Ecosystem Consulting Service, Inc.

Long-Term Project Summaries & Results
Lake Waramaug, Connecticut
Robert Frost Hypolimnetic Treatment System

The Robert Frost Hypolimnetic Treatment System was designed and built in 1983-84, and has been in operation every summer since. The system withdraws iron-rich hypolimnetic water, exposes it to sunlight and air, and returns it at the top of the hypolimnion. Substantial biological communities develop in the treatment basins, including heterotrophic and chemolithotrophic bacteria, attached algae, and floating plants. The primary function of the system is to use the iron, generated by anaerobic respiration at the bottom of Lake Waramaug, as a phosphorus removal coagulation agent (directly analogous to an annual alum treatment, but adding no chemicals). The re-oxidized iron “rains down through the hypolimnion” reducing internal nutrient loading to surface water algae. It removes TP from internal and watershed loading. Water clarity has more than doubled.
Lake Waramaug, Connecticut  
Layer Aeration System

From the research conducted at the Frost Hypolimnetic Treatment System a very specific type of lake aeration was designed and installed in the other end of Lake Waramaug in the late 1980s. Two Layer Aerators are driven by a small rotary screw compressor system. Water is drawn into the aerator from several selected depths: more shallow, warmer, with plenty of oxygen; and deeper, colder, with low oxygen and higher iron. The water is blended, aerated, and returned between the withdrawal depths. This approach utilizes oxygen produced by plants in the lake, to aerate deeper strata of the lake. It uses lake-generated iron as a phosphorus removal mechanism. It maintains mid-depth cool-water habitat for zooplankton and fish. Layer aeration is analogous to artificial circulation (destratification), but it circulates a specific depth range. Since its development, Layer Aeration systems have been successfully deployed in many other lakes, and to maintain high quality water supply layers in reservoirs.

Changes in Total Phosphorus and Soluble reactive Phosphorus observed at Lake Waramaug, Connecticut
During planning and design of a new reservoir to store river water to meet peak summer demands, water quality modeling indicated that oxygen loss, nutrient cycling, and algae blooms were expected to cause treatment difficulties. A Layer Aeration System was designed and built into the new reservoir infrastructure. It has several treatment capabilities, including:

- A full depth circulation system which maintains a well mixed reservoir through May to extend the Spring conditions and delay a shift to summer algae,
- A Layer Aeration system that maintains a well mixed and highly aerobic deep layer to minimize raw water iron, manganese, nutrients, algae, and organic content to make treatment more cost-effective,
- Vented air released from the Layer Aeration Towers is re-diffused to expand the mixed surface water layer down to approximately 20 ft, which inhibits the development of buoyant bluegreen algae (Cyanobacteria) which produce taste and odor compounds and toxins.

Pairs of chemical feed lines go from the compressor building to each of these aeration components to facilitate a variety of reservoir treatments if warranted. The system was designed specifically around the water supply intake depths and locations so the Utility can select the highest quality water during any season. Research continues to follow the establishment of biological communities, and ecological interactions, in this “new lake”.

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### Temperature Profile

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### Oxygen Profile

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Lake Shenipsit (Supply Reservoir), Connecticut
Multiple Layer Aeration

Lake Shenipsit is a large recreational fishery lake used as a major source of water supply to north-central Connecticut. During the late 1970s blooms of *Anabaena* and *Aphanizomenon* were stimulated by oxygen loss and internal cycling of nutrients. Nearly all cold-water habitat for fish and as zooplankton refuge was lost during the summer. The blooms caused serious water supply treatment problems including taste and odor, early exhaustion of activated carbon beds, high chlorine demand (increasing DBP formation). A two stage Layer Aeration System, driven by only 200 SCFM compressed air capacity, was designed and installed. Within three years the summer Cyanobacteria blooms ceased, over 2500 acre-ft of cold water habitat was restored, and zooplankton grazer populations increased.

Summer transparency increased from 4 ft to 4 meters (13 ft). Oxygen has been maintained to 14 m (45 ft) since 1990.

**Depth profiles from July 10, 2008; 3.9m Secchi Transparency**

![Graph showing Lake Shenipsit Secchi and Anoxic Depths 1985 - 1996](image-url)
Lake Prince and Lake Western Branch (1832 acres), Norfolk, VA
Hypolimnetic Aeration

Lakes Prince and Western Branch are the primary water supply reservoirs for the City of Norfolk, VA. They also support a very active recreational fishery. The reservoirs cover 1832 acres to a depth of 30 feet (much of the reservoir bottom is below sea level; spillway elevation is 18 ft MSL). A large capacity hypolimnetic aeration system was installed in 1992-1995 to reduce iron and manganese concentrations in raw supply water. In addition to substantially reducing the metals content of raw water, internal nutrient loading was significantly reduced, decreasing algae productivity, biomass, and total organic carbon (TOC). Full-lift hypolimnetic aerators were designed and installed which meet very specific design criteria: aerate the hypolimnetic waters deeper than 10 feet, accommodate a water level fluctuation range of 10 feet, etc. The initial pilot-scale system at Lake Prince demonstrated the benefits of hypolimnetic aeration for cost-effective water supply treatment in 1992-1994. The facilities were subsequently expanded in Lake Prince and to Lake Western Branch (the direct supply of raw water). Aerating over 1830 acres of the high oxygen demand coastal reservoirs, this is the largest application of hypolimnetic aeration in the world. It has been operated each year since the original pilot project in 1992.

Research conducted on the hypolimnetic aerators by Virginia Tech engineers established well documented pumping rates and oxygen input rates per SCFM of compressed airflow, and the developed several design models for air lift hypolimnetic aeration system sizing.
Alternative Land-Based Facilities

In some cases it is very difficult, or cost-prohibitive, to acquire 3-phase power and to construct a permanent equipment building. Depending on the size of the required system alternatives to house and operate lake restoration equipment are available. Solar power systems, trailer mounted equipment, power converters, wind powered systems, and other innovative approaches are all possible for specific site conditions.

Off-Grid Management Apparatus

Layer Aeration, Hypolimnetic Aeration, and Specific Circulation Approaches (such as down-draft full or partial artificial circulation, epilimnetic expansion, etc.) can be driven by Solar, Wind, or Hybrid Solar-Wind Powered Apparatus (Patents Pending). Pumping nutrient-rich bottom water to the sunlit surface is not the best approach for managing algae blooms and other water quality problems. Approaches that effectively manage lakes and reservoirs, while working in concert with the natural features of stratification, are available. You don’t have to settle for destroying stratification and pumping nutrient-rich bottom water to the surface.
Stafford Reservoir, Connecticut
Water Supply Intake Relocation and Reservoir Partitioning

The Supply Intake was extended into the Northern Bay, Isolated from Agricultural Runoff.

A Dairy Farm located upstream of a Source Water Reservoir resulted in very high nutrient loading, coliform, Cyanobacteria blooms, turbidity, TOC/DOC, and other contaminants. At times demands were so high that it was difficult to add enough chlorine to maintain adequate disinfection and residuals, and DBPs were problematic, as well as taste and odor episodes. Diagnostic research identified a Reservoir Partitioning and Flow Routing approach which substantially avoided water quality impacts related to agricultural runoff. A section of the reservoir was partitioned off by a surface-to-bottom weir curtain at a narrow location. An extension pipe was installed from the existing Supply Intake, anchored on the reservoir bottom, to the northern bay which was now isolated from the stream carrying runoff from the agricultural use area of the watershed.

As seen in the above photo, intense Cyanobacteria blooms continue to occur in the lower basin exposed to agricultural inputs; however, the source water withdrawn from the isolated northern bay exhibits much better water quality (significantly lower NTU, Coliform, Nutrients, Cyanobacteria, Taste & Odor, Chlorine Demand, etc.). An AWWA Publication Reprint providing detailed information and data is available at www.EcosystemConsulting.com / Flow-Routing Intake Isolation.
Oradell Reservoir, United Water Company, New Jersey

Layer Aeration

Oradell Reservoir is the supply source for United Water New Jersey’s Haworth Water Treatment Plant, providing water to 800,000 residents in 60 municipalities in Bergen and Hudson counties. The man-made Oradell Reservoir has a storage capacity of 3.5 billion gallons, and is fed from three upstream storage reservoirs. Intermittent stratification and loss of dissolved oxygen in deep strata resulted in the release and accumulation of nutrients and anaerobic respiration products, causing:

- Taste and Odor Episodes from Cyanobacteria blooms (bluegreen algae)
- Fluctuations in pH and WTP dose rates
- Increased disinfection by-product formation
- Increased Chemical Use in the WTP
- Increased Filter Backwash frequency
- Greater production of Residuals
- Increased Treatment chemical, energy, and labor costs

Installation of a Layer Aeration System in May 2005 stabilized dissolved oxygen concentrations from surface to bottom, maintained a stratified warm surface-cool bottom profile and resulted in lower levels of Cyanobacteria and related water quality problems. The Layer Aeration Units were installed as unitized pairs to reduce the cost of installing the air feed piping in the large reservoir. The Utility estimates an annual treatment plant cost savings of up to $200,000. Most importantly, taste and odor episodes and customer complaints decreased substantially.

Independent Research Publication:
“Large Reservoir Management, Layered Aeration Mixes It Up, Vertically” AWWA Opflow Volume 32, No. 5 May 2006
Wanaque Reservoir, North Jersey District Water Supply Commission

Multiple Layer Aeration

Wanaque Reservoir is a large storage reservoir serving much of Northern New Jersey (200 MGD; 4 Million Population Served). Water is imported from several river sources which exhibit high nitrogen and phosphorus concentrations. In order to maintain raw water quality and avoid Cyanobacteria blooms which could result in taste and odor, elevated DBP precursors, and high concentrations of iron and manganese, a multi level Layer Aeration System was installed. The Layer Aeration includes Layer Aeration of a mid-depth strata which is used as the direct source of supply withdrawals, hypolimnetic aerators to reduce the accumulation of anaerobic respiration products, in the deepest strata, and diffused aeration expanding the epilimnetic mixing depth to avoid blooms of buoyant Cyanobacteria such as *Anabaena sp.* and *Aphanizomenon sp.*

An extensive monitoring and computer modeling program is performed annually to forecast water quality trends and anticipate Water Treatment Plant operation needs. The reservoir management actions have been successful at avoiding Cyanobacteria blooms (and resulting taste and odor episodes) keeping the primary production in Chlorophyta genera (Green algae). Raw water Mn has also been kept at a lower concentration.

Independent Research Publication:


(Copy available at: www.EcosystemConsulting.com)
An integrated reservoir management approach was implemented at Broadbrook Reservoir. A surface containment partition and submerged weir partition baffle were installed at a narrow reservoir location. The surface partition contains buoyant Cyanobacteria “up-reservoir” in the riverine and transition zones. The submerged weir partition contains the anaerobic hypolimnion “up-reservoir”. Only water at middle depths is allowed to pass down-reservoir toward the dam and raw water supply intakes. Two small hypolimnetic aerators and two artificial circulation diffuser lines at two different elevations (depths) are operated seasonally to maintain raw water quality in the lower reservoir (lacustrine zone) nearest the supply intakes. In this approach, the passive reservoir flow routing partitions reduce the area and volume needing aeration; hence improving cost-effectiveness of aeration facilities.
Putnam Reservoir- Aquarion Water Company

Solar Powered Layer Aeration

Putnam Reservoir is a terminal distribution reservoir serving the Greenwich Connecticut area. Raw water typically had elevated iron and manganese during the Summer and early Fall, as well as episodes of taste and odor related to both benthic and phytoplanktonic Cyanobacteria. A Layer Aeration System was designed specifically for the stratification structure of the reservoir and available elevations of water supply intakes. The system is an “off-grid green powered system”: solar photovoltaic panel arrays, load controllers, battery bank, and load controls and DC compressors provide the compressed air to drive the air-lift pumping system. The in-reservoir components blend and aerate water from a selected depth range, redistributing available ambient dissolved oxygen, produced by photosynthesis above the compensatory depth, throughout the layer depth range to offset deeper oxygen deficits. Manganese and iron concentrations decreased by 80% and 60%, respectively.

An extensive monitoring program collects water quality data from the distribution reservoir as well as upstream source water systems. Ongoing research is focusing on reservoir management approaches to improve the water quality entering the terminal reservoir, reducing nutrient concentrations and anaerobic respiration products. Approaches being evaluated for the large upstream reservoir include Depth-Selective Flow Routing, and hybrid Wind-Solar Layer Aeration Circulation approaches.
Lakeville Reservoir #2 - Aquarion Water Company

Solar Powered Layer Aeration & Wind Powered Depth-Selective Circulation

When Solar Layer Aeration and Wind-Driven Circulation were operated raw water NTU, Mn, and Fe were maintained at relatively low concentrations.

In previous years, the Lakeville Water Treatment Plant had to be shut down during August-October due to very high Mn, Fe, and Turbidity (switching to groundwater sources at higher treatment cost).
Glendola Reservoir- New Jersey American Water Company

Multiple Layer Aeration

A Layer Aeration System was installed in Glendola Reservoir during 1997 (first full season of operation was 1998). The system was designed specifically for the configuration of the Reservoir, the Imported Water Diversion, and the Water Supply Intake Locations. Imported water contains more nutrients than had historically been available in Glendola Reservoir. Hence, as the volume of imported water increased over the years the reservoir experienced increasing eutrophication symptoms. Phytoplankton was dominated by bluegreen algae (often taste and odor producing species). Benthic mats of bluegreen algae developed. And the “consequences” of eutrophication caused challenges in the Jumping Brook Water Treatment Plant, including:

- Taste and Odor Complaints,
- Very Short Filter Runs - related to filter-clogging algae and high concentrations of iron and manganese.
Before aeration, internal nutrient loading due to oxygen loss resulted in more than doubling the TP availability. Aeration has overcome that internal loading cycle. Hypolimnetic accumulation of phosphorus during oxygen loss has been prevented.

Layer aeration has significantly reduced the internal accumulation of iron and manganese related to oxygen loss in Glendola Reservoir. The ongoing monitoring by NJ American and ECS, Inc. resulted in changes in operations (for example, shifting the focus of airflow between aerators seasonally). This has resulted in continued improvement, as exemplified by maximum Mn concentration decline.
Ledyard Reservoir, Groton Utilities

Depth-Selective Flow Routing, Layer Aeration, and Wind-Powered Circulation
Lake Rockwell Reservoir, Akron Ohio
Hydrologic Discharge Control Assembly (HDCA)– Enhanced Hypolimnetic Flushing

The HDCA System makes water “fall out of the reservoir spillway from the bottom or a selected depth elevation”. It is entirely passive, requiring no pumping or siphon, and almost no annual maintenance. Natural outflow simply falls over the spillway from the bottom. Reservoir surface level drops to the outlet weir spillway, but doesn’t drop below that due to the system. (Of course, if withdrawals are made below spillway elevation level can continue to drop, but not as a result of HDCA Outflow). HDCA is a method which can increase deep flushing rates; if water budget is healthy (large in comparison to deep strata volumes) anoxia and the accumulation of iron, manganese, and internally released phosphorus and ammonia can be avoided.
Truro Nova Scotia, Water Supply Reservoir
Hypolimnetic Aeration

The source water reservoir serving the City of Truro, Nova Scotia was experiencing very high concentrations of Manganese and Iron in raw water during summer stratification. In order to maintain cold bottom temperatures and avoid stimulating Cyanobacteria blooms resulting from upwelling types of destratification systems (which transport nutrient-rich bottom water to the surface) the City implemented Hypolimnetic Aeration. Ecosystem Consulting Service, Inc. evaluated the available reservoir data and morphometry, supply intake locations and elevations, and designed a partial-lift (submerged) hypolimnetic aeratorspecific to the source of supply. The aerator CAD Designs were provided to a Fiberglass Fabricator in Truro, Nova Scotia for local construction of the tower. The aeration system was then installed by a local Diving Contractor with on-site supervisory assistance by Ecosystem Consulting.
Brick Township Municipal Reservoir, New Jersey
Seasonal Artificial Circulation to Enhance Diatoms and Decrease Cyanobacteria

Research conducted at the Brick Township Reservoir in New Jersey identified a Seasonal Approach to the operation of aeration systems installed during the construction of the reservoir. During 2009 and 2010 the diffuser modules were operated after ice-out to maintain a well mixed condition as the isothermal water column warmed. This was done to prevent intermittent episodes of temporary stratification as the lake heating season progressed, and to keep Diatoms suspended in the water column as the water became warmer (hence less dense and less viscous). Diatoms are heavy due to their silica cell walls and tend to fall out of the water column early in the spring. Once the isothermal mixed temperature reached approximately 15 degrees Centigrade, compressed airflow was redirected to the Layer Aeration Towers which manage how stratification develops relative to water supply intake elevations and to maintain aerobic conditions to prevent increases in nutrients and anaerobic respiration products.

Diatoms have become the dominant phytoplankton during Fall, Winter, and Spring. The Spring Diatom population would naturally crash in mid-March, but is sustained for an extended duration by artificial circulation diffusers (delaying the seasonal succession shift to Greens and Cyanobacteria). Then in late May-Early June the Artificial Circulation is switched to Layer Aeration. That management approach delays the “Clear Water Phase” and results in better water quality later in the Summer.
During 2009 and 2010, spring circulation was enhanced using a diffused air system between ice-out and the data that isothermal temperature reached approximately 15 degrees Centigrade. Then compressed air was re-directed from the diffuser modules to Layer Aeration Towers.

This Seasonal Management Approach resulted in the enhancement of Diatoms, especially during the Spring and Fall.

Peaks in Total Phytoplankton abundance decreased significantly.

Abundance of Cyanobacteria decreased by approximately 75%, and the occurrence was delayed approximately 6-8 weeks.

Abundance of Green Algae also decreased, and exhibited a delay to later in the Summer Stratification Season.

“To DECREASE CYANOBACTERIA during the Summer...ENHANCE DIATOMS in the Spring”
MDC Reservoir, Connecticut
Depth-Selective Flow Routing

A very large, high quality, oligotrophic reservoir (Barkhamsted Reservoir) flows through a tunnel and into a direct source terminal Reservoir 6. A set of Flow Routing Baffle Partitions induce plunge of the cold high quality inflow to Reservoir 6, and deep withdrawal to the WTP. Water is conveyed from the inlet point to the supply withdrawal through the bottom hypolimnetic layer – which benefits raw water quality as well as conditions at the sediment-water interface in Reservoir 6.