Puget Sound National Estuary Program;
- Long Island Sound National Estuary Program;
- Tampa Bay National Estuary Program;
- Delaware Estuary Program; and
- Status and Trends of Key Indicators in the Barataria-Terrebonne Estuarine System, 2001.

There is general agreement in the literature on the purpose, function, and role of an ecological indicator. Indicators are commonly defined as ". . . a measurable feature which singly or in combination provides managerially and scientifically useful evidence of ecosystem quality, or reliable evidence of trends in quality." (ITFM 1992). Indicators are generally designed to provide clear signals about something of interest. They typically communicate information about the status of things, and, when recorded over time, can yield information about changes or trends (NRC, 2000). Indicators also typically simplify information about complex phenomena to improve communication (Hammond et al. 1995). The graphic below (derived from Hammond, et al., 1995 and Braat, 1991) illustrates the role that indicators (and indices) play in presenting a reduced quantity of information and increased condensation of data (relative to primary scientific data).

Figure 1 - The Role of Indicators and Indices



Other key concepts that are widely reflected in the literature regarding ecological indicators include the following:

- *The Number of Indicators* - Several of the programs reviewed maintain extensive lists of as many as 90 indicators. However, most of the programs and reports focus on developing a short list of core indicators, typically 10- 20 depending on the scale and range of ecosystem types represented.

- *The Need for a Suite of Indicators* - Almost all of the programs and reports reviewed advocate development of a suite of indicators that represent a range of ecosystem characteristics and functions.

- *Linking Indicators to Goals and Objectives* - Many of the programs, particularly those focused on specific geographical areas have selected and organized their indicators to reflect larger program goals or objectives. In this capacity, the indicators serve as effective performance metrics for the program, in addition to providing an indication of ecosystem condition and trends.

- *The Value of Conceptual Models* - Useful ecological indicators are typically based on clear conceptual models of the structure and functioning of the ecosystems to which they apply. The models can be empirical or theoretical, quantitative or qualitative but some type of model is essential to ground and rationalize the indicators (NRC, 2000).

- *The Importance of a Reference Condition* - To evaluate and use indicators, it is often highly informative to compare status and trends measured by the indicator against some "reference state." Without such a baseline, it is hard to assess the magnitude of change objectively (NRC, 2000).

- *Selection Criteria* - A variety of criteria have been identified for selecting appropriate ecological indicators. These include considerations of validity, understandability, and availability. Specific criteria frequently used include:

  - <u>Relevant</u> - Relevant to one or more key management questions
  - <u>Appropriate Scale</u> - Representative of the entire area of interest (or some significant sub-unit) over an appropriate time scale.
  - <u>Sensitive/Responsive</u> - Natural variability can be reasonably explained; quickly reflects changes in the environment.

- Meaningful - Interpretable and meaningful to area residents and their political representatives.
- Supported - Supporting dataset is long-term status & trend monitoring, immediately usable, and with a reasonable expectation that monitoring will continue.
- Data Quality - Supporting dataset quality is acceptable.
- Data Available - Data is available in a simple data aggregation or the analyzed/modeled results of the dataset.

4.0 RECOMMENDED FRAMEWORK AND INDICATORS

A review of the existing literature indicates that there is no established approach to identifying ecological indicators. In fact there are a variety of different conceptual frameworks being used. These frameworks differ depending on the scale and focus of the effort as well as the specific region and or ecosystems in question.

Table 1 displays the framework and core ecological indicators recommended for Narragansett Bay and its watersheds. This framework is based the current literature on ecological indicators and incorporates discussions and recommendations from a 2001 PNB workshop on ecological indicators, the 2003 workshop (as described in Section 2 and Appendix A of this report), and input from workshop participants following the workshop itself. In addition to listing the suite of recommended core indicators, Table 1 also highlights ten indicators identified by workshop participants as being particularly important.

The framework shown in Table 1 is similar in many respects, by design, to several well established indicator programs used for other National Estuary Programs across the country. Table 2 displays how the recommended indicators for Narragansett Bay and its watersheds compare with those of other similar programs within the region and across the country.

The recommended framework shown in Table 1 consists of three basic components:

- Management Categories
- Ecosystem Characteristics
- Core Indicators

These components are represented as columns in Table 1 and provide the basic organizational structure for the recommended indicators. Management categories are selected to represent key overarching goals or management questions that need to be addressed. Ecosystem characteristics provide a basic structure for organizing the indicators according to key ecosystem functions and attributes. Finally the core indicators themselves identify the specific attributes that will be measured. Core indicators are further described using a set of very specific metrics,

as described in Section 4.4 below. Based on recommendations from the February 2003 workshop, specific metrics have been identified for the Bay and for the watersheds separately, recognizing that ecological conditions and characteristics may be distinctly different for each.

The recommended framework draws heavily on two organizational constructs: (1) a framework developed and advocated in the recent Heinz Center Report (*The State of the Nation's Ecosystems, 2002*); and (2) the "Hierarchy of Indicators" framework used by the Chesapeake Bay Program and advanced by U.S. EPA EMAP and others (see Figure 2). Both of these frameworks focus on indicators comprised of physical, chemical, and biological measures. In addition, the "Hierarchy of Indicators" framework shown in Figure 2 incorporates a stressor, exposure, response continuum, and recommends that selected indicators reflect all three of these factors. This framework also incorporates explicit feedback loops that emphasize how each indicator fits into a process for relating current status back to management actions. The term "response" in this context refers to a biological response to actions or stressors. This differs from a pressure, state, response framework in which the term "response" refers to an administrative response.

Table 1. - Ecological Indicators Framework for Narragansett Bay and its Watersheds

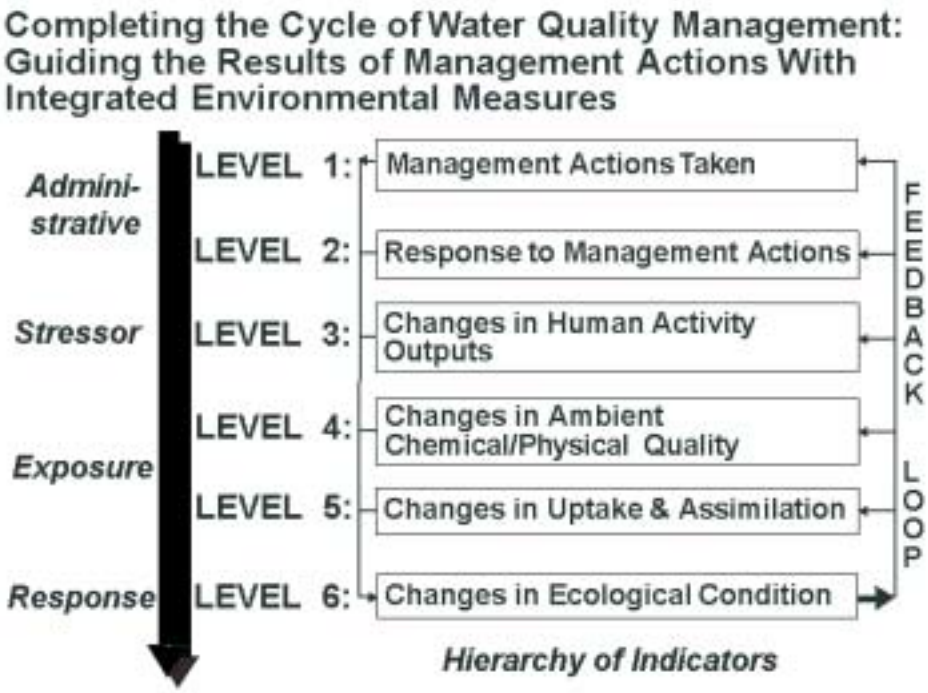
Management Category	Ecosystem Characteristic	Core Indicator	Bay	Watershed
Landscape Composition and Use	Land Cover/Use	Impervious Surface		X
		Shoreline Buffers	X	X
		Protected Undeveloped Land		X
	Demographics	Population Density		X
Water and Sediment Conditions	Water Quality	Water Temperature, Salinity, pH	X	X
	Sediment Quality and Transport	Nitrogen, Phosphorous, Oxygen	X	X
		Pathogens	X	X
		Metals and Organics	X	X
		Acid Volatile Sulfide	X	X
		Total Suspended Solids	X	X
	Hydrology/Hydrodynamics	Flows and Circulation	X	X
Habitat Conditions	Habitat Quantity and Quality	Anadromous Fish Habitat		X
		Coastal and Freshwater Wetlands	X	X
		Benthic Habitat	X	
		Forested Lands		X
Fish and Wildlife Populations and Biodiversity	Species Assemblages and Relative Abundance	Fish and Invertebrates	X	X
		Shellfish	X	
		Benthos/Macroinvertebrates	X	X
		Birds and Mammals	X	X
		Amphibians and Reptiles		X
	Productivity	Chlorophyll	X	X
		Net Primary Production (NPP)	X	X

Two-Thirds or more of surveyed workshop participants indicated shaded indicators as particularly important.

Table 2. – Comparison of Indicators

Ecosystem Characteristic	Recommended Indicators for Narragansett Bay and its Watersheds	Indicator Used in other Estuarine Health Studies			
		Puget Sound	Chesapeake Bay	L.I. Sound	NHEP
Land Cover/Use	Impervious Surface				●
	Shoreline Buffers	●	●	●	●
	Protected Undeveloped Land	●	●	●	●
Demographics	Population Density	●	●	●	●
Water Quality	Water Temperature, Salinity, pH	●	●	●	●
	Nitrogen, Phosphorous, Oxygen	●	●	●	●
	Pathogens	●	●	●	●
Sediment Quality and Transport	Metals and Organics	●	●	●	●
	Acid Volatile Sulfide/Redox			●	●
	Total Suspended Solids		●		●
Hydrology/Hydrodynamics	Flows and Circulation	●			●
Habitat Quantity and Quality	Anadramous Fish Habitat	●	●	●	●
	Coastal and Freshwater Wetlands	●	●	●	●
	Benthic Habitat	●	●	●	●
	Forested Lands		●	●	●
Species Assemblages and Relative Abundance	Fish and Invertebrates	●	●	●	●
	Shellfish	●	●	●	●
	Benthos/Macroinvertebrates	●	●	●	●
	Birds and Mammals	●	●	●	●
	Amphibians and Reptiles				●
Productivity	Chlorophyll			●	●
	Plankton				●

Figure 2 - Hierarchy of Environmental Indicators Framework



Rather than constrain the framework to those indicators for which there is current available data, the framework was developed as an idealized case. The advantage of this approach is that it provides an idealized concept design that can be used to identify gaps and establish a goal to work towards.

In developing the framework particular efforts were made to ensure that it included an adequate representation of biological response indicators. A common criticism of other indicator and monitoring programs is that they focus too heavily on physical and chemical measures which represent potential stressors, but fail to adequately monitor biological response, which is a more direct measure of ecosystem condition.

Because the study area is a specific geographic region (Narragansett Bay and its watersheds), the proposed framework follows a geographic approach that considers all living and nonliving things within a region as part of an overall system. This is consistent with other established indicator programs for large geographic areas such as the Chesapeake Bay Program and Long Island Sound Program. This approach differs somewhat from a land cover approach

that focuses on indicators for discrete ecosystem types (such as forests, fresh waters, and grasslands).

Because of the relatively large size and ecological diversity of the study area, the proposed framework is designed to be applicable to a variety of ecosystem types that are present within the overall system. For example, the framework is designed to consider terrestrial and aquatic habitats as well as both freshwater and estuarine/marine systems present in the region. The specific indicators used from one area to another (within the region) may differ, but the basic organizational structure is designed to be consistent throughout the system. Ultimately, the tracking and reporting of indicators may be done on a sub-regional basis to reflect inherent differences within the system. These individual reportings could then be aggregated for the region.

Each of the primary components of the proposed framework is briefly described below along with a rationale for why specific parameters are proposed to represent each component.

4.1 Management Categories

Many of the indicator frameworks reviewed for this report, including most of those in place for other National Estuary Programs, are organized according to a set of predetermined goals or management questions that reflect of key resource management issues associated with the given ecosystem or eco-region. Management questions such as *"Is water quality getting better?"* are commonly used to organize a suite if indicators such that the management question can be addressed and performance can be evaluated over time.

A set of specific management questions and associated goals and objectives have not been defined for Narragansett Bay and its watersheds as a whole. However, there are a host of existing management programs and goals regarding the Bay and its watersheds. The PNB is also currently working on a set of overarching goals for the area in parallel with this ecological indicators work.

The existing management concerns, programs, and goals affecting Narragansett Bay and its watersheds can be grouped according to a set of four fairly broad management categories:

1. Landscape Composition and Use
2. Water and Sediment Conditions
3. Habitat Conditions
4. Fish and Wildlife Populations and Biodiversity

These categories provide an effective organizing structure for identifying ecological indicators for the area. They encompass known management issues as well as the general goals and objectives of various established management and regulatory programs. These management categories are also similar to those used in other National Estuary Programs, thus providing an opportunity for promoting consistency and coordination at a national level.

The first two management categories (Landscape Composition and Use, and Water and Sediment Conditions) and their associated ecosystem characteristics and core indicators represent primarily physical and chemical measures. They also represent stressor and exposure indicators. The second two management categories (Habitat Conditions, and Fish and Wildlife Populations and Biodiversity) reflect biological measures and biological response indicators.

4.2 Ecosystem Characteristics

The recent Heinz Center Report as well as a number of other existing indicator frameworks in the literature suggest using a set of ecosystem characteristics (e.g. habitat quality, hydrology, etc.) to organize and categorize ecological indicators. These have also been referred to as Essential Ecosystem Characteristics (EECs) in the literature (Hartwell, et al., 1999). These characteristics are typically reflective of physical, chemical, and biological functions and in some cases also include consideration of human uses.

Figure 3 below displays key ecosystem characteristics relevant to Narragansett Bay and its watersheds. These characteristics were selected based on existing research and input from scientists familiar with the Bay and its watersheds, including input gathered at the February 2003 workshop. Figure 3 also provides a general description of the types of indicators that would be measured for each ecosystem characteristic.

Landscape conditions generally serve to describe the basic characteristics of an ecosystem, or combination of ecosystem types. **Land cover/use** is a general measurement of the abundance of ecosystems. It tracks the total area of both natural ecosystems (forests, grasslands, wetlands, etc.) and transformed ecosystems such as dense urban areas and development in rural areas. Knowledge of land cover permits an analysis of the change in the extent of the various ecosystems over time, and thus can provide a general measurement of ecosystem health and viability. Degradation of habitat associated with changes in land cover, including fragmentation into small, disconnected pieces, is a key factor in the reduction of ecosystem integrity. *Ecological Indicators for the Nation (NRC, 2000*) recommends land cover as a key indicator that can provide an important reference point against which to detect and measure change. Land cover and land use both have a direct affect on overall ecosystem condition. Changes in land cover for example typically have a direct impact on habitat availability (positively or negatively) which affects species and potentially populations over time. Land cover changes also can influence run off patterns, erosion, and nutrient loadings. **Demographics**, while not a direct measure of ecosystem condition, are reflective of human induced stressors on the system.

Chemical and physical conditions serve as indicators of basic processes that influence ecosystem functions. **Water quality** is a key factor affecting aquatic ecosystem functions. Water quality parameters such as water temperature and dissolved oxygen represent key ecosystem building blocks. A lack of dissolved oxygen for example can signal problems and can adversely impact species and species diversity. **Sediment quality and transport** are also important physical and chemical characteristics that affect ecosystem functions, both in terms of long-term biological exposure to toxic

contaminants and in terms of the movement of sediments through the system, particularly from the upper watersheds to the bay. **Hydrology/Hydrodynamics** are key physical processes that drive various ecosystems through the delivery and distribution of energy and nutrients.

Figure 3 - Ecosystem Characteristics for Narragansett Bay and its Watersheds.

Ecosystem Characteristic	**Indicator Description**
Landscape Conditions	
Land Cover/Use	Area and quality of a particular ecosystem or land cover type.
Demographics	Density of human activity on the landscape
Chemical and Physical Conditions	
Water Quality	Measures of basic state variables affecting aquatic systems such as temperature, oxygen, and salinity.
Sediment Quality and Transport	Amounts and concentrations of selected contaminants found in sediments and the transport of those sediments.
Hydrology/Hydrodynamics	Frequency, magnitude, and duration of freshwater flows and tidal circulation and frequency of stratification.
Biological Conditions	
Habitat Quantity and Quality	Existence and quality of important habitat types
Species Assemblages and Relative Abundance	Status of native and non-native species and species diversity across various environmental gradients
Productivity	Biomass on land and in the water

Biological conditions represent the ultimate response indicators reflecting broader ecological conditions. Information on **habitats**, particularly the existence and quality of particular habitat types can serve as an indication of basic biological impacts and the capacity of an area to support particular species and communities. These indicators are closely related to landscape condition indicators that reflect land cover and use. Information on **species assemblages and relative abundance**, particularly data on native and non-native species occurrence, distribution, and abundance serve as important

measures of how specific biota are fairing and can be useful in assessing ecological change over time. Species abundance can also be important from a human use perspective, particularly in terms of commercial and/or recreational fisheries. Data on species assemblages goes beyond a single species focus and provides a more holistic characterization of ecosystem health and change, particularly in terms of species diversity. Finally, **productivity**, both production capacity and net primary production is an important measure of ecosystem functioning. Measures of production capacity, such as total chlorophyll per unit area can provide a direct measure of the energy-capturing capacity of terrestrial ecosystems. Measures of net primary production (NPP) provide a direct measure of the amount of energy and carbon that has been brought into an ecosystem.

4.3 Indicators

For each ecosystem characteristic, one or more indicators were selected to represent that characteristic. These indicators represent a range of stressor and biological response variables and were selected based on factors such as biological relevance, ease of monitoring, and public/societal interest. Recommended indicators for Narragansett Bay and its watersheds are listed and briefly described below, including general rationales for why the individual indicators were selected.

4.3.1 Landscape Condition Indicators

Impervious Surface - Impervious surface is an indicator of the level of development of an area and associated anthropogenic impacts including loss of natural terrestrial habitats, fragmentation of habitats, increased run-off, and increased loadings into adjacent waters. Impervious surface is commonly used as an indicator of watershed health.

Shoreline Buffers - Vegetated shoreline buffers serve to reduce non-point source discharge into adjacent waterways and can provide valuable fish and

wildlife habitat. The presence or absence of such buffers, as well as changes in buffers over time can provide a useful indicator of landscape level conditions.

Protected Undeveloped Land - The existence of protected undeveloped land and the amount of this land relative to the overall watershed area can serve as an indication of landscape condition from an ecological perspective. By focusing on "protected" lands, this indicator provides a measure of long-term sustainability.

Population Density - Population density can be an indicator of the degree of human stressors placed on the ecosystem. Many human impacts are directly related to population density, such as waste loadings.

4.3.2 Physical and Chemical Condition Indicators

Water Temperature, Salinity, and pH - These chemical parameters provide basic information about the chemical state of the aquatic environment, both in terms of freshwater and saltwater. Salinity and temperature stratification are also critical physical conditions that drive a number of other chemical and biological conditions.

Nitrogen, Phosphorous, and Oxygen - All three of these elements play key roles in ecosystems. Nitrogen and phosphorous are important plant nutrients, but human activities sometimes increase their levels to a degree that causes water quality problems. Dissolved oxygen is essential for aquatic organisms and is a common measure of water quality conditions. Nutrient runoff, particularly loadings of nitrogen and phosphorus can have major effects on receiving waters. Redox Potential Discontinuity (RPD) depth provides a means of tracing oxygen conditions in sediments.

Pathogens - Pathogens are frequently used to measure water quality conditions and threats to human uses. Pathogens are typically indicative of anthropogenic effects, particularly in rivers and streams. Pathogens are common

components of TMDL analyses that have been conducted in several of the Bay's watersheds.

Metals and Organics - Heavy metals and various organic compounds are known toxins, both for humans and a variety of terrestrial and aquatic animals. Heavy metals are common regulatory parameters measured in aquatic systems and used as indicators of water quality. Acid Volatile Sulfide (AVS) provides a means of testing the degree to which metals in sediments are bioavailable/leacheable. The higher the sulfides, the more the metals are "locked up" and unavailable to organisms. If contaminated sediments are oxygenated by disturbance, AVS can decline significantly allowing metals to leach out.

Flows and Currents - Long-term changes in surface and groundwater flows, particularly stream base flows can have significant adverse impacts on aquatic systems, both physically and biologically. Water withdrawals for municipal, industrial, agricultural, and energy uses can have direct as well as cumulative impacts on the biological integrity of freshwater streams. Withdrawals of groundwater can also affect surface water flows and groundwater flows into the Bay. Changes in instream flows can serve as an indicator of stress on freshwater aquatic systems and ultimately the health of those systems. Freshwater inflows are also recognized as a critically important component of estuarine ecosystems. These inflows support various physical and chemical conditions such as salinity levels and carbon and other nutrient cycling, which in turn provide specific habitats and biological communities (both plant and animal). Because of the complexity of these systems, the driving mechanisms are often difficult to quantify, but long-term changes in freshwater flows (increases or decreases) can serve as an indication of likely changes in biological resources.

Total Suspended Solids (TSS) - Total suspended solids is an indicator of the transport of sediments and other materials in the system, particularly in riverine environments.

4.3.3 Biological Condition Indicators

Biological condition indicators were identified for habitats, species assemblages, and productivity. Though clearly related, each of these characteristics represents a different aspect of a potential biological response, which could provide insights on the state of the ecosystem.

Species assemblage and relative abundance measures for various taxa should be measured across key environmental gradients, including, but not necessarily limited to the following:

- North-South gradients (freshwater/saltwater, undeveloped/developed, stream order)
- Three major passages in the Bay (east/west/Mt Hope-Sakonnet)
- Depth/elevation gradients (inter-tidal/sub-tidal/deeper channels, terrestrial/riparian/aquatic)

Specific biological condition indicators are briefly described below.

Anadromous Fish Habitat - Anadromous fishes represent a key ecological connection between the Bay and its watersheds. Many of these fishes have been cut off from upstream freshwater habitats required for spawning and rearing due to dams and other impediments to upstream passage. Many of these fish are also important elements of the food web supporting other fishes as well as a variety of bird species. Stream habitat available to anadromous fishes can provide an indication of fragmentation of the overall Bay/watersheds ecosystem.

Coastal and Freshwater Wetlands - These habitats provide important ecosystem functions and are typically associated with sensitive and often rare species. Both habitats have declined considerably in the Bay and its watersheds and both are the focus of restoration efforts throughout the area.

Benthic Habitat - This indicator was selected to represent submerged lands and habitats, particularly in near shore areas that may be limited and/or play an important ecological role for certain species.

Fish and Invertebrates - There is good spatial data on finfish in the Bay. Finfish are also economically relevant and changes in abundance reveal long-term changes in community structure. Invertebrate assemblages, particularly for freshwater systems are also good indicators of ecological conditions.

Shellfish - Shellfish, particularly scallops and oysters are sensitive to anthropogenic effects and are indicative of changes in ecosystem structure. Shellfish are also economically relevant and of interest to the general public.

Benthos/Macroinvertebrates - Data on the diversity of benthic organisms and macroinvertebrates, both in the Bay and in its associated freshwater systems provide an indication of overall ecosystem conditions, particularly when compared to a reference condition. Macroinvertebrates are frequently used as indicators, particularly in terms of food web conditions and the ability of the ecosystem to support various community structures.

Birds and M*ammals* - The presence or absence of various bird and mammal species, particularly sensitive species such as colonial nesting birds, can be important indicators of biological conditions. Bird and mammal populations are often difficult to estimate and may be influenced by factors well beyond the geographic scope of the Bay and its watersheds due to migratory behaviors.

Amphibians and Reptiles - Amphibians and reptiles are among some of the most sensitive taxa in terms of responding to stressors. Consequently they typically serve as good indicators of biological condition.

Chlorophyll and Net Primary Production (NPP) - Chlorophyll per unit area provides a direct measure of the energy-capturing capacity of an ecosystem.

The energy brought into an ecosystem is an overall measure of its performance. How much energy a system absorbs can be affected by climate and weather, pollution, and land management practices. Long-term changes in the amount of energy absorbed can have significant implications for the way an ecosystem functions. Net Primary Production provides a direct measure of the amount of energy and carbon that has been brought into an ecosystem and is an important measure of the basis of the food chain.

4.4 Metrics

Metrics represent the actual parameter to be measured for each indicator. For example, acres of freshwater and coastal wetland habitat, or miles of stream available to anadromous fish. Tables 1a-c provide recommended metrics for each of the core indicators sorted by the Bay and watershed areas.

4.5 Connecting Indicators to Management Actions

To support decision making, indicators need to be more than a simple listing of potentially disconnected parameters. The framework needs to also incorporate a process of sequentially analyzing and assessing the information represented by the various indicators to make valid conclusions about the causes of the current ecosystem state. The need for this process component is exemplified in the feedback arrows shown in Figure 2. This element of the framework explicitly recognizes the need to link specific measures and indicators to their role and usage in evaluating management approaches and outcomes.

For the purpose of this report, we have not attempted to define the specific process steps that may be needed to institutionalize the active use of indicators for Narragansett Bay and its watersheds to evaluate management actions. Rather, we have focused on identifying the indicators themselves and emphasizing the need to incorporate them into a broader evaluation process as an inherent component of the framework. The need for this pragmatic process oriented step can not be understated.

Table 1a. - Landscape Composition and Use Indicators and Metrics

Core Indicator	**Metric**
Bay	
Shoreline Buffers	• Miles of Bay shoreline with adequate natural buffers
Watershed	
Impervious Surface	• Aerial extent of impervious surface - build-out potential - percent impervious
Shoreline Buffers	• River and pond miles with adequate natural buffers
Protected Undeveloped Land	• Percent natural land protected and connectivity of this land • Percent agricultural land
Population Density	• Population density for watershed area • Housing starts for watershed area

Table 1b. - Habitat Condition Indicators and Metrics

Core Indicator	**Metrics**
Bay	
Coastal Wetlands	• Acres of coastal wetlands by type and function • Length of coastal wetland shoreline edge
Benthic Habitats	• Extent of submerged land substrate types (rocky, sandy, etc.) • Acres of submerged aquatic vegetation and patchiness
Watershed	
Anadromous Fish Habitat	• Miles/acres of accessible suitable riverine spawning habitat
Freshwater Wetlands	• Acres of freshwater wetlands by type and function • Length of freshwater wetland shoreline edge
Forested Lands	• Acres of forested land • Extent of intact core habitats (dependent on target species)

Table 1c. - Water and Sediment Condition Indicators and Metrics

Core Indicator	Metrics
Bay	
Water Temperature	• Mean temperature
Salinity	• Fresh water influx
Oxygen	• Dissolved oxygen levels • Redox Potential Discontinuity (RPD) depth as a measure of oxygen in sediments
Nitrogen	• Total nitrogen loading
Pathogens	• Presence
Metals	• Presence and concentrations • Concentration of Acid Volatile Sulfide (AVS) as a measure of the bioavailability of metals in sediment • Tissue analysis
Organics	• Presence and concentrations
Total Suspended Solids	• Mass and toxic concentrations
Flows and Circulation	• Freshwater inflow • Groundwater inflow • Bay circulation patterns • Frequency of stratification
Watershed	
Water Temperature	• Mean temperature
pH	• pH in lakes and rivers
Oxygen	• Dissolved oxygen levels in lakes and rivers
Phosphorous	• Phosphate concentrations
Nitrogen	• Total nitrogen concentrations
Pathogens	• Presence (CSO, storm runoff, ambient)
Metals	• Presence and concentrations • Concentration of Acid Volatile Sulfide (AVS) as a measure of the bioavailability of metals in sediment • Tissue analysis
Organics	• Presence and concentrations
Total Suspended Solids	• Mass and toxic concentrations
Hydrology/Flows	• Mean annual august monthly surface flows • Groundwater flows

Table 1d. - Fish and Wildlife Populations and Biodiversity - Bay Indicators and Metrics

Core Indicator	**Metrics**
Bay	
Fish and Invertebrates	• Assemblages and relative abundance across each bay habitat gradient
Shellfish	• Assemblages and relative abundance across north/south habitat gradient
Benthic Organisms	• Assemblages and relative abundance across north/south habitat gradient
Birds and Marine Mammals	• Assemblages and relative abundance across north/south habitat gradient
Chlorophyll	• Chlorophyll per unit area
Primary Production	• Net Primary Production (NPP)
Watershed	
Fish and Invertebrates	• Assemblages and relative abundance
Macroinvertebrates	• Assemblages and relative abundance across north/south habitat gradient
Birds and Mammals	• Assemblages and relative abundance across north/south habitat gradient
Reptiles and Amphibians	• Assemblages and relative abundance across north/south habitat gradient
Chlorophyll	• Chlorophyll per unit area • Lake eutrophication status
Primary Production	• Net Primary Production (NPP)

5.0 RECOMMENDED NEXT STEPS

The framework and core indicators presented in Section 4 represent an initial step towards developing and implementing a more comprehensive monitoring program for the Bay and its watersheds that can be used to evaluate the status and trends for key environmental resources of the Bay and its watersheds. The following identifies several specific next steps that could be pursued to further develop and implement the framework. These steps are not necessarily sequential in nature. Several could be pursued in parallel. However, some steps build on one another.

1. Implement a Pilot Project - Applying the framework on a small geographic area represents a logical next step in development of a comprehensive strategy. A pilot project could be developed to test the applicability of the framework and its indicators to a subregion of the Bay and its watersheds. This testing would allow for a more detailed examination of core indicators and generate information on how to synthesize and present them. Choosing a small, interstate subwatershed would allow data from both Rhode Island and Massachusetts to be examined.

2. Examine Existing Data Sets - During development of the indicators framework, an effort was made to specify sources of existing monitoring data and the degree to which these data could support reporting on each indicator. A more detailed review of the various data sets is needed to better identify potential data gaps, perhaps focused on the pilot test area noted in #1 above. An initial comparison of current data sets against indicators has already proven useful to RIDEM as it develops a comprehensive monitoring strategy for the State.

3. Analyze Existing Data for Certain Indicators - Where data exists for core indicators, analyses could be conducted to synthesize this information and develop presentation formats that would make the information for understandable and tangible to decision makers and the public.

4. Develop Plans for Enhanced Monitoring - Where there are clear data gaps, efforts should be made to define approaches for filling those gaps either by refining and/or expanding existing programs or, where necessary, developing new programs. To ensure more effective, coordinated monitoring actions, this should be closely coordinated with Rhode Island and Massachusetts planning and implementation of governmental monitoring and water quality programs. This could be extremely timely as RI and MA develop or revise their respective statewide monitoring strategies.

5. Explore Institutional Structures and Arrangements - Implementing a more comprehensive monitoring program will require careful review and examination of how information is currently collected, reported and funded, as well as ways in which this process could be improved andintegrated.

6. Reporting & Communications - Information resulting from the Chafee/HUD-project, as well as any future monitoring data collected as part of an organized monitoring program, should be prepared in such a way as to be easily integrated into a monitoring and indicator framework. This information should also be summarized and presented in a format useful to the public and decision-makers, including serving as a key component of an overall communications and reporting strategy that: reports periodic Bay and watershed status and trends; analyzes the data (what do they tell us); and recommends further action regarding monitoring and indicators.

6.0 KEY TERMS

Several key terms used throughout this document are defined below to promote clarity and avoid confusion.

Attribute - A measurable component of a biological system.

Biological Integrity - A set of natural processes identified and used as a reference state for evaluating current conditions and trends (National Academy of Science, 2000).

Ecosystem - An interdependent grouping of living and non-living components in the environment.

Environmental Indicator - A measurable feature which singly or in combination provides managerially and scientifically useful evidence of ecosystem quality, or reliable evidence of trends in quality.

Exposure Indicators - Indicators which provide evidence of biological exposure to a stressors or bioaccumulative agent. Examples include effluent toxicity tests, tissue residues, and biomarkers.

Response Indicators - Direct measures of biological community or population response.

Stressor Indicators - Indicators of activities which have the potential to degrade an ecosystem such as pollutant discharges, land use effects, and habitat modifications.

7.0 REFERENCES

Braat. 1991. The Predictive Meaning of Sustainability Indicators. Pages 57-70 in Kuik, Onno and Verbruggen, Harmen, editors. In Search of Indicators of Sustainable Development. Dordrecht, The Netherlands: Kluwer Academic Publishers.

Hammond et. al. 1995. Environmental Indicators: A Systematic Approach to Measuring and Reporting on Environmental Policy Performance in the Context of Sustainable Development. World Resources Institute. Washington, D.C.

National Research Council (NRC), Committee to Evaluate Indicators for Monitoring Aquatic and Terrestrial Environments. 2000. Ecological Indicators for the Nation. Washington, DC: National Academy Press. http://www.nap.edu/catalog/9720.html.

Roman and Barrett, Conceptual Framework for the Development of Long-term Monitoring Protocols at Cape Cod National Seashore. 1999. USGS Patuxent Wildlife Research Center, Cooperative National Park Studies Unit, University of Rhode Island.

The Heinz Center. 2002. The State of the Nation's Ecosystems, Measuring the Lands, Waters, and Living Resources of the United States. New York, NY: Cambridge University Press. http://www.heinzctr.org/ecosystems.

Yoder and Rankin. 1998. The Role of Biological Indicators in a State Water Quality Management Process. Environmental Monitoring and Assessment 51: 61-88. The Netherlands: Kluwer Academic Publishers.

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