Section 2. Worldwide Applications of Oxygen Supplementation to Rives, Lakes and Harbors

2. Existing Oxygenation System Installations.

I. Background.

Some of the world's most beautiful harbors and lagoons and its most heavily trafficked seaports face severe flooding problems during storm tide seasons. But remedial steps to minimize flood damage may in turn cause other water quality dilemmas, which must also be addressed at the same time.

Venice's magnificent architecture is being threatened by each successive flood season, yet its historic lagoon would also experience serious oxygen depletion if isolated by tidal gates. The busy Thames River's innovative tidal gates are successfully holding back potentially damaging flood tides at this time, but are accompanied by mobile oxygenation barges which alleviate consequent D.O. deficiencies.

Other oxygen poor harbors on the other hand, such as Shanghai Harbor, sustain serious pollution damage during dry seasons and the serious malodorous conditions which have plagued the city's inhabitants for decades have also caused the fish and shrimp to die until rehabilitation efforts were undertaken in 1988, and in 2001 when an oxygenation barge was deployed there with good results.

Savannah Harbor's main pollution source is decaying vegetation from the surrounding marshes. The Stockton, California Deepwater Ship Channel also must address constant new nutrient enrichment problems along with combined sewer overflows. Manchester Ship Canal in England has excessive algae growth, caused by heavy nutrient load and accumulation of sludges on the bottom, with consequent fish kills.

Ship traffic restricts equipment location, which precludes some types of aeration equipment. However, modern oxygenation designs using pure oxygen to raise the D.O. levels show great promise in solving worldwide harbor water quality dilemmas as well as those of rivers, lakes and bays.

II. Descriptions of oxygenation systems and specific equipment site data

Described below in approximate chronological order according to installation dates, are successfully operating installations which use HPO technology to achieve regulatory compliance and enhance resident fisheries.

Richard B. Russell Reservoir Georgia
Newman Lake Washington
Camanche Reservoir California
Thames River England

Tombigbee River Alabama
Logan Martin Dam Alabama
Emscher River Germany
Hallwilersee Lake Switzerland
Patrick Henry Reservoir Tennessee
Douglas Reservoir Tennessee
Fontana Reservoir Tennessee
Androscoggin River Maine
Cardiff Bay Barrage England
Amsterdam Canals, Netherlands
Suzhou Creek, Shanghai Harbor

Richard B. Russell Dam, Georgia, Diffuser Systems

Richard B. Russell Dam is located on the Savannah River above Augusta Georgia. At Richard B. Russell Dam a first ever solution to D. O. depletion using fine bubble diffusers placed along the bottom of the 140 foot deep impoundment at approximately 1 mile in front of the dam. Oxygen supplementation was implemented within the hypolimnion from which layer the turbines withdraw water for power production and then discharge it downstream. Oxygen supplementation is practiced for approximately 7 months out of the year in order to maintain a downstream D. O. concentration of >6 mg/L for enhancement of the fishery therein.

During maximum power generation the dam release is over 60,000 $ft.^3$ per second. Like all deep lakes in the Southeast, Russell Lake stratifies during summers. Warm light waters sit on a colder dense layer in the bottom. Only the top 30 feet, which is the epilimnion is circulated by wind action. With no means to replenish D. O. consumed in biological and chemical activity the D. O. levels in the depths of the lake, namely the hypolimnion layer, are gradually exhausted after stratification sets in. The water quality standards were set at 6 mg/L of D. O. in the reservoir releases. Since Russell Dam's waters needed D. O. improvement from 1 mg/L background to 6 mg/L in the discharge a more powerful oxygen enhancement system was needed than could be achieved by turbine venting or turbine oxygen injection. Proof of concept studies were conducted in the summer of 1975, 1976 and 1977 by a Drexel University team directed by Prof. Speece.

In order to generate absorption data for mass balance and efficiency studies an experimental system was suspended at the face of the dam. Fine bubble diffuser performance were evaluated by placing the diffusers at various depths below the water surface. An 11 foot diameter bubble collection of hood was placed at the surface above the bubble plume, so that the entire off gas from the bubble plume could be captured and quantified. Various diffuser loading rates were observed. Results from Phase 1 indicated that by using low porosity diffusers and O2 loading rates of 0.5 to 2.0 feet per minute 90% of the oxygen was absorbed within a bubble rise of 100 feet. The next evaluation phase involved placing a rack of fine bubble diffusers 100 feet horizontally in front of the penstock intakes and measuring the D. O. in the discharge from those penstocks. When oxygen was injected in front of the hydropower discharge it raised the D. O. from a background level of 2 mg/L to a discharge level of 8.1 mg/L. More than 90% oxygen absorption efficiency was achieved under these conditions.

The prototype diffuser system had two 1200 foot long assemblies of fine bubble diffusers and was suspended 5 feet above the impoundment bottom and located 100 feet apart in parallel. The fine bubble ceramic diffusers had a characteristic porosity of 2 feet per minute.

The first season of oxygen injection began with the onset of lake stratification on April 3, 1985 at an O2 loading rate of 25 tons per day. A maximum oxygen loading rate of a hundred tons per day occurred in September and October of that year. Oxygenated water was shown to stay in the lower layer of the lake and a daily average of 6 mg/L was maintained. By the time injection was terminated in December, after the Fall turnover over 14,000 tons of oxygen had been injected.

In May to November of 1986. Some 10,000 tons of oxygen were injected, peaking at 90 tons per day. In 1987 only 7800 tons of oxygen were injected. Due to the natural aging of the lake the oxygen demand decreased.

This original fine, bubble system using ceramic diffusers was replaced after about 15 years by soaker hose technology.

In 2001 the original ceramic diffusers were replaced with a soaker hose diffuser design utilizing 10 - 4000 foot long lines along the old river channel upstream from the dam. High oxygen transfer efficiencies are achieved by spreading the diffuser hose over a larger area, (Mobley, Adams, Haynes and Sykes 2003).

They continued:

> The diffuser installation in the reservoir was conducted from the surface without divers. The diffusers were assembled from a temporarily closed boat ramp and floated into final position in the reservoir in sections. Floating over a mile of diffuser pipeline at a time, across the popular reservoir required seven work boats, deep anchor points. Long rope spans and patrol boats to warn public boaters. The work boats and anchor points were used to maintain the diffuser location, despite changing wind directions. Once the diffuser was satisfactorily floating above the final location, the buoyancy chamber was pumped full of water to sink the diffuser in a controlled manner to the bottom. The process can be reversed to retrieve the diffuser for maintenance or repositioning.
>
> The diffuser installation was completed with some preliminary testing in September 2001. Results indicated some disparity and individual diffuser line flows and difficulty in attaining full system design flow during test conditions that included temporary piping and flow control.
>
> During 2002 the existing liquid oxygen supply facility was modified to reliably achieve the maximum design flow capacity, a new

oxygen flow control system was installed, and several diffuser lines were modified to provide better flow capacity. Start up testing was completed in August 2002 including operation of the system at over 200 tons of oxygen per day. The oxygen system was operated successfully for the remainder of the 2002 season.

Newman Lake, Washington, Speece Cone Oxygenation

Quoted from Barry C. Moore, Washington State University "Downflow Bubble Contact Aeration Technology (Speece Cone) for Sediment Oxygenation"

Internal phosphorus recycling during summer stratification has led to the accumulation of large amounts of organic sediments in the bottom of Newman Lake, which is the centerpiece of a residential area in western Washington state. The resulting anaerobic sediment water interface allows phosphorus recycling at rates several orders of magnitude greater than under aerobic conditions (Bastrom *et al*, 1988, Funk and Morris, 1988).

A 1985 - 86, study concluded that 3000 pounds of oxygen per day would be required to meet the daily summer hypolimnetic oxygen demand, (McLean and Lean, 1986, Ashley *et al*. 1987). A Speece Cone was installed in 1992 to maintain oxic conditions with the view to eliminating unsightly algae growth visible to the residents and to restore the lake fishery.

Studies on Newman Lake conducted in 1985/1986 allowed calculation of a nutrient budget in which about half of the total net phosphorus loading was estimated to be associated with internal cycling (Funk and Moore, 1988). Therefore, intervention into processes leading to mobilization of sediment phosphorus was determined to be critical for reducing summer algae productivity and for restoring acceptable water quality. For Newman Lake, maintaining aerobic conditions during summer stratification offered the best means to reduce internal phosphorus recycling. Previous studies on sediment transport showed that, if the sediment/water interface is maintained in an aerobic state, then phosphorus solubility and mobility are greatly reduced (Bostrom et al., 1988).

Over the years, export of materials of both natural and anthropogenic origin from the watershed, combined with plant materials produced within the lake basin itself, have led to the accumulation of large volumes of organic sediments on the lake bottom. During summer stratification, microbial breakdown of these sediments exerts oxygen demand that leads to depression and depletion of oxygen in the lake hypolimnion (bottom waters). The resulting anaerobic sediment/water interface allows phosphorus to be recycled into overlying waters at rates several orders of magnitude greater than under aerobic conditions (Bostrom et al., 1988, Funk and Moore, 1988). High phosphorus concentrations in Newman Lake have been determined to be the primary cause of excessive summer algae biomass, which is major water quality problem (Funk and Moore, 1988).

TABLE 1. System specifications for the Newman Lake Speece Cone.

Cone volume	11.1 m^3 (315 ft^3)
Cone height	4.6 m (15 ft)
Oxygen delivery	1,360 kg/day (3,000 lbs/day)
Dual Air/Sep O_2 generators	680 kg/day (1,500 lbs/day) each
Dual rotary screw compressors	50 hp each
In-lake water pump	40 hp @ .73 m^3/sec (21 ft^3/sec)
Distribution manifold	100 ft (31 m) w/ 2” ports @ 2 ft spacing

In 1992, a Downflow Bubble Contact Aerator (DCBA) system, known as a Speece Cone, was installed in Newman Lake, Washington, USA. The principal purpose of the system is to provide sufficient oxygen to prevent hypolimnetic oxygen depletion and to maintain an aerobic sediment/water interface and is the first use of Speece Cone technology for lake restoration application. This later function was targeted to reduce recycling of nutrient compared to flux rates under anaerobic interfacial conditions. The system also contains other significant innovations, including pressure-swing molecular sieve technology for on-site oxygen generation, and a multi-ported exhaust manifold to reduce water velocities and prevent sediment entrainment. Compared to other available technologies, the system also represents significant savings in capital and operating costs. An evaluation of the Speece cone performance using a 17-year data set was made. When operated as designed, the system has been able to maintain elevated dissolved oxygen in the summer hypolimnion. Variations in operational and environmental parameters have provided a wealth of information on the Speece Cone, demonstrating that this is a economic and efficient technology that should receive wider application. Probably most significant are data that support the reality of a phenomenon known as induced oxygen demand, in which post-oxygenation O_2 demand rates exceed those observed prior to implementation.

Moore concludes his study with several recommendations for consideration of sediment oxygenation.

A recent review has concluded that improved water quality can be realized by hypolimnetic oxygenation, and that the method deserves more widespread application (Beutel and Horne 1999). In conclusion, it should be noted that the Speece Cone is an appropriate technology for delivering oxygen in water and sediment oxygenation applications. Methods that account for induced sediment oxygen demand are essential for predicting post-treatment oxygen requirements. Proper sizing of the system to meet that demand is crucial in order to realize environmental oxygenation goals.

When data on the range of environmental variability is limited, it should be understood that the associated high degree of uncertainty necessitates application of liberal safety factors to reduce risk of system under-sizing. For such situations, an economic analysis that balances risk versus cost of increasing system capacity may be an appropriate decision-making tool.

Camanche Reservoir, California, Speece Cone Oxygenation

Horizontal discharge of a super oxygenated sidestream is an important feature of the Speece Cone technology designed for Camanche Reservoir located in the foot hills of California, as may be seen in the photo (Figs -- --). During drought seasons the water depth, which usually varies up 135 feet, drops to only 25 feet. A yearly D.O. pattern of the hypolimnion is depicted in Fig. ---.

This reservoir discharges through a bottom pen stock during most of the stratification season and feeds a coldwater salmon fishery as well as a salmon hatchery immediately downstream from the dam. The discharge of 400 to 800 $ft.^3$ per second during the stratification season is also used to generate power before discharge as the sole headwater of the Mokolumne River, which is a salmon habitat.

The river and hatchery require a coldwater discharge from the reservoir hypolimnion, so stratification must be carefully maintained. By mid June, the D.O. in the hypolimnion discharge is below 7 mg/L, which is the regulated D.O. for rivers in California classified for salmon. Therefore, at this time the hydropower generation must be bypassed and the water discharged through a Howell Bunger valve for aeration. Such cessation of electricity generation results in revenue losses of approximately $5,000 per day per 400 $ft.^3$ per second by-passing the generators.

By late June or early July anaerobic conditions are established in the bottom of the hypolimnion, where the discharge is located, causing iron and manganese to be solubilized and hydrogen sulfide to be produced. Hydrogen sulfide is toxic to the fish, corrosive to electrical connections in the vicinity of the Howell Bunger valve where it is stripped during aeration, and eventually is offensive to personnel and visitors to the river below the dam.

In 1996, a Speece Cone hypolimnion oxygenator with horizontally induced flow, which dissolves 18,000 pounds of oxygen per day to the sidestream discharge from the oxygenation system back into 100 foot long diffuser, was installed on the bottom of the reservoir at the toe of the dam.

When the water is 100 foot deep, the oxygenated sidestream has a dissolved oxygen concentration of about 100 mg/L. A D.O. increase of 4 mg/L was observed in the hypolimnion 10,000 feet from the diffuser two weeks after the oxygen supplementation commenced operation.

Oxygen supplementation of the hypolimnion allows power to be generated, prevents hydrogen sulfide production, and meets river and hatchery D.O. criteria for the State of California. An additional advantage is that the equipment is hidden from public view at the bottom of the reservoir.

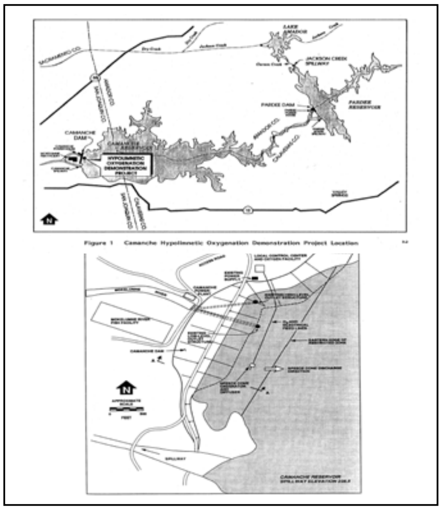


Figure 1 Camanche Hypolimnetic Oxygenation Demonstration Project Location

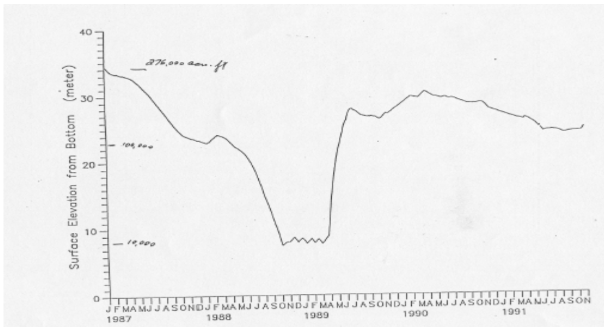


Figure 3. Reservoir Surface Elevation for 1987 to 1991 (bottom at 30.3 meters (100 ft) above sea level)

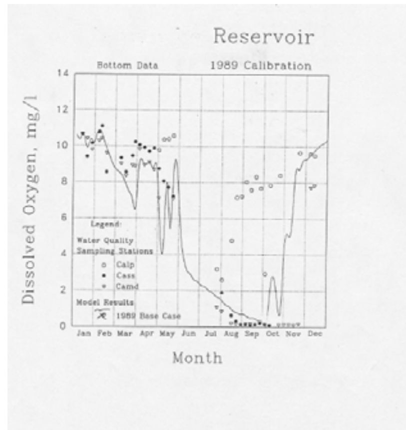


FIGURE 10
DISSOLVED OXYGEN (BOTTOM)
RESERVOIR
CALIBRATION 1989

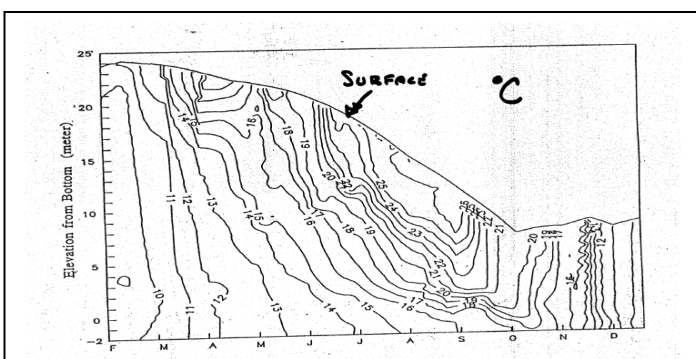


Figure 7. 1988 Reservoir Temperature Isopleths (Celsius)

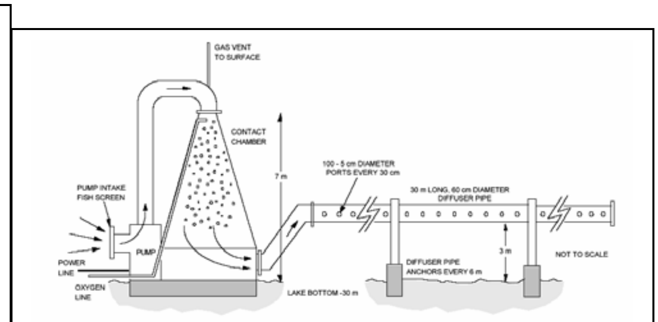


Figure 2 - Schematic of submerged contact chamber oxygenation system used in Camanche Reservoir, California and Newman Lake, Washington.

Thames River, England, Mobile Oxygenation Barge

An early network for the London sewer system was built in the 1850s with various catchments for drainage and pumping stations. Originally the design target was to intercept the dirty water coming down the river and divert it to London's east side, to minimize the pollution for the main part of the city. Both surface runoff and foul sewage enter the Thames. Two London areas, Becton and Crossness on the Eastside and Modem at the top of the tidal stretch of the river are the locations of the main sewage works. (Health and Public Services Committee, September 14, 2004 transcript).

During heavy rains, the system channels excess water back into the Thames. To avoid flooding in the city, according to the report cited above, the networks in London are so convoluted with its legacy that the normal rules do not apply. Therefore you need to have a rather individual approach to try to cure the problem.

The London sewage works are some of the largest in Europe, but when storm flows rise, untreated sewage as well as surface runoff are discharged into the Thames. Storm tank storage is limited so excessive flows cannot be contained. In order to avoid basement and house flooding, the sewage system must release storm runoff as frequently as 50 to 60 times a year, resulting in fish kills nearly every 10 to 16 weeks in the tideway,(*loc. Cit.* 2004).

A Thames Bubbler barge and a Thames Vitality barge authorized by the National Rivers Authority and the British government, containing venturi jets to diffuse the oxygen produced on board, have been deployed to prevent fish kills during storm tides. But even with these and the addition of hydrogen peroxide at the treatment works effluent, these oxygenation systems on the river failed to prevent fish kills in August and September of 2004. About 30 tons per day of oxygen are generated by each barge. Oxygen transfer efficiency is estimated to be about 65% from the venturi jets.

Thames Bubbler

According to the report, it has always been recognized that the Bubbler barges were a temporary solution until something more permanent comes along.

Tombigbee River Alabama, U-Tube Oxygenation

During periods of drought, the normally sufficient D.O. levels in the Tombigbee River, located near two paper mills in Alabama, dropped below minimum state standards. In times of prolonged drought after the 30 day treated effluent storage capacity of each mill becomes full, mill production capacity had to be curtailed to maintain river D.O. levels, negatively impacting mill profits.

Both mills discharge efficiently treated waste water, so an agreement was reached with Alabama state authorities to add D.O. directly to the Tombigbee River. Since the Gulf States mill is located about 35 miles upstream from the James River mill, both mills impact the D.O. concentration downstream of the James River mill discharge. It was therefore a mutual benefit to design one common oxygen supplementation strategy. A D.O. water quality model of the river had demonstrated this oxygen supplementation strategy would allow both mills to operate at full capacity under the most critical low flow and high temperature conditions in the Tombigbee River.

The mutually beneficial agreement between the Gulf States and James River paper mills was reached on a solution for maintenance of the regulated D.O. concentrations in the Tombigbee River to minimize the fraction of river flow which must be moved through the oxygenation system. Therefore the D.O. concentration achieved had to be maximized.

The agreement allows 12,000 pounds per day of D.O. to be added to the James River mill effluent and 40,000 pounds per day of D.O. to be added 35 miles down river. One stipulation is that the D.O. in the river can never exceed 100% of air oxygen saturation, namely 7.9 mg/L at 28° centigrade, which is a typical hot summer river temperature during drought flows.

The James River effluent storage pond is located about 30 feet above the river level and flows by gravity through a U-Tube oxygenation device, where it is superoxygenated to 50 mg/L, and then passes into a diffuser on the bottom of the river. At the second location, called McCarty's Landing, 125 MGD of water must be pumped from the river through the U-Tube oxygenation device and back into a diffuser on the bottom of the river. Here again the D.O. is raised to 50 mg/L for discharge into the river diffuser.

A number of oxygenation systems and oxygen sources were evaluated. Air as an oxygen source was rejected because of the low potential D.O. concentration saturation and also potential dissolved nitrogen supersaturation problems in the river. Conventional surface aerators were rejected because of the excessive energy consumption per ton of D.O. supplemented to maintain the D.O. at 5 mg/L under summertime temperatures. Logistics due to barge traffic and policy considerations would not allow an oxygenation system to be located on the surface of the river, where it would obstruct barge traffic. Diffused aeration was rejected because of the low potential D.O. saturation, which would require pumping the entire river through the diffused aeration basin. Dissolved nitrogen gas supersaturation would result, possibly impairing the health of fish in the river. Again, excessive energy consumption per ton of D.O. supplemented was required to maintain a target D.O. of 5 mg/L.

Pressurized sidestream pipe reactor oxygenation was rejected because of excessive energy consumption per ton of D.O. supplemented and potential effervescent loss of supersaturated D.O. due to turbulence at the throttling valve used to maintain pressure in the reactor. Costs were considerable to supply 1000 feet of stainless steel pipe required to provide the required bubble contact time of over 100 seconds at the 10 fps water velocity necessary to maintain two-phase flow.

The overwhelming economical and practical advantages of using commercial oxygen emerged in the selection process, narrowing the search to two systems, the U-Tube and the Speece Cone technologies. Excessive cost to excavate deeply enough to withstand water levels in the 100 year flood disqualified the Speece Cone. The U-Tube oxygenation system was selected for its energy efficiency and capacity to produce very high D.O. concentrations of 50 mg/L with associated high oxygen absorption efficiency.

The U-Tube oxygenation system incorporates prolonged contact of the oxygen bubbles with the water as well as hydrostatic pressurization of the bubble water mixture as it passes down through the U-Tube. Oxygen transfer is enhanced by the turbulence and extended contact time, but mainly by the hydrostatic pressurization as the water goes down the depth of the U-Tube and back up out the discharge. A depth of 175 feet was selected as the design depth for the U-Tube.

U-Tube oxygenation was selected for both of the two locations on the Tombigbee River. The U-Tube with oxygen injection produced an affluent D.O. of 50 mg/L at 28°C with an oxygen absorption efficiency of 80 to 90% for a unit energy consumption and 94 kWh per ton of D.O. The oxygenation capacity was 5400 mg/L of D.O. per cubic feet per hour and the head loss across the 175 foot deep U-Tube was 5 feet.

A bubble harvester was incorporated to harvest any undissolved bubbles and recycle them back to the influent of the U-Tube. By discharging a highly elevated D.O. sidestream into the river through a diffuser in the bottom, advantage was taken in the hydrostatic head to prevent effervescent loss of D.O. and a high D.O. discharge was mixed throughout the river cross-section within a short distance downstream.

A schematic diagram shown in (Figs. ___) of both a gravity fed U-Tube which puts in 12,000 pounds of D.O. per day, as well as a schematic of the U-Tube where 125 MGD of water is pumped from the river through the U-Tube and then discharged back into the river with 50 mg/L of supersaturated D.O. concentration, resulting in 40,000 pounds per day of D.O. supplementation.

TECHNICAL EDIT

CUTAWAY DIAGRAM

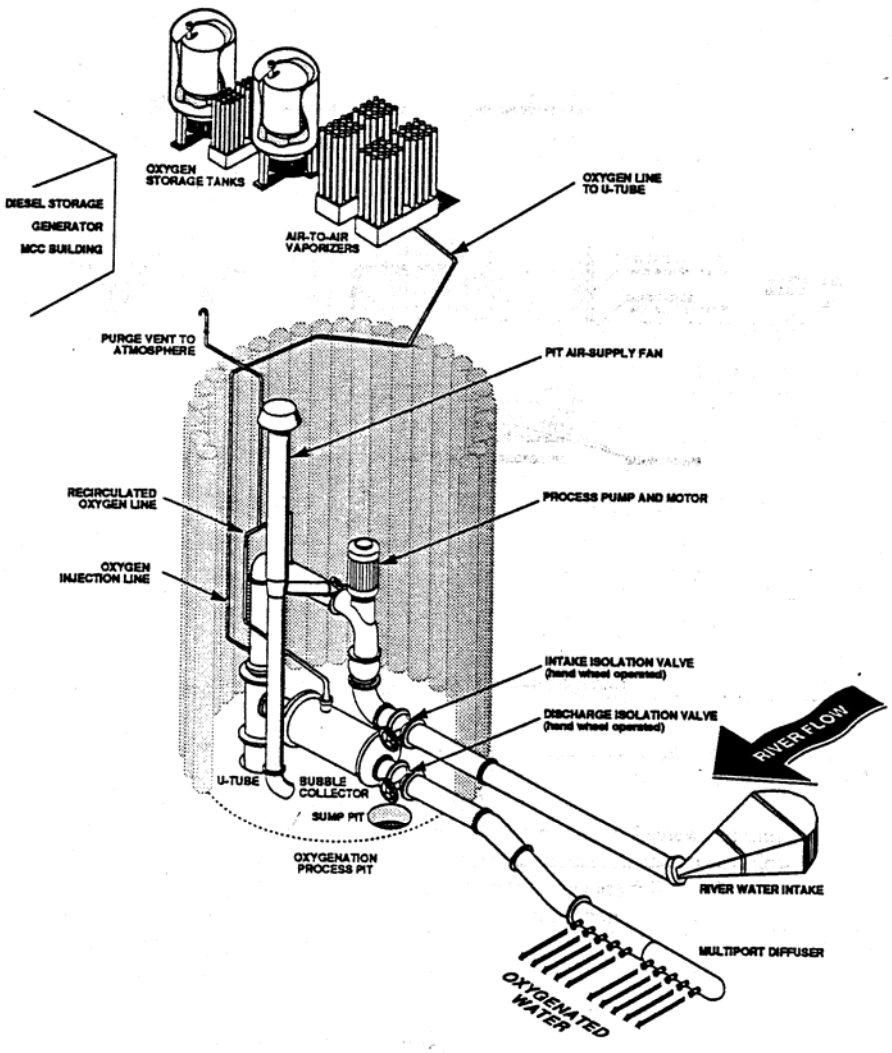


Figure 1.4 *River Oxygenation Equipment Diagram*

6

1.6 **INTRODUCTION**

CUTAWAY DIAGRAM

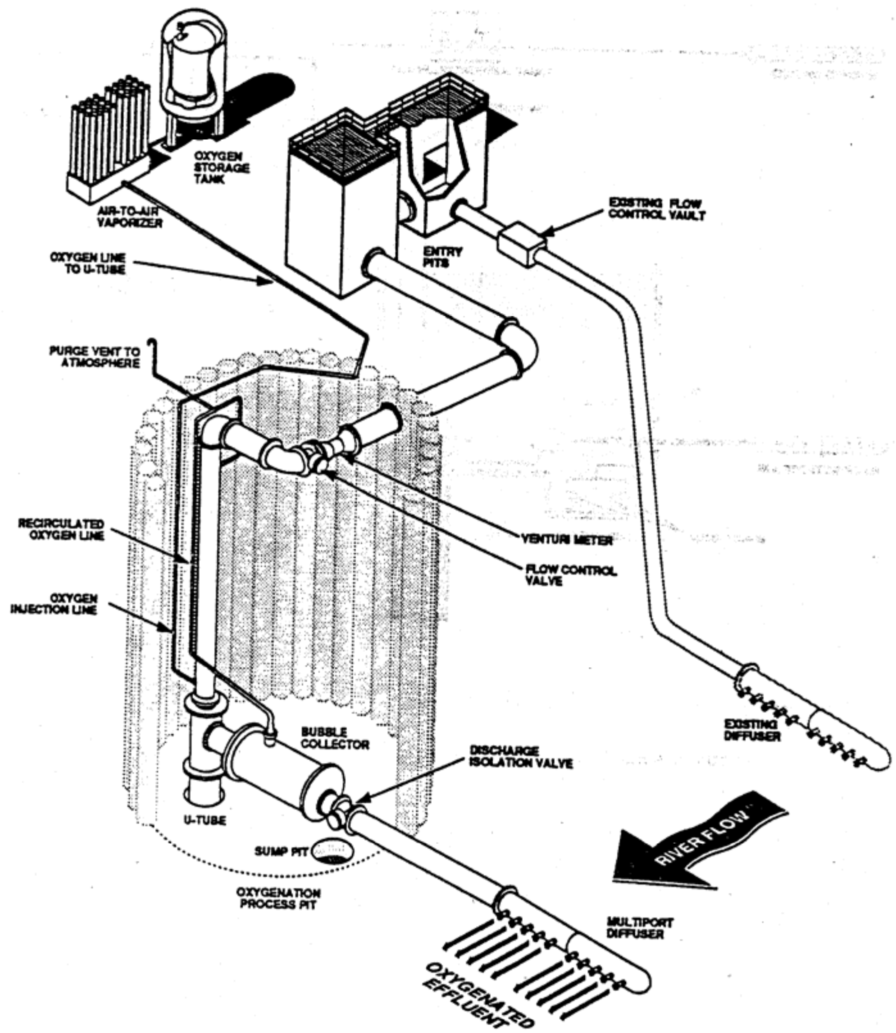


Figure 1.4 *River Oxygenation Equipment Diagram*

James River CORPORATION — Module Two – Foundations / RIVER OXYGENATION SYSTEM – NAHEOLA SITE / Rev 0 – October, 1992 — Gulf States PAPER CORPORATION

Field testing of the oxygenation system performance of the U-Tube installation which oxygenated the treated James River Mill effluent on the Tombigbee River yielded the following data:

- up to 50 mg/L discharge D.O. at 25°C in the water
- 5.3 foot head differential across the U-Tube
- up to 18,000 pounds of D.O. per day oxygen transfer
- 80 to 90% oxygen absorption efficiency

Logan Martin Dam, Alabama, Speece Cone Oxygenation

Logan Martin Dam, owned and operated by Alabama Power Co., is located on the Coosa River and was constructed on a karst stone geological foundation, 60 feet deep near the dam. The river flows 35 miles downstream past a paper mill, with less than 4 mg/L of D.O. on the weekends due to hydropower turbine shut down. Since it is operated as a peaking power dam, water is only released through the turbines between 9 a.m. and 10 p.m. on weekdays, causing approximately 900 cfs of water to leak out through the conduits in the karst foundation, in spite of extensive grouting to prevent it.

These conduits in the rock below the dam are somewhat similar to biological trickling filters in that a biological slime develops on the surface of these conduits. Consequently, even though the water contains about 8 mg/L of D.O. in the reservoir behind the dam, by the time the water leaks through these conduits beneath the dam, essentially all of the D.O. is removed. Then on weekends when water is not released to the hydropower turbines, the only water passing into the tail water zone is comprised of this 900 $ft.^3$ per second of leakage water, which contains essentially zero D.O..

The resident fishery in the tail water below the dam is noticeably stressed during these weekend periods of low D.O. Fish by the dozens can be seen standing on their tails gulping air in an attempt to compensate for the low D.O. in the tail water. By Monday when the water now containing less than 1 mg/L of D.O., slowly passes the paper mill discharge point, the mill must curtail operation until the D.O. level again reaches about 4 mg/L.

In 1990 a Speece Cone oxygenation system was installed to meet one third of the 18,000 pound per day of oxygen required to raise the D.O. in the leakage flow to the required level. The 21 $ft.^3$ per second system also incorporated into the final design an additional system capable of handling another 42 $ft.^3$ per second.

This oxygenation system receives 21 $ft.^3$ per second of water from a pipe connected to the pool above the dam. The Speece Cone oxygenation system was installed at the base in the dam so that the water from above the dam passes through the Speece Cone oxygenator and discharges about 30 foot below the tail water surface. A throttling valve is located at the discharge in the tail water to allow pressurization of the oxygenation system. This pressure corresponds to the difference in water elevation between the upstream pool and the tail water.

The water pressure in the Speece Cone is advantageous because it allows oxygen transfer to take place at a pressure of 50 foot of hydrostatic head above ambient pressure. Consequently, the discharge D.O. has a concentration of approximately 50 mg/L. Approximately 5000 pounds of D.O. is added to the tail water each day by this supplemental oxygenation system. There is a D.O. rich zone in the vicinity of the Speece

Cone discharge into the tail water of Logan Martin Dam which can provide a respite for fish when the bulk of the tail water is very low in D.O.

The performance characteristics of the Logan Martin Dam oxygenation system have been thoroughly evaluated. When the water throughput is at the design level, over 90% oxygen absorption efficiency is realized within the Speece Cone. Maximum oxygen absorption efficiency occurs at a water flow rate of 21 to 25 ft.^{3} per second through the system. A slight reduction of oxygen absorption efficiency occurs below this range and a more rapid decline at higher velocities.

The pressure at the oxygenation discharge with no flow through the system is 52 feet, reflecting the static head of water above the dam with respect to the location of the oxygenation cone. With no oxygen injection the discharge pressure registers 44 and 42 feet at water flows of 22 and 25 ft.^{3} per second, respectively and an oxygen to water injection rate of 4% results in discharge pressures of 38 and 37 feet. It is to be noted that the total head loss across the oxygenation cone is nearly constant at 6.2 feet regardless of water flow through the system when oxygen is subjected at 4% oxygen water ratio.

At the design flow of 21 ft.^{3} per second and 4% oxygen water ratio, the system added 48 mg/L of D.O. to a background influent D.O. of 3.6 mg/L for a total of 5600 pounds of D.O. per day or 9 pounds of D.O. per cubic feet of reactor per day, which is 100 mg/L per minute at 90% oxygen absorption efficiency. The average pressure in the Speece Cone is approximately 29 feet at the centerline of the cone and the water temperature is 86°F. At this pressure and temperature the saturation D.O. concentration would be 66 mg/L, if the gas phase is 100% oxygen. The discharge D.O. was 51 mg/L and the oxygen content of the bubbles within the oxygenation cone was approximately 83% as measured and with a 4% oxygen to water injection rate, indicating the oxygenation system is able to achieve 94% of theoretical saturation under these conditions. These results are indicative of an excellent oxygen transfer system since the hydraulic retention time is only about 30 seconds.

In the flow range of 22 to 25 ft.^{3} per second with an oxygen ejection ratio of 3%, the discharge D.O. was 42 mg/L for a net increase of 38 mg/L over the background level. Under these conditions, the absorption efficiency was 95%.

The Logan Martin Dam with its full-scale application of Speece Cone technology has been in operation for over 10 years.

Emscher River, Germany, UNOX Oxygenation

Located in the Ruhr District of Germany, and a tributary of the Rhine, the Emscher River receives untreated and mechanically treated wastewater from a catchment area of 768 square kilometers. Industrial loading, mainly from chemical and food industries, makes up about 50% of the organic pollution. Up to 80% of the river flow is wastewater during dry weather conditions. (Bjerre, Jacobson, Teichgraber and te Heesen 1995).

At one point along the Emscher the river is diverted through primary clarifiers and farther along it enters a biological treatment plant for removal of dissolved and colloidal organic matter and phosphorus precipitation, before discharge into the Rhine. However hydrogen sulfide problems in transit are an indirect effect of anaerobic processes occurring in the river. An oxygenation station is being used to remediate foul odors experienced by populations living near the river.

The attached photos show the channelized Emscher River. Note the concrete structure, which is similar in concept to the UNOX pure oxygen transfer system with baffles at the beginning and end to enclose a headspace for oxygen enriched gas to be trapped above the river level.

Surface aerators splash the river water in contact with the enriched oxygen to achieve elevated D.O. concentrations so as to avoid odor generation before the water enters a 10 km stretch before reaching the secondary wastewater treatment plant. Dry season flows into the treatment works inlet vary from 9 to 13 m^3 per second, and the detention time is approximately 2 days.

The oxygenation system raises the D.O. in the entire river about 15 mg/L and supplements about 30,000 pounds of D.O. per day to the river.

Halwillersee Lake, Switzerland, Tanytarsus Oxygenation

In 1986, a tanytarsus diffuser system was installed in a medium-size lake in the Swiss plateau, which had experienced anoxia for a century. Lake Halwiler was eutrophic, due to excessive phosphorus loading characteristics of lakes and reservoirs in Switzerland and required deepwater oxygen bubble plume injection to prevent intrusion of hypolimnion water into the thermocline. As described by McInnis, Lorke, Wuest, Stockli and Little 2004, this system can be switched between artificial mixing using coarse air bubbles and hypolimnion lake oxygenation using fine oxygen bubbles. The six diffuser racks are 6 1/2 meters in diameter and are in a 300 m diameter circular configuration near the center of the lake.

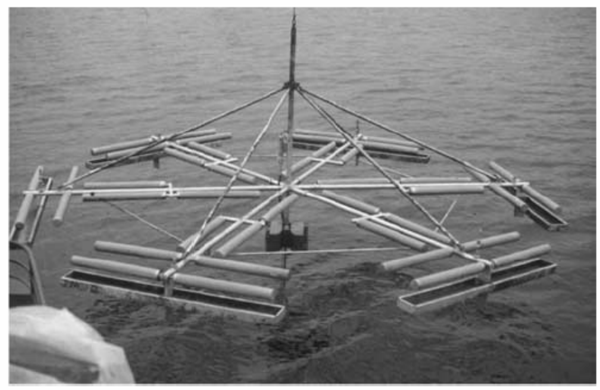


Figure 3. One of the six 6.5-m diameter Tanytarsus diffusers.

The accompanying figures show the whole lake contour plots of typical oxygen distributions with the plume operating with pure oxygen. Of particular note is the observation that this free bubble rise system is unable to oxygenate below the diffuser system. This results in great areas of the sediment water interface, which remain anaerobic even though the water column higher in the hypolimnion is well oxygenated.

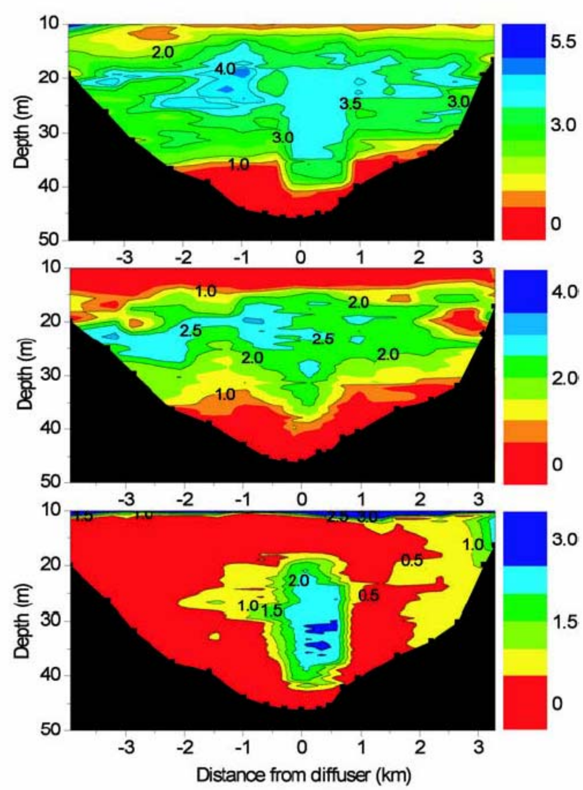


Figure 8. The (top) 24 July, (middle) 16 August, and (bottom) 27 September 2001 DO contours (g m^{-3}). Note different scales. The *x* axis zero point is located at the center of the 300-m-diameter diffuser ring. The contours were interpolated from 18 CTD profiles (locations indicated by black squares at the bottom of the plots) sampled along the centerline of the lake (see Figure 2 map showing 18 sampling stations).

Patrick Henry Reservoir, Tennessee, Ceramic Diffusers

Liquid oxygen and ceramic diffusers, mounted on frames supported by columns anchored on the reservoir bottom, were installed from 1973 to 1976 as a pilot demonstration study (Fain 1978), following Ruane and Vigander's 1972 research on reservoir diffuser systems for hydropower sites for the Tennessee Valley Authority in Tennessee.

Later, following laboratory tests and comparison of diffuser equipment prices, a standard alumina tube with pore sizes of 15 to 20 µ was chosen to be installed on frames about 8 feet above the bottom. Transfer efficiencies were not as high - 30 to 90%, as had been recorded in laboratory tests -- 80 to 90%. However smaller pore size diffusers were found to achieve higher transfer rate (Ruane, Vigander and Nicholas, Journal of Hydraulics Division of the American Society of Civil Engineers, October 1977.

Douglas Dam, TVA, Membrane and Soaker Hose Diffusers

An early hydropower installation using a membrane diffuser was chosen for Douglas Dam in 1988 by the Tennessee Valley Authority. A 20 foot by 33 for diffuser frame was placed on adjustable legs to fit the bottom topography in front of one of the intakes. Oxygen transfer efficiencies of about 72% were measured late in the D.O. season of 1988, when weak stratification conditions existed (Mobley, 1989). D.O. improvements in the releases were about 2 milligram per liter. However, during the peak of the 1989 D.O. season, the oxygen improvement in the releases dropped to nearly 0 mg/L. This was attributed to oxygen demand stirred up from near the reservoir sediments and mixed by the strong plumes induced by the diffusers. No clogging of the membrane diffusers was experienced, but the Unit 4 generator cooling system was clogged with sediment and organic growth due to the pumping action of the diffuser plumes. This necessitated outages for cleaning and chemical treatments to reduce organic buildup. This experience indicated a clear need for a means to spread the bubbles over large areas to reduce mixing and entrainment of the sediments.

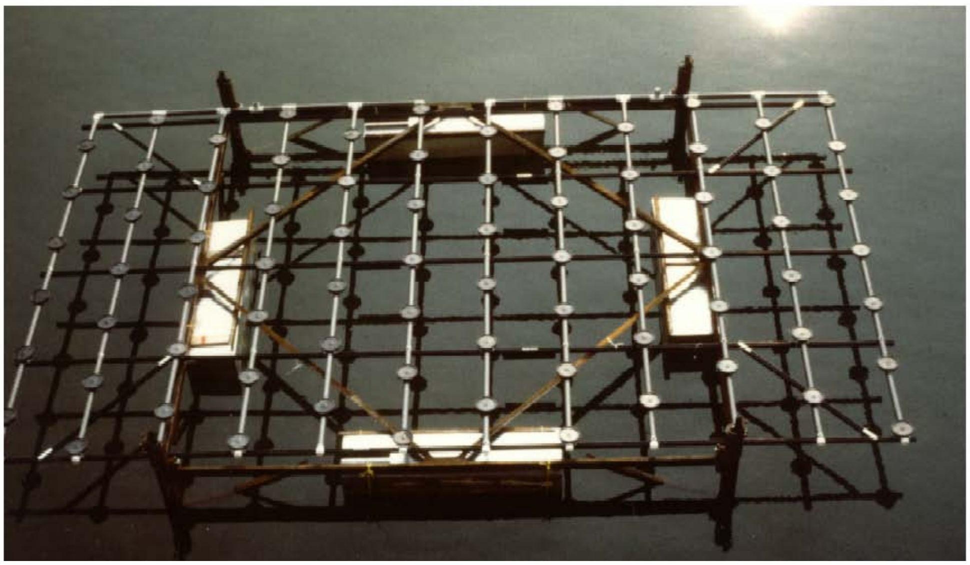
Sixteen smaller PVC diffuser frames, measuring 100 foot by 120 feet, are shown in the accompanying figure and were successfully deployed in the Douglas Reservoir in1993. There were 80 hoses per frame for a total of 12 miles of porous hose. The system capacity was 3000 m^3 per hour or 110 tons per day of oxygen. The redesigned oxygen distribution header was made of flexible hose. These diffusers have been used since 1993, to provide up to 2 mg/L of D.O. improvement in 16,000 $ft.^3$ per second power discharges from the four turbines at Douglas Dam. Although these diffusers are effective and are still in use, the frames and buoyancy connections were too unwieldy and expensive for future designs.

In 1991 soaker hose equipment measuring 400' x 100' suspended on a PVC diffuser frame was built to support 50 foot long porous hoses. The common garden-variety soaker hose stretches slightly under pressurization so that O2 diffuses out through the walls. This was an attempt to distribute the oxygen bubbles more extensively to reduce mixing and oxygen demand from the sediment layer.

Early Hydropower Installations Using Membrane Diffusers

Douglas Dam, TVA: 1988

In 1988, a pilot oxygen diffuser system was installed on Unit 4 at TVA's Douglas Dam. Three bottom-anchored, steel diffuser frames with adjustable legs to fit bottom topography were lowered from a catamaran crane in front of the intake of Unit 4. Each 6-meter by 10-meter (20-foot by 33-foot) frame supported 78 membrane diffusers, as shown in Figure 2. Oxygen transfer efficiencies of about 72% were measured late in the DO season of 1988 when weak stratification conditions existed (Mobley, 1989). DO improvements in the releases were about 2 mg/L. However, during the peak of the 1989 DO season, the oxygen improvement in the releases dropped to nearly zero. This was attributed to oxygen demands stirred up from near the reservoir sediments and mixed by the strong plumes induced by the diffusers. No clogging of the membrane diffusers was experienced, but the Unit 4 generator cooling system was clogged with sediment and organic growth due to the pumping action of the diffuser plumes. This necessitated outages for cleaning and chemical treatments to reduce organic build-up. This experience indicated a clear need for a means to spread the bubbles over large areas to reduce mixing and entrainment of oxygen demands from the sediments.



Installations using line diffusers

The following excerpts were taken from reports by Mark Mobley.

Normandy TVA 1994.

The next diffuser application at TVA was for a nonpower reservoir where aeration was desired to remove dissolved metals and hydrogen sulfide in the reservoir by aeration and precipitation. This system was supplied with compressed air. This installation was the first for the line diffuser design, and the clamps on saddle shoes for hose connections were found to be expensive and leaky. The drilled holes to provide an orifice for flow control, were also found to be expensive and unnecessary.

Blue Ridge TVA 1994,

A linear arrangement of four, 1800 foot long diffuser lines were deployed in the fore bay to provide a 3 mg per liter dissolved oxygen improvement using 24 tons of oxygen system capacity per day. The design used small check valves at hose connections that were determined to be ineffective since the diffusers sank anyway, when left overnight. The long linear arrangement of the diffusers was found to provide insufficient oxygen to the small minimum flow turbine so an additional diffuser was installed immediately upstream of the intake tower.

Cherokee TVA 1994-1995.

Peak hydropower water flows at Cherokee dam can approach 20,000 $ft.^3$ per second and despite having operational installations of both turbine venting and surface water pumps can require up to 2 mg per liter of additional dissolved oxygen improvement for the line diffuser system to meet 4 milligram per liter in the releases. The system capacity was 150 tons per day, with 48,000 lineal feet of line diffuser in the four bay. The system has automatic valves open to provide a high rate of oxygen flow while the turbines are in use. When the turbines flows are often small, oxygen bypasses the valves to maintain a background buildup of D.O. in the reservoir. The oxygen input from the diffusers provided oxygenated cold water in the fore bay that created a striped bass habitat during the warm summer sessions. High concentrations of fish lead to intense fishing pressure. But despite the repeated anchoring of boats in the area, no significant damage to the diffusers has been experienced. At this installation, the elastic cords for anchor attachment failed, allowing sections of the diffuser to float to the surface, creating a boating hazard. A new anchor connection using stainless steel cables was retrofitted by refloating each diffuser.

Fort Loudoun TVA 1995.

This mainstream, Tennessee River dam has hydropower flows approaching 38,000 $ft.^3$ per second. But require only a small boost in D.O., mostly associated with reduced flows during weekends. The Fort Loudoun application included a single 10,000 foot long line diffuser used to spread oxygen input over the reservoir volume of an average day's generation. The diffuser was equipped with progressive orifice sizes at the hose connections to obtain uniform flow over the entire length. The installation was complicated by intense recreational boat use and commercial navigation traffic. The elastic cord anchor connections were redesigned during this installation and retrofitted on the first diffuser.

Hiwassee Dam TVA 1995.

The original designs for the Hiwassee reservoir diffuser system were to use air but the total dissolved gas limitations in the tailrace shifted the design from air to oxygen. The installation of an on-site pressure swing absorption oxygen generation system was attempted for this application with unsatisfactory results. The diffusers are now supplied with liquid oxygen storage tank.

Watts Bar TVA 1996.

Watts Bar is another mainstream hydropower project with flows and oxygen requirements similar to Fort Loudoun. The diffusers were deployed to oxygenate an average daily flow volume and a more compact diffuser placement was utilized immediately upstream of the dam to provide for the increased oxygen needs during initial or single turbine operations. The multi-diffuser design used in the immediate fore bay, proved to be difficult to deploy and retrieve.

Buzzard Roost Hydroelectric Station, Duke Energy 1997.

The line diffuser at Buzzard's Roost was installed to provide enough oxygen input to allow Duke Energy to meet the FERC water quality requirements at the site. This installation included 9000 feet of line diffuser in the shallow excavated hydropower intake channel. The diffuser lines were placed within 20 m of each other in only 40 foot of water as compared with a typical spacing of 100 foot gaps.

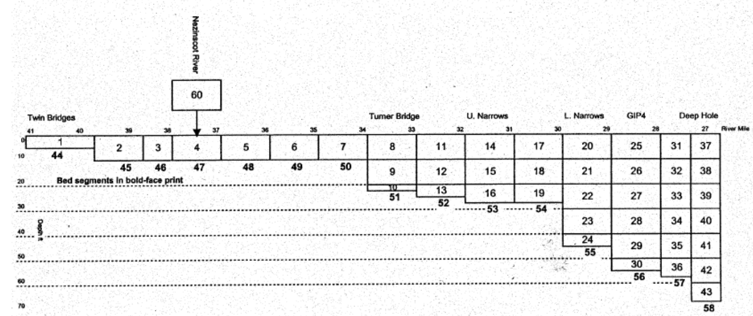
Summary of existing line diffuser installations.

A total of 153,000 feet of line diffusers have been installed at the eight reservoirs described above and three other applications. The diffusers have required no maintenance of the inspection of the bubble pattern at the beginning of each season. Reservoir diffuser installations and other aeration applications have resulted in improved conditions in the hydropower tail waters, according to Scott *et al*. 1996. Installation costs of line diffusers have been $25-$30 per foot.

Androscoggin River, Maine, Bubble Diffusers

The Androscoggin River in Maine has a minimum flow of 1700 $ft.^3$ per second and requires supplemental oxygenation from June the first until September the 30th, the deepest part of the forebay is 60 feet, and the oxygen transfer requirements are 40,000 pounds per day. The ambient D.O. is 5 mg/L and the design D.O. minimum is 6.5 mg/L. Additional mechanical aeration of Gulf Island Pond is a critical component of the overall plan to bring the Androscoggin River into D. O. attainment.The current model indicates that a total of 150,000 pounds per day to 210,000 pounds per day of oxygen must be supplied based on the current transfer efficiency of about 30%. This is in combination with additional controls at the paper mills in order to bring Gulf Island Pond into attainment for D.O.. In addition, the model indicates that attainment of D.O. criteria everywhere in Gulf Island Pond cannot be attained with a single point injection system at its current location. Multiple point oxygen injection systems are needed, unless there is sufficient proof to show that the attainment can be met using a different configuration.

Figure 9
WASP Model Segmentation for Gulf Island Pond



The present oxygen supplementation system injects pure oxygen into fine bubble diffuser plates located at a depth of approximately 30 feet within the Androscoggin River. The diffuser loading rate is about 2 feet per minute. Coalescence of fine bubbles occurs and fouling of the diffusers has been noted over time.

Due to the biological oxygen demand in wastewater discharges from the three paper mills located on the Androscoggin River and the sediment oxygen demand of the river due to the impoundment of the Androscoggin River created by the Gulf Island dam, the D.O. content that is required for class C waters may not be achieved during the summer months of July, August and September. Consequently the paper companies and Central Maine Power Company entered into an agreement to oxygenate the river.

The State of Maine, Department of Environmental Protection board requires that 27,000 pounds of oxygen per day be dissolved into the river water column. This requires a minimum 73,000 pounds per day of oxygen delivered to the river by the oxygen plant based on 35% O2 absorption efficiency. It is expected that this level of oxygen will meet water quality standards over most of Gulf Island Pond during July, August and September. A system was designed to introduce oxygen approximately 4 miles north of Gulf Island Pond through fine bubble porous ceramic diffusers which are located along the river bottom approximately 30 feet below the surface of the water.

Future oxygen supplementation requirements are from 40,000 to 70,000 pounds of oxygen per day to Gulf Island Pond. It is proposed to use 12 foot diameter by 18 feet high Speece Cones, each capable of dissolving 10,000 pounds of oxygen per day. A 100 HP submersible pump will move water through the oxygenation cones. The water flow will be 30 ft.³ per second against 25 foot of head and contain 60 mg/L of D.O. in the discharge. Oxygen absorption efficiency of over 90% is specified and the unit energy consumption will be approximately 400 kWh per ton of D.O.. The discharge will be diluted quickly by a combination of diffuser and banana propeller pumps.

In order to transport the oxygenated discharge from the oxygenation cones at the dam to the upstream pond area, each will be equipped with a 7 foot diameter 10 HP banana propeller pump capable of moving about 200 ft.³ per second horizontally under negligible head.

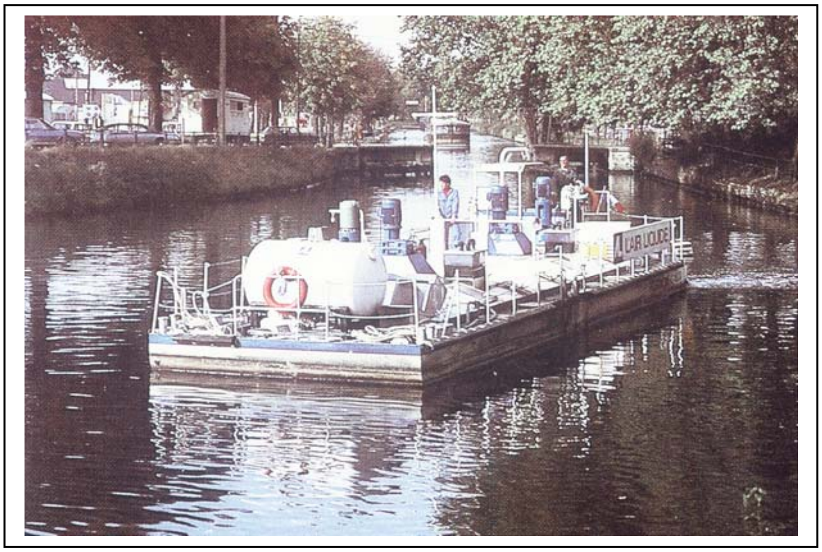
Life Cycle costs are strongly affected by the O2 absorption efficiency achieved in the oxygenation system as shown in the following table.

Table. Comparison of % O2 Absorption and Costs for 40,000 lb D.O./day

%O2 Absorp	O2 Added	O2 Lost	Cost of O2 Lost	Present Worth O2 Lost
	ton/yr	ton/yr	$/yr	$
100	2000	0	0	0
90	2200	200	66,000	693,000
75	2670	666	222,000	2,310,000
60	3330	1330	444,000	4,620,000
50	4000	2000	666,000	6,930,000
40	5000	3000	999,000	10,400,000
25	8000	6000	2,000,000	20,800,000

Amsterdam, Netherlands, Canal Mobile Barge Oxygenation

There is at present no complete sewer system operating in the lovely concentric canals of central Amsterdam, which therefore continually receive raw sewage directly. The low flow velocity in addition to deep waters, and the pooled nature of the canals, all contribute to low reaeration rate and zero D.O. levels. Hydrogen sulfide generation thus mars the historic picturesqueness of the area and assaults the urban population.



A motorized barge, containing a liquid oxygen storage tank and an oxygen injection system was deployed to withdraw canal water, super oxygenate it under elevated pressure, and then discharge it back into the canal. The barge system has been successful in increasing D.O. concentrations in the canals sufficiently to prevent hydrogen sulfide production.

Shanghai Harbor, Suzhou Creek, China, Mobile Oxygenation

As Shanghai has grown commercially to become China's largest industrial center, Suzhou Creek has suffered increasingly severe pollution. From the 1920s the river began to smell and turn a blackish color, causing the extinction of fish and shrimp in the river. Until 1978, the entire Shanghai section of the Suzhou Creek was thoroughly polluted.

Stretches of the 125 km Suzhou Creek have experienced anaerobic conditions, which means there are insufficient levels of oxygen to support fish or other aquatic life. Pumping oxygen into the water, by means of the barge, will assist the natural process of decomposition of pollutants and the restoration of oxygen levels needed to prevent H2S odors and sustain aquatic life.

A decade later, the Shanghai municipal government started a cleanup project to restore the river. A total of 8.7 billion yuan i.e. one billion US dollars, was spent completing the first stage of work on the project. The plan to clean up Suzhou Creek was launched in 1998, with the creation of the Shanghai Suzhou Creek Rehabilitation and Construction Company (SSCRCC). Its goal was to rehabilitate Suzhou Creek, to enable it to reestablish an ecosystem and raise public health standards for nearby residents.

British Oxygen Corp. designed and supplied the environmental technology for China's first mobile oxygenation barge. The self-sufficient barge represents the first step in a 12 year plan to rehabilitate Suzhou Creek. The Suzhou Creek project is China's most ambitious water reclamation project to date. The mobile oxygenation system is capable of generating 5 tons of oxygen per day and injecting it into venturi jets which discharge into the water at 20°C with a concentration of 6 mg/L D.O.

The oxygenation barge, which was officially handed over to the Chinese government in November 2001, contains a BOC Novox TM oxygen generator and two Vitox TM venturi oxygen injectors. Water from Suzhou Creek is withdrawn from the river, oxygenated on the barge at a rate of 5 tons per day, and then returned to the river via 20 Vitox venturi distribution nozzles mounted on each side of the barge.

This is the latest version of Thames Bubbler and Thames Vitality technology that BOC had developed for use in two barges used on stretches of the Thames River in England. Two delegations from SSCRCC, visited Vitality and talked with BOC engineers in Guilford, UK before BOC was awarded the contract for the Suzhou Creek project.

At the official dedication ceremony, which took place in Shanghai on November 2, 2001, Chinese environmental officials said they had originally planned to build several land-based oxygenation stations along the banks of Suzhou Creek, but decided it would be more effective to use a mobile oxygenation station to deal with shock pollutant loads during emergencies. An SSCRCC representative said, “ the barge can go wherever it is needed to improve the oxygen level quicker and cultivate beneficial aerobic bacteria.”

The $1,600,000 barge will be working on a one-month trial basis. More barges are expected to be built to improve Harbor water quality even more.

II. Proposed Appropriate Sites for Oxygen Supplementation to Water Bodies

Oxygenation technology is being considered to remediate D.O. depleted waters in the following locations:

Cardiff Bay, England
Stockton, California Deep Water Ship Channel.
Onondaga Lake, New York
Chicago Canal System, Illinois
Brownlee Reservoir, Snake River, Idaho
Hood Canal, Washington
Manchester, England Ship Channel.
Jamaica Bay, New York.
San Diego water reuse reservoir.
New York City water supply reservoirs.
Venice Lagoon, Italy.
.

Cardiff Bay, England, Speece Cones on Oxy/Cat Mobile Barges

The barrage erected across Cardiff Bay in about 1995 to isolate tidal activity outside and maintain a constant pooled water surface inside the barrage has impounded approximately 440 acres of water in a permanent pool behind the dam. The pool prevents the tidal mud flats from being exposed and their associated bad odors are avoided. It has resulted in a real estate boom on the water front. However characteristically the pooled water is deficient in D.O.

An air diffusion system designed by Ken O’Hara was adopted, but it could not satisfy D.O. standards in the harbor under all conditions. Therefore a mobile oxygenation unit was proposed to serve the impoundment that could be moved to remediate specific oxygen depleted areas. A system was proposed, which incorporated Speece Cone oxygen transfer technology in combination with a twin hauled barge. The design features an adjustable discharge boom, which can deliver a super oxygenated sidestream horizontally through this diffuser to variable depths of between 1 to 8 m in the water column.

More than 90% oxygen absorption can be achieved, while consuming 1100 kWh per ton of D.O. added from an on barge oxygen storage tank. The Oxy/Cat dimensions are 15 m length and 7 1/2 meters width with a loaded draft of 0.75 m and light air draft of 3.5 m. The system is comprised of two Speece Cones, a LOX tank capable of holding 6 tons of liquid oxygen and two Perkins, 185 D diesel engines which drive two 12 inch pumps to move the water through the oxygenators.

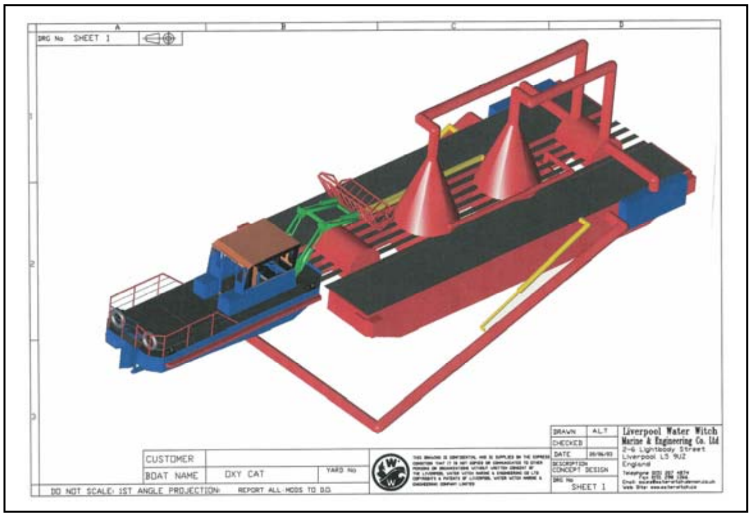
A comparison of the Liverpool Water Witch Marine and Engineering Co. Ltd.'s/ECO2 Oxy/Cat system with the BOC Vitox oxygenation barge reveals several important differences:

Speece Cone oxygenation system.

- 90 % oxygen absorption regardless of the depths to which the water is discharged.
- Gas transfer accomplished **before** discharge into the bay.
- Closed system readily monitored using a flowmeter to determine flow rate in inlet ar meter to measure D.O. prior to discharge.
- No effervescent loss of D.O. due to instant dilution.
- Absorption efficiency not dependent upon water column D.O. concentration.

Vitox System.

- Percent absorption dependent upon deeper depths.
- Gas transfer occurs after discharge into the baying causing turbulence.
- An open system, not easily monitored for flow rate and D.O. levels.
- Dissolving takes place during rise of bubbles to the surface in the water column.
- Absorption efficiency depended upon D.O. concentration in water column.



Stockton Deep Water Ship Channel

Evaluation of Aeration Technology for the Stockton Deep Water Ship Channel.
Report to CAL FED Bay Delta Program.
Sacramento, California.
Dr. Russ Brown.
April 19, 2002.

Quoted from the Executive Summary

This report describes the scientific background for quantitatively understanding aeration processes that transfer oxygen between the atmosphere (gas) and a water volume (dissolved gas). Although water (H_2O) is composed of 89% oxygen, fish and aquatic organisms require D.O. gas (O_2) for respiration and cannot utilize the oxygen in the water molecules. The natural reaeration that occurs at the surface of the San Joaquin River and the Stockton Deep Water Ship Channel (DWSC) is described to introduce the equations and coefficients that are used to quantify this process.

The basic methods that have been used to augment or artificially increase this oxygen gas transfer process in rivers and lakes (or reservoirs) are then described. The performance of the existing Corps of Engineers jet-diffuser device is summarized, and the engineering feasibility of alternative methods to increase D.O. (DO) concentrations in the DWSC with aeration technology are compared. Each alternative is described for possible application to the DWSC worst-case summer design condition where the DO recorded at the Rough & Ready DO monitoring station is assumed to be 2 mg/l below the DO objective for the DWSC.

Figure 1 shows the location of the City of Stockton River water quality stations within the DWSC. The Department of Water Resources (DWR) continuous DO monitoring station is located at the downstream end of Rough & Ready Island, near the R5 sampling station. Data from these stations are used to estimate the DO deficit below applicable water quality objectives for the DWSC (i.e., 5 mg/l from December through August and 6 mg/l from September through November). This DO deficit is the necessary amount of DO augmentation that would be necessary to meet the DO objectives in the DWSC. Based on the daily minimum DO concentrations at the Rough & Ready monitoring station, a total of about 1,000,000 pounds of oxygen would have been needed in the summer of 2001. An aeration device that delivered about 10,000 lb/day would have satisfied the measured DO deficit during the summer of 2001. The required amount of DO supplied by aeration in 1999 and 2000 would have been somewhat less, although the 10,000 lb/day capacity would likely have been needed in each year. For an assumed DWSC reaeration transfer distance of 0.5 m/day with a DO deficit of 4 mg/l, reaeration will supply about 18 pounds of oxygen per acre per day. There are about 250 acres between R3 and R5, so the reaeration in this portion of the DWSC would be about 4,500 lbs/day. The DO concentration increase from one day of reaeration would be about 0.25 mg/l (i.e., 0.06 * 4 mg/l). This is only a moderate reaeration term compared with the RWCF and SJR river loads of BOD, and the assumed transfer velocity of 0.5 m/day is uncertain.

D.O. Concentration Pattern in the DWSC

The DO concentration patterns in the DWSC are controlled by reaeration and algae production of DO as well as BOD (and SOD) decay processes. The BOD loads originate from the Stockton RWCF effluent and from upstream SJR sources, as well as from sediment oxygen demand and algae biomass growing within the DWSC. The City of Stockton water quality model uses a typical first-order DO sag equation coupled to the governing hydrodynamic equations for tidal flow within the DWSC. The current model does not include effects from stratification on algae growth and reaeration (i.e., mixed depth dynamics). The DO modeling simulates the longitudinal DO pattern and identifies the location of the lowest DO concentration (greatest DO deficit.

Figure 2 shows the measured minimum and maximum DO concentrations at the DWR Rough & Ready monitoring station during 2001. The minimum DO concentrations were generally about 3 mg/l during the worst-case episodes. The saturated DO concentration is shown for comparison to indicate that the minimum DO concentrations were generally 4-5 mg/l less than saturation during the summer period. The minimum DO concentrations were therefore about 2 mg/l less than the DO objective of 5 mg/l during these worst-case episodes. The maximum DO concentrations measured during the afternoon are influenced by algae photosynthesis and are usually about 2-3 mg/l higher than the minimum DO values, and may approach saturation concentrations on some days. The reaeration rate, which is controlled by the DO deficit, is therefore less during these afternoon periods. A DO sag may also occur after September 1 when the DO objective changes to 6 mg/l. The pattern and magnitude of DO sag in September is similar to conditions prior to September because water temperatures are slightly cooler and the saturated and measured DO concentrations are slightly higher.

Figure 3 shows the minimum DO pattern measured in 1999 along with the UVM net flow estimates during the year. The daily calculated DO required to satisfy the DO target concentration (DO objective + 0.5 mg/l) are also shown. The DO concentration was below the DO target concentration from about July through September of 1999 (although the DO in October was not recorded). The daily DO deficit was often 10,000 lb/day with a few peaks of 15,000 lb/day. An aeration device with a daily DO delivery of 10,000 lb/day would likely have maintained the DO concentration in the DWSC at the DO target during 1999. The total DO deficit in 1999 was at least 650,000 pounds, although a deficit might have also occurred in October. The total cost for oxygen (at $0.10/lb) in 1999 (including some in October) would have been about $75,000.

Figure 4 shows the minimum DO pattern measured in 2000 along with the UVM net flow estimates during the year. The DO concentration was below the DO target concentration from about mid-June through September of 2000 (although the DO in October was again not recorded). The daily DO deficit was often 10,000 lb/day with a few peaks of 15,000 lb/day. An aeration device with a daily DO delivery of 10,000 lb/day would have maintained the DO concentration in the DWSC at the DO target during 2000. The total DO deficit in 2000 was at least 475,000 pounds, although a deficit might have also occurred in October. The total cost for oxygen in 2000 would have been about $50,000.

Figure 5 shows the daily calculated DO source required to satisfy the DO target concentration in 2001. The DO concentration was below the DO target concentration from early June through early October of 2001. The daily DO deficit was often 10,000 lb/day with a few peaks of 15,000 lb/day. An aeration device with a daily DO delivery of 10,000 lb/day would have maintained the DO concentration in the DWSC at the DO target during 2001. The total DO deficit in 2001 was about 1,000,000 pounds. The total cost for this oxygen would have been about $100,000 in 2001.

Aeration Design Conditions

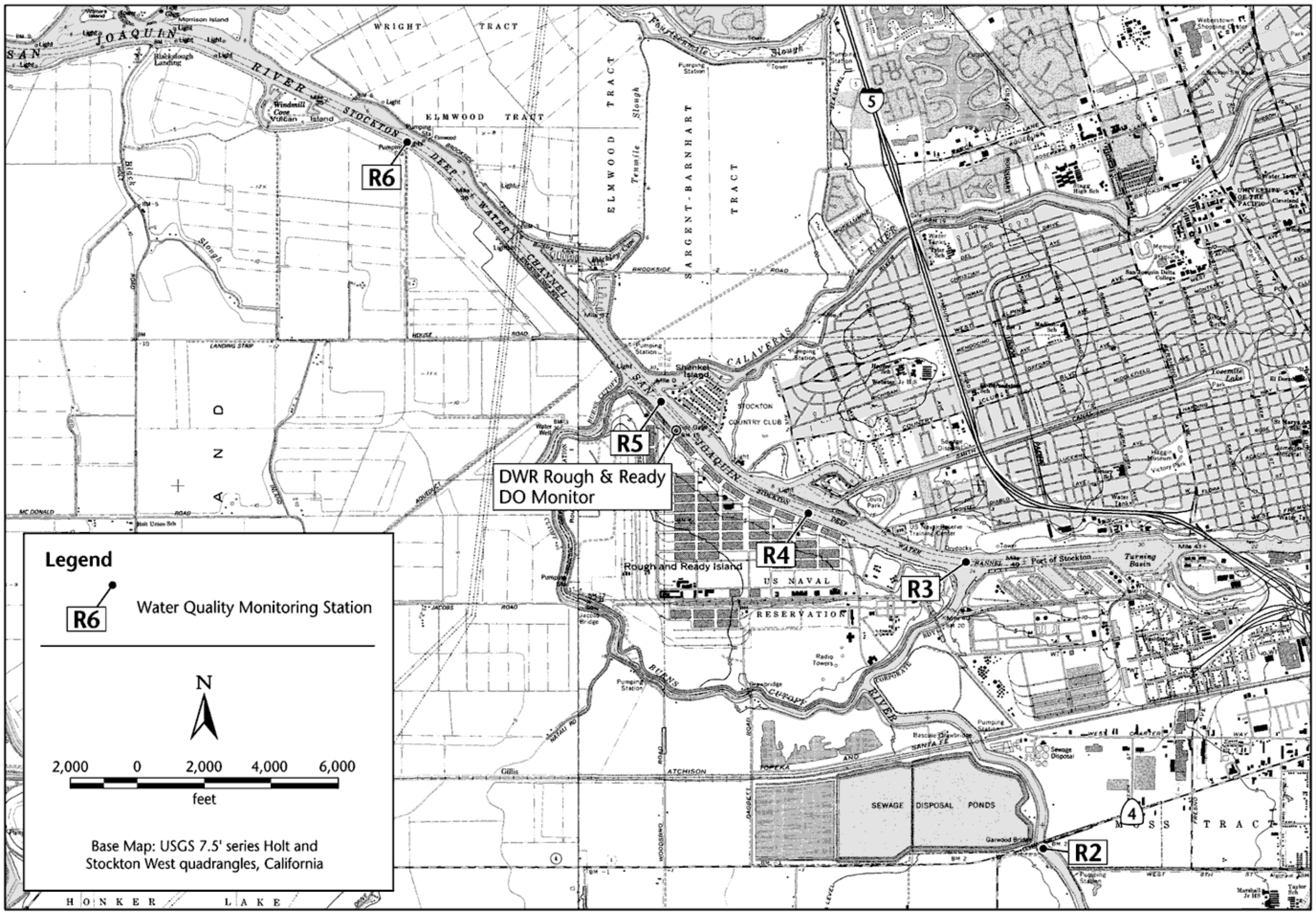
These worst-case summer conditions have been previously characterized with the results from DWR Rough & Ready Island DO monitor as well as City of Stockton water quality monitoring results (Jones & Stokes 1997, 2001). Net SJR flows through the DWSC during low flow summer period of about 500 cfs can be expected to occur on a routine basis, and the travel time for water between R3 and R6 at 500 cfs is about 10 days (because the DWSC volume from the turning basin to R6 is about 10,000 acre-feet). Monitoring data indicates that similar DO sag concentrations can occur to a flow of about 2,000 cfs. Generally, the maximum DO sag is located further downstream in the DWSC as flows increase. When flows exceed 2,000 cfs, the magnitude of the DO sag within the DWSC is reduced due to shorter residence times, higher natural reaeration rates, or lower BOD concentrations entering the DWSC. As hydraulic residence time decreases with increasing flow, the time available for BOD decay is reduced. At higher streamflow rates, a greater portion of the BOD load passes through the DWSC out to the other Delta channels. Higher flows may reduce the SJR concentrations of BOD and dilute the RWCF effluent BOD loads.

At a flow of 1,000 cfs, a 2 mg/l DO decline below the 5 mg/l objective is equivalent to a daily DO mass deficit of 10,800 lb/day (i.e., 5.4 * 1,000 * 2 = 10,800). This is the quantity of oxygen that needs to be added into the DWSC on a daily basis to result in average DO concentrations near the DO sag location that meet the Basin Plan DO objective of 5 mg/l. This is taken as the worst-case design capacity for the alternative DWSC aeration devices.

Figure 6 illustrates the major factors and processes that influence the DO concentration pattern within the DWSC. The initial BOD concentration (and BOD decay rate) along with the sediment oxygen demand (SOD) govern the DO losses along the DWSC. The reaeration is the major source of DO and depends on the DO deficit (below saturation). The net flow controls the travel time as the water moves through the DWSC from R3 to R6. An estimate of worst-case total BOD concentration is about 10 mg/l (equivalent to a 5-day BOD measurement of about 4 mg/l). At a flow of 1,000 cfs, this is a total BOD load of 54,000 lb/day. The City of Stockton RWCF and the SJR are the sources for this BOD load. SOD has been estimated to range from 0.5 to 1.0 g/m^2/day and is assumed to be uniform throughout the DWSC (Litton 2001). This range of SOD exerts a daily oxygen demand of about 1,115 lb/day to 2,230 lb/day based on the channel bottom area (i.e., 250 acres) between stations R3 and R6. The origin of this SOD, however, may be settling of some of the total BOD from the river and RWCF discharge.

1) Reaeration depends on the estimated transfer velocity (i.e., 0.5 m/day) and the DO deficit. For an average deficit of 4 mg/l, the reaeration between R3 and R6 would add only about 4,500 lbs/day. However, the intermittent development of stratification near the water surface may restrict the reaeration of the DWSC. Algae photosynthesis in the surface of the DWSC will add DO but also increase the BOD concentration. Although the net effect of algae growth and respiration in a closed tank would be no change in DO concentration, the effects of algae growth in the DWSC are not well documented. It is apparent from this simple comparison that the BOD loading far exceeds the oxygen source from natural reaeration (with algae growth and respiration assumed to provide no net increase in DO). Artificial aeration or oxygenation will be needed to provide a balance in the DO budget within the DWSC.

2) One problem with the bubble devices as that the aerated water ends up on the surface where the DO may already be high, rather than in the bottom layer where the DO is lowest.



Jones & Stokes

Figure 1
Stockton Deep Water Ship Channel Water Quality Stations

Figure 2. DO Minim and Maximum Measured at Rough & Ready DO Monitor During 2001

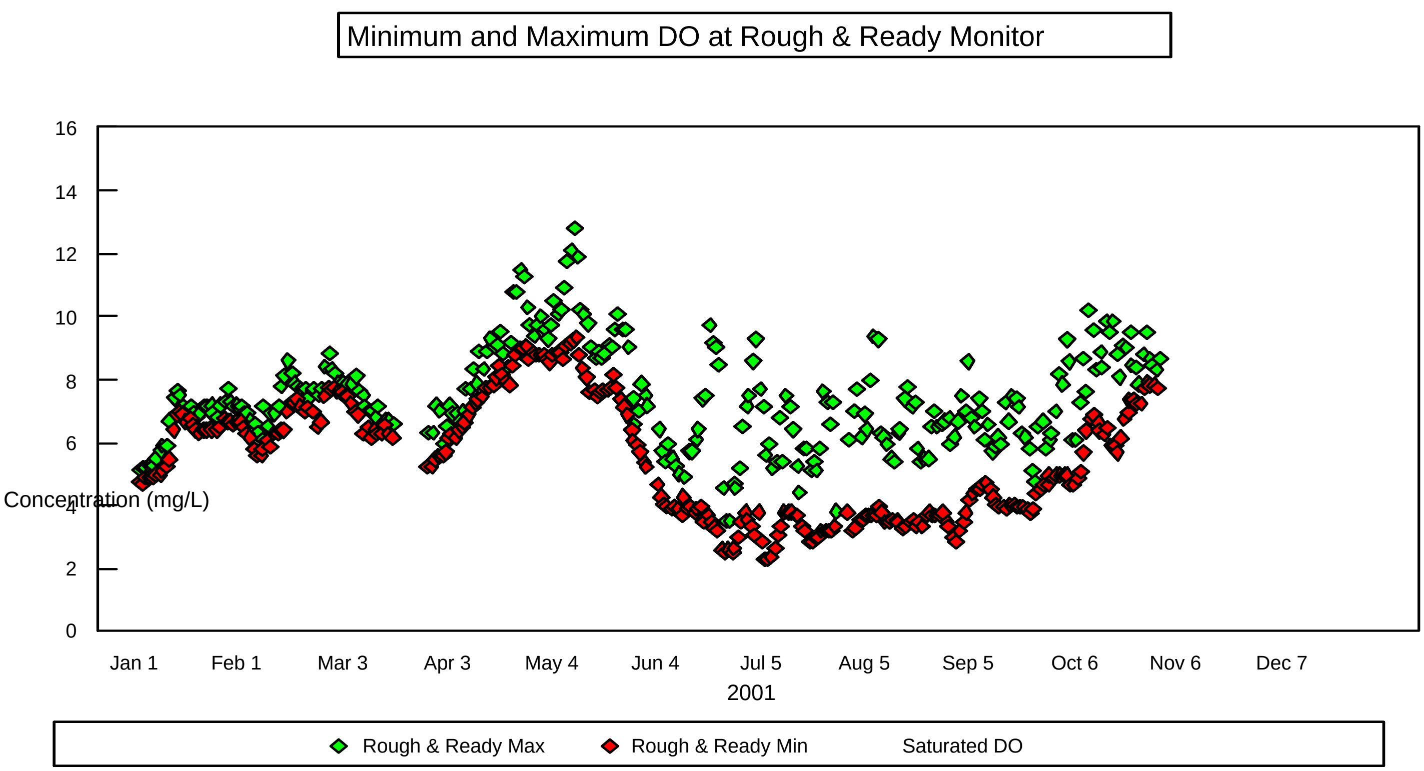
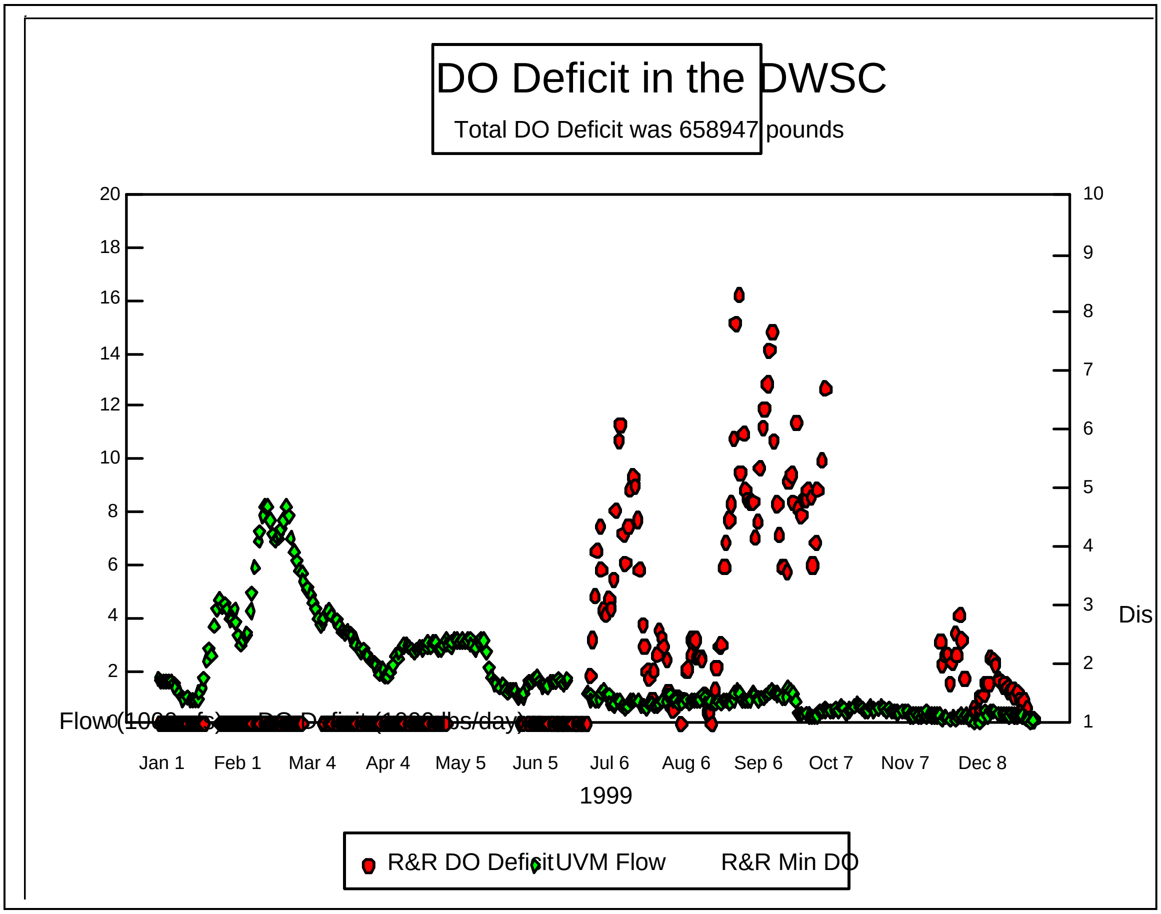
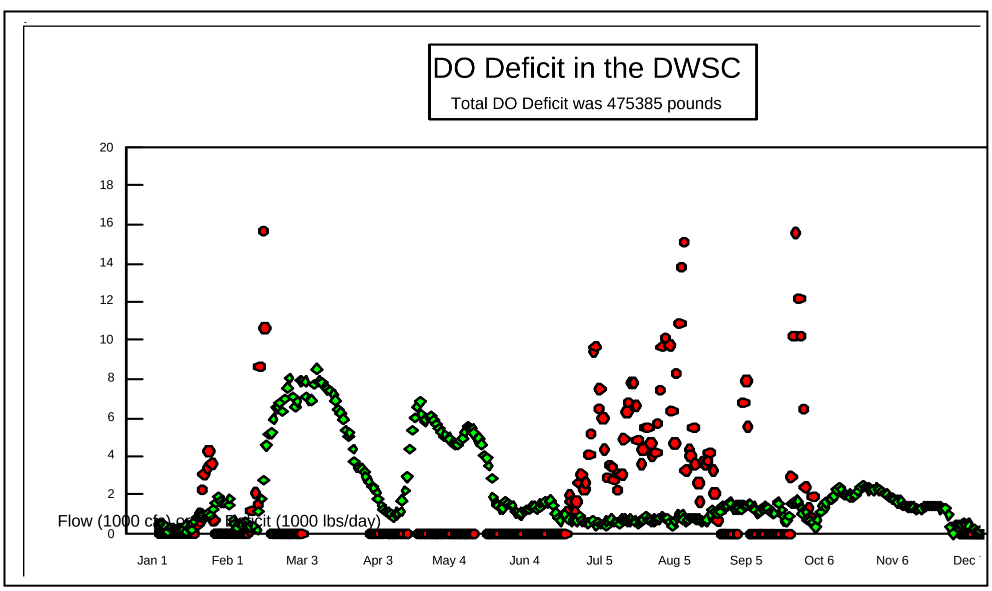


Figure 3. Calculated DWSC D.O. Deficit During 1999.





Onandaga Lake Hypolimnion Oxygenation, Syracuse NY

Taken from US Army Contract Description

Onondaga Lake an urban lake located in metropolitan Syracuse, NY is approximately 4.6 miles long by 1 mile wide has mean and maximum depths of 35 and 63 feet respectively and a drainage basin of 248 square miles. The major hydrologic inputs to Onondaga Lake are several creeks and the Syracuse Wastewater treatment plant. The lake outlet is located at the northern end of the lake where it empties into the Seneca River. Onondaga Lake's present water and sediment quality and biological conditions are the result of more than a century of waste inputs. Contributing factors include extensive quantities of treated domestic wastewater, combined sewage overflows, various industrial wastes, runoff from urban and agricultural land and leaching of various substances from hazardous waste sites around the lake. Another likely factor is the probable release of mercury, phosphorous and other contaminants from the lake's bottom sediments. Fishing was banned in 1970 because of mercury contamination and currently, a fish advisory exists which severely limits fish consumption. Some of the water quality problems in Onondaga Lake result from the fact that the effluent from the municipal wastewater treatment plant represents approximately 20% of the annual inflow to the lake and 60 to 70% of the total inflow during low flow conditions. Pollutant loading in this effluent may contribute to low hypolimnetic D.O. concentration. In addition, during late summer and early fall turnover, Onondaga Lake has undergone temporary lake-wide D.O. depletion resulting in violation of NY State's minimum D.O. concentration of 4 mg/L for several weeks.

The hydraulic residence time in Onondaga Lake is about 3 months. During stratification the hypolimnion waters are basically stagnant while the inflow water flows over the top of the lake and out.

Preliminary recommendations are to supplement approximately 30 tons of D.O. per day to the lake hypolimnion for the next decade to satisfy the accumulated oxygen demand in the sediments and reduce the rate of mercury methylation.

Chicago Urban Canals Supplemental Oxygenation

The urban canals of Chicago receive storm runoff and combined sewer overflows. Their impounded flow prevents periodic scouring of benthic deposits and also results in very limited reaeration capacity. Consequently prior to about 1990 the D. O. was often near zero for extended periods. Chicago's urban canal system is used for barge transportation as well as conveyance of treated waste waters away from the metropolitan area. Lake Michigan is a high-quality water resource that serves as the water supply for Chicago. By federal decree, only an annual average of 90 m^3 per second of water could be diverted from Lake Michigan. A proposed system of 10 strategically placed diffused aeration stations having a combined reaeration capacity of 134,000 kg of oxygen per day was proposed to maintain minimum D. O. concentrations. However, 18 m^3 per second of Lake Michigan water would have still been required as an integral part of this supplemental reaeration scheme.

An economically competitive supplemental reoxygenation system utilizing pure oxygen and a system of five reoxygenation stations was proposed which would maintain the D. O. standards and require no diversion of Lake Michigan water. The diverted water thus saved was freed to serve as a much-needed water supply for communities in the metropolitan area. The reoxygenation stations proposed were two U-Tubes of 75 m depth and capable of raising a sidestream from the canal up to 35 mg/L D. O. This sidestream would then be blended with the canal flow to raise the canal D. O. to approximately 15 to 25 mg/L. Negligible stripping of this supersaturated canal D. O. would have occurred because of the low reaeration rate of this pooled canal. Yet the number of required reaeration stations was markedly reduced from 10 to 5 over the case where air would be used as the oxygen source. Only two reoxygenation stations were required on the canal using U-Tube oxygenation and pure oxygen injection versus 10 for diffused aeration station. Three U-Tube pure oxygen stations were to be located on the outfall of the three major wastewater treatment plants.

The Chicago Canal system consists of three segments, North Shore 12.8 km long, Main 48 km long main and Calumet Sag 26 km. These canals connect with the original river channels to form a 130 km system. The average depth varies from 3.6 m in the North Shore Canal to 7.6 m in the main with width varying from 21 m in the North Shore Canal to 60 to 90 m at places in the Main and Calumet sag segments.

Dry weather flows result in extended travel times of four days in the North Shore, five days in the main and four days in the Calumet sag canals. Combined sewer overflows discharge into the canal system to prevent local flooding. The average frequency of combined sewer overflows was once per four days before the large tunnels were constructed for storage of storm overflows. The average BOD of the overflow events is 273,000 kg. The long-term effects of these combined sewer overflows is the accumulation of sludge deposits of 1 to 2 m depth in the canal system, causing the benthic deposits to exert an oxygen demand of 64,000 kg per day.

The stations would pose no interferences to navigational use of the waterways. Each would be designed to oxygenate a sidestream effluent of canal water drawn out of the main flow through a screen into a pump. The flow to be oxygenated would be pumped into the U-Tube against approximately 4 m of head by a low lift pump station. Pure oxygen would be injected in the down flow leg of the U-Tube at a rate required to produce the desired discharge D. O.. The upflow leg of the U-Tube would discharge into a diffuser pipe located on the bottom of the canal at right angles to the direction of flow and approximately 20 meters downstream from the intake screen.

Main canal. The low flow at the head of the main canal is approximately 19 m^3 per second. By raising the dissolved oxygen concentration from 4 to 14 mg/L. The D. O. standards would be satisfied with no discretionary diversion from Lake Michigan until the flow reached the West Southwest sewage treatment plant. The U-Tube would add 34 mg/L of D. O. to a flow of 7 m^3 per second.

Brownlee Reservoir on the Snake River, Idaho

Taken from "Application for Certification Pursuant to Section 401 of the Federal Clean Water Act for the Relicensing of the Hells Canyon Hydroelectric Complex. FERC No. 1971 Submitted to Oregon Administrative Rules Chapter 340, Division 48 , July 2003

> Brownlee Reservoir is on the Snake River between Idaho and Oregon and is part of the Hell's Canyon Complex of hydropower dams. The water quality standard is 6.5 mg/L. Currently D.O. levels in Brownlee Reservoir do not always meet the D.O. targets nor are they adequate to support all designated beneficial uses. D.O. in Brownlee Reservoir can become severely degraded, especially during summer, a condition that has occasionally caused fish mortality.
>
> The D.O. was below this target 55% of the time in Brownlee Reservoir and the metalimnion had the highest number of measurements below target. Excessive algal profileration is reported to be the cause of the D.O. deficiency and a phosphorous reduction has been recommended.
>
> To fulfill regulatory requirements it is proposed to supplement 1450 tons of O2 per year into Brownlee Reservoir into the transition zone or the upstream end of the lacustrine zone.

Percy Priest Lake

The basic purpose of the Percy Priest Lake oxygenation system is to meet the water quality discharge criteria in the hydropower discharges. This involves D.O., Fe, Mn, and H2S. Is it possible to leverage the engineering solution such that significant additional benefits can be realized without additional costs? It seems kind of a shame to just meet the letter of the law when significant environmental enhancement of the hypolimnion could be realized for not additional cost. In this proposed oxygenation design there are even considerable savings in capital costs as the hypolimnion is enhanced and the discharge water quality criteria are still achieved.

The real burden of the oxygenation system for Percy Priest lies in accommodating the peaking power releases - which may occur only once or twice a summer. An oxygen demand of 37 tons/day is required in the dam vicinity where it will have least enhancement to the fishery habitat. So much oxygen is put into the reservoir for so little time - perhaps a few hours! Two thirds of the total oxygen transfer capacity is required just to meet these sporadic releases.

Why does so much oxygen have to be added at the dam vicinity? Because it is *not* in the water already. If it was already in the water, there would be no need for such large instantaneous oxygen dissolution capacity.

If it is assumed that a given amount of oxygen is required per season, why not buy it a few months early and store it in the hypolimnion? This would require that oxygen injection would have to be initiated about one month earlier than normal when the hypolimnion D. 0. dropped to 5 mg/L to maintain it at that level. In such a case there would be no need to instantaneously meet a sporadic discharge event. Maintenance of 5 mg/L of D.O. in the water column does not cause a significant increase of oxygen demand from the sediments or the water column.

To avoid high peaking oxygen demands, it is necessary to determine the maximum discharge-duration event. If it is assumed the maximum discharge would be 4600 cfs for 7 days, this would be 9000 acre-ft per day of which 80% comes from the hypolimnion or 7200 acre-ft per day times 7 days = 50,000 acre-ft. Since the hypolimnion has a volume of 178,000 acre-ft (below elevation 470 ft.) there is sufficient hypolimnion volume to meet this design event. A volume of 50,000 acre-ft contains 340 tons of oxygen at 5 mg/L.

If it is assumed that the projected oxygen use per season is 2500 tons and the season is 170 days, the base rate of oxygen supplementation is 15 tons per day.

If it is not sufficient to just dissolve the oxygen, it needs to be moved throughout the hypolimnion. The major cost of this oxygen supplementation project is getting the oxygen in solution. A relatively minor cost is involved in moving it horizontally throughout the hypolimnion. To accomplish this function, it is proposed to utilize 3 - 10 HP 8 ft diameter, horizontal axial flow pumps capable of mixing 200 cfs each. The mixing characteristics of such a pump are that it will reach 3 km away in I day and 6 km away in 6 days.

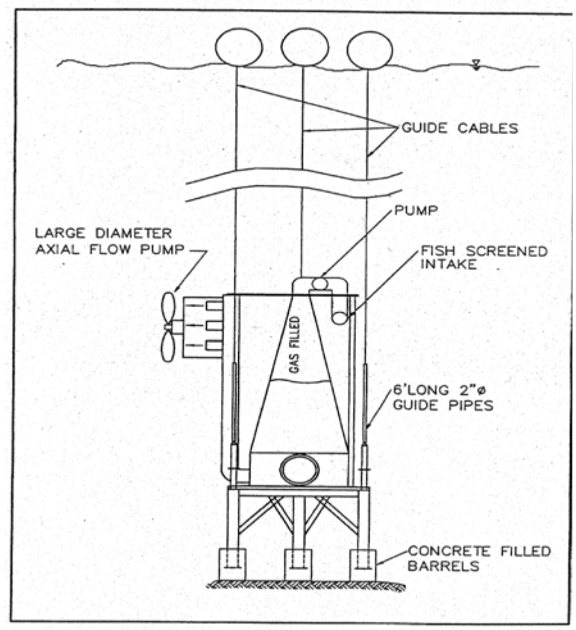
PROPOSED OXYGENATION LAYOUT

A Speece Cone is proposed to be located at the Corps boat dock and has the flexibility of delivering the highly oxygenated side stream in the direction of the dam, in the direction parallel to the dam across the reservoir or upstream in the reservoir in the direction opposite to the dam. Its "zone of influence" can be enhanced over 6 km away within a week by the use of the aforesaid pumps.

It is recommended for this design that a Speece Cone be placed in the old river bed channel near the Corps boat dock. A 10 ton/day Pulsed Swing Adsorption (PSA) oxygen generator would supply this Cone.

An addition Speece Cone is recommended at approximately 5 miles upstream (below Hobson Pike) and having a capacity of 5 tons/day of oxygen dissolution capacity. It would be fed by a PSA oxygen generator of 5 tons/day capacity.

There would be 3 locations where a 200 cfs 10 HP large diameter, horizontal axial flow pump would be located. One would be located at each Speece Cone location and a third would be located above Elm Hill Marina. This third large axial flow pump would move oxygenated water pumped from the Cone at the Corps boat dock and move it further upstream.



ELEVATION VIEW OF TYPICAL SPEECE CONE
WITH HORIZONTAL FLOW PUMP

Gowanus Canal New York City

Following is a proposal for supplemental oxygenation of the Gowanus Canal. It is understood that 6100 lbs of D.O. is to be supplemented each day and that a D.O. of 8 mg/L is to be maintained in the canal under summer temperatures of 25 ^oC. The canal is assumed to be 20 ft. deep. D.O. C_{sat} for air at mid-depth would therefore be 10.4 mg/L (1.3 atm at mid-depth x 8 mg/L C_{sat} at 25 ^oC.) The D.O. deficit at which an aeration process would be working would therefore be 10.4 – 8.0 = 2.4 mg/L.

Super oxygenation technology for discharge horizontally through a diffuser located off the bottom of the canal (to prevent sediment suspension) where it is rapidly diluted down to 8 mg/L D.O. is recommended. This also accomplishes mixing and transport of the D.O. along the canal. A system would raise the D.O. in a sidestream to about 90 mg/L and guarantee over 90% dissolution and retention in the water. The size of this Speece Cone system would be nominally 8 ft in diameter and about 20 ft tall supplied with a 200 HP pump.

The system has an energy consumption of about 1000 kwhr/ton of D.O. added. This would be about $300/day for electricity at $0.10/kwhr to add 6100 lbs D.O. per day. The entire system can be mounted on a barge moored on the side of the canal or placed on land where space is available.

For a permanent solution, the oxygenation vessel could be placed in an excavated caisson about 40 ft deep so that it could use the hydrostatic pressure instead of pumped pressure to achieve superoxygenation. This would reduce the energy consumption to less than 300 kwhr/ton of D.O. as has been done for an industrial client in Oklahoma. In this case 30 cfs was pumped through an oxygenator and raised the discharge D.O. to 60 mg/L in water that was 25 ^oC. It then entered a 5-mile long pipeline flowing full to prevent any hydrogen sulfide formation during transit. This system dissolves about 10,000 lbs of D.O. per day. A 40 HP pump is used to move water through each oxygenator.

New York Water Supply Reservoirs

The New York City Water Department withdraws cold hypolimnion water from stratified New York State reservoirs except during summer months when complete D.O. depletion occurs in some of the reservoirs caused by algae proliferation in warm surface waters. Under such anaerobic conditions, Fe, Mn and H2S production is exacerbated by algae decay, consuming all the D.O. Since no subsequent treatment has been provided to date, these reservoirs must be taken off line until colder weather results in destratification.

Direct supplementation of oxygen to the hypolimnion, however, would avoid this problem while not destratifying the reservoir. In addition the potential problem of dissolved nitrogen supersaturation which often arises when using air may be avoided when superoxygenation is utilized as the treatment protocol.

For stratified reservoirs with D.O. deficiency in the hypolimnion, oxygen can be dissolved directly into the hypolimnion to effectively offset the oxygen demand from algae settling down from the euphotic zone as well as sediment oxygen demand. This would be similar in concept to the Camanche Reservoir hypolimnion oxygenation system utilizing the Speece Cone.

San Diego Water Reuse Reservoirs

One novel application of hypolimnion oxygenation with induced horizontal flow propagation is in regions which have a chronic summer water shortage. Reuse of treated wastewater to augment the water supply is being considered in San Diego. It is desirable to have a storage period delay of over a month after the wastewater is treated before it is used as a water supply. The treated warm wastewater would be discharged and stored in the epilimnion providing the requisite storage delay before reuse and the hypolimnion would have to be supplemented with oxygen to prevent water quality deterioration throughout the stratification season.

Manchester Ship Channel England

Presently supplementation of D.O. is practiced in this ship channel with aeration techniques that incorporate air aspiration into Venturi ejectors. Due to the inability to meet the target D.O. criteria, superoxygenation has been recommended.

Hood Canal Washington

Hood Canal is a long narrow branch off Puget Sound. It is about 50 km long, 2 km wide and an average of 100 m deep with an entrance sill of 50 m. Maximum depth is about 200 m. Persistent stratification is maintained from gradients in both salinity and temperature. There is a strong density difference located at 5 to 10 m depth. Strong water column stratification with low dissolved oxygen levels are typical throughout the year but are more pronoumced in the southern portion of Hood Canal and during the Fall. Because of the canal’s depth and shape, the water exchange is slow, taking about a year for the canal to exchange its waters with Puget Sound. Fish and invertebrate mortalities are believed to be due to low dissolved oxygen . (“First Record of a Heterosigma Akashiwo Bloom in Hood Canal Washington, USA. By Connell, L.B., Newton, J.A. and Craig, S. D.

Weather conditions can cause upwelling in the ocean so that the water flowing into the Puget Sound is also lower in oxygen and higher in nutrients. The daily D.O. demand in the lower regions of the canal is in the order of 100 tons per day.

Venice Lagoon Italy

Storm tides which sometimes flood the beautiful city of Venice, Italy are gradually undermining its magnificent architecture. Future efforts to prevent flood damage, however, must accommodate an additional set of problems. Since the city still has no sewerage collection and treatment system, should tidal gates be built to isolate the lagoon during high tide emergencies to prevent further architectural and artistic deterioration, severe oxygen depletion could soon occur in the lagoon. In the absence of flushing tides the undesirable visual spectacle of algae scum forming and the possibility of serious fish kills occurring would have to be addressed in the design criteria for tidal gate use. This lagoon is an excellent candidate for superoxygenation to achieve water quality objectives.

Jamaica Bay, New York

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Section 3. Air as a Supplemental Oxygen Source

3. Aeration Technology

I. Supplemental Aeration Characteristics

A. Selecting Tertiary Treatment Alternatives

After it has become evident that a more cost-effective solution than tertiary treatment is necessary for removal of a small increment of residual BOD in the treated wastewater, selecting the best oxygenation equipment available is advisable.

The objectives of oxygen supplementation to a harbor differ substantially from ordinary aeration of wastewater. The dissolved oxygen deficit in a harbor is about 4 mg per liter (8 – 4 mg/L), or about half of that found in wastewater treatment (9 – 1 mg/L). The 4 mg per liter dissolved oxygen level must be maintained even during the warmer temperatures in the summer, which reduce the air saturation concentration to 8.2 mg per liter, which constitute the critical seasonal conditions.

The cost of electricity has risen in many areas and must be factored into equipment selection. Since the unit energy consumption of conventional aeration is inversely proportional to the dissolved oxygen deficit driving force, a doubling of energy consumption will result if the D.O. deficit is halved, adding $60 to $120 per ton to the other costs of dissolved oxygen supplemented. At $0.06 per kilowatt hour and in water that has only 2 mg per liter of dissolved oxygen, 1000 to 2000 kWh per ton of dissolved oxygen is required.

Aeration technology utilizes various generic designs for dissolving oxygen from air into water such as surface aeration devices, coarse or fine bubble diffusers, Venturi aspirators and cascade/weir aeration equipment. Each of these systems can effectively dissolve oxygen from air into water if target D.O. in the water is low and the cost of electricity is minimal.

B. Inherent Disadvantages of Aeration in Many Applications

Traditionally aeration technology was developed to meet the need to dissolve a large quantity of dissolved oxygen into wastewater to support the aerobic microbial metabolism of organic pollutants. Therefore the most commonly used aeration techniques were optimized for this purpose. However, it should be recalled that the systems were developed when electricity was still cheap, required bulk D.O. concentrations were 1 to 2 mg/L and compact aeration equipment was not necessary.

Air as a supplemental oxygen source has distinct disadvantages. Since air is composed of 79% nitrogen, the accompanying nitrogen gas can cause serious supersaturation problems if it comes into contact with water at above ambient pressure, which occurs in diffused aeration systems (not a problem with surface aerators). Nitrogen gas supersaturation can impair fish health, and even be lethal to them, (see a more extensive discussion later in this report).

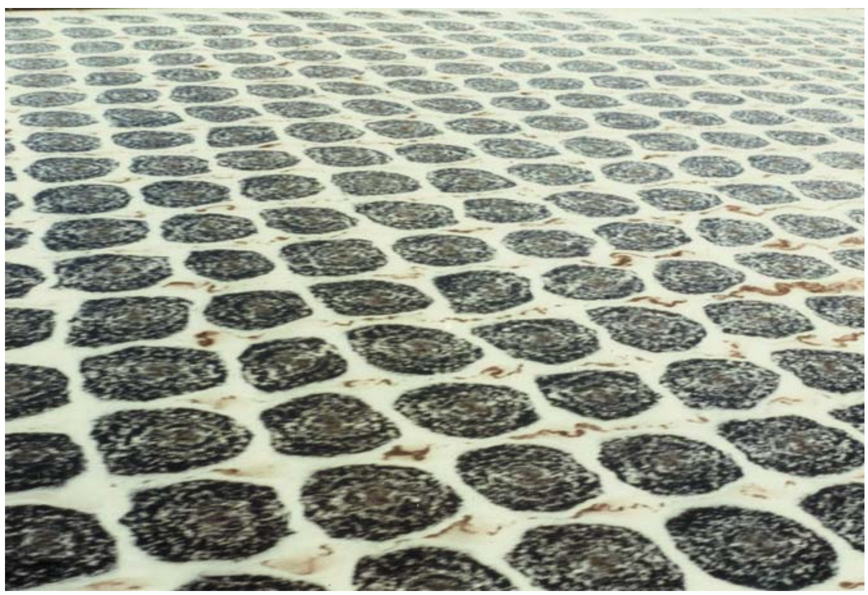
Another disadvantage is that with the air as the oxygen source, if a discharge concentration of less than 5 mg per liter dissolved oxygen is produced by the aeration system, almost 100% of the harbor flow must be moved through the oxygenation system. Significant pumping and river diversion problems must then be addressed.

C. Historical Attempts to Use Surface Aerators for Supplemental Aeration

Shown in these photos are prototype installations which attempted to achieve supplemental aeration in shipping channels. They proved to be rather ineffective and quite energy intensive. The projects were abandoned.

Historical Applications of Surface Aeration for Oxygen Deficient Water Bodies

The following photos show the close spacing required of conventional surface aerators in wastewater treatment. This type of equipment placement is not appropriate for the Savannah Harbor shipping channel, which must remain unobstructed.



Conventional Aeration Systems Occupy Entire Volume of Aeration

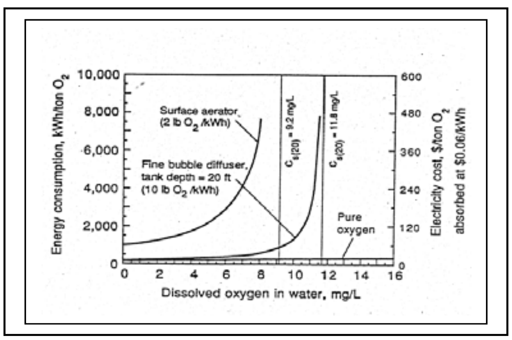
II. Impact of Changing D.O. Requirements on Aeration Technology Applications

A. Aeration Technology Cost Effectiveness

Nowadays the increased cost of electricity has caused conventional aeration technology to become impractical if D.O. standards are set above 4 mg/L. Should dissolved oxygen standards for Savannah Harbor be raised in the future, many systems may even be rendered obsolete. Table I indicates the approximate electricity consumption per ton of D.O. for surface aerators, coarse bubble diffusers or cascade weir aeration at 25 oC.

Table I. Unit Energy Consumption and Costs for Surface Aeration, Coarse Bubble and Cascade Weirs

D.O. (mg/L)	D.O. Deficit (mg/L)	# O2/kw-hr	kw-hr/ton D.O.	$0.05	$0.08	$0.11
				(Dollars/Ton of D.O.)		
0	8.2	2.6	770	38	62	85
1.2	7.0	2.0	1000	50	80	110
2	6.2	1.8	1100	55	88	120
3	5.2	1.5	1300	65	104	143
4	4.2	1.2	1700	85	136	187
5	3.2	0.9	2200	110	176	242
6	2.2	0.6	3300	165	264	363
7	1.2	0.35	5700	285	456	630



The waterfall height required to achieve indicated dissolved oxygen levels, along with attendant unit energy consumption at 25°C. Using cascade/weir aeration, is shown in Table II.

Table II. Height of Cascade Fall to Achieve Indicated D.O. Increase and Resultant Unit Energy Consumption

Change in D.O. (mg.L)	Required height -ft	kw-hr/ton of D.O. added
2 to 3	1.0	903
3 to 4	1.1	1070
4 to 5	1.4	1320
5 to 6	2.0	1890
6 to 7	4.0	3780
2 to 4	1.6	740
3 to 5	2.1	990
4 to 6	3.3	1560
5 to 7	8.1	3830
4 to 7	13.6	4290

Under the conditions described in Table III, superoxygenation becomes more cost effective than conventional aeration technology at 25 oC:

Table III Cost Effectiveness Criteria for Aeration and Oxygenation

Target D.O. mg/L	>5	>3	>1.2
Cost of electricity	$0.05	$0.08	$0.11

An example of the impact of higher D.O. standards and increased energy costs would be the beautiful Chicago Canal Cascade Aeration System (see photo) which already consumes unusually large amounts of electricity (3000 kwhr/ton D.O.) to meet the present low standard of only 3 to 4 mg/L. If higher dissolved oxygen standards are mandated, this system will have to be completely replaced with a more cost effective oxygenation system.

Chicago Canal Cascade Aerators

The following Figures... depict the performance characteristics of cascade/weir aerators. The upstream D. O. is related to downstream D. O as a function of fall height. The energy consumed by the pumps used in the process is shown for the various combinations of D. O. and fall height.

Weir aeration can be expressed as:

$\text{Log } D_o = (0.815 \text{ Log } D_i - 0.385 \text{ Log height of fall}) ((1.024)^{T-20} + 0.062)$

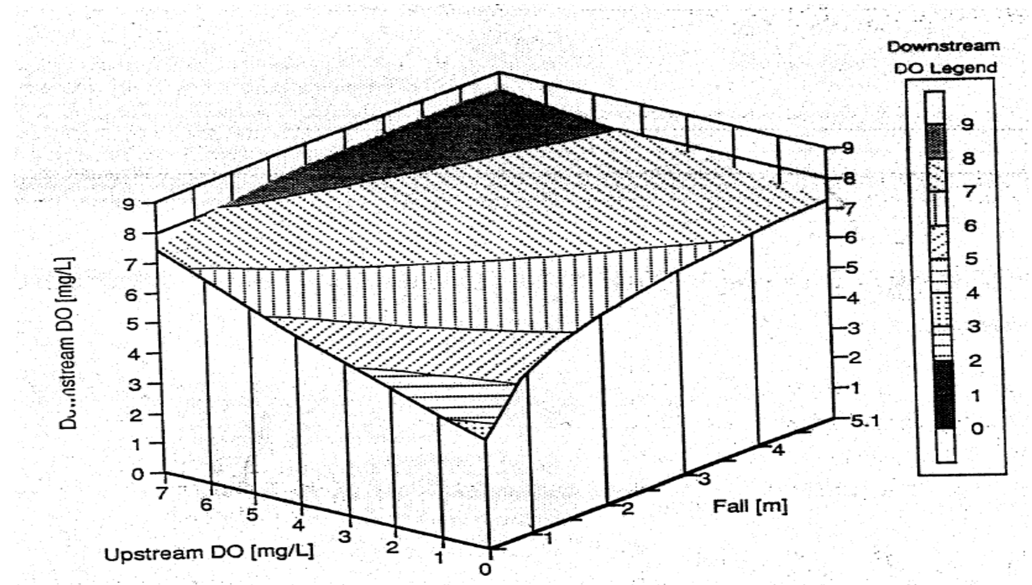


Fig 4. Relationship Between Downstream DO, Upstream DO and Fall at 30ºC

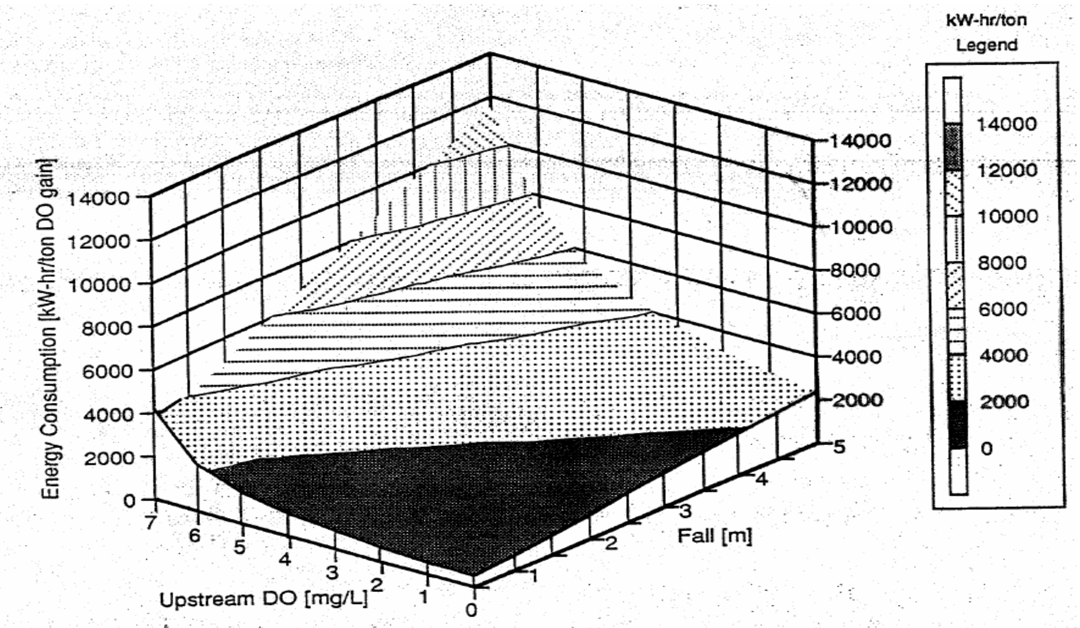


Fig 7. Relationship Between Energy Consumption, Upstream DO and Fall at 30ºC

III. Dissolved Nitrogen Problems Associated with Deep Water Air Injection

A. Reaeration Coefficient (k2) Factors

It is often prematurely assumed that supersaturated gases will be stripped back down to saturation levels in a short distance as the water flows freely downstream. Gas transferred into or out of a river is generally characterized by a parameter called the rearation coefficient (k_2) in units of per day. The rearation coefficient is a function of the depth of the river and the energy dissipation rate. Energy dissipation, in turn, is a function of velocity and the slope or fall of the river. Therefore in a shallow river with a steep slope such as a mountain stream, the rearation coefficient is high, perhaps in excess of 10 per day, and D.O. and DN tend to approach saturation in relatively short distances.

However, hydropower discharges frequently feed deeper slow moving downstream reaches, which often have reaeration coefficients of less than 0.1 per day. For instance the Columbia River is pooled between dams for navigation purposes, and thus has minimal energy dissipation which is compounded by its considerable depth. Consequently in the Columbia River, D. N. values of 130% have been measured with very little decrease over distances of 50 to 80 miles downstream. One cause for this slowness of reaching equilibrium is the gradual warming of the water which increases supersaturation by approximately 2.5% per degree C. increase.

Therefore it is significant that stripping of supersaturated dissolved gases will be intolerably slow in deep harbors and thus cannot be considered as a mitigating factor to achieve compliance with water quality standards for D. O. and DN and /or for total gas pressure (TGP).

B. TGP and D.O./D.N. Ratios in Preventing Fish Mortality

When supersaturation was first recognized on the Columbia River, 110% dissolved nitrogen was adopted by several U. S. northwestern states and the National Academy of Sciences and Oregon adopted 105%, as the maximum standard. However it was later determined that gas bubble disease is related to TGP so at present the U.S. Environmental Protection Agency has established 110% TGP as the water quality criteria. This TGP standard replaces standards based on only dissolved nitrogen (U.S. EPA 1976).

Several studies show that a high dissolved oxygen pressure can reduce the potential of a given TGP to produce gas bubble disease (Rucker 1976; Nebeker, Bouck and Stevens 1976; Nebeker, Hauck and Baker 1979). Even though gas bubble disease is related to TGP rather than just dissolved nitrogen, the D. O./ D. N. ratio is important in determining the severity of symptoms and rate of mortality (Nebeker and Brett 1976). According to their study there was a significant decrease in mortality when the ratio of D. O./ D.N. was increased while holding TGP constant.

C. Need for a New EPA TGP Standard for Superoxygenation

Nebeker and Brett's finding raises a question as to the validity of the present day EPA water quality criteria of 110% TGP being applicable to both spillway discharges and hydropower discharges. It is crucial to differentiate the impacts of air entrainment in spillways and hydropower releases from oxygenation using pure oxygen. The former increases D.N. – the major component in gas bubble disease – while oxygenation with pure oxygen does not increase D.N. at all. These two types of configuration have characteristically different DO/DN ratios, which are a definite factor in fish response in mortality. Bouck previously stated that "a single numerical criterion is a simplistic approach, which can be defended only as a first step in a sequence, culminating in field verification."

As a case in point, two fish kills occurred below the Mactaquac hydroelectric station in New Brunswick, Canada in the summer of 1968. Gas bubbles were observed on the dead and dying Atlantic salmon and eels. Due to the opening of the automatic vacuum breakers at low discharge rates, the DO and DN were elevated to 80% oxygen and 120% nitrogen. Even though this total gas pressure of 112% was only slightly above the present EPA water quality criteria of 110%, it resulted in killing 10% of the 1968 up river run of Atlantic salmon (Mac Donald and Hyatt 1973). This author believes that a revaluation of the present EPA standard of 110% TGP should be undertaken to reflect more accurately N2 or O2 supersaturation as the actual cause of fish stress/mortality . The EPA TGP standard was developed in the context of hydropower and spillway discharges and was developed based on air aspiration at dams and spillways on the Columbia River. However it has been noted that spring water fed to fish hatcheries with diurnal heating that 103% TGP gave 100% kill over long seasons.

D. Gas Bubble Disease: Result of Several Causes

Lethality occurs only at high total gas pressures and is not the sole factor to be considered. Fish under stress can be in a weakened state, making them susceptible to bacterial infections and parasites (McLaughlin and Busch 1981). Elevated D.N. levels are always dangerous to the resident fishery.

Physical symptoms of gas bubble diseases in fish have been reported to be:

- emphysema
- lesions
- gil congestion
- popeye
- cardiac blockage by embolism

(Fickeisen and Montgomery 1978, Bouck 1980, Weitkamp and Katz 1980).

E. Dissolved Nitrogen Problems Associated with Air Injection

When air is introduced into a water column, both oxygen and nitrogen gas are dissolved. Fig. shows the projected D.N. increase when air was injected into a water supply reservoir in Germany. These are rather high D.N. concentrations. This figure indicates that the dissolved nitrogen in the plume of an airlift aeration device is increased from a background saturated level of about 16 mg per liter by an additional 9 mg per liter in the airlift plume, resulting in 150% dissolved nitrogen supersaturation in the discharge.

Injection of air with its 79% N_2 content into a harbor would result in both O_2 and N_2 dissolution in the water column. Natural waters are always 100% saturated with dissolved nitrogen (D.N.) in equilibrium with 0.79 atmospheres partial pressure of N_2, corresponding to about 16 mg/L at 20 ^{o}C and sea level. Aquatic life is not adversely affected by D.N. as long as it remains below ambient air saturation. However injection of air into the water column results in raising the D.N. above this level and can result in gas bubble disease.

The State of Michigan has also reported high mortality rates in fish hatcheries which incorporate deep aeration basins used for the purpose of D.O. enhancement. Therefore caution should be exercised to prevent such an occurrence when using air aspiration into turbine vents of hydropower dams. As mentioned previously oxygenation with pure O2 does not result in an increase in D.N.

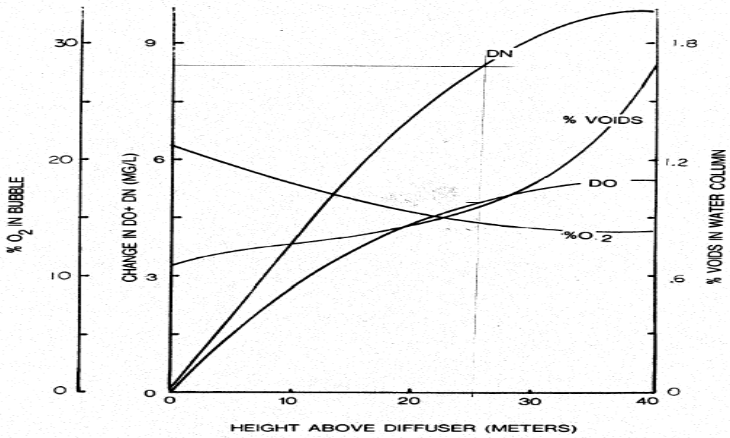


FIG. 1 GAS TRANSFER CHARACTERISTICS OF WAHNBACH SYSTEM

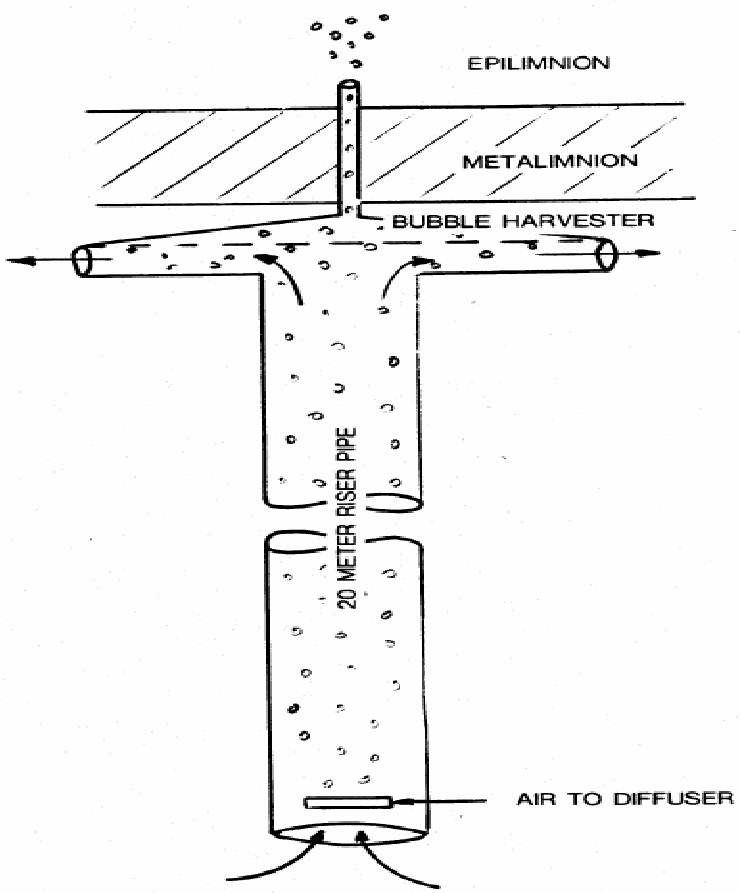


FIG. 2 PROPOSED HYPOLIMNION AERATION MODIFICATION

IV. Aeration System Evaluations

A. Chicago Canal Aeration System

The following section is quoted from a report on evaluation of the cascade aeration system used on the Chicago Canals.

Review of Chicago SEPA Stations Performance by Dr. Russ Brown

> The most well known waterfall facility for aeration of a river is the Metropolitan Water Reclamation District's side-stream elevated pool aeration (SEPA) stations along the Calumet Waterway Cal-Sag channel. This 17-mile long navigation channel (connecting the Des Plaines River with Lake Michigan is 225 feet wide, 9 feet deep, and is extremely slow moving. The low-flow condition in the channel is estimated to be about 1,200 cfs. The DO objective established by the Illinois Pollution Control Board is 3 mg/l. Each of the five SEPA stations are designed to lift about 400 cfs with 2-5 rotary or screw pumps about 12 to 15 feet and discharge over a series of 3-4 waterfalls (i.e., cascade). The number of pumps operated can be adjusted to match the ambient DO conditions to minimize electrical costs. The design assumption was that the waterfalls would increase DO to 95% of saturation. The SEPA stations were completed in 1993 at a cost of about $40 million.
>
> The Illinois State Water Survey (ISWS) conducted a 2-year measurement program following the construction and operation of the SEPA stations to determine the actual performance of the five stations for a range of ambient DO conditions and temperatures.
>
> They report (Butts *et al* 1998) that the cascades (3-4 waterfalls of 3-5 feet each) produced water that was more than 90% saturated with DO. A majority of the aeration occurred in the large screw pumps. A cascade of 3 waterfalls with a combined drop of 10 feet will likely provide a reaeration efficiency of 90%.
>
> The effects of the waterfall stations on the river DO were more difficult to detect (Butts *et al* 2000). Mixing of the waterfall water back into the channel occurred near the surface and the downstream channel measurements could not easily determine an increase compared with the upstream river measurements. Algae and macrophyte (i.e., aquatic plants) productivity and natural aeration caused the surface DO concentrations to fluctuate and made it more difficult to isolate the effects of the waterfall aeration. More attention should be given to mixing the aerated waterfall effluent back into the river.

B. San Joaquin Ship Channel Aeration Performance Evaluation

The San Joaquin River flows from Stockton, California toward the San Francisco Bay and is used for shipping. The current is slow moving, causing the reaeration rate to be quite low, resulting in D.O. deficiency. Note the low oxygen efficiency of the aeration equipment.

The following is quoted from a report by Dr. Russ Brown on the performance of this system.

> The manufacturer design documents suggested that these two sets of bubble-jets would each transfer 1,250 lb/day of oxygen. The depth of 25 feet suggested a maximum transfer efficiency of 20% for the oxygen dissolved from the bubbles into the water. The actual performance on September 26, 2001 was about 75% of the design value for the south jet (i.e., 925/1250 = 75% of design). This seems quite good considering that the DO deficit was only about 2 mg/l. The oxygen absorption would be greater at a higher deficit. The north bubble-jet was operating at less than 20% of the design value (i.e., 225/1250 = 18% of design). It is likely that the performance can be increased considerably by simply turning up the air flow rate to increase the bubble column upwelling and flow-away current. How much of this potential DO increment is transferred to the DSWC depends on the surface DO of the DWSC during the day.

Bubble Jet Aerators

> If the average DO increment measured at the railroad bridge is reliable, the overall efficiency of the Corps aeration device was about 30% of the design value (i.e., 740/2500 = 30% of design). However, because the air bubbles do not appear to be spread across the river channel, and a considerable amount of the compressed air is allowed to vent to the atmosphere, some design changes should be considered. It appears that a single 20 hp air blower (260 scfm) could produce an equivalent air bubble column from traditional diffuser heads (i.e. ceramic head or holes in pipe). The water jets with the two 15 HP jet pumps could be eliminated, and an equivalent amount of oxygen transfer from the upwelling currents could be achieved for less than 30% of the energy (i.e., 20 hp compared to 70 hp for current device).

A preliminary estimate of upwelling flow that could be generated from an equivalent air delivery rate to a single line diffuser can be derived from the equations presented above (Brown et al. 1989). Assuming the 260 scfm is distributed through a 10-m long diffuser, an upwelling flow of about 675 cfs of oxygenated water could be produced. Even with conservative assumptions that the oxygen transfer efficiency is the same between the line diffuser and jet-type aerator, this would represent a slightly greater amount of oxygenated water being distributed into the channel The upwelling equations suggest that similar entrainment of water could be generated without the need for a supplemental water jet pump and its associated power consumption costs.

Another possible design change would replace the air compressor with pressurized (i.e., liquid) oxygen gas, to increase the amount of oxygen dissolved by these relatively shallow bubble columns. The compressor power costs would be saved but the oxygen costs to satisfy the design (i.e., 2,500 lb/day) would be about $250/day. This aeration facility, if converted to an oxygen supply, might allow more than the current increment of 2,500 lb/day of oxygen to be added to the DWSC. The ability to remove the diffusers from the water during the winter and spring remains a very nice design feature of the Corps device. Its location along the side of the SJR channel is another very important design feature.

No measurements of supersaturation levels of D.N. caused by air injection 25 ft below the water surface were made.

V. Conclusions

With low target D.O. levels and inexpensive electricity rates, aeration equipment can suffice in some locations to bring water quality into compliance. However D.O. target levels above 4 mg/L and rising energy costs will preclude many aeration technology applications in the future and mandate replacement of some existing installations now in use.

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Section 4. Oxygenation Technology

4. Oxygenation Technology

I. Background

The unit energy consumption of a successful oxygenation system is relatively insensitive to the discharge D.O. up to about 70 mg/L, as shown in Fig. 2 (Speece, Khandan and Tchobanoglous). But recent developments in superoxygenation technology make possible highly elevated discharge D.O. concentrations economically achieved which solve many water quality issues.

Successful oxygenation of a surface water body is predicated on efficient dissolving of gaseous oxygen into water. The specific design constraints for superoxygenation technology which must be achieved are:

- high oxygen absorption efficiency
- low unit energy consumption (kwhr/ton D.O.)
- side stream superoxygenation (50 to 100 mg/L) at reasonable capital cost
- retention of superoxygenated D.O. in solution

II. Comparison of commercial oxygen vs air as the oxygen source

A. Disadvantages of air as the oxygen source

It may appear counterintuitive to utilize commercial oxygen in raising D.O. concentrations when air is available free. There are several mitigating factors, however, which make the use of commercial oxygen more economical than air in most cases. For instance dissolving oxygen from air into the water involves considerable capital and operating costs. There are also some adverse effects associated with the use of air which are negated using commercial oxygen.

The use of air in contact with water under more than ambient pressure results in supersaturation of the water column with dissolved nitrogen gas with its potential adverse impact on fish. Air as the oxygen source also restricts the maximum dissolved oxygen concentration achievable in a sidestream, and therefore increases the required sidestream flow to achieve a given daily oxygen supplementation mass rate.

In addition the use of air necessitates almost an order of magnitude greater energy expenditure per ton of dissolved oxygen increase when compared to commercial oxygen use. Conventional aeration devices consume 1000 to 2000 kWh per ton of oxygen dissolved, requiring energy expenses of $0.05/kwhr or $50-$100 per ton of oxygen dissolved, with amortization of the capital adding still more cost. Commercial oxygen costs $40 to $200 per ton in bulk, depending on site-specific conditions. Commercial oxygen can be dissolved even in stratified water columns and generally becomes more economically competitive when the target dissolved oxygen goal exceeds 4 to 5 mg/L.

B. Advantages of pure oxygen as the oxygen source

Equipment is now available for superoxygenation (using pure oxygen) to achieve discharge D.O. concentrations of 50 to 100 mg/L. Contrary to a popular misconception, these high D.O. concentrations of less than 100 mg/L do not spontaneously effervesce, but are kept in solution. It is now possible to pull a small sidestream from a river, superoxygenate it, and dilute it back into the main river to satisfy D.O. deficiencies *without treating the entire river*.

To minimize the fraction of river flow thus moved through the oxygenation system, the D.O. concentration achieved must be maximized. This necessitates the use of commercial oxygen, either liquid oxygen (LOX) trucked in or high purity oxygen (HPO) produced on site. Commercial oxygen can be dissolved at elevated pressures without the adverse effects of nitrogen gas supersaturation, which occur when using air under pressure. Use of commercial oxygen allows exceptionally high D.O. concentrations to be produced in the oxygenation system effluent.

Advantages of superoxygenation treatment, when compared to aeration, pollutant reduction, or low flow augmentation in raising the D.O. levels include:

- no measurable negative impact on water quality and the receiving water
- no dissolved nitrogen (DN) supersaturation problems
- a smaller footprint for the oxygenation installation
- less energy consumption
- higher sidestream D.O. levels of 50 to 100 mg/L achieved and kept in solution
- wider spacing of oxygen supplementation stations
- more practicality than tertiary removal of BOD
- less cost than aeration if the dissolved oxygen target exceeds 5 mg/L and electrical costs exceed $.05 per kilowatt-hou

Highly supersaturated D.O. concentrations are possible if special provision is made to prevent effervescent loss before dilution with the bulk harbor water. This makes it possible to supplement the desired oxygen tonnage into a relatively small side stream, minimizing the size of the oxygenation system and associated pumping requirements, and thus increasing the required spacing between oxygenation stations.

A good system for transferring oxygen from air will probably be a poor system for transferring pure oxygen into water. Air dissolution systems are designed to minimize the unit energy consumption and have low O2 absorption efficiencies, because the air is available free. Conversely, a good oxygen absorption system must achieve high O2 absorption efficiency, because the cost of oxygen is the dominant Life Cycle Cost component and the cost of energy consumption per ton is minor (i.e. 200 to 500 kwhr/ton D.O.), being only about 10 % of the oxygen cost.

Even pure oxygen is sparingly soluble in water. In order to assure efficient absorption of pure oxygen in water two requirements must be met:

1) the oxygen gas must be maintained in contact with the water for a prolonged period of time to achieve efficient oxygen absorption
2) dissolved oxygen stripping from the water into the oxygen bubble must be minimized

Since the water is initially saturated with dissolved N2 from being in contact with air, this dissolved N2 will partition back into the pure oxygen bubble. Consequently the partial pressure of O2 in the bubble will be reduced progressively below its initial 100% purity. This in turn will lower the D.O. saturation concentration as well as the D.O. deficit. Higher pressures inside the oxygenation system reduce the stripping potential of nitrogen gas dissolved in the water into the gas phase and therefore tend to reduce dilution of the pure oxygen feed by stripped nitrogen gas.

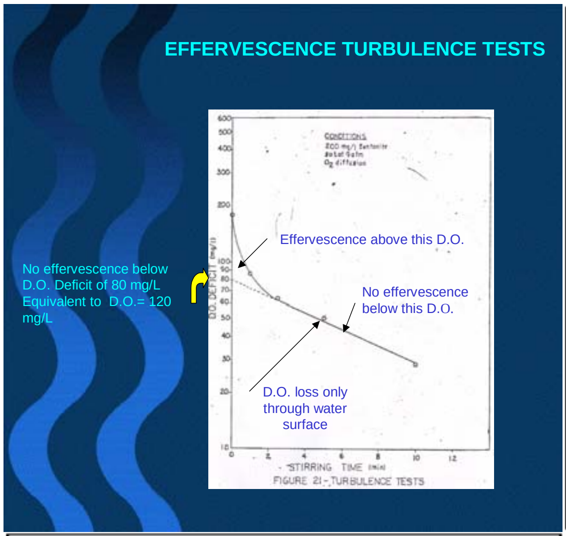
C. Effervescence

At steady state the concentration of D.O. in water will eventually reach that concentration which corresponds to saturation in contact with the gas phase. However the time to reach steady state can be quite prolonged. For instance the Columbia River flows for 80 miles at 130% supersaturation of dissolved gas and loses very little in transit. Of course the rate at which D.O. in undersaturated water reaches equilibrium is the same as the rate at which supersaturated D.O. reaches equilibrium. This is directly a function of the reaeration rate, k2, of the river. Slow moving, deep rivers have very low rates of reaeration while fast moving, shallow rivers have high rates of reaeration. The very low rate of gas exchange at the surface of Savannah Harbor is perhaps the reason for its chronic low D.O. concentrations. Conversely if a gas transfer device were used in the harbor which could raise the D.O. to 10 to 20 mg/L in a restricted region where it was produced, there would be negligible loss to the atmosphere.

In laboratory tests, it has been shown that the D.O. in water can be raised to 120 mg/L (D.O. deficit of 80 mg/L) using pure O2 under pressure and no spontaneous effervescent loss of this high concentration of D.O. will result upon depressurization of the system. This is shown in the accompanying Fig. ___. Furthermore the D.O. can be raised to as high as 250 mg/L using pure O2 under pressure and 90% of this can be retained in solution if it is diluted rapidly with water having a D.O. of less than 10 mg/L. In a third experiment in which water was highly superoxygenated to over 250 mg/L D.O. with pure O2 under pressure, if no care was taken to dilute it rapidly and spontaneous effervescence was allowed to occur, the residual D.O. after all effervescence had ceased was approximately 150 mg/L (380% saturation for pure O2).

These observations are corroborated by results from dissolved air flotation systems. DAF units operate the gas saturation vessel at about 60 psig which is 5 atmospheres absolute or about 400 to 500% saturation in the discharge. If the gas saturation reactor is not operated this high, then relatively little gas effervesces when it passes through the exit throttling valve.

The 45 – 50 ft depth of Savannah Harbor can be utilized advantageously for depressurization of pressurized superoxygenated side streams. The theoretical dissolved oxygen saturation concentration for pure oxygen at a 45 foot depth is 90 mg per liter. Since spontaneous effervescence does not occur below about 250 % of dissolved oxygen saturation when using pure oxygen it would thus be possible to raise the dissolved oxygen to about 2 1/2 times the 90 mg per liter of saturation i.e. 225 mg/L D.O. without the problem of effervescent loss of dissolved oxygen when it leaves a pressurized oxygen transfer vessel.



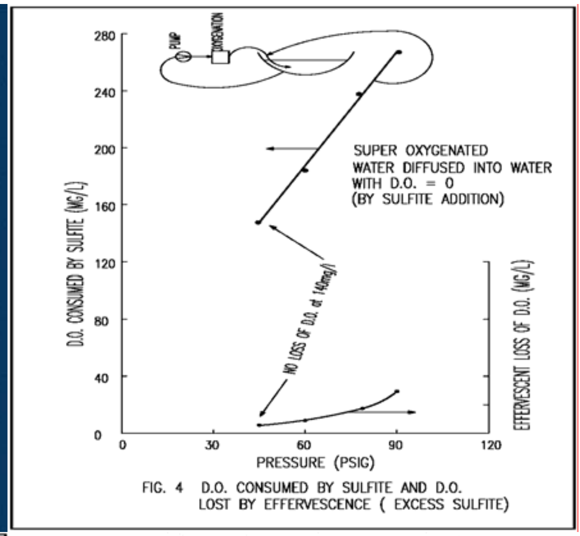


FIG. 4 D.O. CONSUMED BY SULFITE AND D.O. LOST BY EFFERVESCENCE (EXCESS SULFITE)

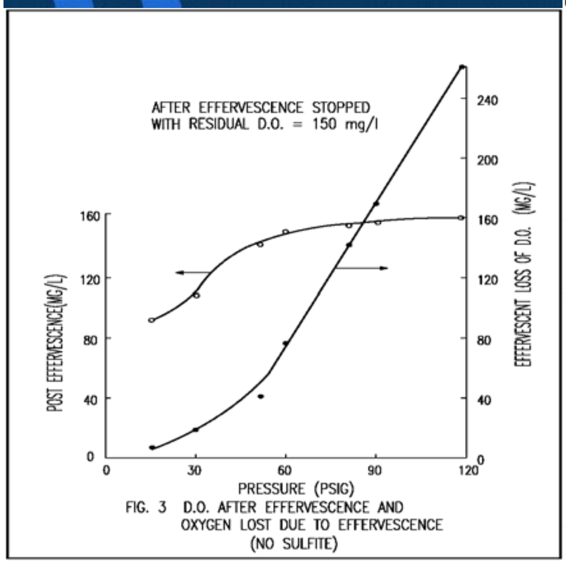
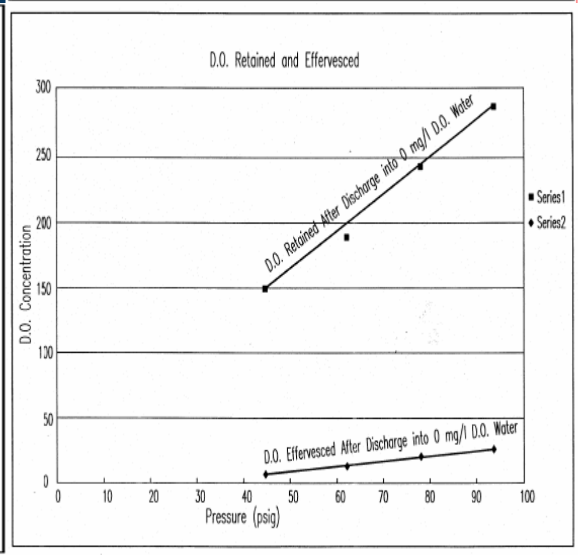


FIG. 3 D.O. AFTER EFFERVESCENCE AND OXYGEN LOST DUE TO EFFERVESCENCE (NO SULFITE)



D. Types of Oxygen Absorption Technology

Pure oxygen absorption systems are generally grouped into the following categories:

Jet/Venturi Aspirators
Soaker Hose
Contained Atmosphere Surface Splashing
Side Stream Pressurization
U-Tube
Speece Cone

E. Pure oxygen source advances

Appropriate technology for supplementation of pure oxygen is determined by the following three factors:

- the present worth of the equipment – (purchase or rental)
- the present worth of total oxygen required (therefore oxygen absorption efficiency becomes important)
- the energy consumption per ton D.O. supplemented.

There is generally a trade-off between equipment cost and oxygen absorption efficiency. At low oxygen absorption efficiency the cost of equipment may be insignificant but the present worth of 'Oxygen Not Dissolved' may be large. An example of a low capital cost system with low O2 absorption efficiency would be injection of gaseous O2 through diffusers in waters with depths of less than 60 to 80 ft. Another example is a Venturi system which shears the bubbles to small diameters but depends on their rise up through the water column for most of the absorption. Thus shallow depths result in lower oxygen absorption efficiency for such a system.

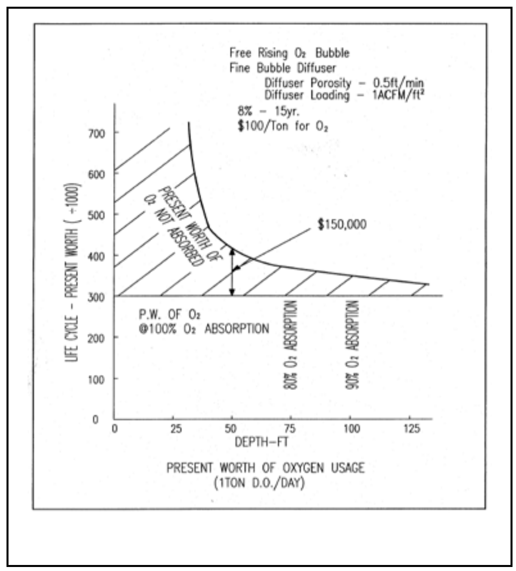


Fig. Present Worth of Oxygen

Optimal high oxygen efficiency and minimal energy expenditure must be incorporated into the design of the oxygenation system adopted. Pressurized systems are desirable for producing superoxygenated D.O. concentrations in the discharge, but it is considerably more energy-efficient to achieve pressurization by hydrostatic head than by pumped head. Generally the unit energy consumption is < 400 kwhr/ton D.O. having a concentration of D.O. of >50 mg/L if the natural hydrostatic head is the means of pressurization vs the case where the pressurization is achieved by pumping against a throttling valve in the discharge line.

A superoxygenation device used in a harbor must be capable of highly superoxygenating a sidestream so that the amount of water to be treated is proportionately smaller. But this system must be located where the oxygen is needed. The Praxair ISO has a small zone of influence. This means that the modules have to be placed within the shipping channel involving many individual units with their electrical power lines strung across the surface area of the shipping channel.

Recent developments in molecular sieves and pulsed swing adsorption (PSA) technology for producing gaseous high purity oxygen (HPO) allow a practical and economical scale-down to capacities of < 1000 lb. O_2/day. PSA oxygen generators are much less complicated than cryogenic oxygen units because they require only a conventional air compressor, an air preparation package to remove water vapor and hydrocarbons from the feed air and molecular sieve beds. In addition there is no on-site storage of oxygen as is the case when using liquid oxygen (LOX).

Vacuum PSA (VPSA) units are as energy efficient as cryogenic oxygen consuming <500 kwhr/ton O_2 for delivery pressure of 0 to 2 psig. The capital costs also are competitive at about $70,000 per 1 ton O_2/day using the PSA system. This capital cost is generally flat over the O2 production capacity of 1 to 40 ton/day. Oxygen purity is 90 to 95%. VPSA systems are operationally more attractive than PSA. For smaller oxygen users, however, the LOX tank rental cost can be almost as much as the cost of the LOX itself.

III. Evaluation of Types of Oxygenation Systems

In evaluating D.O. supplementation technology, the following considerations must be critically addressed:

- D.O. concentration in side stream discharge
- O2 absorption efficiency
- depth of water column
- location in water column where D.O. is needed
- target D.O. in harbor
- mixing requirements
- unit energy consumption per ton of D.O. added
- capital cost of oxygenation system
- required spacing of D.O. supplementation stations
- placement outside the shipping channel

Praxair ISO

Praxair Company markets an oxygen transfer system which consists of a floating device which has a down pumper. There is also a large diameter shroud at the top which captures fugitive bubbles from the system. The down pumping device moves water downward and entrains gas from the headspace into the down flowing water. In this manner the oxygen enriched bubbles are moved down through the water in the downward plume and then the bubbles rise back to the surface as they migrate outside the downflow plume. As the oxygen bubbles rise they are captured as they exit the water by the shroud at the top. This mechanism satisfies the contact time requirement for efficient absorption of high purity oxygen because the bubbles are kept in contact with the water for over a hundred seconds. The pump works under very little head, requiring very little power to move the water in a downward direction.

This device achieves high oxygen absorption efficiency with a capacity of over 90% oxygen absorption efficiency. It also entails low unit energy consumption per ton of oxygen dissolved. However it is not able to raise the dissolved oxygen in a sidestream to more than about 10 mg/L of dissolved oxygen because the Praxair device operates under ambient pressure.

The downward pumping of the water drags bubbles down approximately 10 feet from which they then rise back to the surface. Thus the bubbles are under a maximum of about 1.3 atm absolute of pressure which corresponds to only about 10 foot below the surface in a harbor.

Fig. Aire Liquide Surface Oxygenator

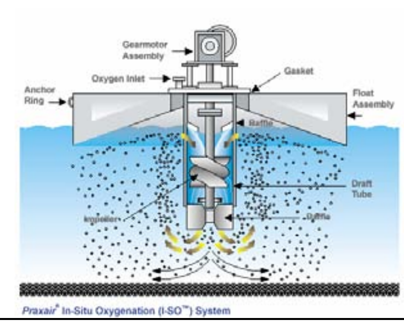


Fig. Praxair ISO Schematic

Fig. Praxair ISO Photo

The performance characteristics of the Praxair ISO system are:

- oxygen absorption efficiency is related to depth of water column
- unit energy consumption – 200 kwhr/ton D.O.
- cost of units - \$/ton D.O./day capacity (rental \$1500/month per unit)
- 5400 lb D.O./day per unit
- 25 Kw pump / unit

Venturi Systems

According to the Venturi principle of oxygen absorption, water is pumped at a high velocity through a Venturi throat section into which high purity O2 is aspirated. Due to the high velocity there is a high degree of shear, which results in the production of very small bubbles forming a high gas/water interface to be generated by the production of very fine bubbles in the throat of the Venturi.

A major drawback is that since the residence time within the Venturi is very short, even though the bubbles are tiny and have a high gas/water interfacial area, the brief contact time precludes efficient absorption. Since these microbubbles are not absorbed in the Venturi they remain in the discharge of the jet where some additional oxygen absorption takes place as the jet containing the microbubbles enters the bulk of the liquid for additional oxygen absorption. But this phenomenon causes the absorption efficiency of any Venturi device to be dependent upon the following factors:

- proper depth of the water column into which the oxygen is being absorbed
- appropriate energy input into the throat of the Venturi
- adequate relative rate of oxygen injection to water flow through the Venturi
- amount of velocity in the throat of the venture
- correct rate of entrainment of the bulk liquid after the water bubble mixture leaves the throat of the Venturi
- efficiency of oxygen dissolution in the bulk liquid
- overall target dissolved oxygen level for the entire system

Oxygen absorption efficiency is increased by deepening the water column, lowering the O2/water injection rates, and lowering D.O. in the water column.

Venturi systems produce oxygen absorption efficiency in the range of 60% and the unit energy consumption per ton of dissolved oxygen is in the range of approximately 1000 kWh per ton of dissolved oxygen. These systems are not able to transfer oxygen into water favorably, producing a discharge of only about 10 mg/L using high purity oxygen. Consequently the required spacing between the supplemental oxygenation units in the system is relatively short. However they could be located at the edge of the shipping channel and discharge their high velocity jet perpendicularly into the shipping channel.

In the evaluation of any Venturi type oxygen transfer system, the four key criteria for evaluation of performance which must be considered are:

- oxygen absorption efficiency
- unit energy consumption per ton of dissolved oxygen
- level of dissolved oxygen which can be achieved in the discharge
- relative spacing between the supplemental oxygenation units within the harbor.

O2 absorption efficiency increases as the relative O2/water ratio decreases, thus reducing the mass rate of D.O. addition per module. Likewise the unit energy consumption increases because the input HP remains constant.

Vendors which utilize the Venturi aspiration principle to achieve absorption of high purity oxygen include Air Products, Mazzei and Linde (similar technology - see photo).

Air Products: Oxy Dep

Venturi aspirators are utilized by these vendors as the oxygen dissolving systems. Water is pumped through a venturi at high velocity and oxygen gas in introduced at the throat. The venturi per se is not an oxygen absorber, but a high turbulence zone. Due to the high velocity/turbulence, the oxygen bubbles are sheared into very small diameters having high gas interfacial area. This enhances oxygen transfer primarily after the water enters the water column. Thus oxygen absorption efficiency is related to the depth below

Fig. Venturi Aspirator Throat

Fig. Air Products Oxy Dep

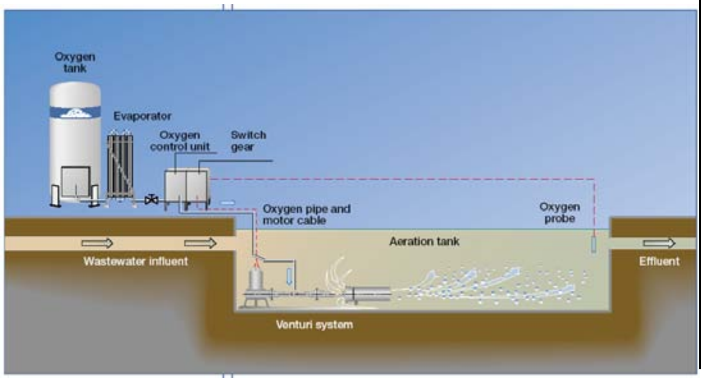


Fig. Venturi Oxygenator Schematic

Fig. Linde Venturi Oxygenator

the surface at which the venturi discharges. The information needed to evaluate the performance of a venturi aspirator oxygenation system is:

- oxygen absorption efficiency for jet/Venturi aspirators injecting pure oxygen over a wide range of oxygen feed rates
- oxygen absorption efficiency as a function of depth of water column
- corresponding unit energy consumption – kwhr/ton D.O.

- cost of units - $/ton D.O./day capacity

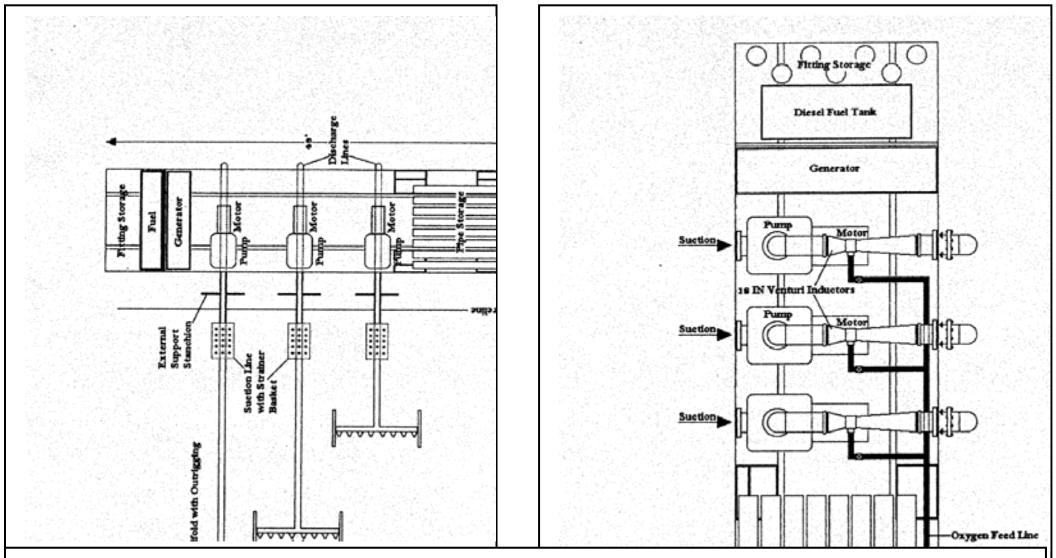


Fig. Mobile Venturi Oxygenator Schematic

Oxygen Bubble Injection

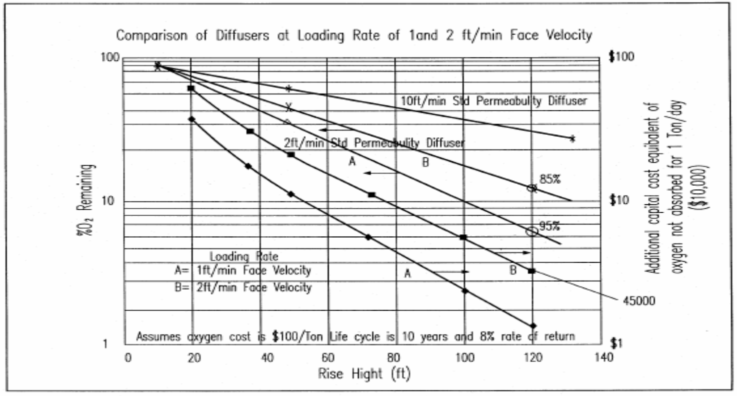
In the past high purity oxygen has been injected directly into various water bodies, but typically inefficiently. The issue is the difficulty encountered in absorbing oxygen into water efficiently at various depths. Table III shows oxygen absorption efficiencies for oxygen injection as fine bubbles associated with a range of depths are indicated. Fig. ___ shows % oxygen remaining vs bubble rise height.

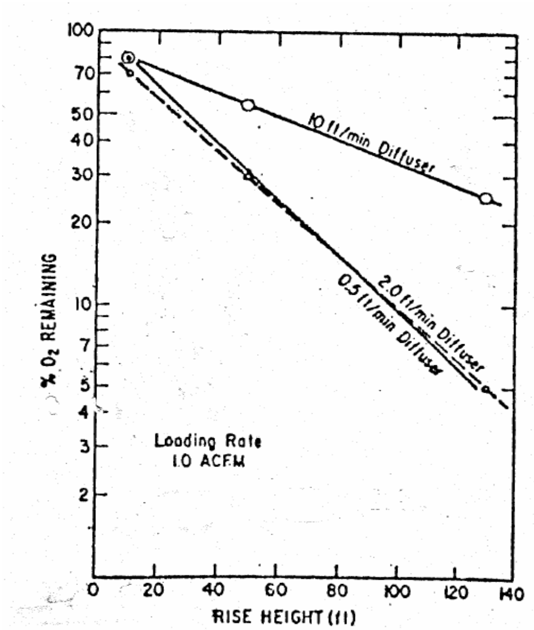
Field evaluation of the O2 absorption efficiency achieved by injection of fine bubbles ~2 mm diameter, into various depths of water columns was made in Clark Hill Reservoir in 1978 and the results are shown in Table III.

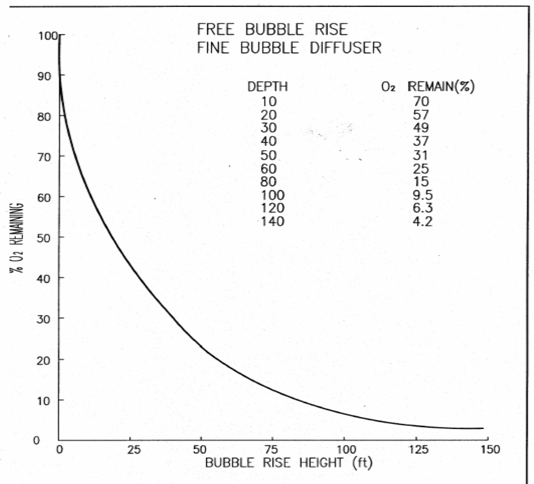
Table III Oxygen absorption efficiency from free rising oxygen bubbles in a 140 ft deep impoundment

Depth-ft	Oxygen Absorption Efficiency-%
10	20
20	45
40	62
60	78
80	85
100	90

Vertically induced flow from a bubble plume has a horizontal recycle cell zone of influence of about 4 times the bubble rise height within the hypolimnion. Thus for a hypolimnion depth of 100 ft, the oxygenated water would distribute itself within a cell of







at most only 400 ft diameter around the bubble source axis. On the other hand although vertical circulation is hindered by density gradients due to temperature, horizontal momentum of a cold-water inflow (which encounters negligible density differences) has been observed to travel the entire 45 miles length of a run-of-the-river impoundment at Clark’s Hill Reservoir in the Savannah River.

Practically it may be of significant benefit in extending the zone of influence within the hypolimnion of the highly oxygenated sidestream to install low speed large diameter impellers directed in the line of flow from the discharge. This boost in momentum after a month of operation potentially could double the effective distance to 4-miles to which the oxygenated water is transported.

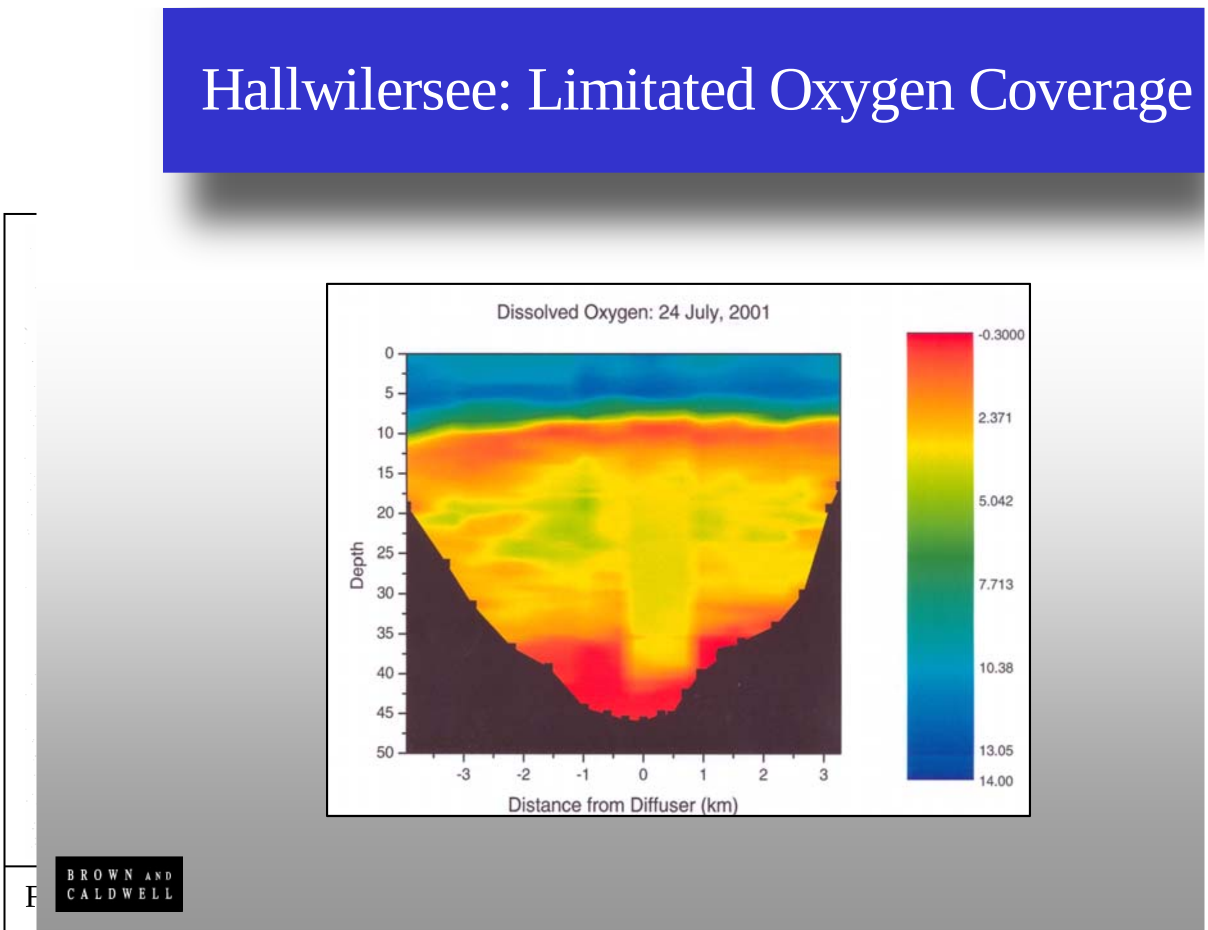
Figs. ___ and ____ demonstrate graphically the inability of free rising oxygen bubble plumes to oxygenate the zone at the sediment water interface. Due to the nature of the mixing in the free rising bubble plume, oxygen supplemented water always comes to equilibrium at some distance above the bubble diffuser. For instance in Lake Hallwilersee in Switzerland, using a fine bubble diffuser fed with pure O2, there is a 4 kilometer zone of sediment water interface which is not supplemented with D.O.

Soaker Hose

The so-called soaker hose oxygen transfer technology utilizes porous tubing similar to the tubing that is used in landscaping that allows water to escape slowly from the hose. The porous nature of the hose is utilized for absorption of high purity oxygen by placing the hose in the bottom of an impoundment and pressurizing it with pure oxygen. A series of feeder hoses and weights are incorporated to anchor the system to the bottom of the impoundment. Since the soaker hose system is a linear diffuser, its operational performance is dependent on the following principles.

- O2 unit loading rate (0.015 to 0.12 scfm/ft – 1.8 to 14 lb O2/ft/day)
- % O2 absorption vs depth
- vertical circulation pattern (not horizontal)

All of the oxygen transfer takes place as the bubbles diffuse from the soaker hose and freely rise up through the water column. Therefore the oxygen absorption efficiency is very much related to the oxygen loading rate on the soaker hose or ft^3 O_2 per min per foot of hose. At low oxygen loading rates relatively smaller bubbles are formed, whereas



D.O. Distribution from Fine Bubble Diffusers in Swiss Lake – Note no D.O. at sediment interface below diffuser

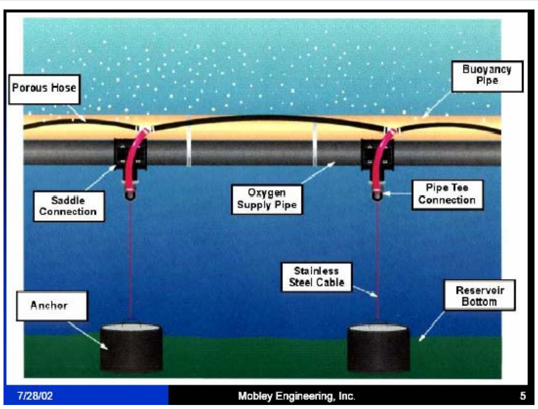
when the oxygen loading rate increases, the relative diameter of the bubbles rising from the soaker hose also increases. Thus at low oxygen loading rates fine bubbles are generated but at high oxygen loading rate relatively larger oxygen bubbles are generated. Since oxygen absorption efficiency in free rising bubbles is related to the size of the bubble, the oxygen absorption efficiency deteriorates as the oxygen loading rate increases.

Another mitigating factor is that the oxygen absorption efficiency is also very much related to the depth of the water column in which the soaker hose is placed. The oxygen absorption efficiency versus water column depth takes on a characteristic pattern, as shown in Fig. __ . Thus to achieve an oxygen absorption efficiency of over 80%, it is necessary that the soaker hose be placed in water columns that are in excess of about 100 feet. Since Savannah Harbor is approximately 50 ft deep, only relatively low oxygen absorption efficiency would result using soaker hose technology. O2 loading rates might need to be reduced by a factor of 10 to achieve more efficient absorption but such a reduction would require 10 times the lineal feet of soaker hose to transfer a given tonnage of O2 in more shallow water columns.

A second disadvantage of soaker hose technology for oxygen transfer in Savannah Harbor is that the soaker hose would have to be placed within the main channel and therefore be subject to the high turbulence of all of the propellers of the large ships traversing the channel.

The installed cost for soaker hose installation is reported to be about $50/lineal foot. In some installations the cost estimate has been as high as $75/ft. The O2 loading rate is controlled by the depth of installation. In order to achieve 90% O2 absorption in 50 ft of water, the O2 loading rate would have to be reduced to <2lb O2/ft/day. At $50/ft installed cost, this would be $50,000 capital cost per ton D.O./day.

No experimental mass balances are available to determine O2 absorption efficiency as a function of depth and O2 loading rate per lineal foot. Claims for O2 absorption efficiency are based on a computer model that was calibrated by air, not O2



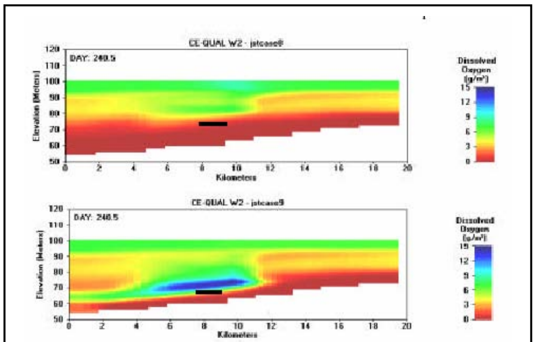


Figure 8: DO Predictions for Different Diffuser Elevations at J. Strom Thurmond

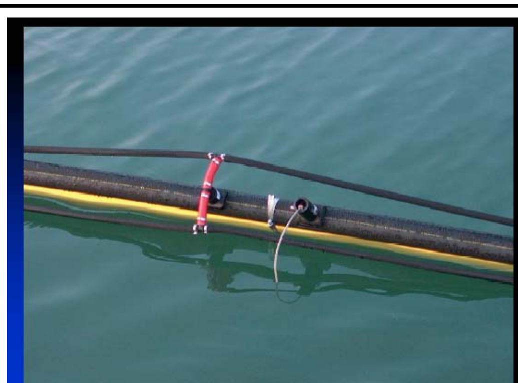


Fig. Soaker Hose Schematic, D.O. Placement and Photo injection, in a 14 meter deep tank.

Speece Cone Oxygenator

The Speece Cone oxygenator incorporates efficient oxygen absorption with low unit energy consumption per ton of D.O. discharged and achieves highly superoxygenated discharge levels. Speece Cone technology can achieve O2 absorption efficiencies in excess of 90% while producing D.O. concentrations of 50 mg/L at unit energy consumption rates of <300 kwhr/ton D.O. if placed on the bottom of a 50 ft deep impoundment or harbor.

An outstanding feature is that *the equipment can be located outside of the shipping channel* by directing its superoxygenated discharge perpendicularly across the ship channel (see Fig. __________). The cone discharges the highly superoxygenated sidestream back into the harbor in a horizontal direction through a diffuser with 2 inch diameter ports at port velocities of 10 to 20 ft/sec. This type of diffuser accomplishes two crucial functions:

- the dilution of the D.O. in the highly oxygenated sidestream
- the transport of this oxygenated water horizontally

Even though the cone discharge is highly oxygenated (50 mg/l) it is not above saturation level for its hydrostatic pressure and therefore has no effervescence potential. The D.O. is diluted down to below approximately 10 mg/l within a short distance of the discharge ports.

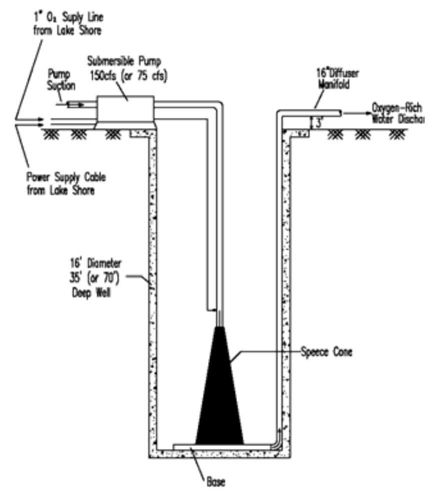
This device incorporates an inverted conical gas transfer vessel in which the water is introduced at the top of the cone, flowing in a downward direction. As the water flows downward its velocity decreases in proportion to the cross-section of the cone. Pure O2 is also injected into the cone and the resulting hydraulic turbulence creates a bubble swarm which has an exceptionally high oxygen/water interfacial area, which greatly enhances oxygen transfer.

By sizing the cross sectional area of the cone so that the downward velocity of the water slows to a point where it is less than the buoyant velocity of the bubbles within the cone, it is possible to retain the oxygen bubbles within the cone for prolonged periods of time, far in excess of the 100 seconds required for efficient oxygen absorption.

The pressure differential across the cone is rather small, being primarily in proportion to the void volume of the bubble swarm within the cone. Thus the unit energy required to pump water through the bubble swarm is relatively small, and therefore the unit energy per ton of D. O. dissolved is also relatively small.

The concentration of D. O. that can be produced in the discharge is related to be depth of submergence or the hydrostatic pressure within the cone. This feature also greatly enhances the oxygen transfer process. The deeper the cone is placed below the surface of the harbor, the higher the dissolved oxygen concentration produced in the discharge. Although the discharge D.O. increases in proportion to depth of submergence, the required pumping energy remains essentially constant, resulting in lower unit energy Kwhr/ton vs depth.

Oxygen transfer is enhanced by pressurizing the oxygen transfer reactor. This allows the achievement of higher dissolved oxygen concentrations in the discharge. Higher oxygen concentration in the discharge, however, has the disadvantage of also consuming more energy per ton of D. O. absorbed. Typically the unit energy consumption per ton of D.O. added is approximately 1000 kWh per ton of D.O. absorbed, if the oxygen transfer takes place under pumped pressurized conditions. However, if placed in an excavated caisson (see Fig. ___) the gas transfer vessel is statically pressurized by the hydrostatic head without the need for pumping against a back pressure throttling valve energy. The water simply flows down into the gas transfer reactor and back out, achieving natural hydrostatic pressurization.



Speece Well Oxygenation System

If a deep caisson is unavailable and pressurization by pumping against a back pressure throttling valve is required, a proprietary system of oxygen transfer is available to recover the energy of the water leaving the pressurized vessel by use of a regenerative turbine or pump (Vendor: ECO2). For instance, if the efficiency of the pump pressurizing the feed to the gas transfer reactor is 80% efficient, and the energy recovery from the pressurized discharge is 80% efficient, then 64% of the energy can be recovered in this arrangement.

This pressurized arrangement allows pressurization with its associated high discharge D.O. concentrations, while consuming only approximately 500 kwhr/ton D.O. added and producing as much as 500 mg/L D.O. in the discharge.

It is possible to operate the cone at even higher pressures than in the water column by pumping through the system against a back pressure imposed by a throttling valve located on the discharge. Whenever water is pumped against an imposed back pressure the unit energy consumption will rise to about 1000 kwhr/ton D.O. This principle holds for pressures required to produce D.O. concentrations over the broad range of 100 to 500 mg/L. Thus if an increased unit energy consumption is acceptable, the tonnage of D.O. /day can be produced in a proportionately reduced size of oxygen transfer reactor. With proper design of the discharge diffuser it is possible to depressurize and dilute these very high D.O. concentrations without effervescent loss of D.O.

Table IV. Expected Results of a Speece Cone Installation at 50 ft Depth

A Speece Cone 12 feet in diameter and 15 ft tall placed 50 ft below the water surface will give the following results using a 45 HP pump:

- 60 mg/L discharge D.O.
- 34 cfs flow through cone
- 12,000 lb D.O. required per day
- >90% oxygen absorption
- 200 kwhr/ton D.O. consumed (if depth is 50 ft.)
- cost of units - $500,000 per 12 ft diameter unit with pump

The excellent results of this system (>90% O2 absorption efficiency) and low unit energy consumption (<200 kwhr/ton D.O. produced) occur in part because turbulence is confined to the inside of the cone with no bottom scouring. *These outstanding results are achieved without interfering with ship channel activity.*

Pressurized Energy Recovery Oxygen Transfer System

This type of exceptionally high superoxygenated discharge has the advantage of requiring fewer supplemental oxygenation stations positioned at greater intervals.

The dissolved oxygen produced in the discharge of the Pressurized Energy Recovery System is proportional to the pressure under which the system operates. If the operating pressure is doubled, the dissolved oxygen concentration in the discharge would also be doubled along with a doubled energy requirement. Consequently the higher the pressure under which the system operates, the higher the dissolved oxygen in the discharge and the higher the energy consumption.

Thus exceptionally high dissolved oxygen concentrations can be produced by a recent proprietary system in pressurized vessels for 1000 kWh per ton of D. O. even at D.O. concentrations of 500 mg/L. Therefore if the D. O. in the discharge is kept below the spontaneous effervescence level, exceptionally high concentrations of D. O. can be produced with a unit energy consumption of approximately 1000 kWh per ton of D.O.

The only practical limit to this concept is the spontaneous effervescence level but this problem can be kept under control by proper dilution. The spontaneous effervescence level for pure oxygen dissolved in water is approximately 250% or 100 mg/L.

Turbine Mixers Operating In Confined Headspace – Emscher River Installation

The Emscher River in Germany has historically served as an open sewer because no prior treatment is applied to the municipal and industrial wastewaters which are all discharged into it. Subsequently the entire river is diverted through primary clarifiers and is then redirected into the river channel where it is completely diverted through an activated sludge treatment facility about 10 miles downstream from the primary clarification location. Ultimately a supplemental oxygenation system was installed on the Emscher River to raise the D.O. to approximately 10 mg/L so that it would remain oxic and thus odor free in this 10 mile stretch

The D.O. supplementation facility consists of a covered concrete tunnel through which the entire river flows. Submerged baffles at the beginning and end of this tunnel serve to provide a confined headspace above the water surface which is filled with an oxygen rich atmosphere into which the river water is splashed to accomplish oxygen transfer by means of surface aeration equipment suspended from the roof of the oxygenation tunnel. This system is similar to the principle of the old UNOX oxygen transfer process.

These systems can achieve high oxygen absorption efficiency with low unit energy consumption but are affected by dissolved nitrogen stripping. Target D.O. levels are limited to about 10 mg/L. Turbine mixers can scour basin bottoms if earthen. It should be noted, however, that these installations must be placed within the river channel to be effective.

Contained Atmosphere Surface Splashing

The original UNOX activated sludge process used pure oxygen and utilized a water sealed head space which was equipped with surface splashing turbines. One version utilized injection of the O2 down a hollow shaft below a submerged mixer as well as surface splashing turbines. Thus the water was splashed in contact with enriched O2 in the head space. The system operated at ambient pressure and was able to keep the O2 in contact with the water for an extended time. It could only operate with a D.O. in the water of less than 10 mg/L to insure an increased D.O. deficit. With a D.O. of less than 10 mg/L the unit energy consumption is below 1000 kwhr/ton of D.O. transferred. The entire reactor surface area is required for oxygen transfer, but achieves > 90% absorption affectively.

Sidestream Pressurized Oxygenation

Sidestream pressurization is a gas transfer technology which withdraws a relatively small sidestream of water, injects pure oxygen into the pressure side of the pump, and pumps it at high pressure through a long pipe loop. The water velocity is maintained sufficiently high enough to assure two-phase flow so that the gas/water interfacial area is quite high to maximize the rate of gas transfer. The system is pressurized to as much as 100 psig by a throttling valve on the discharge end which results in a C_{sat} concentration for pure O2 of 300 mg/L at 25 oC.

Depending on the diameter of the pipe loop, a velocity of at least 10 ft/sec is required to generate the turbulence required to maintain two phase flow. Since it requires nominally about 100 seconds of contact time between the O2 bubbles and the water regardless of the water pressure to achieve > 90% O2 absorption, the pipe loop must be about 1000 ft long. Since this is an excessively long pipe loop, it is common to make it shorter and thus sacrifice O2 absorption efficiency.

Criteria used to evaluate performance of this system involves: the oxygen absorption efficiency attainable, the unit energy consumed per ton of dissolved oxygen added, the dissolved oxygen concentration in the discharge, and the capital cost.

Sidestream systems are able to achieve very efficient oxygen absorption efficiency if the length and retention time within the pipe loop are sufficiently long (at least a hundred seconds). Operated at very high pressures, these systems can produce a highly superoxygenated discharge.

An advantage of such a system in Savannah Harbor would be that the system could be located along the edge of the shipping channel and discharge a highly superoxygenated effluent perpendicular to the harbor axis into the main channel. Disadvantages of the of the system are the high unit consumption required plus the limited oxygen absorption efficiency that is usually obtained if the length of the pipe loop and the residence time is not long enough to achieve very high oxygen absorption efficiencies.

To raise the rate of gas transfer, the gas/water interfacial area should be maximized and the D.O. deficit should also be optimized. Gas/water interfacial area is enhanced by increasing the amount of gas injected per unit volume of water and minimizing the resulting bubble diameter. The D.O. deficit is maximized by pressurizing the gas transfer system. The gas transfer equation is as follows:

$$dc/dt = K_l\,(A/V)(C_{sat} - C_{act})$$

Under these conditions of 100 psig pressurization, it is possible to achieve over 200 mg/L D.O. in the discharge. By proper design, most of this superoxygenated water can be retained in solution. Discharge at 50 ft below the surface and rapid dilution just after the pressure drop at the throttling valve would need to be incorporated. Rapid dilution can be achieved by directing all of this energy in the high velocity discharge into a shroud discharge tunnel which entrains bulk water containing low D.O., similar to that used with Venturi/jet gas transfer systems.

A sidestream pressurization unit capable of dissolving 40,000 lb D.O. per day would have the following design parameters:

- discharge D.O. : 200 mg/L
- flow of side stream ; 37 cfs (if 200 mg/L D.O. in the discharge)
- diameter of pipe constituting contact loop ; 26 inches
- cost of 1000 ft of 26 "diameter 316 SS ;____________________
- pump HP @ 70% efficiency ; 1380 HP (pumping against 100 psig)
- cost of pump ;_____________
- unit energy consumption ; 1200 Kwhr/ton D.O.
- O2 absorption efficiency ; >90% (if pipe loop 1000 ft long)
- operating cost per ton D.O. ;____________(6 months/yr 6%, 15 yr)

Thus high levels of superoxygenation can be achieved, which proportionately reduce the fraction of a side stream required for a given tonnage of D.O. per day. As with all pressurized systems pumping against a throttling valve to achieve pressurization of the gas transfer reactor, the unit energy consumption rate is high, e.g. 1200 kwhr/ton D.O., which is a major drawback. Additionally the length/cost of the pipe loop are comparatively high so that less than 100 seconds detention time frequently results from the short lengths utilized in most cases.

U-Tube Oxygenation Technology

The U-tube aeration concept first applied in the Netherlands in 1958 exhibits excellent potential for dissolution of insoluble gas into a liquid. This process involves passage of a gas water mixture vertically down a shaft underneath the baffle and back up to the surface, providing prolonged contact of the bubbles with the water and pressurization of the bubbles by the hydrostatic head. Water is pumped down the center of this shaft to the bottom and then flows back through an annular space to the surface. A vertical shaft of considerable depth is required for this type of oxygen transfer technology.

Several reactions occur by injecting high purity oxygen into the downward flow: the contact of gaseous oxygen with the water will be in proportion to the depth and velocity characteristics of the system and since the water is flowing vertically downward or vertically upward, there will be no problem in maintaining two-phase flow of the oxygen bubbles and water if the velocity is sufficiently high. Also the head loss across the system will be relatively small due to friction loss (most of the head loss is related to the void volume differential of gas in the down leg and the up leg).

The oxygen absorption efficiency characteristic of a U-Tube oxygen transfer system will be related to the O2/water ratio that enters the system. Consequently at low O2/water injection ratios, higher absorption efficiency will be achieved, but lower discharge D.O. concentrations result. Conversely when the O2/water injection ratio is increased, the oxygen absorption efficiency will decrease but the discharge D.O. concentration will increase. It thus becomes obvious that higher oxygen absorption efficiency is realized at the expense of the D. O. concentration in the discharge.

Even though the depth of the U-tube is approximately 200 feet deep, oxygen absorption efficiency may not exceed 80 - 90% depending upon the water velocity through the system, the depth of the system, and the O2/water injection ratio realized. See Fig. __ for a schematic view of the system.

Advantages of U-Tube Technology

U-Tube oxygenation technology incorporates several desirable features when compared to other methods of raising D.O. levels. The major advantages of U-tube oxygenation are as follows:

- Oxygen transfer occurs in a pressurized reactor, which results in very high D.O. concentrations up to 50 mg/L at 28°C. A high rate of oxygen transfer per unit volume of reactor, up to 5400 mg/L per hour, may be achieved versus 100 mg/L per hour for conventional aeration tanks.
- Unit energy consumption per ton of D.O. is approximately only 400 kWh per ton, which is quite low because the head loss across the system is minimal, even though the oxygen transfer occurs at hydrostatic pressures of up to 175 feet.

- The oxygen bubble contact time is prolonged in transit through the U-Tube.
- Exceptionally high saturation concentrations are generated, enabling supersaturation of D.O. in the discharge.
- Oxygen gas bubble pressurization is accomplished hydrostatically, thus consuming low energy. Contrasted with the excessive energy consumption of pumped pressurization vessels which lose all of the input energy across the pressure throttling valve, no supersaturated D.O. may be lost by effervescence with pumped pressurization.
- No external pumping is necessary if the hydraulic head of the effluent is at least 5 feet above the harbor surface.
- Dissolved nitrogen stripping is minimized from the water as well as nitrogen gas dilution of the oxygen composition of the bubbles because gas transfer occurs in a pressurized vessel. Water saturated with nitrogen gas in air will strip if the nitrogen partial pressure in the gas phase is less than .79 atm. If the process is at atmospheric pressure, the nitrogen composition approaches 79%, but at 4 atmospheres the nitrogen composition approaches only 20%. This results in oxygen compositions of 21 % and 80% for 1 and 4 atm respectively.

The U-tube is comprised of a deep hole about 150 to 200 feet deep. The water flows down an open-ended pipe inside a casing and back up to the top through the annular space between the two pipes. See Fig___. The water velocity is approximately 6 to 10 fps, which greatly exceeds the 1 fps bubble rise velocity of the bubbles. Therefore when oxygen gas is introduced at the inlet, the bubbles are dragged along with the water flow down to the bottom and back to the top. Oxygen transfer is achieved by the hydrostatic pressurization, but also is enhanced by the turbulence and extended contact time. At 175 feet of hydrostatic head, the pressure is over 6 atm and with a 100% oxygen bubble, the saturation D.O. concentration is over 250 mg/L.

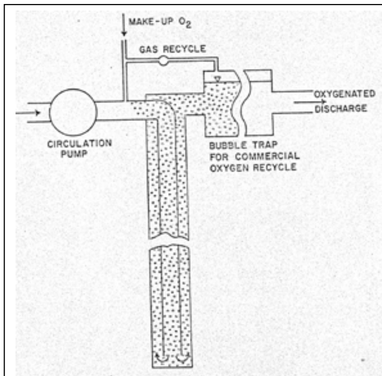


Fig. I U-TUBE OXYGENATION PROCESS SCHEMATIC

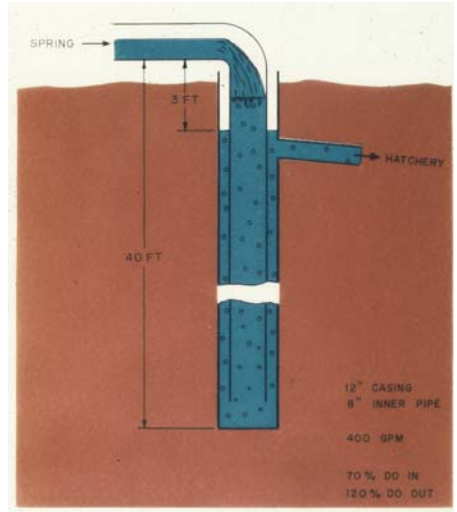


FIGURE 8. FISH HATCHERY OXYGENATION SYSTEM

Hydroflo

HydroFlo technology withdraws a sidestream of water into which high purity oxygen is injected, then directed through equipment in which the oxygen absorption takes place, and sent back into the harbor. Similar criteria are used to evaluate the HydroFlo technology performance as have already been mentioned: the oxygen absorption efficiency achieved, the unit energy consumption per ton of dissolved oxygen, the level of super oxygenated water present in the discharge, and the relative required spacing of units throughout the harbor.

HydroFlo units could be located on the edge of the shipping channel and discharge their high velocity superoxygenated stream back into the ship channel. However proprietary data needed to determine oxygen absorption efficiency which can be achieved by the HydroFlo technology is not available at this time.

Mobile Oxygenation Barge

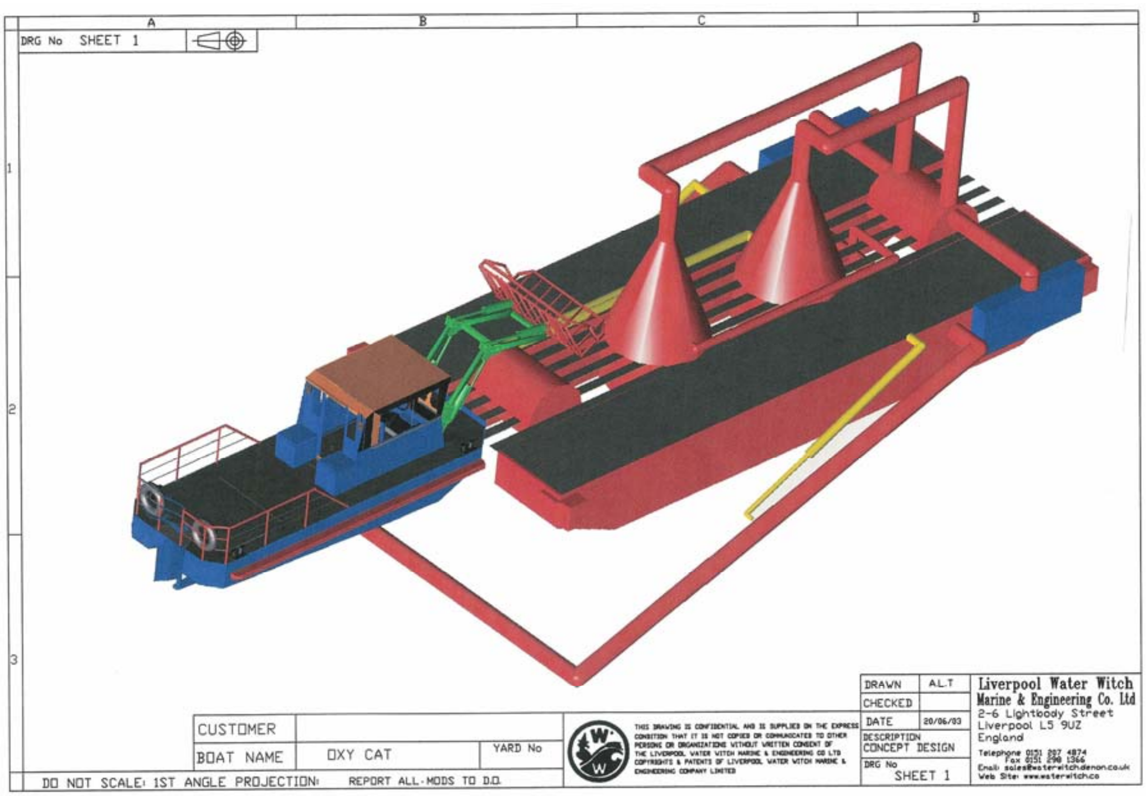
Mixing and transporting of the super oxygenated water within the harbor are key goals which must be achieved in a successful D.O. supplementation project. Oscillating tidal currents will be one of the main mechanisms which can be capitalized upon for movement of superoxygenated side streams away from the zone where they are generated. However a hydraulic model of water movement within the harbor would probably indicate some locations which will not have adequate transport of supplemented D.O. so as to meet compliance. Furthermore these D.O. deficient regions may change with flow and temperature conditions.

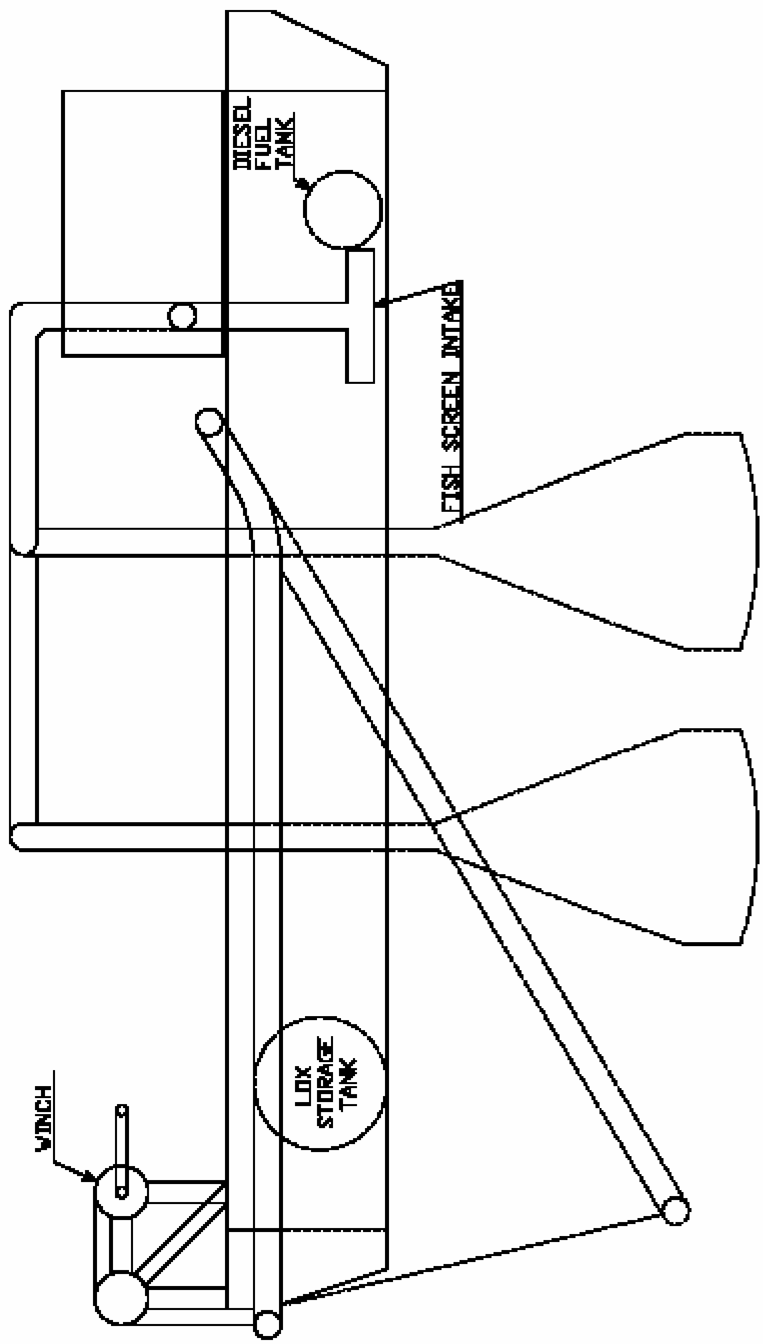
In such cases a logical solution would be to incorporate a means to deliver D.O. directly to the locations which are out of compliance. The concept of a self contained mobile oxygenation system could be used to address such deficiencies in tidal mixing effectiveness for effective transport of D.O. to all regions where needed.

A self-contained mobile oxygenation system would include on-board oxygen generation by pulsed swing adsorption or vacuum swing adsorption. This feature would avoid the safety concern of needing to store oxygen. Diesel or propane driven engines could either directly drive the oxygen generation system and pumps to move water through the oxygen transfer system or could generate electricity on board to power such components.

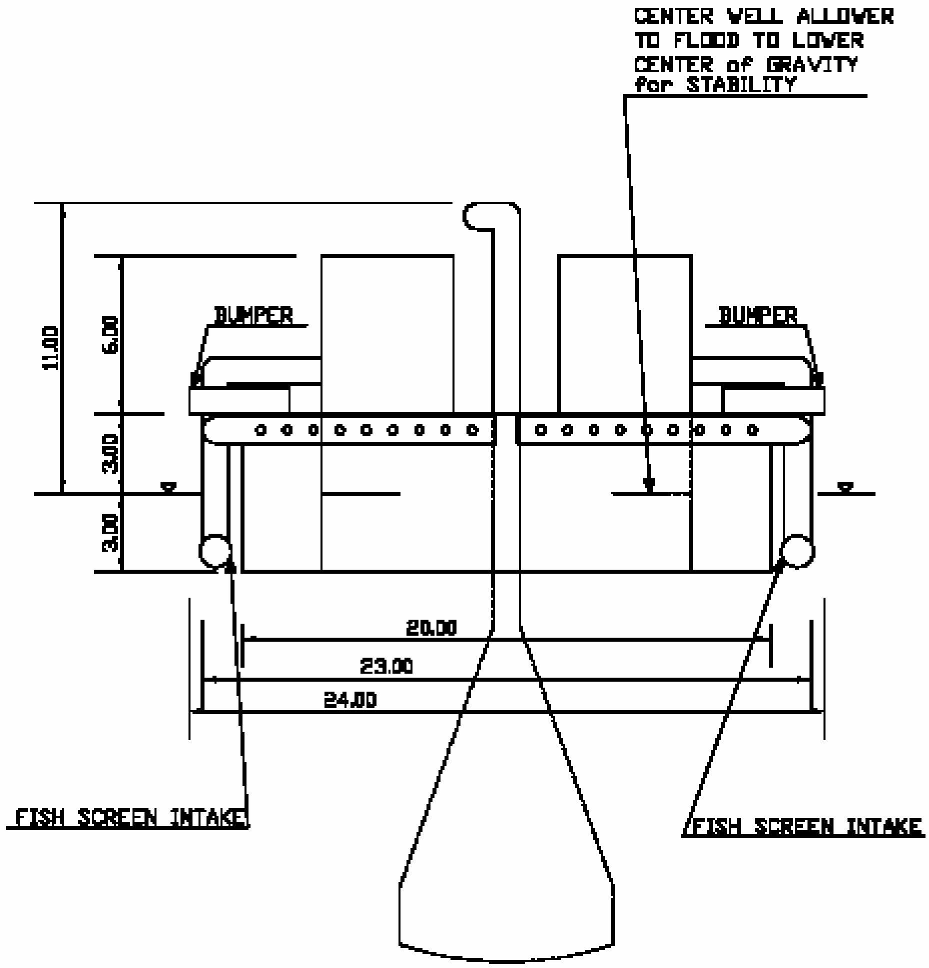
It would be advantageous to capitalize on the hydrostatic depth of the harbor for enhancement of oxygen transfer by placing the oxygen transfer reactor as far below the surface as possible. Of course there may be regions outside the main deep ship channel where the depths are much less deep that may require the aid of a mobile oxygen supplementation system.

The following Figs. __ show schematics of a mobile oxygenation system. It would be capable of withdrawing denser water from the bottom of the water column, superoxygenating it and discharging it horizontally back at the same depth by means of an adjustable discharge boom. Sound insulation for the diesel could mitigate the noise pollution arising therefrom.





Side View


CENTER WELL ALLOWER
TO FLOOD TO LOWER
CENTER of GRAVITY
for STABILITY
BUMPER
BUMPER
11.00
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24.00
FISH SCREEN INTAKE
FISH SCREEN INTAKE

End View

IV. On-Site Performance Studies of Selected Superior Oxygenation Systems

A. Speece Cone Performance, Logan Martin Dam

This oxygenation system was designed to handle 21 $ft.^3$ per second. The top diameter is 20 inches and the diameter at the bottom of the cone is 9 feet with a cone height of 15 feet and a bottom cylindrical skirt that was 5 feet high to contain the discharge piping. It was projected that the 21 $ft.^3$ per second system could add 55 mg/L of D. O. if the inlet D. O. was 0 mg/L and the O2/water ratio injection ratio was 5%.

This proposed system would satisfy about one third full-scale D. O. requirements of 18,000 pounds of oxygen per day for a leakage flow of 700 $ft.^3$ per second to raise the D. O. to 4 milligram per liter in the discharge from a background D. O. concentration of 1 mg/L in the influent. Therefore if this 21 $ft.^3$ per second system was found to be successful it was decided that it would be combined in the final design with an additional system capable of handling another 42 $ft.^3$ per second. This system was installed to determine its operational performance so that scale up problems for a full-size system would be minimized.

Oxygen/Water Ratio

The data are presented graphically showing O2/water ratio ratios of 3, 4, 5 and 6% respectively. The relevant points that can be drawn from the graphs are as follows.

Maximum oxygen absorption efficiency occurred at a water flow rate of 22 to 25 $ft.^3$ per second through the system. A slight reduction in absorption efficiency occurred below this range and a more rapid decline occurred at higher velocities.

All oxygen absorption efficiency decreased with increasing O2/water ratios. Likewise all oxygen absorption efficiencies declined with increasing water flow rate in excess of 22 to 25 $ft.^3$ per second.

The greatest D. O. increase resulted at water flows of 22 to 25 $ft.^3$ per second for all oxygen water ratios, as mentioned previously, because increased water flow resulted in bubbles being swept out of the system prematurely. Thus oxygen absorption efficiency was thereby reduced, as reflected in the lower D. O. concentration in the oxygenation system discharge.

The pressure losses across the system are plotted in Fig. __.   Pressure at the oxygenation discharge with no flow-through the system was 52 feet, reflecting the static head of water above the dam with respect to the location of the oxygenation cone. With no oxygen in the injection, the discharge pressure was 44 and 42 feet at water flows of 22 and 25 $ft.^3$ per second, respectively and at an O2/water injection rate of 4%. Discharge pressures were 38 and 37 foot. It is to be noted that the total head loss across the oxygenation cone was nearly constant at 6.2 feet regardless of water flow through the system when oxygen was injected at 4% O2/water ratio.

Results

The oxygenation cone has a volume of 320 ft.^{3}. The five foot-high cylindrical section on the bottom of the cone that contains the discharge piping also had a volume of 320 ft.^{3}, resulting in a total volume of 640 ft.^{3}. At the design flow of 22 ft.^{3} per second and 4% O2/water ratio, the system added 48 mg/L of D. O. to a background influent D. O. of 3.6 mg/L for a total of 5600 pounds of D. O. per day. This is equivalent to 9 pounds of D. O. per cubic foot per day or 100 mg/L per minute of D. O. at 90% oxygen absorption efficiency. The average pressure in the cone was approximately 29 feet at the centerline of the cone and the water temperature was 86°F. At this pressure and temperature the saturation D. O. would be 66 mg/L, if the gas phase was 100% oxygen. The discharge D. O. was 51 mg/L and the oxygen content of the bubbles within the oxygenation cone was approximately 83%, as measured with a 4% O2/water injection rate, indicating the oxygenation system was able to achieve 94% of theoretical saturation under these conditions. This is indicative of a very good oxygen transfer system since the hydraulic retention time is only about 30 seconds.

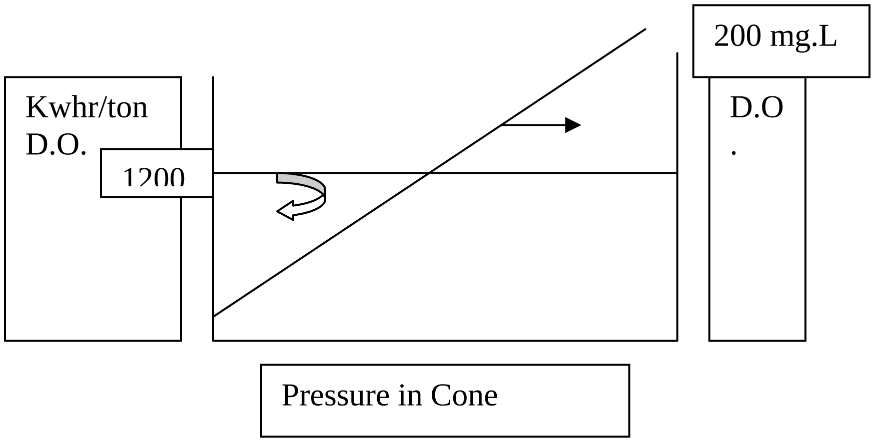
In the flow range of 22 to 25 ft.^{3} per second with an O2/water injection ratio of 3%, the discharge D. O. was 42 mg/L for a net increase of 38 mg/L over background. Under these conditions the absorption efficiency was 95%. When the O2/water injection ratio was increased to 4% under the same water flow conditions, the discharge D. O. was 51 mg/L over the background concentration of 4 mg/L, resulting in an oxygen absorption efficiency of 87%.

Pressurized oxygen transfer

The nature of pressurized oxygen transfer is demonstrated by the fact that when pressurization was incorporated it increased the unit energy consumption rate to about 1200 kWh per ton of D.O. In cases where no pressurization was utilized, such as placing the oxygen transfer device on the bottom of the ship channel 50 foot below the surface, a discharge from a Speece Cone would be about 60 mg per liter of dissolved oxygen. A 12 foot diameter cone can handle 35 ft.^{3} per second of water flow. The head loss across the cone is approximately 10 feet, which would thus require a 55 hp pump, if it were operating at 70% efficiency. Thus each cone could deliver approximate by 11,000 pounds of dissolved oxygen per day and the unit energy consumption would be approximately 200 kWh per ton of dissolved oxygen added.

If the Speece Cone were operated at a pressure of 215 feet of head it would produce a discharge dissolved oxygen level of 200 mg per liter and a 12 foot diameter cone would be able to deliver 38,000 pounds of dissolved oxygen per day. To pump 35 ft.^{3} per second against a head of 215 foot of head plus 8 foot of head loss would require a

1300 hp pump. The unit energy consumption would be approximately 1200 kWh per ton of dissolved oxygen.



These data suggest that a Speece Cone operating under ambient pressure at the bottom of the Savannah Harbor Ship Channel would produce 60 mg/L in the discharge and be able to deliver 11,000 pounds of dissolved oxygen per day with a unit energy consumption of less than 200 kWh per ton of D.O. If the cone was operating at 215 ft of pressure it would produce 200 mg/L D.O. in the discharge and deliver 38,000 pounds of oxygen per day, with a unit energy consumption of 1200 kWh per time of dissolved oxygen.

Life cycle costs of non-pressurized, pressurized, and energy recovery oxygen transfer

Since the above systems achieve greater than 90% oxygen absorption efficiency, whether operated under ambient or pressurized conditions, the key comparison is life cycle cost of energy consumption and additional oxygen transfer volume. The non-pressurized system would require approximately 3 1/2 times as many Speece Cones as would the pressurized system. Therefore the reduction in energy costs must be compared with the increase in capital cost for additional cones.

Assuming 50% utilization of the system throughout the year, the following life cycle costs result for transfer of 38,000 lb D.O. per day.

Assume equivalent power costs for diesel engines to be $0.12/kwhr. Power for non-pressurized system would consume 19 T/d x 200 kwhr/T = 3800 kwhr/day x $0.12/kwh x 180 d/y x PWF of 9.7 (6%@ 15 yr) = $800,000 for the present worth. The equivalent cost for the pressurized system would be 6 times this or $4,800,000. This is considerably more that the cost for an additional 2.5 Speece Cones of 12 ft diameter needed to transfer 38,000 lb D.O./day. Thus it appears that the non-pressurized mode of supplementing D.O. is economically more favorable than the pressurized mode.

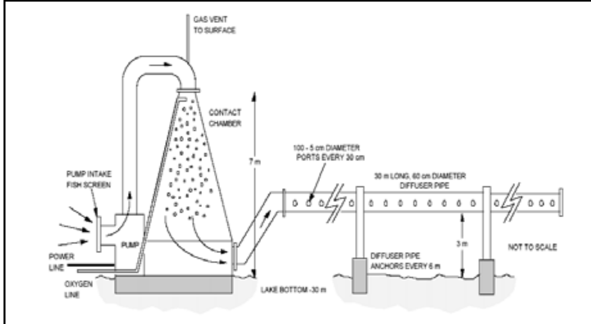
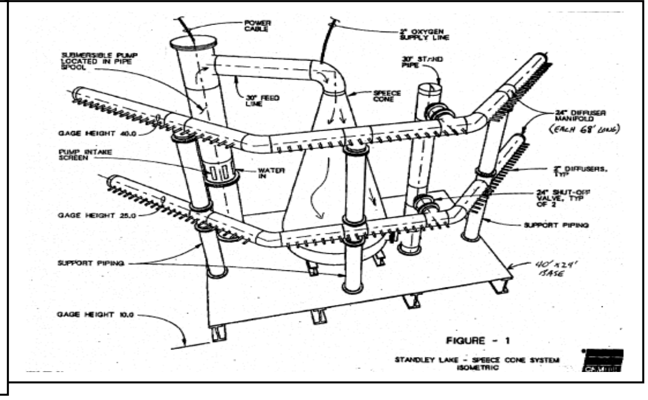


Figure 2 - Schematic of submerged contact chamber oxygenation system used in Camanche Reservoir, California and Newman Lake, Washington.



B. U-Tube Pilot Study

Deep U-Tubes offer excellent potential as energy and cost efficient oxygen transfer systems. The depths of 25 to 60 m appear to be most useful for optimal oxygen absorption.

U-Tubes have been used for aeration of:

- fish hatchery water
- sewer mains
- free-flowing rivers
- activated sludge treatment

Mixed liquor oxygen transfer energy has proved to be comparable or superior to that produced by conventional surface aerators, and produces dissolved oxygen concentrations in the discharge which exceed saturation under ambient conditions. Even D.O. levels in excess of 200% can be produced with an oxygen transfer energy efficiency of 4 kg of oxygen per kwhr.

The ICI deep shaft process is operational at a number of waste water treatment locations in Europe and Canada but there is only operational information available for one depth and velocity at each location. Design criteria were not yet available to estimate rationally sizing costs and to predict the operational characteristics of deep U-Tubes for any of the above potential applications.

In order to include U-tube aeration as an alternative design the design engineer needs to ascertain the following data:

- depth required
- throughput velocity
- appropriate gas/water injection rate
- discharge D.O. target
- head loss across U-tube to determine energy consumption.
- oxygen transfer economy and kilograms of O_2 per kwhr
- oxygen cost per ton, which includes the amortized capital plus the electricity to operate the system.

The pressure loss across a U-Tube system due to oxygen injection is shown in Figure _____ as a crosshatched bar. The pressure loss across the 1/10 meter diameter U-Tube due to frictional losses alone is shown as the open bar on top of the crosshatched bar. The calculated frictional loss of a 1 m² U-Tube is noted on the graph by the solid bar since this larger pipe size would be the best prototype system.

The oxygen transfer per kwhr is calculated for a prototype U-Tube with 1 m² of cross-section in both the up and down legs. This energy consumption data is shown in

Figure ___. It is seen that a U-tube depth of 30 m and 25% O2/water injection ratio yields 12 kg of oxygen per kwhr as the energy consumption ratio. It should be noted that recycle of the gas would change the oxygen composition from 100% to approximately 70%, due to stripping of dissolved nitrogen from the influent water. This would tend to reduce the kilograms of oxygen per kwhr accordingly. There is essentially little practical incentive to attempt to improve oxygen transfer energy consumption beyond 200 kwhr/ton D. O. because such savings in energy per metric ton of oxygen dissolved are negligible. Therefore the high rate of oxygen transfer at 30 m depth and 4% O2/water ratio, which is 25 kg of O2 per kwhr, is not worth exploiting.

Pilot Study Evaluation Criteria

The following parameters were evaluated:

- velocity: 0.9, 1.4, and 1.8 m per second.
- depth: 12, 30, 61 and 103 m deep.
- oxygen injection ratio: 7.5% to 25% oxygen/water ratio.

U-Tube Pilot Study Preparations

A pilot U-tube facility was constructed with 0.1 meter diameter pipe in a 0.3 m diameter hole that was 120 m deep. The U-tube depth was adjusted as desired to evaluate the following parameters:

- depth at 12, 30, 60 and 103 m respectively
- velocity at 0 .9, 1.4 and 1.8 m per second respectively
- injected air and pure oxygen
- pure oxygen gas injection ratio 7 1/2 and 25%
- tap water and simulated wastewater with 5 mg/L of anionic detergent and 100 mg/L bentonite.

The experimental data were collected for each set of conditions according to the inlet D.O., discharge DO, pressure loss across the U-Tube and water temperature. Due to the fact that D.O. concentrations in excess of 100 mg/L were encountered, special procedures were developed to ensure accurate D.O. measurements at these unusually high concentrations.

Throughput velocity was based on the nominal velocity of the water alone without gas injection. Thus the actual velocity in the gas/water mixture would vary somewhat throughout the U-Tube because of the hydrostatic compression of the gas phase. Nominal velocities of 0.9, 1.4 and 1.8 m per second were investigated and are shown in Fig. ___ . There is a practical lower limit of nominal velocity below which the U-tube will not function in a stable manner.

It is noted from Fig. _______ that there is no consistent effect of nominal velocity on the increase in D.O. across the system. In some cases nominal velocity (1.4 m per second) gave slightly higher or lower increase in dissolved oxygen. Lower velocity increased the bubble contact time within the U-Tube as well as lowered the Reynolds number, but apparently these two effects nullified each other.

The pressure at the inlet and discharge was recorded for each set of experimental conditions. The pressure loss across the system was composed of losses due to hydraulic friction, bubble drag and differential void volume in the down and up legs. Hydraulic frictional losses are a function of the pipe diameter. The bubble drag and differential void volumes in the two legs were observed to be independent of pipe diameter.

For each set of experimental conditions pressure readings were taken before any gas was injected into the U-Tube and after the desired gas water injection ratio was established. In this manner, the two components of pressure loss across the U-Tube could be identified.

Oxygen absorption efficiency can be achieved by either of two approaches when using U-Tube technology. The O2/water ratio and the U-tube depth and velocity can be matched to result in 90% oxygen absorption efficiency in one pass through the U-tube. Or with a second approach a high O2/water ratio may be injected into a more shallow depth U-Tube shaft but must provide for capture of the bubbles in the discharge to re-inject these fugitive bubbles back into the inlet.

Low, intermediate and high O2/water ratios were investigated, namely 4, 7.5 and 25%. These results are shown in Figure 13. The dotted line in Figure 13 indicates the 90% oxygen absorption range. It can be noted from this graph that even at 103 m depth less than 90% oxygen absorption occurs with 1% O2/water ratio resulting in a change in D.O. of only 9 mg/L. In this case the increase in D.O. level and U-tube depth are impractical. Consequently the second approach is the best alternative, namely high O2/water injection ratios incorporating gas capture and recycle.

The study revealed that the optimum design of a U-tube oxygenation system operating at minimal cost incorporates a depth of 25 to 60 m, a velocity of 1.8 to 3.0 m per second, and an O2/water injection ratio of 25%.

This portion of the pilot study revealed that a substantial increase in dissolved oxygen resulted at 61 m depth in comparison to 30 m depth. However at 103 m there was little increase in D.O. across the system in comparison to the 61 m depth (see Fig. __).

Results

Fig. __ indicates that only minor variations in change in dissolved oxygen were observed over the velocity range tested. This is fortunate because the maximum nominal velocity was thus limited only by frictional head loss considerations, and therefore permitted very high tonnage of oxygen dissolved per cubic meter of U-tube. Such a high rate of dissolved oxygen offsets to a large degree the capital expenditure for the deep shaft hole.

It was not possible to achieve 90% oxygen absorption in a 103 m deep U-tube even though the injection gas ratio was less than 1%. At such low gas water ratios there would not be any effervescent loss of dissolved gas. Even lower oxygen absorption efficiencies would be observed in water containing surfactants. This observation contradicts the claim of Hemming *et al*, that all of the gas phase is dissolved in deep U-Tubes, and that some subsequently comes back out of solution in the upper region of the up leg.

Very encouraging results were noted with a particular O2/water ratio combined with the 61 m depth shaft: 96 mg/L D.O. concentrations were found in the discharge using a 25 % O2/water ratio. The estimated unit energy transfer and total costs amounted to 12 kg of D.O. per kwhr and $6.50 per ton of D.O. added. But there was little advantage found in operating as U-Tube in excess of 61 m depth.

According to the pilot study when pure oxygen was injected at 25% O2/water ratio at 30 m depth, the dissolved oxygen increased from 68 mg/L to 95 mg/L at 61 m U-Tube depth. Negligible improvement in dissolved oxygen concentrations were observed after 103 m depth.

Over the velocity range investigated of 0.9 to 1.8 m per second, there was no significant effect on increase in D.O. The maximum absorption efficiency for pure oxygen at 7.5 % O2/water injection ratio was observed to be 52% in the 103 m deep U-tube, demonstrating that the U-tube requires capture and recycle of the off gases if it is to be used in an efficient manner as the absorption system for an oxygen supplementation station.

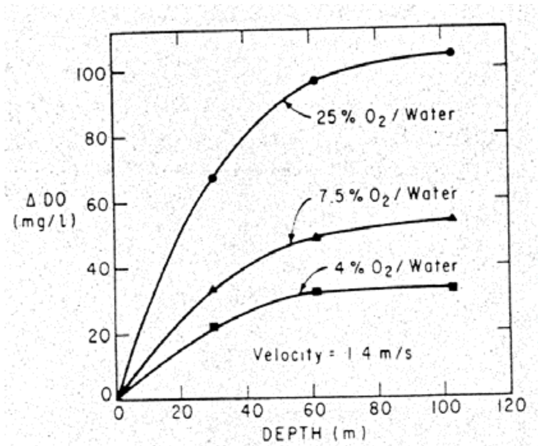


Fig. 11. ΔDO vs Depth for Oxygen Injection

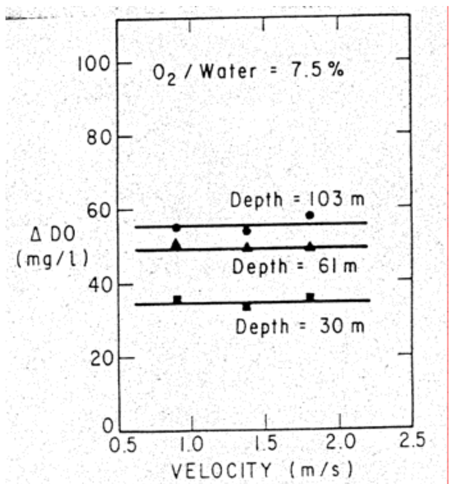


Fig. 12. Effect of Velocity on ΔDO for Oxygen Injection

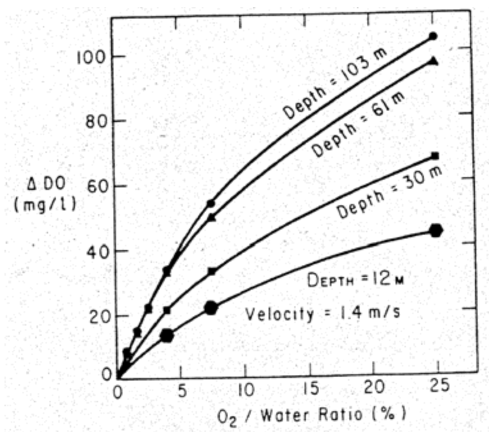


Fig. 13. Effect of O_2 / Water Ratio on ΔDO

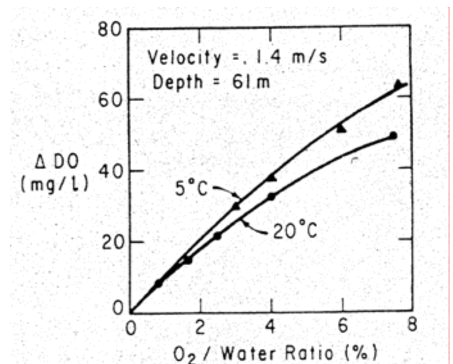


Fig. 14. Effect of Temperature on ΔDO for Oxygen Injection

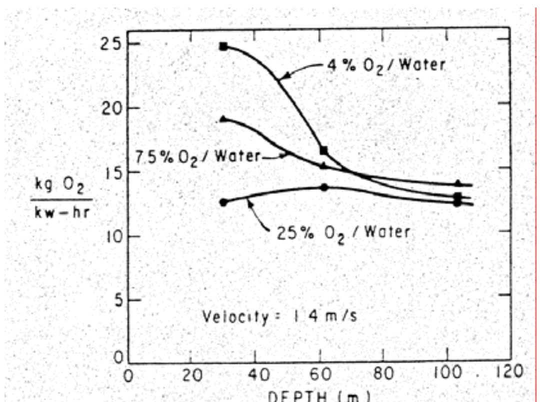


Fig 18 Oxygen Transfer Energy vs Depth - O_2

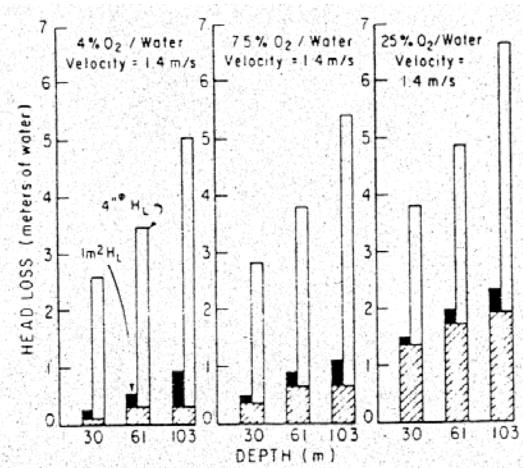


Fig 17 Headloss Breakdown into Frictional Losses and Loss Due to Oxygen Injection

An Existing U-Tube Application on the Tombigbee River, Alabama

U-Tube Oxygenation was selected for the two oxygen supplementation locations on the Tombigbee River. The U-Tube with oxygen injection produced an effluent D.O. 50 mg/L at 28° C. within oxygen absorption efficiency of 80 to 90% for a unit energy consumption of 94 kWh per ton of D.O.. The oxygenation capacity was 5400 mg/L of D.O. per U-Tube volume per hour, and the head loss across the 175 foot deep U-Tube was 5 feet. A bubble harvester is desirable to harvest any undissolved bubbles and recycle them back to the influent of the U-Tube. By discharging a highly elevated D.O. sidestream into the river through a diffuser in the bottom, advantage was taken of the hydrostatic head to prevent effervescent loss of D.O. and a high D.O. discharge was mixed throughout the river cross-section within a short distance downstream.

A schematic diagram is shown of both the gravity fed to U-Tube which puts in 12,000 pounds of D. O. per day, as well as a schematic of the U-Tube where 125 MGD of water is pumped from the river through the U-Tube and then discharged back into the river with 50 mg/L of supersaturated D. O. concentration, resulting in 40,000 lb/day supplementation.

Field testing at James River of the U-Tube, which oxygenated the treated effluent from a James River mill, yielded the following observational operational results:

- discharge D. O. of up to 50 mg/L at 25°C in the water
- head differential across the U-Tube was 5.3 ft and
- oxygen transfer capacity of up to 18,000 pounds of D. O. per day and
- oxygen absorption efficiencies of 80 to 90% were realized.

Advantages of the U-Tube Technology

Table V. The major advantages of U-Tube oxygenation, which led to its selection for remediating the Tombigbee River D.O. depletion problems, were as follows:

1. efficient oxygen absorption of 75 to 90%
2. high rate of oxygen transfer per unit volume of reactor, up to 5400 mg/L per hour, versus 100 mg/L per hour for conventional aeration tanks and
3. unit energy consumption per ton of D. O. add was approximately 100 kWh per ton of D. O., which is low because head loss across the system is low even though oxygen transfer occurs at hydrostatic pressures up to 175 feet
4. high D. O. concentrations of up to 50 mg/L at 28°C
5. exceptionally high D. O. saturation concentrations generated enabling supersaturation of D. O. in its discharge.
6. oxygen bubble contact time prolonged
7. pressurization of the oxygen gas bubbles provided by hydrostatic pressurization
8. negligible energy consumed in contrast to the excessive energy consumption of pumped pressurized vessels which lose all of the input energy across the pressure throttling valve (thus also potentially losing supersaturated D. O. concentrations by effervescence)

9. no external pumping required if the water being discharged was at 30 foot above river level
10. stripping of dissolved nitrogen gas from the water minimized
with consequent nitrogen gas dilution of the oxygen composition of the bubbles because gas transfer is occurring in a pressurized vessel (water saturated with nitrogen in air will strip if the nitrogen partial pressure in the gas phase is less than 0.79 atm.) If the process is at atmospheric pressure the nitrogen compensation approaches a theoretical value of 79%, but at four atmospheres the nitrogen composition approaches a theoretical value of only 20%.

Section 5. Mixing and Transport in Harbors

5. Mixing and Transport of D.O. within Savannah Harbor

I. Requirements for Meeting D.O. Standards for Savannah Harbor

A. Essential Requirements for Harbor Mixing and Transport

The following essential components must be successfully incorporated into an oxygenation system to meet D.O. standards throughout Savannah Harbor:

- dissolving requisite D.O. (lb D.O./day)
- transporting D.O. evenly throughout the harbor
- strategically locating oxygen supplementation stations so that tides, propellers or horizontal flow diffusers can transport superoxygenated discharges effectively
- utilizing large diameter propeller pumps or horizontal flow diffusers to transport the oxygen away from the location where it superoxygenated water is generated

B. Diffuser Design Considerations

Once the sidestream is highly oxygenated it must be reintroduced into the hypolimnion and transported throughout the entire impoundment. Such success requires special considerations in the diffuser design as follows:

- jet velocity in diffuser ports
- number of diffuser ports required
- spacing of diffuser ports
- height of diffuser above sediments
- direction of diffuser ports
- velocity of horizontal jet less than the re-suspension velocity of the sediments when reaching the bottom of the impoundment
- velocity of horizontal jet sufficiently low enough to prevent erosion of the underside of the thermocline when reaching the top of the hypolimnion

C. Horizontal Flow Design Possibilities

Velocity of horizontal jets must be sufficiently low to prevent erosion of the overlying fresh water. Such design considerations are especially critical in shallower impoundments such as Savannah Harbor. In one installation where Prof. Lawrence of the University of British Columbia provided the design of the diffuser, the impoundment was less than 30 feet deep, and the hypolimnion was only about 15 feet deep. After one season of operation, stratification was maintained, bottom sediments were not resuspended and D.O. was transported to regions of the hypolimnion that were approximately two miles away from the oxygenator diffuser.

A key consideration in supplementatal oxygenation of Savannah Harbor is to induce a superoxygenated sidestream to flow horizontally across the bottom layer ofmore dense water where D.O. is more needed than in the upper surface of the water column.

At Camanche Reservoir a diffuser was located at the toe of the dam. It dissolves 18,000 lbs of oxygen per day in a sidestream of 35 ft3/sec withdrawn from the hypolimnion and discharged through a 100 ft long diffuser. It is located near the dam in the vicinity of the bottom penstock. When the water is 100 ft deep, the sidestream that is oxygenated has a D.O. of about 100 mg/l. The diffuser discharges toward the head end of the reservoir and a D .O. increase of 4 mg/l was observed in the hypolimnion 10,000 feet from the diffuser about two weeks after operation commenced. Oxygen supplementation of the hypolimnion allowed power to be generated, prevented hydrogen sulfide production, and met the D.O. criteria for the river and fish hatchery. This system is hidden from public view at the bottom of the reservoir, another strong recommendation.

II. Spacing of Oxygenation Stations for Maximum Mixing and Transport within the Harbor

A. Limitations on Zones of D.O. Supplementation Influence

There is an economy of scale associated with oxygen supplementation stations which favors the utilization of fewer and larger stations. This likewise is reflected in greater distances between oxygenation stations. Since a key consideration in any supplemental oxygenation system is that the superoxygenated water must be transferred away from the location where it is being superoxygenated, this places certain limitations on the spacing of the supplemental oxygenation systems. Transport of the superoxygenated water away from the superoxygenation station can be accomplished by:

- tidal action
- discharge jets
- large diameter slow-moving propellers

Thus, there are certain limitations on the zone of influence for oxygen supplementation from a given fixed location. If there is negligible tidal action and if there is not the availability of large diameter, slow-moving propeller pumps to move the water away from the fixed location, then there will be a limitation on the distance between supplemental oxygenation stations. Also there may be certain regions within the harbor that have very little tidal action mixing or are shielded by peninsulas of land or other such obstructions which prevent the movement of superoxygenated water into that area.

Such isolated zones will require special attention to theincorporation of large diameter propellers or location of oxygenation stations in that particular zone. This may be accomplished by mobile systems as described below.

B. Effective Circulation of Oxygenated Discharges Throughout the Harbor

In addition to the mixing/transport accomplished by tidal action, it may be necessary to incorporate additional mixing/transport mechanisms to move the superoxygenated water away from the location of the oxygenation station. Unless the superoxygenated water is moved away, eventually a ‘hot spot’ of highly oxygenated water will short circuit back through the oxygenation station reducing the efficiency of O2 absorption.

There are various means which can insure that the requisite transport/mixing is accomplished. The large diameter slow moving propellers are very efficient in moving large quantities of water with little energy required. Following are pictures of two types of these devices. In both cases, a screen enclosure is required to preclude harm to swimmers. The results of hydrodynamic modeling of the plumes indicates that the momentum imparted by the propellers can move the water over two miles away from the source. The graphs of such models are shown below.

Properly designed diffusers can also insure that the oxygenated water moves out of the zone where it was produced. Following is also a schematic view of a diffuser designed to insure that the oxygenated water is added at various depths throughout the water column if needed. If it is desirable to place the superoxygenated water in the bottom layer, then only the lowest diffuser would be employed.

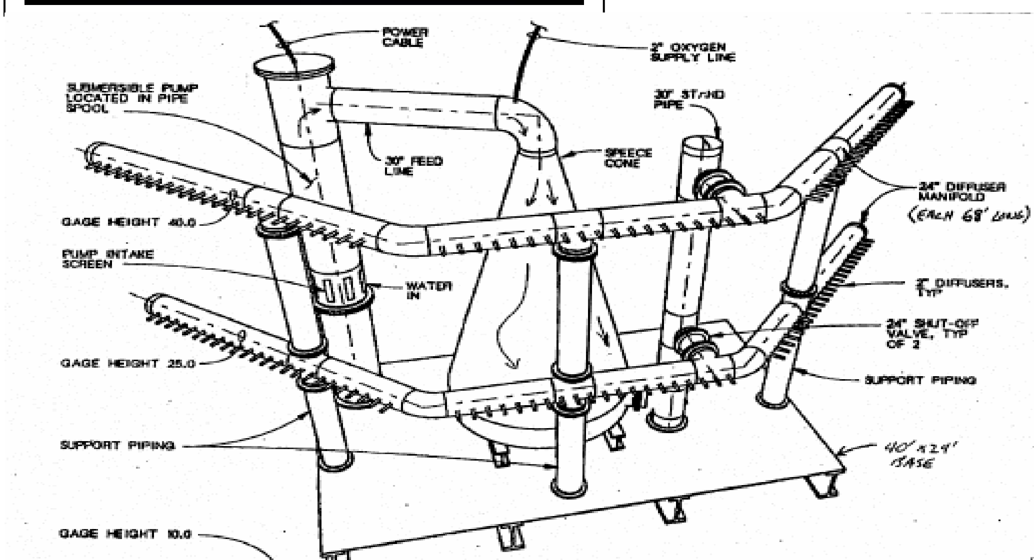


FIGURE - 1

STANDLEY LAKE - SPEECE CONE SYSTEM ISOMETRIC

Figure 1. Cross-reservoir velocity profiles

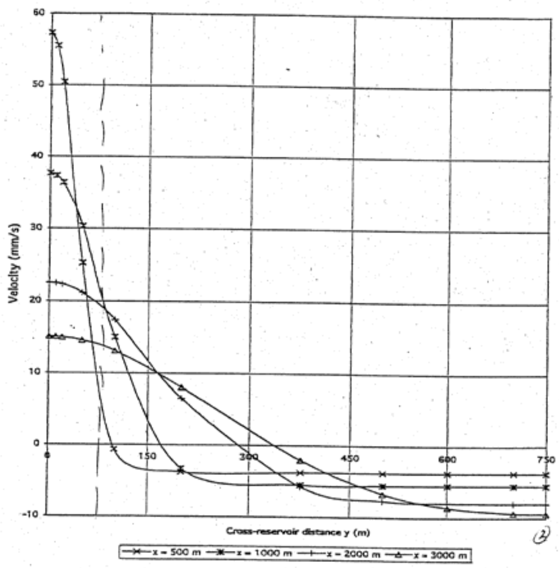
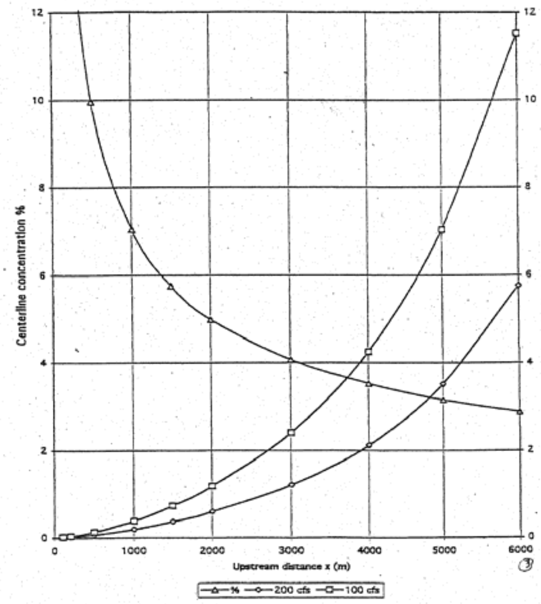
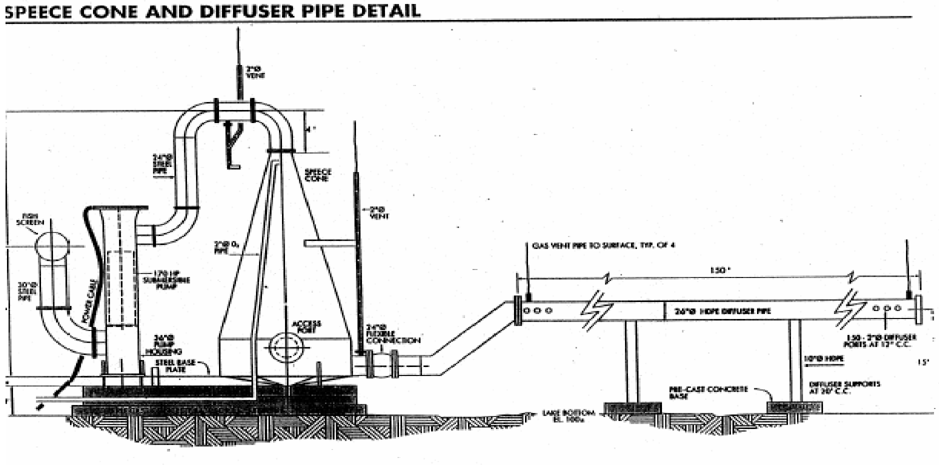


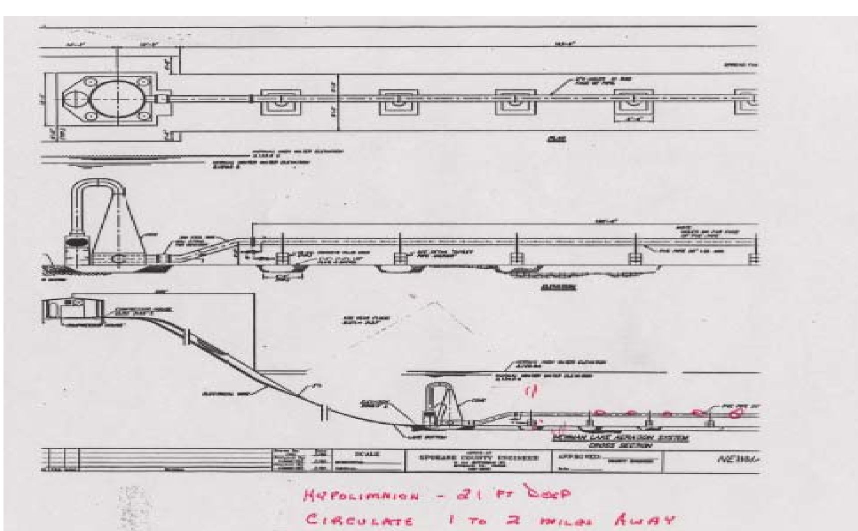
Figure 2. Travel times and dilutions



CAMANCHE HYPOLIMNETIC OXYGENATION DEMONSTRATION PROJECT
SPEECE CONE AND DIFFUSER PIPE DETAIL



DETAIL
(not to scale)



III. Mobile Barge Oxygenation Advances

A. Advantages of Self-Contained Mobile Oxygenation Barges

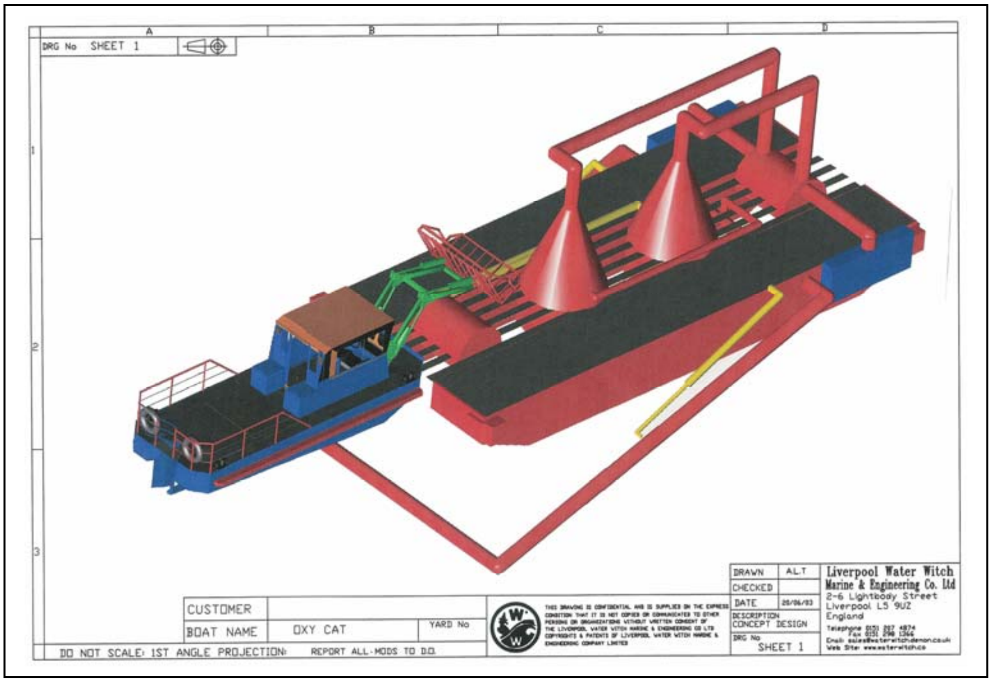
A key consideration in supplementing oxygen to the harbor will be the availability of land at key locations dictated by D.O. deficiency conditions within the harbor, upon which the oxygenation system could be placed. The availability of electricity is another consideration. Generally it is quite expensive to bring in electricity and the demand charge component of the cost can considerable. So these two facets, the availability of the real estate in the vicinity of the place where the oxygen is needed and the availability of electricity brought to that location will be significant economic factors.

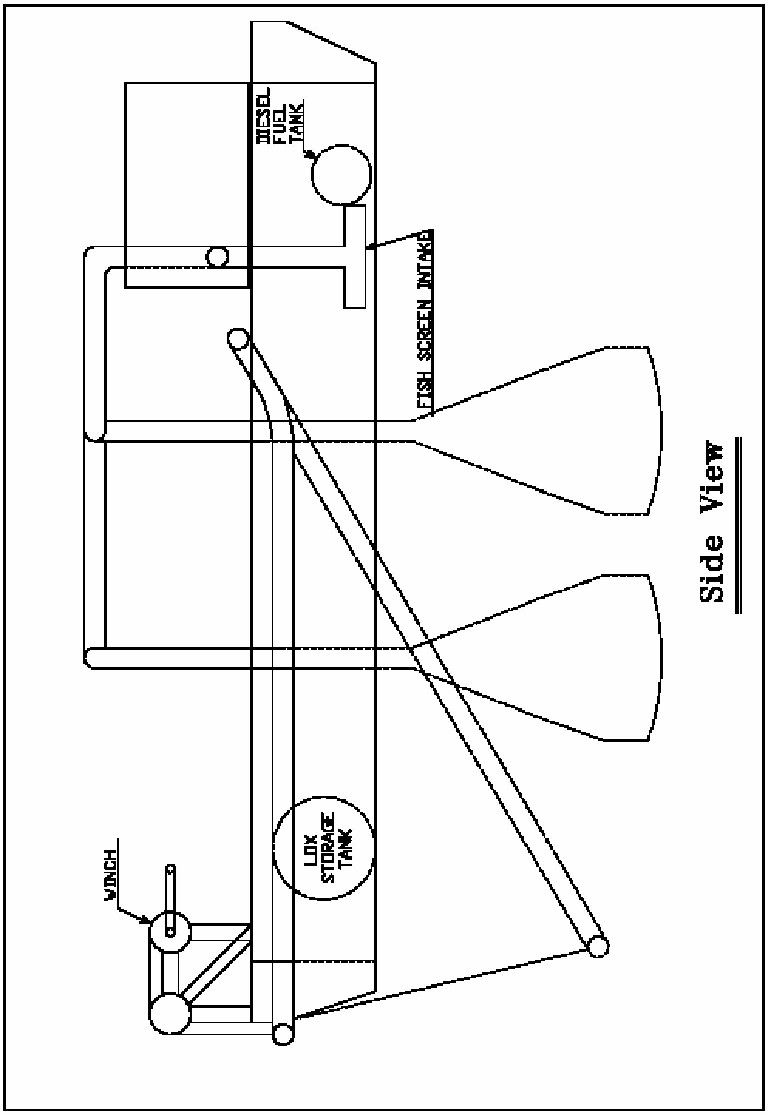
Mobile oxygenation barge systems such as are used in the Thames River, Shanghai Harbor and Cardiff Bay would be a practical choice for use in Savannah Harbor since a barge mounted unit would supplement the oxygen directly into the harbor. Such barge units hold a unique advantage in that they can either be tied up permanently at a given location or moved to various oxygen depleted locations within the harbor, without requiring land use.

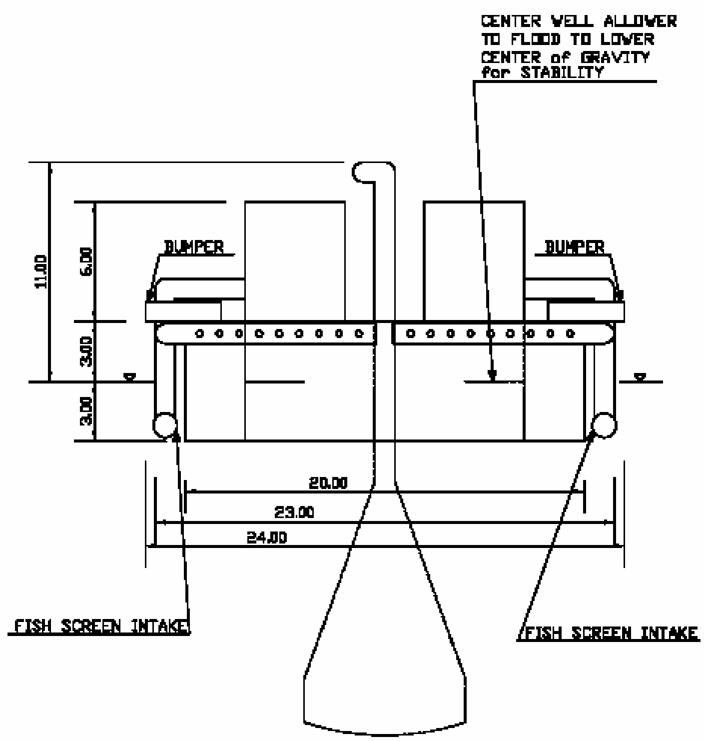
This type of unit can be self-contained with its own PSA oxygen generation source, which could be driven by an internal combustion engine that requires no electrical power being brought in. The pumps required to move water through the oxygen transfer vessel can also be powered by combustion engine driven pumps. Another alternative is to utilize an engine driven electrical generator to power the PSA generation system as well as the pumps supplying the oxygen absorption reactors. Thus the barge units would only need to be supplied with diesel fuel. In some cases, propane driven pumps have been used to anticipate the possibility of a spill in the harbor. Propane with its volatile nature would not present a pollution problem if spilled into the harbor such as diesel fuel would.

Thus in the overall strategy for meeting the dissolved oxygen standard for Savannah Harbor, it may be appropriate to consider the provision of one or more mobile oxygenation units which are self contained except for the need of periodic fuel delivery. These mobile oxygenation units would be moved to areas which were not readily impacted by fixed location supplemental oxygenation stations.

The mobile oxygenation system would operate with the oxygen absorption reactors lowered to the bottom of the harbor to take advantage of the hydrostatic head enhancement of oxygen transfer and would be raised during transport. Schematics of a proposed mobile oxygenation station are shown below.


DRG No SHEET 1
DRAWN A.L.T
CHECKED
DATE 20/06/03
DESCRIPTION CONCEPT DESIGN
DRG No SHEET 1
Liverpool Water Witch Marine & Engineering Co. Ltd
2-6 Lightbody Street
Liverpool L5 9UZ
England
CUSTOMER
BOAT NAME OXY CAT
YARD No
DO NOT SCALE: 1ST ANGLE PROJECTION: REPORT ALL-MODS TO D.O.


DIESEL FUEL TANK
FISH SCREEN INTAKE
WINCH
LOX STORAGE TANK
Side View


CENTER WELL ALLOWER
TO FLOOD TO LOWER
CENTER of GRAVITY
for STABILITY
BUMPER
BUMPER
11.00
6.00
3.00
3.00
20.00
23.00
24.00
FISH SCREEN INTAKE
FISH SCREEN INTAKE

End View

B. Thames River Oxygenation Barges

One large world class ship channel area which employs a mobile oxygenation system is the busy Thames River in London with its “Thames Bubbler and “Thames Vitalizer” self-contained barges.

Historically the Thames River has had occasional oxygen deficiencies. These dissolved oxygen deficiencies have been related to combined sewer overflows resulting from storm events. They are further exacerbated by residual organic loads in the treated effluents being discharged into the river. In an attempt to comply with the dissolved oxygen standard in the Thames River, a mobile oxygenation system that has been dubbed the “Thames Bubbler” was constructed. This system is a motorized barge that contains a 40 ton per day, PSA oxygen generation unit. Thus the oxygen is generated on site and the oxygen transfer system incorporates a series of Venturi jets extending from the barge unit itself. Whenever a section of the Thames River has dissolved oxygen concentrations below the targeted standard, the mobile oxygenation unit is transported to that stretch of the river, where it supplements the oxygen until it meets the targeted D.O. Water is withdrawn from the river and pumped at high pressure and velocity through the venturi jets which aspirate high purity oxygen into the throat of the venturi. The same performance characteristics would apply to these venturi oxygen transfer units, as are described above for evaluation:

- the unit energy consumption per ton of dissolved oxygen
- the relative oxygen absorption efficiency
- the level of super oxygenation, which can be achieved in the discharge

C. Example of Bay Mobile Oxygenation: Cardiff Bay, England

A dam has been constructed across the mouth of Cardiff Bay in England to segregate tidal action from the Bay, thereby eliminating the exposed mud flats at low tide within the Bay which cause malodorous conditions during low tide. In order to comply with D. O. standards within the estuary inside the impounded area, a series of air diffusers was placed on the bottom of the bay. Air was injected into these diffusers in order to mix the water column, as well as provide some oxygen transfer.

Because D.O. deficient conditions occur within the impoundment in the bottom waters in some areas, it was decided to provide a mobile oxygenation system unit, which could be transported to those areas and inject super oxygenated water into the prescribed vertical elevation a wedge of water. An oxygen transfer device was constructed and placed upon a barge, which is moved to any area within the Bay to satisfy the D.O. deficit in a particular layer of water in any region of the bay.

IV. Horizontal Placement of Superoxygenated Discharge in the Water Column

A. Advantages of Horizontal Placement of Superoxygenated Side Stream

Because the anaerobic sediment /water interface is the key location for bottom dwelling organisms and adverse water quality transformations, it follows that any remedial D.O. supplementation scheme should focus on maintaining this interface as oxic as possible to prevent the above mentioned water quality degradation

Superoxygenation of the harbor sediment interface using properly designed equipment is reported to be more beneficial than simply oxygenating the water column near the surface. Such an oxygenation alternative has emerged only recently. This important type of superoxygenation system successfully incorporates the following features:

- the salinity stratification is maintained intact and in place
- highly efficient oxygen absorption must be attained
- oxygen transfer turbulence is contained within the oxygen transfer reactor and is thus minimized to p
- revent destratification
- effective placement is achieved
- benign environmental impact is sustained

The relatively high concentration of microorganisms at the sediment/water interface, compared to their concentration in the water column, results in this zone dominating water quality transformations such as iron and manganese reduction and hydrogen sulfide production.

B. Difficulties of Free Rise Bubble Plume Systems in Sediment Oxygenation of the Water Column

A classic mode of D.O. supplementation is to inject air or oxygen into a diffuser located near the bottom. The buoyant nature of the bubble causes it to rise vertically and thus to impart a vertical movement of the water in the vicinity of the bubbles column. Eventually near the thermocline, the rising bubbles uncouple from the rising water column when the circulation pattern is weak and unable to overcome the water density differential.

If the vertical rise velocity of the water entrained in the bubble plume is sufficiently high, both the bubbles and water rise all the way to the water surface, at which point the water velocity turns horizontally and eventually downward to replace the water moving vertically within the bubble plume.

As shown in Fig. ___ the net result of cooler water mixing with warmer water higher in the bubble plume is that the cold water initially entrained in the bubble plume does not return all the way down to the sediment interface from which it originated, but comes to equilibrium at an elevation some distance above the sediment/water interface. Unfortunately free rising air or oxygen bubble injection within the hypolimnion does not affect the sediment water interface because the internal circulation "cells" within the lake caused by vertically induced currents are confined to the higher elevations above the sediments. This problem is pictured schematically in Fig. ___.

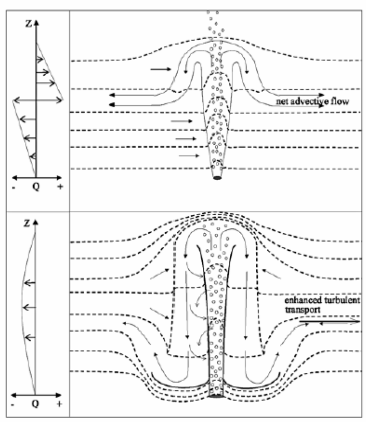
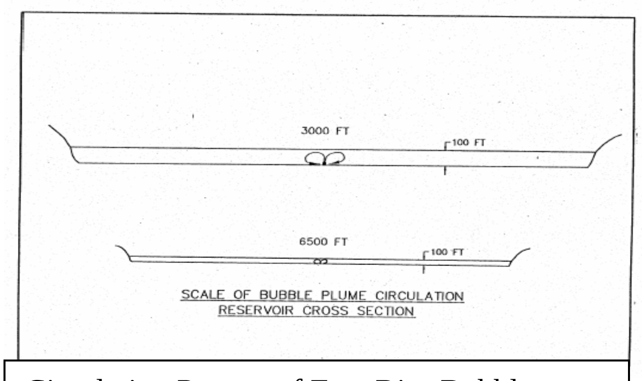


Figure 11. (top) Traditional plume model approach and (bottom) new model concept of plume behavior and short-circuiting in deep lakes (not to scale). Dashed line indicates constant temperature isopleths demonstrating near-field alteration. Left axis shows approximate far-field vertical compensation flow rate distribution (see Figure 12).



Circulation Pattern of Free Rise Bubbles

C. Salt Wedge Flow Oxygenation

If the salt wedge flows into Savannah Harbor are of significant importance then supplementation of D.O. at the mouth of the harbor would transport some of the D.O. into the harbor within the salt wedge tidal action. A superoxygenation station being fed salt water at the mouth of the harbor would exploit this type of circulation possibility.

V. Conclusions

The unique configuration characteristics and use requirements of a moderately deep harbor require sufficient oxygenation circulation to reach locally depleted ares as well as sediment layers without disturbing the sediments with their large oxygen demand or impeding ship channel traffic to maintain adequate D.O. levels throughout.

Innovative new technology which makes possible horizontal flow circulation for significant distances away from the superoxygenated discharge thus enlarging the zones of influence considerably, is an advance with much promise for meeting Savannah Harbor’s mixing and transport requirements.

In addition mobile barge self-contained oxygenation units, already installed successfully in Shanghai Harbor, Cardiff Bay and on the Thames River make possible timely intervention not hindered by stationary placement in the ship channel.

Section 6. Recommendations for Savannah Harbor Supplemental Oxygenation.

Criteria for Choice of Oxygenators

In evaluating D.O. supplementation technology, the following considerations must be critically addressed:

- O_2 absorption efficiency
- unit energy consumption per ton of D.O. added
- D.O. concentration in side stream discharge
- capital cost of oxygenation system
- depth of water column
- location in water column where D.O. is needed
- target D.O. in harbor
- mixing requirements
- required spacing of D.O. supplementation stations
- placement outside the shipping channel
- availability of real estate
- availability of electricity

Life Cycle Cost Components

Appropriate technology for supplementation of pure oxygen is determined by the following three life cycle factors:

- present worth of the equipment – (purchase or rental)
- present worth of total oxygen required (therefore oxygen absorption efficiency becomes important)
- present worth of energy consumption per ton D.O. supplemented.

Life Cycle Cost of Speece Cone - $8,500,000

The Speece Cone oxygenation reactor and pump are estimated to be $85,000 per ton D.O. per day of capacity or **$8,500,000** for a 100 ton D.O./day system.

Calculation of Life Cycle of O_2

Assume that:

- 100 tons/day of D.O. must be supplemented to the Harbor.
- oxygen is generated on-site by PSA units which cost $65,000 per each ton/day capacity and require 600 kwhr/ton of oxygen produced
- 50% utilization of the system per year
- $0.12/kwhr (diesel generated)
- 6% and 15 year life of the project.

Life Cycle Cost of On-Site Generation of Oxygen - $19,000,000

Since the oxygen cost is commonly the major economic component in the life cycle cost for supplemental oxygenation of rivers and harbors, this requires special consideration to select oxygen transfer devices which achieve high oxygen absorption efficiencies. A second aspect is that if the oxygen supplementation system is a mobile system with its own PSA oxygen generator, reduced oxygen absorption efficiencies are reflected in the need for greater oxygen generation capacity to account for the oxygen not absorbed. The Venturi aspirator oxygen absorption system incorporated on the Thames Bubbler is estimated to be about 65% efficient in its absorption of oxygen. Thus the required PSA oxygen generation unit must be 50% larger requiring 50% more power than if the system was 100% efficient in its oxygen absorption system.

The capital cost would be $6,500,000 for 100 ton/day PSA oxygen generation capacity. The energy consumption would be 60,000 kwhr/day for an equivalent cost of $7,200/day. Yearly amortization would be $6,500,000 x 0.1 = $650,000/y. Yearly energy cost would be 600 kwhr/ton x 100 ton/day x $0.12/kwhr x 180 day/y = $1,300,000/year. So the total yearly cost for generation of oxygen would be $1,950,000/year for 18,000 tons oxygen per year or $110/ton of oxygen produced.

The life cycle present worth of $1,950,000/year for O2 at 6% and 15 years (9.7) = **$19,000,000** for 100 ton D.O/day.

Implications of O2 Absorption Efficiency on Life Cycle Costs

The implications of oxygen absorption efficiency on life cycle costs are as follows for a 100 ton/day usage for 180 days per year for $110/ton O2 for 6% @ 15 yrs:

O2 Absorp. %	Ton O2/day Needed	Ton O2/day wasted	O2 wasted ton/yr	Present Worth $ of O2 **not** absorbed
100	100	0	0	0
90	110	10	1,800	1,900,000
80	125	25	4,500	4,800,000
70	145	45	8,100	8,600,000
60	165	65	11,700	12,500,000
50	200	100	18,000	19,200,000

This table indicates that O2 absorption efficiency has a considerable impact on life cycle costs of this project. Therefore selection of the oxygen transfer process is heavily weighted by its inherent absorption efficiency. Low O2 absorption processes will probably be cheaper than efficient ones on a capital cost basis, but will incur proportionately greater life cycle costs as the above table indicates.

Life Cycle Cost of Energy - $4,200,000

For a 100 ton D.O/day system that had a unit energy consumption of 200 kwhr/ton D.O. the daily energy consumption would be 20,000 kwhr/day for 180 days per year and 6% for 15 years (9.7). If the cost of diesel generated electricity is $0.12/kwhr then the daily cost would be $2400/day for 180 days/year = $430,000 /year multiplied by 9.7 SPWF = **$4,200,000.**

Off Channel Oxygenation Systems

The following generic oxygen transfer systems qualify for off channel use to supplement D.O. to Savannah Harbor:

Venturi
Pressurized Side Stream
U-Tube
Speece Cone

Comparison of U-Tube and Speece Cone

Of the four systems above, only the U-Tube and Speece Cone meet the economic criteria. Both the U-Tube and Speece Cone have comparable:

- O2 absorption efficiency - >80 to 90%
- Unit energy consumption per ton D.O. – 200 to 300 kwhr/ton D.O.
- Level of superoxygenation in discharge – 50 to 60 mg/L

Capital cost per ton D.O./day will be a deciding factor.

ADVANTAGES OF THE U TUBE TECHNOLOGY

The advantages of U-Tube oxygenation, which led to its selection for the Tombigbee River, were as follows:

- oxygen transfer occurs in a pressurized vessel
- high D. O. concentrations of up to 50 mg/L at 28°C
- high rate of oxygen transfer per unit volume of reactor, up to 5400 mg/L per hour, versus 100 mg/L per hour for conventional aeration tanks and
- efficient oxygen absorption of 80 to 90%
- unit energy consumption per ton of D. O. add was approximately 200 kWh per ton of D. O., which is low because head loss across the system is low even though oxygen transfer occurs at hydrostatic pressures up to 175 feet
- U-Tube prolongs the oxygen bubble contact time
- generates exceptionally high D. O. saturation concentrations, enabling supersaturation of D. O. in its discharge.

- provides pressurization of the oxygen gas bubbles by hydrostatic pressurization
- consumes negligible energy in contrast with the excessive energy consumption of pumped pressurized vessels which lose all of the input energy across the pressure throttling valve thus also potentially losing supersaturated D. O. concentrations by effervescence.
- requires no external pumping where the water being discharged is at 30 foot above river level
- minimizes stripping of dissolved nitrogen gas from the water with consequent nitrogen gas dilution of the oxygen composition of the bubbles because gas transfer is occurring in a pressurized vessel.

The U-Tube requires a caisson which is 175 ft deep and requires a bubble harvester to capture undissolved bubbles in the discharge for recycle back into the down leg. This is required to achieve the required O2 absorption efficiency.

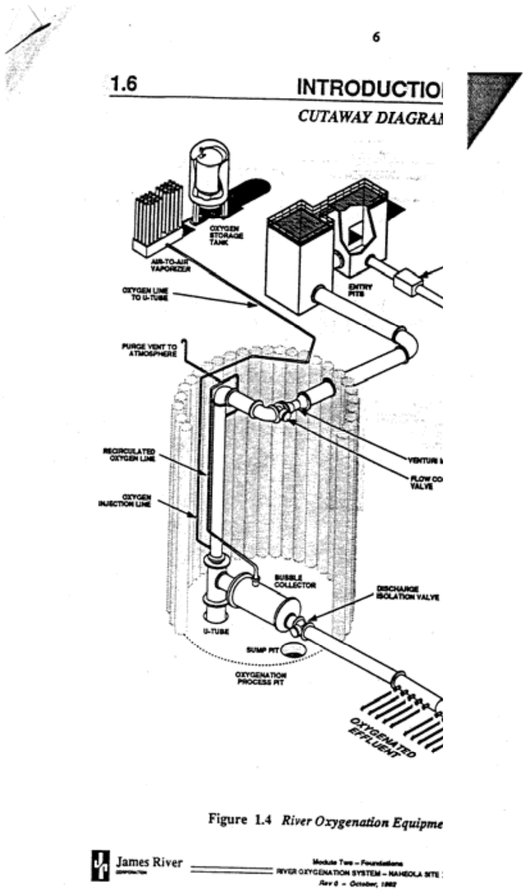
The Tombigbee River U-Tubes cost $10,000,000 for the entire project which included a 35 MGD gravity flow unit and a 125 MGD pumped flow unit. These two units transferred a combined total of 56,000 lb D.O./day. They were placed in a concrete caisson whose top exceeded the 100 year flood level and a diffuser was placed in the bottom of the river to disperse the superoxygenated discharge. I do not have accurate information on the cost of just installing the U-Tubes and their associated bubble harvesters. If it was half of the $10,000,000 total that would be $5,000,000 for 28 ton D.O. per day or $180,000 per ton D.O. per day of capacity. Unfortunately this specific cost information is not available.

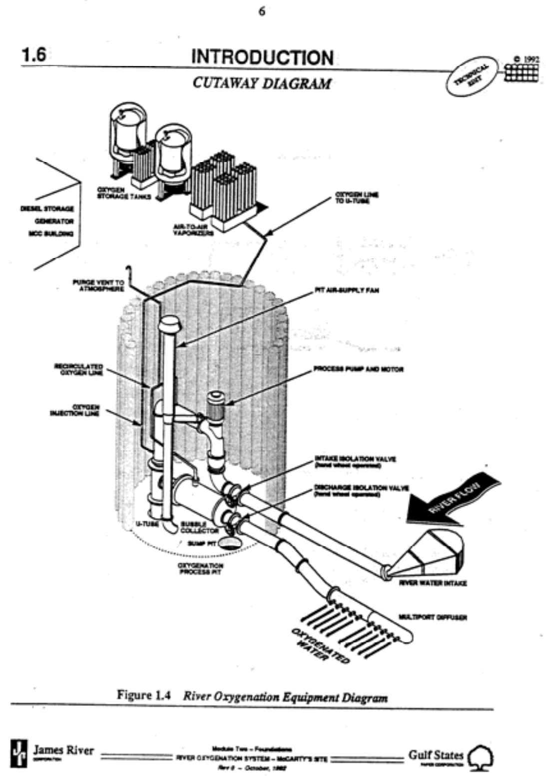
For the pumped unit having 125 MGD flow a 10 ft diameter casing was excavated to a depth of 100 ft. and the lower 75 ft had an 8 ft diameter casing. Inside this casing a 7 ft diameter pipe served as the outer wall of the U-Tube and a 5.5 ft diameter pipe inside the 7 ft diameter wall served as the downcomer pipe. A 350 HP pump pulled water from the river and moved it through the U-Tube. The 35 MGD U-Tube was proportionately smaller.

A schematic diagram is shown of both the gravity fed to U-Tube which puts in 12,000 pounds of D. O. per day, as well as a schematic of the U-Tube where 125 MGD of water is pumped from the river through the U-Tube and then discharged back into the river with 50 mg/L of supersaturated D. O. concentration, resulting in 40,000 lb/day supplementation.

Field testing at James River of the U-Tube, which oxygenated the treated effluent from a James River mill, yielded the following observational operational results:

- discharge D. O. of up to 50 mg/L at 25°C in the water
- head differential across the U-Tube was 5.3 ft and
- oxygen transfer capacity of up to 16,000 pounds of D. O. per day and
- oxygen absorption efficiencies of 80 to 90% were realized.





Advantages of the Speece Cone.

For application of the Speece Cone for supplemental oxygenation of Savannah Harbor, a main advantage is that no excavation costs would be required because the 50 ft depth of the harbor can be utilized.

The Speece Cone incorporates efficient oxygen absorption with low unit energy consumption per ton of D.O. discharged and achieves highly superoxygenated discharge levels. The Speece Cone can achieve O2 absorption efficiencies in excess of 90% while producing D.O. concentrations of 50 mg/L at unit energy consumption rates of <200 kwhr/ton D.O. if placed on the bottom of a 50 ft deep impoundment or harbor.

This device incorporates an inverted conical gas transfer vessel in which the water is introduced at the top of the cone, flowing in a downward direction. As the water flows downward its velocity decreases in proportion to the cross-section of the cone. Pure O2 is also injected into the cone and the resulting hydraulic turbulence creates a bubble swarm which has an exceptionally high oxygen/water interfacial area, which greatly enhances oxygen transfer.

By sizing the cross sectional area of the cone so that the downward velocity of the water slows to a point where it is less than the buoyant velocity of the bubbles within the cone, it is possible to retain the oxygen bubbles within the cone for prolonged periods of time, far in excess of the 100 seconds required for efficient oxygen absorption.

The pressure differential across the cone is rather small being primarily in proportion to the void volume of the bubble swarm within the cone. Thus the unit energy required to pump water through the bubble swarm is relatively small, and therefore the unit energy per ton of D. O. dissolved is also relatively small.

The concentration of D. O. that can be produced in the discharge is related to be depth of submergence or the hydrostatic pressure within the cone. Pressure enhances the oxygen transfer process. The deeper the cone is placed below the surface of the harbor, the higher the dissolved oxygen concentration produced in the discharge. Although the discharge D.O. increases in proportion to depth of submergence, the required pumping energy remains essentially constant, resulting in lower unit energy Kwhr/ton vs depth.

The cone discharges the highly superoxygenated sidestream back into the harbor in a horizontal direction through a diffuser with 2 inch diameter ports at port velocities of 10 to 20 ft/sec. An outstanding feature is that the equipment can be located outside of the shipping channel by directing its superoxygenated discharge perpendicularly across the ship channel.

In summary, a 12 feet diameter Speece Cone 15 ft tall placed 50 ft below the water surface will give the following results

- 60 mg/L discharge D.O.
- 34 cfs cone flow
- 12,000 lb D.O. per day dissolved
- 45 HP pump utilized
- >90% oxygen absorption achieved
- <200 kwhr/ton D.O. consumed depending on depth
- cost of units -$85,000/ton D.O./day ($500,000 per 12 ft diameter unit with pump)

The excellent results of this system (>90% O2 absorption efficiency) and low unit energy consumption (<200 kwhr/ton D.O. produced) occur in part because turbulence is confined to the inside of the cone with no bottom scouring. These

outstanding results are achieved without interfering with ship channel activity.

Self-Contained Mobile or Stationary Oxygenation Barge.

It is recommended that all municipal and industrial effluents be equipped with superoxygenation systems capable of adding D.O. concentrations equivalent to their effluent BOD_L concentration so that no D.O. resources from the harbor are consumed.

For supplying the oxygen demand of decaying vegetation, self contained barge mounted systems capable of supplementing 48,000 lb D.O./day to the harbor are recommended. Each unit would be comprised of 4 – 12 ft diameter Speece Cones each driven by a 45 HP pump. These oxygen transfer reactors would be suspended as far below the barge as possible to capitalize on the increased hydrostatic head. The D.O. in the discharge will be about 60 mg/L. This superoxygenated discharge can be placed near the bottom of the water column where it is needed most. The option is there to place it at any elevation in the water column. This will be rapidly diluted in the discharge diffusers which will be designed so that the discharge velocity and elevation above the sediments do not unduly disturb them resulting in exacerbation of the D.O. demand.

However with the intense turbulence generated by the propeller wake of numerous ships traversing the harbor, it would appear that the sediment/water interface is already continuously perturbed making the relatively minor turbulence caused by the oxygenated side stream a moot point by comparison. These oxygen supplementation systems could be permanently anchored any place within the harbor or be moved to any location within the harbor as needed. The most likely scenario is that some would be permanently anchored at a pier along the harbor where tidal action would be primarily used to move the oxygenated water away

A key consideration in supplementing oxygen to the harbor will be the availability of land at key locations defined by D.O. deficiency conditions within the harbor, upon which the oxygenation system could be placed. The availability of electricity is another consideration. Generally it is quite expensive to bring in electricity. So these two facets, the availability of the real estate in the vicinity of the place where the oxygen is needed and the availability of electricity brought to that location will be significant economic factors.

As has been done on the Thames River and the Shanghai Harbor mobile oxygenation systems, one possibility for Savannah Harbor would be construction of a barge mounted unit that would be able to supplement oxygen directly to the harbor. The advantage of a barge mounted unit, is that it does not require any real estate along the harbor. Another advantage is that it can either be tied up permanently at some location along the ship channel or it could be moved to various points as needed in the harbor where oxygen is deficient. This unit can be self-contained, with its own PSA oxygen generation source, which could be driven by an internal combustion engine that requires no electrical power be brought in. Furthermore, the pumps required to move water through the oxygen transfer vessel can be powered by combustion engine driven pumps. Thus, the barge units would only need to be supplied with diesel fuel. In some cases, propane driven pumps have been used to anticipate the possibility of a spill in the harbor. Propane with its volatile nature would not present a pollution problem if spilled into the harbor such as diesel fuel would.

Mobile Oxygenation Barge

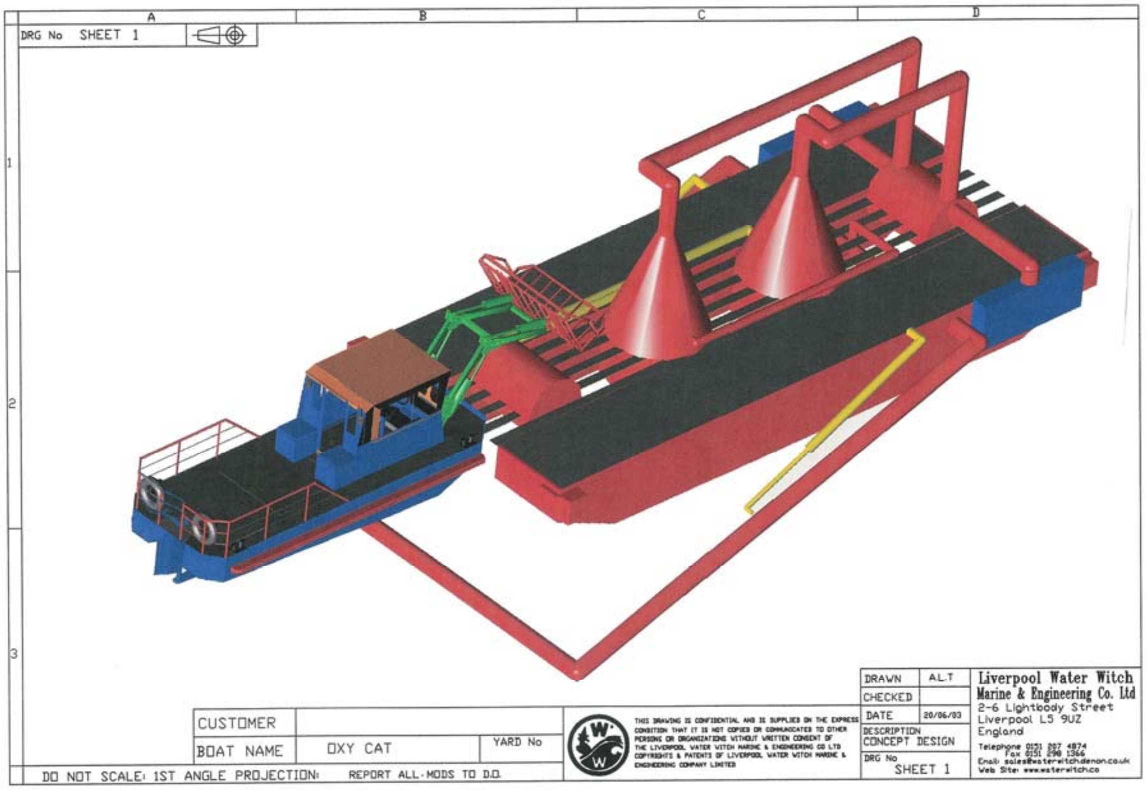
Mixing and transporting of the super oxygenated water within the harbor are key goals which must be achieved in a successful D.O. supplementation project. Oscillating tidal currents will be one of the main mechanisms which can be capitalized upon for movement of superoxygenated side streams away from the zone where they are generated. However a hydraulic model of water movement within the harbor would probably indicate some locations which will not have adequate transport of supplemented D.O. so as to meet compliance. Furthermore these D.O. deficient regions may change with flow and temperature conditions.

In such cases a logical solution would be to incorporate a means to deliver D.O. directly to the locations which are out of compliance. The concept of a self contained mobile oxygenation system could be used to address such deficiencies in tidal mixing effectiveness for effective transport of D.O. to all regions where needed.

A self-contained mobile oxygenation system would include on-board oxygen generation by pulsed swing adsorption or vacuum swing adsorption. This feature would avoid the safety concern of needing to store oxygen. Diesel or propane driven engines could either directly drive the oxygen generation system and pumps to move water through the oxygen transfer system or could generate electricity on board to power such components.

It would be advantageous to capitalize on the hydrostatic depth of the harbor for enhancement of oxygen transfer by placing the oxygen transfer reactor as far below the surface as possible. Of course there may be regions outside the main deep ship channel where the depths are much less deep that may require the aid of a mobile oxygen supplementation system.

The following Figures show schematics of a mobile oxygenation system. It would be capable of withdrawing denser water from the bottom of the water column, superoxygenating it and discharging it horizontally back at the same depth by means of an adjustable discharge boom. Sound insulation for the diesel could mitigate the noise pollution arising there from.



Placement of oxygen within the water column by a variable depth discharge diffuser system.

Recommendation

Speece Cone superoxygenation technology is recommended for remediation of the D.O. resources in Savannah Harbor based on cost, superoxygenation level, flexibility and mobility.

APPENDIX E

TECHNOLOGY CONFIGURATIONS

QUOTATION

Date:	April 6, 2005
To:	Tanya Kinnard
Company:	Mactec Engineering & Associates
Project:	10 Mile Pipeline – 80,000 lbs/day BOD Loading

Thank you for your interest in Mazzei® Injectors. The following items are quoted per your request. Quoted prices are valid for ninety (90) days. If you have not ordered from us before, or if your shipping address has changed, please provide a complete ship to address, including a local contact and phone number.

Item	List Price	Quantity	Total
Model 12050 Stainless Steel Injector	$13,744.00	22	$ 302,368.00
Model N100 Stainless Steel Nozzle*	$2,250.00	44	$ 99,000.00
TOTAL			$ 401,368.00

* Due to changing fabrication and material costs, final price may vary from quoted price.

Mazzei Injector Corporation
Mass Transfer Multiplier (MTM) Nozzle Sizing

Prepared For:	**MacTec**
Project:	**Pipeline Aeration**
Purpose For Aeration:	**BOD Reduction**
Date:	**3/15/2005**

	Units	Value	Comments
Injector Specification			
Mazzei Injector Model	Model #	12050	
Injector Inlet Pressure	PSI	15	
Injector Flow Rate	GPM	2525	
Operating Conditions			
Gas Injection Rate	SCFM	33	
Design Back Pressure	PSI	1	
Pipeline Pressure, ft H2O	Feet	5	Assuming Pipeline is not pressurized
Mass Transfer Multiplier (MTM) Nozzle Specification			
MTM Nozzle Model	Model #	100	Special Fabricated Nozzle
Number of MTM Nozzles	#	2	
Calculated Nozzle Operating Conditions			
Calculated Exit Velocity	ft/s	18.8	
Calculated Back Pressure	PSI	2.2	
Estimated Piping Head Loss	PSI	2.0	
Total Injector Outlet Pressure	PSI	6.4	
Thrust Per Nozzle	Pounds	102.4	

Dissolved Gas Equilibrium Concentration

Prepared For:	MacTec
Project:	Pipeline Aeration
Purpose For Aeration:	BOD Reduction
Date:	3/15/2005

Operating Parameters

		Pressure PSIG	Temperature Centigrade	Gas Volume SCFM	Equilibrium Volume,GPM	Gas Phase H2O Vol %
Inlet PSI	**15**					
Injector GPM	**2525**					
Pump Efficiency, %	**70**					
Equilibrium Ratio	**16.5**	**1**	**20**	**33**	**41662.5**	**2.35**

		Starting		Equilibrium		
Subject Gas	Henry's Constant	Dissolved Conc. mg/l	Gas Phase Vol %	Percent Water Phase	Dissolved Conc. mg/l	Percent Gas Phase
Oxygen	**38000**	**2**	**99**	**94.0**	**9.34**	**6.0**
Nitrogen	**84506**	**15**	**1**	**87.6**	**13.2**	**12.4**
CO2	**1360**	**81**	**0**	**99.8**	**80.82**	**0.2**
Argon	**38000**	**0.5**	**0**	**94.0**	**0.5**	**6.0**
			100			

Oxygen Transferred Into Solution, Pounds/hour	**153.06**
Oxygen Transferred Into Solution, Percent	**91.59**
Power Consumption, Water Horsepower, WHP	**22.09**
Transfer Efficiency, #'s O2/WHPhr	**6.93**
Power Consumption, Brake Horsepower, BHP	**31.56**
Transfer Efficiency, #'s O2/BHPhr	**4.85**

500 Rooster Dr Bakersfield CA USA 93307 661-363-6500

USACE SHEP/SHERS
Chatham County, Georgia

MACTEC Project Number: 6301-05-0001
Contract Number: W912798-04-D-0009:CV01
April 4, 2005
Revised: June 2, 2005

Preliminary Screening Level Opinion of Construction Costs
General Summary

ITEM	WORK DESCRIPTION	TOTAL
Option I-A	Option I-A, All Three Facilities, 12 Hr. HRT, Gravity Discharge to River	$42,400,000
Option I-B	Option I-B, All Three Facilities, 30 Day HRT, Gravity Discharge to River	$51,700,000
Option I-C	Option I-C, All Three Facilities, 60 Day HRT, Gravity Discharge to River	$59,100,000
Option II-A-1	Option II-A-1, International Paper Only, 12 Hr. HRT, Pumped to Discharge Point #1 (River Mile 5.5 +/-)	$43,200,000
Option II-A-2	Option II-A-2, International Paper Only, 12 Hr. HRT, Pumped to Discharge Point #2 (River Mile 0.0 +/-)	$66,000,000
Option II-B-1	Option II-B-1, International Paper Only, 30 Day HRT, Pumped to Discharge Point #1 (River Mile 5.5 +/-)	$49,000,000
Option II-B-2	Option II-B-2, International Paper Only, 30 Day HRT, Pumped to Discharge Point #2 (River Mile 0.0 +/-)	$71,400,000
Option II-C-1	Option II-C-1, International Paper Only, 60 Day HRT, Pumped to Discharge Point #1 (River Mile 5.5 +/-)	$56,000,000
Option II-C-2	Option II-C-2, International Paper Only, 60 Day HRT, Pumped to Discharge Point #2 (River Mile 0.0 +/-)	$81,200,000

Notes:
1) Reference used to generate this Opinion of Cost: Heavy Construction Cost Data, 2004 - 18th Annual Edition by RSMeans and actual costs from recently completed projects

2) All values rounded

Prepared By: Roger O. Blackwell Date: 6-6-05

Checked By: Stephen A. Lind Date: 6/6/05

Table 5.1

Preliminary Screening Level Opinion of Construction Costs, Summary

Identification and Screening Level Evaluation
Savannah Harbor Expansion Project & Savannah Harbor Ecosystem Restoration Project
Chatham County, Georgia

ITEM	WORK DESCRIPTION	ITEM TOTAL	OPTION TOTAL
Option I-A	**Option I-A, All Three Facilities, 12 Hr. HRT, Gravity Discharge to River**		**$42,400,000**
	Weyerhaeuser Pump Station and Piping to Pond (20 MGD, 36" DIP)	$15,500,000	
	International Paper Pump Station and Piping to Pond (30 MGD, 36" DIP)	$8,400,000	
	President Street WWTP Pump Station and Piping to Pond (10 MGD, 24" DIP)	$7,300,000	
	Pond Construction. HRT 12 Hrs, 10.5 AC x 9' Deep	$1,400,000	
	Contingency	$9,800,000	
Option I-B	**Option I-B, All Three Facilities, 30 Day HRT, Gravity Discharge to River**		**$51,700,000**
	Weyerhaeuser Pump Station and Piping to Pond (20 MGD, 36" DIP)	$15,500,000	
	International Paper Pump Station and Piping to Pond (30 MGD, 36" DIP)	$8,400,000	
	President Street WWTP Pump Station and Piping to Pond (10 MGD, 20" DIP)	$6,300,000	
	Pond Construction. HRT 30 Days, 614 AC x 9' Deep	$9,600,000	
	Contingency	$11,900,000	
Option I-C	**Option I-C, All Three Facilities, 60 Day HRT, Gravity Discharge to River**		**$59,100,000**
	Weyerhaeuser Pump Station and Piping to Pond (20 MGD, 36" DIP)	$15,500,000	
	International Paper Pump Station and Piping to Pond (30 MGD, 36" DIP)	$8,400,000	
	President Street WWTP Pump Station and Piping to Pond (10 MGD, 20" DIP)	$6,300,000	
	Pond Construction. HRT 60 Days, 1228 AC x 9' Deep	$15,300,000	
	Contingency	$13,600,000	
Option II-A-1	**Option II-A-1, International Paper Only, 12 Hr. HRT, Pumped to Discharge Point #1 (River Mile 5.5 +/-)**		**$43,200,000**
	International Paper Pump Station and Piping to Pond (30 MGD, 36" DIP)	$8,400,000	
	Pond Construction. HRT 12 Hrs, 5.1 AC x 9' Deep	$1,100,000	
	Pond Outfall Pump Station and Piping (69 CFS, 48" DIP)	$23,800,000	
	Contingency	$9,900,000	
Option II-A-2	**Option II-A-2, International Paper Only, 12 Hr. HRT, Pumped to Discharge Point #2 (River Mile 0.0 +/-)**		**$66,000,000**
	International Paper Pump Station and Piping to Pond (30 MGD, 36" DIP)	$8,400,000	
	Pond Construction. HRT 12 Hrs, 5.1 AC x 9' Deep	$1,100,000	
	Pond Outfall Pump Station and Piping (69 CFS, 54" DIP)	$41,300,000	
	Contingency	$15,200,000	
Option II-B-1	**Option II-B-1, International Paper Only, 30 Day HRT, Pumped to Discharge Point #1 (River Mile 5.5 +/-)**		**$49,000,000**
	International Paper Pump Station and Piping to Pond (30 MGD, 36" DIP)	$8,400,000	
	Pond Construction. HRT 30 Days, 307 AC x 9' Deep	$6,700,000	
	Pond Outfall Pump Station and Piping (69 CFS, 48" DIP)	$22,600,000	
	Contingency	$11,300,000	

ITEM	WORK DESCRIPTION	ITEM TOTAL	OPTION TOTAL
Option II-B-2	**Option II-B-2, International Paper Only, 30 Day HRT, Pumped to Discharge Point #2 (River Mile 0.0 +/-)**		**$71,400,000**
	International Paper Pump Station and Piping to Pond (30 MGD, 36" DIP)	$8,400,000	
	Pond Construction. HRT 30 Days, 307 AC x 9' Deep	$6,700,000	
	Pond Outfall Pump Station and Piping (69 CFS, 54" DIP)	$39,800,000	
	Contingency	$16,500,000	
Option II-C-1	**Option II-C-1, International Paper Only, 60 Day HRT, Pumped to Discharge Point #1 (River Mile 5.5 +/-)**		**$56,000,000**
	International Paper Pump Station and Piping to Pond (30 MGD, 36" DIP)	$8,400,000	
	Pond Construction. HRT 60 Days, 614 AC x 9' Deep	$9,500,000	
	Pond Outfall Pump Station and Piping (92 CFS, 54" DIP)	$25,200,000	
	Contingency	$12,900,000	
Option II-C-2	**Option II-C-2, International Paper Only, 60 Day HRT, Pumped to Discharge Point #2 (River Mile 0.0 +/-)**		**$81,200,000**
	International Paper Pump Station and Piping to Pond (30 MGD, 36" DIP)	$8,400,000	
	Pond Construction. HRT 60 Days, 614 AC x 9' Deep	$9,500,000	
	Pond Outfall Pump Station and Piping (92 CFS, 60" DIP)	$44,600,000	
	Contingency	$18,700,000	

Notes:

1) Reference used to generate this Opinion of Cost: Heavy Construction Cost Data, 2004 - 18th Annual Edition by RSMeans and actual costs from recently completed projects

2) All values rounded

3) HRT = Hydraulic Retention Time

Prepared By: [signature] Date: 6-6-05
Roger O. Blackwell

Checked By: Stephen A. Lind Date: 6/6/05
Stephen A. Lind

Preliminary Screening Level Opinion of Construction Cost

Prepared by: [signature] 6-6-05
Roger O. Blackwell

Checked by: Stephen A. Lind 6/6/05
Stephen A. Lind

Option I, Reroute All Three Facilities

ITEM	WORK DESCRIPTION	UNIT	UNIT PRICE	EST QTY	LINE TOTAL	COST SOURCE[1]	ITEM TOTAL
1.0	**Option I-A, 12 Hr. HRT, Gravity Discharge from Pond to River**						
1.1	**Weyerhaeuser Pump Station and Piping to Pond (20 MGD, 36" DIP)**						**$15,493,249**
	Mobilization & Demobilization	LS	$200,000	1	$200,000		
	Temporary Facilities and Controls	LS	$200,000	1	$200,000		
	Clearing (assume minor clearing 20' wide x length of trench)	AC	$262	17	$4,454	02230-200-0600	
	Silt Fence, Type C (assume double row along length of trench)	LF	$3.00	73,000	$219,000	Recent experience	
	Trench Excavation (assume 4' bottom, 1:1 side slopes & 4' cover over pipe)	CY	$2.54	104,000	$264,160	02315-610-0610	
	36" DIP, Class 150 Installed in Trench	LF	$159	36,500	$5,803,500	02510-730-3000 and American Pipe	
	36" DIP Fittings (assume 5% of pipe cost)	LS	$290,175	1	$290,175		
	Trench Backfill	CY	$2.44	94,500	$230,580	02315-610-3020, 02315-310-5040	
	Jacking/Receiving Pits (excludes dewatering)	EA	$19,300	4	$77,200	02445-300-1101	
	Microtunneling, 48" Diameter (includes casing)	LF	$960	6,500	$6,240,000	02441-400-0110 (adverse conditions)	
	36" DIP, Class 150 Installed in Casing	LF	$159	6,500	$1,033,500	02510-730-3000 and American Pipe	
	8" Air Release Valve	EA	$4,500	4	$18,000	Doug Andrews at Apco Valves. 50% Added for Installation	
	6' Dia Precast MH, 7' Deep	EA	$2,300	4	$9,200	02630-400-1200&1210	
	Energy Dissapation Structure, 3.1 CY/EA	EA	$1,180	1	$1,180	03310-240-4200, GDOT STD 1125 Table I	
	Pumps w/Controls, Instrumentation and Backup Generator (3 (+2) Each Flygt CP3356/810 Impeller/505mm/135 HP Each). Assume housed in existing facility with power from existing facility.	LS	$870,000	1	$870,000	Dana Reid and John Rodriguez of ITT Flygt Corporation, (Emails Dated 3/18/05, 2:46 PM and 3:03 PM). Added 50% for Installation, $100,000 for Generator and $20,000 for Instrumentation.	
	Grassing (assume 20' wide x length of trench)	AC	$1,900	17	$32,300	02920-320-0200	
1.2	**International Paper Pump Station and Piping to Pond (30 MGD, 36" DIP)**						**$8,326,343**
	Mobilization & Demobilization	LS	$200,000	1	$200,000		
	Temporary Facilities and Controls	LS	$200,000	1	$200,000		
	Clearing (assume minor clearing 20' wide x length of trench)	AC	$262	4	$1,048	02230-200-0600	
	Silt Fence, Type C (assume double row along length of trench)	LF	$3.00	15,000	$45,000	Recent experience	

ITEM	WORK DESCRIPTION	UNIT	UNIT PRICE	EST QTY	LINE TOTAL	COST SOURCE[1]	ITEM TOTAL
	Trench Excavation (assume 4' bottom, 1:1 side slopes & 4' cover over pipe)	CY	$2.54	21,500	$54,610	02315-610-0610	
	36" DIP, Class 150 Installed in Trench	LF	$159	7,500	$1,192,500	02510-730-3000 and American Pipe	
	36" DIP Fittings (assume 5% of pipe cost)	LS	$59,625	1	$59,625		
	Trench Backfill	CY	$2.44	19,500	$47,580	02315-610-3020, 02315-310-5040	
	Jacking/Receiving Pits (excludes dewatering)	EA	$19,300	2	$38,600	02445-300-1101	
	Microtunneling, 48" Diameter (includes casing)	LF	$960	5,000	$4,800,000	02441-400-0110 (adverse conditions)	
	36" DIP, Class 150 Installed in Casing	LF	$159	5,000	$795,000	02510-730-3000 and American Pipe	
	8" Air Release Valve	EA	$4,500	2	$9,000	Doug Andrews at Apco Valves. 50% Added for Installation	
	6' Dia Precast MH, 7' Deep	EA	$2,300	2	$4,600	02630-400-1200&1210	
	Energy Dissapation Structure, 3.1 CY/EA	EA	$1,180	1	$1,180	03310-240-4200, GDOT STD 1125 Table I	
	Pumps w/Controls, Instrumentation and Backup Generator (3 (+2) Each Flygt CP3356/810 Impeller/480mm/135HP Each). Assume housed in existing facility with power from existing facility.	LS	$870,000	1	$870,000	Dana Reid and John Rodriguez of ITT Flygt Corporation, (Emails Dated 3/18/05, 2:46 PM and 3:03 PM). Added 50% for Installation, $100,000 for Generator and $20,000 for Instrumentation.	
	Grassing (assume 20' wide x length of trench)	AC	$1,900	4	$7,600	02920-320-0200	
1.3	**President Street WWTP Pump Station and Piping to Pond (10 MGD, 24" DIP)**						**$7,266,050**
	Mobilization & Demobilization	LS	$200,000	1	$200,000		
	Temporary Facilities and Controls	LS	$200,000	1	$200,000		
	Clearing (assume minor clearing 20' wide x length of trench)	AC	$262	5	$1,310	02230-200-0600	
	Silt Fence, Type C (assume double row along length of trench)	LF	$3.00	21,600	$64,800	Recent experience	
	Trench Excavation (assume 4' bottom, 1:1 side slopes & 4' cover over pipe)	CY	$2.54	24,000	$60,960	02315-610-0610	
	24" DIP, Class 150 installed in trench	LF	$83	10,800	$896,400	02510-730-3180	
	24" DIP Fittings (assume 5% of pipe cost)	LS	$44,820	1	$44,820		
	Trench Backfill	CY	$2.44	22,750	$55,510	02315-610-3020, 02315-310-5040	
	Jacking/Receiving Pits (excludes dewatering)	EA	$19,300	4	$77,200	02445-300-1101	
	Microtunneling, 36" Diameter (includes casing)	LF	$960	5,000	$4,800,000	02441-400-0110 (adverse conditions)	
	24" DIP, Class 150 installed in casing	LF	$83	5,000	$415,000	02510-730-3180	
	4" Air Release Valve	EA	$3,000	4	$12,000	Doug Andrews at Apco Valves. 50% Added for Installation	
	6' Dia Precast MH, 6' Deep	EA	$1,975	4	$7,900	02630-400-1200	
	Energy Dissapation Structure, 1.7 CY/EA	EA	$650	1	$650	03310-240-4200, GDOT STD 1125 Table I	
	Pumps w/Controls, Instrumentation and Backup Generator (2 (+1) Each Flygt NP3301/636 Impeller/383mm/70HP Each). Assume housed in existing facility with power from existing facility)	LS	$420,000	1	$420,000	Dana Reid and John Rodriguez of ITT Flygt Corporation, (Emails Dated 3/18/05, 2:46 PM and 3:03 PM). Added 50% for Installation, $100,000 for Generator and $20,000 for Instrumentation.	
	Grassing (assume 20' wide x length of trench)	AC	$1,900	5	$9,500	02920-320-0200	

ITEM	WORK DESCRIPTION	UNIT	UNIT PRICE	EST QTY	LINE TOTAL	COST SOURCE[1]	ITEM TOTAL
1.4	**Pond Construction. HRT 12 Hrs, 10.5 AC x 9' Deep**						**$1,386,705**
	Mobilization & Demobilization	LS	$200,000	1	$200,000		
	Temporary Facilities and Controls	LS	$200,000	1	$200,000		
	Clearing (assume minor clearing)	AC	$262	17	$4,454	02230-200-0600	
	Silt Fence, Type C (assume double row around perimeter of work area)	LF	$3.00	7,000	$21,000	Recent experience	
	Undercut (assume 2' under footprint of berm disposed of onsite)	CY	$3.09	18,500	$57,165	02315-452-0300	
	Stabilization Fabric (Synthetic Industries Geotex 4x4 or equal)	SY	$2.75	30,500	$83,875	Local Contractor	
	Stabilization Stone	TN	$17	27,500	$474,375	02370-450-0100	
	Berm (Assume use of onsite dredge material)	CY	$3.45	62,000	$213,900	02315-520-0190, 02315-310-5040	
	Fine grade bottom of pond	AC	$2,904	12	$34,848	02310-100-0100	
	Conc. Channel Through Pond	CY	$127.00	105	$13,335	03300-240-4840	
	Grassing	AC	$1,900	17	$32,300	02920-320-0200	
	Outfall Trench Excavation (assume 4' bottom, 1:1 side slopes)	CY	$2.54	200	$508	02315-610-0610	
	Inlet Headwall, 4.6 CY/EA	EA	$1,750	1	$1,750	03310-240-4200, GDOT STD 1125 Table I	
	48" DIP Installed in Trench	LF	$372	100	$37,200	02510-730-3000 and American Pipe	
	48" Gate Valve	EA	$10,170	1	$10,170	02080-500-3832 Extrapolated to 48"	
	Energy Dissipation Structure, 4.8 CY/EA	EA	$1,825	1	$1,825	03310-240-4200, GDOT STD 1125 Table I	
	SUBTOTAL:						$32,472,347
	Contingency					30%	$9,741,704
	TOTAL:						**$42,214,051**

1) Source of unit costs (unless otherwise noted): "Heavy Construction Cost Data 2004", by RS Means Company, Inc.

Preliminary Screening Level Opinion of Construction Cost

Prepared by: 6-6-05
Roger O. Blackwell

Checked by: Stephen A. Lind 6/6/05
Stephen A. Lind

Option I, Reroute All Three Facilities

ITEM	WORK DESCRIPTION	UNIT	UNIT PRICE	EST QTY	LINE TOTAL	COST SOURCE[1]	ITEM TOTAL
1.0	**Option I-B, 30 Day HRT, Gravity Discharge from Pond to River**						
1.1	**Weyerhaeuser Pump Station and Piping to Pond (20 MGD, 36" DIP)**						**$15,493,249**
	Mobilization & Demobilization	LS	$200,000	1	$200,000		
	Temporary Facilities and Controls	LS	$200,000	1	$200,000		
	Clearing (assume minor clearing 20' wide x length of trench)	AC	$262	17	$4,454	02230-200-0600	
	Silt Fence, Type C (assume double row along length of trench)	LF	$3.00	73,000	$219,000	Recent experience	
	Trench Excavation (assume 4' bottom, 1:1 side slopes & 4' cover over pipe)	CY	$2.54	104,000	$264,160	02315-610-0610	
	36" DIP, Class 150 Installed in Trench	LF	$159	36,500	$5,803,500	02510-730-3000 and American Pipe	
	36" DIP Fittings (assume 5% of pipe cost)	LS	$290,175	1	$290,175		
	Trench Backfill	CY	$2.44	94,500	$230,580	02315-610-3020, 02315-310-5040	
	Jacking/Receiving Pits (excludes dewatering)	EA	$19,300	4	$77,200	02445-300-1101	
	Microtunneling, 48" Diameter (includes casing)	LF	$960	6,500	$6,240,000	02441-400-0110 (adverse conditions)	
	36" DIP, Class 150 Installed in Casing	LF	$159	6,500	$1,033,500	02510-730-3000 and American Pipe	
	8" Air Release Valve	EA	$4,500	4	$18,000	Doug Andrews at Apco Valves. 50% Added for Installation	
	6' Dia Precast MH, 7' Deep	EA	$2,300	4	$9,200	02630-400-1200&1210	
	Energy Dissapation Structure, 3.1 CY/EA	EA	$1,180	1	$1,180	03310-240-4200, GDOT STD 1125 Table I	
	Pumps w/Controls, Instrumentation and Backup Generator (3 (+2) Each Flygt CP3356/810 Impeller/505mm/135 HP Each). Assume housed in existing facility with power from existing facility.	LS	$870,000	1	$870,000	Dana Reid and John Rodriguez of ITT Flygt Corporation, (Emails Dated 3/18/05, 2:46 PM and 3:03 PM). Added 50% for Installation, $100,000 for Generator and $20,000 for Instrumentation.	
	Grassing (assume 20' wide x length of trench)	AC	$1,900	17	$32,300	02920-320-0200	
1.2	**International Paper Pump Station and Piping to Pond (30 MGD, 36" DIP)**						**$8,326,343**
	Mobilization & Demobilization	LS	$200,000	1	$200,000		
	Temporary Facilities and Controls	LS	$200,000	1	$200,000		
	Clearing (assume minor clearing 20' wide x length of trench)	AC	$262	4	$1,048	02230-200-0600	
	Silt Fence, Type C (assume double row along length of trench)	LF	$3.00	15,000	$45,000	Recent experience	

ITEM	WORK DESCRIPTION	UNIT	UNIT PRICE	EST QTY	LINE TOTAL	COST SOURCE[1]	ITEM TOTAL
	Trench Excavation (assume 4' bottom, 1:1 side slopes & 4' cover over pipe)	CY	$2.54	21,500	$54,610	02315-610-0610	
	36" DIP, Class 150 Installed in Trench	LF	$159	7,500	$1,192,500	02510-730-3000 and American Pipe	
	36" DIP Fittings (assume 5% of pipe cost)	LS	$59,625	1	$59,625		
	Trench Backfill	CY	$2.44	19,500	$47,580	02315-610-3020, 02315-310-5040	
	Jacking/Receiving Pits (excludes dewatering)	EA	$19,300	2	$38,600	02445-300-1101	
	Microtunneling, 48" Diameter (includes casing)	LF	$960	5,000	$4,800,000	02441-400-0110 (adverse conditions)	
	36" DIP, Class 150 Installed in Casing	LF	$159	5,000	$795,000	02510-730-3000 and American Pipe	
	8" Air Release Valve	EA	$4,500	2	$9,000	Doug Andrews at Apco Valves. 50% Added for Installation	
	6' Dia Precast MH, 7' Deep	EA	$2,300	2	$4,600	02630-400-1200&1210	
	Energy Dissapation Structure, 3.1 CY/EA	EA	$1,180	1	$1,180	03310-240-4200, GDOT STD 1125 Table I	
	Pumps w/Controls, Instrumentation and Backup Generator (3 (+2) Each Flygt CP3356/810 Impeller/480mm/135HP Each). Assume housed in existing facility with power from existing facility.	LS	$870,000	1	$870,000	Dana Reid and John Rodriguez of ITT Flygt Corporation, (Emails Dated 3/18/05, 2:46 PM and 3:03 PM). Added 50% for Installation, $100,000 for Generator and $20,000 for Instrumentation.	
	Grassing (assume 20' wide x length of trench)	AC	$1,900	4	$7,600	02920-320-0200	
1.3	**President Street WWTP Pump Station and Piping to Pond (10 MGD, 20" DIP)**						**$6,216,236**
	Mobilization & Demobilization	LS	$200,000	1	$200,000		
	Temporary Facilities and Controls	LS	$200,000	1	$200,000		
	Clearing (assume minor clearing 20' wide x length of trench)	AC	$262	1	$262	02230-200-0600	
	Silt Fence, Type C (assume double row along length of trench)	LF	$3.00	3,700	$11,100	Recent experience	
	Trench Excavation (assume 4' bottom, 1:1 side slopes & 4' cover over pipe)	CY	$2.54	4,100	$10,414	02315-610-0610	
	20" DIP, Class 150 installed in trench	LF	$67	1,850	$123,950	02510-730-3180	
	20" DIP Fittings (assume 5% of pipe cost)	LS	$6,198	1	$6,198		
	Trench Backfill	CY	$2.44	3,960	$9,662	02315-610-3020, 02315-310-5040	
	Jacking/Receiving Pits (excludes dewatering)	EA	$19,300	4	$77,200	02445-300-1101	
	Microtunneling, 36" Diameter (includes casing)	LF	$960	5,000	$4,800,000	02441-400-0110 (adverse conditions)	
	20" DIP, Class 150 installed in casing	LF	$67	5,000	$335,000	02510-730-3180	
	4" Air Release Valve	EA	$3,000	4	$12,000	Doug Andrews at Apco Valves. 50% Added for Installation	
	6' Dia Precast MH, 6' Deep	EA	$1,975	4	$7,900	02630-400-1200	
	Energy Dissapation Structure, 1.7 CY/EA	EA	$650	1	$650	03310-240-4200, GDOT STD 1125 Table I	
	Pumps w/Controls, Instrumentation and Backup Generator (2 (+1) Each Flygt NP3301/636 Impeller/383mm/70HP Each). Assume housed in existing facility with power from existing facility)	LS	$420,000	1	$420,000	Dana Reid and John Rodriguez of ITT Flygt Corporation, (Emails Dated 3/18/05, 2:46 PM and 3:03 PM). Added 50% for Installation, $100,000 for Generator and $20,000 for Instrumentation.	
	Grassing (assume 20' wide x length of trench)	AC	$1,900	1	$1,900	02920-320-0200	

ITEM	WORK DESCRIPTION	UNIT	UNIT PRICE	EST QTY	LINE TOTAL	COST SOURCE[1]	ITEM TOTAL
1.4	**Pond Construction. HRT 30 Days, 614 AC x 9' Deep**						**$9,520,443**
	Mobilization & Demobilization	LS	$200,000	1	$200,000		
	Temporary Facilities and Controls	LS	$200,000	1	$200,000		
	Clearing (assume minor clearing)	AC	$262	650	$170,300	02230-200-0600	
	Silt Fence, Type C (assume double row around perimeter of work area)	LF	$3.00	43,000	$129,000	Recent experience	
	Undercut (assume 2' under footprint of berm disposed of onsite)	CY	$3.09	128,000	$395,520	02315-452-0300	
	Stabilization Fabric (Synthetic Industries Geotex 4x4 or equal)	SY	$2.75	210,500	$578,875	Local Contractor	
	Stabilization Stone	TN	$17	190,000	$3,277,500	02370-450-0100	
	Berm (Assume use of onsite dredge material)	CY	$3.45	430,000	$1,483,500	02315-520-0190, 02315-310-5040	
	Fine grade bottom of pond	AC	$2,904	615	$1,785,960	02310-100-0100	
	Conc. Channel Through Pond	CY	$127.00	105	$13,335	03300-240-4840	
	Grassing	AC	$1,900	650	$1,235,000	02920-320-0200	
	Outfall Trench Excavation (assume 4' bottom, 1:1 side slopes)	CY	$2.54	200	$508	02315-610-0610	
	Inlet Headwall, 4.6 CY/EA	EA	$1,750	1	$1,750	03310-240-4200, GDOT STD 1125 Table I	
	48" DIP Installed in Trench	LF	$372	100	$37,200	02510-730-3000 and American Pipe	
	48" Gate Valve	EA	$10,170	1	$10,170	02080-500-3832 Extrapolated to 48"	
	Energy Dissipation Structure, 4.8 CY/EA	EA	$1,825	1	$1,825	03310-240-4200, GDOT STD 1125 Table I	
	SUBTOTAL:						$39,556,271
	Contingency					30%	$11,866,881
	TOTAL:						**$51,423,152**

1) Source of unit costs (unless otherwise noted): "Heavy Construction Cost Data 2004", by RS Means Company, Inc.

Preliminary Screening Level Opinion of Construction Cost

Prepared by: 6-6-05
Roger O. Blackwell

Checked by: Stephen A. Lind 6/6/05
Stephen A. Lind

Option I, Reroute All Three Facilities

ITEM	WORK DESCRIPTION	UNIT	UNIT PRICE	EST QTY	LINE TOTAL	COST SOURCE[1]	ITEM TOTAL
1.0	**Option I-C, 60 Day HRT, Gravity Discharge from Pond to River**						
1.1	**Weyerhaeuser Pump Station and Piping to Pond (20 MGD, 36" DIP)**						**$15,493,249**
	Mobilization & Demobilization	LS	$200,000	1	$200,000		
	Temporary Facilities and Controls	LS	$200,000	1	$200,000		
	Clearing (assume minor clearing 20' wide x length of trench)	AC	$262	17	$4,454	02230-200-0600	
	Silt Fence, Type C (assume double row along length of trench)	LF	$3.00	73,000	$219,000	Recent experience	
	Trench Excavation (assume 4' bottom, 1:1 side slopes & 4' cover over pipe)	CY	$2.54	104,000	$264,160	02315-610-0610	
	36" DIP, Class 150 Installed in Trench	LF	$159	36,500	$5,803,500	02510-730-3000 and American Pipe	
	36" DIP Fittings (assume 5% of pipe cost)	LS	$290,175	1	$290,175		
	Trench Backfill	CY	$2.44	94,500	$230,580	02315-610-3020, 02315-310-5040	
	Jacking/Receiving Pits (excludes dewatering)	EA	$19,300	4	$77,200	02445-300-1101	
	Microtunneling, 48" Diameter (includes casing)	LF	$960	6,500	$6,240,000	02441-400-0110 (adverse conditions)	
	36" DIP, Class 150 Installed in Casing	LF	$159	6,500	$1,033,500	02510-730-3000 and American Pipe	
	8" Air Release Valve	EA	$4,500	4	$18,000	Doug Andrews at Apco Valves. 50% Added for Installation	
	6' Dia Precast MH, 7' Deep	EA	$2,300	4	$9,200	02630-400-1200&1210	
	Energy Dissapation Structure, 3.1 CY/EA	EA	$1,180	1	$1,180	03310-240-4200, GDOT STD 1125 Table I	
	Pumps w/Controls, Instrumentation and Backup Generator (3 (+2) Each Flygt CP3356/810 Impeller/505mm/135 HP Each). Assume housed in existing facility with power from existing facility.	LS	$870,000	1	$870,000	Dana Reid and John Rodriguez of ITT Flygt Corporation, (Emails Dated 3/18/05, 2:46 PM and 3:03 PM). Added 50% for Installation, $100,000 for Generator and $20,000 for Instrumentation.	
	Grassing (assume 20' wide x length of trench)	AC	$1,900	17	$32,300	02920-320-0200	
1.2	**International Paper Pump Station and Piping to Pond (30 MGD, 36" DIP)**						**$8,326,343**
	Mobilization & Demobilization	LS	$200,000	1	$200,000		
	Temporary Facilities and Controls	LS	$200,000	1	$200,000		
	Clearing (assume minor clearing 20' wide x length of trench)	AC	$262	4	$1,048	02230-200-0600	
	Silt Fence, Type C (assume double row along length of trench)	LF	$3.00	15,000	$45,000	Recent experience	

ITEM	WORK DESCRIPTION	UNIT	UNIT PRICE	EST QTY	LINE TOTAL	COST SOURCE[1]	ITEM TOTAL
	Trench Excavation (assume 4' bottom, 1:1 side slopes & 4' cover over pipe)	CY	$2.54	21,500	$54,610	02315-610-0610	
	36" DIP, Class 150 Installed in Trench	LF	$159	7,500	$1,192,500	02510-730-3000 and American Pipe	
	36" DIP Fittings (assume 5% of pipe cost)	LS	$59,625	1	$59,625		
	Trench Backfill	CY	$2.44	19,500	$47,580	02315-610-3020, 02315-310-5040	
	Jacking/Receiving Pits (excludes dewatering)	EA	$19,300	2	$38,600	02445-300-1101	
	Microtunneling, 48" Diameter (includes casing)	LF	$960	5,000	$4,800,000	02441-400-0110 (adverse conditions)	
	36" DIP, Class 150 Installed in Casing	LF	$159	5,000	$795,000	02510-730-3000 and American Pipe	
	8" Air Release Valve	EA	$4,500	2	$9,000	Doug Andrews at Apco Valves. 50% Added for Installation	
	6' Dia Precast MH, 7' Deep	EA	$2,300	2	$4,600	02630-400-1200&1210	
	Energy Dissapation Structure, 3.1 CY/EA	EA	$1,180	1	$1,180	03310-240-4200, GDOT STD 1125 Table I	
	Pumps w/Controls, Instrumentation and Backup Generator (3 (+2) Each Flygt CP3356/810 Impeller/480mm/135HP Each). Assume housed in existing facility with power from existing facility.	LS	$870,000	1	$870,000	Dana Reid and John Rodriguez of ITT Flygt Corporation, (Emails Dated 3/18/05, 2:46 PM and 3:03 PM). Added 50% for Installation, $100,000 for Generator and $20,000 for Instrumentation.	
	Grassing (assume 20' wide x length of trench)	AC	$1,900	4	$7,600	02920-320-0200	
1.3	**President Street WWTP Pump Station and Piping to Pond (10 MGD, 20" DIP)**						**$6,216,236**
	Mobilization & Demobilization	LS	$200,000	1	$200,000		
	Temporary Facilities and Controls	LS	$200,000	1	$200,000		
	Clearing (assume minor clearing 20' wide x length of trench)	AC	$262	1	$262	02230-200-0600	
	Silt Fence, Type C (assume double row along length of trench)	LF	$3.00	3,700	$11,100	Recent experience	
	Trench Excavation (assume 4' bottom, 1:1 side slopes & 4' cover over pipe)	CY	$2.54	4,100	$10,414	02315-610-0610	
	20" DIP, Class 150 installed in trench	LF	$67	1,850	$123,950	02510-730-3180	
	20" DIP Fittings (assume 5% of pipe cost)	LS	$6,198	1	$6,198		
	Trench Backfill	CY	$2.44	3,960	$9,662	02315-610-3020, 02315-310-5040	
	Jacking/Receiving Pits (excludes dewatering)	EA	$19,300	4	$77,200	02445-300-1101	
	Microtunneling, 36" Diameter (includes casing)	LF	$960	5,000	$4,800,000	02441-400-0110 (adverse conditions)	
	20" DIP, Class 150 installed in casing	LF	$67	5,000	$335,000	02510-730-3180	
	4" Air Release Valve	EA	$3,000	4	$12,000	Doug Andrews at Apco Valves. 50% Added for Installation	
	6' Dia Precast MH, 6' Deep	EA	$1,975	4	$7,900	02630-400-1200	
	Energy Dissapation Structure, 1.7 CY/EA	EA	$650	1	$650	03310-240-4200, GDOT STD 1125 Table I	
	Pumps w/Controls, Instrumentation and Backup Generator (2 (+1) Each Flygt CP3301/636 Impeller/384mm/70 HP Each). Assume housed in existing facility with power from existing facility)	LS	$420,000	1	$420,000	Dana Reid and John Rodriguez of ITT Flygt Corporation, (Emails Dated 3/18/05, 2:46 PM and 3:03 PM). Added 50% for Installation, $100,000 for Generator and $20,000 for Instrumentation.	
	Grassing (assume 20' wide x length of trench)	AC	$1,900	1	$1,900	02920-320-0200	

ITEM	WORK DESCRIPTION	UNIT	UNIT PRICE	EST QTY	LINE TOTAL	COST SOURCE[1]	ITEM TOTAL
1.4	**Pond Construction. HRT 60 Days, 1228 AC x 9' Deep**						**$15,263,623**
	Mobilization & Demobilization	LS	$200,000	1	$200,000		
	Temporary Facilities and Controls	LS	$200,000	1	$200,000		
	Clearing (assume minor clearing)	AC	$262	1,280	$335,360	02230-200-0600	
	Silt Fence, Type C (assume double row around perimeter of work area)	LF	$3.00	61,500	$184,500	Recent experience	
	Undercut (assume 2' under footprint of berm disposed of onsite)	CY	$3.09	184,500	$570,105	02315-452-0300	
	Stabilization Fabric (Synthetic Industries Geotex 4x4 or equal)	SY	$2.75	304,000	$836,000	Local Contractor	
	Stabilization Stone	TN	$17	274,000	$4,726,500	02370-450-0100	
	Berm (Assume use of onsite dredge material)	CY	$3.45	621,000	$2,142,450	02315-520-0190, 02315-310-5040	
	Fine grade bottom of pond	AC	$2,904	1,230	$3,571,920	02310-100-0100	
	Conc. Channel Through Pond	CY	$127.00	105	$13,335	03300-240-4840	
	Grassing	AC	$1,900	1,280	$2,432,000	02920-320-0200	
	Outfall Trench Excavation (assume 4' bottom, 1:1 side slopes)	CY	$2.54	200	$508	02315-610-0610	
	Inlet Headwall, 4.6 CY/EA	EA	$1,750	1	$1,750	03310-240-4200, GDOT STD 1125 Table I	
	48" DIP Installed in Trench	LF	$372	100	$37,200	02510-730-3000 and American Pipe	
	48" Gate Valve	EA	$10,170	1	$10,170	02080-500-3832 Extrapolated to 48"	
	Energy Dissipation Structure, 4.8 CY/EA	EA	$1,825	1	$1,825	03310-240-4200, GDOT STD 1125 Table I	
	SUBTOTAL:						$45,299,451
	Contingency					30%	$13,589,835
	TOTAL:						**$58,889,286**

1) Source of unit costs (unless otherwise noted): "Heavy Construction Cost Data 2004", by RS Means Company, Inc.

Preliminary Screening Level Opinion of Construction Cost

Prepared by: [signature] 6-6-05
Roger O. Blackwell

Checked by: Stephen A. Lind 6/6/05
Stephen A. Lind

Option II, Reroute Only International Paper & Pump from Pond

ITEM	WORK DESCRIPTION	UNIT	UNIT PRICE	EST QTY	LINE TOTAL	COST SOURCE[1]	ITEM TOTAL
1.0	**Option II-A-1, 12 Hr. HRT, Pumped to Discharge Point #1**						
1.2	**International Paper Pump Station and Piping to Pond (30 MGD, 36" DIP)**						**$8,326,343**
	Mobilization & Demobilization	LS	$200,000	1	$200,000		
	Temporary Facilities and Controls	LS	$200,000	1	$200,000		
	Clearing (assume minor clearing 20' wide x length of trench)	AC	$262	4	$1,048	02230-200-0600	
	Silt Fence, Type C (assume double row along length of trench)	LF	$3.00	15,000	$45,000	Recent experience	
	Trench Excavation (assume 4' bottom, 1:1 side slopes & 4' cover over pipe)	CY	$2.54	21,500	$54,610	02315-610-0610	
	36" DIP, Class 150 Installed in Trench	LF	$159	7,500	$1,192,500	02510-730-3000 and American Pipe	
	36" DIP Fittings (assume 5% of pipe cost)	LS	$59,625	1	$59,625		
	Trench Backfill	CY	$2.44	19,500	$47,580	02315-610-3020, 02315-310-5040	
	Jacking/Receiving Pits (excludes dewatering)	EA	$19,300	2	$38,600	02445-300-1101	
	Microtunneling, 48" Diameter (includes casing)	LF	$960	5,000	$4,800,000	02441-400-0110 (adverse conditions)	
	36" DIP, Class 150 Installed in Casing	LF	$159	5,000	$795,000	02510-730-3000 and American Pipe	
	8" Air Release Valve	EA	$4,500	2	$9,000	Doug Andrews at Apco Valves. 50% Added for Installation	
	6' Dia Precast MH, 7' Deep	EA	$2,300	2	$4,600	02630-400-1200&1210	
	Energy Dissapation Structure, 3.1 CY/EA	EA	$1,180	1	$1,180	03310-240-4200, GDOT STD 1125 Table I	
	Pumps w/Controls, Instrumentation and Backup Generator (3 (+2) Each Flygt CP3356/810 Impeller/480mm/135HP Each). Assume housed in existing facility with power from existing facility.	LS	$870,000	1	$870,000	Dana Reid and John Rodriguez of ITT Flygt Corporation, (Emails Dated 3/18/05, 2:46 PM and 3:03 PM). Added 50% for Installation, $100,000 for Generator and $20,000 for Instrumentation.	
	Grassing (assume 20' wide x length of trench)	AC	$1,900	4	$7,600	02920-320-0200	
1.4	**Pond Construction. HRT 12 Hrs, 5.1 AC x 9' Deep**						**$1,034,414**
	Mobilization & Demobilization	LS	$200,000	1	$200,000		
	Temporary Facilities and Controls	LS	$200,000	1	$200,000		
	Clearing (assume minor clearing)	AC	$262	9	$2,358	02230-200-0600	
	Silt Fence, Type C (assume double row around perimeter of work area)	LF	$3.00	5,000	$15,000	Recent experience	

ITEM	WORK DESCRIPTION	UNIT	UNIT PRICE	EST QTY	LINE TOTAL	COST SOURCE[1]	ITEM TOTAL
	Undercut (assume 2' under footprint of berm disposed of onsite)	CY	$3.09	12,900	$39,861	02315-452-0300	
	Stabilization Fabric (Synthetic Industries Geotex 4x4 or equal)	SY	$2.75	21,500	$59,125	Local Contractor	
	Stabilization Stone	TN	$17	19,500	$336,375	02370-450-0100	
	Berm (Assume use of onsite dredge material)	CY	$3.45	43,500	$150,075	02315-520-0190, 02315-310-5040	
	Fine grade bottom of pond	AC	$2,904	5	$14,520	02310-100-0100	
	Grassing	AC	$1,900	9	$17,100	02920-320-0200	
1.5	**Pond Outfall Pump Station and Piping (69 CFS, 48" DIP)[2]**						**$23,755,259**
	Mobilization & Demobilization	LS	$200,000	1	$200,000		
	Temporary Facilities and Controls	LS	$200,000	1	$200,000		
	Clearing (assume minor clearing 20' wide x length of pipe)	AC	$262	22	$5,764	02230-200-0600	
	Silt Fence, Type C (assume double row along length of trench)	LF	$3.00	93,000	$279,000	Recent experience	
	48" DIP Installed Above Ground	LF	$372	46,500	$17,298,000	02510-730-3000 and American Pipe	
	48" DIP Fittings (assume 5% of pipe costs)	LF	$864,900	1	$864,900		
	Pipe Anchor Blocks (assume 2 EA 3'x3'x3' conc @ 100' o.c.)	EA	$263	940	$247,220	03310-240-3800	
	Pipe Anchor Bands (assume 1 EA @ 100' o.c.)	EA	$525	470	$246,750	05540-200-0300 (assume 1/4" x 12" band over pipe)	
	Pump Station (3 (+2) EA Flygt CP3400.835-830/335 HP EA w/Backup Generator installed in new facility)	LS	$3,270,000	1	$3,270,000	Dana Reid of ITT Flygt Corporation, (Email Dated 3/28/05, 5:03 PM). Added 50% for Installation, $250,000 for Generator and $20,000 for Instrumentation.	
	Pumping Station Facility and Power Supply	LS	$1,100,000	1	$1,100,000	Recent experience (Mirsada llic)	
	Grassing (assume 20' wide x length of pipe)	AC	$1,900	22	$41,800	02920-320-0200	
	Energy Dissipation Structure, 4.8 CY/EA	EA	$1,825	1	$1,825	03310-240-4200, GDOT STD 1125 Table I	
	SUBTOTAL:						$33,116,016
	Contingency					30%	$9,934,805
	TOTAL:						**$43,050,821**

1) Source of unit costs (unless otherwise noted): "Heavy Construction Cost Data 2004", by RS Means Company, Inc.
2) Approximately 24 hours required to empty pond at 69 cfs.

Preliminary Screening Level Opinion of Construction Cost

Prepared by: [signature] 6-6-05
Roger O. Blackwell

Checked by: Stephen A. Lind 6/6/05
Stephen A. Lind

Option II, Reroute Only International Paper & Pump from Pond

ITEM	WORK DESCRIPTION	UNIT	UNIT PRICE	EST QTY	LINE TOTAL	COST SOURCE[1]	ITEM TOTAL
1.0	**Option II-A-2, 12 Hr. HRT, Pumped to Discharge Point #2**						
1.2	**International Paper Pump Station and Piping to Pond (30 MGD, 36" DIP)**						**$8,326,343**
	Mobilization & Demobilization	LS	$200,000	1	$200,000		
	Temporary Facilities and Controls	LS	$200,000	1	$200,000		
	Clearing (assume minor clearing 20' wide x length of trench)	AC	$262	4	$1,048	02230-200-0600	
	Silt Fence, Type C (assume double row along length of trench)	LF	$3.00	15,000	$45,000	Recent experience	
	Trench Excavation (assume 4' bottom, 1:1 side slopes & 4' cover over pipe)	CY	$2.54	21,500	$54,610	02315-610-0610	
	36" DIP, Class 150 Installed in Trench	LF	$159	7,500	$1,192,500	02510-730-3000 and American Pipe	
	36" DIP Fittings (assume 5% of pipe cost)	LS	$59,625	1	$59,625		
	Trench Backfill	CY	$2.44	19,500	$47,580	02315-610-3020, 02315-310-5040	
	Jacking/Receiving Pits (excludes dewatering)	EA	$19,300	2	$38,600	02445-300-1101	
	Microtunneling, 48" Diameter (includes casing)	LF	$960	5,000	$4,800,000	02441-400-0110 (adverse conditions)	
	36" DIP, Class 150 Installed in Casing	LF	$159	5,000	$795,000	02510-730-3000 and American Pipe	
	8" Air Release Valve	EA	$4,500	2	$9,000	Doug Andrews at Apco Valves. 50% Added for Installation	
	6' Dia Precast MH, 7' Deep	EA	$2,300	2	$4,600	02630-400-1200&1210	
	Energy Dissapation Structure, 3.1 CY/EA	EA	$1,180	1	$1,180	03310-240-4200, GDOT STD 1125 Table I	
	Pumps w/Controls, Instrumentation and Backup Generator (3 (+2) Each Flygt CP3356/810 Impeller/480mm/135HP Each). Assume housed in existing facility with power from existing facility.	LS	$870,000	1	$870,000	Dana Reid and John Rodriguez of ITT Flygt Corporation, (Emails Dated 3/18/05, 2:46 PM and 3:03 PM). Added 50% for Installation, $100,000 for Generator and $20,000 for Instrumentation.	
	Grassing (assume 20' wide x length of trench)	AC	$1,900	4	$7,600	02920-320-0200	
1.4	**Pond Construction. HRT 12 Hrs, 5.1 AC x 9' Deep**						**$1,034,414**
	Mobilization & Demobilization	LS	$200,000	1	$200,000		
	Temporary Facilities and Controls	LS	$200,000	1	$200,000		
	Clearing (assume minor clearing)	AC	$262	9	$2,358	02230-200-0600	
	Silt Fence, Type C (assume double row around perimeter of work area)	LF	$3.00	5,000	$15,000	Recent experience	

ITEM	WORK DESCRIPTION	UNIT	UNIT PRICE	EST QTY	LINE TOTAL	COST SOURCE[1]	ITEM TOTAL
	Undercut (assume 2' under footprint of berm disposed of onsite)	CY	$3.09	12,900	$39,861	02315-452-0300	
	Stabilization Fabric (Synthetic Industries Geotex 4x4 or equal)	SY	$2.75	21,500	$59,125	Local Contractor	
	Stabilization Stone	TN	$17	19,500	$336,375	02370-450-0100	
	Berm (Assume use of onsite dredge material)	CY	$3.45	43,500	$150,075	02315-520-0190, 02315-310-5040	
	Fine grade bottom of pond	AC	$2,904	5	$14,520	02310-100-0100	
	Grassing	AC	$1,900	9	$17,100	02920-320-0200	
1.5	**Pond Outfall Pump Station and Piping (69 CFS, 54" DIP)[2]**						**$41,250,998**
	Mobilization & Demobilization	LS	$200,000	1	$200,000		
	Temporary Facilities and Controls	LS	$200,000	1	$200,000		
	Clearing (assume minor clearing 20' wide x length of pipe)	AC	$262	34	$8,908	02230-200-0600	
	Silt Fence, Type C (assume double row along length of trench)	LF	$3.00	147,000	$441,000	Recent experience	
	54" DIP Installed Above Ground	LF	$456	73,500	$33,516,000	02510-730-3000 and American Pipe	
	54" DIP Fittings (assume 5% of pipe costs)	LF	$1,675,800	1	$1,675,800		
	Pipe Anchor Blocks (assume 2 EA 3'x3'x3' conc @ 100' o.c.)	EA	$263	1,470	$386,610	03310-240-3800	
	Pipe Anchor Bands (assume 1 EA @ 100' o.c.)	EA	$525	735	$385,875	05540-200-0300 (assume 1/4" x 12" band over pipe)	
	Pump Station (3 (+2) EA Flygt CP3400.835-830/335 HP EA w/Backup Generator installed in new facility)	LS	$3,270,000	1	$3,270,000	Dana Reid of ITT Flygt Corporation, Email Dated 3/28/05, 5:03 PM). Added 50% for Installation, $250,000 for Generator and $20,000 for Instrumentation.	
	Pumping Station Facility and Power Supply	LS	$1,100,000	1	$1,100,000	Recent experience (Mirsada llic)	
	Grassing (assume 20' wide x length of pipe)	AC	$1,900	34	$64,600	02920-320-0200	
	Energy Dissipation Structure, 5.8 CY/EA	EA	$2,205	1	$2,205	03310-240-4200, GDOT STD 1125 Table I	
	SUBTOTAL:						$50,611,755
	Contingency					30%	$15,183,527
	TOTAL:						**$65,795,282**

1) Source of unit costs (unless otherwise noted): "Heavy Construction Cost Data 2004", by RS Means Company, Inc.
2) Approximately 24 hours required to empty pond at 69 cfs.

Preliminary Screening Level Opinion of Construction Cost

Prepared by: 6-6-05
Roger O. Blackwell

Checked by: Stephen A. Lind 6/6/05
Stephen A. Lind

Option II, Reroute Only International Paper & Pump from Pond

ITEM	WORK DESCRIPTION	UNIT	UNIT PRICE	EST QTY	LINE TOTAL	COST SOURCE[1]	ITEM TOTAL
1.0	**Option II-B-1, 30 Day HRT, Pumped to Discharge Point #1**						
1.2	**International Paper Pump Station and Piping to Pond (30 MGD, 36" DIP)**						**$8,326,343**
	Mobilization & Demobilization	LS	$200,000	1	$200,000		
	Temporary Facilities and Controls	LS	$200,000	1	$200,000		
	Clearing (assume minor clearing 20' wide x length of trench)	AC	$262	4	$1,048	02230-200-0600	
	Silt Fence, Type C (assume double row along length of trench)	LF	$3.00	15,000	$45,000	Recent experience	
	Trench Excavation (assume 4' bottom, 1:1 side slopes & 4' cover over pipe)	CY	$2.54	21,500	$54,610	02315-610-0610	
	36" DIP, Class 150 Installed in Trench	LF	$159	7,500	$1,192,500	02510-730-3000 and American Pipe	
	36" DIP Fittings (assume 5% of pipe cost)	LS	$59,625	1	$59,625		
	Trench Backfill	CY	$2.44	19,500	$47,580	02315-610-3020, 02315-310-5040	
	Jacking/Receiving Pits (excludes dewatering)	EA	$19,300	2	$38,600	02445-300-1101	
	Microtunneling, 48" Diameter (includes casing)	LF	$960	5,000	$4,800,000	02441-400-0110 (adverse conditions)	
	36" DIP, Class 150 Installed in Casing	LF	$159	5,000	$795,000	02510-730-3000 and American Pipe	
	8" Air Release Valve	EA	$4,500	2	$9,000	Doug Andrews at Apco Valves. 50% Added for Installation	
	6' Dia Precast MH, 7' Deep	EA	$2,300	2	$4,600	02630-400-1200&1210	
	Energy Dissapation Structure, 3.1 CY/EA	EA	$1,180	1	$1,180	03310-240-4200, GDOT STD 1125 Table I	
	Pumps w/Controls, Instrumentation and Backup Generator (3 (+2) Each Flygt CP3356/810 Impeller/480mm/135HP Each). Assume housed in existing facility with power from existing facility.	LS	$870,000	1	$870,000	Dana Reid and John Rodriguez of ITT Flygt Corporation, (Emails Dated 3/18/05, 2:46 PM and 3:03 PM). Added 50% for Installation, $100,000 for Generator and $20,000 for Instrumentation.	
	Grassing (assume 20' wide x length of trench)	AC	$1,900	4	$7,600	02920-320-0200	
1.4	**Pond Construction. HRT 30 Days, 307 AC x 9' Deep**						**$6,620,645**
	Mobilization & Demobilization	LS	$200,000	1	$200,000		
	Temporary Facilities and Controls	LS	$200,000	1	$200,000		
	Clearing (assume minor clearing)	AC	$262	340	$89,080	02230-200-0600	
	Silt Fence, Type C (assume double row around perimeter of work area)	LF	$3.00	33,500	$100,500	Recent experience	

ITEM	WORK DESCRIPTION	UNIT	UNIT PRICE	EST QTY	LINE TOTAL	COST SOURCE[1]	ITEM TOTAL
	Undercut (assume 2' under footprint of berm disposed of onsite)	CY	$3.09	99,500	$307,455	02315-452-0300	
	Stabilization Fabric (Synthetic Industries Geotex 4x4 or equal)	SY	$2.75	164,500	$452,375	Local Contractor	
	Stabilization Stone	TN	$17	148,000	$2,553,000	02370-450-0100	
	Berm (Assume use of onsite dredge material)	CY	$3.45	335,500	$1,157,475	02315-520-0190, 02315-310-5040	
	Fine grade bottom of pond	AC	$2,904	315	$914,760	02310-100-0100	
	Grassing	AC	$1,900	340	$646,000	02920-320-0200	
1.5	**Pond Outfall Pump Station and Piping (69 CFS, 48" DIP)[2]**						**$22,524,350**
	Mobilization & Demobilization	LS	$200,000	1	$200,000		
	Temporary Facilities and Controls	LS	$200,000	1	$200,000		
	Clearing (assume minor clearing 20' wide x length of pipe)	AC	$262	20	$5,240	02230-200-0600	
	Silt Fence, Type C (assume double row along length of trench)	LF	$3.00	87,000	$261,000	Recent experience	
	48" DIP Installed Above Ground	LF	$372	43,500	$16,182,000	02510-730-3000 and American Pipe	
	48" DIP Fittings (assume 5% of pipe costs)	LF	$809,100	1	$809,100		
	Pipe Anchor Blocks (assume 2 EA 3'x3'x3' conc @ 100' o.c.)	EA	$263	870	$228,810	03310-240-3800	
	Pipe Anchor Bands (assume 1 EA @ 100' o.c.)	EA	$525	435	$228,375	05540-200-0300 (assume 1/4" x 12" band over pipe)	
	Pump Station (3 (+2) EA Flygt CP3400.835-830/335 HP EA w/Backup Generator installed in new facility)	LS	$3,270,000	1	$3,270,000	Dana Reid of ITT Flygt Corporation, Email Dated 3/28/05, 5:03 PM). Added 50% for Installation, $250,000 for Generator and $20,000 for Instrumentation.	
	Pumping Station Facility and Power Supply	LS	$1,100,000	1	$1,100,000	Recent experience (Mirsada llc)	
	Grassing (assume 20' wide x length of pipe)	AC	$1,900	20	$38,000	02920-320-0200	
	Energy Dissipation Structure, 4.8 CY/EA	EA	$1,825	1	$1,825	03310-240-4200, GDOT STD 1125 Table I	
	SUBTOTAL:						$37,471,338
	Contingency					30%	$11,241,401
	TOTAL:						**$48,712,739**

1) Source of unit costs (unless otherwise noted): "Heavy Construction Cost Data 2004", by RS Means Company, Inc.
2) Approximately 60 days required to empty pond at 69 cfs.

Preliminary Screening Level Opinion of Construction Cost

Prepared by: [signature] 6-6-05
Roger O. Blackwell

Checked by: Stephen A. Lind 6/6/05
Stephen A. Lind

Option II, Reroute Only International Paper & Pump from Pond

ITEM	WORK DESCRIPTION	UNIT	UNIT PRICE	EST QTY	LINE TOTAL	COST SOURCE[1]	ITEM TOTAL
1.0	**Option II-B-2, 30 Day HRT, Pumped to Discharge Point #2**						
1.2	**International Paper Pump Station and Piping to Pond (30 MGD, 36" DIP)**						**$8,326,343**
	Mobilization & Demobilization	LS	$200,000	1	$200,000		
	Temporary Facilities and Controls	LS	$200,000	1	$200,000		
	Clearing (assume minor clearing 20' wide x length of trench)	AC	$262	4	$1,048	02230-200-0600	
	Silt Fence, Type C (assume double row along length of trench)	LF	$3.00	15,000	$45,000	Recent experience	
	Trench Excavation (assume 4' bottom, 1:1 side slopes & 4' cover over pipe)	CY	$2.54	21,500	$54,610	02315-610-0610	
	36" DIP, Class 150 Installed in Trench	LF	$159	7,500	$1,192,500	02510-730-3000 and American Pipe	
	36" DIP Fittings (assume 5% of pipe cost)	LS	$59,625	1	$59,625		
	Trench Backfill	CY	$2.44	19,500	$47,580	02315-610-3020, 02315-310-5040	
	Jacking/Receiving Pits (excludes dewatering)	EA	$19,300	2	$38,600	02445-300-1101	
	Microtunneling, 48" Diameter (includes casing)	LF	$960	5,000	$4,800,000	02441-400-0110 (adverse conditions)	
	36" DIP, Class 150 Installed in Casing	LF	$159	5,000	$795,000	02510-730-3000 and American Pipe	
	8" Air Release Valve	EA	$4,500	2	$9,000	Doug Andrews at Apco Valves. 50% Added for Installation	
	6' Dia Precast MH, 7' Deep	EA	$2,300	2	$4,600	02630-400-1200&1210	
	Energy Dissapation Structure, 3.1 CY/EA	EA	$1,180	1	$1,180	03310-240-4200, GDOT STD 1125 Table I	
	Pumps w/Controls, Instrumentation and Backup Generator (3 (+2) Each Flygt CP3356/810 Impeller/480mm/135HP Each). Assume housed in existing facility with power from existing facility.	LS	$870,000	1	$870,000	Dana Reid and John Rodriguez of ITT Flygt Corporation, (Emails Dated 3/18/05, 2:46 PM and 3:03 PM). Added 50% for Installation, $100,000 for Generator and $20,000 for Instrumentation.	
	Grassing (assume 20' wide x length of trench)	AC	$1,900	4	$7,600	02920-320-0200	
1.4	**Pond Construction. HRT 30 Days, 307 AC x 9' Deep**						**$6,620,645**
	Mobilization & Demobilization	LS	$200,000	1	$200,000		
	Temporary Facilities and Controls	LS	$200,000	1	$200,000		
	Clearing (assume minor clearing)	AC	$262	340	$89,080	02230-200-0600	
	Silt Fence, Type C (assume double row around perimeter of work area)	LF	$3.00	33,500	$100,500	Recent experience	

ITEM	WORK DESCRIPTION	UNIT	UNIT PRICE	EST QTY	LINE TOTAL	COST SOURCE[1]	ITEM TOTAL
	Undercut (assume 2' under footprint of berm disposed of onsite)	CY	$3.09	99,500	$307,455	02315-452-0300	
	Stabilization Fabric (Synthetic Industries Geotex 4x4 or equal)	SY	$2.75	164,500	$452,375	Local Contractor	
	Stabilization Stone	TN	$17	148,000	$2,553,000	02370-450-0100	
	Berm (Assume use of onsite dredge material)	CY	$3.45	335,500	$1,157,475	02315-520-0190, 02315-310-5040	
	Fine grade bottom of pond	AC	$2,904	315	$914,760	02310-100-0100	
	Grassing	AC	$1,900	340	$646,000	02920-320-0200	
1.5	**Pond Outfall Pump Station and Piping (69 CFS, 54" DIP)[2]**						**$39,760,744**
	Mobilization & Demobilization	LS	$200,000	1	$200,000		
	Temporary Facilities and Controls	LS	$200,000	1	$200,000		
	Clearing (assume minor clearing 20' wide x length of pipe)	AC	$262	32	$8,384	02230-200-0600	
	Silt Fence, Type C (assume double row along length of trench)	LF	$3.00	141,000	$423,000	Recent experience	
	54" DIP Installed Above Ground	LF	$456	70,500	$32,148,000	02510-730-3000 and American Pipe	
	54" DIP Fittings (assume 5% of pipe costs)	LF	$1,607,400	1	$1,607,400		
	Pipe Anchor Blocks (assume 2 EA 3'x3'x3' conc @ 100' o.c.)	EA	$263	1,410	$370,830	03310-240-3800	
	Pipe Anchor Bands (assume 1 EA @ 100' o.c.)	EA	$525	705	$370,125	05540-200-0300 (assume 1/4" x 12" band over pipe)	
	Pump Station (3 (+2) EA Flygt CP3400.835-830/335 HP EA w/Backup Generator installed in new facility)	LS	$3,270,000	1	$3,270,000	Dana Reid of ITT Flygt Corporation, Email Dated 3/28/05, 5:03 PM). Added 50% for Installation, $250,000 for Generator and $20,000 for Instrumentation.	
	Pumping Station Facility and Power Supply	LS	$1,100,000	1	$1,100,000	Recent experience (Mirsada llc)	
	Grassing (assume 20' wide x length of pipe)	AC	$1,900	32	$60,800	02920-320-0200	
	Energy Dissipation Structure, 5.8 CY/EA	EA	$2,205	1	$2,205	03310-240-4200, GDOT STD 1125 Table I	
	SUBTOTAL:						$54,707,732
	Contingency					30%	$16,412,320
	TOTAL:						**$71,120,052**

1) Source of unit costs (unless otherwise noted): "Heavy Construction Cost Data 2004", by RS Means Company, Inc.
2) Approximately 60 days required to empty pond at 69 cfs.

Preliminary Screening Level Opinion of Construction Cost

Prepared by: 6-6-05
Roger O. Blackwell

Checked by: Stephen A. Lind 6/6/05
Stephen A. Lind

Option II, Reroute Only International Paper & Pump from Pond

ITEM	WORK DESCRIPTION	UNIT	UNIT PRICE	EST QTY	LINE TOTAL	COST SOURCE[1]	ITEM TOTAL
1.0	**Option II-C-1, 60 Day HRT, Pumped to Discharge Point #1**						
1.2	**International Paper Pump Station and Piping to Pond (30 MGD, 36" DIP)**						**$8,326,343**
	Mobilization & Demobilization	LS	$200,000	1	$200,000		
	Temporary Facilities and Controls	LS	$200,000	1	$200,000		
	Clearing (assume minor clearing 20' wide x length of trench)	AC	$262	4	$1,048	02230-200-0600	
	Silt Fence, Type C (assume double row along length of trench)	LF	$3.00	15,000	$45,000	Recent experience	
	Trench Excavation (assume 4' bottom, 1:1 side slopes & 4' cover over pipe)	CY	$2.54	21,500	$54,610	02315-610-0610	
	36" DIP, Class 150 Installed in Trench	LF	$159	7,500	$1,192,500	02510-730-3000 and American Pipe	
	36" DIP Fittings (assume 5% of pipe cost)	LS	$59,625	1	$59,625		
	Trench Backfill	CY	$2.44	19,500	$47,580	02315-610-3020, 02315-310-5040	
	Jacking/Receiving Pits (excludes dewatering)	EA	$19,300	2	$38,600	02445-300-1101	
	Microtunneling, 48" Diameter (includes casing)	LF	$960	5,000	$4,800,000	02441-400-0110 (adverse conditions)	
	36" DIP, Class 150 Installed in Casing	LF	$159	5,000	$795,000	02510-730-3000 and American Pipe	
	8" Air Release Valve	EA	$4,500	2	$9,000	Doug Andrews at Apco Valves. 50% Added for Installation	
	6' Dia Precast MH, 7' Deep	EA	$2,300	2	$4,600	02630-400-1200&1210	
	Energy Dissapation Structure, 3.1 CY/EA	EA	$1,180	1	$1,180	03310-240-4200, GDOT STD 1125 Table I	
	Pumps w/Controls, Instrumentation and Backup Generator (3 (+2) Each Flygt CP3356/810 Impeller/480mm/135HP Each). Assume housed in existing facility with power from existing facility.	LS	$870,000	1	$870,000	Dana Reid and John Rodriguez of ITT Flygt Corporation, (Emails Dated 3/18/05, 2:46 PM and 3:03 PM). Added 50% for Installation, $100,000 for Generator and $20,000 for Instrumentation.	
	Grassing (assume 20' wide x length of trench)	AC	$1,900	4	$7,600	02920-320-0200	
1.4	**Pond Construction. HRT 60 Days, 614 AC x 9' Deep**						**$9,455,655**
	Mobilization & Demobilization	LS	$200,000	1	$200,000		
	Temporary Facilities and Controls	LS	$200,000	1	$200,000		
	Clearing (assume minor clearing)	AC	$262	650	$170,300	02230-200-0600	
	Silt Fence, Type C (assume double row around perimeter of work area)	LF	$3.00	43,000	$129,000	Recent experience	

ITEM	WORK DESCRIPTION	UNIT	UNIT PRICE	EST QTY	LINE TOTAL	COST SOURCE[1]	ITEM TOTAL
	Undercut (assume 2' under footprint of berm disposed of onsite)	CY	$3.09	128,000	$395,520	02315-452-0300	
	Stabilization Fabric (Synthetic Industries Geotex 4x4 or equal)	SY	$2.75	210,500	$578,875	Local Contractor	
	Stabilization Stone	TN	$17	190,000	$3,277,500	02370-450-0100	
	Berm (Assume use of onsite dredge material)	CY	$3.45	430,000	$1,483,500	02315-520-0190, 02315-310-5040	
	Fine grade bottom of pond	AC	$2,904	615	$1,785,960	02310-100-0100	
	Grassing	AC	$1,900	650	$1,235,000	02920-320-0200	
1.5	**Pond Outfall Pump Station and Piping (92 CFS, 54" DIP)[2]**						**$25,120,993**
	Mobilization & Demobilization	LS	$200,000	1	$200,000		
	Temporary Facilities and Controls	LS	$200,000	1	$200,000		
	Clearing (assume minor clearing 20' wide x length of pipe)	AC	$262	19	$4,978	02230-200-0600	
	Silt Fence, Type C (assume double row along length of trench)	LF	$3.00	82,000	$246,000	Recent experience	
	54" DIP Installed Above Ground	LF	$456	41,000	$18,696,000	02510-730-3000 and American Pipe	
	54" DIP Fittings (assume 5% of pipe costs)	LF	$934,800	1	$934,800		
	Pipe Anchor Blocks (assume 2 EA 3'x3'x3' conc @ 100' o.c.)	EA	$263	820	$215,660	03310-240-3800	
	Pipe Anchor Bands (assume 1 EA @ 100' o.c.)	EA	$525	410	$215,250	05540-200-0300 (assume 1/4" x 12" band over pipe)	
	Pump Station (3 (+2) EA Flygt CP3400.835-830/335 HP EA w/Backup Generator installed in new facility)	LS	$3,270,000	1	$3,270,000	Dana Reid of ITT Flygt Corporation, Email Dated 3/28/05, 5:03 PM). Added 50% for Installation, $250,000 for Generator and $20,000 for Instrumentation.	
	Pumping Station Facility and Power Supply	LS	$1,100,000	1	$1,100,000	Recent experience (Mirsada llic)	
	Grassing (assume 20' wide x length of pipe)	AC	$1,900	19	$36,100	02920-320-0200	
	Energy Dissipation Structure, 5.8 CY/EA	EA	$2,205	1	$2,205	03310-240-4200, GDOT STD 1125 Table I	
	SUBTOTAL:						$42,902,991
	Contingency					30%	$12,870,897
	TOTAL:						**$55,773,888**

1) Source of unit costs (unless otherwise noted): "Heavy Construction Cost Data 2004", by RS Means Company, Inc.
2) Approximately 60 days required to empty pond at 92 cfs.

Preliminary Screening Level Opinion of Construction Cost

Prepared by: 6-6-05
Roger O. Blackwell

Checked by: Stephen A. Lind 6/6/05
Stephen A. Lind

Option II, Reroute Only International Paper & Pump from Pond

ITEM	WORK DESCRIPTION	UNIT	UNIT PRICE	EST QTY	LINE TOTAL	COST SOURCE[1]	ITEM TOTAL
1.0	**Option II-C-2, 60 Day HRT, Pumped to Discharge Point #2**						
1.2	**International Paper Pump Station and Piping to Pond (30 MGD, 36" DIP)**						**$8,326,343**
	Mobilization & Demobilization	LS	$200,000	1	$200,000		
	Temporary Facilities and Controls	LS	$200,000	1	$200,000		
	Clearing (assume minor clearing 20' wide x length of trench)	AC	$262	4	$1,048	02230-200-0600	
	Silt Fence, Type C (assume double row along length of trench)	LF	$3.00	15,000	$45,000	Recent experience	
	Trench Excavation (assume 4' bottom, 1:1 side slopes & 4' cover over pipe)	CY	$2.54	21,500	$54,610	02315-610-0610	
	36" DIP, Class 150 Installed in Trench	LF	$159	7,500	$1,192,500	02510-730-3000 and American Pipe	
	36" DIP Fittings (assume 5% of pipe cost)	LS	$59,625	1	$59,625		
	Trench Backfill	CY	$2.44	19,500	$47,580	02315-610-3020, 02315-310-5040	
	Jacking/Receiving Pits (excludes dewatering)	EA	$19,300	2	$38,600	02445-300-1101	
	Microtunneling, 48" Diameter (includes casing)	LF	$960	5,000	$4,800,000	02441-400-0110 (adverse conditions)	
	36" DIP, Class 150 Installed in Casing	LF	$159	5,000	$795,000	02510-730-3000 and American Pipe	
	8" Air Release Valve	EA	$4,500	2	$9,000	Doug Andrews at Apco Valves. 50% Added for Installation	
	6' Dia Precast MH, 7' Deep	EA	$2,300	2	$4,600	02630-400-1200&1210	
	Energy Dissapation Structure, 3.1 CY/EA	EA	$1,180	1	$1,180	03310-240-4200, GDOT STD 1125 Table I	
	Pumps w/Controls, Instrumentation and Backup Generator (3 (+2) Each Flygt CP3356/810 Impeller/480mm/135HP Each). Assume housed in existing facility with power from existing facility.	LS	$870,000	1	$870,000	Dana Reid and John Rodriguez of ITT Flygt Corporation, (Emails Dated 3/18/05, 2:46 PM and 3:03 PM). Added 50% for Installation, $100,000 for Generator and $20,000 for Instrumentation.	
	Grassing (assume 20' wide x length of trench)	AC	$1,900	4	$7,600	02920-320-0200	
1.4	**Pond Construction. HRT 60 Days, 614 AC x 9' Deep**						**$9,455,655**
	Mobilization & Demobilization	LS	$200,000	1	$200,000		
	Temporary Facilities and Controls	LS	$200,000	1	$200,000		
	Clearing (assume minor clearing)	AC	$262	650	$170,300	02230-200-0600	
	Silt Fence, Type C (assume double row around perimeter of work area)	LF	$3.00	43,000	$129,000	Recent experience	

ITEM	WORK DESCRIPTION	UNIT	UNIT PRICE	EST QTY	LINE TOTAL	COST SOURCE[1]	ITEM TOTAL
	Undercut (assume 2' under footprint of berm disposed of onsite)	CY	$3.09	128,000	$395,520	02315-452-0300	
	Stabilization Fabric (Synthetic Industries Geotex 4x4 or equal)	SY	$2.75	210,500	$578,875	Local Contractor	
	Stabilization Stone	TN	$17	190,000	$3,277,500	02370-450-0100	
	Berm (Assume use of onsite dredge material)	CY	$3.45	430,000	$1,483,500	02315-520-0190, 02315-310-5040	
	Fine grade bottom of pond	AC	$2,904	615	$1,785,960	02310-100-0100	
	Grassing	AC	$1,900	650	$1,235,000	02920-320-0200	
1.5	**Pond Outfall Pump Station and Piping (92 CFS, 60" DIP)[2]**						**$44,517,907**
	Mobilization & Demobilization	LS	$200,000	1	$200,000		
	Temporary Facilities and Controls	LS	$200,000	1	$200,000		
	Clearing (assume minor clearing 20' wide x length of pipe)	AC	$262	31	$8,122	02230-200-0600	
	Silt Fence, Type C (assume double row along length of trench)	LF	$3.00	136,000	$408,000	Recent experience	
	60" DIP Installed Above Ground	LF	$540	68,000	$36,720,000	02510-730-3000 and American Pipe	
	60" DIP Fittings (assume 5% of pipe costs)	LF	$1,836,000	1	$1,836,000		
	Pipe Anchor Blocks (assume 2 EA 3'x3'x3' conc @ 100' o.c.)	EA	$263	1,360	$357,680	03310-240-3800	
	Pipe Anchor Bands (assume 1 EA @ 100' o.c.)	EA	$525	680	$357,000	05540-200-0300 (assume 1/4" x 12" band over pipe)	
	Pump Station (3 (+2) EA Flygt CP3400.835-830/335 HP EA w/Backup Generator installed in new facility)	LS	$3,270,000	1	$3,270,000	Dana Reid of ITT Flygt Corporation, Email Dated 3/28/05, 5:03 PM). Added 50% for Installation, $250,000 for Generator and $20,000 for Instrumentation.	
	Pumping Station Facility and Power Supply	LS	$1,100,000	1	$1,100,000	Recent experience (Mirsada llic)	
	Grassing (assume 20' wide x length of pipe)	AC	$1,900	31	$58,900	02920-320-0200	
	Energy Dissipation Structure, 5.8 CY/EA	EA	$2,205	1	$2,205	03310-240-4200, GDOT STD 1125 Table I	
	SUBTOTAL:						$62,299,905
	Contingency					30%	$18,689,972
	TOTAL:						**$80,989,877**

1) Source of unit costs (unless otherwise noted): "Heavy Construction Cost Data 2004", by RS Means Company, Inc.
2) Approximately 60 days required to empty pond at 92 cfs.