4

Problem Diagnosis: Seeing Beyond the Symptoms

Introduction

When problems arise, it is human nature to try to fix what is obviously wrong. A quick fix may be a logical first step, but it is rarely enough and it may take resources away from a better long-term solution.

An example of this is algal blooms. Solving the problem of these smelly, noxious films that can look like paint spills is not simply a matter of poisoning or mopping up the algae, although that goes a long way toward making the lake look nicer. Controlling these blooms requires understanding factors that trigger them, which in turn should focus attention on those actions or sources that contribute to the blooms. Permanent solutions to these problems often require a long-term change in habits rather than an immediate fix.

Controlling algal blooms requires understanding factors that trigger excessive plant growth, such as an abundance of nutrients. Once a cause such as too much phosphorus is determined, the sources of the phosphorus can be identified and a plan made to reduce its input into the lake. The actions needed are different if the source of the phosphorus is lawn fertilizer rather than phosphorus attached to soil particles eroded from upland areas of the watershed. Addressing either of these underlying causes requires changes that go beyond an immediate fix, and involves far more people than those who are experiencing the algae and weed problem.

An analogy may be instructive. When a patient arrives at a doctor's office with a fever, the doctor does not simply prescribe something to relieve the fever. In fact, since fevers are part of the body's defense system, controlling a fever may actually interfere with these defense mechanisms. If a fever is too high, however, it prevents a body from functioning normally, and should be controlled. In addition to bringing a high fever down, the doctor will seek to understand and then treat the cause of the fever, such as controlling a bacterial infection with antibiotics, and educating the patient to reduce the chance of future infection.

Although not a perfect analogy, native plants are like low fevers. Increased native plant growth may be a lake's response to an increasing nutrient and sediment load. It may be a defense mechanism protecting the lake from other more significant responses such as algal blooms or high turbidity. Merely cutting the weeds, like lowering the fever, will do little to solve the real problem.

Connecting symptoms to causes to sources that point to remedial actions, is often crucial to building

Concentration versus load

Water samples collected from a stream are sent to a laboratory to identify the quantities of certain contaminants that may be present. The result of one test may tell how much phosphorus is in a particular amount of water, such as 0.02 micrograms of phosphorus in one liter of water (µg/l).

While concentrations provide useful information about exposure to a pollutant, they do not quantify how much phosphorus a stream is transporting to a lake. To determine the total quantity of a pollutant a stream is contributing, water-flow data are needed. Once the amount of water flowing into a stream at the time of sampling is known, the amount of phosphorus moving through the stream can be determined. A calculation using both the concentration value and the water-flow data gives the amount of phosphorus loading in the stream.

To illustrate it another way, if a one-ounce piece of chocolate has one gram of fat, then the concentration of fat in each piece of chocolate is known. This information alone is not enough. Knowing how many pieces of chocolate are consumed determines the total fat loading from the chocolate. For the health of waterbodies, as for people, loading information can be very informative.

a useful lake and watershed management plan. This is an important model to understand, even if it does not apply to all types of lake problems. Water-quality and lake-use problems may have begun to develop, but have not yet resulted in obvious symptoms or use impairments. An important symptom, such as the loss of a rare plant, may even have gone unnoticed.

Determining the causes of lake problems requires time and effort. It does little to provide short-term relief for those tired of swimming through weeds or suffering from clogged propellers. Comprehensive lake management often provides temporary bandages to cover the wound while long-term healing is taking place. Lake managers, municipal officials, lakefront residents, and taxpayers will continue to debate how much effort and resources should be invested in bandages. Everyone recognizes that bandages are sometimes necessary to allow the wound to stay clean. They also recognize that people are more likely to continue supporting long-term control strategies if those bearing the burden of reducing the flow of nutrients are shown some short-term successes.

This chapter provides tools for systematically diagnosing the underlying causes of common lake problems to develop solutions with long-term benefits.

Monitoring

Monitoring, sampling or testing refers to collecting information, usually from water samples, to evaluate the condition of a lake. Monitoring can reveal water-quality patterns and relationships among water-quality indicators that point to the cause, and sometimes the source, of a problem.

Current data must be collected, using methods that are accurate and reproducible, in order to develop management strategies that address lake problems. It is not enough to have one number indicating, for example, the amount of phosphorus. Where and how often samples are taken, and the type of phosphorus found will affect the usefulness of the information. To analyze and evaluate these data, additional information is required, including weather conditions, lake-bottom contours, watershed activities, and any other factors affecting water quality. The various facets of designing and using monitoring data are broken down into Why?, Who?, What?, Where?, When?, and How?

Why?

This is the first and most important question to answer. Any monitoring program devised without a clear understanding of this question is not likely to generate an acceptable answer to Why? Programs developed with clearly articulated objectives can usually provide easy answers to the Who?, What?, Where?, and When?. The "Why?" of monitoring programs can change or expand once the initial questions are answered, but most of the "Why's" can be summarized as follows:

- *Is the lake safe (for drinking, swimming, eating the fish, etc.)?* Will lake users get sick after consuming the water or fish, or will a wader be injured walking along the lake bottom? It might also relate to whether the lake is safe for the health of the fish and other organisms that share the water.

- *Does the lake support its intended uses?* Chapter two, "From Montauk to Erie," discussed how each of the lakes in New York State is classified for its best intended use, whether it is for drinking water, swimming, fishing, or support of aquatic life. A lake management and monitoring plan should be designed to collect the data require to meet the desired goals.

- *What is the quality of the water?* This includes factors such as the taste or odor of the water, or whether lake users would be offended by excessive algae or weeds, or would enjoy swimming, angling, boating, or looking at the lake. Future water-quality problems, or those not directly related to human use, may also be addressed by this question.

- *What is the condition of the lake?* Many government monitoring programs evaluate general conditions, conduct inventories for water-quality conditions, identify aquatic flora and fauna, identify regional or statewide patterns in lake use, and characterize lake conditions. These programs are frequently developed to meet government reporting or permitting requirements and to identify locations for more intensive or more targeted monitoring.

- *Is the lake condition getting better or worse?* Long-term monitoring programs often identify water-quality trends, which may aid in evaluating patterns.
- *Did we solve the problem?* Many lake monitoring programs are developed after a lake management technique has already been employed, whether it was an activity to improve water-quality conditions or to enhance lake use. These tend to be reactive monitoring programs, rather than proactive, and usually suffer from a lack of pre-management data.
- *What is the relationship between A and B?* Many of the lake-monitoring programs conducted in New York State have been associated with research studies. Academic research is usually less concerned about conditions in specific lakes than with exploring relationships among lake indicators.
- *Is there enough water to support all lake uses and to protect downstream users?* Water-quantity data, such as lake level, tributary and outlet flow, and water-intake quantities, are often collected to evaluate whether specific lake demands are being met.

Who?

This is the easiest question to answer. Anyone can monitor their lake. Many water-quality indicators, however, need to be sampled using specialized equipment and techniques, and the costs to analyze some water-quality parameters may be too expensive for the typical lakefront resident. Monitoring is not rocket science; citizens, students, and laypeople as well as pointy-headed scientists throughout New York State already collect good quality data.

Individual lake associations have for years designed formal and informal water-quality testing programs for their lakes. Some require long-term monitoring and use water-sample data collected during several years to determine general water-quality characteristics and how they have changed through time. Other programs investigate specific problems, and are usually short-term, intensive studies. Both types of programs can be useful.

In addition, government agencies, drinking water suppliers, scientists and researchers may have already collected water-quality data useful for developing a lake management plan, or for answering a specific question about the condition of a lake. Information and old reports can be found at the local library, or in the files of the lake association secretary, town clerk, county agency staff, or state government official. The U.S. Environmental Protection Agency's (EPA) electronic repository for water-quality data, called STORET (STOrage and RETrieval), holds more than 200 million water sample observations from about 700,000 sampling sites for both surface and ground water. Much of the STORET information is accessible through the EPA website. (See Appendix F, "Internet resources")

Long, long ago…1926 to 1980

It is helpful to know the history of lake monitoring to effectively search for previously collected data. The New York State Conservation Department, now the New York State Department of Environmental Conservation (DEC), conducted a biological survey of each of the major drainage basins in New York State from 1926 to 1934, focusing on fisheries resources and stocking. These studies also evaluated lake and stream water quality related to temperature, oxygen and clarity, invertebrates, plankton, aquatic vegetation, and even aquatic parasites. Dozens of small to large lakes were sampled within each basin. Usually only a single sampling session was conducted at each lake, but the samples provided an invaluable snapshot of conditions at that time. These studies can be found at DEC regional offices and selected libraries across the state.

In 1972 EPA conducted a national eutrophication study of 26 lakes in New York State to "investigate the nationwide threat of accelerated eutrophication to freshwater lakes and reservoirs." These studies used lake and stream monitoring to look at nutrient loading in lakes, and evaluated other traditional water-quality indicators and plankton levels. The study results are available through STORET.

Recently defunct programs… 1980 to 2000

The Eastern Lake Survey, conducted in 1984 and 1986, was part of a long-term effort by the EPA known as the National Surface Water Survey. It identified the acidity of surface waters in the United States in areas susceptible to the effects of acid rain. The effort was conducted in support of the National Acid Precipitation Assessment Program. It involved about 1,700 lakes throughout the United States, including 220 lakes in New York State, and these data are available through STORET.

In the 1990s the EPA developed a similar program called the Environmental Monitoring and Assessment Program (EMAP). EMAP was a research program designed to develop the tools necessary to monitor and assess the status and trends of national ecological resources. They planned to sample at four-year intervals a group of lakes within the northeastern United States to determine water-quality changes and trends of a core group of ecological indicators. After about 130 lakes in New York had been sampled from 1991 to 1993, however, the lakes portion of this program shifted to a different region of the country. These data are available through STORET. In recent years this program has changed into a national survey program conducted by EPA in recent years and is described below.

The federal Clean Lakes Program (under Section 314 of the *Clean Water Act*) provided resources to government agencies and others to diagnose water-quality problems (Phase I projects), and to implement water-quality improvement projects (Phase II projects). Water-quality monitoring was conducted from the late 1970s to the mid-1990s on about 25 New York State lakes as part of this program. This program has largely been folded into other federal programs, and the emphasis on water-quality monitoring merged into broader, statewide monitoring efforts. Information about individual lakes surveyed or managed as part of this program is available from DEC's Division of Water (see Appendix F, "Internet resources")

Ongoing programs

The New York City Department of Environmental Protection (NYCDEP) conducts systematic monitoring at each of the 19 reservoirs that supply drinking water to the nearly 10 million residents of the greater New York City area. Summaries of the water-quality results from this monitoring can be found at the NYCDEP's website. (See Appendix F, "Internet resources")

By a cooperative agreement in 1984, the Empire State Electric Energy Research Corporation and DEC established the Adirondack Lakes Survey Corporation to determine the extent and magnitude of acidification of Adirondack lakes and ponds. From 1984 to 1987, the not-for-profit organization conducted an extensive baseline survey of nearly 1,500 lakes within the Adirondacks and high-elevation lakes downstate. In 1992, a long-term monitoring project on a subset of 52 of these lakes began. These data are available through the Adirondack Lakes Survey Corporation website. (See Appendix F, "Internet resources)

The Adirondack Effects Assessment Program is a multi-institutional effort to survey the biological community structure in Adirondack lakes. Institutions involved include Rensselaer Polytechnic Institute, DEC, the U.S. Geological Survey (USGS), and other organizations. The goal is to determine if chemical and biological changes have occurred, and provide baseline information for assessing recovery in the future. These studies began in 1994 and focus on the biological community structure in 30 lakes located in the highly impacted southwest corner of the Adirondacks.

DEC conducts an ambient lake monitoring program on lakes and ponds throughout the state. This program, originally called the Lake Classification and Inventory Survey, sampled lakes in the mid-1970s, and then from 1982 through 1991, and has continued annually since 1996. The program evaluates the trophic condition of previously unmonitored lakes and compares contemporary conditions in lakes with use impairments listed on the state Priority Waterbody List (PWL). It is now part of the Rotating Intensive Basin Surveys (RIBS), the state's ambient surface water-quality monitoring network that each year samples waterbodies within two or three different drainage basins. Approximately 200 lakes have been sampled as part of this program, which was funded from portions of the federal Clean Lakes Program and from ongoing DEC monitoring efforts. Nutrient data collected within this program prior to 2000 are available through the EPA nutrient database from the EPA Office of Water website. Other data are available through the DEC Division of Water. (See Appendix F, "Internet resources")

The DEC Division of Water has also engaged in a long-term monitoring project on the Finger Lakes. Results from this project can be found by searching for, "Water Quality Study of the Finger Lakes" on the DEC website. This project has been taken over by the Upstate Freshwater Institute in Syracuse.

Fisheries staffs at regional DEC offices have been sampling lakes for many years in support of fish stocking and habitat protection activities. Water-quality sampling results, fisheries surveys, fish tissue analyses, and habitat assessments can be obtained by contacting the appropriate DEC Regional Fisheries office. These include special studies of Lake Ontario, the Finger Lakes, and specific contaminant studies such as mercury, PCBs, and other toxins.

Lakes and reservoirs are among the more than 1450 surface water supplies serving more than 15,000 New Yorkers. The New York State Department of Health (DOH) issues an annual water quality report called the DOH Source Water Assessment Program (SWAP). It provides information to

- determine the potable water source;
- inventory potential sources of contamination that may impact public drinking water sources; and
- assess the likelihood of a source water area becoming contaminated.

The DOH Source Water Protection Program works with municipalities and other agencies to monitor and assess pathogenic threats to water supplies, and conducts studies of harmful algal blooms (HABs) in lakes and reservoirs throughout New York state.

A survey of about 900 of the nation's lakes was conducted by EPA in 2007 as part of a continuing series of national surveys. Survey sites were randomly chosen by EPA and sampled by state agencies, consultants, and academicians throughout the country. The DEC surveyed the 12 New York State lakes chosen as part of this survey for a wide variety of physical, chemical, and biological indicators. It is anticipated that these surveys will be repeated in five-year increments, most likely with a different set of lakes.

Academic, local government, and private monitors

State or federal governments or their partners have conducted the majority of the large-scale, multi-lake or multi-year studies of lakes in New York State. County and local governments, academic institutions, consulting firms, and private citizens have managed many smaller studies and monitoring projects.

A number of counties within the watersheds of Lake Ontario and the Finger Lakes have conducted water-quality monitoring on lakes and streams using state funds allocated to them from the Finger Lakes-Lake Ontario Watershed Protection Alliance (FL-LOWPA). Some counties have used these funds to sponsor volunteer water-quality monitoring projects. Others have conducted monitoring programs to evaluate impacts of nonpoint source pollution on lake water quality. Individual programs are discussed in detail at the FL-LOWPA website. (See Appendix F, "Internet resources")

All municipal water supplies are required to monitor the quality of their raw, untreated water supply and issue reports summarizing the results. This includes the multi-use reservoirs found in many parts of the state. Many of these reports can be found on municipality websites. All municipalities with water supplies serving more than 100,000 residents are required to post these reports online. These reports generally contain useful information, even though most of the parameters of interest for lake water quality are not sampled in these drinking-water programs.

The local departments of public works also conduct monitoring of discharges from municipal wastewater-treatment plants, and maintain records associated with the disposal of municipal wastes. This information can provide insights about potential pollutants entering lakes and could be included in lake-monitoring programs.

Many colleges and universities in New York State have been actively involved in water-quality monitoring that complements their educational efforts, supports academic research, and facilitates community relations. Some of these academic institutes or researchers, their research topics, and the waterbodies being studied, are:

- Cornell University: Water quality, aquatic vegetation, fisheries, and ecosystem research in the Finger Lakes, Onondaga Lake, Lake Ontario, Chautauqua Lake, Waneta Lake, Lamoka Lake, and several Madison County lakes.
- Syracuse University: Acid rain and mercury pollution in the Adirondacks.
- Rensselaer Polytechnic Institute: Water quality, aquatic vegetation, and ecosystem research on Lake George, Onondaga Lake, and Adirondack lakes.
- Paul Smiths College: Water quality and paleolimnology studies of Upper Saranac Lake, St. Regis Chain of Lakes, and other Adirondack lakes.
- Colgate University: Water quality and ecosystem research in Central New York lakes.
- Clarkson University: Ecosystem research on Lake Ontario and the Cascade Lakes.
- Finger Lakes Institute: Water quality and ecosystem research and environmental education on the Finger Lakes.
- Hobart and William Smith College (home of the Finger Lakes Institute): Aquatic research on the Finger Lakes, particularly Seneca Lake, and comparisons across the Finger Lakes.
- Institute for Ecosystem Studies: Ecosystem research on Adirondack lakes.
- Keuka College: Water-quality studies of Keuka Lake.
- Southampton College: Water-quality studies of Trout Pond in Southampton and evaluation of algal toxins in freshwater ponds in Long Island.
- SUNY Binghamton: Aquatic vegetation studies of Adirondack lakes and Central New York lakes.
- SUNY Brockport: Aquatic vegetation, fisheries, and ecosystem research on the Great Lakes and Finger Lakes.
- SUNY Buffalo: Water quality and ecosystem studies of the Great Lakes and Finger Lakes.
- SUNY College of Environmental Science and Forestry: Phytoplankton and ecosystem research on the Finger Lakes, Great Lakes, and select Adirondack lakes; algal toxin research throughout the state.
- SUNY Cortland: Water quality in small ponds in Central New York.
- SUNY Fredonia: Water quality, aquatic vegetation, and fisheries studies of Lake Erie, Chautauqua Lake, Cassadaga Lakes, Bear Lake, and Findley Lake.
- SUNY Plattsburgh: Water quality work on Lake Champlain.
- Union College: Water quality, paleolimnology, and ecosystem studies of Ballston Lake, Collins Lake, and select Adirondack lakes.
- Upstate Freshwater Institute: Water quality and paleolimnology studies of Onondaga Lake, the New York City Reservoir systems, several Adirondack lakes, the Finger Lakes, and Central New York lakes.
- Wells College: Water-quality studies of Cayuga Lake.

Several colleges and universities maintain field stations on larger New York State lakes that allow for long-term research and provide a training facility for students and visiting researchers. These include:

- Cornell Biological Field Station at Shackelton Point on Oneida Lake.
- Darrin Freshwater Institute, Rensselaer Polytechnic Institute, on Lake George.
- Huyck Preserve and Biological Field Station at Lake Myosotis.
- SUNY College of Environmental Science and Forestry: Thousand Islands Biological Field Station in the St. Lawrence River; Cranberry Lake Biological Field Station, and the Adirondack Ecological Center on Arbitus and Rich lakes.
- SUNY Oneonta Biological Field Station on Otsego Lake.
- SUNY Oswego Biological Field Station on Rice Creek, Lake Ontario.

Environmental organizations have also been involved in lake monitoring for many years. The Nature Conservancy (TNC) is perhaps the most prominent of these organizations. TNC conducts a number of monitoring programs throughout the state on contract with the DEC through the Natural Heritage Program. They focus on loons in Adirondack lakes, invasive plants on Long Island and in the Adirondacks, and protected plant species throughout the state.

Volunteer monitoring and CSLAP

Volunteer monitoring dates back to the late 1800s with the network of weather watchers assisting the professionals at the National Weather Service to identify long-term weather patterns. In fact, volunteer-staffed stations outnumber professionally staffed stations by more than 40 to 1! Volunteers have also provided a national network of observations on bird populations through the National Audubon Society's Christmas Bird Count, started in 1900, and the U.S. Fish and Wildlife Service's Bird Banding Program, started in 1920.

Volunteer water- and lake-monitoring programs evolved after from the passage of the *Clean Water Act* in 1972. Pioneering lake-monitoring programs formed in Michigan and Maine, and volunteer stream-monitoring programs began in Maryland and through the Izaak Walton League, a nonprofit conservation organization. As state and federal dollars available for government-run monitoring programs continue to decline, or are dedicated to other environmental concerns, large-scale lake monitoring programs have been reduced. In their place, volunteer monitoring programs have played a more prominent role in gathering baseline data for lake managers and lakefront residents.

Individuals interested in lake monitoring will benefit from involvement in an established program rather than working alone. Monitoring programs usually have standardized sampling equipment, materials and testing procedures designed for specific monitoring objectives. Standardization facilitates comparison between lakes and lends validity to the process when sharing data with municipalities or agencies. It may cost more per sample to join a program, but the extra cost may be balanced by access to equipment, expertise in interpreting results, and special arrangements with laboratories and shipping vendors that give bulk-rate discounts to program participants.

There are currently at least ten volunteer lake-monitoring programs in New York State. A much larger number of less formal organizations are dedicated to monitoring a particular parameter such as bacteria levels, invasive plants, and zebra mussels. Others are using monitoring as an educational tool through floating classrooms, lake associations, and other venues. Some monitoring programs are regional. The Adirondack Park Invasive Plant Program (APIPP) is a joint partnership between TNC, the Adirondack Park Agency (APA), DEC, the New York State Department of Transportation (DOT) and others. It trains volunteers to search for exotic plants and works with the DEC and the Darrin Freshwater Institute (DFI) on Lake George to build an inventory of exotic plants found within the Adirondacks and throughout the state. More information can be obtained from the APIPP website. The site also contains lists of related organizations, like the Residents Committee to Protect the Adirondacks, which works with volunteers to evaluate water-quality conditions in about 60 lakes through the Adirondack Lake Assessment Program at Paul Smith's College. (See Appendix F, "Internet resources")

The largest and most extensive volunteer lake-monitoring program is the New York Citizens Statewide Lake Assessment Program (**CSLAP**), a cooperative effort between the New York State Federation of Lake Associations (NYSFOLA), DEC, and lay-volunteer monitors throughout the state. CSLAP was founded in 1986 to collect water-quality data for sound decision-making, identify water-quality problems, and educate lake residents, municipal officials and lake managers. CSLAP volunteers from NYSFOLA member lakes are trained by professional staff to collect water samples, perform field tests, and provide standardized observations about lake conditions and use impairments. DEC provides CSLAP volunteers with equipment and field guides to conduct bi-weekly sampling from May through October. Samples are collected from the deepest part of the lake, and from the bottom of thermally stratified lakes (warm on the top, cold on the bottom). Samples are analyzed at a state certified laboratory (Upstate Freshwater Institute) that has an expertise in lake monitoring and analyses. Aquatic plant samples are also collected and identified for lake associations concerned about invasive plants, rare and endangered species, or other discoveries at their lakes.

More than 225 lake associations and 1,200 volunteers have participated in CSLAP since its inception, collecting more than 18,000 samples. At the end of each sampling season, DEC provides a report for each lake association summarizing water-quality results from previous sampling seasons, including information about management implications for the measured conditions in the lake. Information about participating in CSLAP, and electronic copies of individual lake reports, can be obtained from NYSFOLA and DEC.

What?

In a world where equipment and funds for analytical interpretations were unlimited, a lake monitor could collect a barrel of water and bring it to a laboratory with instructions to "Analyze it for everything." Resources for water sampling are limited and, thankfully, such detailed monitoring is rarely necessary. The results from such an exhaustive investigation would show no detectable levels for the vast majority of lake water-quality indicators.

Most water-quality monitoring projects focus on analyses of a few key indicators that provide the most useful information to answer a defined question. Investigative studies to pinpoint the exact location and cause of a specific problem may employ a sampling protocol with many different parameters. Long-term baseline monitoring to discern how water quality is changing over time may involve only a few parameters tested regularly over a span of years.

While no one set of analyses are appropriate for all water-quality investigations, a core group of limnology procedures and water-quality parameters form the basis of most monitoring programs. Some of these analytical tests, such as Secchi disk transparency, water temperature, algae levels, color and turbidity, are directly related to the symptoms of a problem. Other tests, such as dissolved oxygen, nutrients, and pH levels, can provide significant information about the causes of a problem. In many situations, other water-quality analyses, such as extensive macrophyte surveys, sediment sampling, zooplankton and phytoplankton species identification, or chemical parameters, are needed to gain a greater understanding of the linkage between a symptom and a cause in any particular lake. The results from any given test may determine the direction of future investigations. Many of these water-quality analyses and parameters will provide a good starting point for developing an appropriate monitoring program or testing regime.

Secchi disk transparency

The **Secchi disk** is a 20 cm (centimeter), steel or heavy plastic disk quartered into alternating sections of black and white. It is attached to a measured rope or cable and lowered over the shaded side of a sampling boat to measure the transparency of the lake. Water transparency is the average of two depths: the depth at which the disk first disappears from sight as it is lowered, and the depth at which it re-appears at it is slowly raised. It is an utterly unsophisticated

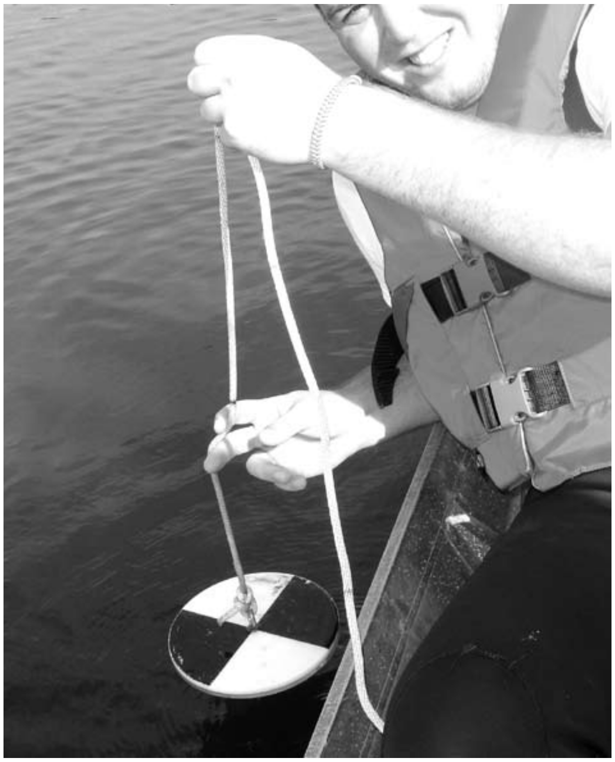

Fig. 4–1. A Secchi disk is a 20 cm disk, quartered into sections, and used for measuring water transparency. (CREDIT: JOHN FOSTER)

but eminently useful tool that dates back to the mid-1860s, when papal cartographer Angelo Pietro Secchi designed it to help him predict circulation patterns in the Mediterranean.

Secchi disk transparency is influenced by concentrations of phytoplankton, suspended inorganic material, such as silt or calcium carbonate ($CaCO_3$), and dissolved organic substances. Each of these substances imparts a color to lake water, ultimately influencing the extent to which light can pass through it. The perceived transparency is also influenced by cloud cover, glare and angle of the sun, wave action, rooted aquatic vegetation, reflection from the lake floor and in extreme cases the vision of the sampler. These interferences can cause a discrepancy between actual and perceived transparency. Despite these interferences, Secchi disk transparency often serves as a surrogate measurement of algae levels in clear lakes with only limited biological productivity (little humic material or other dissolved organic matter), which in turn often provides insights about nutrient levels in the lake.

Temperature and dissolved oxygen profiles

Temperature and oxygen profiles determine the degree of stratification, and the potential for depletion of oxygen, adversely affecting fish and other aquatic organisms. **Dissolved oxygen** is affected by temperature, time of day, and pollution. As water temperature decreases, increasing amounts of oxygen can dissolve in water. During the day, photosynthetic plants create oxygen, and use it at night. Aerobic bacteria and other organisms require oxygen for the consumption of wastes.

Fish and other aquatic organisms require a minimum of four to five milligrams-per-liter (mg/l) of oxygen. The most accurate way to measure oxygen levels is to use a wet-chemistry titration. Reagents are added to a water sample causing a color change when titrated with other reagents. This method, however, is very time-consuming, and requires some pretty nasty chemicals.

Many elaborate lake monitoring programs use electronic meters that utilize miniaturized versions of laboratory tests to collect in-situ (“in place”) measurements of an increasing number of water-quality indicators. Temperature and dissolved oxygen meters constituted the first version of these meters, allowing discrete measurements to be taken from lake surface to lake floor, usually in one-meter intervals. Many of these meters, now referred to as multi-parameter probes, can detect an increasing number of water-quality indicators at various degrees of accuracy and reliability. Since electronic meters are expensive, however, most volunteer monitoring programs seldom use them.

Simple dissolved-oxygen test kits are relatively inexpensive at less than $1.00 per test, and are accurate enough for rough evaluations of oxygenation and **hypoxic** (low-level of dissolved oxygen) or anoxic (insufficient supply of oxygen) conditions. Their use is time-consuming, however, especially for constructing full-depth profiles.

Precipitation and lake level monitoring

Precipitation can greatly affect the overall hydraulic or water budget for lakes, especially in lakes with negligible groundwater, or water that flows from springs. Precipitation can also affect the water level in a lake, resulting in potential recreational and pollution problems by affecting boating and drinking water access, the degree of shore erosion, vegetation levels, or ecosystem dynamics.

Precipitation is accurately measured at more than 100 New York State sites with U.S. National Oceanographic and Atmospheric Agency, National Weather Service (NOAA) gauging stations. It can be measured at a local level by a simple rain gauge installed near the lake surface. Simple rain gauges are not as accurate as those used by NOAA, but provide a more accurate local rainfall measure if the NOAA weather station is a few miles away where weather patterns might be very different.

Lake level can be determined by attaching a staff gauge, calibrated in small increments, to a permanent structure. Frequent measurements, often daily, can determine precipitation totals and water level. Measured simultaneously, precipitation and water-level gauging can determine the influence of direct rainfall on the overall hydraulic budget.

Macrophyte surveys and mapping

Vegetation surveys usually involve some combination of measures or estimates of plant quantities and locations within a lake, which can have a significant affect on recreational access, quality of fisheries, and the overall aesthetic appeal of a lake. This information can provide an understanding of the water quality and use impairments in a lake. The full spectrum of aquatic vegetation surveys, from the simplest to the most sophisticated, is described in a report authored by Madsen and Bloomfield (1993), available through the North American Lake Management Society (NALMS) website. (See Appendix F, "Internet resources") The sophisticated version of a vegetation survey requires the placement of transect lines throughout the lake, running perpendicular from the shoreline to just beyond the maximum depth of aquatic plant growth, to measure plant densities and identify species populations in quadrants placed at regular intervals along the line. Quadrants can range in size from 0.1 square meter (approximately one foot by one foot), to one square meter (a little more than three feet by three feet). They can be examined frequently to determine change in plant densities and coverage. Extensive macrophyte vegetation surveys can be extremely expensive, and may require the time and expertise of qualified specialists, including divers. Individual plant species must be positively identified and their identifications verified to completely address the relationship between macrophyte communities, lake water quality, and use impairment. At the other extreme, simple surface maps can be drawn showing macrophyte coverage areas without regard to plant types.

The most common survey methods fall between the extremes. They involve techniques for collecting plants from the surface, usually using rakes with attached ropes, or observations of plant communities using swimmers or identifications from boats. Rake tosses or other forms of observation can occur at various depths in the weediest areas. Results are more standardized and reproducible if sampling is done using the **point-intercept** method. This technique divides the lake into a series of points, taken from the center or at the intersection points of a grid. These points are then sampled randomly. Recent surveys indicate a strong connection between biomass (the dry weight of plants) and semi-quantitative assessments derived from point-intercept measurements. Point-intercept measurements can generate coverage maps that provide a readily understandable snapshot of plant conditions in a lake (Fig. 4–2). If used in conjunction with the methods described below, the measurements can serve as a surrogate for detailed biomass survey maps.

Vegetation is frequently expressed as a percentage of coverage, or as a qualitative assessment of density, using labels such as rare/trace, scarce/sparse, moderate/medium/common, and dense/abundant.

Cornell University researchers have developed simple, semi-quantitative metrics to evaluate density using easily understood labels such as those shown in Table 4–1 (Lord et al, 2005).

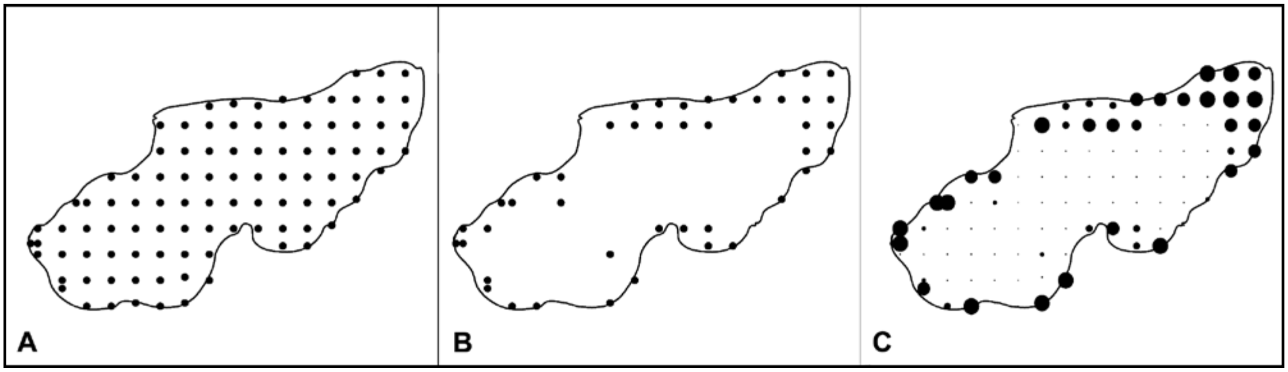

Fig. 4–2. Point-intercept method used to map aquatic plants.

A. *Once the point-intercept grid is overlain on a map, the points can be sampled randomly to reduce bias, or specific points within the littoral zone can be sampled during a period of time to evaluate trends.*

B. *As a result of sampling, one of two types of maps can be created. The middle figure shows the presence/absence distribution map.*

C. *Alternatively, sampling data can be mapped to show the relative abundance of aquatic plants. Larger circles mean greater plant density.*

Density Category	Average Quantity from 2–3 Rake Tosses	Approximate Biomass
No plants	Nothing	0 g/m2
Trace	Fingerful (of plants)	up to 0.1 g/m2
Sparse	Handful	0.1 to 20 g/m2
Medium	Rakeful	20 to 100 g/m2
Dense	Can't Bring in Boat	100 to 400 g/m2

Table 4–1. Estimation of plant density using the rake-toss method. (g/m² = grams-per-square-meter) (Credit: Lord et al)

In lieu of an extensive macrophyte survey, vegetative cover can be mapped over the course of a year, usually during late spring to early summer and again in the fall. This simple survey can be taken using aerial photographs or on-site inspections by lake residents, preferably those who can view the lake from their rooftops! The most common maps indicate the major plant species in each part of the lake, with little differentiation between thick beds and scattered plants. An example can be seen in Fig. 4–3.

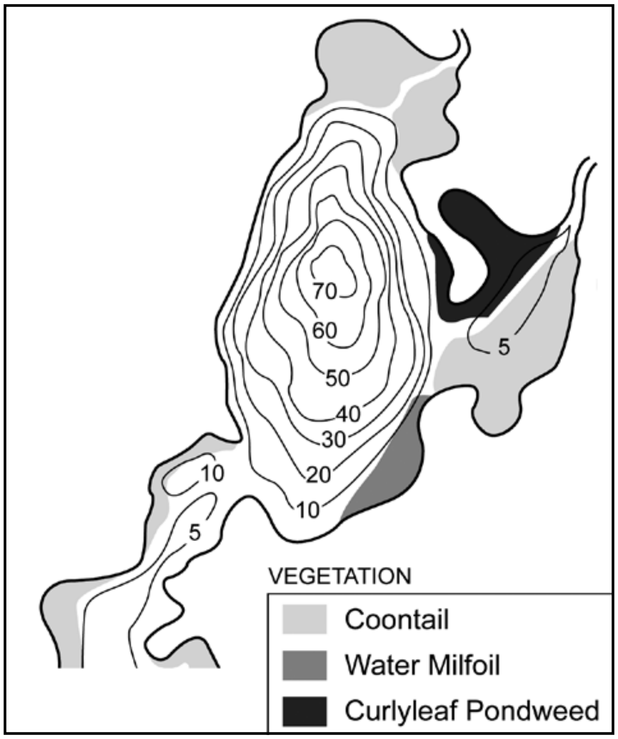

Fig. 4–3. Map indicating location of major plant species within a lake. (Credit: Chris Cooley)

Water chemistry parameters

Water samples can be collected for the analysis of specific chemical parameters depending on the nature of the investigation. Eutrophication studies related to algal blooms are often concerned with clarity, dissolved oxygen and temperature, nutrients, organic carbon, turbidity, and algae levels. Acidification studies might look at pH, alkalinity, conductivity, dissolved organic carbon, and several inorganic ions.

Investigations of specific water-quality problems or use impairments are driven by a list of existing symptoms. For any particular set of symptoms some subset of the following common parameters are likely to be selected for testing.

Sampling techniques

The specific type of water-quality sample to be collected, and the **sampling technique** to be used, will depend on the nature of the use impairment and perceived water-quality problem. Many perceived lake problems involve degradation of surface water quality, while other problems develop from degradation of water near the lake bottom. Samples collected from either surface or bottom waters alone, can be characterized as "grab samples." A single sample with both surface and sub-surface waters mixed together is called an "integrated sample." Unless noted specifically, most of the parameters discussed below are collected in grab samples or integrated samples, with only limited processing required. Some of the parameters require filtration or acidification in the field, using bottles, preservatives (usually acid) and filters provided by the laboratory or program directors.

Grab samples constitute the majority of lake water samples. Grab samples can be collected by manually submerging a sterilized collection bottle to elbow depth (approximately 0.5 meters), or with specialized collection devices. Using these devices minimizes surface-layer contamination and maximizes reproducibility. The devices also allow samples to be collected at any point in the water column from the surface to the lake bottom. Sampling by hand may be most appropriate for near-surface samples in very shallow water, or for streams or tributaries entering the lake. Hand sampling may be adequate for inexpensive monitoring projects for which the water-quality indicator is not particularly sensitive to potential contamination from the sampler.

Integrated samples can be collected from the water surface to the lake bottom. Most integrated sampling methods use a hose or tubing system with a vacuum pump. The hose is lowered to the bottom and samples throughout the water column are pumped to the surface. This allows for the changing water-quality characteristics of each horizontal layer of the water column to be considered in each sample. Since the potential for contamination or unbalanced distribution of layers is great, integrated sampling has not normally been performed in most lake diagnostic studies. For biological studies, integrated sampling can offset the problem of "patchy" growth of algae, bacteria and other biological indicators.

A plankton net is used to collect integrated samples for zooplankton and phytoplankton analyses. It is usually lowered to the depth of the thermocline. As it is raised, plankton are trapped and deposited in a small canister at the bottom of the net.

Sediment samples, or **core samples**, can also be considered integrated samples. They integrate discrete layers of sediment deposited over a period of time. Grab-sediment samples usually combine the upper layers of sediment into a single mixed sample. Core samples are collected by trapping a metal or PVC pipe submerged into the sediment, retaining a column of discrete layers that can be analyzed as needed.

Nutrients

Algae have certain nutritional requirements, consisting of both micronutrients (required and available only in small amounts) and macronutrients (required and available in larger amounts). Most nutrients are present in lakes through natural processes such as precipitation, groundwater input, and biological sources in sufficient quantities to meet algae growth requirements. "Limiting nutrients" restrict or limit algal growth. Either phosphorus or nitrogen serves as the limiting nutrient in most lakes. Excessive algal growth can result in significant use impairment when levels of these limiting nutrients are increased through watershed activities such as agriculture, lawn and garden fertilizers, urban runoff, erosion, septic system failures, and sewage effluents. Measuring the levels of phosphorus and nitrogen can help predict the potential for algal growth.

Phosphorus is most frequently the limiting nutrient in lakes, and thus serves as the focus of most nutrient abatement strategies. It is analyzed in most lakes as total phosphorus or soluble, dissolved phosphorus. Total phosphorus levels of greater than 20-30 µg/l are often found in lakes with significant algae growth. (µg/l = micrograms-per-liter; also referred to as ppb, parts-per-billion)

Unlike phosphorus, **nitrogen** can be supplied as a gas through atmospheric contact and it is less frequently the limiting nutrient. It is usually analyzed as total nitrogen, nitrate-nitrogen, or ammonia. The latter two are common inorganic forms of nitrogen. Like phosphorus, nitrogen levels can vary seasonally.

Nitrogen concentrations are usually less than 1 mg/l in most lakes. (mg/l = milligrams-per-liter, or ppm, parts-per-million). Several forms of nitrogen are measured with the use of multi-parameter probes.

It is also important to verify that samples are analyzed by laboratories that have demonstrated proficiency in the testing procedures associated with these lake indicators. Certification of laboratories is the responsibility of the New York State Department of Health (DOH) under section 502 of the Public Health Law. They established the Environmental Laboratory Approval Process (ELAP) to assure certification and adequate quality control. State certified laboratories are listed on the DOH website (see Appendix F, "Internet resources"). While the certification process identifies laboratories capable of analyzing phosphorus, however, few laboratories in New York State are capable of accurately measuring the small concentrations of phosphorus found in most New York State lakes. Even productive, nutrient-rich lakes have phosphorus readings in the ppb range. Most laboratories that analyze nutrients are set up to evaluate samples from wastewater-treatment effluent, stormwater, and other media that have nutrient levels often measured in the ppm range. The analytical methods and materials useful for detecting higher phosphorus concentrations are not capable of measuring the more diluted concentrations in lake water samples. This greatly limits the number of laboratories that should be used for phosphorus testing on lakes.

Chlorophyll a

The best way to measure algae is to count algal cells visible through a microscope. This process often involves graduate students or others who quickly tire of the eyestrain and monotony. A more practical alternative in most monitoring programs is to approximate the amount of algae by measuring **chlorophyll *a*,** the primary photosynthetic pigment found in all algae and most photosynthetic organisms. It constitutes approximately 1.5 percent by dry weight of algal biomass. Chlorophyll *a* levels greater than 10 µg/l often indicate lakes with excessive algae. This parameter usually requires filtering a water sample in the field and adding a preservative to the filter, which is later analyzed for chlorophyll *a*, although this indicator is also available in some multi-parameter probes. Measures of total phosphorus, chlorophyll *a*, and Secchi disk transparency often strongly correlate.

Plankton

Sampling **plankton** provides useful information about the composition of the microscopic plant and animal communities within a lake. While the chlorophyll *a* test can provide a rough estimate of algal densities, it provides little information about the population dynamics of plankton species. Phytoplankton samples are often collected from raw integrated water samples. Algae are usually abundant in patches throughout the upper waters of a lake, and integrating these samples (either by mixing grab samples or collecting a vertical column of water) allows a representative assessment of the lake. Water samples can also be analyzed for the presence of algal toxins. *Microcystins* are liver toxins (hepatotoxins) produced by a number of *cyanobacteria*, particularly *Microcystis*, that are perhaps the most significant and widespread algal toxins found in New York State lakes. These tests are highly specialized and can be performed only by a small number of research laboratories, but the sample collection and processing procedures are not difficult.

Zooplankton samples are not concentrated enough in grab samples to generate population estimates. They frequently move from depth to depth, so are concentrated for analysis by reeling in a net from the lake bottom to the top of the lake. Zooplankton trapped in the net are rinsed to a collection barrel hooked to the bottom of the net, and prepared for analysis. Both techniques require field preservation and inspection of plankton species through a microscope. These analyses are very time-consuming, and thus are often limited to specialized studies, particularly those related to fisheries management.

Conductivity

Conductivity measures the electrical current that passes through a solution. Since electrical current is carried by charged particles (ions), this is an indirect measure of the number of ions in solution, mostly as inorganic substances**.** Soft water lakes have few dissolved ions, resulting in a specific electrical conductivity of less than 100 µmho/cm (conductivity-per-centimeter).

Hard water lakes often have a conductivity exceeding 300 µmho/cm. Since ions frequently impart hardness to water, conductivity is also a rough indicator of hardness. Conductivity should remain fairly constant for a given lake throughout the year. Any significant changes over a short period of time may indicate a significant amount of precipitation or erosion that may impact water quality. Conductivity testing is best done using field conductivity bridges or electronic multi-parameter meters, but can be closely estimated through laboratory analysis. Conductivity is expressed as specific conductance and referenced to a specific temperature, usually 25^{o}C (Celsius).

Dissolved organic carbon

Although the quantity of organic matter relative to inorganic matter in lakes is small, it can have a significant effect on the chemical and biological processes that determine water quality. Organic matter is primarily in dissolved form, and is best defined by measurement of **dissolved organic carbon** (DOC). High organic carbon levels are not necessarily indicative of poor water quality, and are often characteristic of naturally eutrophic or naturally colored lakes. This test also requires filtering in the field.

Color

All lake water possesses at least some **color**. The apparent or perceived color can be caused by both suspended particles such as algae and silt, and by dissolved matter that is usually organic. The true color, most commonly measured in water-quality studies, measures only the dissolved portion of the color, requiring filtering immediately after sample collection. Color units are measured in comparison to a scaled series of platinum-cobalt color standards. High levels of true color can also be well correlated with dissolved organic carbon values. As a result, color frequently serves as a surrogate for the more expensive DOC analysis. Lakes with waters that measure greater than 30 color units generally are sufficiently colored to be perceived by the human eye. The natural color in these lakes often reduces transparency.

Turbidity

Turbidity is caused by suspended materials that scatter and absorb light instead of transmitting it in straight lines through water. Suspended materials such as clay, silt, algae, and other materials have a major influence on Secchi disk transparency readings and, therefore, on the clarity of water. Turbidity, combined with data for chlorophyll *a*, dissolved organic carbon, and color measurements, can explain low or high lake water transparency. It is particularly important for drinking water-supply sources, since turbidity is often related to substances that impart tastes or odors to water, or clog filters and rapidly increase the cost of water treatment. When lake water is disinfected, high concentrations of these turbidity substances can also create carcinogenic compounds. This can be measured from water samples or via multi-parameter probes.

Alkalinity and pH

Pure water consists of an equal number of hydrogen (H^+) and hydroxide (OH^-) ions. pH is a measure of the number of hydrogen ions in solution. At a pH of 7.0, the number of hydrogen and hydroxide ions are equal. At a pH below 7.0, the number of hydrogen ions exceeds the number of hydroxide ions and the lake is "acidic." At a pH above 7.0, the lake is "basic" or "alkaline." A difference in one pH unit corresponds to a ten-fold difference in the number of hydrogen (and hydroxide) ions (Fig. 4–4).

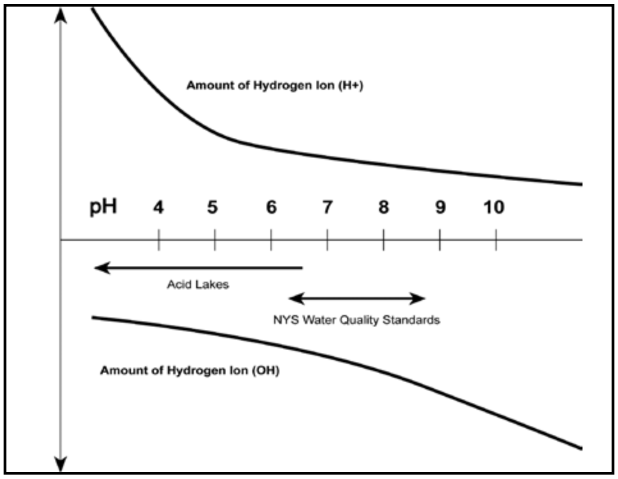

Fig. 4–4. Differences in pH result from changes in the concentration of hydrogen and hydroxide ions.

Most lakes fall within a pH range of 6 to 9, an acceptable range for most aquatic organisms. Pure rainwater has a pH of about 5.6 due to the atmospheric contact with carbon dioxide that forms a weak acid. Acidic precipitation can have a pH as low as 4, nearly 40 times more acidic than normal rainfall, and 1,000 times more acidic than neutral pH 7.0. Low pH is a significant issue for many high-elevation Adirondack lakes. This was discussed in more detail in Chapter one, "Lake ecology."

Alkalinity is the capacity of a lake to neutralize acidic inputs. Lakes overlying limestone deposits often have high alkalinity, and usually have a fairly constant pH in the 6 to 9 range. These are often hard water lakes. Lakes in granitic areas often don't possess this buffering capacity, and may be highly susceptible to acidic inputs. In many Adirondack lake studies, this is more commonly measured as acid neutralizing capacity (ANC), a more accurate measure of buffering capacity in soft water lakes susceptible to acidic inputs.

Alkalinity and pH are best tested in the field. Electronic meters can accurately measure pH, and alkalinity requires titrating water samples to a known pH. Both tests can be done, although less accurately, as lab tests. While the laboratory methodology is more accurate, these indicators can change significantly from field to lab. Lab readings of low pH or alkalinity should be followed with more accurate measures in the field.

Metals, tracers and organic compounds

An increasing number of lakes are being tested for organic compounds and metals. Organic compounds can come from terrestrial pesticides, landfill waste and industrial waste. Metal contamination can be from leaking landfills. It can also enter lakes from atmospheric sources such as mercury as a byproduct of fossil fuel combustion. Calcium, magnesium and other metals that collectively are estimated by conductivity or hardness, may be important indicators of susceptibility to zebra mussel infestation (calcium), taste and odor problems (iron and manganese), or other water-quality problems. Calcium, sodium, and magnesium are often associated with anions, such as chloride, which may indicate problems with road-salting operations. Anions are negatively charged atoms that may serve as tracers for water-quality modeling, since they do not undergo biological or chemical degradation. Other tracers include caffeine, boron, and other compounds generated exclusively from human activities.

Some special study monitoring has looked for the presence of MTBE (methyl tertiary butyl ester), a carcinogenic compound, as an indicator of spent boat fuel in navigable lakes and rivers. This is of even greater concern in lakes in which older, two stroke engines are still used extensively. This compound can only be found at very low levels in most waterbodies, due to the rapid transit, volatility and complex structure of these chemicals. New York State and other states have utilized innovative sampling devices to detect these compounds. PISCES (passive, in-situ concentration/extraction samplers) are temporal or time-composited samplers that possess membranes to allow selective migration of specific pollutants into a collection chamber. These compounds are then concentrated in a hexane solvent over a two-week period. While these samplers don't yield quantitative results, they can be used to compare the relative MTBE levels through time and space. These devices are also used to detect other organic compounds.

Metals and organics must be analyzed at a certified laboratory to accurately evaluate the water quality in a lake. Many of the hazardous organic compounds associated with industrial or landfill waste, such as PCBs and mercury, require specialized collection, laboratory equipment, and advanced laboratory methods. Information from nearby wastewater-treatment plants and local waste-disposal records help identify specific pollutants that may end up in the water, sediments, or fish in a downstream lake. Another effective screening tool is to scan total volatile organics, chemical compounds that vaporize and enter the atmosphere, although they can also enter water and soils. These scans can allow a lake manager to focus on specific pollutants. The very high costs associated with these analyses often limit their use to studies of highly susceptible lakes.

Microbial analyses

When sewage contamination is suspected, a water sample should be sent to a certified laboratory to analyze for **coliform** bacteria. The test is a relatively simple, quick and inexpensive way of determining the risk of waterborne diseases. It requires sterile collection equipment and must be analyzed quickly by a laboratory. The test detects only the contamination level at the time of sampling. The extent of bacterial contamination in a lake can fluctuate from hour to hour, influenced by weather conditions, currents, in-lake cycling, and the degree of bacterial degradation.

Coliform bacteria serve as indicator organisms, meaning they do not pose a health danger themselves, but their presence indicates the likely presence of pathogenic or disease-causing organisms that are more difficult to measure. A high level of coliform bacteria in a lake water sample can indicate sewage contamination and the likelihood that organisms pathogenic to humans may be present, but it does not identify the pathogens. Less common microbiological tests are also available. *Salmonella, cryptosporidium*, enteric viruses, and other pathogenic organisms can be detected in lake water samples, but tests for them are usually quite complicated and typically available at only a few water laboratories.

The large variety of coliform bacteria present in natural waters makes them excellent biological indicators for pathogenic bacteria. Fecal coliform and total coliform are the two tests commonly performed. **Fecal coliform** bacteria grow in the intestinal tracts of warm-blooded animals, including humans, and are present in fecal wastes. The number of bacteria in human feces is estimated to be between 100 billion and 10 trillion per-person-per-day. Positive fecal coliform test results suggest the presence of pathogens that are more dangerous and more difficult to detect. The test for fecal coliform involves growing bacterial cultures from the water samples so a technician can count the number of bacteria.

Total coliform are naturally occurring bacteria that can originate from decaying matter in a lake as well as from feces. Total coliform bacteria are quite diverse and ubiquitous in a lake environment and commonly exist in many places at all times. High total coliform bacteria counts are not necessarily indicative of contaminated waters.

The majority of water testing in New York State lakes has involved either total or fecal coliform testing, consistent with the existing state water-quality standards. Alternative bacteriological tests may provide better indications of human health impacts and the source of bacterial contamination. At the time of this publication, state water-quality standards are in the process of shifting from these more traditional indicators to other bacteriological standards. ***E.coli*** *(Escherichia coli)* is a single species within the fecal coliform group, as shown in Fig. 4–5, adapted from the Tompkins County Department of Health. As with the larger fecal coliform group, *E.coli* are indicators of contamination and are generally not pathogenic. The strain *E. coli 0157:H7,* which has been in the news as causing severe illness, is not a water-quality concern since it is primarily transmitted through food. In some monitoring programs, *E. coli* is the organism of choice to monitor because of its association with intestinal illnesses. The EPA recommends using *E. coli* over fecal coliform as a bacterial indicator, and New York State has adopted federal *E. coli* standards for freshwater systems.

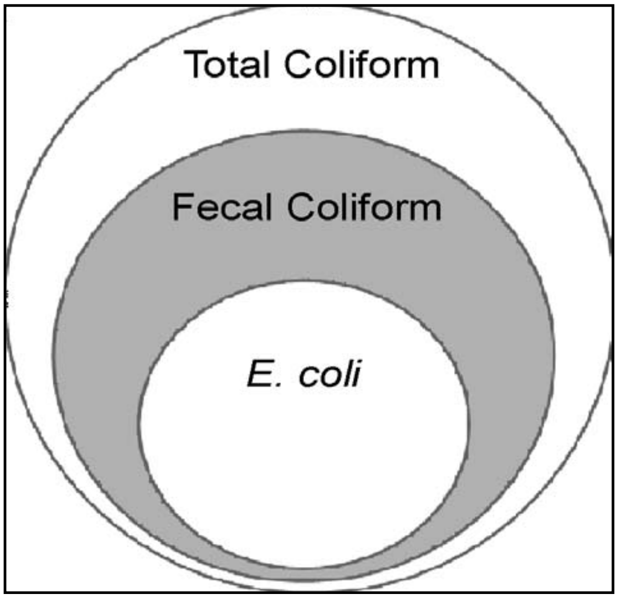

Fig. 4–5. E.coli (Escherichia coli) is a type of fecal coliform, which in turn is a subset of total coliform.
(ADAPTED FROM: TOMPKINS COUNTY DEPT. OF HEALTH)

There are many strains of *E. coli* and they are continually mutating by acquiring new genes. Slight differences in the genetic material of *E. coli* strains show adaptation to different hosts, such as geese, humans and dogs. Comparing the microbe characteristics to a library of microbes from known sources can indicate the type of animal from whose gut it came. This and other processes used to identify the probable source of bacteria or viruses are collectively called Microbial Source Tracking. It is still a new science and somewhat experimental, but one that has been used by Cayuga County to identify the sources of fecal coliform bacteria that have affected Owasco Lake.

Other bacterial tests have also been used. ***Fecal streptococci*** are found in the feces of humans and other warm-blooded animals, especially chickens. Some varieties of fecal streptococci can be attributed to a specific "host" source, while other varieties are short-lived and indicate only recent pollution. The fecal streptococcus test should not be used without other fecal indicators. The ratio of fecal streptococcus to fecal coliform has historically been used to determine the influence of a specific bacterial source relative to the overall bacterial contamination. In recent years, however, this method for evaluating the source of the contamination has fallen out of favor.

Enterococci are a subgroup of fecal streptococcus. The EPA has suggested testing for *enterococci* in salt waters. Their survival there better imitates many pathogens and they are believed to have a higher correlation to human pathogens than *E. coli*.

Sediments hold clues

Water sampling can reveal information about many present-day conditions, but also examining sediments can help develop a fuller understanding of the condition of a lake. Some pollutants, such as heavy metals, may not stay in the water column long enough to be captured in most monitoring programs. Sediment influences rooted aquatic plants more than the water column since the roots take up nutrients and contaminants from the sediments. Sediments can provide historical information about past lake conditions. If fish are found to be contaminated by a heavy metal or hazardous compound, sediment sampling will help to determine the degree to which the concentration of the pollutant is either increasing or decreasing. The sedimentary record can show if a lake ever "naturally" supported a desired condition such as a high degree of water clarity.

Most sediment sampling is conducted from the deepest part of the lake, since sediments tend to focus and migrate toward the deep hole through which most lake water passes. Thus, the deepest part tends to have the most representative conditions. Sediment samples can be obtained by grab samples or by cores using specialized equipment. The suite of tests conducted on a sediment grab or core sample is dictated by the objective of the monitoring. Estimating the extent of sedimentation often requires a paleolimnology investigation of a lake.

When a sediment core is taken, individual slices can be analyzed to look for changes. The rate of eutrophication of a lake can be estimated by looking at diatoms in cores because diatoms remain fairly intact within sediment. The core is studied to determine where the diatom-dominated algae communities shifted to green and blue-green algae-dominated communities. This change often signals a trend toward a higher eutrophic level. A detailed evaluation of the biological communities in the sediment (macroinvertebrates and other benthic organisms) can provide clues about long-term influences on the lake, similar to the use of stream benthic organisms to assess stream-water quality. Changes in chironomid communities (an aquatic midge sensitive to changes in dissolved oxygen), for example, can provide insights about whether deepwater oxygen levels in the lake are naturally low.

The date of changes can be estimated by looking at the levels of lead and cesium in the core. For cores that are at least 150 years old, lead-210 can be used to establish the age of a core because lead-210 is a naturally occurring radionuclide that "ages" at a measurable rate. For younger deposits, layers can be dated using cesium-137, a byproduct of atmospheric testing of nuclear weapons. Its levels will be highest for 1963, corresponding to the peak of the atmospheric testing.

While these tests provide excellent information about the age and aging patterns of lakes, they are also very expensive and can be adequately conducted only by paleolimnologists and other highly trained specialists. They are not, therefore, a standard part of most monitoring programs.

What other information should be collected?

Environmental and socioeconomic patterns within the watershed also influence the lake. Information about these can be gathered by inventorying the natural resources, land and water uses and referring to base maps, land-use surveys, and tax records to help track the sources of water-quality problems. On-lake and watershed cultural and recreational activities may provide some insight into observed changes in water quality. Records from the testing of septic tanks and other on-site waste-disposal systems are useful when trying to determine the sources of excessive nutrients or bacteria, or for educating lake residents about how they may be affecting or protecting their lake. Descriptive information about a lake problem, such as newspaper articles, serves to pinpoint the symptoms associated with most common use impairments.

Some or all of the inventory work may have been done already. A good starting point is to check with county agencies such as the Planning Department, Water Quality Coordinating Committee (WQCC) and Environmental Management Council (EMC). Other sources may include the applicable DEC regional office, or local planning boards. Rather than duplicating an existing study or inventory, lake association members can invest their time in updating or supplementing previous work.

These authorities should also be consulted to see what, if any, monitoring or lake management techniques are currently being used in a lake or watershed. If there is long-range water-quality or watershed monitoring program already underway, the lake association could use the existing data or help supplement the monitoring projects by collecting additional data. It is a waste of time and resources to duplicate monitoring efforts.

Environmental setting

A base map or series of maps can be developed from U.S. Geological Survey (USGS) topographic series maps. Watershed boundaries, areas ill-suited for development, wetlands and critical wildlife habitats can be identified from the maps. The choice of maps should be sufficiently large to encompass the entire watershed, while maintaining sufficient detail to delineate boundaries between specific land types. Some maps are available at a 1:24,000 scale (1 inch equals 2,000 feet). Topographic maps (usually called "topo" maps) can be found at the local planning office, libraries, Soil and Water Conservation District offices, sporting goods stores and bookstores. While some of the existing maps date back to surveys done in the 1950s, many maps have been updated or reworked in the last few years. The most recently updated map should be used whenever possible.

In recent years, much geographic-based information found on topographic maps, soil maps, bathymetric maps, and other maps has been converted into digital data layers. These data layers are a fundamental part of the **geographic information systems** (GIS) developed by government agencies, consulting firms, and others. The New York State GIS Clearinghouse is an excellent, free source of map information available in electronic format. GIS affords an opportunity to develop electronic base maps with digital layers or overlays that contain the information described below. Some of these data are also available through the Environmental Resource Mapper on the DEC website (see Appendix F, "Internet resources"). Maps generated through this on-line program display waterbodies, wetlands, protected plant and animal species, and significant natural communities.

Land uses within the watershed boundary will greatly influence lake water quality. Agricultural land, residential land, commercial land, forested land, park land, or open areas all have different effects. They can change the permeability of the underlying land, and affect the quantity and nature of runoff and nutrient inputs to a lake. Areas of dense development will create hard surfaces impervious to water that will quickly divert contaminants to a water body. Undeveloped areas can act as nutrient traps and provide some buffering of pollution inputs. The high absorption capacity of wetland soils and the vegetated corridors along streams provide a buffer against rising lake levels and flooding during periods of spring runoff or heavy rainfall. Critical wildlife habitats, such as wetlands, nature preserves, and forested corridors are integral to the ecosystem balance and should be identified on the maps so a lake and watershed management plan can aid in their protection. Municipal and industrial point source pollution inputs should also be located on these maps. Land uses may be already delineated on soil surveys available through Soil and Water Conservation Districts (SWCD), or may have been compiled by the local or county planning board or EMC.

An accurate assessment of existing land uses can be used to generate a nutrient or hydraulic budget for the lake. These budgets can be used to determine the expected sources and influence of nutrient and water inputs and outputs. This information can be used to determine a priority list for managing pollution sources, and may help to estimate the effects of any proposed watershed activities on overall water quality. These calculations can be done using computer programs in a process known as modeling that is discussed later in this chapter.

Soil types, underlying bedrock and land slopes also influence water quality. Geological features, such as exposed limestone, can provide buffering against water-quality pollutants, such as high nutrient loads and acid rain. Areas with steep slopes may have the potential for high erosion and sedimentation rates. Considerations of soil erodibility, and the suitability of soils for leach-field placement affect the decision about whether an area is appropriate for development. If soils near a lake shoreline are composed mostly of impervious clays, then construction should be discouraged, because of the high risk of poor permeability and high potential for erosion and runoff. If soil permeability is good, however, controlled development could be permitted, assuming that there are no other limitations and that septic systems are properly installed. Soil surveys, compiled by the U.S. Department of Agriculture's Soil Conservation Service (now called Natural Resources Conservation Service or NRC) are available for many counties. In addition, the New York State Geological Survey (NYSGS) has prepared soil maps for the state (see Appendix F, "Internet resources"). These soil surveys also contain information on geology, topography, erosion potential, depth to bedrock, climate, temperature, precipitation and land use.

Morphological characteristics, such as a lake's depth and shape, influence its original water quality, and may ultimately limit how much water quality can be changed. Shallow lakes may be warmer and naturally eutrophic, so developing a fishery that requires clear, cool water is not feasible. Morphometric maps use the bottom contours of the lake to show the depth and topography, and are commonly used by anglers and lake managers. Maps for several New York State lakes are available online through the DEC Fish and Wildlife website. Planning boards, lake association members, or local anglers may also have constructed maps, or can easily do so by taking depth readings along several transects across a lake. This has become substantially easier with the advent of boat-mounted or handheld electronic depth finders and inexpensive Global Positioning Systems (GPS).

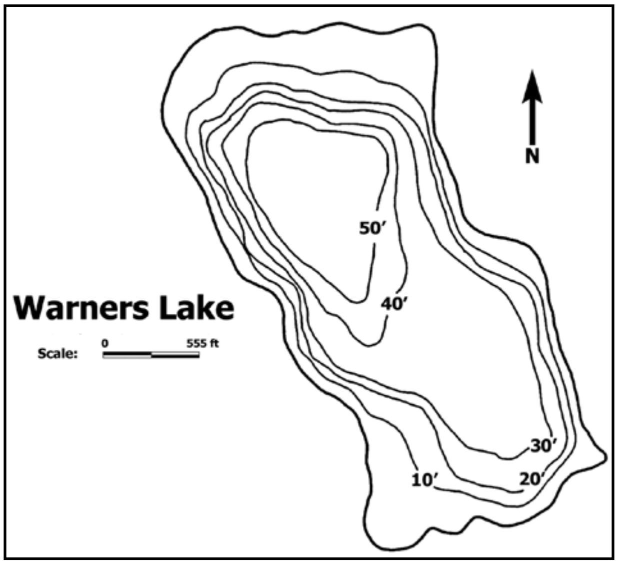

Fig. 4–6. Morphometric map showing lake depths and bottom contours.

(CREDIT: DEC)

Following the flow

It is important to understand where water comes from and where it goes. Many of the pollutants in lakes are carried by rainfall, an incoming stream, direct runoff from nearby land, or seepage from groundwater. The movement of water can be evaluated in a number of ways.

USGS has been gauging large rivers and streams for many years to determine water flow. If a lake association is fortunate enough to have one of these streams entering their lake, they can easily obtain gauging data from the USGS office or online. Gauging information has not been collected, however, for most streams and tributaries in New York State.

Simple staff gauges that measure the height of water can estimate the water coming into the lake through streams and tributaries once the relationship between flow and height is established. This relationship is referred to as a rating curve. Regular or even daily measurements of stream height can be compared to actual flow measurements. Stream flow can be measured accurately with the use of **gauging equipment** that measures stream velocity at specified depths at regular intervals along a cross-section of the stream. An even more simple estimate of stream velocity, though somewhat less accurate, is the use of a float, such as an orange, that can be timed as it passes between two points.

These methods can be used to estimate water flowing out of a lake as well as measuring the water coming into a lake. If the lake is a reservoir or has other regulated withdrawal, records of outflow may be maintained by municipalities, private water companies, utilities, or those who maintain control over water withdrawal or water level.

Accurate measure of groundwater flow is usually done with a series of wells, seepage meters, piezometers (a device that measures water pressure), or other expensive specialized devices. No simple monitoring equipment and techniques have been developed. For many lakes, groundwater flow is mathematically estimated using information about surface flow in and out of a lake, evaporation, and water uptake from domestic intake pipes and other users. This usually results in a "best available," but not very accurate, estimate of net flow, which includes contributions from septic tank discharges.

Dye testing

While fecal coliform analyses can be used to determine the bacteriological condition of a lake, the test cannot be easily used to pinpoint the source of the bacterial contamination. **Dye testing** is a common method for detecting major problems with leaking septic systems. Dye tablets usually come in different colors, such as iridescent red or fluorescent yellow-green, and are usually flushed down the toilet. Another tablet is washed down the kitchen sink if there are separate drainage areas for sewage and for **graywater** from kitchen or non-toilet bathroom uses. After a period of time, usually between fifteen and thirty minutes, the colored dye may be observed in the lake water in front of the home if the septic system is not working properly. This method more effectively focuses on failed leach fields and tanks that have been subject to heavy use, rather than on poorly operating systems. In other words, if the dye is visible that quickly, the septic system is not properly treating the wastewater, but if no dye is visible, the septic system still may not be working correctly. A failed on-site disposal system needs to be upgraded or replaced promptly. NYSFOLA has a protocol available for lake associations interested in instituting a small-scale, voluntary, dye-testing program.

Dam inspection

For lakes originating or expanded through the construction of a **dam**, the status of the dam may be a critical piece of the lake-management puzzle. "High hazard" is the descriptor given to dams when their failure could result in loss of life, serious property or environmental damage, or significant economic loss. Traditionally, the 380 high-hazard dams in New York State are inspected by DEC every two years. Inspections occur every four years for "intermediate hazard" dams, where breaching could damage the environment or property, or affect public utilities or transportation. At the time of this publication, DEC is in the process of revising its dam safety regulations. The proposed changes would make dam owners responsible for operation, maintenance, inspection, repair and emergency planning related to their dam. (See the Text box in Chapter ten, “Legal framework” and the DEC website in Appendix F)

Cultural context

Information concerning human influences, through year-round, seasonal or temporary land-use and recreational interests should be collected and identified on the base map. The local planning office or the county clerk’s tax maps can provide assistance in compiling data on population and human settlements, local economy, industrial and commercial development, and agricultural regions. This information can help to identify potential sources of pollution and help lake managers determine specific land-use trends.

The base map should also show public and private lands that are connected to water-based recreation, along with any associated in-lake structures. Yacht clubs, marinas, beaches, restaurants and hotels all should be considered as lake users. The owners and operators of these enterprises have a vital economic interest in the health of the lake. They can be very helpful participants in lake and watershed management planning and implementation.

Other types of research can also yield useful information. Review of municipal records and discussions with the town historian and with long-term residents can reveal past land uses around the lake, such as farming, logging, old mills, landfills and manufacturing plants. Such information helps to identify some of the current problems affecting lake water quality. Knowing that a tannery operated on the main tributary to a lake from 1853 to 1937 might explain why there are surprisingly high levels of cadmium in lake sediments.

Surveys for qualitative information

This chapter has focused on objectively measured data and information, referred to as quantitative. It is now important to gather subjective or qualitative information. The two forms complement each other. Determinations of many use impairments and the severity of the symptoms are based on qualitative information, while the causes and sources of these lake problems are verified by quantitative information. An angler, for example, may perceive lake conditions as improving when the presence of native aquatic plants improves fishing. In contrast, another lake user views the increase in aquatic plants as a decline in water quality because the weeds are a nuisance for boaters and swimmers. Measurements can determine the amount of increase in weed cover, but it is a subjective decision about whether the existing conditions are acceptable or not.

Interviews, anecdotes, newspaper editorials and user surveys are examples of sources for qualitative information. As seen in the weed example above, different people have different perceptions of the same situation. A survey of lake users is one way to get a large enough sample of opinions that is representative of all users. To provide accurate information, surveys must be carefully worded and distributed. NYSFOLA has sample user surveys and libraries have many books on how to design a good survey.

A survey of lake users is a valuable tool for obtaining their impressions of, and perceptions about, lake conditions. Do they share common concerns about the problems? Are they basing their assumptions on accurate information? Do they agree on the cause and severity of lake problems? What is the trend of problem conditions in their opinion? How has their use of the lake changed? When did they first notice conditions changing? Do they agree about the best course of action? How much are they willing to pay, and should some pay more than others?

The information gathered with user surveys serves many purposes. It can provide information to a lake manager about use impairment and perceived water-quality conditions throughout the lake and watershed. It can help identify important user groups and recreational interests. The acceptability of proposed management strategies can be determined. Surveys can uncover information about the satisfaction of residents with the management and government infrastructure that has previously attempted to restore or preserve lake conditions. User surveys can be used to evaluate and adjust an existing lake-management plan, can pinpoint where a plan is working, and more importantly where a plan has not been adequately addressing use impairments and complaints.

User surveys can help distinguish the difference between perceived and measured water-quality conditions. Some control strategies may provide satisfaction to lake users much like a medical placebo provides relief. This effect may cause a lake association to continue using a lake treatment that cannot easily be verified quantitatively, such as the use of copper sulfate to reduce algae concentrations. Identifying the difference between perceived and measured water-quality conditions may provide guidance in choosing a more appropriate control strategy. It should include planning for actions that brings immediate reduction in symptoms as well as long-term actions to address causes. Incorrect perceptions may point to the need for educational workshops as part of a management plan, recognizing that even misinformed perceptions often have some basis in reality. User perception may indicate that the major sources of pollution are the wastewater-treatment plant and agriculture, while the quantitative evidence actually points to urban runoff, failing septic systems or other nonpoint pollution as the main sources.

Identifying gaps and collecting additional information

Lake and watershed data collection and analysis are lengthy processes. Information gathered about the lake and its watershed, however, is well worth the effort. Both the lake and the broader community will benefit from accurate data when it comes to management planning, applications for funding requests, and securing community support.

As part of the data-gathering process, it is important to evaluate the quality of the data and to identify gaps. Since the overall objective for gathering information is to adequately identify and address each component of the symptoms-causes-sources relationship, it is important to backtrack to see if the questions about each component have been answered. This should be balanced with the knowledge that lake managers may never be able to obtain all the data they desire. While it is important to base recommendations and decisions on sound information, it is not wise to use lack of data as an excuse for not working towards a management plan. It may initially require developing a management plan built solely on available data to gain the support and funds needed to collect the necessary additional data. Generalized statewide or national trends may have to be sufficient for developing and understanding the symptoms, causes, and actions related to a specific lake problem.

Lake managers also need to verify the validity of information gathered from outside sources, such as water-quality data or anecdotes. Water-quality monitoring programs should address **Quality Assurance and Quality Control (QA/QC)**. Any data or information used for generating management plans should come with an assurance that the information accurately represents conditions related to the lake problems. QA/QC programs may involve duplicate sampling, control studies, or other methods used to verify the accuracy of the collecting methods, sample analyses, and study results. Data from outside studies that do not implement an acceptable QA/QC program must be verified, or used only with great discretion.

Once it is determined that there is sufficient data and information and that it is valid and reliable, the data collection process is complete. It will need to be updated periodically, however, to keep the management plan up-to-date as lake and watershed conditions change.

Back to square one

As exhaustingly described above, many indicators, measurements and tests say something about a lake. Such an extensive shopping list can be overwhelming and imposing to someone hungry for more knowledge, but uncertain about where to begin. When the cost and expertise required for some of the analyses are factored in, the natural response of many intimidated lake residents is to do nothing. It doesn't have to be that way since volunteer monitoring programs, such as CSLAP, make lake sampling affordable and relatively pain free. For lake residents not involved in a formal monitoring program, a reasonable starting point could be the following activities:

- *See clearly:* The water transparency of a lake says a lot about its condition. Greenness (algae) and brownness (suspended material or dissolved organic matter) may indicate a lower susceptibility to weeds, but a greater sensitivity to invasive weeds, as well as an indication of where they may grow. Water transparency also says a lot about the safety and palatability of the water for swimming, and how the lake looks. Evaluating water clarity is a surrogate for more expensive water-quality tests. The frequency of water clarity readings less than two meters deep, for example, is often very similar to the frequency of phosphorus readings greater that 20 ppb, which corresponds to the state water-quality standard. Water-clarity tests should be done weekly to detect seasonal trends and impacts of heavy wind and rain.
- *Smell:* Take a whiff of water collected from near the bottom of the lake, whether it has been withdrawn from the bottom of a dam or by using a collection device. If it smells musty, there may be a deepwater oxygen problem. If it smells like a rotten egg, and looks gray to black, there is an oxygen problem. If it stinks in early summer, there is a major oxygen problem.
- *Drop a brick:* Tie a rope to a brick and drop it in the water for a few weeks. It may become a home for zebra mussels (*Dreissena polymorpha*) that were hidden from view before.
- *Feel the foam:* If the foam caused by wave action is perfumy and slick, it may be unnatural. If it smells fishy and looks brownish, it may belong there.
- *Grab a bottom (sample):* If the bottom sediment is sandy, it is less likely to support many invasive species such as water chestnut, or some native plants like lilies, although it may exclude most other plants to the delight of Eurasian watermilfoil (*Myriophyllum spicatum*). Thicker sediments may also support "swimmers-itch" schistosomes, but may not house zebra mussels.
- *Watch the weeds:* Water shield, bladderworts, fanwort, and many of the brown-stemmed milfoils are much more likely to be found in slightly acidic lakes. Ribbon-leafed plants and coontail with an encrusted lime layer indicate harder water and a greater susceptibility to invasion from Eurasian watermilfoil and calcium-limited exotics such as zebra mussels.

Where?

The "where" of lake sampling is largely dictated by the purpose of the monitoring program. An important component of where to sample is the number of sampling locations. Studies designed to investigate a specific problem often warrant multiple sampling sites. A larger number of sampling sites may be required if the problem is isolated, such as multiple weed beds or sites for invasive species, or if the sampling parameter grows or migrates sporadically, such as bacteria. Fewer sampling sites may be adequate if general or lake-wide assessments of water quality are the primary objective. Several sampling locations and depths, however, may be necessary to assure results that are representative of the lake.

Secondary factors that determine where to sample include the lake size, shape, and the configuration of the shoreline and bottom contours. In general, small, geometrically uniform, round lakes may require only a single sampling site at the deepest part of the lake. Larger lakes may require a second site approximately equidistant from both the shoreline and the first site. Lakes with several discrete bays, or several different water sources, may require sites corresponding to each discrete area (Fig. 4–7). Each bay should be sampled at its deepest point to evaluate general water-quality conditions, while samples collected to determine the influence of tributaries should be sampled close to where the tributaries enter the lake.

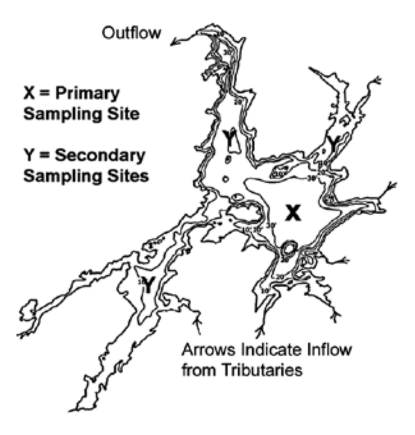

Fig. 4–7. Examples of sampling sites in a lake with discrete bays and different water sources. (CREDIT: DEC)

Open water “surface samples” should be collected at a depth of 0.5 to 2.0 meters to reduce any surface or bottom effects. Deep-water, or “depth,” samples should be collected between the thermocline and the lake bottom. Water-sample depth may depend on the type of analysis to be conducted. Temperature or dissolved oxygen readings are usually taken every meter from the surface to the bottom. Some variables, such as phosphorus or color, are often analyzed in both surface and depth samples.

Sampling for aquatic plants or bacteria should focus on areas where those organisms are most likely to be found, or are creating problems. For plants, this is probably within the littoral (near shore) zone. Lake surveys seeking evidence of new invasive or exotic plants are most likely to find these invaders near launch sites, in high traffic areas, and at inlets and outlets. Bacteria monitoring should focus near swimming areas and water intakes, but could also be directed to areas of suspected septic leaching, stormwater runoff, congregations of waterfowl, or places where dye testing has identified potential hot spots.

When?

Sampling frequency is a function of the nature and degree of the water-quality problem. Long-term, baseline studies may involve sampling on a biweekly or even monthly basis. Samples collected to pinpoint short-term, immediate water-quality changes may require daily or weekly collection. Bacterial monitoring requires at least five samples per month to compare to the state water-quality standards. Evaluating changes in nutrient levels in tributaries during storm events may require hourly sampling. Some studies will be dependent upon the frequency or duration of an event such as a storm or holiday~~s~~ causing heavy use of the lake.

For some projects, single samples are desired to identify conditions representing a snapshot in time. If the purpose of the monitoring is to determine whether a particular invasive species has been found, a single positive identification may be adequate. The lack of a positive identification, however, does not necessarily indicate the absence of this species. This snapshot approach can also be extrapolated into a crude method for assessing trends. If these snapshot samples are repeated weekly, monthly, annually, or at other regular intervals, they can be useful in evaluating changes in the indicators being measured. This is most effective if the intervals are closely spaced, assuring minimal change between snapshots, or if the duration of the project is long enough to minimize the impact from any single snapshot that might not be representative of a long-term trend. This is essentially the approach the EPA uses in developing EMAP, their long-term monitoring program, and the national survey approach built out of EMAP in recent years (see Appendix F, “Internet resources”).

How do we use all these data?

Trophic state

Secchi disk transparency, total phosphorus, and chlorophyll *a* measurements are often used to determine the trophic level or degree of eutrophication of a lake. Trophic status is based on the assumption that changes in nutrient levels (measured as total phosphorus) result in changes in levels of algae (measured as chlorophyll *a*) and other plants and animals, causing changes in lake clarity (measured as Secchi disk transparency). Average summer values for these three indicators can be used to determine an approximate trophic state.

Dr. Robert Carlson of Kent State University devised a Trophic State Index (TSI) to compare the determinations of the three indicators. Carlson (1977) uses formulas based on empirical relationships between total phosphorus, chlorophyll *a*, and Secchi disk transparency to assign a single TSI. TSI is used primarily to compare lakes within a given region, and assess changes in the degree of eutrophication after the implementation of a lake management plan.

The TSI formulas are as follows:

$TSI_{SD} = 60 - 14.41 \ln SD$
$TSI_{Chl} = 9.81 \ln Chl + 30.6$
$TSI_{TP} = 14.42 \ln TP + 4.15$

where

ln = natural logarithm = log10 x 2.30
Chl = chlorophyll a, measured in μg/l
TP = total phosphorus, measured in μg/l
SD = Secchi disk transparency, measured in meters

A TSI computed from any of the above parameters can be used to determine a general trophic status for a lake. TSI values in most lakes range from zero to 100. A TSI of zero corresponds to the lowest productivity, highest transparency and lowest values for total phosphorus and chlorophyll *a*. A TSI of 100 corresponds to the highest productivity, lowest transparency, and highest phosphorus and chlorophyll *a*. Lakes can be compared to each other by comparing their numerical TSI values for each of the measured parameters.

Using the equations shown above, either chlorophyll *a* concentrations, or Secchi disk transparency can be predicted by knowing phosphorus concentrations. This can be particularly useful when a lake or watershed management plan focuses on the reduction of phosphorus levels. Expected changes in levels of phosphorus due to the implementation of a management plan can be used to determine expected changes in algae levels and lake clarity. The relationship between phosphorus and chlorophyll *a* or Secchi disk transparency can be derived from the TSI equations:

$$\ln \text{Chl} = 1.449 \ln \text{TP} - 2.442$$
$$\ln \text{SD} = 3.876 - 0.98 \ln \text{TP}$$

The actual trophic state of given lake may not be well predicted by using TSI. Any two lakes within 10 TSI values probably have the same level of biological productivity. Ranking lakes by their TSI, therefore, can be somewhat misleading. The variation of any one parameter, such as chlorophyll *a,* may be large enough to cause significant variation in the TSI. It is likely that only ranges of TSI values can be used to adequately assess the trophic condition of a lake.

Many lake managers have divided ranges of TSI values into trophic state classifications. Reference values using the formulas above were generated from lakes in the mid-western United States. They indicate that mesotrophic, or moderately productive lakes, have TSI values between 37 and 51. Lakes with TSI values greater than 51 are classified as eutrophic, or highly productive. Lakes with a TSI less than 37 have low productivity and are classified as oligotrophic. Each productivity classification can support a different set of uses. Eutrophic lakes often support excellent warmwater fisheries, while oligotrophic lakes often provide an excellent drinking-water supply. Since TSI formulas were computed for lakes in a different region of the country, however, they have been rounded to the nearest whole number to provide trophic estimates for New York State lakes (Table 4–2).

Parameter	**Trophic State**		
	Oligotrophic	**Mesotrophic**	**Eutrophic**
Total phosphorus	$< 10\ \mu g/l$	$10–20\ \mu g/l$	$> 20\ \mu g/l$
Chlorophyll a	$< 2\ \mu g/l$	$2–8\ \mu g/l$	$> 8\ \mu g/l$
Secchi disk transparency	> 5 meters	2–5 meters	< 2 meters

Table 4–2. Criteria used to designate different trophic state classifications for New York State lakes.

Trophic State indices and classifications can be useful in determining the extent of eutrophication in any given lake but the results cannot be used alone without considering other factors. Since the equations represent the averages for many lakes, any one specific lake may not follow the exact relationships described in the equations. While most lakes will adhere to the general relationships described by the equations, occasionally a lake will not be precisely represented. There is also a tendency to attribute far greater weight than is warranted to changes in TSI. While large changes in TSI for any lake may be important, small changes are probably normal. In addition, each TSI parameter can be affected by other factors. Secchi disk transparency can be influenced by non-algal turbidity, highly colored water, and bottom growth and conditions. To account for some of these interferences, these TSI classifications are valid only for lakes with color-unit values less than 30.

These TSI classifications do not consider how macrophyte levels, dissolved-oxygen concentrations, and other factors influence the degree of eutrophication. They should be used only as part of a larger classification scheme using additional water chemistry and watershed analyses. They should not be used as the sole indicator of either present conditions, or trends in eutrophication or water quality of a lake.

Ratios

The type and growth of algae in a lake is governed by a variety of factors. In highly colored (dystrophic) lakes, algae growth can be limited by poor transmission of light through the water. Lakes filled with poorly rooted plants may have less-than-expected algae growth if these macrophytes outcompete the algae for available nutrients. As discussed in Chapter one, "Lake ecology," some algae cannot grow due to limitations from silica or other micronutrients. In most New York State lakes, however, summer algae growth is limited by either nitrogen or phosphorus. A detailed analysis of water-quality characteristics and of the type of algae in a lake can identify which nutrient limits algal growth. A lake manager who assumes algal growth in a New York State is limited by phosphorus will probably be right most of the time. Nitrogen-to-phosphorus ratios, however, can provide better information. Very high nitrogen-to-phosphorus ratios (usually greater than 30:1) indicate that phosphorus may be in short supply. Very low ratios (usually less than 5:1) suggest that nitrogen may limit algal growth, and may, therefore, cause blue-green algae to be much more common since they can secure nitrogen from the atmosphere as nitrogen gas**.**

Meeting the standards

Most guides for developing lake management plans omit water-quality standards, which is unfortunate. Lake water-quality standards are developed by federal or state governments to confer a degree of protection on lake uses, whether they be recreational or aesthetic uses, human consumption of fish and water, or protection of the lake residents themselves.

Water-quality standards exist for most of the indicators measured in a typical lake monitoring program. It has become clear, however, that the existing standards for most eutrophication indicators are insufficient to prevent highly eutrophic conditions from occurring. For many of these indicators, the lack of an adequate water-quality standard has resulted in state agencies developing **water-quality guidance values**, or criteria that provide thresholds for conditions likely to result in problems, but without all of the regulatory muscle associated with standards (see Table 4.3). Some criteria are narrative rather than numeric, such as "none in amounts that will … impair the water for its best usage." They are still enforceable, however, with the same rigor as numeric standards. For other water-quality indicators, standards and guidance values are inadequate to identify a threshold of concern. Calcium levels exceeding 15 to 20 mg/l, for example, are probably sufficient to support zebra mussel shell growth, yet this number is not reflected in the existing standards. For the most part though, standards and guidance values are critical for evaluating water-quality impacts (See Table 4–3) (NYSDEC, 1999).

Water-quality standards are calibrated for the most sensitive lake use. Aquatic life, primarily fish, is the most sensitive lake use for some water-quality indicators. Extensive toxicology testing conducted for many years has shown that aquatic life will be affected by low-levels of a particular indicator.

For other indicators, drinking water is the most sensitive use. In all cases, a violation of a water-quality standard usually means that a problem either has or will occur. Lake management should focus, therefore, on reducing the incidences of standards violations.

Water-quality results are not graded on a curve. A given lake still gets a failing grade when it does not meet the standard, even if its water quality is better than that of any other nearby lake. When a water-quality standard is not met, a problem exists that could result in use impairments or serious threats to the health of some user group, whether that group be humans or fish.

So what happens when a standards violation occurs? DEC is charged with assessing water resources throughout the state on a regular basis, including water-quality conditions in lakes. EPA and DEC have agreed upon numerical criteria for evaluating water-quality conditions and use impairments in New York State waterbodies. This agreement is referred to as the Consolidated Assessment and Listing Methodology (CALM). The "Listing" part of this phrase refers to the federal *Clean Water Act* requirements, sections **305(b)** and **303(d),** for assessing and listing the

Parameter	Type	Value	Uses Protected	Description
Water clarity	Criteria	4 feet	Swimming	To site new swimming beach (for safety, not to protect water quality)
Dissolved oxygen	Standard	4 ppm	All	To protect aquatic life
Dissolved oxygen	Standard	5 ppm	Coldwater fish (Class T)	To protect fish survival
Dissolved oxygen	Standard	6 ppm	Coldwater fish (Class TS)	To protect fish spawning
Temperature	Standard	Narrative	All	Related to thermal discharges
Total phosphorus	Guidance Value	20 ppb*	Swimming	To evaluate whether tertiary treatment is required for wastewater discharged to lake
Phosphorus, Nitrogen	Standard	Narrative	All	"None in amounts that will result in the growths of algae, weeds and slimes that will impair the waters for their best usages"
Nitrate	Standard	10 ppm	Drinking water	To prevent methamaglobanemia (blue baby disease)
Ammonia	Standard	2 ppm	Drinking water	Separate standard for ammonium only
Color	Narrative	Narrative	All	"None in amounts that will adversely affect the color or impair the waters for their best usages"
pH	Standard	< 6.5; > 8.5	All	Developed for regulating wastewater discharge to streams and lakes
Metals	Standard	various	All	Unique standard for each metal
Organic compounds	Standard	50 ppb	All	General standard for all organic compounds without specific standards
Turbidity	Standard	Narrative	All	"No increase that will cause a substantial visible contrast to natural conditions"
DOC, Alkalinity, Conductance, Chlorophyll a	None			
Fecal coliforms	Standard	1 colony / 100mL	Drinking water	Average of minimum of 5 measurements in one month
Fecal coliforms	Standard	200 colonies / 100mL	Swimming	Average of minimum of 5 measurements in one month
Total coliforms	Standard	2400 colonies / 100mL	All	Average of minimum of 5 measurements in one month
E.coli	US Standard	126 colonies / 100mL	All	

Table 4–3. New York State has identified thresholds for water-quality parameters that are likely to result in problems. Legal definitions appear in quotation marks.

**Site-specific phosphorus guidance values exist for Onondaga Lake, the Great Lakes, the New York City reservoirs, and various parts of Lake Champlain.*

condition of waterbodies. The general summary of waterbodies in each state is usually called the "305b Report," and the list of impaired waterbodies is called the "303d List" (NYSDEC). New York State also maintains a separate, in-state assessment referred to as the state Priority Waterbody List (PWL), in which all of the waterbodies in the state are identified as one of the following (NYSDEC, 2002):

- Precluded: The intended uses of the lake, based on its water-quality classification, cannot be realized at an acceptable frequency.
- Impaired: Lake use is severely compromised, although the lake can be used at an acceptable frequency.
- Stressed: Lake-use impacts occur, although they are not significant.
- Threatened: No lake-use impacts occur, although conditions exist that might lead to impacts in the near future.
- Not Impacted: No lake-use impacts occur, and no threats to lake use have been identified.
- Unassessed: Lake-use impacts and/or water-quality conditions have not been evaluated.

Due to the recent addition of non-impacted and unassessed waterbodies to this list, the PWL is perhaps better described as a Waterbody Inventory (WI), so the more cumbersome acronym PWL-WI is more frequently used. Numerical thresholds linked to water-quality standards, guidance values, and criteria have been attached to each of these classifications. A high frequency of violations of these standards usually results in listing a water body as "Impaired," although other evidence may also be required. Other evidence includes beach closures or fish-consumption advisories, signs of "impairments" such as the need for regular algae or weed control, or complaints about water quality. EPA and DEC frequently apply the "10-25 rule." Standards violations greater than 25 percent of the time frequently lead to "impaired" listings; between 10 percent and 25 percent result in "stressed" listings; and up to 10 percent result in "threatened" listings.

Lakes identified as "impaired" or "precluded" are usually placed on the federal 303d list of impaired waterbodies. A 303d listing requires the development of a strategy for determining the sources and acceptable levels of the pollutants that triggered the listing. This is usually called the **TMDL** process, which references the **Total Maximum Daily Load** of a pollutant allowable to maintain the designated uses.

Most of the New York State lakes identified as "precluded" are on this list due to acid rain impacts on aquatic life, particularly fish propagation or fish survival. Several lakes have fish consumption advisories due to organic compounds such as PCBs, or due to metals, particularly atmospheric deposition of mercury as a byproduct of burning of coal in mid-western power plants. Many of the "impaired" lakes found in all parts of the state are due to eutrophication.

Budgets for water, nutrients and other pollutants

Most people think of budgets as an inventory of debits and credits leading to a monetary bottom line. Budgets can also track water or pollutants as they enter and leave a lake.

Water budgets are a way to evaluate the transport of pollutants into a lake as well as the flow of more pristine water that may dilute pollutants. Water budgets can either serve as crosschecks to make sure that all pollution vectors are included within monitoring programs, or they can be used to determine which vectors, if any, can be adequately assessed through previous studies. Water budgets can be calculated for an entire lake, or for a portion of a larger lake that may be subject to a detailed evaluation to isolate the symptoms-causes-sources relationship in a problem spot.

To calculate a water budget, information on water entering and leaving the lake is collected. As noted earlier, many rivers and streams have been gauged by USGS. A lake manager can often obtain estimates of stream flow from nearby gauged rivers or streams if long-term local flow data is not available. Precipitation can be measured by rain gauges or nearby weather stations. Estimates of evapotranspiration for most regions of the state are readily available from NOAA. Water intake or withdrawal through water pipes and dams are often documented or can be estimated by municipalities. Reasonable estimates of domestic water use and discharge from septic systems per watershed resident have also been developed. Groundwater flow tends to be the most difficult to estimate, but is still often calculated to balance the hydrologic ins and outs of the lake. Determining the water budget lays the foundation for looking at the movement and budgets of pollutants, such as nutrients and solids.

Excess phosphorus, quantified by a phosphorus budget**,** is a concern for many lakes. A nitrogen budget may also be important, if nitrogen limits the growth of algae or rooted plants. Interest in some other element, such as mercury, can lead to the development of a lake's mercury budget, and so on. The phosphorus budget may be limited to the lake, or extend to include both the lake and its watershed. It may be a budget for one year or for a shorter period, such as for the ice-free season.

The amount of pollutants coming into the lake from outside sources is the "external load." This can come from precipitation, stream inflow, and direct runoff not entering the lake through permanent streams. It can also come from groundwater discharge, including the effluent from septic leach fields, or any direct discharges to the lake, such as from wastewater-treatment or industrial facilities. Particulate material, such as waterfowl feces and dry fallout, including dust, pollen and leaves, are other sources of pollution. These are the primary external sources for most "conservative pollutants," meaning those that do not undergo significant chemical or biological change. Conservative pollutants include some solids, total phosphorus, and chloride (often used as a "tracer" in water-quality studies).

Water-quality monitoring of the output from hydrologic sources, such as the mouth of tributaries, can help determine the extent to which each of these sources contribute to the pollutant loading in a lake during a designated time period. The most accurate way to estimate stream loading into a lake is to collect large amounts of stormwater and dry-flow data and build an extensive database for the major tributaries entering a lake.

Accounting for the entire external load can be challenging. For at least some pollutants, rainfall, water quality, and groundwater-flow data may already have been collected. If not available for a given lake, data from nearby lakes can provide an estimate. The biggest missing piece of a nutrient budget tends to be direct runoff and stream inflow data. Nutrient loading from direct runoff to a lake is usually estimated from the loading calculated for other typical land-use activities. Estimates can be extrapolated from data collected for tributaries within a lake watershed, or from values found in literature of samplings collected as close as possible to a specific lake.

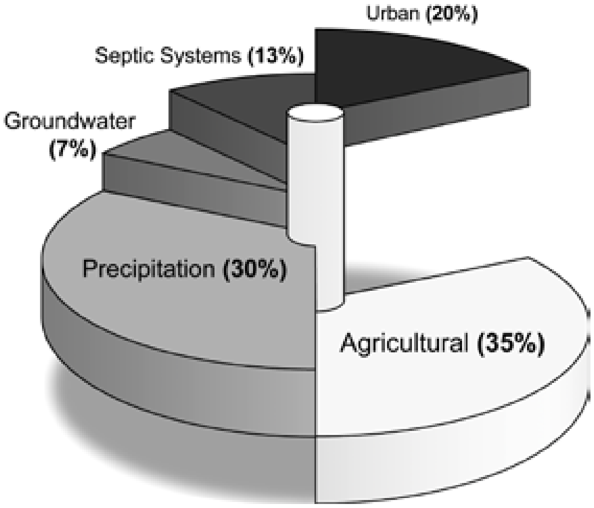

Fig.4–8. Example of a nutrient budget, showing sources of pollutants entering a lake. (CREDIT: CHRIS COOLEY)

Researchers have attempted for years to estimate nutrient export coefficients that show the typical level of nutrient loading derived from specific land uses. Many simple models use nutrient export coefficients to provide an estimate of nutrient loading from land-use activities when local data are not available. These coefficients are only general guides, since they are usually listed as wide ranges and have been developed for groups of many lakes throughout the country. Some coefficients have been specifically developed for lakes within the northern temperate climate, although few exist for land-use activities specific to New York State. Direct measurement of nutrient concentrations in tributaries with a variety of flow regimes can help determine if literature values for these export coefficients are reasonable for a particular lake. The different flow regimes include snowpack melt, storm flow during spring runoff, dry flow, and storm flow during dry periods.

Some pollutants, such as phosphorus, also have internal sources. Phosphorus can be released into the water column from sediment under anoxic conditions, primarily in thermally stratified lakes. Nutrient release from sediments also occurs under highly oxygenated conditions, but it is generally assumed that this is a short-lived phenomenon. During the summer, as the difference between air and bottom-water temperature widens, the thermocline is found at a greater depth. This can allow some bottom nutrients to become entrapped, and eventually mix with upper layers of lake water during lake turnover. See Chapter one, "Lake Ecology," for a more thorough explanation of lake stratification and mixing.

Internal and external sources constitute nutrient loading to a lake. The picture of nutrients in a lake is not complete, however, without accounting for the amount of pollutants leaving through water withdrawal, groundwater outflow, and surface outflow. The calculation of loading to a lake minus what leaves a lake is called net loading**.** Net loading exerts a greater influence on the concentrations of pollutants in a lake than loading alone. As discussed in Chapter one, "Lake ecology," a study of the hydrologic cycle serves as a reminder of how some materials can enter and leave a lake.

To make things even more complicated, many lake studies focus on the concentration of phosphorus in the upper waters of a lake, particularly in a thermally stratified lake. It is in this portion of a lake (epilimnion) that high nutrient levels can trigger algal blooms, and for which water-quality standards are most often written. In addition to net loading, therefore, the migration of pollutants from the upper to lower layers of a lake by settling and other phenomena also needs to be considered.

While all this can seem rather imposing, simple nutrient budgets can be generated with small amounts of water-quality data and water-budget information. Armed with a nutrient budget, a lake manager can identify the primary sources of nutrients to a lake and direct the focus of management efforts to reduce overall nutrient loading.

Taking advantage of relationships and interconnections

Based on individual water-quality indicators, the results from water-quality monitoring studies are often used to either evaluate the present condition of a waterbody, or evaluate whether conditions have changed through time. The relationship between these indicators can also yield other important information about a lake. The correlation between phosphorus and chlorophyll *a*, whether through calculations of TSI, N to P ratios, or plotted against each other, helps to evaluate whether algae are limited by a lack of phosphorus. This also serves as a predictive tool to project what amount of decrease in phosphorus loading to a lake will result in significant decrease in algae densities. A similar correlation between chlorophyll *a* and Secchi disk transparency, or some other measure of turbidity, will help to translate changes in algal density to increases in water clarity. Survey data collected over a wide variety of conditions in a lake can be used to generate projections about improved public perception and improved recreational opportunities. Comparing the trophic indicators to each other and to assessments of lake condition provides a tool for linking water-quality improvement strategies (such as reducing nutrient loading) to lake management objectives (such as improving recreational suitability of the lake).

Individual water-quality indicator linkages have been identified for lakes throughout the country and within New York State as part of the nutrient criteria development process pioneered by a cooperative effort between the DEC, EPA and the states of Minnesota and Vermont. These studies have determined that lakes in common ecoregions often display similar correlations, even if the correlations for individual lakes may ultimately be different from those identified for larger groups of lakes. For lakes in the Adirondacks, for example, people seem to have a common standard for how clear the water must be for swimming. It takes less loss of water clarity in the Adirondacks than in other regions of the state before people complain of reduced recreational conditions related to swimming. This is due in large part to the local perception that high clarity is normal and, therefore, expected within the Adirondacks. Perceived recreational impacts as a result of reduced water clarity tend to occur at Secchi disk transparency readings that are fairly similar throughout the Adirondack Park. This perception of "normal" is so strongly ingrained in the public acceptance of lake water-quality conditions that it can be used as a benchmark, which ultimately affects the management of these lakes.

The correlation among trophic indicators can be used to determine if management objectives are unlikely to be achieved by a particular water-quality improvement strategy. For instance, dissolved organic matter naturally colors some lakes. If that coloration limits water transparency, reducing phosphorus levels will probably not result in a substantial increase in water clarity, although it may still reduce the number of algal blooms. In these lakes, improving water clarity is probably not an achievable management objective because the natural condition for these lakes accounts for much of the lack of transparency. In lakes in which phosphorus and chlorophyll *a* are not well correlated, such as those with very high flushing rates, phosphorus control is unlikely to substantially reduce algal blooms. These scenarios are uncommon in New York State lakes.

More common are lakes where poor water clarity limits light transmission enough to limit weed densities. If a management objective is to improve conditions for swimming by reducing algae to increase water clarity, there may be some unintended consequences. Reducing algae allows more light to penetrate to the bottom of the littoral zone, promoting weed growth that could harm swimming in the future. This phenomenon has occurred in many New York State lakes, including Saratoga Lake. For these lakes, weeds may exert a more substantial impact on recreation than algal blooms. The ancillary benefits of reduced algal blooms, such as better drinking-water quality, and fewer incidences of algal toxins or oxygen deficits, may ultimately make the effort worthwhile. This example illustrates the importance of evaluating the interconnected values of multiple water-quality and lake-use indicators.

Interconnectedness of other water-quality indicators can also be explored. Some studies indicate an apparent correlation between trophic indicators and deepwater oxygen levels. This relationship can be used to identify whether a lake is likely to support salmonids or other coldwater fish that require a balance of cold water and high oxygen levels. Another correlation to examine is the connection between water quality and rainfall or runoff for identifying the relative influence of different sources of external loading. Health officials, for example, have consistently linked heavy rainfall with high bacteria levels at a swimming beach on Owasco Lake, pointing to stormwater runoff rather than waterfowl as a prime source of the contamination. This realization readily made the symptom-causes-sources connections that led to effective management.

Modeling

All water-quality data collected can be entered into water-quality **models**, which are essentially tools to predict changes in lake conditions. These models can be very simple, with input information limited to just a few key water-quality indicators, or very complex, requiring substantial data for a variety of indicators collected frequently during a long period of time. Models will attempt to diagnose a problem in a lake based on the existing relationships among water-quality factors, or to predict future water quality. Many complex models build both diagnostic and predictive capabilities into their processes. Some models focus only on in-lake activities, while others are watershed models that focus on inputs to lakes. While both lake and watershed models can operate independently, the best models combine equations describing the watershed with equations describing the lake.

Lake and watershed models are based on mathematical formulas or equations quantifying cause and effect relationships that trigger specific lake responses. A lake model will include equations that describe the relationship between the average depth of a lake and its phosphorus loading to its trophic condition. The figure below demonstrates this relationship, and is often referred to as a Vollenweider Plot (1975), named for the Canadian limnologist Richard Vollenweider. The relationship between the conditions of a lake, its phosphorus loading, and its depth can be used to show that shallower lakes are more susceptible to phosphorus loading than deep lakes. This is discussed in more detail in Chapter two, "From Montauk to Erie", as it relates to New York State lakes.

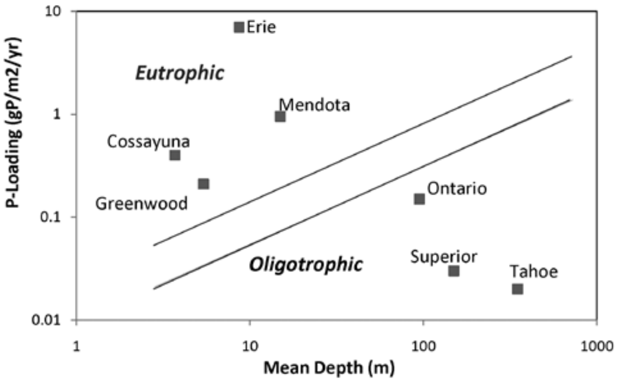

Fig.4–9. Vollenweider Plot showing the relationship between a lake's depth, phosphorus loading, and trophic state. (Adapted from Vollenweider, 1975)

The Vollenweider Plot can also be used to predict the future condition of a lake based on its nutrient loading and depth. The accuracy of the prediction can be increased by making the calculations more complex within the models. Additional information is factored into the equations such as:

- lake-flushing rate, or how quickly water moves through the lake;
- lake volume;
- sedimentation rate, or how quickly material falls through a lake from the surface to the bottom;
- outflow rate, and
- other physical characteristics.

Models developed by Dillon and Rigler (1974) and by Vollenweider (1976) continue to be useful for relatively simple estimates of either phosphorus concentrations within the lake or nutrient loading to the lake. When combined with simple watershed models that use nutrient export coefficients to estimate nutrient loading from various land uses within a watershed, simple nutrient budgets can be developed to identify potential hot spot locations for focusing management efforts.

There are increasingly complex, computer-based versions of these models. EUTROMOD is a lake-input response model available through the NALMS website. BATHTUB is a U.S. Army Corps of Engineers model that evaluates lake eutrophication response to various nutrient loads. Two examples of loading models are BASINS, "Better Assessment Science Integrating Point and Nonpoint Sources," an EPA model, and SWAT, "Soil and Water Assessment Tool," a U.S. Department of Agriculture (USDA) public-domain model. (See Appendix F, "Internet resources") These models use a combination of information, such as site-specific data collected from the lake, historical data collected in similar lakes, and general estimate data for lakes or lake watersheds in the particular region, or other parts of the country. Some of these models predict long-term, lake-wide average conditions, while others predict short-term conditions, local water-quality conditions, and changes through time. For all of these models, larger and more complex data sets collected for the lake and watershed in question enhance the accuracy of the model.

The general public can use many of the simple lake models, but as the models increase in complexity, they require complicated computer software and extensive data not readily available for most lakes. The more complex models tend to be employed by researchers, government agencies, and lake-management professionals involved in intensive management or restoration of high profile waterbodies. Such models can take many years to develop and master. While the diagnostic and predictive powers of these models are very high, they are often not required for the breadth of management likely to be undertaken by lakefront property owners, lake users, and most municipalities.

How much will it cost?

This can literally be the million-dollar question. The cost of monitoring ranges from no-cost and relatively inexpensive volunteer monitoring programs, to studies costly in terms of human resources and equipment, to Cadillac programs conducted on very high-profile lakes.

The only clear generalization that can be made regarding the cost of a monitoring program is that it should be dictated by the objective of the monitoring. Long-term monitoring programs involving water-quality indicators, such as metals or organic compounds, will generally cost more than simple evaluations of contemporary lake conditions. The extent of monitoring and related costs may be very high if the monitoring requires high precision and legally defensible results. There may be little leeway in containing costs if the study is part of litigation or compliance, such as pollutant discharge limits imposed on wastewater treatment. For most lake associations, cost and effort should ultimately be governed by the needs of the data user.

As this book goes to publication, water-quality parameters such as color, pH, turbidity and conductivity tend to cost about $10 per sample or less. Nutrients, chlorophyll *a,* and bacteria tend to cost between $10 and $50 per sample. Metals, organic compounds, and microbiological identifications for phytoplankton, zooplankton and bacteria species tend to cost more than $50 per sample, although many of these analyses provide data for multiple parameters. While metals samples can be expensive, for example, the analytical methodology usually provides results for several metals types, since these are analyzed simultaneously.

Water-sampling equipment costs are quite variable. High-end electronic sampling devices tend to cost up to $10,000, particularly those with data loggers that record data for multiple water-quality indicators. Most of these devices collect instantaneous temperature, oxygen, pH and conductivity readings. Some of the more expensive units also measure some nutrients, chlorophyll *a*, and other water-quality indicators. Electronic meters that only measure temperature and oxygen cost less than $1,500 and tend to be a little less temperamental than more expensive units. Water-sampling devices for collecting grab samples at a variety of depths usually cost about $500, mostly owing to the need for a reliable tripping device. As with the aforementioned electronic devices, however, less expensive versions have also been developed. Integrated samples are usually collected with weighted hoses attached to calibrated lines. These samplers can also be made of materials as diverse as reinforced tubing or simple garden hoses, to PVC pipes with stop valves, to peristaltic pumps. Sediment samplers can range in cost from less than $500 for simple grab samplers, to more than $10,000 for piston-driven corers. Secchi disks can be made inexpensively using instructions readily available on the Internet, but can also be purchased for under $50 from several vendors.

The lake looks bad

Collecting and synthesizing all this information may seem daunting, but it is imperative that the symptoms-causes-sources relationship be adequately investigated and documented. The process of objectively understanding the basis of a water-quality complaint is critical to successful lake and watershed management. Based on the complaint "The lake looks bad," the following illustrates how to determine the symptoms-causes-sources relationship discussed in this chapter.

Symptoms determination

- Determine the number of residents "offended" by aesthetics, through surveys or questionnaires and categorize responses by groups of lake users.
- Determine if all user groups share this opinion, or if it is limited to a single group, and other groups believe that lake conditions have improved for their uses.
- Determine whether this is a recent and/or seasonal problem.
- Identify whether the whole lake or just isolated areas look bad.
- Determine if the complaint is associated with "normal" conditions in the lake or if this represents a change in lake condition.
- Identify any other use impairments that occur as a result of this condition.
- Determine if similar complaints occurred when lake conditions were different. For example, did "the lake look bad" when clarity was high and weeds were high, or when clarity was low and weeds were low?

Causes determination

- Collect water-quality data to determine if the aesthetic problem is related to water-quality problems, particularly those related to trophic indicators. Make sure that the indicators evaluated relate to the use of the lake for swimming, drinking, and fishing.
- Compare contemporary water-quality data to any historical data to determine if changes have occurred and, if so, whether these changes have been sudden or gradual.
- Identify any correlations among water-quality indicators, to evaluate triggers that resulted in impacts, including relationships between weather and these indicators.
- Determine if conditions are different in the area that "looks bad," particularly if the complaint does not represent a lake-wide problem.
- Determine the extent of rooted plant growth in the lake, both within the offending area and in other parts of the lake. This would include identification of dominant plant species throughout the lake, and how their community structure and densities change during the recreational season.
- Compare plant coverage maps to historical information, when possible, to determine if changes in plant densities or plant community composition (species) have occurred.
- Determine the level of understanding the residential community has about weed growth, particularly in regards to the specific weed(s) of concern. Are their concerns driven by the mere presence of weeds, or just the specific types and densities in the lake?
- Determine sediment types throughout the lake to see if they are conducive to uncontrolled growth of the "feared" weed, and investigate whether the offending plants grow invasively in lakes that are similar with regard to water quality, sediment types, slope, climate, etc.
- Determine if any control mechanisms have been previously attempted or are currently in progress to address the algae or weed problem. If there are, determine the results of those control programs.

Sources determination and actions

- Collect present day and historical records of land-use surveys to determine whether watershed activities are bringing sources of nutrients or sediment into the nearshore and shallow areas, including any swimming areas or fishing corridors.
- Conduct septic dye testing to determine the number of leaking and failing septic tanks and other on-site wastewater disposal systems, and relate the results of that testing to the influx of plant nutrients.
- Determine if the effluent from any wastewater-treatment facilities within the watershed is discharging directly to the lake by surface flow or groundwater.
- Conduct stream, precipitation, and lake-level gauging to determine the percentage of watershed nutrient and sediment sources contributing to the lake water and nutrient budgets. Determine whether the use impairments are directly attributable to changes in water and nutrient levels from watershed or atmospheric sources.
- Collect information on lawn fertilizer use in the watershed. Determine the location of fertilizer and failing septic tank "hot spots" relative to excessive algae or weed growth.
- Investigate development and subdivision records to determine the relationship between changes in residential use or density and changes in vegetation levels and use impairment.
- Survey public boat launch areas, such as boat ramps, roadside launch points, beaches and inlets, to determine if aquatic plants can easily enter the lake through these sites. Inspect the near shore area and the shoreline in the vicinity

of launch sites to determine if weed infestations are more significant, or if there is evidence that plant fragments may be entering the lake from trailers or boat props.

- Determine if waterfowl use the lake, and if lake residents feed or otherwise encourage the waterfowl to congregate.
- Use nutrient and source information to construct a simple nutrient budget for the lake. If it is determined that sediment composition has changed, particularly in weed-infested areas, identify the most likely source of sediment for the lake or for weed-affected hot spots.

Each component of the symptoms-causes-sources relationship listed above may provide the key pathway for a successful lake and watershed management plan. Development of each component may force the development of other components, and direct the collection process toward previously unexplored questions. Information collection cannot be completed without addressing each of these components.

Why?

After all the bottles of water have been collected and all of the maps drawn, it is time to stand back and again ask "Why?'. If the data is not sufficient to answer all of the questions posed in this chapter, then a lake manager's work is not done.

If the management plan is built around supporting and protecting lake fisheries, for both the fish and the anglers, were anglers surveyed about the quality of the fisheries? Has funding sources to support stocking been secured? Were enough data collected about the native fish to be assured that the stocked fish will not create cascading ecological problems? Is the water-quality data collected specific to fish survival and propagation, including dissolved oxygen, temperature, pH, metals, chlorophyll *a*, phytoplankton identification, zooplankton counts, benthic communities, and macrophyte coverage? Are there aquatic plant coverage maps to aid anglers in identifying prime fishing locations? Is there secured lake access or regulated access for non-resident anglers? Is there a consistent message to lakefront residents to assure they are not recklessly removing all weeds? Is there a boat inspection program to prevent the introduction of zebra mussels and other exotics? While some of these questions are outside the realm of monitoring and problem diagnoses, they all point to the need to revisit data collecting and management planning goals to assure the plan is moving in the right direction. Data collection is a time-consuming and expensive process and should always be undertaken with specific objectives in mind. Purposeless data is bad data.

Summing it up

While it is natural to want to solve an in-lake problem with an immediate solution, such quick fixes are not enough. The cause of the problem must be analyzed and understood before a lake/watershed management plan can be designed to try to solve it. Collecting the necessary information requires asking the questions: Why?, Who?, What?, Where?, When? How? and then Why? again. Sampling methods to answer the questions can range from simple observation and weed identification to the use of very expensive equipment and laboratory testing.

If additional sampling is warranted, it should be integrated with the wealth of information already collected by government-sponsored programs as well as ongoing academic, private and volunteer programs. At the end of the process, there should be confidence that sufficient data has been collected and evaluated to determine the likely cause(s) of the initial complaint, and that the most significant source(s) of the problem has been identified.

The next chapter will take an in-depth look at the health of fisheries, an area with specialized assessment methods and management options.