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BROWN AND CALDWELL

March 15, 2002

Christopher Foe, Ph.D.
Regional Water Quality Control Board
Central Valley Region
3443 Routier Road, Suite A
Sacramento, California 95827

21347-009/5

Subject: Review of Draft Strawman Allocation of Responsibility Report for the Stockton Deep Water Ship Channel Dissolved Oxygen TMDL

Dear Dr. Foe:

The Turlock Irrigation District (TID) appreciates the opportunity to comment on the Draft Strawman Allocation of Responsibility Report for the Stockton Deep Water Ship Channel Dissolved Oxygen TMDL (January 2002 draft). We have also reviewed the Evaluation of Aeration Technology and the Downstream Tidal Exchange reports and provided some relevant comments.

The TID is one of the members of the San Joaquin River Group Authority (SJRGA). The TID agrees with the comments submitted by Mr. Allen Short, on behalf of the SJRGA, and is providing the enclosed comments to augment those already presented.

The TID very much appreciates the efforts of the Regional Board staff members who have been working with the DO TMDL Steering Committee on the Strawman and looks forward to continued involvement in the TMDL process.

Very truly yours,

BROWN AND CALDWELL

Cynthia Paulson, Ph.D., P.E.
Vice President

CP:ka
Enclosure

DRAFT STRAWMAN ALLOCATION OF RESPONSIBILITY REPORT COMMENTS ON BEHALF OF THE TURLOCK IRRIGATION DISTRICT

Prepared by Cindy Paulson, Ph.D., P.E., and Marc Beutel, Ph.D.
Brown and Caldwell
March 15, 2002

An important first step for the Stockton Deep Water Ship Channel (DWSC) dissolved oxygen TMDL is to review existing data and information and to determine what is known and what remains unknown about the system. The Strawman does not accomplish this objective, but rather seems to begin with a preconceived notion (i.e., a "conceptual model of dissolved oxygen impairment") and then aims to evaluate three hypotheses for the model, based on incomplete data and information. It would be more appropriate and useful for the Strawman to stay focused on characterization of the dissolved oxygen impairment (e.g., extent of low dissolved oxygen, both spatially and temporally), the causes of the impairment, and feasible strategies to address the problem. It would also be useful for the Strawman to provide a more comprehensive overview of existing data and future data and research needs.

As the draft Strawman acknowledges, the existing water quality model is not well calibrated and yet it goes on to apply the Systech model in support of various hypotheses. There are also significant data gaps that make it very difficult to adequately address the three hypotheses laid out as part of the "conceptual model." Given the limitations of existing data and models, it does not seem feasible to take these hypotheses to a higher level or to quantify the relative importance of each factor with any degree of confidence at this time.

ALLOCATION OF RESPONSIBILITY

The Draft Strawman Allocation of Responsibility Report indicates that the oxygen impairments within the Deep Water Ship Channel ("DWSC") would not likely exist if the channel had not been constructed. Given the data collected immediately upstream and downstream of the channel that indicate no oxygen impairments outside the channel, it appears that the ship channel has increased the sensitivity of the system to nutrients and organic loadings, resulting in dissolved oxygen impairment. In the case of the Stockton DO TMDL, where the focus is on the area of hydrologic modification (i.e., the DWSC), it is appropriate to assign responsibility to the entity that created the condition by modifying the channel and exacerbating the dissolved oxygen issue. Therefore, the initial TMDL evaluation should focus on direct mitigation for the DWSC. These analyses are imperative prior to preparing a DO TMDL for DWSC that would impose requirements on upstream sources.

Mitigation via an aeration device was required pursuant to Section 404 of the Clean Water Act as a remedy under the existing permit to cover the last dredging operation to deepen the DWSC. As a prerequisite to the DO TMDL, it would be appropriate to determine whether the aeration mitigation is operating sufficiently and whether it is providing adequate mitigation for the current operations.

The work by Brown (2002a) does address the effectiveness of the existing water-bubble jet device and it appears that the system does not fully meet its original design capacity. It would be important to revisit the permit requirements and determine if any modifications of the existing system are in order. In addition, it would be appropriate to address any further mitigation required for future dredging of the DWSC that is currently planned for fall 2002. It is imperative that before upstream sources are required to modify their loads, that there be assurances that previously required mitigation is operating adequately and that new channel modification activities are also appropriately mitigated.

APPROACH NEEDED TO MANAGE WATER QUALITY

To attain water quality objectives in the Stockton DWSC through sustainable means, we urge the RWQCB to consider TMDL control measures beyond reductions in organic loading. Specifically, tools that could be considered within the Stockton DO TMDL process include recirculation via the use of barriers to promote flow through the DWSC, and direct aeration or oxygenation of the DWSC. The planned construction of a permanent barrier at Old River by 2005 to allow recirculation of water through the DWSC will provide an opportunity to measure the value of this option. Going beyond recirculation to consider upstream increases in flow, however, is unacceptable. Ideas and approaches to consider direct aeration or oxygenation of the DWSC are offered in greater detail below. It is important for the Strawman to acknowledge the strong potential of both of these tools – recirculation and oxygenation – and to encourage broader consideration by the Regional Board as part of the TMDL process.

DIRECT AERATION / OXYGENATION: A VIABLE TECHNOLOGY FOR THE DWSC

Direct aeration or oxygenation of the DWSC would be a relatively cost-effective, reliable, and direct means to address the low dissolved oxygen problems in the DWSC. Work performed to date is encouraging (Brown 2002a), but we believe that a detailed and comprehensive feasibility study of aeration and oxygenation alternatives is needed to ensure that a system, if selected for implementation, is appropriate for the setting of the DWSC, as well as capable of meeting oxygen demand in the DWSC. The draft Strawman does not acknowledge this tool and does not provide sufficient data and information to fully evaluate the possibilities. Because aeration / oxygenation has not yet been widely applied in TMDLs, it will be very important to sufficiently evaluate and test this potential tool in the early stages to ensure successful application for the DWSC. We believe strongly in the viability of aeration / oxygenation as a cost-effective solution for the DWSC and would like to see this approach receive every possible consideration.

More Data Needed to Better Characterize Oxygen Demand

The Draft Strawman Report currently presents limited dissolved oxygen (DO) data for two stations on the San Joaquin River and one in the DWSC in Table 3 (note - all numbers listed as integer values, while DO is generally reported to the nearest one-tenth mg / L). The report needs to better define the temporal and spatial extent of DO conditions in the DWSC. The magnitude, timing and location of the oxygen deficit need to be defined so that the feasibility of various alternatives to address the deficit can be fully explored. Without more data, it is difficult to draw any real conclusions about the dissolved oxygen impairment in the Strawman.

Some additional dissolved oxygen data and data analysis are apparently going to be included in the San Joaquin River Low Dissolved Oxygen TMDL: Interim Performance Goal and Final Target Analysis Report (Gowdy and Foe, 2002). This report states that "an analysis of data from existing DO monitoring programs that illustrate some of the temporal and spatial variability of DO experienced within the DWSC" is under development. We strongly support this effort and expansion of the Strawman to include an overview of all the available relevant data. Particular data that need to be collected and/or discussed in the Strawman Report include the following.

- **DO Profiles.** Profiles are needed vertically down the water column in the channel, as well as horizontally along the channel to evaluate the proper system design for any aeration or oxygenation system.

- **Diurnal Variation.** Data on diurnal cycling of DO both vertically and horizontally in the channel are needed to assess the value of systems to redistribute the dissolved oxygen produced by algae in surface water to lower levels and throughout the water column.

- **BOD and Chlorophyll Data in the DWSC.** The Strawman Report presents BOD and chlorophyll data only from the river. Data also should be collected in the DWSC to experimentally confirm the rates of oxygen consumption estimated via mass balance calculations.

Estimates of Oxygen Demand

A critical design parameter of any aeration or oxygenation system is the magnitude and spatial extent of the oxygen demand that needs to satisfied. However, the Strawman does not provide this information for the DWSC. For the purposes of these comments, we have provided rough estimates of oxygen sources and sinks (Table 1) using data from Brown (2002a) and the Draft Strawman Report. Based on the assumptions presented below, the oxygen demand in the DWSC ranges from 0 to 8.2 metric tons per day (one metric ton is 1,000 kg or 2,205 lbs). We have also estimated the oxygen demand as the product of river flow rate and the deficit observed in the field defined as the difference between measured oxygen concentrations and the current Regional Board water quality objective of 5 mg/L. Based on Figure 6 of the Strawman (DO concentration versus channel flow for 1994-2001), DO deficits of 2 to 3 mg/L are associated with flow of 300 to 1,000 cfs. The product of these components (2 mg/L deficit at 300 cfs and 3 mg/L deficit at 1,000 cfs) yields a demand estimate of 1.5 to 7.4 metric tons/day. Both of these estimating techniques confirm DO demands of up to 8 metric tons/day in the DWSC. It would be appropriate to refine these rough estimates with more specific measures of affected area and dissolved oxygen conditions under various flow scenarios.

Table 1. Estimated Magnitude of DO Sources and Sinks in Stockton DWSC

Source/Sink	Magnitude of source/sink	Flow or Area	Oxygen Demand (metric tons/day)
Water column oxygen	4-10 mg/L	500 cfs	4.9-12.2
Sediment oxygen	0.5-1 $mg/m^2/day$	Sediment area of 1,000 acres[1]	2.0-4.1
Reaeration	Reaeration transfer velocity of 0.5 m/day (assuming DO levels at 4 mg/L below saturation)	Surface area of 1,000 acres[1]	-8.1
Total Demand			0-8.2

[1] Brown (2002a) states that 3 miles of channel is 330 acres and Strawman states that low DO is observed over a 8-10 mile stretch of channel. Based on these assumptions, the estimated area of the impaired channel would be 1,000 acres.

Consideration of Aeration or Oxygenation Systems for the DWSC

The estimated oxygen demand observed in the DWSC (up to 8 metric tons/day) is well within the magnitude that can be alleviated with an engineered oxygenation system (Beutel and Horne 1999), and perhaps by an aeration system as well. Brown (2002a) discusses some aeration and oxygenation alternatives in his recent report. In addition, we provide a brief evaluation of additional systems below. Rather than haphazardly testing one system or another, we recommend that a detailed feasibility study concerning aeration and oxygenation of the DWSC be performed. A feasibility study will enable selection of a system that is most appropriate for the dynamic physical, chemical and biological conditions of the channel.

Several aeration and oxygenation systems could be included in an evaluation of options for the Stockton DWSC (Table 2). A rough planning level estimate of costs for an aeration or oxygenation system in the DWSC is approximately $1 million in capital costs and $400 to $1,000 per day in operating costs. The systems in Table 2 are listed in the order of estimated operating cost but some of the lower cost options may lack the operational flexibility needed to assure that adequate DO levels are maintained in the channel.

For example, propeller pumps are very efficient at moving large qualities of water over long distances. But as an aeration system, the option relies on oxygen produced by algae in surface waters as a source of oxygen - a highly variable biological process. This oxygen source may not always be capable of meeting oxygen demand throughout the DWSC when DO production by algae is low (e.g., during nighttime, on cloudy days, after an algae die off). In the case of algal bloom crashes, natural DO supply is cut off just when it is needed the most. Additionally, propeller operation could mix algae downward and away from sunlight. This tends to lower rates of algal oxygen production and could kill algae due to rapid changes in hydrostatic pressure (Cooke et al., 1993, p. 419-428). Less algal activity results in lower amounts of oxygen available to supplement bottom water low in DO. As this example illustrates, there are a number of potential pitfalls associated with systems that depend on complex biological interactions for a source of oxygen.

Because of their high operational flexibility and wide range in oxygen delivery capacity, a pure oxygen system may be best suited to meet the dynamic DO conditions in the DWSC. Unlike aeration systems that rely on oxygen transfer from the atmosphere or from algae, oxygenation systems can literally be ramped up and down with the turn of a dial. These oxygenation systems are discussed in more detail in the section below, but while we focus on oxygenation, we support a comprehensive study of both aeration and oxygenation in regards to alleviating low DO conditions in the DWSC.

Existing Applications of Oxygenation Systems

Pure oxygenation systems have been used in a number of rivers and reservoirs to improve low oxygen conditions. Oxygenation systems generally consist of a liquid oxygen storage facility on shore. Evaporators transform the liquid oxygen to gas, and the gas is dissolved into lake or river water through an on-shore contact chamber or u-tube, a contact chamber submerged under water, or a system of diffusers located under water. The low unit-cost of liquid oxygen combined with the ability to dissolve high levels of oxygen into water results in small-scale facilities capable of economically dissolving large amounts of oxygen into water. A number of examples are discussed below for each major type of system.

Line Diffusers. A number of line diffuser systems have been installed in large hydropower reservoirs to oxygenate water discharged from the reservoirs (Mobley and Brock 1995). Advantages of the line diffuser system include no pumping costs and good horizontal distribution of oxygen. Oxygen delivery capacities for these systems are high and generally range from 50 to 100 tons of oxygen per day. A new system was recently installed in Richard B. Russell Reservoir, Georgia, (1 million acre-feet) to create a well-oxygenated refuge for striped bass (Mobley and Proctor 1997). The system has a capacity of over 150 tons per day and includes over 9 miles of line diffuser. Smaller systems are being installed to improve water quality in a number of California drinking water reservoirs. For example, roughly 2 miles of line diffuser was installed in Upper San Leandro Reservoir, California, (40,000 acre-feet) a drinking water reservoir operated by East Bay Municipal Utility District. The system delivers 2 to 7 tons per day of oxygen, roughly the same demand observed in the Stockton DWSC. While line diffuser systems generally use pure oxygen, a 3,500-foot system uses air to deliver roughly 1 ton per day of oxygen to Spring Hollow Reservoir for the County of Roanoke Utility District, Virginia (Dr. John Little, personal communication). The drawback of using air rather than oxygen is that nitrogen gas can build up in bottom water and potentially injure fish.

Table 2. Possible Aeration and Oxygenation Systems for the Stockton DWSC

System (reference)	Capital Cost ($)	Operating Cost[1] ($/d)	Advantages	Disadvantages
Line diffuser using air (Mark Mobley pers. comm.)	~$2 million	~$360	Low operating cost. Good horizontal and vertical distribution of oxygen. No liquid oxygen storage required.	Extensive gas lines along bottom of channel. High gas flow rates. Potential for nitrogen supersaturation.
Propeller pump[2] (Brown 2002a, Fast 2002)	~$0.7 million	~$375	Low energy requirements. No liquid oxygen storage required.	Irregular source of oxygen. No assurance of meeting nighttime oxygen demands. Low operational flexibility. Structures on surface of channel.
Pure oxygen submerged chamber (Beutel 1999)	~$1 million	~$840	High operational flexibility. Very high oxygen transfer efficiency.	Need for a submerged pump and chamber.
Deep pure oxygen u-tube (Speece 1996)	Not reported	~$990	Low operating cost. High operational flexibility.	Need to construct 175-foot deep u-tube.
Pure oxygen line diffuser (Mark Mobley pers. comm.)	~$1 million	~$1,000	No pumping. Good horizontal and vertical distribution of oxygen. High operational flexibility.	Moderate amount of gas lines along bottom of channel.
Shallow pure oxygen u-tube (Speece 1996; Brown 2002a)	Not reported	~$1,070	Low operating costs. High operational flexibility. Tube only 20-30 feet deep.	
Waterfall[3] (Brown 2002a)	~$20 million	~$2,530	No liquid oxygen storage required.	High pumping cost. High capital cost. Low operational flexibility. Multiple units required.
Pure oxygen on shore pressurized chamber (Brown 2002a; Speece 1996)	Not reported	~$2,910	Most facilities on shore. High operational flexibility.	High pumping cost.

[1] Costs based on the following assumptions: liquid oxygen at $150/metric ton; energy at $0.10/kWh; intermediate oxygen demand in DWSC of 5 metric tons/day over 8 to 10 miles of the DWSC.

[2] Operating costs based on data from Brown (2002a). DO difference between surface and bottom water assumed at 1.5 mg/L and 4 pumps assumed to deliver 1,800 kg of oxygen. Capital costs estimated from Fast (2002).

[3] Costs based on data from Brown (2002a). Operating cost based on $0.23 per pound of oxygen delivered. Capital costs estimated from Chicago case study ($40 million to deliver an estimated 9-10 tons of oxygen along 17 miles of river).

Submerged Contact Chambers. A handful of oxygenation systems have been installed that utilize a submerged contact chamber (Speece 1994). Advantages of this system include very high transfer efficiency and the ability to not disturb thermal stratification. In addition, the system can discharge oxygenated water horizontally over the sediment-water interface, the main source of problematic reduced compounds. A 2-ton-per-day system is operated in Newman Lake, Washington, (23,000 acre-feet) to provide lake trout with well-oxygenated, cold-water habitat in the bottom of the lake during the summertime. A 20-ton-per-day system has been proposed to ameliorate fish kills in Lake Elsinore, California, a shallow, 3,000-acre lake in Riverside, California. Another 20-ton-per-day system is being implemented as a demonstration project at Upper Klamath Lake, another large, shallow lake (90 square miles) with a history of fish kills (Speece and Horne, 2001).

In 1993, an 8-ton-per-day system was installed in Camanche Reservoir, California, (417,100 acre-feet), a large eutrophic multi-purpose reservoir operated by the East Bay Municipal Utility District (Jung et al., 1998). The Camanche Reservoir system assures that cold, well-oxygenated bottom water reaches a fish hatchery that rears Chinook salmon and steelhead trout near the dam. Intensive water quality monitoring in the reservoir after system start-up showed that a well-oxygenated plume of bottom water extended 2 miles upstream of the contact chamber (Brown and Caldwell 1995). The system continues to operate effectively today, several years after start-up.

Side-Stream Aeration. Speece (1996) has developed a low energy oxygenation system that uses a u-tube to oxygenate a side-stream of river water. River water is mixed with oxygen and discharged into a 175-foot-deep u-tube. The hydrostatic pressure in the tube promotes the dissolution of oxygen gas into the water and DO concentration in the water discharged back into the river is around 50 mg/L. Speece (1996) designed and implemented two u-tube systems that deliver 5 tons per day and 18 tons per day to the Tombigbee River, Alabama. The oxygenation is a cost-effective mitigation for the discharge of BOD in effluent from two paper mills located along the river. Speece (1996) vigorously argues for the use of u-tube systems instead of on shore pressurized chambers, since operating costs to maintain pressure in on-shore chambers can be 20 to 30 times more expensive.

Oxygen Distribution

The dynamic nature of water movement in the channel would help to distribute any localized high-oxygen discharge throughout the 8 to 10 miles of channel experiencing low DO conditions. For example, summer channel flows on the order of 500 to 1,000 cfs move water roughly 0.5 to 1 mile per day. In addition, roughly two tidal cycles occur each day, which accelerate channel water back and fourth approximately 1 mile (Brown 2002b). So, during a single day, channel water flows back and forth twice about 1 mile while moving a net mile down stream. This dynamic water movement should promote distribution of an oxygen-rich discharge. In fact, within 1 to 2 weeks of operation, a properly designed oxygenation system should keep the entire 8 to 10 miles of impacted channel length well oxygenated.

ORGANIC LOAD REDUCTIONS

The Strawman indicates that the San Joaquin River at Hwy 165, Salt and Mud Sloughs account for more than 90 percent of the total chlorophyll load at Maze Boulevard and Mossdale, based on an “algal growth model.” The Strawman goes on to suggest that algal control methods should be investigated for these upstream sources to improve dissolved oxygen conditions in the DWSC. Before seriously considering upstream nutrient and algae reductions, it would be appropriate to apply a more sophisticated algal model than the simple one presented in the Strawman. Algal growth models typically incorporate many other factors known to affect algal growth, beyond temperature.

Changes in phytoplankton concentration are a function of several interrelated factors including initial phytoplankton concentration, rates of photosynthesis, rates of sinking out of the photic zone, rates of zooplankton grazing, and rates of natural death (Horne and Goldman, 1994, p. 236). Simple models developed to estimate phytoplankton concentrations in flowing waters generally include such factors as travel time and the net gain rate of phytoplankton, which in turn is a function of rates of growth, kinetic losses (respiration, excretion, death), and settling (Chapra, 1997, p. 645). Furthermore, many of these rates are functions of additional environmental factors including nutrient concentrations, light intensity, and temperature. These interrelated factors are typically included in accepted water quality models, including the EPA-supported CE QUAL W2 (Wells and Cole 2001).

One factor that could be particularly important for algal growth dynamics in the San Joaquin River and downstream effects in the Stockton DWSC is the effect of algal self-shading and light limitations. Given the high concentrations of algae found in the system, self-shading is likely to result in light limitations on growth. If the system is in fact light limited, then upstream reductions of algae could prove to be irrelevant, merely making more light available for downstream algae growth to occur and not ultimately reducing organic loading to the Stockton DWSC.

ADAPTIVE MANAGEMENT APPROACH

As the draft Strawman acknowledges, there are still many uncertainties in the understanding of dissolved oxygen dynamics and impairment in the Stockton DWSC. The Interim Performance Goal and Final Target Analysis Report also recognizes the size and complexity of the TMDL, as well as a possible re-evaluation of the existing Basin Plan DO water quality objective. Given the complexity and uncertainties involved in the Stockton DO TMDL, an adaptive management approach is appropriate.

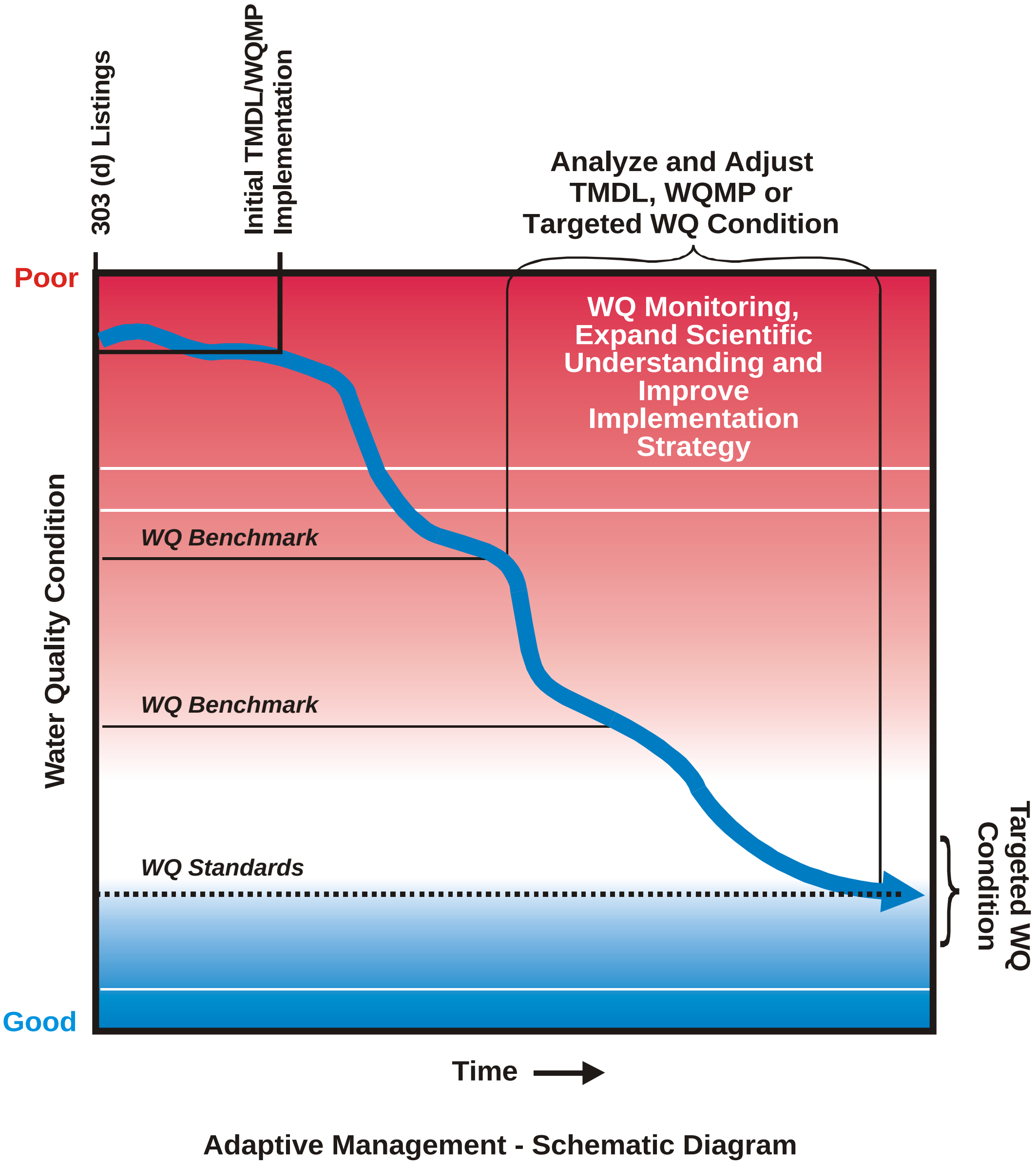
Adaptive management, or an iterative approach, provides flexibility in TMDL development and implementation. It allows stakeholders to take some initial steps toward water quality improvements, while monitoring progress toward water quality standards. EPA has authorized “phased TMDLs” to allow for an iterative approach to TMDL development and adaptive management approaches that can target the most effective TMDL implementation strategies. Adaptive management also encourages stakeholders to start implementation sooner because there are future opportunities to refine the science and to re-evaluate implementation strategies. The states of Oregon and Idaho have both applied the adaptive management concept in TMDLs recently, including two current draft TMDLs – the Upper Klamath Lake Drainage TMDL and the Snake River-Hells Canyon TMDL (Idaho DEQ, 2001, and Oregon DEQ, 2001). The adaptive management model applied by Oregon and Idaho (depicted on Figure 1) includes continued monitoring and evaluation of progress toward water quality objectives with periodic opportunities to review and revise TMDLs as needed over time.

A phased approach to the Stockton DWSC TMDL, could begin with a first phase of improvements that might include the following components.

- Implementation of aeration required pursuant to dredge and fill permits.
- A demonstration project for a recommended aeration or oxygenation technology, based on a feasibility study.
- Recirculation, to be enabled with the construction of permanent barriers by 2005.
- Consideration of the technical basis for the Basin Plan DO objective and modification of the objective, as appropriate.

Following the implementation of a first phase of improvements, monitoring and evaluation of progress toward the dissolved oxygen objective would determine whether any additional improvements would be necessary in subsequent phases.

Figure 1. Adaptive Management—Schematic Diagram
(taken from Oregon DEQ, 2001)



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