Ecologically Based Small Pond Management

Volume 1: Management Strategies for the Small Pond Owner

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This report was prepared by G. Winfield Fairchild, Department of Biology, West Chester University, with assistance from David Velinsky, Academy of Natural Sciences of Philadelphia. We gratefully acknowledge the scientific and editorial advice of Harry Campbell (Gannett Fleming Engineers), Barb Lathrop (PA Department of Environmental Protection), Chotty Sprenkle (Chester County Conservation District) and Alfred Wright (Chester County Water Resources Authority) for their reviews of earlier drafts of this manuscript. The Chester County Department of Computing and Information Services and the Chester County Water Resources Authority are also acknowledged for providing digital data, mapping and geographic information.

This project was sponsored in part by Growing Greener Grant ME# 351439 provided by the Pennsylvania Department of Environmental Protection. The views expressed herein are those of the author(s) and do not necessarily reflect the views of the Department of Environmental Protection.

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Cover: Pond at Crebilly Farm, Westtown Township.

January, 2004

Introduction

In the piedmont of southeastern Pennsylvania, the importance of an increasing number of man-made ponds which now dot the landscape has been largely unnoticed. Over 3000 such ponds occur within Chester County. Most are small (< 1 acre), shallow and have their own small **watersheds** within much larger stream basins. Collectively the ponds serve a number of human uses within the county, including recreation (e.g., fishing, boating), water supply (nurseries, golf courses and livestock), aesthetic enhancement, and stormwater retention. In addition, they function as habitat for a diverse community of plant and animal species, very different from the flora and fauna of streams, and modify water flow and water quality within the landscape.

Because of their shallow nature and location within suburban or agricultural watersheds, most ponds in Chester County are **nutrient**-rich, often heavily impacted by non-point source nutrient inputs (especially **nitrogen** and **phosphorus**) from surrounding land uses. The most important problem arising from excessive nutrient loading, as perceived by landowners, is the excessive growth of algae and aquatic plants. Excessive algal or plant growth in turn affects a wide range of other ecosystem properties, including water chemistry and fish. Although non-point sources of nutrients are often difficult to control, a variety of management options, both within and directly surrounding the pond, are available for controlling algal and plant growth. Evaluation of pond problems can thus lead to effective pond restoration.

This project is funded by the Growing Greener program, Commonwealth of Pennsylvania. The grant, awarded to West Chester University of Pennsylvania, established a collaborative research initiative also involving the Academy of Natural Sciences of Philadelphia and the Chester County Water Resources Authority.

This Report consists of two "volumes". **Volume 1** is directed toward landowners and other non-scientists with interests in ponds. Management alternatives are outlined, with emphasis on methods within reach of most landowners or homeowners associations. The ecological implications and side effects of each management approach are described, emphasizing the need for caution in applying particular restoration methods. The information is intended as a first step in focusing on a particular management approach, the engineering aspects and costs of which can then be obtained from purveyors, in print or on the internet. Readers may negotiate more difficult terms and concepts identified in **bold print** the first time they are used using the Glossary at the end of volume 1, and are urged to consult relevant portions of the text in volume 2 for further information. Superscripted numbers within the text cite references in the Bibliography, are accessible to the general reader and provide excellent, more detailed information on small pond management techniques.

Volume 2 is intended primarily for lake managers and environmental professionals. It provides a more technical description of shallow ponds, summarizing general features of ponds in the county and more detailed information based on fieldwork at the 13 target ponds. Although it can be used as a stand-alone document, it is also meant to provide more detailed information relevant to pond management. A summary of Metric Conversions provides clarification of units and symbols used in the text. A Literature Cited section provides access to more technical literature on the topics covered.

Questions regarding the report should be addressed to Dr. G. Winfield Fairchild, Department of Biology, West Chester University, West Chester, PA 19383 (wfairchild@wcupa.edu). Another useful source of information, created as part of this project to summarize the ecology and management alternatives for shallow ponds in southeast Pennsylvania, is the website **http://darwin.wcupa.edu:16080/ponds/**.

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A. Preliminary Assessment and Monitoring

Ponds in Chester County have been built to fill a range of purposes and are valued in different ways by their owners. They vary in size and shape, and occur within watersheds of varying size, land use and topography. Not surprisingly, there is no single management "recipe". Instead, pond owners need to become knowledgeable about the range of management options available, and to recognize that management tools rarely affect just the target organism or environmental problem of interest; as will be repeatedly emphasized in this document, all major components of the pond ecosystem are interconnected by nutrient and energy flow. In deciding on a management plan, it is also important to concede that there are natural limits to feasible outcomes of management. With few exceptions, ponds in Chester County are nutrient rich, highly productive systems, and no amount of effort or expenditure is likely to change those fundamental attributes. More simply stated, pond owners should learn to love the color green.

A useful first step before considering any form of pond management is the acquisition of available data concerning the **watershed**. Aerial photographs and topographic maps needed to delineate watershed boundaries and categorize land use within the watershed are available from the Chester County Planning Commission. Knowing the extent of land influencing the pond means being more fully aware of potential impacts associated with new home development, roadwork and other changes in land use (see Section B below).

Second, we suggest, for those owners with the interest and ability, development of a simple, self-sustained monitoring program to record seasonal and yearly trends in water quality and in the occurrence of particular plant and animal species. Involving older children in data collection, for example, can provide an excellent educational activity during summer or as a school science project. Longer-term measurements by a retiree or other resident near the pond are especially helpful if carried out consistently. Some ideas for measurements and equipment needed to develop a monitoring program are summarized in Table 1. Some equipment can be built at home (e.g., **secchi disk**[1]), and several companies sell testing kits appropriate for pond owner use[2,3] . Even limited amounts of information can lead to a much clearer perception of what to do when the pond begins to "act differently".

Table 1. Suggestions for developing a monitoring program to detect changes in pond water quality. Sources of equipment are included in the Bibliography.

Measurement	Equipment	Monitoring Recommendations
Light Penetration	Secchi Disk	Every two weeks
Temperature and Dissolved Oxygen	Dissolved Oxygen Meter or Hach Test Kit	Every two weeks
Water Level	Staff Gage	Every two weeks
Spec. Conductance	Conductivity Meter	Monthly

Third, a great deal of information and advice can be obtained through the internet, self-help manuals and professional societies focused on lake or pond management. Perhaps the best single first step is to contact both the North American Lake Management Society[4] and Pennsylvania Lake Management Society[5] to find out about their publications and upcoming meetings. Penn State's Cooperative Extension and Pennsylvania Fish and Boat Commission jointly maintain a very complete website with access to publications on a wide range of management topics[6]. Another good starting point is Cornell University's Cooperative Extension website, which has links to a number of other websites focused on pond management[7]. The Chester County Conservation District office provides a free Pond Management Packet upon request[8]. Finally, a careful reading of volume 2 of this Report, more specifically describing the ecology of small ponds in Chester County, can help "put the pieces together" in terms of how ponds function as ecosystems, and thus lead to more informed management decisions.

B. Watershed Protection

Water quality in a pond usually depends strongly on inputs from the watershed of 1) water (which helps to determine water volume and flushing rate), 2) dissolved nutrients (which directly control the growth of algae and aquatic plants), and 3) soil particles (which become pond sediments and also contain growth-promoting nutrients) from the watershed.

Nutrient (especially nitrogen and phosphorus) inputs are often the biggest concern, as high concentrations in ponds typically lead to excessive algal or aquatic plant growth. Nitrogen and phosphorus originate from a variety of land uses within the watershed. The N:P:K formula in lawn and agricultural fertilizers, for example, refers to the relative amounts of nitrogen, phosphorus and potassium being added. Domestic sewage is typically high in both nitrogen and phosphorus, and septic drain fields release substantial quantities of both to groundwater which may ultimately enter the pond. Rainfall is actually a major source of nitrogen (but not phosphorus) in southeast Pennsylvania. Volume 2 (Section M) describes a method for estimating phosphorus inputs from all sources within the watershed as a first step toward reducing levels of phosphorus entering the pond.

Inputs of water, sediments and dissolved nutrients may all change over time. For example, heavy rains during the growing season in some years may greatly increase nutrient loading to the pond, causing unusual amounts of algal growth. New housing construction, if proper erosion controls are not followed, may contribute enough sediment in a short time via **surface runoff** to substantially impair pond water function. Less obviously, increased housing density may lead directly to pond problems through inputs of nutrients from septic tanks and fertilized lawns. Control by pond owners over watershed influences may be limited, but depends both on good stewardship of the portion of the watershed owned and an understanding of the legal responsibilities of other landowners within the watershed.

C. Dams and Standpipes

Water levels in most ponds in Chester County are controlled by standpipes, capable of preventing excessively high water levels during rainfall events but incapable of regulating minimum water levels during droughts. A frequently-encountered problem in older ponds is corrosion of the standpipe, often leading to persistently low water levels and erosion of exposed bank sediments (Fig. 1). A small expenditure in fixing an old standpipe can delay the much larger expense of dredging eroded sediments from the pond basin.

Fig. 1. Rusted standpipe at a pond in West Brandywine Township.

Standpipes with bottom withdrawal capability are a very helpful feature in allowing water levels in the pond to be drawn down, as is sometimes required for shoreline erosion control projects, removal of aquatic plants, or the removal of fish. If a standpipe needs repair, addition of a bottom withdrawal valve should be considered.

When water levels are controlled by an earthen dam, inspection and any needed maintenance of the dam should be, at a minimum, an annual event. Unlike most of the shoreline, the dam should be maintained as mowed grass. Trees and shrubs are best kept off of the earthen dam embankment as the root systems will reduce the strength of the dam and its ability to hold the water in the pond. Any damage caused by burrowing animals (e.g., ground hogs) should be repaired on a regular basis for the same reason.

Whether the water level is controlled by a dam or standpipe, there should be a carefully maintained overflow spillway near the outlet of the pond. Spillways, like most earthen dams, normally consist of mowed grass. Further information is available from PA Department of Environmental Protection – Bureau of Waterways Engineering – Dam Safety division.

D. Protecting the Shoreline

The shoreline is the interface between terrestrial inputs and in-pond processes, and its protection is a major component of pond protection. This report focuses on three general shoreline considerations.

First, soil erosion of the shoreline (e.g., slumping banks) can be a major source of suspended particles in the water column (reducing light penetration, inhibiting the growth of **primary producers**, and discoloring the water), and nutrient input (especially phosphorus, large quantities of which are loosely attached to soil particles) (Fig. 2).

Fig. 2. Turbid, brown water is usually an indication of sediment runoff, and can rapidly fill in a pond if not checked. Sediments are also particularly rich in P, and can thus stimulate algal growth.

Shoreline erosion may be exacerbated by fluctuations in the pond water level (leaving exposed soil) and by livestock (which may be a substantial contributor of both suspended sediments and nutrients) (Fig. 3). Engineered solutions for protecting shorelines from erosion

Fig. 3. (above) A mud bank exposes much of the shoreline to erosion during dry times of the year. (below) Cows are frequent visitors to ponds in agricultural landscapes when given the opportunity, eroding banks and adding nutrients (photo courtesy of B. Lathrop).

have traditionally included "hard armor" such as "riprap" (large, loose stones placed atop screening) along banks to control sediment erosion during storm events. More recently, **bioengineering** approaches have used the roots and stems of natural vegetation to stabilize shorelines[9,10]. Biodegradable organic materials such as coconut fiber are used initially to prevent erosion while new plantings are becoming established. Eventually, the plants take over the task of bank stabilization as the organic materials slowly decompose. Bioengineered shorelines provide additional aesthetic benefits, serve as wildlife habitat and, once established, require little further maintenance, whereas traditional “hard armor” structures may weaken over time. Many ponds in Chester County use riprap or concrete “sea-walls”, which are really more appropriate to environments receiving heavy wave stress than to the banks of small ponds.

Second, establishing **riparian buffer** strips of vegetation along the shoreline to replace mowed lawn (currently the predominant riparian land use in Chester County (see Volume 2 Section C) may likewise improve pond water quality. Turf grass has little root penetration and proportionally little capacity for sediment and nutrient retention, and the application of lawn fertilizers can add to the pond’s nutrient load. Just how wide a riparian buffer should be is subject to debate, but minimum widths of 7.5 m (25 feet) are often recommended[11]; any buffer is better than none. It is often useful to plan both an upland zone and aquatic zone within the buffer. Useful suggestions for planting and landscape design are available[9].

A riparian buffer zone of natural meadow, shrubs or trees improves sediment and nutrient retention, enhances wildlife habitat and discourages Canada geese. The property manager at a farm in East Bradford Township recently replaced 2 acres of mowed grass with wildflowers. The initial estimated cost of $1400 for seeding was recouped within approximately 1 year by reduced mowing expenses, and the profusion of wildflowers enhanced the scene shown in Figure 4.

Fig. 4. View of a farm in East Bradford Township, with yellow wildflower plantings on the far shore.

Trees can be a hindrance to recreational uses, and may interfere with the view of the pond. One way to have a riparian buffer while at the same time retaining an attractive "viewscape" is to trim lower branches and reduce the height of the herb and shrub layers The creation of adequate access points for fishing and landscaping specific locations where the pond can be seen, while keeping much of the remaining shoreline protected, can likewise facilitate enjoyment of the pond while maintaining its water quality[9] (Fig. 5).

Fig. 5. Selective removal of riparian vegetation at key access locations can enhance recreational use while maintaining pond water quality. View of A. Fairchild fishing at a pond in Westtown Township.

Third, protection of an inflowing stream can be just as important as protecting the shoreline of the pond itself. **Bathymetric** (depth contour) maps of most ponds (see Volume 2 Section F) show that the shallowest areas occur near the inflow, typically because of sediments carried in by the stream. If land is scheduled to be developed upstream, properly installed sediment fences and well designed erosion control measures are absolutely necessary for pond protection. Where sediment inflows cannot be reduced by streamside buffers, a portion of the pond near the inflow can sometimes be engineered with a berm built just below the surface, forming a sediment trap in which the suspended material settles before entering the main portion of the pond (Fig. 6). Trapped sediments must be removed regularly, however, for the design to be effective. Alternatively, the inlet area of the pond can be graded to encourage the growth of emergent aquatic plants, forming a wetland that will also function to trap sediments as they enter the pond.

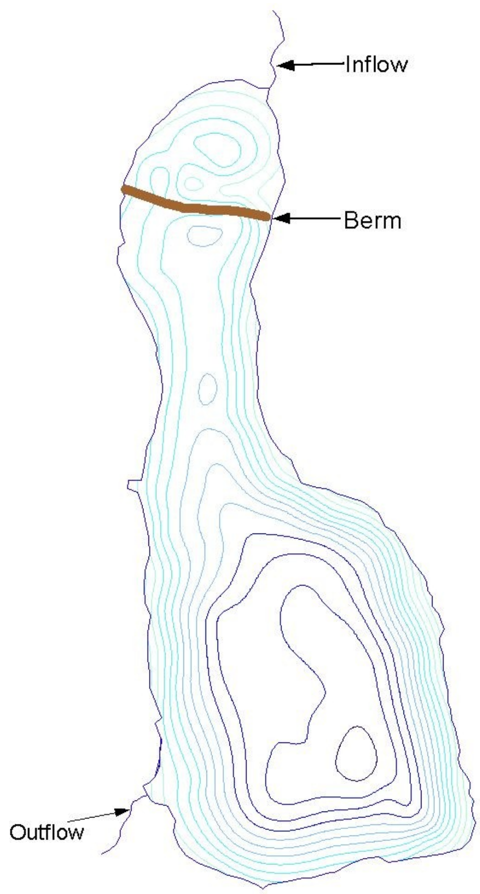


Fig. 6. Map of a pond in Westtown Township, showing the location of an underwater berm designed to trap sediments entering the pond.

E. Discouraging Canada Geese

Since they first became established in Pennsylvania in the 1930's, resident Giant Canada geese (*Branta canadensis maxima*) have undergone rapid increases in population size[12]. Giant Canadas differ from migratory Canada geese in size (they are nearly 50% heavier) and in their year-round residency. They have been identified as a major problem by landowners because of the damage caused by their feeding on lawns, and by the abundance of feces and feathers often produced (Fig. 7).

Fig. 7. This pond in East Marlborough Township seasonally supports up to 200 Canada geese, which account for most of its nutrient input each year.

A particular problem to pond management is the large quantities of nutrients in the form of goose feces. A study of Wintergreen Lake, MI[13] estimated that migrant Canada geese contributed 69% of all carbon, 27% of all nitrogen and 70% of all phosphorus entering the lake. Moore and colleagues[14], in their phosphorus budget analysis of Waban Lake, MA, estimated that phosphorus from Canada geese was more than seven times greater than all other external sources of P combined during a particularly dry year with little stream inflow. Although effects of geese on smaller ponds have not been as well studied, such information implies that Canada geese may greatly increase the quantities of phosphorus, which in turn may directly control the abundance of primary producers.

A good place to begin developing a management strategy is to consult the United States Department of Agriculture Wildlife Services in Pennsylvania, which provides both advice and contract services[15]. A variety of measures for making ponds less attractive to Canada Geese have been tried by land owners, with varying success. These include 1) modification of shoreline vegetation, 2) the use of dogs, swans and “scaregeese” such as plastic owls or alligators, and 3) the deployment of fences, wires or monofilament line in the pond or on the shoreline.

A fertilized lawn, providing high-quality grazing and directly abutting a pond that provides refuge from predators, is a habitat highly preferred by Canada geese. Riparian buffer strips of natural vegetation, especially bushes, can greatly lessen the attractiveness of a pond by physically impeding movement from land to water and providing the threat of harboring potential predators. Trees surrounding smaller ponds also make landings and take-offs more difficult. Riparian buffers are thus a good idea, not just for controlling sediment and nutrient flow into the pond (see Section C above), but also for discouraging a principal culprit in nutrient loading.

F. Phosphorus Precipitation

For ponds in which phosphorus is the limiting nutrient, precipitation of P can be an effective means of controlling the growth of **phytoplankton** (microscopic algae suspended in the water column), **metaphyton** (filamentous, scum-forming algae) and non-rooted aquatic plants such as duckweed and watermeal[16,17,18]. This is commonly accomplished by adding buffered **alum** (aluminum sulfate, mixed with sodium aluminate or calcium compounds to prevent lowering of **pH**). The product is typically mixed with pondwater, then delivered to the water column as a slurry from a boat. The alum scavenges the **orthophosphate** (PO_4^{3-}) from the water, transporting it as an insoluble precipitate to the sediments. The presence of the alum precipitate also serves as a "cap" at the sediment surface, reducing internal fertilization of the pond by the recycling of P from the sediments to the water column. An additional benefit of alum treatment is the precipitation of suspended sediments. Thus, increased water clarity is achieved, not only by reducing nutrient support of algal growth but also by the settling of non-living particles. Improvements in water clarity and reductions in phytoplankton following treatment can last for more than 5 years in shallow water bodies with long **hydraulic residence times**[19].

Buffered alum should not currently be applied in Pennsylvania, however, without prior discussion with the Department of Environmental Protection. The state's policy regarding alum treatment, currently under review[20], arises from several concerns. First, long-term effects of repeated alum application on sediment particle composition and chemistry are not well understood (preliminary information suggests that at least some **benthic invertebrates** are largely unaffected by the presence of the alum precipitate[21]). Second, the precipitate, once settled, may have little further effect on orthophosphate regenerated subsequently within the water column (e.g., by **zooplankton** grazing of phytoplankton, or algal decomposition), or added with influent streamwater. Rooted aquatic plants, by drawing P from the sediments then later releasing it during decomposition, also circumvent the effectiveness of the alum blanket. Third, the settled alum may be resuspended during storm events in very shallow ponds. Fourth, although alum is commonly used to clarify drinking water and is found in some foods (e.g., pickles), little is known about health effects of aluminum, particularly with respect to Alzheimer's disease. Because of these uncertainties, alum treatment remains a promising but infrequently used management alternative in Pennsylvania at the present time.

G. Aeration

The basic purpose of **aeration** is to add oxygen to the water column. This is usually accomplished by pumping air to a point near the bottom of the pond. Pond water mixes with the air bubbles as they rise to the surface, and absorbs oxygen both during ascent and at the surface. Commercially-available aerators may be powered by electrical, solar or wind energy, and come in a variety of designs suitable for a wide range of pond sizes. They are rather inconspicuous, evident largely by the roiling of water at the surface (Fig. 8a).

Fountains are also frequently seen in ponds of this region (Fig. 8b). Fountains often provide some degree of aeration, but in many cases draw already well oxygenated water from just below the surface. The function of many fountain systems thus is largely one of decoration rather than of pond management.

Aeration actually accomplishes several objectives. First, adding oxygen to the water column helps prevent fish kills during seasons of operation. Second, oxygenating the water near the sediments tends to keep phosphorus as an insoluble precipitate (see Volume 2 Section K), and prevents it from entering the water column. Third, adequate oxygen should promote the aerobic decomposition of organic matter in the water column and at the sediment surface (there is little evidence, however, that aeration increases decomposition sufficiently to reduce the filling in of pond basins with organic sediments).

One concern about the ecological effects of aeration is the “destratification” of the water column that would normally occur in many ponds during summer (circulation in ponds with aerators occurs from top to bottom). As discussed in Volume 2 Section I, stratification helps to limit phytoplankton growth in many ponds by separating nutrient supply (more abundant in the bottom waters) from light (more abundant at the surface). Whether the reductions in P release from the sediments by aeration systems are sufficient to offset the natural advantages of stratification and thereby achieve a net decrease in phytoplankton growth is not well documented.

Further information about pond aeration systems is available from the large number of purveyors advertising on the internet. A general introduction to aeration technology is provided in The Lake and Pond Management Guidebook[10].

←An underwater ‘bubbler”in East Nantmeal Township is barely visible just in front of the ducks. Its primary intent is to add

Fountains, such as this one in Pennsbury Township, serve as aesthetic additions to ponds, and may also

Fig. 8. Aeration devices in common use in Chester County.

H. Dredging

Sediment removal can provide a variety of long-term benefits, and thus can be viewed as cost-effective despite its considerable expense up front. First, the increase in water volume provided by dredging increases hydraulic retention time (= volume/outflow **discharge**), and also provides a larger reservoir of water to buffer against night-time or seasonal declines in dissolved oxygen. Dredging can thus reduce the possibility of fish kills.

Second, highly organic, nutrient-rich sediments, consisting largely of the partly decomposed remains of pond organisms, are removed from the system. The release of nutrients from such sediments when oxygen becomes depleted near the bottom during summer can cause the return of phosphorus to the water column, defeating attempts to control external inputs of phosphorus from the riparian zone or larger watershed. (By contrast, removal of inorganic sediments resulting from bank erosion or stream transport, while providing benefits of pond deepening, does less to counteract internal nutrient recycling.) Determining particle size composition is important because smaller particles are more likely to be resuspended during storms, decreasing water clarity. Particle sizes also help to determine the ease of sediment removal, and thus may influence the cost estimate for the project.

Third, deepening a pond that has previously mixed from top to bottom during summer may cause it to stratify, achieving spatial separation of nutrients and light and thereby reducing phytoplankton growth (see Volume 2 Section I). Just how deep the pond must be to achieve stratification is dependent primarily on light penetration (see Volume 2 Section H), but an average depth of 2 m is probably adequate to produce stratification during summer in most small ponds in Chester County.

Fourth, shallow ponds experience frequent resuspension of sediments during storms. The suspended material not only adds nutrients to the water column but also greatly reduces light penetration, often suppressing the growth of aquatic plants.

There are also some potential side effects of dredging. First, deepening the pond changes the availability of light for primary producers. A good way to evaluate the effect of pond deepening on light reaching the bottom is to compare the present and proposed future depths of the pond with the **compensation depth**, the depth to which 1% of incident light penetrates and below which few plants can grow. If the pond is deepened uniformly to a depth exceeding the compensation depth, the growth of rooted aquatic plants is likely to be suppressed, releasing phytoplankton and making the pond appear greener than before. One recommendation is to dredge portions of the pond while leaving shallower areas near shore to sustain healthy plant communities.

There are a wide variety of techniques for dredging, involving either barges positioned on the pond, or more commonly equipment operated from shore. Prior **drawdown** of the pond is often a cost-effective first step to allow equipment into the pond basin (Fig. 9).

Fig. 9. Dredging following drawdown during winter at a development in Willistown Township (photograph courtesy of R. Stephanou).

Both state and federal permits are required before starting a dredging project (some excavation companies will handle the permitting process for the client). The principal permitting concern relates to disposal of the dredged material. The permits require sediment testing for toxic substances, which, if found, restrict the options for sludge disposal. On-site disposal is less expensive, but requires a natural, non-wetland depression. Off-site disposal involves shipment of the material elsewhere by dump truck. In either case, dewatering is a necessary first step in treatment of the dredged material.

Additional information regarding dredging is available in the Lake and Pond Management Guidebook[10]. Because the procedure is expensive, cost considerations should be carefully researched; dredging companies are well advertised on the internet.

I. Controlling Phytoplankton

In **eutrophic** ponds with high nutrients, phytoplankton cells may become so abundant that the water color turns a murky green. Light is rapidly intercepted within the water column, and rooted plants don't receive enough light to compete successfully with the algae above. Excessive phytoplankton growth, by taking the place of rooted aquatic plants needed to reduce sediment resuspension and provide food and protection for fish (see Volume 2 Section T), can thus greatly reduce the value of the pond as an aesthetic and recreational resource.

Phytoplankton are most frequently controlled by 1) nutrient reduction (see Volume 2 Section O), or 2) the regular application of **algicides**. Less commonly, 3) colorants are added to reduce light needed for phytoplankton growth, or 4) densities of herbivorous zooplankton are increased to graze down phytoplankton abundance.

The most commonly used **algicides** are copper-based compounds, including copper sulfate ($CuSO_4$) or chelated copper compounds like Cutrine-Plus® (a mixture of copper ethanolamines) (Fig. 10). Copper sulfate is less expensive, but is less effective in hard water and requires more frequent application; chelated copper compounds are less sensitive to **hardness** effects and remain active for a longer period. Algal death following treatment is quite rapid, and the decomposition of the settled, dead algal material by bacteria can cause **anoxia** at the bottom of the pond, sometimes causing fish kills. Bacterial decomposition further liberates a large portion of the nitrogen and phosphorus stored by the algae, making them available for new growth once toxicity levels have declined. The effect of copper build-up in the sediments is not fully understood, but may be a concern for long-term health of the pond. A permit is required to apply algicides in Pennsylvania[22]. Licensed applicators are often contracted to provide a regular schedule of treatments.

Fig. 10. Copper sulfate crystals (a) and Cutrine applied as a liquid (b).

The use of barley straw is sometimes viewed as an attractive alternative to commercial algicides (Fig. 11). Some evidence suggests that barley straw, when allowed to decompose in pondwater, produces an “algistatic” effect, inhibiting algal growth but not killing already-existing algal cells. The suggested method of application is to loosely enclose the straw in mesh bags or tubular netting (e.g., Christmas tree wrap), then tether the material just beneath the surface. Application in early spring is recommended, as barley straw is presumed to have little effect on already-established algal blooms. The principal ecological concern regarding the technique is the largely unknown long-term impact of repeatedly adding large quantities of organic matter to the pond ecosystem. This concern can be reduced by making sure that the straw is removed from the pond at the end of the growing season.

Despite the widespread appeal of barley straw as a “natural” form of chemical treatment, the chemical reactions underlying the inhibitory effect on algae are not well understood[23], and the degree of response appears to vary widely[24,25,26]. Because of uncertainties regarding its mode of action, barley straw is not a product that is currently registered by the U.S. EPA.

Fig. 11. Barley Straw, marketed both as straw and pellets, of a size useful for small ornamental garden ponds.

Colorants act to reduce the penetration of wavelengths of light needed for photosynthesis (Fig. 12). The pond is typically treated at the beginning of the growing season as a means of reducing the growth of primary producers. While often effective and relatively inexpensive, the unnatural tint to the water imparted by the colorant may be aesthetically displeasing.

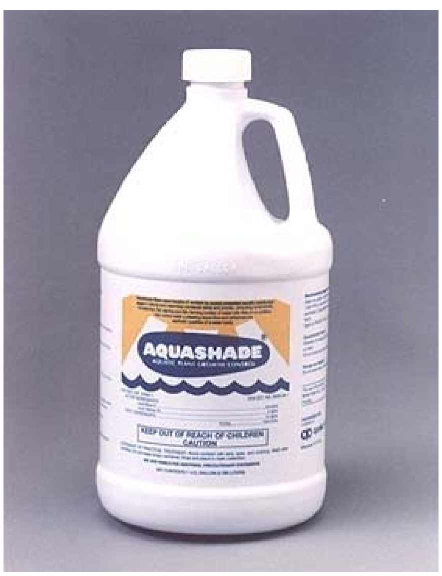


Fig. 12. Colorants seek to limit the photosynthesis of algae and plants by reducing light penetration in the water column. An unnatural post-treatment "tint" of the water column is often evident.

Enhancement of zooplankton densities to control algal growth, also known as **biomanipulation**, requires complete fish removal or a substantial reduction in the abundance of smaller, planktivorous fish (Fig. 13). One way of removing all fish is to apply rotenone (permit required from PA Fish and Boat Commission). Increasing the abundance of piscivorous fish (e.g., **largemouth bass**) may also depress the densities of fish that feed directly on zooplankton. Increased zooplankton densities can in turn apply sufficient grazing pressure to reduce phytoplankton biomass and thus clarify the water.

While biomanipulation has frequently been effective in larger lakes, its usefulness in small ponds is not as well documented. One concern is that increased grazing by zooplankton may simply favor kinds of algae that are either inedible or too large to be eaten. Such shifts in the species composition of the phytoplankton community circumvent efforts at reducing phytoplankton abundance.

In order to be successful, the densities of planktivorous fish have to be maintained at low levels until rooted aquatic plants have become well established, a process which may require several years. Biomanipulation is thus a good example of a management strategy that affects the entire pond ecosystem and requires considerable long-term planning. A good reference to the theory and application of biomanipulation in ponds is <u>A Guide to the Restoration of Nutrient-Enriched Shallow Lakes</u>[27].

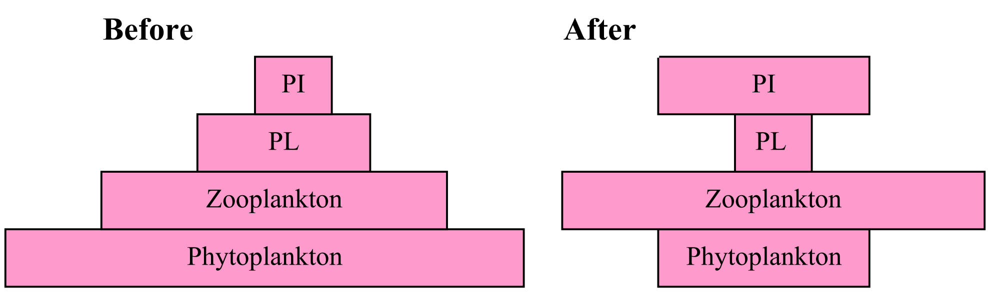


Fig. 13. Relative abundances (indicated by compartment size) of phytoplankton, zooplankton, planktivorous fish (PL) and piscivorous fish (PI) before vs. after biomanipulation. In the figure at right, introduction of a

J. Removing Metaphyton

Severe problems with scums of filamentous algae, or metaphyton, are usually associated with high nutrients and light penetration to the bottom (see Volume 2 Section Q). Nutrient reduction and pond deepening are thus the most logical preventative approaches for reducing metaphyton abundance. There are also two general treatment options: 1) application of algicides, and 2) mechanical removal.

Metaphyton may be treated with the same algicides used to control phytoplankton. Slow diffusion of the algicide into the often dense clouds of metaphyton may delay algal death and necessitate higher dosage levels. If massive scums of metaphyton are present at the time of algicide application, their death and decomposition may cause oxygen depletion within the water column, resulting in fish kills and offensive odors.

An effective alternative approach in many ponds that avoids the side effects of chemical treatment is the physical removal of floating mats using long-handled threshing rakes, seines, or specially designed screens (Fig. 14). These may be operated either from shore or from boats.

Fig. 14. (left) Boat at a pond in East Bradford Township, outfitted with screen to move metaphyton to shore, where it is collected for disposal outside the watershed, (right) a "lake rake" for removal of metaphyton and aquatic plants (photo courtesy of The Pond Guy, Inc.).

A major advantage of this approach is that not only the algae but also their stored nutrients are removed from the pond. It should be recognized, however, that filamentous algae near the bottom in deeper areas of the pond are less easily collected and these will produce additional surface scums over time.

An important planning consideration is what to do with the metaphyton once it is harvested. Piling the material near shore should be avoided, and the receiving area should ideally be out of the watershed. The material is rich in protein, and should potentially make excellent compost. To date, however, little is known about how to recycle metaphyton effectively.

K. Working with Aquatic Plants

Aquatic plants are an important component of the pond system, and their complete elimination can often lead to algal blooms, discoloration of the water by suspended sediments and greatly impaired fishing[28]. Perhaps the best approach to managing aquatic plants is to encourage those species that add aesthetic and ecosystem value (Fig. 15). This has been termed "lakescaping" (or "aquascaping"), conveying the idea that the edges of ponds respond to careful management just as do gardens and other landscaping. Henderson's Lakescaping for Wildlife and Water Quality[9] is an excellent starting point for developing and maintaining preferred aquatic plants along the shoreline.

An overabundance of plants sometimes interferes with boating or swimming, however, leading homeowners to seek ways for effective control. Distinguishing the general growth forms of aquatic plants targeted for control is an important first step in deciding on a management approach. Most plants are classified as "emergent" (along the shoreline and with stems and leaves mostly out of the water), "rooted-floating" (e.g., water lilies), "rooted-submersed" (e.g., most pond weeds, elodea), or "free-floating" (e.g., duckweeds, watermeal) (see Volume 2 Section S). These growth forms differ in the ways they obtain light and nutrients, and in their effects on other components of the pond ecosystem.

Fig. 15. Example of aquascaping in a pond in East Marlborough Township. Terrestrial plantings are seen in the foreground, with aquatic plants at the pond edge.

Plant management options are detailed in a comprehensive and very readable manual prepared jointly by the North American Lake Management Society and the Aquatic Plant Management Society[29]. A manual specific to plant control in Pennsylvania[30] is also available through Penn State University. Aquatic plants may be removed from undesired areas by 1) physical removal, 2) habitat modification designed to reduce growth rates, 3) chemical treatment, 4) **biological control**, and 5) winter drawdowns.

Physical removal from small ponds is usually done by hand, using rakes, shears or cutter bars dragged along the bottom. As with the physical removal of metaphyton, a big advantage of this approach is the concurrent removal of stored nutrients, and harvesting should therefore take place before the plants decompose (mid- to late summer is a good time for most species). The plant material should be transported away from the shoreline so that nutrients don't reenter the pond, and can be composted for use in gardens.

Habitat modification usually seeks to 1) reduce light penetration to the sediments, either by adding colorants (dyes) to the water column (see Section I above), or 2) deepen the pond by dredging, again effectively reducing light penetration to the bottom and also removing nutrient-rich organic sediments. Dredging in particular has wide-ranging system-wide effects (see Section H above).

Chemical treatment with **herbicides** is a commonly used management tool, but should be considered with caution, with an understanding of which species are likely to be affected by treatment, how rapidly they act, and the longevity of the chemical within the pond. A general list of commonly used herbicides is provided in Table 2. Homeowners who choose to apply chemical treatments themselves must apply to the Commonwealth for an "Application and Permit for Use of an Algicide, Herbicide, or Fish Control Chemical in Waters of the Commonwealth"[22]; usually the service of a licensed applicator is recommended. The guide <u>Aquatic Plant Management in Lakes and Reservoirs</u>[29] provides an excellent overview of the many options available.

Table 2. Herbicides commonly used to control aquatic plants. For mode of action, SYS = systemic, CON = contact; for selectivity, SEL = selective, BR = broad spectrum.

Herbicide	Common Brands	Mode of Action	Selectivity	Half Life (wks)
2,4-D	2,4-D Ester	SYS	SEL	1-7
Copper	Cutrine Plus	CON	BR (incl. algae)	very long
Diquat	Weedtrine	CON	BR	1-2
Endothall	Aquathol Endothal	CON	BR	1-2
Fluridone	Sonar	SYS	BR	3-15
Glyphosate	Rodeo	SYS	BR	2

Herbicides that are considered "broad spectrum" are typically used to remove all aquatic plants, regardless of species. Others are more "selective", targeting particular plants. Most modern herbicides have relatively short durations of activity, breaking down into less harmful constituents. Exceptions are formulations of copper, which do not readily break down and may accumulate in the sediments.

Herbicides differ in their general modes of action. Some are termed "contact" herbicides, and rather rapidly cause the death of those plant tissues with which they come in direct contact. They have little effect, however, on other plant parts, so regrowth from the roots is likely and may necessitate repeated treatment during the growing season. The commonly used contact herbicides are copper, diquat and endothall.

In contrast, "systemic" herbicides generally produce visible effects more slowly, but are taken up and transported to all tissues, with the ultimate result of killing the entire plant. Their long-term effectiveness can thus be much greater than for contact herbicides. Systemic herbicides include 2,4-D, fluridone and glyphosate.

Plant control with herbicides should also be considered with caution because of fish kills and increased algae that may result. The rapid death of massive amounts of plant biomass can often lead to high rates of bacterial decomposition and consequent oxygen sags, resulting in the death of fish and other pond organisms (slower-acting systemic herbicides may thus be more appropriate if plant densities are high). Decomposition also has the added unfortunate side effect of releasing nitrogen and phosphorus, previously stored in plant tissues, in forms that are directly usable by rapidly growing phytoplankton. Thus, herbicide use may be viewed as indirectly creating a problem with excessive algae. As stated at the beginning of this section, and explained in greater detail in Volume 2 Section S, aquatic plants are key components of healthy pond ecosystems, and long-term ecological problems caused by their removal are likely to outweigh any short-term benefits.

Biological control may be used to reduce plant abundance. The introduction of triploid grass carp (*Ctenopharyngodon idella*) can provide effective control of many aquatic plants (Fig. 16)[31,32]. The fish are typically introduced at a size (approximately 12" in length) to avoid their immediate consumption by piscivorous fish (e.g., largemouth bass), and at a density sufficient to impact the plant species of concern. Most studies have indicated that grass carp do not prefer filamentous algae. Increased densities of either phytoplankton or metaphyton thus can often occur within a few years of grass carp introduction. A permit is required to introduce grass carp in Pennsylvania. Pond owners should contact the Triploid Grass Carp Coordinator, PA Fish and Boat Commission[33] for an application and suggestions regarding stocking procedures. A number of commercial hatcheries have been designated by the Commonwealth to acquire and sell grass carp.

Fig. 16. Photo of triploid grass carp, taken at Kurtz Fish Farm, Elverson, Chester County.

Like grass carp, many species of ducks and swans can be effective herbivores on aquatic plants. Unlike grass carp, however, numbers cannot be carefully controlled, and waterfowl are usually considered more of a problem than a management tool.

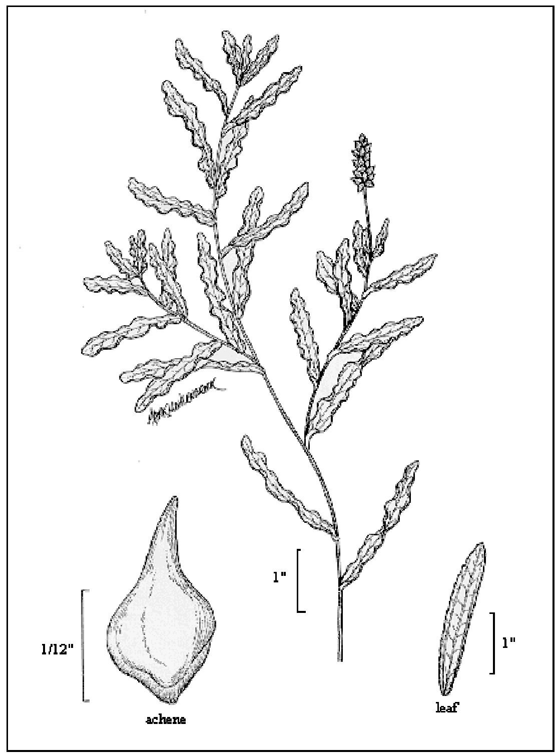
Winter **drawdowns** are a useful management tool in ponds with bottom drains. Pond levels are dropped during winter to expose the root systems of aquatic plants to freezing, thus clearing much of the shallower water of plants the following spring. Some species of plants, however, are relatively resistant to winter freezing, and these species may become increasingly dominant in the pond over time if drawdowns are repeated each winter.

L. Invasive Species of Aquatic Plants

A diverse community of aquatic plants is generally recommended to suppress phytoplankton, support fish and provide a number of other functions important to pond water quality. In some instances, however, invasive species may take over and impair pond function. Pond owners are advised to attempt their removal before they become well established. Three species likely to colonize ponds in southeast Pennsylvania are described below.

Curly-leaf pondweed (*Potamogeton crispus*) is an aggressive underwater plant, originally from Europe, that has become well established in ponds and streams of Chester County (Fig. 17)

Fig. 17. Potamogeton crispus (curly-leaf pondweed) can be identified by its wavy, green or reddish-green leaves (diagram courtesy of USGS.



Whereas most aquatic plants germinate and begin to grow actively in spring or early summer, completing their life cycle in fall, curly-leaf pondweed germinates in fall, grows rapidly during early spring, setting seed and decomposing by early July[34]. Because of its unusual life cycle, it helps to control phytoplankton by taking up nutrients and regulating water movement in spring, but may stimulate phytoplankton growth when it senesces in mid-summer (see Volume 2 Section S).

Eurasian water milfoil (*Myriophyllum spicatum*) is a submersed, rooted species with deeply divided, featherlike leaves usually arranged in whorls of four (range 3-6) (Fig. 18). It can be distinguished from other aquatic milfoils by the higher number of filiform extensions (14-24) on each side of the central leaf axis[35]. Like curly-leaf Pondweed, eurasian water milfoil propagates rapidly, tolerates low light levels and is an effective competitor for nutrients[36]. Based on a survey of 50 ponds in Chester County during summer 2003, eurasian water milfoil appears to be rare in Chester County, but is likely to be a threat to ponds in the region in the future.

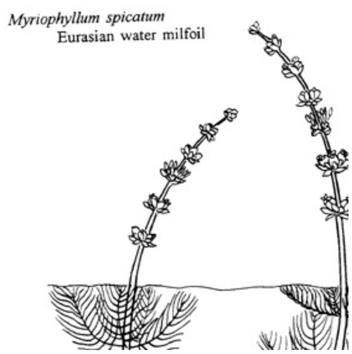


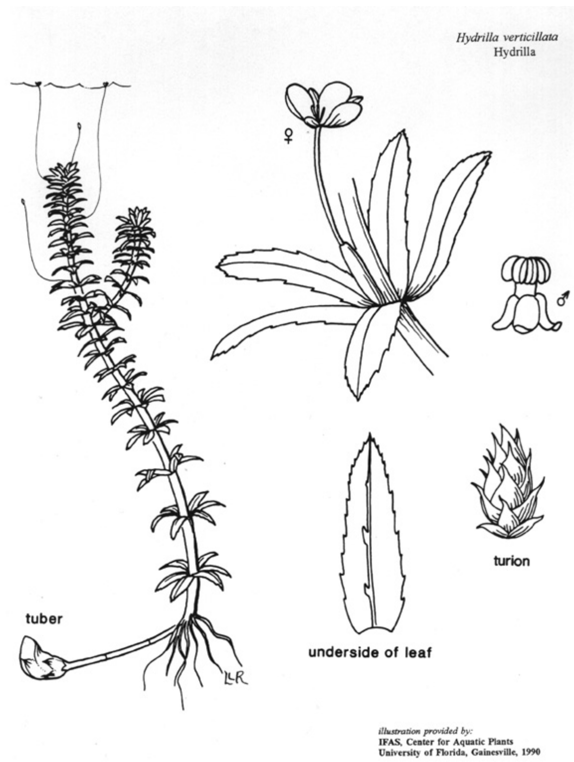
Fig. 18. Eurasian water milfoil can be differentiated from other native milfoils by its very "feathery" leaves with long filiform extensions. Diagrams courtesy of the University of Florida, Center for Aquatic and Invasive Plants.

Hydrilla (*Hydrilla verticillata*) is also a submersed, rooted species with long stems typically reaching the surface (Fig. 19). It can be distinguished from elodea (*Elodea canadensis*, a similar but native species commonly found in ponds in Chester County), by the presence of teeth on the leaf margins and underside of the midrib, and by the larger number of leaves per whorl on the stem (hydrilla has 4-8; elodea typically has 3)[37].

Dispersal of these invasive species likely occurs without human assistance (e.g., by the movements of waterfowl). If one of them does become established, an aggressive, multifaceted management plan to eliminate it or greatly reduce its abundance is warranted.

Such a plan might include a combination of herbicides, drawdowns or mechanical removal. Use of specialist aquatic insect herbivores as biological controls may also soon become feasible based on promising current research. Sadly, unless completely removed, the plants are likely to require continued management efforts.

Fig. 19. Hydrilla is a highly invasive exotic, distinguished from the similar native species Elodea canadensis by the larger number of toothed leaves per whorl. Diagrams courtesy of the University of Florida, Center for Aquatic and Invasive Plants.



M. Managing the Fish Community

Fish are important consumers of energy produced in pond food webs. The abundance and body condition of particular species often provide a good indication both of pond habitat quality and of influences exerted by other fish species. As consumers, fish can also deplete their food sources, directly or indirectly affecting algae and benthic invertebrates.

The two most common species in warmwater fish assemblages of this region are **bluegill** (*Lepomis macrochirus*) and **largemouth bass** (*Micropterus salmoides*), forming a relationship in which the bluegill consume zooplankton and benthic invertebrates, and the bass rather quickly become large enough to consume bluegill (Fig. 20).

The bluegill (Lepomis macrochirus) is distinguished from other sunfish species by the pointed pectoral fin and dark vertical bars. →

← Largemouth bass (Micropterus salmoides) is a piscivore. Its growth depends in large part on the abundance of smaller fish.

Fig. 20. Bluegill and largemouth bass frequently co-occur in small ponds in Chester County.

Bluegill sunfish are common not only in ponds but also pools and backwaters of local streams. Spawning takes place during much of the growing season, with larger females producing multiple clutches each year. Bluegill sunfish typically become mature at ages 2-3 at this latitude. Nests are dish-like cleared out areas, in shallow water on sand or gravel, and are guarded by the male. Young-of-the-year and smaller juveniles feed predominantly on zooplankton in open water, while larger fish feed on benthic invertebrate prey in amongst plants in shallower parts of the pond.

Largemouth bass, like bluegill, are widespread in both streams and ponds of southeast Pennsylvania, and share similar spawning habits. Spawning typically occurs at lengths of 9-10” (ages 3-4), with the male guarding a dish-shaped nest in somewhat deeper water than is typical of the bluegill. The fry begin life as plankton feeders, but soon switch to consuming larger invertebrate prey and fish (largemouth bass can eat bluegill up to 1/3 their size). Concerns about fisheries management normally arise over several years of perceived declines in fishing success, or more suddenly from a fish kill. Management approaches usually focus either on 1) habitat restoration, or 2) fish removal and/or stocking to change the relative abundances of fish species.

Habitat restoration should seek to enhance portions of the pond needed for spawning, foraging and shelter. Spawning areas, for example, can be enhanced by adding sand to areas with shallow gradients. A healthy plant community can provide critical food as well as shelter, and the survival of smaller fish can be greatly enhanced by retention of plant beds in parts of the pond[38]. Although too many plants may sometimes interfere with fishing, their absence is therefore usually of greater concern.

Careful attention to the bathymetry (depth contouring) of a pond provides the best means of insuring both shallow habitat that can be colonized successfully by plants, and deeper, open water needed by larger fish. Undercut banks, logs and other structures providing cover, and deep holes can likewise improve physical habitat for fish. One benefit of dredging can be the planning of specific areas within a pond as fish habitat.

Guidelines for manipulating the relative densities of largemouth bass and bluegill are provided by the PA Fish and Boat Commission[39]. An ideal ratio of bluegills/bass is considered to be approximately 5:1 by total weight. Higher ratios (e.g., 8:1) indicate an excess of bluegills. Overcrowding of the bluegill population can lead to interference with bass nesting success, further reducing bass population numbers, and causes stunting of the bluegills (undersized fish) which must compete more heavily with each other for limited food. Drawdowns are sometimes used to remove protective cover for the bluegills, making them easier prey for the bass and thereby helping to create more optimal ratios of prey/predators.

In extreme cases of last resort, rotenone may be used to completely remove the fish community, and start over by restocking. Rotenone is a plant extract that interferes with oxygen consumption by gill-breathers. A permit is required from the Commonwealth of Pennsylvania for rotenone application. A month after fish are removed, desired species can be restocked.

N. Integrated Pond Management

Although major pond management tools were discussed under separate headings, in reality a management plan typically consists of several tools, used either synchronously or in sequence. For example, a program to control excessive phytoplankton might involve first lowering the water level during summer to permit a greater proportion of incident light to reach the bottom, thereby encouraging colonization of the bottom by aquatic plants. Once a healthy plant community has been established, a second step might be to reduce the abundance of small fish by stocking with largemouth bass. This would release predation pressure on the zooplankton, and their increased abundance would help control phytoplankton growth.

A second example involves an effort to improve fishing in an excessively shallow pond subject to periodic winterkills. The plan might begin with dredging a portion of the pond basin to provide deeper water for fish during warm summer months and as a refuge during winter. Rather than dredge the entire pond to uniform depth, portions are kept shallow in order to retain plant beds, thereby harboring important food and shelter for the fish. An aerator might then be installed to maintain high oxygen levels in the deeper water. Finally, species abundances within the fish community could be manipulated to encourage rapid growth of sport fish of particular interest.

As a third example, reductions in metaphyton abundance might be achieved by a combination of periodic alum treatment to precipitate phosphorus and reduce P release from the sediments. Floating algal scums could be washed toward shore with a centrally-placed fountain. Metaphyton could then be raked from shore.

If these examples seem a bit complicated, they are! Successful pond management is rarely a matter of adding a chemical, then sitting back to wait for the restorative result. Ponds may be maintained in healthy condition, often at very reasonable cost. The process requires, however, the same sort of ecological understanding that avid gardeners apply in home landscaping. Several good books are available with details on low-cost management methods[40,41,42,43]. Finally, natural history guides can be consulted for information on the diversity of plants and animals that can be watched or collected.

O. Planning an ecologically sound pond restoration project

The first step in developing a pond management plan is to generate a "mission statement", designed as a list describing the intended services or resources provided by the pond (Fig. 20). These may be the purposes for which the pond was created, or perhaps its currently desired uses. Such services might include aesthetics (e.g., a visually pleasing addition to the view from the porch), recreation (e.g., fishing, swimming), water supply (e.g., for livestock or plants), or wildlife habitat. Then create a second list of actual uses of the pond. The difference between the two lists forms the basis for pond management, to achieve desired but currently unavailable services.

The next step is to become knowledgeable, with respect to both the pond itself and pond management in general. Useful information regarding the pond can be obtained from topographic maps and aerial photos of its watershed, often available from a local planning agency (e.g., Chester County Planning Commission). Measurements such as those described in Section A above, or simply notes on visual observations (e.g., the summer the duckweed first appeared), can also be helpful in understanding changes in the pond system. Secondly, a huge amount of information is available on the internet regarding management options. Most are company websites and don't discuss drawbacks and ecological side effects; books on pond ecology can provide that insight.

Step 3 is financial. It involves placing a monetary value on the services provided by the pond, and inquiring about the cost of particular management options. The questions to be asked are similar to those involved in deciding to repaint the house or sign up for professional lawn care – how much of an improvement can be expected given the cost involved? Budgetary constraints usually bring a fresh perspective to the pond "wish list" created in step 1. For example, swimming may be an attractive idea, but unreasonable given the costs of establishing a sandy beach and removing plant growth. Some pond improvements can be achieved by land owners or homeowners association members at low cost, while other procedures require professional services and may be less consistent with the budget allotment. It is important to develop a <u>long-term perspective</u>; the pond will be there for a long time. Chemical treatments to control algae, for example, are
relatively inexpensive per application, but applications may be required more than once

each year. By contrast, dredging a pond may be very expensive up front, but effects are likely to last many decades.

Once an economically viable, tentative management plan has been created it is important to review the individual components in terms of how they affect the pond as a whole. Elements of an integrated plan should not be “at odds” (for example, removing aquatic plants may be incompatible with producing larger fish). The review should also establish a time line, with some line items preceding others (for example, management of a pond impacted by soil erosion should seek first to control the sources of the sediments before dredging is attempted).

Finally, pond restoration measures should be accompanied by monitoring to evaluate their success. The pond owner has the responsibility to do this, even if the work is performed by a contractor. Successes and failures lead to improved knowledge of “how the pond works”, such that the same mistakes aren’t repeated. The improved knowledge (being able to identify the plants and animals, knowing what effect the plants have on the frogs) also enhances the value of the pond. Ponds are inherently fascinating places, and should be a source of pleasure and inquiry for their owners.

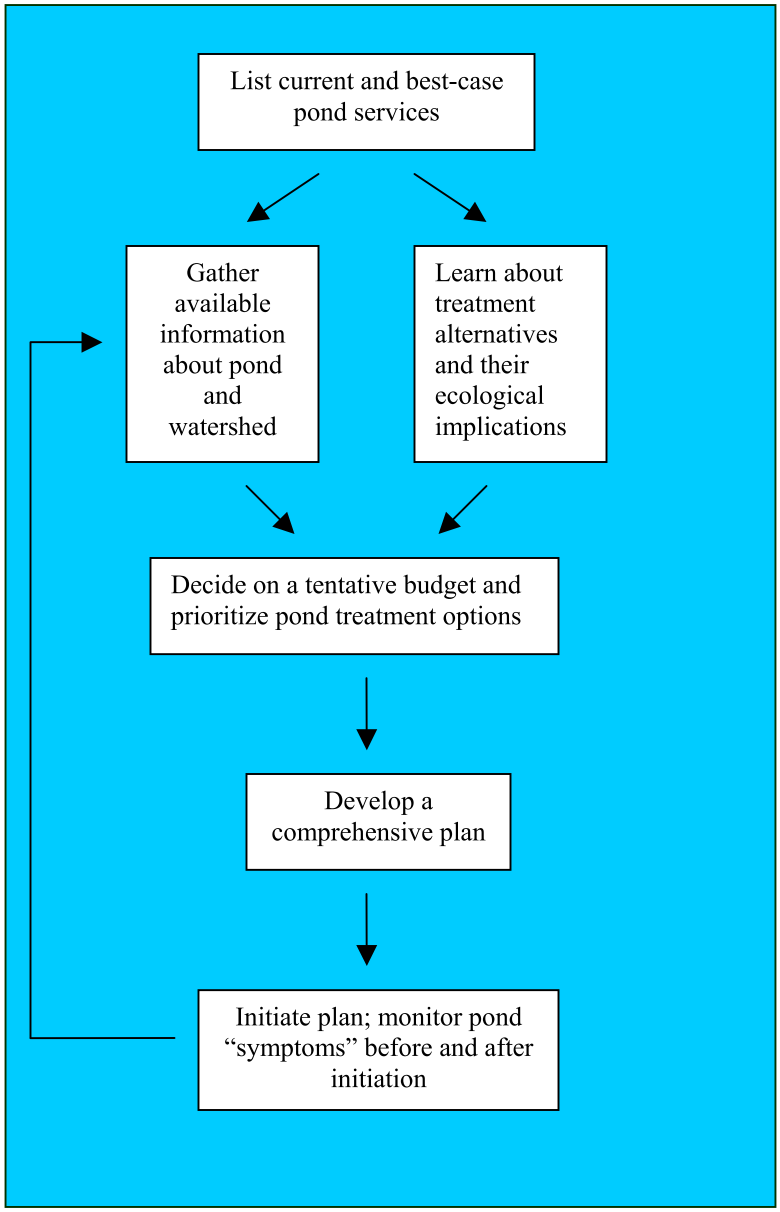


Fig. 20. Flow diagram for designing a pond management plan.

Glossary

alum – a mixture of aluminum compounds added to a pond to precipitate **orthophosphate** and thus limit phytoplankton growth.

anoxia – the absence of oxygen, usually near the bottom of **stratified** ponds during summer.

aeration – the bubbling of air into the water column to enhance mixing and increase oxygen levels.

algicide – chemical applied to a pond to control algal **phytoplankton** or **metaphyton** growth.

alkalinity – the concentration of ions (especially bicarbonate) that collectively raise the **pH** above neutrality.

alternative stable states – shallow ponds typically exhibit dominance either by aquatic plants or by phytoplankton; once established, each of these two communities tends to suppress the other.

ammonium - an oxygen-poor form of nitrogen (NH_4^+) used by primary producers as a nutrient.

bathymetric map – map of a lake or pond with contour lines indicating depths.

benthic invertebrates – aquatic insects, snails and other animals (not including fish and amphibians) associated with pond sediments, rocks or plant surfaces.

biological control – reducing the abundance of a noxious species by importing its natural enemies.

bioengineering – bank stabilization using organic construction materials and living plants.

biomanipulation – enhancement of zooplankton abundance (usually by reducing fish) in order to suppress phytoplankton growth.

blue-green algae – Species of the algal division Cyanophyta, also termed cyanobacteria, and typically small-celled members of phytoplankton, **periphyton** and **metaphyton** communities. Many are unpalatable or toxic to zooplankton, tolerate warm temperatures and often proliferate in summer.

bluegill – *Lepomis macrochirus*, a prevalent and frequently stocked forage fish in ponds of this region.

carbon – an element (symbol C) serving as the structural base or organic molecules, and needed in large quantities by **primary producers**.

chlorophyll-a – the green photopigment used by **primary producers** in **photosynthesis**, and frequently used as an indicator of the abundance of algae in ponds.

cladocerans – members of the crustacean Order Cladocera and common in the **zooplankton**; most species are effective grazers on phytoplankton.

compensation depth – the depth reached by 1% of surface light, and assumed to be the depth below which most plants and algae cannot sustain net growth.

consumers – animals that directly or indirectly feed on **primary producers** such as plants and algae.

copepods - members of the crustacean Order Copepoda and common in the **zooplankton**; many species are grazers on phytoplankton.

diatoms – algae forming cell walls of **silica**, typically favored by cooler temperatures and often especially dominant in the **periphyton**.

discharge – the volume of water flowing into or out of the pond per unit time, often measured in cubic feet per second (cfs), liters per second (L/sec) or m^3 per second.

dissolved oxygen – oxygen (elemental symbol O) present as a gas dissolved in water; concentrations are determined largely by **photosynthesis**, **respiration**, water temperature and exchange with the atmosphere.

drawdown – lowering the water level in a pond to consolidate sediments or control weedy plant species; often performed in winter.

ecosystem – an ecological unit, such as a pond, involving interactions of a biological community of species and its abiotic environment.

epilimnion – the upper zone of water, mixed by wind activity, in a **stratified** pond during summer.

eutrophic – describing a pond with abundant nutrients and high rates of growth by primary producers.

evapotranspiration – loss of water to the atmosphere via evaporation directly from the surface of a pond or from land in the watershed, together with transpirational loss of water vapor from plants.

green algae – a diverse group of species belonging to the algal division Chlorophyta; interwoven filaments of green algae typically dominate the **metaphyton**.

groundwater – water in the saturated soil below the **water table**, potentially contributing water to or receiving water from a pond.

hardness – the combined concentration of calcium and magnesium ions present in water; high hardness values typically reflect large amounts of limestone in the **watershed**.

herbicide – chemical targeted specifically for the control of aquatic plants. Some products may also function as **algicides** (causing mortality of algae).

hydraulic residence time – the average duration of a parcel of water within a pond, computed as [pond volume]/[discharge at the **outfall**].

hypereutrophic – describing a pond with very high nutrient concentrations and excessive growth by primary producers.

hypolimnion – the zone of water below the **thermocline** near the bottom of a **stratified** pond during summer.

largemouth bass – a warmwater sport fish (*Micropterus salmoides*) often stocked as a **piscivore** in ponds of this region.

macrophytes – aquatic plants (or occasionally large algae) that are clearly visible to the naked eye.

mean depth – the average depth of the water column, determined as the quotient of a pond's volume/area (V/A_s).

mesotrophic – describing a pond having intermediate nutrient concentrations and moderate growth of **primary producers**.

metaphyton – free-floating clouds of filamentous algae, originating at the bottom of a pond but usually observed at or near the surface.

microcrustacea – microscopic or barely visible invertebrates of the class Crustacea. Most species are consumers of algae, bacteria and dead organic materials associated with the **periphyton** and **metaphyton**.

nitrate – an oxygen-rich form of **nitrogen** (NO_3^-) taken up by **primary producers** as an important **nutrient**.

nitrogen – an important, and often growth-limiting nutrient (symbol N); although found in water in a number of other forms, only **nitrate** and **ammonium** are directly usable as a nutrient by **primary producers**.

nutrient – an element critical to, and often limiting, the growth of **primary producers**; potentially limiting nutrients include **phosphorus**, **nitrogen** and **silica**.

oligotrophic – describing a pond with low concentrations of **nutrients** and correspondingly little growth by **primary producers**.

orthophosphate – the principal form of **phosphorus** utilized directly by primary producers; concentrations in ponds are often sufficiently low to limit the abundances of algae and plants.

outfall – the location at which surface water leaves the pond, usually via a standpipe or dam spillway.

periphyton – the community of algae found associated with the sediments and on rocks and plant surfaces.

pH – a measurement scale (range 1-14) of the acidity of water; pH values progressively lower than < 7 indicate higher acidity, while water with pH greater than 7 is termed “basic”.

phosphorus – an important, and often critically limiting **nutrient** (elemental symbol P) needed by plants and algae for growth.

photosynthesis – the incorporation of **carbon** into organic molecules by **primary producers**, requiring sunlight as an energy source.

phytoplankton – the community of microscopic algae suspended in the water column.

pond morphology – physical pond attributes (e.g., depth, surface area, volume).

primary producers – green plants and algae that obtain their nutrition through **photosynthesis**.

respiration – the metabolic process of converting the stored chemical energy in glucose to usable energy, producing carbon dioxide and water as byproducts.

riparian buffer – an area of land adjacent to a water body (e.g. pond) which is vegetated and maintained for the benefit of the water body. Benefits include trapping, filtering and converting sediments, nutrients and other chemicals and supplying food, cover and thermal protection to fish and other wildlife.

riparian vegetation – terrestrial plants growing directly adjacent to the pond edge.

rotifers – microscopic animals of the phylum Rotifera, often dominant in the zooplankton in spring.

Secchi disk – a disk 20 cm in diameter, either white or more commonly with white and black quadrants, lowered into a pond to its point of disappearance, and used as a measure of light penetration in the water column.

silica – a nutrient (SiO_2) needed in large quantities for cell wall construction by **diatoms**.

specific conductance – a means of describing total ion content in water, measured as the ability of the water to pass an electric current.

stratified – describing a pond with distinct density layers, including an upper **epilimnion** and lower **hypolimnion** separated by a **thermocline**; typically occurring during summer.

surface runoff – overland flow from the **watershed** into a pond, whether via a stream or as sheet flow on the ground surface.

thermocline – a zone of rapid temperature (and density) change (more than $1^{o}C/m$) within the water column, reducing mixing of water in the **epilimnion** (above) with water in the **hypolimnion** (below).

total nitrogen – the combined concentrations of all forms of **nitrogen** in the water column.

total phosphorus – the combined concentrations of all forms of **phosphorus** in the water column.

trophic state – a general term describing the concentrations of nutrients and growth of **primary producers**, and including more specific pond classifications of **oligotrophic**, **mesotrophic**, **eutrophic**, **hypereutrophic**.

trophic state index (TSI) – a quantitative measure of pond **trophic state** based on **secchi** depth, **total phosphorus** and **chlorophyll-a**.

turbidity – the concentration of suspended particles in the water column, affecting light penetration.

watershed – the drainage basin or catchment, consisting of surrounding land that potentially contributes water, nutrients, and other materials to a pond.

water table – the depth at which the soil becomes saturated with **groundwater**.

zooplankton – the community of microscopic invertebrates (especially cladocerans, copepods and rotifers) found in the water column.

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