Aeration Research and Implementation Analysis Study for the Stockton Deep Water Ship Channel

Prepared for:

California Bay-Delta Authority
650 Capital Mall, 5th Floor
Sacramento, CA 95814

Prepared by:

Jones & Stokes
17310 Red Hill Avenue, Suite 320
Irvine, CA 92614
Contact: Tom Trexler
949/260-1080
949/260-1081 (fax)

January 2004

Jones & Stokes. 2004. Aeration Research and Implementation Analysis Study for the Stockton Deep Water Ship Channel. January. (J&S 03-189.) Irvine, CA.

Contents

Tables and Figures

Acronyms and Abbreviations

CBDA	California BayDelta Authority
cfs	cubic feet per second
Corps	U.S. Army Corps of Engineers
DO	dissolved oxygen
DWR	California Department of Water Resources
DWSC	Stockton Deep Water Ship Channel
fps	foot per second
hp	horsepower
kW	kilowatt
kWh	kilowatt hours
kWh/day	kilowatt hours per day
lbs	pounds
lbs/day	pounds per day
mg/l	milligrams per liter
MOBI	mounted oxygen bubble injector
msl	above mean sea level
ºC	degrees centigrade
ºF	degrees Fahrenheit
psi	pounds per square inch
RWCF	Stockton Regional Wastewater Control Facility
scfm	Standard cubic feet per minute
TMDL	Total Maximum Daily Load
USGS	U.S. Geological Survey

Executive Summary

This document provides three products. It provides a compilation of data and research on the Stockton Deep Water Ship Channel (DWSC) in the form of a comprehensive list of citations and a brief summary of relevant studies. Secondly, this document describes all potential aeration technologies that may be used to increase the dissolved oxygen (DO) levels in the DWSC and prevent the recurrence of fish kills. In addition, this section describes an evaluation process used to recommend three aeration technologies that would be most suitable for use in the DWSC and that will be forwarded for further analysis. Implementing an aeration technology would increase the DO levels in the DWSC and prevent the recurrence of large fish kills. The third product is a description of suggested evaluation techniques that will be used on the three technologies to select a single preferred technology.

Previous studies (Brown 2003) have estimated that an input of up to 10,000 pounds per day (lbs/day) of DO is necessary during the summer months when DO levels in the DWSC are at a minimum. These inputs will sustain the DO levels in the DWSC at or above the minimum DO objective of 5 mg/l. Although the DO problems in the DWSC are a result of many factors, aerating the channel can serve as a temporary or partial solution.

To determine which aeration technologies are most capable of providing the 10,000 lbs/day of DO to the DWSC, selection criteria were developed and applied to a variety of technologies. The technologies evaluated aerate a water body by introducing either compressed air or oxygen into the water column, by mixing the water to redistribute water with higher DO to areas with lower DO, or by passively introducing DO from atmospheric sources by creating more turbulence. Technologies that were evaluated include hypolimnetic aerators, water fans, bubble column aerators, pressurized aerators (U-tube and Speece Cone), waterfalls, hollow fibers, and floating aerators. Two criteria used in recommending a technology were that a technology could not interfere with ship traffic or harm fish in the DWSC. Other selection criteria include an ability to provide the 10,000 lbs/day of DO, oxygen transfer efficiency of the technology, capital costs, operational costs, environmental effects, and implementation feasibility. The implementation feasibility criterion required that each technology would be able to input the required 10,000 lbs/day of DO with fewer than five devices. Aeration technologies received qualitative scores of *low*, *moderate*, or *high* for each selection criterion with the exception of the ability to meet maximum demand (10,000 lbs/day of DO) criterion. Scores for the ability criterion were either *acceptable* or *unacceptable*. The three technologies with the most *high* scores were recommended if fewer than five devices were required.

A U-tube pressurized aerator, a Speece Cone pressurized aerator, and bubble column aerators were chosen as the three recommended technologies. Each of these aerators would actually use commercial oxygen gas instead of air to increase the transfer efficiency in the relatively shallow DWSC. Preliminary monitoring plans were created for each recommended technology to be experimentally evaluated *in situ* for the DWSC sometime in the future.

Chapter 1

Aeration Technologies and Implementation Study

Introduction

High algae and ammonia nitrogen in the DWSC and the resulting low DO levels have caused water quality objective violations and may be responsible for fish kills in recent years. Although a variety of strategies will eventually be used to prevent the DO declines, aeration technologies can be used as a temporary and/or partial solution to the low-DO problem.

Aeration technologies can increase DO levels in water bodies by a variety of methods. Some of these techniques include adding oxygen or air (i.e., bubbles) directly to the water body, adding oxygen-saturated water to the water body, or mixing the water to facilitate diffusion of atmospheric oxygen into the water. Although there are a number of aeration technologies, the implementation costs, actual operating efficiency, and environmental impacts of each technology are highly variable and uncertain.

This document was created to serve as the first step in selecting a suitable aeration technology for the DWSC. Specific objectives of this document were to:

- develop a summary and bibliography of past and ongoing data collection and research efforts focused on DO impairment in the DWSC;
- review aeration technologies relevant to the design of an aeration system and existing monitoring programs in the DWSC;
- develop selection criteria for the purposes of selecting up to three preferred aeration technologies that will be evaluated in a future feasibility study;
- develop a feasibility study plan that will evaluate up to three preferred aeration technologies in the DWSC or a similar environment for the purposes of identifying a single recommended technology for implementation; and
- develop a monitoring plan to establish baseline conditions by identifying spatial and temporal variability of testing locations for the purposes of identifying a single recommended technology for implementation.

Future *in-situ* (i.e., field) experiments, using this document's three preferred technologies, will be designed by engineers and performed in the DWSC or a similar environment to select a single recommended technology. Suggested experimental procedures and concurrent environmental data collection procedures are described in this document. Information from the experiments and this document will be used by the California Bay-Delta Authority (CBDA) and the San Joaquin River Dissolved Oxygen Total Maximum Daily Load (TMDL) Steering Committee (Steering Committee) to select and implement an optimum aeration technology for the DWSC.

Background

The Stockton DWSC is a maintained (i.e., dredged) portion of the San Joaquin River that begins in the San Francisco Bay and terminates in Stockton, California. It is used as a shipping channel allowing large hauling vessels access to the interior of the Central Valley from the open sea. The terminus of the shipping channel is at the Port of Stockton East Complex. Additionally, there is a sizable turning basin that allows the vessels to reverse their orientation before departing. The DWSC is dredged to a depth of at least 35 feet measured at the lowest low diurnal tidal cycle (mean low low water, or MLLW).

The concentration of DO in the San Joaquin River is a function of three primary factors: alteration of flow conditions in the river, the presence of the DWSC, and upstream contributions of algae and oxygen-depleting constituents (e.g., ammonia). High San Joaquin river flows, greater than 2,000 cubic feet per second (cfs), can prevent low DO levels by diluting oxygen-depleting substances in the DWSC and by transporting the substances from the DWSC faster than lower river flows. The DWSC's depth causes San Joaquin river flows to slow through the channel, thereby reducing the rate of oxygen transfer from the atmosphere into the water. Although algae can grow near the surface of the DWSC, the depth of the DWSC limits the net algae growth, and most of the inflowing algae will settle and decay in the DWSC. The algae can provide DO to the DWSC through photosynthesis but the net effect of algae is to reduce DO levels as the algae respire and as bacteria decompose dead algae. Ammonia in the DWSC is derived from discharges by the Stockton Regional Wastewater Control Facility (RWCF) and some upstream San Joaquin River sources.

As previously described, DO levels in the DWSC are affected by algae, ammonia, river flows, and the physical characteristics of the DWSC, but the concentration of DO in any water body is also dependent on its saturation concentration, which is a function of temperature. For example, the saturation concentration of DO at 9 degrees centigrade (ºC) (48 degrees Fahrenheit [ºF]) (the monthly average water temperature of the San Joaquin River near Stockton in January) is 12 milligrams per liter (mg/l). In August, the average temperature of the river increases to 25ºC (77ºF) and causes the saturation DO concentration to be reduced to 8 mg/l. The combination of warmer water temperatures and lower flows in the late summer and early fall provides the perfect conditions for the oxidation of organic material and the nitrification of ammonia, resulting in the rapid depletion of DO in the water column.

The TMDL process addresses the three primary factors in detail. The purpose of this aeration evaluation is to define the most effective means of artificially maintaining DO at an acceptable level for an indefinite period until other nonaeration solutions reduce or remove the need for this approach. The California Department of Water Resources' (DWR's) continuous DO monitoring station is located at the downstream end of Rough & Ready Island, a land parcel adjacent to the DWSC. Data from the DWR's station and from a United States Geological Survey (USGS) tidal flow station are used to estimate the DO deficit below applicable water quality objectives for the DWSC (5 mg/l from December through August, and 6 mg/l from September through November). The DO deficit in the DWSC is calculated using the following equation:

DO deficit (lbs/day) = 5.4 (Net Flow (cfs) ([Target DO (mg/l) – Minimum DO (mg/l)]

Where lbs/day = pounds per day.

This DO deficit represents the amount of DO augmentation necessary to meet the DO objectives in the DWSC. Based on the daily minimum DO concentrations at the Rough & Ready monitoring station and the daily net flow measured at the U.S. Geological Survey (USGS) tidal flow station, about 1 million pounds (lbs) of oxygen would have been needed in the summer of 2001. Estimated DO deficits in the DWSC during 1999, 2000, and 2001 are shown in Figures 1—3. As shown in the figures, the highest DO deficit occurred in 2001. An aeration device that delivered about 10,000 lbs/day would have satisfied the measured DO deficit during the summer of 2001. It should be noted that water year 2001 was a slightly below-normal year and that during a dry or critical year with less precipitation and lower river flows, the oxygen deficit could be greater than 10,000 lbs/day. However, the maximum daily DO deficit was generally the same during 2002 and 2003.

The U.S. Army Corps of Engineers (Corps) has installed and intermittently operated a water–jet air bubble device in the DWSC since 2001 to help alleviate the DO deficit. The device uses two identical 16-foot-wide platforms holding a 15-horsepower (hp) (11-kilowatt [kW]) water pump and eight water jet nozzles, with 2-foot spacing. A 20-hp (15-kW) air blower provides the airflow of about 260 standard cubic feet per minute (scfm) to the eight jets. The device was designed to input up to 2,500 lbs/day of DO into the DWSC but is suspected to input much less. The actual performance of the device has not been measured. The electrical cost to operate the two water pumps and two air blowers is about $125 (1250 kWhr at $0.10/kWhr). If the Corps's device proves capable of diffusing 2,500 lbs/day of DO into the DWSC, supplemental aeration technologies will need to input only 7,500 lbs/day instead of 10,000 lbs/day of DO and will be designed accordingly.

Compilation of Deep Water Ship Channel Data and Research

A number of studies exist as a result of previous efforts by the TMDL process and related study efforts. These studies present a comprehensive list of past and ongoing data collection and research efforts focused on DO impairment in the DWSC. Information from these studies was used to choose aeration technologies and selection criteria described in this document. The studies include:

- Lee, G. Fred, and Anne Jones-Lee, 2003. *Synthesis and Discussion of Findings on the Causes and Factors Influencing Low DO in the San Joaquin River Deep Water Ship Channel near Stockton, CA: Including 2002 Data*. Report submitted to the Steering Committee/Technical Advisory Committee and CALFED Bay-Delta Program. March 2003.

  As the title suggests, this document presents a comprehensive analysis of the dynamics that influence DO in the DWSC. It is a compilation of observations, analyses, and data prepared for the TMDL effort. It draws directly upon the work of multiple scientists and cites 115 references. The report is more than 200 pages long, and a digital copy has been provided on the enclosed CD.

- Brown, Russ T., 2003. *Evaluation of Aeration Technology for the Stockton Deep Water Ship Channel*. Report to CALFED Bay-Delta Program Project No. 01-N61-05. January.

  Dr. Brown's evaluation forms the basis for the evaluation presented in this report. A complete copy has been provided on the enclosed CD.

- HDR Engineering, Inc. 2001. *Final Report—Water Quality Improvement Project Phase 1 Report: Causes and Solutions*. Prepared for the City of Stockton. October.

  This engineering report addresses the impairment of water quality resulting from frequent algae blooms in the Stockton channel that extends from the turning basin to downtown Stockton (Weber Point). The report also analyzes several aeration technologies, and it develops a preferred alternative.

These three documents provide the most comprehensive analysis of potential aeration solutions to low DO in the DWSC. Additional resources are available on the TMDL web site at http://www.sjrtmdl.org/technical/index.html, and may be downloaded.

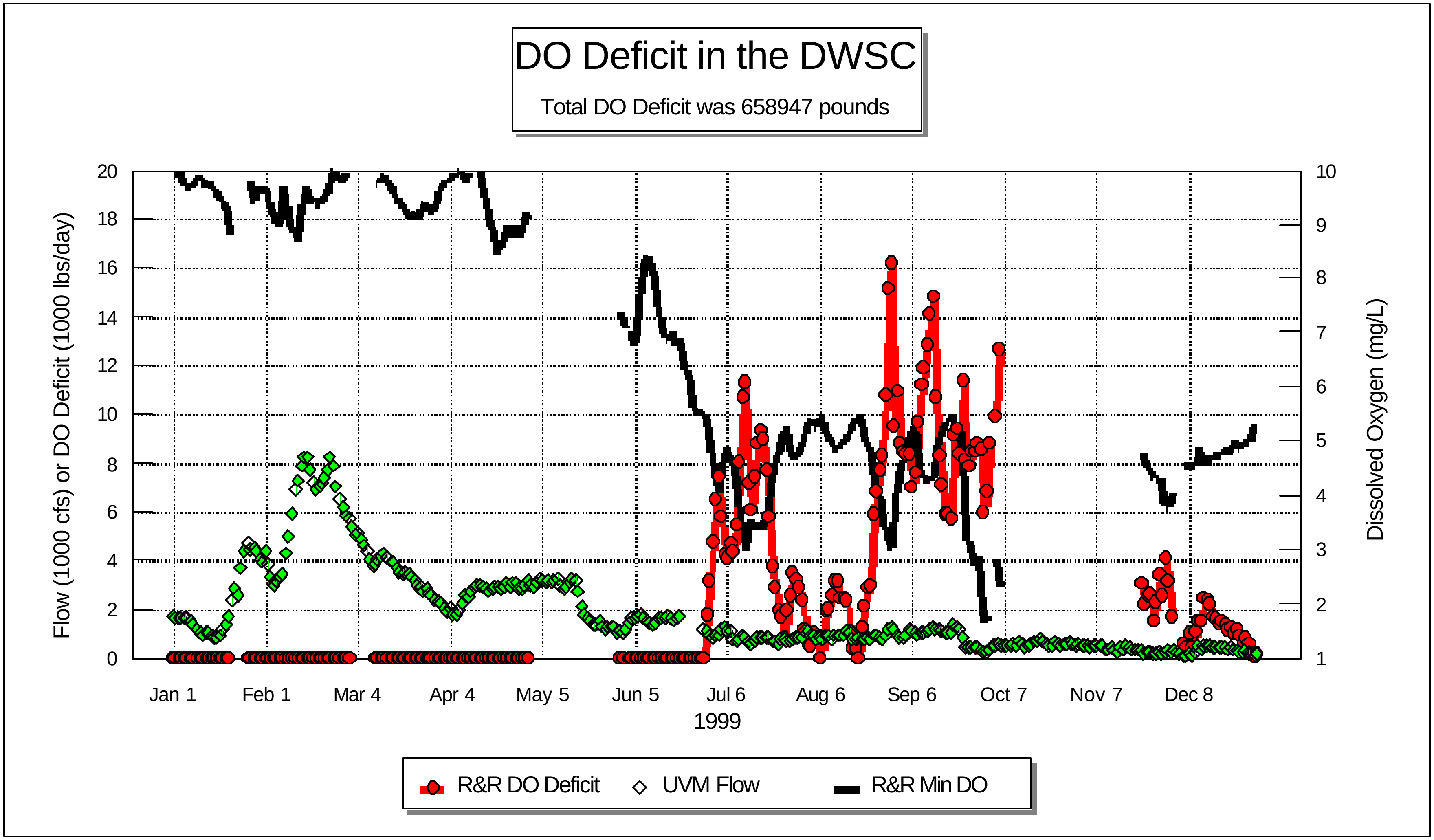

Figure 1. DO Deficit in the DWSC Calculated for 1999

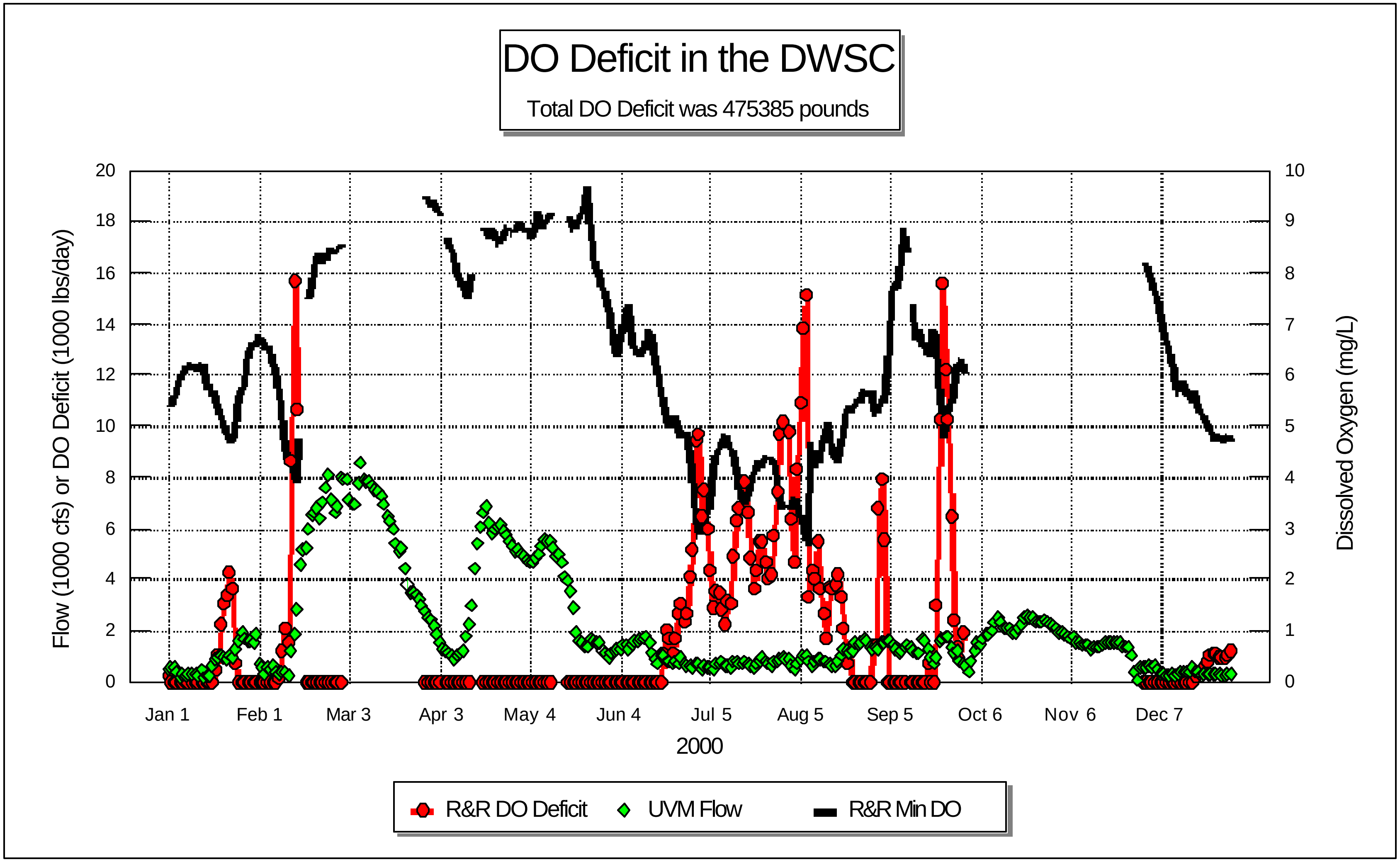

Figure 2. DO Deficit in the DWSC Calculated for 2000

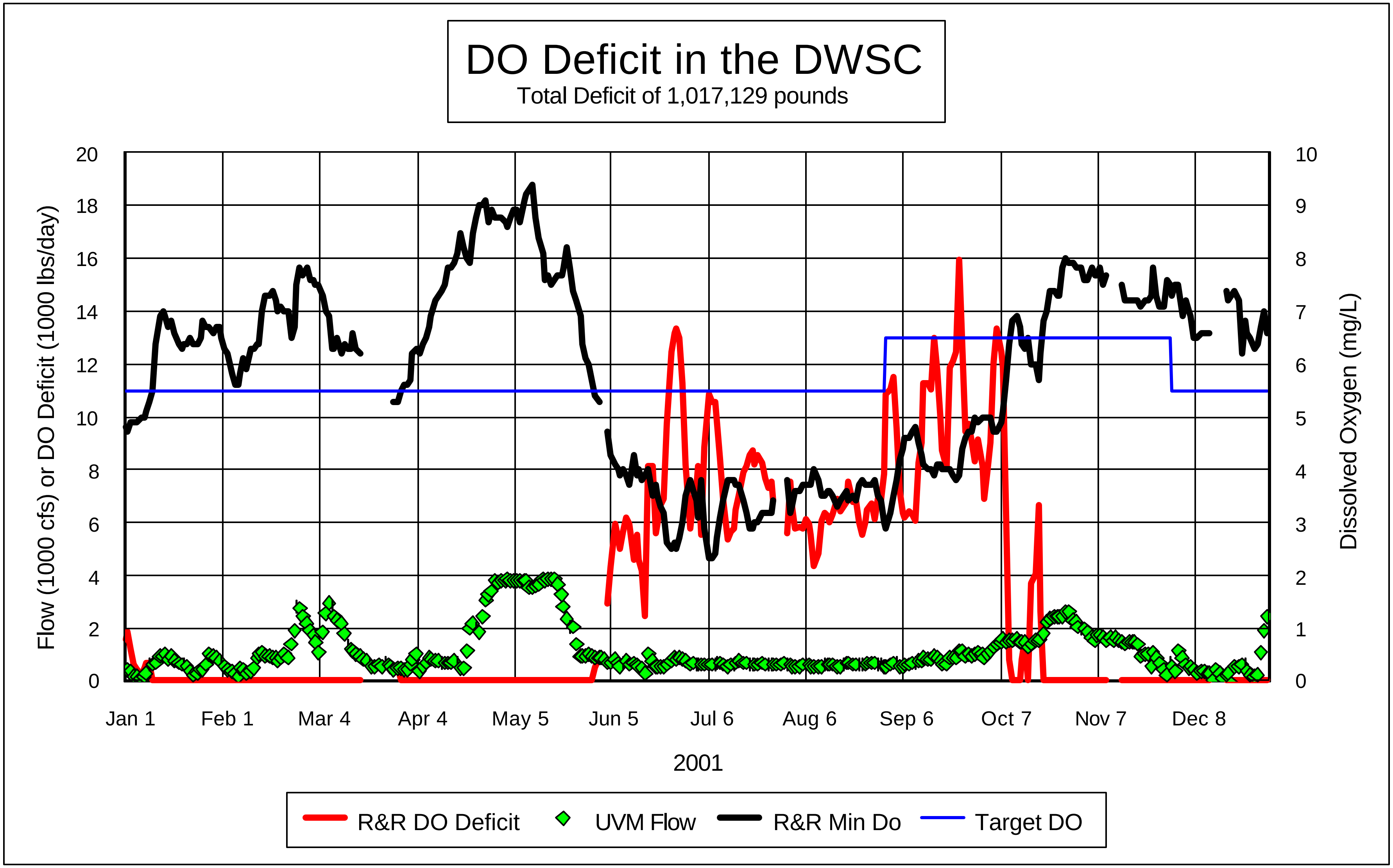

Figure 3. DO Deficit in the DWSC Calculated for 2001

Chapter 2
Design Criteria and Considerations

Objectives and Constraints

The general objective of this document and the future experimental studies it supports is to recommend an aeration technology that will provide sufficient quantities of oxygen to the DWSC to meet the DO objectives (a minimum DO concentration of 5 mg/l year-round). To meet the DO objectives, the technology's DO input must equal or exceed the channel's DO deficit of 10,000 lbs/day during the summer months. In addition to providing the required amount of oxygen (no greater than 1,000,000 lbs/year), the recommended technologies also have to meet physical and environmental constraints. The technologies assessed in this document meet the following minimum requirements:

- does not interfere with ship traffic in the DWSC or with maintenance dredging activities, and
- does not adversely affect migratory or resident fish populations

Selection Criteria

Each technology described in this document has been applied and operated in certain circumstances and has been shown to effectively introduce oxygen into water bodies. Practical constraints are associated with installing, operating, and maintaining each option. This section describes the selection criteria that will be used to determine which three aeration technologies will be considered most promising for further review.

Aeration techniques will be given qualitative scores of *low, moderate*, or *high* for each selection criterion except for the ability to meet the maximum demand criterion. *Acceptable* or *unacceptable* scores will be given for the ability to meet the maximum demand criterion. *Low* scores for the cost criteria will represent high economic costs for a technology, and *high* scores will represent low economic costs. Similarly, *low* scores for the environmental effects criterion will represent high environmental impacts, and *high* scores will represent low environmental impacts.

The most important selection criterion is the ability to meet maximum demand because the main objective of this study is to recommend a technology that can eliminate the DO deficit. A technology cannot be one of the three recommended technologies if it receives an *unacceptable* score for this criterion. Additionally, if a technology requires more than five devices to input the 10,000 lbs/day of DO, it cannot be a recommended technology. The remaining selection criteria are considered equally important. The three technologies with the most *high* or *moderate* scores will be chosen as the recommended technologies.

Ability to Meet Maximum Demand

This criterion looks at whether the technology is capable of meeting the performance objective. In this case, whether the options are capable of raising the DO in the river to the required levels (greater than 5 mg/l) would be evaluated. This can also be expressed in terms of pounds of oxygen per day added to the river. As previously described, the device(s) would have to be able to contribute up to 10,000 lbs/day. This study assumes that the use of multiple devices set up in various locations in the DWSC would be considered in order to ensure proper distribution of DO if river circulation alone is inadequate. Note that the term *deliver* expressly means the amount of DO that *diffuses* into the water column. As described in the next criteria, this means that efficiency of oxygen transfer may be more critical than the simple ability to place bubbles in contact with the water. The device must deliver the oxygen while maintaining the DO concentration above 5 mg/l. An aeration device has been installed and operated by the Corps in the Port of Stockton. The device was designed to diffuse up to 2,500 lbs/day during specific times of the year. For the purposes of this analysis, we have assumed that the inputs of this device will not be factored into the objective of 10,000 lbs/day. This assumption is based upon the fact that the device is not currently operated throughout the entire year and that the device may not actually deliver the designed quantity of oxygen as it is currently operated.

Technologies that fail to meet the DO objective are no longer considered viable. Scoring methodology for the ability to meet the maximum demand criterion is as follows: a score of *Acceptable* is given if a technology can likely meet the 10,000 lbs/day; a score of *unacceptable* is given if a technology could not meet the 10,000 lbs/day DO objective.

Oxygen Transfer Efficiency

The device must be able to transfer oxygen to the water efficiently. The oxygen transfer efficiency is the fraction of supplied oxygen that is dissolved. These efficiencies are estimated for the selection process from each technology's previously reported values. For the three preferred technologies, actual efficiencies are determined by measuring the rate at which oxygen is supplied to the device and the relative efficiency of transfer into the water as incremental DO. Devices will rely on meeting the maximum demand by using pure oxygen where possible. Estimates of the efficiency of oxygen transfer are factored into the cost selection criteria (as oxygen supply or air blower size). Oxygen transfer efficiency scoring is as follows: a *low* score is given for efficiencies less than 30%, a *moderate* score is given for efficiencies ranging from 30 to 60%, and a *high* score is given for efficiencies greater than 60%.

The effective DO concentration difference for each technology is also estimated because it contributes to the overall transfer efficiency selection criterion. Effective DO concentration differences indicate the potential difference between the DO concentration of water in the DWSC prior to aeration and the DO concentration after it has been aerated by each technology. The post-aeration concentration is related to the pressure inside the device and the oxygen concentration of the gas supplied. For example, a higher DO concentration difference indicates the device is using pure oxygen gas (instead of 20% oxygen in air) and/or is exposing the water to a high pressure so that the oxygen saturation concentration is higher. The overall performance efficiency of each technology is a function of both the oxygen transfer efficiency and the effective DO concentration difference. Lower operating costs typically reflect increased performance efficiency.

Installation and Operating Costs

Another important criterion in the evaluation of options is the cost to install and operate the full system. Capital and operating costs are estimated from previous reported costs and presented as normalized to the 10,000 lbs/day of oxygen introduced to the river. Each device is assumed to be capable of operating for 10 years. Construction costs and operational costs for the duration of operation are included in the analyses. Operating costs include electricity, oxygen, supply, transportation, and maintenance.

Each technology's capital and operating costs are scored separately. Costs are compared relative to each other technology and are given a score of *low*, *moderate*, or *high*. Capital cost scoring is as follows: a score of *high* is given for costs less than $3 million, a score of *moderate* is given for costs ranging from $3 to $5 million, and a score of *low* is given for costs more than $5 million. Scores for the operating cost criterion are as follows: a *high* score is given for costs less than $1,500, a *moderate* score is given for costs ranging from $1,500 to $3,000, and a *low* score is given for costs greater than $3000.

Implementation Feasibility

The implementation feasibility is a qualitative criterion describing the practical considerations associated with installing and operating the equipment. Thus the criterion indicates the likelihood of success. Evaluation of options with respect to this criterion can result in several outcomes. Options can be simply considered impractical to install and operate, based on some practical, physical constraint. One constraint used to decide the implementation feasibility for a technology is that no more than 5 devices will be installed. Thus, although no single device will be required to meet the 10,000 lbs/day of DO standard on its own, if a single device cannot deliver at least 2,000 lbs/day, it will be considered inadequate, and will receive a Low score for this criterion. For example, floating aerators are judged to be impractical because they would likely interfere with boat traffic and more than 5 units would be required.

Environmental Effects

The considered aeration technologies are also screened based on their potential to cause negative environmental impacts. The main environmental effect evaluated is the potential to entrain fish into intake pipes that remove water from the DWSC. Technologies with high flows are more likely to entrain fish and thus receive environmental effects criterion scores of Low. For each option, the potential to cause substantial environmental harm is scored. Technologies that could cause substantial environmental degradation that could not be mitigated are eliminated from further consideration.

Chapter 3
Assessment of Aeration Techniques

Aeration Technology Evaluation

This section provides a summary of each aeration technique, preliminary design, and cost requirements for technology operations in the DWSC, and application of the selection criteria to each technique. Information on the costs, efficiencies, power, and flow requirements for each technique are adapted from Brown (2003).

Pressurized Aeration

Pressurized aeration serves to increase the oxygen transfer efficiency by infusing air or oxygen into the water at elevated hydrostatic pressures, thereby increasing the peak saturation DO concentration and associated DO transfer in the water. A number of systems can be designed to take advantage of this principle. Pressurized aeration refers to withdrawing a portion of the source water into a pressurized chamber and injecting oxygen. The highly oxygenated water is then mixed back into the source water to increase the net source water DO concentration. Mixing of the highly oxygenated water with the source water is typically accomplished using a diffuser device. A U-tube device (i.e. deep well) uses hydrostatic pressure to increase the DO transfer of bubbles moving through the U-tube. Another pressurized side-stream aeration device is a Speece Cone, which aerates water within a submersed cone by supplying oxygen gas.

A deep well U-tube device could be used to increase the DO concentration in the DWSC. The oxygenated water can be discharged at a depth of 35 feet where the DO saturation is 80 mg/l (with oxygen gas). A 50 mg/l increment could be used as the design goal for the device. The oxygenated water would be discharged with a jet diffuser located under the Rough & Ready dock to achieve a dilution of about 5 that would provide a DO concentration of about 10 mg/l in the diffuser plume. This oxygenated water would continue to mix in the DWSC and provide the needed increment of DO.

The head loss through the U-tube well device is only about 5 feet, and because of the tidal variation, the total pumping head would probably need to be 20 feet (to supply a U-tube facility located at an elevation of 15 feet above mean sea level (msl) to be higher than flood stage). A fish screen would be needed for the water intake.

Because less than 40 cfs would need to be pumped through the U-tube device, the power requirements would be less than 2,000 kilowatt hours per day (kWh/day) (i.e., 2 /0.8 $*$ 40 cfs $*$ 20 feet = 2,000) with a power cost of less than $200/day assuming power cost $0.10/kWhr. The oxygen costs for 10,000 lbs/day maximum delivery would be about $1250/day assuming a transfer efficiency of 80% and a cost of $0.10/lb. This would be a very economical and effective alternative.

A Speece Cone device also could likely be designed for the DWSC to operate effectively at a depth of only 25 feet. Several cones could be placed under the Rough & Ready Island dock. It is believed the Speece Cone could be effective in the DWSC because a Speece Cone installed in the Camanche Reservoir has been successful in increasing the DO levels. Although the Camanche Reservoir Speece Cone has not been tested to directly determine its efficiency, the performance of a cone for the DWSC would probably need a different combination of cone volume, water flow, and oxygen feed rate. Nevertheless, it would appear that the 10,000 lbs/day might be achieved with five devices, each designed to produce 2,000 lbs/day. Assuming a transfer efficiency of 60% and flows of approximately 60 cfs, it would cost $1750 per day for oxygen. The electricity costs for the Camanche device are about $300 per day for the 127-kW pump at $0.10/kWhr. The pumps that will be needed for the DWSC devices will require slightly more total power because more water will be pumped to supply the DO for the DWSC (lower saturation DO concentration in shallow depth). If electricity costs of $750/day are assumed, the total cost will still be less than $2,500 per day. Construction costs for the assumed five DWSC cones would likely be less than $5 million, based on the $1.2 million cost for the larger Camanche device in 1993.

Application of Selection Criteria

A pressurized aerator (U-tube or Speece Cone) would be a very efficient and effective device for increasing the DO levels in the DWSC. Efficiency scores for the U-tube and Speece Cone are *high* and *moderate*, respectively, based on the U-tube efficiency of 80% and the Speece Cone efficiency of 60%. Both aerator types would be capable of adding the necessary 10,000 lbs/day of DO to the channel and thus received an *acceptable* score for the ability to meet the maximum demand criterion. The effective DO concentration difference for the U-tube is 150 mg/l, while the Speece Cone's effective DO concentration difference is 50 mg/l. Implementation of the U-tube would result in a high effective DO concentration because the pressure in the tube is higher than in the Speece Cone and more oxygen would be dissolved into the water. The Speece Cone would be expected to have environmental impacts similar to the U-tube method because the intake flows for the cones would be similar to the U-tube's flows. Therefore, both technologies receive *moderate* scores for the environmental effects criterion. The difficulty to implement criterion scores for the U-tube and the Speece Cone are *high*. Both devices (cones or diffuser jets) could be placed below the Rough & Ready dock, would not be expected to interfere with any ship traffic or dredging activities, and could meet the 10,000 lbs/day of DO requirement with fewer than five devices. The pressurized aeration method using the U-tube would have total operational costs of $1,500/day and has an operational cost score of *high*. Total costs for operating the Speece Cone device would be approximately $2,000/day. Thus, the Speece Cone has an operational cost score of *moderate*. Construction costs for the Speece Cone would likely be less than $4 million and support a capital cost score of *moderate*. Capital costs for the U-tube are expected to be less than $5 million, and as such the capital cost score for the U-tube is *moderate*.

Hypolimnetic Aeration

Submerged bubble chamber devices use air or oxygen bubbles that are confined in a tube or chamber so the oxygenated water can be returned to the deeper portion of the lake or reservoir (i.e., hypolimnetic aerators). The simplest possible device that might work in the DWSC is an inverted U-tube. An oxygen bubble device is placed at the opening of the tube and bottom water is drawn into the tube by the buoyancy of the bubbles. The bubbles partially dissolve in the tube as the bubbles rise, and the oxygenated water is returned to near the bottom of the DWSC in the other section of the inverted U-tube. This design is called a mounted oxygen bubble injector (MOBI) device. A prototype device was constructed and tested in the DWSC. The field test results indicated that a 20% oxygen transfer efficiency was achieved with a water flow to gas flow ratio of about 50 (Brown 2003).

Results from field testing of the MOBI device in the DWSC, as well as results from other experiments with hypolimnetic aerators (Burris and Little 1998), suggest that the maximum transfer efficiency in 25 feet of water will be about 20%. The likely DO capacity of a full-scale 3-foot-diameter tube device would be about 500 lbs/day if oxygen gas is used. The optimum capacity of each tube device can be better determined with additional field measurements using a full-size device in the DWSC. If the oxygen transfer capacity is assumed to be 500 lbs/day for each device, for example, 20 devices could be located along the Rough & Ready Island dock to provide the 10,000 lbs/day of DO. The dock has sufficient overhang to allow the devices to be placed underneath the dock, without any danger of damage from ship collisions or anchor line dragging. The dock is about a mile long, so the 20 devices could be located every 250 feet.

There are no other energy costs for water pumping or air compressors. If the tube devices can be operated with 20% transfer efficiency, the needed amount of liquid oxygen will be five times the estimated DO deficit of 10,000 lbs/day. The cost is therefore estimated to be $5,000 per day. The annual supply is estimated to be 5 million lbs, with an estimated cost of $500,000. The upwelling water flow through the tube devices is similar to tidal river flows (i.e., 1 foot per second [fps] or 125 cfs) and is not expected to harm small fish that might be entrained in the upwelling flow. The upwelling flow will allow the aerated water to be discharged into the DWSC with an initial jet velocity that will enhance the lateral mixing from the tidal flows in the DWSC.

Application of Selection Criteria

Hypolimnetic aerators likely would not be as efficient as pressurized aerators. These devices would be expected to be only 20% efficient in transferring oxygen to the DWSC. Thus the oxygen transfer efficiency score for hypolimnetic aerators is *low*. The low efficiency rate would require the use of at least 20 hypolimnetic aerators to add the required 10,000 lbs/day of DO to the DWSC. Because more than five devices are needed to add the 10,000 lbs/day of DO, this technology receives an implementation feasibility score of *moderate*. The ability to meet maximum demand criterion score is *acceptable* because the devices could input 10,000 lbs/day of DO. The effective DO concentration difference for the hypolimnetic aerators would be 50 mg/l because the pressure is low inside the aerators (about 1 atmosphere) and pure oxygen gas would be used. Total costs for operating hypolimnetic aerators in the DWSC would be $5,000 per day and are the highest operating costs of all the analyzed technologies. The operational cost score for this criterion is *low* to indicate the operational costs are very high. The costs could be reduced if the oxygen transfer efficiency increased to 40%. The capital cost is estimated at $2 million and supports a capital cost score of *high*. Similar to the pressurized side-stream aerators, the hypolimnetic aerators would be located underneath the Rough & Ready dock and would not be expected to interfere with daily DWSC operations. The implementation feasibility score for hypolimnetic aerators is *moderate*. The *high* environmental effects criterion score indicates no substantial environmental impacts would be expected if this technology was implemented.

Bubble Column and Hollow Fiber Aeration

Bubble diffusers produce bubble columns near the bottom of the water column that rise to the surface with a nearly constant speed of about 0.75 fps. This rising bubble plume creates an upwelling flow of water that generally rises to the surface. Some of the oxygen from the bubbles will dissolve into the water that is upwelling with the bubbles, but most bubble systems provide additional aeration from circulation of surface water into the deeper layers of the lake or reservoir. Bubble column aerators have been used to restore DO water quality in lakes, rivers, and harbors worldwide.

A bubble diffuser line could be located along the Rough & Ready Dock at a depth of about 25 feet. A gas transfer efficiency of 40% might be achieved (DeMoyer et al 2001). With oxygen gas, about 2.5 times the daily average DO deficit of 10,000 lbs/day would be supplied to the diffuser line that might be 5,000 feet long. The bubbles would produce a large upwelling flow that would circulate water across the DWSC. The cost for the daily supply of 25,000 lbs of oxygen would be about $2,500. No compressors or water pumps would be needed if oxygen gas were used because the liquid oxygen tank evaporator pressure is sufficient to supply the oxygen gas to the diffuser. The design and construction costs would likely be less than $2.5 million, based on the recent installations at Los Vaqueros Reservoir and Upper San Leandro Reservoir.

Hollow fiber membranes are an alternative to bubble columns and have a much higher oxygen transfer efficiency that may approach 90% (Weiss et al. 1994, Ahmed and Semmens 1996). Hollow fiber technology uses bundles of microporous fibers with outside diameters of a few millimeters that provide a large surface area for gas transfer. Air or oxygen is fed to the fibers at elevated pressures (up to 100 pounds per square inch [psi]), which effectively increases the partial pressure exerted at the water interface and thereby increases the gas transfer rate. This technique creates a large partial pressure of oxygen from the gas side (rather than from hydrostatic pressure of the water).

A series of hollow fiber bundles located under the Rough & Ready Island dock may be more efficient than a bubble column device. The number of hollow fiber bundles that would be required to supply the necessary oxygen will depend on the oxygen transfer capacity of the hollow fiber devices but would likely be more than five. Results from laboratory experiments suggest that the fibers will operate at about 4 atmospheres and that 50,000 square feet of fibers would transfer 10,000 lbs/day. The fibers cost less than $2 per square foot of surface area, so the necessary fibers themselves would cost less than $100,000. The remainder of the oxygen supply lines should be less than $2 million. The daily oxygen cost would be about $1,250 if the transfer efficiency is assumed to be 80%. The oxygen supply pressure from the liquid oxygen evaporator should be sufficient to operate the hollow fiber bundles. The tidal flows in the DWSC are probably adequate to maintain the oxygen transfer rate from the hollow fibers to the water under the dock. However, the lateral distribution of the high DO water might be limited because there is no upwelling water flow to circulate the high DO water across the DWSC. Two drawbacks of using this technology are that the technology has not been tested *in situ* before, and the long-term efficiency is unknown.

Application of Selection Criteria

Bubble column aerators used in the DWSC would inject oxygen into the water, thereby creating bubbles at the bottom of the water column. The efficiency of bubble column aerators is estimated to be 40%, and thus they receive a score of *low* for the efficiency criterion. Bubble column aerators have an ability to meet maximum demand score of *acceptable* because they would be expected to input the needed 10,000 lbs/day of DO into the DWSC. The effective DO concentration difference for the bubble column aerators is 50 mg/l because oxygen gas would be used and the water would be exposed to a low pressure. Bubble column aerators that would inject oxygen into the channel would cost approximately $2.5 million to construct. The capital cost score for this technology is *high*. Daily costs for the aerators would be $2,500 for oxygen, and thus they warrant an operational cost score of *moderate*. The implementation feasibility score for bubble column aerators is *moderate* because the devices could be placed below the Rough & Ready dockand would not be expected to interfere with any DWSC activities, but more than five devices would be required. The environmental effects score for bubble column aerators is *high* because no water is pumped and no significant detrimental environmental effects would be expected.

If hollow fibers were used instead of a typical bubble column, the efficiency of oxygen transfer would increase to 80%. The oxygen transfer efficiency score for hollow fiber technology is *high*. Construction costs for the hollow fibers would be approximately $1 million, and the daily operation costs would be about $1,250. Based on these cost estimates the capital cost score for hollow fibers is *high*, and the operational cost score is *high*. The effective DO concentration difference for hollow fibers would be 150 mg/l because the technology would use pure oxygen gas and use a higher pressure to dissolve the oxygen. This technology would be expected to provide the 10,000 lbs/day of DO and receives an *acceptable* score for the ability to meet maximum demand criterion. However, the actual effectiveness of this technology may be limited because there would be no upwelling water flow to circulate the high DO water across the DWSC. The possible long-term performance degradation from "fouling" of the fibers should be tested before implementing this technology. The implementation feasibility score for this technology is *low* because more than five devices would be required to meet the 10,000 lbs/day of DO and this technology has not been tested *in situ*. The use of hollow fibers in the DWSC would not be expected to cause substantial environmental effects. Thus, the hollow fibers technology has an environmental effects score of *high*.

Floating Aeration and Water Fans

Floating aerators, common in the wastewater treatment industry, can also be placed in the river to enhance surface aeration (Dickson pers. comm.). These are simply propellers, driven by a vertically mounted electric motor. The propellers churn the water surface and increase the rate of natural aeration. Purchase costs for a 25-hp and a 50-hp floating aerator are estimated to be $10,000 and $19,000, respectively (Epic International pers. comm.). The oxygen transfer efficiency for the 50-hp device is estimated by the manufacturer to be 2.5 lbs/hp/hr. Therefore the device would likely use 2,500 kWh/hr. The efficiency is most likely calculated for water bodies that have DO concentrations of 0 mg/l and a higher effective DO concentration difference. The actual transfer efficiency in the DWSC would probably only be 1 lb/hp/hr because the effective DO concentration difference would be less assuming the initial DO concentration in the DWSC is at least 5 mg/l instead of 0 mg/l. A 50-hp device should be able to input approximately 1,000 lbs/day of DO. Therefore, 10 devices would be needed to input the 10,000 lbs/day of DO required. Estimated capital and operating costs for the 10 devices are $1 million and $1,000, respectively.

Water fans are used to pump surface water deeper into the lake or impoundment to aerate the deeper water with higher DO concentrations from the surface. The original design used an airplane propeller and is referred to as a Garton pump (Garton 1978). The flow velocities are relatively low (i.e., 1 to 3 fps), but the volume of water moved can be high (i.e., 500 cfs from a 15-foot-diameter pump with a 55-kW motor). The propeller is suspended at a depth of 3–5 feet and pumps surface water down into the lake. These low-speed surface water fans are different from high-speed surface aerators that rely on propellers to create surface turbulence and mixing. No oxygen is added directly by a submerged surface water fan. This device relies on the vertical DO gradient caused by algae or surface aeration, and the majority of the energy is used to pump water between the surface and bottom layers. The aeration efficiency of the device depends on the natural DO gradient that develops between the two layers of water. Because the DWSC can stratify, forming a surface layer that prevents transfer of higher DO water from the surface, a surface water fan may be an effective device during periods of low DO to increase the average DO in the DWSC. Water fans might be used in combination with bubble devices to redistribute the upwelling high DO water back into the deeper portions of the DWSC. Afternoon maximum DO concentrations at the Rough & Ready DO monitoring station are usually at least 2 mg/l higher than other DO concentrations because of oxygen inputs by algae photosynthesizing. Surface fans might be used to transfer this aerated water down into the DWSC.

The energy requirement for these surface pumps would be 1,350 kWh/day, with a power cost of about $135 per day. There would be no additional oxygen or air compressor costs. If the average DO gradient between the surface water and the bottom water was 1 mg/l during 6 hours of afternoon pumping, the surface pumps would transfer about 2,700 lbs of oxygen into the DWSC. If the DO difference were 2 mg/l, these same pumps would transfer 5,400 lbs of oxygen into the DWSC. This is an option for improving DO conditions in the DWSC during periods when there is sufficient DO production at the surface from algae photosynthesis (which appears to be June–September). However, it is uncertain how much of this afternoon surface DO is already mixed into the DWSC during mixing that occurs as the surface water cools at night. The surface water fans might increase the amount of photosynthesis produced in the surface layer by moving more algae biomass through the surface layer where light would allow more algae growth. The surface water fans might also increase the natural aeration from the atmosphere by slightly reducing the surface DO concentration in the DWSC during the day. These water fan performance uncertainties can be addressed only with a pilot demonstration and DO measurement effort. The fans are not expected to produce the full 10,000 lbs/day of DO required.

Application of Selection Criteria

Floating aerators would input DO to the channel by simply mixing the water with propellers. The estimated capital cost for this technology is $1 million, and the capital cost criterion score is *high*. The operating costs are also relatively low (at only $1,000/day) and support an operational cost score of *high*. The exact efficiency of floating aerators is not known so the oxygen transfer efficiency score is *unknown*. The estimated effective DO concentration difference is 4 mg/l because only air (not oxygen gas) would be added to the water and the pressure would be minimal. However, floating aerators would be expected to input at least 10,000 lbs/day of DO and receive an ability to meet maximum demand score of *acceptable*. This technology would be easy to implement, but the implementation feasibility score is only *moderate* because more than five devices would be required to dissolve the 10,000 lbs/day of DO. Floating aerators would probably cause minimal environmental effects; therefore, the environmental effects criterion score is *high*.

Water fans are used to pump surface water deeper into the lake or impoundment to aerate the deeper water with higher DO concentrations from the surface. Water fans would not be able to provide the 10,000 lbs/day of DO and receive an *unacceptable* score for the ability to meet maximum demand criterion. Selection criteria were not further applied to the water fan technology because the device could not meet the maximum demand criterion.

Waterfall Aeration

The use of waterfalls can increase DO while providing an aesthetically pleasing aeration structure. Increased aeration at waterfalls is caused by the increased surface area and increased turbulence (i.e., transfer velocity) as the water flows over the waterfall. A series of field and laboratory studies has provided a reasonable estimate of the aeration efficiency. The aeration efficiency is defined as the fraction of the DO deficit that is reduced by the waterfall:

Efficiency (%) = 100 ((DO saturation – DO downstream) / (DO saturation – DO upstream)

The DO downstream will be closer to the DO saturation value than the DO upstream.

If the assumed waterfall aeration efficiency is 75% for a cascade of two 5-foot waterfalls, the increment of DO concentration that will be achieved by the waterfall is a function of the intake (i.e., upstream) DO concentration. The DO increment will be largest for the lowest intake DO. For protecting a given DO objective (i.e., 5 mg/l), the intake should be located near where the lowest DO is expected. The lowest possible intake DO will be equal to the DO objective of 5 mg/l. For summer conditions, the water temperature will be warmer than 21ºC (70ºF) and the saturated DO will be less than 9 mg/l. A cascade of two waterfalls would increase the DO from 5 mg/l to 8 mg/l, increasing the DO concentration by about 3 mg/l. To provide the assumed supply of about 10,000 lbs/day, the waterfall flow would need to be about 620 cfs.

A 620-cfs waterfall cascade would require a pumping head of at least 15 feet because there is a 4-foot tidal range in the DWSC, and the waterfall needs to be located slightly above high-tide elevation. The power requirement can be estimated from the following equation:

Power (kWh) = 2 / Pump efficiency ∗ flow (cfs) ∗ head (feet)

Where kWh = kilowatt hours

The energy requirement for a 620-cfs waterfall with a pumping head of 15 feet and a pump efficiency of 0.8 would be about 25,800 kWh per day. At an assumed price of $0.10/kWh, the electricity cost for the waterfall would be about $2,500 per day. The design for the waterfall facility would include an intake (with fish screen) located near the bottom of the DWSC so that the water pumped to the waterfall has the lowest possible DO concentration to improve the waterfall performance. The waterfall facility should also have a return pipe to return the aerated water near the bottom of the DWSC. This can be easily accomplished with gravity assuming a small head difference (1–2 feet) at high tide. Locating the waterfall pond at elevation 5 feet msl, there will always be sufficient head to return the aerated water to the bottom of the channel through a large discharge pipe.

Application of Selection Criteria

The efficiency score for the waterfall technology is *high*, and the ability to meet maximum demand criterion score is *acceptable*. The effective DO concentration difference is estimated to be 4 mg/l because waterfalls add only air to the water and do not add pressure to the water. Daily operating costs for the waterfalls would be approximately $2,500, and they are scored *moderate*. The capital cost score for the waterfalls is *low* because the device would likely cost more than $10 million. The implementation feasibility score for waterfalls is *low* because of the high flows required. Waterfalls could cause negative environmental impacts by entraining fish in the intake pipes. The high flow rates in the waterfalls and the high pumping rates suggest an environmental effects criterion score of *low* for this technology.

Aeration Technology Comparisons

A summary of the costs, oxygen transfer efficiencies, and environmental effects of implementing each technology in the DWSC are listed in Table 1. Factors affecting the implementation feasibility and the effective DO concentration difference are also listed.

Table 1. Performance Summary of Evaluated Aeration Technologies

Technology	Meet Maximum Demand	Oxygen Transfer Efficiency (%)	Effective DO Concentration Difference (mg/l)	Estimated Capital Costs ($)	Estimated Operating Costs ($)	Implementation Feasibility	Environmental Effects
U-tube	Acceptable	80	150	5 million	1,500	Easy to implement	Flows of 40 cfs; need fish screens
Speece Cone	Acceptable	60	50	4 million	2,000	Easy to implement	Flows of 60 cfs; need fish screens
Hypolimnetic Aerators	Acceptable	20	50	2 million	5,000	More than 5 devices needed but easy to implement	Upwelling Flows of 125 cfs; no fish screens needed
Bubble Column Aerators	Acceptable	40	50	2.5 million	2,500	Easy to Implement	No pumped flows; no fish screens needed
Hollow Fibers	Acceptable	80	150	2 million	1,250	More than 5 devices needed; never tried *in-situ*	No fish screens needed
Floating Aerators	Acceptable	Unknown*	4	1 million	1,000	More than 5 devices needed but easy to implement	No pumped flows; no fish screens needed
Water Fans	Unacceptable	Unknown	2	Unknown	135	Easy to Implement	No pumped flows; no fish screens needed
Waterfalls	Acceptable	75	4	>10 million	2,500	Difficult to implement	Flows of 600 cfs; fish screens needed

* Although the oxygen transfer efficiency is unknown, this device is estimated to input 1lb of DO per kWhr.

The water fan technology received an *unacceptable* score for the ability to meet maximum demand criterion and was not further evaluated. Qualitative scores were given to the remaining technologies and are shown in Table 2. Selection criteria scores and recommended technologies were chosen by following the guidelines previously described.

Table 2. Selection Criteria Scores for Potential DWSC Aeration Devices

Technology	Oxygen Transfer Efficiency	Capital Costs	Operation Costs	Implementation Feasibility	Environmental Effects
U-Tube	High	Moderate	High	High	Moderate to Low
Speece Cone	Moderate	Moderate	Moderate	High	Moderate
Hypolimnetic Aerators	Low	High	Low	Moderate	High
Bubble Column Aerators	Moderate	High	Moderate	Moderate	High
Hollow Fibers	High	High	High	Low	High
Floating Aerators	Unknown	High	High	Moderate	High
Waterfalls	High	Low	Moderate	Low	Low

The three technologies with the highest selection criteria scores were U-tubes, Speece Cones, and bubble column aerators. Hollow fibers, hypolimnetic aerators, and floating aerators could not meet the DO demand with fewer than five devices and therefore could not be recommended. High flow rates required for waterfalls made this technology difficult to implement and increased the risk of entraining fish. The three recommended technologies will be investigated further to select the optimum technology to aerate the DWSC.

Chapter 4
Monitoring Plans for Aeration of the DWSC

The objectives of the DWSC field monitoring plan for aeration (or oxygenation) technologies are to verify the performance of the selected devices and identify the likely changes in DO concentrations throughout the DWSC, in the turning basin, and in the Stockton downtown channel that can be expected with the aeration equipment operating. A related topic is the demonstration of the operating performance of the Corps aeration device (i.e. water-jet aeration nozzles) that is being transferred to the Port of Stockton and will be operated more continuously during the summer and fall months.

Some field testing of aeration equipment performance and measurements of the variability of temperature and DO concentrations within the DWSC has been performed recently as documented in the previous reports by Brown (2003) and HDR (2003). These previous experiences form the basis for the recommended monitoring plans.

Field Testing of Corps Aeration Device

Four different field measurement efforts were conducted as part of the previous CALFED aeration project. Two field tests of the Corps jet aerator were performed. One study method measured the upwelling flow and DO concentrations from each jet diffuser with a series of near-surface velocity and DO profiles at various points around each jet diffuser. The south jet had a measured flow-away current estimated to be 215 cfs. Because water is entrained from the entire water column as the bubble plume rises, the average DO increment in the upwelling flow is difficult to estimate. The DO increment was estimated to be 0.8 mg/l and the flow-away current carried about 925 lb/day of oxygen. This is about 75% of the design aeration capacity of 1,250 lb/day for each of the two jet diffusers. The north jet was also tested, but less air was upwelling to the surface. The resulting flow-away current was measured to be only 40 cfs, and although the DO increment was 1.4 mg/l, the north jet only added an estimated 225 lb/day of oxygen. This is less than 20% of the design aeration capacity of 1,250 lb/day.

Another method used to measure the performance of the bubble-jet device was to compare the velocity and DO concentrations across the channel at the Port of Stockton railroad bridge, located 600 feet upstream, with the aeration device turned on and then turned off. Velocity and DO profiles were measured during the period of relatively constant upstream (i.e., flood-tide) flow. The overall change in the estimated DO mass flux was about 740 lb/day. This would indicate a performance that is 30% of the design capacity of 2,500 lb/day. However, the variability in the DO profiles was much greater than expected, and the uncertainty of this mass-balance method of DO differences is considered too high to be reliable.

DWSC Temperature Stratification

A second field study measured the diurnal temperature stratification that may influence the performance of aeration devices operated in the DWSC. A string of temperature recorders was installed at the DWR Rough & Ready Island water quality monitoring station to determine the strength of the vertical temperature stratification in the DWSC during the summer period. The temperature differences identify periods of thermal stratification (during the day) within the DWSC. There was a very consistent diurnal temperature variation of about 1ºF at the 12-foot and 18-foot depths. The surface temperatures warm much more than this average diurnal variation during the afternoon, and some stratification was observed almost every day. The afternoon stratification was often 2ºF and sometimes as much as 5ºF. Stratification was weakest during cooling periods and was strongest when average DWSC temperatures were warming.

Determining how the stratification may influence the DO is more difficult because there are no vertical DO measurements at the DWR Rough & Ready Island station. The DO variations may track the vertical temperature stratification, suggesting that days with the strongest stratification will also have a greater near-surface variation in DO concentration. Surface stratification may provide an ideal habitat for sustained algae growth, but it isolates the lower layers of the DWSC from the surface reaeration. More specific studies of the vertical DO gradient throughout the day in the DWSC will be required to resolve these possible effects of stratification on DO concentrations in the DWSC.

Performance Testing of Hypolimnetic Aerator Device

The third field study tested the performance of a prototype design for a MOBI device that could be located under the Rough & Ready Island dock in 25 feet of water. The device was tested for a range of oxygen gas flow rates. Performance was observed with direct measurement of the upwelling water flow, the DO increment, and the overall oxygen transfer efficiency. The MOBI pilot-scale oxygenation device gave a maximum oxygen transfer efficiency of 20%. The upwelling flow can be directed into the DWSC as a jet to improve the distribution of the oxygenated water into the DWSC. Maintenance requirements of this device are likely to be relatively low

Dye Study of DWSC Mixing

The fourth field measurement effort was a dye study to evaluate the lateral spreading of aerated water from the Rough & Ready Island dock across the DWSC. This lateral spreading and mixing of the dye was used to indicate how well an aeration or oxygen injection system that might be located under the Rough & Ready Island docks would spread water with an increased DO concentration across and throughout the DWSC. This field study verified that dyed water, representing the discharge from an oxygen injection device that might be located under the docks, would be adequately spread across the DWSC by the tidal movement of water in one day.

Recommended Monitoring Plans

Aeration or oxygenation technology appears to be appropriate and feasible for improving the DO concentration in the DWSC. Full-scale pilot testing of alternative devices should be conducted to determine the actual oxygen transfer efficiency in the relatively shallow DWSC. There are three aspects of a successful monitoring plan:

(1) Operating Performance of the Aeration Device in the DWSC. Like the previous field-testing of the Corps and MOBI aeration devices, the upwelling flow, the incremental DO concentration and the overall oxygen transfer efficiency and electrical power use should be carefully measured at the DWSC operating depth of 25 feet.

(2) Natural Variability of DO Concentrations in the DWSC. The continuous (i.e., 15-minute) measurements from the DWR water quality monitoring station at the northern end of Rough & Ready Island indicates that there are strong diurnal fluctuations in temperature and DO in the DWSC. Periodic profiles in the turning basin suggest more persistent temperature stratification and a much lower DO concentration near the bottom. More diurnal profiles and continuous DO measurements from other bottom locations in the DWSC are needed to identify the existing DO concentration gradients.

(3) Increases in DO Concentrations from Aeration in the DWSC. The changes in DO concentrations in the DWSC resulting from the aeration device must be verified with field measurements. The difficulty will be isolating the effects of the aeration device from those changes in DO concentration within the DWSC that might have occurred without the aeration device operating.

A monitoring plan has been identified for each of the recommended aeration devices that require additional testing to confirm the assumptions used in the selection process. The Corps aeration device consists of two platforms that can be lowered to a depth of 25 feet. The jet-nozzle devices may be replaced (by the Port of Stockton) with other diffusers and the air blower might be replaced with an oxygen gas supply to increase the performance of the device. This platform might also be used to mount and test other recommended aeration devices.

Isolated Testing of the Corps Aeration Device

The performance of the Corps aeration device was difficult to test (Brown 2003) because the airflow rate was not measured and because the upwelling flow and initial DO concentration were difficult to identify from field measurements. These problems must be overcome to allow an accurate assessment of the performance of the device (existing or modified). The airflow rate can be measured directly with a combination of pressure (i.e., pitot tube) or direct airflow (i.e., velocity) indicator gages. The performance of the device can then be tested for a range of airflow rates.

The bubble column–induced upwelling water flow and the surface flow-away current and the associated DO concentrations would be much easier to measure if the platform could be partially isolated from the DWSC. An isolation chamber can be built with plastic curtains around the Corps device platform to allow the device performance to be accurately measured. Two plastic curtains can be installed at either end of the platform to prevent any side-currents from entering or leaving the aeration device testing area. These two curtains would extend from the front of the platform to the channel bank, with sandbags to seal the bottom and floats at the surface. Allowance for the 3–4 feet tidal fluctuation in water surface elevation would be made. A third curtain would be placed along the front of the platform with a 10-feet high opening along the bottom and a 5-foot-high adjustable opening at the surface. These openings would force the bubble column–induced upwelling water to enter from near the bottom of the channel. The initial DO concentrations can be measured by lowering a probe to the depth of this opening. The upwelling flow and DO concentration can be measured in the surface flow-away current that is now forced to flow through the 5-foot-deep surface (i.e., floating) opening along the front of the platform.

The airflow or oxygen flow can now be changed and a systematic testing program implemented. The incremental influence on DO in the DWSC during subsequent periods of downstream (i.e., ebb-tide) flows and in the San Joaquin River channel during upstream (i.e., flood-tide) flows can also be measured with a data-logger system that is available from Dr. Gary Litton at the University of Pacific Civil Engineering Department. The influence of the aerated water should be evident from analysis of the longitudinal DO concentrations upstream and downstream of the aeration device.

Isolated Testing of a Speece Cone Oxygenation Device

A Speece Cone pressurized oxygenation device has been operated in Camanche Reservoir at a depth of about 100 feet. The performance of the device at a depth of only 25 feet has not been accurately determined.

One measurement strategy is to obtain permission from EBMUD to raise the barge platform from Camanche Reservoir and test the existing device in just 25 feet of water. This might be impractical because the device is mounted on a barge platform and permanently attached to the diffuser array. A second strategy is to further test a device that is located at Logan Martin Dam in Alabama that is operated with a hydraulic head of 50 feet.

However, construction of a prototype device that could be lowered on one of the Corps aeration device platforms may be the most practical. This would allow direct measurements of the performance at the limited 25-foot depth of the DWSC. A device could be designed by Dr. Speece to provide 2,500 pounds per day, which would be 25% of the full DWSC design. If successful, an additional device could be placed on the other Corps platform, and two more devices could be located under the Rough and Ready Island dock.

The performance of the Speece Cone can be measured directly by comparing the water flow rate and the initial and final DO concentrations. Because the DO saturation concentration with a 15-foot hydrostatic head is about 60 mg/l during the summer, the DO measurements must be accurate at high DO concentrations of up to 50 mg/l. The efficiency of the oxygen transfer depends on the residence time of the bubbles in the chamber, and the relative supply of the water and oxygen gas. A 5% oxygen-to-water-flow rate (i.e., 3 scfm of oxygen for each cfs of water) provided an 80% efficiency at the Logan Martin Dam.

The second performance measurement should involve far-field sampling of temperature and DO patterns in the vicinity of the aeration platform. Continuous DO monitoring devices should be placed at four to six locations surrounding the platform. Longitudinal profiling of temperature, DO, and pH can also be made with Dr. Litton's boat (UOP). The outflow from the Speece Cone device would need to be connected to a diffuser to mix the supersaturated DO water into the DWSC. The jet nozzles that are part of the existing Corps device might be used for this purpose.

The Speece Cone device should be operated with an on–off sequence that is coordinated with the tidal cycle to allow the changes in DO concentrations to be measured during ebb-tide (downstream) flow and during flood-tide (upstream) flow. However, the output from the device may not be sufficient to detect the change in DO because the tidal flow is about 1,500 cfs, so a device delivering 2,500 lb/day would change the DO concentration by only 0.3 mg/l. A second strategy would be to collect the far-field temperature and DO measurements for 2 days (e.g., Monday and Tuesday) and then operate the Speece Cone for 3 days e.g., Wednesday through Friday). The DO changes that are measured as the DO increases within the tidal mixing flow (i.e., tidal prism volume of about 1,000 acre-feet) would be analyzed to determine the fraction of the Speece Cone direct output of oxygen that was actually detected in the DWSC.

A dye study could also be used to identify the relative concentration of water from the Speece Cone. For this test, dye would be introduced during a complete tidal cycle so that the longitudinal influence of the water from the Speece Cone could be traced with Dr. Litton's dye-tracking boat system. Measurement of the DO changes in the DWSC will be more difficult to interpret than the direct measurements of the DO increment within the Speece Cone.

Initial Testing of a Deep-Well (U-Tube) Oxygenation Device

A U-Tube oxygenation device has been constructed on the Tombigbee River in Alabama from a design by Dr. Speece (175-foot deep-well device). Additional performance data might be obtained from this operating treated paper pulp effluent facility. Alternatively, an aboveground version of this pressurized device could be constructed and tested at the Port of Stockton. A possible design would use a 100-foot-high double pipe (i.e., one inside the other), with pumps and oxygen supply lines to allow the performance of this pressurized chamber to be evaluated. A design from Dr. Speece for 2,500 lb/day would use the same oxygen supply facility as the Speece Cone. The water pumping head of 125 feet for this initial test facility will require a different pump from the Speece Cone water pump.

Sampling ports would be located at 25-foot intervals so that the DO concentrations can be measured in the downflow and upflow pipes. The oxygen gas is supplied at the top of the pipe and is expected to be totally dissolved by the high hydrostatic pressures near the bottom of the pipe (i.e., 3x atmospheric or 45 psig). The water flow and oxygen flow rates are the basic design parameters. A higher oxygen/water ratio (i.e., 10%) should be possible because of the higher hydrostatic head. A lower water flow rate would therefore deliver the 2,500 lb/day of DO.

The outflow from the deep-well device would flow to a diffuser, just like the Speece Cone device. The far-field measurements of DO changes in the DWSC and the San Joaquin River would be identical to the Speece Cone monitoring plan. A dye study could be performed by injecting dye into the diffuser device, just as proposed for the Speece Cone device.

Isolated Testing of a Bubble-Column Aerator Device

An open bubble-column oxygenation device might also be effective in the DWSC. The main uncertainty with this simple "soaker-hose" diffuser device that might be placed under the Rough & Ready Island dock is the oxygen transfer efficiency. This test can most effectively be made using the isolated curtain chamber that is described for testing the existing Corps aerator device. A single soaker hose would be attached along the front of the two platforms (combined width of 50 feet) and lowered to a depth of 25 feet. The upwelling flow that is created by the bubble column and the increment in DO that results should be measured the same way as described for the existing Corps device. The possibility of designing multiple hose devices can be investigated by placing two or more soaker hose lines along the front of the platforms. These direct measurements of upwelling flow and DO increase will allow the direct performance of the bubble column to be measured. The soaker hose is able to deliver about 4 lb/day per foot of hose when located at a depth of more than 100 feet. The performance might be less than 1 lb/day per foot of soaker hose at a depth of just 25 feet.

The far-field measurements would be the same as described for the existing Corps device and for the measurements of the pressurized devices. A dye-experiment could be performed by releasing dye within the isolated chamber and measuring dye concentrations within the DWSC. It is possible that some of the initial increment of DO concentration that is achieved with the bubble column would be lost in the far-field because the high DO concentrations would be in the flow-away current near the surface and may exchange with the atmosphere. DO and dye concentrations would be expected to be higher near the surface until vertical mixing is effective in distributing the DO and dye. Both the isolated direct measurements of DO increments and the far-field DO measurements should be obtained and compared.

Isolated Testing of a Hollow Fiber Aerator Device

The hollow fiber oxygenation device might achieve much higher transfer efficiencies than the soaker hose device because of the higher oxygen pressure that is applied. However, this device has not been manufactured commercially and has only been tested in an experimental university setting. If the hollow fiber bundles can be fabricated into an oxygen diffuser-type pipe arrangement, this technology could be tested in the isolated curtain chamber and compared with the soaker hose device.

The curtains should be removed for the far-field testing because there will not be an upwelling current. The mixing of the high DO water with the DWSC water will require the tidal flows to move past the hollow fiber bundle arrays. A dye-release experiment could be done by releasing dye near the hollow fiber bundle array and sampling for dye concentrations within the DWSC. The far-field temperature and DO measurements would be identical to those for all the other devices tested from the Corps aerator platform.

Chapter 5
References Cited

Printed References

Ahmed, T. and M.J. Semmens. 1996. Use of transverse flow hollow fibers for bubbleless membrane aeration. *Water Resources* 30(2): 440–446.

Brown, R.T. 2003. *Evaluation of aeration technology for the Stockton Deep Water Ship Channel.* (Report to CALFED Bay-Delta Program) Calfed Project No. 01-N61-05.

Burris, V.L. and J.C. Little. 1998. Bubble dynamics and oxygen transfer in a hypolimnetic aerator. *Water Science Technology* 37(2) 293–300.

DeMoyer, C.D., J.S.Gulliver, and S.C. Wilhelms. 2001. Companion of submerged aerator effectiveness. *Lake and Reservoir Management* 17(2):139–152.

Garton, J.E. 1978. Improved lake quality through lake destratification. *Water Wastes Engineering* 15:42–44.

Weiss, P.T., et al. 1994. The performance of a vertical fiber membrane aerator. In *Aeration Technology* R.E.A. Arndt and A. Prosperetti (eds.), pp. 59–66. A compendium of presentations at the 1994 ASME Fluids Engineering Division Summer Meeting, Lake Tahoe, Nevada, June 19–23, 1994. American Society of Mechanical Engineers, New York, NY.

Personal Communications

Dickson, Bonneau. Consulting Sanitary Engineer. Letter to Robert Howard—July 16, 2002.

Epic International. 2004. Company Salesman. www.epicintl.com. January 19.