Project Number: 51-SNJ-0020

Eutrophication Of Ponds:

A Study At The Worcester EcoTarium

An Interactive Qualifying Project Report

submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

by

Joseph A. Brown **Jason H. Fuller** **Mikal R. Rosendahl**

Date: May 31, 2001

Approved:

Stephen N Jasperson

Professor Stephen N. Jasperson, Advisor

Abstract

The process of eutrophication of ponds is discussed. Eutrophication's natural roots and the influence humans have upon it are examined. Methods for preventing or reversing eutrophication are explored. The indications and counter-indications for human intervention are discussed. The Upper and Lower Ponds at the Worcester EcoTarium are presented as a case study. A recommendation is made to the EcoTarium staff, in order to meet their goal of reversing the eutrophication of the Upper Pond.

Table of Contents

Chapter 1: Introduction

Water is essential to all life on earth; therefore, the cleanliness of this water is of much concern. Much of the water on earth is becoming increasingly polluted. Among the many types of pollution, a significant portion consists of an excess of nutrients. Nutrient buildup can be caused by a number of factors. Industrial and agricultural causes, however, have been studied extensively to date; therefore this report will focus on residential and urban sources of nutrient pollution. Further, bodies of water that are significantly shallower than average tend to experience an increase in nutrient concentrations more quickly than deep lakes or oceans, and tend to experience more damaging effects for a given concentration of nutrients. This report will focus on these smaller bodies of water. More specifically, the focus will be on nutrient buildup that directly affects the eutrophication (the growth of excessive amounts plant life in a body of water) of such ponds. In all, this report will discuss the causes leading to cultural eutrophication (eutrophication resulting from residential and urban sources), its effects on small lakes and ponds, as well as various techniques for preventing and treating eutrophication.

Presented here, as a case study, will be the example of the Worcester EcoTarium. The EcoTarium is a science center whose mission is to educate children about the environment. On the grounds of the EcoTarium, there are two ponds. One, called the Upper Pond, as of the writing of this report, is well on its way to becoming eutrophic. There is an over-abundance of aquatic plants, as well as a significant amount of algae. This gives the pond an aesthetically displeasing appearance. The second pond, called the Lower Pond suffers from none of these problems. As will be discussed in more detail later, the two ponds have very similar water chemistry, partially due to the fact that the Upper Pond drains into the Lower Pond (both named due to their geographic elevation, and the resultant direction of water flow). Therefore, by comparing and contrasting these ponds, the causes of eutrophication, and the complex interactions between those causes, will become more readily apparent.

It is the goal of this report to provide the reader with a reasonable understanding of what eutrophication is, how it is affected by humans, how it affects humans, what steps can be taken to mitigate eutrophication, and in what cases those steps are appropriate.

Chapter 2: Background

What is Eutrophication?

Lakes and ponds are involved in natural aging processes. As scientists have studied this cycle, they have also developed a classification system for lakes and ponds. Very deep, clear lakes and ponds, which are also devoid of dead plant and animal matter, and have few plant or animal species in them are called olgiotrophic. Lakes and ponds with more animal and plant growth are called mesotrophic. Eutrophic lakes and ponds are those that are the most aged and productive with many species of fish and plant and algae life in them. Eutrophic waters tend to have less visibility through the water past four or five feet, and they often suffer algae blooms and periods with large amounts of aquatic plant growth. Eutrophication is the term used to describe the process by which ponds change from olgiotrophic, to mesotrophic, to eutrophic. Although eutrophication is a natural process, it can also be affected by human activity and pollution, especially nutrient pollution. Eutrophication caused or accelerated by human influences is commonly referred to as 'cultural eutrophication,' to separate it from natural eutrophication processes.

Many studies have yielded guidelines to designate a water body as eutrophic or olgiotrophic, such as the *Organization for Economic Cooperation and Development*[1]

(O.E.C.D.) or the *International Cooperative Program on Monitoring of Inland Waters.* Some are quantitative systems where specific value ranges for nitrogen concentrations, phosphorus concentrations, chlorophyll amounts, and Secchi depth (a measure of water clarity) are used to denote trophic categories of olgiotrophic, mesotrophic, eutrophic and hypertrophic. Other systems are quantitative and provide guidelines such as these:

Table 1. Qualitative Eutrophic Classification System.

Parameter	**<u>Olgiotrophic</u>**	**<u>Eutrophic</u>**
Aquatic plant and animal production:	Low	High
Number of plant and animal species:	Few	Many
Relative quantity of green and blue-green algae:	Low	High

Table 2. Quantitative Eutrophic Classification System.[2]

	Olgiotrophic	**Mesotrophic**	**Eutrophic**	**Hypertrophic**
Total Phosphorus (mg/m3)				
Mean	8	26.7	84.4	
Range	3.0-17.7	10.9-95.6	16-386	750-1200
N	21	19	71	2
Total Nitrogen (mg/m3)			1875	
Mean	661	753	393-6100	
Range	307-1630	361-1387	37	
N	11	8		
Secchi Transparency Depth (m)				
Mean	9.9	4.2	2.45	
Range	5.4-28.3	1.5-8.1	0.8-7.0	0.4-0.05
N	13	20	70	2

The most general cause of eutrophication is an excess of nutrients in the water body. The most important of these nutrients leading to eutrophication from plant and algae growth are nitrogen and phosphorus. These two nutrients commonly get into waters by various means, such as outflow from sewage treatment plants, industrial plant output, erosion, urban runoff, and fertilizer runoff due to agriculture. These are the most common sources that result in what is commonly referred to as cultural eutrophication. The primary social problem with this cultural eutrophication is that it commonly occurs in water that society depends on for its survival. With the increase in trophic, or dead plant and animal matter, the water becomes increasingly difficult to filter to acceptable quality levels for use as drinking water. Harmful bacteria counts are also more common in eutrophic waters. The elevated levels of nitrogen in water can be toxic for humans, especially babies, to drink. It must be kept in mind, though, that eutrophication is a natural process that has been influenced by our current technology and way of living and now it occurs in unnatural ways due to our society's technological influences. Urban runoff that is not properly maintained greatly affects our basic need for fresh drinking water because it results in the pollution of that water.

Nutrient Cycles[3]

Nitrogen is one of the most abundant elements on earth. It is also a required nutrient for plant and animal life. In water, nitrogen is found as dissolved nitrite (NO_2^-), nitrate (NO_3^-), ammonium (NH_4^+), as dissolved nitrogen gas (N_2), and in organic nitrogen compounds. Only as nitrate and ammonium is nitrogen in a useable form for plant life. Nitrogen gets into water bodies from various methods. Among the natural methods are: atmospheric sources (mainly rain and snow), nitrogen fixation in water and sediments by blue-green algae and bacteria, and input from the surrounding drainage area (rivers, streams and groundwater inlets). Unnatural or manmade introduction of nitrogen into a water system usually occurs as a result of agricultural runoff, as well as industrial and sewage effluents. These manmade inputs usually have high enough levels of nitrogen in them to adversely effect the water into which they flow. Natural means of nitrogen inflow are also being disrupted by manmade influences. Air pollution from industry increases the amount of nitrogen compounds in the air resulting in higher levels of it in precipitation, which leads to elevated nitrogen levels in the affected water bodies. Nitrogen may be lost to a water body by occurrences such as effluent outflow from the water body, bacterial denitrification, and permanent sedimentation loss.

Of these main sources of nitrogen, in an average body of water, a case for which one introduces the most nitrogen per year cannot be made. The location of the water body, its depth, and the ecology of the surrounding area all are factors that may affect how much nitrogen is derived from each source. For example, the average from atmospheric sources, for the entire United States, is approximately 0.1 g $\frac{N}{m^2 \bullet year}$ (grams of nitrogen, per square meter, per year) of nitrogen inflow. However, around the Southern Great Lakes region, it averages approximately 1 g $\frac{N}{m^2 \bullet year}$ of nitrogen inflow. In some lakes, N_2 fixation accounts for only 1% of the total combined nitrogen of a lake, but in other lakes, such as highly eutrophic ones, it can account for up to 43% of the nitrogen inflow to a lake. Some water bodies with surrounding wetlands experience up to 22.5 g $\frac{N}{m^2 \bullet year}$ of nitrogen inflow. This is due to nitrogen fixation by the plants living in these wetlands, followed by the leaching of this nitrogen-laden water into the nearby water body. It can be seen that the variety of locations and conditions make it impossible to target one source of nitrogen as the main source into a water body without extensive research and testing.

Phosphorus is another nutrient essential for plant growth. Compared with other essential nutrients, phosphorus is almost always the limiting nutrient to plant and algae growth. This means there is usually an excess of nitrogen and other necessary nutrients present in water bodies, but phosphorus is not available in excess to the amount needed by plants, making it the factor that limits more plant and algae from growing. The resulting situation is that even when small amounts of extra phosphorus are added to an aquatic system, a dramatic increase in plant and algae growth is usually found. Adding nitrogen and other nutrients without extra phosphorus will not result in more plant and algae growth.

Plants use phosphorus primarily in the form orthophosphate (PO_4^{3-}). Its cycle in water bodies is much like that of nitrogen. Main sources of phosphate in water are precipitation, surface water runoff, the decay of macrophytes (aquatic weeds), and phosphorus release from the sediments. As with nitrogen, manmade sources, varying in origin from agricultural and industrial runoff, to sewage effluents, also affect the phosphorus levels in water. Phosphate also has many factors that take this useable form of phosphorus out of the phosphorus cycle. First, it is not easily dissolved in water, it also reacts with other chemicals in the water turning it into unusable forms and lastly it is readily absorbed by plant and algae growth. The phosphate levels in water are also influenced by many varying factors in the water such as dissolved oxygen levels, light levels, pH, and many others, often with complex interactions.

Hydroseeding

Hydroseeding is a method of planting grass and other similar groundcovers. To hydroseed, a mixture of water, grass seed, fertilizers, plant foods, other additives, mulch (consisting of either shredded paper or wood fibers), and a sort of glue-like substance called 'tackifier' is created. This mixture is then pumped through a hose and nozzle system, which is used to apply it to the ground. The 'tackifier' helps glue the wood or paper mulch to the ground, which in turn holds the grass seeds and a significant amount of water (in which the added chemicals are dissolved). The mulch retains a certain percentage of this chemical-laden water during the initial application, and a certain percentage runs off. These percentages are widely variable in relation to the specific conditions of a given application. For example, on a highly sloped surface, gravity causes more of the water to run off, while on a shallower surface, water is more likely to collect. Atmospheric humidity, ambient temperature, soil consistency (e.g., clay versus sand), soil moisture, and the percentage of water in the hydroseed spray are all variables which can affect the amount of water which runs off from the application area. In the case of the EcoTarium ponds, it has been postulated that this runoff percentage is responsible for the algae bloom in the Upper Pond.

Interestingly enough, in many cases hydroseeding is an ecological choice rather than an economic one, as the mat of mulch helps prevent erosion, as well as helping the grass seeds to more quickly take hold, after which point the grass itself helps prevent erosion even more effectively. A hydroseeded area typically shows grass growth within 5 to 7 days and, in the case of a lawn, is ready to be mowed in 20 to 30 days.[4] Additionally, the cases where hydroseeding is most likely to be of ecological benefit - those where extreme slopes present a greater instance of erosion - are also the cases where gravity is most likely to cause excess runoff. In order for the grass to survive and prevent erosion, the mulch must retain a sufficient amount of the water/fertilizer solution. This means that additional solution must be added to the initial mix, which results in even more runoff. It would appear that hydroseeding is nearly always an ecological 'double-edged sword,' where the potential drawbacks go hand-in-hand with the potential benefits.

Fertilizer choices for hydroseeding can vary widely, but are very uniformly high in nitrogen, a key component in eutrophication. According to The Highridge Corporation (a landscaping firm who offer hydroseeding services), an 18-3-6 or a 24-4-8 fertilizer with a minimum of 40 percent water-soluble nitrogen is a good mixture for initial applications.[5]

A related technology, called 'hydromulching,' relies on a thicker layer of mulch material to retain a greater amount of water.[6] However, as a result of the greater thickness of the mulch blanket and, therefore, the greater average distance from the seeds to the soil, it can often take longer for hydromulched turf to reach the same level of erosion protection as hydroseeded turf. Hydromulching typically uses a more balanced fertilizer (typically a 17-17-17 ratio[7]), which may make it safer for use near ponds.

With the multitude of variables both in the variables which control the amount of fertilizer-containing runoff which will occur, and in the choices of seed varieties, mulches, fertilizers, other additives, and tackifiers, it is no real wonder that hydroseeding firms rarely do a detailed advance analysis of the ecological effects of their installations. It is far easier, and more economic, from their standpoint, to make a 'best guess' as to the correct mixture for a given property and then fine-tune the results at a later time. Often, firms will use the same mixture, or one of a few 'standard' mixtures, for all applications.

Hydroseeding, it seems, can be both a blessing and a curse. When used in such a way as to prevent erosion from damaging hillsides, and introducing large quantities of topsoil into the watershed, it is highly beneficial. When used in such a way as to cause excess runoff of nutrient-rich water into the watershed, however, it can be very dangerous. Additionally, in most – if not all – cases, there will not be a single 'right answer.' For example, some runoff may have to be accepted in order to prevent erosion. Add to that the complexity of analyzing, in detail, the effect that hydroseeding may have, and it becomes clear that this technique must be approached with caution.

Eutrophication Reversal Methods

Science has developed a very good understanding of the nutrient cycles that occur in lakes and ponds. This information has helped the development of many methods for the cleaning of eutrophic water bodies, allowing these bodies to meet water quality standards both for drinking and for recreational uses. These clean-up approaches can be classified into preventative and curative methods.

There are various preventative methods which may be used to avert eutrophication, including discharge control, pre-impoundment, and diversion, among others. Many of these are not very complicated, and some are simple common sense.

Discharge control is the regulation of the water being discharged into a particular water body. There are two primary forms of discharge control. **Pre-impoundment** is a good way to control phosphorous levels. Water inflow to a pond or lake is directed through an artificially constructed pre-impoundment, or through a preexisting marsh or wetland that is used as a pre-impoundment, before it is allowed to enter the pond or lake. This allows for the settling of phosphoric, trophic and particulate material and sometimes for nutrient intake by algae and plants in the pre-impoundment structure, resulting in cleaner water entering the water body under protection. **Diversion** simply transfers polluted water from one place to another, sometimes to be used for irrigation or some other purpose where the elevated nutrient levels would not be a hindrance, or might actually be beneficial. Since the nutrient-rich water is diverted around the protected body of water, eutrophic conditions are avoided.

The following are more often seen as curative methods of eutrophication. These may be applied to water bodies that have already become eutrophic. **Dilution** or **flushing** of water is accomplished by adding extra water that is not nutrient-rich, or it can be accomplished by pumping out nutrient-rich water and allowing it to be replaced through natural processes by nutrient-poor groundwater. **Dredging** a body of water helps to take away the nutrient-rich top layer of sediment. By removing this layer, the overall nutrient load of the water body is reduced. **Nutrient removal** and **nutrient inactivation** involve chemical processes and reactions to remove nutrients from a water body or to turn them into a form unusable by plants and algae.

One very popular method fighting eutrophication is capable of being used both for prevention of eutrophication in ponds that are at-risk, and for reversal of eutrophication in ponds which have already become eutrophic. **Aeration** involves the addition of oxygen to the water, which makes it less hospitable to plants, and more hospitable to fish and other marine animals that then proceed to eat the excess plant growth. Of course, excess oxygen is no better than too little oxygen, but if a reasonable balance is achieved, eutrophication cannot take place, and may actually be reversed to some extent, depending upon the severity of the eutrophication. In a pond that is too eutrophic for aeration to be useful, aeration may be combined with a more direct method, such as dredging, to speed the recovery of the pond, and prevent future eutrophication.

Aeration may be achieved in several ways. One popular method is to actually pump air to nozzles or diffusers located below the surface of the pond, and allow that air to bubble up through the water, which dissolves some of the oxygen from those air bubbles. Another popular method does the opposite, and pumps the water upward, exposing it to the air, from which it dissolves oxygen. This method may consist of a fountain, or similar jet of water. Alternatively, it may consist of a more subtle treatment, in which the water forms either a decorative function, such as running over the paddlewheel of a miniature decorative mill, or a more natural quality, such as an artificial stream or (more helpfully) an artificial waterfall.

While not the most aesthetically pleasing option, generally the most effective method of aeration is to pump air to the bottom of the pond, and allow it to bubble to the surface. This method is helpful for a number or reasons. First, when contrasted with methods such as artificial waterfalls and streams, which remove water from the surface, aerate it, and then return it to the surface, it is clear that bubble aeration adds oxygen to the water at a much lower depth, while these other methods only oxygenate the surface water. Since bottom-feeders are largely responsible for removing decaying plant and animal matter, before it can fuel the growth of algae blooms, and since these bottom-feeders rely on oxygenated water for respiration, it can be seen that an immediate effect of oxygenating the lowest water of the pond will allow bottom-feeders to survive and remove a sizeable portion of the dead organic matter in the pond.

Second, not only does bubble aeration oxygenate the water at the bottom of the pond, but a properly-designed system will actually cause the bubbles to 'drag' water with them as they rise, turning over the water in the lake. By bringing cool bottom water to the surface of the pond, temperature of the surface water of the pond is lowered, making it less hospitable to blooms of blue-green algae. In addition, the movement of the water due to these artificially induced currents makes the pond even less hospitable to blue-green algae, since such algae prefers to grow in large colonies, which cannot exist as easily in flowing water. Finally, the circulation of oxygen-deficient bottom water to the surface allows that water to absorb oxygen directly from atmospheric contact, in addition to the oxygen that it dissolves from the bubbles.

It should be noted here that not all bubble aeration systems are comparable. The size of bubbles produced can vary greatly between systems, and greatly affects the efficiency of the system. A plume of large bubbles offers less water-air surface area for a given volume of air pumped than does a plume of smaller bubbles. Since oxygen can only transfer across this water-air interface, smaller bubbles offer a greater efficiency of oxygen transfer. Additionally, due to fluid dynamics effects relating to laminar flows (the specifics of which are beyond the scope of this report), small bubbles will more efficiently drag water with them, 'turning over' the pond more often, incurring the various benefits of that process.[8]

One company[9] that was discovered during the course of this research actually offers a system that mixes a metered portion of ozone into the compressed air that it injects into the pond. It appears that the benefits and drawbacks of this system have not been fully explored. However, it may be hypothesized that introduction of an agent like ozone into a highly eutrophic pond might well act as an environmentally safe poison (due to its quick decay rate), allowing the excess growth to be killed off, without the chance that toxin-containing runoff would escape the pond. It should also be noted that ozone is toxic to animal life as well, so this system might not be a good choice for a pond that is closer to healthy, containing fish and other marine animals. This is only a hypothesis, however, as it awaits hard evidence to back it up or refute it.

As stated earlier, the other main type of aeration works by pumping bottom water to the surface, and discharging it in such a way as to expose it to the outside air for significant time, so that it may absorb oxygen and return to the pond with that oxygen. This method offers many of the same advantages as the former method, but does have some important differences. First, it is far more natural and aesthetically pleasing, which may be important to some. Second, and more importantly, it has some significant disadvantages when compared to bubble aeration. It requires far more energy to lift water to the surface of a pond (and somewhat above) than it does to pump air to the bottom, so it is more expensive to operate. While this method does help to 'turn over' the pond, it does so at a much slower rate than bubble aeration. Also, it does not do as much to lower the surface temperature of the pond as bubble aeration. These disadvantages may make this method a poor choice when compared with bubble aeration, unless the aesthetic properties it offers are deemed important enough to justify the greater expense and lower effectiveness.

All forms of aeration also help to reduce the dissolved-carbon-dioxide levels within the pond water.[10] As the water dissolves more oxygen, carbon dioxide must be released to 'make room.' Lower levels of carbon dioxide help to limit plant growth, since plants rely on a steady intake of carbon dioxide in order to survive. If the levels are lowered, less plant life can be sustained.

Several aeration firms[11] actually produce windmill-powered aeration pumps to operate bubble aeration hoses. This makes aeration not only ecologically sound, in terms of reversing eutrophication, but also environmentally sound, in terms of not producing pollution during its operation. Aeration might also be achieved by utilizing solar-electric technology to drive a traditional electric pump. Although research into a variety of firms offering aeration products and services produced no instances of this type of system being operated, there does not seem to be any fundamental reason why it could not. It is estimated here that such systems most likely *are* used, especially by landowners with ponds in areas remote enough to make traditional electric power impractical, but that such instances have simply not received significant attention.

Another point worth mentioning is that some commercially available forms of aeration only aerate the surface water of a pond. These methods, while usually less expensive than the other methods mentioned here, fail to aerate bottom water, or to 'turn over' the water in the pond, so they are significantly limited in their usefulness. Most often, this type of aeration either pumps air a small distance below the surface and releases it, or pumps water up from a small distance below the surface and releases it at the surface, often in the form of a fountain. In either case, water at lower depths is left as it was, so the pond is really only healthy in its surface layers, and will most likely revert to its eutrophic state at some point in the future.

In summary, aeration, while not a 'magic bullet,' is a very important method of preventing, arresting, and in many cases, even reversing eutrophication. Bubble aeration is the most efficient form of aeration, both in terms of energy used, and in terms of the quickness with which it combats eutrophication. Fountains and other forms of aeration which lift water, rather than pumping air to the bottom, are less efficient on both of these accounts, but are more aesthetically pleasing and, when properly installed, can still offer an effective means of combating eutrophication. Aeration works, simultaneously, in many different ways and on many different processes within the cycle of eutrophication, making it a very versatile option. This versatility allows one method to be used in many different situations by many different individuals – from a landscaper installing a pond that s/he knows will be used to collect runoff, and therefore has great risk of becoming eutrophic, to a homeowner whose decorative pond is starting to become an eyesore instead of a decoration, to an ecologist who wishes to save an important piece of the water cycle. All these and more may be benefited by an aeration system.

Aesthetic methods

The preceding have been general means of controlling eutrophication. Included now are a variety of specific methods for regulating unwanted aquatic weed and an algae growth, one of the effects of eutrophication. There are many methods that are currently being used to control nuisance aquatic weed and algae growth. Depending on how much labor one is willing to invest in the process and whether or not chemicals are considered an acceptable means of control, one may make a choice among these various methods, or a combination thereof.

One of the most basic means of controlling visible growth of plants is **manual removal.** This is a completely reactionary approach to the problem. It will not keep the growth problem from getting worse but will prevent it from being an aesthetically unpleasing aspect of a pond. This method is very labor intensive and, depending on the size of the pond that is being cleaned, could require specialized equipment for covering the large water area and for the specific kinds of weeds that are to be removed. A benefit of this method for those interested in composting is that the removed material will make a good addition to compost piles.[12]

For experienced gardeners, excellent methods to control excess growth are **landscaping** and **aquascaping**. Specific plants are planted in specific places, thereby preventing unwanted species from growing. The downside of this method is it requires extensive knowledge of plants, how and where they grow, and their interactions with other plants.[13]

Also, like manual removal, it could be quite labor-intensive – and quite costly in materials – to design an area and buy plants for the area. This method will do little to control algae growth, and if the pond to be aquascaped has nuisance plants in deeper waters, this method will not be able to do much to control them, as aquascaping is primarily restricted to shallow areas.

Since plants root in the bottom soils and sediments of lakes and ponds, a good control method is to cover the sediments, thereby preventing plants from growing in them. Using **bottom barriers** is the method of choice to achieve this. These barriers are suggested for use in shallow water to control weed growth.[14] They come in a variety of materials such as plastic and fiberglass. Drawbacks start with installation, due to the difficulty of installing them and securing them to the bottom of a pond. They must be weighed down and, on occasion, gas bubbles will accumulate underneath them and cause an otherwise well-secured barrier to be displaced. Sediment will also accumulate on the barrier, necessitating periodic cleaning and reinstallation, or total replacement. Besides changing the weed habits of the area, they can also disrupt fish spawning.[15]

Biomanipulation can also be used to try to control nuisance species. Some already-occurring species in natural waters, such as water fleas (daphnia), eat algae for food. So, in hopes of reducing algae growth, zooplankton are added to the water and are also given a protective habitat, such as submerged aquatic weeds that fish will not enter, so plankton-eating fish will not eat them. Additionally, to help keep the levels of these zooplankton high, game fish which eat plankton-eating fish are stocked in numbers sufficient to control the population of the planktonvorish fish. This is a rather difficult technique to employ. It is difficult to control the numbers of planktonvorish fish to levels in which they will not affect the zooplankton population.[16]

Another common biomanipulation method is the use of a species of fish called 'grass carp' or 'tilapia.' Grass carp are used for weed control and tilapia for algae. Neither is native to the United States and one or both are illegal in many states. Although grass carp can often be sold sterile (so they will not reproduce), it is still frowned upon to use this method. The idea of introducing foreign species to our natural waters has become very unfavorable in recent years, with fears that these species will dominate native species and dramatically alter our native ecosystems.[17]

Chemical remedies to unwanted growth in ponds and lakes are many. First, there are liquid dyes. These are simply dyes to tint the water blue. This absorbs the sunlight so the plants and algae in the water cannot use it for photosynthesis (Lake Smarts 48). These are offered as non-toxic dyes, so they will not harm wildlife or fish, nor do they restrict swimming in a treated area. They work best in small bodies of water with a long holding time, meaning ones with little in and outflow. These dyes break down in sunlight, being effective for only 6-10 weeks.[18]

Next in chemical additions to slow or kill unwanted growth are herbicides. There are many commercially available herbicides. These are separated by the ways in which they kill plants. There are contact, systemic, and heavy metal herbicides. A contact herbicide kills a plant once it comes into direct contact with it. A systemic herbicide works by coming in contact with the plant and entering the plant's internal system and then killing the entire plant.[19] Finally heavy metal herbicides kill by using heavy metals to poison the aquatic weeds or algae. However many of the long-term impacts of these herbicides have not been largely studied and are still not completely understood. There is no way of telling the entire impact on the ecosystem after any of these products has been used.[20] Here is a listing with information on many commercial brands of herbicides and how they work:

Table 3. Herbicides and How They Function.

Herbicide	Form sold in	Active ingredient	How it works	How it kills
Aquathol	Liquid or Granular	Dipotassium endothal	Contact herbicide	Inhibits protein synthesis from membrane
Hydrothol 191	Liquid or Granular	Amine endothal	Contact herbicide	Inhibits protein synthesis
Cutrine Plus	Liquid or Granular	Cutrine plus	Systemic herbicide	Inhibits photosynthesis
Diquat	Liquid	Diquat dibromide	Contact herbicide	Destroys cell membranes
Rodeo	Liquid	Glyphosate	Systemic herbicide	Stops growth, causes cellular disruption then death
Sonar	Liquid or Pellet	Fluridone	Systemic herbicide	Inhibits pigment synthesis making chlorophyll degrade in sunlight

There are also chemical additions that reduce the amount of available phosphorus for plants, resulting in less growth. Primarily, buffered alum is used. Buffered alum is a combination of aluminum sulfate (alum) and calcium compounds.[21] When added to water it forms nontoxic precipitates that absorb phosphorus as they fall through the water. An added benefit is that they also remove particulate matter as they fall through the water, thus reducing turbidity or the treated pond.[22] Once these precipitates have settled to the bottom sediments, they keep the phosphorus in a form that plants cannot use. Additionally, they also transform a quantity of the phosphorus in the sediments into an unusable form. Therefore, they lower available phosphorus levels not only in water but also in the sediments. This method is beneficial since it keeps the phosphorus levels reduced after being added to a water body and thus reduces plant growth.

Another chemical group commonly used is calcium compounds. These are used to remove algae and particles from the water. Most commonly used are calcium carbonate and calcium hydroxide (lime). To successfully control growth with these compounds you must dose a pond several times a year.[23]

Drawdown is another choice to try and reduce some problem growth in ponds and lakes. Usually the water level is lowered or completely drained and the pond area is allowed to freeze over the winter. The following table lists the effects of drawdown on many common aquatic plants:

Table 4. Drawdown Results.[24]

Species that usually decrease with a drawdown	**Species that do not change or whose response is variable**	**Species that usually increase**
Watershield	Coontail	Hydrilla
Eurasion watermilfoil	Elodea	Common naiad
Brazillain elodea	Water celery	Sago pondweed
Fanwort	Water hyacinth	Alligator weed
Musk grass	Cattail	Cutgrass
Southern naiad	Curly leaf pondweed	Smartweed
Fern pondweed		Soft-stem bulrush
Richardson's pondweed		
Water lilies		

The Worcester EcoTarium Upper and Lower Ponds: A case study

The EcoTarium, a place dedicated to science and learning, is fortunate to have these two ponds. They appear to be very similar small ponds, but they are in fact very different. The Upper Pond is somewhat smaller and, from what can be deduced of the water flow, it has fewer springs feeding it and more runoff from surface sources. It is in a very sunny location and receives the runoff from two different paved areas. The Lower Pond has more springs feeding it and received surface runoff primarily in the form of overflow from the Upper Pond. It is also completely surrounded by trees, giving it not only more dead trophic matter but also more shade. It is often overlooked to review the past history of the Upper Pond. Through the years, it has experienced many periods of unwanted growth conditions, whereas the Lower Pond has never experienced this sort of problem. The Upper Pond should not be expected to have the same history as the Lower Pond, because it experiences different natural conditions. These ponds, although somewhat similar, still manage to appear vastly different, when one looks at them with an eye towards studying eutrophication.

In addition to the physical differences between the two ponds, it is also important to point out that the Upper Pond is manmade; it is not a natural ecosystem and should not, necessarily, be expected to act as a pristine ecosystem would. It is located in an urban area, subjecting it to far more chemical exposure and other non-natural processes – more than this study will be able to test for, let alone significantly explore the effects of. Like any manmade creation subjected to manmade conditions resulted from our technological advances, constant maintenance of this structure is required if it is expected to continue year to year in the same, desired conditions. The Upper Pond might not naturally be an aesthetically pleasing pond, like the Lower Pond. Although we like to have ponds that are clean and clear, this may not always be the case when natural processes come into play. The EcoTarium will have to choose between the natural state of the Upper Pond, which may be unpleasant to humans at times, or an unnatural state which will be clean, clear, and aesthetically pleasing.

Selected basic water tests were conducted on water samples taken from the Upper and Lower Ponds. A HACH machine was used to conduct these tests. This piece of equipment measures absorption of light by the water sample after certain chemicals are added to the sample, depending on what is being tested. The absorption of the sample is directly related to the concentration of the compound being studied, after the test chemicals are added. The water samples from the EcoTarium's ponds were tested for suspended solids, nitrates, nitrites, phosphate, and air temperature was recorded for each testing session. The results of these tests are presented in Table 5.

Table 5. Date from water testing of the EcoTarium's ponds.

12/4/00	Upper Pond	Air Temperature: -2 °C		
	Suspended Solids	Phosphate	Nitrite	Nitrate
Sample	mg/L	mg/mL PO_4	Mg/L	mg/L
1	40	0.35	0.016	0.9
2	18	0.275	0.02	1
3	8	0.41	0.017	1.1
4	10	0.35	0.01	0.9
12/12/00	Upper Pond	Air Temperature: 3 °C		
5	10	0.31	0.017	1.3
6	8	0.3	0.007	0.8
12/12/00	Lower Pond			
7	3	0.45	0.011	0.9
8	25	0.32	0.012	0.9
9	10	0.48	0.011	1
10	18	0.41	0.029	1.1

The following table shows what are considered to be normal levels of several common chemicals that would be tested-for to assess eutrophication.

Table 6. Basic Water Quality Data.[25]

		(all in mg/L)	
Chemical Parameter	Low	Common, Moderate	High, Eutrophic
Phosphate	<.01	.02-.04	>.05
Nitrate	<.05	.1-.5	>1.0
Nitrite	<.01	.02-.05	>.1
Dissolved Oxygen	2.0-5.0	>5	>8.0
Suspended Solids	<25	30-80	>100

Comparing these values to the values obtained during testing, it can be seen that the Upper and Lower Ponds both register an excessive amount of phosphates. This, along with the warm, sunny conditions that the Upper Pond receives during the summer, could explain the excess submerged plant and algae growth in the Upper Pond. The Lower Pond has been most likely shielded from this growth due to its shaded surroundings. Large amounts of trophic matter like fallen tree leaves, is a common cause for small ponds, like the EcoTarium's, to enter into periods of excessive and unwanted plant and algae growth. Although the Lower Pond is more subject to this sort of nutrient influx, it seems likely that the shading of the trees helps to reduce sunlight levels, hindering photosynthesis and maintaining cooler water temperatures, which are less suited for plant and algae growth. Additionally, the larger abundance of springs feeding the Lower Pond may provide a higher water turnover rate. These conditions could all lead to less growth in the Lower Pond, even with similar phosphate levels.

The two ponds on the EcoTarium's grounds are good examples of different water ecosystems, a less eutrophic pond and a more eutrophic pond. These two ecosystems should be embraced as a learning tool. They are living examples of two different kinds of ponds, geographically very close to each other, and of the natural progression of ponds. Although this progression of ponds may not be pretty, it is natural. The Upper Pond does not necessarily have to be thought of as a situation that must be 'fixed.'

Chapter 3: Discussion

Cultural Eutrophication:

There are many urban causes associated with the cultural eutrophication of waters. Indirect human influence should not be overlooked. Things that happen because humans populate an area, such as the construction of reservoirs and wastewater treatment facilities, should not be overlooked as urban influences, as they are the direct result of urbanization. It should be remembered not to merely take into consideration pollution from sewage and fertilizers, but also to consider other factors that affect the rate of water flow through ponds and lakes. Technologies such as dams, which are not *directly* a polluting technology, may also have affects that result in excess nutrient loading in ponds, with associated negative consequences.

Another common reason that cultural eutrophication occurs is due to the installation of wastewater treatment plants, with their associated effluent release into water bodies. Wastewater is treated for many things, but often nitrogen and phosphorus levels are overlooked. This leads to a drastic increase of nitrogen and phosphorus levels in the water bodies and even though it is 'clean' sewage outflow – devoid of pathogens such as typhus - it may still be contaminated with nutrients, leading to pollution of water bodies. The technology is now available for wastewater to be treated in such a way as to reduce excess nitrogen and phosphorus levels. It is hoped that existing wastewater treatment facilities will upgrade to take advantage of these new technologies, and that any newly constructed plants will be designed with nutrient pollution issues in mind.

Another urban influence on eutrophication is paving and buildup of cities. Water, instead of being allowed to follow its natural path has a disrupted flow, diverted through drainage systems. Besides disrupting the natural path of the water, this water picks up large quantities of trash and particulate matter on the streets, fertilizers and pesticides from lawns, and bird and animal feces that may be on the paving. This urban runoff water is seldom treated before it is discharged, resulting in the release of nutrient- and chemically-contaminated water, directly into the ecosystem. Even slight pretreatment such as building containing ponds so the particulate matter and trash have a chance to settle out of the water is a great improvement over discharging the water directly. Paved areas change water flow and effect water quality, as in the case of the Upper Pond, which is no doubt affected by the inflow of one small parking lot and paved area. Given the effect which this small parking lot has had on the Upper Pond, the impact of large cities and vast amounts of paved area on the natural flow and conditions of water is clearly significant. It has been shown that urban runoff decreases water quality by increasing B.O.D., total organic carbon, total phosphorus, turbidity and oil and grease levels.[26] B.O.D. is the 'biochemical oxygen demand,' defined as the oxygen demand required by the decomposition process of organic material in water.

How natural is Nature?

Small ponds, such as the ones described in this report, used to be very widespread in this country, due to the actions of one force: *Castor Canadensis*, the North American beaver. These ponds acted as natural filters, returning much of the excess nutrients in the water to the food chain. It has been proposed that the near-elimination of this species, and its pond-construction work, from much of the continent has done more to increase levels of water pollution than excess production of pollutants.[27] That is, it is not necessarily that humans produce an excess of pollutants; it is that the natural filtration system has been compromised, so those pollutants build up.

With that said, it can be seen that many highly eutrophic ponds may be suffering from that ailment simply because they are ones of but a few ponds, trying to do the filtration work of many. Since there are not enough ponds to properly filter the groundwater, these overworked ponds tend to receive an influx of nutrients faster than those nutrients can be filtered out and returned to the food chain. This disparity may very often result in eutrophic conditions.

This, then, may imply that simply attempting to leave ponds in their 'natural state' might often be in vain, as their natural state (as we now experience it) may be drastically different from what their natural state originally was, before Europeans began settling this continent. In other words, since humans have altered the situation so drastically by the over-hunting of the beaver (and in other ways, as well, such as the increase of pollution levels), it has become apparent that humans must either assist nature in its work, or watch that nature slowly disappear.

Chapter 4: Conclusion

Most people hear the word 'eutrophication' and immediately think it is a negative thing. Most people do not realize that eutrophication is a natural process and all water bodies eventually eutrophy. Eutrophication becomes a bad thing when the process of cultural eutrophication is a common problem in the environment today. Many people are unaware of the causes of eutrophication, and even less aware of remedies.

In the test study of the EcoTarium ponds, several things were learned. The first thing learned was that occasionally sampling and testing do not go as smoothly as one would prefer. For instance, it is a lot easier to sample a thawed pond than one that has frozen over, as was required with the majority of the samples taken for this report. Furthermore, not all testing went as planned. The majority of these tests were performed using the HACH spectrometer and, unfortunately, after several attempts at getting consistent readings, the total phosphates test could not be confirmed as accurate. This fact brings into question all of the various test results preformed using the HACH instrument.

Overall, the nitrate and nitrite readings seemed to stay within an acceptable deviation level, between various tests of the same samples. The nitrite readings seemed to fall in the common to moderate range and were fairly consistent when rechecked, while the nitrate readings, also consistent, were in the high to eutrophic region, as expected, and these results will be accepted as accurate. This would seem to indicate that the pond was contaminated by a nitrate source, not a nitrite one, lending credence to the theory that the pond was contaminated by fertilizer.

The suspended solids readings, on the other hand, varied somewhat. This may be due, in part, to the sampling method that was used. In order to obtain the majority of the samples, it was necessary to cut through the frozen surface of the ponds, which may have caused otherwise-settled solids on the bottom to mix with the water. Overall, the readings appeared to be low, which may be explained by the low temperature and the time of year (December) when the samples were taken.

The synthesis of the above research, and the chemical, geographic, and historical data from the EcoTarium's ponds leads to the conclusion that there are two solutions which would best reverse the eutrophication of the Upper Pond, and prevent further cases, while doing so in a manner consistent with the EcoTarium's mission. These recommendations are to install an aeration system and to manually remove some quantity of the existing plant and algae growth. The aeration system is a long-term solution to reverse and prevent the rapid eutrophication that the Upper Pond has a history of. The effects of aeration on reversing the existing eutrophication will require significantly more time to present themselves than the removal of this excess plant matter. This removal of excess plant growth from the pond will expedite its recovery, after which the aeration will maintain the pond in its pre-eutrophic state.

There are several reasons why aeration is recommended over this manual removal of plants alone. While manual removal is less expensive in the short term, it must be repeated indefinitely in order to maintain the pond's cleanliness. The initial installation of an aeration system is more expensive, but it must be viewed as a long-term investment, both in that it will cost less than repeated growth removal, and in that it will prevent eutrophication, rather than requiring one to wait until eutrophic conditions develop in order to fight them.

Removing the plants and algae from the pond is seen as important as well. Most basically, aeration increases dissolved oxygen (D.O.) levels. This increase of D.O. may actually decrease the biological oxygen demand (B.O.D.) of the pond by reducing nitrates, nitrates, ammonia levels, and phosphate levels through a process of oxidation. So aeration is capable of changing the amount of nutrients available to algae and plants. Further, with the reduced contaminates there will be water clarity, adding to the health of the ponds. The immediate effects of aeration on plant and animal life are minimal, and only increase the ability of the water body to support more animal life. Physical plant and algae removal should further clarify the water, allowing for more light penetration, and decreasing the B.O.D., allowing even more diversity to be sustained in the pond. With the plants and algae removed and an aeration system installed, the two ponds should remain healthy for as long as the system is run.

The major goal of an IQP is to study the way technology affects society. This study of how cultural eutrophication affects water bodies and how science can be used to solve these problems would seem to qualify this project as an IQP. Furthermore, the use of the studies by the EcoTarium to actually solve their eutrophication problem assures that this project is indeed an interaction between science and technology. Overall, this IQP has been a valuable experience for each of the authors. The conclusions and information contained within this IQP will hopefully be beneficial not only to the EcoTarium, but to others who face similar problems as well.

Appendix 1: Questions and Answers

Q: What is an IQP?

A: An IQP is an Interactive Qualifying Project. The purpose of in IQP is to encourage WPI students interact with the community outside of everyday schoolwork. The IQP is a research-based project that should draw a conclusion about the interaction between technology and society.

Q: What is the EcoTarium?

A: The EcoTarium is an interactive science center for youth. Its main focus is on environmental exploration.

Q: What is hydroseeding?

A: Hydroseeding is the process of planting grass by applying a mulch mixture consisting of water, grass seed, fertilizers, plant food, and tackifier to an area.

Q: What is bacterial augmentation?

A: Bacterial augmentation is the introduction of a species of bacteria in order to control another species of plant, animal, yeast, or algae, or to control the chemical properties within the body of water.

Q: Does bacterial augmentation work?

A: During the course of this research, no supporting information for bacterial augmentation was found, other than the claims made by distributors of these products. It is hard to say whether it does or does not work, since it is such a secretive field, yet there are many commercial bacterial augmentation products on the market, leading one to believe that it does work, at least in some cases. It is assumed that an ineffective product would not survive long in the competitive marketplace for water treatment. The only scientific paper found during this research that made study of bacterial augmentation failed to support the claims made by distributors. However, the ability to apply that artificially constructed study to the natural world comes into question, and the anecdotal evidence *does* support bacterial augmentation.

Q: What is cultural eutrophication?

A: Cultural eutrophication is a form of eutrophication caused by modern urbanization. Common influences are industrial waste, fertilizer runoff, and high-phosphate detergents. These contaminants decrease water quality by adding excess nutrients to a body of water and causing rapid plant and algae growth.

Q: How does one determine water quality?

A: There are multiple ways to determine water quality. Quality is dependent on what one is looking for in the water and, therefore, many different standards of water quality exist. The most common are the Shannon Water Quality Index, the Simpson Water Quality Index, and the O.E.C.D. recommendations. Common tests performed on water samples include nitrogen concentrations, phosphate concentrations, chlorophyll amounts, Secchi depth (a measure of water clarity), coliform counts, dissolved oxygen concentrations, and pH.

Q: What is the importance of phosphorus?

A: Phosphorous is an essential nutrient in plant growth. The amount of plant growth can be directly correlated to the amount of available phosphorous in the water. This has been shown though scientific experiments on actual lakes such as ELA lake 226.[28]

Q: What is the importance of the nitrogen?

A: Nitrogen is a chemical, essential in plant growth. Nitrogen comes in three useable forms for aquatic plants and algae: nitrates, nitrites, and ammonia. Ammonia is toxic to other forms of life and levels should be kept to a minimum.

Q: What is the difference between a nitrate and a nitrite?

A: Nitrite is nitrogen oxidized less than nitrogen in the form of nitrate. In other words nitrites have a lower oxidation state that nitrates. This causes different chemical reactions and therefore the two forms of nitrogen must be tested for separately.

Q: What is the importance of dissolved oxygen?

A: The level of dissolved oxygen is probably the most important factor in the eutrophication of a body of water. Low dissolved oxygen levels can cause a lake or pond to stop its natural self-cleaning cycle, and actually reverse that cycle. This reversal causes sediments from the bottom of the lake to be recycled and can be just as harmful as fertilizers and other watershed contaminants, since these sediments are very rich in nutrients, which are suddenly released into the water. Increasing the amount of dissolved oxygen (though aeration) can prevent this from happening and actually help to reverse it by oxidizing nitrogen and phosphorous, causing them to be released into the air instead of the pond and improving water quality.

Q: How can I prevent eutrophication in my pond?

A: Many preventive techniques have been outlined throughout this IQP. The best and most popular method would seem to be aeration. Other methods include, but are not limited to: aquascaping, bacterial augmentation, pre-impoundment, diversion and pollution control.

Appendix 2: Glossary

Aquascaping	Aquatic landscaping; the planting of various plants in a practical or aesthetically pleasing manner around and in a body of water.
Bacterial augmentation	The use of bacteria in order to control other organisms or chemical conditions within a body of water.
Biochemical oxygen demand (B.O.D.)	The total biological and chemical demand for oxygen per unit of volume in a body of water.
Biomanipulation	The use, replacement, or shifting of organisms in an ecosystem to produce a desired effect.
Bioremediation	The use of organisms to fix an environmental problem.
Cultural eutrophication	Eutrophication caused by modern influences such as industrial waste.
Eutrophic	A body of water with a high amount plants and animals.
Eutrophication	The process by which olgiotrophic ponds become eutrophic.
Hydroscaping	Planning and designing aquatic systems for practical or aesthetically pleasing purposes.
Hydroseed	A mulch mixture consisting of water, grass seed, fertilizers, plant food, and tackifier.
Hydroseeding	The process of planting grass by applying hydroseed to an area.

Hypertrophic	A body of water with an excessively high amounts plants and animals.
Macrophytes	Plants which, unlike algae, grown on the multi-cellular level.
Nitrogen	A nutrient essential to plant growth.
Olgiotrophic	A body of water with few plants and animals.
Phosphorous	A nutrient essential to plant growth.
Ultra-olgiotrophic	A body of water with very little to no plants and animals.

References

[1] Organization for Economic Cooperation and Development. *Eutrophication of Waters: Monitoring, Assessment and Control.* Report. Paris: O.E.C.D. Publications.

[2] Wetzel, Robert G., *Limnology*, 2nd ed. Philadelphia, PA : Saunders, c1983. -- pg. 293

[3] Wetzel, Robert G., *Limnology*, 2nd ed. Philadelphia, PA : Saunders, c1983.

[4] JB Instant Lawn, Inc. http://www.jbinstantlawn.com/

[5] The Highridge Corporation, Oregon. http://www.highridge.com/

[6] Fairway Greens Landscape Services. http://www.fairwaygreens.com/

[7] Fairway Greens Landscape Services. http://www.fairwaygreens.com/

[8] Clean-Flo International. http://www.Clean-Flo.com/

[9] Long Island Fountain Company (http://www.lifountain.com/).

[10] Long Island Fountain Company (http://www.lifountain.com/).

[11] Joe Mescan Windmill and Supply (http://www.pondaeration.com/) & Quality Pond Aeration (http://www.qualitypond.ca/).

[12] McComas, Steve. *Lake Smarts: The First Lake Maintenance Handbook.* 1st Ed. Washington, DC: Terrene Institute. -- pg. 5

[13] Maston, Tim. *Earth Ponds: The Country Pond Maker's Guide to Building, Maintenance and Restoration.* 2nd Ed. Woodstock, Vermont: Countryman Press.& McComas, Steve. *Lake Smarts: The First Lake Maintenance Handbook.* 1st Ed. Washington, DC: Terrene Institute. -- pg. 45

[14] McComas, Steve. *Lake Smarts: The First Lake Maintenance Handbook.* 1st Ed. Washington, DC: Terrene Institute. -- pg. 45

[15] McComas, Steve. *Lake Smarts: The First Lake Maintenance Handbook.* 1st Ed. Washington, DC: Terrene Institute. -- pg. 45

[16] McComas, Steve. *Lake Smarts: The First Lake Maintenance Handbook.* 1st Ed. Washington, DC: Terrene Institute. -- pg. 74

[17] McComas, Steve. *Lake Smarts: The First Lake Maintenance Handbook.* 1st Ed. Washington, DC: Terrene Institute. -- pg. 51

[18] McComas, Steve. *Lake Smarts: The First Lake Maintenance Handbook.* 1st Ed. Washington, DC: Terrene Institute. -- pg. 48

[19] McComas, Steve. *Lake Smarts: The First Lake Maintenance Handbook.* 1st Ed. Washington, DC: Terrene Institute. -- pg. 49

[20] McComas, Steve. *Lake Smarts: The First Lake Maintenance Handbook.* 1st Ed. Washington, DC: Terrene Institute. -- pg. 49

[21] McComas, Steve. *Lake Smarts: The First Lake Maintenance Handbook.* 1st Ed. Washington, DC: Terrene Institute. -- pg. 64

[22] McComas, Steve. *Lake Smarts: The First Lake Maintenance Handbook.* 1st Ed. Washington, DC: Terrene Institute. -- pg. 64

[23] McComas, Steve. *Lake Smarts: The First Lake Maintenance Handbook.* 1st Ed. Washington, DC: Terrene Institute. -- pg. 65

[24] McComas, Steve. *Lake Smarts: The First Lake Maintenance Handbook.* 1st Ed. Washington, DC: Terrene Institute. -- pg. 52

[25] Worcester Polytechnic Institute, *Water Studies* course.

[26] Lazaro, Timothy R., *Urban hydrology : a multidisciplinary perspective*, Revised Edition, Lancaster : Technomic Pub. Co., c1990. -- pg. 48

[27] Outwater, Alice, *Water: A Natural History.* New York, NY: BasicBooks, c1996.

[28] University of Manitoba. http://www.umanitoba.ca/institutes/fisheries/eutro.html

Bibliography

Aerators, Inc. http://www.aeratorsinc.com/

Air Diffusion Systems. http://www.airdiffusion.com/

Aquatic Eco-Systems, Inc. http://www.aquaticeco.com/

American Wind Energy Association. http://www.awea.org/faq/aeration.html

Baker, Katherine H. and Herson, Diane S. *Bioremediation*. McGraw-Hill, Inc.

Bryan Beckwall, beckwall@silk.net Kelowna, British Columbia, Canada

Biswas, Asit K. *Water Resources: Environmental Planning, Management, and Development*. McGraw-Hill.

Caduto, Michael J. *Pond and Brook: A Guide to Nature in Freshwater Environments*. 1st ed. Hanover and London: University Press of New England.

Interview: Professor Ronald Cheetham, department head, biology/biotechnology WPI

Chiayvareesajja, S.; Boyd, C. F.: *Effects of Zeolite, Formalin, Bacterial Augmentation, and Aeration on Total Ammonia Nitrogen Concentrations*. Aquaculture 116: 33-45, 1993.

Clean-Flo International. http://www.Clean-Flo.com/

Enviro-Reps International, LLC. http://www.enviro-reps.com/

Fairway Greens Landscape Services. http://www.fairwaygreens.com/

General Environmental Systems, inc. http://www.airation.com/

Editor: Glass, Gary E. *Bioassay Techniques and Environmental Chemistry*. 1st ed. Ann Arbor, MI: Ann Arbor Science Publishers Inc.

Henderson-Sellers, B. and Markland, H. R. *Decaying Lakes: The Origins and Control of Cultural Eutrophication*. 1st ed. New York: John Wiley and Sons.

The Highridge Corporation, Oregon. http://www.highridge.com/

JB Instant Lawn, Inc. http://www.jbinstantlawn.com/

Joe Mescan Windmill and Supply. http://www.pondaeration.com/

Keeton Aquatics. http://www.keetonaquatics.com/

Lazaro, Timothy R., *Urban Hydrology : A Multidisciplinary Perspective*, Revised Edition, Lancaster : Technomic Pub. Co., c1990.

Long Island Fountain Company. http://www.lifountain.com/

University of Manitoba. http://www.umanitoba.ca/institutes/fisheries/eutro.html

Maston, Tim. *Earth Ponds: The Country Pond Maker's Guide to Building, Maintenance and Restoration.* 2nd Ed. Woodstock, Vermont: Countryman Press.

McComas, Steve. *Lake Smarts: The First Lake Maintenance Handbook.* 1st Ed. Washington, DC: Terrene Institute.

Interview: Bob Mitchell, EcoTarium employee, custodial staff. Discussion on October 12, 2000 regarding the histories of the Upper and Lower Ponds.

Morris, Pat and Burgis, Mary J. *The Natural History of Lakes.* 1st ed. New York, NY: Cambridge University Press.

Organization for Economic Cooperation and Development. *Eutrophication of Waters: Monitoring, Assessment and Control.* Report. Paris: O.E.C.D. Publications.

Outwater, Alice, *Water: A Natural History.* New York, NY: BasicBooks, c1996.

Pond Cure International. http://www.pondcure.com/

Quality Pond Aeration. http://www.qualitypond.ca/

Editors; Ryding, Sven-Olaf and Rast, Walter *The Control of Eutrophication of Lakes and Reservoirs.* 1st ed. Park Ridge, NJ: The Parthenon Publishing Group Inc.

Wetzel, Robert G., *Limnology*, 2nd ed. Philadelphia, PA : Saunders, c1983.