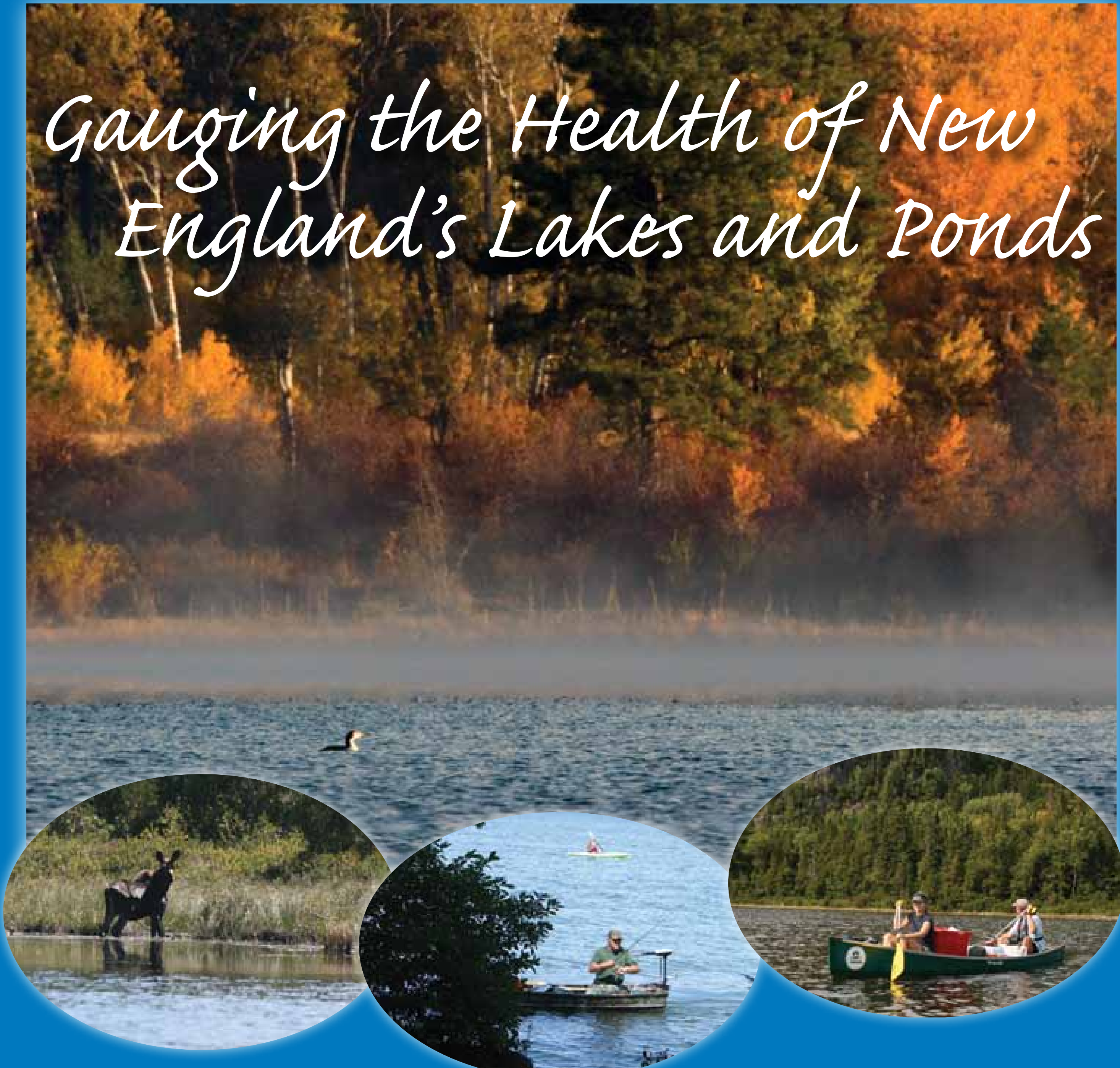
Gauging the Health of New England's Lakes and Ponds

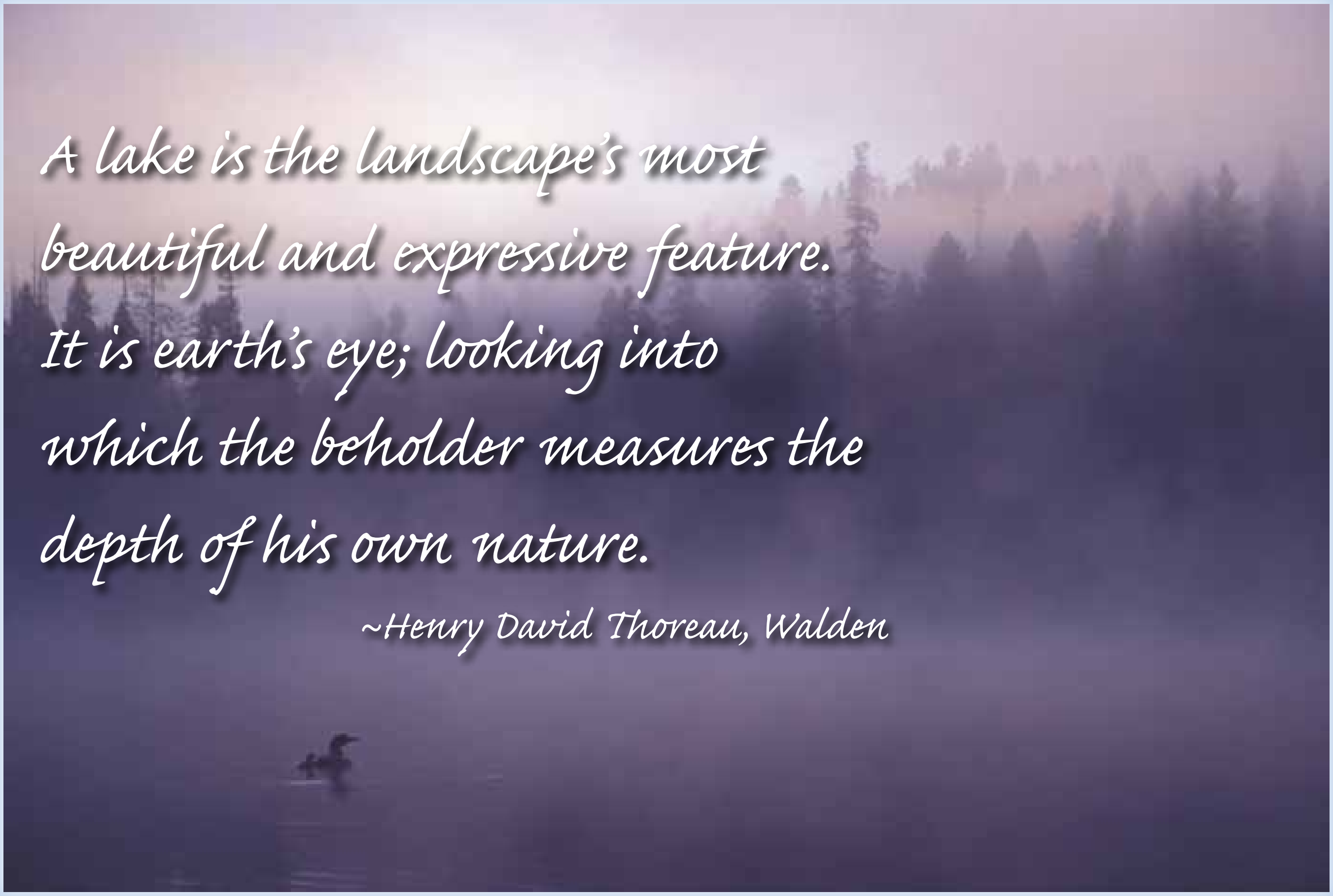


A Survey Report and Decision-Making Resource

OCTOBER 2010

NEIWPCC
New England Interstate Water Pollution Control Commission

EPA United States Environmental Protection Agency



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COLLABORATORS

Connecticut Department of Environmental Protection
Maine Department of Environmental Protection
Massachusetts Department of Environmental Protection
New Hampshire Department of Environmental Services
Rhode Island Department of Environmental Management
Vermont Department of Environmental Conservation
University of New Hampshire Center for Freshwater Biology
University of Rhode Island Cooperative Extension

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Walt Galloway, US EPA Atlantic Ecology Division; *Katrina Kipp* and *Hilary Snoo*k, US EPA Region 1, Chelmsford Laboratory; and *Beth Card* and *Kerry Strout*, New England Interstate Water Pollution Control Commission.

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What This Report Tells You

Section 1

This New England Lakes and Ponds (NELP) project report is designed to serve as a useful resource for evaluating the overall health of the region's lakes and ponds and for taking steps to restore water body integrity, where needed. It is intended for use by a broad group of stakeholders, managers, and policymakers throughout the region.

The report consists of the following key components:

- **Findings of a multi-year, probability-based assessment of the ecological health and integrity of New England's lakes and ponds, comparing these findings with those from research undertaken simultaneously at the national level.** The assessment provides a characterization of the overall condition of regional water bodies and identifies associated stressors based on statistically representative survey samples.
- **A description of innovative lake management assessment tools and technologies** developed and tested as part of this project through collaborations with state and federal agencies and academic institutions.
- **A Lake Attitash case study**, showcasing one approach to assessing lake condition that illustrates what can be accomplished through collaborative partnerships. It describes efforts to implement and develop new technologies that can be transferred and shared with other stakeholders, bringing together the various pieces of information collected during this project.
- **Access to tools, data, and other useful information** for lake managers and decision makers, which includes links to this project's companion website *(www.epa.gov/region1/nelp)* and other resources.

What Is the New England Lakes and Ponds Project?

Section 2

The NELP project was designed to evaluate the condition of the region's water bodies as a population and to establish a baseline from which to compare future studies. It was a collaborative effort involving the United States Environmental Protection Agency (EPA), New England Interstate Water Pollution Control Commission (NEIWPCC), New England state environmental agencies, academic institutions, lake associations, and other stakeholders.

The project utilized new lake assessment technologies and tested new methods, with the goal of making this information transferable to other monitoring programs. Although initiated in 2006, the NELP project was designed to integrate with the 2007 National Lakes Assessment (NLA) and provide opportunities for enhancing the spatial resolution and statistical confidence levels of lake results within the New England states. (For more information on the NLA, go to www.epa.gov/lakessurvey)

COLLABORATIONS

The NELP project featured a number of successful collaborative efforts among federal and state agencies, universities, and local lake associations. For example, researchers at the University of New Hampshire (UNH) employed DNA bar-coding as a protocol for zooplankton identification and developed improved microcystin detection methods.

In another example, EPA, National Aeronautics and Space Administration (NASA), New Hampshire Department of Environmental Services (NHDES), UNH, UNH Cooperative Extension, and University of Rhode Island Cooperative Extension collaborated to develop and test remote sensing technology as a new approach to monitoring water quality and lake productivity through chlorophyll-*a* content and to predict and track cyanobacterial blooms in lakes. This approach is called hyperspectral remote sensing, which is an innovative approach to *in situ* (on-lake), real-time, water-quality data collection. A concurrent project inspired by the NELP project applied hydro-acoustic technology when monitoring the highly impaired Lake Attitash.

These collaborations and others are described in more detail later in this report.

WHY THIS PROJECT IS NEEDED?

In 1972, the U.S. Congress passed the Clean Water Act (CWA) to protect the nation's vital water resources. That Act provides the statutory foundation for reporting on the condition of the nation's water bodies. Through this framework, state environmental agencies monitor the condition of their waters and report results to EPA. EPA summarizes this information for congressional leaders who secure funding and program support for the improvement and protection of aquatic resources in the United States.

States have historically been responsible for assessing the health of their waters. However, these assessments are rarely uniform or comparable across geopolitical boundaries because each state typically employs its own assessment goals, analytical methods, and reporting formats. Consequently, it has been a challenge to appraise the condition of lakes, track trends, and judge the effectiveness of remediation efforts at the regional or national scale.

To address these shortcomings, EPA undertook the National Lakes Assessment (NLA) in 2007, the first nationally comprehensive survey of lake conditions. The NLA employed state-of-the-art survey techniques and a common set of monitoring indicators and analytical methods, providing a uniform and consistent data set for lakes across the country.

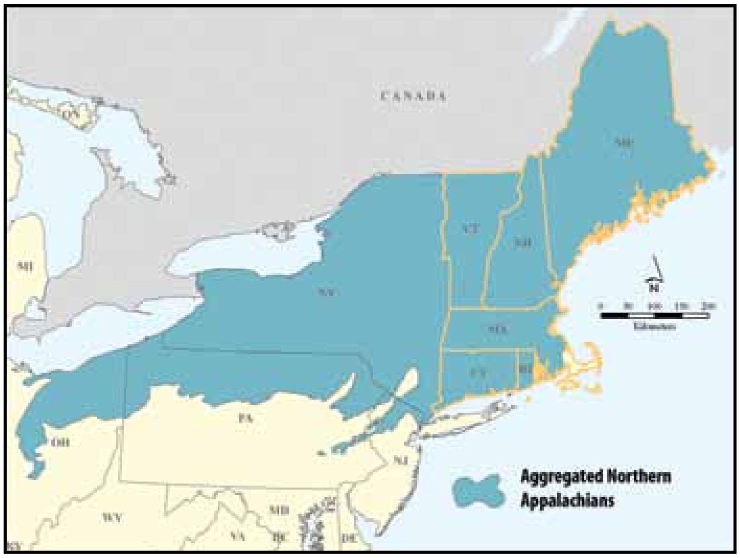


Figure 2-1. *The NELP project encompassed the six New England states, in contrast with the larger Northern Appalachian ecoregion shown on this map, one of nine ecoregions assessed by the NLA.*

The NELP project began testing new methods and technologies in 2006, and then built upon the 2007 NLA study to assess additional lakes in the Northeast. While the NLA project was divided into nine ecoregions for assessment purposes (Figure 2-1; New England is within the Northern Appalachians ecoregion), the NELP project was confined to the six New England states. The NELP project incorporated the same methods and indicators as the NLA for its assessment of specific ecoregions. The project has proven to be an invaluable opportunity to develop improved assessment tools and conduct in-depth studies of issues of particular interest to the region.

PAST STUDIES

Although the NELP is the first comprehensive assessment of the condition of lakes and ponds across the region, it is not the first major lake survey conducted in New England. A *Survey of Problem Lakes in the U.S. (pre-1970)* was the first such survey, followed by the *National Eutrophication Survey* in the 1970s and *The Northeast Lake Acidification Survey/Paleo-ecological Investigation of Recent Lake Acidification (PIRLA)* in the 1980s.

Following the 1990 Clean Air Act amendments, the next major lake survey in New England was a component of the national Environmental Monitoring and Assessment Program (EMAP), EMAP-Northeast Lakes (EMAP-NE), which collected data from 1991 to 1993. EMAP-NE was an assessment of trophic state and trophic change using paleolimnology. It was the first survey to highlight fish contaminants and the response of zooplankton to ecological stressors. The data collected from EMAP-NE were instrumental as a springboard for many projects with wide and varied applicability, especially for those involved in research on the environmental impacts of atmospheric mercury deposition.

From 1992 to 1994, under the Regional Environmental Monitoring and Assessment Program (REMAP), a *Survey of Mercury (Hg) in Fishes of Maine Lakes* was carried out. Maine REMAP was the first random-probability lake survey conducted by an individual New England state. The survey looked specifically at mercury in fish tissue and found that mercury was a pervasive and widespread environmental and human health problem in the Northeast. The data collected were used for New England's first mercury-specific fish-consumption advisory.

The success of the Maine REMAP prompted other New England states to undertake their own REMAP surveys on mercury. From 1998 to 2000, Vermont and New Hampshire carried out their own mercury surveys, which were the first large-scale random-probability surveys investigating the effects of mercury and methylmercury across the food web and in lake water and lake sediments.

The surveys preceding the NELP project may have had a limited geographic scope, but their findings and results have had significant regional impacts. (See *www.epa.gov/owow/lakes/lakessurvey/nov05workshop/NALMS05_Kamman.ppt*)

UNIQUENESS OF NEW ENGLAND'S LAKES AND PONDS

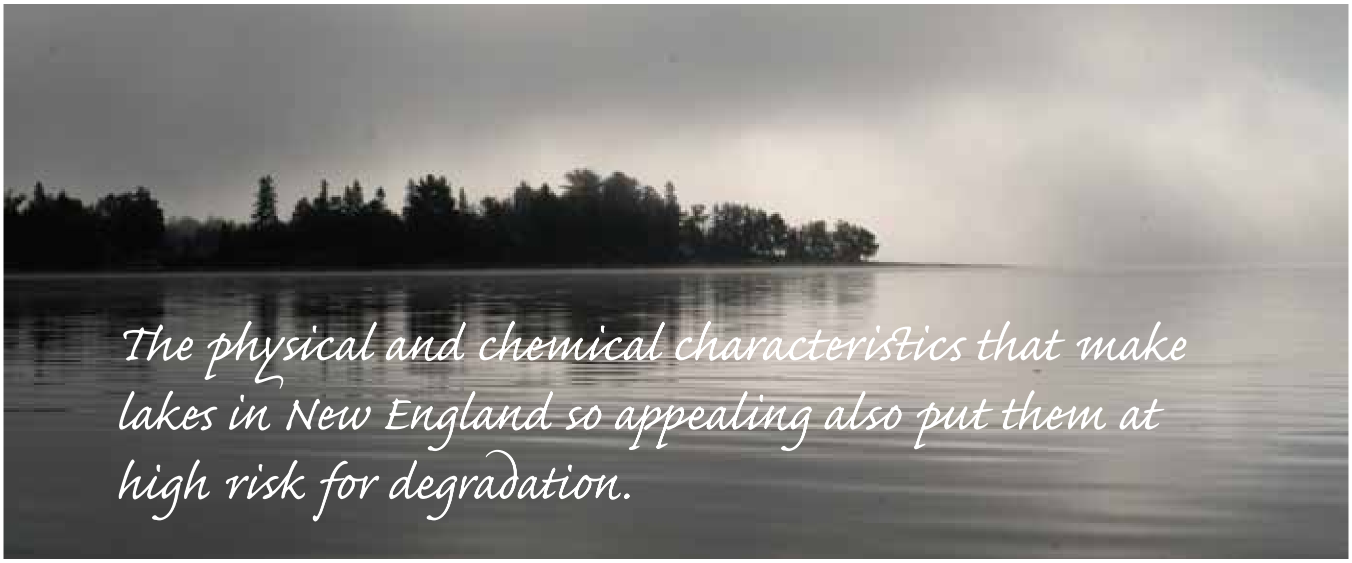
The New England landscape was carved out by advancing glaciers during the last ice age (the Wisconsin), which took place approximately 10,000 years ago and contributed significantly to the uniqueness of the region. Advancing across the landscape, an enormous ice sheet (the Laurentide) was at times more than a mile high, exerting tremendous forces that pressed over mountains and gouged depressions in the resistant bedrock. As the ice sheet advanced, it traversed over large chunks of broken off glacial ice, enormous boulders, and voluminous masses of ground-up rocks and soils called moraines.

As the glaciers from the ice sheet began to recede, areas of gouged-out bedrock filled with the melt water and became ice-scour lakes, basins comprised primarily of bedrock with surrounding watersheds of thin nutrient-poor soils. They tend to be deep, clear, cold-water bodies that support minimal aquatic life. They are highly valued for their natural clarity and recreational potential; therefore they are highly desirable for development along their shorelines.

Some New England lakes were formed by depressions made in the moraine by advancing ice and are commonly known as depression lakes. Others were formed by pooling behind dams and berms of soil and rock built up by the advancing ice. These lakes often have inlets and outlets and watersheds comprised of glacial till, a conglomeration of unsorted boulders, sands, silts, and clays. Farmers in New England have long lamented these poor soils, as they are fraught with large stones and cobbles that make agricultural activity in the region an endless challenge.

As blocks of ice were deposited by the receding glaciers, they left behind gently sloping lake basins comprised mainly of sands and gravels. These lakes dominate many parts of New England landscape and are called "kettle" lakes. Kettles may or may not have inlet or outlet streams. Water is supplied to these systems solely from groundwater and precipitation.

Generally, New England lakes are trophically designated as oligo-mesotrophic, glacial in origin, and



Definitions

- **Oligo:** Greek word for few—low-nutrient content, little to sustain life.
- **Meso:** Moderate.
- **Trophic:** From the Greek word trophikos; to feed or relating to nutrition.
- **Eutrophic:** High nutrient content.
- **Oligo-Mesotrophic:** Moderately nutrient-poor lakes.

nutrient-poor. They predominantly lie in non-calcareous bedrock or high silicate soils, providing the lakes little buffering capacity from acidic inputs such as acid rain. They typically have low chlorophyll levels, low total phosphorus values, and high clarity.

The physical and chemical characteristics that make lakes in New England so appealing also put them at high risk for degradation. Prevailing winds carry emissions from power-generating facilities in the Midwest to the Northeast, where they are deposited along with regional emission sources throughout the landscape. Over time these emission particulates acidify the landscape, mobilizing some metals that are toxic to plants (e.g., aluminum) and stripping away other important plant nutrients. The emissions also transport air-borne mercury into the system, where it settles into New England water bodies, making its way up the aquatic food chain.

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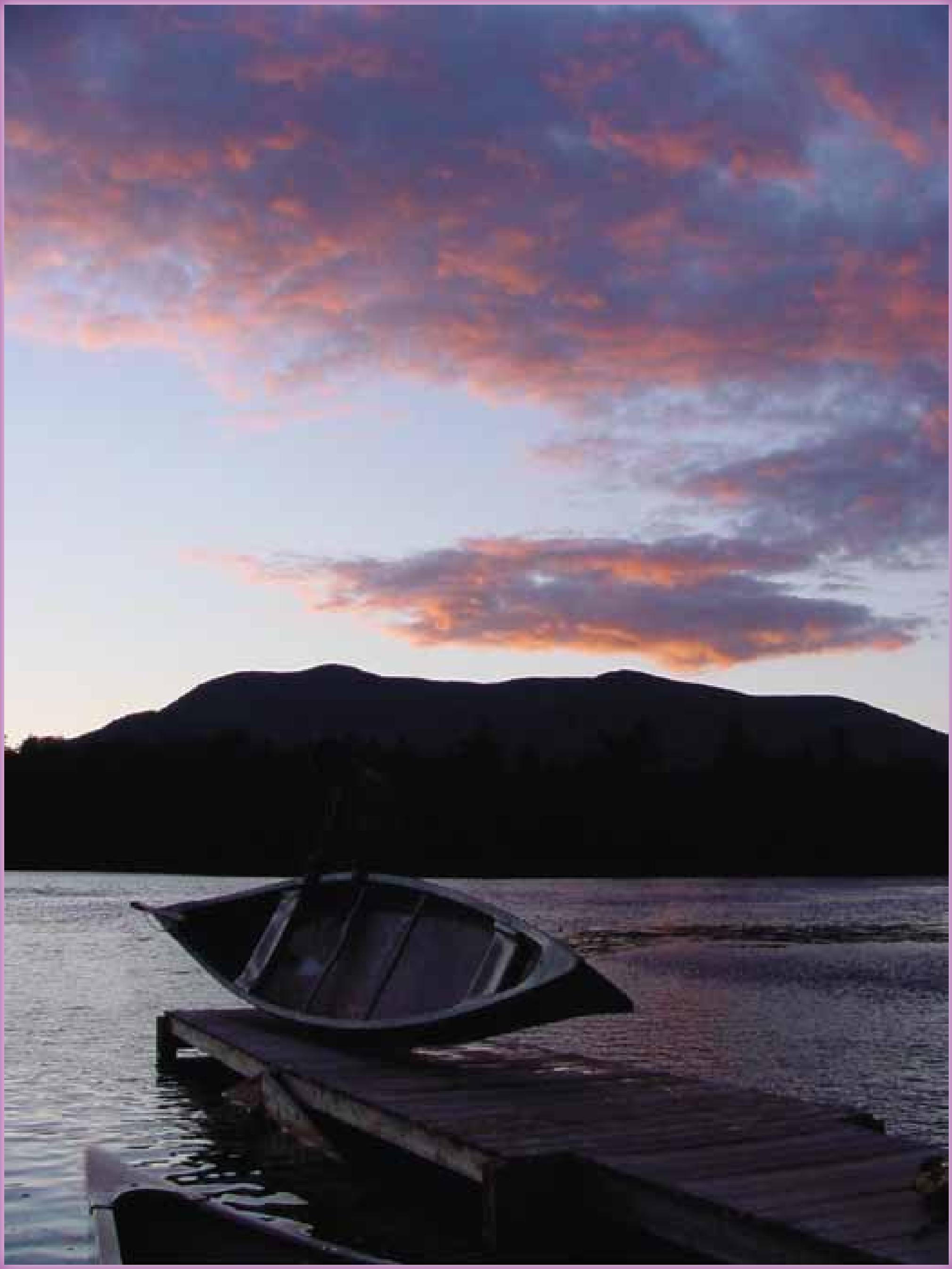


Survey Design and Results

Section 3

The NELP project further amplifies aspects of the NLA in the six New England states and adheres closely to the NLA survey design and monitoring methods (www.epa.gov/lakessurvey). The probabilistic sampling design, with its random selection of sites, allows for a statistically valid representation of the entire population of eligible lakes in the region. Such surveys are used to determine the condition of a prespecified population of water resources while sampling only a small subset of that population. This approach provides statistically unbiased estimates of the condition of a resource at known confidence levels.

The NELP survey was designed to dovetail with the NLA to provide regional and national consistency. Its intent was to develop new methods and implement new technologies that could be transferred to states, while providing opportunities to enhance the statistical confidence levels and geospatial resolution of surveys at the state level.

The regional study almost doubled the number of lakes surveyed in New England by the national program and provided an opportunity for the states to complement existing monitoring and analysis techniques. States were given the opportunity and support to undertake more comprehensive assessments of their lakes, and Vermont, New Hampshire, and Connecticut chose to do so. (For more information on random probability-based surveys, go to www.epa.gov/nheerl/arm/designpages/design&analysis.htm)

SURVEY DESIGN

Between 2007 and 2009, EPA randomly selected and assessed 202 lakes and ponds located across the six New England states (Figure 3-1). Consistent with the national program, only lakes with surface areas greater than 10 acres and more than 1 meter deep were considered for the survey. Almost half of the sites (98) were sampled in summer 2007 as part of the NLA; the rest were sampled during summer 2008 and 2009 with participation from state agencies.

To accurately assess the current condition of New England water bodies, a benchmark, or "reference lake," was necessary in order to compare results. Establishing biological, chemical, and habitat reference conditions is key to representing the ecological potential for lakes in the absence of human activity or pollution. The reference lakes were selected using NLA probability-based screening protocols and verified by New England state lake-monitoring staff to ensure that they represented the most pristine, undisturbed water bodies. The reference lake distribution serves as a baseline for determining thresholds for good, fair, and poor conditions for each of the lake-condition indicators.

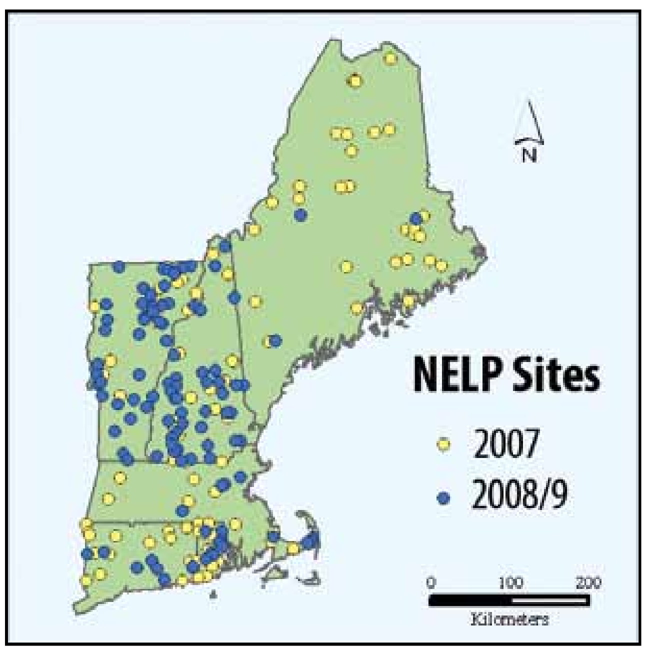


Figure 3-1. *Location of lakes sampled in the 2007-2009 NELP survey.*

Definitions

- **Reference Lake:** Natural or man-made lake that has characteristics (e.g., biology, water quality) similar to those expected in a natural or least-disturbed environmental setting.
- **Reference Condition:** An estimation of the least-disturbed condition (best range of values) that can be expected for a region.
- **Threshold:** A quantitative limit or boundary. For example, an assessment threshold is the particular percentage of the reference condition or cut-off point at which a condition is considered good, fair, or poor.
- **Ecoregion:** Ecological region that is similar in climate, vegetation, soil type, and geology. Water resources within a particular ecoregion have similar natural characteristics and similar responses to stressors.
- **Indicator:** Measurement of specific lake characteristics and their associated ecology used to assess the overall health and biological condition of a water body.

In both the national and New England surveys, lakes were rated good, fair, or poor based on thresholds defined in one of two ways. For indicators such as dissolved oxygen and trophic state, where there is general agreement on what threshold values define the categories, all lakes were evaluated against the same thresholds regardless of location. For most other indicators, thresholds were based on the regional reference conditions. Specific reference conditions were established for ecoregions comprised of similar climate, vegetation, soil type, and geology. Each ecoregion had its own set of definitions for good, fair, and poor. NLA planners identified three water-quality-threshold nutrient ecoregions in New England (Figure 3-2).

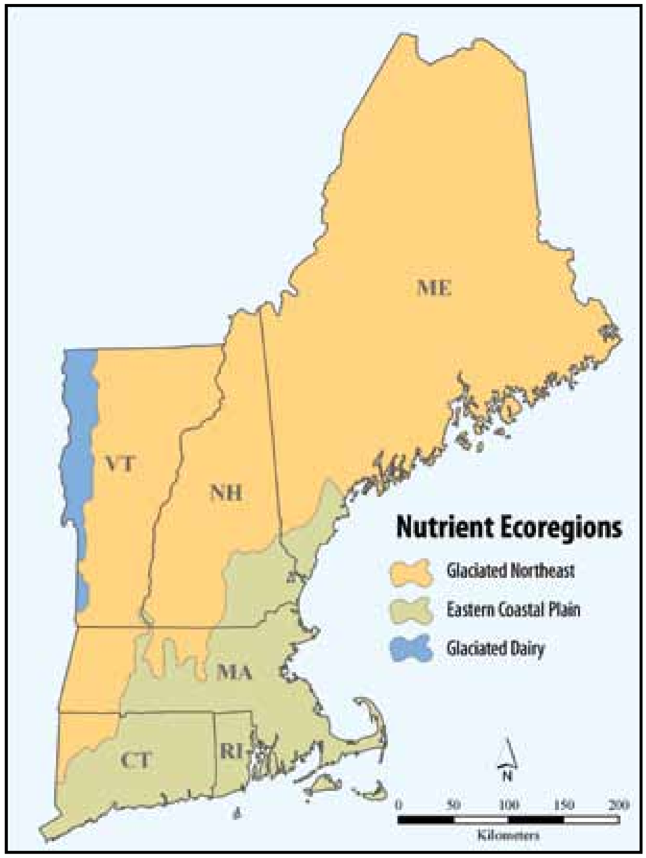


Figure 3-2. *Three nutrient ecoregions in New England were used to set water quality thresholds for this report.*

WHAT WAS MEASURED?

Lake-condition indicators must represent important aspects of water-resource quality, ecological integrity, and use. While indicators are often useful measurements in and of themselves, their real power is when they are combined to formulate indices of condition, representing a cumulative measurement of lake condition.

Suites of biological, chemical, physical, and recreational indicators were selected based on EPA-defined screening and evaluation criteria, including indicator applicability, cost-effectiveness, and the ability to reflect several elements of ecological condition. All of these indicators contribute to the holistic evaluation of the condition of a water body. The NELP survey adopted the suite of indicators used by the NLA, providing regional and national consistency. Four indicator categories—biological, chemical,

Biological	Chemical	Physical	Recreational
• Taxa Loss * • Diatom IBI * • Trophic State (Chla)	• Total Phosphorus • Total Nitrogen • Chlorophyll-*a* • Turbidity • Acid Neutralizing Capacity • Dissolved Oxygen	• Lakeshore Disturbance * • Lakeshore Habitat * • Shallow Water Habitat * • Physical Habitat Complexity *	• Chlorophyll Risk • Cyanobacteria Risk • Microcystin Risk • Microcystin Presence

Table 3-1. *Indicators used in the NLA and NELP surveys. * Indicators calculated at sites surveyed in 2007 only.*

physical habitat, recreational—were defined to determine the proportion of lakes in good, fair, or poor condition (Table 3-1). These indicators are intimately linked to uses defined in the Clean Water Act, having direct relevance to water quality standards adopted and incorporated into state and federal water quality programs.

- **Biological indicators:** A gauge of how well lakes can support healthy plant and animal communities. These data include the number of species present relative to the number expected, an index of biotic integrity calculated from many individual metrics, and the trophic status of a lake.
- **Chemical indicators:** A measure of various stresses that affect the biological community. Chemical indicators include nutrients and algal concentrations, dissolved oxygen levels, water clarity, and a factor especially important to New England waters—the ability to neutralize acid rain.
- **Physical habitat indicators**: A measure of various shoreline attributes that are critical to fish and other biota, including humans. These include factors such as the amount and type of vegetation above and below the water's surface and the degree of human disturbance.
- **Recreational indicators**: A measure of specific microbial organisms, algal toxins, and other contaminants present in lakes that can affect people's health as a result of recreational (e.g., swimming, boating, fishing) contact. The NELP program evaluated the presence/absence of microcystins, a type of algal toxin; cyanobacteria, an algae that often produces toxins; and chlorophyll, a measure of potentially harmful algal blooms.

For details on specific indicators and field sampling protocols go to *www.epa.gov/lakessurvey.*

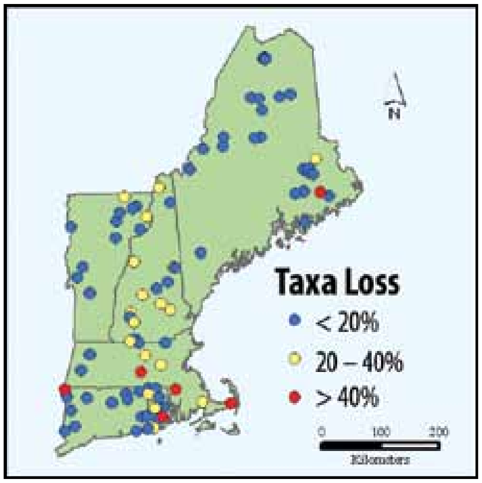
SURVEY RESULTS

Biological Condition

Biological indicators are tools for evaluating whether lakes are supporting healthy plant and animal communities. The Index of Taxa Loss model provides an assessment of the condition of lake phytoplankton and zooplankton communities—the microscopic organisms that form the base of the food web.

TAXA: Taxonomic grouping of living organisms, such as family, genus, or species, used for identification and classification purposes. Biologists describe and organize organisms into taxa in order to better identify and understand them.

The index estimates the number of taxa we would expect to find in healthy communities, based on the reference lakes, and then counts the number of taxa actually found. The New England study found that 56 percent of New England's lakes were able to support healthy biological communities when compared with the least disturbed sites. The same extent was evident for the nation (Figure 3-3). The lakes region in the Upper Midwest fared best in the nation by this indicator, with over 90 percent of lakes in "good" condition. New England and the Pacific Northwest showed comparable results; taxa losses were greater elsewhere.



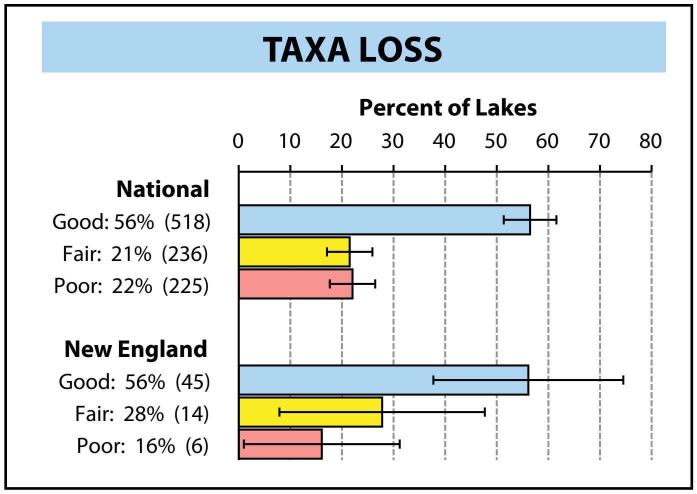


Figure 3-3. *Extent of taxa loss relative to reference sites measured in 2007. Bar plot indicates the percentage of lakes in condition categories, with a 95th percentile confidence interval. (The number in parenthesis indicates the number of lakes. The uncertainty bars for New England estimates will narrow when 2008/9 data are included.)*

Only 2007 results were available for this estimate of taxa loss in New England. Note that the uncertainty in the condition estimates (indicated by error bars in the graph above) is significantly greater for New England than for the nation. Confidence in the results increases with the number of sites sampled, thus the uncertainty will narrow when 2008/9 data are included in the New England estimates.

Trophic Condition

The biological well-being of a lake can also be evaluated using a four-level trophic scale. The trophic levels are defined based on levels of nutrients and rates of plant growth in the water body. Oligotrophic lakes are clear, have low nutrient concentrations, and contain relatively few plants. These lakes are favored by swimmers and are suitable for drinking water sources. Clear lakes can have exceptional fish habitat, but because they lack the nutrients necessary to support productivity, they are often lacking fish, or have less fish diversity and sparser populations.

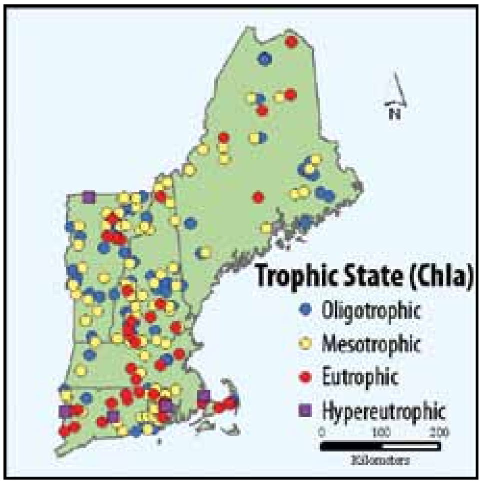
In contrast, eutrophic lakes are nutrient-rich, have high rates of primary production, and are biologically diverse, often supporting abundant fish, plants, and wildlife—preferred by anglers because they provide opportunities for excellent fishing. Lakes that fall in between oligotrophic and eutrophic are termed mesotrophic. The most extreme trophic level is called hypereutrophic. This designation is usually a result of excess human activity, and biota often exist under stressed conditions.

Aside from hypereutrophic, no one trophic state is intrinsically better than another, and lakes naturally transition between these states slowly over decades and centuries. However, poorly managed agriculture or land-use practices can accelerate increases in nutrient concentrations and promote unchecked plant growth. This unbalanced and accelerated process, called eutrophication, can result in nuisance or harmful algal blooms, murky water, foul odors, depleted oxygen levels, and loss of fish and other aquatic life, severely limiting the beneficial uses it provides to wildlife, under impaired resource conditions.

Figure 3-4 shows that about 58 percent of New England lakes are classified as mesotrophic, based on chlorophyll concentrations (a measure of algal biomass). New England displayed the lowest incidence of hypereutrophic lakes of any region in the nation. Only the Pacific Northwest had a greater abundance of oligotrophic lakes.

Extent of Chemical Stressors

The biological community is most directly affected by chemical and physical factors such as nutrient levels, algal concentrations (measured as chlorophyll-*a*



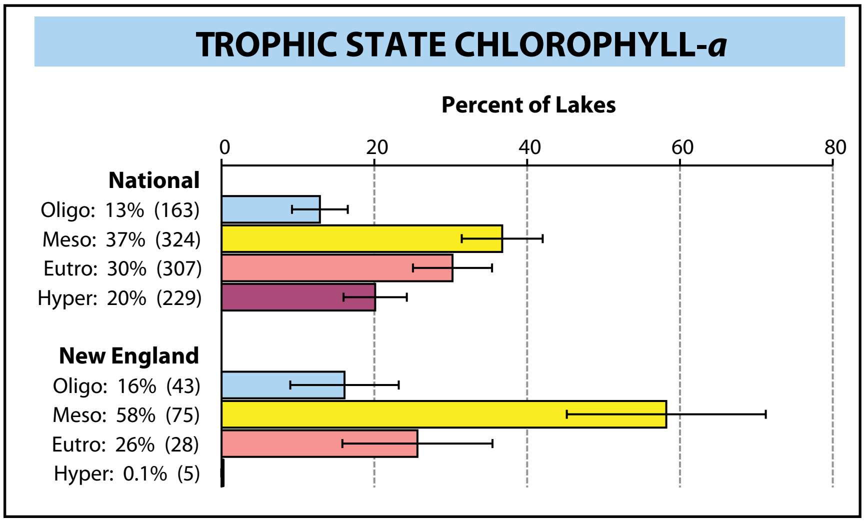


Figure 3-4. *Trophic levels based on chlorophyll-*a *concentration. (The number in parenthesis indicates the number of lakes.)*

Threshold	Reference Ecoregion	Total Nitrogen µg/L	Total Phosphorus µg/L	Chlorophyll µg/L	ANC µeq/L
Good-Fair	Glaciated Dairy	828	24	8.6	50
	Glaciated Northeast	666	16	7.6	50
	Eastern Coastal Plain	629	26	29	50
Fair-Poor	Glaciated Dairy	1410	102	46	0
	Glaciated Northeast	1174	36	13	0
	Eastern Coastal Plain	2311	75	76	0

Table 3-2. *Threshold condition categories based on regional reference lake conditions.*

concentrations), dissolved oxygen levels, and a factor especially important to New England waters—the ability to neutralize acid rain. Nutrient, chlorophyll, and turbidity levels were evaluated relative to thresholds that varied among nutrient ecoregions across the nation.

Three such nutrient regions are present in New England (Figure 3-2 and Table 3-2). New England measured up well compared with other regions of the country; 80 to 90 percent of New England's lakes were judged to be "good" relative to the least-disturbed reference lakes in the Northeast. Moreover, the actual concentrations of phosphorus and nitrogen nutrients and chlorophyll are among the lowest measured in the national study (Figure 3-5). Dissolved oxygen concentrations were rated "good" in 94 percent of New England lakes, and less than 1 percent were rated "poor." Dissolved oxygen results were similar for the rest of the nation.

Lake acidification, whereby airborne acidic compounds from coal-fired power plants are deposited on land through atmospheric deposition and precipitation, is a particular concern in New England because the granitic composition of the underlying geology does little to neutralize the acid rain that drains into the lakes. Acidic pH levels in lakes disrupt the life cycles of fish and other aquatic organisms and intensify the mobilization and bioaccumulation of toxic mercury compounds in the food web.

Acid neutralizing capacity (ANC) is a measure of how well compounds like bicarbonate ions can buffer

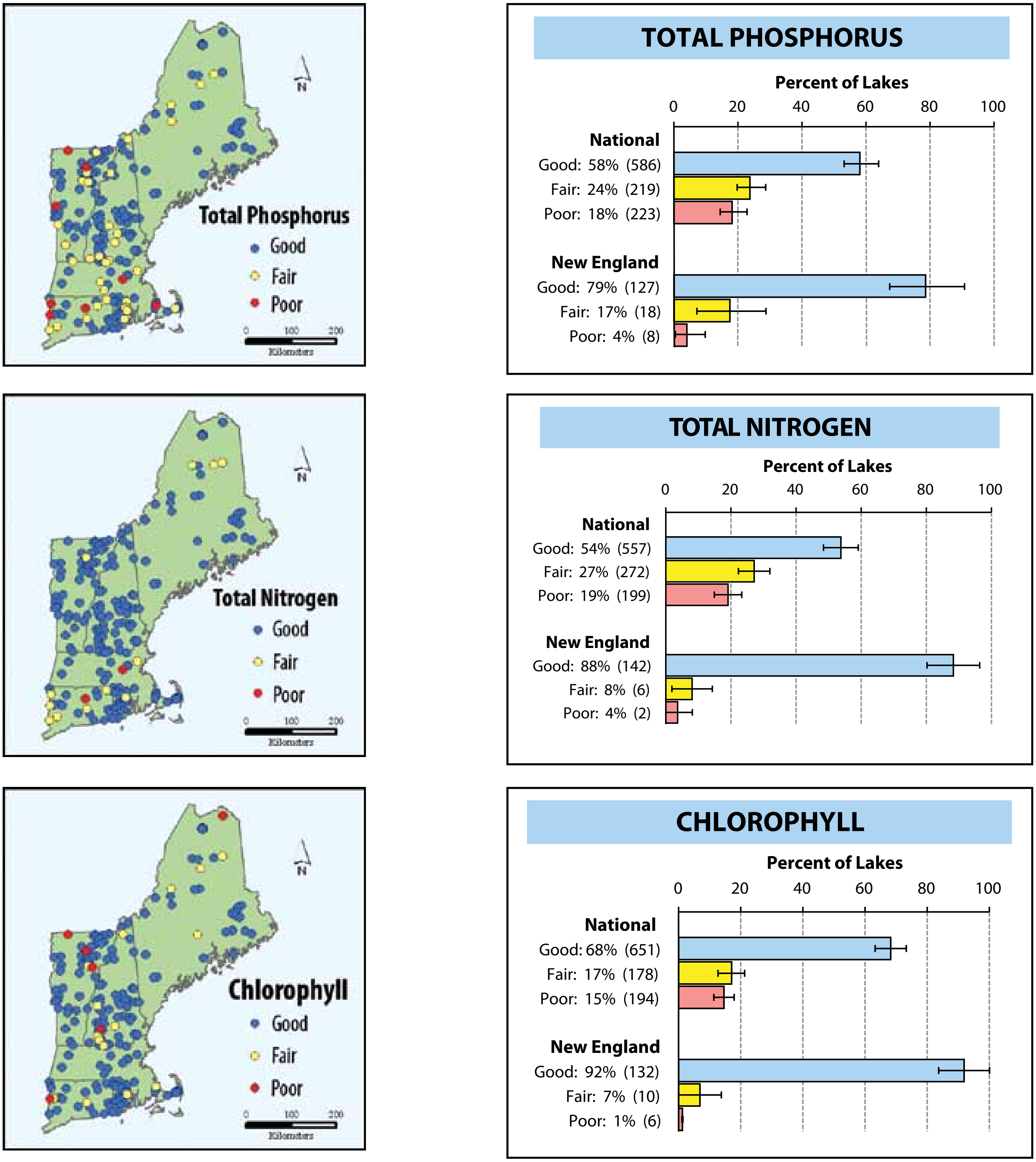
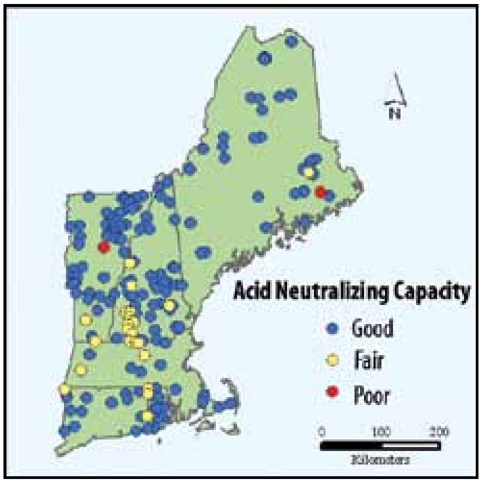


Figure 3-5. *Maps and charts illustrate the extent of chemical and physical stressors in New England lakes. These indicators are judged relative to least-disturbed lakes in the Northeast. Thresholds defining the trophic levels are listed in Table 3-2. (The number in parenthesis indicates the number of lakes.)*



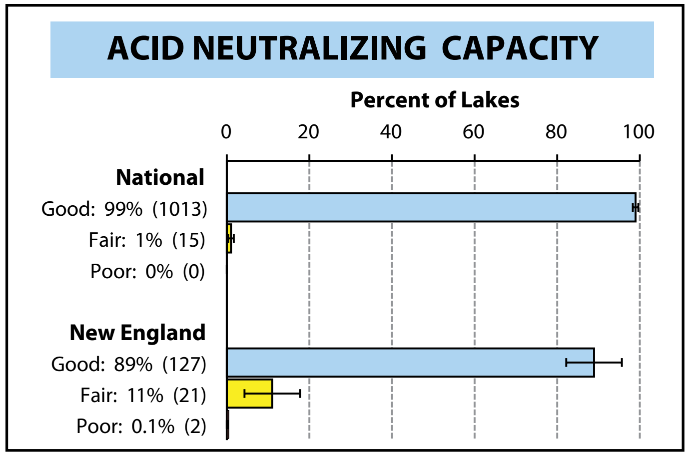


Figure 3-6. *Acid neutralizing capacity for lakes in New England. (The number in parenthesis indicates the number of lakes.)*

acidic inputs. Figure 3-6 indicates that lake acidification is not a widespread national problem; more than 99 percent of the nation's lakes provide adequate neutralizing capacity; however, about 11 percent of the selected New England survey lakes have compromised buffering capacity. Only lakes in the NLA Southeast Coastal Plain and Upper Midwest ecoregions show measurable impairment by this indicator (less than 3 percent in "fair" condition).

It is important to note that the NLA and NELP studies were not well suited for evaluating lake acidity. Earlier studies suggest that lake acidification is more common in higher-elevation lakes smaller than 10 acres (Kahl et al., 2004), a size category not studied in this survey. Many of those studies also document a steady decrease

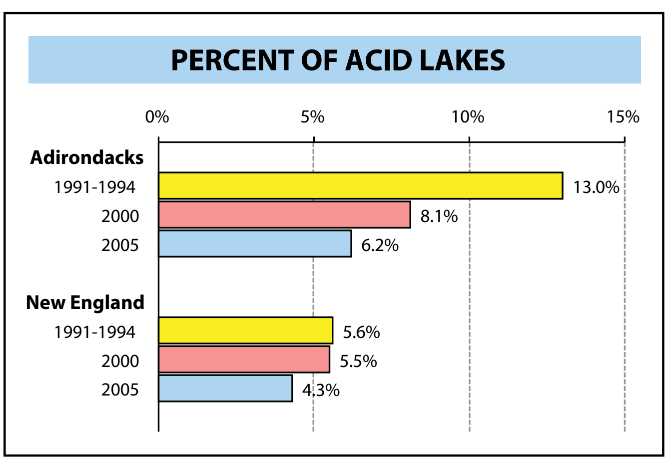


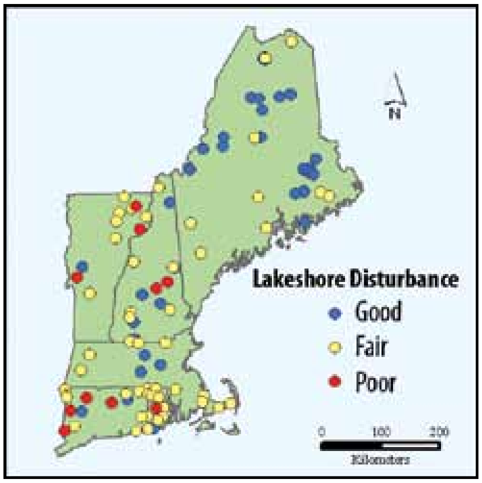
Figure 3-7. *Trend in extent of "chronically acid" lakes in Northeast region. (Driscoll et al.)*

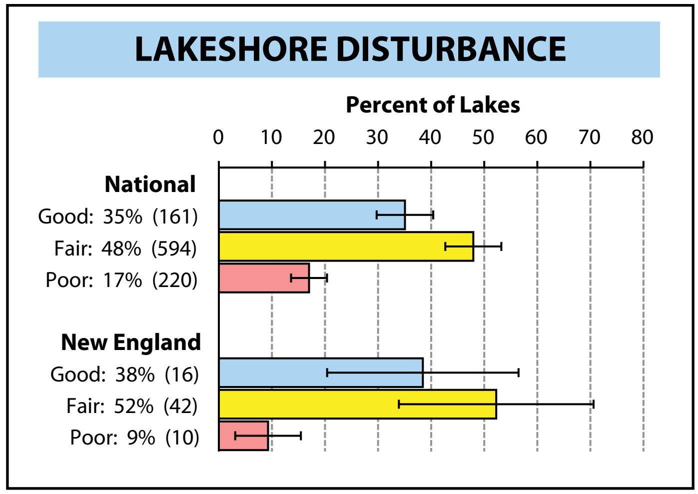
in the percentage of lakes classified as "chronically acid" in the Adirondack Mountains and New England since the early 1990s, a trend attributed to reduced emission and deposition of acidic oxides of sulfur and nitrogen (Figure 3-7).

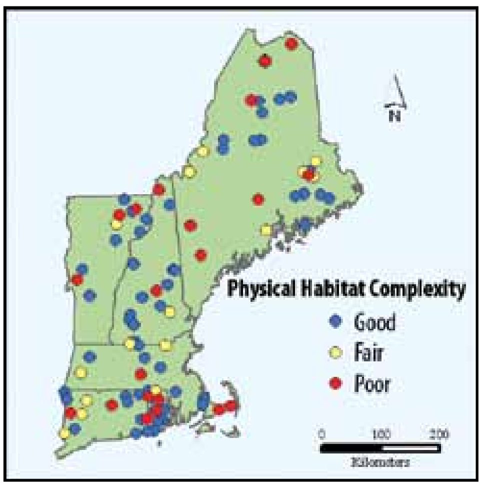
Physical Condition

Both the NLA and NELP surveys evaluated the condition of several lakeshore habitats using four indices:

- **Lakeshore habitat indicator:** A measure of the amount and type of shoreline vegetation in the understory grasses, mid-story shrubs, and overstory trees. Favorable scores for this metric indicate that vegetation cover is high in all three layers.
- **Shallow water habitat indicator:** An assessment of the variety and complexity of habitats, such as overhanging vegetation, woody snags, plants, brush, and rocks in shallow water. Lakes with higher scores are better able to support aquatic life.
- **Physical habitat complexity indicator:** A combination of the lakeshore and shallow water indicators. It estimates the amount and variety of all cover types at the water's edge.
- **Index of lakeshore human disturbance:** A measure of direct human alteration, such as removal of trees or creation of retaining walls or artificial beaches, that can contribute to loss







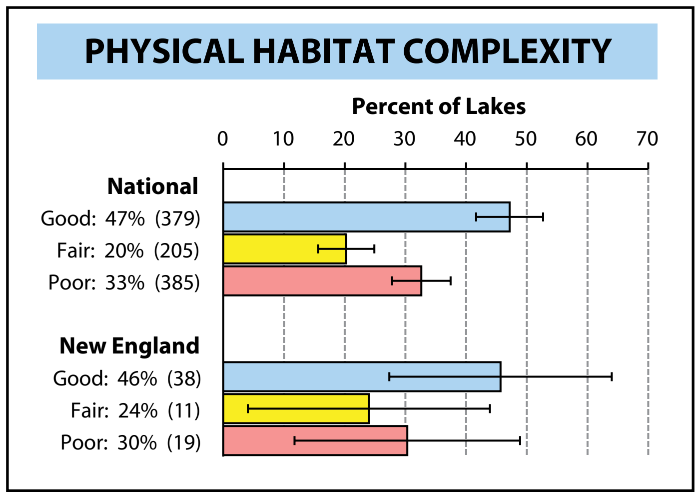


Figure 3-8. *Habitat condition indicators for New England lakes. Only 2007 data for New England are shown. The error bars will narrow when the 2008/9 data are included. These indicators are judged relative to least-disturbed lakes in the Northeast. (The number in parenthesis indicates the number of lakes.)*

of critical niche space. Sites rated "poor" may be expected to exhibit alteration of native plant communities and loss of habitat structure and substrate types, which can negatively affect many species of fish and wildlife.

All four indicators were judged relative to conditions in reference lakes, using thresholds that vary regionally. One quarter to one third of New England lakes were judged to be in poor condition by the lakeshore, shallow water, and habitat complexity indicators. This mirrors the national survey results that identified degraded lakeshore habitat as the most significant problem assessed. Figure 3-8 presents the results for two of the indices (lakeshore disturbance and physical habitat complexity), illustrating the similarity between regional and national conditions.

Recreational Suitability

Along with the biological, chemical, and physical parameters used for the New England assessment, lake condition is also assessed to determine whether a water body can support recreational uses such as swimming, fishing, and boating. Sections 101(a) and 303 of the Clean Water Act require that these uses be protected. Recreational suitability depends on the safety of the water in terms of the presence of microbes, algal toxins, and other contaminants that pose potential human health hazards.

Indicator	Low Risk	Moderate Risk	High Risk
Chlorophyll-*a* (µg/L)	<10	10 - 50	>50
Cyanobacterial cell counts (#/L)	<20,000	20,000 - 100,000	> 100,000
Microcystin (µg/L)	<10	10 - 20	>20

Table 3-3. *World Health Organization thresholds of risk associated with potential exposure to cyanotoxins.*

This risk was evaluated indirectly based on the concentrations of algae, cyanobacteria, and microcystins measured in the survey lakes. Certain groups of phytoplankton, the cyanobacteria (blue-green algae), which are natural components of freshwater environments, are known to produce a variety of toxins called cyanotoxins. In lakes with high nutrient concentrations (eutrophic conditions), cyanobacteria can proliferate under the right conditions and grow at accelerated rates, causing potentially harmful algal blooms (HABs).

A Massachusetts Department of Public Health on-site advisory posting, which is displayed when cyanobacteria cell counts exceed 70,000 cells/mL.

Cyanobacterial blooms are unattractive, foul smelling, and can accumulate on the water surface. Under the right conditions, they can form dense mats that concentrate the algae and associated algal toxins. These blooms are potential health and recreational hazards because they can produce toxins at high concentrations and increase the risk of exposure. In addition, when the blooms begin to die off and decompose, they can deplete the concentration of dissolved oxygen, resulting in hypoxic or anoxic conditions. Low- or no-oxygen conditions can lead to fish kills or stressed conditions for aquatic biota.

Microcystin is a cyanotoxin of particular concern because it is a potent liver toxin, tumor promoter, and possible human carcinogen. Since exposure to microcystin has potentially hazardous effects on humans, several states have issued guidelines on recreational use advisories regarding the presence of microcystins.

The World Health Organization (WHO) has determined thresholds of risk associated with potential exposure to cyanotoxins based on chlorophyll-*a*, cyanobacterial cell counts, and microcystin (Table 3-3 and Figure 3-9).

Using these thresholds, 19 percent of New England lakes exhibited moderately severe algal bloom conditions, about half the risk evident nationwide. Moderately elevated cell counts of cyanobacteria were observed at only two lakes surveyed in New England—again, better than the nation as a whole. Microcystin concentrations greater than the 10 µg/L threshold were not observed in the New England survey and were rare elsewhere in the nation. Using a much more stringent threshold to evaluate presence or absence of microcystin (a detection limit of 0.1 µg/L, indicative of very low risk by WHO guidelines), the microcystin

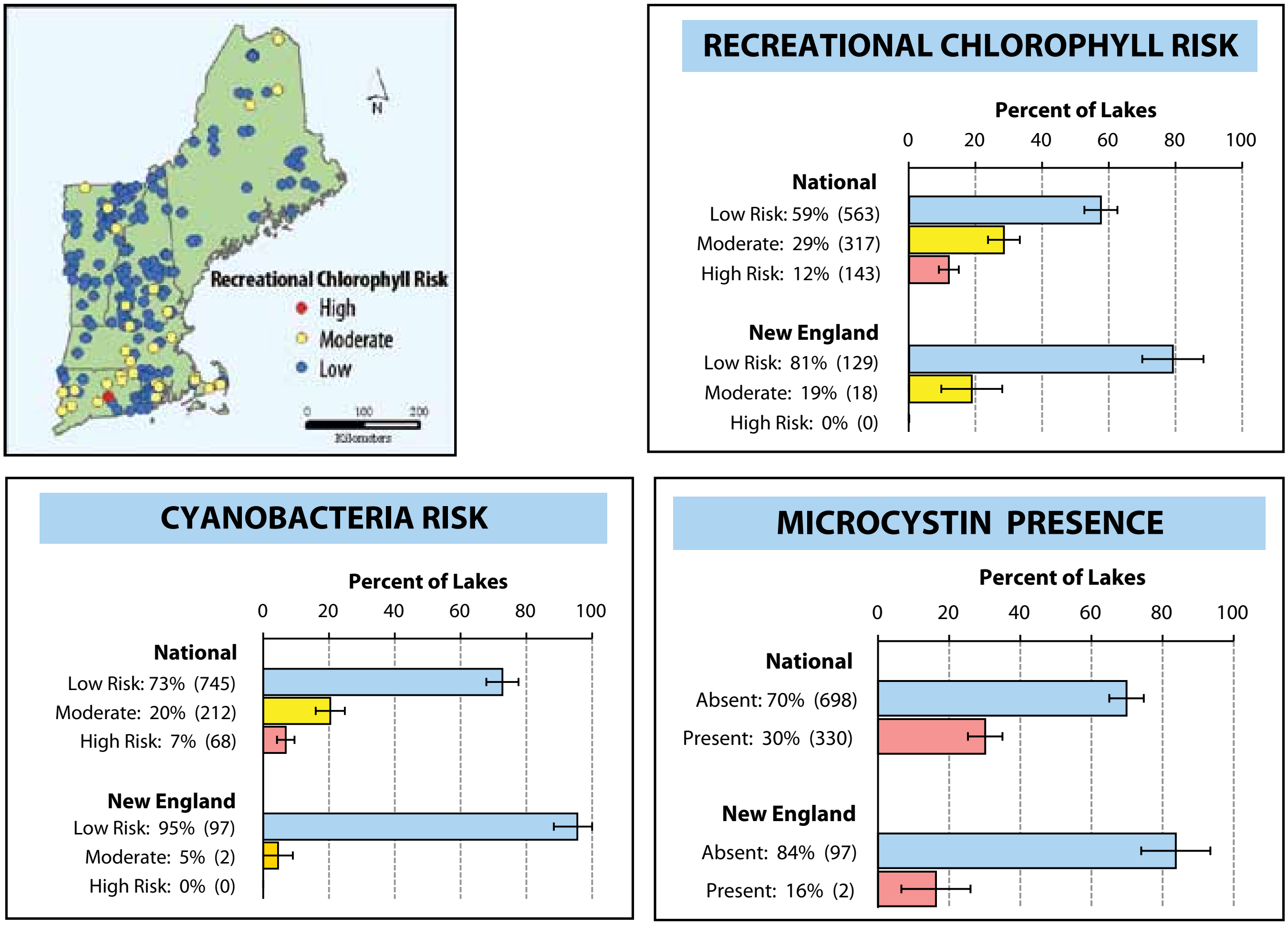


Figure 3-9. *Indicators of risk to human health from algal toxins. (The number in parenthesis indicates the number of lakes.)*

toxin was detected in 16 percent of New England lakes, compared with 30 percent in the nation.

Evaluating the risks associated with microbial toxins was one of the more insightful and controversial assessments in both the national and regional lake surveys. Careful consideration is given to several issues regarding the sampling, analysis, and interpretation of this type of assessment. For instance, water samples were collected from mid-lake, whereas wind-blown accumulations of cyanobacteria often accumulate in near-shore areas where human contact and exposure are more likely. Chlorophyll-*a* levels, cyanobacteria densities, and cyanotoxin concentrations can change rapidly; thus it was unlikely that a single visit to a lake and a single collected sample coincided with a toxic incident.

Also, some states provisionally use exposure risk guidelines for microcystin that are more rigorous than WHO guidelines. (WHO recommends that where cell counts are at or above 100,000 cells/mL, swimming should be discouraged and on-site advisory signs should be posted. This reflects concern that cell-bound toxins may be at concentration levels of 20 ppb, which has proven to cause health-related effects (WHO 2003)). Finally, it is unknown how well microcystin occurrence correlates with other classes of microtoxins.

For those reasons, the NELP survey results may provide a conservative estimate of the risk of algal toxins in lakes. A later section in this report describes new methods of detecting microcystin that were tested as part of the New England survey.

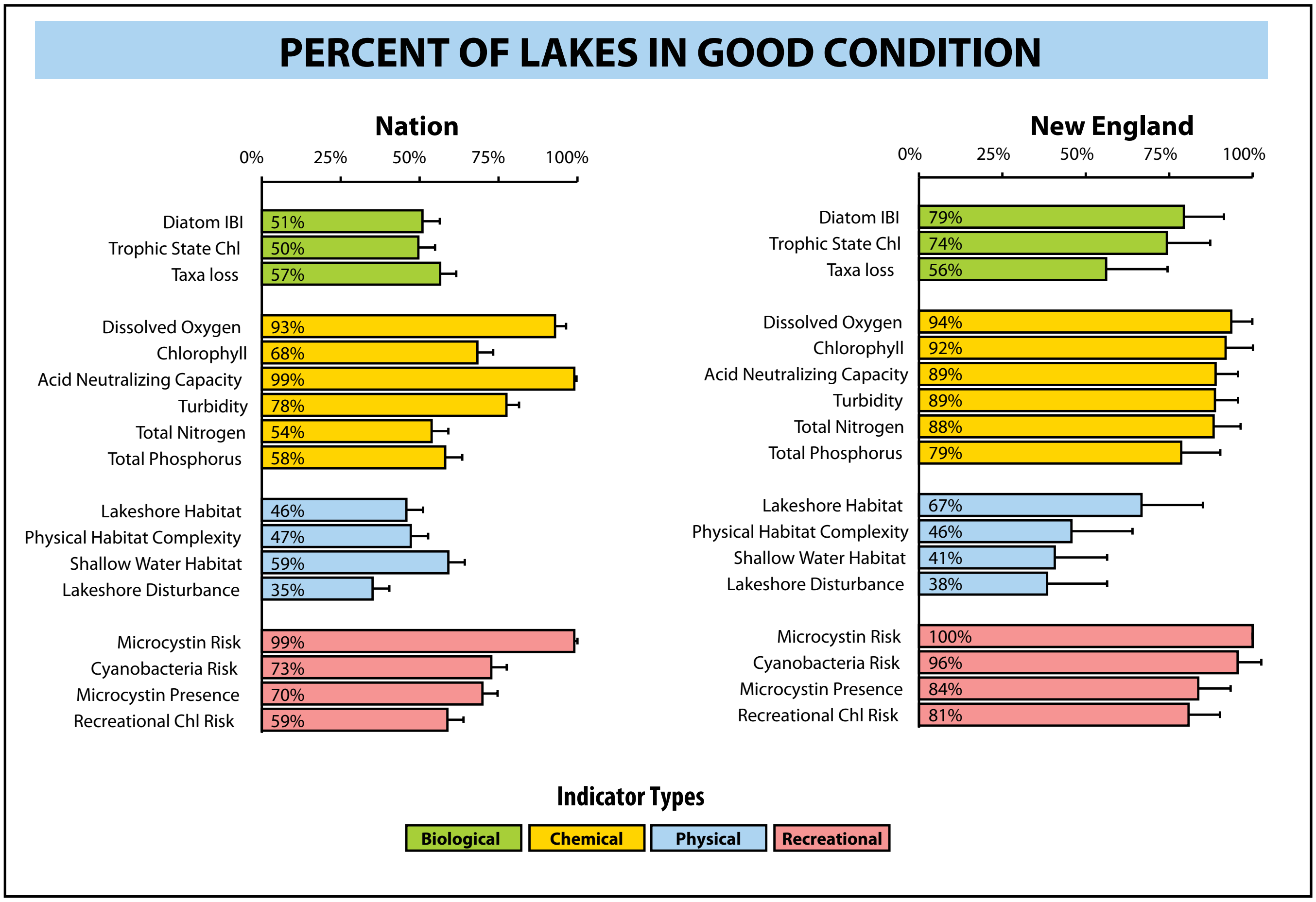


Figure 3-10. *The percentage of lakes in good condition in New England compared with the nation, as measured by survey indicators.*

SURVEY FINDINGS

Figures 3-10 and 3-11 summarize the results of the NELP survey in the context of the NLA results. The 17 survey indicators are ranked separately for the nation and New England according to the percentage of lakes rated as good (Figure 3-10) or poor (Figure 3-11) using the methods described in this section. Indicators are color-coded to reflect whether they represent biological, chemical, physical, or recreational conditions in lakes. The error bars signify the uncertainty in the estimates at the 95th percentile confidence level. These uncertainty limits are relatively wide for biological and habitat indicators (green and blue bars) because only results measured in 2007 were used to calculate these estimates. The uncertainty intervals for these metrics will narrow when 2008/9 data are included.

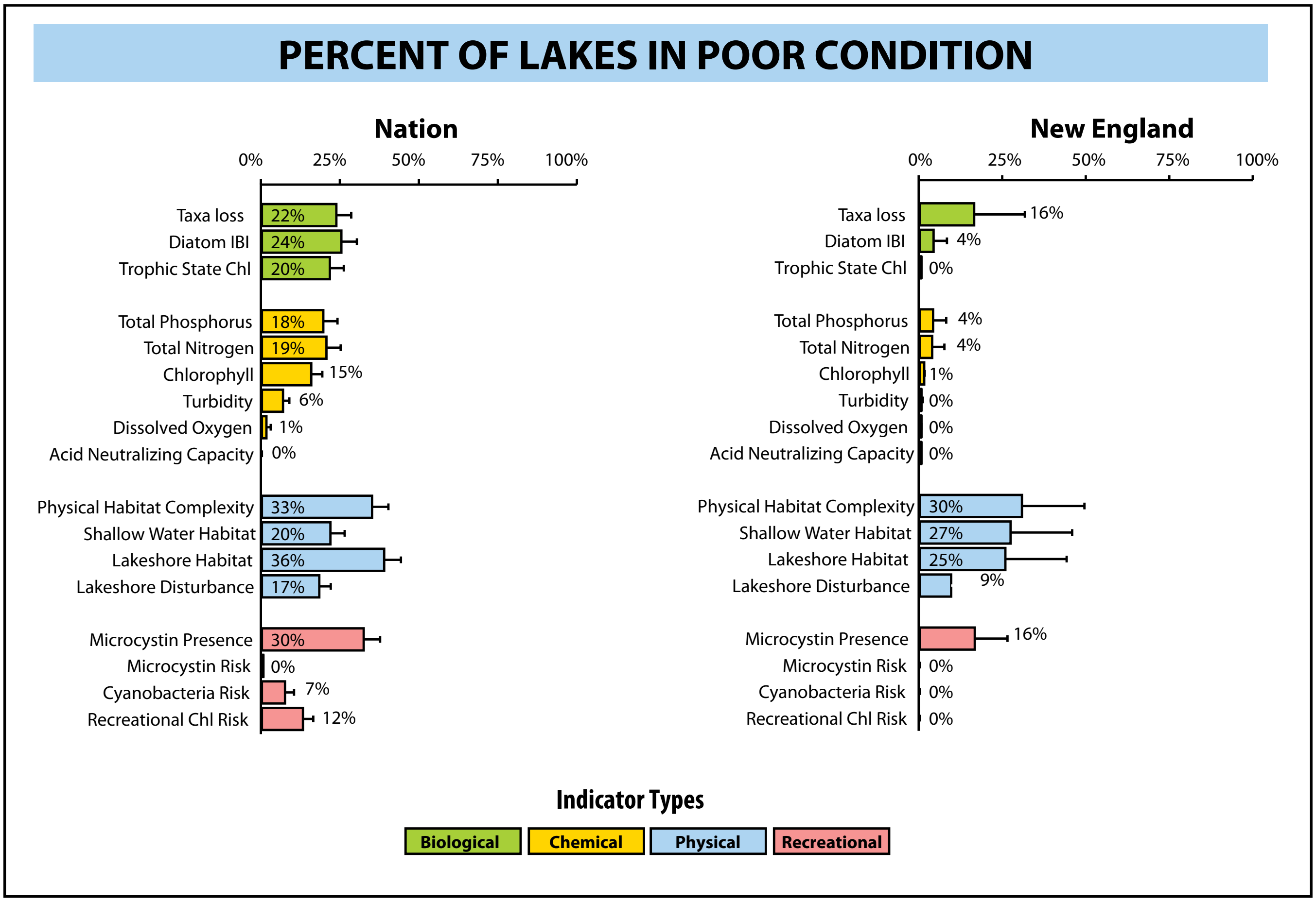


Figure 3-11. *The percentage of lakes in poor condition in New England compared with the nation.*

The New England region is most similar to the Pacific Northwest and the lakes district in the upper Midwest of the nation, often exhibiting the largest extent of lakes rated "good" for indicators in any region.

Note the approximate agreement in the order of the indicators in New England and the nation in Figure 3-11. Lakeshore habitat concerns are evident in 25 to 35 percent of lakes both in New England and nationwide and indicate the largest divergence from reference condition in both the NLA and NELP assessments. The presence of microcystin in lakes and the diminished capacity to support healthy biotic communities are also significant problems in 20 to 30 percent of the nation's lakes and 16 percent of New England lakes.

Signs of excessive nutrient and algal levels (indicators of eutrophication) are evident in 15 to 20 percent of national lakes but in only a few percent of New England lakes. The NLA report highlights conditions in nine distinct ecoregions in the lower 48 states (US EPA 2009, and on the Web at *www.epa.gov/lakessurvey*).

The survey results at both the national and regional levels point out that habitat loss and alteration are as much of a concern in the aquatic environment as they are in the terrestrial environment—and equally as critical to lake condition as water-quality impairments. Habitat and lake water condition are integrally intertwined. These findings highlight the need for renewed efforts to promote sustainable lakeshore land-use practices, and to incorporate them into effective lake water-quality management strategies.

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www.epa.gov/nheerl/arm/designpages/design&analysis.htm

www.epa.gov/lakessurvey

Honing New Techniques

Section 4

New Englanders attach a great deal of value to the region's water resources, and the NELP project provided an invaluable opportunity to develop, test, and apply new technologies and lake monitoring methods that could change the way water resource assessments and policies are viewed and designed in the future. One of the outstanding features of the NELP project is that it facilitated collaborations with other state agencies, local lake associations, and academic institutions. These collaborations were experimental, biological, and technological in their scope, and included community outreach and education.

The partnerships that grew out of the NELP project will continue to have regional and local impacts as people see what can be accomplished when federal and state agencies, universities, lake associations, and other stakeholders pool their resources and their ideas.

The projects highlighted in this section illustrate the innovative and technologically advanced methods and ideas that were developed and tested through the NELP project. They also bring to the forefront several issues that warrant further investigation, including the need for better sampling methods for microcystin detection, the promotion of non-lethal fish tissue sampling, and the possible standardization of chlorophyll methodologies and analyses.

The collaborations also emphasize the need for enhancing public awareness and education on the effects of mercury pollution and acid deposition, increasing sedimentation rates, and the eutrophication of lakes and their surrounding watersheds. Finally, with the development and use of remote sensing and aerial flyovers as a way to monitor chlorophyll and cyanobacterial blooms, innovative approaches are in the works to enhance traditional monitoring methods.

The project highlights that follow are arranged into three major lake ecosystem components: Biological, Trophic, and Chemical.

HIGHLIGHT

The Biological Component

AN INTERACTIVE, IMAGE-BASED ZOOPLANKTON KEY

Zooplankton are integral components of the food web and nutrient cycling, and serve as valuable lake monitoring indicators. They are responsible for transferring energy from primary producers, such as phytoplankton and cyanobacteria, and, in turn, play a significant role in providing nutrients to larger predators.

A COMPREHENSIVE, USER-FRIENDLY KEY

Identification of zooplankton species, body size, and assemblage is crucial to determining what environmental stressors may be present. The NELP project, in collaboration with the Center for Freshwater Biology (CFB) at the University of New Hampshire (UNH), worked to improve the utility of a comprehensive image-based taxonomic zooplankton key that has been developed and modified since 2000 (*http://cfb.unh.edu/CFBKey/html/*). The key was constructed as a user-friendly alternative to more conventional keys that are often designed for experienced taxonomists.

Figure 4-1. *Home page of the University of New Hampshire's image-based zooplankton key.*

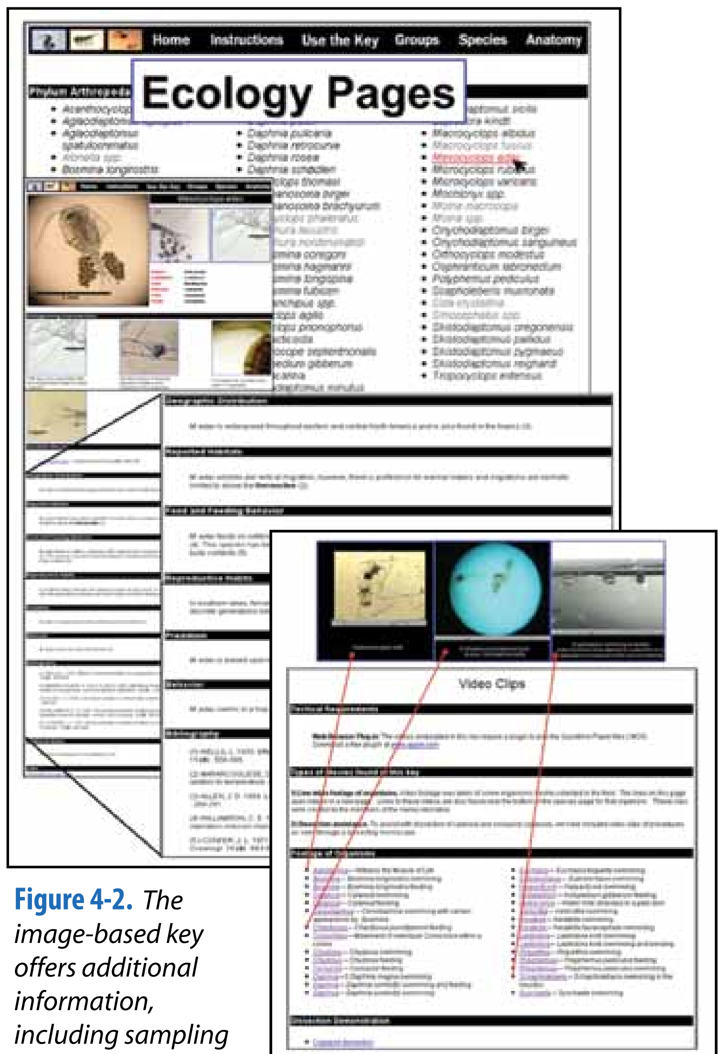

Figure 4-2. *The image-based key offers additional information, including sampling approaches, quick-time images of key taxonomic features, genetic barcoding information, and general ecology.*

An Interactive, Image-Based Zooplankton Key

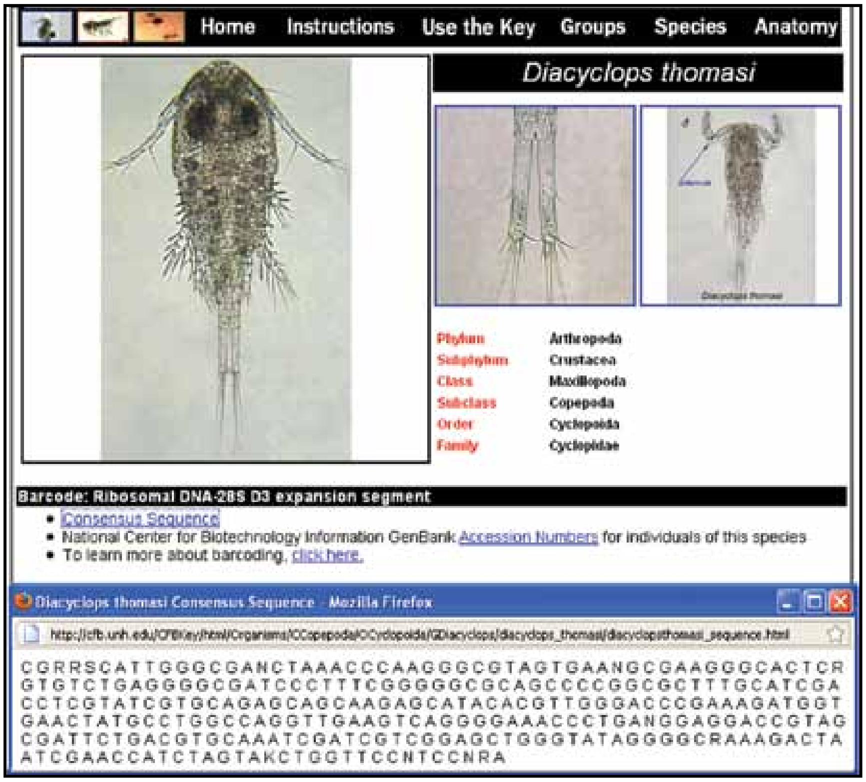

Figure 4-3. *The web page of UNH's barcoding addition to the zooplankton key. Consensus barcodes for the copepod species are provided in the key, as well as links to the original barcodes for each individual copepod in the study. Links are also provided to GENBANK, where biologists can compare DNA sequences among species as well as determine species identification with BLAST searches. This approach will help with positive species identification of individuals that may be difficult to identify by morphological features, such as immature or partially intact specimens.*

With its well-labeled images detailing important morphological features, videos of zooplankton swimming and feeding behavior, species-specific ecological notes and research literature, and a Basic Local Alignment Search Tool (BLAST) for genetic barcodes of copepods, the key is an extraordinary tool for promoting interest in the ecology and biodiversity of zooplankton found in the lakes of New England.

COPEPOD GENETIC BARCODING

Like the UPC system of barcodes employed to uniquely identify manufactured goods, a genetic barcode represents a short segment of DNA that can be used to identify an individual species based on its nucleotide sequence. It can distinguish species when differences in DNA sequences between species (interspecific variation) are greater than differences within a species (intraspecific variation).

Genetic barcodes for a total of nine copepods were established by identifying individuals using morphological keys, sequencing DNA from those individuals, and submitting ID vouchers for public access to verify correct identifications. Genetic barcoding is an expanding taxonomic tool that uses DNA for species diagnostics to assist in proper identification when visual characteristics are inadequate. It is a cutting-edge technique in the expansion of CFB's image-based zooplankton key.

This highlight was provided by Dr. James Haney and Amanda Murby, UNH Center for Freshwater Biology.

HIGHLIGHT *The Biological Component*

TRAINING IN NEW TECHNIQUES FOR ANALYZING FISH TISSUE FOR MERCURY

During the 1980s, human and animal consumption of fish with elevated levels of accumulated methylmercury became a major concern to state agencies in the Northeast. Prevailing winds carry mercury-laden particulates from carbon emission sources across the country. These particulates end up settling over the New England landscape, ultimately finding their way into regional water bodies. Once deposited, microbial activities enable mercury to move up through the food chain and accumulate in the tissues of organisms. Organisms higher in the food chain, such as large mouth bass, gain increasing levels of mercury in their bodies.

TAKING A NON-LETHAL APPROACH

A key goal for EPA's regional monitoring efforts is to promote the transfer of new technologies and methods that are applicable at state and local levels. Improved techniques in fish tissue analysis provided just such an opportunity. In New England, state environmental agencies have primary responsibility for collecting fish for mercury analysis. The collection and analysis is carried out by state laboratories and then reported to state departments of public health,

Researcher taking a large mouth bass tissue biopsy sample for mercury analysis, Lake Attitash, Massachusetts, 2006.

Training in New Techniques for Analyzing Fish Tissue for Mercury

The Milestone mercury analyzer combusts tissue while collecting mercury on a gold column.

which issue consumption advisories when elevated fish-tissue mercury levels are found.

Historically, the process of tissue collection, which includes sampling an array of fish sizes, ages, and species, has required that the fish be sacrificed. This practice has had serious drawbacks in that many large and highly prized trophy game fish and important forage fish species have been sacrificed over the years to get what amounts to relatively small tissue samples necessary for mercury analysis. This approach also demands an inordinate amount of staff time in fish processing and analytical prep work, not to mention the disposal cost for unused tissue samples.

A relatively new approach to fish-tissue mercury analysis has evolved over the past few years through various research efforts, including those carried out through EPA's offices of Research and Development (Peterson, 2004) and others (Baker, 2004). This approach has incorporated the use of medical biopsy punches to collect non-lethal tissue samples from fish. The small sample size is collected and run through a discrete mercury analyzer that combusts the tissue while collecting mercury on a gold column. Tissue mercury concentrations can be read directly from the instrument. Veterinary-grade antiseptic superglue is applied to the fish biopsy incision, and the fish is immediately returned to the water body.

Reaping the Benefits

During the course of the NELP project, states expressed interest in learning the new protocol and technique necessary to effectively collect mercury tissue samples and properly handle and protect the collected fish. The EPA Region 1 Laboratory provided the training, and now several states have adopted the technique and acquired the necessary field tools and analytical instrumentation.

Feedback is positive from laboratory personnel, who are dealing with far less sample preparation, analysis, cleanup, and associated costs.

References

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Peterson, S.A., et.al. 2004. "A Biopsy procedure for Determining Filet and Predicting Whole-Fish Mercury Concentration." *Archives of Environmental Contamination and Toxicology* 48, 99-107 (2005)

HIGHLIGHT

The Biological Component

DEVELOPMENT OF A CITIZEN-BASED CYANOBACTERIA MONITORING PROGRAM

The Center for Freshwater Biology (CFB) at the University of New Hampshire (UNH) has initiated a citizen cyanobacteria-monitoring program (CCMP). With the widespread awareness of the potential health problems associated with cyanobacteria in lakes, there is a growing need for monitoring programs to track both cyanobacteria and levels of cyanotoxins. Citizen monitors provide an excellent means to accomplish this, as many volunteers live along these lakes and are extremely interested in knowing more about overall lake condition. By taking part in monitoring efforts, they have the benefit of becoming more knowledgeable about the causes and potential health risks associated with "their lake" and cyanotoxins.

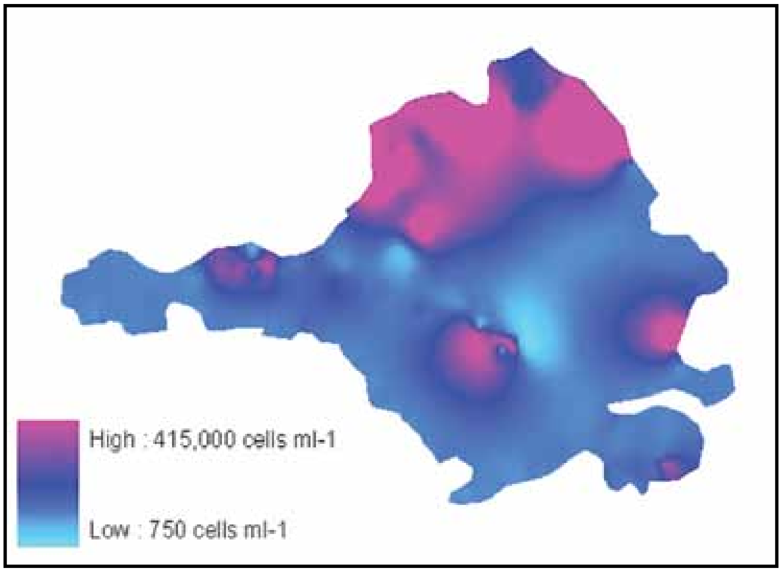

Figure 4-4. *Cyanobacteria concentrations across Willard Pond in Dover, NH, June 26, 2009.*

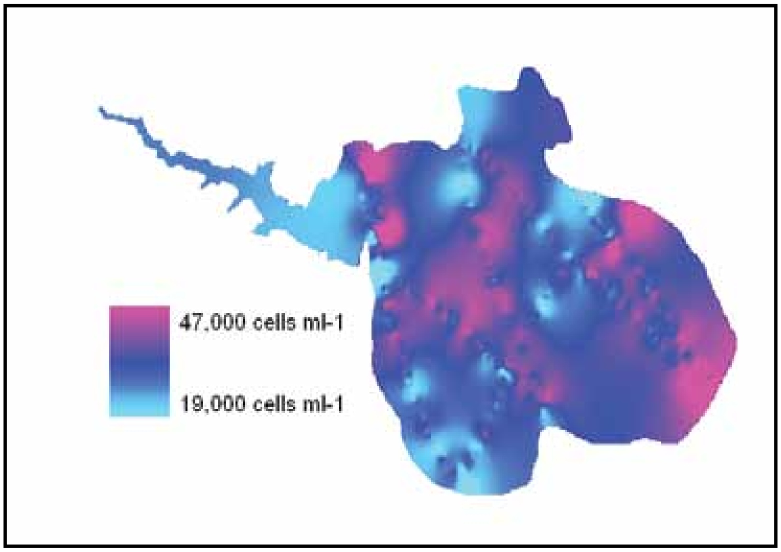

Figure 4-5. *Cyanobacteria concentrations across Lake Attitash in Amesbury and Merrimac, MA, July 7, 2010.*

Because cyanobacteria often have patchy distributions in lakes, sampling can be problematic, especially during bloom periods when they tend to accumulate along beaches and within embayments (Figures 4-4 and 4-5). Cyanobacteria are able to regulate their location in the water column to optimize access to sunlight, enabling them to multiply rapidly during the hot, still days of summer. When wind-generated waves disrupt their stable location in the water column, they accumulate on the surface and are blown toward windward shores, greatly increasing algal concentrations and the potential for human exposure. During these usually short time periods, there may be sudden appearances of localized and highly concentrated toxic cyanobacteria, a typical scenario in many New England lakes, even those with modest levels of nutrients.

SAMPLING PROTOCOL

In general, water quality monitoring programs provide both rapid feedback on acute water quality problems and data on long-term trends. To achieve these objectives with cyanobacteria monitoring, the CCMP uses two types of sampling approaches: "bloom sampling" and "integrated lake sampling."

Bloom sampling involves the collection of near-shore blooms or scum that can present potential health risks to recreational users, pets, and wildlife. This approach is used by the Massachusetts Department of Public Health to track bloom concentrations and toxin levels, information used as a basis for posting advisories.

Integrated lake sampling involves weekly water sampling at a minimum of five locations distributed across a lake, including the lake's deep location. To obtain an integrated sample of the epilimnion, the samples are collected using a 3-meter tube sampler. Once collected, samples may be either combined for a composite sample, to depict average lake-wide concentrations, or analyzed separately, to determine point-location concentrations. These samples are then analyzed for the liver toxin, microcystin, and assessed for population counts and species of cyanobacteria taxa present.

EPILIMNION: A warm layer of upper-surface water in a lake, often differentiated from deeper lake water by a marked change in temperature.

DATA INTERPRETATION

Bloom data provide a valuable record of the timing, frequency, and cyanotoxicity of near-shore cyanobacteria accumulations, as well as the basis for an alert system for potential health threats to lake users. Blooms identified as potentially toxic are reported to state or local health authorities for follow-up testing and, if necessary, the posting of health advisories.

Integrated whole-lake water samples provide a more accurate assessment of whole-lake populations of cyanobacteria and cyanotoxins, and can be useful for tracking long-term changes in lake conditions. This is helpful in tracking and evaluating the effectiveness of management strategies, such as those aimed at reducing nutrient loading into lakes.

RISK ASSESSMENT

Many public health agencies base their advisories on the number of cyanobacteria cells found in a volume of water taken from the near-shore area; the vicinity most likely to be used by swimmers and bathers, and who would be at the greatest risk of exposure to algal toxins. These near-shore windward areas often harbor cyanobacteria concentrations hundreds and even thousands of times greater than those found in the more open water areas of a lake. This makes it challenging to compare shoreline cyanobacteria data collected by public health agencies to mid-lake sampling data collected by water monitoring groups. However, it would be very useful to be able to determine potential elevated cyanobacteria levels for a given lake before they occur. The UNH CFB is working on new approaches to bridge this gap.

The UNH CFB is working to establish an additional system of risk assessment for integrated cyanobacteria sampling, such as a simplified risk system based on a lake's potential to redistribute and concentrate the cyanobacteria population within the entire lake. An aggregation factor could be calculated based on the concept that many blooms are largely the result of vertical and horizontal spatial compressions of a cyanobacteria population into specific regions in a lake.

For example, a realistic scenario would be to determine the change in concentration of cyanobacteria cells existing in the top three meters of lake water if they were suddenly concentrated into the top ten centimeters of surface water, which typically happens under bloom conditions. The next step is to approximate cyanobacteria concentrations when the algal-concentrated surface water is blown toward a windward shore and concentrated even further. Based on a survey conducted on 50 New Hampshire lakes with a median microcystin concentration of roughly 10 nanograms microcystin per liter (nm/L) from whole-lake water, the potential concentration in the surface bloom covering one half of the lake would be 20 mg/L, above the current recommended limit of 14 mg/L, for recreational use in Massachusetts lakes. A risk factor of low, medium, or high could then be assigned to the predicted algal bloom microcystin concentrations.

The example above is used to illustrate a potential avenue for developing a risk assessment model that could be used to interpret and report cyanotoxin monitoring data. The above assumptions are in the process of being tested against actual spatial-distribution data collected in the field.

The CCMP is being implemented, beginning in 2010, through work with the NELP and participation by the Lake Attitash Association. The summer 2010 monitoring efforts will produce interesting results and provide a good indicator as to the potential success of the program, as well as health implications. Lake Attitash has undergone periodic Department of Public Health advisories due to elevated cyanobacteria levels above advisory thresholds. Citizen cyanobacteria monitoring data, alongside state and local health department monitoring, will provide valuable information on the future utility of this innovative approach.

This highlight was provided by Amanda Murby, UNH Center for Freshwater Biology. More information on cyanobacteria and progress of the CCMP can be found at www.cfb.unh.edu.

HIGHLIGHT

The Biological Component

COMPARING HISTORICAL AND CURRENT WATER QUALITY IN PRISTINE AND IMPACTED NEW ENGLAND LAKES

A higher percentage of lakes in New England are currently eutrophic than at any time in the recent past (Dixit 1999). Identifying the extent to which increased nutrient enrichment has an effect on New England lakes, and monitoring the trends of the impairment, is particularly difficult due to a lack of historical water quality data. This lack of data makes it challenging to define baseline conditions preceding human activity and influence for a particular lake. It also impedes our ability to set realistic water quality goals and establish lake-appropriate remediation and watershed management plans.

The primary method used to assess historical water quality is the examination of lake sediments, which act as a time capsule for lake condition over time. Both the rate at which sediments accumulate and the remains of organisms that can be seen in the sediments provide important information on lake trends and conditions. To provide a better context for historical water quality in the region, the NELP project team collected sediment cores from several lakes and analyzed a subset for historical sedimentation rates, using the radioisotope Lead (^{210}Pb), and for historical water quality, using an index based on sediment diatoms.

Nutrient loading resulting from intensive anthropogenic activities and related increased sedimentation rates has been deemed largely responsible for the eutrophication in Northeastern lakes. Increased sedimentation is of particular concern in lakes because it can accelerate the rate of water quality degradation by disrupting natural cycles in lake chemistry and dynamics, such as increasing anoxic conditions (especially in shallow lakes). A change in the rate of sedimentation can be used as an indicator for a change in water quality, whereby a higher sedimentation rate often indicates increasing eutrophic and degraded conditions.

A core sample taken from lake-bottom sediments, Pleasant Lake, Maine, 2007.

EVALUATING SEDIMENTATION RATES USING ^{210}PB

Of the sediment cores collected for the NELP assessment, 11 lakes were selected for evaluation of sedimentation rate using ^{210}Pb. These lakes represented both impacted and pristine lakes selected by state lake scientists from all six New England states. ^{210}Pb is commonly used for lake sediment dating because it is found naturally in sediments and has a half-life of approximately 22 years, making it particularly useful for examining post-industrial changes in lakes (i.e.,

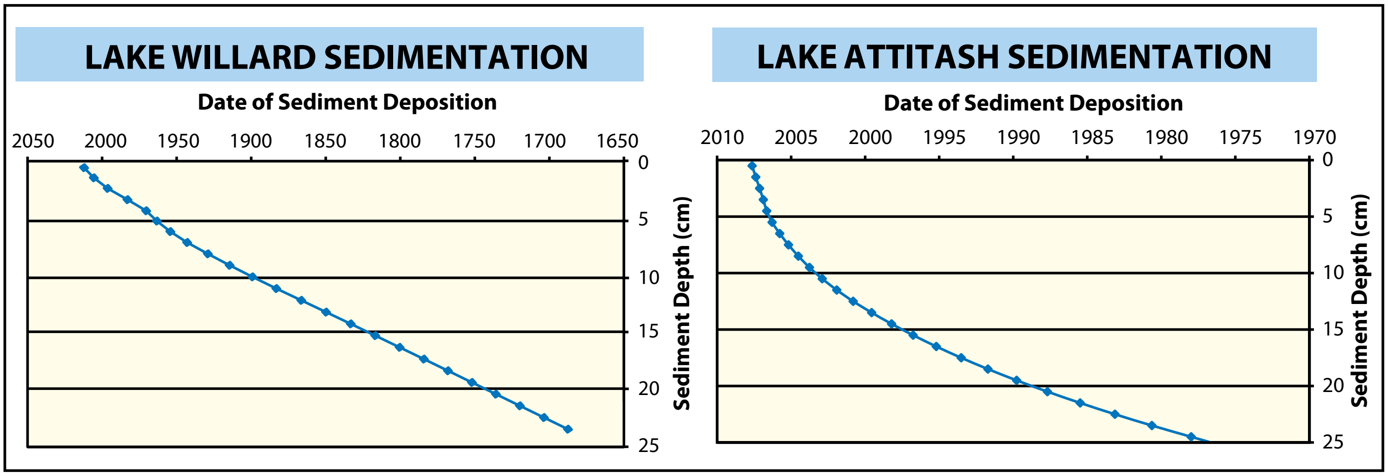

Figure 4-6. *Based on the ^{210}Pb dating, the rate at which sediment is deposited in Willard lake has remained unchanged since the late 1700s, as defined by the straight line. Lake Attitash demonstrates an ever increasing sedimentation rate, beginning in the late 1970s and dramatically increasing after the year 2000 to the present, clearly highlighting the increasing nutrient inputs to the lake and resulting productivity.*

over the past 100-150 years). (Van Metre et al., 2004 and *http://esp.cr.usgs.gov/info/lacs/lead.htm*).

To determine the sedimentation rate, samples are taken from the sediment core at a series of depths, then tested for ^{210}Pb content. The lower the amount of ^{210}Pb that is still radioactive, the older the age of the sediments. Once the age of sediment at each depth is determined, the rate at which the sediments accumulated can be calculated. If the sedimentation rate remains constant, the current condition of the lake is likely quite similar to the historic condition of the lake. If a lake is found to have a sharp change in sedimentation rate, it is likely to have a much different trophic status than was typical of the natural condition of the lake.

FASTER SEDIMENTATION LEADS TO GREATER IMPAIRMENT

The results of the ^{210}Pb sediment dating clearly showed that increasing sedimentation rates are usually indicative of increasing lake impairment. The best example of this is seen in the results from Lake Attitash, a known eutrophic and heavily impacted lake.

Historically, the sedimentation rate of Lake Attitash was constant at approximately 0.38 cm per year. Around 1980 (see Figure 4-6), sedimentation rates began to increase slightly (0.40 cm/year). Between 1980 and 2000, 11 cm of sediment were deposited in Lake Attitash (0.55 cm/year); the rate increased even further between 2000 and 2007 (1.57 cm/ year). This trend in the sedimentation rate coincides with increased lake eutrophication brought about by increased recreational, agricultural, and residential pressures on the lake.

ACCESSING HISTORIC LAKE CONDITIONS THROUGH DIATOMS

Detecting changes in sedimentation rates can be used to indicate that a change has occurred and provide a timeline for pre-impacted conditions. However, sedimentation data in and of itself does not provide specific details on historic lake conditions. A method that is gaining traction in assessing historical lake conditions is the use of sedimentary diatoms—microscopic algae that are distinct from the rest of the phytoplankton community due to their production of silicon dioxide (glass) cell walls.

Diatoms integrate the physical and chemical conditions of the lake and its watershed. For example, depending on the species, a diatom can be indicative of nutrient-rich or of pristine conditions. When diatoms die, their silica cell walls remain intact, sinking

Comparing Historical and Current Water Quality In Pristine and Impacted New England Lakes

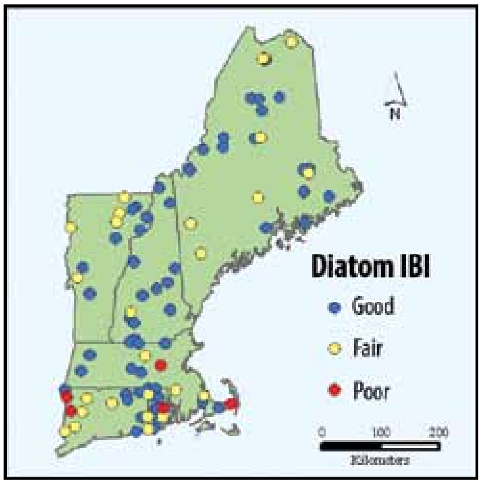

Figure 4-7. *Ranking of New England lakes utilizing the Lake Diatom Condition Index (LDCI).*

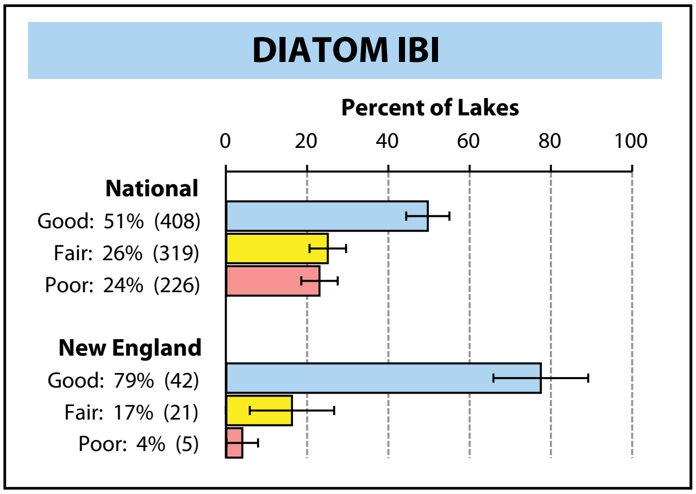

Figure 4-8. *Comparison of lake condition (utilizing the LDCI) in New England with that of the rest of the nation. (The number in parenthesis indicates the number of lakes.)*

to the bottom of the lake where they are permanently preserved in the lake sediments. This seasonal deposition pattern provides a way to track changes in community structure through time and determine past and present conditions, based on species-specific environmental requirements.

Of the sediment cores collected as part of the NELP project, 56 lakes were selected for sedimentary diatom analysis. The method is based on the fact that the top (0-1 cm) layer of diatom sediments represents present-day lake conditions, since they normally contain diatoms that have accumulated within the last few years. The bottom (>30 cm) sediments from natural lakes represent pre-industrial (pre-1850) conditions. Sediment dating and sedimentation rates, along with sedimentary diatom analysis, provide an accurate historical record of lake conditions, and thus a useful means for determining trends in lake conditions.

The National Lakes Survey developed a Lake Diatom Condition Index (LDCI), an innovative tool for assessing the NLA lakes utilizing sediment diatoms (*http://water.epa.gov/type/lakes/upload/nla_chapter3.pdf*). The LDCI is based on the taxonomic characteristics of the diatoms found in a particular section of sediment. Taxonomic richness, composition of the various taxa found within the section, diversity and morphology of taxa, and the tolerance of found taxa to stresses from pollutants are all factors that determine the index value.

The survey showed that in New England, based on the LDCI, good and fair quality lakes are evenly distributed across the region, but poorer quality lakes are primarily in the southernmost part of the region (Figure 4-7). A greater percentage of New England lakes were found to be in good condition, compared with the rest of the nation, and lakes in poor condition are much less prevalent in New England (Figure 4-8).

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http://esp.cr.usgs.gov/info/lacs/lead.htm

HIGHLIGHT *The Trophic Component*

USING REMOTE SENSING TO MONITOR WATER QUALITY IN NEW ENGLAND LAKES

Remote sensing has emerged as a promising new tool for measuring water quality in lakes. The technology has the potential to combine current monitoring efforts with satellite and aerial imagery to provide a more comprehensive lake monitoring program than is possible through traditional lake sampling. Chlorophyll concentrations (for trophic status) and cyanobacteria populations (for public health) have become two of the water quality characteristics of greatest interest for applying remote sensing technology to lakes.

Although it is not possible or prudent to rely solely on remote sensing data for all lake monitoring, the spatial and temporal information available through the use of this technology can enhance the understanding of lake ecosystem conditions and dynamics. While traditional lake sampling yields a significant amount of data over a range of depths for a limited number of locations per lake, remote sensing excels at providing measurements over the entire surface of the lake and/or repeated measurements of the same lake over time. If properly developed and implemented, remote sensing methods can make accurate water quality measurements, even in the absence of matching lake sampling data on a given day, greatly expanding the number of lakes that can be monitored and increasing the frequency of monitoring.

The NELP project provided a unique opportunity to develop the use of remote sensing technology to monitor water bodies in the region through collaborations among EPA, state agencies, and academia.

Definitions

Remote Sensing: The small- or large-scale acquisition of data by the use of either recording or real-time sensing device(s) that are not in physical or intimate contact with the object (such as by way of aircraft, spacecraft, satellite, buoy, or ship).

Algorithm: A mathematical formula that converts remote sensing measurements to water quality characteristics (i.e., chlorophyll concentration).

Spectral Library: A collection of spectral measurements representing the range and variability found across lakes in a region.

METHOD DEVELOPMENT FOR NEW ENGLAND LAKES AND PONDS

Before remote sensing can be used reliably for measuring lake water quality, studies must be conducted to develop techniques appropriate for the types of lakes found in a given region.

The biggest challenge with using remote sensing to monitor lakes and ponds in New England is that most published algorithms for chlorophyll and cyanobacteria detection have been developed for lakes with much higher turbidity and more eutrophic conditions (Dall'Olmo and Gitelson 2005, Simis et al. 2005, Randolph et al. 2008) than those typically encountered in New England. Rather than assuming that these algorithms will apply to the clear and relatively chlorophyll-poor lakes in our region, the remote sensing development study set out to determine which remote sensing method would provide the most accurate and consistent approach for monitoring New England lakes and ponds.

To develop remote sensing methods for use in New England, two important tasks had to be accomplished:

1. Create a detailed spectral library of lakes in the region paired with simultaneous measurements of lake water quality.
2. Use the spectral and water quality data to determine the best remote sensing methods for measuring chlorophyll and cyanobacteria.

CREATING SPECTRAL LIBRARIES WITH ON-LAKE REMOTE SENSING

While it might seem apparent that a New England lakes and ponds spectral library would be developed by making coordinated sampling trips coincident with satellite overpasses, agencies such as NASA and the European Space Agency (ESA) rarely use this approach when developing remote sensing algorithms for oceans or inland waters. Using satellite data for developing remote sensing techniques is problematic. There is the potential for lags between image collection and lake sampling. There may also be difficulty in relating relatively large image pixels to water quality samples, variable cloud cover, variable bands for each satellite, and degradation of measurements due to atmospheric effects.

Definitions

BANDS: Discrete colors (wavelengths) of light that a remote sensing device has been designed to measure; many satellites used to measure water quality have between 4 and 15 different bands ranging from 10 to 150 nm wide.

SPECTRAL RADIOMETER: An electronic device that measures intensity of different colors (wavelengths) of light.

To avoid many of these issues during method development, agencies and university researchers typically create the spectral library through measurements made with a portable spectral radiometer (similar to the cameras on satellites) carried on a boat and used at the sampling location to spectrally characterize lakes. These radiometers are used to collect highly detailed, hyperspectral measurements of lakes captured simultaneously with relevant water quality measurements. A series of *in situ* measurements are made to determine the spectral qualities a satellite would measure for that same lake.

This on-lake remote sensing approach provides the purest, most detailed measurement possible of the light leaving the surface of a lake, ensuring the high-quality library needed to develop a reliable remote sensing method. The hyperspectral nature of these measurements can be used to simulate any number and combination of satellite bands, making the library a valuable resource for developing water quality algorithms for any satellite past, present, or future.

DEVELOPING A SPECTRAL LIBRARY FOR NEW ENGLAND LAKES

To develop a spectral library of New England lakes using the hyperspectral on-lake remote sensing approach, the NELP team collaborated with New England state agencies, volunteer lake monitoring programs, and universities. Water quality sample collection, sample processing, and logistical field support were provided by NELP field teams; state agency staff from Connecticut, Vermont, and Maine; the University of Rhode Island Cooperative Extension volunteer monitoring program; and the Department of Biological Sciences at the University of New Hampshire (UNH). Spectral measurements using the spectral radiometers were coordinated by the UNH Cooperative Extension and carried out by both extension staff and the NELP field teams.

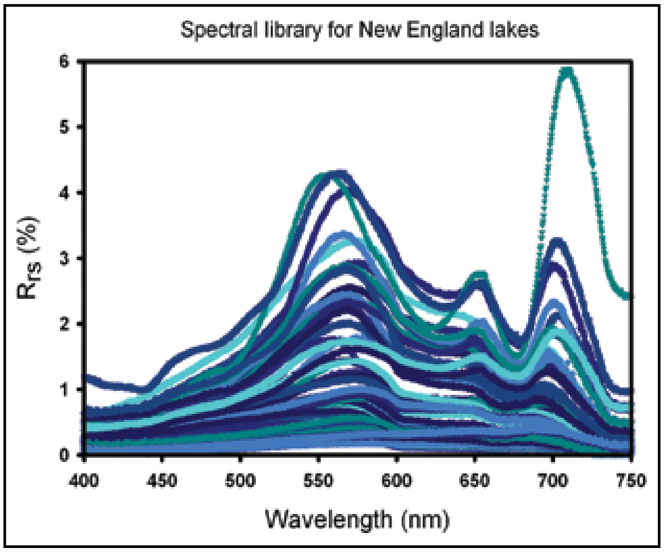

Figure 4-9. *Image library of spectral wavelength signatures of New England lakes collected by NELP participants. Wavelengths important for measuring chlorophyll and blue-green algae concentrations fall within the 550 to 750 nanometer range.*

The partnership leveraged technical knowledge and specialized equipment from UNH, along with the contributions from the NELP project, including probabilistic lake selection, complex logistical coordination, field collection, and analysis of a wide variety of water quality parameters.

During the NELP project, approximately 1,250 *in situ* spectral measurements were used to characterize a total of 63 lakes and ponds throughout the region. Spectral measurements taken at each lake were processed by the UNH Cooperative Extension to produce characteristic reflectance spectra over the range of wavelengths important for remote sensing of water (390 nm to 750 nm).

The variability captured by the probabilistic sampling of NELP water bodies provided an opportunity to measure spectra across the entire range of lakes present in the region, which will prove crucial in algorithm development. While relatively little variability is shown in the blue end of the spectra (400nm to 500nm), a significant amount of spectral variation can be seen in the green, red, and near-infrared areas (550 nm to 750 nm) (Figure 4-9).

These spectra, when combined with lake data collected simultaneously, provide a high-quality, high-resolution spectral library that can be used to develop and test remote sensing methods for water quality features of interest in New England, including chlorophyll concentration and cyanobacteria populations. In addition to proving extremely valuable to the NELP project, these data will continue to support lake remote sensing projects for New England lakes and ponds in the future.

DETERMINING THE BEST REMOTE SENSING METHODS FOR THE REGION

To determine the best remote sensing methods for New England water bodies, key areas of the spectra were confirmed for use in the development of an algorithm based on published research and visual analysis (Figure 4-10). Many of the key spectral features important for chlorophyll measurement and cyanobacteria detection were noticeable and well captured, including the green peak (light green), cyanobacterial pigment absorption (aqua and cyan), chlorophyll absorption (dark green), and a crucially important scattering peak (blue). As shown in Figure 4-10, the concentration of a potential cyanobacteria toxin (microcystin) exhibited a tendency to change in concert with specific changes in the lake spectra.

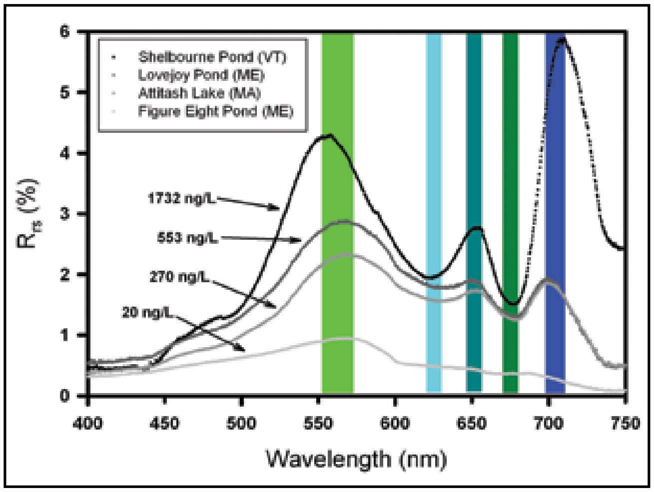

Figure 4-10. *Four different spectral signatures and the spectral wavelengths (bands) important for measuring chlorophyll and detecting cyanobacteria. Note the chlorophyll-*a *concentration for each lake in nanograms per liter (ng/L).*

A variety of the published algorithms developed by using hyperspectral remote sensing measurements to determine chlorophyll concentration have been tested using the spectral library. While some approaches used in more turbid and eutrophic systems have not proved useful in the region's lakes, several of the algorithms have shown significant promise. Among the best suited for the region (explaining 91 percent of the variability) is the method focusing on the valley caused by chlorophyll absorption near 675 nm, and the scattering peak caused by increasing numbers of cells in the water present around 705 nm (Figure 4-11).

Additional new algorithm development will be explored and based on a variety of published algorithms.

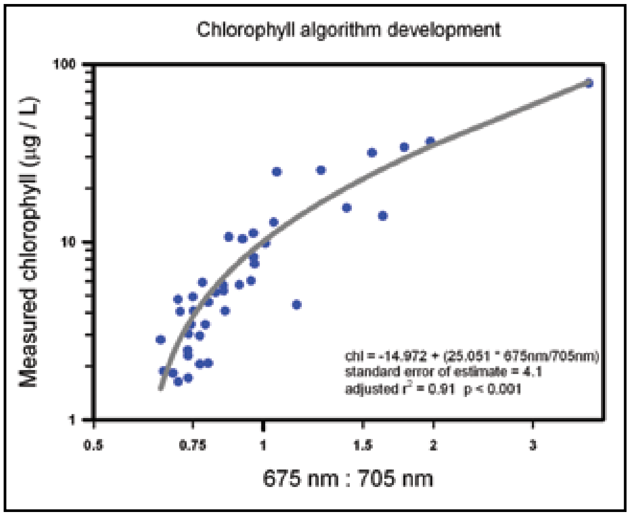

Figure 4-11. *Relation between measured chlorophyll from lake water samples and the ratio between chlorophyll-a absorption (675nm) and light scattering from algal cells (705nm).*

They will rely on the diverse dataset collected by the NELP survey from 2005 to 2007. A central focus will be the wavelengths specific to the absorption of freshwater photosynthetic pigments of chlorophyll-*a* (675 nm) and phycocyanins (625 nm), as well as the fluorescence and scattering peaks at 685 nm and 705 nm, respectively. The algorithms will be tested by using imagery from a hyperspectral aircraft and a multispectral satellite (MERIS from the European Space Agency).

The spectral library will also be used to determine the best-case scenario for water quality measurements from a range of NASA and ESA satellites, as well as airplane-borne sensors (such as were used during the NELP/NASA flyover effort highlighted in this report), providing for a concrete, real-world approach to introducing remote sensing to lake monitoring efforts in the region. The spectral library created by the NELP project has already been mined for information on the development of remote sensing techniques for monitoring New Hampshire lakes.

This highlight was provided by Shane Bradt, UNH Cooperative Extension.

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HIGHLIGHT

The Trophic Component

THE AERIAL FLYOVER: A REAL-WORLD REMOTE SENSING TEST OF LAKE CONDITION

As discussed in the preceding highlight, remote sensing can provide measurements of lake condition over entire lake surfaces or repeated measurements of lakes over time. The NELP project provided an opportunity to develop a fundamental understanding of how remote sensing can best be used to measure lake water quality in New England. The project also provided a tremendous opportunity to test a real-world application of remote sensing for New England lakes with "on-the-ground" sampling in conjunction with aerial flyovers.

Remote sensing measurements made from aircraft can be a powerful tool in understanding lake ecosystem dynamics, providing spatial resolution and spectral information superior to that available from satellites. While aerial remote sensing is extremely useful, it can also be organizationally intensive. Many pieces need to be in place and in motion simultaneously for an effective series of measurements to be made. Owing to the logistical challenges of coordinating aircraft flight schedules and mobilizing a large and geographically distributed group of lake-sampling teams, a regional survey of lake water quality using aerial remote sensing had not previously been attempted in New England.

With coordination through the NELP project, the logistical hurdles (typical of collaborative efforts) involved with testing an aerial remote-sensing approach in New England were overcome in late summer 2009. The NELP project coordinated lake sampling efforts timed with the flyover, and was responsible for both analyzing water chemistry and compiling the lake sampling data. The Remote Sensing of Phytoplankton Research Program at the EPA Atlantic Ecology Division (AED) arranged and executed the flyover component through a cooperative effort with the NASA Langley Aerospace Research Center (LARC).

THE FLYOVER

The NELP project team identified a number of mesotrophic to hypereutrophic lakes to survey and coordinate with AED/LARC for the flyover. Using a NASA Cessna 206 aircraft equipped with three hyper-spectral radiometers supplied by AED, a total of 55

NASA Cessna 206 aircraft used for aerial flyover.

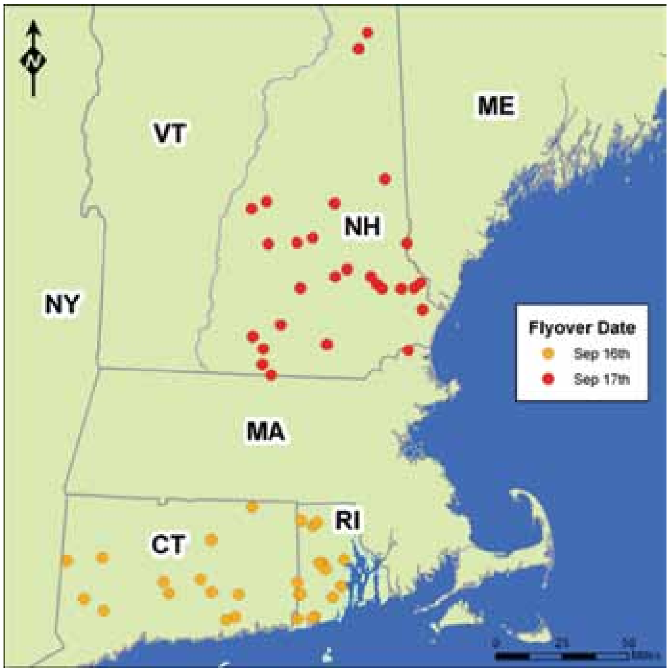

Figure 4-12. *Map showing the location of the 55 New England lakes sampled during the aerial flyover.*

The Aerial Flyover: A Real-World Remote Sensing Test of Lake Condition

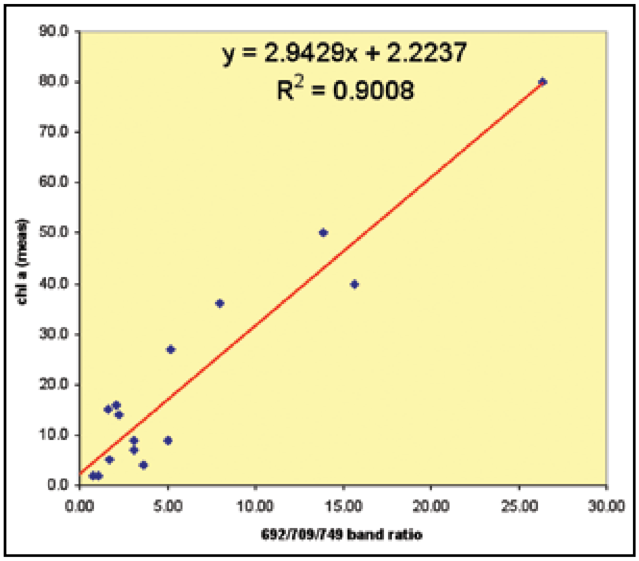

Figure 4-13. *Preliminary comparison of predicted chlorophyll-*a *values and measured chlorophyll-*a *values from three wavelengths of the NELP/NASA aerial remote sensing measurements (692 nm, 705 nm and 750 nm), demonstrating a 90 percent concurrence.*

lakes in Connecticut, Massachusetts, New Hampshire, and Rhode Island were surveyed on September 16 and 17, 2009 (Figure 4-12).

Nearly all water samples were collected from target lakes on the day of the aircraft flyover by field-sampling teams from the EPA Region I laboratory, Connecticut Department of Environmental Protection, New Hampshire Department of Environmental Services, University of New Hampshire, UNH Cooperative Extension, and University of Rhode Island Cooperative Extension (a small number of lakes were sampled within one week of the flyover).

The samples were later analyzed in a laboratory setting for water quality parameters, including chlorophyll-*a* and the presence of cyanobacterial toxins. The data from these samples were used to validate estimates derived from the remote sensing measurements recorded by the aircraft. On-lake spectral data were also collected from several lakes, concurrent with the flyover, to provide data with which to assess the quality of the spectral measurements made by the aircraft.

From the aircraft spectral data, algorithms were created to estimate concentrations of chlorophyll-*a*, phycocyanin, and colored dissolved organic matter.

The remotely sensed estimates were validated by *in situ* chlorophyll-*a* and lake-color data from 43 of the flyover lakes. Initial analysis of remotely derived chlorophyll-*a* concentrations (using spectral data from three wavelengths 692 nm, 705 nm, and 750 nm) with chlorophyll values measured from the lake water samples, proved quite promising, explaining 91 percent of the variability.

A FOUNDATION FOR FUTURE MONITORING

The remote-sensing data collected during the 2009 flyover represents the first true test of the application of aerial remote sensing for lake monitoring in the New England region, providing detailed spectral measurements over a wide range of geography, altitude, and trophic conditions. These measurements will be combined with the spectral library of on-lake measurements developed during the NELP project to determine the best techniques for the application of remote sensing to lakes in this region.

The preliminary results from the flyover indicate that remote sensing can play a valuable, real-world role in lake monitoring in our region. While a great deal of work remains to be done before a reliable and functional approach can be routinely applied to regional monitoring efforts, these measurements collected during the NELP/AED/LARC collaborative flyover offer a high-quality starting point from which to design a valuable remote sensing component of a regional lake monitoring program.

This highlight was provided by Shane Bradt, UNH Cooperative Extension.

HIGHLIGHT *The Chemical Component*

ATMOSPHERIC CONTAMINANTS: MERCURY AND ACID RAIN

Of the many stressors that affect lakes, atmospheric contaminants are perhaps the most difficult to address. This is because sources of atmospheric contaminants are often hundreds or even thousands of miles from the lakes into which the contaminants are ultimately deposited. The intertwined issues of freshwater acidification and mercury contamination are not new; the popular press began reporting on acid rain in the 1970s. It took another 10 to 15 years for the press to also focus on mercury. Today, people are aware of both issues, yet they often do not fully comprehend nor appreciate the degree to which the two are linked. In both cases, these pollutants begin their movement through the environment with emissions into the air. Both the NELP project and the NLA focused a key part of their efforts on assessing the concentrations and effects of this persistent contaminant.

MERCURY

Mercury is a naturally occurring metal that is found in the environment in many forms, all of which are toxic to varying degrees. The release of mercury to the environment is enhanced by human activities, such as the combustion of fossil fuels (coal and petroleum). In the United States, the largest sources of mercury are coal-fired power generators or utility boilers, followed by waste incinerators. Mercury is also present in many household items, notably thermostats and fluorescent lamps, and is released when these items end up in landfills or incineration facilities. Depending on its chemical form, air-borne mercury may remain in the atmosphere for a period of minutes (as reactive gaseous mercury), days (as particulate mercury), weeks, or years (as gaseous elemental mercury).

Methylmercury, one of the most toxic forms of mercury, is prevalent in fish and has documented adverse health effects on humans. The U.S. Centers for Disease Control and Prevention estimates that up to 6 percent of women of childbearing age have blood mercury levels in excess of established safety levels. Fish and fish-eating wildlife, such as the common loon and American bald eagle, are also at risk from mercury toxicity. While the process by which mercury moves through the lake environment is quite complex, there are five basic stages: emission, deposition, methylation, bioaccumulation, and finally sequestration by lake sediments.

METHYLATION: The natural and biologically mediated process by which mercury is transformed into toxic organic methylmercury.

ACID RAIN

Lake acidification is brought about by airborne pollutants that are transported from emission sources, such as coal-fired plants and motor vehicles, and eventually deposited on the earth through precipitation (e.g., rain, snow) and dust. Among the pollutants released into the air are acid-forming chemicals, most notoriously sulfur dioxide and nitrogen oxides. Sulfur dioxide, like mercury, is largely associated with the burning of fossil fuels. Some forms of coal are very rich in sulfur; poorly controlled facilities released massive quantities, particularly between 1960 and 1992.

Both sulfur dioxide and nitrogen oxides are common components of vehicular emissions, diesel trucks in particular. Nitrogen oxide also comes from passenger-vehicle exhaust. Once emitted, these two compounds undergo complex atmospheric transformations, acidifying precipitation so it contains dilute concentrations of nitric and sulfuric acids. The Clean Air Act Amendments of 1990 have resulted in profound reductions in acid-forming precursors. In very sensitive regions, however, lakes remain at risk from acidification, as many sources remain, even with reduced levels of acid rain.

Atmospheric Contaminants: Mercury and Acid Rain

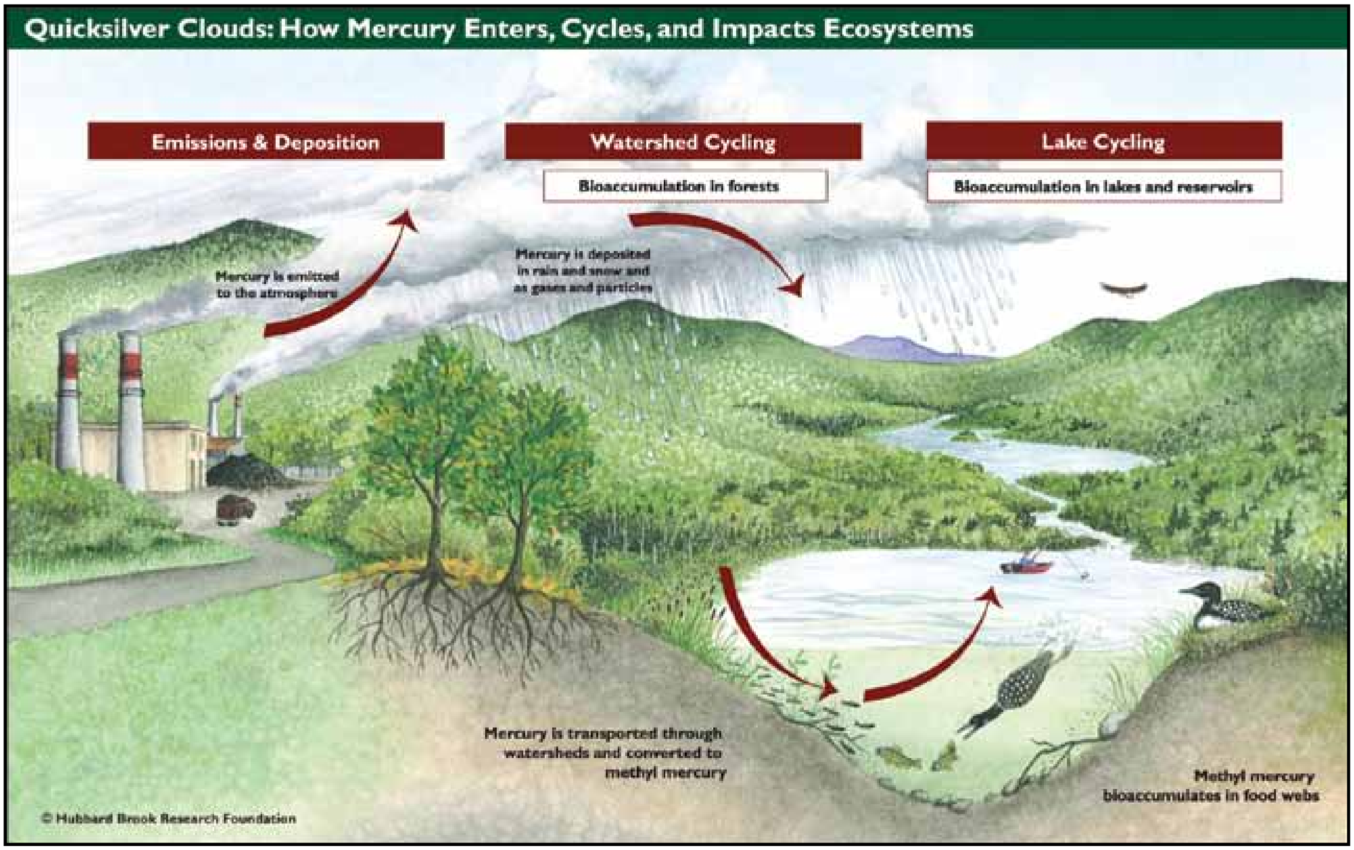

Figure 4-14. *Graphic depiction of methylmercury bioaccumulation in lake biota. This figure is reproduced from the Hubbard Brook Research Foundation's ScienceLinks publication* Mercury Matters: Linking Mercury Science with Public Policy in the Northeastern United States.

THE ACID RAIN-MERCURY CONNECTION

The process of lake acidification is not as complex as that of mercury accumulation in that there is neither methylation nor acid bioaccumulation. Yet acidification has more harmful effects that tie in with mercury deposition and exacerbate lake problems. As watersheds acidify they become more efficient at creating and transporting methylmercury, along with other soil-bound metals such as aluminium, to lakes. Moreover, acidification of the lakes themselves renders the bioaccumulation of methylmercury more efficient. Therefore, acidic lakes (a) receive more mercury from their watershed, (b) have more of the mercury in the toxic methylated form, and (c) more readily bioaccumulate methylmercury.

Studies throughout the United States, Canada, Russia, and Scandinavia all show a very strong connection between lake acidification and mercury bioaccumulation. Researchers have documented the occurrence of mercury hotspots in various parts of the U.S. and attributed these to one of three basic causes—proximity to poorly controlled emissions sources, water level management in reservoirs, or acid-sensitive landscapes. In regions of North America where lake acidification is, in fact, already improving (Stoddard et al, 1999), minor reductions in mercury in fish and fish-eating wildlife can be anticipated. Much more consequential reductions in environmental mercury contamination are expected as EPA and states control mercury emissions from coal-fired utilities and other sources.

As part of the NLA, the potential for lakes to be affected by acid rain was measured directly using alkalinity as the indicator. Sediment samples were also collected to determine mercury and methylmercury levels. These tests provide only an indirect indication of the potential for the severity of fish mercury contamination, but they will serve as an excellent baseline against which to measure progress in reducing mercury inputs to lakes.

Two large-scale monitoring initiatives associated with acidification are the National Atmospheric Deposition Monitoring Program and the National Status and Trends Network. A National Mercury Monitoring Network has been designed to track changes in mercury in indicator habitats and species over time. More information can be found at:

Acid Rain: *www.epa.gov/acidrain/index.html*

Mercury: *www.epa.gov/mercury/*

This highlight was provided by Neil C. Kamman, Vermont Department of Environmental Conservation.

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NELP field team member enters survey data into an electronic data capture device, utilizing new technology for efficient and accurate record keeping.

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Putting It Together at Lake Attitash: A Case Study of Cooperative Collaboration

Section 5

Lake Attitash, located in the towns of Amesbury and Merrimac, Massachusetts, is a poster child for the uses and abuses that many of our nation's lakes undergo today. Yet this heavily stressed lake provided the NELP project the opportunity to shine a spotlight on its problems and showcase some of the ways in which people have collaborated and invested their energies into improving a resource they truly care about. Work began at Attitash when it was chosen as a pilot lake for testing and evaluating new methods and technologies for use with NELP and NLA projects. This work is ongoing and has evolved into a multi-agency, citizen, and academic effort to evaluate, monitor, and remediate worsening water quality and habitat conditions that directly affect people's lives and livelihoods. The lessons learned at Lake Attitash have been transferred to other lakes assessed during the NELP project, providing benefits to other groups of stakeholders and their lakes and ponds,.

THE USES

The beneficial uses that Lake Attitash provides are numerous. The town of Merrimac, Massachusetts, manages two wellfields adjacent to the lake, withdrawing close to half a million gallons per day of fresh water to support the needs of 1,900 households. The town of Amesbury also utilizes the lake as a secondary water supply during drought conditions, supplementing the needs of approximately 6,000 households in a community that requires approximately 2.5 million gallons per day of fresh water. The lake is the site of public and private bathing beaches, a public boat launch with parking for 25-30 vehicles with trailers, a boys camp that has been in existence since the 1930s, a private enterprise that offers water sports for disabled people, and a small residential boat anchorage.

The shores of Lake Attitash are home to 200 residences; rows of houses are often three to five deep, emanating away from the lakeshore. This near-coastal freshwater body provides an important stopover for migratory waterfowl in the fall, when inland waters are frozen, and an important and well-known recreational and subsistence sport fishery during the summer. Adjacent wetlands are home to abundant wetland wildlife and serve as the major filtering and flood control mechanism for surface water inputs to the lake. During winter months, the lake supports avid ice skating, cross-country skiing, ice boating, and ice fishing activity.

THE ABUSES

As with many lakes in New England, Attitash has transitioned from being a tranquil summer retreat destination to a busy year-round hub of recreational and development activity. Small summer cottages have given way to large permanent residences or, at minimum, homes that have been built up on their original footprint to accommodate the needs of year-round living. Lawn care practices associated with these homes have increased nutrient loading in the lake, as fertilizers are applied, and increased shoreline erosion, as lawns are cut to the water's edge.

While the old, seasonally used septic systems have been replaced with sewers, what was once a problem of nutrient input into the lake from septic-system leachate has given way to stormwater runoff from

The exotic invasive water chestnut, Trapa natans, *is becoming an increasingly problematic aquatic plant in southern New England, and has recently shown up in Lake Attitash.*

Aerial photo of a "trenched" wetland on Lake Attitash, short-circuiting an important filtering function for water entering the lake.

Monitoring the boat-launch traffic counter at Lake Attitash.

impervious surfaces, such as paved roads, rooftops, and driveways. Strides have been made in keeping the coarse stormwater sediments out of the lake, but finer stormwater particulates, often rich in nutrients that accelerate aquatic plant growth, still enter the water body relatively unchecked.

Transient boat activity has brought invasive aquatic plant species to the lake, and high-horsepower boat traffic contributes to the resuspension of nutrient-rich bottom sediments that increase turbidity and promote the growth of aquatic plants to nuisance levels. Agricultural activities in the watershed have attracted nuisance levels of seagulls to the lake during certain times of the year, and farming practices in the watershed are suspected of adding nutrients to the lake.

The effective filtration and flood control performed by wetlands has been short-circuited by historic trenching measures undertaken for the purpose of dewatering, thereby eliminating one of the most important natural functions of a wetland. Finally, Lake Attitash has been identified as a hotspot for mercury deposition due to prevailing winds and regional emission sources. The presence of mercury in the lake has implications for the health of wildlife within the lake ecosystem and for human health through consumption of affected fish.

Anyone involved with lake management has either dealt with or run across at least a few of the issues mentioned above. The social and economic benefits that lakes provide humans and wildlife and the uses imposed upon these lakes often lead to complex and problematic dilemmas. Aquatic resource managers often struggle in efforts to balance these competing uses while attempting to maintain the sustainability of the resource. Attitash has been no exception, but through exceptional collaborative efforts highlighted in this section, the lake serves to demonstrate what stakeholders at all levels can contribute to improving and maintaining the desired conditions of our lakes and ponds. Some approaches to acquiring the right kinds of information for making sound management decisions are also highlighted.

TAKING A HARD LOOK AT BOAT TRAFFIC

The 360-acre Lake Attitash is the only freshwater lake within a 30-mile radius that accommodates public access with boat-trailer parking. Hence, a very large boating community, with crafts ranging from ocean-worthy runabouts to kayaks and canoes, enjoys the lake. To begin determining the extent of this boating community and the potential boat carrying capacity of the lake, a traffic counter was placed at the boat ramp during summer 2008.

Carrying capacity: A limit or threshold at which an acceptable resource use level is exceeded.

As suspected, Attitash is a highly used resource by boaters, exceeding 200 boat launches weekly during the summer months. Excessive boat traffic can

Retaining walls have been a historic remedy for eroding shorelines (note the storm-drain outfall pipes).

Dragonflies rely on shoreline areas for survival, living in the aquatic environment throughout much of their immature life stages and near water environments as adults.

overwhelm the recreational carrying capacity of the lake, having an impact on the health of the lake, as discussed earlier. For this reason, one step of many that will be needed for the lake is to begin looking at acceptable use levels. This will be accomplished through further monitoring, necessary for determining realistic thresholds for boat densities.

The constant wave action caused by heavy boat traffic on Lake Attitash accelerates erosion of shoreline properties. In fact, it has been a principal reason for the construction of concrete retaining walls over the years in an effort to save eroding properties. These "fixes" often shift the problem from one area or form to another. For example, properties adjacent to retaining walls are often eroded away faster as wave energy is transferred along the retaining wall and on to neighboring shorelines.

Waves from boat traffic also reflect back into the water body from retaining walls, creating a "bathtub" effect that resuspends sediments and adds turbidity and nutrients to the water column. Retaining walls also have an impact on critical habitat along the shoreline, eliminating safe havens for juvenile fish and other beneficial aquatic life that are dependent on these near-shore and shoreline areas for survival.

This detrimental trend in "fixing" degrading shorelines was noted decades ago, and efforts were made

Before and after pictures of the Attitash shoreland protection project. (Left) Note the rock stains of the normal summer water level mark in the lower right corner. (Right) Native shoreland plants and natural indigenous stone overlying erosion-protective filter fabric will stabilize the previously eroding shoreline, provide important lakeshore habitat, and enhance aesthetics and property values.

Mapping submerged vegetation using hydroacoustics can be useful in low-clarity waters.

A completely undeveloped New England lake, exhibiting persistent blue-green algal blooms from farming practices that occurred at the turn of the century.

to educate lake property owners about the ecological, aesthetic, and economic benefits of pursuing alternative approaches to protecting their shores. The NELP project, through consultations with national experts, presentations at lake association meetings, and discussions with individual property owners, brought to light the concept of bioengineering—an ecological and environmentally friendly alternative to concrete retaining-wall structures.

Bioengineering: The use of various live plants for the structural stabilization and enhancement of shorelines and near-shore habitats.

As a result of these interactions, the first "official" bio-engineering shoreline protection project took place in early summer 2010 (see photos on bottom of page 48). The project has attracted a great deal of positive attention from the resident lake community, neighboring lake associations, and local conservation agents. The aesthetic appeal, alone, has been welcomed, and other lakeshore owners are now considering similar approaches for their waterfronts.

USING HYDROACOUSTICS TO MAP UNDERWATER HABITAT FEATURES

The ability to assess habitat and habitat changes over time is a valuable tool for resource managers. Monitoring residential and agricultural pressures, plant densities, and physical habitat changes around a water body can provide insight on appropriate management practices for these resources. Lake Attitash was selected to showcase the value of applying hydroacoustics, a relatively new approach for monitoring underwater habitat and vegetation in lakes.

Hydroacoustics: Use of sound waves in water to detect, assess, and monitor biological and physical underwater characteristics.

The digital echosounder, a hydroacoustic instrument, has several useful capabilities that include mapping lake bathymetry, bottom (sediment) typing, and aquatic plant abundance and distribution. Hydroacoustic technology is a useful way to evaluate overall underwater habitat and habitat complexity. It

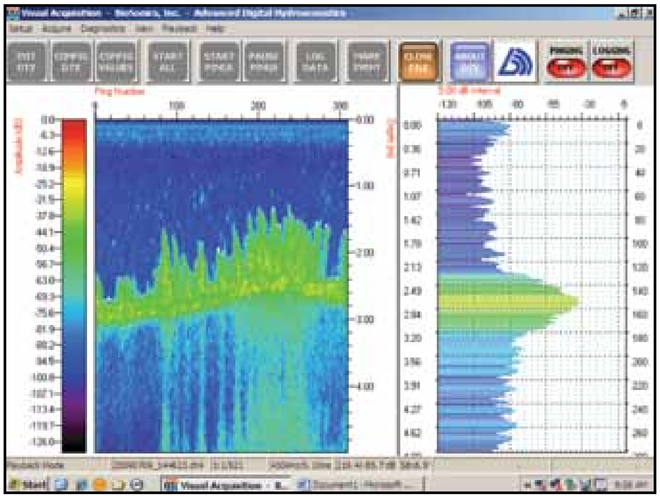


Figure 5-1. *A hydroacoustic profile of submerged vegetation.*

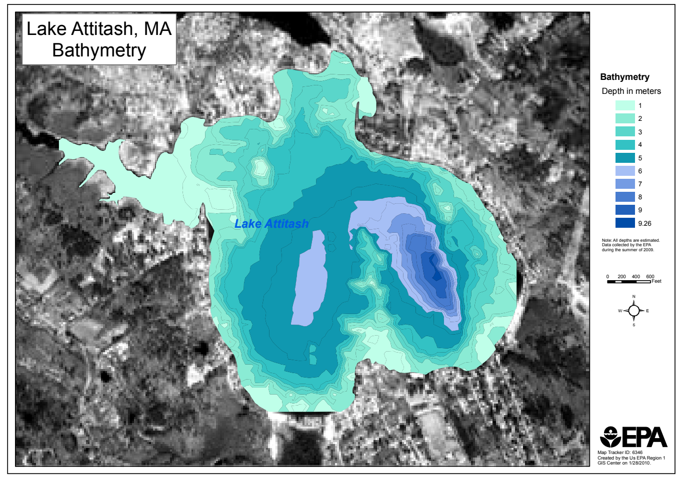


Figure 5-2. *Bathymetric map using hydroacoustic and GIS technology.*

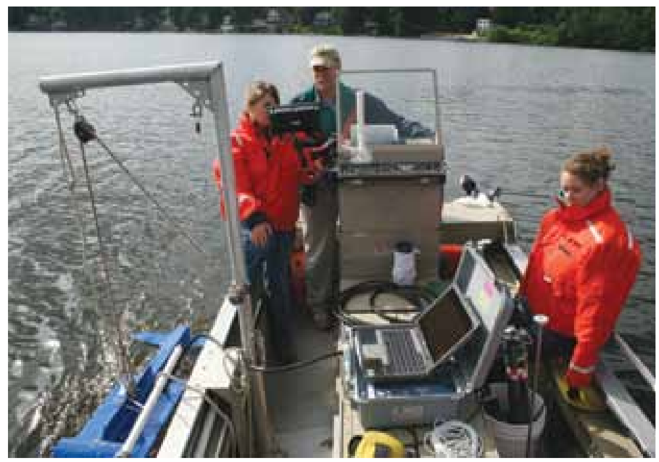
is easy to use both in the field and in post-processing, making it a valuable tool for monitoring aquatic resources within reasonable time frames. It has been used in marine environments to track changes in eelgrass beds in coastal estuaries along the eastern seaboard, and is now being used for freshwater applications.

GATHERING BATHYMETRIC DATA

Lake Attitash is a shallow, 360-acre lake with a maximum depth of 9.5 meters. The greater part of the lake is less than five meters deep and includes a large but shallow photic zone. Such shallow lakes tend to have high productivity, as is the case in Lake Attitash. Lakes with high nutrient input and productivity tend to have increased cyanobacterial blooms and prolific plant growth, affecting the use of the lake for swimming and other water sports. Lake Attitash has high levels of phosphorus, the primary freshwater nutrient affecting water quality, resulting from a long history of residential and agricultural land uses that contribute to frequent cyanobacterial blooms and heavy plant growth during the summer months.

> **Bathymetry:** The measurement of depths of large bodies of water.

Bathymetric maps are the aquatic equivalent to topographic maps, allowing scientists to view important features and calculate important measurements that are crucial to understanding how a lake system functions (e.g., benthic habitat complexity, surface area mean depth). The application of hydroacoustic technology for gathering bathymetric data in Lake Attitash proved to be useful for mapping bottom composition and delineating lake depth and bottom contours. These characteristics are an important means for understanding habitat complexity, overall ecological integrity, and suitability for supporting aquatic life.



Preparing to deploy for a hydroacoustic survey.

MAPPING AND CLASSIFYING BOTTOM SEDIMENT

Sediment mapping and bottom profiling are useful tools for identifying and monitoring changes in lake bottoms resulting from near-shore development,

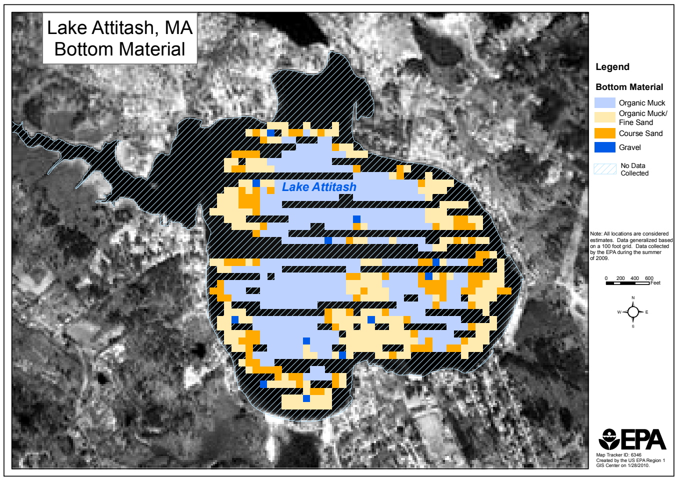


Figure 5-3. *Preliminary bottom composition map developed from hydroacoustic transects across Lake Attitash.*

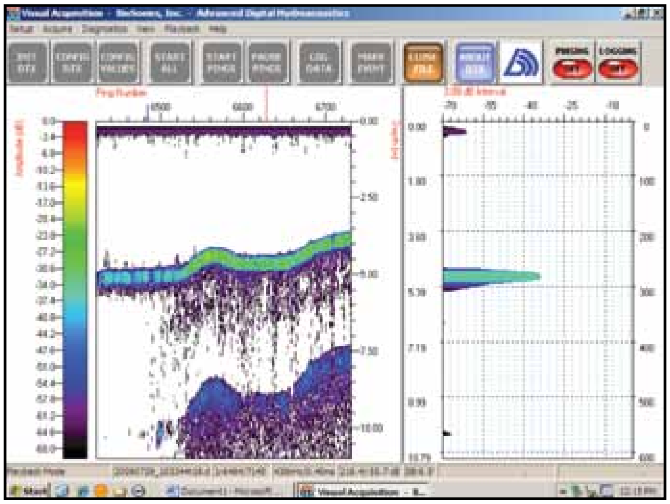


Figure 5-4. *An acoustic profile of lake sediments.*

sedimentation, historical impacts, and structural habitat alterations that impact the ecological integrity of a system. Bottom profiling can also be used to identify critical habitat types and determine the depths and volumes of organic sediments overlaying lakebed sands, gravels, and rock.

Categorizing sediment types on Lake Attitash required the collection of physical samples from different areas within the lake in order to ground-truth the acoustic signals. Once sediment types were verified and categorized, computer sonar images were assigned a color code for each type, based on the returning signal. The Lake Attitash bottom has four classifications—gravel, coarse sand, organic muck interspersed with fine sand, and organic muck. The hydroacoustic output provided detailed imagery representing the distribution of lake sediment types (Figure 5-3).

Bottom substrates in Lake Attitash are dominated by organic muck interspersed with a mixture of sand and organic muck. The majority of this muck originates from decaying plant matter. The dominant inlet to Lake Attitash provides a large influx of this organic material, causing increased turbidity during heavy rains and seasonal runoff events. Mapping the bottom type over periods of time and under certain conditions can allow lake managers to determine major deposition areas and changes in bottom habitat composition.

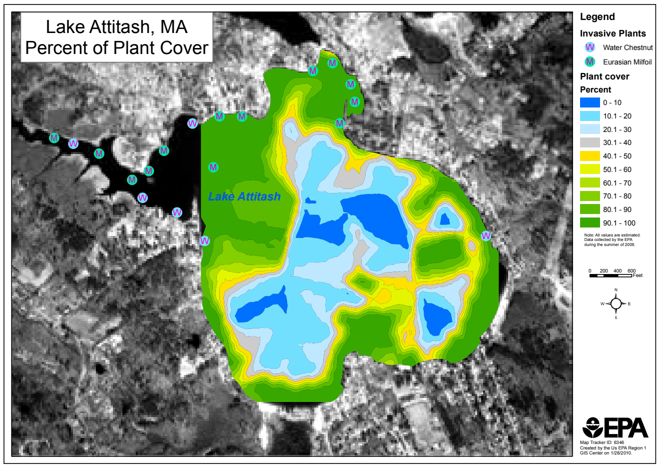


Figure 5-5. *Hydroacoustic-generated map delineating the percent cover of submerged aquatic vegetation.*

MAPPING AQUATIC PLANT ABUNDANCE AND DISTRIBUTION

Similar to the sediment classification, low-frequency sonar allows lake managers to delineate differences in aquatic plant species based on the return signal. Acoustic images help quantify plant height and density for specific plant species. Vegetative maps can then be produced for the surveyed water body. This technology can be helpful in identifying the annual expansion or depletion of particular submerged plant species, plant densities, and the proliferation of invasive species. This information can be particularly useful for determining costs associated with management efforts, such as plant harvesting or chemical treatments.

Prolific aquatic plant growth can reach nuisance levels and impair uses of the lake for humans and wildlife.

Lake Attitash has a large, shallow photic zone, causing plant growth to be a significant issue. Using digital sonar technology along with physical identification of plant species, accurate and detailed dominant-species and plant-density maps were generated, serving as a useful tool for formulating a weed management plan for Lake Attitash.

Acoustically generated maps indicate that the photic zone of Lake Attitash has greater than 50 percent plant cover—75 percent is submerged aquatic plants and 25 percent is emergent aquatic plants. More than 20 species are present in the lake; the three most abundant are *Vallisneria americana, Elodea canadensis*, and *Naiad*. Both *Myriophyllum alterniflorum* and *Trapa natans* were detected, with the majority of the two species inhabiting the outlet and primary inlet areas.

Aquatic plants can be instrumental to the survival of all aquatic organisms; they provide oxygen, shelter, and nurseries for different aquatic species, but in excess they can be a burden to the lake's ecosystem, decreasing the recreational and ecological value of the resource. Excessive plant growth can lead to suffocation, uninhabitable densities, and decomposition that add nutrients to feed a growing algal problem.

The acoustic mapping provided a detailed view of the densities, areal extent, and heights of submerged vegetation in Lake Attitash under conditions of very low water clarity. It provided accurate maps of the thicknesses of nutrient-rich bottom sediments, the type of sediments deposited, and the key sediment-deposition areas in the lake. These findings provide information that will be useful for future lake management decisions that pertain to controlling nuisance aquatic plant species and monitoring the effects of implemented controls over time. Hydroacoustic data will also be useful for monitoring sediment and developing effective strategies for addressing nutrient-rich sediments and their associated impacts.

TRACKING THE ANOXIC LAYER IN LAKE ATTITASH

The amount of dissolved oxygen (DO) present in a lake is a direct indicator of how well and how much aquatic life a lake can support. DO levels in lakes vary with lake depth, temperature, and the number of plants and animals consuming the DO. As the DO is utilized, an anoxic (oxygen deficient) layer is formed at the bottom of the lake that can vary in size and duration, depending on the rate at which DO is consumed.

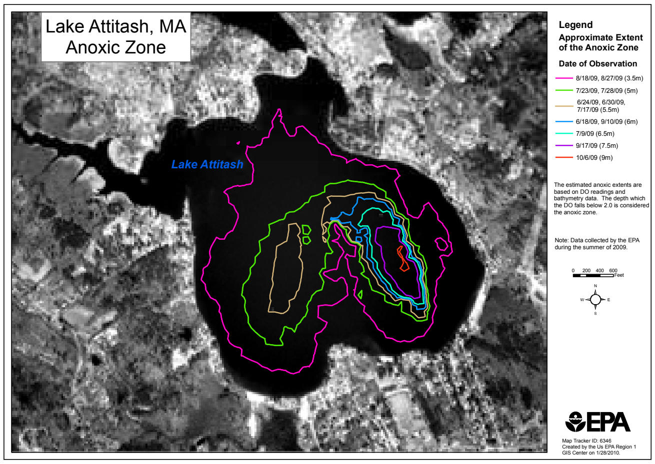


Figure 5-6. *Seasonal expansion of the anoxic layer in Lake Attitash greatly reduces the amount of available habitat for fish and other aquatic species, leading to stressful conditions that can cause fish kills.*

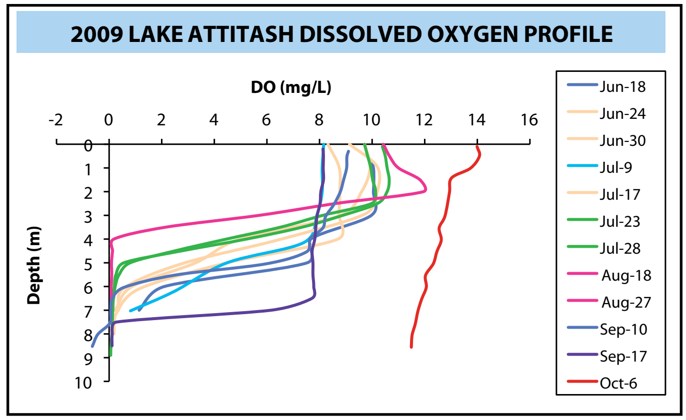


Figure 5-7. *Dissolved oxygen in the lower depths of Lake Attitash is increasingly depleted through the summer months until the fall turnover, when dense, oxygen-rich surface waters sink to the lake bottom and displace the oxygen-poor bottom waters.*

The formation of an anoxic layer affects the release of nutrients from the sediments and can lead to increased algal blooms both at the surface and at deeper depths close to the anoxic layer. During the summer, when rates of DO consumption exceed the rates of oxygen production by resident algae and phytoplankton, extensive anoxic layers can form, degrading and limiting the habitats of fish and other lake biota. Lake eutrophication, caused by nutrients in sediments, often leads to anoxic conditions; as a result, deep-water fauna become increasingly oxygen impoverished, leading to stressed aquatic-life conditions and possible fish kills.

Eutrophic and hypereutrophic conditions deplete lake oxygen levels, creating stressful and often lethal conditions for fish and other aquatic life.

DYNAMICS OF THE ANOXIC LAYER

Lake Attitash is an example of a eutrophic lake that becomes seasonally hypereutrophic during the summer months. As a result, the extent of the anoxic layer that forms can fluctuate drastically throughout the summer and fall. Using hydroacoustics to determine precise lake bathymetry in conjunction with routine dissolved oxygen profile measurements, the NELP study team tracked the extent of the anoxic layer throughout the summer and into fall 2009. Studying the formation and extent of the anoxic layer provides insight into the extent of the effects of oxygen deficiency and nutrient cycling, the effects on fish and their habitats, and the potential extent of any proposed remedial efforts.

As both the map (Figure 5-6) and the DO profile graph (Figure 5-7) indicate, the anoxic layer in Lake Attitash in mid-June (blue outline and blue line on graph) is moderately small in size. However, by mid-August (fuchsia outline and fuchsia line on graph), the anoxic layer has expanded to cover most of the lake, which suggests that fish and other fauna habitats have

FALL TURNOVER:
Occurs when cooling air temperatures decrease the surface water temperature while increasing its density. Turnover occurs when the density of the oxygenated surface water exceeds that of the now warmer anoxic bottom waters and sinks to the bottom of the lake, displacing the bottom waters to the surface.

Blue-green algae scums can be common and problematic in eutrophic lakes during the warm summer months.

become more and more compressed and limited. By the first week in October (red outline and red line on graph), the lake has undergone "fall turnover," and the anoxic layer dramatically diminishes to the point of being almost non-existent. Combining new tools and tried-and-true methods, hydroacoustic mapping, in conjunction with vertical profiling, can provide useful outputs for lake characterization assessments and future resource management.

TEAMING UP TO TACKLE BLUE-GREEN CYANOBACTERIA

The depletion of dissolved oxygen (DO) levels in lakes is often a result of accelerated algal growth during the warm and sunny summer months. During the "dog days" of summer, blue-green cyanobacteria algae proliferate in Lake Attitash. The NELP project sought the support of the University of New Hampshire's (UNH's) Center for Freshwater Biology (CFB) to develop innovative methodologies for monitoring cyanobacteria in lakes. Using this team approach during method development, valuable educational and research opportunities presented themselves as a result of the interactions between a lake association, an educational institution, and a range of governmental agencies.

The water quality issues in Lake Attitash were first brought to the attention of the CFB by staff at the EPA Region 1 Laboratory, who were conducting research on the lake. During an initial exploratory field trip, the CFB Biotoxins Lab Research Team discovered high concentrations of potentially toxic cyanobacteria. These high cyanobacteria levels raised concerns and were reported to the Massachusetts Department of Public Health (MDPH). Additional sampling took place and a health advisory was issued against recreational use of the lake.

These exploratory efforts prompted MDPH to conduct routine sampling of the near-shore area of the lake. As additional sampling between MDPH and CFB began to take place, discussions between the two organizations revealed distinct differences in the sampling techniques used. The CFB measured lake-scale populations in the open water of the lake, while MDPH focused on sampling near-shore accumulations of cyanobacteria that represent the greatest exposure to swimmers. While these two approaches were distinctly different, they complemented one another and provided a relatively holistic assessment of blue-green algae conditions in Lake Attitash during the 2009 sampling period.

These efforts helped secure an MDPH grant to monitor Lake Attitash on a weekly basis in 2010 while the CFB research team and Lake Attitash Association established an in-lake, citizen-based cyanobacteria

A sediment core is retrieved by the UNH CFB from a deep site in Lake Attitash.

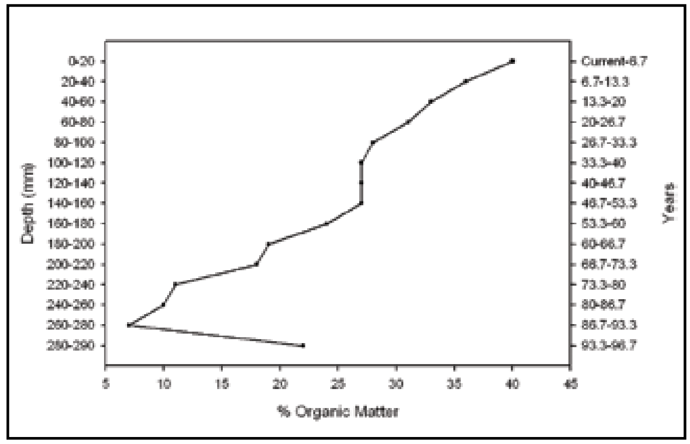


Figure 5-8. *Changes in the organic content of lake sediments in Lake Attitash. Approximate ages at depth in the core were estimated using an assumed sedimentation constant, based on lake trophic condition.*

monitoring program through the summer (see Section 4 of this report). While bacteria advisory thresholds were once again exceeded and advisories posted for 2010, the process provided stakeholders, including local boards of health and water supply purveyors, with a heightened awareness of water quality problems and a heightened interest in trying to resolve them. This resulted in the creation of a well-established and technically proficient monitoring program.

UNH FIELD STUDIES SEEK TO UNDERSTAND AND SOLVE PROBLEMS

A guiding principle of the University of New Hampshire's Center for Freshwater Biology (CFB) is that research and education go hand-in-hand and enhance one another. Supervised students can conduct valuable research while transferring what they have learned on how to solve challenging problems to the public. These experiences are highly educational, and the CFB encourages students to complete their scientific training by submitting completed manuscripts for review by professionals in the field. Students are encouraged to publish their scientific work in an on-line journal, the CFB Research Series (*http://cfb.unh.edu/publications.htm*). These publications contribute to the general literature and often focus on lakes of regional interest to the public.

As interest in Lake Attitash and its multitude of issues has continued to build, Attitash has become a study lake for the UNH capstone course "Field Studies in Lake Ecology," which generally selects lakes with issues that need solutions. For example, coring the lake sediments revealed a pattern of changes in organic matter. Findings suggested that for the past 90 years the lake has experienced a steady increase in nutrient enrichment, as indicated by the continuous increase in organic content (Figure 5-8). Curiously, however, beginning in the 1960s, the rapid change temporarily abated for about a 20-year period. These and other results of the class's investigation were summarized in both a video and an oral presentation given at the annual meeting of the Lake Attitash Association.

WHEN LEARNING INTERSECTS WITH THE REAL WORLD

With interest piqued by the reports of the water quality problems in Lake Attitash, a team of UNH undergraduates interested in the management of lakes set out to gather background information on the lake using the *New Hampshire Comprehensive Lake Inventory,* a data-collection questionnaire developed by the NH Department of Environmental Services (*http://des.nh.gov/organization/commissioner/pip/publications/wd/documents/wd-07-31.pdf*).

Students from Project SMART sampling cyanobacteria at various depths in Lake Attitash.

The students completed a comprehensive lake inventory and management plan for Lake Attitash (*http://cfb.unh.edu/PDF/Special/Lake_Attitash_Management_Plan_2010.pdf*). Using this resource as well as the CFB water quality data and information from discussions with members of the Lake Attitash Association, the UNH lake management team developed a lake management assessment plan and an educational brochure, describing the problems of nutrients and toxic cyanobacteria present in the lake.

Lake Attitash water quality problems have provided many educational opportunities as well as heightened awareness throughout the region and beyond. For example, in summer 2009, a class of 18 high school students from seven U.S. states and three other countries paddled canoes to the deepest location in Lake Attitash. There they logged data on the vertical distribution of chlorophyll-*a* and phycocyanin (cyanobacteria pigment) as part of the Marine and Environmental Science module of UNH's Project SMART (Science & Math Acquired through Research Training) and an outreach/educational activity of the CFB.

The class travelled to Lake Attitash to study a lake now known for its abundance and diversity of toxic cyanobacteria. During the following weeks, students learned to identify the four major taxa of cyanobacteria residing in the shallow and deep waters of Lake Attitash. Potentially toxic cyanobacteria accounted for over 70 percent of the net phytoplankton observed in the lake on that visit.

Of equal interest to the students was a layer of cyanobacteria they discovered three meters below the surface, at a density of approximate 95,000 cells per mL and above the 70,000 cells per mL recreational threshold set by the state. That simple finding had scientific, hands-on, and interactive learning value, as it raised important questions and provoked lively discussions among the students.

A major discussion centered on whether a deep layer of potentially toxic cyanobacteria should be viewed as a public health threat, even though it may be unlikely to be detected in MDPH samples collected near the shore and at the surface, and most lake users are unlikely to come in contact with the layer. However, cyanobacteria are well known for their ability to regulate their buoyancy and accumulate on the surface when their equilibrium has been disrupted. These cyanobacterial observations in Lake Attitash were passed on to the lake association and to MDPH, where they will provide impetus for further discussions about the monitoring, regulation, and management of cyanobacteria.

A storm drain conveying road salts and fine sediments into Lake Attitash.

THE POWER OF COLLABORATION

Other important collaborative efforts involving Lake Attitash are taking place. The Massachusetts Department of Environmental Protection and EPA Region 1 have teamed up to look at potential historical and present day impacts on the lake from adjacent agricultural and urban land-use activities . They are also continuing with ongoing monitoring efforts. EPA is looking into potential opportunities for restoring the trenched wetlands leading into the lake and is partnering with the lake association to evaluate stormwater impacts to help in developing a nutrient budget for the lake.

Nuisance invasive plant species have been making their way into Lake Atttitash, and lake association members have been actively engaged in tracking plant proliferation and developing management strategies to help bring these species under control. EPA has worked in conjunction with these efforts, developing submerged aquatic vegetation maps with low-frequency hydroacoustics.

The lake association has set up aquatic plant identification workshops, sponsored by the Massachusetts Department of Conservation and Recreation (*www.mass.gov/dcr/watersupply/lakepond/lakepond.htm*), to assist the association in gaining more technical expertise and professional input on the most appropriate management strategies. All of these efforts are the result of collaboration, networking, and a willingness to combine efforts toward the common goal of improved water quality and aquatic habitat.

Many of the issues and problems found in Lake Attitash took years and decades to manifest themselves. Many are common problems associated with the lakes of New England and elsewhere and more than likely will take years to resolve. The competing uses of this water body and the complex problems and issues that surround it do not make for easy solutions. However, enthusiasm is contagious, and with the ever-growing network of concerned citizens, universities, and state and federal agencies working on these issues, the sustainability of Lake Attitash and the rest of New England's cherished lakes and ponds is looking brighter.

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Moving Forward...

Section 6

The NELP project demonstrated the power and effectiveness of collaboration. Environmental problems and their surrounding issues are complex, and more often than not, they must be addressed by a broad spectrum of professionals and concerned citizens. Lake associations have their local, in-depth, and historical perspective. State agencies can provide resources for consistent and ongoing monitoring efforts, establish site-specific best management practices, and implement regulatory measures to improve lake condition. Federal agencies can provide additional layers of expertise, provide funding avenues, and introduce new technologies that are often beyond the reach of local and state funding resources. Universities can provide needed research and valuable learning opportunities.

This mixture of attributes provides a tremendously rich resource pool for addressing lake problems. The NELP project has worked hard to foster such collaborative efforts and garner the vast wealth of knowledge and expertise in the region. These partnerships help inform water and land use management decisions at local to regional scales, and provide the keystones to ensuring that the beneficial uses associated with optimal water quality and healthy ecological conditions are improved upon, or at a minimum, maintained in the region.

LIKE A BRIDGE MENDING TROUBLED WATERS

While national and regional statistical probability surveys provide valuable insights on resource conditions and trends at vast geographic scales, their utility to state programs immersed in site-specific lake problems is limited. These large-scale surveys are not statistically designed for detailed lake-specific assessments, or to address resource conditions at state geographic scales. They can be an important and critical component to enhancing traditional state monitoring programs, highlighting common and ubiquitous stressors that are regional or national in scope, and providing a catalyst for cooperative opportunities and additional methods development. Many states have adopted the probability survey approach, and based on additional probability sampling, make unbiased statewide assessments.

The NELP project, in conjunction with the National Lakes Assessment, provided a crucial bridge for supporting states with the resources necessary to implement statistical surveys at the state level. This level of resolution is important to state lake program managers and extends the usefulness of larger-scale efforts. The NELP probability survey is one of many tiers to effective lake management, all of which are important to improving aquatic resource conditions.

Not only can it be beneficial to explore, test, and adopt new monitoring designs and techniques, it is vital to look back at approaches that are currently being implemented and explore ways to improve or derive additional benefits from them. As an example, within the six New England states there are six very different field and laboratory methods for the collection and analysis of Chlorophyll-*a*. Do these different methods yield similar results? A preliminary round robin of state chlorophyll-*a* methods and analyses indicates that they are comparable, showing potential that traditional state monitoring data can be useful in regional assessments.

Another simple example involves the use of view scopes for secchi transparency—some New England states use them while others do not. As it turns out, both approaches can be used simultaneously, adding mere minutes to a survey effort and providing valuable and consistent region-wide trophic indicator data that can be aggregated for more refined assessments. Continuously striving to improve on methods and explore additional opportunities without compromising or negating previous efforts has been an important aspect of the NELP project.

An effective means for addressing identified stressors has been to promote or implement educational efforts

about the stressors, concurrent with implementing best management practices (BMPs) wherever possible. Education along with implementing sustainable practices builds the knowledge level of concerned citizens and resource managers alike, while demonstrating ways to identify and resolve problems. This approach worked well for NELP projects where site-specific BMPs for shoreland protection were implemented and citizen cyanobacteria monitoring programs were developed through collaboration with the University of New Hampshire.

VISIT NELP'S ONGOING WEB RESOURCE

Often final reports are just that—final. The end product of months or years of effort culminates in a narrative document that eventually loses its utility as new projects and reports take its place. The painstakingly reaped data and findings are often lost or soon forgotten, revived only through historical institutional knowledge or an inordinate amount of searching and data gathering.

The NELP project is attempting to maximize the utility of its efforts and avoid this historical pitfall by developing a web resource that will provide access to project data, report narratives, graphics, script codes, and tools used to generate graphics and data assessments. The site will also provide links to other important and relevant websites.

The web design is an attempt to augment a static document (this report), and its supporting data, with a readily available dynamic resource packed with information and tools useful to a wide array of users. The web page is designed to allow users to easily extract data and tools relevant to their needs. The goal is to make this pilot web page a continuous work in progress as new tools are explored and developed and new data are acquired. As national resource and regional probabilistic surveys continue to cycle through, evolving data and associated assessment tools will be added to the site.

Some of the key website elements in development include:

- **All NELP Data:** Data for the NELP project has come from a multitude of sources. State agencies, NELP and NLA teams, academic institutions, and water quality and taxonomic laboratories have all contributed data for this project. Data included on the web page is much more extensive than what has been incorporated into this report. This additional web-accessible data has undergone numerous iterative quality assurance reviews to ensure that it is of the highest integrity and as complete as possible. This information should provide additional insights into New England's lake systems as the data continue to be assessed and evaluated.
- **NELP Data Analysis and Display Tools:** Data from this report will be available for all types of users and will be accompanied by a variety of tools that allow users to quickly generate assessment graphics and summary statistics as found in the report and on the web page. Other data formatted in a like manner or combined with the NELP data can be integrated with these graphics and assessment tools to generate site-specific summary results similar to those in the NELP report. For example, a report card for an individual lake can be compared with those for all other lakes in New England's NELP/NLA project to determine where the lake falls relative to its current trophic condition. (See Water Quality Report Cards highlighted on page 64.) This evaluative process helps point to gaps in data collection efforts and areas where lake managers may find it most prudent to focus their efforts.

THE CLOUD-COMPUTING LINK

The National Institute of Standards and Technology (NIST) defines cloud computing as a "model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction." It is an evolving paradigm.

A cloud-computing pilot project is now under development in collaboration with the Federal Geographic Data Committee (FGDC) and will be a component of the NELP web page. Cloud computing involves access to computing power distributed over the Internet—combining computing power, software resources, and other relevant data and information stored elsewhere that end-users can access.

Cloud-computing applications can be made available to end-users through an Internet web browser or web service, overcoming the need for the end-user to install additional or specialized software. A number of technical design and maintenance challenges remain to be worked out. In the initial pilot-study phases, EPA Region 1 plans to focus on a few specific applications designed to inform public end-user needs, using open-source software and databases and some specialized licensed software. EPA's Office of Research and Development (ORD) is designing additional applications for the more technical needs of EPA policy and regional offices and state regulatory agencies.

As this innovative approach for data analysis and information delivery is further tested, a number of issues still need to be considered:

- Designing, implementing, and testing applications for public end-user client needs
- Addressing more technical end-user needs of EPA and state regulatory agencies
- Securing long-term operational support to maintain cloud-computing applications

User needs assessments are in progress as part of the initial EPA Region 1 and ORD phases of these efforts. Additional discussions will take place related to hardware and software requirements for client-server, cloud-computing applications to determine if these are to be maintained over the long term. If long-term maintenance issues are worked out, additional applications can be designed, tested, and launched. In concept, this is a new way of doing business, and reliability, bandwidth, associated costs, and other considerations still need to be worked out.

EPA Region 1 will be developing and testing specific applications designed for the public, primarily for education, outreach, and to better inform non-regulatory decision making. In parallel, the EPA ORD, Atlantic Ecology Division is designing and testing more involved web-based applications for automated reporting, GIS visualization, and GIS server analyses. These applications are being designed by EPA to facilitate more technical decisions regarding EPA policy and regional offices. A few state environmental regulatory agencies have already expressed interest in this new approach and will be reviewing prototype applications currently being tested inside EPA.

These approaches could change the way data and information are provided to the public. They can help inform non-regulatory decision making, and provide data and information to state environmental agencies in support of water quality standards development and regulatory decision making. As illustrated in the Lake Attitash case study summarized in Section 5 of this report, informing non-regulatory and regulatory decision making is essential to achieving the collective goal of restoring, protecting, and sustaining the many benefits associated with lakes and ponds in New England.

HIGHLIGHT

WATER QUALITY REPORT CARDS

Section 305(b) of the federal Clean Water Act requires states to prepare periodic reports on the status of and trends in their local water quality. The Massachusetts SMART (Strategic Monitoring and Assessment for River-basin Teams) Monitoring Program developed a water quality report card to standardize, store, and report this information. The report card aims to satisfy the need to relate water quality in simple non-technical terms for a variety of audiences. The report card can to be used to:

- **Guide** *water quality management decisions.*
- **Coordinate** *monitoring activities with various groups.*
- **Communicate** *to the public on the progress of state environmental programs.*

REPORT CARD FORMAT

The water quality report card is a simple matrix that presents standardized water quality assessment information for a given water body on a single page. Originally developed for reporting on rivers and streams in Massachusetts, it is currently being tested for its applicability in lake assessment reporting; Lake Attitash is being used as the pilot-test lake. *(Note: a more detailed explanation with accompanying examples of how this approach was originally developed for rivers and streams can be found at the NELP website: www.epa.gov/region1/nelp.)*

The left-hand column of the report card lists the sampling year (this column may also be used to delineate specific lake sampling areas/stations). The indicators being used for assessments are itemized across the top of the report card. At each intersection of the sample-year row and indicator column, the assessment for that lake sampling year and indicator is reported by color code:

Blue: excellent, comparable to reference conditions
Green: good, meets criteria
Yellow: threatened, meets criteria but quality is declining
Orange: fair, partially meets or usually meets criteria
Red: poor, does not meet criteria
Gray: not assessed, information lacking

The colors represent the best professional judgment of the assessors, based on the standardized rules for 305(b) reporting. By displaying colors, instead of raw data, the science is "built in" and the report card is accessible and easily interpreted by non-technical audiences; problem areas can be seen at a glance (Figure 6-1).

The indicators are divided into 10 groups, selected to correspond with the national water-use goals established by the Federal Clean Water Act pertaining to aquatic life, recreation, and fish edibility. The indicator groups represent three environmental compartments in which pollutants may reside—water column, sediments, fish tissue. Response indicators, such as biologic community data, reflect the status of the water-use goals; indicator groups related to exposure are used to diagnose problems. The groups correspond with regulatory programs in Massachusetts to better identify remedial action responsibility. The groups were crafted to show water quality trends over time.

COORDINATING MONITORING ACTIVITIES

The report card can be used to coordinate monitoring activities for various groups so they can make more efficient use of available resources. It has standardized

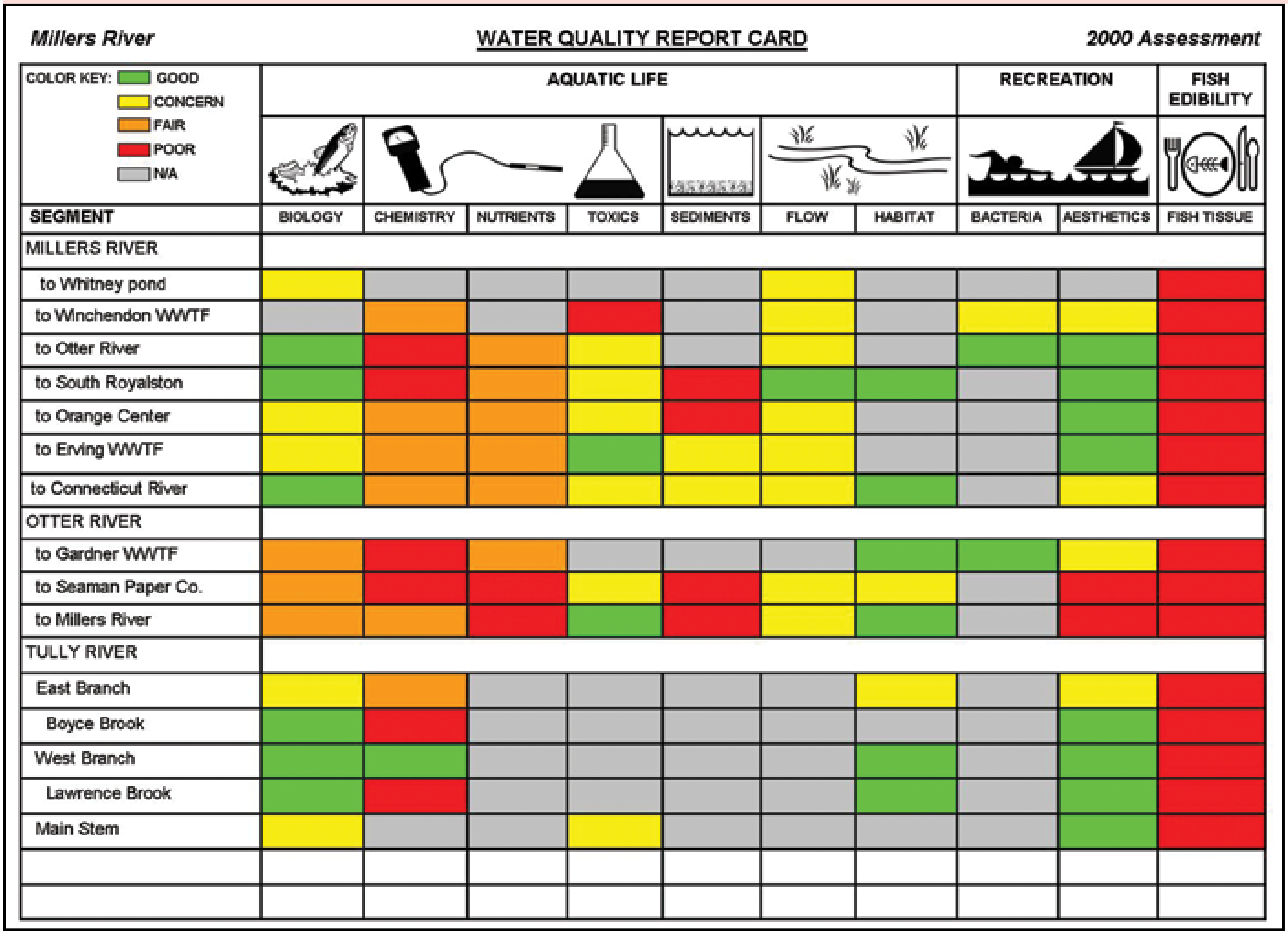


Figure 6-1. *The report card color-coding makes problem areas readily discernible.*

metadata levels for each indicator group. Levels range from 1 to 4—level 4 corresponds with the most rigorous information, level 1 with the least rigorous information. The numeric metadata levels can be superimposed on the indicator cell to inform the resource manager about the level of data behind the assessment (Figure 6-2). Level 3 and 4 metadata are generally acceptable for 305(b) reporting, whereas 1 and 2 metadata levels may be lacking or suspect in some regards. This format is useful in that it highlights areas with insufficient information for sound decision making—knowing what you don't know can be valuable information for planning.

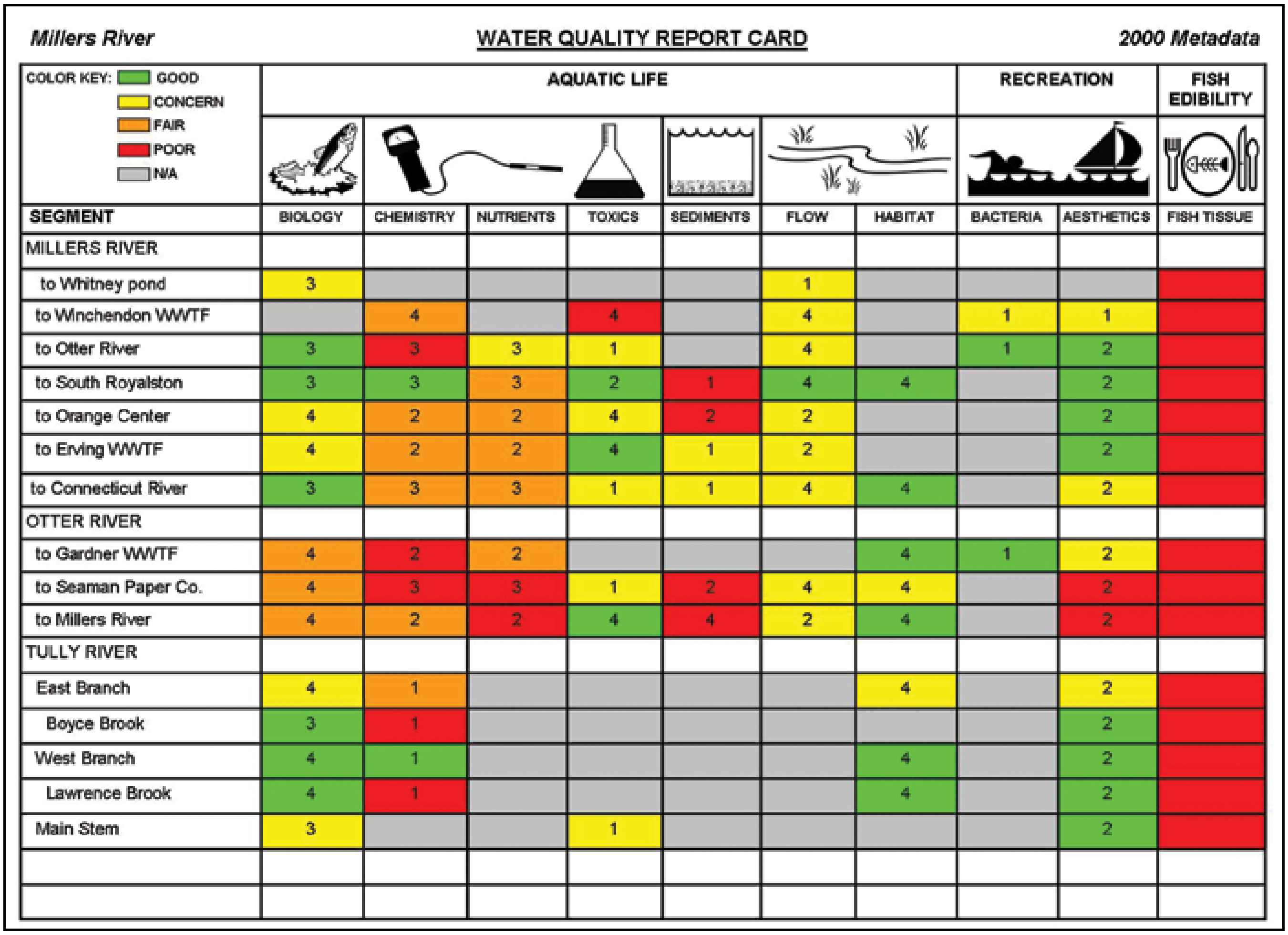
A GUIDE FOR DECISION MAKING

Report cards are useful tools for decision makers at all levels of resource management. The format brings distilled data to an interpretable level that visually highlights problem areas and easily portrays the level of data supporting the assessments. Large and complex datasets can be easily understood by the average citizen and acted upon by lake associations and state water quality resource managers alike. Identified problem areas can then be targeted to best optimize management and cost, while tracking changes to the resources over time.

COMMUNICATING TO THE PUBLIC

The public has the right to know how our environmental programs are working, and the government has a clear obligation to inform the public. This process should be as transparent as possible. The public is the government's best ally in securing the resources needed to accomplish its regulatory mission.

Water Quality Report Cards



Millers River			WATER QUALITY REPORT CARD							2000 Metadata
COLOR KEY: GOOD, CONCERN, FAIR, POOR, N/A	AQUATIC LIFE							RECREATION		FISH EDIBILITY
SEGMENT	BIOLOGY	CHEMISTRY	NUTRIENTS	TOXICS	SEDIMENTS	FLOW	HABITAT	BACTERIA	AESTHETICS	FISH TISSUE
MILLERS RIVER										
to Whitney pond	3					1				
to Winchendon WWTF		4		4		4		1	1	
to Otter River	3	3	3	1		4		1	2	
to South Royalston	3	3	3	2	1	4	4		2	
to Orange Center	4	2	2	4	2	2			2	
to Erving WWTF	4	2	2	4	1	2			2	
to Connecticut River	3	3	3	1	1	4	4		2	
OTTER RIVER										
to Gardner WWTF	4	2	2				4	1	2	
to Seaman Paper Co.	4	3	3	1	2	4	4		2	
to Millers River	4	2	2	4	4	2	4		2	
TULLY RIVER										
East Branch	4	1					4		2	
Boyce Brook	3	1							2	
West Branch	4	1					4		2	
Lawrence Brook	4	1					4		2	
Main Stem	3			1					2	

Figure 6-2. *Sample report card for a major river basin showing metadata levels superimposed over the assessment colors.*

The report card has proved itself effective in this role. Water quality trends can convey the most convincing evidence of environmental success or failure.

EPA EFFORTS

EPA's Atlantic Ecology Division is working to automate the processes for creating prototype report cards, using Excel spreadsheet applications and other licensed software. The automated reporting approach could be adapted by states that embrace the goal of making their environmental reporting process easy, reliable, and adaptable for any state's reporting structure.

The prototype Excel applications include all numerical and narrative information needed to evaluate the resource condition, which is copied to Excel worksheets and organized in a workbook. Template graphics are included on individual worksheets to display relationships and trends in data and aid in lake-assessment decisions. For example, the nutrient concentration may be plotted versus time relative to a threshold value specified by the user.

The use of these worksheets and simple graphic displays of information can help the assessor draw a conclusion regarding nutrient-impairment status. The user can generate any additional graphics to explore data structures and relationships of particular interest. The assessor then uses the graphics and narratives to specify the indicator status, metadata level, and pollution-source assignments, needed to create the report card. The worksheets have designated

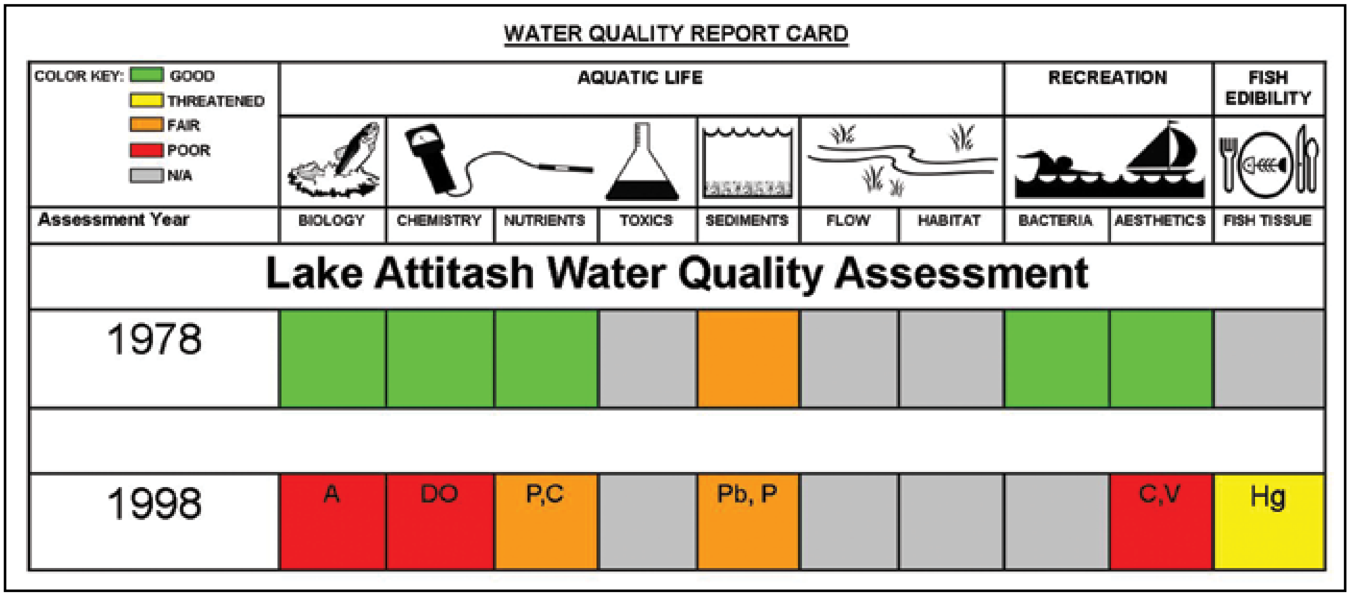


Figure 6-3. *Sample report cards for Lake Attitash spanning a 20-year period.*

locations for this information, and are designed to help automate the process. They serve as an archive of raw information and help document the decision process used by the assessor to evaluate environmental conditions.

This process is valuable with regard to a state regulatory agency's transparency. It allows the agency to easily "recreate" an assessment in standardized reporting terms, even in the absence of the original assessor. Finally, in the prototype calculator tool, macro-driven algorithms can be designed to automatically convert the assessor's decisions into the colored, annotated cells in the report card. The automated process should help speed technology transfer of computation methods and encourage other states to adopt automated water quality report cards as useful assessment and reporting tools.

THE LAKE ATTITASH REPORT CARD

The NELP findings were applied to the water quality criteria used to make the assessment decisions. In Figure 6-3, the report card is being used to show the 20-year trend in water quality for Lake Attitash in Amesbury and Merrimac, Massachusetts. During this 20-year timeframe the lake's trophic status went from oligotrophic to eutrophic, bordering on hypereutrophic. Dissolved oxygen levels now drop to near zero, and the lake is plagued with blue-green algal blooms that degrade the aesthetics of the resource and pose possible public health risks. Water clarity has decreased and phosphorus levels have increased.

The report card clearly displays this declining trend in water quality and can be a useful tool to both alert citizens to these problems and serve as the basis for planning lake restoration activities. The lake's problems stem from various nonpoint sources of pollution, including stormwater runoff from agriculture, residential areas, highways, and construction activities. Sand and gravel operations and the suspension of nutrients from lake sediments may also contribute to impaired conditions. Finally, atmospheric deposition is responsible for precautionary advisories for mercury contamination in fish tissue, and the lake locality has been identified as a hotspot for mercury deposition from regional sources.

This highlight was provided by Warren Kimball, MA DEP.

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NELP Resources

Section 7

Visit the NELP Website at: *www.epa.gov/region1/nelp*

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Connecticut DEP: **Bureau of Water Protection and Land Reuse, 860-424-3000**

Maine DEP: **Bureau of Land and Water Quality, 207-287-7688**

Massachusetts DEP: **Bureau of Resource Protection, 508-792-7650**

New Hampshire DES: **Water Division, 603-271-3503**

Rhode Island DEM: **Division of Water Resources, 401-222-6800**

Vermont DEC: **Monitoring, Assessment and Planning Program, 802-241-3770**

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