Chapter 7
Lake Restoration and Acidic Water Control

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Contents

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L. K. Wang, M. -H. S. Wang, Y. -T. Hung, N. K. Shammas (eds.), *Integrated Natural Resources Management*, Handbook of Environmental Engineering 20,
https://doi.org/10.1007/978-3-030-55172-8_7

Abstract The steps leading to the demise of a lake are discussed. One of the primary causes of the death of lake is excessive biological growth, called eutrophication. Biological growth is limited primarily by the availability of the nutrients necessary for growth. It has been shown that phosphorus is most frequently the limiting nutrient to control biological growth in a lake, but nitrogen is also commonly limiting. Phosphorus may be permanently removed from a lake by various processes, whereas nitrogen is difficult to remove permanently due to the fact that certain blue-green algae can fix atmospheric nitrogen as a nitrogen source. Thus, emphasis has been placed on removal of phosphorus. There are various methods for treatment of wastewaters to remove the nutrients before being discharged to a body of water. Once in a lake, phosphorus removal is most frequently achieved by producing an insoluble aluminum salt of the phosphorus, but iron salts are effective under aerobic conditions. Calcium salts are effective in removing phosphorus, but they generally adversely increase the pH of the lake. Precipitated aluminum phosphate salts may be allowed to settle to the bottom of the lake, or they may be removed from the water column. A study showed that removing the phosphate-rich hypolimnetic waters from a summer-stratified temperate climate lake, precipitating the phosphorus as either aluminum or iron salts, separating the precipitate by DAF, and returning the phosphate-reduced water to the lake were very effective in controlling the phosphorus nutrient content in Devils Lake, WI, USA.

Acid rain is formed when sulfur dioxide and nitrogen oxides reach the air and are transformed into sulfate or nitrate particles. When combined with water vapor, they are converted into sulfuric or nitric acids. Acid rain can adversely affect aquatic life at all levels of the food chain that can be harmed by acid rain. Destruction begins at the lowest level of the food chain, when the tiny microorganisms that are food for minnows and other small organisms die. As food sources dwindle, more and larger fish die. Acid in the water may also interfere with oxygen circulation, harm fish gills, and cause heart problems in fish. The chemistry and control of acid rain are also discussed. A case history involving the use of lime or sodium aluminate for neutralization of acid rain contaminated reservoir water is also presented.

Keywords Dedication · Donald B. Aulenbach · Nutrients · Productivity · Biological activity · Stratification · Eutrophication · Remediation · Phosphorus precipitation ·

Acid rain control · Algae separation · Dissolved air flotation · DAF · Acid rain · Neutralization · Sulfur dioxides · Nitrogen oxides · Causes · Monitoring · Regulations · Environmental effects · Reduction and control · AquaDAF

Nomenclature

ANC	Acid neutralization capacity
ARP	Acid Rain Program
CEM	Continuous emissions monitor
COD	Chemical oxygen demand
CSAPR	Cross-State Air Pollution Rule
DAF	Dissolved air flotation
HAPs	Hazardous air pollutants
NAAQS	National Ambient Air Quality Standards
NADP	National Atmospheric Deposition Program (NADP)
NAPAP	National Acidic Precipitation Assessment Program
USEPA	US Environmental Protection Agency
USGS	US Geological Survey
WDNR	Wisconsin Department of Natural Resources

1 Importance of Lakes

All lakes and reservoirs have a finite life. That life may be measured in geological time or in human lifetimes. The general pattern of aging of a lake is for the lake to fill in with either allochthonous materials (carried into the lake from inlet streams or direct runoff) or autochthonous materials (generated by biological growth within the lake). As a lake ages, the water becomes more shallow. The decreased volume of water concentrates the same nutrient input. This encourages more biological growth, which further fills in the lake with dead biomass. When the depth decreases to about 2 m, rooted aquatic plants proliferate due to their access to direct sunlight. This further increases the filling in of the lake. Most frequently (but not always) when a lake reaches this point, it becomes a wetland or a bog. At this point emergent plants and eventually trees appear. These tend to take up the moisture, drying out the system. The wet organic material may progress to peat, a useful source of fuel. In geologic time, with the aid of pressure, this progressed to coal, a very valuable source of energy.

However useful peat and coal may be as a source of energy and raw materials, lakes are considered more important for their water. All life depends upon water and its unusual characteristics. In addition to water for drinking, water is essential for irrigating crops. Irrigation is the largest consumer of water on Earth today. As the Earth's population grows, there will be a greater demand for food, much of it needing irrigation. Other industries require water, including process water and cooling water. Thus water is essential for life as well as for the living of modern-day life.

In addition, water in its place, such as a lake, is important to our livelihood. Besides its use in transportation, many recreational activities, such as swimming and boating, depend upon lakes and streams. Further, lakes have an aesthetic quality. Many poems and stories have been written about lakes. The beauty and tranquility of lakes adds to our consolation. Storms on a lake inspire awe. Thus it may be seen that lakes are essential to our way of life.

In this chapter, reservoirs are considered in the same manner as lakes. By definition, reservoirs are artificial lakes, generally constructed to serve a specific purpose. That purpose may include drinking water supply, flood control, low flow augmentation, travel enhancement, storage for periods of low precipitation, recreation, and any combination of these. The life of a reservoir mimics that of a lake, although the factors that influence the life of a reservoir may be somewhat different, or in different magnitude, from those that impact the life of a lake. In both cases these factors are so variable that to predict the life of a lake, each lake must be studied as its own entity. No two lakes or reservoirs are exactly the same, nor have the same needs.

It may be concluded that the preservation of lakes and the extension of their lives is important to the continuation of human life on Earth.

2 Characteristics of Lakes

Even though each lake has its own characteristics, we can make generalities on the factors that influence the life of a lake or reservoir. By understanding these characteristics, we can devise means of slowing the aging process and in some cases even reversing that process. By studying ancient lakes and terminal lakes, we can describe the factors that have either preserved the lake or hastened its demise.

There are numerous factors that control the life of a lake. Not in any preferred order, the morphology of a lake is an initial factor. Deep lakes with steep sides seem to have greater longevity. Large shallow areas tend to encourage rooted plant growth, which leads to the more rapid filling in of the lake. Steep sides may even limit human habitation as experienced in Crater Lake, Oregon, formed in the caldera of a former volcano. The smaller the ratio of the watershed to the lake surface area, the longer its life; again Crater Lake is a prime example. Larger lakes such as the Great Lakes of North America have a long life. The underlying geological formations in the lake may contribute essential nutrients that may allow biological growth. A forested watershed will lessen the amount of nutrients being carried into the lake. Conversely, farmed areas contribute large amounts of nutrients from fertilizers. Human development may contribute significantly to the demise of a lake. Whereas everyone enjoys the beauty and the recreation attractions of a lake, more inhabitants result in more direct surface runoff to the lake and more domestic wastes containing nutrients to ultimately reach the lake. A significant impact is lakeside homeowners who pride themselves with their green lawns, right down to the water's edge, kept green with fertilizers, which readily reach the lake. Again, no two lakes are identical, and the combination of factors affecting a lake's life is infinite.

Deep lakes in temperate climates exhibit an interesting circulation pattern. Under ordinary conditions there is a period of stratification during ice cover in the winter and another period of stratification during the summer. There are also two periods during which the water is completely mixed from top to bottom by the impact of wind at the surface. This occurs when the water temperature is uniform and usually occurs just before ice formation (fall turnover) and just after ice-out (spring turnover). Such a lake is called dimictic. This pattern is the result of the temperature-density relationship and the anomalous condition of water's being most dense at 4 ° C. Thus in winter the bottom temperature is 4° while the ice on the surface is at zero. During the summer the surface is warmed by the sun while the bottom may remain at or near 4 ° C. During the summer thermal stratification usually occurs as a result of a combination of solar heating of the surface, the impact of wind, and the temperature-viscosity relationship of the water. This summer stratification prevents surface reaerated water from being carried to greater depths, a factor that also contributes to the long-term demise of the lake.

The temperature succession in a lake may be shown starting with ice cover in winter. The surface ice is at or below 0 ° C, while the bottom is at 4 ° C. There is no mixing of this water, because the ice cover prevents any wind effects. Biological activity is also at a minimum. As spring comes, the sun melts the ice and then begins to warm the surface of the lake. As all of the water approaches 4 ° C, even a gentle wind will mix this isothermal water from top to bottom, called the spring overturn. As the sun warms the surface of the lake, the warmer water will tend to float on the surface due to its lower density. If this heating occurs during a period of strong wind, there may still be complete mixing and the entire lake will be heated to the temperature of the surface. However, if warming occurs during a period of light or no wind, a point is reached at which the wind does not have sufficient energy to mix the upper warmer water with the cooler lower layer of water with greater density and viscosity. This forms a period of summer stratification where there is circulation near the surface, but none below a certain depth. Frequently in large deep temperate lakes, the level of stratification occurs at about 10 m depth. Further, the shape and orientation of the lake to the wind have an influence on the depth of the upper mixed zone. During the summer in a typical temperate lake, there is a warm upper layer that is equally mixed by the wind, then a zone in which there is a rapid decrease in temperature with depth, and finally a layer of relatively cold uncirculating water near the bottom. Thus the lake is divided into three layers in which the upper layer is called the epilimnion, the middle layer the metalimnion or the thermocline, and the bottom layer the hypolimnion, as shown in Fig. 7.1.

The summer stratification may last up to 5 months, during which time there is little to no mixing in the hypolimnion and no opportunity for oxygen from surface aeration to reach this area. So long as only a little decomposable organic matter is present at the onset of stratification, the available oxygen present may not be entirely consumed. The colder bottom water temperature also contributes to a slower biological activity, thereby conserving the oxygen supply. This condition is conducive to supporting a cold-water fish habitat. However, if large amounts of decomposable organic matter settle into the hypolimnion, the limited amount of oxygen available

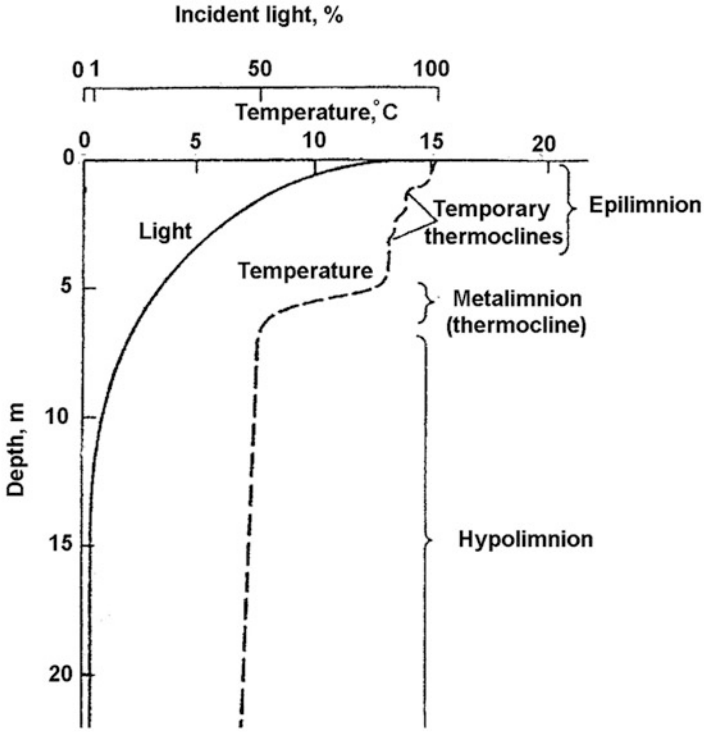


Fig. 7.1 Temperature and light profiles in a temperate climate lake during summer stratification

may be consumed and the hypolimnion will become anaerobic. Not only will this interfere with fish life, it also results in the release of certain nutrients, specifically phosphorus, that are insoluble in aerobic conditions, but soluble under anaerobic conditions. The presence of more nutrients may increase oxygen-consuming biological activity that will further create anaerobic conditions.

As fall approaches, the surface of the lake is cooled and the cooler water circulates to a depth of equal temperature and/or density. This tends to lower the thermocline until the lake becomes uniform in temperature. Now even a light wind can circulate the water from top to bottom and the period of fall overturn occurs. During this time complete oxygen saturation of the water usually occurs and aerobic reactions persist.

As the air temperature reaches 4 ° C and becomes colder, the surface of the lake will approach 0 ° C, but the denser 4 ° C water will remain on the bottom. When ice covers the surface, the period of winter stagnation begins. The duration of this depends upon latitude, altitude, weather conditions, and numerous specific lake conditions. Lakes with significant warm underground springs have been found to have less ice cover and, in some instances, have holes in the ice above the location of the spring. Very deep lakes such as Lake Baikal, Crater Lake, and Lake Tahoe contain so much heat energy in the water that they do not freeze. Figure 7.2 summarizes the circulation/depth patterns during the seasons in a deep temperate climate lake.

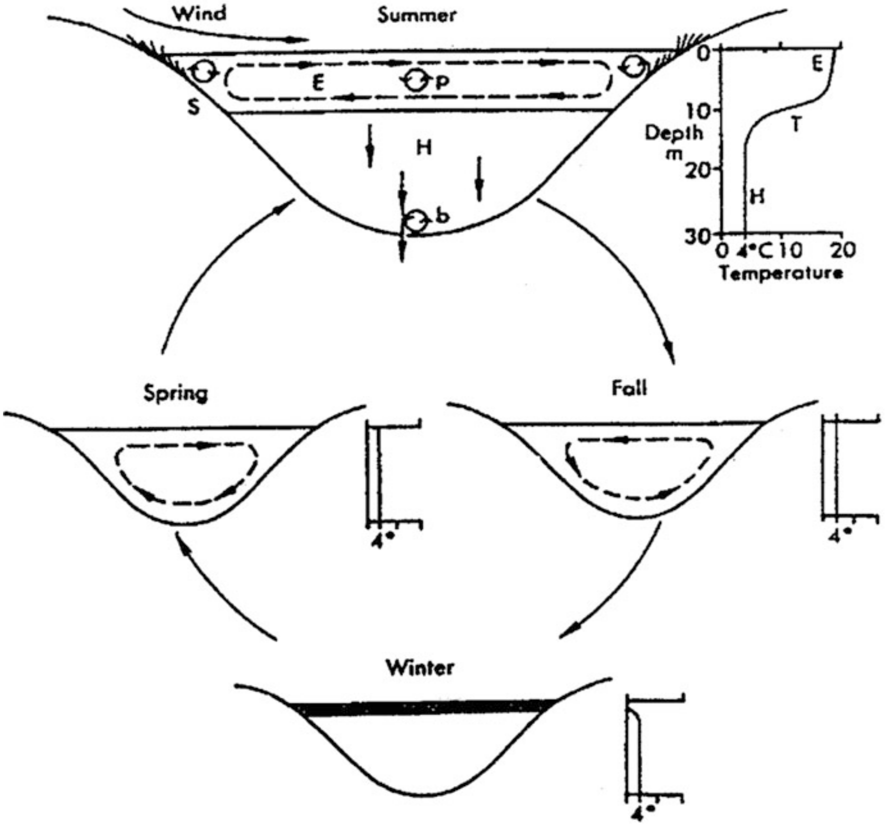


Fig. 7.2 Seasonal circulation patterns in a deep temperate climate lake

3 Importance of Biological Activity

It may be noted in this discussion that the interrelationship between nutrients and biological activity represents a continuing thread in the study of the life of a lake. Thus an understanding of the relationship between biological activity in a lake and its aging process is essential [1].

A lake contains many biological communities. Within the water column are numerous organisms of microscopic size. The floating microscopic organisms are called plankton, which may be subdivided into two groups: the phytoplankton or plant life, which includes algae, fungi, and pollens that fall into the lake, and the zooplankton or animal forms. The plankton may also be broken down into the nekton, or free swimming organisms, and the benthon, which exist on the bottom.

A prime concern is the algae, the microscopic green plants floating in the water column. These organisms represent the base of the food chain in that they can convert simple inorganic matter into organic matter with the aid of sunlight in the process called photosynthesis. In this process of cell growth, oxygen is also produced. It has been estimated that ¾ of the Earth's supply of oxygen is generated by algae in the ocean. In terms of the food chain, the algae may be consumed by the zooplankton, which in turn are consumed by larger animal forms, which may be consumed by small fish, which may be consumed by larger fish, which may be consumed by larger vertebrates, including humans. The microscopic algae are the start of this food chain.

All biological systems require the presence of the proper nutrients to grow and reproduce. For larger organisms, the smaller organisms provide both the nutrients and the energy. However, algae obtain their nutrients from dissolved inorganic materials and their energy from the sun. Organisms that rely on inorganic nutrients are called autotrophic, whereas those that rely on organic matter are called heterotrophic. Besides nutrients and energy, growth may depend upon other factors such as temperature, light, etc. Nutrients in a lake may vary with location, including depth, and time. Specific organisms may have individual nutrient and environmental requirements. However, common to most are carbon, hydrogen, oxygen or another electron acceptor, nitrogen, and phosphorus. Carbon may be obtained from the solution of carbon dioxide. Hydrogen may be obtained from electrolysis or from bicarbonates dissolved in the water. Oxygen is most frequently obtained from the dissolved oxygen in the water. Nitrogen is secured from dissolved nitrogenous materials including ammonia, nitrites, and nitrates. Certain blue-green algae can obtain gaseous nitrogen from the atmosphere. Phosphorus is usually obtained from geological materials and from the breakdown of other organic materials. A general rule for the ratio of nutrients to support the growth of organisms is 60 parts carbon to 15 parts nitrogen to 1 part phosphorus. Some trace substances may also be essential. One of these is sulfur, which may be present in the soil, and is available in decaying organic matter. Another is silicon, which is required to form the shell case, called the frustule, of diatoms.

Every species of organism has a specific requirement for nutrients. Other factors being satisfactory, organisms will continue to grow until one of the essential nutrients has been completely utilized. Then growth may be retarded or completely stopped. Conversely, providing the limited nutrient will encourage additional growth. Frequently limiting nutrients such as nitrogen and phosphorus are contained in wastes, including human wastes. Conventional wastewater treatment does not remove nitrogen and phosphorus. Thus additional treatment to remove these nutrients is frequently required before discharge into a lake.

Productivity in a lake is commonly expressed as the amount of fishable fish in a lake. Since the number of fish is directly related to the fish's food and the food ultimately is a function of algae in the food chain, which in turn is a function of the available nutrients, we can use measurement of the nutrients to estimate the potential productivity of a lake. Whether or not productivity is desirable is up to individual taste. A lake that is low in productivity will be clear and have a low fish population. A lake that is high in fish population tends to be turbid and frequently accompanied by extensive shoreline weed growths. Moreover, the fish population will vary in each case with game fish such as trout and salmon predominant in less productive lakes and pan fish such as bass, pickerel, and catfish predominant in highly productive lakes.

The term oligotrophic has been used to describe lakes low in nutrients and consequently low in productivity. Lakes high in productivity are termed eutrophic. As a general rule, lakes proceed from oligotrophic to eutrophic as the lake ages. Some researchers add the word mesotrophic to designate lakes on the verge of becoming eutrophic. These terms are not intended to imply that all eutrophic lakes are undesirable or that all oligotrophic lakes are desirable. The desirability of a specific level of productivity is a function of the specific use of the lake. Probably what is desirable is a mixture of lakes of the different types. The long-range problem is that as lakes age, the nutrients accumulate within the lake. New nutrients are brought into the lake from allochthonous inputs. Siltation may decrease the volume of water within the lake, thus concentrating the nutrients. Anthropogenic inputs such as wastewaters and fertilizers add significantly to the nutrient level. Deforestation results in more rapid runoff, which carries both silt and nutrients into the lake. All these combine to increase eutrophication in a lake.

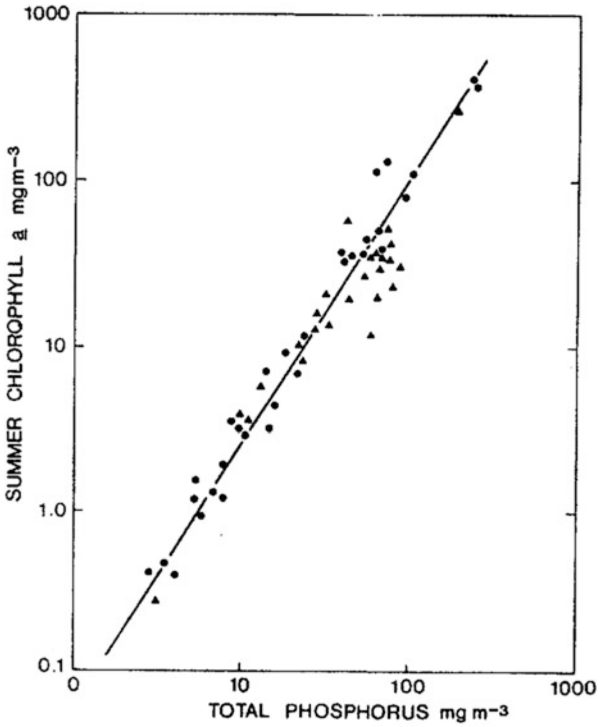
4 Considerations in Remediation

In order to prolong the life of a lake, actions must be taken to reduce the rate of eutrophication. Very little can be done to overcome the natural process of eutrophication. However, much can be done to overcome the anthropogenic impacts. It is easy to say just stop any human activities that contribute to the eutrophication, but that is difficult to achieve. The best that can be done is to determine what activity will provide the best return for the effort and/or expenditure.

Sakamoto [2] showed a direct correlation between the phosphorus concentration in a lake at the time of spring turnover and the amount of productivity as measured by the amount of chlorophyll-α present during the summer (Fig. 7.3). Correspondingly, the greater the chlorophyll-α content, which indicates the presence of algae, the greater the turbidity of the water, and, therefore, the lower the clarity of the water as measured by the Secchi disk depth. Whereas there was good coordination between the phosphorus content and the chlorophyll-α, there was poor correlation between chlorophyll-α and the clarity of the water. Substances other than chlorophyll-α can impact the turbidity of the water. These include the presence of zooplankton that feed on the phytoplankton and particulate matter, such as fine clay or silt that is carried into the lake in the runoff.

Numerous models have been derived to correlate certain specific parameters with the trophic state of a lake. Two stand out as being quite reliable and simple. Both relate total phosphorus loading to the trophic state of the lake as a function of the body of water. In the original work by Vollenweider [3], he showed a correlation between the total phosphorus loading and the mean depth of the lake. Many lakes were studied and there was a good correlation between these two parameters. Later Vollenweider and Dillon [4] improved the model by comparing phosphorus loadings with the mean depth and the retention time of the lake (Fig. 7.4). The correlation was poor with lakes that were not phosphorus limited.

Fig. 7.3 Total phosphorus concentrations at spring turnover vs. average summer chlorophyll-α concentrations



Notes: Dots represent data from Sakamoto, 1966
Triangles are for other lakes in the literature
Line is the regression line for Sakamoto points
Correlation coefficient (r) is 0.97

5 Treatment to Prevent Nutrient Discharges

It is apparent that the most effective measure to control eutrophication would be to control the nutrient inputs. However, this is not always possible nor practical. It is nearly impossible to lower the total carbon inputs to a lake, because there is always some dissolved carbon dioxide present from the atmosphere that can become available as a carbon source. It is not desirable to limit the oxygen, as that would encourage anaerobic decomposition with its odors and other undesirable conditions. Nitrogenous materials can be removed from a wastewater treatment plant effluent, but certain blue-green algae can utilize nitrogen from the atmosphere. Phosphorus can also be removed from wastewater effluents. Unless there is a large phosphate deposit in the watershed or the lake bed, this can result in a permanent removal of the phosphate so long as the lake maintains aerobic conditions. Thus phosphorus removal has received much attention in the effort to limit primary productivity. Furthermore, in his study of lakes around the world, Vollenweider [3] observed that the nutrient most frequently limiting productivity in lakes was phosphorus.

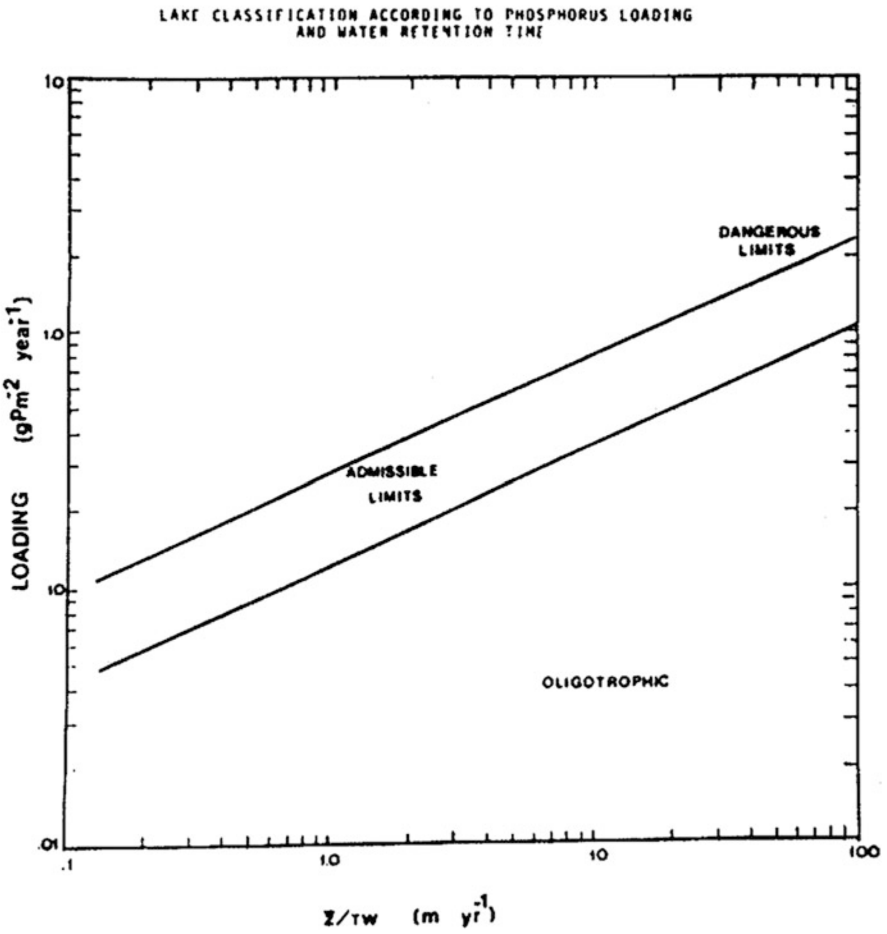


Fig. 7.4 Trophic state of a lake based on its mean depth and hydraulic residence time

Since phosphorus is most frequently the limiting nutrient in a lake, more efforts have been directed toward finding means of reducing phosphorus inputs to a lake. Means that have been applied include diversion of all stormwater runoff from the lake, installation of stormwater infiltration basins, removal of phosphorus from treatment plant effluents, the use of land application of wastewaters, and passing treatment plant effluents through wetlands before they enter the lake.

Another reason phosphorus has been chosen as the nutrient to be removed is the ease of precipitating phosphorus with iron, aluminum, or calcium salts, with the subsequent removal of the solids. Phelps [5] showed that limiting the phosphorus concentration in a lake at the time of spring turnover to less than 10 μg/L would limit excess productivity in most lakes.

Removal of phosphorus from wastewaters in treatment processes is important in limiting phosphorus discharges to streams and lakes. These include both biological and chemical treatment systems.

Most biological treatment systems rely on a peculiar trait of many organisms, specifically those present in typical biological wastewater treatment systems, especially activated sludge systems. When these organisms are starved for phosphorus, such as under anoxic conditions, and then subjected to normal aerobic activated sludge aeration, they take up more phosphorus than immediately needed, a term called luxury uptake. Thus treatment involves alternate anoxic and aerobic treatment in separate tanks or alternate conditions in a single tank, with removal of the excess phosphorus in the waste sludge.

Wilson [6] summarized some of these processes, sometimes known as the Ludzack-Ettinger and Johannesburg or Bardenpho processes, which are patented. Variations include the number and order of anoxic and aerobic tanks, the location of both return activated sludge and mixed liquor suspended solids to help create anoxic conditions, and the use of an added carbon source, such as methanol, to create the anoxic conditions. If effluent requirements require phosphorus levels less than 0.3 mg/L, additional chemical treatment is usually needed. Wilson compared biological and chemical phosphorus removal and concluded that multiple aeration tanks consume energy; return activated sludge and mixed liquor suspended solids require more energy; the cost of a carbon source (methanol) may be great; multiple tanks require more space; and for low phosphorus effluent demands, chemical treatment is needed anyway. He also pointed out that the additional volume of sludge created by the addition of chemicals is small compared to the volume of waste sludge already created.

In order to achieve total phosphorus levels in wastewater discharges of less than 0.1 mg/L, chemical precipitation is very useful. Phosphorus forms insoluble salts with aluminum, iron, and calcium. Aluminum is most commonly used. The iron phosphate sediment must be kept aerobic to prevent the release of the phosphorus when less soluble iron sulfide is created. Calcium is usually applied as lime, which has a high pH. This may be detrimental under certain circumstances. Availability and cost of the chemicals has a large role in the choice of chemical. Eberhardt [7] has published a report on calculating the optimum aluminum dose.

Tabor [8] evaluated two patented treatment systems for phosphorus removal. The Actiflo process consists of coagulant addition with rapid mix, polymer and sand addition, slow mix for particle agglomeration and floc formation, plate settlers for solids/liquid separation, separation of the sand from the solids in a hydrocyclone, and return of the sand to the system. The DensaDeg process consists of coagulant with rapid mix, polymer and thickened return activated sludge addition, a plug flow zone for particle agglomeration and floc formation, tube settlers for solids/liquid separation, and thickening of solids for recycle and disposal. Both systems are capable of removing total phosphorus to less than 0.2 mg/L.

Patoczka [9] described upgrading an existing conventional activated sludge treatment plant utilizing a backwashable sand filter to achieve an effluent total phosphorus content of less than 0.1 mg/L. Chemical addition was shown to be effective. Both alum and iron salts were studied, and the optimum dosages and pH for each were determined for the particular waste. The effects of chemical addition at the primary settling tank, the aeration tank, and the final clarifier were studied. The most effective location for adding the chemicals and the most effective chemical for phosphate removal were the addition of alum at the final clarifier, but some chemical savings could be achieved by addition to the aeration unit due to the return of some of the chemical in the return activated sludge. Alum addition increased the sludge generation in the range of 0.5 to 0.7 lb of dry sludge per lb of alum used. Chemical addition aided sludge settling in the final clarifier and also increased BOD and TSS removal.

The Federal Highway Authority has issued a report for the best management practices for stormwater management [10]. A simple method is an alum injection system that adds alum directly to a stormwater channel at a flow-controlled rate. The precipitated chemicals are merely discharged to the receiving stream or lake where thy settle to the bottom (under appropriate flow conditions). The added solids in lake sediment are considered insignificant. Total phosphorus in Lake Ella, Florida, was reduced by 89%, and total nitrogen by 78% [11]. Pitt [12] described a multichamber treatment train that consists of a series of treatment units that mimic a conventional wastewater treatment plant. In the first tank mild aeration separates the heavy solids from the lighter ones. In the bottom of the second tank, most of the solids are settled out by an inclined tray settler, and above this a DAF system lifts floatables and oil to the surface. The final tank uses a sand/peat filter for final treatment. Total phosphorus removal was determined to be 88%. Allard et al. [13] patented the StormTreat System for treating stormwater. It consists of a circular holding tank 1.2 m deep with discharge to the subsurface of a surrounding wetland. Overall the system removed total phosphorus by 89%. Claytor and Schueler [14] have described a constructed vegetated rock filter for biological treatment of stormwater, with application to the subsurface of the filter. This achieved 82% removal of total phosphorus.

Farming is a major source of nutrient discharges to streams and ultimately to lakes. Runoff from fertilized fields carries the excess fertilizer off the field. This can be controlled by establishing an unfertilized buffer zone between an active field and the waterbody. Also the trend toward large feedlots has exacerbated runoff problems. A large combined animal and plant farm in the United Kingdom has installed an environmentally sound water and wastewater system [15]. The collected liquid wastes are treated in a DAF system before entering a reedbed treatment system. The effluent flows into a lake whose overflow passes into a willow plantation. Water from the lake is used for irrigation and pig wallowing. Seepage under the lake is pumped out a sufficient distance away to allow for reuse. The lake also serves as a fish and wildlife habitat.

In studies at the Lake George Village, NY, sewage treatment plant using trickling filters and alum addition before the secondary clarifiers, with the final effluent being dosed onto deep natural sand beds, Aulenbach [16] found that total phosphorus was reduced to less than 1 mg/L within 7 m of vertical transport through the sand. In another study of phosphate removal in the soil, Aulenbach et al. [17] traced a septic tank effluent in shallow soil and found removal to less than 1 mg/L within 35 ft of horizontal transport.

6 Recovery of Eutrophic Lakes

The best way to prolong the life of a lake is to control the nutrient inputs to the lake before it progresses through the mesotrophic state to the eutrophic state. This is sometimes difficult or even impossible. If upon study of a lake recovery is considered possible, numerous methods are available [18–20].

6.1 Aeration

Several variations of aeration are available to prevent the hypolimnion from becoming anaerobic. This will tie up the phosphorus in an insoluble form and keep the surface of the bottom deposits aerobic to prevent resolubilization of the phosphorus. Aeration is generally more applicable to small lakes. The pressure to pump air to the bottom of a deep lake requires special equipment.

When air is used, the system is designed to create a circulation within the lake so that anaerobic hypolimnetic water is brought to the surface where natural reaeration occurs. Whereas some reaeration results from the addition of the air, the surface aeration is responsible for most of the reaeration. More than one air system may need to be placed in a lake depending upon the shape of the lake. A disadvantage of the complete circulation system is that the thermocline is destroyed and the lake becomes isothermal from top to bottom at a mean temperature. Air systems must be turned on before the hypolimnion becomes anaerobic. These systems are relatively inexpensive.

A modification of the plain aeration system is a hypolimnetic aeration system. This consists of two concentric vertical tubes normally placed entirely in the hypolimnion. The top of the larger tube is sealed. Water from near the bottom of the lake enters the smaller inner tube where an aerator both lifts the water and aerates it at the same time. At the top of the inner tube, the water overflows into the larger outer tube and is carried back downward. The aerated discharge from the larger tube is generally above the intake to minimize short circuiting back to the inlet tube. Since the entire device is placed in the cold hypolimnion, there is little impact on the temperature in the hypolimnion. Judicious placement of the intake and the discharge minimizes the impact on the lake bottom, and the system maintains the normal thermal stratification of the lake.

Oxygen has also been used instead of air. In this case, the oxygen provides the source of the reaeration. This usually requires on-site generation of the oxygen.

6.2 Weed Harvesting

A common situation in eutrophic lakes is to have a shallow (<2 m deep) shoreline filled with both submerged and emergent growths. These are considered unsightly, interfere with boating, make swimming undesirable, and make fishing nearly impossible. At the same time they provide a breeding ground for fish. Weed harvesting has been used under the guise of reducing the nutrient inputs to a lake. However, it has been estimated that they represent only in the order of 1% of the phosphorus content of the lake. They are usually harvested by a special boat that may not be able to reach the shallowest portion or certain bays in a lake. Here weeds may be removed by rake or hand pulling while wading in the shallow water. Also, the weeds harvested must be removed from the shore, or the nutrients will return to the lake as the weeds decompose. Harvesting the extensive Eurasian watermilfoil in Lake Wingra, WI, resulted in the reduction of only a small fraction of the lake's metabolically active nutrient pool [21]. This is a relatively expensive treatment for the amount of nutrient reduction accomplished. It does remove the unsightly and undesirable weeds.

Related to weed harvesting is the use of herbicides to kill the weeds. This must be applied before the weeds reach full growth and may have to be repeated during the growing season. Any dead weeds should be removed. The use of herbicides may have other undesirable environmental impacts, and they are not recommended if the water is used for drinking.

6.3 Dredging

The principle of dredging is to remove the organic sediments on the bottom of the lake that add to the nutrient supply when the hypolimnion becomes anaerobic [22, 23]. This is an expensive technology and is impractical for deep lakes. It also destroys the natural bottom of the lake. It is somewhat practical in artificial lakes or reservoirs where the water level can be drawn down (usually during the winter), and surface equipment such as bulldozers can be used for the dredging. Any dredged material must be handled in an environmentally safe way. If any hazardous contaminants are shown to be present, this could be costly. Starting in mid-August of 2012, the US Environmental Protection Agency (US EPA) has targeted up to US$57 million in Great Lakes Restoration Initiative funds for two projects in the Sheboygan River, focusing on dredging contaminated sediment from the Great Lakes' river area. [42]. Dissolved air flotation (DAF) is one of the best processes for treatment of the dredged materials [43–45]. Appendixes A, B, C, and D document the pollutant contents of the dredge materials from Ashtabula and Fairport of Ohio, USA. The pollutants in the dredged materials contain high concentrations of total phosphorus, nitrogen, oil and grease, chemical oxygen demand (COD), toxic heavy metals, and toxic volatile solids. Appendix E is a US EPA control technology summary for dissolved air flotation [46]. It appears that DAF can adequately treat the dredged materials for removal of nutrients, heavy metals, and other conventional and volatile pollutants.

6.4 Sediment Fixation

Eutrophic lakes are synonymous with significant organic bottom deposits. When these become anaerobic, they release their nutrients, specifically phosphorus. As the lake overturns, these nutrients are distributed throughout the lake, enabling more biological growth, which ultimately dies and settles to the bottom. Instead of trying to remove these sediments, chemicals may be added to more permanently precipitate the phosphorus. Aluminum salts have been found to be most effective since the aluminum phosphate remains insoluble so long as the surface of the sediments, in contact with aerobic water, remains aerobic [24, 25]. Iron salts are effective in precipitating phosphates, but in the deep anaerobic sediments, the iron combines with reduced sulfur to form ferrous sulfide that is more insoluble than the iron phosphate, thus releasing the phosphate back into solution. Calcium salts are also capable of forming precipitates of calcium phosphate; however, their high alkalinity may undesirably raise the pH of the water. This may be desirable in acid lakes. Thus, aluminum salts have been found to be most effective in tying up the phosphate permanently in the sediments. As more organic material settles to the bottom, reapplication may be necessary in future years. This becomes extremely expensive for large lakes.

One difficulty in binding the sediment phosphate is establishing adequate contact. The alum must be spread fairly uniformly over the bottom to be effective. This is usually achieved by the use of boats crisscrossing the lake. A novel system was set up in a sewage oxidation pond in California [26]. A mechanical mixer was installed in the middle of the pond, providing both mixing and aeration. Alum was applied at the mixer, which was solar powered. This eliminated a long power cord. The alum combined with both the sediment phosphorus and the soluble or suspended phosphorus in the pond, settling to the bottom. Excessive biological growth was eliminated, and the upper liquid layer met the phosphorus discharge limits to the receiving water.

7 Hypolimnetic Phosphorus Removal by DAF

A different approach is to remove the excess phosphorus from the anaerobic hypolimnion. Here the phosphorus level may be high enough to be removed by conventional precipitation by aluminum, iron, or calcium salts. A flocculation/filtration system located on the shore could accomplish this. Successful use of such a program at three lakes in Germany has been reported [27]. Further, a DAF system could be installed at the lakeshore without the cost and obstruction of a conventional sedimentation basin.

A study conducted [28] using water from eutrophic Laurel Lake in Massachusetts, adding 40 mg/L ferric chloride and subjecting it to DAF with sand filtration, showed removal of 96% to 98% of the phosphate (Tables 7.1 and 7.2.) with no iron residual. This was used to set up a pilot study for the removal of hypolimnetic phosphorus in Devils Lake, Wisconsin.

Devils Lake is surrounded by ancient bluffs in the east, west, and south [28]. The preglacial Wisconsin River flowed through a gap between these bluffs in the south range of the Baraboo Hills. Devils Lake was formed at the end of the last ice age by terminal moraines deposited at the north and the southeast ends of the gap, diverting the Wisconsin River to the east around the Baraboo Hills.

Figure 7.5 shows the depth profile of the lake [29]. Its surface area is 149 ha and its maximum depth is 14.3 m. Its mean depth averages about 9.3 m. The east and west shorelines between the bluffs are steep, while the lake's littoral zones are mostly at the north and south ends of the lake. The watershed area is relatively small, 6.86 km^2, and the ratio of watershed to lake surface area is only 4.6. Most of the watershed is forested [30]. There is only one small inlet that drains through a small wetland and no outlet. The lake water level is maintained by fluctuations in ground water level and the balance of precipitation and evapotranspiration [28].

In 1991 the Wisconsin Department of Natural Resources (WDNR) began evaluating whether hypolimnetic withdrawal and phosphorus removal would reduce sediment phosphorus concentrations with concomitant lower sediment phosphorus release during anaerobic hypolimnion periods. WDNR measured iron-bound phosphorus concentrations in profundal sediments around the lake both before and after

Table 7.1 Results of Laurel Lake bench-scale DAF studies – summer

Parameter	Units	Raw influent	DAF/filtration	Removal efficiency
Temperature	°C	16		
pH	unit	7.3	7.1	
Turbidity	NTU	7.9	0.7	91%
Color	PCU	48	<1	99%
Iron, Fe	*mg/L*			
PO_4^{3-}	*mg/L*	0.72	0.03	96%

Table 7.2. Results of Laurel Lake bench-scale DAF studies – late fall

Parameter	Units	Raw influent	DAF/filtration	Removal efficiency
Temperature	°C	8		
pH	unit	7.0	7.0	
Turbidity	NTU	17	0.3	99%
Color	PCU	132	3	98%
Fe Residual	*mg/L*	0.61	0.47	*
PO_4^{3-}	*mg/L*	1.16	0.02	98%

*Note: Iron residual after DAF is 23% below *influent* concentration

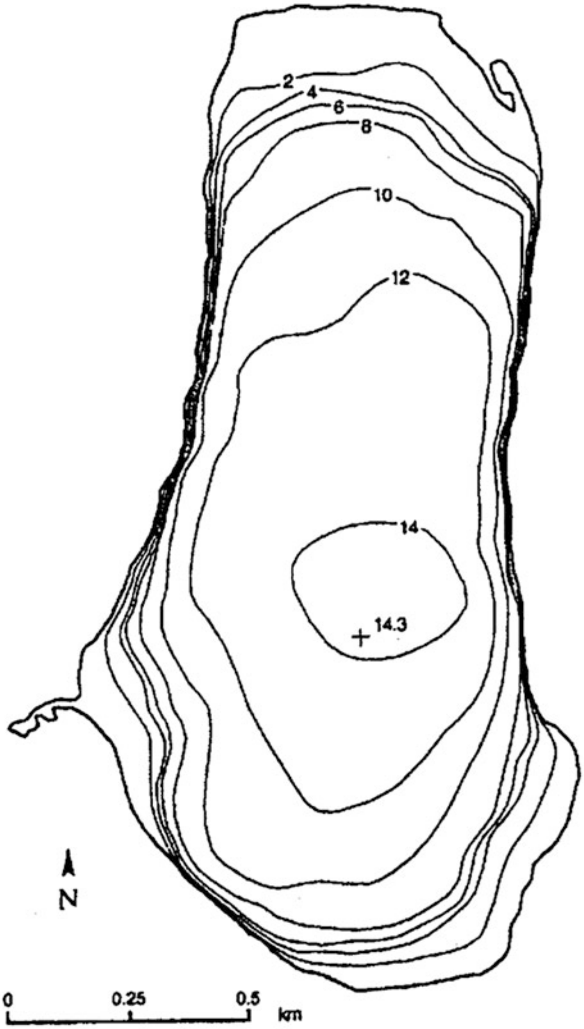


Fig. 7.5 Depth profile of Devils Lake, WI

hypolimnetic anoxia occurred in order to estimate the amount of phosphorus released to the overlying water during each season. Similar long-term laboratory column studies were conducted to support those results. The US Geological Survey (USGS) also studied lake level and water budgets to model the impact of removal of water from the hypolimnion [28]. Although a temperature-depth profile of the lake was not available, data from the phosphorus concentrations in Table 7.3. indicate that the thermocline was located at about 13 m depth on September 20, 1996. This indicates that the hypolimnion existed in only approximately 1.3 m of the bottom of the lake. It is likely that some lake cooling had occurred before September 20 and that during the warmer summer period, the thermocline was higher.

Table 7.3. Profile of Devils Lake – September 20, 1966

Depth (m)	pH (unit)	TP (mg/L)	Fe (mg/L)
0 (surface)	7.9	0.007	–
4	–	0.007	–
10.3	–	0.013	–
11.3	–	0.018	0.09
12.3	–	0.021	0.13
12.8	–	0.077	0.84
13.3	–	0.216	2.6
13.8	6.9	0.408	3.9
14.1 (0.5m off bottom)	–	0.432	4.1

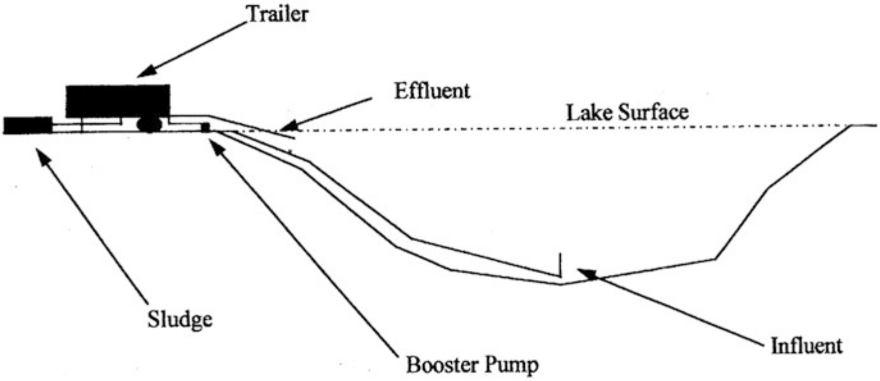


Fig. 7.6 Pilot plant setup for removal of phosphate from the hypolimnion of Devils Lake by DAF

A pilot DAF system with sand filtration was set up on the shore of Devils Lake (Fig. 7.6) and operated from September 25, 1996 through October 3, 1996 [28]. A 150 hp pump brought the hypolimnetic water to the treatment plant by means of an approximately 0.5 mile pipe that terminated approximately 14.5 m deep in the lake. The water intake had a vertical intake covered with a screen mesh to keep out bottom debris. Treated water was returned to the surface of the lake.

The coagulants used were alum, aluminum chlorohydrate (A/C), and ferric chloride, with Percol added as a coagulant aid to all tests. Each coagulant was studied individually. Dosages were varied to provide a range of results that would indicate an optimum dose. Alum dosages varied between 13.2 and 49.5 mg/L, ferric chlorides varied between 5 and 50 mg/L, and A/C varied between 6.6 and 23 mg/L. The Percol dosages varied between zero and 0.7 mg/L. Flows through the pilot plant were varied between 35 and 60 gpm.

The results of the 9-day operation of the pilot plant are shown in Table 7.4. Figures 7.7, 7.8, and 7.9 depict the results for the use of ferric chloride, A/C, and alum, respectively. It may be seen that effective phosphorus removal required a minimum of 40 mg/L of ferric chloride. Doses as low as 7 mg/L A/C resulted in

Table 7.4. Results of DAF pilot studies of phosphate removal from Devils Lake

Chemical addition mg/L	Date mo/d/yr	Influent TP mg/L	Effluent TP mg/L	Flow rate gpm	Percent removal %
49.5 Alum	092596	0.496	<0.007	40	99
47.6 Alum	092596	–	<0.007	40	99
23.0 A/C	092596	–	<0.007	40	99
20.8 Ferric	092696	0.495	0.036	35	93
13.2 Ferric	092696	–	0.045	35	93
19.8 Ferric	092696	–	0.058	30	88
15.8 Ferric	092696	–	0.204	50	59
5.0 Ferric	092796	0.436	0.130	35	70
9.4 Ferric	092796	–	0.222	35	49
10.2 Ferric	092796:	–	0.326	52	25
32 Ferric	092796	0.411	0.096	45	77
29 Ferric	092796	–	0.082	50	80
26.4 Alum	092896	0.492	0.007	45	99
17.6 Alum	092896	–	0.016	45	97
13.2 Alum	092896	–	0.013	45	97
14.4 Alum	093096	0.575	0.087	55	83
22.8 Alum	093096	–	0.019	55	96
20.4 Alum	093096	–	0.022	65	96
6.6 A/C	100196	0.588	<0.007	60	98
8.8 A/C	100196	–	0.008	60	98
7.5 A/C	100196	–	0.011	55	98
35 Ferric	100396	–	0.028	55	95
50 Ferric	100396	–	<0.007	55	99
40 Ferric	100396	–	<0.007	55	99
40 Ferric	100396	0.516	<0.007	55	99
38.1 Ferric	100396	–	<0.007	45	99

Note: alum as aluminum sulfate, ferric as ferric chloride, and A/C as aluminum chlorohydrate

effective phosphorus removal. An alum dose of 25 mg/L or more is needed to achieve effective phosphorus removal. There did not seem to be any correlation of flow rate with treatment efficiency at the flow rates studied. Considering that flocculation is slower in the cold hypolimnion waters, this represents satisfactory operation for phosphorus removal.

Based upon WDNR Table 7.1, the depth of the thermocline on September 20 was estimated to be at 13 m. Thus, at this time the volume of water in the hypolimnion was relatively small. However, the results of the phosphorus content of the inlet to the treatment system showed that hypolimnetic water was consistently used during this study. From the contour map of the lake (Fig. 7.5), the volume of the lake at its normal level would be 13,641 million m^3 (481,660 million ft^3 or 3,602,817 MG). The volume below 13 m depth was only 83,040 MG. Nevertheless, at an average pumping rate of the treatment system of 50 gpm, it would take 1,153 days to deplete

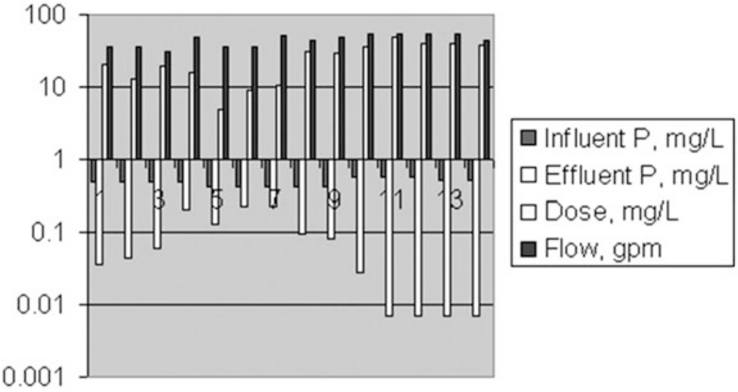


Fig. 7.7 Results of DAF pilot plant study for removal of phosphorus from the hypolimnion of Devils Lake using ferric chloride

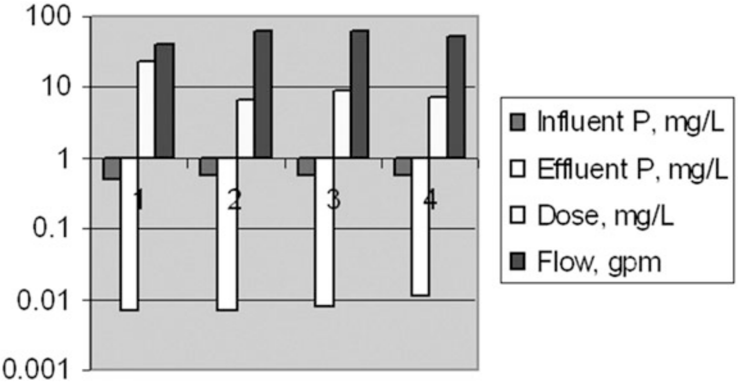


Fig. 7.8 Results of DAF pilot plant study for removal of phosphorus from the hypolimnion of Devils Lake using aluminum chlorohydrate (A/C)

the volume in the hypolimnion. Thus, it was considered that the water removed by the pilot study had minimal impact on the available water in the hypolimnion.

An estimate was made of the relative costs of the coagulants studied. Based on the 2015 US cost and the concentration needed, the following comparison was made:

Coagulant	Cost, cents per 1,000 gal (or 3,785 L)
Aluminum sulfate	0.98
Aluminum chlorohydrate	3.63
Ferric chloride	20.75

Appendix G is a US Army Corps of Engineers Civil Works Construction Yearly Average Cost Index for utilities, which has been used for the above cost estimation. An advantage of using A/C is that it does not result in any aluminum residual.

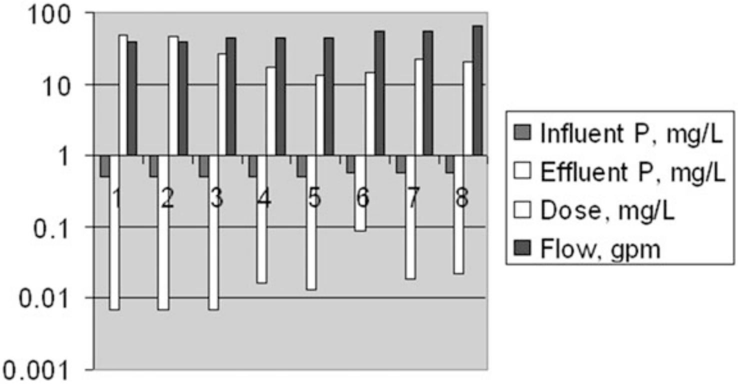


Fig. 7.9 Results of DAF pilot plant study for removal of phosphorus from the hypolimnion of Devils Lake using alum

Aluminum is toxic to some fish. Ferric chloride is not recommended due to its high cost and its potential to leave a residual color.

In order to apply the technique of phosphate removal from a hypolimnion, the first step would be to determine the volume of the hypolimnion. DAF/filtration systems of the type used in this study are available up to 13,000 gpm (49,205 L/ min). Knowing the existing phosphorus concentration and the treated effluent concentration a calculation can be made of how much volume of water would have to be treated to bring the phosphorus concentration down to an acceptable level. This may require several years of operation. However, if the lower nutrient level will reduce the biological growth to a level where the hypolimnion may remain aerobic, there will be less release of phosphorus from the benthic deposits. A further consideration is that DAF involves aerating the water. If the effluent is discharged to the hypolimnion, it may provide sufficient additional oxygen to maintain aerobic conditions. This should enter into the calculation and influence the final decision to utilize DAF/filtration (DAFF) to control lake eutrophication. The US Environmental Protection Agency (US EPA) has summarized the performance data of DAF alone (Appendix E) and supplemental filtration (Appendix F).

8 Sources, Chemistry, and Control of Acid Rain

Acid rain is a serious environmental problem that affects large parts of the United States and Canada. Acid rain is particularly damaging to lakes, streams, and forests and the plants and animals that live in these ecosystems. Acid rain is rain consisting of water droplets that are unusually acidic because of atmospheric pollution [47]; it is rain with a higher concentration of positively charged atomic particles (ions) than normal rain. Acid rain and its frozen equivalents, acid snow and acid sleet, are part of a larger problem called acid deposition. Acid deposition also includes direct deposition, in which acidic fog or cloud is in direct contact with the ground, and dry deposition, in which ions become attached to dust particles and fall to the ground. "Normal" or unpolluted rain has an acidic pH, but usually no lower than 5.7, because carbon dioxide and water in the air react together to form carbonic acid, a weak acid according to the following reaction:

$$\mathrm{H_2O(liquid) + CO_2(gas) \rightleftharpoons H_2CO_3(aqueous)}$$

Carbonic acid then can ionize in water forming low concentrations of hydronium and carbonate ions:

$$\mathrm{H_2O(liquid) + H_2CO_3(aqueous) \rightleftharpoons HCO_3{}^{-}(aqueous) + H_3O^{+}(aqueous)}$$

However, unpolluted rain can also contain other chemicals, which affect its pH (acidity level). A common example is nitric acid produced by electric discharge in the atmosphere such as lightning [48]. Acid deposition as an environmental issue (discussed later in the chapter) would include additional acids to H_2CO_3.

Acid rain is one type of atmospheric deposition. Atmospheric deposition includes any precipitation, airborne particles, or gases deposited from the atmosphere to the Earth's surface. Other forms of atmospheric deposition may also be by wet or dry methods. Much of the material in atmospheric deposition may be a nuisance but does not harm the environment. Some air pollutants, such as those in acid rain, can cause environmental problems (Fig. 7.10). It was not until the late 1960s that scientists began widely observing and studying the acid rain phenomenon [49]. Over many decades, the combined input of contaminants to sensitive environments can lead to widespread environmental problems. Smaller particles with a diameter of 10 μ (.004 in.) or less are too light to be deposited and so remain in the atmosphere where they can cause health problems. They pose a different problem and are regulated as particulates, or PM.

Acid rain occurs when sulfur dioxide and nitrogen oxides [50] are emitted into the atmosphere, undergo chemical transformations, and are absorbed by water droplets in clouds. The droplets then fall to the Earth as rain, snow, or sleet (see Fig. 7.11). This can increase the acidity of the soil and affect the chemical balance of lakes and streams. Decades of enhanced acid input has increased the environmental stress on high elevation forests and aquatic organisms in sensitive ecosystems. In extreme cases, it has altered entire biological communities and eliminated some fish species from certain lakes and streams. In many other cases, the changes have been subtler, leading to a reduction in the diversity of organisms in an ecosystem. This is particularly true in the northeastern United States, where the rain tends to be most acidic and often the soil has less capacity to neutralize the acidity. Acid rain also can damage certain building materials and historical monuments. Some scientists have suggested links to human health, but none have been proven. Public awareness of acid rain in the United States increased in the 1970s after *The New York Times* published reports from the Hubbard Brook Experimental Forest in New Hampshire of the myriad deleterious environmental effects shown to result from it [51]. Industrial acid rain is also a substantial problem in China and Russia [52].

Fig. 7.10 Atmospheric pollution (US EPA)

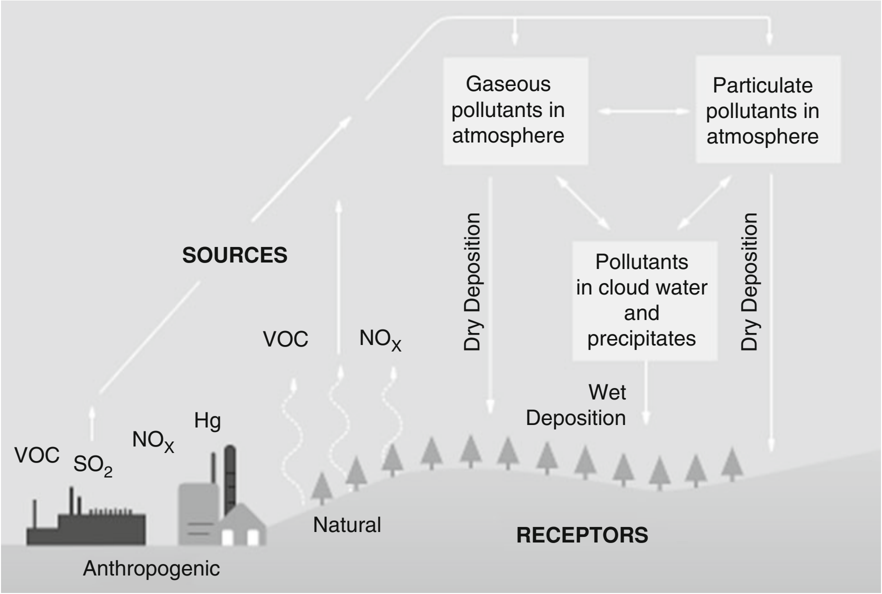


Fig. 7.11 Processes involved in acid deposition, http://www.epa.gov/acidrain/images/origins.gif (US EPA)

Acidity is measured on the per-hydrogen or pH scale. This is a measure of the concentration of positively charged ions in a given sample. It ranges from 14 (alkaline or negatively charged ions) to 0 (acidic or positive ions). Pure water has a pH of 7 (neutral). Most rainwater is slightly acidic (pH about 6). A change in the pH scale of one unit reflects a tenfold (10X) change in the concentration of acidity. Generally, rain with a pH value of less than about 5.3 is considered acid rain. Most of the rainwater, which falls in the Eastern United States, has a pH between 4.0 and 5.0. This is generally lower (more acidic) than the national average. The use of tall smokestacks installed to reduce local pollution has contributed to the spread of acid rain by releasing gases into regional atmospheric circulation, with deposition occurring at a considerable distance downwind of the emissions [53].

8.1 Effects of Acid Rain

The impacts of acid rain and deposition are varied and often interrelated, creating complex and far-reaching consequences to aquatic and terrestrial ecosystems, visibility, and public health:

1. Acid precipitation can increase the acidity of lakes and streams by either passing through soils or falling directly on water bodies. Changes in the acidity of lakes and streams can impact the survival of fish and amphibian populations by impairing the ability of certain fish and water plants to reproduce, grow, and ultimately survive.
2. Terrestrial ecosystems can also be altered by increasing acidity of precipitation and heavy metal deposition. Acids strip forest soils of essential nutrients needed to sustain plant life. This process threatens the reproduction and survival of trees and other forest vegetation.
3. Acid deposition of acidic particles is known to contribute to the corrosion of metals and to the deterioration of stonework on buildings, statues, and other structures of cultural significance, resulting in depreciation of the objects' value to society. Acid deposition can also damage paint on buildings and cars.
4. Additionally, the same gases that cause acid deposition are responsible for the formations of small particles in the air that greatly reduce visibility and can adversely affect human health. Sulfate aerosol particles and, to a lesser extent, nitrate particles in the atmosphere produced from SO_2 and NO_x emissions account for more than 50% of the visibility reduction in the Eastern United States and heavily influence concentrations of small particles or PM. These particles are small enough in size to be inhaled deeply into lung tissue, aggravating the reparatory and cardiopulmonary systems, especially in sensitive populations (people with asthma, emphysema, or other respiratory illnesses).

The most obvious environmental effect of acid rain has been the loss of fish in acid-sensitive lakes and streams. Many species of fish are not able to survive in acidic water. Acid rain affects lakes and streams in two ways: chronic and episodic

[47]. Chronic or long-term acidification results from years of acidic rainfall. It reduces the alkalinity (buffering capacity) and increases the acidity of the water. Chronic acidification may reduce the levels of nutrients and minerals such as calcium and magnesium, which, over time, may weaken the fish and other plants and animals in an aquatic ecosystem:

$$2\ \mathrm{H}^+(\text{aqueous}) + \mathrm{Mg}^{2+}(\text{clay}) \rightleftharpoons 2\ \mathrm{H}^+(\text{clay}) + \mathrm{Mg}^{2+}(\text{aqueous})$$

$$2\ \mathrm{H}^+(\text{aqueous}) + \mathrm{Ca}^{2+}(\text{clay}) \rightleftharpoons 2\ \mathrm{H}^+(\text{clay}) + \mathrm{Ca}^{2+}(\text{aqueous})$$

Most of the effects on forests are subtle. Acid deposition may influence forest vegetation and soils. Acid rain weakens the trees' natural defenses, making them more vulnerable to diseases. Acid rain has been cited as a contributing factor to the decline of the spruce-fir forests throughout the Eastern United States. Acid rain may remove soil nutrients such as calcium and magnesium from soils in high elevation forests and cause damage to needles of red spruce. Acid rain may also help weaken natural defenses of some trees, making them more vulnerable to some diseases and pests.

Episodic acidification is a sudden jump in the acidity of the water. This can result from a heavy rainstorm. It also happens in the spring, because the sulfates and nitrates will concentrate in the lowest layers of a snowpack. In the spring, when that snow melts, it will be more acidic than normal. Episodic acidification can cause sudden shifts in water chemistry. This may lead to high concentrations of substances such as aluminum, which may be toxic to fish.

Acid rain deposits nitrates that can lead to increases in nitrogen in forests. Nitrogen is an important plant nutrient, but some forest systems may not be able to use all they receive, leading to nitrogen saturation. In the Eastern United States, there is evidence of nitrogen saturation in some forests. Nitrates can remove additional calcium and magnesium from the soils. Continued nitrogen deposition may alter other aspects of the nutrient balance in sensitive forest ecosystems and alter the chemistry of nearby lakes and streams.

Excess nitrogen may cause eutrophication (over nourishment) in areas where rivers enter the ocean. This may lead to unwanted growth of algae and other nuisance plants. As much as 40% of the total nitrogen entering coastal bays on the Atlantic and Gulf Coasts may come from atmospheric deposition. Table 7.5 shows estimates of the percentage of nitrogen deposition, which comes from the atmosphere.

Acid rain can react with aluminum in the soil. Trees cannot absorb naturally occurring aluminum, but acid rain may convert it to aluminum sulfate or aluminum nitrate. These can be absorbed by the trees and may adversely affect them. The effects of acid rain, combined with other environmental stressors, leave trees and plants less able to withstand cold temperatures, insects, and disease [54]. The pollutants may also inhibit trees' ability to reproduce. Some soils are better able to neutralize acids than others. In areas where the soil's "buffering capacity" is low, the harmful effects of acid rain are much greater.

Table 7.5 Nitrogen input from the atmosphere to New England bays and estuaries [1]

Bay	Atmospheric contribution as % of total nitrogen input
Casco Bay (ME)	About 40%
Massachusetts Bay (MA	5–27%
Waquoit Bay (MA)	29%
Narragansett Bay (RI)	4–12%
Long Island Sound (CT)	About 20%

Acid rain has not been shown to be harmful to human health, but some of the particles, which can be formed from sulfate and nitrate ions, can affect respiration. They can be transported long distances by winds and inhaled deep into people's lungs. Fine particles can also penetrate indoors. Many scientific studies have identified a relationship between elevated levels of fine particles and increased illness and premature death from heart and lung disorders, such as asthma and bronchitis.

Acid deposition has also caused deterioration of buildings and monuments. Many of these are built of stone that contains calcium carbonate. Marble is one such material. The acid rain can turn the calcium carbonate to calcium sulfate (gypsum). The calcium sulfate can crumble and be washed away:

$$\mathrm{CaCO_3(solid) + H_2SO_4(aqueous) \rightleftharpoons CaSO_4(solid) + CO_2(gas) + H_2O\ (liquid)}$$

Acid rain also increases the corrosion rate of metals, in particular iron, steel, copper, and bronze. Figure 7.12 shows how Harvard University wraps some of the bronze and marble statues on its campus with waterproof covers every winter, in order to protect them from erosion caused by acid rain and acid snow.

8.2 History and Regulations

Acid rain was first observed in the mid-nineteenth century, when some people noticed that forests located downwind of large industrial areas showed signs of deterioration. The term "acid rain" was coined in 1872 by Robert Angus Smith, an English scientist [47]. Smith observed that acidic precipitation could damage plants and materials.

Acid rain was not considered a serious environmental problem until the 1970s. During that decade, scientists observed the increase in acidity of some lakes and streams. At the same time, research into long-range transport of atmospheric pollutants, such as sulfur dioxide, indicated a possible link to distant sources of pollution. Many power plants use coal with a relatively high concentration of sulfur as fuel. Scientists realized that sulfur dioxide emitted from many of these plants could be transported to the Northeast. When we began to see acid rain as a regional, rather than a local, problem, the federal government had to become involved.

Fig. 7.12 Harvard University wraps some of the bronze and marble statues on its campus, with waterproof covers every winter, in order to protect them from erosion caused by acid rain and acid snow (Wikipedia) https://en.wikipedia.org/wiki/Acid_rain#/media/File:Bixi_stele_(wrapped),_Harvard_University,_Cambridge,_MA_-_IMG_4607.JPG

In 1980, the US Congress passed an Acid Deposition Act. From the start, policy advocates from all sides attempted to influence NAPAP (National Acid Precipitation Assessment Program) activities to support their particular policy advocacy efforts or to disparage those of their opponents [55]. This Act established a 10-year research program under the direction of the NAPAP program. NAPAP looked at the entire problem. It enlarged a network of monitoring sites to determine how acidic the precipitation actually was and to determine long-term trends and established a network for dry deposition. It looked at the effects of acid rain and funded research on the effects of acid precipitation on freshwater and terrestrial ecosystems, historical buildings, monuments, and building materials. It also funded extensive studies on atmospheric processes and potential control programs. Significant impacts of NAPAP were lessons learned in the assessment process and in environmental research management to a relatively large group of scientists, program managers, and the public [56].

In 1991, NAPAP provided its first assessment of acid rain in the United States. It reported that 5% of New England Lakes were acidic, with sulfates being the most common problem. They noted that 2% of the lakes could no longer support brook trout and 6% of the lakes were unsuitable for the survival of many species of minnow. Subsequent reports to Congress have documented chemical changes in soil and freshwater ecosystems, nitrogen saturation, decreases in amounts of nutrients in soil, episodic acidification, regional haze, and damage to historical monuments.

Meanwhile, in 1990, the US Congress passed a series of amendments to the (CAA) Clean Air Act. One was the inclusion of section 112(m), Atmospheric Deposition to Great Lakes and Coastal Waters (ADGLCW). The biennial report required by this section of the CAA amendments is to cover the following [57]:

1. The contribution of atmospheric deposition to pollution loadings in the Great Waters
2. The environmental and public health effects of any pollution attributable to atmospheric deposition to these waterbodies
3. The sources of any pollution attributable to atmospheric deposition to these waterbodies
4. Whether pollution loadings in these waterbodies cause or contribute to exceedances of drinking water or water quality standards or, with respect to the Great Lakes, exceedances of the specific objectives of the Great Lakes Water Quality Agreement
5. Descriptions of any revisions of the requirements, standards, and limitations of relevant CAA and federal laws to ensure protection of human health and the environment

The *First* and *Second Great Waters Reports to Congress* on atmospheric deposition to the Great Waters were published in May 1994 (US EPA 1994) and June 1997 (US EPA 1997). The first two reports presented the programmatic background and covered the scientific issues that are addressed by the Great Waters program. The *Third Great Waters Report to Congress* provides an update to the information presented in previous reports and specifically highlights progress made since the *Second Report to Congress*, including changes in pollutant emissions, deposition, and effects, as well as recent advancements in the scientific understanding of relevant issues. In addition, the report discusses recent activities and accomplishments of the many different initiatives that help protect the Great Waters from pollutants deposited from the atmosphere.

The amendments also established research, reporting, and potential regulatory requirements related to atmospheric deposition of HAPs (hazardous air pollutants) to the “Great Waters. Title IV of these amendments established a program designed to control emissions of sulfur dioxide and nitrogen oxides. Title IV called for a total reduction of about 10 million tons of SO_2 emissions from power plants. It was implemented in two phases. Phase I began in 1995 and limited sulfur dioxide emissions from 110 of the largest power plants to a combined total of 8.7 million tons of sulfur dioxide One power plant in New England (Merrimack) was in Phase I. Four other plants (Newington, Mount Tom, Brayton Point, and Salem Harbor) were added under other provisions of the program. Phase II began in 2000 and affects most of the power plants in the country.

Emissions of nitrogen oxide and nitrogen dioxide, generally called NO_x, have been reduced by a variety of programs required under the Clean Air Act. NO_x is emitted by anything burning fuel, such as power plants, large factories, automobiles, trucks, and construction equipment.

In New England, between 1990 and 2000, we have seen a 25% decrease in NO_x emissions from all sources (from approximately 897,000 tons to 668,000 tons). Between 2000 and 2006, NO_x emissions from acid rain-affected power plants in New England have further decreased by more than 31,000 tons. During that same period, SO_2 emissions from those power plants have decreased by 54% (from approximately 211,000 tons to 96, 500 tons).

During the 1990s, research has continued and gradually developed a better understanding of acid rain and its effects on the environment. A closer look at soil chemistry showed how acid rain has changed the balance of calcium, aluminum, and other elements. Since acid rain makes waters acidic, it causes them to absorb the aluminum that makes its way from soil into lakes and streams. Sulfur dioxide pollution mostly from coal-fired power plants was causing acid rain and snow, killing aquatic life and forests. A debate ensued: Regulation would direct all plant owners to cut pollution by a set amount, but this method, critics argued, would be costly and ignore the needs of local plant operators. The solution was devised to cap-and-trade approach, written into the 1990 Clean Air Act. It required cutting overall sulfur emissions in half, but let each company decide how to make the cuts. Power plants that lowered their pollution more than required could sell those extra allowances to other plants. A new commodities market was born. Sulfur emissions went down faster than predicted and at one fourth of the projected cost. Since its launch, cap-and-trade for acid rain has been regarded widely as highly effective at solving the problem in a flexible, innovative way [58]. Since this first historic success, efforts were expanded to help create new market mechanisms that account for the impact to the environment. This solution has served as the inspiration behind one of the most powerful tools we have to fight climate change: carbon markets [58].

The success of the Acid Rain Program has led to consideration of other programs based on setting an emissions cap. The NO_x budget program, which began in 1999, places a limit on NO_x emissions from power plants and some other sources during the warmer months of the year. Its purpose is to control ground level ozone, but it will have some effect on acid rain also. Massachusetts, New Hampshire, and Connecticut have designed their own programs to further limit emissions of NO_x and SO_2. Connecticut's rule contributed to a 68% decrease in SO_2 emissions from large sources from 2001 to 2002 [47].

On March 10, 2005, US EPA issued the Clean Air Interstate Rule (CAIR). This rule provides states with a solution to the problem of power plant pollution that drifts from one state to another. CAIR permanently capped emissions of SO_2 and NO_x in the Eastern United States. US EPA's CAIR addressed regional interstate transport of soot (fine particulate matter) and smog (ozone), which are associated with thousands of premature deaths and illnesses each year. CAIR required 28 eastern states to make reductions in sulfur dioxide (SO_2) and nitrogen oxide (NO_X) emissions that contribute to unhealthy levels of fine particle and ozone pollution in downwind states. Once it was fully implemented, CAIR reduced SO_2 emissions in 28 eastern states and the District of Columbia by over 70% and NO_x emissions by over 60% from 2003 levels [59]. CAIR was replaced by the Cross-State Air Pollution Rule (CSAPR), as of January 1, 2015.

On July 6, 2011, the US Environmental Protection Agency finalized the rule that protects the health of millions of Americans by helping states reduce air pollution and attain clean air standards. This rule, known as the Cross-State Air Pollution Rule (CSAPR), requires states to significantly improve air quality by reducing power plant emissions that contribute to ozone and/or fine particle pollution in other states [60]. In a separate, but related, regulatory action, US EPA finalized a supplemental rulemaking on December 15, 2011 to require five states – Iowa, Michigan, Missouri, Oklahoma, and Wisconsin – to make summertime NO_X reductions under the CSAPR ozone season control program. CSAPR requires a total of 28 states to reduce annual SO_2 emissions, annual NO_X emissions, and/or ozone season NO_X emissions to assist in attaining the 1997 ozone and fine particle and 2006 fine particle National Ambient Air Quality Standards (NAAQS).

8.3 Causes of Acid Rain

Two elements, sulfur and nitrogen, are primarily responsible for the harmful effects of acid rain. Sulfur is found as a trace element in coal and oil. When these are burned in power plants (see Fig. 7.13) and industrial boilers, the sulfur combines with oxygen to form sulfur dioxide (SO_2). Because SO_2 does not react with most chemicals found in the atmosphere, it can travel long distances. Eventually, if it comes in contact with ozone or hydrogen peroxide, it can be converted to sulfur trioxide. Sulfur trioxide can dissolve in water, forming a dilute solution of sulfuric acid. In the gas phase sulfur dioxide is oxidized by reaction with the hydroxyl radical via an intermolecular reaction:

$$SO_2 + OH\bullet \rightarrow HOSO_2\bullet$$

which is followed by:

$$HOSO_2\bullet + O_2 \rightarrow HO_2\bullet + SO_3$$

In the presence of water, sulfur trioxide (SO_3) is converted rapidly to sulfuric acid:

$$SO_3(\text{gas}) + H_2O\ (\text{liquid}) \rightarrow H_2SO_4(\text{aqueous})$$

Nitrogen makes up about 78% of the atmosphere. When heated to the temperatures found in steam boilers and internal combustion engines, it can combine with oxygen from the atmosphere to form nitrogen oxide and nitrogen dioxide (NO_x). NO_x is the sum of nitrogen oxide and nitrogen dioxide in a given parcel of air. These can dissolve in water, forming weak solutions of nitric and nitrous acids. Nitrogen dioxide reacts with OH to form nitric acid:

Fig. 7.13 The coal-fired Gavin Power Plant in Cheshire, Ohio https://upload.wikimedia.org/wikipedia/commons/7/75/Gavin_Plant.JPG (Wikimedia) Clouds of sulfuric acid coming from the vertical column stacks. The emissions from the Cooling Towers are just water vapor

$$NO_2 + OH\bullet \rightarrow HNO_3$$

NO_x and SO_2 can come from natural or human-made (anthropogenic) sources. Volcanoes and sea spray are typical natural sources of SO_2. Lightning is the most common natural source of NO_x. Contributions from natural sources are generally small compared to those from anthropogenic sources.

US EPA classifies the sources of anthropogenic emissions of pollutants into three groups: point (or stationary) sources, area sources, and mobile sources. Point sources include factories, power plants, and any other large “smokestack” facilities. Area sources consist of smaller facilities, which occur in greater numbers. These include residential heating equipment, small industry, and other categories in which it is impractical to analyze each individual emission source. Mobile sources include anything that can move. They can be divided into on-road sources (including cars, trucks, buses, motorcycles, etc.) and non-road (tractors, snowmobiles, boats, airplanes, lawnmowers, etc.).

Point sources emit the largest amount of SO_2. Of these, coal-fired power plants are the highest emitters. The Brayton Point Station in southeastern Massachusetts is the largest point source for SO_2 in New England. In 2006, 16 units at eight facilities emitted a total of 82,129 tons of sulfur dioxide.

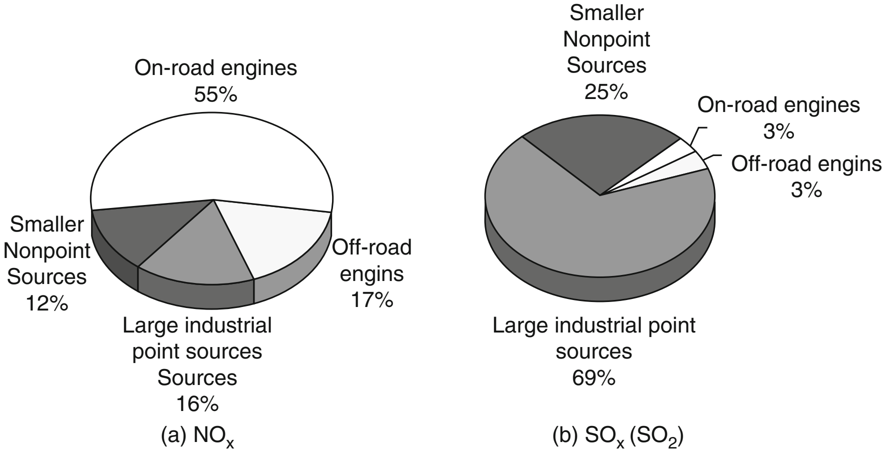


Fig. 7.14 Emissions of NO_x and SO_x (SO_2) in New England in 2002 [15]

Figure 7.14 charts show how much each group contributed to emissions of NO_x and SO_x (SO_2) in New England in 2002 [47, 61]: Once SO_2 and NO_x have been released into the air, they can be transported by the wind. The prevailing winds above most of the United States flow from west to east. Storm systems and other meteorological events may alter this flow. The final effects of these pollutants may occur as much as 1000 miles from where they were released. Eventually, these elements will dissolve in water droplets and be converted into nitrate and sulfate ions. In this form, they may return to Earth through acid deposition. Acid deposition occurs when these ions are deposited to the ground. It may be in the form of wet deposition, either indirect (acid rain, acid snow) or direct (acid fog), or dry deposition.

Prior to the mid-1990s, most scientists felt that the most common method of acidic deposition was by rain and other forms of wet deposition. This is the most visible and best understood means of deposition. It is easy to measure, and its effects are most obvious. Acid snow tends to carry less acidity per unit of water, since the chemistry is slower in cold weather, but since snow accumulates over the course of a season, when it melts, it releases a surge of acidity. At higher altitudes, direct deposition can occur when clouds descend to the surface. This can cause a severe problem because it may last for hours [47].

Dry deposition occurs when sulfate or nitrate ions do not dissolve in water, but rather fall to the surface as small particles or go directly from gaseous form in the atmosphere to soil or water. Unlike wet deposition, dry deposition is not easily measured. Very little falls at one time or at one location, but since dust is constantly settling to the Earth’s surface and the atmosphere is constantly in contact with the Earth, it can potentially have a large impact. As we have learned more about it, we realize it is an important part of acid deposition, and as the amount of acidity in rain decreases, dry deposition has become a more prominent route for deposition. Dry deposition now accounts 20–60% of the total deposition.

8.4 Reducing Acid Rain

Reducing emissions of SO_2 and NO_x is necessary if we are to reduce acid deposition. The first attempts at reducing SO_2 took place in 1936 at the Battersea Plant in London, England. In recent years, we have made considerable progress in finding ways to reduce emissions of both SO_2 and NO_x.

There are two principal methods for reducing sulfur emissions at power plants and other facilities that burn coal or oil: fuel switching and scrubbing. Fuel switching means replacing coal or oil, which contains more sulfur, by fuels such as natural gas, which has little or no sulfur. Scrubbing means removing sulfur by electrostatic or chemical (wet or dry scrubbing) means. Electrostatic involves placing electrically charged plates, called electrostatic precipitators, inside the industry's stack. These attract the positively charged sulfur particles to the surface. The surface is periodically cleaned, removing the sulfur before it gets into the air. Wet scrubbing means injecting water or a chemical solution into the exhaust gases. Dry scrubbing involves a chemical such as lime, which reacts with the gases without the use of water. The sulfur will react with the water or chemical and fall out. All types of scrubbing do pose a problem; we must find an environmentally acceptable way of disposing of the sulfur after we have removed it.

There are several methods of reducing NO_x emissions. Some are mechanical: changing the ratio of air to fuel or changing the temperature of the combustion. The cooler the flame is, the less NO_x the furnace gives off. Others are chemical: injecting chemicals such as ammonia, which will react with the NO_x and convert it back into nitrogen and oxygen.

US EPA's Acid Rain Program (ARP) has given the utility industry a reason to reduce SO_2 and NO_x emissions. This program was established by Title IV of the 1990 Clean Air Act Amendments. It set a cap on the amount of SO_2 power plants can emit. The program also addressed NO_x emissions, but only set maximum emission rates based on the type of boiler [62].

The Acid Rain Program focused on power plants, the largest single source of SO_2 emissions and a major source of NO_x emissions. The plants affected by the program submitted permit applications explaining how they planned to comply with the program. US EPA issues permits to each facility. The program also requires the use of continuous emissions monitors (CEMs), which measure their emissions and transmit the information directly to US EPA.

A unique element of the program is its use of emissions trading as a compliance option. Although the national cap on emissions limits the total SO_2 released into the air, companies may decide the most cost-effective method. Each plant is assigned a number of "allowances," based on their average annual SO_2 emissions during the period from 1985 to 1987. These could be bought, traded, sold, or held. At the end of the year, each facility has to surrender one allowance for each ton of SO_2 it emitted. US EPA set up an allowance tracking system and also set up auctions and direct sales to enable plants, which were not assigned allowances to obtain those they needed to operate. In 1990, the 263 units designated as part of the Phase I program emitted 10.0 million tons of SO_2. In 1995, the first year in which the units were required to comply with Phase I of the program, they reduced their emissions to 5.3 million tons. This is a 47% reduction in emissions over 5 years [62].

Phase II of the program began in 2000. It affects more power plants and gives all of the plants fewer allowances. Merrimack Station in New Hampshire had 31,343 allowances per year in Phase I. They have 13,530 allowances in Phase II. This will lead to further reductions in SO_2 emissions.

The SO_2 cap and allowance trading system proved successful and is now being used or considered for use to regulate several other pollutants, including NO_x and carbon dioxide.

The Acid Rain Program (ARP) also monitors and limits emission of NO_x. In New England, the acid rain NO_x rules have not had a noticeable effect, because other programs have imposed more stringent limits.

The Acid Rain Program also promotes the use of renewable energy and energy conservation. Some allowances were set aside to award to companies, which encouraged residential, commercial, and industrial conservation or used certain forms of renewable energy. Six New England companies were awarded 4,186 allowances for energy conservation and for using biomass and landfill gas as a source of energy. Allowances are also available for solar, wind, and geothermal energy.

New England states have also been active in the fight against acid rain. Prior to 1990, Massachusetts and New Hampshire had passed laws limiting the emissions from power plants. In 2001, Massachusetts adopted regulations that will further limit emissions from large power plants by as much as 75% of SO_2 and 50% of NO_x. Connecticut has adopted regulations that will further limit emissions by as much as 50% of the SO_2 and 30% of the NO_x currently being emitted.

The United States has been working with Canada to reduce transboundary effects of acid deposition. A bilateral Air Quality Agreement was signed in March 1991. The third biennial report, published in 1996, focused on the progress made by the United States and Canada in achieving emissions reduction goals. Their 2006 Annual Progress Report reported that both countries have made progress in reducing emissions, which lead to acid rain. The Integrated Atmospheric Deposition Network (IADN) was established in 1990 to collect data that can be useful in assessing the relative importance of atmospheric deposition. The IADN program established a database for atmospheric deposition data in both countries.

Individuals can also help prevent acid rain by conserving energy. The less electricity people use in their homes, the fewer chemicals power plants will emit. Vehicles are also major fossil fuel users, so drivers can reduce emissions by using public transportation, carpooling, hybrid and electric cars, biking, or simply walking wherever possible [2].

8.5 Acid Rain Permit Program

US EPA's Acid Rain Program was developed in response to Title IV of the 1990 Clean Air Act Amendments. The program requires most power plants and other facilities that choose to participate in the program to obtain a permit [63, 64].

An Acid Rain Permit tells us how the power plant plans to comply with the Acid Rain Program. It may be issued separately from other permits required by US EPA, but eventually becomes part of the plant's Title V Permit [65]. The owners of the plant send an application to the appropriate agency. The agency, after checking to see if the application is complete, reviews the application and issues the permit.

During Phase I of the Acid Rain Program (1995–2000), US EPA Regional Offices issued permits to those power plants, which participated. In New England, Merrimack Station in Bow, NH, was the only station required to participate. Four other power plants (Newington Station, Portsmouth, NH; Mount Tom, Chicopee, MA; Salem Harbor, Salem, MA; Brayton Point, Somerset, MA) also participated in Phase I under other provisions of the program. US EPA New England issued Phase I permits to each of these plants. The Phase I permits expired on January 1, 2000.

During Phase II (2000–present), the permits are issued by the states. Each New England State has a program, which issues permits. In Vermont, the Acid Rain Permit is generally issued as part of the Title V Permit. Other states generally issue the Acid Rain Permit first and later incorporate it into the Title V Permit. Acid Rain Permits are usually issued for a period of 5 years [66]. Each of these facilities has filed an Acid Rain Permit application with the appropriate state, and the state has issued a permit.

8.6 Acid Rain Monitoring

Continuous emissions monitors (CEMs) tell us how much of a pollutant a power plant (or other affected facility) emits. Under the Acid Rain Program, each affected unit must monitor emissions of sulfur dioxide and nitrogen oxides. Most also measure carbon dioxide. CEMs are the most common way to monitor emissions, but in some cases, utilities may use an approved alternate method. For example, if a unit burns oil and they know the sulfur content of the oil and the amount they used, they can compute the amount of sulfur dioxide they will emit.

Each plant in the Acid Rain Program must submit a monitoring plan to US EPA and revise it as their monitoring system changes. This document tells which monitors will be used, where they will be located, and how the data will be gathered and sent to US EPA. If a plant's monitoring system changes, they must revise their monitoring plan.

There are several ways to monitor emissions from a plant. Nitrogen oxides are measured by taking a sample of the gas emitted thought the plant's smokestack and analyzing it. In some cases, sulfur dioxide is measured this way, but it can also be computed sulfur emissions from the fuel's sulfur content. When plants use natural gas, which contains only traces of sulfur, it may be estimated by assuming the gas contains a certain low amount of sulfur. Sulfur emissions from such plants are so low that an actual measurement of sulfur dioxide is impractical.

Power plants must submit data whenever they are operating. If their monitor is not operating, they must report a "default" value, which is generally the maximum amount of the pollutant they can emit. US EPA gathers the data and tabulates the emissions from each plant. The latest, 2013, ARP, and CAIR emission reductions are as follows [67]:

1. CAIR and ARP Annual SO_2 Emissions: 3.2 million tons (69% below 2005)
2. CAIR and ARP Annual NO_x Emissions: 1.7 million tons (53% below 2005)
3. CAIR Ozone Season NO_x Emissions: 470,000 tons (41% 2005)
4. Ambient particulate sulfate concentrations have decreased since the ARP was implemented, with average concentrations decreasing by 60 to 65% in observed regions from 1989–1991 to 2011–2013
5. The Northeast and Mid-Atlantic have showed the greatest improvement with an overall 64% reduction in wet sulfate deposition from 1989–1991 to 2011–2013

8.7 Acid Rain Allowances

The Acid Rain Program uses a market-based approach to control sulfur dioxide emissions from power plants. Under the current system, known as a "cap and trade" system, it limits, or caps, sulfur dioxide emissions by issuing a fixed number of allowances and allowing only one ton of SO_2 to be emitted per allowance. The total number of allowances is distributed by US EPA each year. Each power plant that was operating during the years from 1985 to 1987 is assigned a number of allowances based on their emissions of sulfur dioxide during that period. Each power plant must hold one allowance for each ton of SO_2 they emit. At the end of the year, these facilities must surrender a number of allowances equal to the number of tons of SO_2 they emitted during the year. If they emit more SO_2 than they have allowances, they must buy additional allowances. Conversely, if they can further reduce their emissions, they can sell their excess allowances. Some allowances were withheld by US EPA and are made available through an annual auction. By limiting the number of allowances, US EPA can limit the amount of SO_2 the power plants release.

The Acid Rain Program was implemented in two phases. During Phase I (1995–2000), 11 units at five New England Stations were allocated a total of 167,779 allowances. During Phase II (starting in 2000), 27 facilities (about 80 units) in New England received a total of 273,150 allowances. The number per unit was reduced during Phase II, so the total amount of SO_2 was also reduced. The five units in Phase I received only 91,136 allowances per year in Phase II [68].

New units, which were not operating in 1987, are not assigned allowances. They must obtain the necessary allowances from other units or buy them.

In 1995, US EPA issued about 8.7 million allowances to Phase I units. If all were used, this would have resulted in a 2.2-million-ton reduction from the 1980 level. Actual emissions in 1995 were 5.3 million tons. That means that in 1995, SO_2 was reduced by 5.6 million tons. Of the 3.4 million unused allowances in that year, about 36,000 were sold or donated to private individuals or environmental groups and "retired." This effectively lowered the cap for SO_2 emissions for that year. The other allowances were held either by brokerage firms or by the utilities themselves.

Holding allowances does not automatically allow a plant to emit SO_2. They are still subject to other state and federal permit conditions, which may further limit their emissions. Also, they may not cause exceedances of US EPA's National Ambient Air Quality Standards (NAAQS) or Prevention of Significant Deterioration (PSD) limits.

8.8 Acid Rain Measurement

In the 1970s, we realized the importance of monitoring the acidity of rainfall. The National Atmospheric Deposition Program (NADP) was formed in 1977 to investigate and measure acid deposition. There were 22 stations nationwide in 1978. Currently, the National Trends Network, which now conducts measurements for NADP, has nearly 220 stations. Each station (Fig. 7.15) collects a sample once a week. Samples are collected in a container. This container is covered until rain begins. The presence of water automatically opens the container, and it remains open until the rain stops. These samples are analyzed and sent to a central location. The data go into a database, which now stores data from over 20 years, and give us a feel for how acidity varies with location and also the trend over this period. This picture above shows a typical acid rain monitor. The container on the left represents an attempt to measure dry deposition. When precipitation begins, a sensor causes the cover to move from the right container to the left. Rainwater will then collect in the right container [69].

Fig. 7.15 Acid rain monitor, Glacier National Park, MT, USA [23]

Dry deposition is difficult to measure directly. There have been attempts to use a method similar to that for wet deposition, but it usually takes too long to cover the collector when rain starts. It takes only a few drops of rain to contaminate a dry deposition sample. The Clean Air Status and Trends Network (CASTNet) calculates dry deposition using atmospheric conditions, meteorological data, and information on land use, vegetation, and surface conditions.

Other programs have looked at changes in the acidity of lakes, streams, and soil. Monitored data for some lakes are available from as early as 1980. Facilities such as Hubbard Brook in New Hampshire have been measuring the acidity of streams and lakes on their 7800-acre property. They also have looked at soil chemistry and effects on the entire ecosystem.

In addition to specific efforts to measure acid rain, EPA maintains monitoring networks for monitoring SO_2 and NO_2 in the air for other programs. Although these programs are not intended to consider acid rain, they do give us an idea of the amount of these chemicals in the air at certain locations.

8.9 Trends

Figures 7.16 and 7.17 show how SO_2 and NO_x emissions from power plants in New England in the Acid Rain Program have decreased since 1990 to 2011. Data for 1995 and later years come from continuous emissions monitor data as reported by US EPA's Clean Air Markets (CAM) Division's Acid Rain Progress Reports 2013 or Emissions Data and Compliance Reports [70].

Data for 1990–1994 are estimates based on fuel usage and US EPA's conversion factors. It is provided by the Clean Air Markets Division.

The graphs presented above show how emissions (i.e., what we put into the air) have changed over time. We next look at some observations of how deposition (i.e., what comes out of the air) has changed over time.

As emissions of sulfur dioxide have decreased, we have noticed some improvement in the atmosphere in recent years. A recent report prepared for EPA by Paul Miller of the Northeast States for Coordinated Air Use Management (NESCAUM) shows a decrease of about 25% in average sulfate deposition in Maine between 1980 and 1999. Similar decreases in sulfate deposition have been observed through much of the Northeast.

Data for 1993 through 1998 show no marked systematic trend of pollutants in precipitation for the New England sites. Sulfate deposition in 1995 showed a marked decline at every monitoring site in New England, except the Acadia NP site in Maine. The average 1995 sulfate deposition in New England was the lowest ever recorded during the 20 years of sulfate deposition monitoring. The 1996 data indicate that sulfate deposition increased in eight of the ten sites. Nonetheless, sulfate levels in 1996 were about 16% below historical averages (1979–1995). The 1996 data show similar increases occur for nitrate at most sites, and these increases appear to be further enhanced in 1997. In 1998, however, nitrate deposition decreased at

Fig. 7.16 SO_2 emissions from all New England facilities in US EPA Acid Rain Program, 2013 [24]

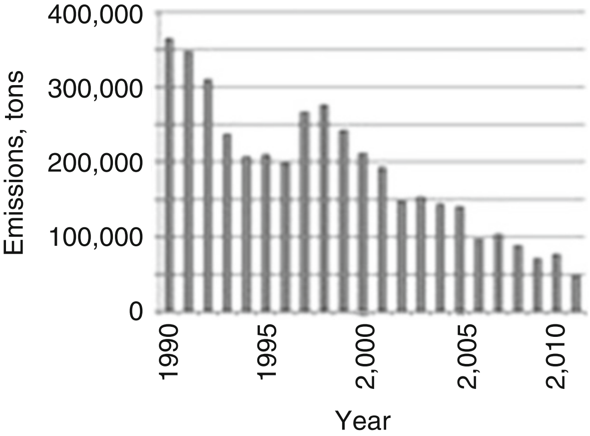
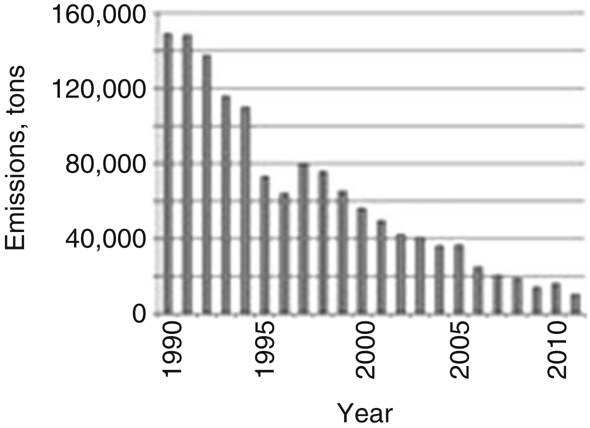


Fig. 7.17 NO_x emissions from all New England facilities in US EPA's Acid Rain Program, 2013 [24]



each of the ten trend sites. Nitrate deposition during 1998 remained virtually the same as the historical average (1979–1998). In the years since 1998, the we have seen a trend toward less sulfate in precipitation in New England. Until about 2000, trends in nitrate remained fairly constant, but since 2000, even the nitrate deposition in New England has begun to decrease.

The year-to-year variation that is recorded at the NADP sites can be attributed to differences in precipitation and prevailing wind patterns, as well as emission sources. This is characteristic of precipitation data and should be viewed as normal. Trends in pollutant deposition within New England, whether due to long-term changes in pollutants emitted to the atmosphere or trends in climate, will be evident only after many years (10–20+ years).

Lakes and streams have been slower to respond, but we have begun to see improvement. A report in *Nature* Magazine in 1998 showed some improvement in lakes in Maine, but not elsewhere in New England. In 2003, US EPA compiled an assessment of the surface chemistry of lakes and streams in the Northern and Eastern United States. This assessment showed that the concentration of sulfate in New England lakes is decreasing. About 30% of the lakes in New England that were acidic are no longer considered acidic. In New England, the "acid neutralization capacity" (ANC), the ability of the environment to neutralize acidic precipitation, has not significantly improved, but this was observed in the Adirondacks and in other areas. The soil in New England is slower to react than that in the Adirondacks, so it will take longer for the ANC in New England to improve.

The full recovery of New England's aquatic ecosystems will take more time. In some cases, it will be decades before we see ecosystems fully restored to their pre-industrial condition.

8.10 Acid Rain and Other Pollution Problems

In addition to the direct effects of acid rain, both the emissions and the attempts to control them affect other forms of environmental pollution.

Sulfur and nitrate emissions can also lead to the formation of small particles. These particles are too small to fall out of the atmosphere. They can get deep into your lungs, and some may even get into your bloodstream. Exposure to such particles can affect both the lungs and the heart. Larger particles are of less concern, although they can irritate the eyes, nose, and throat [71].

Also, small particles scatter light, which can reduce visibility. This detracts from our appreciation of the many magnificent scenic vistas in New England and the rest of the world. This is called Regional Haze problem [72]. US EPA and other agencies have been monitoring visibility in national parks and wilderness areas since 1988. In 1999, the US Environmental Protection Agency announced a major effort to improve air quality in national parks and wilderness areas. The Regional Haze Rule calls for state and federal agencies to work together to improve visibility in 156 national parks and wilderness areas such as the Grand Canyon, Yosemite, the Great Smokies, and Shenandoah [72].

The rule requires the states, in coordination with the Environmental Protection Agency, the National Park Service, US Fish and Wildlife Service, the US Forest Service, and other interested parties, to develop and implement air quality protection plans to reduce the pollution that causes visibility impairment.

Nitrogen oxides are also important in the formation of ground-level ozone. In the presence of sunlight, they can react with other chemicals to increase the concentration of ozone to a point where it can lead to health effects. Ground-level or "bad" ozone is not emitted directly into the air, but is created by chemical reactions between oxides of nitrogen (NOx) and volatile organic compounds (VOC) in the presence of sunlight. Emissions from industrial facilities and electric utilities, motor vehicle exhaust, gasoline vapors, and chemical solvents are some of the major sources of NOx and VOC. Breathing ozone can trigger a variety of health problems, particularly for children, the elderly, and people of all ages who have lung diseases such as asthma. Ground-level ozone can also have harmful effects on sensitive vegetation and ecosystems [73].

Coal-fired power plants also emit mercury, another trace element found in coal. Once in the atmosphere, the mercury can be deposited on the Earth. It finds its way into lakes and streams, where it is absorbed by microscopic plants and animals. These can be consumed by fish. The fish will store the mercury. When humans eat the fish, they can get a potentially harmful dose of mercury.

Burning of fossil fuels can also release other toxic chemicals such as cadmium, benzene, and formaldehyde. Usually these are released in very small amounts, but over time, and when combined with emissions from other sources, they can accumulate.

The same actions, which will help reduce acid rain, will also affect the climate. In addition to nitrates, power plants emit large amounts of carbon dioxide. Gases, which hold heat better than dry air, are called “greenhouse gases.” Carbon dioxide and most oxides of nitrogen are both greenhouse gases, and so increasing the concentration of them makes the atmosphere hold more heat. This can lead to an increase in the global average temperature. Many scientists feel they already have evidence that this is happening and feel that increased concentrations of greenhouse gases will have serious consequences. By reducing our use of electrical energy, increasing the efficiency of power plants, and using sources of energy, which do not require combustion (wind, solar, etc), we can reduce acid rain and emissions of greenhouse gases [74].

8.11 Future Efforts

While we have made progress in reducing the acidity of rainfall and are beginning to see positive effects in our environment, it is not yet possible to declare victory. We still must continue to reduce our emissions of atmospheric pollutants. Clean fuels, renewable energy, and increased efficiency are important ways to reduce our dependence on coal and oil as a source of energy [75].

Fuels such as natural gas and wood chips emit fewer acid rain causing pollutants per unit of electricity. By converting some of our existing plants to run on these fuels and building new facilities that can replace some of our older, less efficient plants, we can generate electricity with fewer emissions.

Renewable energy sources such as wind, hydroelectric, and solar are contributing to cleaner air in New England and slowing the region’s increase in fossil fuel consumption. Some states are calling for increasing amounts of electricity from renewable resources. Wind power, in particular, has become a more important source of electricity due to the fact that its costs are now similar to that of traditional fossil fuel resources.

Conservation programs such as US EPA’s Energy Star, Green Buildings, and the New England Community Energy Challenge will help us reduce the demand for electricity. Energy Star [76] identifies products that are more energy efficient. Green Buildings encourages the planning and construction of more energy efficient buildings. Recently, in New England, US EPA launched the New England Community Energy Challenge, a municipal energy efficiency program.

Cleaner fuels, renewable sources of energy, and conservation programs will help us conserve energy. The result will be a cleaner environment, and this will benefit all of the inhabitants of the Earth.

9 Case Histories

9.1 Lake Brazos, Waco, TX

On the Brazos River, a few hundred yards downstream from the La Salle Avenue Bridge lies the Low Water Dam or, more recently, the Lake Brazos Dam. About 40 years ago city leaders decided that a dam below Waco would significantly widen the river and stabilize the river level. These improvements would enhance the natural beauty of the Brazos River through Waco. Additionally, the dam would create an impoundment from which up to 5,600 acre-ft of water can be withdrawn annually for municipal purposes [31].

Since the original dam was constructed, there have been many new developments. McLennan Community College has built the Bosque River Stage and Amphitheater. Baylor University has developed all along the eastern edge near the river including a new law school, natural history museum, and a soon to be finished science building. These improvements along with a world-class athletic complex have been built immediately adjacent to the Brazos River. In addition, Baylor operates a marina on the Brazos River to facilitate sailing and canoeing opportunities. Other colleges from Colorado and Kansas routinely travel to Waco for early spring rowing practices.

The City of Waco has also made many improvements including miles of riverwalk and various parkway improvements that include landscaping, lighting, and a boat dock in Cameron Park. Recent improvements include the Texas Sports Hall of Fame and upgrades to the Texas Ranger Museum. There have also been many private developments such as the Brazos Queen (dining boat), the Spirit of the Rivers paddleboat, Lake Brazos Steakhouse, Dock's Restaurant, and kayaking. Even with the enormous amount of improvements, the unmet potential remains tremendous.

With so much focus and activity along the Brazos River, there is a tremendous need to ensure a reliable, constant-level town lake. The existing dam was completed in 1970. The structure, which originally consisted of two drum gates, has quite a history for poor or non-performance. The original design, despite several modifications, did not function as intended for a reliable town lake. In 1985, hydraulic cylinders were attached to the underside of the massive gates (117 ft each) to provide a positive control mechanism for maintaining the level of Lake Brazos. This modification, while expensive to maintain, has restored quite a bit of reliability. Through decades of modifications and expensive maintenance, it was time to replace the structure with a new dam, which will offer reliability while requiring less maintenance. The new dam will be a concrete labyrinth weir. The new dam is scheduled for completion in fall 2007.

The City of Waco remains committed to providing a safe and plentiful supply of water for its citizens. Work has begun on 80 million USD in improvements to the water treatment system. The first phase has been completed with the completion of construction on the 42″ water distribution line and upgrades at the Mount Carmel Water Treatment Plant. This will improve the treatment capacity at that plant from 45 to 66 MGD. Similar improvements will take place at the Riverside Plant, and when the entire project is completed, the City of Waco will be able to treat a maximum of 130 MGD of water.

The City of Waco is also making the transition to a new dissolved air flotation (DAF) treatment process. This will address issues with the taste and odor problems caused by by-products of algae in the North Bosque River Watershed. The second phase of the Water Quality and Quantity project is designed to dramatically improve the taste of the finished water. In order to complete this task, the City of Waco is constructing a new clarification facility, featuring DAF for the removal of algae and other suspended particles from the raw water supply. DAF is particularly effective on waters with significant amounts of lightweight particles such as algae. Algae are the primary source of taste and odor-causing compounds in Texas waters.

DAF works by attaching air bubbles to particles suspended in the raw water and floating them to the surface of a tank for removal. The process includes flocculation to bind particles suspended in the raw water into larger flocs that can more easily be removed, a saturator that entrains air into a side stream for injection into the process, an air nozzle header that releases extremely fine air bubbles that attach to the flocculated particles, a skimmer which removes the suspended particles after they float to the surface of the basin, and effluent laterals which collect the clarified water off the bottom of the basin.

The odor-causing compounds MIB and geosmin are found inside the algae cells and get released to the water when the algae is killed or damaged. By removing the algae at the lake site (see Fig. 7.18) before it has a chance to be killed or damaged during piping to the treatment plant or the water treatment process itself, water quality will be significantly improved. The reduced levels of MIB and geosmin in the raw water once the algae is removed will allow any residual taste and odor compounds to be more easily removed in later stages of the treatment process. After DAF clarification, the water will be treated with chlorine dioxide for primary disinfection and then sent to the two treatment plants where it will be filtered through sand and granular activated carbon for removal of residual taste and odor-causing compounds and any remaining suspended materials.

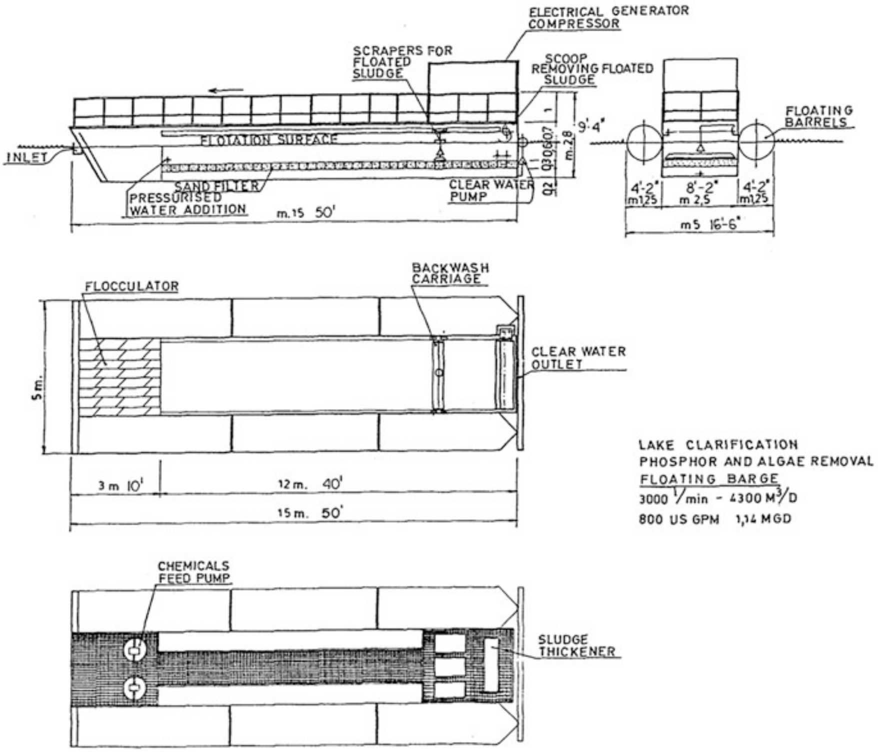


Fig. 7.18 Floating barge for algae removal from lake water

9.2 Water Treatment from Lake Roine, Tampere, Finland

In the 1960s, the City of Tampere, Finland, began drawing water from Lake Roine when the quality of water from its original lake source deteriorated. A horizontal sedimentation basin was constructed in the early 1970s, and a laminar flotation process was implemented in 1989. Activated carbon replaced sand filtration in 1996, but the City was still not satisfied with its drinking water quality [33].

In 1997, a pilot dissolved air flotation (AquaDAF) system was retrofitted in one of the conventional sedimentation basin flocculators. The DAF pilot demonstrated much higher flotation rise rates than those previously achieved with the laminar DAF units. In 2000, retrofitting of all laminar DAF units was completed. Today, the plant uses only the AquaDAF for clarification. The system was retrofitted in the original basins and sludge channels. The new structure is constructed entirely of wood.

The AquaDAF™ system utilizes hydraulic flocculation underneath the flotation area. Two very small unpacked saturators operate at a design recycle rate of 10%. The only submerged moving part is the effluent weir used for desludging. Water quality and system performance is shown in Table 7.6.

Table 7.6 System performance (Lake Roine water temperature range = 0.1°–17 ° C)

Parameter	Raw influent	Clarified effluent	Filter effluent
Turbidity, NTU	0.40–0.60	0.15–0.90	0.05–0.20
Dissolved organic carbon (DOC), mg/L	4.5–5.9	<2.0	
pH	6.2–7.5	5.0–7.0	

9.3 Restoration of Lake Apopka, FL, USA

Environmental problems led the governor of Florida on April 4, 1967, to appoint a technical committee to evaluate the restoration of Lake Apopka [34]. Sixteen agencies, including the Federal Water Pollution Control Administration (FWPCA), agreed to participate in the project. An FWPCA study begun in 1968 revealed that 90% of the bottom was covered with unconsolidated bottom sediment (muck) averaging 1.5 m thick. These sediments and peat sediments found along the shoreline were anaerobic and provided limited suitable substrate for desirable biota. Only 5% of the bottom was covered with sand, clay, and shell. The top meter of lake sediment contained 225 million kg of total nitrogen and 2 million to 4 million kg of total phosphorus. Chemical oxygen demand (COD) in the muck samples (dry weight) was 1,100 mg/g. The FWPCA also made a crude nutrient budget and emphasized that restoration of the lake must include reduction of nutrient input. Although direct rainfall on the lake and high nutrient input from citrus grove runoff were important, the principal controls on inputs emphasized by the FWPCA were point sources such as agricultural runoff pumped directly into the lake from muck farms and municipal and industrial wastes. In addition to control of external nutrient sources, several solutions for improving lake water quality are listed below. These include [35]:

1. Dredging to remove nutrient-rich unconsolidated bottom sediments to increase lake depth and reduce internal nutrient recycling.
2. Using lake drawdown to expose and subsequently consolidate large areas of lake bottom by oxidation and compaction.
3. Adding an inert sealing material to stabilize bottom sediments.
4. Engaging in hydroponic farming to remove dissolved nutrients.
5. Harvesting to remove algae by flotation, filtration, precipitation (not within the lake), or centrifugation (recovered algae could be used as a feed supplement).
6. Harvesting fish to remove nutrients "on a large scale." Harvested fish could be used as a protein supplement.

The governor of Florida assigned complete responsibility for a 1970 restoration of Lake Apopka to the Florida Air and Water Pollution Control Commission. This agency decided to proceed with the lake drawdown approach by allowing gravity drainage to lower the lake level 60 cm beginning in December 1970. The effect of this lowering was to be evaluated, and the lake would then be drained further by pumping to 25% of its original area. This final drawdown would occur in the spring of 1971. It was anticipated that two beneficial effects would result from the drawdown:

1. Nutrient recycling would be reduced or eliminated from dried, compacted sediments.
2. Suitable substrate for rooted aquatic vegetation would also be a result.

This plan to lower the lake about 7 ft below normal water level was not implemented, however, because of the projected cost (20 million USD) and because of concern about environmental and economic impacts [36]. For example, the loss of lake volume would minimize the freeze protection citrus growers received from the large heat capacity of the lake.

In the 1970s, additional studies were conducted on water quality problems and on restoration of Lake Apopka [37]. Studies of techniques that might be used to restore the lake have continued. Biomanipulation of algal standing crops with gizzard shad may actually increase standing crops of undesirable algae. A multimillion-dollar feasibility study on growing and harvesting water hyacinths to remove nutrients from the lake was launched [38]. The field test of this project in Lake Apopka was abandoned when the enclosure that was to have been used for the experiment was destroyed by water movements in the lake.

The St. Johns Water Management District began a feasibility study on using marsh restoration to improve water quality in the lake [39]. The water management district purchased muck farmland that will be flooded to restore the wetland by using the wetland as a filter to remove nutrients. The hydrology of the wetland will be manipulated so that highly nutrient-enriched water will flow from the lake into the wetland and nutrient-depleted water from the wetland will be directed back to the lake. If successful, this project will result in both a restored wetland and a restored lake.

There seem to be two divergent views about Lake Apopka. One group contends that the lake can be restored. This viewpoint is supported by the need to reduce nutrient inputs to prevent accelerated eutrophication. Schneider and Little [35] commented that the history of Lake Apopka “is not atypical” because other lakes in Florida and reservoirs all over the south were being subjected to similar attacks. They stated that the lake could be restored, but only with great expense and difficult decisions (e.g., the extent to which a 10 million USD plus marginal muck farming operation could expend money for nutrient removal). “The technical capabilities to prevent accelerated eutrophication are and have been available for some time. The planning and foresight needed to prevent the early demise of our lakes, however, has come into being only lately. Today, we must consider the full ecological impact of all our resource development activities if we are to eliminate the Lake Apopka syndrome from our aquatic environment,” they emphasized.

At the other extreme is the viewpoint that restoration should not be attempted because it will meet with failure or it is too expensive. This viewpoint can be supported to a certain extent with results of studies on Lake Tohopekaliga (Lake Toho), Florida. A number of restoration measures have been instituted on Lake Toho since 1971, with little evidence of improvement in water quality [39]. In this lake, nutrient inputs have been reduced by sewage treatment and by stormwater detention and filtration. In addition, drawdown has been used as a restoration measure. What is not known is whether water quality would have been degraded even more if remedial measures had not been instituted. Dierberg et al. [40] point out that evaluation of restoration practices in Florida lakes has been hampered by the lack of long-term data and the consequent limitation on the use of robust statistical approaches in evaluating effectiveness.

9.4 Water Treatment from Lake DeForest in Clarkstown, NY, USA

United Water New York draws about 80% of its water supply from wells throughout Rockland County. The remaining 20% is supplied from a surface source, Lake DeForest in Clarkstown, NY [41].

The process of Lake Water treatment begins by pumping the water from the Lake DeForest Reservoir into the treatment plant. During the pumping process chemical is added to oxidize inorganic material, and the water passes through screens which remove large objects prior to entering the pumps. The water then proceeds to the new DAF (dissolved air flotation) system. A coagulant (aluminum sulfate) is added as the water enters the DAF system. This allows smaller particles to form larger flocs, getting the water ready to enter the final step of the DAF process. In this step, millions of microbubbles are added to the water floating the flocs to the top. The float (residuals) is removed and the clean water proceeds to the filters. It is during this step that chlorine is added. Chlorine destroys bacteria and viruses in the water. The water passes through the filters (layers of coal, sand, and gravel) to remove the smallest remaining particles. Next, the water receives another small dose of chlorine to be sure that the water remains pure and safe. Finally, corrosion control chemicals are added. This step helps prevent corrosion of the water pipes and plumbing. It also reduces the chance of lead dissolving in the water from plumbing.

10 Summary

A major factor in the death of a lake is eutrophication, which is the result of increased biological growth within the lake, or acidification, which is the result of increased release of sulfur dioxide and nitrogen oxides from industrial plants, or acid mine drainage waters from mines. Biological life may be controlled by limiting the nutrients or pH in the lake.

Reduction or elimination of external pollutant sources certainly is important for lake restoration and water quality improvement. Many eutrophic and hypereutrophic lakes, however, exhibit a very slow improvement in water quality even several years after major external pollutant sources were eliminated.

Lakes with high hydraulic retention times and/or having received excessive pollutant (note: mainly nutrient, acid, heavy metals, spills, etc.) loadings can experience significant internal loading of nutrients and pollutants from the sediments during anoxic periods. In such cases effective treatment of lake water and/or lake sediments may be warranted.

Among the lake water improvement technologies, physical and chemical processes are feasible for pollutant inactivation, precipitation, and biotic harvesting.

Lake water aeration is a physical process. There are many lake water aeration systems available. They increase the oxygen content of the lake water through mechanical mixing/agitations, air injection, or pure oxygen injection. These aeration systems either aerate lake waters at all depths causing thermal destratification or they preserve the thermal gradient and aerate the bottom lake waters only applying hypolimnetic aeration. For lake restoration, thermal destratification is beneficial for most warm water fisheries, and hypolimnetic aeration can create or greatly expand the cold water fishery potential of a lake.

Phosphorus is generally the nutrient that can be significantly removed. Phosphate removal is usually the primary objective of lake restoration. Using pollutant (mainly nutrient) inactivation or precipitation for treatment of standing bodies of lake water has been practiced since 1983 when 2 mg/L of ferric chloride was applied to a few selected reservoirs and lakes in Berkshire County, MA, USA. The first lake-wide application of aluminum sulfate for nutrient inactivation occurred at Langston, Sweden, in 1968. Since 1970 most of the larger lake water treatments using aluminum sulfate have occurred in the United States, such as Horseshoe Lake, Wisconsin, Dollar and Twin Lakes in Ohio, and Liberty Lake and Medical Lake in Washington, USA. In 1971 to 1974, the highly eutrophic Cline Pond near Corvallis, Oregon, USA, was treated by sodium aluminate and zirconium tetrachloride. In all the aforementioned cases, chemicals were dosed to lake waters by barge distribution and/or manifold injection. Most of the lakes treated by chemicals have shown reduced phosphorus content and less nuisance algal growth as well as higher hypolimnetic dissolved oxygen [45]. There are many ways to control the nutrients entering a lake, to control the existing nutrients within a lake, and to reduce the existing nutrients within a lake. Each lake must be studied individually to determine the best method to control eutrophication.

Biotic separation and harvesting is an important technique of nutrient removal that can lead to a reversal of eutrophic conditions in lakes. Algae and other aquatic plants such as water hyacinths, *Typha latifolia*, etc., can produce more biomass containing phosphorus and nitrogen. Harvesting of these aquatic plant species thus is an efficient method for nutrient removal from lakes. However, even the greatest potential harvest will not remove enough nutrients to offset moderate to heavy nutrient loading to lakes. Biotic harvesting as a lake restoration technique may work only where phosphorus loading has already been reduced to less than 1 g/m^2/year [45]. A wide variety of mechanical harvesters has been designed for aquatic weed harvesting. The most efficient and cost-effective technique for water-algae separation and algae harvesting appears to be dissolved air flotation [43–46].

Whereas algae may be undesirable in lake water treatment, algae are also being harvested in some places for their nutrient value. The use of dissolved air flotation for harvesting cultivated algae for animal feed has been shown to be an efficient means of separating algae from their watery growth medium. The algae have been used as a livestock feed since they have a high nutrient and protein content and are reported to be highly acceptable to livestock. Another important benefit of the algae harvesting from lake water is reduction of chlorine dosage as an algicide, in turn, reduction of trihalomethanes, taste, and odors in drinking water when the lake water is used as the freshwater supply [45].

Acid rain and acid mine drainage pollute lake waters everywhere and have become a serious international problem. In order to develop alternative remedial methods for recovery of acid lakes believed due to acid rain and/or acid mine drainage, many engineering and management studies have been conducted on various chemical manipulation methods for lake water neutralization [45]. The materials evaluated for lake water neutralization include calcium hydroxide, sodium carbonate, agriculture limestone, fly ash, water treatment softening sludge, cement plant bypass dust, di-calcium silicate, calcium oxide, and magnesium oxide. It has been known [45] that the use of lime products is an effective way to neutralize acidified lake waters if properly administrated.

If acid lakes are contaminated by acid mine drainage, not only the water's high acidity shall be neutralized, but also its heavy metal concentrations (copper, zinc, cadmium, lead, iron, manganese, etc.) shall be reduced to safe or desirable levels. Chemical precipitation is a common process for inactivation of soluble metal ions. The precipitated insoluble metals in floc forms can be further separated by sedimentation, dissolved air flotation, and/or filtration.

The dissolved air flotation (DAF) investigated in this research is of an innovative process [83–87]. The treated effluent containing an almost saturated concentration of dissolved oxygen can be discharged to the lake bottom for hypolimnetic aeration. The use of aluminum sulfate, sodium aluminate, and lime in a flotation system can accomplish phosphate removal, biotic separation, and harvesting. Either sodium aluminate or lime can be used in the flotation system for neutralization of acidity caused by acid rain and acid mine drainage. A DAF plant built on a boat is one method that should be considered for phosphate removal, acid neutralization, or algae harvesting in a lake. Lake restoration may be effective in extending the service life of a lake. Other lake restoration technologies, such as chemical feeding, mixing, acid neutralization, chemical precipitation, coagulation, flocculation, filtration, nitrogen removal processes, dredging, algae harvesting, etc. can all be found from the literature [32, 42, 43, 77–83, 88]. AquaDAF was investigated for lake restoration. The AquaDAF process is introduced in detail in the literature [87]. Although AquaDAF has been demonstrated successfully for lake water treatment, all other manufacturers' DAF equipment, such as Supracell, Sandfloat, KAMET, Clari-DAF, etc., may also be used for successful lake restoration under the conditions that the types and dosages of chemicals must be correct, and the operators must know what they are doing.

Glossary [83–87]

Acid rain	Precipitation having a pH lower than the pH range commonly found in natural waters, caused by absorption from the atmosphere of sulfur dioxide (SO_2) gas and/or other acid-causing substances, such as nitrogen oxides NOx, which then forms sulfuric acid and nitric acid, respectively, in solution. It is also called acid precipitation.
AquaDAF	A rectangular dissolved air flotation clarifier (DAF) manufactured by and commercially available from SUEZ Water Technologies and Solutions, 8007 Discovery Drive, Richmond, VA 23229, USA
Clari-DAF	A rectangular dissolved air flotation clarifier (DAF), manufactured by and commercially available from Xylem Water & Wastewater, 227 S. Division St, Zelienople, PA 16063, USA
Dissolved air flotation (DAF)	One of dissolved gas flotation (DGF) processes when air is used for generation of gas bubbles. See dissolved gas flotation (DGF).
Dissolved gas flotation (DGF)	It is a process involving pressurization of gas at 25–95 psig for dissolving gas into water and subsequent release of pressure (to one atm) under laminar flow hydraulic conditions for generating extremely fine gas bubbles (20–80 microns) which become attached to the impurities to be removed and rise to the water surface together. The impurities or pollutants to be removed are on the water surface are called float or scum which scooped off by sludge collection means. The clarified water is discharged from the flotation clarifier's bottom. The gas flow rate is about one percent of influent liquid flow rate. The attachment of gas bubbles to the impurities can be a result of physical entrapment, electrochemical attraction, surface adsorption, and/or gas stripping. The specific gravity of the bubble-impurity agglomerate is less than one, resulting in buoyancy or non-selective flotation (i.e., Save-All).
KAMET	Krofta Advanced Municipal Effluent Treatment, which is a circular combined Supracell-Sandfloat (DAF-D AFF) package plant manufactured by and commercially available from Krofta-related companies worldwide.
Lake	It is an inland body of water, fresh or salt, of considerable size (usually more than 50 acres (more than 200,000 square meters)) and occupying a basin or hollow on the Earth's surface.
Lake restoration	Clean the lake water or soil in order to restore it to original natural conditions.
LIWT	Lenox Institute of Water Technology, which is a nonprofit educational organization with a goal of scientific development and world peace.
Sandfloat	A circular combined dissolved air flotation and sand filtration package plant (DAFF) manufactured by and commercially available from Krofta Engineering Corporation-related companies worldwide.
Supracell	A circular dissolved air flotation clarifier (DAF) manufactured by and commercially available from Krofta-related companies worldwide.

Appendix A

Pollutant contents as percentage of total solids in dredged materials

Parameters	Ashtabula samples				Fairport samples			
	1A	2A	3A	4A	1F	2F	3F	4F
Chemical oxygen demand	4.334	2.483	1.987	4.037	0.237	16.567	4.567	4.010
Oil and grease	0.210	0.094	0.065	0.265	TRACE	0.275	0.468	0.520
Kjeldahl nitrogen	0.138	0.043	0.048	0.152	0.016	0.065	0.167	0.020
Total phosphorus	0.004	0.001	0.008	0.030	0.007	0.009	0.006	0.003
Mercury	0.00004	0.00001	0.00002	0.00007	0.00001	0.00003	0.00004	0.00006
Iron	2.104	1.750	1.299	2.100	1.105	1.000	1.599	1.790
Chromium	0.008	0.010	0.007	0.014	0.002	0.002	<0.018	0.020
Cadmium	<0.0001	<0.0001	0.0001	<0.0001	0.001	0.0001	<0.0001	<0.0008
Arsenic	<0.0001	<0.00008	<0.0002	<0.0005	<0.00009	<0.0003	<0.0002	<0.0001
Zinc	0.018	0.015	0.013	0.017	0.006	0.006	<0.005	0.008
Lead	0.010	0.010	0.010	0.002	0.002	0.035	0.005	0.009
Copper	0.003	0.001	0.002	0.031	0.0009	<0.0009	0.002	0.003
Nickel	0.001	0.001	0.001	0.001	0.0009	0.009	0.001	0.001
Manganese	0.055	0.045	0.040	0.060	0.035	0.030	0.040	0.040
Volatile solids	4.905	4.150	18.100	—	2.400	—	—	8.499
Dissolved solids	0.093	0.082	0.116	0.693	0.053	0.139	0.188	0.589

Appendix B

Settling-test data, Sample 2A from Ashtabula Harbor, Ohio

	Before settling	Remaining after 1 h of settling	Remaining after 4 h of settling	Remaining after 18 h of settling	Remaining after 40 h of settling
Chemical oxygen demand, mg/L	14,900	110	108.8	81.5	77.6
Total solids, mg/L	600,000	800	—	780	872
Dissolved solids, mg/L	490	490	490	490	490

(continued)

Settling-test data, Sample 2A from Ashtabula Harbor, Ohio

	Before settling	Remaining after 1 h of settling	Remaining after 4 h of settling	Remaining after 18 h of settling	Remaining after 40 h of settling
Suspended solids, mg/L	599,510	480	—	290	—
Turbidity, JTU[a]	87,500	500	—	150	39
Total phosphorus, mg/L	8.0	0.03	0.09	0.05	0.10
Surfactants, mg/L	—	0.06	—	—	—
Sediment, ml/L	—	600	—	—	—
Kjeldahl nitrogen, mg/L	259	—	29.0	25.1	25.6
Oil and grease, mg/L	565	<1.00	—	nil < 1	nil < 1
Iron, mg/L	10,500	41.00	—	—	—
Chromium, mg/L	60	0.50	0.045	0.020	0.020
Cadmium, mg/L	<0.6	0.04	0.055	0.020	0.022
Zinc, mg/L	90	1.1	0.170	0.095	0.075
Manganese, mg/L	270	3.10	—	0.021	0.0187
Copper, mg/L	8.0	0.12	0.055	0.040	0.020
Nickel, mg/L	<6.0	—	—	<0.015	—
Chlorides, mg/L	—	25.0	—	—	—

[a] *JTU* Jackson Turbidity Unit

Appendix C

Settling-test data, Sample 4F from Fairport Harbor, Ohio (analyzed by Calspan Corporation, Buffalo, NY)

	Before settling	Remaining after 1 h of settling	Remaining after 4 h of settling	Remaining after 18 h of settling	Remaining after 40 h of settling
Chemical oxygen demand, mg/L	14,540	202	133	97	101
Total solids, mg/L	363,000	4,240	—	2,712	2,460
	2,140	2,140	2,140	2,140	2,140

(continued)

Settling-test data, Sample 4F from Fairport Harbor, Ohio (analyzed by Calspan Corporation, Buffalo, NY)					
	Before settling	Remaining after 1 h of settling	Remaining after 4 h of settling	Remaining after 18 h of settling	Remaining after 40 h of settling
Dissolved solids, mg/L					
Suspended Solids, mg/L	360,860	2,130	—	672	320
Turbidity, JTU[a]	155,000	780	—	195	52
Total phosphorus, mg/L	10	0.280	—	0.58	0.16
Surfactants, mg/L	—	0.06	—	—	—
Sediment, ml/L	—	700	—	—	—
Kjeldahl nitrogen, mg/L	696	56.5	—	38.2	—
Oil and grease, mg/L	1,865	4	—	<10	<10
Iron, mg/L	6,500	22.5	—	—	—
Chromium, mg/L	73	0.20	—	0.040	0.035
Cadmium, mg/L	<0.4	0.03	0.052	0.051	0.048
Zinc, mg/L	29	0.15	0.099	0.025	0.025
Manganese, mg/L	145	2.20	—	0.021	0.019
Copper, mg/L	11	0.07	—	0.060	0.070
Nickel, mg/L	<3.6	—	—	<0.015	—
Chlorides, mg/L	—	284	—	—	—

[a] *JTU* Jackson Turbidity Unit

Appendix D

Dredging supernatant water quality versus US drinking water standards

Parameters	Water quality after 18 h of settling (mg/L)		Proposed federal drinking water standards (mg/L)
	Sample 2A Ashtabula	Sample 4F Fairport	
Oil and grease	nil < 1	<10	absent

(continued)

Parameters	Water quality after 18 h of settling (mg/L)		Proposed federal drinking water standards (mg/L)
	Sample 2A Ashtabula	Sample 4F Fairport	
Chromium	0.020	0.040	0.5
Cadmium	0.020	0.051	0.01
Zinc	0.095	0.025	5.0
Copper	0.040	0.060	1.0

Appendix E

Control technology summary for flotation (Source: US Environmental Protection Agency, September 1981)

Pollutant	Effluent Concentration		Removal efficiency %	
	Range	Median	Range	Median
Classical pollutants, mg/L:				
BOD (5-day)	140–1000	250	4–87	68
COD	18–3200	1200	8–96	66
TSS	18–740	82	6–98	88
Total phosphorus	<0.05–12	0.66	50–>99	98
Total phenols	> 0.001–23	0.66	3–>94	12
Oil and grease	16–220	84	57–97	79
Toxic pollutants, μg/L:				
Antimony	ND-2300	20	4–95*	76
Arsenic	ND-18	<10	8–>99	45
Xylene	ND-1000	200	95–>99	97
Cadmium	BDL-< 72	3	0–>99	98*
Chromium	2–620	200	20–99	52
Copper	5–960	180	9–98	75
Cyanide	<10–2300	54	0–<62	10
Lead	ND-1000	70	9–>99	98
Mercury	BDL-2	BDL	33–88	75
Nickel	ND-270	41	29–>99	73
Selenium	BDL-8.5	2		NM
Silver	BDL-66	19		45
Thallium	BDL-50	14		NM
Zinc	ND-53000	200	12–>99	89
Bis(2-ethylhexyl) phthalate	30–1100	100	10–98	72
Butyl benzyl phthalate	ND-42	ND	97–>99	>99
Carbon tetrachloride	BDL-210	36		75
Chloroform	ND-24	9	20–>99	58
Dichlorobromomethane		ND		>99

(continued)

Control technology summary for flotation (Source: US Environmental Protection Agency, September 1981)				
	Effluent Concentration		Removal efficiency %	
Pollutant	Range	Median	Range	Median
2,4-Dichlorophenol		6		NM
Di-n-butyl Phthalate	ND-300	20	0–>99	97
Diethyl phthalate		ND		>99
Di-n-octyl phthalate	ND-33	11	61–>99	78
N-nitrosodiphenylamine		620		66
N-nitroso-di-n-propylamine		84		NM
2-Chlorophenol		2		NM
2,4-Dimethylphenol	ND-28	14		>99
Pentachlorophenol	5–30	13		19
Phenol	9–2400	71	0–80	57
2,4,6-Trichlorophenol		3		NM
Benzene	5–200	120		NM
Chlorobenzene		57		NM
Dichlorobenzene	18–260	140		76
Ethylbenzene	ND-970	44	3–>99	65
Toluene	ND-2100	580	10–>99	39
Fluoranthene	0.5-<10	5.2		NM
Fluorene		14		NM
Naphthalene	ND-840	96	33–>99	77
Pyrene	0.3–18	9.2		0
Anthracene/phenanthrene	0.2–600	10	45–>98	81
2-Chloronaphthalene		17		0

Blanks indicate data not available; BDL, below detection line; ND, not detected; NM, not meaningful; *, approximate value

Appendix F

Control technology summary for filtration						
	Data points		Effluent concentration		Removal efficiency, %	
Pollutant	Pilot scale	Full scale	Range	Median	Range	Median
Classical pollutants, mg/L:						
BOD(5)	3	6	5.3–23,000	23	8–48	22
COD	11	9	29–260,000	150	0–59	24
TSS	19	15	<1–7,300	17	6–>99	76
TOC	8	6	17–25,000	43	6–49	14
Total phosphorus	10	4	<0.07–14	1.1	7–86	52

(continued)

Control technology summary for filtration

	Data points		Effluent concentration		Removal efficiency, %	
Pollutant	Pilot scale	Full scale	Range	Median	Range	Median
Total phenols	15	9	0.001–64	0.02	0–60	23
Oil and grease	7	10	<0.5–9,900	12	0–>98	39
Fluoride		3	2.2–11	9.0	0–63	32
Aluminum	10	4	0.04–47	0.5	15–99	34
Manganese	11	5	0.007–3.2	0.12	0–88	15
Vanadium	10	17	0.001–0.52	0.02	0–67	4
Barium	10	3	<0.001–11	0.01	0–>99	24
Iron	11	4	0.06–100	0.34	0–92	32
Tin	8	3	0.02–0.48	<0.02	0–56	3
Titanium	9	4	>0.001–15	0.004	0–99	23
TS		1		12,000		45
TDS		1		4,900		36
Sulfides	4	1	<0.005–<0.2	0.01	0–94	50
Palladium		1				NM
Calcium	9	4	4.5–800	7.6	0–98	13
Magnesium	10	3	1–37	3.7	0–62	6
Sodium	9	3	54–400	180	0–6	0
Molybdenum	10	2	0.01–0.2	0.01	0–0	0
Cobalt	10	3	0.006–0.11	0.007	10–70	20
Boron	10	1	0.006–2	0.27	0–33	0
Silicon	10		1.3–15	3.4	0–48	3
Ammonia	5	2	0.22–23	2.6	0–99	21
Nitrate	5	2	0.12–6.5	3.4	0–52	10
Strontium	9	1	0.02–0.26	0.05	0–29	0
Tellurium		1		<0.004		NM
Ammonia nitrogen	1			0.58		17
Nitrate nitrogen	1			0.25		11
Yttrium	1			<0.003		<50
Platinum	1			<0.005		NM
Gold	1			<0.002		NM
TVS	1			7,500		38
Toxic pollutants, μg/L:						
Antimony	13	13	BDL – 700	<25	0–92	>44
Arsenic	14	8	BDL – 100	7	0–>99	55
Asbestos, total (fibers/L)	1			4.7E8		90
Asbestos, chrysotile (fibers/L)	1			3.3E8		>99
Beryllium	17	1	<0.02–<10	1.1	0–7	71
Cadmium	15	14	ND – 97	<2	0–>99	67

(continued)

Control technology summary for filtration

	Data points		Effluent concentration		Removal efficiency, %	
Pollutant	Pilot scale	Full scale	Range	Median	Range	Median
Chromium	17	15	<4–320	34	0–99	43
Copper	17	18	<4–4,500	32	0–>99	42
Cyanide	11	11	3–260	11	0–>99	54
Lead	19	18	BDL – 2,100	50	3–>99	47
Mercury	8	5	0.1–2,900	0.5	0–89	57
Nickel	17	13	BDL – 700	36	0–>99	19
Selenium	10	6	BDL – 100	9	0–10	0
Silver	15	12	BDL – <100	<5	0–91*	17
Thallium	11	5	0.1–<50	<15	NM	NM
Zinc	20	18	16–18,000	160	0–>99	55
Hexavalent chromium	2		20–20	20	0	0
Bis(2-ethyl hexyl) phthalate	9	12	BDL – 16,000	29	21–98	77
Butyl benzyl phthalate	3	4	ND – 10	2.5	52–>99	77
Di-n-butyl phthalate	7	12	ND – 1,300	6	0–96	11
Diethyl phthalate	3	4	ND – 11,000	1	50–>99	61
Dimethyl phthalate	2	1	ND – BDL	BDL	99*–>99	99*
Di-n-octyl phthalate		3	ND – 4	2	50–>99	64
Xylene		1		12,000		75
N-nitrosodi phenylamine	1	1	ND – 0.4	0.2	>99	>99
N-nitroso-di-n-propylamine	1	1	ND – BDL	0.05	>99	>99
2-Chiorophenol		2	2–17	10	0	0
2, 4-Dichlorophenol	3	2	ND – 2	BDL	67–>99	83
2, 4-Dimethylphenol	2	1	BDL – 29	0.9	NM	NM
Pentachlorophenol	2	4	ND – 12	10	>99	>99
Phenol	8	4	ND – 34,000	5	22–>99	32
2, 4, 6-Trichiorophenol		1		69		80
p-chloro-m-cresol	3		BDL – 1.1	0.6	NM	NM
Benzene	4	4	ND – 200	6.9	29–>99	41
Chlorobenzene	2	1	0.1–470	4.8	98	98
1, 2-Dichlorobenzene	4		BDL – 5.8	3.5	44–97*	55
Ethylbenzene	9	2	ND – 2	BDL	0–>99	89*

(continued)

Control technology summary for filtration

	Data points		Effluent concentration		Removal efficiency, %	
Pollutant	Pilot scale	Full scale	Range	Median	Range	Median
Nitrobenzene		1		ND		>99
Toluene	10	10	ND – 200	1.2	0–>99	67
1,2,4-Trichlorobenzene	1	2	ND – 94	84	3.7	3.7
Acenaphthene	1	2	ND – 10	0.6	73–>99	86
Acenaphthylene		1		500		NM
Anthracene	6	4	ND – <32,000	0.5	0–99*	59
Benz(a)anthracene		1		7,300		NM
Benzo(a)pyrene	2		0.2–0.8	0.5	NM	NM
Benzo(k) fluoranthene	1			0. 1		NM
Fluoranthene	3	2	0.05–93	0.2	20–50	29
Fluorene	2	1	BDL – 10,000	0.05	NM	NM
Naphthalene		5	BDL – 160	1.5	86	86
Phenanthrene	2	4	ND – 3, 200	5.3	67	67
Pyrene	3	2	0.09–32,000	0.3	0–10	0
Anthracene/phenanthrene		3	0.1–3.5	2	50–65	58
Aroclor 1016		1		480		16
Aroclor 1221		1		650		20
Aroclor 1232		1		480		16
Aroclor 1424		1		650		20
Aroclor 1248		1		480		16
Aroclor 1254		1		650		20
Aroclor 1260		1		480		16
Carbon tetrachloride		3	ND-55	15	89–>99	93

Appendix G

US Army Corps of Engineers Civil Works Construction Yearly Average Cost Index for Utilities[*]

Year	Index	Year	Index
1967	100	1995	439.72
1969	112.17	1996	445.58
1970	119.75	1997	454.99
1971	131.73	1998	459.40

(continued)

Year	Index	Year	Index
1972	141.94	1999	460.16
1973	149.36	2000	468.05
1974	170.45	2001	472.18
1975	190.49	2002	486.16
1976	202.61	2003	497.40
1977	215.84	2004	563.78
1978	235.78	2005	605.47
1979	257.20	2006	645.52
1980	277.60	2007	681.88
1981	302.25	2008	741.36
1982	320.13	2009	699.70
1983	330.82	2010	720.80
1984	341.06	2011	758.79
1985	346.12	2012	769.30
1986	347.33	2013	776.44
1987	353.35	2014	791.59
1988	369.45	2015	786.32
1989	383.14	2016	782.46
1990	386.75	2017	807.94
1991	392.23	2018	827.52
1992	399.07	2019	844.07
1993	410.63	2020	860.96
1994	424.91		

[*] US ACE, Yearly Average Cost Index for Utilities. In: *Civil Works Construction Cost Index System Manual*, 1110-2-1304, US Army Corps of Engineers, Washington, DC. Amendment #1 30 September 2017. DF file is available on the Internet at http://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-2-1304.pdf?ver=2017-11-17-073237-627 (2018).

Acknowledgment and Dedication This book chapter is one of many book chapters and technical papers published in memory of our co-author, Dr. Donald B. Aulenbach, who worked closely with Professors Lawrence K. Wang, Mu-Hao Sung Wang, Nazih K. Shammas, William A. Selke, Milos Krofta, and Daniel Guss from 1981 to 2019 for developing an environmental humanitarian engineering program at the Lenox Institute of Water Technology (LIWT), teaching/researching there as an adjunct professor for almost two decades, and publishing many research papers and textbooks for academic contribution to the humanity. The senior author, Dr. Lawrence K. Wang, was also a colleague with Drs. Donald B. Aulenbach, Lenore S. Clesceri, and Nicholas L. Clesceri at Rensselaer Polytechnic Institute (RPI), Troy, NY, USA, in 1973–1978, where/when the happy RPI faculty team conducted so many lake investigations together. Dr. Aulenbach's lifetime accomplishments at both LIWT and RPI are duly acknowledged. The following is a Warm Tribute from RPI faculty representatives:

A Warm Tribute to Our Dear Friend and Colleague, Professor Emeritus Donald Bruce Aulenbach (Aulie) from Professor Emerita Lenore S. Clesceri and Professor Emeritus Nicholas L. Clesceri of Rensselaer Polytechnic Institute, Troy, NY, USA

When we returned from our post-docs in Switzerland in 1965, to begin teaching at Rensselaer, Don was among the first friends we developed. His help and friendship will always be highly valued. His good humor is legendary.

He was very involved in the research at Lake George and the development of the Lake George Water Research Center (LGWRC) with Nick.

Reflecting on the early days, Don and Nick made quite a few trips to Gull Bay in Putnam County on the eastern shore of Lake George, specifically, to Smith Bay. It seemed that each time we ventured forth, we encountered snow, which we could have anticipated at that time of the year. But, Nick and Don never faltered! Lots of Fun…

As things started to take shape, President Richard Folsom and Provost Clayton Dohrenwend encouraged us to see what might occur. Nick and Don had many meetings with them, keeping them "in the loop." Then, Professor Steve Wiberley (and later, Provost) was tasked by Provost Dohrenwend to work with us on developing the LGWRC. As fate would have it, Steve viewed the Gull Bay area for suitability for a fledgling LGWRC with Nick and Don…In a SNOW STORM!

Through President Folsom, we made connections with RPI Board of Trustee Member, Mr. Harold Strang, retired GE VP, who lived in summers at Smith Bay. In addition, Mr. Strang owned an adjacent former camp for youngsters. Mr. Strang offered his camp as a location to initiate LGWRC research. As was standard, and expected, at that stage, Nick and Don were the principle salesmen.

BUT, this historical sojourn would take many more pages to describe; however, a few things alert the brain cells, namely, "around-the-clock" lake water sampling, "through-the-ice" water sampling, and stream sampling, to name just a few things that Don did so well.

Bringing things to the present, this ultimately led to RPI's Darrin Fresh Water Institute, located in Bolton Landing, NY, on the western shore of Lake George.

Don's research was far-ranging, from Radiological Health, to Public Health to his forward-thinking work with his students on the Village of Lake George Wastewater Treatment Facility. He literally probed the subsurface as he studied the sand infiltration beds, which functioned as tertiary treatment for this system. This research placed Don in a small cadre of fellow researchers from around the world who were seeking understanding of sand infiltration capability for tertiary treatment. He collaborated with them and presented at specialty conferences.

Lastly, Don's contributions in the Department's educational endeavors were manifold. He was a key figure in the Department gaining the first-in-country ABET accredited degrees in Environmental Engineering. Nick and Don team-taught a number of courses, which was always constructive for the Department's reputation. Don also taught a Limnology course at the Lake George facility, which Lenore inherited.

On a personal note from Nick, in addition to the brief notes above, Don was a Father, Family man, Educator, Patriot and God-Fearing human being. He faithfully served his Church in Clifton Park, NY, for decades. How full a life is that!!

I consider him a BROTHER.

Aulie, Rest In Peace, dear friend.

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