Synopsis of Issues in Developing the San Joaquin River Deep Water Ship Channel DO TMDL[1]

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August 2000

In 1994, the Central Valley Regional Water Quality Control Board (CVRWQCB) classified the San Joaquin River (SJR) Deep Water Ship Channel (DWSC) as "impaired" because dissolved oxygen (DO) concentrations routinely fell below the water quality objective (standard) (WQO) in the late fall. This listing requires that a total maximum daily load (TMDL) be developed to control the loads/conditions that cause violations of the DO WQO.

In 1998, the Regional Board classified the dissolved oxygen impairment as a high priority problem for correction, and staff committed to develop and submit to US EPA a TMDL report for controlling the problem by June 2003. Furthermore, the Regional Board, under the Bay Protection Plan agreed to allow a Steering Committee of local vested interests to help develop the control program if they committed to provide the Regional Board staff all the elements of the TMDL, including an implementation plan, by December 2002. If at any time the Steering Committee appeared unlikely to be able to do so then staff would take back development of the TMDL control plan.

This synopsis presents an overview of the DWSC DO depletion problem and the issues that need to be considered by the Steering Committee in developing a technically valid cost-effective TMDL that will enable compliance with the DO WQO. This is a summary of a more extensive 275-page discussion of the issues that will need to be addressed in oxygen demand TMDL development and allocation of the loads among the stakeholders presented by Lee and Jones-Lee (2000).

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 tidal river with about a 3 foot tidal range and a 2,000 to 4,000 cfs tidal flow. The non tidal flow is highly regulated with net flow at Stockton ranging from negative (upstream flow) associated with upstream diversions at Old River to net downstream flows between 100 to 2,000 cfs. Beginning at the Port, the SJR DWSC is dredged to 35 feet to allow ocean cargo ships to bring 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 flow of 2,000 cfs to about 30 days at 100 cfs.

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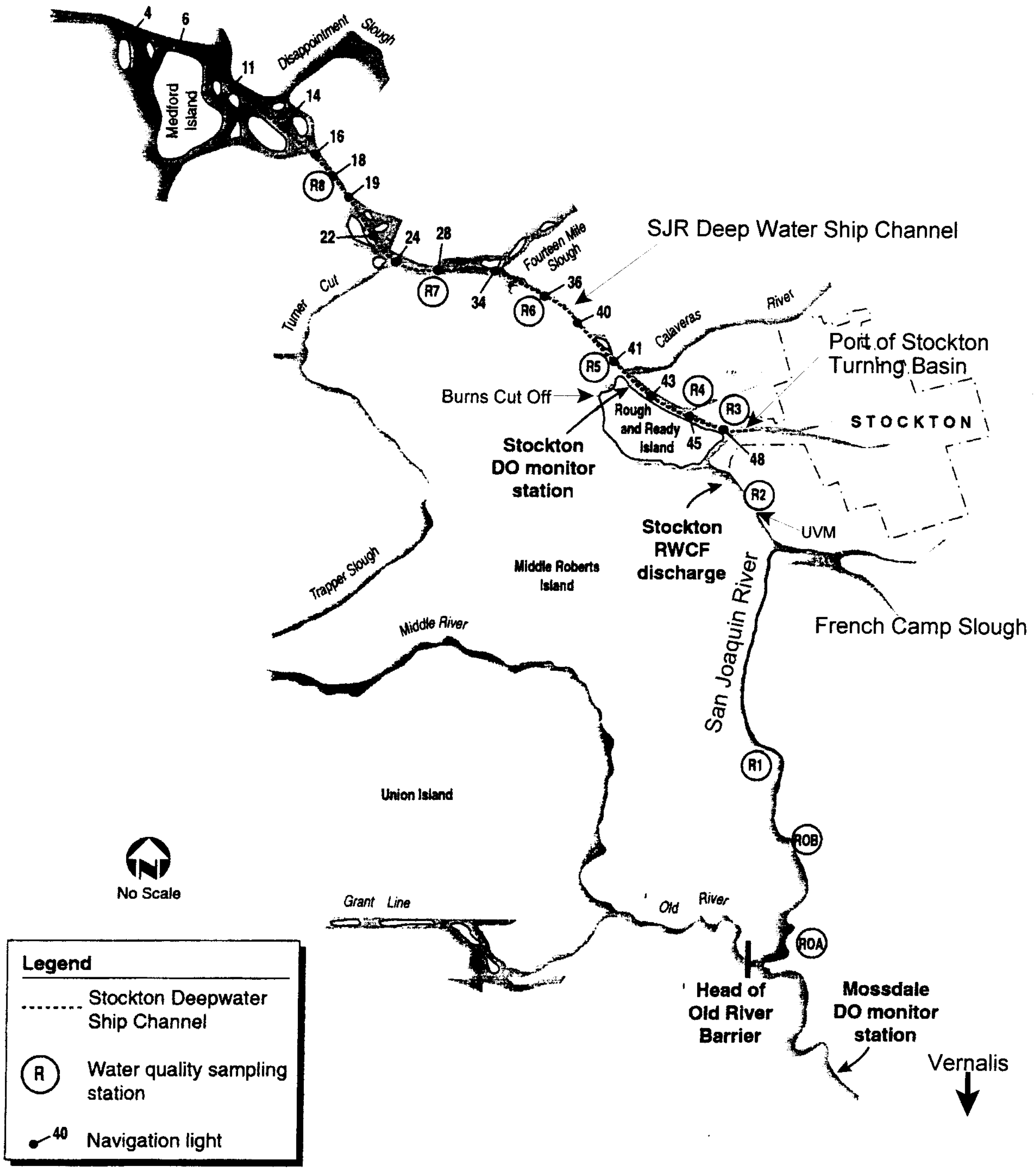
1 Report to SJR DO TMDL Steering Committee and the CVRWQCB, G. Fred Lee & Associates, El Macero, CA, August (2000)

Figure 1



Jones & Stokes (1999)

Location of Water Quality Stations and Navigation Lights on the San Joaquin River in the Vicinity of Stockton

The short hydraulic residence time of the DWSC has important implications for determining when the oxygen demand loads to the DWSC are potentially significant in leading to DO violations of the WQO. With hydraulic residence times of less than one month, the winter/spring SJR high flows and their associated oxygen demand/nutrient loads are not a significant contributor to DO depletion within the DWSC during summer and fall. All oxygen demand that is added during the winter/spring period is flushed through the DWSC during this time.

Dredging the DWSC altered 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 decreasing the amount of reaeration/unit volume of the channel. Further, the greater volume of the DWSC increases water volume and dilutes the algal photosynthetically produced dissolved oxygen (DO). Also, the sediment oxygen demand (SOD) impact is diluted over a greater volume in the DWSC. These factors, coupled with upstream diversions by the State and Federal Water Projects (CVP and SWP) and other municipal and agricultural intakes, lead to DO concentrations in the DWSC below the CVRWQCB WQO. The objective during September through November is 6 mg/L and during December through August is 5 mg/L. While the primary time of concern for DO depletions below the WQO is summer and fall, there also can be DO WQO violations at other times such as during spring low flow.

Characteristics of the San Joaquin River Watershed

The SJR is one of California's primary rivers. It originates in the central Sierras, flows through the agricultural Central Valley and discharges 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 Central Valley between Fresno and Stockton. It has a 7,345 sq mi watershed that is composed of 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 contains the metropolitan areas of Stockton, Modesto, Merced and Fresno. There are also substantial dairies and other animal husbandry activities. The current estimated urban population in this watershed is approximately two million. The SJR watershed urban population is rapidly expanding with a rate of growth of 2 percent/yr and expected to double to about 4 million people by 2040.

Upon entering the San Joaquin Valley floor, the SJR quality deteriorates due to agricultural, municipal and industrial stormwater runoff, wastewater discharges; municipal, industrial, dairy and animal feed lot/husbandry activities and natural/riparian runoff/drainage. In addition to adding oxygen requiring substances (carbonaceous and nitrogenous BOD), the discharges contribute substantial amounts of nutrients (N and P compounds) which develop into algae. The death of these algae are a source of oxygen demand in the DWSC where SJR at Vernalis flows represent a significant part of the flow into the DWSC. Vernalis is located about 30 miles upstream of the DWSC. Between Vernalis and the DWSC is the Old River diversion which can at times divert substantial flow into the South Delta.

Also, it is possible that detritus (dead plant and animal remains and waste products-manure) derived from the SJR watershed may contribute to the oxygen demand that is present at Vernalis and, under certain SJR flow/diversion conditions, exerts oxygen demand in the DWSC. The processes that cause oxygen demand below the WQO are listed in Table 1 and presented in Figures 2 and 3.

The SJR at Vernalis typically has several mg/L nitrate N and about 0.1 to 1 mg/L soluble orthophosphate P. These nutrients result in the SJR at Vernalis and the DWSC containing 20 to 100 µg/L planktonic algal chlorophyll during late summer. The death of these algae in the DWSC is one of the primary sources of DWSC oxygen demand.

Table 1
Factors Influencing DWSC DO Depletion Below Water Quality Objectives

DWSC: Flow (Channel Residence Time), Depth, Turbidity, Temperature, Nutrients (N and P), Algae, Light, Ship Traffic, Sediment Oxygen Demand

Local (below Vernalis) and Upstream of Vernalis: CBOD, Ammonia, Organic N, Phosphorus, Algae

DWSC 1999 Characteristics

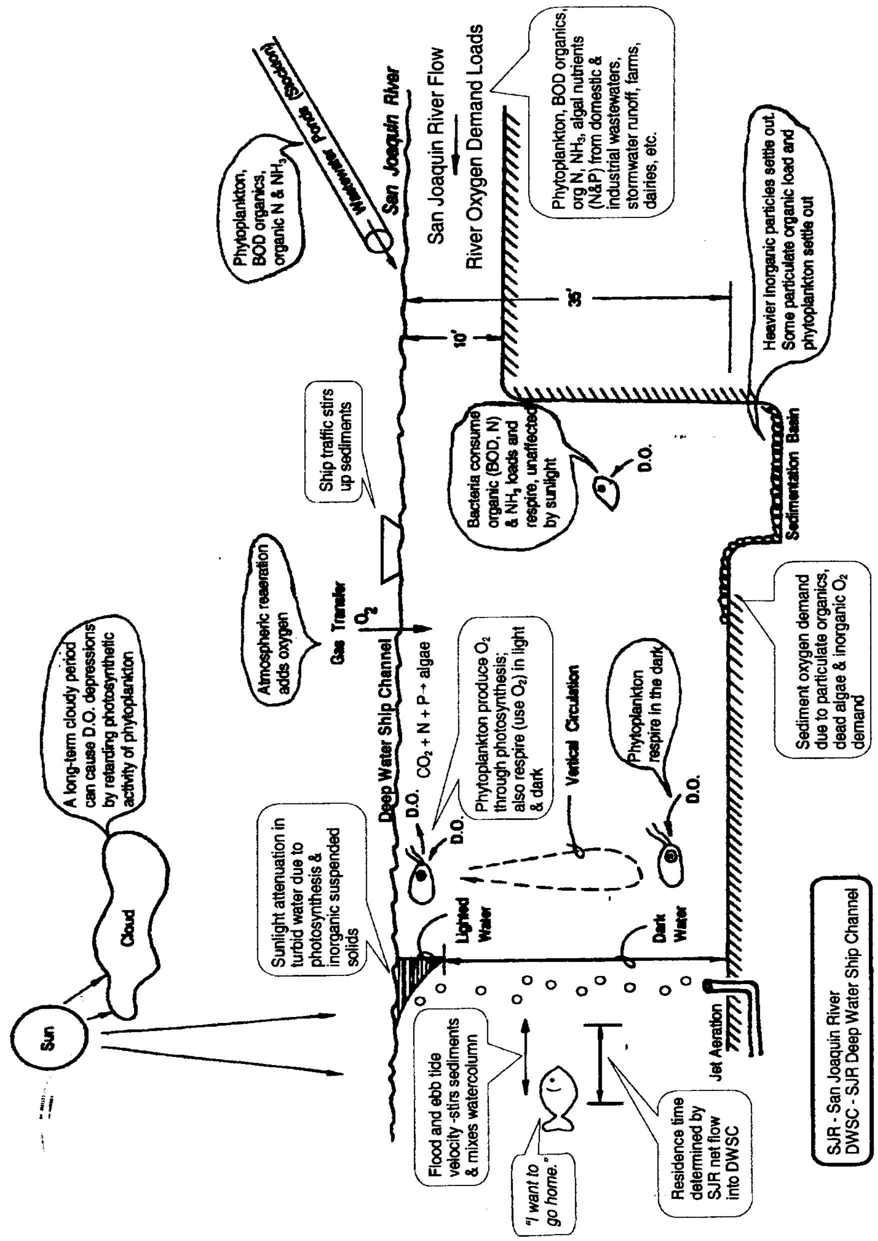
A study was conducted of the oxygen demand sources and DO depletion in the DWSC by the SJR Technical Advisory Committee (TAC) during the late summer and fall 1999. Part of the data from these studies are presented in Figure 4. Station 41 is near the point where the SJR enters the DWSC at the Port of Stockton. Station 18 is about 10 miles downstream of this point.

It was found that the DO concentrations in the DWSC decreased below the WQO of 5 mg/L in August and 6 mg/L during September through early December 1999. During August and most of September the SJR flow into the DWSC was about 900 cfs. In late September through October the SJR flow into the DWSC ranged from about 100 to 900 cfs as a result of upstream SJR diversions into Old River. Under the low flow conditions, the DO in some areas of the DWSC decreased to about 2 mg/L. Further, during November and early December 1999 the concentrations of ammonia in the SJR just upstream of where it enters the DWSC was over 3 mg/L N. Ammonia at these concentrations and the SJR DWSC temperature and pH is toxic to many forms of aquatic life and also can be a significant source of oxygen demand. This ammonia was primarily derived from the city of Stockton's domestic wastewater discharge just upstream of the DWSC. Table 2 and Figure 5 present a summary of the oxygen demand sources for the DWSC.

Table 2
Sources of Oxygen Demand for DWSC

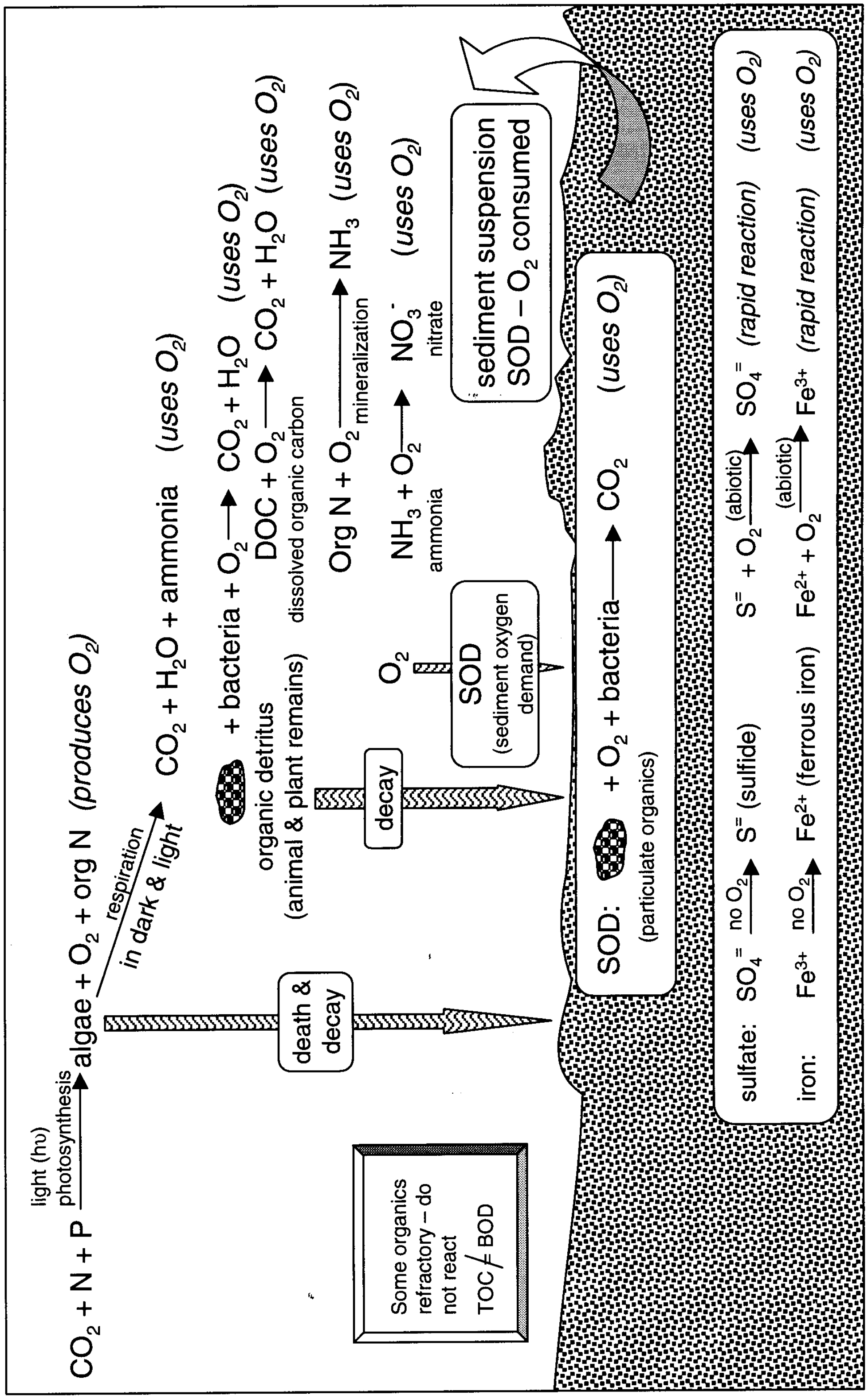
- Domestic and Industrial Wastewater Discharges and Stormwater Runoff
- Agricultural Stormwater Runoff and Irrigation Return Water
- Dairies, Commercial Animal Facilities
- Riparian Runoff
- Groundwater Discharges of Nitrate to SJR Tributaries and Main Stem
  The groundwater nitrate is due to agricultural activities, dairies, and domestic wastewaters that are applied to land

Figure 2



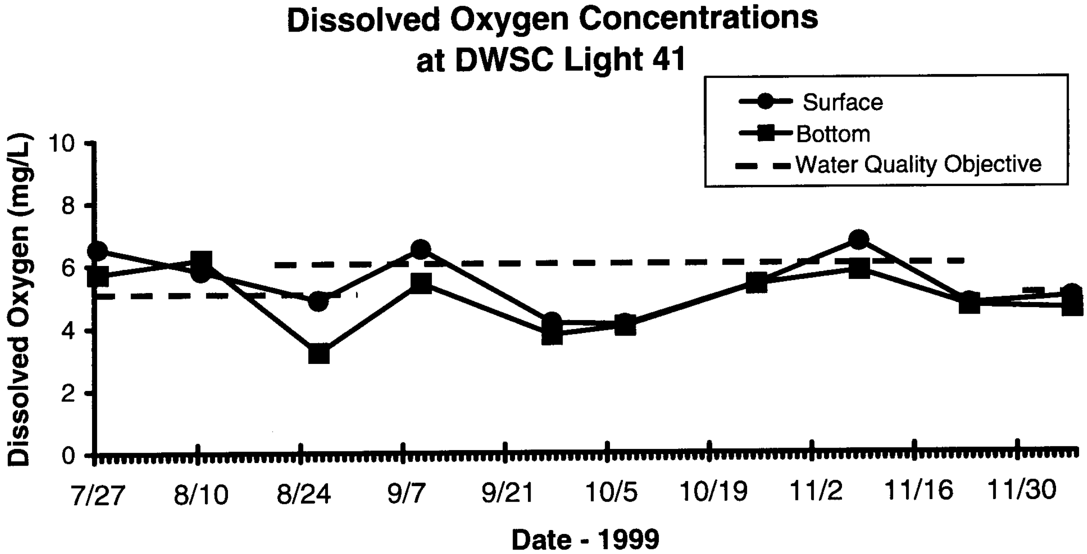
Factors Affecting Dissolved Oxygen in the Ship Channel
(adapted from COE, 1988)

Figure 3



Algae & Organic Detritus
as Sources of Oxygen Demand
$CO_2 + N + P$ light (hυ) photosynthesis algae + O_2 + org N (produces O_2)
respiration in dark & light
$CO_2 + H_2O$ + ammonia (uses O_2)
+ bacteria + O_2 → $CO_2 + H_2O$ (uses O_2)
organic detritus
(animal & plant remains)
DOC + O_2 → $CO_2 + H_2O$ (uses O_2)
dissolved organic carbon
Org N + O_2 → NH_3 (uses O_2)
mineralization
$NH_3 + O_2$ → NO_3^- (uses O_2)
ammonia
nitrate
death & decay
decay
O_2
SOD
(sediment oxygen demand)
sediment suspension
SOD – O_2 consumed
Some organics refractory – do not react
TOC ≠ BOD
SOD: + O_2 + bacteria → CO_2 (uses O_2)
(particulate organics)
sulfate: $SO_4^=$ no O_2 → $S^=$ (sulfide) $S^=$ + O_2 (abiotic) → $SO_4^=$ (rapid reaction) (uses O_2)
iron: Fe^{3+} no O_2 → Fe^{2+} (ferrous iron) Fe^{2+} + O_2 (abiotic) → Fe^{3+} (rapid reaction) (uses O_2)

Figure 4
DWSC DO Data Summer/Fall 1999
Adapted from DWR Lehman (2000)



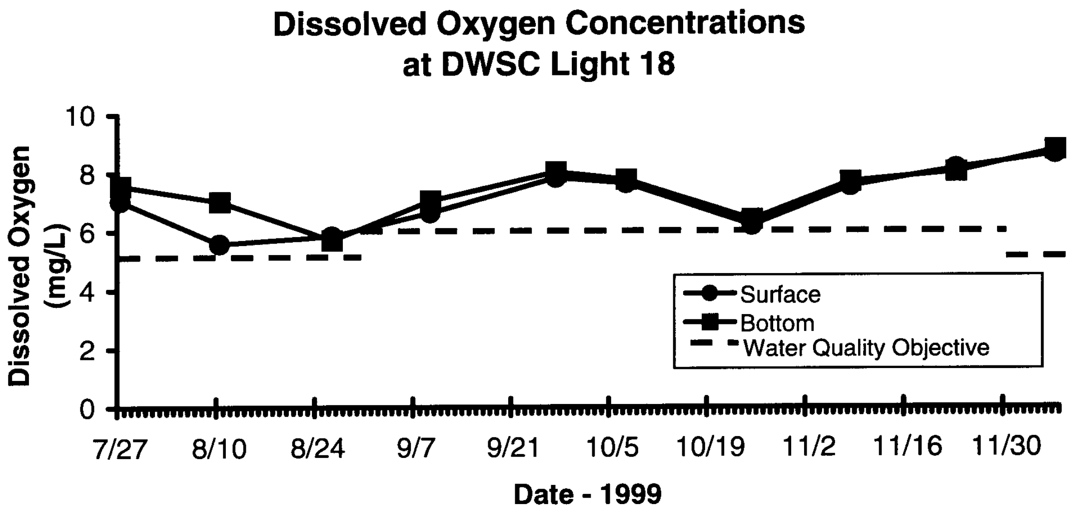
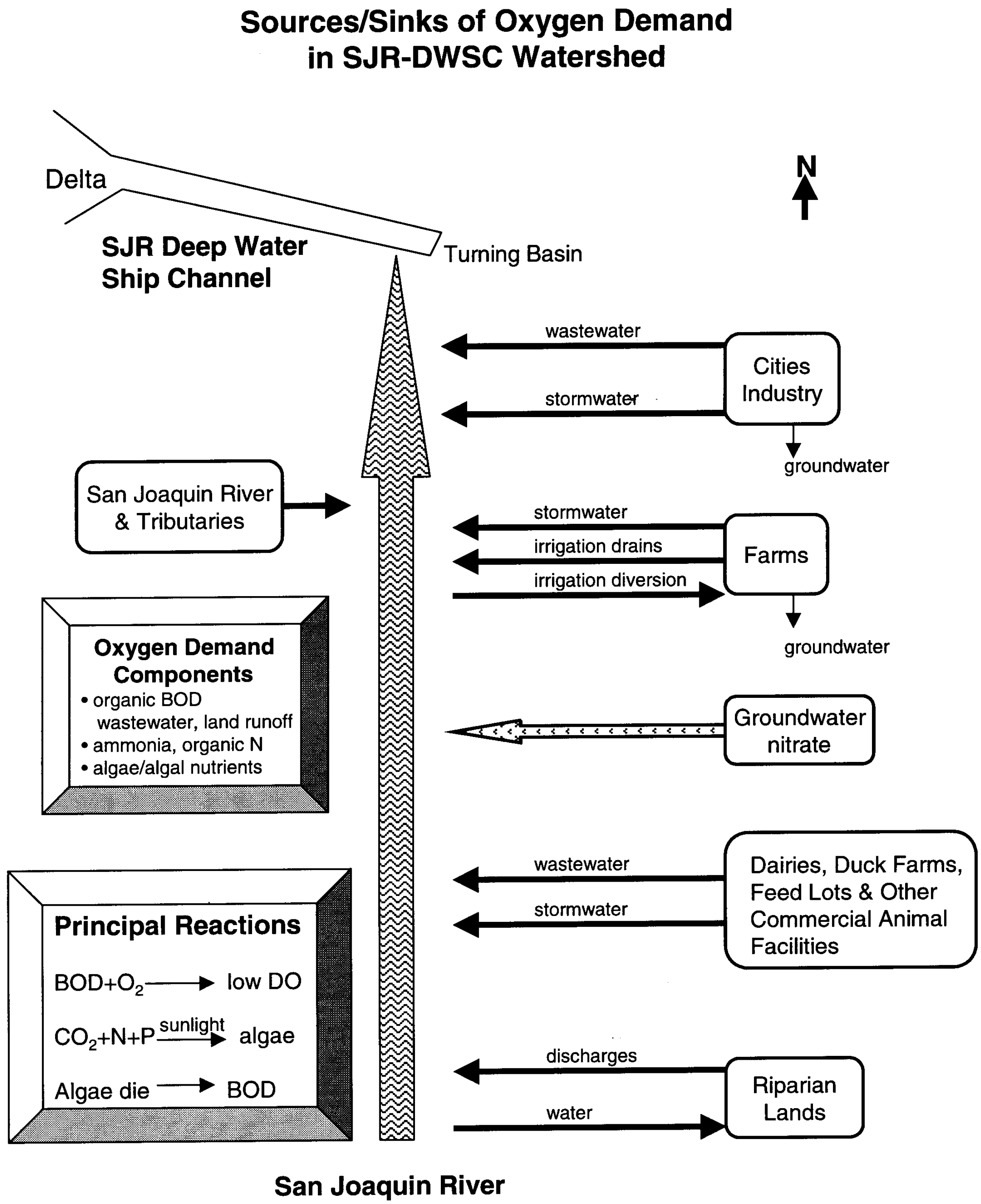
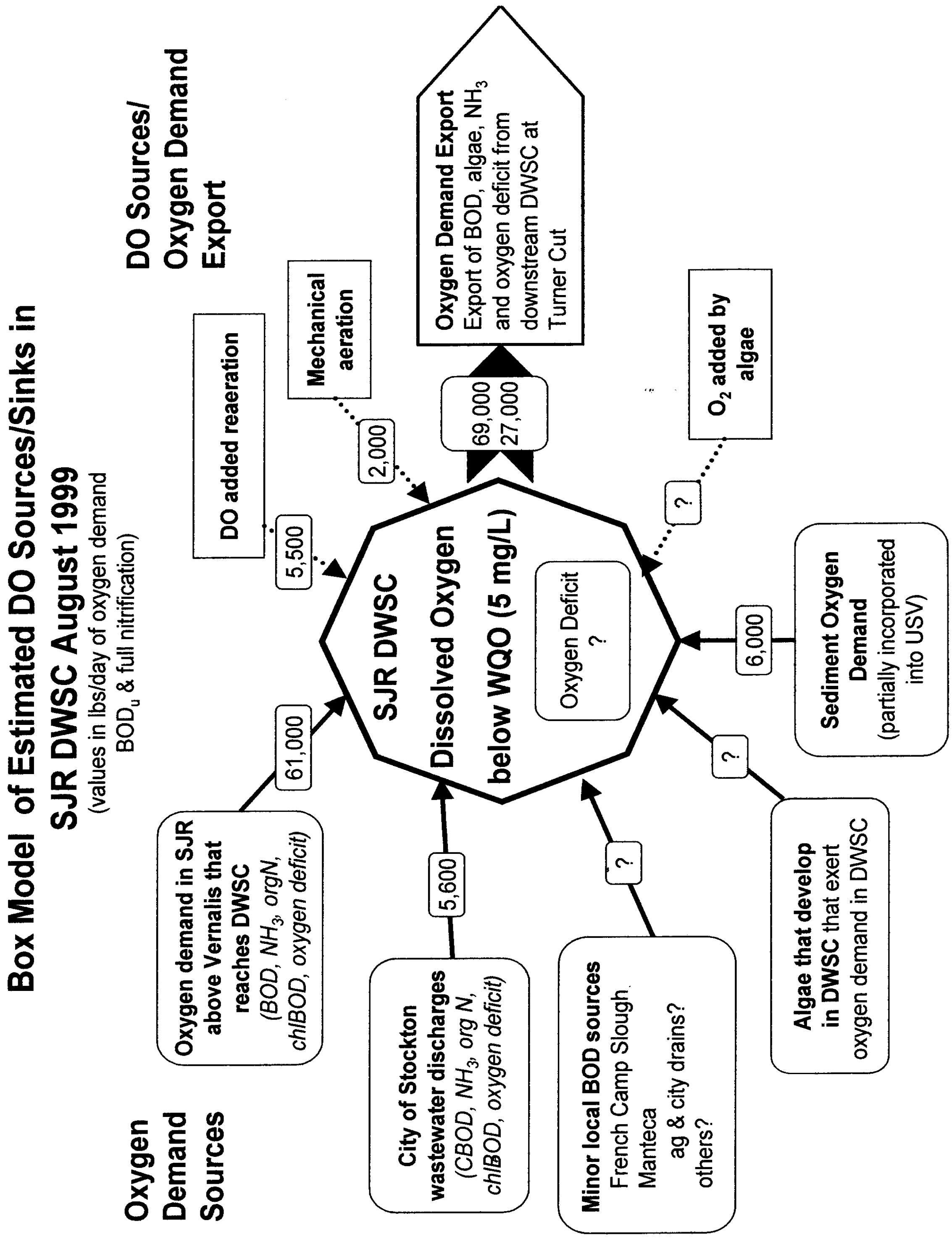


Figure 5



The box model calculations of oxygen demand sources for the SJR DWSC for August 1999 are shown in Figure 6. Table 3 presents the results of box model calculations of the major sources of oxygen demand during the summer/fall 1999.

Figure 6



Box Model of Estimated DO Sources/Sinks in SJR DWSC August 1999
(values in lbs/day of oxygen demand BOD_u & full nitrification)
Oxygen Demand Sources
DO Sources/ Oxygen Demand Export
Oxygen demand in SJR above Vernalis that reaches DWSC (*BOD, NH_3, orgN, chlBOD, oxygen deficit*)
61,000
City of Stockton wastewater discharges (*CBOD, NH_3, org N, chlBOD, oxygen deficit*)
5,600
Minor local BOD sources
French Camp Slough
Manteca
ag & city drains?
others?
?
Algae that develop in DWSC that exert oxygen demand in DWSC
?
Sediment Oxygen Demand (partially incorporated into USV)
6,000
SJR DWSC
Dissolved Oxygen below WQO (5 mg/L)
Oxygen Deficit
?
DO added reaeration
5,500
Mechanical aeration
2,000
69,000
27,000
Oxygen Demand Export
Export of BOD, algae, NH_3 and oxygen deficit from downstream DWSC at Turner Cut
O_2 added by algae
?

Table 3
Summary of DWSC Oxygen Demand Sources Summer/Fall 1999

Source	BOD_u (lbs/day)				
	August	September	**October**		
SJR Flow (cfs):	~900	~900	**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	?	?	?

The primary source of the oxygen demand to the DWSC during August and September 1999 was algae, detritus and other organics in the SJR from above Vernalis. During August and September, the City of Stockton wastewater discharges were a small part of the oxygen demand load to the DWSC. However, in late September-early October when the flow of the SJR into the DWSC was about 150 cfs, the upstream of Vernalis flow and its associated oxygen demand load was largely diverted down Old River. Under these conditions the City of Stockton wastewater flow of about 40 cfs and its associated about 20 mg/L N ammonia was an important source of oxygen demand to the DWSC.

These results demonstrate that the upstream diversions of SJR water are important in determining the source of the oxygen demand loads contributed to the DWSC. These results also show 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 enter the DWSC.

The city of Stockton supported Chen and Tsai (1997) to develop a mathematical model of oxygen demand/DO impacts in the DWSC. This model, with appropriate modification, will be used to develop the oxygen demand TMDL as a function of SJR flow through the DWSC. Also a model is being developed to relate oxygen demand and nutrients discharged to the SJR and its tributaries in the SJR watershed upstream of Vernalis to oxygen demand in the DWSC.

TMDL Development and Allocation

The SJR DWSC oxygen demand TMDL is being developed by a Technical Advisory Committee (TAC) of the SJR DO TMDL Steering Committee. Excessive DO depletion in the DWSC has been a long-standing problem. Brown and Caldwell (1970) determined that the DWSC could assimilate 40,000 lbs/day BOD_u. Since that time, the SJR DWSC has been deepened by an additional five feet. Further, the Brown and Caldwell estimated allowable BOD_u load did not include the safety factor required in TMDL development. It appears that the required load reduction to meet the TMDL will likely be on the order of 20,000 to 40,000 lbs/day BOD_u. This means that the oxygen demand load of BOD, including algae, will likely have to be reduced by at least 50 to 75 percent. This amount will be refined by additional studies and modeling.

Calculation of the 1999 oxygen deficit suggests that the maximum deficit in the DWSC during both August and September was about 75,000 pounds of oxygen. The DWSC average hydraulic residence time was about 10 days during both months. This suggests the loading rate would have to be reduced to about 7,000 to 8,000 pounds of oxygen requiring substances/day to meet the Basin Plan objective. Actually, the loading rate will need to be reduced even more than this since a substantial part of the oxygen demand added to the DWSC can, at flows greater than about 1,000 cfs, be exported into the central Delta.

Some relief from this oxygen demand load reduction may be achieved by increased flow of SJR water through the DWSC. In the summer and fall of 1998 the SJR flow through the DWSC was over 2,500 cfs. The DO in the DWSC did not fall below the WQO. However, there is no information on whether 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 as part of evaluating how SJR flows into the DWSC impact DO depletion below a WQO.

Another important factor that will have to be considered in developing the TMDL is that the population in the SJR DWSC watershed is projected to double in the next 40 years. This increase in population will increase the demand for water and the potential for wastewater discharges to increase the oxygen demand load to the SJR DWSC.

CALFED has made available $866,000 during 2000 for the SJR DO TMDL TAC to conduct some of the additional studies needed to better define the relationship between oxygen demand load to the DWSC and DO depletion below the WQO. It is expected that at least this amount will be obtained from CALFED in 2001 to do further work on oxygen demand sources and their potential control.

Steering Committee Responsibilities

The SJR DO TMDL Steering Committee is composed of stakeholders in the SJR DWSC watershed. There are a variety of issues this Committee will need to resolve as part of providing guidance to the CVRWQCB in developing and implementing this TMDL. These include establishing an appropriate DO TMDL goal, with particular reference to whether the DO concentration goal of 6 mg/L for September through November and 5 mg/L for the rest of the year should be interpreted as a worst-case standard not to be violated at any time or location, including the early morning hours and near the sediment water interface. The US EPA (1986, 1987) has indicated that the primary impact of DO depletion below 5 mg/L but above about 4 mg/L is on the rate of fish growth. The importance of DO excursions below 5 mg/L but above about 4 mg/L on the fisheries resources of the DWSC, San Joaquin River and the Delta need to be better understood. A potentially large difference in allowable oxygen demand load could exist between achieving a worst case-based DO goal versus an "average" daily water column DO goal.

The allocation of the oxygen demand load/responsibility among the oxygen demand dischargers in the DWSC watershed to meet the TMDL will be a challenging task that the Steering Committee must complete by December 2002 in order to meet the CVRWQCB deadline. Failure to meet this deadline will mean that the CVRWQCB will establish the TMDL allocation.

Another important issue that will need to be addressed by the Steering Committee/ 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 impact the ability of the SJR in the DWSC to accept oxygen-demanding materials without violations of the DO water quality objective.

An area of particular concern in this balancing is the potential for solving some of the DO depletion problems in the DWSC through aeration of the SJR DWSC. The Steering Committee/stakeholders will need to consider how the construction and especially the operation of the aerators would be funded and whether responsible entities, including oxygen demand and nutrient dischargers, water diverters and the Port of Stockton/those who benefit from the existence of the Port, will fund the aeration of the channel and other remedial approaches that will evolve out of the implementation of the TMDL.

Other issues that need to be addressed/defined/assessed include:

- Export/loss of BOD_u, CBOD, NBOD, algae, N and P between source - land runoff/discharges and DWSC
- Assess additional oxygen demand and nutrient loads to the SJR between Vernalis and Channel Point in the DWSC
- Impact of SJR flow at Vernalis and in the DWSC on DWSC DO depletion
- Understanding the factors controlling SJR flow through the DWSC on DO depletion below WQOs
- Understanding the significance of DWSC DO excursions below 5 mg/L that occur for a few hours to a few days on the growth rates of fish in the DWSC
- Assessing the significance of DO depletions below 6 mg/L in serving as a inhibitor of upstream Chinook salmon migration
- Cost of controlling N, P, NBOD and CBOD from wastewater, stormwater runoff and irrigation return (tail) water
- Can a reliable oxygen demand load - DO depletion below WQO model for a given SJR DWSC flow be developed that can be used to establish an oxygen demand TMDL?
- How best to manage the increasing urbanization (~ 2 percent/yr) of the SJR DWSC watershed with its 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 and Stokes (1998).

Acknowledgment

The authors acknowledge the assistance provided by the SJR DO TMDL TAC in developing the SJR DO TMDL Issues report upon which this synopsis of issues is based. We also wish to acknowledge the reviewers of this report, especially Dr. Chris Foe, CVRWQCB; Dr. Gary Litton University of the Pacific; Kevin Wolf of Kevin Wolf Associates and Dr. C. Kratzer of the USGS.

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