Impact of San Joaquin River Deep Water Ship Channel Watershed and South Delta Flow Manipulations on the Low-DO Problem in the Deep Water Ship Channel

G. Fred Lee, PhD, DEE
G. Fred Lee & Associates
27298 E. El Macero Drive, El Macero, CA 95618
Ph: (530)753-9630 Fx: (530)753-9956 Em: gfredlee@aol.com
www.gfredlee.com

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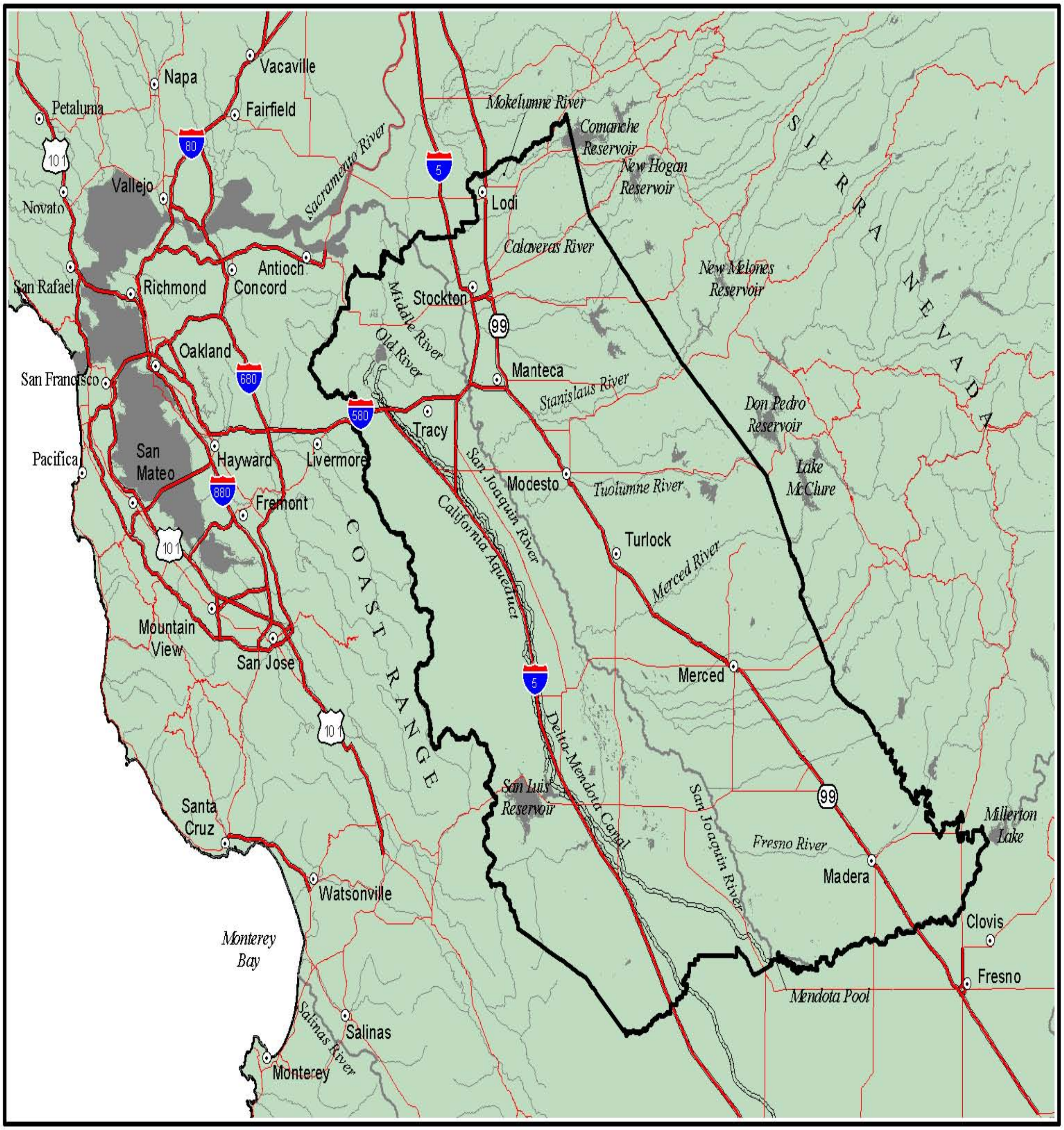
Recently, the California Bay-Delta Authority (CBDA) held a two-day workshop, "Science Symposium on Environmental and Ecological Effects of Proposed Long-term Water Project Operations," organized by the CBDA Science Program. The focus of this workshop was a review of the information available on how flow manipulations in the San Joaquin and Sacramento River watersheds and Delta impact fisheries of the Delta and its tributaries. This workshop provided an opportunity to become familiar with the approaches being used for managing flow in the San Joaquin River (SJR) watershed and Delta to protect/enhance fish in the Delta tributaries and Delta.

At the workshop mention was made that the agencies responsible for managing flow within the San Joaquin River watershed and the Delta are reviewing impact of flow management approaches. In connection with this review, those responsible for managing flow in the San Joaquin River watershed and in the South Delta should become aware that the current flow management approaches are having a significant adverse impact on the dissolved oxygen (DO) resources of the first seven miles (critical reach) of the Deep Water Ship Channel (DWSC) below the Port of Stockton.

The current flow management in the SJR watershed and Delta for protection of fish and for domestic and agricultural water supply is at times strongly detrimental to fish and other aquatic life in the SJR DWSC near Stockton. The problem is the low-DO situation in the first seven miles (critical reach) of the SJR DWSC just downstream of the Port of Stockton. The cause and impacts of low DO in the SJR DWSC have been intensively investigated during the past four years. Based on the information developed in these and other studies on the SJR DWSC low-DO problem, **future management of flow within the San Joaquin River watershed and the Delta should incorporate into management practices the impacts on the DO resources of the critical reach of the Deep Water Ship Channel. Where possible, flows should be managed to control the low DO in the DWSC.**

Figures 1 and 2 are maps showing the reach of the SJR DWSC and its local watershed of concern in the low-DO problem.

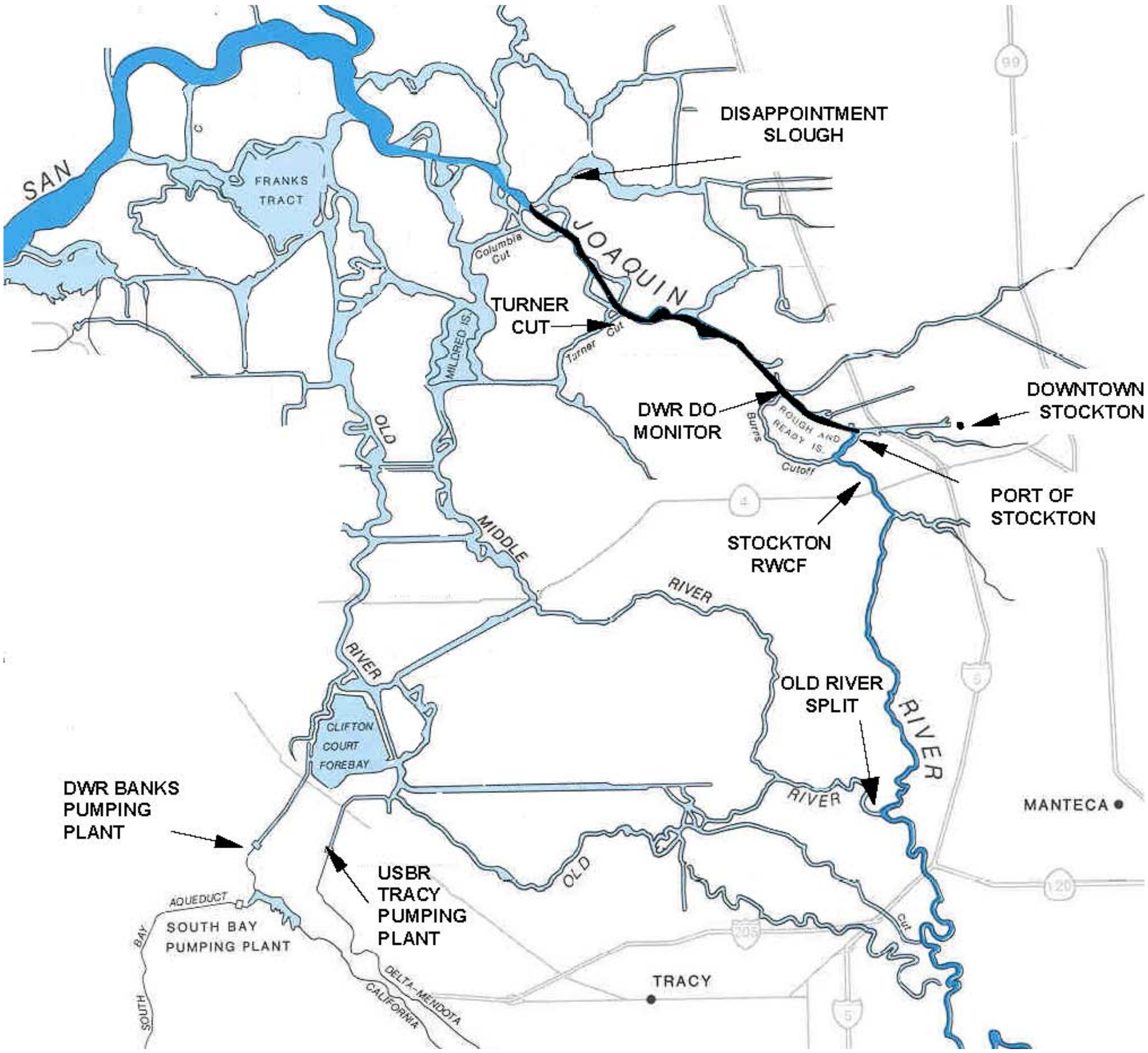
Figure 1. Map of the Area of Concern in this Review
From Gowdy and Grober (2003)



Background to the Impact of SJR DWSC Flow on Low DO in the DWSC

Beginning in the summer of 1999, with CALFED support, approximately $4 million of studies have been conducted on the low-DO problem that occurs in the Deep Water Ship Channel near Stockton. Based on the first year's (1999) study results, Dr. Anne Jones-Lee and I developed an "Issues" report (Lee and Jones-Lee, 2000), which discusses the issues as understood then that influence low DO in the Deep Water Ship Channel.

Figure 2. Map of the Delta Showing the Critical Reach of the DWSC
From Gowdy and Grober (2003)



This report was reviewed by the SJR DO TMDL stakeholders and others interested. One of the issues that influence the occurrence of DO concentrations below the water quality standard (objective) (WQO) was identified as low SJR flow through the DWSC. One of the issues that was tentatively identified as a cause of low SJR flow through the DWSC was San Joaquin River diversions upstream of the Deep Water Ship Channel, which reduced the net advective flow of the San Joaquin River through the DWSC. Based on the 1995 - 1999 USGS data it was found that when SJR DWSC flows were above about 2000 cfs there were no DO WQO violations. Also in 1999 when the SJR DWSC flow was below about 500 cfs there were severe low-DO problems in the DWSC.

Subsequently, we served as coordinating PIs for a $2-million CALFED grant devoted to further investigating the factors influencing low DO in the Deep Water Ship Channel. In March 2003, in accordance with our CALFED contract, we developed a 280-page Synthesis Report (Lee and Jones-Lee, 2003), which covered the four-year period August 1999 through February 2003. The May 2002 draft of this report was peer-reviewed by an external peer review panel, and the February 2003 final draft of this report was internally reviewed by the stakeholders to the SJR DWSC low-DO problem. The results of the previous four years of study clearly demonstrated that flow manipulations in the SJR DWSC watershed can be significantly adverse to the DO resources in the Deep Water Ship Channel. A summary of the findings are presented below. Further information, including the backup data for this summary, is available in the Synthesis Report or in other reports referenced in the Synthesis Report.

The impact of SJR flow through the DWSC on dissolved oxygen concentrations in the DWSC relates to the fact that the travel time (hydraulic residence time) of water in the first seven miles (critical reach) of the DWSC between the Port of Stockton and Turner Cut depends on SJR net flow through the DWSC. As discussed by Lee and Jones-Lee (2003), the hydraulic residence time in the critical reach of the DWSC can change from a couple of days at 2000 cfs or greater SJR flow through the DWSC, to 30 days when the flows are on the order of 100 cfs. During these extended periods of time, algae that develop in the upstream DWSC watershed, as well as ammonia in the city of Stockton's wastewater discharges, cause an oxygen demand load that is exerted in the first seven miles of the DWSC.

Ordinarily, in the riverine situation, the location of maximum DO depletion (oxygen sag) shifts downstream under elevated flow. However, the DWSC location of maximum DO depletion never occurs below Columbia Cut, and rarely occurs below Turner Cut. This is because the State and Federal projects' export of water from the South Delta causes a strong Sacramento River cross SJR DWSC flow. This cross-flow of Sacramento River water, which has a low oxygen demand, limits the downstream extent of DO depletion. During high flow of the SJR through the DWSC, most of the oxygen demand that enters the DWSC from upstream sources is not oxidized in the channel. It is transported rapidly through the channel and enters Turner Cut and Columbia Cut. At least for Columbia Cut, there is appreciable dilution of the unexerted oxygen demand by the low-oxygen-demand Sacramento River water. It is not clear at this time whether low DO occurs in the Central Delta during periods of elevated SJR DWSC flow, when a large part of the oxygen demand added to the DWSC is not exerted in the critical reach of the DWSC.

Because of the importance of flow in contributing to the low-DO problem in the DWSC, the stakeholders for this problem look on those who manipulate the flows in the SJR watershed that increase the hydraulic residence time of oxygen demand added to the SJR DWSC as being responsible parties, in part, for the DO problem. One of the ways to help solve the low-DO problem is through aeration. Stakeholders are discussing the possibility of having those who manipulate the flows in such a way as to contribute to the low-DO problem help pay for aeration of the DWSC and the control of oxygen demand loads to the DWSC.

It is somewhat ironic that part of the flow manipulations that are occurring for the purpose of benefiting fisheries in parts of the Delta and its tributaries under the current flow management operations are strongly contrary to fisheries, including the homing of the fall-run Chinook salmon and the egress of smolt through the DWSC.

Manipulations of Flow in the SJR DWSC Watershed

The USGS and DWR data collected since 1995 when SJR DWSC flows first began to be monitored by the USGS, and the CALFED and other supported studies of the past four years show that flow manipulations in the SJR DWSC watershed which cause the net advective flow of the SJR through the DWSC to be less than about 1500 cfs are contrary to maintaining DO in the DWSC above the water quality objective. SJR DWSC flows less than a few hundred cfs cause severe DO depletion in the DWSC, which can lead to DO concentrations as low as 0 mg/L as measured at Rough and Ready Island, which results in fish kills.

Old River SJR Flow Diversions. A review of the SJR Vernalis flows (see the Synthesis Report, Lee and Jones-Lee, 2003) shows that during the past four years, it was rare that the flow of the SJR at Vernalis was less than 2000 cfs. However, on a number of occasions in 1999, 2001, 2002 and thus far in 2003, the SJR DWSC flows were less than 100 cfs. This arose because of the diversion of essentially all of the SJR at Vernalis flow down Old River as part of the export pumping by the State and Federal projects. As an example of this situation, while prior to the winter 2003 in some winters there would be a few days of low SJR DWSC flow because of upstream flow manipulations, in February 2003 when the SJR flow at Vernalis was about 2000 cfs, the SJR DWSC flow was on the order of 50 to 100 cfs. For several weeks, during this time, the DO measured at the DWR Rough and Ready Island monitoring station, was at 0 mg/L in early morning, and would, on some days, increase to 0.25 to 0.5 mg/L later in the day. There were fish kills in the DWSC at that time. This situation was directly attributable to upstream of the DWSC flow manipulations.

Rapid Decreases in SJR DWSC Flow. In addition to low SJR DWSC flow leading to low DO in the DWSC, rapid decreases in the SJR DWSC flow, such as occur at the end of VAMP, lead to severe DO depletion in the DWSC. Over the past four years there have been several instances where there has been a rapid decrease in the SJR DWSC flow that was associated with very low DO concentrations in the DWSC. This situation occurred in 2002 at the end of the VAMP. It has also just occurred in 2003. It is found that the VAMP flows in 2003 of the SJR through the DWSC range from about 1500 to about 2700 cfs. On May 18, the VAMP flow was 1512 cfs. On May 19, it was 878 cfs. By May 24 the SJR DWSC flow was about 500 cfs. This decrease in flow of the SJR through the DWSC led to DO concentrations less than the 5 mg/L WQO at the DWR Rough and Ready Island monitoring station.

The DO depletion below the WQO associated with the termination of the VAMP flows arises from the fact that, during the summer and fall, under elevated flow of 1000 cfs or so, the DWSC has large amounts of oxygen demand transported into it primarily in the form of upstream-derived algae. With the rapid decrease in flow, such as the shut-off of the VAMP flows, or with removal of the South Delta barriers in the fall, the algae that are in the DWSC exert their oxygen demand, leading to severe DO depletion. Basically this is a situation where the DWSC is loaded with an elevated oxygen demand load that, under higher flow conditions, is mixed with cross-flow of Sacramento River water and does not cause WQO violations in the SJR DWSC. However, with the termination of VAMP flows, the oxygen demand load is fully exerted in the DWSC due to long residence time of the water in the critical reach of the DWSC.

The VAMP flow water from upstream reservoirs during April and May to help anadromous fish return to the sea leads to adverse impacts on anadromous and other fish through creating low-DO problems in the DWSC. If the VAMP flows were used to help maintain the SJR DWSC flows in June through November the low-DO problems in the DWSC could be reduced.

OCAP BA CVP-OCAP

The US Bureau of Reclamation OCAP BA CVP-OCAP (USBR, 2003) is an update on the "biological assessment" associated with the long-term operations of the Central Valley Project (CVP) by the Bureau of Reclamation and the State Water Project by the California Department of Water Resources. The purpose of the biological assessment is stated to be an evaluation of the potential effects of proposed actions on the listed and proposed species and designated and proposed critical habitat, and to determine whether any such species or habitats are likely to be adversely affected by the proposed actions.

Chapter 5, devoted to "Factors in the Influence of Abundance and Distribution of Winter-Run, Spring-Run and Fall/Late Fall-Run Chinook Salmon," contains a discussion on pages 5-34 and 5-35 of some of the factors that can impact the migration of Chinook salmon. There is need to expand the discussion in this section to include the impact of the low-DO problem in the SJR DWSC on these fisheries. The studies of the past four years on the San Joaquin River Deep Water Ship Channel characteristics have shown that, at times during the late spring, summer and fall, including in some winters (such as in February 2003), the DO concentrations in the Deep Water Ship Channel can be strongly detrimental to juvenile Chinook salmon migration from upstream waters through the Delta to the ocean. Page 5-52 has a section devoted to "Contaminants," yet there is no mention of the low-DO problem that exists in the Deep Water Ship Channel and the South Delta, which can at times be lethal to fish. This is a significant omission that should be corrected in the final report. These issues need to be incorporated into the operations of water management.

CVRWQCB DO TMDL

The low DO in the DWSC caused the Central Valley Regional Water Quality Control Board to list the first seven miles of the SJR DWSC as Clean Water Act 303(d) "impaired" due to DO concentrations below the CVRWQCB Basin Plan water quality objective (WQO). During September 1 through November 30, the WQO for the critical reach of the DWSC was established by the State Water Resources Control Board to be 6 mg/L. The rest of the year the WQO is 5 mg/L. The 6 mg/L concentration was established to protect the spawning homing migration of fall-run Chinook salmon. It is based, in part, on the work of Hallock, *et al.* (1970). The 5 mg/L WQO is established by the CVRWQCB (1998) Basin Plan. In some years, the DO during the late summer and fall in the SJR DWSC is frequently below the 6 mg/L WQO. This situation could be inhibitory to fall-run spawning homing migration of Chinook salmon. Since the low-DO situation has been found to be due in part to low SJR flow through the DWSC, there is need to manage flows of the SJR through the DWSC to minimize the low-DO problem to protect the fall-run Chinook salmon homing migration.

The CVRWQCB listing of the critical reach of the DWSC as DO impaired requires that a total maximum daily load (TMDL) be developed to eliminate DO concentrations below the WQO from occurring by any amount at any location in the listed reach of the DWSC more than once every three years. On July 1, 2003, the CVRWQCB staff (Gowdy and Grober, 2003) released "Total Maximum Daily Load for Dissolved Oxygen in the San Joaquin River." This report was submitted to the US EPA Region 9 to meet Clean Water Act TMDL requirements. Flow-related excerpts from this report are appended to these comments.

The CVRWQCB has determined that SJR DWSC watershed and Delta flow management practices are responsible in part for the low-DO problem in the DWSC. It has assigned one-third of the responsibility for the low-DO problem to low SJR DWSC flow conditions. As additional information is obtained in Phase I of the TMDL it may be possible to modify the allocation of responsibility for the SJR DWSC low DO. The further studies, however, will not change the fact that upstream of the SJR DWSC and South Delta flow manipulations are responsible in part for a large part of the low-DO problem. Further, increased SJR DWSC flow through the DWSC to above about 1500 cfs will essentially eliminate the low-DO problem in the DWSC.

The CVRWQCB TMDL report states,

> "*Because reduced flow does not discharge any substances, no wasteload or load allocations are assigned to responsible entities. Instead, the SWRCB can use its water rights authority and, in some cases, the CVRWQCB or SWRCB can use its CWA Section 401 water quality certification authority to require mitigation based on this TMDL. Numerous entities are responsible for upstream diversions and consumptive use that reduce flow in the DWSC.*"
>
> *"CVRWQCB staff intends to propose for adoption by June 2004, the TMDL and program of implementation. The TMDL, however, will likely rely upon the SWRCB to take appropriate action to address the impacts of reduced flow in the DWSC that are integral to successful implementation."*
>
> *"In addition to providing this TMDL, the CVRWQCB anticipates consulting with the SWRCB Division of Water Rights during the preparation of water right permits and decisions that have the potential to affect the DO impairment in the DWSC."*

> *"In addition to SWRCB water rights authority, the SWRCB or CVRWQCB has CWA Section 401 water quality certification authority over the SDIP* [South Delta Improvement Project]. *As the SDIP will involve dredging in some South Delta channels and construction of other in-stream structures, they will require a CWA Section 404 permit from the USACOE and a CWA Section 401 certification from the State. In order to obtain this certification, the SDIP will need to provide adequate mitigation of impacts, among other things, to DO conditions in the DWSC."*

Lee and Jones-Lee (2003) have discussed the fact that both the US EPA Region 8 and 9 senior staff have indicated that the Clean Water Act TMDL regulations can be used to correct hydromodifications that contribute to violations of water quality standards.

Impact of Flow Management on Other Delta Water Quality Issues

There are others who are concerned about DWR, USBR and fisheries managers' management of SJR DWSC watershed and South Delta flows. At the CBDA Drinking Water Subcommittee meeting held on June 27, 2003, discussions were held on the need for those who control the operations of the Federal and State South Delta water export Projects to operate these projects to consider impacts of the project operations on water quality, including drinking water quality. The "Draft Framework for a Policy on Drinking Water Quality and CALFED Projects and Actions" (Gartrell, 2002) states,

"DRAFT POLICY FRAMEWORK

…

3. *The information on water quality impacts/benefits, mitigation measures incorporated into projects and potential alternatives for CALFED projects should be considered as part of the CALFED decision-making and implementation process for both the project and the program as a whole. CALFED should endeavor to bundle projects for implementation to ensure that the CALFED target of continuously improving Delta water quality for all uses is achieved.*

5. *The water quality assessments of projects and actions should include the following:*
    a) *The spatial and temporal parameters of linked projects or actions should be explicitly considered, described, and delineated.*
    b) *A project's or action's mitigation monitoring plan (under CEQA) may provide a vehicle for monitoring of impacts and implementation of this policy.*
    c) *Water quality forecasts from CALFED agencies should provide an accompanying forecast of water quality. Such forecasts include annual or more frequent water supply allocations, as well as long-term or ad hoc planning efforts, such as DWR's Bulletin 160 series (The California Water Plan Update) or the Governor's Critical Water Shortage Contingency Plan.*
    d) *Operational decisions made in CALFED forums or processes, such as the CALFED Operations Groups ("CALFED Ops"), the Water Operations*

Management Team and the Environmental Water Account, should be balanced and should consider water quality impacts on equal footing with water supply and fishery impacts. Operations decision processes should explicitly consider and report impacts to water quality. When such decisions are not protective of drinking water quality, mitigation should be provided for unavoidable significant adverse impacts."

Overall Conclusion

It is evident from several perspectives, including low DO in the SJR DWSC and Delta water quality, that there is need to incorporate the impact of flow management on water quality issues into developing and managing SJR and Sacramento River and Delta flows.

References

CVRWQCB, "The Water Quality Control Plan for the Sacramento River Basin and the San Joaquin River Basin," Central Valley Regional Water Quality Control Board Fourth Edition. Sacramento, CA (1998).

Gartrell, G., "Draft Framework for a Policy on Drinking Water Quality and CALFED Projects and Actions," CALFED Drinking Water Subcommittee, Sacramento, CA, August (2002).

Gowdy, M., and Grober, L., "Total Maximum Daily Load for Low Dissolved Oxygen in the San Joaquin River," Staff Report of the California Environmental Protection Agency Regional Water Quality Control Board, Central Valley Region, Sacramento, CA, June (2003).

Hallock, R. J.; Elwell, R. F. and Fry, D. H., "Migration of Adult King Salmon, *Oncorhynchus tshawytscha* in the San Joaquin Delta as Demonstrated by the Use of Sonic Tags," California Department of Fish and Game, Fish Bulletin 151 (1970).

Lee, G. F. and Jones-Lee, A., "Issues in Developing the San Joaquin River Deep Water Ship Channel DO TMDL," Report to Central Valley Regional Water Quality Board, G. Fred Lee & Associates, El Macero, CA, August (2000).

Lee, G. F. and Jones-Lee, A., "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

USBR, "Draft Long-Term Central Valley Project OCAP BA CVP OCAP," Preliminary Working Draft, US Department of Interior, Bureau of Reclamation, Mid-Pacific Region, Sacramento, CA (2003).

Excerpts from
"TOTAL MAXIMUM DAILY LOAD FOR LOW DISSOLVED OXYGEN IN THE SAN JOAQUIN RIVER," Staff Report of the CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY REGIONAL WATER QUALITY CONTROL BOARD CENTRAL VALLEY REGION
June 2003

Numerous studies over the last several years have provided significant data and information on the causes of the DO impairment. The most recent round of studies were peer-reviewed in June 2002 by an independent science panel and summarized in the Synthesis Report (Lee and Jones-Lee, 2003). The three main contributing factors to the DO impairment identified in these studies are as follows:

- Loads of oxygen demanding substances from upstream enter the DWSC where they oxidize and exert an oxygen demand.
- The DWSC geometry reduces the capacity of the DWSC to assimilate loads of oxygen demanding substances by (i) reducing the efficiency of natural re-aeration mechanisms and (ii) magnifying the effect of oxygen demanding reactions.
- Reduced flow through the DWSC reduces the assimilative capacity by reducing upstream inputs of oxygen to the DWSC and increasing the residence time for oxygen demanding reactions that further impact DO concentrations.

Flows from the Upper SJR and its headwaters are diverted at the Friant Dam via the Friant-Kern Canal to irrigate crops outside the SJR Basin. This leaves much of the river dry between Friant Dam and the Mendota Pool, except during periods of wet weather flow and major snow melt. Water is imported to the basin from the southern Delta via the Delta Mendota Canal (DMC) to replace the flows that are diverted out of the basin to the south. Some water in the DMC is delivered directly to the west side of the SJR for agricultural supply, but the majority of DMC water is delivered to the Mendota Pool and distributed from there via irrigation canals to the west side. Water is also released to the SJR from Mendota Pool to meet the needs of various agricultural users between the Mendota Pool and the Sack Dam. Most or all of the remaining flow in the river is diverted at Sack Dam. As a result, the SJR downstream of Sack Dam and upstream of Bear Creek frequently has little or no flow except during flood flows. During non flood-flow periods, this reach of the SJR flows intermittently and is composed of groundwater accretions and agricultural return flows.

3.4 Reduced Flow Through the Stockton Deep Water Ship Channel

Flow in the DWSC portion of the San Joaquin River may be reduced by (i) consumptive use in the San Joaquin River watershed, and (ii) the diversion of San Joaquin River flows down Old River that result from the operation of the pumping plants at the State Water Project by DWR and the federal Central Valley Project by USBR. Extensive data supports the connection between flow rates and DO concentrations in the DWSC. Although more studies are required, reduced flow through the DWSC appears to both reduce oxygen inputs to the DWSC and increase the residence time for oxygen demanding substances to impact DO concentrations.

3.4.1 Reduced Flow at Vernalis

The hydrology of the San Joaquin River is complex and highly managed through the operation of dams, diversions, and supply conveyances. Annual discharge from the San Joaquin River watershed is considerably lower than the unimpaired runoff that would occur if there were no reservoirs or consumptive use of water. Between 1979 and 1992 the measured runoff in the basin as measured at Vernalis was 2.4 million acre-feet lower than the mean annual unimpaired discharge of 6.1 million acre-feet (USGS, 1997). The difference is due to consumptive use, attributable mostly to water use for agriculture (DWR, 1994).

Based on SJR flow data at Vernalis, the fifteen-year moving average[1] of annual discharge in the late 1990's was approximately 800,000 acre-feet lower than in the late 1940s. Almost all of this reduction in annual watershed discharge occurs during the months of April through August (Oppenheimer and Grober, 2002). Another study found the San Joaquin River flow at Vernalis reduced by 44-56 percent from pre-1944 levels between the months of April through September (Water and Power Resources Service and South Delta Water Agency, 1980).

3.4.2 Flow Split at Head of Old River

The California Department of Water Resources (DWR) and U.S. Bureau of Reclamation (USBR) both operate pumping facilities west of the City of Tracy that have a significant impact on the routing of flow in the Delta and the DWSC. As part of the State Water Project (SWP), DWR operates the Banks Pumping Plant, which supplies water for the South Bay and California Aqueducts. The Banks Pumping plant draws water from Clifton Court Forebay, which is currently permitted to divert an average of 6,680 cubic feet per second (cfs) water from the DWR is in the process of planning to increase diversions into Clifton Court Forebay from the Delta to an average of 8,500 cfs. As part of the Central Valley Project (CVP), USBR operates the Tracy Pumping Plant to supply flow for the Delta-Mendota Canal. The Tracy Pumping Plant is currently permitted to draw an average of 4,400 cfs water from the Delta.

Water is conveyed to these two pumping plants through the Delta from the Sacramento and San Joaquin Rivers via a network of man-made and natural channels, including Old River. The southeastern reach of Old River diverges from the San Joaquin River just west of Manteca, CA about 14 miles upstream of the DWSC and flows into the south Delta. The northwestern reach of Old River continues north out of the south Delta and rejoins the San Joaquin River near Disappointment Slough. When the SWP and CVP pumps are operating, the northwestern reach of Old River conveys water from the north

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[1] The fifteen-year moving average helps identify long-term trends that may be obscured by annual variability of discharge.
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and central Delta, while the southeastern reach of Old River conveys water from the San Joaquin River through the south Delta.

One of the effects of SWP and CVP pumping is an increase in the amount of flow that diverges from the San Joaquin at the head of Old River, thereby reducing the flow that continues in the San Joaquin River through the DWSC. As the combined SWP and CVP export rates increase relative to the San Joaquin River flow upstream of the head of Old River, the percentage of flow diverted down Old River (and away from the DWSC) increase. During periods of low flow when SWP and CVP exports are greater than San Joaquin River flows, up to 90 percent of the river flow can be diverted down Old River and away from the DWSC. When combined SWP and CVP exports are less than San Joaquin River flows, Old River flows and SJR flows through the DWSC are nearly equal (Brown and Renehan, 2001).

Beginning in 1969, with an memorandum of understanding between fishery and pumping project agencies, a temporary rock diversion barrier has been installed each fall at the head of Old River in order to increase flow in the SJR past Stockton. When the barrier is in place, an increased percentage of flow remains in the San Joaquin River and flows downstream to the DWSC. Monitoring data show that installation of the barrier in the fall usually improves DO concentrations in the lower SJR, especially in years with relatively low SJR flows. Modeling performed for Water Right Decision 1641 found that significant improvements to DO conditions in the DWSC were not achievable without the temporary barrier (SWRCB, 2000, pg. 77).

Since 1991, as part of its South Delta Temporary Barriers Project, DWR has been collecting performance data on the temporary diversion barriers. This data is being used in their planning for their South Delta Improvement Projects (SDIP). The SDIP is proposing to provide a number of permanent operable flow diversion barriers (including at the head of Old River) and other improvements that will mitigate impacts on water quality and supply from an increase of the average allowable diversion capacity into Clifton Court Forebay from 6,680 to 8,500 cfs. The draft environmental impact report for the SDIP, as required by the California Environmental Quality Act (CEQA), is scheduled for release in the fall of 2003. CVRWQCB staff will be working with DWR to ensure that adequate consideration is given to the impact of this project on the DO impairment in the DWSC.

3.4.3 Effect of Reduced Flow on Dissolved Oxygen Impairment

The nature of the relationship between reduced flow through the DWSC on the severity and spatial extent of the DO impairment is discussed in detail in the Draft Strawman Source and Linkage Analysis for Low Dissolved Oxygen in the Stockton Deep Water Ship Channel (Foe, et al. 2002). The working hypothesis of this report is that as flow at a given DO concentration (oxygen input rate) through the DWSC is reduced, less oxygen demand can be exerted on that flow before DO concentrations drop below the Basin Plan objectives. Also, the increased residence times associated with reduced flows through the

DWSC are thought to magnify the affect of chemical, biological and physical mechanisms that oxidize oxygen demanding substances (Foe, et al., 2002, pg. 7 - 8). This effectively reduces the assimilative capacity of the DWSC for a given load of oxygen demanding substances.

This relationship between flow and low DO is also clearly demonstrated in Figure 3-1, which plots the daily minimum DO concentrations measured at the DWR DO monitoring station at Rough & Ready Island against the net daily flow rate in the DWSC[2] on the same day. The plot includes 1,168 data points, one for each day between November 1995 and September 2000 that has both a minimum DO reading and a corresponding net daily flow value. For net daily flow above 3,000 cfs, there were no violations of either the 5.0 or the 6.0 mg/L Basin Plan DO objectives. Below 3,000 cfs, the DO concentrations decrease with decreasing flow. At flows below 1,000 cfs, about half of the daily minimum DO concentrations were below 5.0 mg/L.

Another analysis of DWR boat cruise data found that DO concentration profiles in the DWSC appear to follow a sag profile similar to one predicted by a simple Streeter-Phelps water quality model. This analysis found the location of the low point in the sag profile moved downstream as flow increased. It also appears that reduced flow tends to increase the BOD concentrations entering the DWSC from upstream, which had the effect of increasing the severity of the impairment at the low point in the sag curve. Some of these observations were based on limited amounts of data and warrant further investigation. More data and detailed modeling in the DWSC is required (Foe, et al., 2002, pgs. 9 – 15).

The rate at which flow is reduced through the DWSC also appears to be of particular concern. This can occur with sudden changes in SJR flow associated with reservoir operations and/or operation of the flow diversion barriers at the head of Old River and in the south Delta. It has been hypothesized that the higher loads of oxygen demanding substances present before a sudden decrease in flow, overload the assimilative capacity present in the DWSC after the loads are decreased. Further study of this phenomenon is needed (Lee and Jones-Lee, 2003, pg. 67).

Even with clear empirical relationships, however, more field and laboratory studies are required to better understand the effects of flow on the various mechanisms that create oxygen demand in the DWSC. Water quality modeling is then needed to understand the net effect of all these mechanisms on DO concentrations and their sensitivity to changing environmental variables (e.g. changes in flow, temperature).

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[2] Net daily flow in the DWSC is calculated from tidal flow data collected at the USGS Stockton UVM meter, including consideration of semi-diurnal tidal periods and other tidal variations. See Brown and Renehan, 2001 for detailed description.
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Table 1-1: Temporal Distribution of Low Dissolved Oxygen Impairment
(From Gowdy and Grober, 2003)

Year		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1983	Excursion rate (%)[1]	n/a	n/a	n/a	n/a								
	Minimum [DO] [2]												
1984	:				1	7	84	91	62	2			
	:				*4.4*	*3.9*	*3.0*	*2.8*	*4.0*	*4.7*			
1985	:				6		48	78	15				
	:				*4.4*		*3.3*	*3.5*	*4.2*				
1986	:	29				5		21	9				
	:	*4.4*				*3.1*		*4.5*	*4.8*				
1987	:					44	43	3		29		<1	
	:					*3.5*	*3.6*	*4.6*		*3.9*		*4.9*	
1988	:	51	52	52			3		10	62			
	:	*3.5*	*3.3*	*3.8*			*4.8*		*4.4*	*2.3*			
1989	:			65	<1		37	2		38	14		
	:			*3.7*	*4.9*		*4.1*	*4.8*		*2.4*	*4.2*		
1990	:			1	5	3	11	<1	<1				
	:			*4.8*	*4.6*	*4.7*	*4.5*	*4.8*	*4.9*				
1991	:		<1	8	37	34	1	5	14	55	99		
	:		*4.7*	*4.3*	*4.4*	*4.2*	*4.9*	*4.7*	*4.4*	*1.8*	*0.4*		
1992	:		21	100	60	29	43	39	97	100	77	6	
	:		*3.1*	*2.1*	*1.9*	*3.8*	*3.7*	*3.7*	*2.8*	*0.5*	*1.3*	*4.7*	
1993	:			25	8	2	29	54	87	81	23		1
	:			*3.7*	*4.7*	*4.8*	*3.6*	*3.7*	*2.6*	*2.6*	*1.6*		*4.8*
1994	:		2		<1		61	80	63	16	46		
	:		*4.8*		*4.9*		*4.0*	*3.7*	*3.4*	*4.3*	*3.2*		
1995	:							2	61	6			
	:							*4.8*	*3.0*	*4.6*			
1996	:	15	n/a				8	63	94	89	15	18	
	:	*4.1*					*4.8*	*3.4*	*2.0*	*2.5*	*3.7*	*4.3*	
1997	:						14	74	88	83	44	2	11
	:						*3.6*	*3.1*	*3.3*	*2.4*	*2.2*	*4.7*	*4.5*
1998	:												
	:												
1999	:					n/a	<1	48	20	43	100	93	39
	:						*4.9*	*3.0*	*3.1*	*1.8*	*1.7*	*3.8*	*3.8*
2000	:	4	11				11	61	28	1			12
	:	*4.7*	*3.9*				*2.9*	*2.9*	*2.7*	*4.8*			*4.7*
2001	:	5					69	75	73	61			n/a
	:	*4.7*					*2.5*	*2.3*	*3.0*	*2.9*			
Average [3]	:	5	6	14	6	6	27	34	37	36	23	3	4

1. Excursion rate is the number of hourly average DO measurements from the DWR monitoring station below 5.0 mg/L divided by the total number of such measurements recorded that month, shown as a percent.
2. The minimum hourly average dissolved oxygen measurement for the month in mg/L
3. Average excursion rate is not the simple average of all monthly data-- it is weighted to account for months that had only partial data sets

4.3 Assumptions Regarding Non-Load Related Factors

4.3.1 Impact of Non-Load Related Factors

Apportioning loading capacity between the three contributing factors is complicated by the existence of technical rationale for why each is 100 percent responsible for the low DO impairment. For example, the USACOE has argued that the impairment in the DWSC would not exist if there were no loads of oxygen demanding substances entering the DWSC from upstream (ACOE, 1990). Conversely, no DO impairment exists in the San Joaquin River upstream of the DWSC in spite of the presence of these oxygen demanding substances (Foe, et al., 2002, pg. 17). It can be reasonably argued that if either of these two contributing factors were eliminated, the low DO impairment would not exist. As discussed in Section 3.4, the impact of reduced flow on the loading capacity of the DWSC under current DWSC geometry and variable loading conditions has been well documented. For given DWSC geometry and loading conditions, the impairment could be eliminated if flow through the DWSC were increased.

4.3.3 Assumptions - Flow in the Stockton Deep Water Ship Channel

The impact of reduced flow on the loading capacity of the DWSC has been well documented under current DWSC geometry and variable loading conditions. As flow into the DWSC at a given DO concentration is reduced, less oxygen demand can be exerted on that flow before DO concentrations drop below the Basin Plan objectives. It has also been hypothesized that there is an additional impact related to increased DWSC residence times. With increased residence time, the impact of oxygen demanding substances on DO concentrations is magnified, effectively reducing the loading capacity further.

Although the empirical relationships between reduced flow through the DWSC and the DO impairment are clear, further field analysis and modeling studies are required to better understand the specific oxidation mechanisms, and the variables that affect them, both within the DWSC and upstream. The effect of sudden changes in flow rates on both DWSC and upstream mechanisms also needs to be studied. From this, the conversion of oxygen demanding substances into oxygen demand in the DWSC can be better quantified for the development of wasteload and load allocations. Section 5 outlines the process by which further study will be conducted to fill these data gaps and to consider potential mitigation measures that may be required. As further information becomes available from these studies, the relative apportioning of loading capacity between the contributing factors may be modified.

As described in Section 4.3.1, this TMDL will assume that one-third of the total theoretical loading capacity will be addressed by entities responsible for reduced flow in the DWSC (LC_{Flow}). Because reduced flow does not discharge any substances, no wasteload or load allocations are assigned to responsible entities. Instead, the SWRCB can use its water rights authority and, in some cases, the CVRWQCB or SWRCB can use its CWA Section 401 water quality certification authority to require mitigation based on this TMDL. Numerous entities are responsible for upstream diversions and consumptive use that reduce flow in the DWSC.

The activities that affect flow in the DWSC fall under two categories: (i) consumptive use in the San Joaquin River watershed, and (ii) the diversion of San Joaquin River flows down Old River that result from the operation of the State Water Project (SWP) by DWR and the federal Central Valley Project (CVP) by USBR. Following is a brief discussion of the SWRCB and CVRWQB authorities over activities in these two categories.

Reduced San Joaquin River Flows:

There are currently no minimum required flows in the San Joaquin River past the head of Old River through the DWSC or requirements that water right permit holders provide any mitigation for the DO impairment. The SWRCB adopted Water Right Decision 1641 (D-1641) in December 1999, among other things, to allocate responsibility for achieving water quality objectives contained in the 1995 Water Quality Control Plan for the San Francisco Bay / Sacramento-San Joaquin Delta Estuary (Bay-Delta Plan) to water right holders whose diversions affect the beneficial uses in the estuary (SWRCB, 2000). After considering extensive testimony and analysis, the SWRCB decided in Section 9.3 of D-1641 that:

> "…the SWRCB will not take any water right action to meet the (Bay-Delta Plan) DO objectives at this time. The RWQCB should determine effluent limits based on TMDL results. The SWRCB will wait until the RWQCB has established a TMDL and has implemented it before taking further action to achieve the (Bay-Delta Plan) DO objectives." (SWRCB, 2000, pg. 79).

CVRWQCB staff intends to propose for adoption by June 2004, the TMDL and program of implementation. The TMDL, however, will likely rely upon the SWRCB to take appropriate action to address the impacts of reduced flow in the DWSC that are integral to successful implementation.

In addition to providing this TMDL, the CVRWQCB anticipates consulting with the SWRCB Division of Water Rights during the preparation of water right permits and decisions that have the potential to affect the DO impairment in the DWSC.

South Delta Improvements Project

DWR is in the planning process for their South Delta Improvement Project (SDIP). This project is intended to increase the maximum allowable diversion capacity into Clifton Court Forebay, from which the State Water Project pumps its water. At the same time it allows increased diversion, the SDIP intends to provide for adequate water supply and improved water quality in the South Delta and DWSC. One of the alternatives being considered as mitigation for the effects of increased diversion is the installation of operable flow control barriers at the head of Old River and other locations in the south Delta. These barriers will act to reduce the amount of SJR flow being diverted down Old River towards the pumps and away from the DWSC.

In Section 9.2.1 of D-1641, the SWRCB stated that:

> "Flow moving past Stockton is the largest single controllable factor that affects DO. Although the 1995 Day-Delta Plan contains flow objectives for the San Joaquin River at Vernalis, modeling shows that implementation of the 1995 Bay-Delta flow objectives alone will not significantly improve DO concentrations at Stockton. A barrier at the head of Old River can increase flows in the San Joaquin River at Stockton by reducing the

> proportion of flow that enters Old River. If a head of Old River barrier is constructed and is operated in conjunction with implementing the 1995 Bay-Delta flow objective, DO should improve. (SWRCB, 2000, p. 77).

After further discussion of operational and other considerations, the SWRCB concluded Section 9.2.1 by stating that:

> "…this decision does not require the construction of permanent barriers in the southern Delta channels. Nevertheless, the SWRCB encourages the parties involved in constructing and regulating the barriers to consider the effects of the barriers on DO and to make their best efforts to achieve the benefits of the barriers to DO while avoiding or mitigating their adverse effects." (SWRCB, 2000, p. 78)

In addition to SWRCB water rights authority, the SWRCB or CVRWQCB has CWA Section 401 water quality certification authority over the SDIP. As the SDIP will involve dredging in some South Delta channels and construction of other in-stream structures, they will require a CWA Section 404 permit from the USACOE and a CWA Section 401 certification from the State. In order to obtain this certification, the SDIP will need to provide adequate mitigation of impacts, among other things, to DO conditions in the DWSC.

6.0 REFERENCES

Brown, R. T., Renehan, S. G., "Evaluation of San Joaquin River Flows at Stockton," Report to the City of Stockton, Jones & Stokes, Sacramento, CA (2001).

Foe, C., Gowdy, M., McCarthy, M., "Strawman Source and Linkage Analysis for Low Dissolved Oxygen in the Stockton Deep Water Ship Channel," Report of the California Regional Water Quality Control Board, Central Valley Region, Sacramento, CA (2002).

Kratzer, C. R., Shelton, J. L., "Water Quality Assessment of the San Joaquin-Tulare Basins, California: Analysis of available data on nutrients and suspended sediment in surface water, 1972-1990," Professional Paper 1587, U.S. Geological Survey, (1998).

Lee, G. F., Jones-Lee, A., "Issues in Developing the San Joaquin River Deep Water Ship Channel DO TMDL," Report to the San Joaquin River Dissolved Oxygen Total Maximum Daily Load Steering Committee and the California Regional Water Quality Control Board, Central Valley Region, G. Fred Lee & Associates, El Macero, CA (2000).

Lee, G. F., Jones-Lee, A., "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 to the San Joaquin River Dissolved Oxygen Total Maximum Daily Load Steering Committee and the CALFED Bay-Delta Program, G. Fred Lee & Associates, El Macero, CA (2003).

Oppenheimer, E. I., Grober, L. F., "Total Maximum Daily Load for Salinity and Boron in the Lower San Joaquin River," Report of the California Regional Water Quality Control Board, Central Valley Region, Sacramento, CA (2002).

SWRCB, "Water Right Decision 1641," State Water Resources Control Board (SWRCB Order WR 2000-02), Sacramento, CA (2000).

USACOE, "Finding of No Significant Impact San Francisco Bay to Stockton Ship Channel: Dissolved Oxygen Mitigation Implementation," Letter from Jack A. Le Cuyer, U.S. Army Corps of Engineers, Sacramento District, Sacramento, CA, 25 May (1990).

USEPA, "Ambient Water Quality Criteria for Dissolved Oxygen," EPA 440/5-86-003, U.S. Environmental Protection Agency, Washington D.C. (1986).

USGS, "Water Resources Data – California, Water Year 1997," U.S. Geological Survey Volume 3, Southern Central Valley Basins and the Great Basin From Walker River to Truckee River, Sacramento, CA (1997).

Water and Power Resources Service and South Delta Water Agency, "Effects of the CVP Upon the Southern Delta Water Supply Sacramento-San Joaquin River Delta, California." Stockton, CA (1980).