# 7

# Algae and Other Undesirables: Getting Rid of Yuck

## Introduction

Aquatic macrophytes, or rooted aquatic plants vex many New York State lake users, but they are not the only significant in-lake problem. Algal blooms, nuisance species, and poor water quality may be nearly as, or more, troublesome than macrophytes. This chapter describes immediate and sometimes short-term techniques for coping with these three common concerns.

The in-lake management strategies presented in this chapter and in Chapter six, "Aquatic plants," are the primary mechanisms for correcting the most prevalent water-quality problems. Those solutions may alleviate the symptoms but do not solve the underlying cause. Approaches that deal with the underlying problem will lead to solutions that last longer than those that only address symptoms. Chapter nine, "Watershed management," will discuss the long-term, watershed-based strategies that are the best way to address the real cause of in-lake problems. Dealing with "the big picture," however, requires much effort and time. The interim methods for dealing with the symptoms usually keeps lake users happy while longer-term solutions are being developed.

## Algae control by physical means

Algal blooms are among the most significant and common lake problems encountered in New York State lakes and, therefore, algae management is discussed first. Techniques are grouped by physical, chemical and biological control.

The three management techniques that control most algae through physical means all involve lake stratification. Lakes in New York State may stratify in summer and winter. When a lake is stratified, colder, heavier water sinks to the bottom and lighter, warmer water rises to the top. This creates distinct layers that do not mix easily. In relatively deep lakes, these layers become less distinct during the spring and fall months and mix together in the process known as destratification or turnover. See Chapter one, "Lake ecology" for a full discussion of stratification and related terms. Figure 1-7 illustrates stratification and turnover.

During stratification, the bottom water, or hypolimnion, receives little or no exposure to the atmosphere, which can lead to oxygen depletion. This is usually much more severe in the summer stratification, during the four warmest months of the year. The hypolimnion is the location for reactions with the sediment, degradation of organic materials that have settled out of the water column, and significant biological activity. This combination of oxygen depletion and chemical reactions can lead to deoxygenated, high-nutrient conditions.

### *Artificial circulation*

#### *Principle*

Artificial circulation is the process which injects compressed air from a pipe or ceramic diffuser into the hypolimnion. With some circulators, water is moved through the use of solar-powered impellors. Either method can eliminate thermal stratification and improve the flow and movement of water within a lake. This may improve fisheries and reduce taste and odor problems associated with ammonia, iron and manganese by changing them to a reduced state. It may also lower algae levels by inhibiting the release of phosphorus from oxygen-depleted bottom sediments. A reduced state is the opposite of an oxidized state, changing the oxidation state of an atom by gaining electrons.

There are several ways that artificial circulation can correct algae problems. Lake sediments may release bound phosphorus under low-oxygen conditions, which encourages algal blooms when the lake turns over in the fall. Increased circulation will restore sufficient oxygen to bottom waters and minimize this nutrient release. In a lake with light-limited algae, mixing that extends to the lake bottom will decrease the time that individual algae cells are exposed to light, thus restricting their growth. This is referred to as the "critical depth" concept. Circulation may improve zooplankton survival and increase predation, which can reduce algae levels. Algae species may shift from blue-green to less noxious green algae from the increased surface water contact with the atmosphere, a lowering of the pH and incorporation of carbon dioxide-rich bottom waters.

The rising column of bubbles from the aerator, if sufficiently powered, will produce lake-wide mixing that eliminates temperature differences and results in a constant temperature throughout the water column. The disintegration of the thermal layers allows mixing that exposes bottom waters to the atmosphere. When the temperature and density differences between upper and lower layers are nearly eliminated, wind and other natural mixing mechanisms will assist in maintaining well-mixed conditions.

## *Advantages and disadvantages*

Artificial circulation can be used in most lakes that exhibit summer thermal stratification and have a distinct epilimnion and hypolimnion. Artificial circulation is a popular technique since it is best used alone. Many of the benefits in algae control, such as light-limitation and lower pH, are not easily achieved by other restoration techniques.

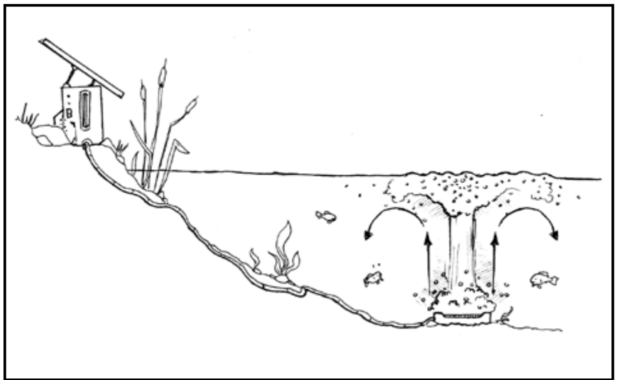

*Fig. 7–1. Artificial circulation using solar power, showing compressor on the shore and pipe and hose to diffusers sitting on the lake bottom.*

(CREDIT: CHRIS COOLEY)

Complete mixing by artificial circulation will increase the temperature in the hypolimnion as much as 15ºF to 20ºF. This could have disastrous effects, however, on the cold-water fish species that thrive in the hypolimnion.

Artificial circulation may adversely affect lakes that are not thermally stratified. Its use, therefore, should be limited to stratified lakes. Portions of the lake, such as shallow coves or bays, are not good candidates for this treatment if they are separated from mixing with the stratified layers in the rest of the lake; if there is a significant littoral zone; and if the algae growth is nutrient-limited.

In stratified lakes where algae are nutrient-limited in the epilimnion, artificial circulation may increase the phosphorus levels in the upper layers, promoting increased algae growth. This would decrease transparency, and perhaps raise the pH, shifting the dominant algae from green to blue-green. The same scenario may occur when only partial destratification is achieved, especially in lakes that do not possess a distinct epilimnion and hypolimnion. These effects may be temporary since migration of nutrients from sediment to hypolimnion to epilimnion may be reduced once deepwater oxygen levels rise.

Failure to achieve the desired objective with artificial circulation may be caused by lake chemistry, insufficient design, or equipment failure. Correct air flow pressure, system sizing, flow rate, and depth of air release depend on the site conditions, and must be properly designed to maximize success. Even when artificial circulation is successful, the perceived benefits are usually delayed.

## *Costs*

Costs for artificial circulation are low, relative to other management techniques. The primary costs are for the compressor and installation of pipes and air diffusers. The cost for artificial circulation is approximately $150 per acre of surface area.

### *Regulatory issues*

Circulators generally do not require permits, but the local New York State Department of Environmental Conservation (DEC) Regional Office should be consulted to determine if wetland or other site-specific permits may be needed.

### *History and case studies in New York State*

Artificial circulation was originally employed to reduce winter fishkills caused by oxygen depletion, but is now commonly used to control eutrophication problems in small ponds and reservoirs. It has been rarely used in large New York State lakes, although the frequency of use in recent years has increased. These projects have not been well documented.

## *Hypolimnion aeration*

### *Principle*

Hypolimnion aeration is used to increase oxygen circulation within a lake and increase oxygen content of the deep waters without causing enough turbulence to disrupt the stratified layers. Aeration of the lake bottom waters uses an air-lift device to pump or lift the deep, stagnant water layer for exposure to the atmosphere. This results in aeration and the loss of some gases such as carbon dioxide and methane. Then the water sinks back to the hypolimnion. Hypolimnetic aeration may also be accomplished by injecting pure oxygen or air into the bottom waters or by using an air-lift device along with injection.

When the hypolimnion has sufficient oxygen, release of phosphorus from oxygen-depleted bottom sediments will be minimized, and this may result in decreased algae levels. Aeration also allows the lake to maintain sufficient oxygen levels for coldwater fish such as trout, without adversely increasing the water temperature or destratifying the lake. It can also reduce taste or odor problems associated with ammonia, iron and manganese, an important consideration if deep water is being withdrawn for drinking water purposes. Aeration may also improve the quality of hypolimnetic water discharged downstream.

### Case study: Artificial circulation in East Sidney Reservoir

**Lake setting**: East Sidney Reservoir is a 210-acre impoundment in the north branch of the Susquehanna River in south-central New York State.

**The problem**: High nutrient (phosphorus) concentrations resulted in excessive algal blooms, reduced water clarity, and hypolimnetic anoxia. Runoff from a largely cattle and agricultural watershed increased nutrient loading in the lake.

**Response**: An artificial circulation system was installed in 1989 to prevent anoxia in the bottom waters. The system consisted of a 15-horsepower compressor, 122 meters (m) of galvanized pipe, 305m of flexible hose, and eight 331m PVC pipe diffusers. The diffusers were joined, and a manifold and valve system controlled airflow to each section. The diffusers were sited at a depth of about 9m from 1990 through 1992. The system was generally operated for 23 hours-per-day from late May through mid-October. Airflow ranged from 0.3 to 1.1 cubic meters per minute during this period.

**Results**: Deepwater oxygen levels in the reservoir increased during the course of the study, resulting in lower phosphorus and metals concentrations in the bottom waters of the reservoir. Maximum total phosphorus levels in the hypolimnion ranged from 130 to 170 parts-per-billion (ppb) before and after the study, but only reached about 50 ppb during most of the study. Surface phosphorus readings were actually higher in 1991. Average deepwater phosphorus readings also dropped from about 70 ppb before the artificial circulation to about 40 ppb during the study. Similar reductions occurred in manganese and iron concentrations. Summer water clarity and chlorophyll a readings were essentially unchanged as a result of the artificial circulation, and weak thermal stratification still occurred, resulting in intermittent dips in dissolved oxygen levels and occasional nutrient and metals release from bottom sediments.

**Lessons learned**: Artificial circulation systems can be successful for minimizing some water-quality effects associated with deepwater anoxia, but these systems must be carefully designed to assure full circulation and to assure destratified conditions during the peak stratification period of late spring through mid-fall (Barbiero et al, 1996).

## Advantages and disadvantages

Hypolimnetic aeration is appropriate when lakes are stratified and have a large hypolimnion. Aeration systems are generally used only during summer stratification and not used during winter stratification due to the decreased biological activity and higher solubility of oxygen in cold waters.

The use of hypolimnetic aeration in shallow lakes and reservoirs with only partial stratification should be considered with great caution. Shallow lakes without hypolimnion do not benefit from summer aeration. Some type of winter aeration might be beneficial in preventing fishkills in the most productive shallow lakes and ponds because ice cover that lasts for months can prevent natural aeration.

Although the stratified layers are usually maintained during deep-water aeration, nutrients may diffuse from the hypolimnion to the epilimnion during the process. This may increase the algae levels in the epilimnion and the thermocline.

Another potential disadvantage to hypolimnetic aeration is the supersaturation of bottom waters with nitrogen gas, which can lead to “gas-bubble disease” in fish. Since the nitrogen-rich gas cannot be dissipated through exposure to the atmosphere, nitrogen build-up can be significant in lakes that remain stratified for several months.

## Costs

Costs of aeration are dictated by the amount of compressed air required to fully aerate the hypolimnion. This is a function of the lake’s hypolimnetic area, the rate at which oxygen is used up, and the extent to which the lake is stratified.

Aeration projects can be extremely expensive. Typical operating costs for six months of operations are estimated to be at least $2,500 per acre of surface area. The capital cost for the equipment tends to be very high, and the operating costs increase proportionally to the size of the lake. Most hypolimnetic aeration projects are funded by a research institute or corporation. The funds necessary to carry out an aeration project are usually well beyond the means of most lake associations.

## Regulatory issues

Permits to install and operate an aerator are required by DEC under Article 15 of the Environmental Conservation Law (ECL), and by the Adirondack Park Agency (APA) if the lake is within the boundaries of the Adirondack Park.

## History and case studies in New York State

There have been very few attempts to aerate the hypolimnion of lakes in New York State. The only major project was Lake Waccabuc in Westchester County (see Case study on aeration). This project was somewhat successful at increasing oxygen levels at the sediment-water interface and reducing the migration of pollutants out of the lake sediment, but these benefits were neither sustained nor extended higher in the water column.

### Case study:
### Aeration in Lake Waccabuc

**Lake setting**: Lake Waccabuc is a 140 acre lake in Westchester County, just north of New York City.

**The problem**: The lake experiences water-quality problems and invasive plant growth typical of eutrophic lakes with high nutrient loads entering the lake through stormwater drains and other sources. The lake thermally stratifies in the spring, and exhibits anoxic conditions throughout the hypolimnion during much of the summer, resulting in an internal phosphorus loading that represents nearly half of the overall nutrient loading to the lake (Martin, 2004).

**Response**: The Three Lakes Council represents Lake Waccubuc, Lake Oscaleta, and Lake Rippowam. In the early 1970’s, the Council and Union Carbide utilized local interest in protecting water quality and their desire to conduct an aeration study to develop a project in these three lakes. In 1972 two hypolimnetic aerators were installed at a depth of 45 feet on the bottom of Lake Waccabuc. Lake Oscaleta and Lake Rippowam were untreated in order to serve as control studies.

**Results**: The study conducted by Union Carbide reported the following (Three Lakes Council, 2001):

- a decrease in the in-lake nutrient concentrations which otherwise would have been available for algae production;
- an improvement in water-quality conditions by eliminating or decreasing hydrogen sulfide, iron and manganese levels; and
- creation of a suitable environment which can support a coldwater (trout) fishery.

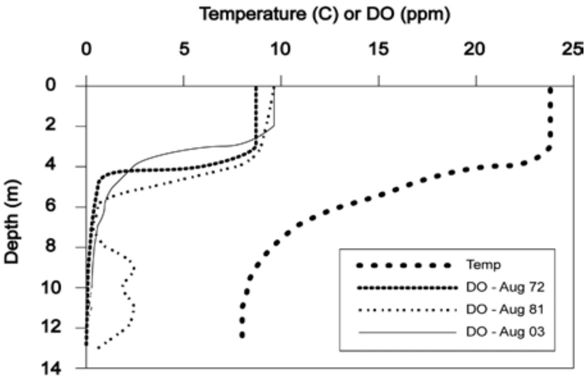

*Fig. 7–2. Temperature / Oxygen profiles in Lake Waccabuc August of 1972, 1982, and 2003.*

It is not clear from an evaluation of these data (Fig. 7–2) that coldwater fisheries could thrive as a result of aeration. In-lake nutrients, such as deepwater phosphorus, hydrogen, sulfide, iron and manganese levels may have dropped due to the elimination of anoxia near the lake bottom. It also appears that by 2003, these aerators were not functioning as efficiently as they had in the 1970's and early 1980's.

Once the two-year experiment was completed, Union Carbide funded the operation of the aerators by the lake association for several years, after which local contributions covered the $15,000 per year cost of the system. The lake association and local community also engaged in septic and stormwater management activities to reduce external nutrient sources to the lake. They developed multiple water-quality monitoring programs to evaluate long-term changes in the lake. In 2004, the aerators operated at a cost of about $9,000 annually. In 2005, the Three Lakes Council planned to conduct an additional feasibility study for upgrading the aeration system.

**Lessons learned**: It is not clear from this study if aeration would be successful in other lakes in oxygenating all of the hypolimnion, and if it would be adequate to support the stocking of coldwater fish. These data do indicate that some of the problems associated with an anoxic hypolimnion will be reduced, mostly those related to formation of hydrogen sulfide and related compounds.

## Hypolimnetic withdrawal

### Principle

Hypolimnetic withdrawal is most often accomplished through the installation of a pipe or siphon along the bottom of the lake, usually at the outlet. Water flows out of the hypolimnion by gravity, past the outlet to the receiving waters. If there is insufficient elevation for gravity flow, an auxiliary pump can be installed.

The benefits from hypolimnetic withdrawal should be greatest during the months of significant stratification and nutrient release, usually June through August. Summertime hypolimnetic withdrawal serves to remove the high-nutrient waters, thus reducing the potential for algal blooms when the epilimnion and hypolimnion mix during fall turnover. Some coldwater algae species common to New York State lakes, including some species of *Oscillatoria* and other blue-green algae capable of regulating their buoyancy, may also be selectively removed with this strategy.

The withdrawal serves to decrease oxygen deficits and elevated nutrient (phosphorus) concentrations in the hypolimnetic waters of lakes. In time, the oxygen and nutrient conditions in the bottom waters significantly improve, and the supply of nutrients available for release from the sediments may be ultimately exhausted. The hypolimnetic withdrawal takes advantage of the higher solubility of oxygen in cooler water to help restore oxygenated conditions to the lake bottom. It may also help preserve the coldwater fisheries that may exist, or allow restoration of one that historically existed in the bottom waters.

Hypolimnetic withdrawal can be used in stratified lakes or small reservoirs with oxygen-poor or nutrient-rich bottom waters. It has been particularly effective for lakes where reductions in external nutrient loading have been made but internal lake loading has not been addressed.

### Advantages and disadvantages

This is a relatively passive lake management tool. Withdrawal valves and water flow are mostly inconspicuous and can achieve oxygenation and algae control without the use of algae-killing chemicals or large, artificial circulation or aeration equipment.

The most significant adverse effects of hypolimnetic withdrawal involve the discharge waters. Important fishery streams below the lake outlet are particularly susceptible. Hypolimnetic waters with low oxygen and high nutrient content can cause oxygen depletion, algal blooms, and taste or odor problems in receiving waters. There may be noxious odors in the discharge waters due to the production of hydrogen sulfide in the hypolimnion, rendering the mixture aesthetically unpleasant for downstream residents. Hypolimnetic waters may also contain elevated levels of ammonia, arsenic, or other dangerous compounds. The downstream side-effects generally occur if the receiving waters are nutrient-limited, or if the flow from the discharge constitutes a large percentage of the receiving waters. The flow associated with the discharge, like that from a surface discharge, may need to be sufficiently large to meet downstream flow and water-quality needs. This may dictate the sizing of the pipes and valves used to regulate this discharge.

Conversely, there may be some benefits for downstream waters, such as coldwater conditions to support fish propagation, but the additional need for high water quality may require treatment of the discharge. As more hypolimnetic waters are released from the lake, the water quality of the discharges should improve as oxygen conditions in the hypolimnion improve.

Hypolimnetic withdrawal can also produce thermal instability and possibly destratification. This introduces nutrient-rich anoxic water to the epilimnion, causing algal blooms, odor and taste problems, and recreational and aesthetic impairments. If withdrawal rates are greater than inflow rates, withdrawal may cause an unintended lake drawdown. This is less of an issue when using surface withdrawals, since these are often self-regulated by the height of the boards, depth of the weir, or physical constraints of the control structures.

### Costs

For lakes with sufficient elevation to generate gravity flow (head), hypolimnetic withdrawal can be one of the least expensive lake restoration techniques available. For lakes with poor gravity flow, it may be necessary to install pumps and a piping system, which significantly increases the costs. The costs can be low to moderate even with the cost of the pumps and associated plumbing. Typical installation, maintenance, and operation costs for a pumped and pipe withdrawal system has run from $35,000 to $130,000 capital costs, and about $10,000 per year operating cost.

### Regulatory issues

The DEC requires a State Pollution Discharge and Elimination System (SPDES) permit for hypolimnetic discharges. Special attention is given to preserving the quality of the receiving waters. Freshwater wetland permits would also be required by the APA for lakes within the Adirondack Park.

### History and case studies in New York State

The use of hypolimnetic withdrawal as an in-lake management tool has not been attempted in any New York State lake, although it has been proposed for several large lakes. Galway Lake in Saratoga County has used a controllable gate about 20 feet below the surface of the lake to reduce overall phosphorus concentrations in the lake. The gate is opened from two to eight inches during the summer for intervals of up to two weeks.

Hypolimnetic withdrawal is occasionally used in New York State lakes and reservoirs for other objectives, such as supporting trout populations in downstream rivers and streams. Bottom water from the Ashokan Reservoir in the Catskills, for instance, is released to support trout fisheries in Esopus Creek.

One of the few well-documented instances of a hypolimnetic withdrawal in a New York State lake is an innovative project by Cornell University. Cold, hypolimnetic water from Cayuga Lake acts as a heat sink and provides air conditioning and refrigeration to portions of the Cornell Universitiy campus. This is not a lake-management strategy since the benefits associated with the project are not conferred to the lake itself. Environmental benefit associated with the utility heat exchange comes from the reduction of contributions to global warming, since the alternative would be the continued burning of fossil fuels for campus cooling. Cornell benefits from reduced energy costs. Questions remain regarding potential impacts to the lake with respect to:

- Increased primary productivity associated with the introduction of nutrient-enriched hypolimnetic waters into the shallow, southern end of the lake; and
- Aquatic ecosystem concerns related to damage to small crustaceans (*mysids*) at the intake (Callinan, 2004).

## Algae control with chemicals

### *Algacides*

#### *Principle*

Algacides are generally copper-based chemicals used to kill algae cells, and to reduce the use impairments associated with excessive algal growth. The copper inhibits the photosynthetic ability of the algae cells, and may affect the way nitrogen compounds are metabolized within the cell. Copper is sometimes combined with some herbicides to reduce standing populations of rooted plants as well as algae.

**Copper sulfate** is the most common algacide and one of the most popular algae control techniques. Copper sulfate is usually applied in granular form, often dragged in burlap bags behind an applicator boat to ensure slow release. Liquid forms of copper sulfate can be applied where other copper formulations might bind with suspended particles, dissolved organic matter, or carbonate ions, rendering them ineffective for algae control. Copper sulfate can be used to control algal blooms, and in extreme situations, to control excessive rooted plant growth.

Some formulations of algacides use chelated copper, which consists of copper combined with other agents to prevent staining. Compared to copper sulfate, chelated copper tends to be less toxic, takes longer to work and persists in the water longer.

Not all algacides are copper based. Non-copper algacides, usually involving an oxidizing agent, are use to remove algae from the water and from hard surfaces such as boats and docks. Chlorine can serve as an algacide in controlling flagellated algae that move with the use of a whip-like tail, including dinoflagellates species common to many New York State lakes. In very small ponds, non-copper algacides may be used to oxidize algae cells, but will generate hydrogen peroxide when the active ingredient reacts with water. Algacides using sodium carbonate peroxyhydrate have been registered for use in New York State.

#### *Advantage and disadvantages*

Algacides are one of the few algae control strategies that work very quickly. These can be useful in providing short-term relief while management plans are developed for the long-term problem of controlling nutrient in-flow. The quick action and low cost of algacides accounts for its popularity. Copper sulfate could, theoretically, be effective on any lake with a flushing time greater than a few weeks since the contact time to destroy algae using copper is very low. Copper sulfate has been used in a wide variety of lakes, from small swimming ponds and lakes to the swimming beaches of very large lakes.

The use of algacides is also a multi-use control strategy. It can be applied to waters used for recreation and it can even help control swimmers itch. Some of the copper compounds have been approved for use in drinking-water supplies, and may help to reduce algae populations that can produce toxins or taste and odor compounds. This advantage may become more prominent as municipalities become increasingly aware that chlorinating water supplies with heavy algae concentrations produces trihalomethanes and other carcinogens. Use of algacides may be limited in lakes supplying drinking water since copper can impart an unpleasant taste. Oxidizing algacides, such as those using sodium carbonate peroxyhydrate, cannot be used in treated drinking-water reservoirs.

Copper sulfate application may be restricted to particular sites within a lake. This is due to the mixing capabilities of the treatment lake, the dose rate, and the proximity to the treatment site of any significant recreational sites, inflow-outflow streams and water-intake pipes.

There are only limited data on the toxicological effects of copper on either humans or aquatic organisms. Nearly all of these data consider only the acute or short-term toxicity effects. Non-target organisms may be adversely affected by copper sulfate treatments. Some fish species and amphibians are particularly sensitive to even moderate copper levels. Copper levels as low as five ppb may have adverse effects on some aquatic organisms. Copper sulfate will also kill zooplankton, the microscopic animals that feed on algae. Snails are susceptible to copper, and this has been exploited as a means for addressing swimmers itch problems as discussed later in this chapter.

Studies in New York State and Vermont have shown conflicting results about the effect of copper on benthic organisms. The DEC study of lakes treated with copper sulfate found elevated copper levels in the sediments, and some effect on the macroinvertebrate diversity, particularly mayflies. These effects could not be definitively tied to sediment toxicity, since lakes requiring copper treatments may suffer loss of diversity due to the effects from eutrophication.

It is not clear that copper sulfate is acting as anything but a placebo even if the side effects after copper sulfate treatment were either overestimated or mistakenly tied to the treatment. Water-quality data collected from several lakes that have been treated with algacides have not shown any significant changes in either water transparency or algae levels after treatment (NYSDEC, 2004). The residents of the communities surrounding these lakes, however, believe that the copper sulfate improved water quality in their lakes. It is unclear whether the same changes would have been perceived after the application of other control techniques or after no action at all. The effectiveness of any control technique should be verified by both quantitative methods, through water-quality testing and measurements and qualitative measures, through resident surveys and an assessment of changes in recreational uses of the lake.

Algae usually grow faster than zooplankton. Copper sulfate treatment may cause a “rebound” effect shortly after application when algae levels increase faster than zooplankton levels. For many lakes, multiple treatments may be required to keep algae levels in check through the growing season and the summer recreational season. Due to the potentially significant ecological side effects and limited effectiveness of the treatment, however, it is likely that is has achieved its popularity as an algacide primarily due to its immediate control and low cost.

While copper can have a detrimental effect on target and non-target organisms, certain species of blue-green algae may be tolerant to copper, including the noxious species *Aphanizomenon, Oscillatoria,* and *Anabaena.* This may result in blue-green algae concentrations greater than those that occurred before treatment.

Many of the potentially observable changes within the ecosystem after copper application may be masked by other water-quality changes. Many lakes experiencing algal blooms are also affected by other problems that previously altered the ecosystem. The potential side effect associated with algacides may not be easily detectable.

Algacides have been called “a temporary poison for a permanent problem: (Stewart, 1986). It is “temporary” due to the resiliency and fast growth rate of algae. It is “poison” due to the potentially toxic effects of copper on several organisms within the food web. Copper serves as a micronutrient in the human diet, and is toxic to humans only at very large doses. It is a “permanent problem” because only the symptoms are addressed by copper sulfate treatments, not the causes or sources of excessive algae. While copper has an immediate effect on existing algae concentrations, the effect is usually temporary. Since this control strategy does not address the problem of excessive nutrient levels, or reduce internal or external nutrient cycling, algae may return to pre-treatment levels within a short time. Some lake communities may find it necessary to apply copper several times over the course of a summer.

## Case study: Algacides in Ballston and Kinderhook Lakes

**Lake setting**: Ballston Lake is a nearly 300-acre lake in Saratoga County, just south of the southeast portion of the Adirondack Park. Kinderhook Lake is a 350-acre, 12-meters deep impoundment of the Valatie Kill just south of the Capital District region of New York.

**The problem**: Ballston Lake suffers from frequent algal blooms, and the lake has relatively high phosphorus concentrations of about 25-30 ppb. Secchi disk transparency readings are typically about 2 meters, indicating low-water clarity. Like Ballston Lake, Kinderhook Lake has a long history of copper sulfate treatments, with regular and multi-year treatments since 1960. The lake association became concerned over long-term loading of copper in the lake and sediments, and conducted an experimental study of the use of alum.

**Response**: Copper sulfate has been regularly used to control excessive algae levels in Ballston Lake since at least the early 1960s. There were whole-lake treatments after 1973, although treatments have not occurred since 1999. Typically, 1200 pounds of copper sulfate were applied in late June or early July, resulting in application rates of about 0.3 parts-per-million.

**Results**: The range of water-clarity readings in Ballston Lake in the late 1970s was from 1.7m to 2.4m, slightly more compressed but approximately equivalent to the same range found from the late 1980s through the present day. Phosphorus and algae levels were in the same range. A DEC study of the lake in the mid-1990s found that sediment copper levels of 175 milligrams per kilogram (mg/kg) were above copper levels in untreated lakes (10–20 mg/kg), and above the state sediment standard expected to result in "contaminated" sediment. Although these readings frequently result in toxicity for many benthic macroinvertebrates, this was not found to be true in Ballston Lake. It was found in many copper-treated New York State lakes evaluated in this study, including Kinderhook Lake.

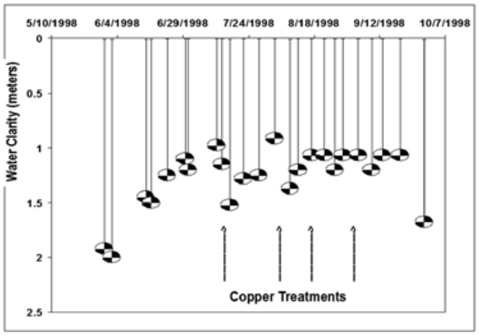

*Fig. 7–3a. Effect of copper treatments on Kinderhook Lake clarity.*

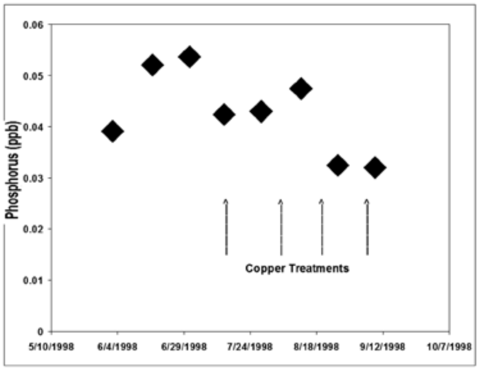

*Fig. 7–3b. Effect of copper treatments on Kinderhook Lake total phosphorus.*

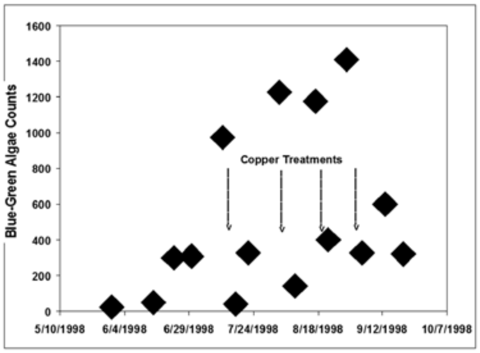

*Fig. 7–3c. Effect of copper treatments on Kinderhook Lake blue-green algae.*

In a typical year in Kinderhook Lake, copper was applied to the lake in two-week intervals during the peak recreational season, resulting in four copper treatments. The impact on blue-green algae levels and water clarity can be seen in the following plots for copper treatments in 1998. (Collins, 2004; NYSDEC, 2004)

The results from the water-quality monitoring indicate that blue-green algae levels dropped immediately after the treatments. This resulted in an increase of about one foot in water clarity. Within a week, clarity readings dropped again and blue-green algae levels increased. By the time of the next treatment, both water-clarity and blue-green algae readings returned to the levels they had prior to the treatment.

**Lessons learned**: Copper treatments in both Ballston Lake and Kinderhook Lake have not resulted in long-term decreases in algae levels, and increase in water clarity appeared to be short-lived. Sediment toxicity did not appear to occur in either lake. While the residents of Kinderhook Lake have experimented with the use of other methods for reducing algae levels, copper continues to be used extensively in many New York State lakes, including Ballston Lake.

### Costs

Copper sulfate is one of the least expensive control techniques. Costs consist of chemicals and fees required by the licensed applicators. Chemical costs area $5 to $25 per **acre-foot** (one acre of surface area to a depth of one foot). The applicator costs usually are not substantial. Costs for controlling snail populations should be comparable to algae control costs.

### Regulatory issues

Copper sulfate use is governed by both state law (6NYCRR Part 327) and approved pesticides labels. Permits and licensed applicators are required for treatment of public lakes with copper sulfate or other algacides. Purchase permits suffice for ponds of less than one acre with no outlet. Purchase permits allow for the use of copper sulfate by the general public, rather than a licensed applicator, provided that the label instructions are followed. When copper sulfate is to be used for treatment of snails or macroinvertebrates, permits have not always been required, although that is currently under review by regulatory agencies.

Treatments are generally restricted to the time period from May to September. Treatments after Labor Day require special authorization by DEC. Repeat treatments are not allowed at intervals of less than two weeks, and use of the lake for bathing and livestock watering is prohibited for at least 24 hours following a treatment. Dosages are not to exceed 0.3 ppm copper sulfate or 0.2 ppm for chelated copper in the upper six feet in ponds or lakes with over two acres of surface area. For lakes with low alkalinity, lower dosage rates are computed based on alkalinity measurements, and product labels indicate that it should not be used if carbonate hardness of the water is less than 50 ppm. It must be applied as a liquid (spray) or solid (with burlap bags), not by direct broadcasting of the crystalline form.

Non-copper algacides are restricted-use pesticides. They are available for use only by licensed applicators, not by the general public, and thus are subject to the same regulations as copper products.

### History and case studies in New York State

Copper sulfate has been used for many decades in New York State lakes, some on a biweekly to annual basis. It is used yearly on more than 300 lakes and ponds throughout the state, mostly on small ponds of less than three acres. Most of these small-pond treatments have not been well document. Case studies from Ballston Lake and Kinderhook Lake are typical of copper treatments (see Case study on algacides).

## Nutrient precipitation and inactivation

### Principle

Nutrient precipitation uses a chemical agent, such as alum, to remove phosphorus from the water column. Nutrient deactivation works by sealing the bottom sediments to prevent the release of phosphorus to the overlying water with low oxygen concentrations. These two actions reduce nutrient concentrations in the water and often result in decreased algae levels and increased water clarity. Phosphorus precipitation and inactivation are used primarily on lakes with significant internal nutrient loading and where the external nutrient loads have been reduced as much as possible. This method is also commonly used on small swimming ponds and lakes that are plagued by nuisance algal blooms.

In a process called flocculation, the chemical agent binds to phosphorus, causing it to form heavier aggregates that precipitate out of the water column. Aluminum and, less frequently iron salts are used to flocculate due to their high affinity for phosphorus. Aluminum sulfate, or **alum**, the most commonly used binding agent, can be used in either granular or liquid form.

Alum added at small dose rates can achieve phosphorus precipitation but may not be sufficient to provide inactivation. Alum applied at a large dose can provide long-term inactivation that includes sealing the bottom sediments. This minimizes the release of biologically available phosphorus from the lake sediments when oxygen is depleted from the hypolimnion. Larger doses are often added directly to the hypolimnion to reduce the exposure of near-shore organisms to the toxic effects of aluminum. Hypolimnetic addition may reduce the potential for phosphorus precipitation from the upper waters as bound in algae cells. The application rates are dependent on the initial pH and buffering capacity (alkalinity) of the water. Large doses must neither compromise environmental safety nor exceed acceptable levels of aluminum and acidity. Whole-lake treatments should consider the relative depth, volume and alkalinity of each section of the lake to avoid overdosing or underdosing any given section.

Incoming streams and other inlets can also be treated with aluminum or iron salts to reduce the concentrations of phosphorus. This may require sedimentation basins to improve the time available for the precipitation reactions to occur. This treatment may be limited to lakes with one or two very large surface inlets and little, if any, spring or groundwater flow.

### *Advantages and disadvantages*

Alum has a long history of use in the municipal drinking water treatment process, and may not have the same stigma that often accompanies other chemicals applied to lakes. This is particularly true in the context of removing pollutants, such as toxin-producing algae that might otherwise affect lake users. The ability of alum and other coagulants to purge particles from the water column is a significant advantage as both a short-term and long-term strategy for reducing suspended material in the lake.

For many New York State lakes, this technique may be a reasonable alternative to either algacides, which are often ineffective, or sediment removal, which is expensive and public acceptance is difficult to obtain. Compared with other alternatives, such as whole-lake dredging, phosphorus precipitation and inactivation can be extremely cost-effective and equally long-lasting. Depending on the alum dose rate, the quantity of nutrients bound within the sediments, and the existence and success of external nutrient control, phosphorus precipitation and inactivation may be effective for many years. Data suggest that alum may effectively seal lake nutrients for 10 years in unstratified lakes, and 20 years in stratified lakes.

Like algacides, alum can work very quickly, often within an hour. Unlike algacides and other less expensive treatments, alum addition goes beyond cosmetic repair. Alum addition may be ineffective if external nutrient sources are not “turned off,” just as aquatic plant controls are less effective if the targeted nuisance species continue to re-infest the lake.

Adding alum may also dramatically increase transparency by precipitating the suspended phosphorus and reducing the algal turbidity. While this is normally an advantage, clearer water may result in a substantial increase in rooted aquatic vegetation, particularly in lakes where deeper weed growth is currently limited by poor light transmission.

The most serious disadvantage of using alum is the potential for elevated aluminum levels and low pH. The toxic effects of dissolved aluminum on non-algal, aquatic organisms and humans are not well documented. Dissolved concentrations of free aluminum above 100 ppb can be toxic to many fish species, while other species may show acute or chronic toxicity symptoms at concentrations as low as 50 ppb. Large doses of alum can potentially increase the levels of free aluminum, and lower pH to levels that could be dangerous for many animal species. Free aluminum is the most biologically available form of aluminum. The addition of aluminum salts to a lake serves to lower the pH. At pH levels near 5, dissolved aluminum is toxic to fish. Most professional lake consultants will check the buffering capacity of a lake before applying alum. Pre-buffered alum is also commercially available to minimize this concern.

Many of the concerns about aluminum toxicity may not be warranted. In highly productive, well-buffered, hard water lakes, which are the usual recipients of alum treatment, alum addition sufficient to provide adequate phosphorus inactivation and binding will not drop the pH to dangerous levels. In these lakes, most aluminum quickly drops out of the water column, and remains bound in the sediment, unavailable to aquatic organisms. Poorly buffered lakes, including many lakes within the Adirondack Park, may not be good candidates for alum addition.

Some species of pathogenic bacteria can survive for short periods during flocculation but prior to precipitation. These pathogens could be ingested when the water is used for drinking or recreational purposes. This danger may warrant a period of restricted use immediately following application of alum.

## *Costs*

Phosphorus precipitation or inactivation will have a high initial cost for labor and equipment. The cost ranges from $100 to more than $500 per acre, depending on whether the primary goal of the treatment is phosphorus precipitation or inactivation. Phosphorus inactivation is a long-term treatment. Its initial cost can be amortized over several years, so alum can be among the least expensive algae control techniques.

## *Regulatory issues*

As a general rule, Environmental Impact Statements (EIS) will need to be completed and accepted for the use of alum in most New York State lakes. Beyond that, at the time of this publication, there remains uncertainty about the regulatory status of alum.

The New York City Department of Environmental Protection (NYCDEP) has determined that alum additions to the tunnels of some of the upstate drinking-water reservoirs will not have a significant negative effect on the environment. The DEC has ruled that alum discharges from the reservoir tunnels would violate the narrative water-quality standard for settleable solids and result in the deposition of an environmentally harmful quantity of accumulated particulate matter on the reservoir bottom. Some DEC offices have determined the SPDES permits would be required. Others maintain that permits issued through other program would be adequate, such as wetland permits issued through Article 24 of the ECL.

Alum may serve to reduce algae or even weed growth by binding phosphorus otherwise available to these plants, but it is not registered for use as an aquatic pesticide in New York State. Aquatic herbicide permits under Article 15 of the ECL, therefore, cannot be issued for alum, and alum treatments intended to control algae and other aquatic plants, or potentially even the nutrients that specifically cause algae growth, cannot be approved since they would require the use of an illegal, unregistered herbicide.

The DEC may eventually identify conditions under which alum can be used without applying for permits through one of three programs. Consistent statewide regulations for the use of alum are likely to be implemented in the near future. Until that time, DEC regional offices must be consulted when alum additions are considered.

The use of alum in lakes within the Adirondack Park is a regulated activity, requiring a permit from the APA if the activity could substantially impair the functions served by or the benefits derived from freshwater wetlands. It is not clear if APA jurisdiction applies if alum is injected directly and solely to the deepwater region of a lake with greater than two meters depth, although shallower treatments clearly require wetland permits.

The regulatory uncertainty of this treatment in New York State may significantly curtail its use as a lake-management tool, at least in the near future. Regulators faced with controversial decisions may not be inclined to issue permits or entertain proposals for the use of this management strategy within the realm of existing regulatory structures, such as SPDES. The only permits issued in recent years have been through the wetlands permitting program. Until government regulators determine the most appropriate permitting mechanisms for alum, and outline the procedures for these permits, it is unlikely that alum will be used extensively as a lake-management tool in New York State. Even if these thorny regulatory questions are resolved, heightened awareness of the issues associated with alum treatments will result in much greater scrutiny than for other physical control strategies that operate under similar principles.

## *History and cases studies in New York State*

Saratoga Lake and Irondequoit Bay have been treated with alum in an experimental manner to determine its effectiveness in phosphorus inactivation. Irondequoit Bay in Rochester was treated during the summer of 1987. It showed an increase in water clarity, reduced surface algae levels and lower phosphorus readings within the hypolimnetic waters. This lasted

## Case study: Nutrient inactivation (alum) in Kinderhook Lake

**Lake setting**: Kinderhook Lake is a 350-acre, 12-meter deep impoundment of the Valatie Kill just south of the Capital District region of New York State.

**The problem**: Copper sulfate had been regularly used since at least the 1960s to manage blue-green algal blooms common to the lake. Sampling was conducted by the Kinderhook Lake Corporation through the Citizens Statewide Lake Assessment Program (CSLAP), and DEC monitoring through the Lake Classification and Inventory (LCI). These surveys concluded that blooms were triggered by excessive loading of phosphorus in the lake. As much as half of this loading may have been due to internal sources caused by phosphorus released from bottom sediments under anoxic conditions. Although surface phosphorus concentrations generally were below 50 to 60 ppb, deepwater phosphorus levels at times exceeded 800 ppb.

**Response**: The Corporation was issued a DEC wetlands permit for the application, since the lake is classified as a DEC Article 24 wetland. It conducted an experimental low-level alum treatment of the lake beginning in 2001, hoping to reduce the perpetual need for copper additions, and to protect the lake from significant zooplankton toxicity and dangerous drops in pH. Alum was added in 1000-1500 pound (lb) doses in regular intervals from late May through late August. Alum dose rates were devised to increase water clarity to no greater than four to five feet to prevent the transformation of the lake from an algae-dominated to a macrophyte-dominated system. Excessive growth of Eurasian watermilfoil, water chestnut, curly-leafed pondweed, bushy naiad, and Sago pondweed has regularly occurred when water clarity is "too high". Throughout the experiment, they documented changes in nutrient concentrations, water clarity, algae levels, and speciation. The goals for surface and deepwater nutrient levels were originally 20ppb and 1000ppb respectively. Alum treatments were modified after 2002 in an attempt to lower deepwater phosphorus levels, surface water nutrient concentrations, and to increase water clarity.

**Results**: The following results were obtained from the experimental alum treatment of Kinderhook Lake (Collins, 2007):

Treatment strategies were modified each year after analyzing the water quality and microscopic results from the previous year. Alum was injected directly into the hypolimnion in 2002, and more extensively in 2003, in an attempt to reduce deepwater phosphorus concentrations. Alum was added to the Valatie Kill in 2004 in hopes of reducing external nutrient loading to the lake. Overall, surface and deepwater phosphorus levels decreased, while algae community dominance shifted from blue-green algae to green algae. Continued use of this promising management technique is caught in the uncertainty over the permitting and evaluation of alum projects.

**Lessons learned**: Public perceptions of the treatments were generally favorable, and the lake association was considering coupling alum treatments with low-level copper treatments when blue-green algae counts exceeded 100. They were also considering installation of aerators to increase deepwater oxygen levels in a portion of the lake with high organic sediments that reduce the effectiveness of the alum treatment.

| Year | Alum Added (lbs/yr) | Copper Added (lbs/yr) | % Surf TP Samples Exceeding 20ppb | % Surf Samples Exceeding 40 ppb | Max. Hypo TP (ppb) | % Water Clarity Readings < 4ft | Max. Blue-Green Algae Counts |
|---|---|---|---|---|---|---|---|
| 1998 | none | | 100% | 100% | 800 ppb | 60% | 1400 |
| 1999 | none | | 100% | 40% | NA | 60% | 2600 |
| 2001 | 25,000 | | 80% | 20% | 550 ppb | 70% | 700 |
| 2002 | 24,400+<br>20,000# | | 75% | 13% | 800 ppb | 45% | 600 |
| 2003 | 12,000+<br>43,050# | | Not measured | Not measured | 200 ppb | 30% | 350 |
| 2004 | 15,000+<br>20,500#<br>8,000@ | 1,000 | Not measured | Not measured | 175 ppb | 35% | 550 |
| 2005 | 9,000+<br>10,500# | 1,000 | Not reported | Not reported | 500 ppb | 35% | 550 |
| 2006 | 10,000+<br>15,000#<br>1,700@ | 1,000 | 100% | 33% | 250 ppb | 45% | 600 |
| 2007 | 1,500+<br>20,500# | 180 gallons | Not reported | Not reported | 275 ppb | 25% | 450 |
| 2008 | none | 5,850 | Not reported | Not reported | 400 ppb | 8% | 200 |

+ alum added to the surface waters, # alum added directly at a depth below 10 feet
@ alum added to the inlet stream and shoreline runoff areas

*Table 7–1. Effect of alum treatment in Kinderhook Lake from 1998 through 2007.*

for many years. In Saratoga Lake, there was no appreciable improvement in water quality as a result of the alum application due to the small treatment area and low application rates.

An experimental, low-level alum treatment, in which alum essentially replaced copper sulfate, was conducted in Kinderhook Lake. Surface phosphorus and algae levels were lowered to some degree. Drastic algae reductions were not desired due to the potential for increases in rooted aquatic plants as a result of higher water clarity. Deepwater nutrient levels proved more difficult to control (see Case study on nutrient inactivation).

## Algae control through biology

### *Biomanipulation and fish stocking*

#### *Principle*

Biomanipulation is a broad term that describes any biological introduction to an ecosystem for the purpose of shifting ecological conditions to the advantage of a desired species of lake condition, or to enhance recreational conditions. It is used primarily to alter the ecosystem dynamics for the purpose of controlling specific fish populations and reducing algae levels. Aquatic plant management by stocking herbivorous insects and fish is also a form of biomanipulation, as discussed in Chapter six, "Aquatic plants." Gamefish stocking is utilized to enhance the population of fish species prized by anglers, but is not done with the intent of biomanipulattion, though it may have biomanipulation consequences. Desired sports fish have been stocked for many decades, as discussed in Chapter three, "Lake problems." Its use as a water-quality management tool dates only from the mid-1970s.

Biomanipulation can generally be divided into two categories:

- stocking specific organisms, usually fish, to enhance zooplankton grazing, which will reduce algae populations; and
- removal of specific organisms, usually bottom-dwelling fish, to enhance water clarity.

Fish stocking to reduce algae usually involves piscivorous (fish-eating) fish that outcompete or prey on planktivorous (plankton-eating) fish that consume large zooplankton. Examples include stocking piscivorous large-mouth bass, lake trout and walleye that target the planktivorous bluegills and alewives. The reduction of planktivores populations tends to increase the size and abundance of zooplankton, such as *Daphnia*, that feed on algae populations. The result is increased water clarity. This is often referred to as "top-down" management of the food web since it involves manipulating the top of the web, the largest secondary consumers. This is achieved in a number of ways:

- increasing piscivores populations by stocking new or existing species;
- restricting fishing access or angler removal of piscivores; and
- improving piscivores habitat to increase populations.

Fish removal is used to control bottom-feeding fish that often cause turbidity and increase nutrient concentrations by their disturbance and consumption of organic material near the lake bottom. Carp are the most prevalent bottom-feeding species, but brown bullhead, suckers, and other bottom-dwellers are also found in New York State lakes. These are removed by a number of mechanisms, including fish poisoning, water-level manipulations, and targeted catches. Rotenone, a natural substance found in tropical plants that inhibits the ability of fish to use oxygen, has been used more than 150 times in New York State since the 1940s to control undesirable species. Concentrations of rotenone cannot exceed 1 ppm. Other piscicide fish poisons, such as **TFM (trifluoromethl-nitrophenol)**, have been used to control lamprey in Lake Champlain.

Several million fish are stocked by DEC in more than 1,200 waterbodies throughout the state. Sports fish such as brook, brown and rainbow trout, walleye, salmon, bass, perch and muskellunge are stocked in lakes and ponds to enhance the fishing experience, not as a means to manipulate water-quality conditions. Stocking programs are conducted on heavily used lakes and streams with public access to enhance sports fisheries and to restore native fish species to the full extent of their historical range. Fingerlings, young fish three to five inches long, are generally stocked in the summer or fall. Yearlings, older fish six to nine inches long, are stocked in the spring. These fish are raised in one of the twelve DEC fish hatcheries around the state. Each hatchery typically specializes in one or more of the stocked species. Private fish and game clubs, lake associations, local governments, and individuals interested in promoting or enhancing sports fisheries also stock fish in New York State lakes, frequently using fish raised at one of about 50 private or out-of-state hatcheries permitted by DEC.

### *Advantages and disadvantages*

This top-down approach may be as effective as the bottom-up approaches that utilize nutrient controls to reduce algae levels. Biomanipulation may serve to achieve multiple water-quality objectives, while at the same time increasing the population of desired fish species and removing "trash" fish. The longevity of biomanipulation may be greater than other in-lake algae control strategies, such as algacides. It is most effective if the stocked fish survive and propagate, if removed species are prevented from re-entering the lake by fish barriers, and if selective fishing pressures prevent the removed species from becoming re-established as a dominant species. Stocking must be balanced by maintaining low fishing pressure on the stocked species.

Stocking policies intended primarily to enhance sports fisheries could also potentially benefit a larger lake user group. It can help to restore lake fisheries impacted by temporary or transient problems. Those problems include an unusual winter fishkill, chemical reclamation such as using rotenone, or after another lake problem have been "solved" such as using lime to neutralize a fishless acidic lake. Fish can also be introduced into a newly created pond or otherwise fishless lake.

The concept of biomanipulation is a nice theory, and will sometimes work in practice. Like all biological introductions or manipulations, however, the results are not easily predictable. Stocking fish that are not naturally found at sufficiently high concentration levels to meet the stocking objectives may cause unexpected side effects. Insufficient concentrations of a desired fish species, or abundance of "trash fish," may be associated with water-quality conditions, existing fishing practices or policies, or plankton communities controlled by something other than predator-prey relationships, such as toxins or micronutrient levels. The increase in zooplankton grazing as a result of piscivores stocking may selectively control more palatable algae, such as diatoms, and leave less edible plankton, such as blue-greens. Blue-green algae are often the most dominant algae in highly productive lakes, making them among the most likely candidates for biomanipulation. These algae may be found in long filaments and large colony size, or may exude toxins or gelatinous coatings that render them inedible to zooplankton. There is some evidence that large, benthic invertebrate predators and insects will also benefit from reduction in planktivorous fish, and this may have a negative effect on the zooplankton. This will serve to increase algae levels, since these invertebrate predators do not include algae within their prey.

Selective removal of brown bullhead *(Istalurus nebulosus)* and carp *(Cyprinus carpio)* can be very difficult. These fish are prolific and often spawn in areas not subject to disturbance during drawdown. Although drawdown is not always effective, the use of rotenone or other fish poisons can be very controversial unless the target is an exotic or invasive fish. Several desirable fish species, such as walleye and rainbow trout, are more sensitive to rotenone than are many of the potential target species, such as carp. Brown bullhead, in particular, may also be considered a desirable species by some anglers.

Fish stocking can introduce non-native fish into a "natural" fish community, or may introduce pathogens or illnesses associated with the hatchery-raised stocked fish. Genetic diversity is affected when large quantities of hatchery-raised, genetically homogeneous species are introduced. Some desired sports fish, such as alewives, can exert a negative biomanipulation effect on a lake system by selectively removing zooplankton or other algal grazers. Biomanipulation to increase water clarity and light penetration can also result in increased macrophyte growth.

For lakes with existing native populations of stocked piscivores, biomanipulation is more likely to be considered a natural control strategy. Even without a pre-existing population, biological control is perceived to be more "natural" then algacides, and more inconspicuous than physical controls. Biomanipulation, therefore, does not always result in the controversies that surround other control strategies. Biomanipulation remains an experimental procedure, however, with regard to water quality enhancement. Similar to other biological control mechanisms, the introduction of a new element into the predator-prey relationships that may otherwise be stable can bring unexpected and unpredictable results. It can create controversy about fish removal with the use of fish poisons, or through large-scale fishing tournaments that create user conflicts or lake overcrowding. These effects can complicate the process of building cooperation among lake user groups and others contributing to the holistic management of the lake. While fish stocking may enhance the recreational use of the lake for lake residents, it often makes the lake a more desirable destination for visitors on lakes with public access, and this can be a double-edged sword. While it can bring economic benefits to a region, it also has the potential for triggering water-quality problems through increased use of the lake. As such, biomanipulation and stocking should be evaluated and utilized with great caution, and must have the early involvement of all parties, including lake users, residents, and regulatory agencies (see Case study on biomanipulation).

## Costs

The typical price of the fish associated with fish stocking is $100 to $200 per hundred fish, with a minimum order required. Stocking rates of anywhere from 100 to 1,000 fish per acre have been recommended for biomanipulation. The broad range accounts for highly variable water-quality conditions, plankton levels, existing fish populations and stocked species. For sports fishery stocking, a standard rate is about 500 trout fingerlings per acre, about 100 bass fingerlings per acre, and about 500 bluegill fingerlings per acre. Lower stocking rates are used for older fish. DEC recommends stocking older walleye at a rate of 20 per acre. The cost for removing fish is about $500 to $1,000 per acre. The cost for rotenone control is about $20 per acre-foot of lake volume.

## Regulatory issues

Article 11 of the ECL (ECL 11-0507) states: "Fish or fish eggs shall not be placed in any waters of the state unless a permit is first obtained from the [New York State] Department [of Environmental Conservation]" This even applies to private farm ponds. Stocking permits can be obtained through DEC Regional Fisheries offices. They have also been folded into the Farm Fish Pond License, a free, five-year license, also required by DEC to take fish from these ponds. The use of rotenone requires a licensed New York State pesticide applicator and a permit from DEC. A freshwater wetlands permit is also required from the APA for waters within the Adirondack Park.

## History and case studies in New York State

Although biomanipulation has been commonly used in New York State as a fisheries-management tool, it has not been regularly utilized or documented as a lake-management activity to restore or enhance water-quality conditions. A small-scale biomanipulation project suggested for highly eutrophic Lake Neatahwanta involves stocking predator fish, such as largemouth bass and northern pike, to feed on zooplanktivorous fish such as yellow perch and rudd. Among the more controversial proposals for the lake is a suggestion to stock the lake with zebra mussels to reduce algae populations. Walleye and other top predator fish have been stocked at high rates in several Madison County lakes to feed on bluegills and pumpkinseed that consume milfoil weevils, as discussed in Chapter six "Aquatic plants."

An evaluation of 44 published reports in which piscivorous fish were stocked in waterbodies to improve trophic status found that planktivorous fish declined, although less so in lakes with lower productivity. In nearly 75 percent of these studies, zooplankton size and density increased, but this led

## Case study: Biomanipulaton in Moe Pond

**Lake setting**: Moe Pond is a 38-acre impoundment created in 1939 in the Central New York Leatherstocking Region of the state.

**The problem**: Although it was probably naturally acidic, the lake has exhibited high nutrient and algae levels since at least 1970. It was dominated by blue-green algal blooms. These blooms resulted from high nutrients and a reduction in acidity as a result of the introduction of 50 metric tons of crushed limestone in 1966 and 1967 to irrigate a downstream golf course. In the early 1970's, phosphorus concentrations in the pond ranged from 40 to 70 ppb. By 1994, while phosphorus levels had dropped slightly (to 37 ppb), algae levels (37 ppb) and water clarity readings (0.9m) were typical of lakes suffering from extensive algal blooms. This 1994 survey determined that the fish community was composed of only brown bullhead (*Ictalurus nebulous*) and golden shiner (*Notemigonus crysolucas*). The latter is a planktivorous fish thought to be responsible for the lack of large zooplankton, which in turn allowed for high algal densities. It was suggested that if predators of golden shiner were introduced, the zooplankton would proliferate and algal grazing would increase, thereby increasing water transparency.

**Response**: Although a biomanipulation stocking project was planned, it was discovered that an unauthorized stocking of piscivorous fish had occurred by the spring of 1999. It contained both largemouth bass (Micropterous slmoides) and smallmouth bass (Micropterous dolomiem). The pond is so remote that it is likely that the fish were transported to the pond in buckets, and thus were probably limited in number. Subsequent monitoring by SUNY Oneonta focused on water quality and biological changes to the pond. Water-quality indicators related to eutrophication were evaluated, when available, before and after the fish stocking.

**Results**: It appears that water clarity increased significantly, triggered by a decrease in algae levels (chlorophyll a) and phosphorus concentrations in the pond. The decrease in algae levels was also triggered by an increase in zooplankton, particularly rotifers and Copepods, which in turn increased due to the drop in planktivorous fish.

The decrease in phosphorus concentrations, along with the increase in water clarity may have triggered a shift from algae dominance to macrophyte dominance. Prior to 2000, the presence of a common waterweed (*Elodea canadensis*) was not noted in the lake. These plants were first observed by 2000. By 2003 they were found in dense stands reaching the surface of nearly the entire pond, growing from a depth of as much as two meters.

**Lessons learned**: Biomanipulation projects can work, although it is unlikely the future poorly planned projects will be as successful, at least from the perspective of water quality rather than nuisance weed growth (Albright et al, 2004).

| | 1972 | 1994 | 1999 | 2000 | 2001 | 2002 |
|---|---|---|---|---|---|---|
| **Secchi Depth (m)** | - | 0.9 | - | 1.2 | 1.1 | >2.2 |
| **Total Phosphorus (ppb)** | 40-70 | 37 | - | - | - | 26 |
| **Nitrite+Nitrate-N (ppm)** | - | <0.05 | - | - | - | 0.14 |
| **Chlorophyll a (ppb)** | - | 37 | - | 27 | 20 | 12 |
| **Rotifers (# per L)** | - | - | 673 | 425 | 1251 | 2842 |
| **Cladocera (# per L)** | - | - | 378 | 785 | 234 | 1307 |
| **Copepods (# per L)** | - | - | 370 | 276 | 174 | 838 |
| **Golden Shiners (# per L)** | - | 8,142 | 3,210 | 1,040 | 1,708 | |
| **L.Mouth Bass (# per L)** | - | 0 | 1,588 | 811 | 3,724 | |
| **S.Mouth Bass (# per L)** | - | 0 | 958 | 576 | 504 | |

*Table 7–2. Effects of biomanipulation in Moe Pond from 1972 through 2002.*

to lower algae levels and higher water clarity in only about 20 percent of the studies (DeMelo, 1992). In a separate review of 41 eutrophic lakes in which piscivores stocking was the only management action pursued, only about 30 percent exhibited some water-quality improvement (Drenner, 1999).

Rotenone has been used within the Adirondacks to restore native brook trout by removing other fish that compete with the brook trout, but this was not intended to improve water quality. Biomanipulation has been limited to either accidental introductions of exotic species, such as zebra mussels or Eurasian watermilfoil, or unintended results from the introduction of fish, such as the alewives introduced into Conesus Lake.

## Barley straw

### Principle

Barley straw has been used to reduce algae levels in ponds and lakes, resulting in clearer water and few incidences of algal blooms. This treatment was first utilized by farmers in England in the early 1990s (Holz, 2000). Barley straw research results are available through the Center for Aquatic Plant Management in England (CAPM) (see Appendix F, ”Internet resources”).

How barley straw affects algae is not understood, but most of the research suggests one or more of the following:

- Barley straw or the fungi that decompose it in the water, releases hydrogen peroxide or organic compounds (oxidized polyphenolics) that inhibit the growth of new algae.
- Rotifers released from the barley straw decompose algae cells.
- Algae cells or phosphorus attach to the straw, or the organic materials released from the straw, and are decomposed by bacteria.
- Bacteria utilize carbon from decomposing barley straw, resulting in expansive bacterial growth that may outcompete algae cells for nutrients.

There has not been a very consistent track record on the use of barley straw. Some studies have found good control of most types of algae. Others have found that barley straw does not work very well, and still others have found that filamentous (mat-forming) algae may actually increase. Algae control may be delayed if the water temperature is too cold and the period for degradation of the straw is delayed. The decay of high doses of straw, and the resulting algae loss, may trigger delayed algal blooms and oxygen deficits, but this usually requires very higher dose rates. Some evidence indicates that barley straw is less effective in controlling nuisance algae in lakes and ponds with a retention time of less than 50 days.

Dried straw should be used, rather than barley hay or fresh barley. The barley straw must be loosely netted to allow air and water contact across a large surface area to maximize oxygen exchange within the straw. Netting that holds Christmas trees or even large onion bags are often used. Typical application rates are two to five bales per acre (100 to 250 pounds), with higher rates used for lakes with a history of algae problems. The application rate does not appear to be dependent upon water depth. Effective control is less likely when algae are growing at depths that exceed four feet. Anchored floats are used to keep the netted straw properly located in the upper three to four feet of water. This enhances exposure of straw to areas of most intense algae growth and associated use impairments.

The straw is more effective at controlling new algae growth than it is at removing pre-existing algae. The straw, therefore, should be put in place when water temperature is high enough to support decomposition but before dense algae stands have developed. Algae control, if achieved, will usually occur shortly after straw decomposition begins. Decomposition takes about two months in the spring versus about two weeks in early summer. The effect will last until the decomposition is complete, usually in 30 to 90 days. Second doses are sometimes applied if algae levels increase again. This generally corresponds to the remainder of the growing season in New York State lakes.

## *Advantages and disadvantages*

Barley straw appears to be one of the few algae control mechanisms that actually reduces the amount of algae rather than controlling the nutrients that trigger the blooms. Unlike copper sulfate or other chemical means of algae control, barley straw does not control algae through toxicity or chemical algacidal effects. It is less likely to trigger public complaints because it is more likely to be perceived as "natural." It is also one of the few lake management activities that anyone can do. It doesn't require a license and is easily employed by anyone, without extensive training or expertise. Loading the bales into the lake, however, and especially removing water-logged bales from the lake may not be for the weak of arm!

Barley straw can be effective in controlling either planktonic (green dots) or filamentous (long green strands) algae, although the latter may require a dose rate as high as 400 to 600 pounds per acre. Oxygen deficits associated with rapid bacterial degradation of the decaying algal cells are minimized because the rate of algae decrease appears to be gradual.

Given the quantity of straw required to control algal blooms, particularly filamentous algae, and the work required assembling the bags, this may not be a practical strategy for algae control in lakes or ponds larger than 100 acres. It might be effective in managing algae isolated bays of larger lakes. Bale removal can also be very taxing since "spent" bales weigh about 150 pounds.

In many ways, barley straw, like herbivorous insects, represents the future of lake management. Both embody innovative biological control mechanisms that rely on "natural" interactions to address excessive "unnatural" vegetation growth. Yet both are largely replete with greater parts of promise and potential than achievement for neither has yet translated into viable and reproducible management strategies. Their proponents often claim success when none can yet be verified, and continued interest in these tools is often buoyed more by hope than by progress. Both have worked, in some cases, though perhaps more often through observations of what happened naturally than what was induced by intent or aspiration.

The future of barley straw as a management tool in New York State is likely to be dictated by regulatory constraints. Federal and state governments have yet to make a determination about the appropriate marketability of this product, and the permitting structure governing the use of these produces in "public" waterbodies is unclear. Until these uncertainties are resolved, many lake residents and especially lake associations may be unable to apply barley straw to lakes. Even then, it may still ultimately be more of a pond management tool than a lake restoration technique.

## *Costs*

The use of barley straw is among the least expensive lake management strategies. Farmers capable of growing barley straw, or lake residents fortunate enough to befriend such a farmer can utilize this technique at little cost. For those without such connections, the cost of the straw depends on the quantity required. Several vendors within New York State sell quantities for use in small farm ponds, usually in 30-pound bales, at a cost of $150 to $400 per acre. Lower prices might be available through county agencies working cooperatively with local farmers to investigate the use of this control strategy. Barley straw has been offered by several Soil and Water Conservation Districts (SWCD) at a cost of about $6 to $10 per bale. In the Midwestern states, where barley straw has been more commonly used, farmers charge about $5 per bale, or about $20 to $50 per acre.

## *Regulatory issues*

The regulatory structure that governs the use of barley straw appears to be a moving target that is taking a lot of left turns. The U.S. Environmental Protection Agency (EPA) and DEC require that barley straw be regulated as a pesticide under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) if the product claims herbicidal benefits. Since it has not been registered for use as a pesticide, however, it cannot be applied by commercial applicators or others in the business of managing lakes. Neither can it be sold for the purpose of algae control, explicitly or implicitly for any waterbody, large or small, by garden shops or nurseries.

Landowners with private ponds on their property may be able to purchase barley straw for landscaping purposes or as a "home remedy" for clarifying or conditioning water. New York State has not yet determined a statewide policy about whether it would be allowable to use barley straw on "public" waterbodies for purposes other than algae control. Given these regulatory uncertainties, it is not clear if the conditions by which barley straw is produced for, marketed, or applied in New York State lakes will change dramatically in the near future.

The use of barley straw in lakes within the Adirondack Park is a regulated activity, requiring a permit from the APA if the activity could substantially impair the functions served by or the benefits derived from freshwater wetlands.

### *History and case studies in New York State*

Because of its relative novelty and the uncertain regulatory framework of this management tool, it is not surprising that barley straw has not been used extensively in New York State. Several county agencies, particularly in the western part of the state, have partnered with farmers and individual landowners to promote the use of barley straw. Some experimental work has been conducted through Cornell University, but these treatments have not been well documented. No lake-size treatments have been reported in the literature, although it is anticipated that increased documentation will surface when this technique moves from anecdote to history.

## Other in-lake problems

The earlier parts of this chapter, and Chapter six, "Aquatic plants," have discussed management techniques used to control nuisance weeds and algae. While these are two of the most common lake problems, they are not the only ones. Techniques to manage nuisance species and the water-quality problems of acid rain, unpleasant taste and undesirable odors are the next topics to be discussed. Many of the other lake problems discussed in Chapter four, "Problem diagnosis," are either too new for innovative lake managers to have developed any in-lake management tools, or are much better addressed through source-management strategies discussed in Chapter nine, "Watershed management."

## Nuisance species management

For some lake residents, a nuisance species includes anything that doesn't call the lake home, and some of the ones that do. Generally "nuisance species" refers to exotic or non-native plants or animals, and some very abundant home-grown pests. Nuisance species may upset not only the ecological balance of the lake, but also the recreational or aesthetic uses of the lake. Chapter six, "Aquatic plants," discusses control of nuisance aquatic plants. There are a number of other lake invaders that are as unwelcome and sometimes as difficult to control. These include aquatic pests such as zebra or quagga mussels, sea lamprey, leeches and waterfowl that trigger problems such as swimmers itch and other bacterial outbreaks.

### *Waterfowl control strategies*

The sight of swans sailing across the Pine Barrens of Long island, or the sound of honking Canada Geese *(Branta canadensis)* streaming above New York State lakes and ponds can be as fundamental to the pastoral outdoor experience as the bellow of the bullfrog or the changing of the leaves. For many lake residents, however, these sights and sounds are stark reminders of the problems that plague many lakes. Canada Geese are perhaps the most prominent example, leaving pellet reminders of their affinity for lakefront flatlands, pathogenic evidence of their congregations, and perhaps even mocking calls in their status as a protected species. (See the Case study on waterfowl) Migratory Canada Geese using New York State waterways as aquatic landing strips in transit are protected by the U.S. Fish and Wildlife Service under the Migratory Bird Treaty Act of 1918 and the Migratory Bird Conservation Act of 1927. There are questions about whether these birds have become non-migratory and recognition that they have moved to nuisance status during the last 25 years. The U.S. Fish and Wildlife Service and several state wildlife agencies now allow limited hunting and control of Canada Geese from September 1st through March 10th, and are now being allowed to establish August hunting seasons.

The most effective deterrent is to discourage the geese from visiting the lake and partaking in crusty bread provided by otherwise well-meaning lake residents and unsuspecting visitors. "Don't feed the ducks" is the single most effective waterfowl management strategy available, particularly on small, crowded lakes. This may be in conflict with the desires of the younger crowd who enjoy throwing bread crumbs and stale heels to geese, swans and other feathered friends. Waterfowl feeding should be strongly discouraged to protect water quality and to keep the wildlife wild. The end of handouts might also prevent the birds from becoming too comfortable around people, and may encourage them to migrate to warmer climates with better winter dining.

A second defense is to modify their habitat. This can be achieved by discouraging grazing and eliminating easy pathways for goslings to migrate from water to land. Physical barriers at least 6 to 30 inches above the ground will provide roadblocks for many geese. Landowners can make a simple fence of string, with attached hanging aluminum strips or shiny tape, supported 6 to 12 inches above the ground at the water's

## Case study: Waterfowl control on Collins Lake

**Lake setting**: Collins Lake is a 70-acre urban lake in the village of Scotia, just west of the Capital District region of New York State.

**The problem**: Canada Geese *(Branta canadensis)* discovered the lake in the late 1980s and apparently told all their friends. The change in waterfowl populations was discussed in Chapter three, "Lake problems." The beach at Collins Lake was increasingly blanketed by goose droppings, and this contributed to increasing concerns about bacterial contamination and other health issues.

**Response**: In 2000, the Village of Scotia initiated an aggressive waterfowl control program that included fencing the beach, and addling the eggs (puncturing with a metal skewer). Trustees from the Village elected not to euthanize the geese due to public opposition to hunting and trapping the birds. From 2000 to 2005, about 200 eggs were addled annually under a permit issued by the U.S. Fish and Wildlife Service. An orange plastic fence was erected along the perimeter of the beach shoreline to prevent the geese and goslings from walking onto the beach. Park staff also raked and removed droppings from the beach on a daily basis during the summer recreational season (Marx, 2007).

**Results**: After steady increases in resident goose populations from 1988 to 2000, populations stabilized at about 115. Bacterial levels stayed well below state water-quality standards. Bacterial counts rose sharply in 2005, coincident with heavy spring and midsummer heat and rainfall, with substantial increases in goose droppings on the surrounding park lands. It is believed that the egg-addling program initially controlled local geese, but the populations were greatly augmented by transient geese. Local geese ultimately utilized the nearby Mohawk River for nesting and sustenance. By 2005, this resulted in a rise in transient populations to about 180. As a result of the elevated bacterial levels, the Village and the Schenectady County Health Department agreed to close the beach for the most of summer 2005. In 2006, local environmental groups "gently" harassed the geese, keeping them out of the lake and surrounding park land. Trained border collies were enlisted in 2007. This reduced the goose population and eliminated the need for the village to start a goose extermination plan. The Village improved lake circulation by installing aerators, and by controlling nuisance curly-leaf pondweed and Eurasian milfoil populations with herbicides. The fecal coliform levels dropped substantially by midsummer, allowing the swimming beach to reopen in August (Martialay, 2005). Fecal coliform readings were close to drinking-water standards in 2007, and the beach remained open for the entire year.

**Lessons learned**: Canada Geese control can be achieved with significant and consistent efforts from the affected community. It appears, however, that the populations adapted and found nearby contiguous habitat that still impacted the lake through major runoff events. Vigilant efforts were required to remove the geese and improve water-quality conditions.

edge. Goslings cannot cross these fences, and the adults will not cross if it means leaving the goslings behind. Some lake communities install temporary fencing, removable during recreational hours, along swimming beaches and adjacent to large manicured lawns or other tempting buffet plots. The same objectives can also be achieved by planting dense shrubbery along the shoreline and walkways. Many native shrubs, such as ivy and juniper, are not palatable to geese and also serve to minimize shoreline erosion, providing an added benefit to the lake. Alas, many New York State lake residents report less than stellar results using these habitat modification methods.

Modifying human habitat can be equally effective at reducing human-waterfowl conflicts. Exposure to bacteria or pathogens found in the fecal matter of the waterfowl can be minimized by avoiding flat areas with heavy concentrations of waterfowl, and by minimizing ingestion of lake water potentially contaminated with pathogens.

The next level of goose control involves actions to offend their senses. Some people have tried Mylar tape that reflects sunlight and produces a humming noise in the wind. Noisemakers and pyrotechnics work best before geese are established in an area rather than after nesting pairs are oblivious to all but the beating of their hearts. These noisemakers can take the form of starting pistols, sirens, and explosive devices. Many of these require special permits. Some people have treated waterfront lawns with grape-flavored spray (*methyl anthranilate)* that the geese supposedly avoid. Only one such product (ReJeXIT©) can be used in New York State, and it requires a DEC permit. Other grape juice substitutes are no doubt used in other places.

Perhaps the most effective deterrents have been the use of trained dogs, usually border collies, to chase away the offending birds. Once established as a goose menace, usually through several chases every day for several weeks, the dogs can control the goose populations with less frequent romps. In most cases, the geese do not become acclimated to the situation. This method has been very successful on Collins Lake (see Case study on Collins Lake).

The most controversial control measures have involved destroying the eggs or the geese themselves. Several lake communities have undertaken egg-addling projects, puncturing, shaking or oiling the eggs to prevent hatching or to allow bacterial contamination to enter the egg. This has been effective, but only when utilized for many years throughout a large geographic area surrounding the lake. For most lake communities, these draconian measures should constitute the last resort given the volatile brew of spicy emotions and half-baked truths that often pepper the accompanying public dialogue.

The capture or killing of geese, like disrupting eggs or nests, requires state and federal permits. Permits are only issued when other measures have been deemed ineffective. Given the uncertainty of their status as a protected species, permits are usually required from DEC for the trapping or lethal control of Canada Geese. Rules promulgated in 2006 by the U.S. Fish and Wildlife Service allow public health officials and municipalities to remove nests and eggs, and to round up birds, after securing federal permits if they can demonstrate a threat to public health.

## *Swimmers itch*

Nothing ruins the fine memory of a nice day at the beach more than an outbreak of swimmers itch. Copper sulfate, used as an algacide, is also used to kill snails, the intermediate carrier for this topical bacterial infection that may result in rashes and external itching. Copper sulfate has been extensively used to break the duck-snail-flatworm cycle (see Fig. 7–4 and Chapter three, “Lake problems”). It is applied at a rate of about 10 pounds of copper sulfate per acre-foot of water. Chemical costs of copper for snail control are similar to costs for algae control, $5 to $25 per acre-foot.

More drastic measures have included inoculating geese to prevent the production of the schistisome flatworm, either by injections or by treating their food sources. This has been effective only for resident geese populations that have caused persistent problems. It was utilized as a control measure in Lake Pleasant and Sacandaga Lake in the central Adirondacks.

Pumpkinseed sunfish *(Lepomis gibbosus)* and freshwater drum *(Aplodinotus grunniens)* are sometimes stocked in small ponds because they feed on the snails that are part of the infection cycle. Management strategies for waterfowl control discussed above can assist with long-term strategies for dealing with swimmers itch. Outbreaks of swimmers itch are localized since the *cerceriae,* the microscopic flatworm juvenile stage that causes the itch, only live 24 hours, and only travel short distances.

The most common strategies for dealing with swimmers itch have ranged from preventing the flatworm from penetrating the skin, to using topical steroids to reduce the symptoms of the irritation. The *cerceriae* will penetrate the skin after the water evaporates from the swimmers. By rigorously drying with a rough towel before the water evaporates, swimmers can break the *cerceriae* loose from the skin. The rash and itching tend to be focused on the lower extremities, but any body part expose to the water can be affected. The entire body should be vigorously rubbed.

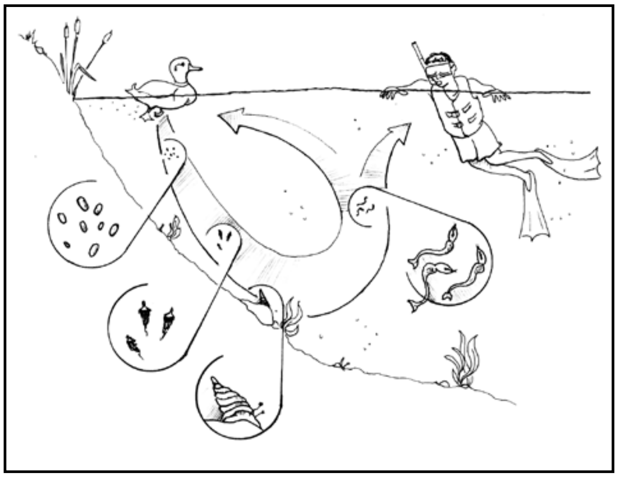

*Fig. 7–4. Life cycle of cerceriae that cause swimmers itch. Flatworms in waterfowl feces burrow into the skin of unsuspecting swimmers. (not drawn to scale)*
(CREDIT: CHRIS COOLEY)

## Muscling out the zebra (and quagga) mussels

The shells of both zebra and quagga mussels have the black-and-white stripes of their equine namesakes, but they are much less well received. Quagga mussels *(Dreissena rostriformis bugensis)* are one of the new exotic invaders. They are beginning to outnumber zebra mussels *(Dreissena polymorpha)* in some of the western Great Lakes, although they presently are far less common in New York State lakes. Management of these invasive bivalves is similar to the strategies listed below for controlling zebra mussels.

The most effective control measures for zebra mussels involve preventing them from entering the lake in the first place. This is achieved by inspecting boat hulls, trailers and especially the bilge water in powerboat engines. The mussels are very hardy, but are ultimately susceptible to drying periods of at least three days, and to rinsing with high-pressure hot water.

Large-scale infestations in lakes are impossible to eradicate. Ecological and substrate modifications associated with zebra mussel infestation can rarely be reversed. There are, however, some measures that have been taken to remove or repel the mussels.

- *Pluckin' the shells* is a technique only effective for very small infestations, particularly in areas where the opportunities for re-infestation are limited by substrate or water chemistry. The zebra mussel populations in Lake George appear to have been well managed by this technique, but it is a very labor-intensive control strategy (see Case study on invasive species).

- *Dose 'em with chemicals.* Chlorine and copper have been used by municipalities to control zebra mussels, particularly in water-intake pipes. Exposure time is too low, however, to effectively control these animals in most large waterbodies. The higher doses and contact time required to control zebra mussels in larger waterbodies would also have significant environmental repercussions.

- *Unpleasant tastes* from chemical repellents that are added to paints used on boat hulls and other hard surfaces have been shown to repel the mussels.

- *Noise and vibration* can be effective at reducing zebra mussel populations. Studies by Cornell University on Oneida Lake found that ultrasonic waves below 200Hz were effective.

- *Predatory control* research continues on the use of diving ducks, freshwater drums, viral agents and other organisms that feed on zebra mussels. These methods have not been developed to a degree useful for commercial applications.
- *Changes all around them. C*ontrolling zebra mussels by altering the physical environment in which they thrive. This concept includes winter drawdown, utilized in the Niagara River, as well as research on modifying temperature and humidity during air exposure.
- *Biocontrol*. The New York State Museum recently identified a bacterium (*Pseudomonas fluorescens)* lethal to zebra mussels when ingested, even as dead cells, suggesting that mortality is due to a natural toxin rather than infection. They have developed a commercial product that may be available for use in managing zebra mussels in controlled settings, such as the end of pipes or fish hatcheries, as early as 2009 (Foss, 2008) This biopesticide is not practical, however, for use in open systems such as lakes or reservoirs. (See Appendix F, "Internet resources.")

## *Leeches*

These predatory, worm-like creatures may have been prized by medieval barbers and alternative medicine practitioners, but they are not welcome guests at a swimming beach. Leeches are usually found in shallow, protected waters, concealed among aquatic plants or under stones, logs and other debris, at least until encountered by an unsuspecting toe. They are attracted to water disturbances that occur near docks and swimming areas and are most active in summer.

Leech control can be achieved most easily using bait buckets or small, coffee-can sized metal containers with a closable lid that has been punctured with small holes that are approximately the size of

### Case study: Invasive species control in Lake George

**Lake setting**: Lake George is a 28,000-acre lake located in the southeast corner of the Adirondack Park.

**The problem**: Like many Adirondack lakes, Lake George was considered to be immune to infestation by zebra mussels *(Dreissena polymorpha)* due to substrate and water chemistry limitations. Calcium levels are too low in the lake to support shell generation. Local sources of calcium from inflow streams and concrete structures near the shore, however, contribute to microenvironments capable of supporting zebra mussels. The first two zebra mussel shells were found in 1999 growing on a bottle along the southwestern side of the lake. Subsequent surveys found a much larger population of mussels confined to a 15,000 square-foot area about 50 feet from shore, corresponding to a zone where calcium levels were four times greater than in the main lake. The majority of the lake was still considered inhospitable to colonization by zebra mussels.

**Response**: The Darrin Freshwater Institute (DFI) conducted an extensive hand-harvesting program to remove zebra mussels from Lake George. Divers worked for more than 250 hours in April of 2000, before the water temperature rose to more than the 55ºF that allows mussels to multiply. They removed nearly 20,000 adult mussels attached to hard surfaces primarily along the lake bottom. An additional 300 mussels were removed during one of the four survey sweeps of the lake later that summer (Yusco, 2000; Cappiello, 2000). The Lake George Association (LGA) also initiated a "Drop a Brick on Zebra Mussels" program, utilizing volunteers and lake residents to site bricks to which zebra mussels could attach. The intention was to identify other locations in the lake that could support the growth and proliferation of these mussels (Lake George Association, 2003).

**Results**: Most scientists involved in zebra mussel research do not believe that all of the mussels were removed from the lake, although water-quality monitoring conducted by DFI did not find any evidence of zebra veligers (mobile juveniles) anywhere in the lake.

**Lessons learned**: The intensive zebra mussel hand-harvesting activities on Lake George demonstrated that these invasive animals can be kept under control. It is successful, however, only when zebra mussels are confined by chemistry or substrate to manageable portions of the lake, or in very small ponds or lakes, and only with extreme vigilance and effort.

leeches. Raw meat in the bottom of the can attracts the leeches, which feed and then cannot escape through the jagged side of the holes. The can should be placed in shady water since leeches do not like direct sunlight.

Other control methods for nuisance leech populations in small ponds include winter drawdown. Water levels must be lowered below the frost line to freeze the overwintering leeches in the bottom muds. Ducks prey on leeches, but duck stocking programs create their own problems. Copper sulfate pentahydrate, applied at a rate of about five ppm, about the same dosage rate as for snail control, may also kill non-swimming species of leeches.

### *Sea lamprey*

These jawless fish are usually associated with the marine environment, but have significantly affected fisheries in the Great lakes and Lake Champlain in recent years. The most common control strategy for sea lampreys is the use of TFM (*trifluoromethyl-nitrophenol)* to destroy the larval stage of the lamprey. This has been used in more than 175 streams tributary to the Great Lakes. Barriers have also been used to block upstream movement of the lamprey, including velocity generators that can be effective against these poor-swimming fish. Adjustable height barriers have also been used to block the lampreys, but allow the movement of other fish during their critical migratory seasons. Sterilized males have been introduced to affect species spawning success, and trapping has also been utilized.

### *Just skimmin' the surface*

A lot of junk can wash up or float on the surface of lakes. This can be three-dimensional foam, bubbling surface mats of filamentous algae, detached weeds and garbage; or other stuff like duckweed, pollen and oil slicks. The appropriate management of plant cuttings and surface algal blooms is discussed in Chapter six, "Aquatic plants," and earlier in this chapter. For the other surface irritants, prevention remains the best cure.

While foaming events are often natural, they can be exacerbated or even caused by introducing surfactants (bubbling agents) to lakes. While New York State and other lands sharing the Great Lakes have made progress in reducing foam by banning phosphorus in laundry detergents, most dishwasher detergents still contain phosphorus, and phosphorus-laden laundry products can still be purchased from non-Great Lakes states. Algae, macrophytes, and zebra mussels appear to be very efficient at creating the organic material necessary to agitate the water into an unpleasant froth. It may not be worth the effort to control this flotsam when it is localized. This is particularly true for small surface foam or oil deposits.

Larger or more concentrated debris can often be removed with netting or screens. Rolls of fiberglass window screening attached to wooden dowels can be used to skim surface flotsam. Most filamentous algae do not stick to nets and screens, so they can be easily cleaned. Algae can be very dense and heavy.

## Water-quality problems

### *Mitigating acid rain effects through liming*

#### *Principle*

Lime, calcium carbonate, is used to increase pH in acidified lakes and to provide alkalinity to buffer future acidic inputs. The ultimate goal is to improve the habitat required to support fish and other aquatic life. In New York State, those lakes acidified by acid rain are those most often scheduled for liming. Until this acidic precipitation is prevented, liming will provide only temporary neutralization of lake waters. Liming may have some very limited applicability in precipitating phosphorus within the water column (see Case study on lake neutralization). Liming may also benefit some lakes that have become acidified due to the application of copper sulfate or alum, although existing regulations governing the use of these produces are unlikely to result in lake acidification.

## Case study: Lake pH neutralization in Wolf Pond

**Lake setting**: Wolf Pond is a 50-acre kettle pond in the northeastern corner of the Adirondack Park.

**The problem**: Like many of its neighboring small, high-elevation Adirondack lakes, Wolf Pond became culturally acidified before the early 1970s. The pH of the lake was measured at 4.9 by the DEC in 1973, and the lake was neutralized by adding approximately 50 tons of hydrated lime by November of that same year. While there may have been a temporary improvement in pH, trout stocked by the DEC in the lake after the neutralization had disappeared by 1980, when the pH of the lake had fallen back to 4.5.

**Response**: A research study was conducted by Cornell University and the Church and Dwight Company, parent company for Arm & Hammer. Wolf Pond was neutralized with 14 tons of USP grade sodium bicarbonate (baking soda, $NaHCO_3$), in August of 1984 (Kishbaugh, 1985).

**Results**: The experimental neutralization of Wolf Pond with sodium bicarbonate brought the pH of the lake up to 6.8 at two months post-treatment, with aluminum levels dropping by half. By August of 1985, the pH had dropped back to 6.5, and by the following year it had slowly dropped back to highly acidic readings. The lake was again neutralized with 20 tons of sodium bicarbonate in July 1987, bringing the pH up to approximately 7.5. By the following summer, however, pH had dropped back to 6.6, following the same pattern found with the initial neutralization. With pH above 6 during the majority of this period, however, brook trout stocked after the neutralization survived well, and the pond was heavily fished by the local fish and game club.

**Lessons learned**: Neutralization, whether with lime, sodium bicarbonate, or other alkaline agents, can be effective for temporarily restoring pH to normal levels in even dilute, acidic Adirondack lakes. The effects are short-lived, however, and will largely be erased by continued exposure of these sensitive ecosystems to continuing acidic rainfall and runoff (Bisogni and Arroyo, 1991).

Neutralization liming involves application of a basic agent to either the lake water or the surrounding watershed. Both techniques involve the use of calcium-based neutralizing agents, usually crushed lime [$Ca(OH)_2$], hydrated lime, or limestone ($CaCO_3$). These agents restore the alkalinity of lakes by increasing the quantity of carbonate ($CO_3^{2-}$) and hydroxide ($OH^-$), the basic anions that neutralize acidic inputs. This helps maintain pH at a sufficiently high and stable level to provide a suitable habitat for most aquatic organisms. It also brings the pH, alkalinity and calcium to a level where dissolved aluminum toxicity is less of a threat to aquatic organisms.

Other sodium-based neutralizing agents, such as sodium bicarbonate (baking soda, $NaHCO_3$) and soda ash ($Na_2CO_3$) can eliminate some of the problems associated with lime-based agents, such as pH “hot spots”, organic alkalinity precipitation, and the insolubility of lime agents. These agents can be used in direct lake application, or injection into sediments to react with the acidic cations in the overlying water, and may be more appropriate for lakes with higher flushing rates. Sodium compounds cannot be added directly to watersheds, due to sodium-soil interactions that may damage the soils.

Neutralizing agents are transported to the lake by truck or by air, depending on the available access to the lake, or the proximity of the lake to the chemical supplier. The most common applications are by airplane, by hand or mechanical application at several locations throughout the lake, or injection into the lake sediment. Direct lake application can be done along the roadside with the lime added to the water. Watershed applications are usually along the shoreline or into feeder streams.

Dose rates depend on the degree of acidification, size of the lake, flushing rate, and neutralizing agent. Typical applications are from 0.2 to 2 tons per acre for direct lake application. For application in the watershed, the dose rate is 2 to 4 tons per acre of lake surface. Slightly overdosing allows settling to the lake bottom, providing greater longevity to the treatment. A large portion of the neutralizing agent may sink to the bottom of the lake, and ultimately may be covered with deposited materials. In general, lime requires a smaller dose rate than limestone, due to the greater solubility of lime.

## *Advantages and disadvantages*

Liming works! It has been shown to effectively restore pH and alkalinity in lake systems. Liming and biomanipulation techniques can be combined to alter the chemical and biological makeup of a lake, usually to the benefit of a prized or once naturally occurring fish species.

Liming is not a one-time solution. Lake neutralization efforts will always be hampered by the continual acidic rainfall, and will achieve long-term successes only in lakes where the acidic input is low relative to the volume of the lake. Liming may provide at least a stopgap measure for improving acidified conditions to restore recreational uses, and to improve the habitat for fish and other aquatic organisms. Some believe, however, that the use of lime may prevent politicians from making difficult decisions about long-term control of the sources of acid rain.

Neutralization success has been limited to lakes with long flushing times. Lakes with a flushing rate of greater than one year are usually approved for neutralization in New York State. Even lakes with long flushing times may re-acidify within several months, depending on weather conditions, type of neutralizing agent, and the thickness and acidity of the ice pack within the watershed. This pulse of acidity occurring in the weeks after ice-out may have the most significant influence on re-acidification. As a general rule, the effects of liming last about twice as long as the retention time of the lake. Retention time is the time required to replace all of the water in the lake.

Lime also serves as a settling agent. It will combine with phosphorus and algae cells to reduce both the algae densities and the potential for future growth. Liming could be considered for use in alkaline lakes suffering from high phosphorus or algae levels. Most lakes that are candidates for neutralization liming are unlikely to suffer from algal blooms or excessive phosphorus concentrations.

The most significant ecological effects may be from aluminum toxicity. Lake neutralization usually brings the pH back to 7.0 or above. The pH change from 4.4 to 5.4 corresponds to the range of greatest aluminum toxicity. Fish and other aquatic organisms may be killed from exposure to these aluminum levels during neutralization, and are also susceptible if the pH drops to that level during re-acidification. The calcium lime product precipitates any organic matter present in the water column, and removes some organic alkalinity in the lake. Lime precipitation and buried sediments may increase the susceptibility of the lake to re-acidification.

Since liming has a long history in the agricultural industry, the use of limestone has been well studied in the terrestrial environment, and it is available at a relatively low cost. Some water companies also use lime to prevent acid corrosion of water-intake pipes, a testament to its non-toxic qualities. As with most other chemical treatments, liming introduces an element to lakes that has potentially large side effects. Although lime is not toxic at the dose rates required for lake neutralization, it is a strong base, and over-neutralization with hydrated lime can result in pH “hot spots” or elevated pH levels at the treatment site. In these locations, pH could rise to greater than 9 or 10, and this could be as dangerous as low pH levels.

The long-term effects of neutralization are not well understood. Lakes which have undergone multiple neutralizations may have experienced permanent changes in the ecosystem structure of the lake, with organisms that can tolerate sharp pH changes dominating other species. Plant communities which are the recipients of deposited, inactivated lime or limestone may have been altered by the changing pH in the sediment. Neutralized lakes will frequently become more biologically productive, by providing a more suitable habitat for many links in the food web. While this might ultimately represent a restoration of historical levels of lake productivity, the resulting decrease in water transparency and increase in algae levels may create some ecological stress or limited recreational effects.

## *Costs*

Costs will vary widely with choices about the neutralizing agent, dose rate, distance from the chemical distributor to the lake, and treatment method. Lime treatment at easily accessible lakes will vary in cost from about \$25 to \$100 per acre of surface area, including chemicals and applications costs. Sodium-based compounds are as much as 10 times more expensive. Cost of treatment at less accessible lakes could increase tenfold. Stream or watershed applications should approximate the costs of direct lake application for easily accessible lakes.

It has been estimated that neutralizing and restocking each of the verified acidic lakes within the Adirondack Park would cost more than $20 million.

### *Regulatory issues*

Liming and other neutralization efforts on public waters require permits from DEC, issued through the lake liming program summarized below, and from the APA on all lakes within the Adirondack Park. The use of lime as a precipitant has not been evaluated as a general management tool, so regulatory frameworks have not yet been enacted.

### *History and case studies in New York State*

The DEC began neutralizing certain acidic waters with agricultural limestone in 1959 as a management tool to help restore or protect valuable fisheries. In recent years, the DEC liming program has included 32 waterbodies, all located within the Adirondack Park. The program has worked cooperatively with researchers and other government agencies, including the U.S. Army Environmental Center at Fort Drum. Some of these lakes have been restocked with trout or other native fish species after the neutralization. As another alternative to mitigate the harmful effects of high acidity, the EPA's Lake Acidification Mitigation Project (LAMP) conducted research on watershed liming to determine the effects of liming the entire ecosystem on the water chemistry, terrestrial vegetation and soil biota (see Case study on large scale management).

Despite the media attention devoted to acid rain, most of the lakes in New York State have not yet been acidified. Acid precipitation has affected lakes in only a few regions of the state, primarily in the higher elevation areas in the Adirondack Mountains, and some portions of the Catskills. Figure 7–5 shows the regions in the Adirondacks where acidic lakes (pH <5.5) have been found.

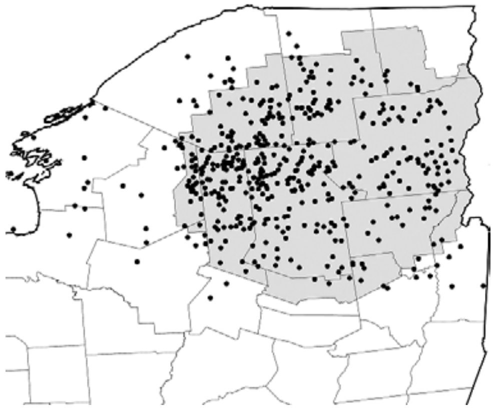

*Fig. 7–5. Distribution of acidic lakes in New York State with pH <5.5.* (CREDIT: DEC, 2008)

While rainfall remains acidic throughout New York State, liming or other methods of lake neutralization need not be considered by most lake residents at this time. Acidified lakes in New York State tend to be up in the clouds, in remote locations, with slopes and soils (mostly granitic) that do not support septic systems and road networks. These tend to be lakes that are only sparsely developed.

Unlike many other lake problems, long-term solutions to acidification are not presently available to the individual resident or lake association. The only effective solution to acid precipitation is controlling the sources of air pollution, primarily nitrous and sulfur oxides that combine with water vapor to form acids. Mitigating these sources is a scientific and political process that is beyond the scope of any one lake association. Control must be done at the origin of the pollutants, including emissions from fossil fuel combustion of factories, industrial facilities, power plants, automobiles, and others. Through cap and trade programs initiated in 2005, there have been some significant strides in this direction. Federal *Clean Air Act* legislation has reduced the acid rain precursors, sulfur and nitrogen compounds, as well as mercury, in recent years. These cap and trade programs led to a 50 percent reduction of nitrous oxides ($NO_x$) and 33 percent reduction in sulfur dioxide ($SO_2$) emissions from 2003 to 2006. With litigation against electric generators, $SO_2$ emission reductions have exceeded 80 percent since 1990. This has resulted in chemical and limited biological improvements in some Adirondack lakes. New York State has proposed cutting mercury emissions by 50 percent (capping releases at about 800 pounds per year) by 2010 and 95 percent by 2015, more stringent than the 70 percent cut proposed by the federal government for 2018.

## Taste and odor problems

### Not so clear

In most New York State lakes, turbidity equals algae, and the most common measures for controlling algae have already been discussed. There are some lakes, however, in which turbidity is associated with suspended sediments, inorganic compounds and other small particulate matter such as clay. Maintaining a

### Case study: Large scale management—Lake pH neutralization with lime

The DEC began liming acidified lakes in 1959. Prior to that, systematic lake management programs conducted in the state consisted of fish stocking programs begun as early as the 1930s. More than 100 lakes and ponds with surface pH readings below 5.7, and retention times greater than two years, were neutralized with agricultural limestone or hydrated lime. Liming of 30 to 50 lakes has been done on a more regular basis since 1990 to provide recreational fishing opportunities not otherwise available. These liming activities were not intended, however, to be an alternative to improving the emission controls necessary to promote long-term restoration of these lakes.

Cornell University also conducted an Extensive Liming Study (ELS) to evaluate changes in water chemistry, and stocked brook trout populations in response to liming. The pH of Mountain Pond rose from 4.7 to 7.0 within a few days after aerial application of agricultural limestone in late October 1983. Although the limestone dissolved less than 10 percent initially, and was still dissolving after two years, the pH had dropped to pre-neutralization levels within four months due to the rapid flushing time of the lake. In the spring, pH rose slightly as more limestone dissolved, resulting in several more months of circumneutral (near neutral) pH readings. By March 1985, pH levels were lower than prior to neutralization.

The Lake Acidification Mitigation Project (LAMP) in the 1980s was conducted by a consortium of Cornell, Syracuse and Indiana Universities, Clarkson College, and U.S. Geological Survey (USGS). It involved the use of finely ground calcium carbonate sprayed by helicopter. Two lakes included in this liming program were Woods Lake and Cranberry Pond, with respective flushing rates of 2.1 and 5.9 times per year. Both lakes were limed in May 1985 with agricultural limestone, restoring the pH over a period of several days from approximately 4.5 to greater than 9.0. Woods Lake pH readings remained nearly neutral at 7.0 for about six months, but were below 5.5 within a year. The lake was limed again the following year with 38 tons of calcium carbonate, applied to penetrate the bottom waters and sediments of the lake. Cranberry Pond pH readings dropped below 7.0 in less than four months. At seven months, pH levels top to bottom in the lake had dropped below 5.0. The deeper waters in both lakes remained acidic after neutralization. Both lakes were fishless prior to the neutralization, even though Woods Lake had been stocked the year before. Stocked brook trout survived well following the liming, and were limited more by lack of suitable spawning substrate than by water chemistry. Diatom and phytoplankton (algae) populations also increased after the neutralization. Liming did not appear to adversely affect the zooplankton levels in the lake (NYSDEC, 1990).

healthy balance of aquatic and semi-aquatic plants along the shore can prevent significant turbidity by keeping soil attached to a rigid network of roots.

Turbidity in a drinking-water supply is often addressed at the water-treatment plant through filtration, coagulation, or other standard water-treatment operations (see Chapter nine, "Watershed management"). In-lake management of turbidity in large lakes is usually not cost effective, but a number of measures have been employed in small ponds. One method is to use gypsum (hydrous calcium sulfate, plaster of Paris), to precipitate the suspended particulates at a rate of about one pound per 750 gallons of water. Aeration can be used when the turbidity is associated with a reduced form of chemical compounds, such as iron and manganese.

### *I'm not gonna drink that!*

Most taste and odor problems associated with the use of raw lake water for household purposes can be solved, or at least addressed, by water treatment. Lakefront property owners or municipal water suppliers can remove pollutants or odoriferous compounds through the use of activated carbon, activated charcoal, filtration, or potassium permanganate. Most offending compounds tend to be reduced forms of iron, sulfur, manganese or certain types of algae. These can all be exacerbated by the low-oxygen levels commonly found in the bottom of lakes, which is where intake pipes are occasionally located.

Taste and odor issues can be addressed in the long term by instituting watershed management actions such as reducing nutrient loading through septic, stormwater, and fertilizer management, and implementing in-lake management actions to increase deepwater oxygen levels. Some treated water may have a chlorine taste imparted to the water in the disinfection process. A chloride taste may also occur naturally due to conditions such as the breakdown of chloride salts and runoff from road-salting operations. Many of these methods are discussed in Chapter nine, "Watershed management."

Some water providers modify the depth of the water intake rather than institute management actions to reduce pollutants triggering the production of these various compounds. This usually requires a balancing act. Intakes too close to the lake surface can suck in the algae that congregate in the warm, well-lighted surface waters. Intakes near the lake bottom are more likely to suck in poorly oxygenated, poorly circulating water, and the chemically reduced pollutants found in deeper waters. Potable water issues may be resolved by switching from lake water to well water. Drilled wells, however, can be expensive and may encounter a new cascade of problems associated with groundwater quality or quantity.

## Other in-lake management solutions for water-quality problems and why they are given short shrift here

### *Dilution and flushing*

Lake management texts describe how high-quality water can be used to dilute pollutants or flush them out of lake systems. In most New York State lake watersheds, the quality of nearby surface water sources is similar to the water in the lake, so flushing or dilution are not likely to result in significant improvements. High-quality groundwater can be used to dilute and flush small ponds if adequate quantities are available, but this management technique has been used in only a few small lakes and ponds in New York State. More information about this tool is provided in other references listed in Appendix G, "References cited" and Appendix H, "Additional readings".

### *Fungi, bacteria, and viral pathogens*

Each of these biological control agents has been used experimentally on at least one lake in the New York Downstate region as a means to attack algae or the biochemical oxygen demand exerted by other organic compounds. Bacillus spores, microorganisms, and enzymes have been marketed as a "natural" means to clean bottom muck, clear the water, and reduce odors. They were originally developed for use in hatcheries to clean up uneaten fish food and waste. Like other means of biomanipulation, these are largely experimental, and the permit structure governing their use is uncertain. At present, the permitting situation is similar to that for barley straw. Permits may not be required if the products claim to clarify the water, not act as algacides or pesticides. Bacterial agents may have some applicability in small ponds, since they are similar to the microbial cleansers added to septic systems, but have only limited utility. They have not been well studied in New York State lakes as a control agent for larger lakes.

### *Sediment oxidation*

Sediment oxidation is accomplished by injecting calcium nitrate into sediments to break down organic matter, and injecting ferric chloride to bind available phosphorus released from the sediments. Sediment oxidation has not been used as a lake management technique in New York State. Given the uncharted regulatory territory and scientific complexity of the technique, it is unlikely to be utilized in the near future, although some lake consultants have used these techniques in other states.

### *Nutrient addition*

Nutrient control is often the foundation for developing lake management plans. Research suggests, however, that adding nitrogen may shift algae dynamics to favor algae that are either more palatable to zooplankton, or are less likely to trigger use impairments, or may free iron to bind with phosphorus (Kortmann and Rich, 1994; Tilman, 1982). No applications of this technology have been reported in New York State. Increased nutrient additions in surface waters could enhance the warmwater fisheries of a lake, and has been discussed in the context of fisheries management in Lake Ontario. The addition of a perceived pollutant to the water, such as nitrogen, would be inconceivable to most lake communities.

### *Can't stand the noise*

One of the newest strategies for dealing with excessive algae growth is to emit ultrasonic sound waves in the water to destroy the vacuoles of the algal cell walls that provide buoyancy. This is similar to one of the techniques used to control zebra mussels. The commercially marketed sonic devices use transducers of less than 50 watts, and are reported to be applicable for small ponds of up to three acres per sonic unit. The use of ultrasonic devices was also discussed briefly in Chapter six, "Aquatic Plants". This management treatment has not been used, or at least well-documented, in any New York State lakes, and thus cannot be evaluated at this time.

## Summing it up

Historically, lake management was often equated with algae control and many of the management techniques described in this chapter have a long history. Some have been improved in recent years to reflect advances in delivery systems. Others, such as biomanipulation, are riding a wave of renewed interest in biological control. Barley straw, one of the newest management techniques, perhaps reflects just one old farmer's simple method for dealing with an age-old pond problem.

In recent years, nuisance weed control has become the focus of an increasing number of lake management plans. The age of wastewater treatment shifted the focus of water-pollution control to control of stormwater and toxic materials. The slow resolution of algae, aquatic weed and water-quality problems may ultimately shift attention to conflicts about how these improving water resources can be used. Once the lake is clear and the surface is weed free, competition for the use of the lake demands increasing attention. Chapter eight discusses "People problems" on New York State lakes, and some techniques that can be used to address these concerns.