Update on the Understanding of the Low-DO Problem in the San Joaquin River's Deep Water Ship Channel

G. Fred Lee, Anne Jones-Lee (G. Fred Lee & Associates), gfredlee@aol.com

The Winter 2001 IEP Newsletter contained an article by Lee and Jones-Lee (2001) describing some of the major issues in developing the San Joaquin River (SJR) Deep Water Ship Channel (DWSC) Dissolved Oxygen (DO) TMDL. The following is a brief summary of some of the major findings from a CALFED-funded review of 1999-2003 studies (Lee and Jones-Lee 2003). Additional information is provided on the SJR DO TMDL website at http://www.sjrtmdl.org, and on http://www.gfredlee.com in the San Joaquin River watershed section.

DO Depletion in the DWSC

California Department of Water Resources (DWR) described the occurrence of low DO in the SJR DWSC (Figure 1) based on the monitoring cruises conducted during the late summer and fall of each year (Ralston and Hayes, 2002). Lee and Jones-Lee (2003) have summarized the DWR cruise data from 1995 through 2002. Dissolved oxygen concentrations in the DWSC water column from just downstream of the Port to, at times, as far as Columbia Cut, are depleted at times one to several mg/L below the water quality objective of 5 mg/L during the summer through August, and 6 mg/L from September through November.

Under low SJR DWSC flow conditions of a few hundred cfs, the DO concentrations in the DWSC waters can be as low as about 1 to 2 mg/L. The DO concentrations near the bottom of the DWSC are sometimes 1 to 2 mg/L lower than those found in the surface waters. This difference is not due to thermal stratification within the DWSC, but is related to inadequate vertical mixing of the water column by tidal currents "coupled with" algal photosynthesis in the near-surface waters and suspended particulate biochemical oxygen demand (BOD) in the near-bottom waters.

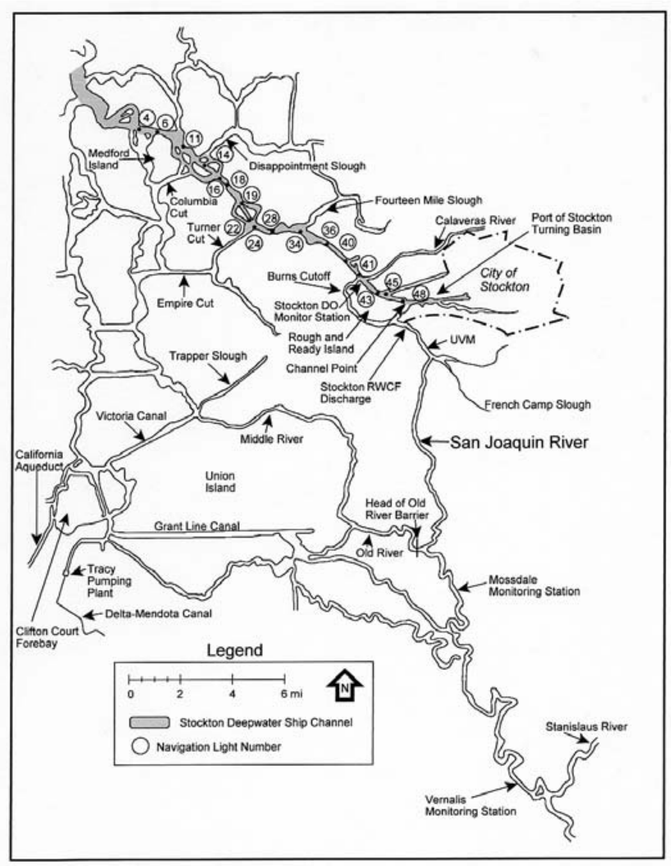

Figure 1 **Map of the Lower SJR and DWSC Study Area**

Constituents Responsible for Oxygen Depletion

The depletion of DO below the water quality objective is caused by carbonaceous biochemical oxygen demand (CBOD) and nitrogenous BOD (NBOD). The CBOD occurs primary in the form of algae. The NBOD is composed of ammonia and organic nitrogen that is mineralized to ammonia, which is biochemically oxidized to nitrite and nitrate (nitrification). The city of Stockton discharges its treated domestic wastewaters to the SJR approximately 2 miles upstream of where the SJR enters the DWSC at Channel Point. At times, especially during high ammonia concentrations in the wastewater effluent and low SJR DWSC flows, the city's wastewater effluent can contribute over 80% of the total oxygen demand load to the DWSC. At other times, the city's contribution to the oxygen demand load can be on the order of 10 to 20% of the total oxygen demand load to the DWSC.

The primary source of carbonaceous and, to some extent nitrogenous, oxygen demand for the DWSC occurs in the form of algae that develop in the SJR upstream of the DWSC. At times the upstream oxygen demand loads represent on the order of 90% of the total oxygen demand load to the DWSC. The relative proportion of the city of Stockton and upstream algal oxygen demand loads is variable, dependent on the city's wastewater effluent ammonia concentrations, the planktonic algal concentrations in the SJR that are discharged to the DWSC, and the flow of the SJR through the DWSC.

Factors Influencing DO Depletion in the DWSC

There are a number of factors that have been found to influence the DO depletion in the DWSC for a given oxygen demand load. These include the following:

- ***Port of Stockton.*** The development of the DWSC to the Port of Stockton greatly reduced the oxygen demand assimilative capacity of the SJR below the Port by transforming the channel from a shallow, rapidly moving water body to a long, thin lake, thereby increasing hydraulic residence time for BOD exertion. The former channel configuration would not have produced the current low-DO problems given similar inputs. The development of the Deep Water Ship Channel basically transformed the former undredged SJR channel through the Delta from a shallow, rapidly moving waterbody, to a long, thin, lake with a significantly increased hydraulic residence time for BOD exertion. It has been found that, if the Deep Water Ship Channel did not exist, there would be few, if any, low-DO problems in the channel.

- ***SJR Flow through the DWSC.*** The flow of the SJR through the DWSC influences DO depletion by affecting the hydraulic residence time (travel time) of oxygen demand loads through the critical reach. Under high flow conditions (> about 2,000 cfs), DO depletions below the water quality objective do not occur in the DWSC. SJR flows through the DWSC of a few hundred cfs lead to the greatest DO depletion below the water quality objective. The flow of the SJR through the DWSC influences the amount of upstream algal (oxygen demand) load that enters the DWSC, with greater oxygen demand loads occurring with higher flows. The magnitude of the oxygen deficit below the water quality objective is SJR DWSC flow-dependent.

- ***Sacramento River Cross Channel/Delta Flow.*** The export pumping of South Delta water by the state and federal projects to Central and Southern California creates a strong cross-Delta flow of Sacramento River water. This cross-Delta flow limits the downstream extent of DO depletion within the DWSC to upstream of Disappointment Slough/Columbia Cut.

- ***Growth of Algae within the DWSC.*** Appreciable algal growth occurs within the DWSC; however, this growth does not add to low-DO problems in the surface waters of the DWSC, since it is accompanied by photosynthetic oxygen production. The increased algal growth within the DWSC is likely causing increased DO depletion in the near-bottom waters of the DWSC, due to the settling and death of the DWSC-produced algae.

- ***Sediment Oxygen Demand (SOD).*** Measurements of the bedded sediment oxygen demand within the DWSC show that it tends to be somewhat lower than normal SOD for "polluted" waterbodies. However, the tidal velocities that occur within the DWSC have been found to be sufficient to suspend bedded sediments and to hinder the settling of particulate oxygen demand. This leads to an increased oxygen demand associated with particulates in the near-bottom waters of the DWSC.

- ***Atmospheric Aeration.*** Since the surface waters of the DWSC tend to be undersaturated with respect to dissolved oxygen, except possibly during late afternoon when intense photosynthesis is occurring in the surface waters, there is a net transfer of atmospheric oxygen to the DWSC through atmospheric surface aeration.

- ***Light Penetration.*** Secchi depths typically on the order of 1 to 2 ft are found in the SJR and in the DWSC during the summer and fall. This limits the photic zone (depth to which algal photosynthesis can occur) to about 6 ft. The inorganic turbidity derived from watershed erosion significantly reduces the depth of the photic zone, compared to photic zone depths that are found in most waterbodies where light penetration is controlled by light scattering and absorption by algae.

- ***Algal Nutrients.*** The concentrations of algal available nutrients (nitrate and soluble orthophosphate) within the SJR upstream of the DWSC and within the DWSC are at least 10 to 100 times surplus of those that are algal growth-rate-limiting. Algal growth within the SJR and DWSC appears to be controlled by light limitation.

- ***Temperature.*** Increases in temperature in the SJR and DWSC increase algal growth rates and rates of DO depletion reactions. Increased temperature also decreases the solubility of oxygen. Some of the year-to-year variations in DO depletion in the DWSC may be related to temperature differences, which influence algal growth in the SJR watershed and oxygen depletion within the DWSC.

A “Strawman” analysis of oxygen demand loads and impacts on DO depletions within the DWSC shows that the planktonic algal concentrations present in the SJR at Mossdale are related to the DO depletion at the DWR Rough and Ready Island (RRI) continuous monitoring station. High planktonic algal chlorophyll *a*, which is correlated to high BOD at Mossdale as well as upstream in the SJR, tended to be associated with the greatest DO depletion at the DWR RRI station.

Examination of the dissolved oxygen concentrations found in the DWSC at the RRI monitoring station shows that DO depletions below the water quality objective occur in the winter in some years. During 2002 and 2003, DO depletions at the RRI station occurred below the WQO during January, February, and/or March. In mid-February 2003, surface water DO levels of 0 mg/L were found at this station for several weeks. Further, there was a period in late January through early March 2003 when the surface water DOs at the RRI station were below 3 mg/L. The low-DO conditions found in late January through early March 2003 were related to city of Stockton wastewater ammonia discharges and low SJR DWSC flow.

During the low-DO period when there were low SJR flows through the DWSC, the SJR at Vernalis flows were in excess of 1,800 cfs, which means that the low SJR DWSC flows were due to diversion of most of the SJR flow at Vernalis into the South Delta for export to Central and Southern California. Without this diversion of SJR water into Old River, the extremely low DO that occurred in the winter of 2003 and at other times in 2002 would not have occurred since the hydraulic residence time of the DWSC would have been decreased to a few days from the over 30 days that occurred.

Oxygen Demand Loads

Box Model Load calculations were made for the 43 monitoring runs that the city of Stockton made during the summer/fall 1999, 2000, and 2001. Figure 2 presents a diagram of the three-year summer/fall average loads of oxygen demand in the SJR at Mossdale plus the city’s oxygen demand wastewater loads, export of oxygen demand from the DWSC at Turner Cut and the magnitude of oxygen deficit below the water quality objective within the DWSC between Channel Point and Turner Cut.

Water quality monitoring and flow measurements of the SJR and tributaries enabled us to determine that the oxygen demand of water entering the DWSC was equivalent to the combined discharges of algae from Mud and Salt sloughs and the SJR upstream of their confluences.

The studies of the past four years plus other data have provided information that can be used to formulate a management plan to control the DO problem in the DWSC. Information on these issues is provided by Lee and Jones-Lee (2003). They include aeration of the Deep Water Ship Channel, control of the city of Stockton’s wastewater effluent ammonia, and control of nutrients that lead to high algal growth in the Mud and Salt Slough and SJR upstream of Lander Avenue. Also, the potential for increasing the flow of the SJR through the DWSC to eliminate the long hydraulic residence times that are found under extremely low flow conditions is being evaluated. Further studies are needed to evaluate the potential efficacy of each of these approaches.

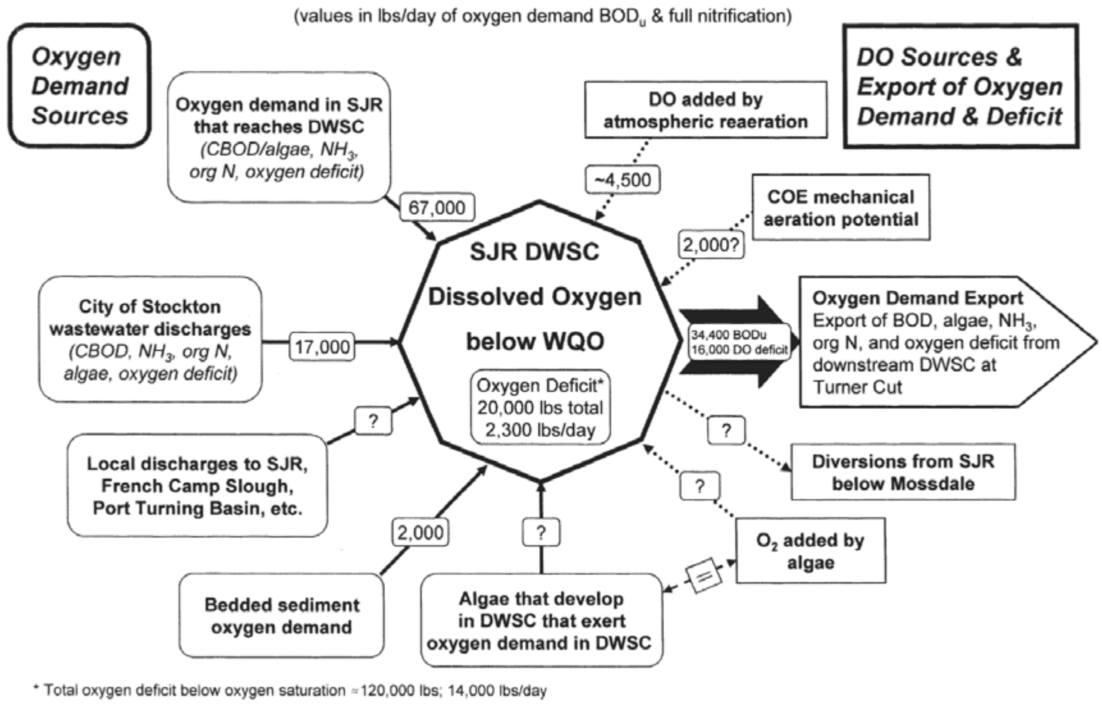

Figure 2 Box model of estimated DO sources/sinks in SJR DWSC (SJR DWSC Flow: 930 cfs; Travel Time: 8.6 days)

References

Lee, G. F. and Jones-Lee, A., 2001. "Synopsis of Issues in Developing the San Joaquin River Deep Water Ship Channel Dissolved Oxygen TMDL," IEP Newsletter 14(1):30-35, Winter (2001).

Lee, G. F. and Jones-Lee, A. 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 SJR DO TMDL Steering Committee and CALFED Bay-Delta Program, G. Fred Lee & Associates, El Macero, CA, March 2003. http://www.gfredlee.com/SynthesisRpt3-21-03.pdf

Ralston, C. and Hayes, S. P., "Fall Dissolved Oxygen Conditions in the Stockton Ship Channel for 2000," IEP Newsletter 15(1):26-31, Winter (2002).

Review of the Environmental Monitoring Program

Zachary Hymanson (California Bay-Delta Authority) and Anke Mueller-Solger (DWR), Zachary@calwater.ca.gov

The Interagency Ecological Program (IEP) has a policy that requires review of each IEP monitoring program once every five years. The intent of this policy is to provide a means for considering the structure and function of ongoing, and in most cases longstanding, monitoring programs to ensure they remain relevant and effective. In 2001 the IEP requested a review of the Environmental Monitoring Program (EMP).

Although operated under the auspices of the IEP, the CA Department of Water Resources (DWR) and the US Bureau of Reclamation (USBR) are required to implement the EMP as a condition of CA State Water Resources Control Board (SWRCB) Water Right Decision 1641 (D-1641)[1]. This water right decision prescribes conditions