Protecting Our Water Environment

Metropolitan Water Reclamation District of Greater Chicago

100 EAST ERIE STREET CHICAGO, ILLINOIS 60611-3154 312.751.5600

Richard Lanyon
General *Superintendent*

312-751-7900 FAX 312.751.5681

January 23, 2007

Mr. Toby Frevert, Manager
Division of Water Pollution Control
Bureau of Water
Illinois Environmental Protection Agency
1021 North Grand Avenue East
P.O. Box 19276
Springfield, Illinois 62794-9276

Dear Mr. Frevert:

Subject: Evaluation of Management Alternatives for the Chicago Area Waterways: Investigation of Technologies for Supplemental Aeration of the North and South Branches of the Chicago River, Flow Augmentation of the Upper North Shore Channel, and Flow Augmentation and Supplemental Aeration of the South Fork of the South Branch of the Chicago River

The Metropolitan Water Reclamation District of Greater Chicago, at the request of the Illinois Environmental Protection Agency (IEPA), hereby submits the enclosed reports entitled "Technical Memorandum 4WQ: Supplemental Aeration of the North and South Branches of the Chicago River", "Technical Memorandum 5WQ: Flow Augmentation of the Upper North Shore Channel", and "Technical Memorandum 6WQ: Flow Augmentation and Supplemental Aeration of the South Fork of the South Branch of the Chicago River."

Using the services of Consoer Townsend Envirodyne Engineers, Inc., these reports have been developed to evaluate technologies and costs for Supplemental Aeration of the North and South Branches of the Chicago River, Flow Augmentation of the Upper North Shore Channel, and Flow Augmentation and Supplemental Aeration of the South Fork of the South Branch of the Chicago River.

If you have any questions, please contact Mr. Lou Kollias at (312) 751-5190.

Very truly yours,

R Lan VNI--

Richard Lanyon U
General Superintendent

JS:TK
Attachments
cc: L. Kollias, MWRD
R. Sulski, IEPA

FINAL 01/12/07

TECHNICAL MEMORANDUM 4WQ

SUPPLEMENTAL AERATION OF THE NORTH AND SOUTH BRANCHES OF THE CHICAGO RIVER

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

NORTH SIDE WATER RECLAMATION PLANT AND SURROUNDING CHICAGO WATERWAYS

Submitted by:

CTE | AECOM

Revision 4 – January 12, 2007

MWRDGC Project No. 04-014-2P
CTE Project No. 40779

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SUPPLEMENTAL AERATION OF THE NORTH AND SOUTH BRANCHES OF THE CHICAGO RIVER (TM-4WQ)

INTRODUCTION

Background

Consoer Townsend Envirodyne Engineers, Inc. (CTE) was retained in 2005 by the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) to provide engineering services to prepare a comprehensive Infrastructure and Process Needs Feasibility Study (Feasibility Study) for the North Side Water Reclamation Plant (WRP). As part of the scope of work for the Feasibility Study, CTE was directed to determine the technologies and costs of water quality management options which originated from the on-going Use Attainability Analysis (UAA) being conducted by the Illinois Environmental Protection Agency (IEPA) of the Chicago Area Waterways (CAWs). The CAWs are shown in Figure 4.1.

This report presents the results of a study of one of the water quality management options that originated from the UAA, namely supplemental aeration of the North and South Branches of the Chicago River (NBCR and SBCR, respectively). The principal objective for this supplemental aeration study is to improve the dissolved oxygen concentrations in the NBCR and SBCR. Supplemental aeration of the NBCR and SBCR is among several water quality management options studied by CTE. Other water quality management options are discussed in separate reports. These reports are not designed to determine which (if any) of the water quality management options should be implemented. Such a determination can only be made by conducting a comparison of the costs and benefits of all the management options and then developing a water quality management plan which combines the most cost effective option into an integrated strategy for improving water quality of the CAWs. Such an integrated study has not been developed at this time.

UAA Process

The Clean Water Act requires the states to periodically review the uses of waterways to determine if changes to the existing water quality standards are needed to support a change in use. Based upon a study of the CAWs, the IEPA had decided that a change may be required in the dissolved oxygen (DO) standards for these waterways.

As part of the UAA the IEPA suggested several water quality management options for improving the DO of the CAWs and asked that the MWRDGC determine the technologies and costs for these options. One of the options that was suggested by the IEPA was supplemental aeration of NBCR and SBCR.

Supplemental Aeration

Supplemental aeration is a water quality management option which has the potential for improving the DO of NBCR and SBCR. This option was studied in this report.

Supplemental aeration is already being practiced in the CAWs by the MWRDGC. Two supplemental aeration stations exist on the North Shore Cannel (NSC) and the North Branch of the Chicago River (NBCR) at Devon and Webster Avenues, respectively. These stations provide aeration by means of porous ceramic diffusers at the bottom of the waterway. The diffusers are supplied with air from an on-shore blower facility at each station. Along the Little Calumet River, Calumet River and Cal-Sag Channel waterways, the MWRDGC has five supplemental aeration stations utilizing sidestream aeration where low lift pumps remove a portion of the flow from the waterway and aerate this flow using a free-fall weir system which subsequently returns the flow back to the waterway.

Objective and Scope of Study

As noted above, the IEPA requested that the MWRDGC study the potential technologies, opinion of probable costs and impacts for supplemental aeration of the NBCR and SBCR. The objective of this study was to determine the potential supplemental aeration technologies and opinion of probable costs to achieve possible future regulatory dissolved oxygen (DO) levels for these waterways.

CTE developed a long list of supplemental aeration alternatives. Using an evaluation matrix based upon criteria fromTM-1 and input from the MWRDGC, CTE then prepared a short list of potential supplemental aeration alternative technologies.

Based upon simulation runs using the Marquette University model, the aeration capacity and location of supplemental aeration stations needed to supplement the dissolved oxygen in the NBCR and the SBCR was determined. For each short listed alternative, CTE then prepared a conceptual layout and cost estimate for the aeration stations determined from the Marquette Model.

The MWRDGC did not intend this study to reach a conclusion regarding the best supplemental aeration technology for implementation or to provide design criteria of a supplemental aeration system for the NBCR and SBCR. Therefore, CTE prepared a short list of potential technologies and estimated the costs to illustrate the potential range of expenditures for supplemental aeration of the SBCR and NBCR. The cost estimates are planning level opinion of probable costs with a potential variation of $\pm$ 30 percent.

This study also was not intended to reach a conclusion as to whether supplemental aeration of the NBCR and SBCR should be implemented. Such a decision should be reached only after integrated study of all IEPA requested water quality management options is conducted. This study would determine the relative costs and benefits of these options and then determine their priority for potential implementation. Such an integrated study is beyond the scope of this Technical Memorandum.

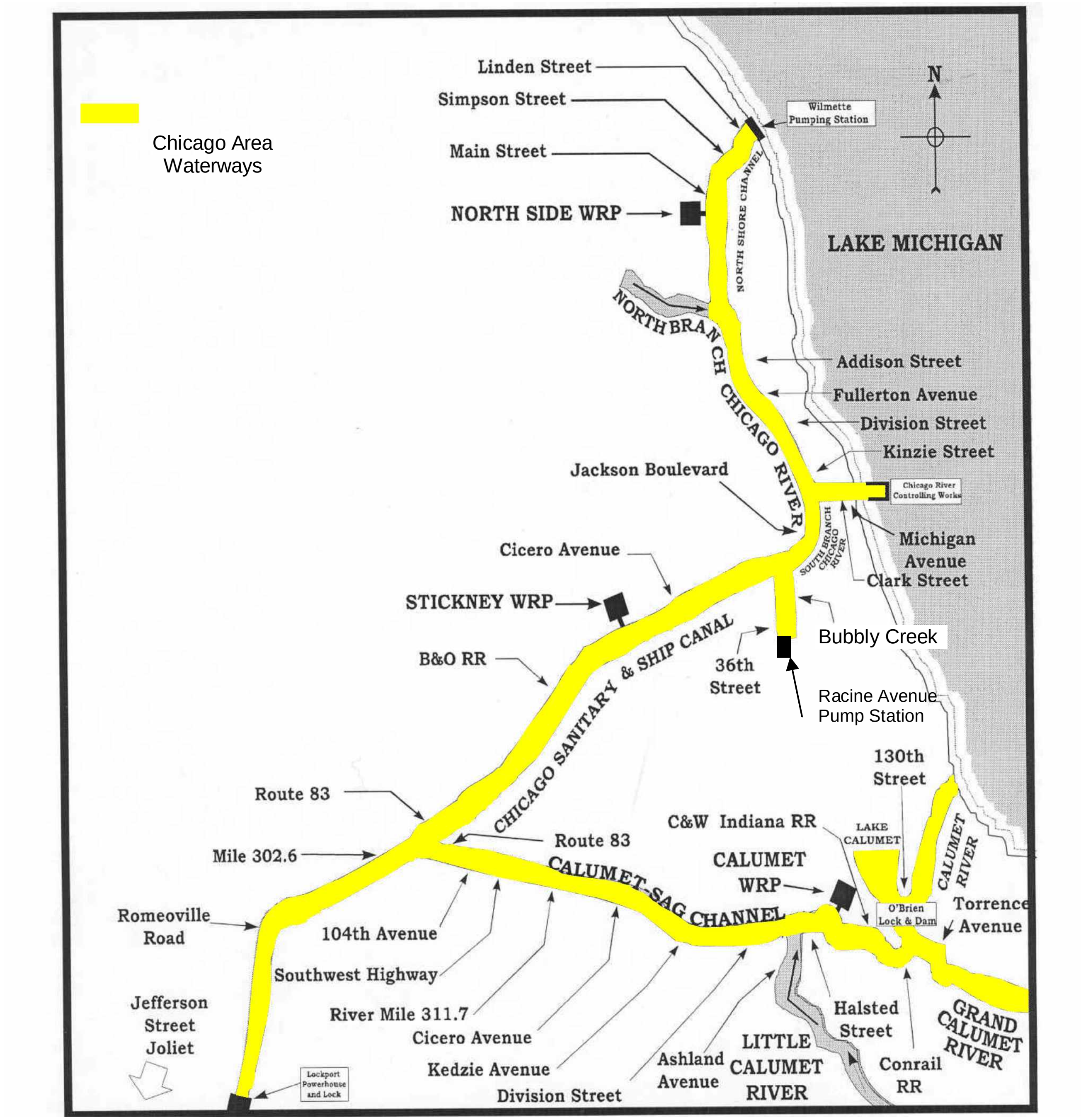

Figure 4.1 – The Chicago Area Waterways

Waterway Target Dissolved Oxygen Standards

The IEPA has not yet made a decision as to the dissolved oxygen standards for the NBCR and SBCR. However for the purposes of this supplemental aeration study of the NBCR and SBCR, it was necessary to assume a target dissolved oxygen standard.

After discussions with the MWRDGC, it was concluded that the target dissolved oxygen water quality standard would be 5 mg/l. Because of the highly variable nature of the NBCR and SBCR due to wet weather flows, etc., it was decided that 90% compliance with the 5 mg/l standard would be reasonable. Thus, this is the regulatory target used to determine the size and location of supplemental aeration of the NBCR and SCBR. The model was used to locate and size the station needed in addition to the existing MWRDGC station at Devon and Webster Avenues.

It should be stated here that the DO regulatory target should not be considered to be a recommendation of the MWRDGC for the NBCR and SBCR. This target was chosen because it is necessary to have a target in order to determine the size and location of supplemental aeration stations on the SBCR and NBCR. It may well be that a lower standard will be protective of the SBCR and NBCR. It is hoped however that the IEPA will recognize that it is virtually impossible to meet a standard 100 percent of the time. Thus a standard which requires less than 100% compliance should be considered in the UAA process as was done in this report.

Chronology of Past Supplemental Aeration Studies

The MWRDGC has been at the forefront of the development and the implementation of innovative concepts to improve wastewater treatment and instream water quality since its inception over a hundred years ago. Consequently, not surprisingly, it has been a leader in developing systems and methods for improving instream dissolved oxygen levels via supplemental aeration. During 1914, the MWRDGC studied the feasibility of aerating a portion of the Sanitary and Ship Canal (SSC) flow in galvanized steel tanks and returning it to the waterway. The objective was to determine if the oxygen returned to the canal satisfied an equivalent amount of dissolved biochemical oxygen demand (BOD). The results were inconclusive.

In 1921, a small-scale study was performed by the MWRDGC where Chicago River water was aerated in 100 gallon vitrified tile tanks, indicating that the stream BOD could be satisfied when DO levels near saturation were achieved. Continuing along these experimental lines, tests were conducted by the MWRDGC during 1923 in a wooden tank using air blowers and bottom diffusers. The results of this pilot study were positive. This led to a full-scale instream study. During 1924, an old boat lock (137 feet by 22 feet) at the Lockport power dam was deemed equivalent to a full-scale channel section of water and appropriate for use. Studies considering the effects of water temperature, aeration times, and types and combination of diffuser plates on dissolved oxygen uptake rates were conducted.

The interest in developing techniques and/or methodologies, for achieving supplemental instream aeration by the MWRDGC was reborn in the mid 1950s. During this time, an engineering study was conducted to determine the feasibility of using hydro-turbine aeration (turbine venting) at the Lockport power dam to supply DO to the depleted DO in the waters upstream of the dam as these waters pass through the penstocks and turbines. A conclusion was reached that it was not economically feasible to do so because compressed air would be needed to entrain air into the draft tubes below the turbine runners.

However, in lieu of the less than encouraging results of the turbine venting evaluations conducted in the mid 1950s, other instream aeration methods were considered for use for supplementing the DO in the waters immediately above Lockport. A 1958 report published by the MWRDGC considered using diffused air distributed by porous plates laid on the bottom of the Sanitary and Ship Canal.

A full-scale, instream study was conducted by the MWRDGC in 1963 using two commercially available surface mechanical aerators. The aerators were placed in the forebay above the Lockport dam. The aerators added significant DO poundage to the canal water, but the conclusions were ambiguous as evidenced by the following quote from the report:

> "Engineering studies as to optimum staging of aerators in a waterway system to cope with existing pollution loads would be of value in comparing costs for different techniques of aeration."

During the 1960s and 1970s, the United States Environmental Protection Agency (USEPA) (or precursors) discouraged the use of supplementing instream DO via artificial methods. On April 5, 1977 the General Counsel for the USEPA ruled on a request from the Deputy Assistant Administrator for Water Enforcement entitled "Use of In-stream Mechanical Aerator to Meet Water Quality Standards". This ruling was adamantly against supplemental aeration as quoted below:

> "In-stream aerators should not be recognized as being analogous to low-flow augmentation. Therefore, the Office of Enforcement recommends that the use of these aerators as means of achieving water quality standards following Best Available Treatment (BAT) be denied."

However, the State of Illinois viewed the situation quite differently. On August 29, 1972, the Illinois Pollution Control Board (IPCB) acted upon a three part petition submitted by the MWRDGC on May 3, 1972. Part III requested approval to install instream aerators in the North Shore Channel and North Branch of the Chicago River waterways. The board ruled favorably (by a 5-0 vote) as follows:

> "The MWRDGC's statement mentions its Board of Trustees action of April 29, 1972 authorizing a $1,500,000 instream aeration system for the North Shore Channel to be operative by April 1, 1974…..Instream aeration has been shown to be perhaps three to five times cheaper than higher treatment….and can be installed quickly…..We urge the instream aeration system be completed as soon as possible."

Consequently, to maintain-stream DO levels at or above applicable standards, the MWRDGC adopted an instream aeration implementation program in 1975. This led to the installation of the diffused air system at Devon Avenue, which started operation on February 8, 1979, and at Webster Avenue, which started operating, on June 6, 1980. They have been operating on a seasonal basis since.

The MWRDGC also concluded that DO supplementation was needed on the Cal-Sag Channel/Little Calumet River/Calumet River waterway system. The possible use of methods other than diffused aeration for supplementing DO along the length of the Cal-Sag waterway system was explored. One methodology that was considered was the use of side channel weirs to aerate a portion of the total flow and return it to the main channel. During the summer of 1987 an in-depth weir aeration study was undertaken by the MWRDGC using a full scale pilot plant located on the banks of the Sanitary and Ship Canal. The experimental results indicated that water falling freely over stepped weirs produced excellent aeration. Consequently, the decision was made to install five side stream weir aeration stations along the Cal-Sag waterway system. The stations are now referred to as SEPA (Sidestream Elevated Pool Aeration) stations and have provided oxygen supplementation since they went on-line during 1992 and 1993.

Waterway Modeling of Supplemental Aeration

The MWRDGC retained Marquette University to develop a simulation model of the Chicago Area Waterways including the NBCR and SBCR. This model is described in the report entitled, "Preliminary Calibration of a Model for Simulation of Water Quality During Unsteady Flow in the Chicago Waterway System and Proposed Application to Proposed Changes to Navigation make-Up Diversion Procedures," dated August, 2004. This report was produced by Dr. Charles Melching from the Institute for Urban Environmental Risk Management at Marquette University (Milwaukee, Wisconsin).

The Marquette Model was used to determine the aeration capacity and location of supplemental aeration stations on the NBCR and SBCR. Marquette University conducted various simulation runs to determine the aeration capacity and location of supplemental aeration stations sufficient to achieve 5 mg/l of dissolved oxygen, 90% of the time in the NBCR and SBCR. Percent compliance was determined over all time periods simulated in the Marquette Model.

These time periods were:

Year	Time Period
2001	July 12 to September 14
2001	September 1 to November 10
2002	May 1 to August 11
2002	August 10 to September 23

Model simulations in the Marquette Model include overlapping times periods. It is inappropriate to use overlapping time periods for the evaluation of water quality management options. Therefore, percent compliance in this report does not include overlapping periods. For this report, all the results for the July 12 to September 14, 2001 and May 1 to August 11, 2002 times periods were used, those parts of the time periods of September 1 to November 10, 2001 and August 10 to September 23, 2002 which overlapped with these periods were not used.

For each location in the NBCR and SBCR simulated in the Marquette Model, the percent compliance was calculated based upon the total number of hours out of all time periods that the hourly dissolved oxygen was at or above 5 mg/l. The percent compliance was based upon the new stations needed to be added to augment the existing aeration stations at Devon Avenue and Webster Avenue.

The various modeling runs conducted by Marquette University were based upon discussions between CTE and University staff prior to the runs. The location and sizing of aeration stations on the NBCR and SBCR based upon these modeling runs were discussed at a workshop held with the MWRDGC. The final selected location and sizing of the aeration stations described in this report represent the results of this workshop

Supplemental Aeration Modeling Runs

The Marquette Model was used to determine the aeration capacity and location of supplemental aeration stations on the NBCR and SBCR. For these modeling runs, the following conditions were assumed.

1. Tunnel and Reservoir (TARP) Tunnels are fully operational
2. TARP Reservoirs are not on-line.
3. Other IEPA Requested Water Quality Management Options are not on-line.
4. The existing Devon and Webster in-stream aeration stations are fully operational with three blowers assumed to be in service.

Various model simulation runs were conducted. After discussions between Marquette University, CTE and the MWRDGC, it was agreed that the following supplemental aeration station locations and aeration capacities represent a reasonable scenario for conceptual cost estimation.

Waterways	Location (Cross Street)	Required Oxygen Delivery Capacity
NBCR	Diversey Avenue	30 g/s (5,700/lbs/day)
NBCR	Chicago Avenue	30 g/s (5,700/lbs/day)
SBCR	18th Street	30 g/s (5,700 lbs/day)
SBCR	Halsted Street	80 g/s (15,200 lbs/day)

It should be noted that the 18th Street Station on the SBCR was originally shown by the Marquette Model to be located about 1 mile further upstream. But land availability was lacking at the upstream site. Subsequent model runs showed that the 18th street location achieved the water quality target using the same oxygen capacity (5,700 lbs/day) as found necessary for the upstream site.

This set of supplemental aeration stations achieves a 5 mg/l water quality standard 90 percent of the time for both the NBCR and SBCR. Figure 4.2 is a graph illustrating the percent compliance for this set of supplemental aeration stations from the outfall of the North Side WRP to the junction of the SBCR and the South Fork of the South Branch of the Chicago River (Bubbly Creek). As shown in Figure 4.2, the percent compliance was calculated for all time periods simulated in the Marquette Model.

Figure 4.3 shows a map of the Chicago Area Waterways with the locations of the four supplemental aeration stations as determined by the Marquette model. Also shown in Figure 4.3 are the existing MWRDGC aeration stations at Devon and Webster Avenues.

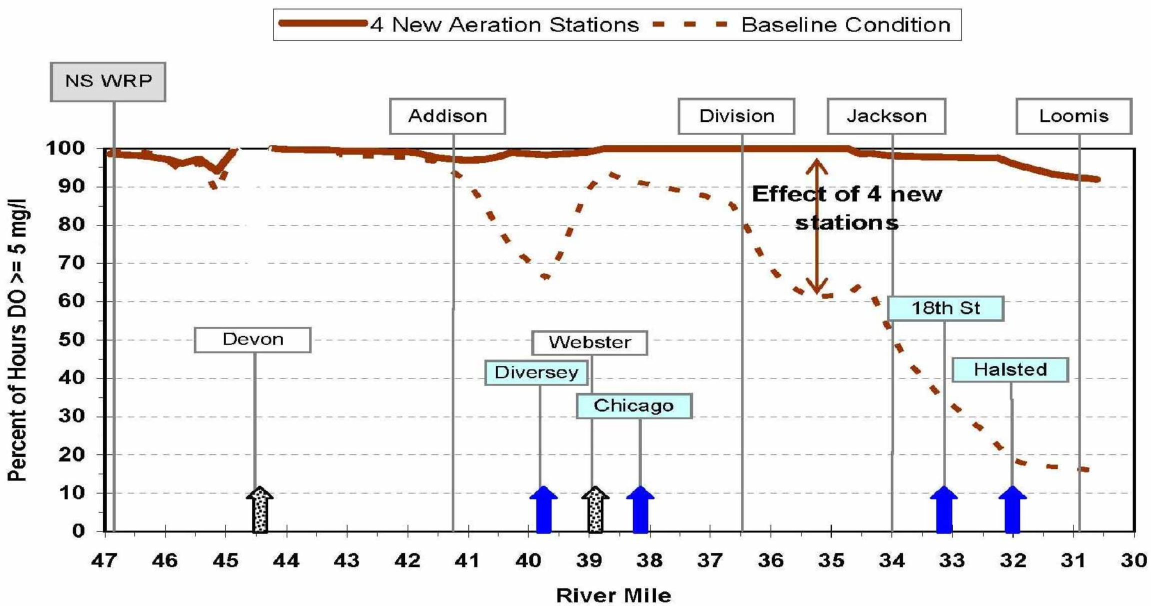

Figure 4.2 – Supplemental Aeration of North and South Branches of Chicago River, Percent of Hours Complying with 5 mg/l Criterion, All Time Periods

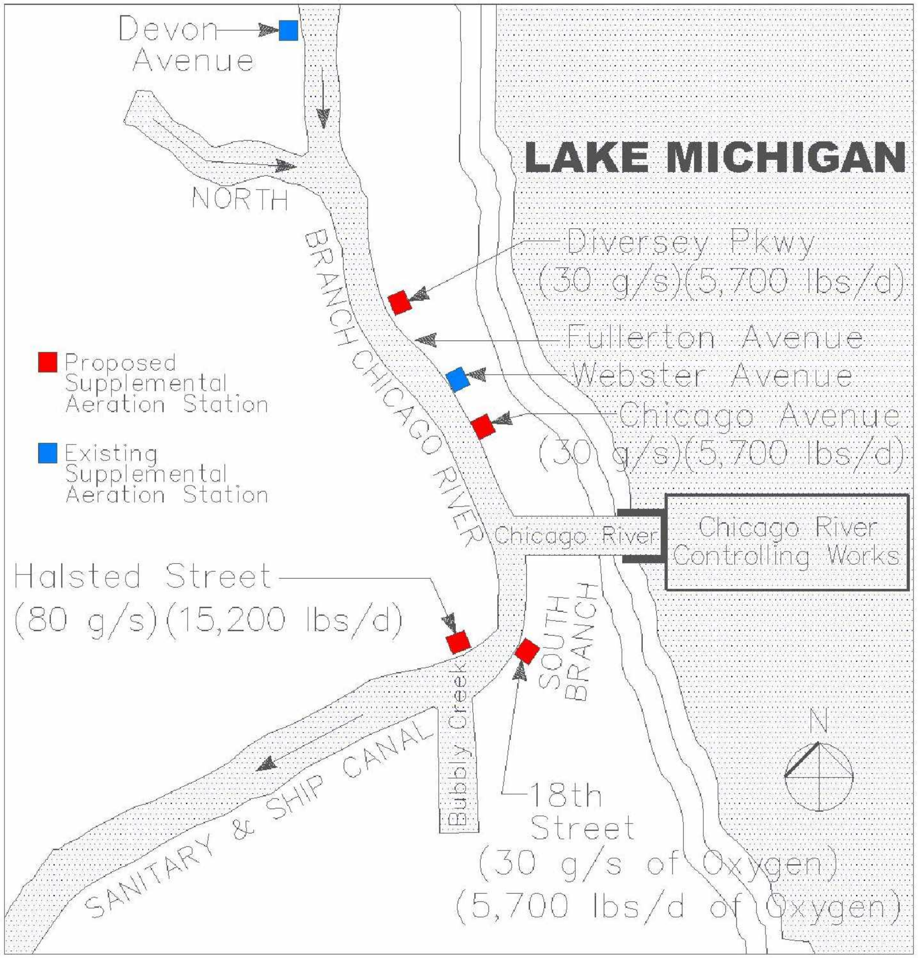

Figure 4.3 – Proposed Aeration Station Sites

LONG LIST OF TECHNOLOGIES

Over the past 25 to 30 years, significant advances in supplemental aeration technologies have been made. Many experts place supplemental aeration methods or procedures into two categories, namely, aeration and oxygenation.

Aeration is defined as using atmosphere air as the oxygen source; whereas, oxygenation is defined as using manufactured oxygen gas as the source. Each of the two categories has many divisions and subdivisions some of which are common to each except for the fact that the sources of oxygen differ.

The acquiescence by regulatory agencies, starting in the late 1970s, in the use of supplemental aeration as a means of improving stream water has led to supplemental aeration equipment and methodologies to be developed and marketed. The object of this section is to explore the possibilities that are currently available for potential use in solving the DO situations that occur in the study area.

The range of options available for supplemental aeration technologies is listed below:

- I. Pressurized Air Diffusers
  - A. Porous Ceramic Diffusers
  - B. Membrane Diffusers
  - C. Jet Ejectors

- II. Head Loss Structures
  - A. Free Fall Weirs
  - B. Cascades

- III. Mechanical Aerators

- IV. U-Tube Bubble Contactors
  - A. Compressed Air Injection

- V. Vaporized High Purity Liquid Oxygen (HPO)
  - A. Pressurized Water Injection with Diffusers
  - B. U-Tube Bubble Contactor
  - C. Mobile (Barge-Mounted) Dispersion

- VI. Screw Pump Aeration

A brief description and discussion of each long list technology will be presented below.

In the sections below, oxygen transfer efficiency (OTE) is defined as the amount of oxygen actually transferred from the gas phase to the liquid phase as a percentage of the oxygen supplied in the gas phase.

I. *Pressurized Air Diffusers:* Many instream aeration systems use atmospheric oxygen supplied by blowers located on shore with the air distributed via instream diffusers. One major design concern is selecting the proper diffuser system to meet instream DO needs while being reasonably compatible with the physical characteristics of a stream.

A. Fine Bubble Porous Ceramic Diffusers. The MWRDGC's Devon and Webster Street instream aeration stations consist of blower-induced air distributed to porous ceramic plates located on the bottom of the North Branch of the Chicago River as shown in Figure 4.4. The stations have been operating continuously for about 25 years; however, both have experienced operation and maintenance problems. Typically these fine bubble diffuser air systems have an OTE of 10-30 percent.

B. Membrane Diffusers: Membrane diffuser systems are generally very flexible and resist fouling due to the following characteristics:

- The membranes are normally closed until sufficient air pressure opens the units to begin operation.
- When the air is interrupted, the membranes close preventing liquid/solids entry.
- Membrane diffusers have only an exterior surface phenomena as the liquid and air interface is at the exterior surface of the membrane compared to the interior of a ceramic rigid media material.
- Operation of a membrane unit involves major flexing during on/off operation with major flexing even during normal airflows. This flexing tends to minimize the accumulation of surface inorganic materials.

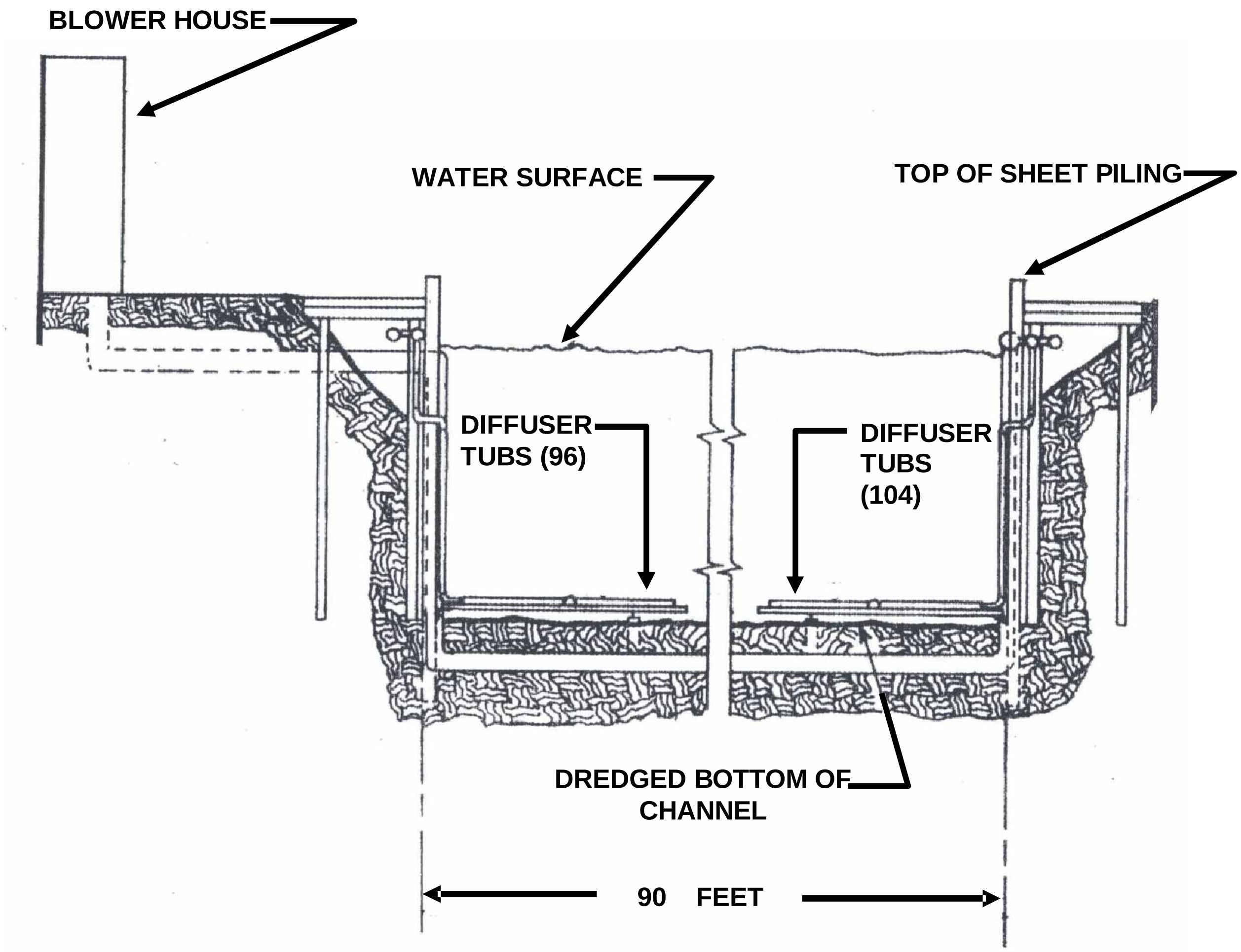

Figure 4.4 – Schematic Diagram of Devon Avenue Instream Aeration Station

- The surface of some membrane materials is quite smooth and slick. These smooth, slick surfaces minimize or eliminate calcium carbonate and other contaminant build-up.
- Typically membrane diffusers have a OTE of 10-30 percent.

C. *Jet Ejectors.* Jet ejectors mix air and water together using a venturi and provide a jet of water containing air bubbles. This jet of water creates good horizontal movement of water over a defined radius or area. Figure 4.5 shows a typical arrangement for a jet aeration system that would apply to waterway aeration.

The horizontal travel of the plume maintains a gas/liquid transfer interface for a much longer period of time than conventional diffused aeration systems. The horizontally mixed plume is enriched with fine bubbles which will rise slowly to the surface providing for excellent oxygen absorption. All mixing occurs below the surface eliminating mist and/or spray problems.

Typically, jet aerators have OTE of 10-25 percent.

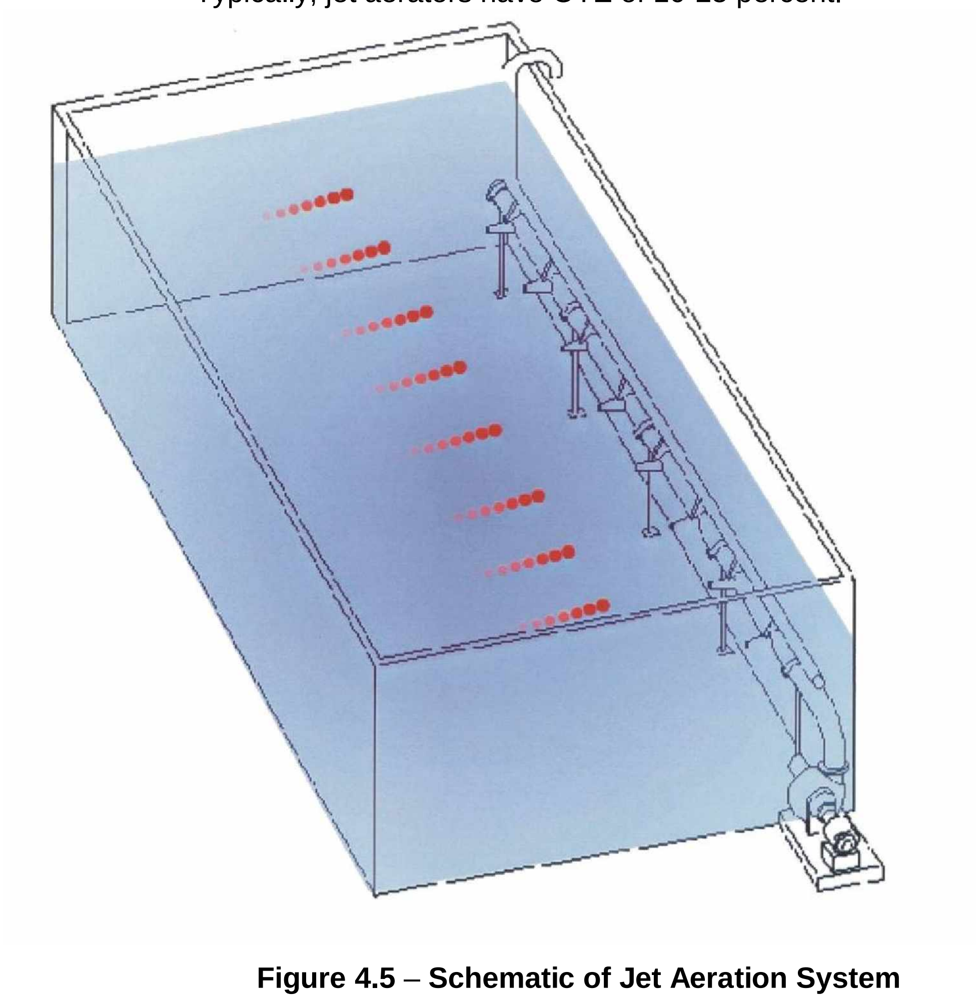

Figure 4.5 – Schematic of Jet Aeration System

II. *Head Loss Structure.* Head loss structures within the stream or waterway can result in aeration. The net gain in DO at the structure depends upon the geometry of the structure versus conditions upstream. Aeration from head loss structures is usually expressed by an equation relating the DO downstream of the structure to the DO upstream, saturation DO and a dam aeration coefficient which is dependent upon the type of head loss structure. The dam aeration coefficient is expressed per unit length of the structure. Structures with higher coefficients have higher aeration efficiencies.

A. Free-Fall Weirs. Sharp-crested, free-fall weirs have clearly been shown to be excellent aeration devices. Step weirs are a series of free-fall weirs with each free-fall discharging into a deep pool. Step weir installations can be used to supplement instream DO, but they must be built on sidestream diversion channels, similar to the MWRDGC's Cal-Sag waterway SEPA stations. SEPA stations require access to a significant stretch of land parallel and adjacent to the waterway.

Figure 4.6 is a schematic of a three-step weir aeration station.

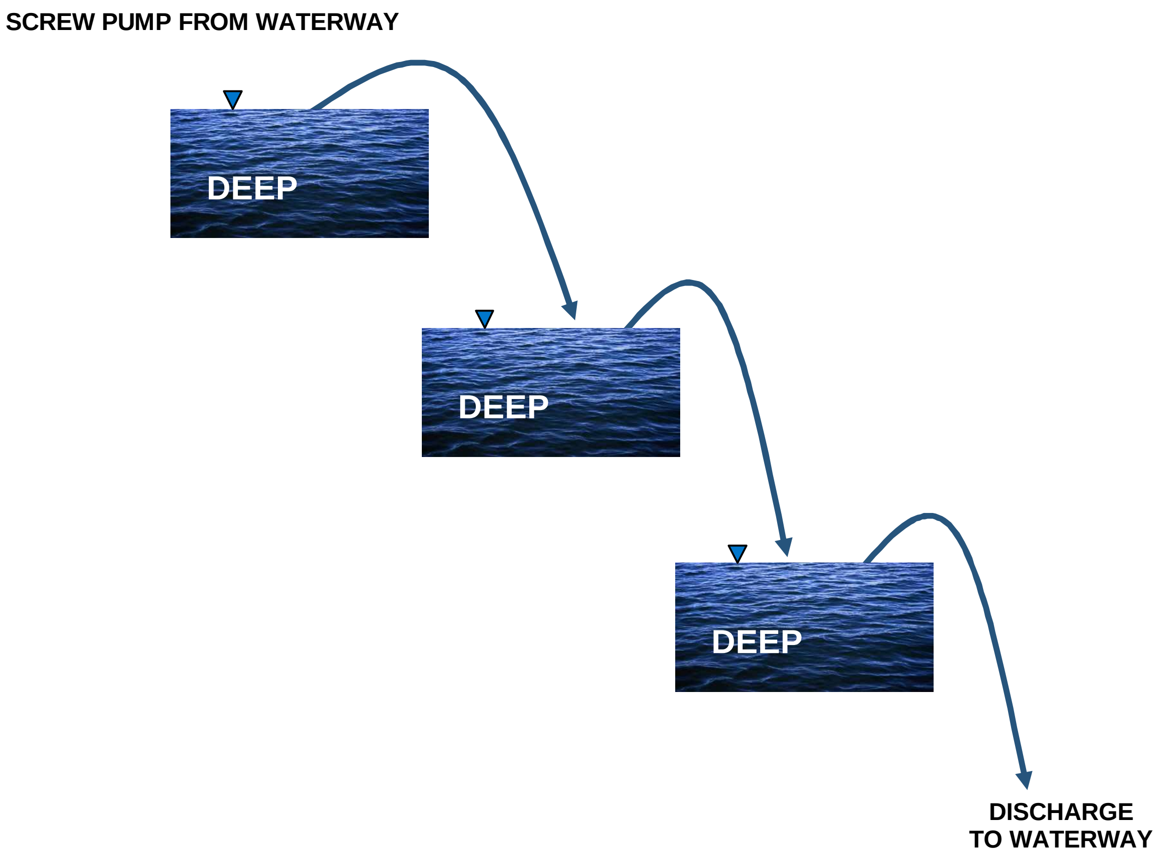

Figure 4.6 – Schematic of 3-Step Weir Supplemental Aeration System

B. *Cascades.* Cascades are defined as structures which cause water to rapidly flow down step inclines in a violent manner without intermittent free-falls followed by pooling.

Three-step cascades are located on two dams in the Fox River in Northeastern Illinois. The dam aeration coefficient for these two dams, determined from extensive field measurements, are 0.65 and 0.72. These values are only a fraction of the range of values (2.4-4.1) recorded for the 3-step SEPA facilities on the Cal-Sag Channel.

III. *Mechanical Surface Aerators.* Historically, mechanical aerators have been classified relative to the axis of rotation, i.e., either horizontal or vertical. These classifications are further subdivided into surface and submerged types. Modern innovations, however, have produced hybrid systems that differ from these simple forms. Virtually all mechanical aerators are designed to mix, aerate, and facilitate the movement of water, and are quite adaptable for use in supplementing stream DO. Typically mechanical aerators have an oxygen transfer rate of 2.0 to 4.0 lbs 0_2/HP-hr.

Critics of mechanical surface aerators say they provide more mixing than aeration and that in deep water minimal turnover of the deeper water is achieved. Moreover, they are vulnerable to damage during high wind, cold weather, high stream flows and from floating trash. Also, their aeration efficiency can be reduced when eddy currents and wind move the downstream aerated water slightly upstream.

Basic surface mechanical aerators have been in use for over 60 years. The MWRDGC's instream aeration studies conducted during warm weather conditions above the Lockport dam during 1926 and 1963 used a Yeoman's Brothers Company HiCoWave Aerator. In the U.S., the earliest installation of surface mechanical aerators as instream aerators was on the Great Miami River in Ohio. Full scale instream aeration studies were conducted during 1965 on the Upper Passaic River and during the late 1960's on the Delaware tidal basing.

Figure 4.7 shows a schematic of a mechanical surface aerator.

IV. *Compressed Air U-Tube Bubble Contactor.* A U-Tube aeration system is a gas transfer process. The "U-Tube" designation is derived from the vertically-oriented, geometric configuration of the water flow into which air or oxygen is injected.

A deep shaft or hole is bored near the water body and is divided by either a flat baffle or a concentric tubular baffle. The shaft and baffle are extended a few feet above the surface of the water body. The baffle ends a few feet above the bottom of the shaft. Aerated or oxygenated water is forced down one side of the flat baffle or inside the tubular one.

The downward water velocity is designed to exceed the buoyant velocity of the air or oxygen bubbles that are released into the water column. Consequently, the bubbles are transferred downward and around the end of the baffle at the bottom, thus, the name U-Tube. This process temporarily pressurizes the bubbles via the large increase in hydrostatic head with the U-Tube. This increases the saturation concentration which, in turn, increases the DO deficit thereby creating a greater driving force for the adsorption of oxygen into the water column. At sea level, a 34-foot head of water creates approximately two atmospheres of pressure inside a gas bubble (one due to the air pressure and one due to the water pressure).

Figure 4.8 shows a schematic of a flat-baffled U-Tube being fed low-pressure compressed air.

Typically, U-tubes can produce OTE's as high as 90 percent.

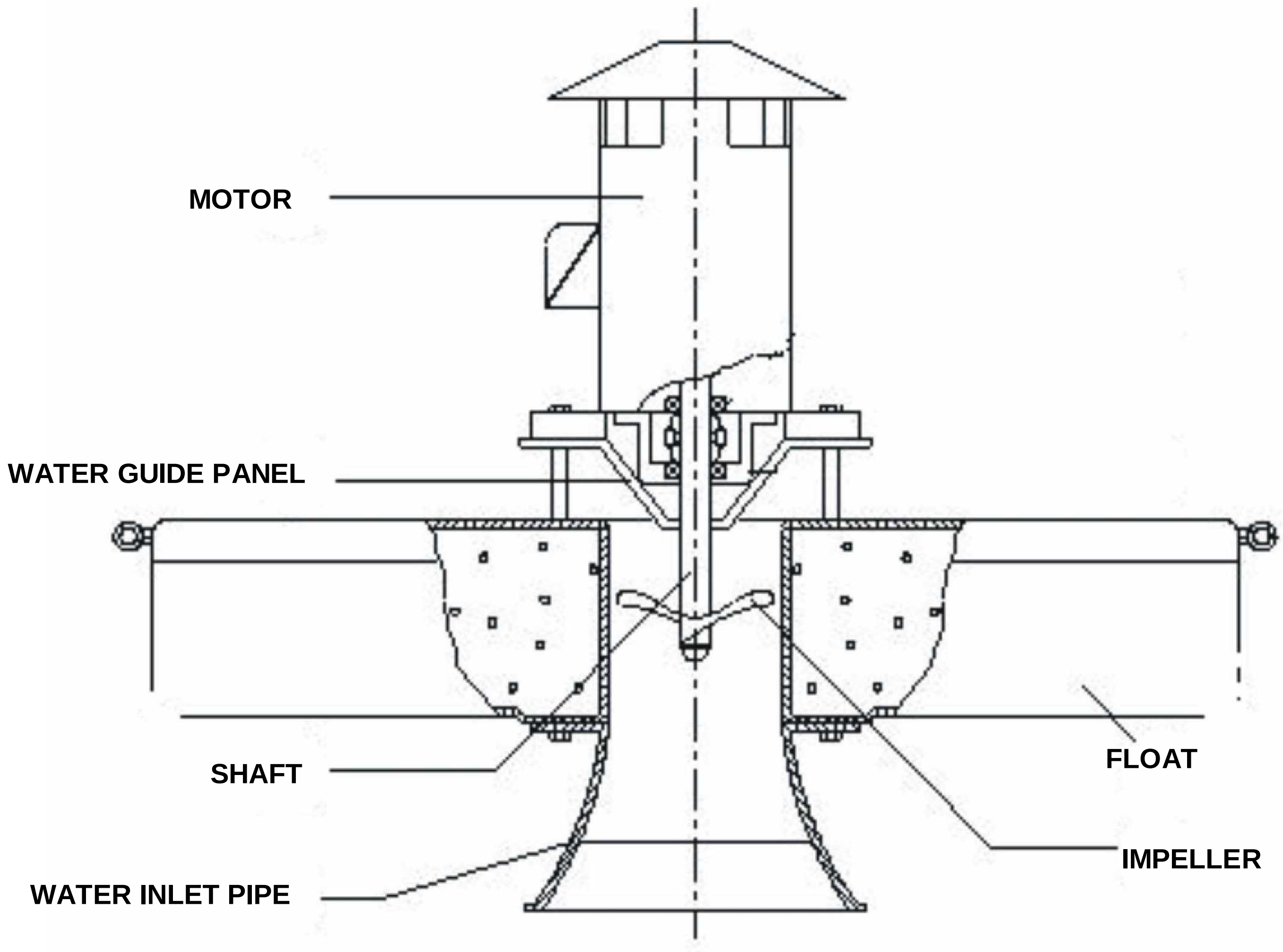

Figure 4.7 – Mechanical Surface Aerator

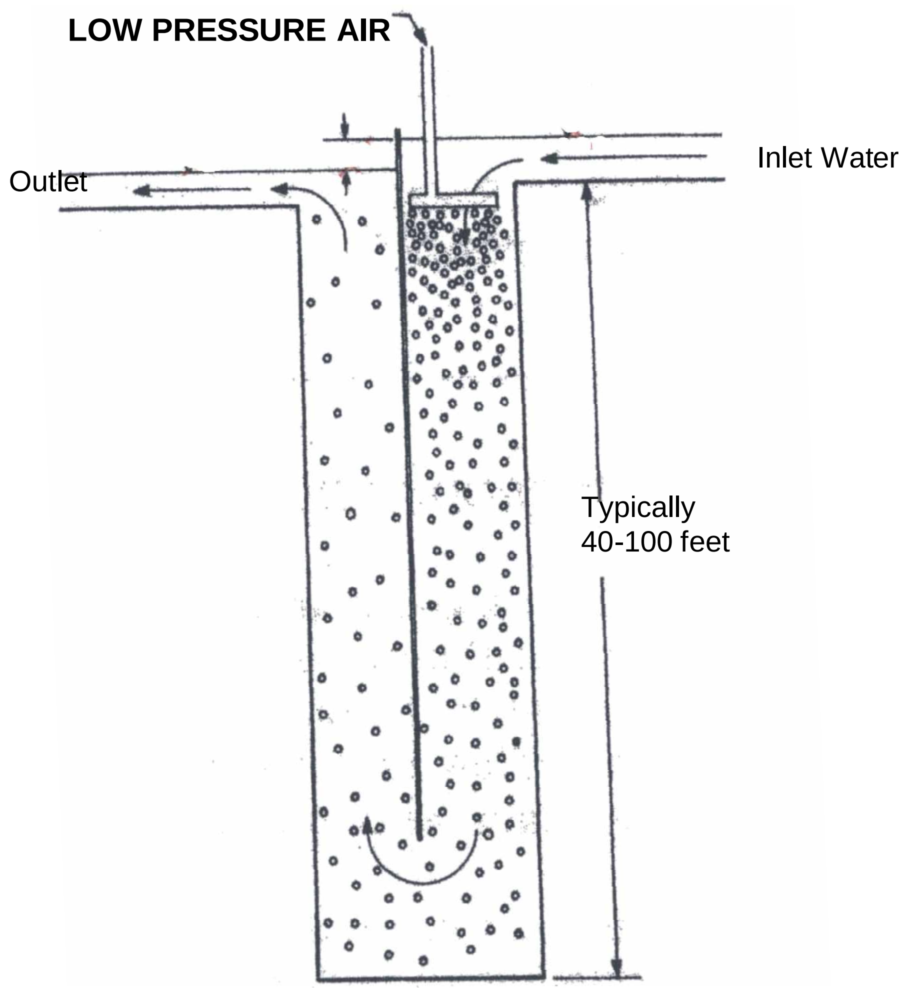

Figure 4.8 – Schematic of Compressed Air U-Tube Contactor

V *Vaporized High Purity Oxygen* (HPO). The use of pure oxygen injection into a water body in lieu of atmospheric oxygen has been heavily promoted for over 35 years. Most installations used "trucked-in" liquid oxygen stored in pressurized cylinders. However, a few installations have been designed to generate pure oxygen on site.

Most applications are for deep water bodies such as lakes, reservoirs, and deep running rivers such as those found below high head hydropower dams. Some success has been achieved by creating artificially deep injection points by injecting the pure oxygen into excavated deep vertical shafts. The basic units inclusive in all designs are a liquid oxygen storage tank, an air-to-air vaporizer, a pressure control system, a bank-side contactor for open water applications, or a side-stream contactor for injection back into the waterway.

The OTEs of HPO systems are highly variable but can be as high as 90 percent.

A. *Pressurized Water Injection With Diffusers.* This system mixes oxygen and water in a pressurized contactor tank. A stream of water is pumped from the water body for use in the contactor. The oxygenated water is then returned to the water body where it is distributed. Several proprietary systems are available, of which the Speece Cone system marketed by ECO_2 is typical.

A conical contactor can be used to mix pressurized water with atomized pure oxygen. These units are typically found in deep lakes, estuaries, and sidestreams on large rivers below hydropower dams. Figure 4.9 shows a schematic of a conical pressurized water HPO contactor. This super oxygenation technology reportedly can produce supersaturated DO concentrations from 50 to 100 mg/L in water when mixed with pure oxygen in the gas-water cone contactor.

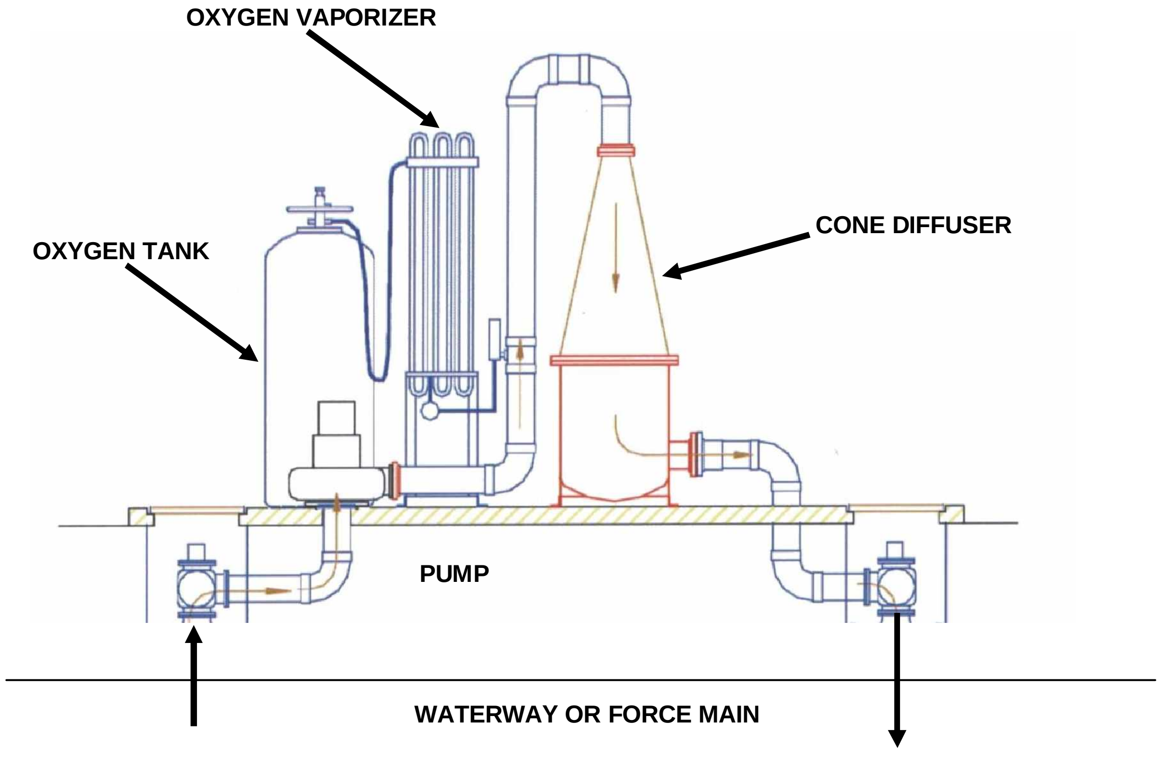

Figure 4.9 – Schematic of Pressurized HPO Contactor

B. *U-Tube Bubble Contactor.* The concept of a U-Tube bubble contactor was previously discussed. While these installations can operate using either compressed air or pure oxygen, many are designed to use pure oxygen "trucked" to the site.

Successful U-Tube oxygenators have been established on deep rivers like the 35-foot deep reach of the Tombigbee River in Alabama. A 175-foot deep bore hole was needed. It produces a 50 mg/l DO concentration at the injection point. The relatively deep river prevented an immediate loss of oxygen to the atmosphere. However, shallow streams and rivers may not be capable of absorbing the oxygen before it comes into contact with air and becomes lost as a gas into the atmosphere.

C. *Mobile (Barge-Mounted) Dispersion.* During the early 1970s researchers at Rutgers University conducted experiments oxygenating the Passaic River estuary with pure oxygen. The oxygen tank and diffusers were mounted on a barge that would transverse the low-DO water in the estuary and disperse the oxygen via the diffusers which were submerged along side the barge.

In 2004, the Liverpool England Harbor authorities deployed a mobile oxygenation barge specifically designed and constructed to treat the harbor for low DO problems (Figure 4.10). A fine bubble diffuser distributes the super oxygenated water at depths from 3 to 25 feet. This system can achieve OTEs as high as 90%.

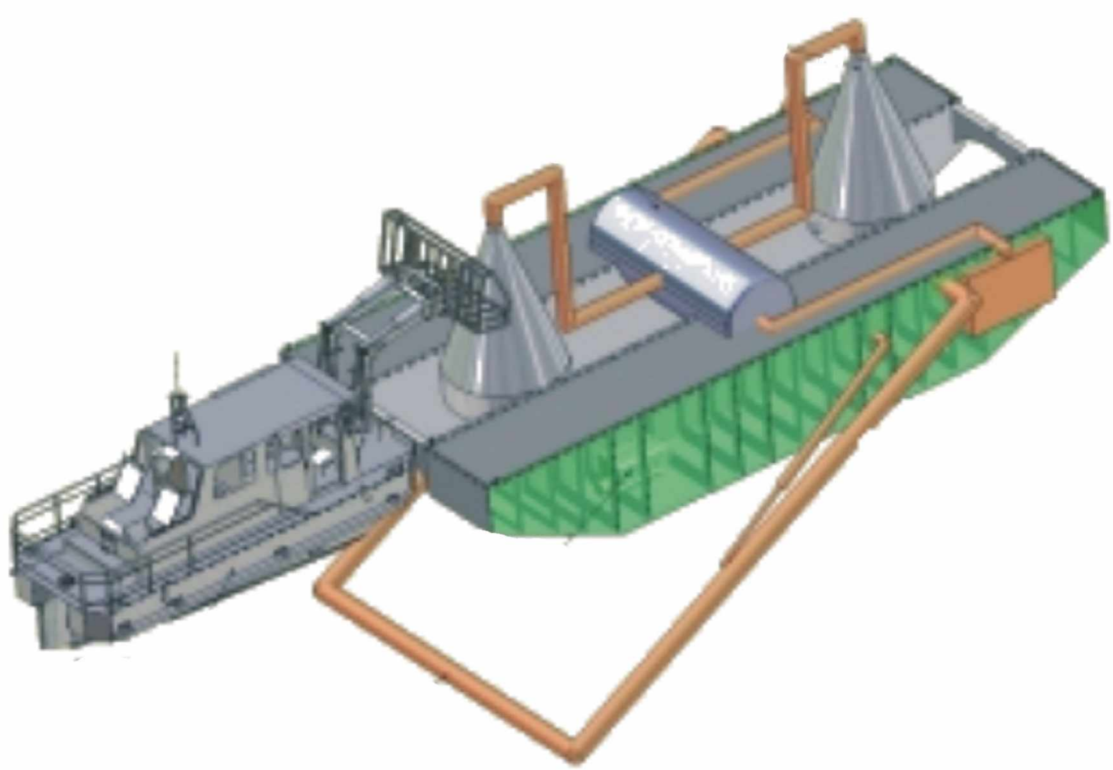

Figure 4.10– Barge Mounted HPO Diffuser System

VI. Screw Pump Aeration. The screw pumps for the existing SEPA stations exhibit significant aeration capabilities. The Oxygen Transfer Rate (OTR) of screw pumps is expressed as pounds of oxygen transferred to the liquid per unit horsepower-hour of the drive motor. The average OTR for Stations 3, 4, and 5 screw pumps were found by the MWRDGC to be 0.91, 0.97 and 0.91 lbs O_2/hp/hr,respectively. Conceivably, a side stream aeration station could be specifically designed using only screw pumps for providing aeration.

EVALUATION

Advantages and Disadvantages of Technologies

In order to simplify the discussions of the advantages and disadvantages of the long listed alternatives, these technologies will be grouped into the following categories:

1) Air Diffusion Systems
2) Head Loss Structures
3) Mechanical Aerators
4) U-Tube Aerators
5) High Purity Oxygen Systems
6) Screw Pumps

Below is a discussion of the advantages and disadvantages of these six categories.

<u>Air Diffuser Systems</u>

The use of compressed air diffusion systems is a proven method for supplemental aeration of waterways. Although there have been operational issues associated with the Devon and Webster in-stream aeration stations, these compressed air diffusion systems have been in operation for over 25 years and are a fairly reliable method for providing aeration of the NBCR.

Jet aerators have not been applied to waterway aeration but this method of air diffusion has been proven to be reliable and effective in wastewater treatment aeration tanks. Jet aerators offer the advantage of good mixing and the elimination of dead zones. Jet aerators are much less likely to clog compared to fine bubble diffusers.

Table 4.1 contains a summary of the advantages and disadvantages of air diffusion systems.

TABLE 4.1
AIR DIFFUSION SYSTEMS – ADVANTAGES & DISADVANTAGES

Advantages	Disadvantages
Proven and well known	Diffuser area will tend to collect waterway debris
No significant waterway traffic obstruction	Diffusers can clog due to sediment accumulation
Blowers and pumps are simple to operate and maintain	Periodic replacement of diffusers is required
With appropriate design, can meet variable oxygen demands	Requires significant shore area for blowers or pumps
Widely available from many manufacturers	May not be applicable to areas where periodic dredging is required.
Can be purchased based upon performance specification	
Jet aerator may aid mixing and eliminate dead zones	Little operating experience for jet aerators for supplemental aeration

Head Loss Structures

Head loss structures offer a simple way of adding oxygen to waterways. The existing SEPA stations are an example of head loss structures which have been in operation for many years providing a reliable method of waterway aeration.

The MWRDGC SEPA stations do have operational issues. These include aquatic weed growth and excessive sediment deposits in the pools. Since these structures need to be placed on-shore to prevent waterway traffic obstruction, the shore space required is quite high especially compared to compressed air diffusion systems.

Table 4.2 contains a summary of the advantages and disadvantages of head loss structures.

TABLE 4.2
HEAD LOSS STRUCTURES – ADVANTAGES & DISADVANTAGES

Advantages	Disadvantages
Except for pumping to side stream sites, no mechanical or electrical equipment is operated or maintained.	Pumping to a side stream site is required to avoid waterway traffic obstruction
Hydraulic structures are generally aesthetically pleasing	Side stream sites can only treat a fraction of the total stream flow
Proven design parameters for free-fall sharp-crested weirs have been developed	Aquatic weed growth and sediment deposits require periodic maintenance of side stream pool
Low lift screw pumps provide beneficial additional aeration	

Mechanical Surface Aerators

Mechanical surface aerators have been successfully used to provide supplemental aeration to waterways. These units are simple and rugged with low maintenance requirements.

However, they have high power demand compared to compressed air diffusion systems, which explains why mechanical aeration systems used in wastewater treatment have been replaced by compressed air fine bubble aeration systems. Also, the units are not attractive and they cause nuisance noise.

Table 4.3 contains a summary of advantages and disadvantages of mechanical surface aerators.

TABLE 4.3
MECHANICAL SURFACE AERATORS – ADVANTAGES & DISADVANTAGES

Advantages	Disadvantages
Simple to operate	Presents waterway traffic obstruction; this can be mitigated
Rugged systems with low maintenance	Are not aesthetically pleasing
Widely available from a number of manufacturers	Vulnerable to damage from high wind, cold weather and high stream flows
Proven technology	High sound level
Can be purchased based upon performance specification	High power demand

U-Tube Aerators

U-Tubes have a high oxygen transfer efficiency and can provide a wide range of aeration quantities. But they have high capital costs and access for maintenance is difficult.

Table 4.4 summarizes the advantages and disadvantages of U-Tube aeration systems.

TABLE 4.4
COMPRESSED AIR U-TUBE CONTACTORS – ADVANTAGES & DISADVANTAGES

Advantages	Disadvantages
High oxygen transfer efficiency	
Can provide wide range of aeration quantities	Access for maintenance is difficult since the tubes are usually placed underground

High Purity Oxygen Systems

The use of high purity oxygen (HPO) in conjunction with various diffusion systems has been highly promoted over the past 30 years, and its application has increased significantly over the last decade. The fact that dissolved oxygen concentrations in water can be significantly increased under pressurized conditions is not disputable, however, what is questionable is how much of this supersaturated gas remains in solution and remains usable upon exposure to normal atmospheric pressure. The HPO supplemental aeration systems, historically, have been applied only to deep bodies of water such as reservoirs and deep rivers such as those which commonly prevail below high-head power dams and flood control structures. Release to water depths of 60 feet or more, with little turnover or mixing, provides the time for the DO to disperse and mix before reaching the surface of a water body. Shallow rivers and streams may not provide the detention time needed for the dispersion of the DO in the water body before being lost to the atmosphere upon exposure at the water surface. Efficient dispersion of supersaturated water in a low D.O. stream is dependent upon the design of the diffuser system which delivers the supersaturated water stream.

Table 4.5 contains a summary of the advantages and disadvantages of High Purity Oxygen systems.

TABLE 4.5
HIGH PURITY OXYGEN – ADVANTAGES & DISADVANTAGES

Advantages	Disadvantages
Excellent oxygen transfer efficiency	Dependent on future price for pure oxygen
Small on-shore space requirements Small space required for trucked in-oxygen More space required for site generated oxygen	Increased truck traffic
Can be operated to meet varying oxygen demands	Complicated oxygen delivery/generation system
	On-site storage of a potentially hazardous material
	Complicated operation and maintenance
	May not be efficient for shallow waterways

<u>Screw Pumps</u>

As stated previously, screw pumps have OTR's of about 0.9 lbs 0_2/hp/hr. This is a rather low OTR compared to fine bubble systems with OTR of 1.97 – 3.2 lbs 0_2/hp/hr ("Wastewater Treatment Plants, Planning Design and Operation" by S. Quasim) or even mechanical surface aeration with OTE's of 1.0 to 2.0 lbs 0_2/hp/hr. Thus, screw pumps by themselves are low efficiency aerators and their use would not be justified unless they would be useful for operation in conjunction with other aeration devices. For example, screw pumps are used in conjunction with free fall weirs at the MWRDGC SEPA stations.

Therefore, screw pumps were eliminated as a long list supplemental aeration technology. However, they will be carried forward as a low lift pumping method for head loss structures.

Scoring of Qualitative Economic and Non-economic Criteria Matrix

The final long list of possible supplemental aeration technologies is as follows:

IA Fine Bubble Porous Ceramic Diffusers
IB Membrane Diffusers
IC Jet Aerators

IIA Free-Fall Step Weirs with Screw Pumps
IIB Cascades with Screw Pumps
III Mechanical Surface Aerators
IV. Compressed Air U-Tubes
VA Pressurized Oxygen Contactor
VB. U-Tube Oxygen Contractor
VC Barge Mounted Diffusers

These long list alternatives were evaluated using the following criteria and weighting factors. These criteria and weighting factors were a consensus decision between CTE and MWRDGC and can be found in Technical Memorandum-3 (TM-3).

Criteria	Weighting Factor
Life Cycle Costs	50
Maintainability	5
Operability	10
Reliability	15
Energy Efficiency	5
Impacts Upon Neighbors	10
Expandability	5
Total	100

Each alternative was scored for each of the above criteria according to the following scale:

Good – 3
Average – 2
Poor – 1

Each alternative was then evaluated relative to the weighting factor for each criteria. For each criteria, the score for each alternative is multiplied by the criteria's weight to arrive at a total score for that criteria. For example, if an alternative receives a score of 3 for a criteria with a weight of 10, the total score for that criteria is 3x10 = 30.

In other technical memorandums, only whole numbers were given as scores for alternatives. However, CTE technical experts found that it was necessary to give fractional scores to some alternatives. This was due to the relatively small differences between some of the supplemental aeration technologies.

Table 4.6 contains the scoring for each alternative for the evaluation matrix. Below is an explanation of the scoring shown in Table 4.6.

<u>Life Cycle Costs</u>

Life cycle costs were based upon the general knowledge of the costs associated with the systems and not based upon a specific cost estimate.

High purity oxygen systems are mechanically complex and the cost to purchase or generate (on-site) the oxygen is high. Therefore all HPO systems were given a score of 1.0.

Mechanical surface aerators are high users of electrical power compared to other aeration systems. Given the rising cost of electricity, this technology was given a score of 1.0.

Cascades are poor aerators requiring high capital costs for a large pump station and a large cascade. This technology was given a score of 1.0..

Free fall step weirs with screw pumps (SEPA concept) have better oxygen transfer efficiency than cascades but require substantial land area and large structures and pump stations. This was given a score of 1.5.

Jet aerators normally require a large blower station compared to fine bubble ceramic diffusers since they have a lower oxygen transfer efficiency. Jet aerators also require a substantial pump station. This technology was given a score of 2.0.

Membrane and ceramic diffusers have a high oxygen transfer efficiency and thus require a relatively small blower station and do not require a pump station. However, membrane facilities have a higher capital cost than ceramic diffusers. Thus, membrane diffusers were given score of 2.0 and ceramic diffusers were given a score of 2.5.

Compressed Air U-Tubes have an excellent oxygen transfer efficiency and due to the high dissolved oxygen achieved, require a small pump station. This technology was given a score of 2.5.

TABLE 4.6

EVALUATION MATRIX

Alternative		Life Cycle Cost	Maintainability	Operability	Reliability	Energy Efficiency	Impacts on Neighbors	Expandability	Total Score
I. Air Diffusion									
I.A. Fine Bubble Ceramic Diffusers	Rank	2.5	2	3	2	2.5	3	3	
	x	X	X	X	x	X	x	x	
	Weight	50	5	10	15	5	10	5	
	Score	**125**	**10**	**30**	**30**	**12.5**	**30**	**15**	**252.5**
I. B Membrane Diffusers	Rank	2	2.0	2.5	1	2.5	3	3	
	x	X	X	X	x	X	x	x	
	Weight	50	5	10	15	5	10	5	
	Score	**100**	**10**	**25**	**15**	**12.5**	**30**	**15**	**207.5**
I.C. Jet Aerators	Rank	2	2	3	1.5	1.5	3	3	
	x	X	X	X	X	X	X	x	
	Weight	50	5	10	15	5	10	5	
	Score	**100**	**10**	**30**	**22.5**	**7.5**	**30**	**15**	**215**
II. Head Loss Structures									
II.A. Free Fall Step Weirs with Screw Pumps	Rank	1.5	2.5	3	3	2.0	3	1.5	
	x	X	X	X	x	X	x	x	
	Weight	50	5	10	15	5	10	5	
	Score	**75**	**12.5**	**30**	**45**	**10**	**30**	**7.5**	**210**
II.B. Cascades with Screw Pumps	Rank	1.0	2.5	3	1	1	3	1.5	
	x	X	X	X	x	x	x	x	
	Weight	50	5	10	15	5	10	5	
	Score	**50**	**12.5**	**30**	**15**	**5**	**30**	**7.5**	**150**

TABLE 4.6 -EVALUATION MATRIX

III. Mechanical Surface Aerators									
III. Mechanical Surface Aerators	Rank	1.5	2	2	2	1	1	3	
	x	X	X	X	x	x	x	x	
	Weight	50	5	10	15	5	10	5	
	Score	**75**	**10**	**20**	**30**	**5**	**10**	**15**	**165**
IV. Compressed Air U-Tube Contactors									
IV.A. Compressed Air U-Tube Contactors	Rank	2.5	2.5	3	1.5	2.5	3	2.5	
	x	X	X	X	x	x	X	x	
	Weight	50	5	10	15	5	10	5	
	Score	**125**	**12.5**	**30**	**22.5**	**12.5**	**30**	**12.5**	**245.0**
V. High Purity Oxygen									
V Pressurized Contactor	Rank	1	1.5	1.5	2.0	1	2	3	
	x	X	X	X	x	x	x	x	
	Weight	50	5	10	15	5	10	5	
	Score	**50**	**7.5**	**15**	**30**	**5**	**20**	**15**	**142.5**
V. U-Tube Contactor	Rank	1	1.5	1.5	2	1	2	2.5	
	x	X	X	X	x	x	x	X	
	Weight	50	5	10	15	5	10	5	
	Score	**50**	**7.5**	**15**	**30**	**5**	**20**	**12.5**	**140**
V Barge-Mounted Diffusers	Rank	1	1	1	2	1	1	3	
	x	X	X	X	x	x	x	X	
	Weight	50	5	10	15	5	10	5	
	Score	**50**	**5**	**10**	**30**	**10**	**10**	**15**	**130**

3 = Good

2 = Average

1 = Poor

Maintainability

HPO systems were given the lowest scores (1.0 to 1.5) because of their mechanical complexity. Barge mounted HPO diffusion was given the lowest score (1.0) of the HPO alternatives because of the need to also maintain the barge transportation system.

Fine bubble ceramic diffusers are a proven technology but based upon the MWRDGC experience at the Devon and Webster stations for supplemental aeration, this technology was given a score of 2.0.

Membrane diffusers should have similar maintenance issues as fine bubble diffusers and were given a score of 2.0.

Mechanical aerators are simple to maintain but maintenance in a waterway will be difficult and these devices were given a score of 2.0.

Although compressed air U-Tube facilities are relatively small due to a high oxygen transfer efficiency, pumps and blowers must be maintained and this technology was given a score of 2.0.

Although the existing SEPA stations have had maintenance issues, maintenance has not been excessive and a score of 2.5 was assigned to this technology.

Lastly, jet aerators were given a score of 2.5 since there are no diffusers to replace or maintain.

Operability

HPO systems are complex to operate and were given the lowest scores. Barge mounted diffusion requires significant navigation skills and was given a score of 1.0 and the other two HPO systems were given a score of 1.5.

Mechanical aeration systems can only be turned off or on as needed to meet DO conditions. As such, they present operational challenges and were given a score of 2.0.

Membrane diffusers were given a score of 2.5 because of their short operating history and no known use for waterway aeration.

Fine bubble ceramic diffusers, jet aerators, free fall weirs, U-tubes and cascades were all given a score of 3.0. These devices are relatively simple to operate and offer the operator significant control.

Reliability

Cascades and membrane diffusers were given the lowest score of 1.0. Cascades are poor aerators and their ability to reliably produce the desired waterway DO level is questionable. There is no known use of membranes for waterway aeration, thus reliability for this application is unknown.

HPO systems can be reliably operated to meet a variety of waterway DO levels, thus these systems were given a score of 2.0.

Fine bubble ceramic diffuser systems have proven reliability for wastewater applications but the MWRDGC experience at the Devon and Webster aeration stations indicates that a score of 2.0 should be applied to this technology.

Step weirs have been used by the MWRDGC to reliably provide supplemental aeration of waterways and were given a score of 3.0.

U-tubes and jet aeration do not have a significant operating history for supplemental aeration and were given a score of 1.5.

<u>Energy Efficiency</u>

Mechanical aerators, cascades and the three HPO options were all given a score of 1.0. Mechanical aerators have a very high energy demand to transfer oxygen. Cascades produce poor aeration in relation to the pumping energy required. The HPO systems utilize high head pumping and significant energy is required to generate the HPO whether it is purchased or produced on-site.

Jet aerators have high energy demands for pumping and blowers and were given a score of 1.5.

Compressed air U-Tubes, and fine bubble ceramic and membrane diffusers require relatively low electrical energy and were given a score of 2.5.

Free fall step weirs using screw pumps are relatively energy intensive since screw pumps are not energy efficient. Thus this technology was given a score of 2.0.

<u>Impacts on Neighbors</u>

Mechanical aerators and barge mounted HPO diffusers were given the lowest score of 1.0. Mechanical aerators are noisy, produce a visible water spray, and represent a hindrance to boat traffic. A barge mounted aerator can hinder boat traffic, is highly visible and will not be aesthetically pleasing.

A HPO contactor will require the use of HPO which would be generated on-site or transported to the site. The operation of a HPO generation plant or transportation of HPO to the site would be objectionable to nearby residences. These systems were given a score of 2.0.

All other aeration systems were given a score 3.0 due to their minimal impacts on neighbors.

<u>Expandability</u>

Free fall step weir facilities and cascades require considerable land space and significant site preparation. Thus these facilities were given a score of 1.5.

Compressed air U-Tubes and HPO U-Tubes were given a score of 2.5 because of the deep excavation required for this technology. All other technologies were given a score of 3.0 because of ease of expansion.

Short List of Technologies

Based upon the evaluation matrix discussed previously, the following four technologies received the highest total scores:

Technology	Total Score
Ceramic Fine Bubble Diffusers	252.5
Compressed Air U-Tube	245.0
Jet Aerators	215.0
Free Fall Step Weirs	210.0

Thus these four technologies constitute the short list of supplemental aeration technologies.

It should be noted that this short list includes two supplemental aeration technologies which have a relatively long operating experience for the MWRDGC (namely Ceramic Fine Bubble Diffusers and SEPA Stations) and two technologies which have relatively little past operating experience for use in supplemental aeration (U-tubes and Jet Aerators). Since the main objective of this study was to determine the relative costs for supplemental aeration and not to select a single technology for possible implementation, no attempt will be made to recommend one of these technologies. Instead, a detailed cost estimate for each of the four technologies will be conducted. Selection of a technology for possible application to the SBCR and NBCR should be done after an extensive review of the operating history of units currently being used for supplemental aeration elsewhere. In addition, it would be worthwhile based upon the expenditures for supplemental aeration to conduct pilot or lab studies of some or all of the short listed technologies before making a final selection and beginning final design.

Since the passage of boat traffic is an important aspect of any supplemental aeration system, this issue should be carefully considered as part of the recommended pilot or lab studies. Also, boat traffic passage should be carefully considered when reviewing the operating history of a supplemental aeration technology.

Land Availability for Supplemental Aeration

Figures 4.11 through 4.14 contain conceptual layouts for the 80 g/s (oxygen) (15,200/lbs/day of oxygen) aeration stations for all four short-listed technologies. This layout for the largest station was prepared so that the maximum space requirements for the four technologies could be determined. The SEPA technology requires the most area with a space requirement of about 1 acre for the 80 g/s (15,200 lbs/day) station. A 30 g/s SEPA station would require about ½ acre.

Using the space requirements for the SEPA station as the maximum space requirement, aerial photographs were examined to determine if sufficient vacant land was available at each of the four supplemental aeration sites. Appendix D contains four figures which show each of the four aeration station locations with an overlay showing the land requirements for the SEPA technology. The Diversey site was not large enough for a 1 acre footprint. However, it is large enough for a ½ acre footprint, which is the size required at this location. The overlay on the Diversey figure in Appendix D shows a ½ acre overlay. Each site has the available vacant land space available for the SEPA technology. Thus, any of the sites could be used for any of the four short-listed technologies without the need for building demolition.

The cost estimates assume that the land needed for the supplemental aeration stations would have to be purchased at a cost of $1.2 million per acre. This land cost is probably conservative since the MWRDGC Engineering Department estimated the highest land cost for property along the NBCR and SBCR to be $675,000 per acre. For simplicity, the SEPA station land requirements were used to obtain land costs for each of the four technologies. That is, one acre was assumed to be needed for a 80 g/s (oxygen) station and 1/2 acre was needed for 30 g/s (oxygen) station.

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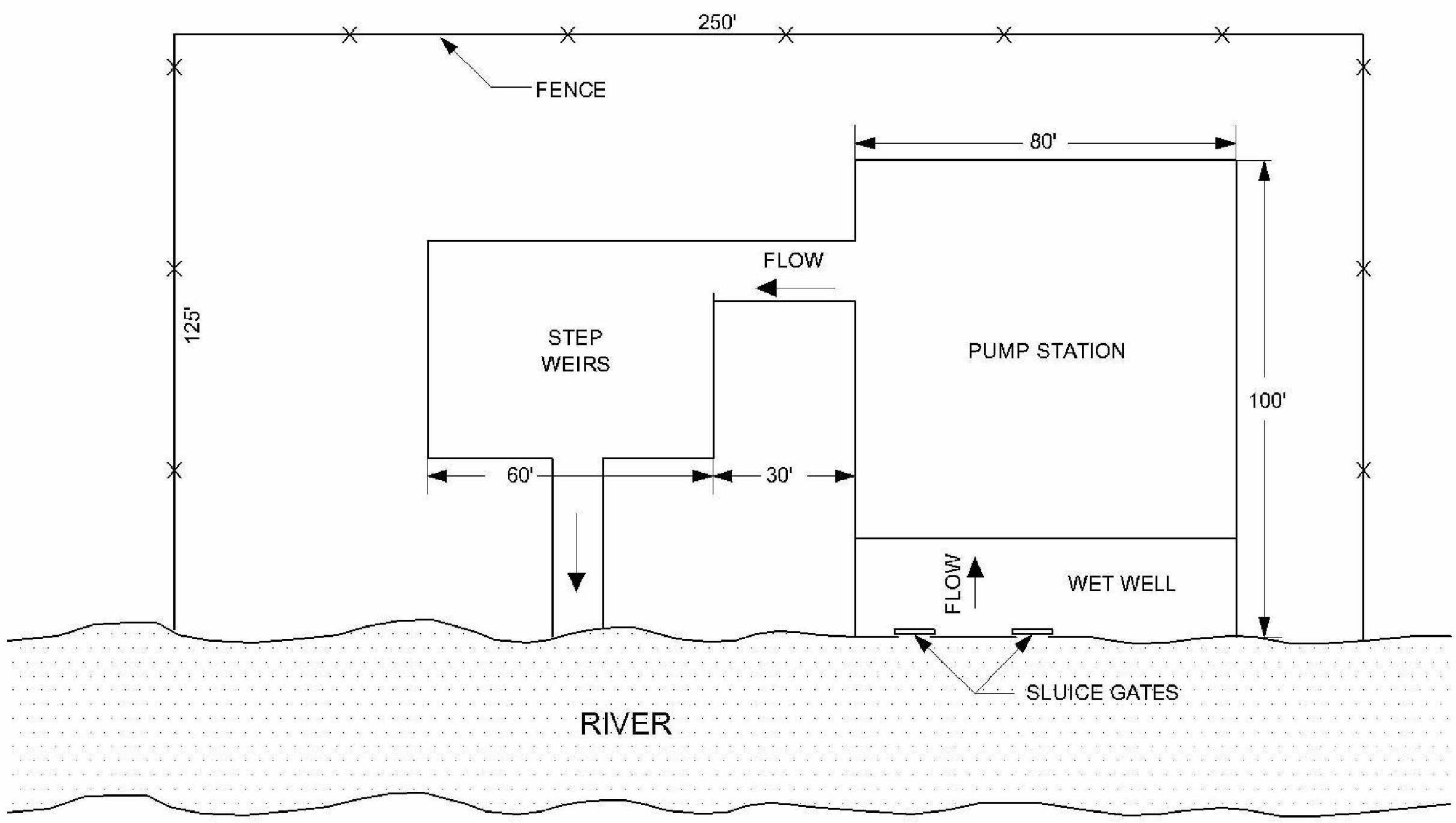

Figure 4.11 – 80 g/s (Oxygen) SEPA Station Conceptual Layout

The jet aeration system requires a building which would contain 19 pumps and 15 blowers. This arrangement is typically used for the KLA Systems Inc. (Assonet, MA) jet aeration process used for cost estimation purposes for this report. This process uses individual manifolds each with 32 jets. For the 80 g/s of oxygen aeration station, a total of 19 manifolds are required. In the typical KLA system design, each manifold uses a single pump and thus 19 separate pumps are required. To supply air to the 19 manifolds, the KLA system design includes 15 blowers (2 standby). The use of this large number of blowers allows flexibility in supply and controlling air to the jet aeration manifolds. If a design of a jet aeration system is contemplated in the future, in all probability a smaller number of pumps and blowers would be selected. However for conceptual cost estimation purposes, this initial design of the jet aeration system is sufficient.

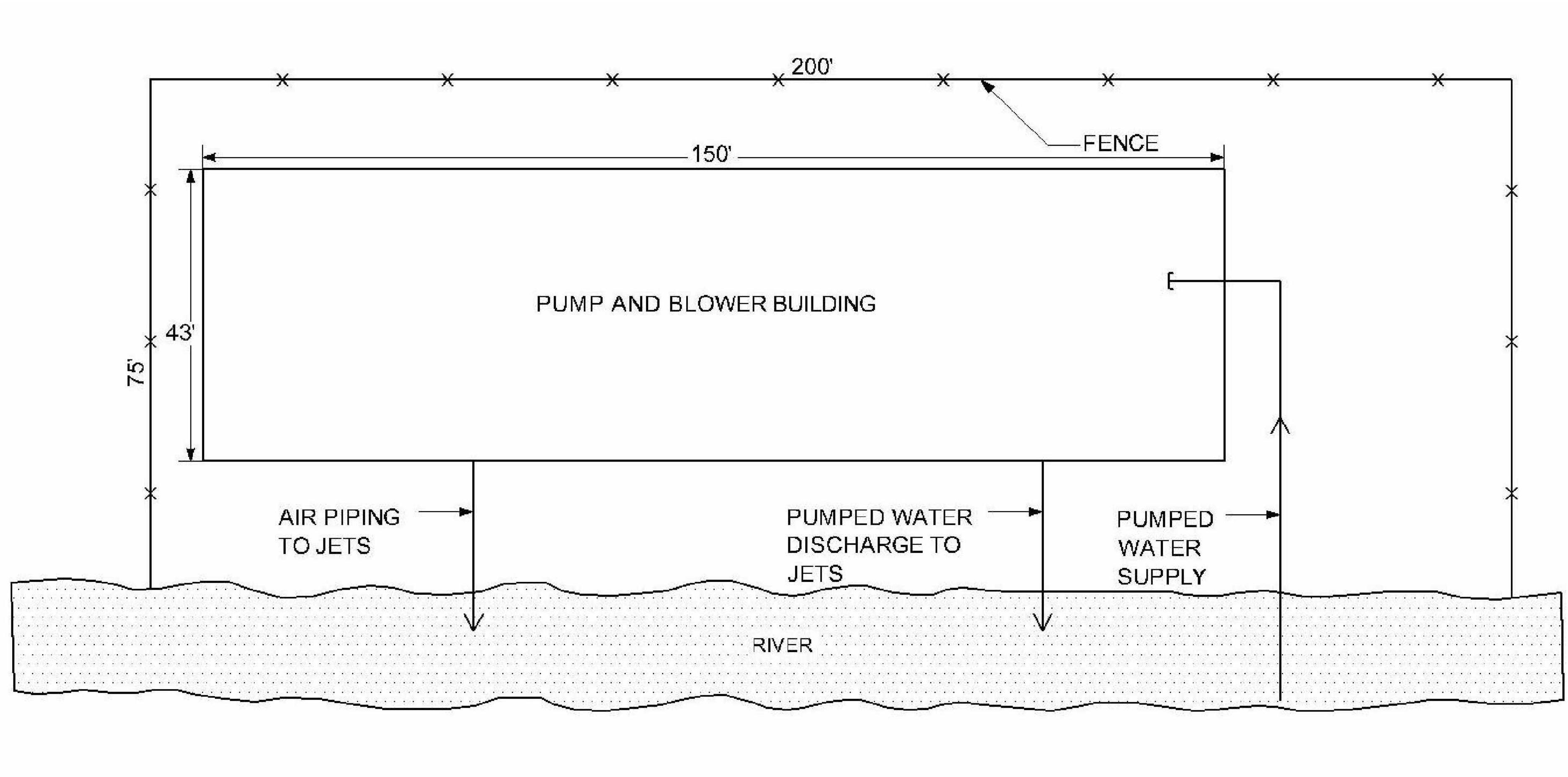

Figure 4.12 – 80 g/s (Oxygen) Jet Aeration Station Conceptual Layout

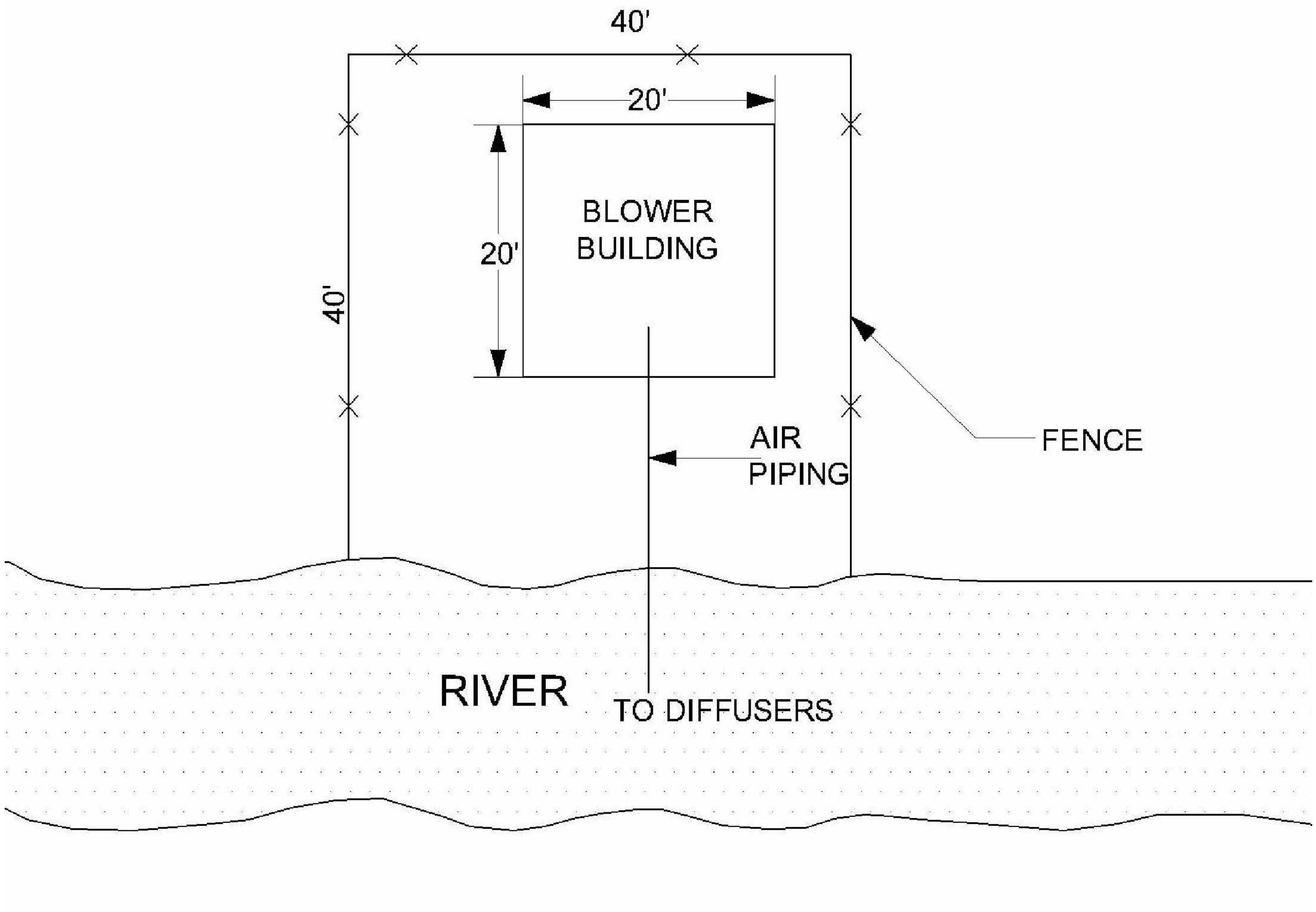

Figure 4.13 – 80 g/s (Oxygen) Ceramic Fine Bubble Diffuser Station Conceptual Layout

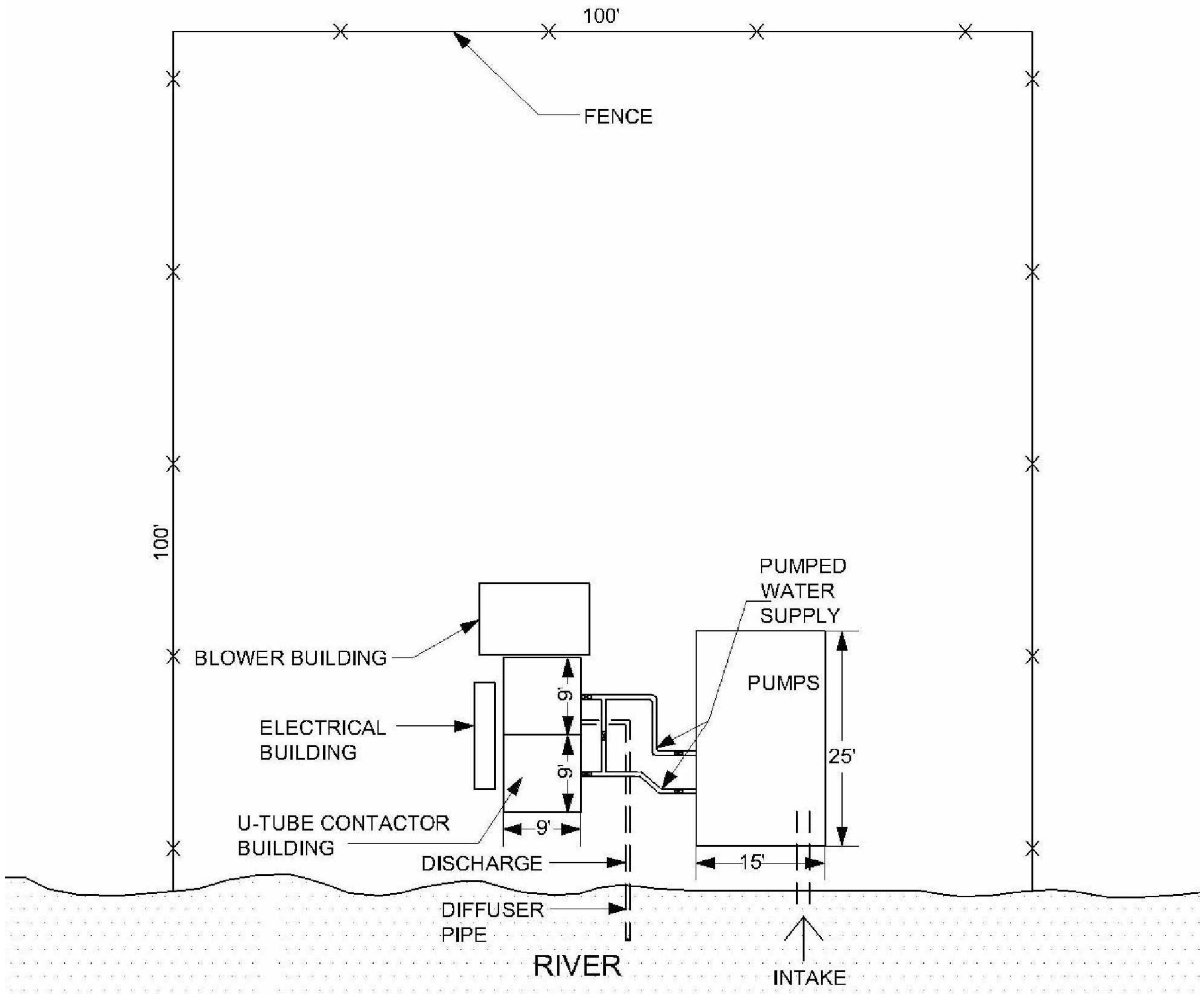

Figure 4.14 – 80 g/s (Oxygen) Compressed Air U-Tube Station Conceptual Layout

Cost of Supplemental Aeration Stations

Appendix A contains the various unit costs utilized to determine the Capital and Operating costs for the four supplemental aeration stations. The unit costs were derived either from TM-3 and/or TM-1WQ.

Appendix B contains the detailed spreadsheets that were used to estimate the capital costs for the 30 g/s (oxygen) supplemental aeration stations. Appendix C contains the detailed spreadsheets that were used to estimate the operating and maintenance costs for the 30 g/s supplemental aeration stations. Cost estimates for the 80 g/s aeration stations were extrapolated based upon the costs for the 30 g/s (oxygen) stations.

Capital and operating costs were estimated for each of the short-listed supplemental aeration technologies which were:

1. U-Tubes
2. SEPA Stations
3. Ceramic Diffusers
4. Jet Aeration

The scope of this conceptual level study precluded an analysis of the application of the four short listed technologies to the various supplemental aeration sites. It may well be that site conditions will dictate the choice of a supplemental aeration technology. Also it may be necessary to conduct full-scale and/or pilot plant studies to determine the design criteria for supplemental aeration stations. For example, the MWRDGC conducted pilot-plant tests of the SEPA concept and the information from these tests were used to design the existing five SEPA stations on the Cal-Sag Channel.

Table 4.7 contains a summary of the capital and annual maintenance and operation costs for the four short-listed technologies. These are the total costs for implementing these technologies at the four locations and aeration capacities determined by the Marquette Modeling runs.

U-tubes and ceramic diffusers represent the lowest present worth. However, these cost estimates are planning level and are based upon general design factors which may not be applicable to the site-specific conditions on the SBCR and NBCR. As stated previously, it would be prudent to select a supplemental aeration technology based upon a review of the operating history of the existing MWRDGC supplemental aeration facilities and other similar facilities elsewhere. Also the design criteria for the supplemental aeration stations should be verified by pilot and/or laboratory studies.

Lastly, a rigorous use of the Marquette Model should be undertaken complete with a sensitivity analysis to determine the final sizing and locations of the supplemental aeration stations. If necessary the model may be refined to ensure that this sizing and location represents the best simulation for the NBCR and SBCR.

TABLE 4.7
SUMMARY OF CAPITAL AND ANNUAL COSTS

Cost of Four Supplemental Aeration Stations on NBCR and SBCR			
	Total Capital	**Annual O&M**	**Total Present Worth**
U-Tubes	$36,282,000	$554,000	$47,362,000
SEPA	$89,939,000	$2,141,000	$132,759,000
Ceramic Diffusers	$35,518,000	$1,070,000	$56,918,000
Jet Aeration	$54,145,000	$2,594,000	$106,025,000

As can be seen in Table 4.7, the range of costs for supplemental aeration for the NBCR and SBCR are as follows:

Capital Costs

$35.5 Million – $89.9 Million

Annual Operation and Maintenance Costs

$554,000 – $2.6 Million

Total Present Worth

$47.4 Million – $132.6 Million

SUMMARY AND CONCLUSIONS

A planning level study was conducted to determine the potential technologies and costs for adding supplemental aeration to the NBCR and SBCR. The supplemental aeration provided would be in addition to the aeration provided currently at the Devon and Webster Avenue diffused aeration stations. To determine the size and location of the additional aeration stations, a water quality simulation model developed by Marquette University for the MWRDGC was used. Since the IEPA has not reached a decision on the DO target levels for the NBCR and SBCR, a target DO of a minimum of 5 mg/l to be achieved 90% of time was selected.

After a review of a long list of technologies using an evaluation matrix which included both non-economic and economic factors from four technologies were selected for a detailed opinion of probable cost estimate.

The opinion of probable cost estimate was based upon constructing a total of 4 additional stations on the SBCR and NBCR. These 4 stations were found to be necessary by Marquette Model runs to achieve the DO target levels 90% of the time for the data base simulated in the Marquette Model (2001 and 2020). The total capital cost ranged from $35.5MM to $89.9MM. The total annual operation and maintenance cost ranged from $554K to $2.6 MM.

It should be noted that the main purpose of the study was to determine the magnitude of the costs associated with supplemental aeration of the NBCR and SBCR and not to select a technology for possible application. Thus, it would be necessary to conduct an in depth study of the operating experience of the four technologies for supplemental aeration. This is especially true for jet aerators and U-tubes where there is little operating experience. Also pilot and full-scale studies of some or all of the technologies should be initiated to refine the cost estimates, help to select a technology for possible implementation, and develop design criteria.

It should also be emphasized that a decision to implement supplemental aeration of the NBCR and SBCR should only be reached after an integrated study of all IEPA requested water quality management options has been undertaken. This study would determine the relative costs and benefits of these options and then determine their priority for potential implementation. Such an integrated study is beyond the scope of this Technical Memorandum.

APPENDIX A
Unit Costs Used in Cost Estimates

UNIT COSTS USED IN COST ESTIMATES

Life cycle cost (LCC) analysis requires the development of certain constants that will be used throughout the evaluation of alternatives. Values used for constants are presented below. These values have been developed in consultation with MWRDGC staff and represent actual values or agreed upon assumptions.

1.	Present Worth Factors for Life-Cycle Costs	
	• Years	20
	• Annual interest rate	3%
	• Annual inflation rate	3%
	• Annuity Present Worth Factor (with inflation)	19.42
2.	Design Life	
	• Structural Facilities	20
	• Mechanical Facilities	20
3.	Electrical Cost	$0.075/kW-hr
4.	Labor Rates Per Hour Including Benefits (1)	
	• Electrician	$159.50/hr
	• Operations	$90.00/hr
	• Maintenance	$90.00/hr
5.	Parts and Supplies	5 percent
6.	Contractor Overhead and Profit (2)	15%
7.	Planning Level Contingency (3)	30%
8.	Engineering Fees including Construction Management (4)	20%

(1) A multiplier of 2.9 was used to reflect benefits as provided by the MWRDGC.
(2) Percent of Total Construction Cost
(3) Percent of Total Construction Cost plus Contractor Overhead and Profit
(4) Percent of Total Construction Cost, Contractor Overhead and Profit plus Contingency

APPENDIX B
Detailed Capital Cost Estimates for Four Short-Listed Supplemental Aeration Technologies

APPENDIX C
Detailed Annual Cost Estimates for Four Short-Listed Supplemental Aeration Technologies

APPENDIX D
Figures Showing Land Availability for Four Supplemental Aeration Stations

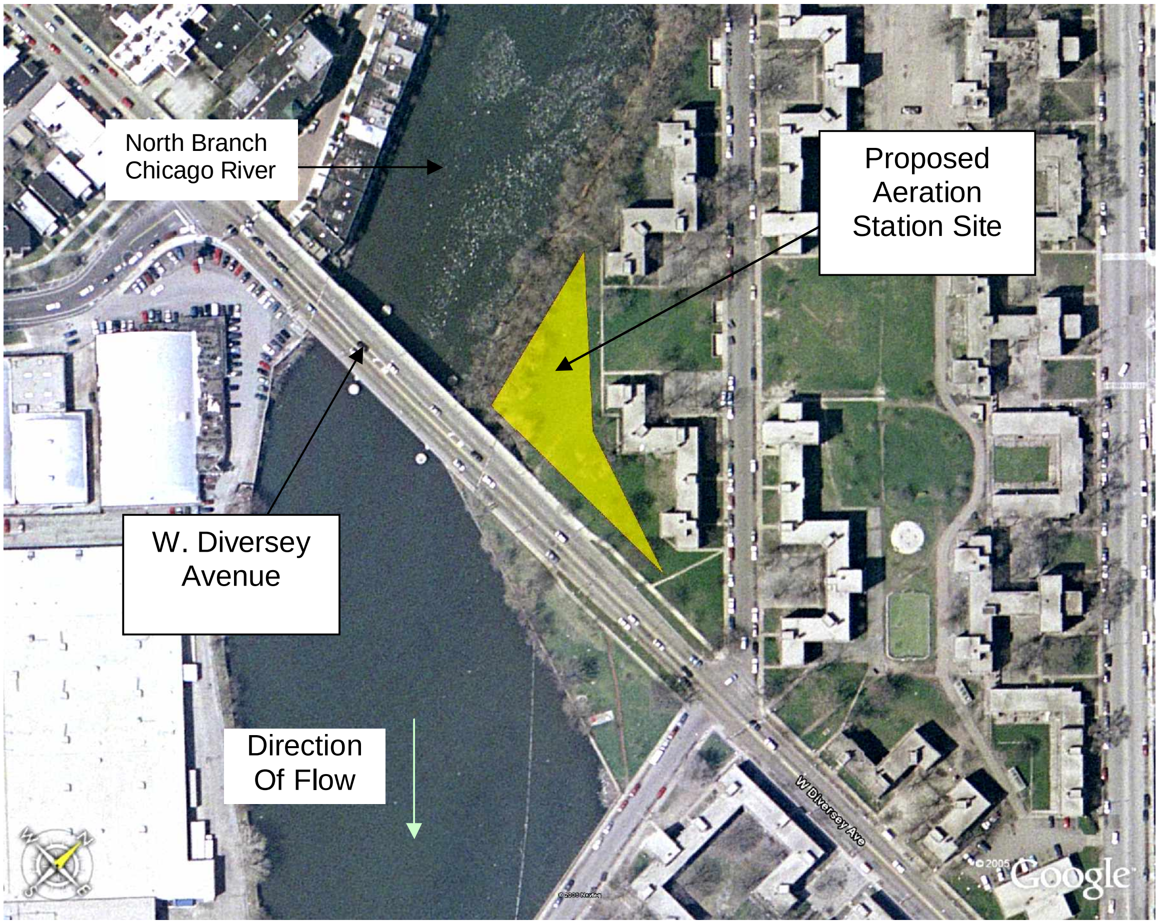

Figure D-1 – Land Availability for 30 g/s SEPA station at Diversey Avenue and the North Branch Chicago River

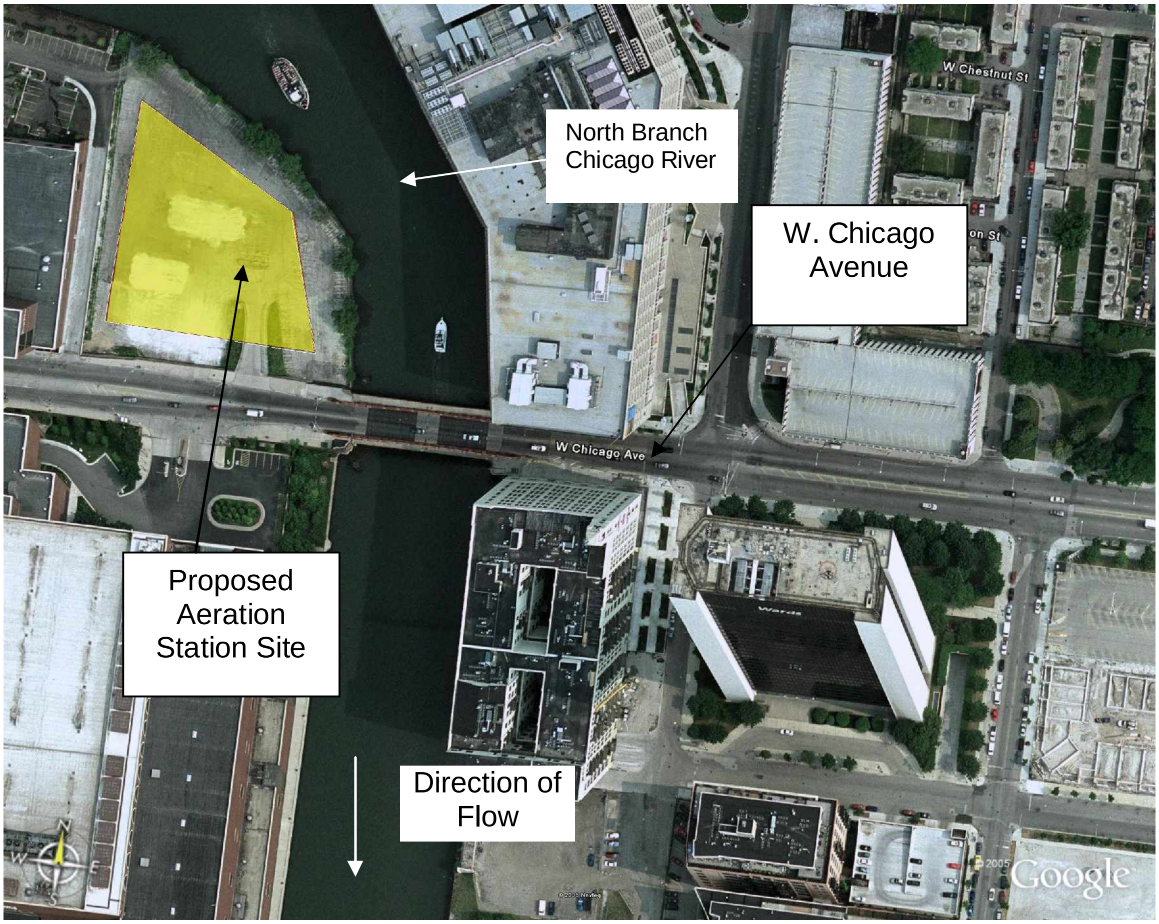

Figure D-2 – Land Availability for 30 g/s SEPA station at Chicago Avenue and the North Branch Chicago River

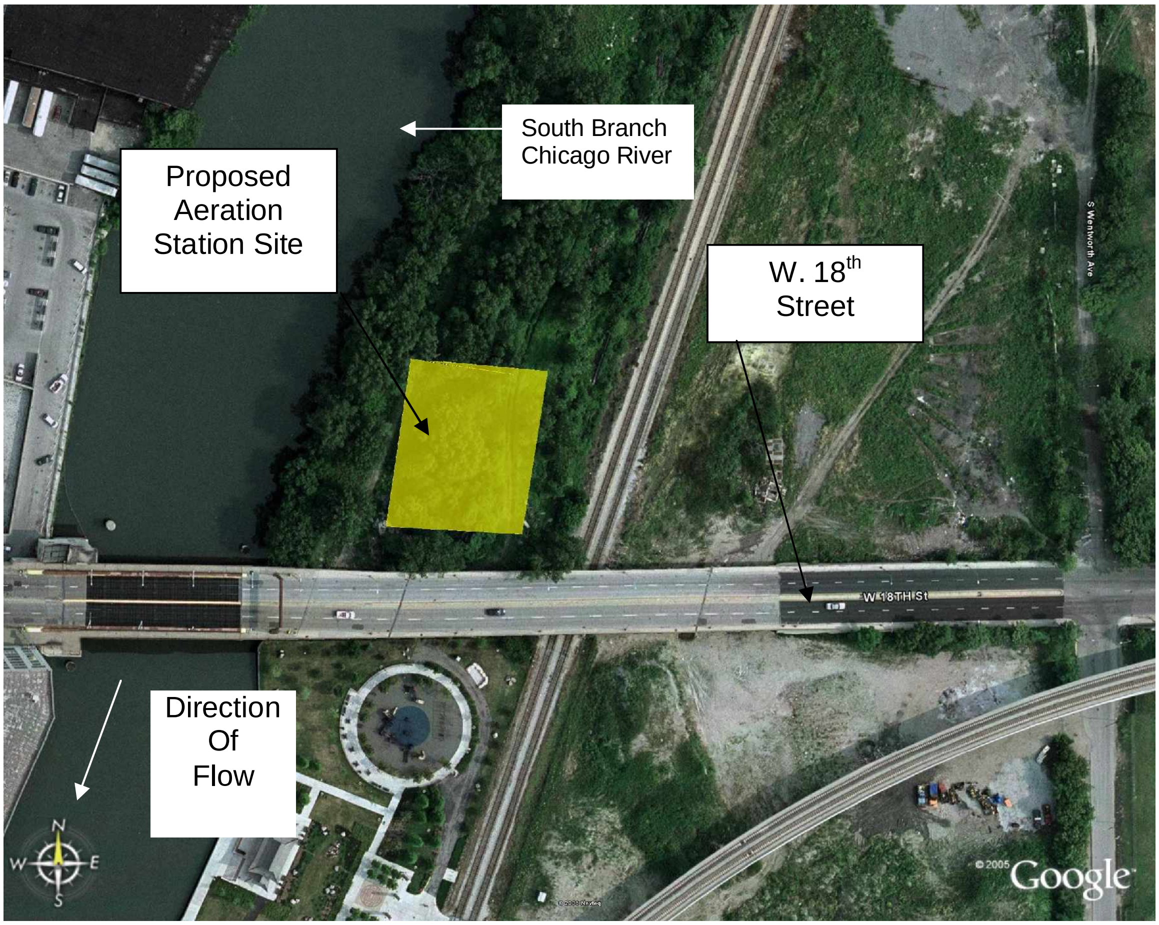

Figure D-3 – Land Availability for 30 g/s SEPA Station at 18th Street and the South Branch Chicago River

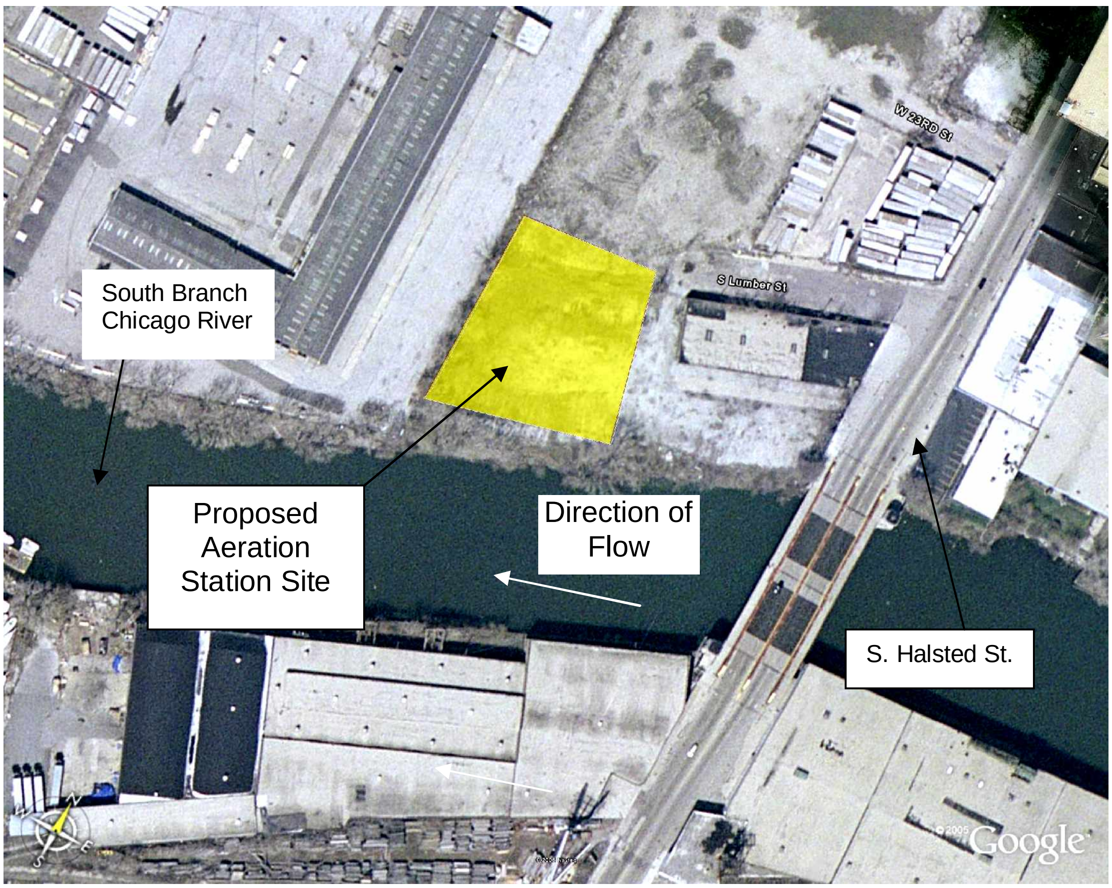

Figure D-4 –Land Availability for 80 g/s SEPA station at Halsted Street and the South Branch Chicago River

APPENDIX B
Detailed Capital Cost Estimates for Four Short-Listed Supplemental Aeration Technologies

TABLE B.1
CAPITAL COST ESTIMATION FOR U-TUBE SUPPLEMENTAL AERATION (30 g/s)
PROJECT NO. 40779

DIVISION	ITEM DESCRIPTION	UNITS	NO.	MATERIAL UNIT COST	MATERIAL TOTAL COST	LABOR % MAT COST	LABOR UNIT COST	LABOR TOTAL COST	INSTALLED COST TOTAL
1	GENERAL REQUIREMENTS								$138,576
2	SITEWORK								
	Cut/Fill	CY	1450	$5.00	$7,250				$7,250
	Removable Bollards	EA	12	$300.00	$3,600				$3,600
	Fencing	LS	2	$6,500.00	$13,000				$13,000
	Miscellaneous Sitework	CY	100	$36.00	$3,600				$3,600
	Miscellaneous Sitework	SF	3200	$5.00	$16,000				$16,000
3	CONCRETE								
	Slabs	CY	84	$500.00	$42,000				$42,000
	Wet Well	LS	1	$19,500.00	$19,500				$19,500
9	MASONRY								
	Split Block Masonry Building	SF	2000	$100.00	$200,000				$200,000
10	FINISHES								
	Coatings	LS	1	$20,000.00	$20,000				$20,000
11	EQUIPMENT								
	Vertical turbine Pumps and Appurtenances	EA	8	$76,500.00	$612,000				$612,000
	Blower	EA	3	$8,200.00	$24,600	40%		$9,840	$34,440
	Drill & Prep 12' dia U-Tube Shaft	FT	115	$1,742.00	$200,330				$200,330
	Casing Material (Welded Steel, 1")	LB	87300	$2.00	$174,600				$174,600
	Install U-Tube Casing	FT	115	$100.00	$11,500				$11,500
	Install Bottom Plug (Concrete and Mortar)	CY	25	$750.00	$18,750				$18,750
	Pump Water from Shaft and Prepare Casing	LS	1	$52,500.00	$52,500				$52,500
	Bubble Collector and Appurtenances	EA	1	$16,000.00	$16,000				$16,000
	Diffusers	LS	1	$12,000.00	$12,000				$12,000
13	SPECIAL CONSTRUCTION								
	Pressure Gages/Transmitters	EA	2	$1,500.00	$3,000				$3,000
	Flow Meter (12" Mag)	EA	2	$13,500.00	$27,000				$27,000
15	MECHANICAL								
	Air Supply Piping and Appurtenances	LF	250	$12.00	$3,000				$3,000
	Control Valve	EA	8	$3,000.00	$24,000				$24,000
	20" Pump control Valve	EA	8	$28,000.00	$224,000				$224,000
	Isolation Valves	EA	10	$14,000.00	$140,000				$140,000
	20" DIP	LF	153	$180.00	$27,450				$27,450
	30" DIP	LF	50	$270.00	$13,500				$13,500
	20" Flexible Piping	LF	300	$180.00	$54,000				$54,000
	Inner Piping system	LF	150	$450.00	$67,500				$67,500
	HDPE Diffuser Pipe	LF	4,000	$15.00	$60,000				$60,000
	Pressure Regulating Station	EA	20	$5,000.00	$100,000				$100,000
	Diffuser Supports	EA	400	$150.00	$60,000				$60,000
	Lateral Installation (Within Water Column)	LF	4,000	$94.00	$376,000				$376,000
16	ELECTRICAL AND INSTRUMENTATION								
	Supply	LS	1	$75,000.00	$75,000				$75,000
	Control systems and Instrumentation	LS	1	$50,000.00	$50,000				$50,000
	Control wiring	LS	1	$10,000.00	$10,000				$10,000
	SUBTOTAL								**$2,910,096**
	Contractor OH&P @ 15%								**$436,514**
	Subtotal								**$3,346,610**
	Planning Level Contingency @ 30%								**$1,003,983**
	Subtotal								**$4,350,594**
	Misc. Capital Costs								
	Legal and Fiscal Fees @ 15%								**$652,589**
	Engineering Fees including CM @ 20%								**$870,119**
	Subtotal								**$1,522,708**
	Project Total								**$5,873,301**

TABLE B.2
CAPITAL COST ESTIMATION FOR JET AERATION (30 g/s)
PROJECT NO. 40779

DIVISION	ITEM DESCRIPTION	UNITS	NO.	MATERIAL		LABOR			INSTALLED COST
				UNIT COST	TOTAL COST	% MAT COST	UNIT COST	TOTAL COST	TOTAL
1	GENERAL REQUIREMENTS								$212,953
2	SITEWORK								
	Mobilization for dredging	LS	1	$56,500.00	$56,500				$56,500
	River Dredging	CY	8333	$20.00	$166,667				$166,667
	Sheet Piling	SF	15000	$30.00	$450,000				$450,000
	Coffer Dam	SF	20000	$52.50	$1,050,000				$1,050,000
	Diversion Pumping	DAY	20	$3,600.00	$72,000				$72,000
	Blower & Pump Bldg. Excavation	CY	8167	$7.00	$57,167				$57,167
	Backfill	CY	5204	$8.00	$41,630				$41,630
3	CONCRETE								
	Wetwell	LS	1	$20,000.00	$20,000				$20,000
9	MASONRY								
	Pump and Blower Building	SF	5000	$100.00	$500,000				$500,000
10	FINISHES								
	Coatings	LS	1	$20,000.00	$20,000				$20,000
11	EQUIPMENT								
	Pumps, Blowers, Manifolds	LS	1	$950,000.00	$950,000	40%		$380,000	$1,330,000
13	SPECIAL CONSTRUCTION								
	Pressure Gages/Transmitters	EA	1	$1,500.00	$1,500				$1,500
	Flow Meter (12" Mag)	EA	1	$13,500.00	$13,500				$13,500
15	MECHANICAL								
	Air Supply Piping and Appurtenances	LF	800	$12.00	$9,600				$9,600
	Control Valve	EA	7	$3,000.00	$21,000				$21,000
	20" Pump control Valve	EA	7	$28,000.00	$196,000				$196,000
	Isolation Valves	EA	7	$14,000.00	$98,000				$98,000
	20" DIP	LF	100	$180.00	$18,000				$18,000
	30" DIP	LF	50	$270.00	$13,500				$13,500
	Priming System	EA	1	$5,000.00	$5,000				$5,000
16	ELECTRICAL AND INSTRUMENTATION								
	Supply	LS	1	$50,000.00	$50,000	40%		$20,000	$70,000
	Control systems and Instrumentation	LS	1	$30,000.00	$30,000	40%		$12,000	$42,000
	Control wiring	LS	1	$5,000.00	$5,000	40%		$2,000	$7,000
	SUBTOTAL								**$4,472,016**
	Contractor OH&P @ 15%								**$670,802**
	Subtotal								**$5,142,819**
	Planning Level Contingency @ 30%								**$1,542,846**
	Subtotal								**$6,685,664**
	Misc. Capital Costs								
	Legal and Fiscal Fees @ 15%								**$1,002,850**
	Engineering Fees including CM @ 20%								**$1,337,133**
	Subtotal								**$2,339,982**
	Project Total								**$9,025,647**

TABLE B.3
CAPITAL COST ESTIMATION FOR SEPA 30 g/s STATION
PROJECT NO. 40779

DIVISION	ITEM DESCRIPTION	UNITS	NO.	MATERIAL		LABOR			INSTALLED COST
				UNIT COST	TOTAL COST	% MAT COST	UNIT COST	TOTAL COST	TOTAL
1	GENERAL REQUIREMENTS								$361,986
11	EQUIPMENT								
	SEPA Station (1)	$/gpm	133333	$54.30	$7,239,715				$7,239,715
	SUBTOTAL								**$7,601,701**
	Contractor OH&P @ 15%								**$1,140,255**
	Subtotal								**$8,741,956**
	Planning Level Contingency @ 30%								**$2,622,587**
	Subtotal								**$11,364,543**
	Misc. Capital Costs								
	Legal and Fiscal Fees @ 15%								**$1,704,681**
	Engineering Fees Including CM @ 20%								**$2,272,909**
	Subtotal								**$3,977,590**
	Project Total								**$15,342,133**

(1) Costs were obtained from existing SEPA station construction costs, updated to 2006 rates using ENR index of 7660.

TABLE B.4
CAPITAL COST ESTIMATION FOR CERAMIC DIFFUSER SYSTEM (30 g/s)
PROJECT NO. 40779

DIVISION	ITEM DESCRIPTION	UNITS	NO.	MATERIAL UNIT COST	MATERIAL TOTAL COST	LABOR % MAT COST	LABOR UNIT COST	LABOR TOTAL COST	INSTALLED COST TOTAL
1	GENERAL REQUIREMENTS								$135,394
2	SITEWORK								
	Mobilization for dredging	LS	1	$56,500.00	$56,500				$56,500
	River Dredging	CY	8333	$20.00	$166,667				$166,667
	Sheet Piling	SF	15000	$30.00	$450,000				$450,000
	Coffer Dam	SF	20000	$52.50	$1,050,000				$1,050,000
	Diversion Pumping	DAY	20	$3,600.00	$72,000				$72,000
	Blower Bldg. Excavation	CY	667	$7.00	$4,667				$4,667
	Backfill	CY	481	$8.00	$3,852				$3,852
3	CONCRETE								
9	MASONRY								
	Blower Building	SF	2500	$100.00	$250,000				$250,000
10	FINISHES								
	Coatings	LS	1	$20,000.00	$20,000				$20,000
11	EQUIPMENT								
	Diffusers	LS	1	$90,000.00	$90,000	40%		$36,000	$126,000
	Blower	EA	3	$25,000.00	$75,000	40%		$30,000	$105,000
	Local Inlet Filter	LS	1	$20,000.00	$20,000				$20,000
	Spray Pump	LS	1	$15,000.00	$15,000				$15,000
	Blower Actuator	LS	1	$19,000.00	$19,000				$19,000
	PLC	EA	1	$100,000.00	$100,000				$100,000
13	SPECIAL CONSTRUCTION								
15	MECHANICAL								
	Air Supply Piping and Appurtenances	LF	1000	$29.00	$29,000	40%		$11,600	$40,600
	Control Valve	EA	3	$3,000.00	$9,000	40%		$3,600	$12,600
	HDPE Diffuser Pipe	LF	1000	$15.00	$15,000	40%		$6,000	$21,000
	Diffuser Supports	EA	80	$150.00	$12,000	40%		$4,800	$16,800
	AC Unit	EA	1	$5,000.00	$5,000	40%		$2,000	$7,000
16	ELECTRICAL AND INSTRUMENTATION								
	Supply	LS	1	$60,000.00	$60,000	40%		$24,000	$84,000
	Control systems and Instrumentation	LS	1	$40,000.00	$40,000	40%		$16,000	$56,000
	Control wiring	LS	1	$8,000.00	$8,000	40%		$3,200	$11,200
	SUBTOTAL								**$2,843,279**
	Contractor OH&P @ 15%								**$426,492**
	Subtotal								**$3,269,771**
	Planning Level Contingency @ 30%								**$980,931**
	Subtotal								**$4,250,703**
	Misc. Capital Costs								
	Legal and Fiscal Fees @ 15%								**$637,605**
	Engineering Fees Including CM @ 20%								**$850,141**
	Subtotal								**$1,487,746**
	Project Total								**$5,738,449**

TABLE B.5
CAPITAL COST ESTIMATION FOR U-TUBE SUPPLEMENTAL AERATION (80 g/s)
PROJECT NO. 40779

DIVISION	ITEM DESCRIPTION	UNITS	NO.	MATERIAL UNIT COST	MATERIAL TOTAL COST	LABOR % MAT COST	LABOR UNIT COST	LABOR TOTAL COST	INSTALLED COST TOTAL
1	GENERAL REQUIREMENTS								$369,536
2	SITEWORK								
	Cut/Fill	CY	3867	$5.00	$19,333				$19,333
	Removable Bollards	EA	32	$300.00	$9,600				$9,600
	Fencing	LS	1	$34,666.67	$34,667				$34,667
	Miscellaneous Sitework	CY	267	$36.00	$9,600				$9,600
	Miscellaneous Sitework	SF	8533	$5.00	$42,667				$42,667
3	CONCRETE								
	Slabs	CY	224	$500.00	$112,000				$112,000
	Wet Well	LS	1	$52,000.00	$52,000				$52,000
9	MASONRY								
	Split Block Masonry Building	SF	5333	$100.00	$533,333				$533,333
10	FINISHES								
	Coatings	LS	1	$53,333.33	$53,333				$53,333
11	EQUIPMENT								
	Vertical turbine Pumps and Appurtenances	EA	21	$76,500.00	$1,632,000				$1,632,000
	Blower	EA	8	$8,200.00	$65,600	40%		$26,240	$91,840
	Drill & Prep U-Tube Shaft	FT	115	$4,645.33	$534,213				$534,213
	Casing Material (Welded Steel, 1")	LB	232800	$2.00	$465,600				$465,600
	Install U-Tube Casing	FT	115	$266.67	$30,667				$30,667
	Install Bottom Plug (Concrete and Mortar)	CY	25	$2,000.00	$50,000				$50,000
	Pump Water from Shaft and Prepare Casing	LS	1	$140,000.00	$140,000				$140,000
	Bubble Collector and Appurtenances	EA	1	$42,666.67	$42,667				$42,667
	Diffusers	LS	1	$32,000.00	$32,000				$32,000
13	SPECIAL CONSTRUCTION								
	Pressure Gages/Transmitters	EA	2	$4,000.00	$8,000				$8,000
	Flow Meter	EA	2	$36,000.00	$72,000				$72,000
15	MECHANICAL								
	Air Supply Piping and Appurtenances	LF	250	$32.00	$8,000				$8,000
	Control Valve	EA	8	$8,000.00	$64,000				$64,000
	20" Pump control Valve	EA	8	$74,666.67	$597,333				$597,333
	Isolation Valves	EA	10	$37,333.33	$373,333				$373,333
	20" DIP	LF	407	$180.00	$73,200				$73,200
	30" DIP	LF	133	$270.00	$36,000				$36,000
	20" Flexible Piping	LF	800	$180.00	$144,000				$144,000
	Inner Piping system	LF	400	$450.00	$180,000				$180,000
	HDPE Diffuser Pipe	LF	10,667	$15.00	$160,000				$160,000
	Pressure Regulating Station	EA	53	$5,000.00	$266,667				$266,667
	Diffuser Supports	EA	1,067	$150.00	$160,000				$160,000
	Lateral Installation (Within Water Column)	LF	10,667	$94.00	$1,002,667				$1,002,667
16	ELECTRICAL AND INSTRUMENTATION								
	Supply	LS	1	$200,000.00	$200,000				$200,000
	Control systems and Instrumentation	LS	1	$133,333.33	$133,333				$133,333
	Control wiring	LS	1	$26,666.67	$26,667				$26,667
	SUBTOTAL								**$7,760,256**
	Contractor OH&P @ 15%								**$1,164,038**
	Subtotal								**$8,924,294**
	Planning Level Contingency @ 30%								**$2,677,288**
	Subtotal								**$11,601,583**
	Misc. Capital Costs								
	Legal and Fiscal Fees @ 15%								**$1,740,237**
	Engineering Fees Including CM @ 20%								**$2,320,317**
	Subtotal								**$4,060,554**
	Project Total								**$15,662,137**

TABLE B.6
CAPITAL COST ESTIMATION FOR JET AERATION (80 g/s)
PROJECT NO. 40779

DIVISION	ITEM DESCRIPTION	UNITS	NO.	MATERIAL UNIT COST	MATERIAL TOTAL COST	LABOR % MAT COST	LABOR UNIT COST	LABOR TOTAL COST	INSTALLED COST TOTAL
1	GENERAL REQUIREMENTS								$567,875
2	SITEWORK								
	Mobilization for dredging	LS	1	$150,666.67	$150,667				$150,667
	River Dredging	CY	22222	$20.00	$444,444				$444,444
	Sheet Piling	SF	40000	$30.00	$1,200,000				$1,200,000
	Coffer Dam	SF	53333	$52.50	$2,800,000				$2,800,000
	Diversion Pumping	DAY	53	$3,600.00	$192,000				$192,000
	Blower & Pump Bldg. Excavation	CY	21778	$7.00	$152,444				$152,444
	Backfill	CY	13877	$8.00	$111,012				$111,012
3	CONCRETE								
	Wetwell	LS	1	$53,333.33	$53,333				$53,333
9	MASONRY								
	Pump and Blower Building	SF	13333	$100.00	$1,333,333				$1,333,333
10	FINISHES								
	Coatings	LS	1	$53,333.33	$53,333				$53,333
11	EQUIPMENT								
	Pumps, Blowers, Manifolds	LS	1	$2,533,333.33	$2,533,333	40%		$1,013,333	$3,546,667
13	SPECIAL CONSTRUCTION								
	Pressure Gages/Transmitters	EA	1	$4,000.00	$4,000				$4,000
	Flow Meter	EA	1	$36,000.00	$36,000				$36,000
15	MECHANICAL								
	Air Supply Piping and Appurtenances	LF	2133	$12.00	$25,600				$25,600
	Control Valve	EA	19	$3,000.00	$56,000				$56,000
	20" Pump control Valve	EA	19	$28,000.00	$522,667				$522,667
	Isolation Valves	EA	19	$14,000.00	$261,333				$261,333
	20" DIP	LF	267	$180.00	$48,000				$48,000
	30" DIP	LF	133	$270.00	$36,000				$36,000
	Priming System	EA	1	$13,333.33	$13,333				$13,333
16	ELECTRICAL AND INSTRUMENTATION								
	Supply	LS	1	$133,333.33	$133,333	40%		$53,333	$186,667
	Control systems and Instrumentation	LS	1	$80,000.00	$80,000	40%		$32,000	$112,000
	Control wiring	LS	1	$13,333.33	$13,333	40%		$5,333	$18,667
	SUBTOTAL								**$11,925,376**
	Contractor OH&P @ 15%								**$1,788,806**
	Subtotal								**$13,714,183**
	Planning Level Contingency @ 30%								**$4,114,255**
	Subtotal								**$17,828,438**
	Misc. Capital Costs								
	Legal and Fiscal Fees @ 15%								**$2,674,266**
	Engineering Fees Including CM @ 20%								**$3,565,688**
	Subtotal								**$6,239,953**
	Project Total								**$24,068,391**

TABLE B.7

CAPITAL COST ESTIMATION FOR SEPA 80 g/s STATION

PROJECT NO. 40779

DIVISION	ITEM DESCRIPTION	UNITS	NO.	MATERIAL UNIT COST	MATERIAL TOTAL COST	LABOR % MAT COST	LABOR UNIT COST	LABOR TOTAL COST	INSTALLED COST TOTAL
1	GENERAL REQUIREMENTS								$965,295
11	EQUIPMENT								
	SEPA Station (1)	$/gpm	355555	$54.30	$19,305,907				$19,305,907
	SUBTOTAL								**$20,271,203**
	Contractor OH&P @ 15%								**$3,040,680**
	Subtotal								**$23,311,883**
	Planning Level Contingency @ 30%								**$6,993,565**
	Subtotal								**$30,305,448**
	Misc. Capital Costs								
	Legal and Fiscal Fees @ 15%								**$4,545,817**
	Engineering Fees including CM @ 20%								**$6,061,090**
	Subtotal								**$10,606,907**
	Project Total								**$40,912,355**

(1) Costs were obtained from existing SEPA station construction costs, updated to 2006 rates using ENR index of 7660.

TABLE B.8
CAPITAL COST ESTIMATION FOR CERAMIC DIFFUSER SYSTEM (80 g/s)
PROJECT NO. 40779

DIVISION	ITEM DESCRIPTION	UNITS	NO.	MATERIAL		LABOR			INSTALLED COST
				UNIT COST	TOTAL COST	% MAT COST	UNIT COST	TOTAL COST	TOTAL
1	GENERAL REQUIREMENTS								$361,051
2	SITEWORK								
	Mobilization for dredging	LS	1	$150,666.67	$150,667				$150,667
	River Dredging	CY	22222	$20.00	$444,444				$444,444
	Sheet Piling	SF	40000	$30.00	$1,200,000				$1,200,000
	Coffer Dam	SF	53333	$52.50	$2,800,000				$2,800,000
	Diversion Pumping	DAY	53	$3,600.00	$192,000				$192,000
	Blower Bldg. Excavation	CY	1778	$7.00	$12,444				$12,444
	Backfill	CY	1284	$8.00	$10,272				$10,272
3	CONCRETE								
9	MASONRY								
	Blower Building	SF	6667	$100.00	$666,667				$666,667
10	FINISHES								
	Coatings	LS	1	$53,333.33	$53,333				$53,333
11	EQUIPMENT								
	Diffusers	LS	1	$240,000.00	$240,000	40%		$96,000	$336,000
	Blower	EA	3	$66,666.67	$200,000	40%		$80,000	$280,000
	Local Inlet Filter	LS	1	$53,333.33	$53,333				$53,333
	Spray Pump	LS	1	$40,000.00	$40,000				$40,000
	Blower Actuator	LS	1	$50,666.67	$50,667				$50,667
	PLC	EA	1	$266,666.67	$266,667				$266,667
13	SPECIAL CONSTRUCTION								
15	MECHANICAL								
	Air Supply Piping and Appurtenances	LF	2667	$29.00	$77,333	40%		$30,933	$108,267
	Control Valve	EA	3	$8,000.00	$24,000	40%		$9,600	$33,600
	HDPE Diffuser Pipe	LF	2667	$15.00	$40,000	40%		$16,000	$56,000
	Diffuser Supports	EA	213	$150.00	$32,000	40%		$12,800	$44,800
	AC Unit	EA	1	$13,333.33	$13,333	40%		$5,333	$18,667
16	ELECTRICAL AND INSTRUMENTATION								
	Supply	LS	1	$160,000.00	$160,000	40%		$64,000	$224,000
	Control systems and Instrumentation	LS	1	$106,666.67	$106,667	40%		$42,667	$149,333
	Control wiring	LS	1	$21,333.33	$21,333	40%		$8,533	$29,867
	SUBTOTAL								**$7,582,079**
	Contractor OH&P @ 15%								**$1,137,312**
	Subtotal								**$8,719,390**
	Planning Level Contingency @ 30%								**$2,615,817**
	Subtotal								**$11,335,207**
	Misc. Capital Costs								
	Legal and Fiscal Fees @ 15%								**$1,700,281**
	Engineering Fees Including CM @ 20%								**$2,267,041**
	Subtotal								**$3,967,323**
	Project Total								**$15,302,530**

APPENDIX C
Detailed Annual Cost Estimates for Four Short-Listed Supplemental Aeration Technologies

TABLE C.1
ANNUAL O&M COSTS FOR U-TUBE 30 g/s AERATION SYSTEM

PRESENT WORTH FACTOR	
LIFE,N	20
INTEREST, i	3
INFLATION, j	3
PRESENT WORTH FACTOR	**19.42**

Energy Cost, $
Average $0.0750 $/kWh

ITEM	OPERATING (kW)	TIME OF OPERATION (hrs/day)	POWER USAGE (kw-hr/day)	ENERGY COST ($/day)	ANNUAL COST ($)	PRESENT WORTH FACTOR	PRESENT WORTH ($)
OPERATIONS							
ENERGY - ELECTRICAL	33.46	24	802.9	$60.22	$14,654	19.42	$284,575
SUBTOTAL					**$14,654**		**$284,575**

	NO. OF OPERATORS (per day)	TIME (hrs/day/operator)	TOTAL TIME (hrs/day)	LABOR RATE ($/hr)	ANNUAL COST ($)	PRESENT WORTH FACTOR	PRESENT WORTH ($)
MAINTENANCE							
ROUTINE MAINTENANCE							
Blowers	1	0.12	0.12	$90.00	$3,942	19.42	$76,554
Pumps	1	0.12	0.12	$90.00	$3,942	19.42	$76,554
LABOR - OPERATOR							
Blowers & Pumps	1	0.24	0.24	$90.00	$5,256	19.42	$102,072
ELECTRICIAN	1	0.06	0.06	$159.50	$3,493	19.42	$67,835
SUBTOTAL					**$16,633**		**$323,014**

	CONSTRUCTION COST OF NEW EQUIP. & PIPING ($)	% FOR ANNUAL PARTS AND SUPPLIES	NUMBER OF LAMPS REPLACED PER YEAR (UV ONLY)	COST PER LAMP ($)	ANNUAL COST ($)	PRESENT WORTH FACTOR	PRESENT WORTH ($)
PARTS AND SUPPLIES							
PARTS AND SUPPLIES	1,438,050	5%			$71,903	19.42	$1,396,347
SUBTOTAL					**$71,903**		**$1,396,347**

TOTAL ANNUAL O&M	**$103,189**	
TOTAL PRESENT WORTH O & M COST		**$2,003,936**

TABLE C.2
ANNUAL O&M COSTS FOR JET AERATION 30 g/s SYSTEM

PRESENT WORTH FACTOR	
LIFE,N	20
INTEREST, i	3
INFLATION, j	3
PRESENT WORTH FACTOR	**19.42**

Energy Cost, $
Average $0.0750 $/kWh

ITEM	OPERATING (kW)	TIME OF OPERATION (hrs/day)	POWER USAGE (kw-hr/day)	ENERGY COST ($/day)	ANNUAL COST ($)	PRESENT WORTH FACTOR	PRESENT WORTH ($)
OPERATIONS							
ENERGY - ELECTRICAL	862.5	24	20700.0	$1,552.50	$377,775	19.42	$7,336,391
SUBTOTAL					**$377,775**		**$7,336,391**

	NO. OF OPERATORS (per day)	TIME (hrs/day/operator)	TOTAL TIME (hrs/day)	LABOR RATE ($/hr)	ANNUAL COST ($)	PRESENT WORTH FACTOR	PRESENT WORTH ($)
MAINTENANCE							
ROUTINE MAINTENANCE							
Pumps	2	0.1	0.2	$90.00	$6,570	19.42	$127,589
Blowers	2	0.1	0.2	$90.00	$6,570	19.42	$127,589
LABOR - OPERATOR							
Blowers & Pumps	2	0.1	0.2	$90.00	$4,380	19.42	$85,060
ELECTRICIAN	1	0.05	0.05	$159.50	$2,911	19.42	$56,529
SUBTOTAL					**$20,431**		**$396,768**

	CONSTRUCTION COST OF NEW EQUIP. & PIPING ($)	% FOR ANNUAL PARTS AND SUPPLIES	NUMBER OF LAMPS REPLACED PER YEAR (UV ONLY)	COST PER LAMP ($)	ANNUAL COST ($)	PRESENT WORTH FACTOR	PRESENT WORTH ($)
PARTS AND SUPPLIES							
PARTS AND SUPPLIES	1,311,100	5%			$65,555	19.42	$1,273,078
SUBTOTAL					**$65,555**		**$1,273,078**

TOTAL ANNUAL O&M **$463,761**

TOTAL PRESENT WORTH O & M COST **$9,006,236**

TABLE C.3
ANNUAL O&M COSTS FOR 30 g/s SEPA STATION

PRESENT WORTH FACTOR	
LIFE,N	20
INTEREST, i	3
INFLATION, j	3
PRESENT WORTH FACTOR	**19.42**

Energy Cost, $
Average $0.0750 $/kWh

ITEM	OPERATING (kW)	TIME OF OPERATION (hrs/day)	POWER USAGE (kw-hr/day)	ENERGY COST ($/day)	ANNUAL COST ($)	PRESENT WORTH FACTOR	PRESENT WORTH ($)
OPERATIONS							
ENERGY - ELECTRICAL	745.6	24	17894.4	$1,342.08	$326,573	19.42	$6,342,044
SUBTOTAL					**$326,573**		**$6,342,044**

	NO. OF OPERATORS (per day)	TIME (hrs/day/operator)	TOTAL TIME (hrs/day)	LABOR RATE ($/hr)	ANNUAL COST ($)	PRESENT WORTH FACTOR	PRESENT WORTH ($)
MAINTENANCE							
ROUTINE MAINTENANCE							
Cut & Landscape	2	0.4	0.8	$90.00	$17,520	19.42	$340,238
Pump Maintenance	1	0.1	0.1	$90.00	$3,285	19.42	$63,795
LABOR - OPERATOR	1	2	2	$90.00	$43,800	19.42	$850,596
ELECTRICIAN	1	0.05	0.05	$159.50	$2,911	19.42	$56,529
SUBTOTAL					**$67,516**		**$1,311,158**

	CONSTRUCTION COST OF NEW EQUIP. & PIPING ($)	% FOR ANNUAL PARTS AND SUPPLIES	NUMBER OF LAMPS REPLACED PER YEAR (UV ONLY)	COST PER LAMP ($)	ANNUAL COST ($)	PRESENT WORTH FACTOR	PRESENT WORTH ($)
PARTS AND SUPPLIES							
PARTS AND SUPPLIES	72,397	5%			$3,620	19.42	$70,298
SUBTOTAL					**$3,620**		**$70,298**

TOTAL ANNUAL O&M	**$397,709**	
TOTAL PRESENT WORTH O & M COST		**$7,723,500**

TABLE C.4
ANNUAL O&M COSTS FOR CERAMIC DIFFUSER SYSTEM 30 g/s SYSTEM

PRESENT WORTH FACTOR	
LIFE,N	20
INTEREST, i	3
INFLATION, j	3
PRESENT WORTH FACTOR	19.42

Energy Cost, $
Average $0.0750 $/kWh

ITEM	OPERATING (kW)	TIME OF OPERATION (hrs/day)	POWER USAGE (kw-hr/day)	ENERGY COST ($/day)	ANNUAL COST ($)	PRESENT WORTH FACTOR	PRESENT WORTH ($)
OPERATIONS							
ENERGY - ELECTRICAL	375	24	9000.0	$675.00	$164,250	19.42	$3,189,735
SUBTOTAL					**$164,250**		**$3,189,735**

	NO. OF OPERATORS (per day)	TIME (hrs/day/operator)	TOTAL TIME (hrs/day)	LABOR RATE ($/hr)	ANNUAL COST ($)	PRESENT WORTH FACTOR	PRESENT WORTH ($)
MAINTENANCE							
ROUTINE MAINTENANCE	1	0.1	0.1	$90.00	$3,285	19.42	$63,795
LABOR - OPERATOR	1	0.1	0.1	$90.00	$2,190	19.42	$42,530
ELECTRICIAN	1	0.05	0.05	$159.50	$2,911	19.42	$56,529
SUBTOTAL					**$8,386**		**$162,854**

	CONSTRUCTION COST OF NEW EQUIP. & PIPING ($)	% FOR ANNUAL PARTS AND SUPPLIES	NUMBER OF LAMPS REPLACED PER YEAR (UV ONLY)	COST PER LAMP ($)	ANNUAL COST ($)	PRESENT WORTH FACTOR	PRESENT WORTH ($)
PARTS AND SUPPLIES							
PARTS AND SUPPLIES	389,000	5%			$19,450	19.42	$377,719
SUBTOTAL					**$19,450**		**$377,719**

TOTAL ANNUAL O&M **$192,086**

TOTAL PRESENT WORTH O & M COST **$3,730,308**

TABLE C.5
ANNUAL O&M COSTS FOR U-TUBE 80 g/s AERATION SYSTEM

PRESENT WORTH FACTOR	
LIFE,N	20
INTEREST, i	3
INFLATION, j	3
PRESENT WORTH FACTOR	19.42

Energy Cost, $
Average $0.0750 $/kWh

ITEM	OPERATING (kW)	TIME OF OPERATION (hrs/day)	POWER USAGE (kw-hr/day)	ENERGY COST ($/day)	ANNUAL COST ($)	PRESENT WORTH FACTOR	PRESENT WORTH ($)
OPERATIONS							
ENERGY - ELECTRICAL	89.22	24	2141.2	$160.59	$39,077	19.42	$758,868
SUBTOTAL					**$39,077**		**$758,868**

	NO. OF OPERATORS (per day)	TIME (hrs/day/operator)	TOTAL TIME (hrs/day)	LABOR RATE[1] ($/hr)	ANNUAL COST ($)	PRESENT WORTH FACTOR	PRESENT WORTH ($)
MAINTENANCE							
ROUTINE MAINTENANCE							
Blowers	1	0.1	0.1	$90.00	$3,285	19.42	$63,795
Pumps	1	0.1	0.1	$90.00	$3,285	19.42	$63,795
LABOR - OPERATOR							
Blowers & Pumps	1	0.2	0.2	$90.00	$4,380	19.42	$85,060
ELECTRICIAN	1	0.05	0.05	$159.50	$2,911	19.42	$56,529
SUBTOTAL					**$13,861**		**$269,178**

	CONSTRUCTION COST OF NEW EQUIP. & PIPING ($)	% FOR ANNUAL PARTS AND SUPPLIES	NUMBER OF LAMPS REPLACED PER YEAR (UV ONLY)	COST PER LAMP ($)	ANNUAL COST ($)	PRESENT WORTH FACTOR	PRESENT WORTH ($)
PARTS AND SUPPLIES							
PARTS AND SUPPLIES	3,834,800	5%			$191,740	19.42	$3,723,591
SUBTOTAL					**$191,740**		**$3,723,591**

TOTAL ANNUAL O&M **$244,677**

TOTAL PRESENT WORTH O & M COST **$4,751,637**

TABLE C.6
ANNUAL O&M COSTS FOR JET AERATION 80 g/s SYSTEM

PRESENT WORTH FACTOR	
LIFE,N	20
INTEREST, i	3
INFLATION, j	3
PRESENT WORTH FACTOR	19.42

Energy Cost, $
Average $0.0750 $/kWh

ITEM	OPERATING (kW)	TIME OF OPERATION (hrs/day)	POWER USAGE (kw-hr/day)	ENERGY COST ($/day)	ANNUAL COST ($)	PRESENT WORTH FACTOR	PRESENT WORTH ($)
OPERATIONS							
ENERGY - ELECTRICAL	2300	24	55200.0	$4,140.00	$1,007,400	19.42	$19,563,708
SUBTOTAL					**$1,007,400**		**$19,563,708**

	NO. OF OPERATORS (per day)	TIME (hrs/day/operator)	TOTAL TIME (hrs/day)	LABOR RATE(1) ($/hr)	ANNUAL COST ($)	PRESENT WORTH FACTOR	PRESENT WORTH ($)
MAINTENANCE							
ROUTINE MAINTENANCE							
Pumps	2	0.1	0.2	$90.00	$6,570	19.42	$127,589
Blowers	2	0.1	0.2	$90.00	$6,570	19.42	$127,589
LABOR - OPERATOR							
Blowers & Pumps	2	0.1	0.2	$90.00	$4,380	19.42	$85,060
ELECTRICIAN	1	0.05	0.05	$159.50	$2,911	19.42	$56,529
SUBTOTAL					**$20,431**		**$396,768**

	CONSTRUCTION COST OF NEW EQUIP. & PIPING ($)	% FOR ANNUAL PARTS AND SUPPLIES	NUMBER OF LAMPS REPLACED PER YEAR (UV ONLY)	COST PER LAMP ($)	ANNUAL COST ($)	PRESENT WORTH FACTOR	PRESENT WORTH ($)
PARTS AND SUPPLIES							
PARTS AND SUPPLIES	3,496,267	5%			$174,813	19.42	$3,394,875
SUBTOTAL					**$174,813**		**$3,394,875**

TOTAL ANNUAL O&M **$1,202,644**

TOTAL PRESENT WORTH O & M COST **$23,355,351**

TABLE C.7
ANNUAL O&M COSTS FOR 80 g/s SEPA STATION

PRESENT WORTH FACTOR	
LIFE,N	20
INTEREST, i	3
INFLATION, j	3
PRESENT WORTH FACTOR	**19.42**

Energy Cost, $
Average $0.0750 $/kWh

ITEM	OPERATING (kW)	TIME OF OPERATION (hrs/day)	POWER USAGE (kw-hr/day)	ENERGY COST ($/day)	ANNUAL COST ($)	PRESENT WORTH FACTOR	PRESENT WORTH ($)
OPERATIONS							
ENERGY - ELECTRICAL	1988	24	47718.4	$3,578.88	$870,861	19.42	$16,912,117
SUBTOTAL					**$870,861**		**$16,912,117**

	NO. OF OPERATORS (per day)	TIME (hrs/day/operator)	TOTAL TIME (hrs/day)	LABOR RATE[1] ($/hr)	ANNUAL COST ($)	PRESENT WORTH FACTOR	PRESENT WORTH ($)
MAINTENANCE							
ROUTINE MAINTENANCE							
Cut & Landscape	2	0.4	0.8	$90.00	$17,520	19.42	$340,238
Pump Maintenance	1	0.1	0.1	$90.00	$3,285	19.42	$63,795
LABOR - OPERATOR	1	2	2	$90.00	$43,800	19.42	$850,596
ELECTRICIAN	1	0.05	0.05	$159.50	$2,911	19.42	$56,529
SUBTOTAL					**$67,516**		**$1,311,158**

	CONSTRUCTION COST OF NEW EQUIP. & PIPING ($)	% FOR ANNUAL PARTS AND SUPPLIES	NUMBER OF LAMPS REPLACED PER YEAR (UV ONLY)	COST PER LAMP ($)	ANNUAL COST ($)	PRESENT WORTH FACTOR	PRESENT WORTH ($)
PARTS AND SUPPLIES							
PARTS AND SUPPLIES	193,059	5%			$9,653	19.42	$187,460
SUBTOTAL					**$9,653**		**$187,460**

TOTAL ANNUAL O&M **$948,030**

TOTAL PRESENT WORTH O & M COST **$18,410,735**

TABLE C.8
ANNUAL O&M COSTS FOR CERAMIC DIFFUSER SYSTEM 80 g/s SYSTEM

PRESENT WORTH FACTOR	
LIFE,N	20
INTEREST, i	3
INFLATION, j	3
PRESENT WORTH FACTOR	19.42

Energy Cost, $
Average $0.0750 $/kWh

ITEM	OPERATING (kW)	TIME OF OPERATION (hrs/day)	POWER USAGE (kw-hr/day)	ENERGY COST ($/day)	ANNUAL COST ($)	PRESENT WORTH FACTOR	PRESENT WORTH ($)
OPERATIONS							
ENERGY - ELECTRICAL	1000	24	24000.0	$1,800.00	$438,000	19.42	$8,505,960
SUBTOTAL					**$438,000**		**$8,505,960**

	NO. OF OPERATORS (per day)	TIME (hrs/day/operator)	TOTAL TIME (hrs/day)	LABOR RATE[1] ($/hr)	ANNUAL COST ($)	PRESENT WORTH FACTOR	PRESENT WORTH ($)
MAINTENANCE							
ROUTINE MAINTENANCE	1	0.1	0.1	$90.00	$3,285	19.42	$63,795
LABOR - OPERATOR	1	0.1	0.1	$90.00	$2,190	19.42	$42,530
ELECTRICIAN	1	0.05	0.05	$159.50	$2,911	19.42	$56,529
SUBTOTAL					**$8,386**		**$162,854**

	CONSTRUCTION COST OF NEW EQUIP. & PIPING ($)	% FOR ANNUAL PARTS AND SUPPLIES	NUMBER OF LAMPS REPLACED PER YEAR (UV ONLY)	COST PER LAMP ($)	ANNUAL COST ($)	PRESENT WORTH FACTOR	PRESENT WORTH ($)
PARTS AND SUPPLIES							
PARTS AND SUPPLIES	1,037,333	5%			$51,867	19.42	$1,007,251
SUBTOTAL					**$51,867**		**$1,007,251**

TOTAL ANNUAL O&M **$498,253**

TOTAL PRESENT WORTH O & M COST **$9,676,064**