SYNOPSIS OF ISSUES IN DEVELOPING THE SAN JOAQUIN RIVER DEEP WATER SHIP CHANNEL DISSOLVED OXYGEN TMDL[1]

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ABSTRACT

In 1994, the Central Valley Regional Water Quality Control Board (Board) classified the San Joaquin River (SJR) Deep Water Ship Channel (DWSC) "impaired" because dissolved oxygen (DO) concentrations routinely fell below the water quality objective (standard or WQO) in the fall. This classification requires development of a total maximum daily load (TMDL) to control loads and conditions that cause violations of the DO WQO. In 1998, the Board classified the dissolved oxygen impairment a high priority problem for correction. Staff committed to develop a TMDL plan for controlling the problem and submit it to the US Environmental Protection Agency by June 2003. Furthermore, the Board, under the Bay Protection Plan, agreed to allow a Steering Committee of local vested interests help to develop the control plan if they committed to provide Board staff all the elements of the TMDL, including an implementation plan, by December 2002. If at any time the steering committee was unable to do so, then staff would resume control over the development of the TMDL control plan. This article presents an overview of the DWSC DO depletion problem and many of the issues that are in need of consideration by the Steering Committee and Board in developing a technically valid, cost-effective TMDL that will enable compliance with the DO WQO. This article is a synopsis of a more extensive report by Lee and Jones-Lee (2000), which presents the issues that need to be addressed in oxygen demand TMDL development and load allocation among stakeholders.

BACKGROUND

As part of developing the Port of Stockton (Port), a navigation channel was dredged in the SJR through the Delta to Stockton (Figure 1). The SJR, just upstream of Stockton, is typically about 8 to 12 feet deep. It is a freshwater, tidally influenced river with a three-foot tidal range and tidal flow that typically ranges between 2,000 and 4,000 cfs. The non-tidal flow during summer and fall is highly regulated with net flow at Stockton, ranging from negative (upstream) flow associated with upstream diversions at Old River to net downstream flow between 100 to 2,000 cfs. Beginning at the Port, the SJR DWSC is dredged to 35 feet deep to allow passage of ocean cargo ships bringing bulk materials to Stockton. This dredging greatly slows the net downstream transport rate of SJR water. The first 15 miles of the DWSC can have a hydraulic residence time that varies from about 5 days at a net downstream flow of 2,000 cfs to about 30 days at 100 cfs. The relatively short hydraulic residence time of the DWSC has important implications for determining when oxygen demand loads to the DWSC may potentially lead to violations of the DO WQO. With hydraulic residence times of less than one month, high winter and spring SJR flows and associated oxygen demand and nutrient loads do not significantly contribute to DO

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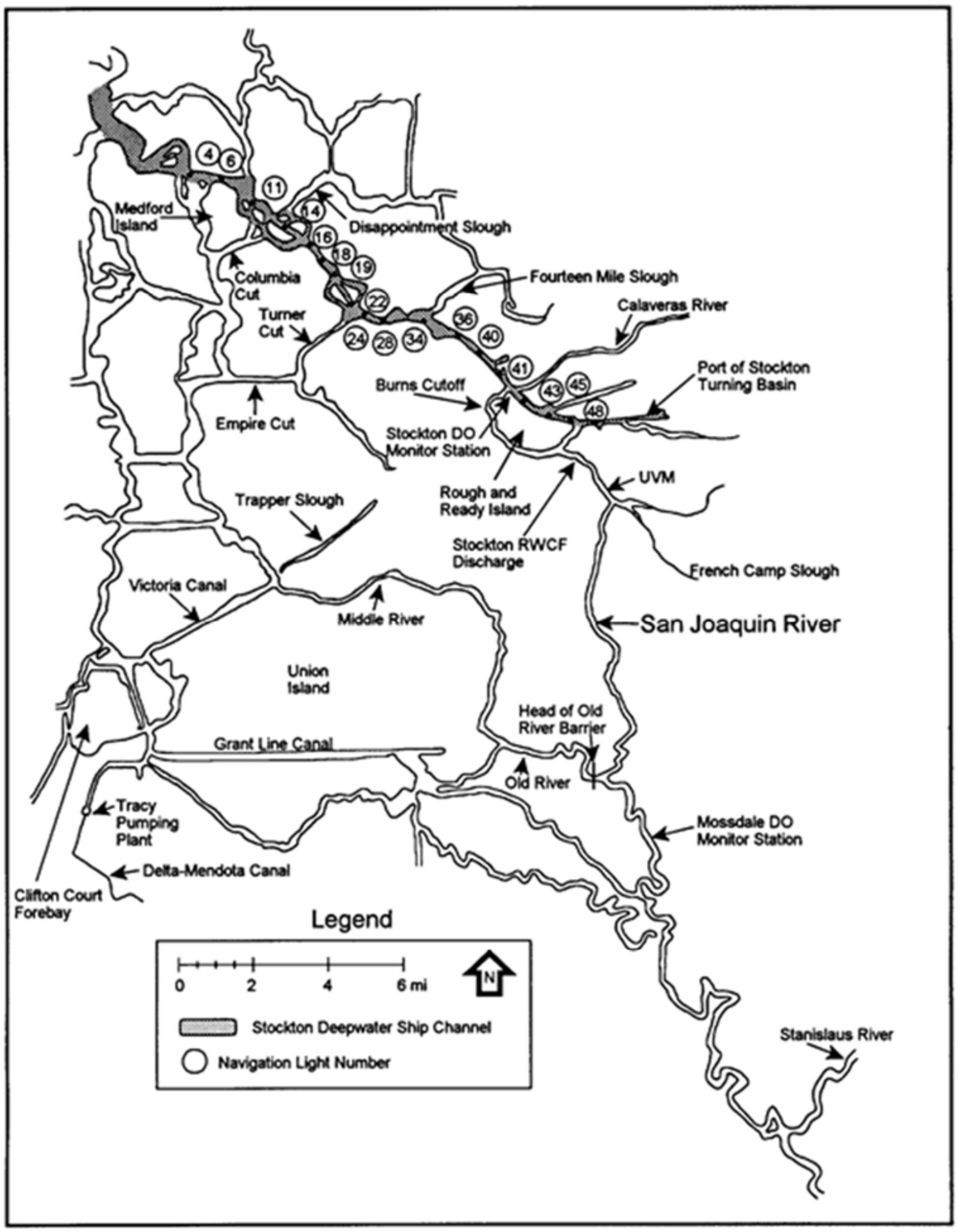
depletion within the DWSC during summer and fall. All oxygen demand added during the winter and spring is flushed through the DWSC during this time.

Figure 1 Location of water quality stations and navigation lights on the San Joaquin River in the vicinity of Stockton



Dredging the DWSC alters the oxygen demand assimilative capacity of the SJR for about 10 to 15 miles downstream of the Port (critical reach) by increasing the hydraulic residence time of the water and by decreasing the amount of re-aeration per unit volume of the channel. Also, greater water volume in the DWSC as a result of dredging dilutes the dissolved oxygen photosynthetically produced by algae. Further, the effect of sediment oxygen demand (SOD) is diluted for the same reason. These factors, coupled with diversions by the State and federal water projects (CVP and SWP) and other municipal and agricultural intakes, lead to DO concentrations below the WQO. The WQO is 6 mg/L from September through November and 5 mg/L from December through August. While DO depletions below the WQO is critical in summer and fall, there also can be violations at other times, such as during spring low flow.

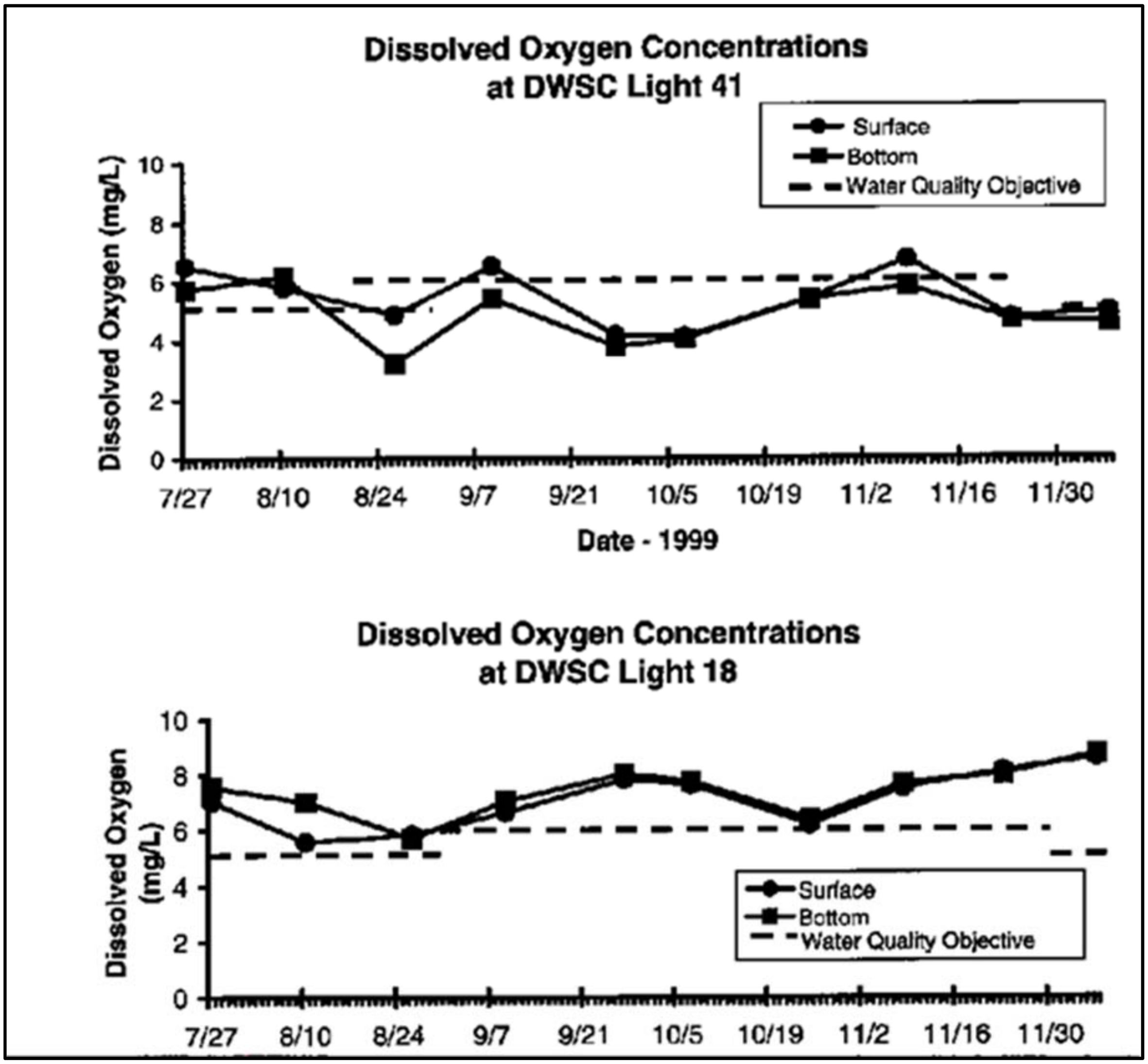
CHARACTERISTICS OF THE SAN JOAQUIN RIVER WATERSHED

The San Joaquin River is one of California's primary rivers. It originates in the central Sierra Nevada, flows through the San Joaquin Valley and into the Delta, where it mixes with the Sacramento River before discharging into upper San Francisco Bay or being diverted by the CVP and SWP. The SJR drains the San Joaquin Valley between Fresno and Stockton. It has a 7,345 sq mi watershed that contains about one million acres of irrigated agriculture (Kratzer and Shelton 1998). The primary crops are fruits and nuts (almonds), corn, pasture, and cotton. The SJR watershed includes the metropolitan areas of Stockton, Modesto, Merced, and Fresno, and numerous dairies and feedlots. The current estimated urban population in this watershed is approximately two million and, at a growth rate of two percent per year, is expected to double to about four million people by 2040.

Upon entering the San Joaquin Valley floor, SJR water quality deteriorates due to agricultural, municipal, and industrial stormwater runoff; wastewater discharges; municipal, industrial, and husbandry activities; and natural and riparian runoff or drainage. In addition to adding oxygen requiring substances (carbonaceous and nitrogenous biochemical oxygen demand [BOD]), the discharges contribute substantial amounts of nutrients (N and P compounds), which can support algal growth. Many of the algae die due to a lack of light upon entering the DWSC, which has a photic zone of about 1 meter. The dead algae are a source of oxygen demand in the DWSC where flows in the SJR at Vernalis represent a significant part of the flow into the DWSC. (Vernalis is located about 30 miles upstream of the DWSC.) Located between Vernalis and the DWSC, the Old River diversion can at times divert substantial flow into the South Delta. Also, it is possible that detritus (dead plant and animal remains and waste products like manure) derived from the SJR watershed contributes to the oxygen demand present at Vernalis and, under certain SJR flow and diversion conditions, exerts oxygen demand in the DWSC. The SJR at Vernalis typically has several mg/L of nitrate N and about 0.1 to 1 mg/L soluble orthophosphate P. These nutrients can support substantial algal biomass (20 to 100 µg/L chlorophyll *a*) in the SJR at Vernalis and the DWSC during summer.

STOCKTON DEEP WATER SHIP CHANNEL
1999 WATER QUALITY CHARACTERISTICS

A study was conducted of the oxygen demand sources and DO depletion in the DWSC by the SJR Technical Advisory Committee (TAC) during late summer and fall 1999. Some of the data from these studies are presented in Figure 2. Station 41 is near the downstream end of Rough and Ready Island, about two miles from the point where the SJR enters the DWSC at the Port. Station 18 is about 10 miles downstream of this point.



DO concentrations in the DWSC decreased below the WQO in August 1999 and September through early December 1999. During August and most of September, SJR flow into the DWSC was about 900 cfs. In late September through October, flow ranged from about 100 to 900 cfs as a result of upstream diversions into Old River. Under these low flow conditions, DO in some areas decreased to about 2 mg/L. Further, during November and early December 1999, concentrations of ammonia in the SJR just upstream of where it enters the DWSC were over 3 mg/L N. According to the EPA (1999), ammonia at these concentrations, combined with SJR DWSC temperature and pH, is toxic to many forms of aquatic life over a 30-day period and can be a significant source of oxygen demand. The ammonia was primarily derived from Stockton's domestic wastewater discharge just upstream of the DWSC.

Table 1 presents the results of box model calculations of the major sources of oxygen demand during summer and fall 1999. In general, they are based on measured concentrations of oxygen demand constituents and flow, summed to yield a total daily load of oxygen demand from each major source. Box model calculations suggest the primary sources of DWSC oxygen demand during August and September 1999 were algae, detritus, and other organics in the SJR above Vernalis. During August and September, Stockton wastewater discharges were a small part of the oxygen demand load to the DWSC. However, in late September to early October, when SJR flow into the DWSC was about 150 cfs, SJR flow upstream of Vernalis and associated oxygen demand load was largely diverted down Old River. Under these conditions, Stockton wastewater flow (about 40 cfs) with a 20 mg/L N ammonia load was an important source of oxygen demand to the DWSC.

Table 1 Estimated Oxygen Demand Sources for the DWSC During Summer and Fall 1999

Source	BOD_u (lbs/day)				
	August	September	October		
SJR Flow (cfs)	~900[a]	~900[a]	150	400	1,000
Upstream of Vernalis	61,000	70,000	6,300	14,130	35,325
City of Stockton	5,600	9,300	12,200	12,000	12,000
Local DWSC	?	?	1,750	1,750	1,750
SOD	6,000	6,000	6,000	6,000	6,000
Aeration (Natural)	5,500	5,500	?	?	?
Aeration (Mechanical)	2,000	2,000	?	?	?
DWSC Algae	?	?	?	?	?
Export from DWSC	27,000	27,000	?	?	?

[a] Values are approximate.

These results suggest upstream diversions of SJR water are important in determining the source of the oxygen demand loads contributed to the DWSC. These results also indicate that it will be necessary to expand the TMDL load analysis to the SJR watershed upstream of Vernalis. Both carbonaceous and nitrogenous BOD and algal nutrients derived from irrigated agriculture are potentially important sources of oxygen demand that enters the DWSC.

The City of Stockton supported Chen and Tsai (1997) in the development of a mathematical model of oxygen demand and DO effects in the DWSC. This model, with appropriate modification, will be used to develop an oxygen demand TMDL as a function of SJR flow through the DWSC. In addition, another model is being developed to relate oxygen demand and nutrients discharged to the SJR and its tributaries upstream of Vernalis to oxygen demand in the DWSC.

TMDL DEVELOPMENT AND ALLOCATION

A Technical Advisory Committee of the SJR DO TMDL Steering Committee is developing the SJR DWSC oxygen demand TMDL. Excessive DO depletion in the DWSC has been a long-standing problem. Brown & Caldwell (1970) determined that the DWSC could assimilate 40,000 lbs/day BOD_u. Since then, the SJR DWSC has been deepened by an additional five feet, which further reduces its oxygen demand assimilative capacity. Further, Brown & Caldwell's estimated allowable BOD_u load did not include the safety factor required in TMDL development. Work is underway as part of a "strawman" effort to develop preliminary estimates of the allowable oxygen demand load to the DWSC, considering the effect of SJR flow through the DWSC on DO depletion for a given oxygen demand load.

Some relief from this oxygen demand load reduction may be achieved by increasing SJR flow through the DWSC. In summer and fall 1998, SJR flow through the DWSC was over 2,500 cfs and DO in the DWSC did not fall below the WQO. However, there is concern that these high SJR flows lead to DO depletion elsewhere in the central Delta. Similarly, the diversion of SJR flow down Old River could be causing low DO in the South Delta. Both of these issues will need to be examined in determining how SJR flows into the DWSC affect DO depletion. Another important factor to consider in developing the TMDL is the population increase in the SJR DWSC watershed. This population increase will increase the demand for water, wastewater discharges, and oxygen demand load to the SJR DWSC.

CALFED provided $866,000 during 2000 for the Technical Advisory Committee to conduct additional studies needed to define the relationship between oxygen demand load to the DWSC and DO depletion below the WQO. The Steering Committee submitted a Directed Action proposal in the amount of $2 million/yr to CALFED in 2001 to continue field studies devoted to evaluating the relationships between discharge of oxygen-demanding substances to the DWSC and the resulting DO depletion that occurs in the DWSC, as a function of SJR flow through the DWSC. This proposal was funded by CALFED.

STEERING COMMITTEE RESPONSIBILITIES

The Steering Committee is composed of stakeholders in the SJR watershed. The committee will need to resolve a variety of issues in developing and implementing the TMDL. The committee will need to establish an appropriate DO TMDL goal and evaluate how current standards should be interpreted. The EPA (1986, 1987) has indicated that DO depletion between 4 and 5 mg/L primarily affects the rate of fish growth; however, the effect of DO concentrations between 4 and 5 mg/L on fishes of the DWSC, San Joaquin River, and the Delta needs more study. There could be a large difference between a "worst-case-based" DO goal versus an "average" daily water column DO goal.

The allocation of the oxygen demand load and responsibility among dischargers in the DWSC watershed will be a challenging task. The Steering Committee must complete this allocation by December 2002 to meet the Board's deadline. Failure to meet this deadline will result in the Board establishing the TMDL allocation. Another important issue that will need to be addressed by the Steering Committee and stakeholders is how to balance the control of oxygen demand constituents, including aquatic plant nutrients that develop into algae that exert an oxygen demand in the DWSC, with the significantly reduced assimilative capacity of the DWSC associated with upstream of DWSC diversions of SJR water for the City of San Francisco, other communities and various irrigation districts, as well as the development and maintenance of the 35-foot navigation channel through the San Joaquin River to the Port of Stockton. The diversions of SJR water and the 35-foot navigation channel significantly adversely affect the ability of the DWSC to accept oxygen-demanding materials without violations of the DO water quality objective.

Some of the DO depletion problems in the DWSC could be achieved through aeration of the SJR DWSC. The Steering Committee and stakeholders will need to consider how the construction and operation of the aerators would be funded.

Below are issues that need to be further addressed or defined:

- Export and loss of BODu, CBOD, NBOD, algae, N and P between source-land runoff, discharges, and DWSC.
- Additional oxygen demand and nutrient loads to the SJR between Vernalis and Channel Point in the DWSC
- Effects of SJR flow at Vernalis and in the DWSC on DWSC DO depletion.
- Factors controlling SJR flow through the DWSC on DO depletion below WQOs.
- Significance of DWSC DO depletions below 5 mg/L on fish growth rates in the DWSC.
- Significance of DO depletions below 6 mg/L inserving as a inhibitor of chinook salmon immigration.
- Cost of controlling N, P, NBOD and CBOD from wastewater, stormwater runoff, and irrigation return (tail) water.
- Development of a reliable model for a given SJR DWSC flow to establish an oxygen demand TMDL?
- Management of increasing urbanization in the SJR DWSC watershed for potentially increased oxygen demand load.

Further information on the issues pertinent to the DO depletion problem in the DWSC is discussed by Lee and Jones-Lee (2000) and Jones & Stokes (1998).

ACKNOWLEDGMENT
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The Lee and Jones-Lee papers and reports as well as other information are available from www.gfredlee.com. Also additional information on the SJR DWSC DO problem is available from http://www.sjrdotmdl.org/.