Exhibit CSPA-62
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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

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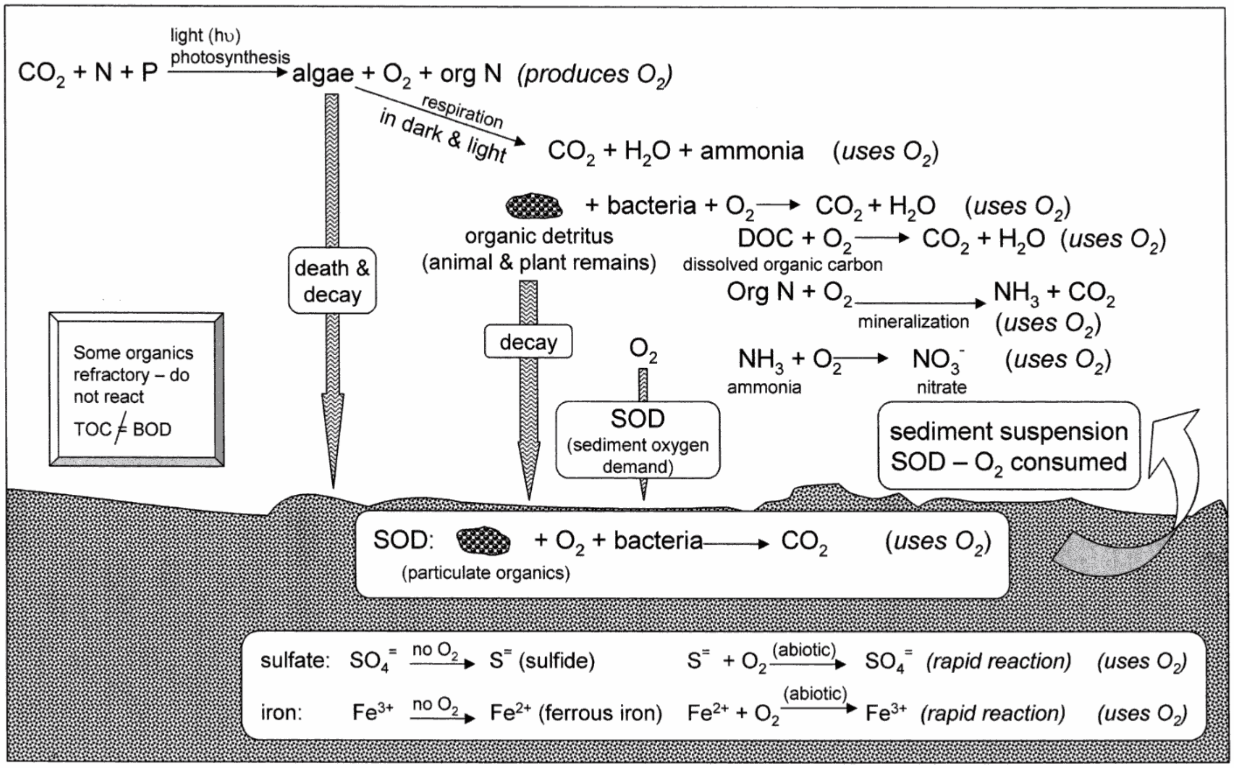

Conceptual Model of DO Depletion Reactions in the SJR DWSC

Report Submitted to
SJR DO TMDL Steering Committee/Technical Advisory Committee
and
CALFED Bay-Delta Program

March 2003

Preface

This report presents a synthesis of the information available on the causes and factors influencing the occurrence of dissolved oxygen concentrations in the San Joaquin River (SJR) Deep Water Ship Channel (DWSC) near the city of Stockton below the water quality objective (standard). In accord with the scope of work for the Synthesis Report contract with the National Fish and Wildlife Foundation (NFWF), *"The approach* [for development of the Synthesis Report] *will be to update the August 2000 'Issues' report, incorporating new information that evolves from the Directed Action-supported projects, Strawman activities, and other sources."* This report presents the authors' discussion of these issues relative to information in the literature and their professional expertise and experience pertinent to this issue. In addition the 2002 SJR DWSC oxygen demand loads to the SJR DWSC and the DO concentrations as measured at the Department of Water (DWR) Resources Rough and Ready Island (RRI) continuous monitoring station are presented and discussed. This report also serves as the final report for the "Administrative" component project of the CALFED 2001 Directed Action project. This report is referred to herein as the "Synthesis Report," with the understanding that it covers more than just a synthesis of the CALFED-supported low-DO projects.

DO depletion in the DWSC during the summer and fall below the water quality objective (WQO) has been a long-standing problem that, under TMDL provisions of the Clean Water Act regulatory requirements, must begin to be controlled. The Central Valley Regional Water Quality Control Board (CVRWQCB) developed an approach for solving this problem that involved the formation of a SJR DO TMDL Steering Committee of stakeholders. The Steering Committee developed a Technical Advisory Committee (TAC). As originally developed, this Steering Committee was to, by the end of December 2002, develop an implementation plan to control DO excursions below the water quality objective that would be acceptable to the CVRWQCB. In order to assist the Steering Committee and the CVRWQCB in developing the low-DO control program, approximately $3.5 million in research has been devoted to the study of the SJR DWSC and its watershed over the past three and a half years. This report presents a synthesis of the current technical information that has been developed from these studies that can help guide the formulation of a Phase I TMDL implementation plan to control low DO in the DWSC.

The technical studies had two primary purposes. One was to determine the assimilative capacity of the DWSC for oxygen-demanding materials of various types and under the various conditions that can influence the oxygen demand constituent assimilative capacity of the DWSC. The other was to provide a technical base of information upon which the Steering Committee/CVRWQCB can potentially assign a technical allocation of responsibility for control of oxygen-demanding substances, to control oxygen depletion below the water quality objective. While the responsibility for solving water quality problems of this type may not necessarily be allocated based on strictly technical reasons, such as the relative contribution of the oxygen demand constituents responsible for DO depletion below the WQO in the DWSC, the allocation of responsibility based on a technical analysis of the sources of the loads and those responsible for adversely impacting the oxygen demand assimilative capacity of the DWSC is an appropriate point to start the allocation of responsibility process.

The results presented in this report represent the efforts of scientists and engineers that, through CALFED and other sources of financial support, have developed a series of project reports on the low-DO problem. The May 2002 draft of this Synthesis Report was designed to aid a CALFED-organized external peer review that was conducted in June 2002 of the current information presented in these reports on the causes and factors influencing the low-DO problem in the DWSC. The peer review panel addressed the issue of the adequacy of the technical information base to begin to formulate a water quality management plan for the SJR DWSC that will ultimately lead to the elimination of the violations of the dissolved oxygen water quality standard (objective). This final report includes a discussion of the peer review panel's comments on these study results that were submitted to them in early May 2002.

Many individuals have contributed to the development of the information upon which this report is based. The principle investigators for the component projects (R. Brown, Jones & Stokes; C. Chen, Systech Engineering; P. Hutton, H. Rajbhandari, K. Jacobs, P. Lehman, P. Nader, CA Department of Water Resources; C. Kratzer, and P. Dileanis, USGS; G. Litton, University of Pacific; N. Quinn, and W. Stringfellow, Lawrence Berkeley Laboratory; and A. Tulloch, Tulloch Engineering) made major contributions to the results summarized in this report. C. Foe, M. Gowdy, and T. King of the CVRWQCB provided significant technical information and guidance in conducting these studies. R. Dahlgren of the University of California, Davis, made available to these studies the results of his studies on the characteristics of waters in the SJR watershed. Further, significant contributions were made by S. Hayes, C. Ralston and J. Giulianotti, Department of Water Resources, through providing data on the characteristics of the DWSC. C. Ruhl, of the USGS provided the recent SJR DWSC flow data. E. Van Nieuwenhuyse of the USBR provided technical guidance in several areas. The assistance of J. McGahan, of Summers Engineering, in describing the Mud and Salt Slough watersheds is appreciated. Alex and Mary Hildebrand, through Mary's chairmanship of the SJR DO TMDL Steering Committee and Alex's advice on South Delta flow management issues, contributed significantly to the development of the information presented in this report. The assistance of T. Quasebarth of CDM in review of the draft report is appreciated. The assistance of Debra Stevens in preparation of this report is greatly appreciated.

Financial support for these studies and this Synthesis Report was provided primarily by CALFED through grants to the SJR DO TMDL component projects, where B. Marcotte was a primary CALFED contact for these studies. She was assisted by S. Harader of CALFED. S. Luoma, Director of the CALFED Science Program, also played a major role in developing the results summarized in this report. Significant support was provided by the Steering Committee members' institutions through donation of time and, for some, financial support. Of particular importance is the approximately $500,000 of support provided by the city of Stockton. W. Jennings, the DeltaKeeper, provided, through California Sportfishing Protection Alliance litigation settlements with the cities of Manteca and Turlock, over $120,000 in support of the technical effort to develop information that can be used to manage the DWSC low-DO problem.

The senior author of this Synthesis Report, G. F. Lee, has been involved in studies of this type over the past 42 years. The experience gained from working on problems of this type in other locations has been incorporated into a discussion of the issues presented in this report.

Because of time constraints between when 2001 study reports were made available and the need to develop an assessment of the current understanding of oxygen demand loads and impacts for the peer review panel meeting scheduled for June 2002, and because of funding limitations, this Synthesis Report is based on a partial review of the total database available from the past three years' studies of oxygen demand sources, loads and impacts in the DWSC. It is anticipated that it will be updated as time and funds permit further review of the existing database. Further in-depth data review will likely clarify some of the issues that at this time are partially understood. This report has been made available to the SJR DO TMDL Steering Committee and its Technical Advisory Committee members, as well as others, for their review and comment. Comments received have been considered and appropriate changes have been made in the report. We want to thank those who made comments on the draft report; these comments have improved the quality of this report.

Originally it was planned that this Synthesis Report would be finalized immediately after the external peer review that took place in mid-June 2002. The finalization would include responses to the peer reviewers' general comments on the project. Draft responses to the peer reviewers' comments were distributed to the SJR DO TMDL Steering Committee and the TAC for review and comment. Based on these comments, final responses to the peer reviewer comments are included as a section of this final report.

In June 2002 the PIs for the Directed Action component projects requested a three-month no-cost extension of their contracts to complete their reports. This extension established August 31, 2002, as the due date for the final reports from each of the component projects. It was intended that the final Synthesis Report would be completed in September 2002. However, many of the PIs for the component projects did not submit their final reports by the August 31, 2002, due date. As of March 18, 2003, K, Jacobs, C. Kratzer, P. Lehman and N. Quinn have not submitted final Directed Action 2001 project reports.

In May 2002 the SJR DO TMDL Steering Committee and CALFED determined that it would be desirable to issue a contract which would add an additional task to Dr. Lee's contract which would develop guidance on developing and funding a DWSC aeration pilot study. This task was undertaken by URS Corporation in a subcontract through Dr. Lee's Directed Action component project. The URS subcontract was conducted by Lisa Hunt with the assistance of Steve Ritchie. A final report for the additional task was completed by the end of October 2002. A summary of this task final report is presented in this final Synthesis Report.

NFWF and CALFED approved rebudgeting of some of the funds in the Lee and Jones-Lee Directed Action component project to support the administration of the component projects during the three-month extension. Also, some of these funds were to be used to continue the Synthesis Report data review that could not be completed during the project period. In early July CALFED redirected this effort from further data review to developing a suggested monitoring program for Phase I of the TMDL implementation program. The recommended monitoring program is included as a new section of this final Synthesis Report.

The final Synthesis Report includes new information on the potential impact of urban stormwater runoff as a source of oxygen demand that leads to DO depletion in the DWSC below the water quality objective. In early November 2002 several inches of rainfall occurred in Stockton. The DeltaKeeper monitored the DO concentrations in the Stockton waterbodies that drain stormwater to the DWSC. A review of these data, as well as the DWR RRI monitoring data is presented in this final Synthesis Report.

In September 2002 R. Brown requested that his aeration project be expanded to include $40,000 to cover additional work on aeration evaluation. This expansion was approved by the SJR DO TMDL Steering Committee, NFWF and CALFED. The expanded project budget period ended December 31, 2002. In January 2003 R. Brown submitted a final report covering his aeration component project. The results of R. Brown's additional work on aeration evaluation have been summarized in this final Synthesis Report.

In September CALFED issued a request for topics that should be included in an EIS/EIR for its South Delta Project. This project is designed to enable greater export of Delta water to Central and Southern California. G. F. Lee provided comments to CALFED on the need for the EIS/EIR to include an assessment of the impact of the current as well as future increased export of Delta water. G. F. Lee's comments are included in this final Synthesis Report.

During the winter 2002-2003, G. F. Lee examined the DO monitoring data obtained from the DWR RRI station for 2002 through mid-March of 2003. Data from this period show some of the greatest DO depletions in the DWSC that have been recorded. This led G. F. Lee to develop estimated oxygen demand loads to the DWSC during 2002. A section of this Synthesis Report has been developed which presents this information. Included in this section is a discussion of the low-DO conditions that occurred in mid-February/March 2002, and that occurred in mid-January and February 2003. During mid-February 2003, the DO at the RRI monitoring station reached a low of 0 mg/L, which was accompanied by a fish kill. These studies have shown the importance of gaining an understanding of the need for winter oxygen demand load DWSC DO response studies, in order to understand how best to manage the DO WQO violations that have occurred during the past two winters, and occasionally in previous winters.

Overall, this Synthesis Report fulfills the objectives of the scope of work for the CALFED Low-DO Directed Action "Administrative" project of updating the information base that is available through mid-March 2003 on the causes and factors influencing the occurrence of low DO in the DWSC and the sources of constituents responsible for low-DO conditions in the DWSC. It also provides information on the approach that should be followed during the Phase I TMDL program. It is anticipated that, as time and funds permit, supplements to this Synthesis Report will be developed as new information becomes available.

G. Fred Lee and Anne Jones-Lee
March 2003

About the Authors

Dr. G. Fred Lee is President and Dr. Anne Jones-Lee is Vice President of G. Fred Lee & Associates, a specialty consulting firm located in El Macero, California. Dr. G. F. Lee obtained a bachelors degree from San Jose State College in environmental health sciences in 1955, a Master of Science in Public Health degree focusing on water quality from the University of North Carolina in 1957, and a PhD from Harvard University in 1960 in environmental engineering, focusing on water quality and aquatic chemistry. His undergraduate and graduate course work included biology, chemistry, geology and engineering courses pertinent to public and environmental health protection and management.

For 30 years, he taught university graduate-level environmental engineering/environmental sciences at several major US universities, during which time he was involved in a number of research and part-time private consulting activities devoted to water supply water quality, water and wastewater treatment, water pollution control and solid and hazardous waste management. He has been the principal investigator in over $6 million in research and has published over 850 papers and reports on his work.

Dr. Anne Jones-Lee obtained a bachelors degree in biology from Southern Methodist University in 1973, a masters degree in 1975 and a PhD in 1978 in environmental science from the University of Texas at Dallas. Her undergraduate and graduate course work included biology, toxicology, chemistry and environmental engineering courses. For 11 years she held university graduate-level teaching and research positions at several major US universities. She and Dr. G. F. Lee have worked as a team since the mid-1970s in research and consulting on water quality investigation and management. Considerable parts of this work have direct applicability to the low-DO problem in the San Joaquin River Deep Water Ship Channel. Drs. G. F. Lee and A. Jones-Lee were part-time consultants to governmental agencies and industry while they held university professorial positions. In 1989, they expanded their part-time consulting activities into a full-time activity.

Dr. G. F. Lee became involved in the San Joaquin River Deep Water Ship Channel low-DO investigations in the spring of 1999. On behalf of the SJR DO TMDL Steering Committee and TAC, with Central Valley Regional Water Quality Control Board support, in August 2000 he and Dr. Jones-Lee completed a comprehensive "Issues" report on the nature of the low-DO problem in the Deep Water Ship Channel. In November 2000 Dr. G. F. Lee was selected by the Steering Committee to develop and then serve as the PI for a $2 million per year CALFED Low-DO Directed Action project. For the past three and a half years, Dr. Lee has worked with the Steering Committee in translating technical issues into information that the Steering Committee members and the Central Valley Regional Water Quality Control Board can use in formulating approaches for managing the low-DO problem in the Deep Water Ship Channel.

Drs. G. Fred Lee and Anne Jones-Lee have developed a website, www.gfredlee.com, where they make available some of their publications in the various areas in which they are active, including their work on the SJR DWSC low-DO problem. Further information on their activities is available from Dr. Lee at gfredlee@aol.com.

Regulatory Background to the Investigations of the Low-DO Problem in the SJR DWSC near Stockton

The low-DO problem in the San Joaquin River near Stockton requires that the Central Valley Regional Water Quality Control Board (CVRWQCB) develop a TMDL to control the depletion of DO below the water quality objective. The TMDL timeline requires that the CVRWQCB develop an assessment of this problem that can be submitted to the US EPA as a technical TMDL in June 2003. In addition, the CVRWQCB will adopt an implementation plan to control DO depletion below the water quality objective, within about a year of the submission of the technical TMDL to the US EPA. The investigations that serve as the basis for this Synthesis Report have been formulated/conducted to provide the information needed to meet this TMDL timeline. From the beginning it has been understood that, as with all TMDLs for complex issues, this TMDL will be conducted in a phased approach where the first phase will be specifically directed to implementation of the management plan to control the low-DO problems in the DWSC. It is understood that directed implementation studies will need to be conducted during the first phase. To assist reviewers of this report in understanding the CVRWQCB Phase I implementation plan, the authors of this Synthesis Report suggested that the CVRWQCB staff (Dr. Chris Foe and Mark Gowdy) provide information on their current plan for implementation of the TMDL Phase I. This information is being provided in separate documents (Foe, 2002; CVRWQCB, 2003). These documents are available from the SJR DO TMDL website (www.sjrtmdl.org). They should be reviewed as background to a review of this Synthesis Report since they provide information on how the results of the studies reported herein will be implemented into a low-DO management plan. In mid-March 2003 the CVRWQCB reviewed the staff's proposed approach for developing Phase I of the TMDL implementation plan. They approved the approach recommended by the staff in their February 2003 report.

Executive Summary

During the summer and fall, the first approximately seven miles of the San Joaquin River (SJR) Deep Water Ship Channel (DWSC) near the Port of Stockton frequently experiences dissolved oxygen (DO) concentrations below the water quality objective (standard). This has led to a Clean Water Act (CWA) section 303(d) designation as an "impaired" waterbody, which in turn requires the development of a total maximum daily load (TMDL) to control the violations of the DO water quality objective. Beginning in the summer of 1999, through the fall 2001, members of a Technical Advisory Committee (TAC) to the SJR DO TMDL Steering Committee of stakeholders conducted about $3 million of studies on the causes and sources of constituents responsible for violations of the DO water quality objective in the DWSC.

This Synthesis Report presents a synopsis of the results of these studies, as well as information based on other studies and the authors' experience. Particular attention is given to providing an overview discussion of the current understanding of the constituents responsible for low DO, their sources and the factors influencing how oxygen-demanding constituents added to the DWSC lead to violations of the DO water quality objective. Also, information is provided on potential approaches to control low DO in the DWSC.

Physical and Hydrological Characteristics of the SJR and DWSC

(Maps showing the locations of the areas discussed in the Executive Summary are located in the beginning of the report text, as Figures 1 through 5.)

The SJR watershed consists of over 7,000 square miles in the Central San Joaquin Valley of California below the eastside reservoirs. The total watershed, which includes the Sierra-Nevada mountains above the reservoirs is estimated to be 13,536 square miles. It is bounded on the east by the Sierra-Nevada mountains, and on the west by the Coast Range mountains. It extends north from Fresno to the Sacramento-San Joaquin River Delta. The eastside rivers (Merced, Tuolumne and Stanislaus Rivers), including the San Joaquin River, which drain the western slopes of the Sierra-Nevada mountains, are the primary sources of water for the SJR. Upstream of the Port of Stockton, the SJR is about 150 feet wide and eight to 10 feet deep, and is freshwater tidal, with about a three-foot tide at the Port of Stockton. At the Port the River is about 250 feet wide and is dredged to a depth of 35 feet to San Francisco Bay.

The flow of the SJR during the summer and fall is highly regulated by upstream reservoir releases and agricultural and other water diversions. These diversions increase the hydraulic residence time of the critical reach (first seven miles) of the DWSC, and thereby contribute to the low-DO problem within the DWSC. During the summer months, the flow in the SJR through the DWSC can range from a negative flow (i.e., upstream to Old River), to typically 500 to 1,200 cfs net downstream flow, to, at times, several thousand cfs downstream flow. The net downstream flows occur with a background of 2,000 to 4,000 cfs tidal flow.

The city of Stockton discharges its treated domestic wastewaters to the SJR approximately two miles upstream of where the SJR enters the DWSC at Channel Point. There are several other domestic and commercial wastewater discharges to the SJR and its tributaries in the SJR DWSC watershed. Further, there are numerous points where agricultural irrigation tailwater discharges to the SJR and its tributaries occur throughout the watershed.

The critical reach of the SJR DWSC for low-DO problems is approximately the seven miles just downstream of the Port to Turner Cut. This reach has experienced DO depletion below the water quality objective over the past 40 years or so. The hydraulic residence time of the critical reach can vary from about four days, with SJR DWSC flows of 2,000 cfs, to approximately 30 days at 250 cfs. These travel times are important in determining the amount of time available for oxygen demand exertion within the DWSC before the oxygen demand is diluted by the cross-SJR DWSC flow of the Sacramento River at Disappointment Slough/Columbia Cut arising from the export pumping of South Delta water to Central and Southern California by the State and Federal Projects. This cross-SJR DWSC flow limits the downstream extent of DO depletion in the DWSC.

DO Depletion in the DWSC

During the summer and fall months, dissolved oxygen concentrations in the DWSC water column from just downstream of the Port to, at times, as far as Turner Cut, are depleted 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 at or near the bottom can be as low as about 1 to 2 mg/L. The DO concentrations near the bottom of the DWSC are sometimes one to two 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, algal photosynthesis in the near-surface waters and suspended particulate BOD in the near-bottom waters.

The point of maximum DO depletion in the critical reach of the DWSC is a function of the flow of the SJR through the DWSC, where higher flows cause the point of maximum DO depletion to shift downstream. During periods of significant algal photosynthesis, where planktonic algal chlorophyll *a* is greater than about 20 to 30 µg/L, there can be a several mg/L diel DO change in the surface waters of the DWSC.

Constituents Responsible for Oxygen Depletion and Their Overall Sources

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, with city of Stockton residual CBOD present in their wastewater effluent, as well as CBOD derived from other sources. The NBOD is composed of ammonia and organic nitrogen that is mineralized to ammonia, which is biochemically oxidized to nitrite and nitrate (nitrification). 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 percent 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 percent 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 percent of the total oxygen demand load to the DWSC. The relative proportion of the city of Stockton and upstream oxygen demand loads is variable, dependent on the City's wastewater effluent ammonia concentrations, the planktonic algal concentrations in the SJR that discharges to the DWSC, and the flow of the SJR through the DWSC.

The limitation of the downstream extent of the DO depletion caused by the cross-SJR DWSC flow of the Sacramento River at Columbia Cut results in some situations where part of the oxygen demand load to the DWSC from the City and upstream sources is not exerted in the critical reach of the DWSC – i.e., it is transported into the Central Delta, where it is diluted by the cross-channel flow of the Sacramento River. As a result, an issue that must be better understood in order to appropriately manage the low-DO problem is a determination of the part of the oxygen demand load from the City and upstream sources that is exerted within the critical reach that leads to DO concentrations below the water quality objective. Additional information is needed on the amount of the oxygen demand load from the various sources and constituents that is exerted in the DWSC that leads to DO concentrations below the WQO.

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. 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 oxygen production through photosynthesis. 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. The bedded sediment oxygen demand of the DWSC between Channel Point and near Turner Cut is estimated to be about 2,000 lb/day, which is at the upper end of the measured SOD values.
- ***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. It has been estimated that about 4,500 lb/day of oxygen is typically added to the critical reach of the DWSC through 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. The inorganic turbidity derived from watershed erosion, significantly reduces the depth of the photic zone, where algal photosynthesis can occur, compared to photic zone depths that are found in most waterbodies where light penetration is controlled by light scattering and absorption by algae. Current efforts to control erosion within the SJR watershed could lead to increased water clarity and greater algal growth. It also appears that, at times, colored waters derived from the Mud and Salt Slough watershed wetlands areas can contribute sufficient color to the SJR and DWSC to reduce light penetration and thereby inhibit algal photosynthesis. This may lead to significantly greater DO depletion in the DWSC than would occur in the absence of the colored water.
- ***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 Rough and Ready Island 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 Rough and Ready Island station.

Using a deterministic model of oxygen demand loads and their impacts on DO in the DWSC, it is found that increasing the flow of the SJR through the DWSC decreased the dissolved oxygen deficit within the DWSC. At SJR flows through the DWSC above about 2,000 cfs, there were few DO depletions below the water quality objective. These modeling results are in accord with the monitoring studies of the past three years and the past eight years of monitoring conducted by the Department of Water Resources.

The magnitude of the oxygen deficit below the WQO has been found to be dependent on SJR flow through the DWSC. In the SJR DWSC flow range between 500 and 1,500 cfs, the interactions of flow, oxygen demand loads and oxygen depletion are not readily discernible based on mass balance calculations. There is need for a more comprehensive sampling program of oxygen demand loads and impacts to gain additional insight into the impact of SJR flow through the DWSC on DO depletion.

The Interagency Ecological Program (IEP) has been monitoring various water quality parameters in the Delta since 1971. Continuous monitoring of DO, temperature, electrical conductivity, etc., has been conducted at Rough and Ready Island for the past 19 years. A statistical examination of these data shows that there is a strong correlation between DO depletion at the DWR Rough and Ready Island monitoring station and the planktonic algal concentrations measured at Vernalis. There were also correlations between the city of Stockton's ammonia discharges to the SJR and DO depletion at the Rough and Ready Island monitoring station.

Examination of the city of Stockton stormwater runoff oxygen demand concentrations shows that there is sufficient BOD in stormwater runoff from the city of Stockton to add a substantial oxygen demand load to the DWSC. It appears that a November 2002 DO depletion situation in the DWSC was caused, at least in part, by city of Stockton stormwater runoff-associated BOD.

Examination of the dissolved oxygen concentrations found in the DWSC at the DWR Rough and Ready Island 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, a surface water DO of 0 mg/L was found at this station. 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 a large winter algal bloom, 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.

Box Model Calculations of Load of Oxygen Demand and Oxygen Deficit

Calculations were made of the oxygen demand loads in the SJR at Mossdale and discharged by the city of Stockton in the City's treated domestic wastewaters on the 43 dates that the City conducted monitoring runs on the SJR DWSC and upstream during August through October 1999, and June through October 2000 and 2001. The average BOD_5 measured in the SJR at Mossdale during the summer and fall, from August 1999 through October 2001, was 3.7 mg/L. The range was from 1.3 to 7.0 mg/L, with values less than about 2 mg/L occurring in October.

The average sum of the chlorophyll *a* plus pheophytin *a* was about 64 µg/L during the three summer/fall periods. The low values occurred in October.

The average flow of the SJR through the DWSC during summer/fall 1999, 2000 and 2001 was about 930 cfs. The flows ranged from a low of 395 cfs to a high of 2,416 cfs. Many of the values were in the range of 600 to 1,200 cfs. The average BOD_u load over the three summer/fall periods was 86,000 lb/day, with the City's contribution to this load averaging about 25 percent. During the study period, the City's percent contribution to the total load of BOD_u to the DWSC ranged from about 5 percent to about 54 percent. The City's $CBOD_u$ plus $NBOD_u$ loads ranged from about 3,000 lb/day to 30,000 lb/day during the summer/fall months. The total BOD_u load (Mossdale + City) shows that this load, at times, especially under elevated SJR flows through the DWSC, can be as much as 150,000 lb/day. During 2002 the City's monthly estimated oxygen demand loads to the DWSC ranged from about 10 percent to 87 percent of the total oxygen demand load to the DWSC.

The amount of oxygen that needs to be added to the DWSC to eliminate violations of the water quality objective at various locations in the DWSC between Channel Point and Turner Cut has been computed. While there were a number of sampling runs made in 2000 where there were no deficits below the WQO, in 1999 over 78,000 lb of oxygen would be needed to satisfy the deficit that occurred on October 19. Similarly, on September 19, 2001, approximately 47,000 lb of oxygen would be needed to satisfy the DO deficit below the water quality objective. The overall average deficit below the WQO for the three-year study period was 20,000 lb. The average deficit, for those sampling runs where there was a deficit below the water quality objective, was about 8,000 lb of oxygen during 2000. During 2001, the average deficit, for those sampling runs where there was a deficit below the water quality objective, was 22,000 lb.

Atmospheric oxygen reaeration in the DWSC, with a 4 mg/L deficit from saturation, is about 4,500 lb/day. The SOD in the DWSC is estimated to be on the order of 2,000 lb/day of dissolved oxygen, which is at the upper end of the measured SOD values. On a per-unit-sediment-area basis, the DWSC SOD is somewhat lower than that typically measured for other waterbodies.

Mass balance calculations of oxygen demand loads and oxygen sinks/exports from the DWSC show that the total loads were on the order of 86,000 lb/day, while the total sinks/exports were on the order of 70,900 lb/day. On the average, there is about a 15,100 lb/day difference between the BOD_u loads and the sum of the BOD_u and DO deficit exports and in-channel deficits below saturation. At this time, it is unknown whether this difference is largely due to sampling and analytical variability or due to some other factor that is not yet understood.

Based on the results of the summer/fall 2000 studies of the Deep Water Ship Channel and upstream SJR, the algal load from growth in the DWSC was found at times to be equal to that from upstream sources. The algal growth in the DWSC is accompanied by oxygen production, and therefore does not represent an additional oxygen demand load to the DWSC, since the photosynthetically-produced oxygen is available to satisfy the increased oxygen demand caused by the algae produced in the DWSC. Ordinarily the surface waters of the DWSC are undersaturated with respect to DO and, therefore, photosynthetically-produced oxygen would remain in the water column and be available to satisfy oxygen demand. A possible exception to this could occur during late afternoon, when short-term DO supersaturation could occur in the surface waters due to algal photosynthesis that would result in some of the photosynthetically-produced oxygen being lost to the atmosphere through gas transfer through the surface water air interface. Algal growth within the DWSC is light-limited, where light penetration is primarily controlled by inorganic suspended particles.

The relationship between SJR DWSC flow, oxygen demand loads and DO deficits on a particular day is not readily discernible from the information available. The DO deficit is a function of the interplay between SJR DWSC flow, oxygen demand loads, type of oxygen demand loads (different forms of CBOD and NBOD), hydraulic residence time of the DWSC as a function of SJR flow, algal growth in the DWSC, algae and detritus settling in the DWSC, mixing in the DWSC, etc. At this time the relationships between these factors are not well understood.

Sources of Oxygen Demand

During 2000 and 2001, studies were conducted in the SJR watershed upstream of Mossdale to define the sources of oxygen demand that cause the SJR at Mossdale to have elevated oxygen demand concentrations/loads. Based on SJR and its tributary monitoring and measured flows, it was found that the primary sources of oxygen demand are discharges of algae from Mud and Salt Sloughs to the SJR and the SJR watershed upstream of Lander Avenue (Highway 165). This area consists of substantial irrigated agriculture and managed wetlands, which are used for wildlife refuges and duck clubs.

Based on monitoring of planktonic algal chlorophyll *a* and BOD along the SJR from where Mud and Salt Sloughs discharge to the SJR down to Vernalis, it has been found that the algae/oxygen demand that are discharged by Mud and Salt Sloughs to the SJR continue to develop in the SJR, ultimately leading to greatly elevated planktonic algal chlorophyll *a* and BOD concentrations and loads at Mossdale. At times, 50 to 80 percent of the Mossdale loads of BOD originate from the Mud and Salt Slough discharges to the SJR and the SJR upstream of Lander Avenue. It has been found that, on the average during the summers of 2000 and 2001, 1lb of algal oxygen demand discharged by Mud and Salt Sloughs to the SJR, as well as in the SJR at Lander Avenue, develops into 8 lb of oxygen demand at Mossdale.

The eastside rivers (Tuolumne, Stanislaus and Merced Rivers) have been found to discharge high-quality Sierra Nevada derived water to the SJR which has a low planktonic algal content and oxygen demand concentration, and therefore are not a major source of oxygen demand contributing to the low-DO problem in the DWSC.

The westside tributaries (except Mud and Salt Sloughs), such as Los Banos Creek, Orestimba Creek and Spanish Grant Drain, have been found to contribute a small part of the oxygen demand load and chlorophyll *a* to the SJR that ultimately are present in the SJR at Mossdale. The Harding Drain (TID 5), an eastside tributary, has been found to contribute oxygen demand to the SJR that is apparently not associated with algal chlorophyll *a*. This oxygen demand may be due to upstream domestic wastewater discharges from Turlock and from dairies.

From the information available, wastewater discharges and stormwater runoff from the large municipalities in the SJR watershed upstream of Mossdale are not normally major sources of oxygen demand that cause DO depletion in the DWSC during the summer and fall months. These municipalities are prohibited from discharging wastewaters to the SJR or its tributaries during the summer and early fall. During this time, the wastewaters are disposed of on land. While there is normally no rainfall runoff in the SJR watershed from June through September, there is a potential for municipal, commercial, industrial and agricultural stormwater runoff to be a source of oxygen demand associated with the rainfall runoff events that typically occur in October and November. Examination of the city of Stockton stormwater runoff-associated oxygen demand loads shows that a stormwater runoff event lasting one to two days can add as much BOD to the DWSC as is contributed from upstream of the DWSC sources during this same period.

SJR Water Diversions

There are substantial municipal and agricultural diversions of SJR water upstream of the DWSC. These diversions decrease the amount of SJR flow through the DWSC and therefore, increase the hydraulic residence time of oxygen-demanding substances in the DWSC. This leads to reduced oxygen demand assimilative capacity and greater DO depletion within the DWSC. All water diversions and managed shifts from summer flow to spring flow that decrease the flow of the SJR through the DWSC during the summer and fall below about 2,000 cfs contribute to the low-DO problem in the DWSC. This is especially true during the time when there is a rapid decrease in the SJR flow through the DWSC associated with the early June termination of the Vernalis Adaptive Management Plan (VAMP) flows, as well as in the fall, when the South Delta barriers are removed, which results in greater SJR flow down Old River.

There are several major upstream diversions, such as by the Central Valley Project (CVP) at Friant Dam, the city of San Francisco and various irrigation districts, that are potential contributors to the low-DO problem. While the impacts of low SJR flow through the DWSC leading to low DO are well documented, at this time there is an inadequate understanding of the impact of these upstream diversions on the flow of the SJR through the DWSC during the summer and fall months and therefore the magnitude of the DO depletion below the WQO associated with these diversions.

It has been found during the summer months that approximately 500 cfs of SJR water is diverted for agricultural irrigation between where the Merced River discharges to the SJR and Mossdale. These diversions reduce the SJR flow through the DWSC and, therefore, contribute to the DO depletion problems within the DWSC. At times from 25 to 50 percent of the SJR flow at Vernalis, in the 1,000 to 2,000 cfs range, is diverted from the SJR for agricultural use upstream of Vernalis. However, the SJR diversions below the confluence with the Merced River during the summer also divert substantial amounts of algae/oxygen demand loads. It is estimated that about 30,000 lb/day of BOD_u is diverted from the SJR between the Merced River and Mossdale, associated with water diversions for agricultural use.

The irrigation diversions are generally accompanied by some tailwater return to the SJR or its tributaries. This has been estimated to be about 15 percent of the diverted water and about 20 percent of the SJR flow at Vernalis. The irrigation return water (tailwater) appears to contribute about 2 percent of the chlorophyll *a* load in the SJR at Mossdale.

The federal Central Valley Project (CVP) and State Water Project (SWP) export through the Delta-Mendota Canal and California Aqueduct, respectively, up to about 11,000 cfs of South Delta water to Central and Southern California. The export pumping of South Delta water artificially changes the flows in the South Delta which results in more of the San Joaquin River going through Old River. These Old River diversions can significantly reduce the SJR flow through the DWSC, thereby directly contributing to the low-DO problem in the DWSC.

An analysis of the 2002 and thus far 2003 SJR DWSC flow data shows that there were several periods of low SJR flow through the DWSC, with flows less than 200 cfs. Examination of the SJR at Vernalis flows during 2002 and 2003 shows that the low flows of the SJR through the DWSC were not due to low SJR at Vernalis flows, but were due to diversion of most of the SJR flow at Vernalis down Old River for export through the CVP and SWP. The export of South Delta water, which led to very low SJR flow through the DWSC, was related to severe low-DO problems in the DWSC.

Water Quality Modeling

Several water quality modeling approaches have been used in this study. They include mass-balance box-model calculations of loads and responses, statistical evaluation of the 19-year IEP database and deterministic modeling. A one-dimensional deterministic water quality model has been developed for the DWSC which can be tuned to match somewhat the oxygen demand load DO deficit response found in the DWSC. There are, however, significant deviations between the tuned-modeling results for any particular year and the measured values at various times during the year. It is unclear at this time whether these differences are related to problems with the model structure and parameters and/or inadequate monitoring of the DWSC.

CALFED has funded two additional modeling efforts for the purpose of trying to improve this modeling. This additional modeling includes an attempt to expand the modeling from a one-dimensional to a two-dimensional model to account for the transitory thermal stratification that occurs in the DWSC. There is a daily transitory thermal stratification that occurs in the near-surface waters of the DWSC. However, this thermal stratification is lost each night. A critical review of the existing data shows that, while there is no permanent vertical stratification with respect to dissolved constituents other than oxygen, there is vertical stratification with respect to particulate constituents, where the near-bottom waters normally have higher concentrations than the mid-depth or surface waters. Attempts to develop a model based on a thermal stratification driving force for the vertical changes in DO in the DWSC will likely prove to be unreliable, since thermal stratification does not appear to be the primary cause of the changes in DO from the near-surface waters to the near-bottom waters.

Long-term BOD measurements have shown that the BOD rate constants for waters taken from the SJR upstream of the DWSC and within the DWSC are somewhat lower than those normally used for oxygen demand modeling. The long-term BOD measurements show that BOD exertion did not show any lag due to a period of time associated with the death of algae and delayed BOD exertion in the BOD test that has been found in other studies involving algae as a dominant source of BOD.

There are significant questions about the reliability of using nitrification-inhibited BOD tests to estimate the carbonaceous and nitrogenous BOD rate constants. The approach that should be used to estimate these rate constants involves measurement of ammonia disappearance and nitrate appearance within the BOD test. Rate constants developing using this approach should be evaluated based on field studies involving Lagrangian monitoring of water masses as they pass through the critical reach of the DWSC.

There is some indication that the rates of nitrification that occur within the DWSC are somewhat elevated (enhanced) compared to a typical NBOD rate constant of 0.1 per day. If this is verified through further studies during the summer, fall and winter, nitrogenous BOD, such as the city of Stockton's wastewater ammonia discharges, would cause a greater oxygen deficit in the DWSC per unit BOD_u load to the DWSC than would be predicted based on typical nitrification rate constants. This is an area that needs further study in order to properly allocate the responsibility of the oxygen demand loads between the City's wastewater source and the upstream sources.

An issue that has not been addressed in these studies is the potential for zooplankton and clam grazing of algae that could, at times, cause changes in phytoplankton concentrations. While not quantified, there is some evidence for zooplankton grazing being potentially significant under certain conditions. Current measurements and modeling have not measured or incorporated the potential for zooplankton and clam grazing of phytoplankton as a factor that could influence phytoplankton populations in the SJR upstream of the DWSC and within the DWSC. Further, it is possible that pesticide-caused zooplankton toxicity pulses that are found in the SJR and DWSC influence zooplankton concentrations, which in turn influence phytoplankton populations.

South Delta Barriers

Temporary rock barriers are installed each year in three Delta channels. These barriers trap incoming tides to mitigate for the lowered water levels caused by the operation of the SWP and CVP export pumps which draw Sacramento River water across the Delta. The barriers also are meant to re-establish unidirectional flow in these channels to improve water quality. CALFED is obligated to replace the temporary rock barriers with permanent operable barriers by 2007. Modeling has been conducted of whether it would be possible to operate the permanent barriers to raise the water level sufficiently in the South Delta so that a reverse flow of South Delta water could occur into the SJR via Old River. It has been found that, through low-head, reverse-flow pumping across the permanent barriers, there could be addition of South Delta water to the SJR at Old River, which would increase the flow of the SJR through the DWSC. The reverse-flow, low-head pumping approach would introduce higher quality Sacramento River water into the South Delta and thereby, not only be a benefit to increasing the flow of the SJR through the DWSC, but also to reducing the magnitude of the water quality problems that have been found in the South Delta. This approach could potentially be used to help stabilize the flow of the SJR through the DWSC, and thereby minimize or eliminate the large changes in this flow that occur at times associated with the operation of the South Delta barriers. Further, stabilized flow would be an asset to managing aeration in the DWSC.

DO Water Quality Objectives

Currently, the Central Valley Regional Water Quality Control Board (CVRWQCB) Basin Plan DO water quality objective (DO standard) is 5 mg/L at any time and location in the DWSC between the Port of Stockton and Turner Cut during December 1 through August 31. During September 1 through November 30, the DO objective is 6 mg/L. The 5 mg/L WQO is similar to, but not the same as, the US EPA's national water quality criterion for DO. The current US EPA national water quality criterion for DO allows for averaging and for low-DO concentrations to occur near the sediment water interface. The 6 mg/L WQO was adopted to protect the fall run of Chinook salmon migration through the DWSC to their upstream home waters.

The CVRWQCB staff have proposed a Phase I TMDL water quality goal of a seven-day average of the daily minimum DO concentration of 5 mg/L with no DO concentrations below 3 mg/L. This goal would apply everywhere between Channel Point and Turner Cut for the time period of June 1 through November 30. For the remainder of the year, the current water quality objective of 5 mg/L at any time and location would be applicable as the Phase I target concentration. The final water quality objective for the DWSC has not yet been determined. With respect to the proposed interim DO concentration target for Phase I of the TMDL, there is concern that the minimum 3 mg/L specified in the draft target may not be protective, where this value should be raised to at least 4 mg/L as the minimum that can occur at any time and location.

Implications of Technical Studies for Managing the Low-DO Problem

The studies of the past three years plus other data have provided information that can be used to formulate a management plan to control the DO problem in the DWSC. A summary of these results is presented herein.

Port of Stockton. Since the DO depletion problems that occur in the first seven miles of the DWSC below the Port of Stockton would not occur if the DWSC had not been dredged, it seems appropriate that the future budget for the maintenance dredging of the DWSC performed by the Corps of Engineers under its Congressional mandate, should be expanded for this reach of the DWSC to include funds to control the low-DO problem created by the continued existence/ maintenance of the DWSC. Justification for this approach stems from the fact that, without continued maintenance of the 35-foot deep DWSC, the DWSC would soon shoal and thereby become better able to assimilate the oxygen demand loads that are delivered to it from the SJR upstream of the Port. The SJR upstream of the Port is 8 to 10 feet deep. It has the same oxygen demand loads as the DWSC, but does not experience DO depletions below the water quality objective.

Supplemental Aeration. Preliminary studies have shown that it appears to be technically and economically feasible to provide supplemental aeration of the DWSC to control DO depletions below the WQO. The box model calculations, Strawman analysis and the Brown evaluation of aeration for the DWSC show that, based on the past three years' data, on the average about 2,300 lb/day of oxygen needs to be added to the DWSC to eliminate violations of the DO WQO. Considering the worst-case conditions for DO depletion below the WQO found in the box model calculations for data collected over the past three years, on the order of about 6,000 lb/day of DO would be needed to keep the DWSC from violating a WQO. Other approaches for estimating the needed aeration have shown that, typically, a few thousand to ten thousand lb/day of oxygen is needed to eliminate WQO violations. It has been estimated that the amount of needed aeration can be obtained for a construction cost of less than $2.5 million dollars, with annual operating expenses of less than $500,000. An engineering evaluation leading to pilot studies of DWSC aeration is needed to develop an aeration system that can control DO concentrations in the DWSC above the WQO.

It is likely that a combination of supplemental aeration, upstream oxygen demand load control and increased flow of the SJR through the DWSC will be used to control the low-DO problem in the DWSC. It should be noted, however, that increased flow through the DWSC would require increased amounts of aeration with the result that there is need to optimize increased flow versus aeration to control the DO depletion problem in the most cost-effective manner.

Nutrient/Algae Control in the Mud and Salt Slough and SJR Upstream of Lander Avenue Watersheds. It was found during the summer/fall 2000 and 2001 studies that the Mud and Salt Slough and SJR upstream of Lander Avenue watersheds are the primary sources of algae/oxygen demand that lead to the DO problem in the DWSC. There is little understanding at this time of algal growth dynamics and nutrient sources that lead to high algal populations in discharges to the SJR from these areas. There is need to conduct studies within these watersheds to understand the specific sources of nutrients that lead to elevated concentrations of algae in the discharges (from Mud and Salt Sloughs and the SJR above Lander Avenue) to the SJR that ultimately lead to low-DO problems in the DWSC. Through such an understanding, it may be possible to effect some control of the high algal concentrations/loads that are discharged to the SJR from these watersheds during the summer/fall months that cause high oxygen demand in the DWSC.

It will be important to evaluate the relationship between decreased algae/BOD from the Mud and Salt Slough and SJR at Lander Avenue watersheds and decreased algae/BOD concentration/load at Mossdale. Guidance is provided in this Synthesis Report on the studies that should be done in the Mud and Salt Slough watersheds to determine if it is economically feasible to control oxygen demand loads from these watersheds that impact DO depletion in the DWSC. The recommended approach involves the use of alum addition to bind the available phosphorus, thereby limiting algal growth in the headwaters of the Mud and Salt Slough watersheds.

City of Stockton Wastewaters. The city of Stockton wastewater discharges of elevated ammonia at times can be a significant contributor to the low-DO problem in the DWSC. The city of Stockton's wastewater oxygen demand load, which is principally in the form of ammonia, can represent up to about 90 percent of the total BOD load to the DWSC. The CVRWQCB has recently adopted a revised NPDES wastewater discharge permit for the city of Stockton that limits the monthly average ammonia concentration in the effluent to 2 mg/L for aquatic life toxicity reasons. The city of Stockton's appeal of this permit to the State Water Resources Control Board (SWRCB) was not supported by the Board. At this time, it appears that the city of

Stockton may appeal the Board's decision to the courts. If the permit is upheld, then the oxygen demand load would be reduced by up to about 20,000 lb/day BOD_u.

While there can be little doubt that, when the city of Stockton is discharging 25 to 30 mg/L ammonia nitrogen in its effluent to the SJR, and the SJR DWSC flows are a few hundred cfs or less, the City's wastewater ammonia oxygen demand loads are the principal source of oxygen demand for the DWSC, there are questions about the significance of the City's wastewater oxygen demand loads as a cause of DO depletion in the DWSC when the concentrations of ammonia in the effluent are a few milligrams per liter, especially when the SJR DWSC flows are above about 800 cfs. An issue that needs to be resolved is whether the City's ammonia discharges are subject to "enhanced" nitrification rates, which would lead to a greater proportion of the ammonia being oxidized in the critical reach of the DWSC before it is diverted/diluted into the Central Delta at Columbia Cut. This is an area that needs further study.

Additional Areas that Need Attention

In addition to those mentioned above, there are several areas that have evolved from the past three and a half years' studies that need attention through further studies. These are briefly summarized below.

DO "Crashes" in the DWSC. At times there will be short-term DO depletions in the DWSC to relatively low levels -- i.e., 2 mg/L. These DO "crashes" are particularly significant since they may ultimately become the controlling DO depletions that must be managed. At this time, the causes of the DO crashes are not understood, but may be related to pulses of higher-than-normal algal concentrations in the SJR that enter the DWSC, or pulses of increased inorganic turbidity that decrease light penetration in the DWSC and thereby reduce the oxygen produced by algal photosynthesis in the surface waters of the DWSC. They may also be due to pulses of colored waters released from upstream wetlands areas that decrease algal photosynthesis in the DWSC. There is need for intensive field studies involving more frequent monitoring of sources and DO depletion than has been conducted in the past three years. Such studies should be designed to understand and thereby control the DO crash episodes that occur occasionally in the DWSC.

DO Depletions during the Winter. During the winters of 2001-2002 and 2002-2003 significant DO depletions below the WQO have been found in the DWSC off of Rough and Ready Island. There is need to understand the oxygen demand loads and other factors that lead to these low-DO conditions.

DO Depletions within the South and Central Delta. There are DO depletions below the water quality objective in some of the South Delta channels. The role of algal related oxygen demand added to these channels from the SJR via Old River has not been determined. It could be part of, or the primary cause of, the low-DO problems that are now occurring in the South Delta channels. This is an area that needs investigation.

At times, especially under high SJR DWSC flow, large amounts of oxygen demand and oxygen deficit are exported into the Central Delta at Turner Cut and especially Columbia Cut by the cross-DWSC flow of the Sacramento River on its way to the South Delta to be exported to

Central and Southern California by the State and Federal Projects. At this time, no studies have been conducted to determine if low-DO problems are occurring in Turner Cut, Columbia Cut and/or Middle River due to the oxygen demand loads from the DWSC. These studies are needed as part of any implementation program that would alter flows through the DWSC. Particular attention should be given to the Turner Cut situation since the SJR flows that enter Turner Cut during ebb tide are not diluted to a significant extent by Sacramento River water.

Impact of Urban Stormwater Runoff Oxygen Demand Load on DO Depletion. City of Stockton stormwater runoff has been found to contain about 14 mg/L BOD_5. It is estimated that a 0.5-in storm in Stockton will result in a BOD load to the DWSC equal to the upstream BOD load from the SJR DWSC watershed including the City's wastewater treatment plant load. In November 2002 several inches of rainfall occurred in the Stockton area. Prior to the rainfall the DO in the DWSC was above the water quality objective. Within a few days the DO in the DWSC was below the WQO for several weeks. At the same time the DO concentrations decreased to low levels in the creeks and sloughs that drain Stockton rainfall runoff to the DWSC. There were major fish kills in these waterbodies apparently because of low DO. It appears that potentially significant DO depletion could occur in the DWSC associated with rainfall-runoff-associated BOD derived from urban areas. This is an area that needs further evaluation through examination of the DO concentrations as measured by the DWR Rough and Ready Island monitoring station and the occurrence of fall-winter rainfall runoff events.

Development of a TMDL and its Technical Allocation

There is sufficient information to develop a technical TMDL to control the low-DO problem in the DWSC. There is also sufficient information to allocate technical responsibility to tributary river mouths for the sources of oxygen demand loads that cause DO depletion problems in the DWSC. It is understood that the allocation may change somewhat during droughts. The approach that can be used is to assign an oxygen demand load allocation to the city of Stockton ammonia and the stakeholders in the Mud and Salt Slough and SJR at Lander Avenue watersheds. This allocation would need to assume that worst-case SJR flow and no aeration of the DWSC occurs. To the extent that assured funding can be developed for aeration of the DWSC from federal and/or state legislatures, the Port of Stockton and those who benefit from the existence of the Port and/or those who divert water from the SJR upstream of the DWSC (other responsible parties for the low-DO problem in the DWSC), the Mud and Salt Slough and SJR at Lander Avenue watershed stakeholders' oxygen demand load allocations can be reduced accordingly. Further, the funding from the other responsible parties could also be used to support the control of nutrients that lead to algae in the upstream watershed that are a significant source of oxygen demand in the DWSC.

TMDL Phased Approach. The TMDL will be conducted in a phased approach where the first phase will be largely devoted to obtaining additional information on the specific sources of oxygen demand in the Mud and Salt Slough and SJR upstream of Lander Avenue watersheds, and their potential control. Further, the initial phase of the TMDL will need to be devoted to pilot studies of aeration of the DWSC to control the low-DO problem. In addition, an engineering evaluation of the potential to achieve at least control of flow, if not enhanced flow, of the SJR through the DWSC will need to be conducted during the initial phase of the TMDL implementation.

An important issue that will need to be addressed during the Phase I TMDL effort is the potential secondary impacts of the programs that could be developed to control the low-DO problem in the DWSC. Any study that is conducted to develop information needed to evaluate a potential control program of the DO WQO violations in the DWSC should include studies to determine if the control program could lead to other adverse impacts to the beneficial uses of the waters in the SJR, DWSC and/or South and Central Delta. This information will be needed as part of developing the California Environmental Quality Act (CEQA) evaluation of potential control programs.

The initial phase of the TMDL implementation will likely require about five years. At that time, with continued substantial support of ongoing studies specifically directed toward evaluating the implementation of control programs, it should be possible to formulate a low-DO management program for the DWSC which would represent the final phase of the TMDL.

Phase I TMDL Monitoring

This report provides information on various aspects of the monitoring programs that will need to be conducted as part of the Phase I TMDL. Monitoring programs are needed in the SJR DWSC watershed, the DWSC and the South and Central Delta. The justification for comprehensive Phase I monitoring efforts in these areas is provided, along with the characteristics of the monitoring programs.

A monitoring program proposal, developed by some upstream watershed stakeholders, has recently been submitted to CALFED to develop information needed as part of the Phase I TMDL associated with defining the sources and transformations of oxygen-demanding materials in the SJR DWSC watershed. This proposed monitoring program does not adequately consider the existing information on the characteristics of the monitoring program needed to provide the information on the sources and potential approaches for control and benefits of control of upstream oxygen demand sources on reduced loads within the DWSC. The monitoring proposal submitted to CALFED by the SJR upstream stakeholders contains, as one of its tasks, studies on the transport and transformation of oxygen demand constituents between Mossdale and the DWSC. This is an important study area that should be supported.

The proposal also contains several tasks, such as laboratory studies on algal growth dynamics and an attempt to use isotopes to try to determine the origin of the oxygen demand, that should not be supported. These tasks will not provide reliable or useful information for the Phase I TMDL effort. The modeling task contained in this proposal is a duplication of the HydroQual modeling project that has already been approved by CALFED. The CALFED proposal should be the focus of the modeling effort.

The task devoted to monitoring of the SJR and its tributaries needs to be modified to better support the modeling effort. Additional monitoring parameters such as zooplankton and other grazing of algae should be added. One of the most important changes needed in the monitoring task is an increased frequency of monitoring to weekly, rather than every two weeks during the summer and fall and monthly in the winter. The proposal monitoring frequency will be not be adequate to provide needed information for the Phase I TMDL.

The proposal is significantly deficient in addressing one of the most important areas that needs attention during the Phase I TMDL – i.e., defining the origin and potential for control of the algal "seed" that develops in the Mud and Salt Slough and SJR upstream of Lander Avenue watersheds that leads to the high algal BOD that develops in these waterbodies' watersheds. Information in this area will be needed to reliably define the potential to economically control some of the oxygen demand loads from these watersheds. Without this information the TMDL Phase II decisions on the control of oxygen demand in these watersheds will have to be made without an adequate information base. The funds that are currently proposed for the laboratory algal growth and isotope studies and the proposed duplication of the HydroQual modeling should be shifted to support the increased monitoring frequency and the upstream oxygen demand source definition and control studies.

Peer Review

An external peer review of the CALFED-supported studies was conducted by CALFED in June 2002. This report contains information pertinent to the organization and the results of the external peer review that was conducted in June 2002. Also G. Fred Lee, as the CALFED Directed Action project PI, provides responses to the issues raised by the peer review panel.

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Acronyms and Definitions

Biochemical Oxygen Demand (BOD) The dissolved oxygen consumed by biochemical processes associated with the bacterial and other organism respiratory conversion of organic matter to carbon dioxide, water and/or other forms of organics. It also includes the bacterial conversion (nitrification) of ammonia to nitrite and nitrate. BOD is estimated based on laboratory incubation of water samples where dissolved oxygen depletion is typically measured at 5 (BOD_5) or 10 (BOD_{10}) days. The ultimate BOD (BOD_u) is estimated based on long-term (20-30 day) laboratory BOD tests.

Deep Water Ship Channel (DWSC) The San Joaquin River has been dredged through the Delta to the Port of Stockton to a depth of 35 feet. The dredged channel is called the Deep Water Ship Channel or Stockton Deep Water Ship Channel. The primary area of the DWSC of concern with respect to low dissolved oxygen is the reach of the channel between the Port of Stockton and Columbia Cut/Disappointment Slough. Normally, the greatest concern for low DO occurs between the Port of Stockton and Turner Cut.

Organic Detritus (Detritus) The remains of plants and animals and their particulate waste products. This detritus can be a source of particulate oxygen demand and SOD.

Oxygen Demand The oxygen demand of a water is the sum of all of the processes that consume dissolved oxygen. It is composed of the organic (carbonaceous) BOD, nitrogenous BOD due to nitrification of ammonia, the death and decay of algae, and the oxygen consumed by biotic and abiotic reactions associated with bedded and suspended sediment particles.

SJR DWSC Critical Reach The reach of the SJR DWSC where the DO falls below the CVRWQCB WQO. This reach is normally the first seven miles below the Port of Stockton.

ac	acre
ac-ft	acre-feet
BOD	biochemical oxygen demand
BOD_5	five-day BOD
BOD_{10}	ten-day BOD
BOD_u	BOD ultimate (~30-Day)
BPTCP	Bay Protection & Toxic Cleanup Plan
CBOD	carbonaceous BOD
CEQA	California Environmental Quality Act
cf	cubic feet
cfs	cubic feet per second
CO_2	carbon dioxide
Corps/COE	US Army Corps of Engineers
CVP	Central Valley Project (Federal Project)
CVRWQCB	California Regional Water Quality Control Board, Central Valley Region (RWQCB)
CWA	Clean Water Act
DFG	California Department of Fish and Game

Acronyms (continued)

DO	dissolved oxygen
DOC	dissolved organic carbon
DWR	California Department of Water Resources
DWSC	Deep Water Ship Channel
EC	electrical conductivity
ft	feet
ft/sec	feet per second
g	grams
H_2O	water
lb/day	pounds per day
m^2	square meters
mgd	million gallons per day
mg/L	milligrams per liter
mi	miles
µg/L	micrograms per liter
µmhos/cm	micromhos (reciprocal ohms) per centimeter
µS/cm	microsiemens per centimeter
m/sec	meters per second
msl	mean sea level
N	nitrogen
NBOD	nitrogenous BOD
NEPA	National Environmental Protection Act
NH_3	un-ionized ammonia or ammonia, which is the sum of NH_3 plus NH_4^+
nitrate-N	nitrate-nitrogen
NO_2^-	nitrite
NO_3^-	nitrate
NPDES	National Pollutant Discharge Elimination System
O_2	oxygen
Org N	organic nitrogen
P	phosphorus
RRI	Rough and Ready Island (location of DWR continuous monitoring station)
RWCF	Regional Wastewater Control Facility (City of Stockton)
RWQCB	Regional Water Quality Control Board, Central Valley Region
SJR	San Joaquin River
SJR TAC	San Joaquin River DO TMDL Technical Advisory Committee
SOD	sediment oxygen demand
sq mi	square miles
SWP	State Water Project (State Project)
SWRCB	State Water Resources Control Board
TSS	total suspended solids
TKN	total Kjeldahl nitrogen = NH_3 plus OrgN
TMDL	total maximum daily load
TOC	total organic carbon

Acronyms (continued)

USBR	US Bureau of Reclamation
UVM	ultrasound velocity meter
USGS	US Geological Survey
VAMP	Vernalis Adaptive Management Plan
VSS	volatile suspended solids
WQO	water quality objective

Conversion Factors

To Convert	Multiply By	To Obtain
acres	4.35×10^4	sq. ft.
acre-feet	3.26×10^5	gallons
cu ft/sec	4.49×10^2	gallons/min
feet	3.048×10^1	cm
inches	2.54	cm
miles (statute)	5.28×10^3	ft
miles (statute)	1.609	km
pounds	4.54×10^2	grams
mgd	1.55	cfs

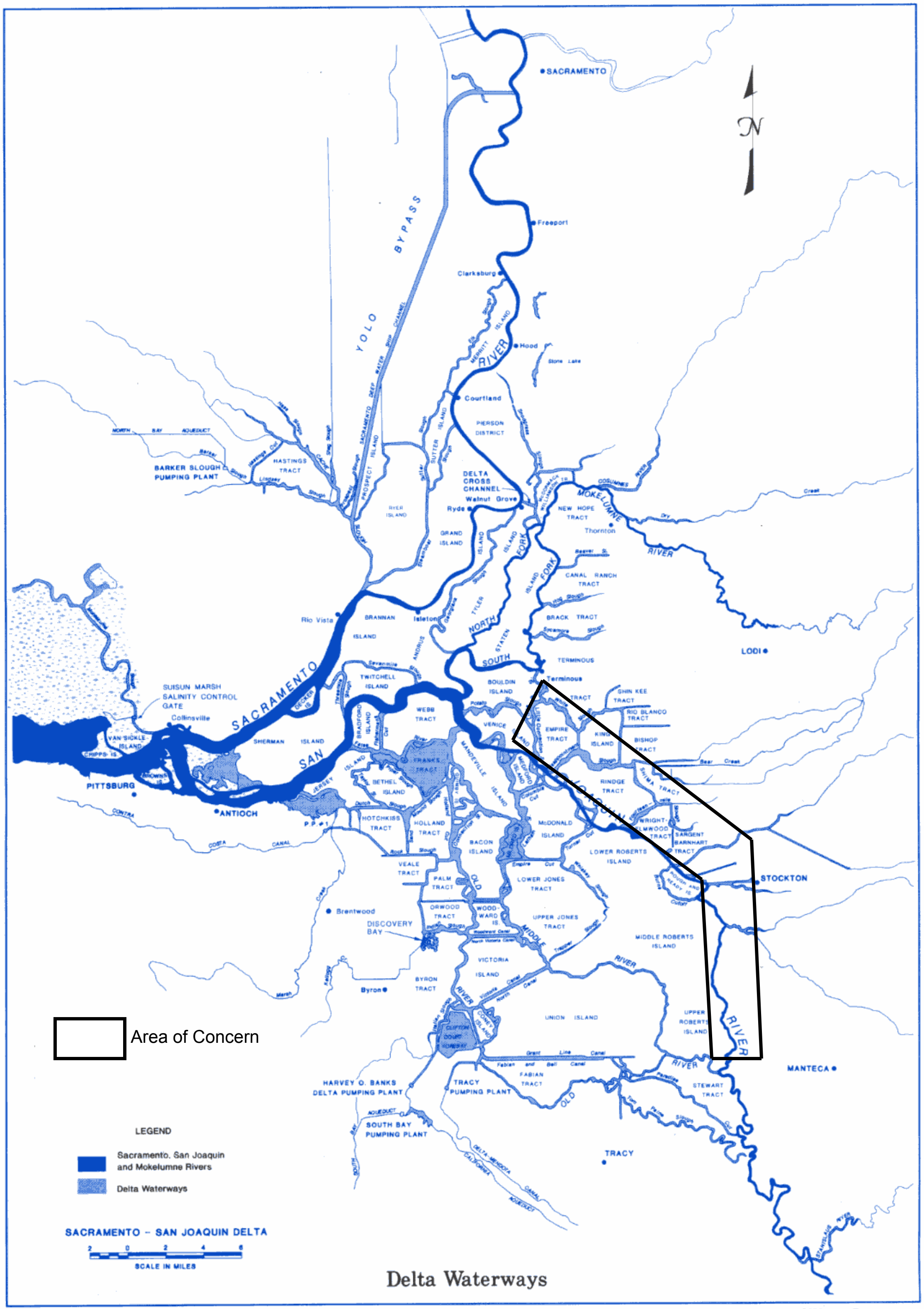
Synopsis of the
Current Understanding of the Low-DO Problem in the
SJR Deep Water Ship Channel

The San Joaquin River, through the Sacramento/San Joaquin River Delta (see Figure 1), has been dredged to a depth of 35 feet in order to enable ocean-going ships to transport bulk cargo to and from the Port of Stockton at Stockton, California. This dredging significantly changed the hydraulic characteristics of the San Joaquin River (SJR). Upstream of the Port of Stockton, the San Joaquin River (undredged) is about eight to ten feet deep and does not experience DO depletion below the water quality standard (objective) (WQO). Beginning at the Port, through the Delta, a 35-foot dredged navigation channel greatly increases the hydraulic residence time of water and its associated oxygen-demanding materials. This leads to a significantly reduced oxygen demand assimilative capacity, which in turn leads to DO depletions below the water quality objective for protection of fish and aquatic life for a distance of about seven miles from the Port to Turner Cut (see Figures 2 and 3). Further, DO depletion below 6 mg/L potentially inhibits the fall run of Chinook salmon through the Delta via the SJR DWSC to their home waters in the SJR watershed. The DO violations of the water quality objective in the DWSC led to the State Water Resources Control Board (SWRCB, 1999a) designating the DWSC between the Port and Turner Cut as a Clean Water Act (CWA) section 303(d) “impaired” waterbody, which in turn requires the development of a total maximum daily load (TMDL) to control the violations of the DO water quality objective. Bain, *et al.* (1968) discussed the low-DO problem in the San Joaquin River near Stockton. Lehman, *et al.* (2001) reported that low-DO conditions have occurred in the first 10 miles or so of the SJR DWSC near Stockton for at least the past 30 years. Jones & Stokes (1998) presented a comprehensive review of the low-DO problem in the DWSC.

The Central Valley Regional Water Quality Control Board (CVRWQCB) (SWRCB, 1999b), as part of developing an approach for controlling the low-DO problems in the DWSC, provided the opportunity for the stakeholders (dischargers of oxygen demand constituents, entities whose activities influence the oxygen demand assimilative capacity of the DWSC, environmental groups and others) to develop an approach which would include an allocation of responsibility for solving the low-DO problem. The stakeholders organized the SJR DO TMDL Steering Committee. The Steering Committee organized a Technical Advisory Committee (TAC).

In order to formulate a technically valid, cost-effective water quality management plan to control dissolved oxygen concentrations below the water quality objective that occur in the San Joaquin River Deep Water Ship Channel (DWSC), the TAC organized multi-year studies of the sources of oxygen-demanding materials and the factors influencing how oxygen-demanding materials added to the DWSC impact dissolved oxygen concentrations below the water quality objective in the DWSC. With CALFED and other support, approximately $3.5 million has been spent over a three-year period determining the constituents that are added to the DWSC that are responsible for DO depletion below the water quality objective and the factors that influence the oxygen demand assimilative capacity of the DWSC and thereby control the amount of allowable oxygen

Figure 1
Sacramento-San Joaquin River Delta



Sacramento–San Joaquin Delta Atlas *Department of Water Resources*

Figure 2
Map of the Lower SJR and DWSC Study Area

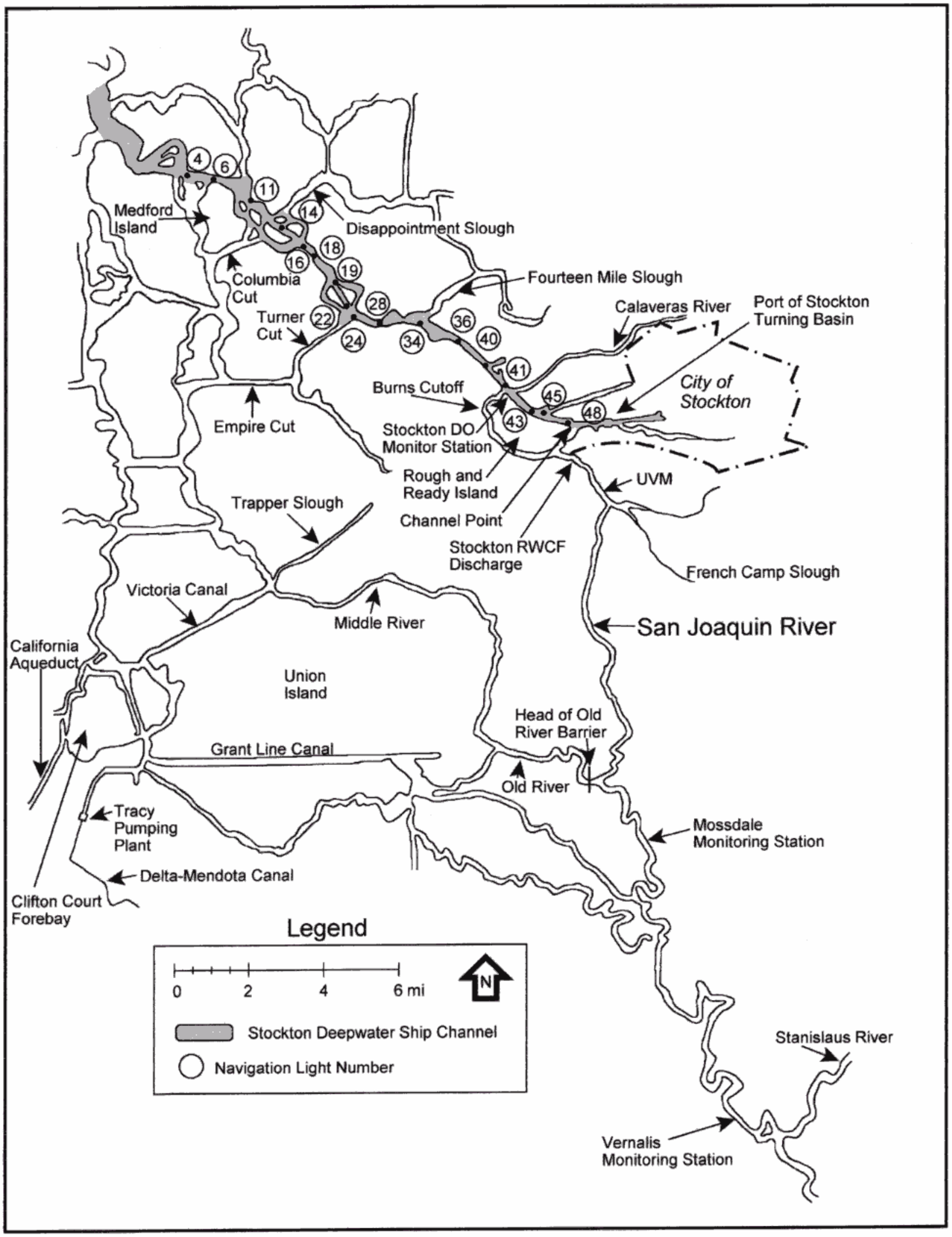
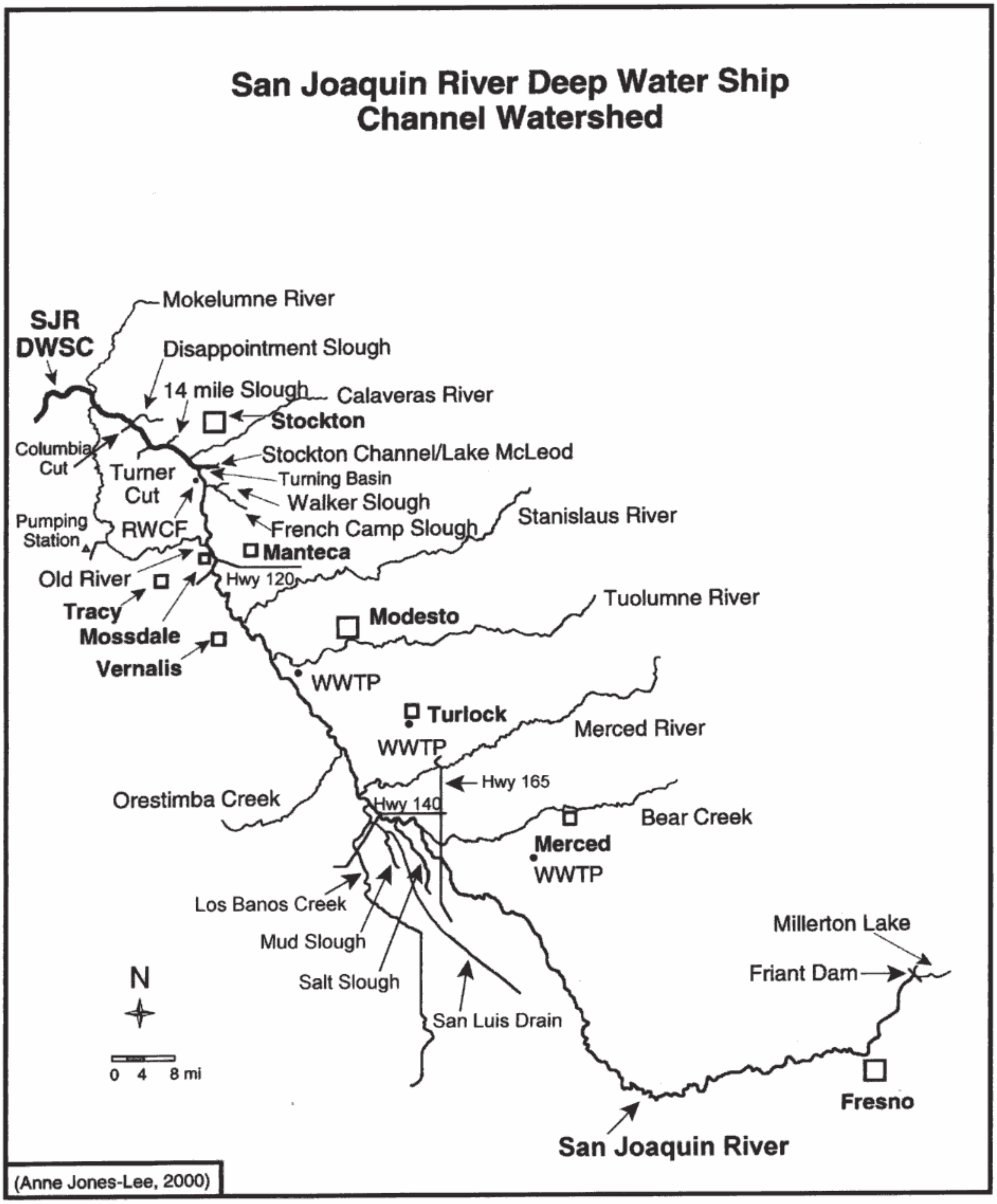


Figure 3
San Joaquin River Deep Water Ship Channel Watershed



demand that can be added to the DWSC without causing DO depletions below the WQO. This Synthesis Report summarizes the current understanding of oxygen demand sources and loads to the DWSC and their impacts on DWSC DO concentrations. It also provides guidance to the literature, which contains additional information on these issues.

The technical studies had two primary purposes. One was to determine the assimilative capacity of the DWSC for oxygen-demanding materials of various types and under the various conditions that can influence the oxygen demand load assimilative capacity of the DWSC. The other was to provide a technical base of information upon which the Steering Committee and the CVRWQCB could potentially assign a technical allocation of responsibility for control of oxygen-demanding substances, and/or altered flow, as well as funding of an aeration system to control oxygen depletion below the water quality objective. While it is understood that the responsibility for solving water quality problems of this type may not necessarily be allocated based on strictly technical reasons, such as the relative oxygen demand sources/loads of the constituents responsible, this is an appropriate point to start the allocation of responsibility process.

Organization of the Studies

Appendix A presents a discussion of the evolution and organization of the studies that have been conducted during 1999, 2000 and 2001 to define oxygen demand constituents, their sources, impacts and factors influencing their impacts. As discussed, because of the short timeline for development of a TMDL and its allocation among stakeholders, there have been significant problems in conducting these studies within the timeframe allowed.

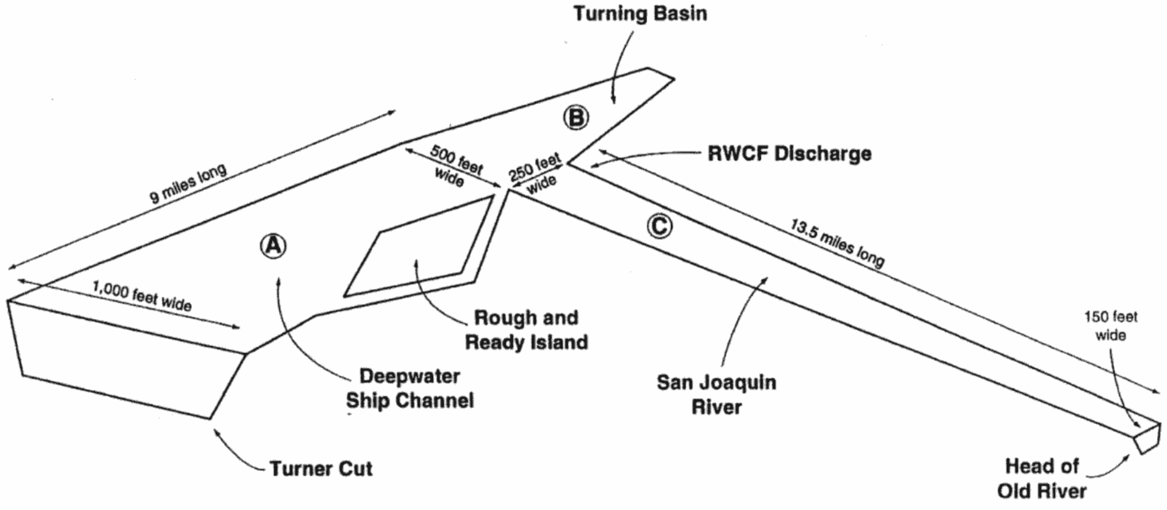
Physical and Hydrological Characteristics of the SJR and DWSC

Jones & Stokes (1998) provided a diagrammatic representation of the lower San Joaquin River between the Head of Old River and Turner Cut associated with the DWSC. This diagram is presented as Figure 4. At the Head of Old River, the SJR is about 150 feet wide. At the point where the SJR enters the DWSC, it is about 250 feet wide. The average depth of the River through this reach is about 8 to 10 feet. The volume of the River in this reach is about 2,500 acre-feet.

As presented by Jones & Stokes (1998), the reach of the DWSC of concern with respect to low dissolved oxygen starts at the point where the SJR enters the DWSC at Channel Point (see Figure 2). It extends about seven miles to Turner Cut. The depth of the River in the DWSC increases to a navigation depth of 35 feet. There is a section near Channel Point along Rough and Ready Island where the River is dredged to 40 feet. The additional five feet below the navigation depth is used as a sediment trap to collect part of the sediment loads that come into the DWSC from the SJR. According to Jones & Stokes (1998), the volume of the DWSC between Channel Point and Turner Cut is about 15,000 acre-feet. Over the past 30+ years, low DO concentrations have been encountered in the DWSC to Turner Cut, and occasionally, below Turner Cut. However, as discussed below, low DO concentrations have not been encountered below Disappointment Slough/Columbia Cut (see Figure 2).

Figure 4

Characteristics of the Deep Water Ship Channel (DWSC)



from Jones & Stokes (1998)

As shown in Figure 4, associated with the DWSC is the (ship) Turning Basin. While the Turning Basin is part of the DWSC, it has no significant tributary input, and, although tidal, it is treated as an appendage to the DWSC, since the main flow path for the SJR is down the former SJR channel from Channel Point to Disappointment Slough/Columbia Cut. Low dissolved oxygen concentrations occur in the Turning Basin. While there is limited tributary flow into the Turning Basin, there is significant tidal mixing of waters within, upstream and downstream of the Turning Basin.

The flow of the SJR is gaged at Vernalis. Downstream of Vernalis part of the SJR at Vernalis flow is split into Old River when the Head of Old River barrier is not in place (see Figure 2). The remainder of the SJR at Vernalis flow, except for irrigation diversions and discharges, passes through the DWSC. Lee and Jones-Lee (2000a) provided additional information on the hydrology of the SJR relative to flows into Old River versus through the DWSC.

Appendix B presents the daily flows of the SJR through the DWSC during the study period 1999 through 2002. The 1999 through 2001 flows were estimated by R. Brown (pers. comm., 2002) of Jones & Stokes based on the USGS UVM flow measurements which are made just upstream of where the SJR enters the DWSC, and by C. Ruhl of the USGS for the 2002-2003 flow data. Brown (2001) provides background information on the approach used to estimate SJR flows through the DWSC when the UVM was not operating. The SJR flows through the DWSC are highly regulated based on upstream reservoir releases and agricultural as well as municipal diversions. The federal Central Valley Project (CVP) and State Water Project (SWP) export through the Delta-Mendota Canal and California Aqueduct, respectively, up to about 11,000 cfs of South Delta water to Central and Southern California. The export pumps artificially change the flows in the South Delta which results in more of the San Joaquin River going through Old River. At Old River the State and Federal Projects can, depending on the barriers that are located in the South Delta channels (see Figure 5), essentially take all of the water in the SJR at Vernalis into Old River for diversion to Central and Southern California. As discussed below, the State and Federal Project diversions of SJR water at Old River, as well as upstream diversions and reservoir releases, have a highly significant impact on the amount of flow through the DWSC. As shown in Appendix B, during the study period 1999-2001, the SJR flow through the DWSC during the summer and fall typically ranged from a few hundred cfs to about 2,500 cfs, with many of the flows on the order of 700 to 1,200 cfs.

Table 1 provides information on the distances from Channel Point (where the SJR enters the DWSC) to various locations upstream in the SJR and downstream in the DWSC. Of particular concern to the studies reported herein is the location of the SJR Mossdale sampling station, which is about 14 miles upstream from Channel Point; Old River, which is located about 12 miles upstream; and the city of Stockton's wastewater discharge, which occurs about one mile upstream. Turner Cut is located about seven miles downstream from Channel Point, and Columbia Cut, about 10 miles downstream from Channel Point. The critical reach of the DWSC with respect to DO depletion is the seven-mile reach between Channel Point and Turner Cut.

The SJR below Vernalis, but above Mossdale and the DWSC, is a freshwater tidal system with about three-foot tides at Channel Point. Table 1 presents the estimated tidal excursions (range of upstream to downstream movement with each tidal cycle) developed by Brown (2002a) in the upper part of the DWSC near Rough and Ready Island and at Turner Cut. As shown, near Rough and Ready Island the tidal excursion is about one mile, and it is about 2.5 miles at Turner Cut. In the San Joaquin River just upstream of Channel Point the tidal excursion is estimated to be about 2.8 miles. This means that the city of Stockton wastewater effluent is not carried upstream to Old River so long as there is net downstream flow of the SJR through the DWSC.

Litton (2003) and Brown (2002a) have reported that at the maximum tidal flow of about 4,000 cfs, the DWSC velocity is about 0.2 to 0.25 ft/sec. The tidal action within the DWSC and the SJR upstream to Mossdale, plays an important role in mixing of the River and DWSC. Brown (2002a) reported that the SJR maximum tidal-induced velocity between Mossdale and Channel Point is on the order of 1 ft/sec.

Based on the geometry of the SJR upstream of Channel Point and within various reaches of the DWSC, Brown (2002a) estimated the hydraulic travel time in each reach as a function of SJR flow through the DWSC. These estimates are presented in Figures 6 and 7. These travel times are updated from those presented by Lee and Jones-Lee (2000a). As shown in Figure 6, the hydraulic travel times between Mossdale and Channel Point are on the order of one to two days,

Figure 5. South Delta Area and Facilities

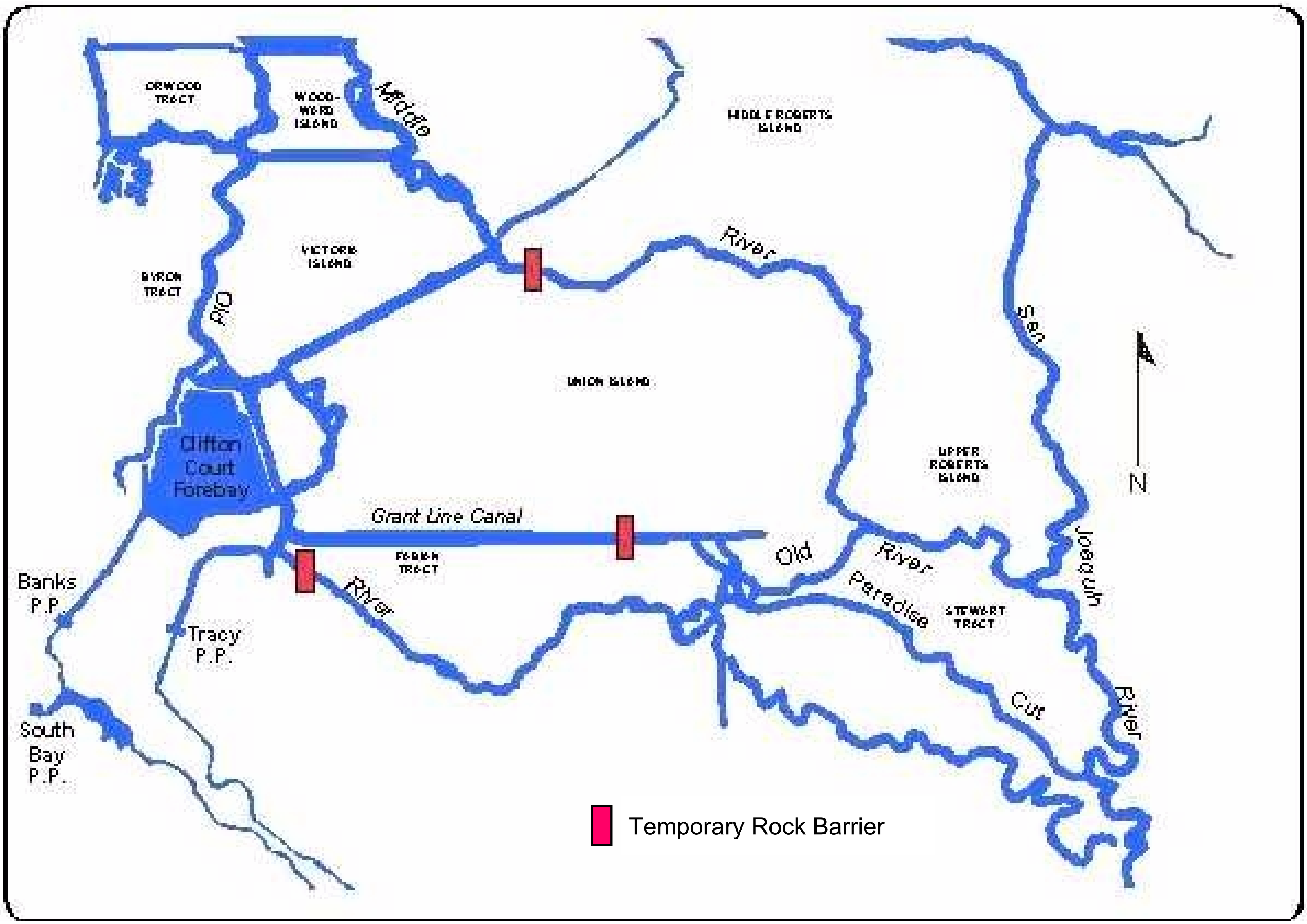


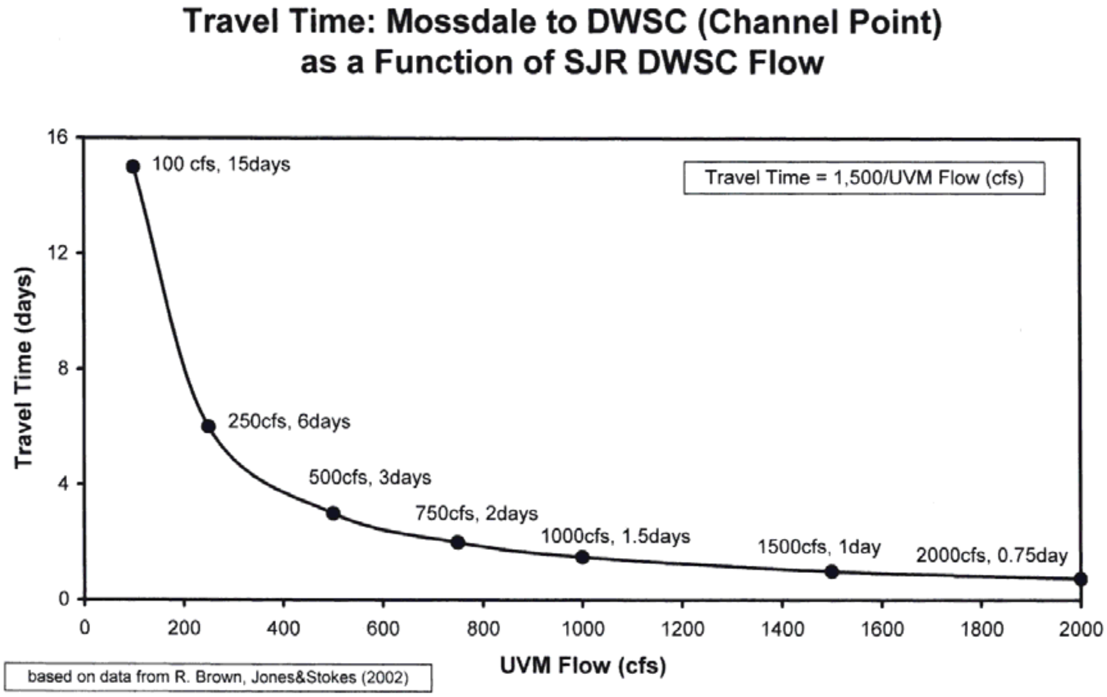
Table 1
Distances from DWSC Channel Point

DWR Station No.	City of Stockton Station	Navigation Lt. Number	Location	Distance (miles)	Tidal Excursion* (miles)
--	--	--	Mossdale	-14.4	--
--	R0A	--	Old River	-12	--
--	R0B	--	--	-8	--
--	R1	--	--	-7	--
--	--	--	French Camp Slough	-2.6	--
--	R2	--	--	-1.5	--
--	--	--	Stockton Wastewater Outfall	-0.9	2.8
14	--	--	Turning Basin	+1.1	--
--	--	--	Channel Point	0	--
13	R3	48	--	0.2	--
--	R4	45	--	1.1	1.25
12		43	--	1.4	--
--	--	--	DWR Rough & Ready Monitoring Station	1.8	--
			Calaveras River	2.0	--
11	R5	41/42	--	2.3	--
10	--	39/40	--	3.3	--
--	R6	35/36	--	4.1	--
9	--	33/34	--	5.3	--
8	--	27/28	--	6.4	--
--	R7	23/24	Turner Cut	7.1	2 miles up 3 miles down
7	--	19/20	--	8.2	--
6	R8	17/18	--	9.2	--
5	--	13/14	Columbia Cut	10.4	--
4	--	11/12	--	11.5	--
3	--	5/6	--	12.7	--
2	--	3/4	--	13.5	--
1	--	57	Prisoner's Point	14.9	--

Based on NOAA Sacramento River and San Joaquin River Nautical Chart 18661 and information provided by R. Brown (Jones & Stokes, 2002) and Casey Ralston, DWR (pers. comm., 2002)

* Information provided by R. Brown (Jones & Stokes, 2002)

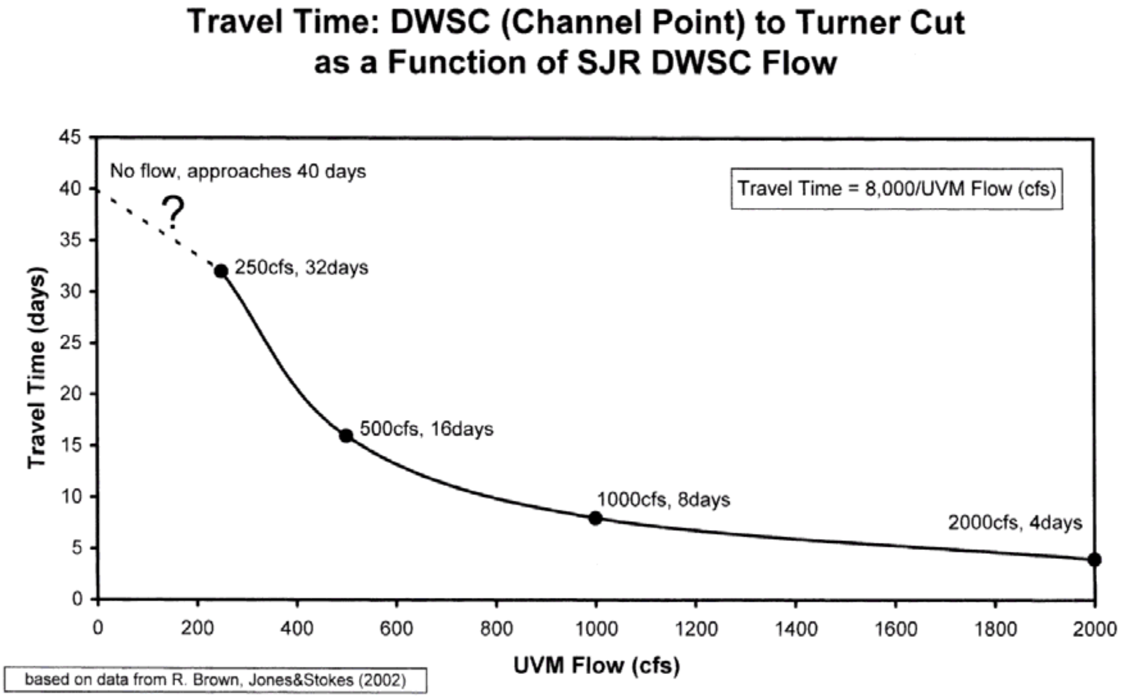
Figure 6



Travel Time: Mossdale to DWSC (Channel Point) as a Function of SJR DWSC Flow

based on data from R. Brown, Jones&Stokes (2002)

Figure 7



Travel Time: DWSC (Channel Point) to Turner Cut as a Function of SJR DWSC Flow

based on data from R. Brown, Jones&Stokes (2002) provided that the flow of the SJR through the DWSC is in excess of about 750 cfs. At flows of 100 or so cfs, the hydraulic travel times can be on the order of 10 to 15 days.

From the information provided in Figure 7, for the SJR DWSC flows typically encountered during the study period, which ranged from about 700 to 2,000 cfs, the hydraulic travel times between Channel Point and Turner Cut are from about 12 days to 4 days. As discussed in a subsequent section, this range of hydraulic travel times is important in determining the oxygen depletion that occurs in the DWSC for a particular oxygen demand load to the DWSC.

The above discussion of hydraulic travel time or residence time refers to the movement of water or dissolved substances through the SJR and/or the DWSC. As discussed in a subsequent section, the travel time for particulate substances, such as algae and detritus, can be somewhat longer than the hydraulic residence time. Litton (2003) has estimated that particles of algae/detritus are transported through the DWSC in the near-bottom waters a factor of two to three times slower than the hydraulic residence time.

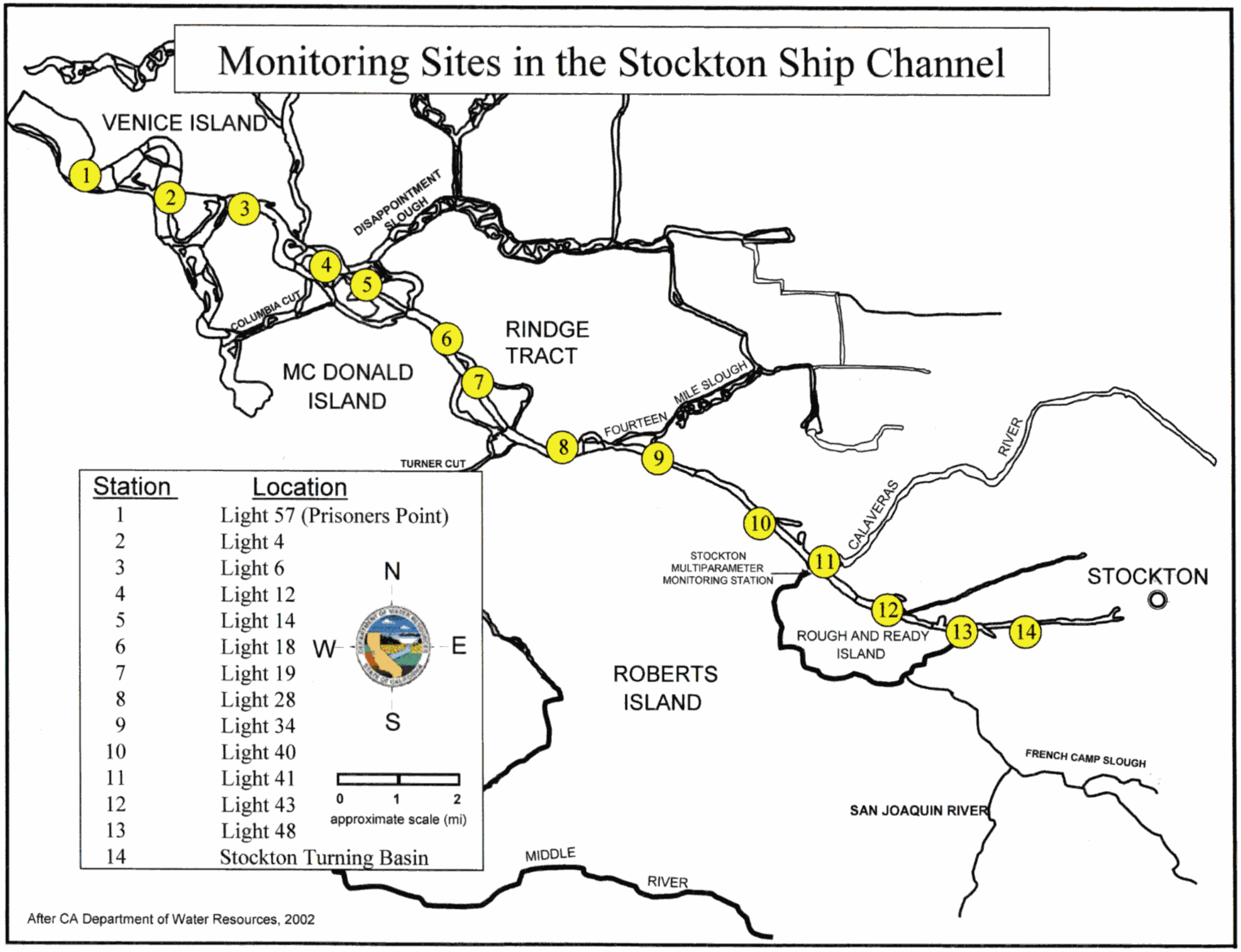
DO Depletion in the DWSC

The California Department of Water Resources (DWR) Bay-Delta Monitoring and Analysis Section has been conducting monitoring of dissolved oxygen at selected locations in the DWSC at the surface and bottom about every two weeks during the late summer and fall since 1968 (Hayes and Lee, 2000). This program is part of the DWR Operations and Maintenance DO Channel Program. This monitoring is referred to herein as the "Hayes cruise data." The DWR monitoring stations are shown in Figure 8. The data collected on these monitoring runs for the period 1995 through 2002 are presented in Appendix C. According to Hayes (pers. comm., 2003), the cruises are conducted so that the sampling at each of the stations is designed to coincide with low water slack tide at that station. Recently Ralston and Hayes (2002) have reviewed the fall DO conditions in the Stockton Deep Water Ship Channel for 2000.

Figure C-1 in Appendix C also shows the applicable water quality objective for the DWSC. The objective for the period December 1 through August 31 is 5 mg/L at any time and location. For the period September 1 through November 30, the objective is 6 mg/L at any time and location between Channel Point and Turner Cut. As discussed by Gowdy and Foe (2002), this difference is based on a State Water Resources Control Board decision designed to prevent DO concentrations less than 6 mg/L from inhibiting the fall run of Chinook salmon through the DWSC to their home waters in the eastside rivers (Stanislaus, Merced and Tuolumne Rivers).

The Appendix C Hayes cruise data have been reduced to a multi-page figure (Figure 9) which summarizes the DO depletion below the water quality objective for selected locations in the DWSC. The Hayes cruise data provide information on the occurrence, frequency and location of DO depletions below the water quality objective for the period 1995 through 2002 in the late summer and fall for surface and bottom waters. Figure 9 presents shaded areas showing the duration and magnitude of DO concentrations below the WQO for nine stations from downstream to upstream. The duration of each incidence is interpolated between the sampling

Figure 8



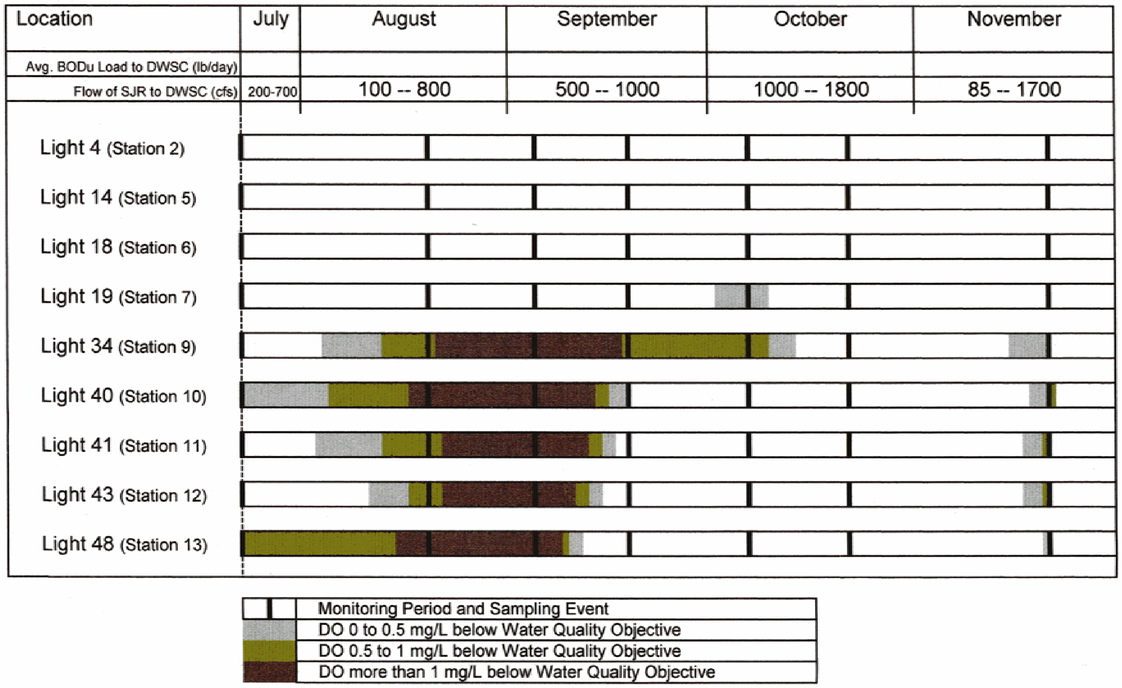
Monitoring Sites in the Stockton Ship Channel

Station	Location
1	Light 57 (Prisoners Point)
2	Light 4
3	Light 6
4	Light 12
5	Light 14
6	Light 18
7	Light 19
8	Light 28
9	Light 34
10	Light 40
11	Light 41
12	Light 43
13	Light 48
14	Stockton Turning Basin

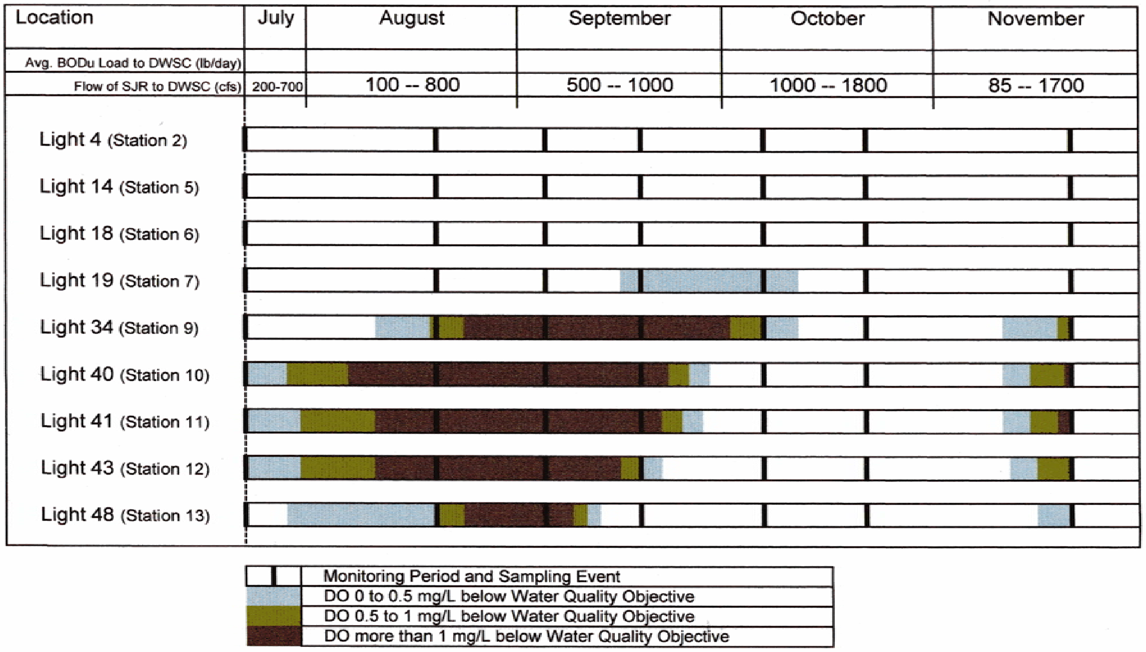
After CA Department of Water Resources, 2002

Figure 9

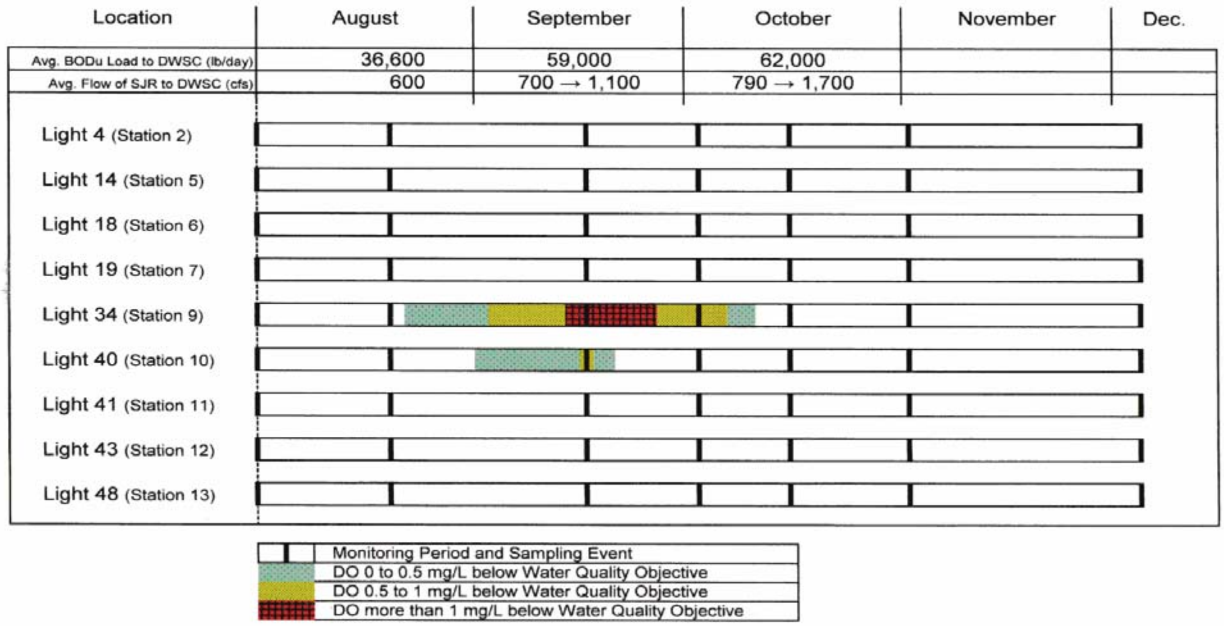
Incidence of Dissolved Oxygen below WQO
Surface Water 2002



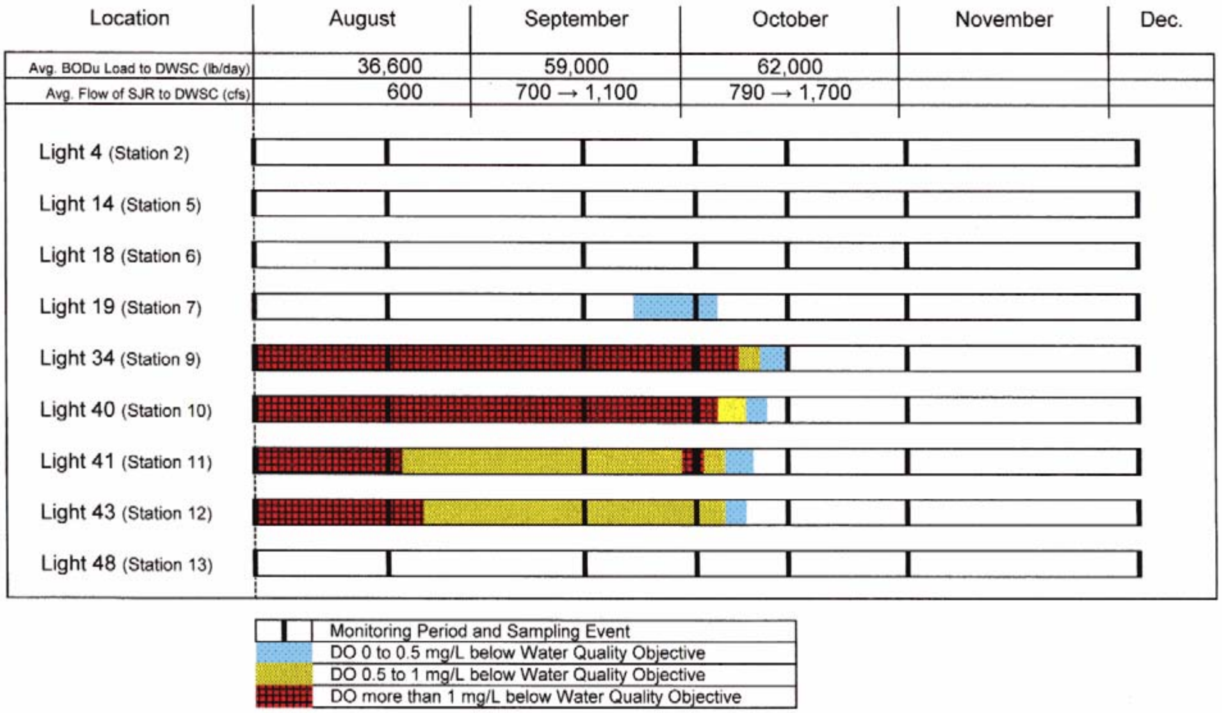
Incidence of Dissolved Oxygen below WQO
Bottom Water 2002



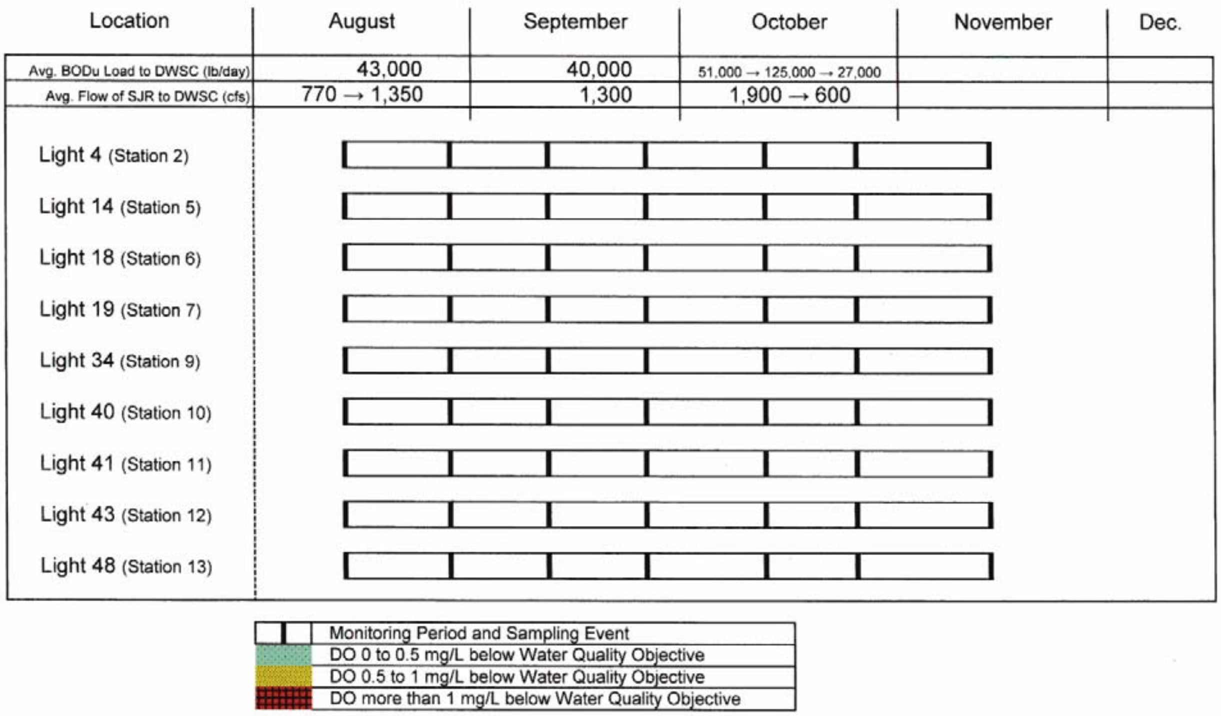
Incidence of Dissolved Oxygen below WQO
Surface Water 2001



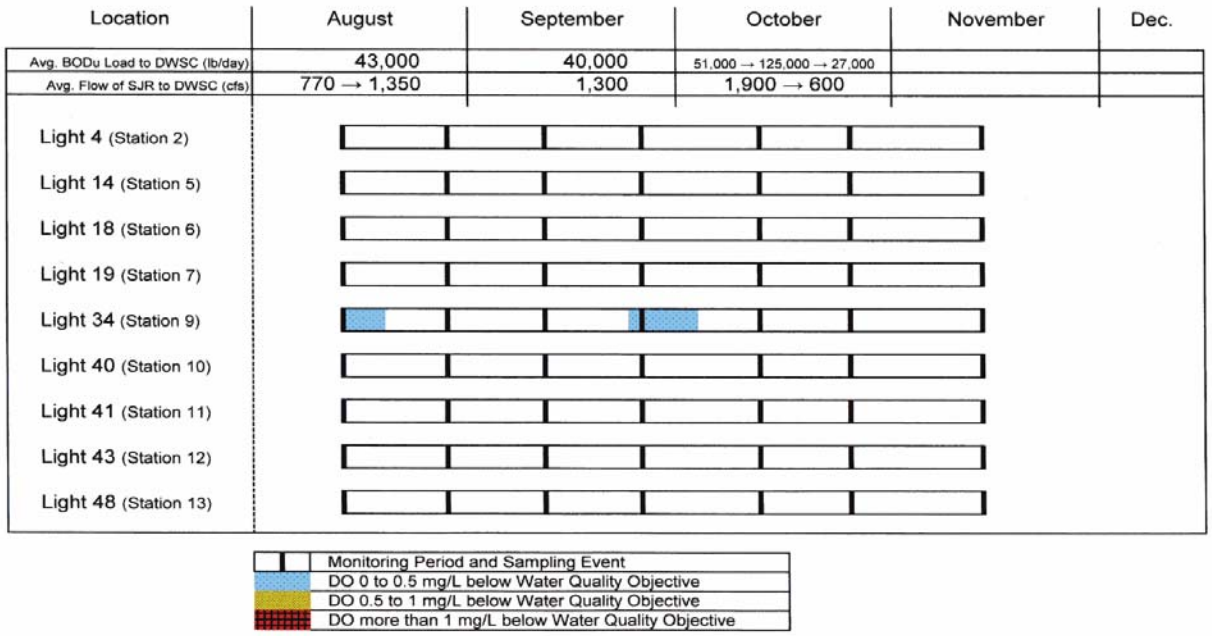
Incidence of Dissolved Oxygen below WQO
Bottom Water 2001

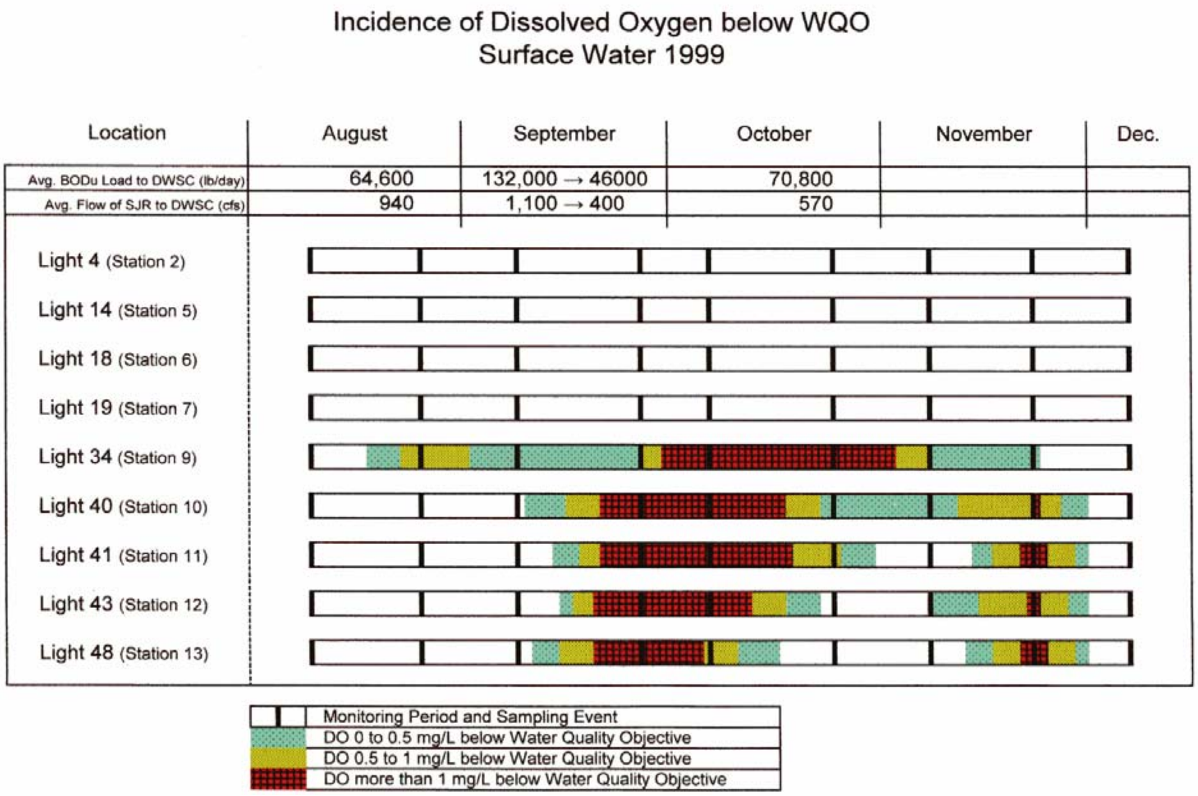


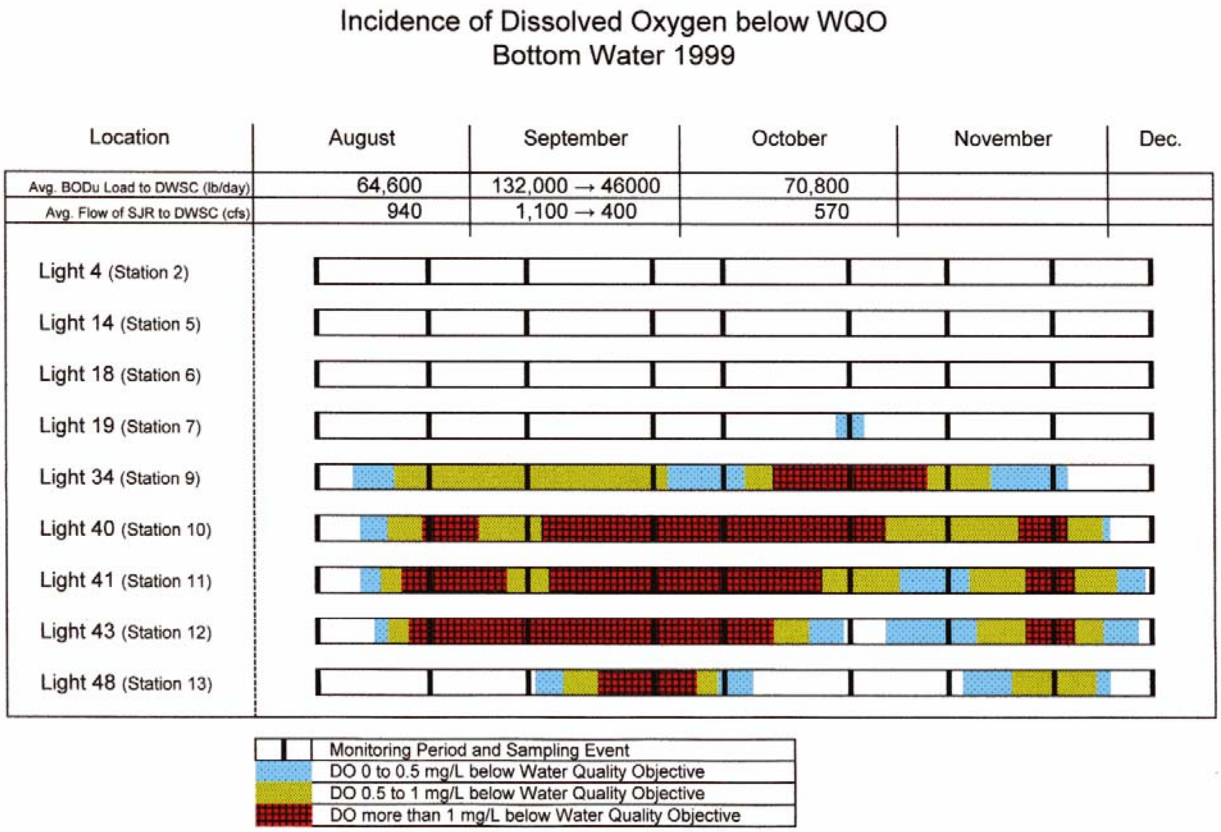
Incidence of Dissolved Oxygen below WQO
Surface Water 2000



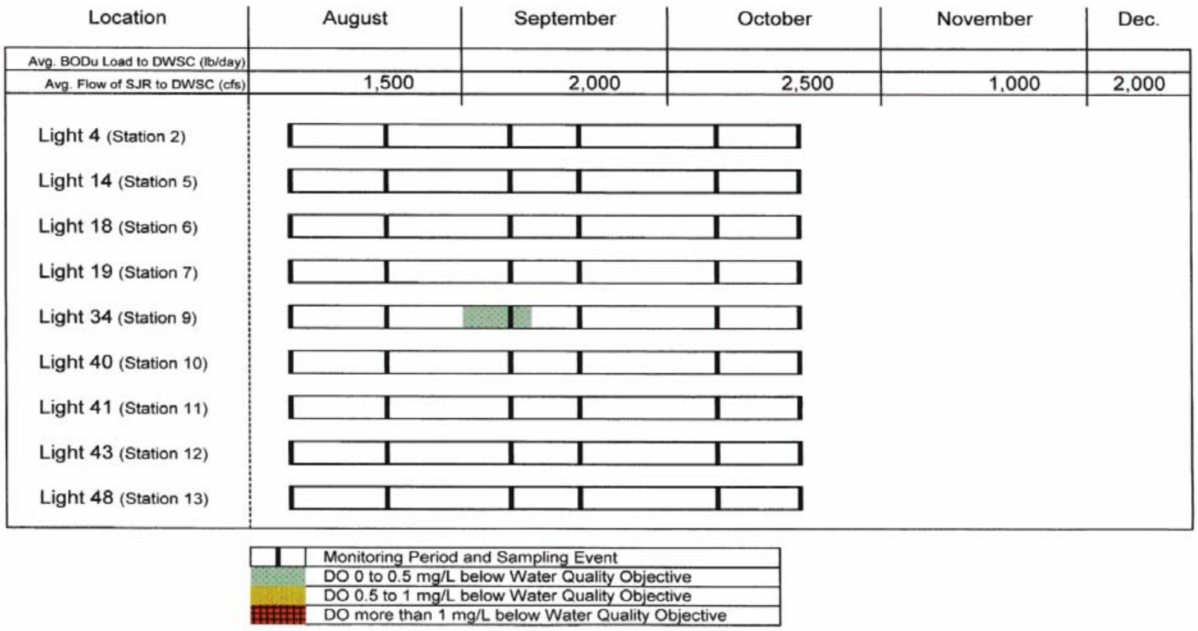
Incidence of Dissolved Oxygen below WQO
Bottom Water 2000



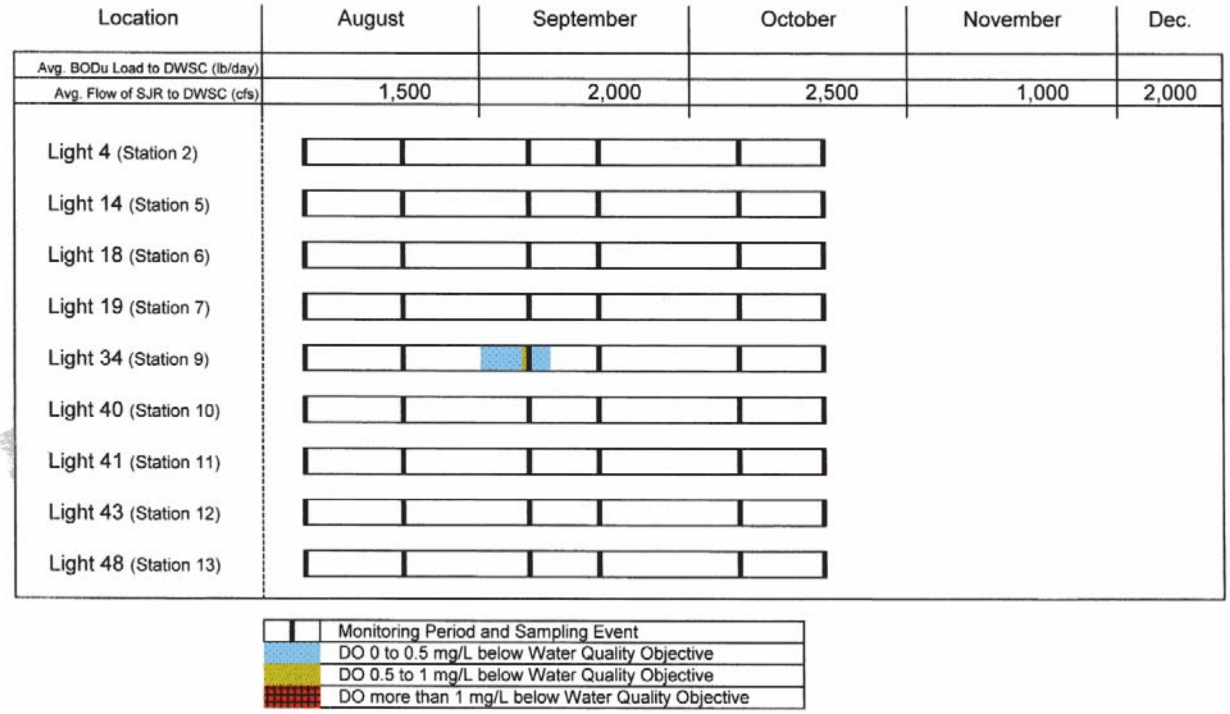

Incidence of Dissolved Oxygen below WQO
Surface Water 1999

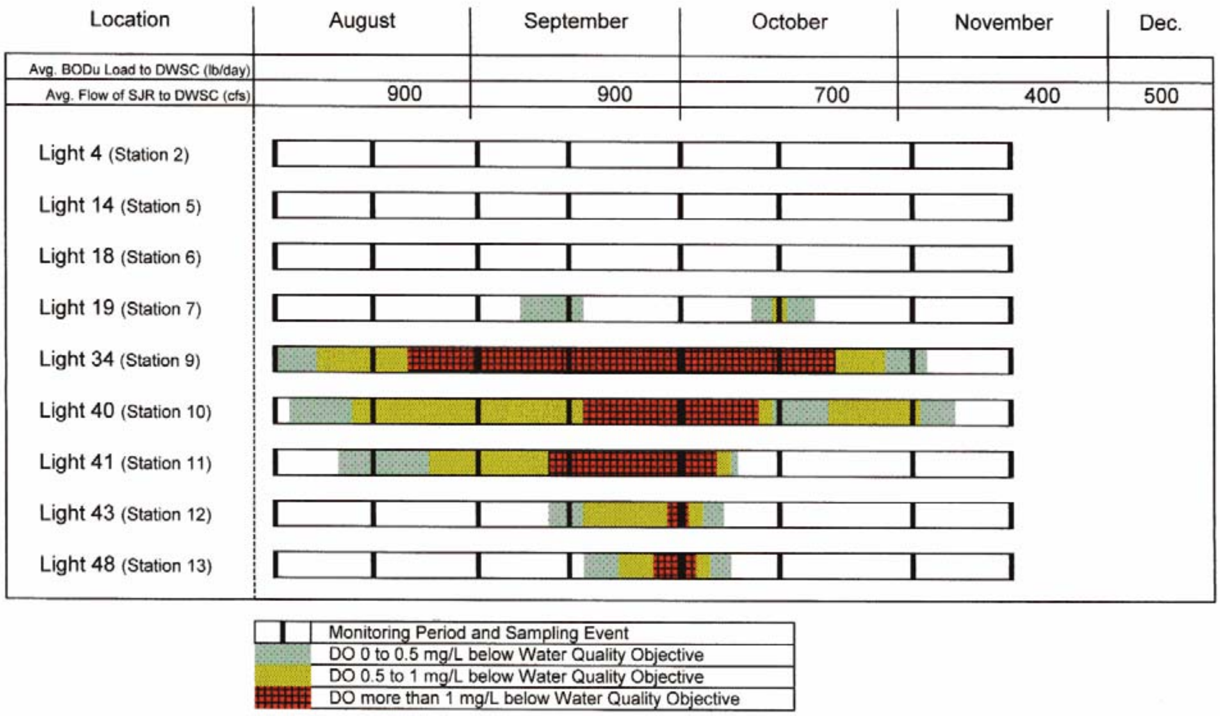

Incidence of Dissolved Oxygen below WQO
Bottom Water 1999

Incidence of Dissolved Oxygen below WQO
Surface Water 1998

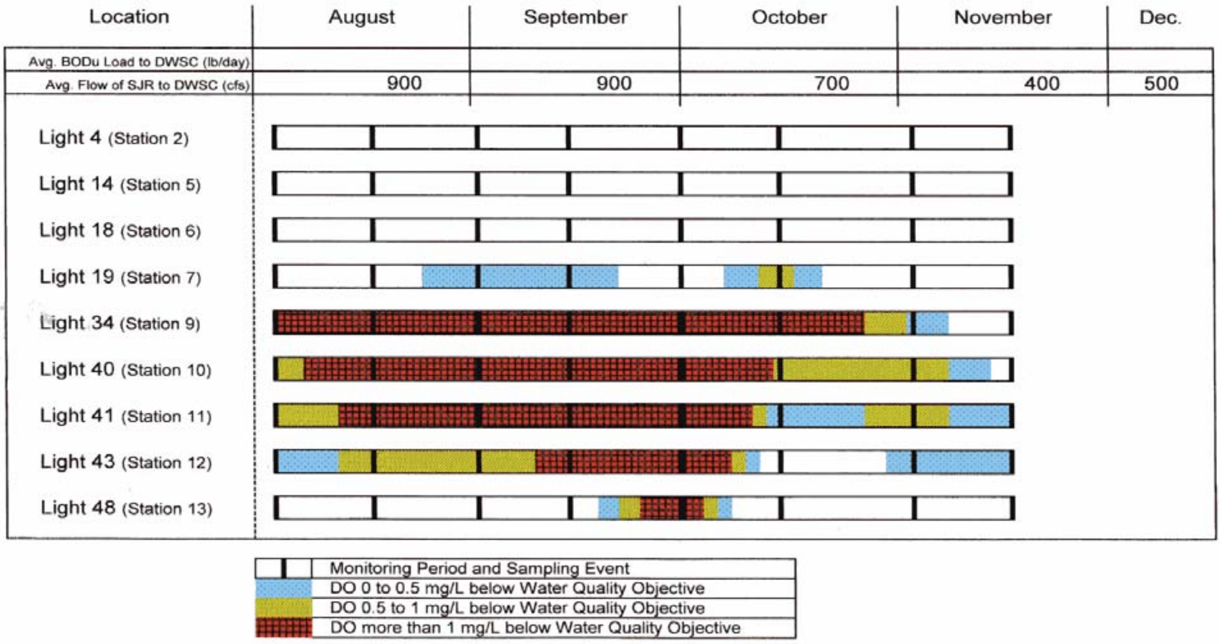


Incidence of Dissolved Oxygen below WQO
Bottom Water 1998



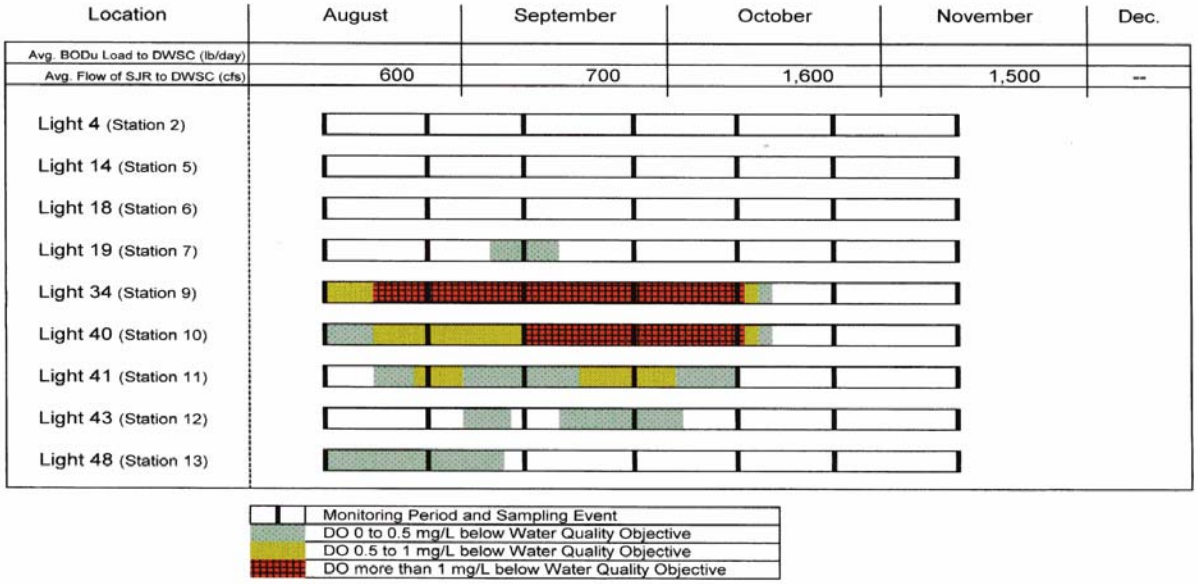


Incidence of Dissolved Oxygen below WQO
Surface Water 1997

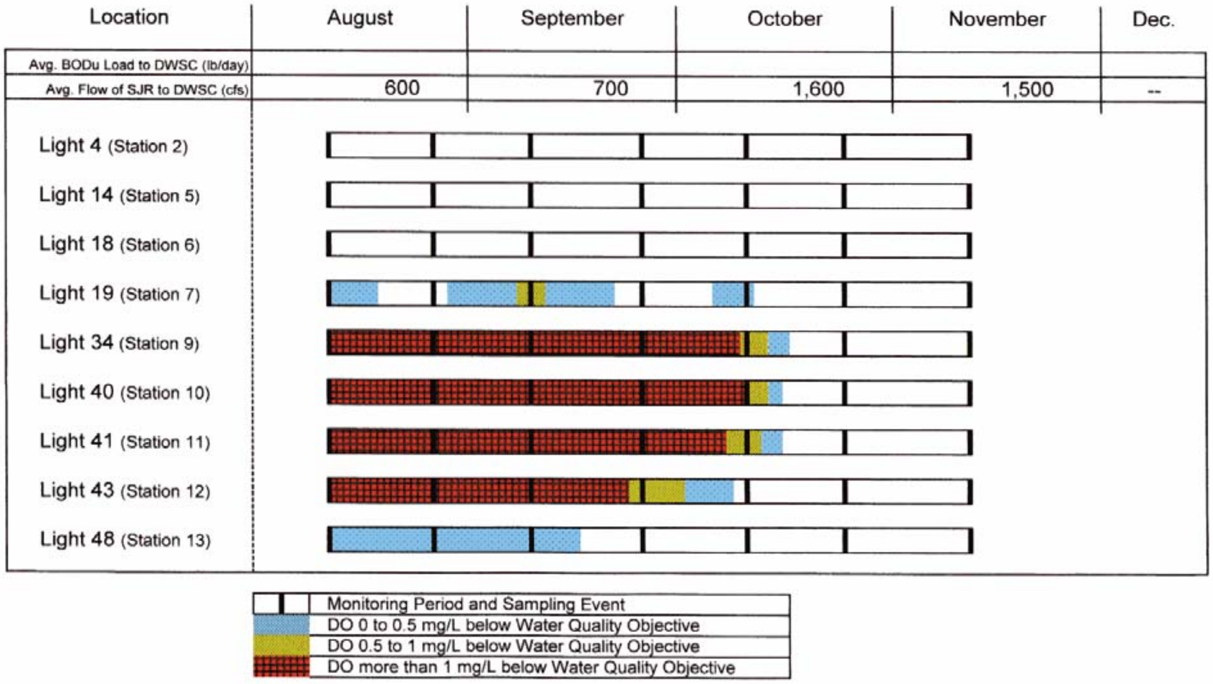


Incidence of Dissolved Oxygen below WQO
Bottom Water 1997

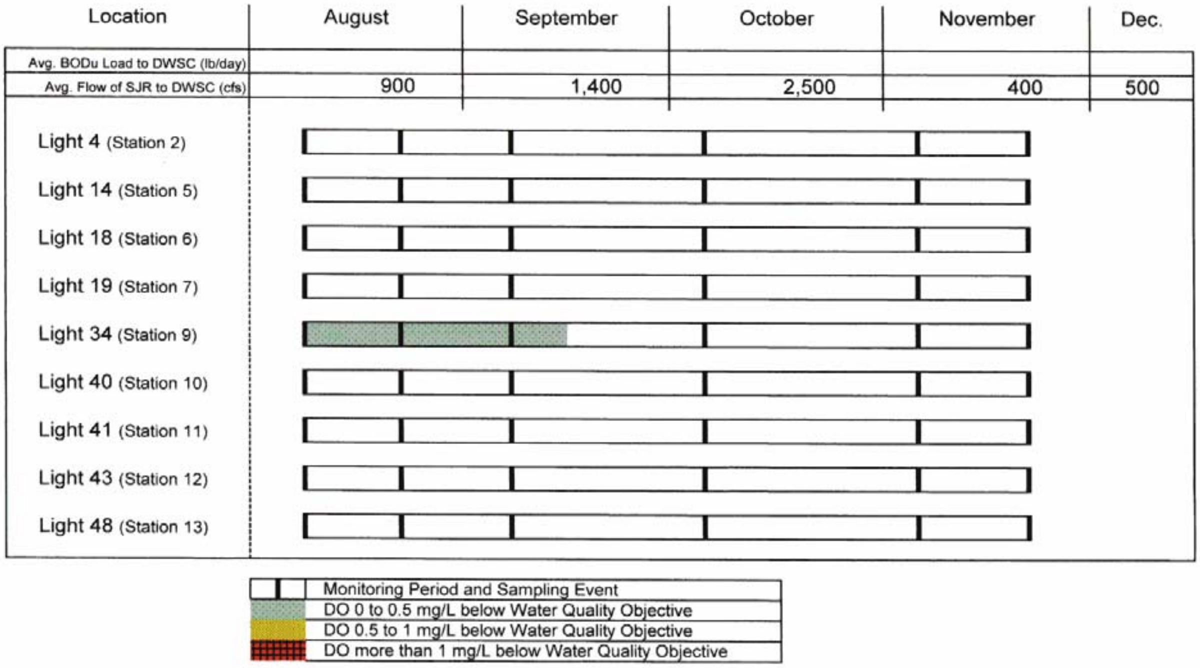
Incidence of Dissolved Oxygen below WQO
Surface Water 1996



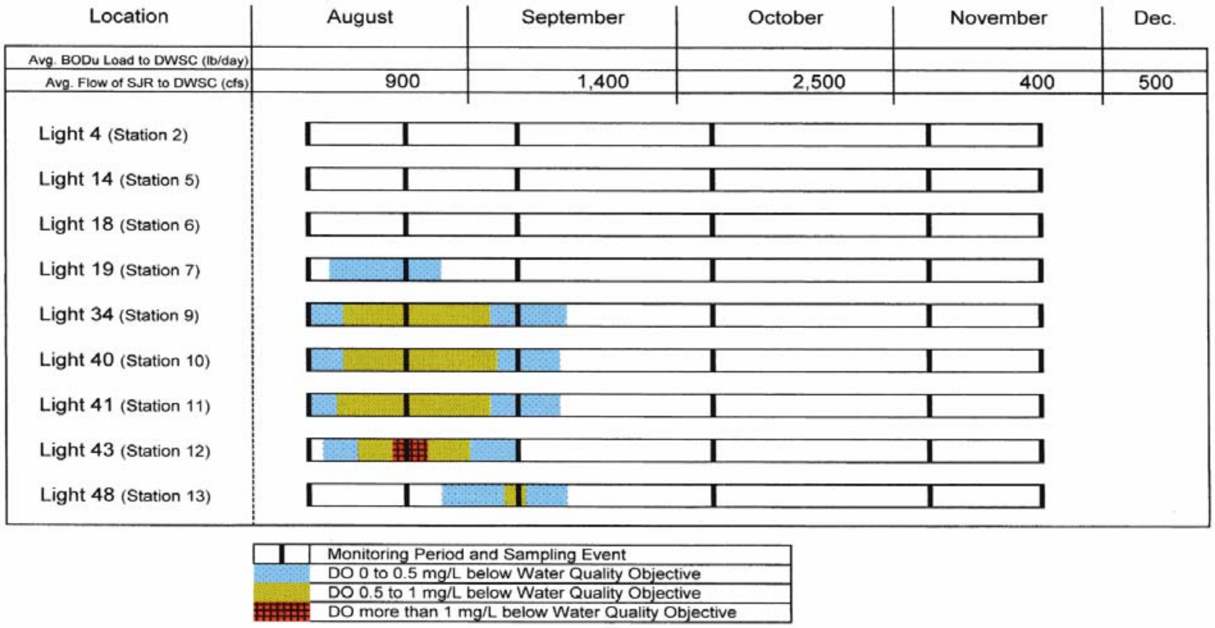
Incidence of Dissolved Oxygen below WQO
Bottom Water 1996



Incidence of Dissolved Oxygen below WQO
Surface Water 1995



Incidence of Dissolved Oxygen below WQO
Bottom Water 1995



events, which are depicted as vertical bars. The estimated BOD_u loading (lb/day) and average daily flow for the indicated month are also presented.

As discussed in a subsequent section, there are also significant DO depletions below the WQO during the early summer, and occasionally in the winter and spring. Examination of the Hayes cruise data presented in Appendix C and Figure 9 shows that, during some years, there is significant DO depletion below the water quality objective that is applicable to the time and location of monitoring.

Appendix D contains a detailed presentation and discussion of the DWR Rough and Ready Island (RRI) continuous DO monitoring data for 2002. It is of interest to compare the RRI DO monitoring results to those of the Hayes cruise data during the summer and fall 2002. On July 23, 2002, the low point of the Hayes-measured DO data was near Rough and Ready Island. Examination of the July 23, 2002, Hayes cruise data for Light 41, which is the position that is near the DWR Rough and Ready Island monitoring station, shows that the measured DO by Hayes cruise personnel in the surface waters was between 5 and 6 mg/L, while the bottom waters were just below 5 mg/L. At that same time, the DWR RRI station showed a DO as high as 9 mg/L in the late afternoon, to about 3 mg/L by early the following morning. The next two days shows the substantial diel DO changes that were occurring at that location, from 3 to about 8 mg/L – i.e., a diel DO swing of about 5 mg/L.

The conclusion is that, at this time, the Hayes cruise data collected about noon near the DWR RRI station did not properly reflect the extremes in DO that occurred over a 24-hour period, and especially did not reflect the fact that the DO measured at about noon was about 3 mg/L higher than the DO that occurred earlier that morning or the following morning. This change is important since, by midday, it would be concluded based on the Hayes cruise data that the DO is above the water quality objective, yet in early morning it is substantially below the water quality objective.

On August 20, 2002, the Hayes cruise data showed DO concentrations near RRI of around 4 mg/L on the surface, and about 3.5 mg/L near the bottom. Rough and Ready Island monitors on that same day showed a DO as low as 2 mg/L, with a peak near 5 mg/L. The noon value, which is about when the Hayes data were collected, was between 3 and 4 mg/L, with a rapid increase from about noon until late afternoon. Again, the Hayes cruise data do not reflect the extreme low DO values that were occurring on the same days as the cruise, during the early morning hours. As in July, the minimum DO for the Channel occurred near Rough and Ready Island, with the result that the RRI station was measuring worst-case DO conditions for the Channel.

A Hayes cruise was conducted on September 5, 2002. DO concentrations were measured in the surface and bottom between 3 and 3.5 mg/L, with the lowest DO values occurring in the vicinity of the DWR RRI monitoring station. The DO measured by the DWR RRI monitoring station ranged from about 2.8 to 4 mg/L, with somewhat less diel change than found on previous cruises.

A Hayes cruise occurred on September 19, 2002. The data for the surface near the Rough and Ready Island monitoring station showed a DO concentration of 6 mg/L, while near the bottom the DO was about 4.3 mg/L. This time the location of the minimum DO for the Channel had shifted downstream from the RRI monitoring station. The September 5, 2002, flow of the SJR through the DWSC was 512 cfs, while by the 19th, the flow was 738 cfs. The September 19 monitoring showed DOs at RRI of 4 to 6 mg/L, with a mean value of about 5 mg/L. This is similar to what was measured by the Hayes cruise.

A Hayes cruise took place on October 7, 2002. The DO measured at the RRI station in the surface and bottom waters was just above and below 8 mg/L. However, the position of the minimum DO had now shifted to Light 19, which is just below Turner Cut. On October 7, 2002, the SJR flow through the DWSC was 1162 cfs. It is evident that, in the 500 through about 700 cfs range of SJR DWSC flows, the minimum DO begins to shift downstream below the RRI monitoring station. By 1100 cfs, the minimum DO is downstream of Turner Cut. The DO values measured at the RRI station by Hayes cruise personnel of about 8 mg/L on October 7 were much higher than the 2.5 mg/L that was measured at the RRI station. There may, however, have been some problems with the RRI station response during this time, since the pattern of DO versus time during the day, while showing a small diel change, appears to have been in error.

A Hayes cruise took place on October 22, 2002. The DO near the RRI station in the surface waters was about 11 mg/L, while the bottom waters had just above 8.5 mg/L DO. The minimum DO was still downstream, just below Turner Cut. The SJR DWSC flow was 1391 cfs. On October 22, the RRI station was showing a DO minimum of about 8.5, with a maximum in late afternoon of 11 mg/L. While the Hayes data gave the impression that there was adequate DO in the DWSC, actually, the DO just below Turner Cut was likely in violation of the WQO in the early morning, since by late morning it was measured in the Hayes cruise at 6 mg/L.

A Hayes cruise took place on November 21, 2002. This time the minimum DO was located near the RRI monitoring station. The SJR DWSC flow was 85 cfs. The surface DO measured by Hayes cruise personnel at this station was about 5.5 mg/L, with the bottom DO at about 4.9 mg/L. On November 21 the DWR RRI station measured DO concentrations just below and just above 5 mg/L, which is similar to the Hayes data taken at about noon. These data do not reflect the fact that there were significant water quality objective violations at this location on this date.

Hayes (pers. comm., 2003) provided the following information on the low DO situation that was occurring in mid-February 2003:

> *"Strikingly Low Dissolved Oxygen Levels Detected Within the Eastern Stockton Ship Channel- In response to recent fish kills within the Stockton Ship Channel and sustained low winter dissolved oxygen levels detected at the Continuous Compliance Monitoring Station at Rough and Ready Island, Bay-Delta Monitoring and Analysis Section staff conducted a dissolved oxygen (DO) study in the Channel at low-water slack on February 18th using the San Carlos. Surface and bottom DO levels in the western Channel from Prisoner's Point to Columbia Cut (Light 14) were robust at > 9.0 mg/L due to tidal mixing and relatively cool water temperatures (11-12°C). Within the central Channel,*

> *surface and bottom DO levels dropped from > 8.0 mg/L west of Turner Cut (Light 19) to 3.0 mg/L at the surface and 2.0 mg/L at the bottom at Fourteen Mile Slough (Light 34). Within the eastern portion of the Channel from Buckley Cove (Light 40) to the middle of Rough and Ready Island (Light 43), DO levels were strikingly low at the surface (<3.0 mg/L) and at the bottom (<2.0 mg/L). A minimum surface DO of 1.4 mg/L and bottom DO of 0.2 mg/L were measured at the western end of Rough and Ready Island (Light 41). Low San Joaquin River inflows to the eastern Channel, slightly warmer water temperatures (12-13°C), an ongoing algal bloom within the eastern Channel, and reduced tidal circulation all appear to be contributing to the anomalous mid-winter DO findings within the central and eastern portions of the Channel. However, the lack of DO stratification within the Channel indicates that factors other than the ongoing algal bloom may be contributing to these values. The results of nutrient and BOD samples are pending, and follow-up studies are anticipated."*

From this information it appears that the low-DO conditions that occurred in the DWSC during late January and February 2003 were associated with an algal bloom, low SJR flow through the DWSC and city of Stockton wastewater discharges of ammonia. This issue is discussed in another section of this report.

Overall, it can be concluded that the Hayes cruise data, which involve discrete sampling at selected locations at one time during the day, where in the critical reach the readings are made in late morning through early afternoon, are not a reliable indicator of the minimum DO that occurs near the Rough and Ready Island station under SJR DWSC flow conditions of less than about 600 cfs, when the minimum DO has been found to occur in 2002 off of Rough and Ready Island. Further, under periods of SJR flow through the DWSC greater than about 700 cfs, the minimum DO values measured at the RRI station are elevated above the actual minimum DOs that are occurring in the Channel, as a result of the minimum DO concentrations having shifted downstream of Rough and Ready Island.

Several general trends are evident from a review of the Hayes cruise data:

- Frequently, the DO concentrations below the water quality objective occur off of Rough and Ready Island near the beginning of the DWSC, and may extend to Turner Cut (DWR station 7).
- The point of greatest DO depletion tends to be shifted downstream toward Turner Cut with increased SJR flow through the DWSC.
- DO concentrations below the applicable water quality objective do not occur downstream of Disappointment Slough/Columbia Cut, and rarely occur downstream of Turner Cut.
- Frequently, there is slightly greater DO depletion below the water quality objective in the near-bottom waters than in the surface waters. Foe, *et al.* (2002) found, upon examination of the temperature and DO data from 615 DWR Hayes cruises conducted since 1983, that there was on average about a 0.3 mg/L difference in DO between the surface and bottom waters in the critical reach of the DWSC. This difference is not related to thermal stratification within the DWSC, but relates to inadequate mixing of the

water column by tidal currents, algal photosynthesis in the near-surface waters and suspended particulate BOD in the near-bottom waters.

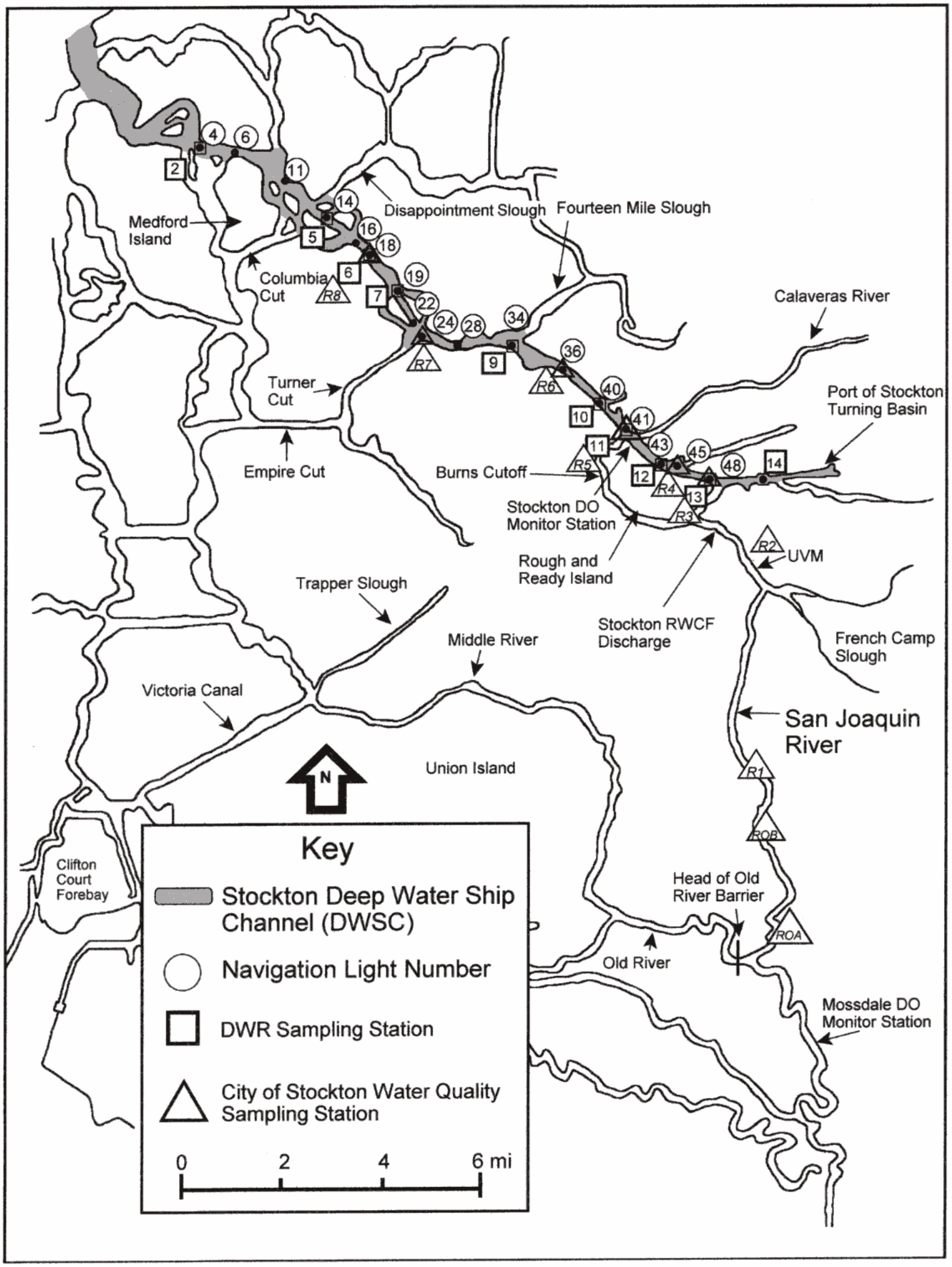
- During those "wet" years (e.g., 1998, 2000) when the SJR flows through the DWSC were in excess of about 2,000 cfs, DO depletions below the water quality objective rarely occurred.
- During "dry" years or when the SJR was essentially completely diverted down Old River (i.e., the flows in the SJR through the DWSC were a few hundred cfs), the DO depletion in the DWSC was the greatest, with some values below 2 mg/L.
- The Port of Stockton Turning Basin which is an extension of the DWSC frequently has higher algal concentrations in the surface waters. This can lead to significant DO surface water supersaturation. Further, the bottom waters of the Turning Basin frequently show greater DO depletion than the main channel. Because of tidal water excursion, Turning Basin waters are mixed to some extent with main channel waters with each tidal cycle.

During the study period (1999 to 2001), the city of Stockton conducted about weekly monitoring runs through the DWSC during part of the summer and fall. These data have been presented by the city of Stockton (Jones & Stokes 2000, 2001, 2002). The locations of the City's sampling stations are shown in Figure 10. This figure also shows the DWR Hayes cruise data sampling locations. The City only measured DO at mid-depth at each of its sampling locations. A summary of the City's data is presented in Appendix D. These data also show that, at times and locations during the study period, there are significant violations of the DO water quality objective at mid-depth in the DWSC.

A third set of monitoring data for the DWSC occurs at the DWR Rough and Ready Island continuous monitoring station (http://iep.water.ca.gov/cgi-bin/dss/dss1.pl?station=RSAN058). Van Nieuwenhuyse (2002) has presented a summary of the DWR Rough and Ready Island DO and temperature measurements for the period 1983 to 2001. He has also presented a discussion of these data relative to factors that may be influencing DO within the DWSC. Lee and Jones-Lee (2003a) have presented the Rough and Ready Island DO monitoring data for 2002. A discussion of these data is presented in Appendix D.

As a result of how this monitoring station samples the water for DO measurements, this monitoring station measures a somewhat undefined integration of the dissolved oxygen concentrations in about the upper third of the water column. During periods of high algal concentrations in the surface waters, the near-surface DO concentrations in the late afternoon at the monitoring station would be greater than that reported, and the early morning DO concentrations in the near-surface waters would be less than that reported by the station. These changes are due to the diel photosynthesis/respiration that occurs in the near-surface waters of the DWSC. Examples of the diel photosynthesis/ respiration data obtained for the DWSC have been presented by Jones & Stokes (2001, 2002). The daily DO change in the upper three feet of water can be on the order of 3 to 4 mg/L. Further, the DO concentrations near the sediments at the monitoring station can be significantly less than that reported for the Rough and Ready Island monitoring station.

Figure 10
Sampling Locations in San Joaquin River



Foe, *et al*. (2002) have provided a detailed review of the DO concentration violations below the water quality objective for the period 1983 through 2001 for the DO measurements made at the DWR Rough and Ready Island station. They have focused on a comparison between the minimum DO found each day and the WQO. Overall, there is significant DO depletion below the water quality objective typically occurring during the summer and fall months in the first seven miles of the DWSC. In accord with Clean Water Act TMDL requirements, the CVRWQCB must develop a management program to eliminate the violations of the water quality objective within the DWSC.

Additional information on more recent dissolved oxygen concentration WQO violations in the DWSC has been obtained through examination of the DWR RRI 2002 monitoring data. These data are presented in Appendix D. Examination of Appendix D shows that there were appreciable DO concentration violations below the WQO in the DWSC at the RRI station during the period June through November 2002. During the summer months, at times the diel DO swing was as much as 7 mg/L. Further, during mid-February through early March 2002, DO concentrations at the RRI monitoring station were below the water quality objective.

Beginning in mid-January through early March 2003, there were severe DO depletions below the water quality objective at the RRI monitoring station. A low DO concentration of 0 mg/L was recorded during this period. The DO concentrations in the surface waters near the RRI station were above the WQO at the beginning of January 2003. There was a steady decline in the DO concentrations through the month, which extended into early February, with DO concentrations around 2 mg/L during the first week of February. By mid-February, the DO concentrations at the RRI station were near 0 mg/L each morning, with a slight diel increase each day. It was not until early March that the minimum DOs increased above the WQO of 5 mg/L.

Oxygen Demand Constituents

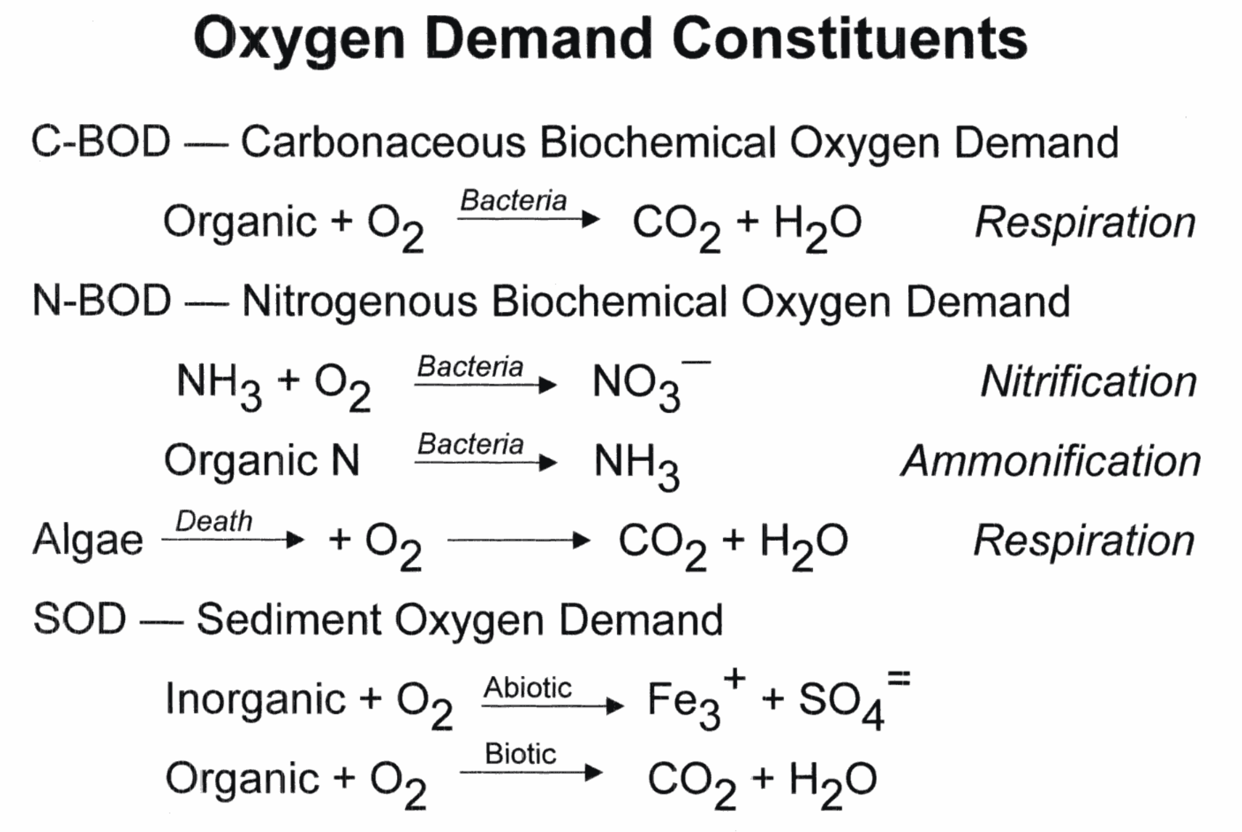
The constituents responsible for causing DO depletion in the DWSC below the WQO are carbonaceous biochemical oxygen demand (CBOD) and nitrogenous BOD (NBOD). Figure 11 presents the chemical reactions involved. Organic chemicals that can be used by microorganisms as a source of energy through respiratory reactions constitute the CBOD. The NBOD is composed of organic nitrogen compounds that are converted to ammonia, where this ammonia undergoes nitrification reactions (conversion to nitrate). Nitrification is a biochemical process that is carried out by microorganisms that utilize dissolved oxygen in converting ammonia to nitrite and then to nitrate.

The potential significance of aquatic plant nutrients (nitrogen and phosphorus) as an ultimate source of oxygen demand is shown in equation (1).

$$(CH_2O)_{106}(NH_3)_{16}H_3PO_4 + 138(O_2) \Rightarrow 106CO_2 + 122H_2O + 16HNO_3 + H_3PO_4 \qquad (1)$$

The typical stoichiometry (composition) of algae is 106 C, 16 N to 1 P, on an atomic basis (see Table 2). The death and decay of an algal stoichiometric molecular unit with complete mineralization will consume 138 oxygen molecules. Algae represent potentially significant sources of CBOD and NBOD. Chlorophyll *a* to carbon ratios range from 10 to 50 µg chlorophyll *a* per mg C. Based on the studies of King (2000), it has been found that about 10 µg/L of chlorophyll *a* is equivalent to about 1 mg/L BOD_5. This is the value that has been found for the chlorophyll *a* plus pheophytin *a* to BOD_5 ratio for the DWSC (see Appendix E). Pheophytin is an algal chlorophyll pigment that has lost the magnesium atom. It is an indication of dead algae. Each mg/L of algae yields a theoretical oxygen demand of 1.2 mg/L, where about 25 percent of the oxygen demand is due to the nitrification of organic nitrogen in the algae to nitrate. As part of this mineralization, 16 atoms of nitrogen and one phosphorus atom are released. One mg/L ammonia N or organic N can consume 4.57 mg/L O_2, as part of nitrification of the ammonia to nitrate. One mg C in the form of organic matter that is oxidized to CO_2 requires about 2.7 mg O_2.

Figure 11



Oxygen Demand Constituents

C-BOD — Carbonaceous Biochemical Oxygen Demand

$\text{Organic} + O_2 \xrightarrow{\text{Bacteria}} CO_2 + H_2O$ *Respiration*

N-BOD — Nitrogenous Biochemical Oxygen Demand

$NH_3 + O_2 \xrightarrow{\text{Bacteria}} NO_3^-$ *Nitrification*

$\text{Organic N} \xrightarrow{\text{Bacteria}} NH_3$ *Ammonification*

$\text{Algae} \xrightarrow{\text{Death}} + O_2 \longrightarrow CO_2 + H_2O$ *Respiration*

SOD — Sediment Oxygen Demand

$\text{Inorganic} + O_2 \xrightarrow{\text{Abiotic}} Fe_3^+ + SO_4^=$

$\text{Organic} + O_2 \xrightarrow{\text{Biotic}} CO_2 + H_2O$

Table 2
C, N, P Composition of Algae

C	N	P
(atomic) 106	16	1
(mass) 1272	224	31
40%	7.2%	1%

Based on Redfield numbers, Litton (2003)

As discussed by Lee (1971) and Lee and Jones-Lee (2002a, 2003b), oxygen depletion in waterbodies is a characteristic of excessively fertile (eutrophic) waterbodies. Many eutrophic (high algal content) waterbodies experience DO depletion in the bottom waters, especially if there is limited mixing between the surface and bottom waters. Under conditions of high algal growth/loads, such as occurs in the DWSC, mid-depth and surface water oxygen depletion can also occur, particularly if background turbidity severely limits the photic zone.

Conceptual Model of the SJR DWSC Oxygen Demand Processes. Lee and Jones-Lee (2000a) presented a conceptual model of the major processes governing oxygen depletion in the DWSC. Figure 12 presents a pictorial representation of some of the important processes and issues governing DO depletion in the DWSC. Examination of the figure shows that the SJR, which is from eight to 10 feet deep, enters the DWSC at Channel Point. Just upstream of this location, the city of Stockton's treated wastewaters are discharged to the DWSC. These wastewaters, in addition to containing conventional wastewater treatment plant residues, such as carbonaceous and nitrogenous BOD, also at times can contain appreciable concentrations of algae, which develop in the City's wastewater ponds. While the City has the ability to filter the algae out of the effluent, this is not always done, with the result that, at times, there is an additional algal load added to the DWSC from these ponds. This additional algal load, as measured by chlorophyll *a*, does not represent a significant additional chlorophyll *a* concentration discharged to the DWSC.

The upstream oxygen demand load, including algae, enters the DWSC and soon becomes mixed through the water column, principally through tidal action. The SJR flows entering the DWSC during the summer and fall at times (under drought conditions), can be negative, due to upstream diversions of water down Old River and by agricultural use for irrigation, to several thousand cfs downstream through the DWSC. As discussed by Brown (2001, 2002a), the overall flows in the DWSC are controlled primarily by tidal action, where there are from 2,000 to 4,000 cfs of tidal flow associated with each tide. The large tidal flow, compared to the normal summer/fall net SJR downstream flow, makes it somewhat difficult to reliably determine the net downstream flow, since it can be on the order of 100 to 1,000 or so cfs, relative to a background tidal flow of 2,000 to 4,000 cfs.

The algae that enter the DWSC, which are usually the principal source of oxygen demand, are soon dispersed through the water column. While in the San Joaquin River, because of its shallow depth, algae are periodically exposed to some sunlight and, therefore, are able to continue to reproduce. However, the algae and inorganic turbidity of the DWSC limit light penetration that can lead to photosynthesis, to about the upper three to six feet. This means that there are over 30 feet of the DWSC where there is insufficient light to enable algae to continue to grow through photosynthesis. This, in turn, leads to their death and decay, which exerts an oxygen demand. These processes are shown in the upper part of Figure 13. The lower part of Figure 13 is discussed in the section on sediment oxygen demand.

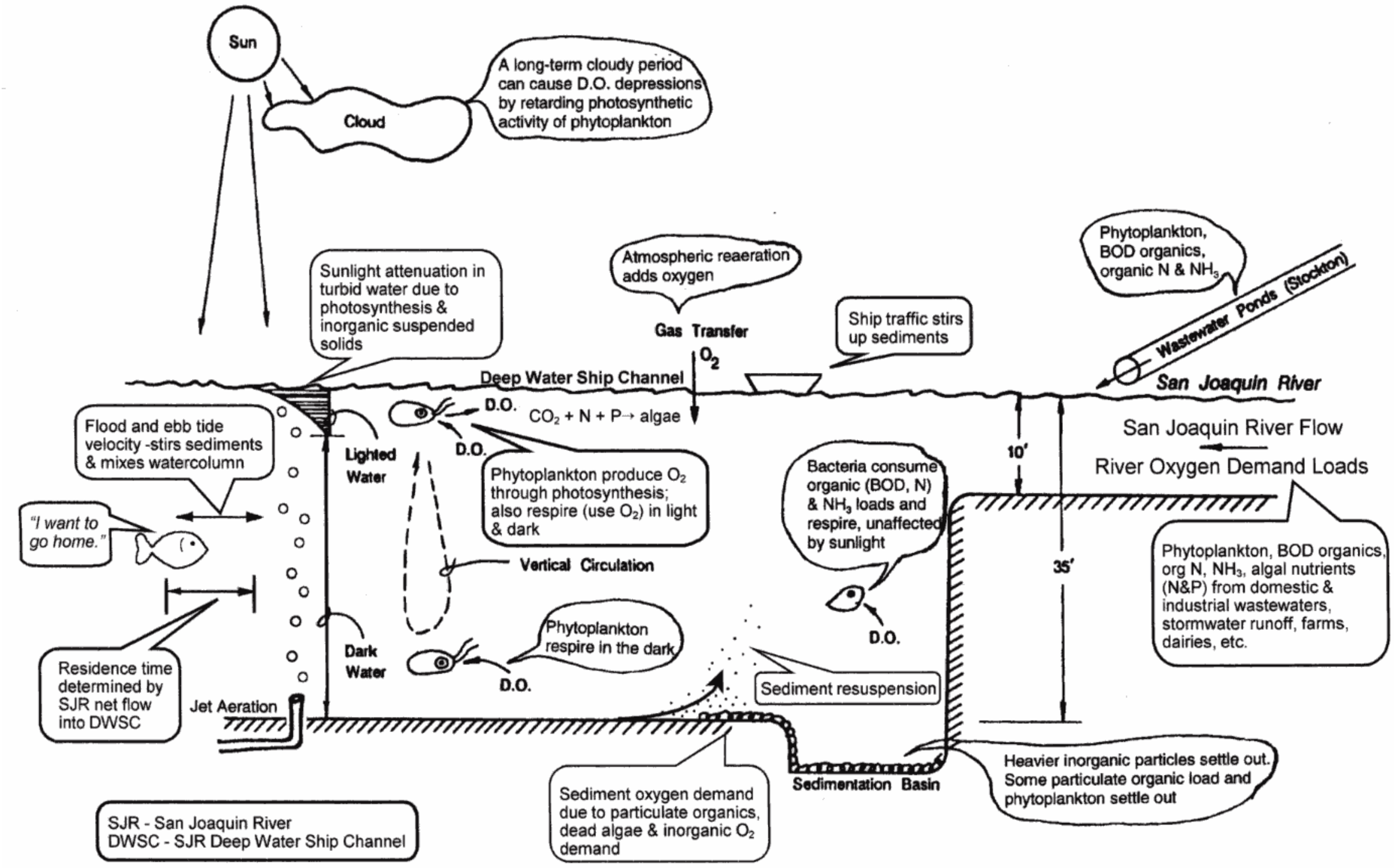


Figure 12. Factors Affecting Dissolved Oxygen in DWSC
(adapted from COE, 1988)

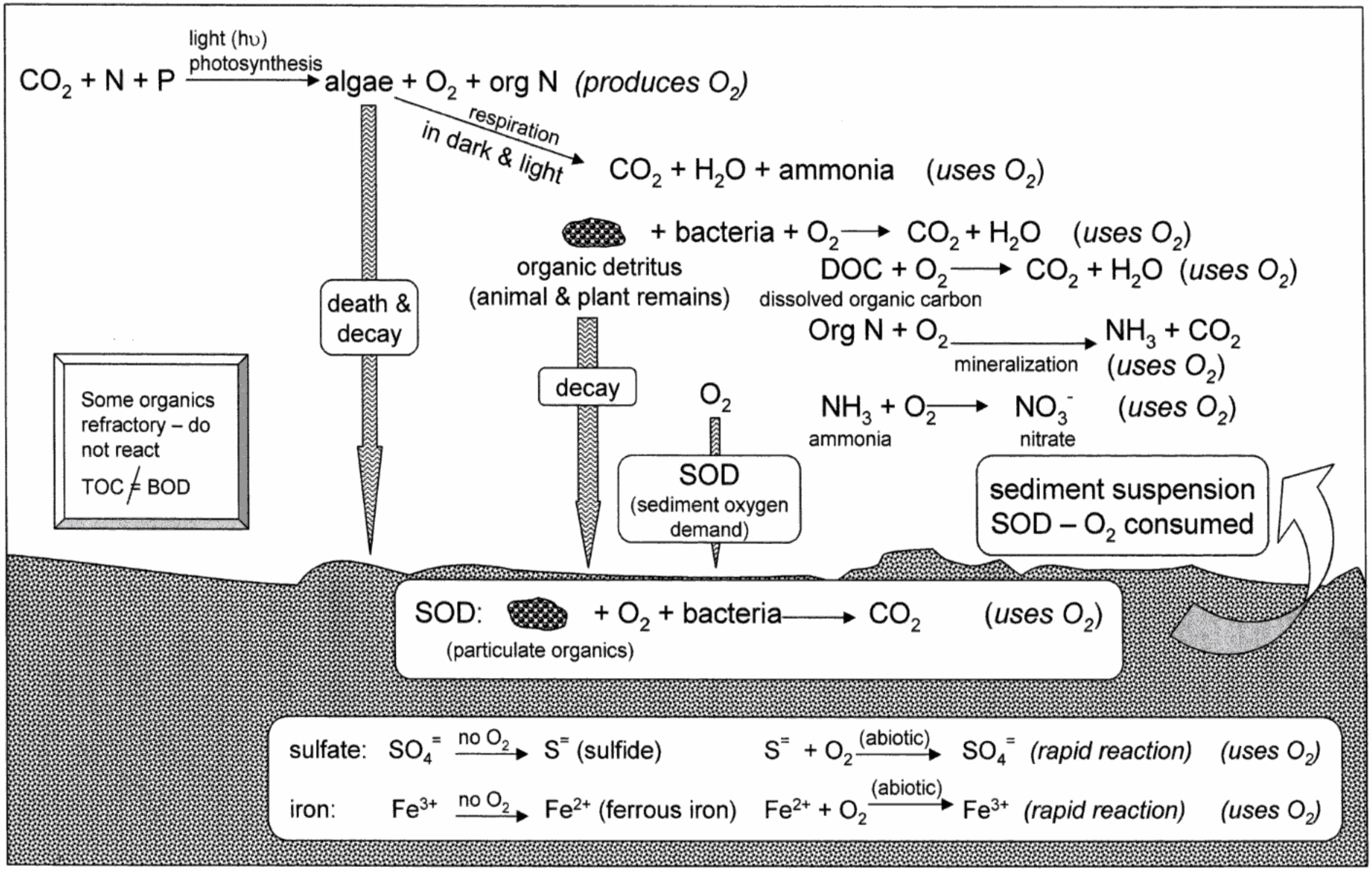


Figure 13. Algae & Organic Detritus as Sources of Oxygen Demand

The tidal-caused, wind-induced and net SJR flow-induced mixing within the DWSC typically prevents the DWSC from becoming stratified for any significant period of time, and tends to mix the water column fairly well most of the time. There appear to be periods of a few hours to a few days where the mixing that occurs is not sufficient to fully mix the water column in the DWSC. These periods may be important in causing localized areas of DO depletion.

An important component of the conceptual model is the settling and resuspension of algae and other forms of oxygen demand, such as algal-derived detritus within the DWSC. These processes influence the transport of particulate BOD through the DWSC, and therefore their potential impacts on DO within the DWSC, especially in the near-bottom waters.

The principal water quality issue of concern in the DWSC is DO depletion below the water quality objective in the water column, which is adverse to aquatic life habitat. This is primarily manifested in slowing the rate of growth of fish and other aquatic life. DO depletions can be sufficiently severe to cause fish kills; however, in recent years, adult fish kills due to low DO have not been observed in the DWSC. Larval fish kills and death of organisms that provide fish food are often difficult to observe. In addition to affecting fish and other aquatic life within the DWSC that inhabit this area, there is also concern about the impacts on the homing migration of anadromous fish, in particular the fall run of Chinook salmon, which pass through the DWSC as part of their homing to tributary waters upstream of the DWSC.

Algae as an Oxygen Demand Constituent. An issue of primary concern to the TAC in conducting these studies of oxygen depletion problems in the DWSC is an assessment of the relative significance of the various constituents which serve as oxygen demand sources in the DWSC. The NBOD constituents can be assessed from the ammonia and the organic nitrogen concentrations/loads to the DWSC through the kinetics (rates) of ammonification and nitrification reactions. However, the components of the CBOD cannot be as readily assessed. Several investigators (King, 2000; Foe, *et al*., 2002; Dahlgren, 2002; Lehman, 2002; Litton, 2001, 2003) have developed correlations between the planktonic algal chlorophyll *a* concentrations in the water and the measured BOD at various locations in the SJR and DWSC.

It is of interest to examine the city of Stockton data for 1999, 2000 and 2001 for the relationship between BOD_5 and the sum of the chlorophyll *a* and pheophytin *a*. Using the sum of the chlorophyll *a* and pheophytin *a* as a potential estimate of oxygen demand is based on the results of Foe, *et al*. (2002) and Dahlgren (2002). Brown also recommends this approach (pers. comm., 2002). A discussion of this issue is presented in Appendix E. Litton (2003) demonstrated that phytoplankton concentrations were best characterized by the pigment sum, and that there was a one-to-one conversion of chlorophyll *a* to pheophytin *a*.

In general, there was a fairly good relationship for most locations between BOD_5 and the sum of planktonic algal chlorophyll *a* and pheophytin *a* during 2000 and 2001. The scatter about the line of best fit is due to the variety of factors that are known to affect this relationship, such as variable algal chlorophyll *a* content. This relationship supports the position that algae and their remains are the primary source of oxygen demand in the SJR at Mossdale and within the DWSC. However, while Litton (pers. comm., 2002) found a good correlation in 2001 near the city of

Stockton station R3 (Channel Point), at the city of Stockton station R5 the correlation was poorer. He also indicated that he saw a very poor correlation between BOD and planktonic algal chlorophyll *a* at this location in 2000. The reason for these differences is unknown.

Litton (2003) and Lehman (2002), as well as the city of Stockton (Jones & Stokes, 2002) have made BOD measurements in the presence of a nitrification inhibitor. The results of the inhibited CBOD tests conducted in the SJR studies show that from 40 to 60 percent of the BOD_5 in the San Joaquin River samples taken from Mossdale, within the DWSC and from the City's wastewater discharges, is CBOD. However, as discussed by Standard Methods (APHA, *et al.*, 1998), NCASI (1985) and Baird and Smith (2002), the nitrification-inhibitor approach can yield unreliable assessments of the CBOD, since the inhibitor also inhibits the growth of some bacteria that utilize the CBOD. Outside of measuring the increase in nitrate concentrations in the BOD test, the nitrification-inhibitor approach is a frequently used, although sometimes unreliable, approach to estimate CBOD in a sample. The recommended approach for determining the NBOD in a sample is through measuring the increase in nitrite/nitrate that occurs during the test. Baird and Smith (2002) have recently completed a comprehensive review of the BOD test. This review should be consulted for additional information on factors influencing the test results. A subsequent section of this Synthesis Report discusses previous studies by Fitzgerald (1964) which indicate that the BOD of algae is influenced by a variety of factors.

The investigators in this study have concluded that a significant part (if not most) of the CBOD measured is derived from algae, either in the form of live algae that die in the BOD test, or dead algae that are present in the water sample tested. A significant part of the NBOD present in the samples is derived from the organic nitrogen in algae that are present in the water samples tested for BOD.

Factors Influencing DO Depletion in the DWSC

There are several factors which influence the oxygen demand assimilative capacity of the DWSC. The most important include the construction of the Deep Water Ship Channel and the flow of the SJR through the DWSC.

Significance of the Port of Stockton. In the winter of 2001, Foe of the CVRWQCB, with the assistance of several members of the TAC, initiated work to begin to define the TMDL of oxygen-demanding materials that can be added to the DWSC without causing DO depletion below the water quality objective. This effort has been called a "Strawman" analysis of oxygen demand loads and impacts. Also considered in this effort were some of the factors, such as SJR flow through the DWSC and DWSC morphology (depth), that apparently were affecting the DO depletion that occurs within the DWSC as a function of oxygen demand load to the DWSC. Further, initially based on the year 2000 data collected during the summer and fall, Foe conducted an analysis of the sources of oxygen demand in the SJR DWSC watershed that appear to be responsible for DO depletion in the DWSC below water quality objectives.

In the winter of 2002, Foe expanded the Strawman analysis to include, where possible, consideration of the summer/fall 2001 data on the DWSC and the sources of oxygen demand in the SJR DWSC watershed. Foe has written up the results of his 2000 and 2001 Strawman analysis in a report (Foe, *et al*., 2002).

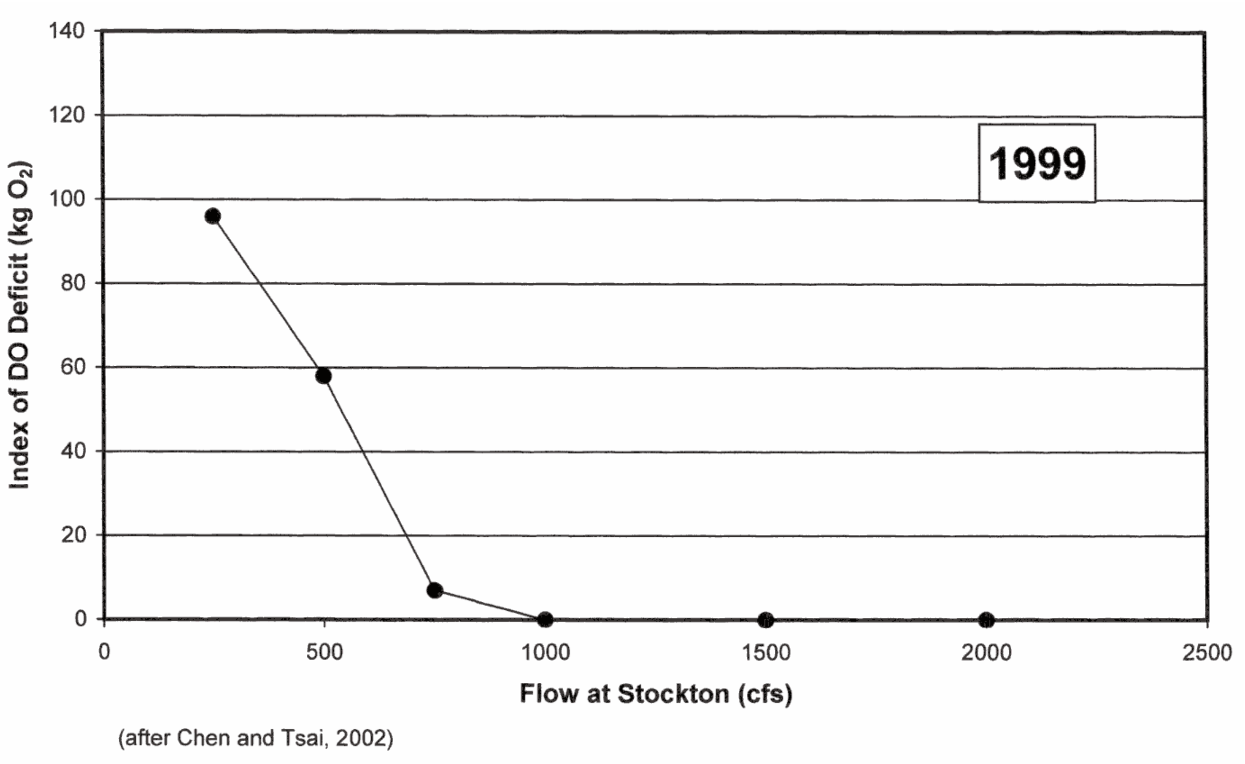
As part of the Strawman analysis, studies were conducted on the impact of DWSC morphology (depth) on DO depletion, using the Chen-Systech model discussed below (Chen and Tsai, 2002). Chen and Tsai (2002) reported (see Figure 14a) that, if the DWSC had not been constructed – i.e., the SJR downstream of Stockton were 8 to 10 ft deep, as it is upstream of the City – the DO depletion below the Port of Stockton in the critical reach would not exist, especially with SJR flows through the DWSC above about 500 cfs, or would be small at flows less than about 500 cfs.

In developing Figure 14a, Chen and Tsai (2002) assumed that the SJR below the Port of Stockton had the same depth as the SJR immediately upstream of Stockton. The Chen-Systech model was then run with this SJR geometry for the purpose of assessing the magnitude of the oxygen deficit that would be found in the SJR downstream of the Port if the DWSC had not been developed. As shown in the upper part of Figure 14b, during summer 1999 at 1,000 cfs of SJR flow through the DWSC and the current DWSC geometry, there is a predicted 4,000 kg oxygen deficit in the DWSC, while in 2000 (Figure 14b, lower) the predicted oxygen deficit at 1,000 cfs of SJR flow through the DWSC would be essentially zero. The difference between summer 1999 and summer 2000 is that during the summer 2000 the flow of the SJR through the DWSC was typically in excess of about 1,500 cfs.

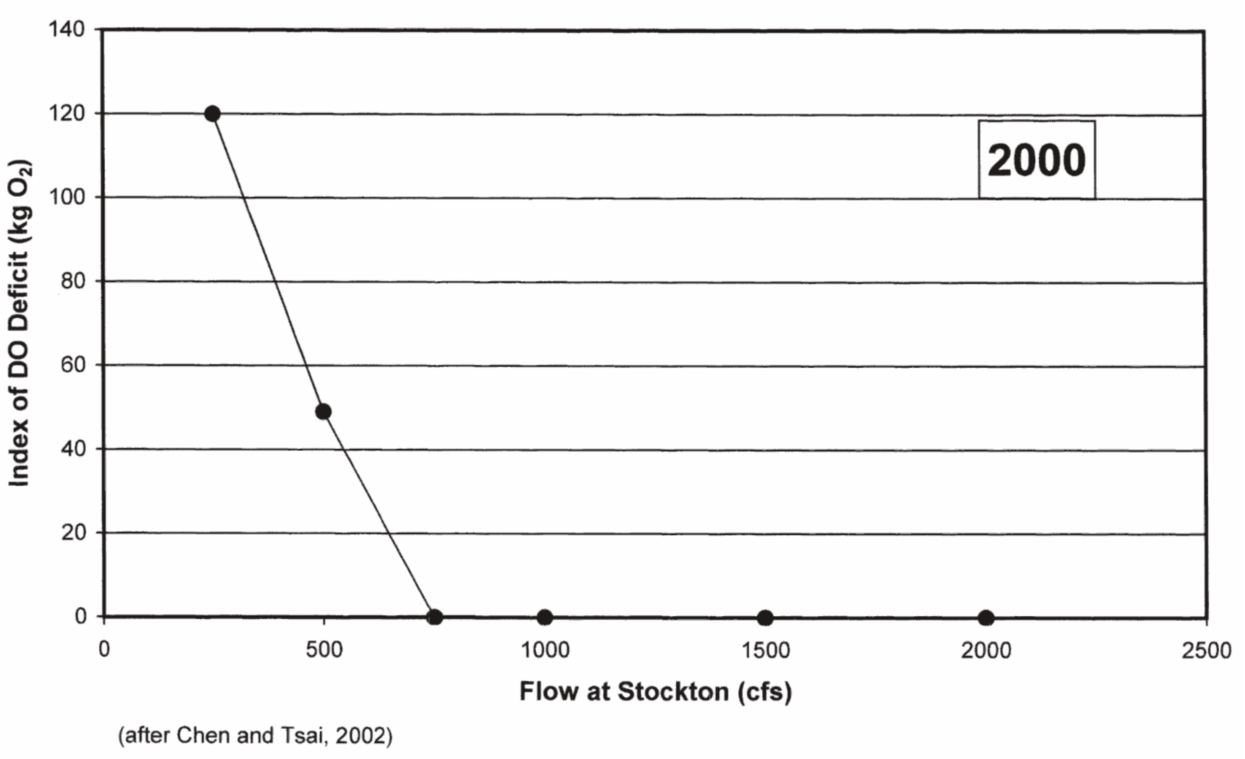
As shown in Figure 14a, at the pre-dredging depth, at a SJR flow through the DWSC of 1,000 cfs, the oxygen deficit would be predicted to be zero for both 1999 and 2000 conditions. It is only at SJR DWSC flows of about 250 cfs (see Figure 14a) that there would be any potentially measurable DO deficit in the undredged Channel. The results of this modeling are in accord with the situation found in the SJR upstream of the City, where the 8 to 10 ft deep SJR does not experience DO depletions below water quality objectives. In fact, it is often supersaturated with respect to DO, due to algal photosynthesis.

It is, therefore, concluded that the existence of the DWSC, beginning at the Port of Stockton, where the SJR changes from 8 to 10 feet deep to 35 to 40 feet deep, is a major factor in causing DO depletion below the water quality objective. The primary responsible party for the DWSC DO depletion problem is the Port of Stockton and those who benefit from the existence of the Port. The primary beneficiaries are the agricultural and commercial interests that utilize the Port for low-cost transport of goods to and from the Port. According to Port-provided information (Port of Stockton, 2002), the principle exports handled through the Port are grain, coal, sulfur, coke, scrap steel, almonds, steel coils, beet pulp pellets, logs, bagged wheat seed, bagged rice and steel pipe, while the imports include fertilizers (dry and liquid), anhydrous ammonia, molasses, cement, machinery, steel beams, steel coils, sugar, magnesite and grain.

Figure 14a
DO Deficit under Historic Channel Depth of 7ft
100% Stockton Load & 100% River Load



(after Chen and Tsai, 2002)

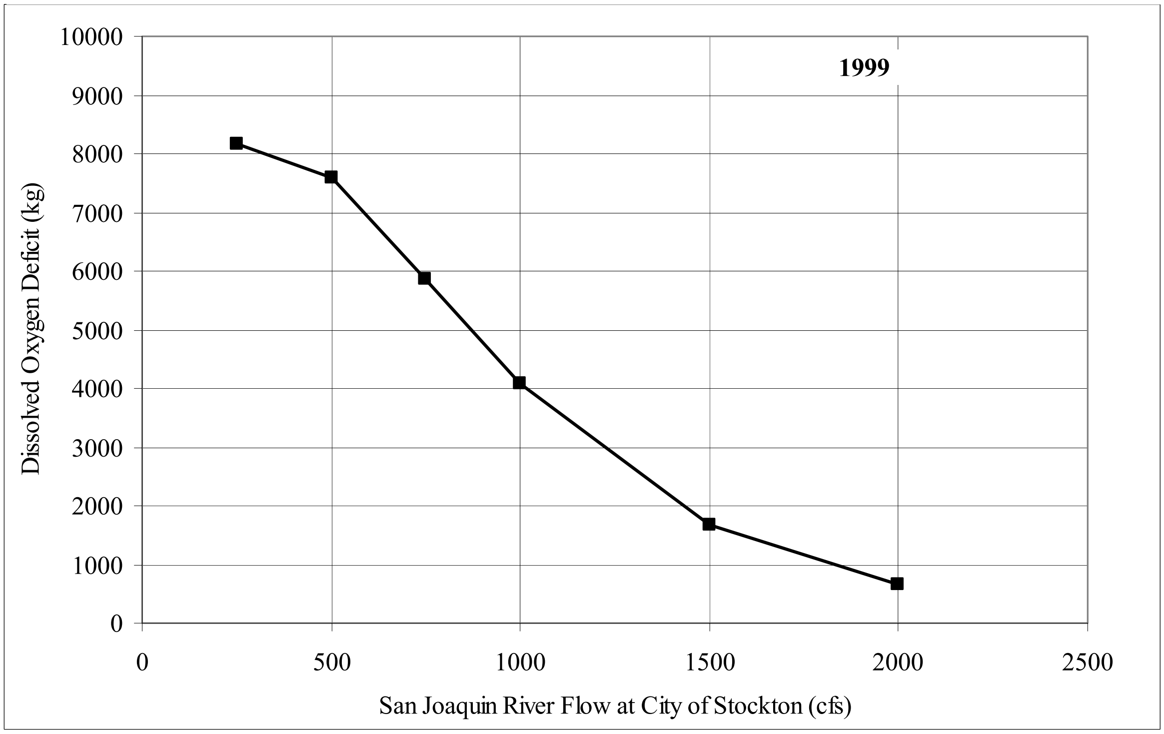


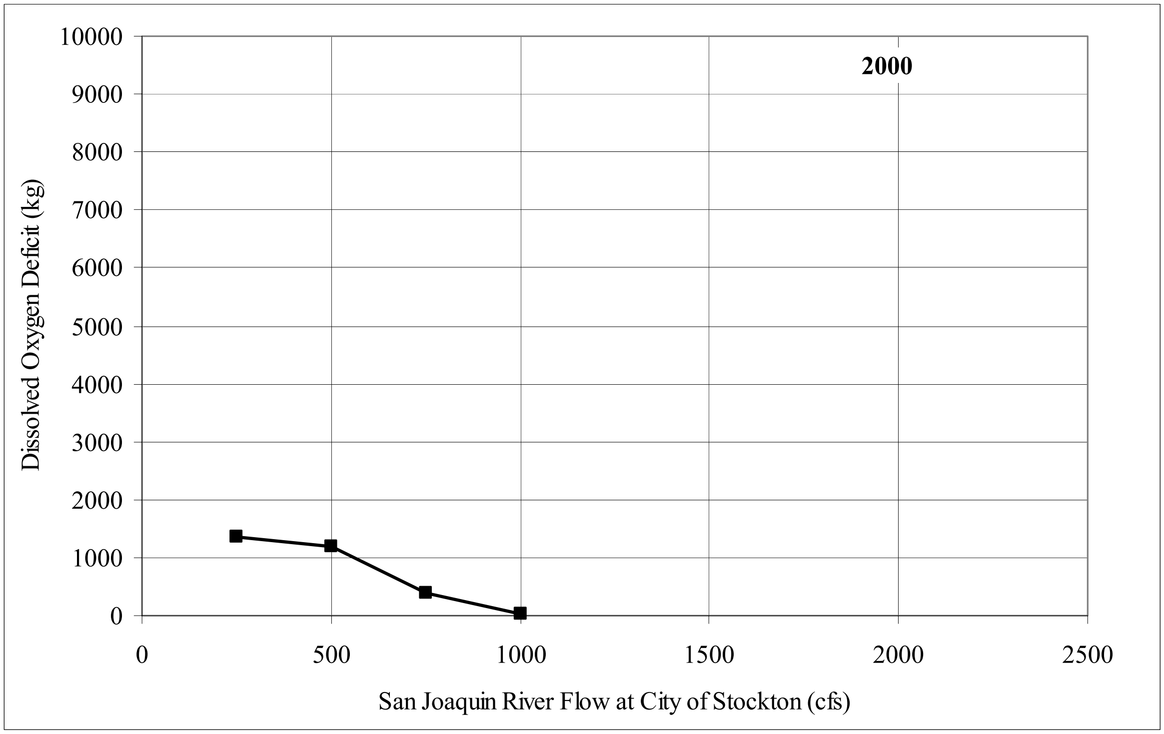
(after Chen and Tsai, 2002)

Figure 14b

Predicted Impact of SJR DWSC Flow on DO Deficit (from Foe *et al*., 2002)

Upper Figure: Based on 1999 conditions
Lower Figure: Based on 2000 conditions





Impact of SJR Flow through the DWSC. The amount of SJR flow that enters the DWSC has two opposing effects. Greater SJR flow into the DWSC normally increases the oxygen demand load to the DWSC, since it transports greater oxygen demand loads in the form of algae into the DWSC; however, the increased flow also decreases the hydraulic residence time of the critical reach of the DWSC. As discussed above and in Appendix C, it has been found that, during summers/falls when the SJR flow through the DWSC is above about 2,000 cfs, there are few DO depletion problems below the water quality objective. It has also been found that, when the SJR flow through the DWSC is a few hundred cfs, the DO depletion problems in the DWSC are severe, sometimes with DO concentrations below 2 mg/L. It is important to emphasize that reported UVM flows below a few hundred cfs are not highly reliable. This issue was discussed by Foe in the Lee and Jones-Lee (2000a) "Issues" report.

The Strawman analysis has provided estimates of the allowable oxygen demand loads to the DWSC as a function of SJR flow through the DWSC. Figure 14b shows the results of the modeling (Chen and Tsai, 2002) of the magnitude of the oxygen deficit in the DWSC as a function of SJR DWSC flow. These results are based on the use of the Chen-SysTech model to examine how the flow of the SJR through the DWSC and its associated oxygen demand load influences DO depletion in the DWSC. As shown, when the SJR DWSC flows are above about 2,000 cfs, the magnitude of the DO depletion in the DWSC below water saturation is small. There is, however, a steep gradient in DO deficit versus flow in the range of about 500 cfs to about 1,500 cfs. These results are in general agreement with the DWSC measurements made by DWR in the Hayes cruises (Figure 9) and by the city of Stockton in their monitoring of the DWSC in 1999, 2000 and 2001. The data collected on the DWSC over the years shows that during wet, high-flow years, with flows through the DWSC above about 2,000 cfs, there were few DO depletions below the water quality objective.

Even though increasing the flow of the SJR through the DWSC increases the total oxygen demand load added to the DWSC, in the form of algae derived from upstream of Mossdale, this increased load of BOD_u is not exerted in the seven-mile critical reach of the DWSC (to Turner Cut) where DO depletion below the water quality objective has been found to occur. Also, as discussed above, SJR DWSC flows of a couple of hundred cfs tend to cause the greatest depletion of DO in the DWSC.

The impact of flow on DO depletion seems to be primarily related to the changes in the hydraulic residence time of the critical reach of the DWSC. During low flow, even relatively small loads of oxygen demand have sufficient time to be fully exerted in the DWSC before mixing with the cross-channel flow of Sacramento River water that occurs at Turner Cut and Columbia Cut. At high SJR flows through the DWSC, the hydraulic residence time (travel time) of BOD_u through the first seven miles of the DWSC is sufficiently short so that a large part of the BOD_u load is not exerted in the critical reach, and is transported into the Central Delta via Turner Cut and, especially, Columbia Cut.

The SJR flow through the DWSC during the summer and early fall is controlled by tributary eastside river reservoir releases; supplemental flow from the Delta-Mendota Canal, which is part of the Federal Project; agricultural, municipal and other diversions; agricultural tailwater;

subsurface (tile) drain water; shallow groundwater discharges and recharge to the SJR and its tributaries; and municipal and industrial wastewater discharges. One of the most important causes of decreased flow of the SJR into the DWSC is the diversion of SJR water into Old River near Mossdale. Associated with the development of the Central Valley Project (Federal Project) and the California State Water Project (State Project) devoted to exporting water from the South Delta to Central and Southern California, it was found that there was need to install temporary rock tidal barriers in the South Delta. These temporary rock barriers are installed each year in three Delta channels. The location of these barriers is shown in Figure 5.

These barriers trap incoming tides to mitigate for the lowered water levels caused by the operation of the SWP and CVP export pumps which draw Sacramento River water across the Delta. The barriers also are meant to re-establish unidirectional flow in these channels to improve water quality. As part of the CALFED Record of Decision (ROD), the temporary barriers are to be replaced by permanent, operable barriers which can be used to control the flow in a South Delta channel as a function of tide stage. The existence of the temporary tidal barriers has been found to be a significant factor in controlling the amount of SJR water that is allowed to go downstream in the SJR channel to the DWSC, versus down Old River to the export pumps. This is especially important during the fall, associated with the removal of the barriers, which causes much of the SJR flow at Vernalis to enter Old River. At this time, the flows of the SJR through the DWSC can be greatly diminished, which has been associated with low DO concentrations in the DWSC.

In addition to the tidal barriers, there is also a Head of Old River temporary rock barrier that is typically installed in April to provide increased SJR flow down the SJR to the DWSC in order to help young salmon migrate to the sea. The Head of Old River barrier is removed during the end of summer to enable greater SJR flow into Old River. When the Head of Old River barrier is in place, essentially all of the SJR flow at Vernalis enters the DWSC. Brown (Jones & Stokes, 2002) has discussed how the installation and removal of the South Delta temporary rock barriers influence the amount of SJR water present at Vernalis that enters Old River. In late September 1999, for a period of about a week, when the Head of Old River barrier was not in place, the removal of the Grant Line barrier in the South Delta (see Figure 5) resulted in essentially all of the SJR flow present at Vernalis being taken/pumped down Old River to the export pumps. The net result was that the hydraulic residence time of the DWSC changed from about a week to almost three weeks. The DO depletion associated with this low flow (estimated to be about 200 cfs) of SJR water through the DWSC led to the lowest DO concentrations (about 2 mg/L) experienced that year in the DWSC.

Impact of Sacramento River Cross Channel/Delta Flow. Increased SJR flow through the DWSC tends, as expected, to push the oxygen demand point of greatest depletion (sag) further downstream. Ordinarily, in a typical river situation, this would simply shift the location of the low-DO problem. However, the State and Federal Projects' export of South Delta water to Central and Southern California creates a strong cross-Delta flow of Sacramento River water toward the export pumps located near Tracy and Clifton Court (see Figure 1). Sacramento River water, year-round, including summer and fall, has a low oxygen demand. Dahlgren (2002) has found that during summer and fall of 2000 and 2001 the Sacramento River at Freeport, which is just upstream of the Delta, has planktonic algal chlorophyll *a* of 0.5 to about 2 µg/L. At the same time, the SJR DWSC near Turner Cut typically has planktonic algal chlorophyll *a* of 2 to 12 µg/L. This export pumping of South Delta water by the State and Federal Projects causes the Sacramento River water to cut off the downstream movement of the San Joaquin River water through the DWSC.

This cross-channel flow of Sacramento River water begins to occur at Turner Cut (Brown, 2002a), under low SJR flow through the DWSC, and primarily occurs through Columbia Cut. As discussed above, the Hayes cruise monitoring of the SJR DWSC below Columbia Cut over the last 15 years or so has never found a DO problem. Rarely do low-DO problems occur below Turner Cut. This is a result of the SJR DWSC water that exists upstream of Disappointment Slough/Columbia Cut being mixed with the cross-DWSC flow of the Sacramento River water. The net result is that the residual oxygen demand load that is not exerted between Channel Point and Disappointment Slough/Columbia Cut (which can be a significant part of the total load to the DWSC, especially under high SJR DWSC flow -- i.e., short hydraulic residence time) is transported into the Central Delta as part of the export pumping by the State and Federal Projects. While there is appreciable mixing/dilution of the residual oxygen demand from the SJR DWSC present at Disappointment Slough/Columbia Cut, it is unclear whether there are any low-DO problems that occur in the Central Delta as a result of the export of oxygen demand into this area from the SJR DWSC. From the information available it appears that the most likely location for low-DO conditions to occur in the Central Delta is downstream of where Turner Cut intersects the DWSC. Under ebb tide conditions, much of the water in Turner Cut is SJR water and, therefore, has an appreciable oxygen demand. There is need to investigate whether the export of DWSC water down Turner Cut leads to low-DO conditions.

Under low SJR DWSC flow (less than about 500 cfs), it has been found by Brown (2002a) that there is potentially significant upstream transport of Sacramento River water into the DWSC, due to tidal action. This tidal-caused upstream transport of Sacramento River water into the DWSC dilutes the oxygen demand present in the SJR at Turner Cut and contributes to its diversion down Turner Cut during ebb tides.

Growth of Algae within the DWSC. While Lehman and Ralston (2000), Lehman, *et al*. (2001) and Lehman (2002) have found that there is appreciable algal growth within the DWSC, this growth, through photosynthesis, also produces oxygen, which, since the waters of the DWSC are normally undersaturated with respect to DO during the summer and fall, is available to satisfy the oxygen demand associated with the death of the algae that developed within the DWSC. As a result, algal growth within the DWSC is not a significant contributor to the low-DO problem in the surface and mid-depth waters. Algal growth within the DWSC may, however, contribute to the greater oxygen depletion that occurs during periods when there is not complete mixing in the near-bottom waters of the DWSC. Litton (2003) reported that the settling and resuspension rates for particulates in the near-bottom waters are about equal. Litton also reported that the transport of settled phytoplankton is about two to three times the hydraulic travel time. This means that the near-bottom particulate BOD (upstream algae and detritus and in-channel-produced algae) has a longer period of time to be exerted than the BOD that is transported in the upper water column. Litton (pers. comm., 2002) and Van Nieuwenhuyse (2002) suggest that the elevated suspended solids in the near-bottom waters of the DWSC may be the site for increased biological activity on their surfaces. This may be particularly important for nitrification reactions. As discussed in a subsequent section, it appears that this may be an important factor influencing the DO depletion significance of ammonia discharges to the DWSC by the city of Stockton.

Sediment Oxygen Demand (SOD). Litton's (2001, 2003) and Litton and Nikaido's (2001) studies of sediment oxygen demand have shown that the bedded sediment oxygen demand is not a major cause of oxygen depletion in the DWSC. Based on the information in Hatcher (1986) and Bowie, *et al*. (1985), the DWSC bedded SOD values tend to be lower than for many waterbodies. Litton (2003), using sediment cores, reported that the sediment oxygen demand of bedded sediments was on the order of 0.3 to 0.8 $g/m^2/day$. Suspending these sediments, however, or measuring the oxygen demand of the suspended sediments taken from near the bottom of the DWSC, showed greater oxygen demand than that found for the bedded sediments.

As discussed in Appendix C, the Hayes cruise data have shown that, frequently, there is slightly greater DO depletion in the DWSC in the near-bottom waters than at the surface, or at mid-depth. This appears to be associated with short-term vertical stratification (lack of complete vertical mixing) of the water column, where bedded sediment oxygen demand and that associated with suspended sediments stirred by tidal action from the bottom into the water column exert an oxygen demand in the near-bottom waters. Litton (2003) has reported that the maximum tidal flows of about 4,000 cfs create currents of about 0.2 ft/sec which are sufficient to suspend DWSC bedded sediments. Brown (2003) has reported that, based on Litton's SOD values, the SOD of the DWSC would exert an oxygen demand of about 1,115 to 2,230 lb/day between Channel Point to just upstream of Turner Cut.

Figure 13 (shown previously) shows the various sediment oxygen demand reactions of concern in the DWSC. These include the particulate organics (principally dead algae) serving as a source of oxygen demand through bacterial respiration. Associated with ammonification of the organic nitrogen in the particulates is the nitrification of ammonia present in the water column near the sediments. While there is DO depletion near the bottom of the DWSC, the DO concentrations of the near-bottom waters have been found to be sufficient to support nitrification.

In addition to the biotic reactions that occur in the suspended and bedded sediments, there are also abiotic reactions involving the oxidation of reduced iron and sulfur chemical species to ferric iron and sulfate by dissolved oxygen. These reactions are extremely rapid, and can consume large amounts of DO over short periods of time. Further information on these reactions has been provided by Lee and Jones-Lee (2000a). The significantly elevated SOD values reported by Litton (2003) associated with increased stirring of the water in the sediment cores are likely due to the abiotic reactions of dissolved oxygen with ferrous iron and sulfides.

Atmospheric Aeration. Using classical approaches for estimating reaeration based on water velocity, waterbody physical characteristics and other factors influencing atmospheric reaeration, Brown (2003) reported that the magnitude of atmospheric reaeration that is occurring in the DWSC due to the DO undersaturated conditions that typically exist in the surface waters of the DWSC, results in addition of oxygen from the atmosphere on the order of 4,500 lb/day with an oxygen deficit from saturation of 4 mg/L. During the summer when the water temperatures are 20 to 26ºC with a DO saturation of about 8 mg/L, this deficit is about 2 mg/L below the 6 mg/L WQO. Based on the calculations of Brown (2003), the bedded SOD equals about one-half of the dissolved oxygen added to the DWSC by atmospheric reaeration of the DWSC between Channel Point and just upstream of Turner Cut. Litton (2003) has indicated that Brown's estimate of bedded SOD of 2,000 lb of oxygen per day is on the upper end of his measured values. Generally, the bedded SOD was less than this amount.

Light Penetration. The studies of light penetration based on Secchi depth measurements by Kratzer and Dileanis (2002), Lehman (2002), Lehman and Ralston (2000), city of Stockton (Jones & Stokes, 2000, 2001, 2002), Litton (2001, 2003) and Litton and Nikaido (2001) have shown that Secchi depth of the DWSC is typically on the order of 1 to 3 ft. This Secchi depth translates to a photic zone (one percent depth of light penetration) -- i.e., where there is sufficient light for algal photosynthesis -- of 2 to 6 ft. Lind (1979) has reported that the Secchi depth is usually between 0.5 to 0.2 of the photic zone. Secchi depth is often found to be about 85 percent of the surface radiation. Lehman (2002) has reported that the photic zone in the DWSC is about 6 ft.

Lee, *et al.* (1995), based on a review of the limnological literature, have developed a general relationship for Secchi depth and chlorophyll *a*, where the light penetration is primarily controlled by algae causing light absorption/scattering. They found that for the range of planktonic algal chlorophyll *a* concentrations found in the SJR and the DWSC, the Secchi depth should be on the order of 3 to 6 ft. It is evident, since the DWSC Secchi depths are typically much less than these values, that inorganic turbidity in the SJR and DWSC greatly increases light scattering and absorption by particulate matter in the water column. The inorganic turbidity severely reduces the light penetration compared to light scattering and absorption due only to algae – i.e., self-shading. This reduced light penetration reduces the amount of oxygen added to the DWSC by algal photosynthesis. This reduced light penetration is a result of inorganic and organic turbidity derived from the SJR watershed, especially from the westside tributaries. The inorganic turbidity is due to erosion in the SJR watershed. Current efforts to control erosion in the SJR watershed could lead to increased algal growth in the SJR and the DWSC.

An additional source of reduced light penetration appears to be discharges of inorganic turbidity from the Mud and Salt Slough watersheds as well as other westside tributaries, and the colored water discharges from the managed wetlands wildlife refuges and gun clubs during the fall. These discharges have been found by Quinn (pers. comm., 2001) to release highly colored water which at times has apparently been transported down the SJR into the DWSC. It appears that, in the fall 1999 on at least one occasion (Litton, pers. comm., 2000), the dark-colored water that was present in the DWSC reduced light penetration sufficiently so that the normal algal photosynthesis that occurs in the surface waters was depressed, and a greater than normal DO depletion occurred as a result of this situation. The wetlands release of colored water in the fall is likely due to the flushing of the wetlands areas. Quinn (pers. comm., 2002) indicated that the wetlands discharges are accompanied by a *"recognizable sulphorous smell which persisted for 1-2 weeks."*

Temperature. Van Nieuwenhuyse (2002) has summarized the DWR Rough and Ready Island continuous monitoring station temperature measurements for the period 1983 to 2001. During the months of June through October (i.e., the normal period of low DO occurrence), temperatures ranged from about 20ºC to about 27ºC, with the maximum temperature normally occurring in July and August. Changes in temperature can have a significant impact on DO depletion within the DWSC. The reactions governing BOD exertion typically have a temperature dependence of rate doubling for each 10ºC increase in temperature. This means that there will be a significantly increased rate of BOD exertion in the DWSC during July and August, when the temperature is the highest.

Temperatures are also important in influencing the rate of algal growth in the SJR, upstream of Mossdale and within the DWSC. Further, increased temperatures decrease oxygen solubility. The impact of temperature on these various processes may be an important factor in influencing the year-to-year variability of DO depletion, especially during cooler summers and elevated SJR DWSC flows. Under these conditions, an oxygen demand load would be exerted at a slower rate, and therefore, with increased flows, there could be increased export of oxygen demand past Turner Cut into Columbia Cut-Central Delta that does not cause low DO in the DWSC. Week-to-week changes in temperature, which can be several degrees, may be influential in causing some of the variability of oxygen demand load DO depletion response within the DWSC. Additional information on temperature dependence issues is discussed in the subsequent modeling section.

Algal Nutrients. The various investigators in these studies have found that the concentrations of algal-available nutrients (nitrate and soluble orthophosphate) found in the SJR upstream of the DWSC, as well as within the DWSC, are typically on the order of at least 10 to 100 times those that have been found to be algal growth-rate-limiting. Nitrate concentrations in the DWSC are typically several mg/L nitrate N. Soluble orthophosphate concentrations are typically several tenths of a milligram per liter P. These concentrations are surplus of algal needs and are not significantly depressed during algal blooms. It is evident that the growth of algae in the SJR and the DWSC is not limited by available nutrients. This growth appears to be primarily controlled by limited light penetration, which is influenced by the inorganic turbidity derived from upstream erosional materials.

Forms of CBOD and NBOD. CBOD is composed of many different compounds, each with a specific rate of biochemical reaction with dissolved oxygen. While it has been found that algae and their remains are correlated with the BOD in the SJR at Mossdale and in the DWSC, it is understood that the BOD of algae depends on a variety of factors. Fitzgerald (1964) conducted studies on the factors influencing the measurement of BOD of algae. The wastewater treatment literature (see Fitzgerald, 1964) contains several papers reporting on the problems in trying to reliably measure the BOD of samples that contain large amounts of algae. Fitzgerald (1964) found that several types of algae can remain viable for several days to several weeks in the dark in a BOD bottle environment. This means that the long-term oxygen demand of some algae may be underestimated by the BOD_5 or even the BOD_{10} test although, based on the results of Fitzgerald, the 10-day BOD would likely better incorporate the algal oxygen demand than the 5-day test. Fitzgerald reported that a variety of factors, such as algal types, algal nutritional status, health, presence of algal remains and other materials, etc., influenced the measurement of the BOD of algae in short-term BOD tests. Based on these results, it is to be expected that there would be considerable variability in the relationship between planktonic algal chlorophyll *a* and BOD.

Foe, *et al*. (2002) showed a fairly constant relationship between the BOD_{10} and the BOD_5 for the SJR at Mossdale samples, where the 5-day value was about 65 percent of the 10-day value. Based on these results, it appears that the Mossdale samples that Foe, *et al*. (2002) used for the longer term BOD tests, where BOD was measured as a function of time, did not demonstrate the problems found by Fitzgerald (1964) and others in measuring BOD of samples with high algal content.

The CBOD loads to the SJR DWSC include the residual CBOD in the city of Stockton wastewater effluent that is of domestic/industrial origin. This CBOD would also be expected to have a different oxygen demand exertion rate than the CBOD in the SJR derived from algae in the SJR/DWSC.

The primary components of NBOD are ammonia and a variety of organic nitrogen compounds each with its own NBOD exertion rate. Since organic nitrogen compounds must be converted to ammonia before they can be nitrified and since the conversion rate of organic N to ammonia is typically modeled (see Bowie, *et al.*, 1985) with a first order rate constant of 0.1 per day, under elevated flows of the SJR through the DWSC, there would not be adequate time for all organic nitrogen compounds to be ammonified and nitrified to nitrate within the critical reach of the DWSC. Under SJR DWSC flows of 1,500 cfs or greater where the travel time through the DWSC is less than a week, much of the organic N added to the DWSC would not be converted to nitrate.

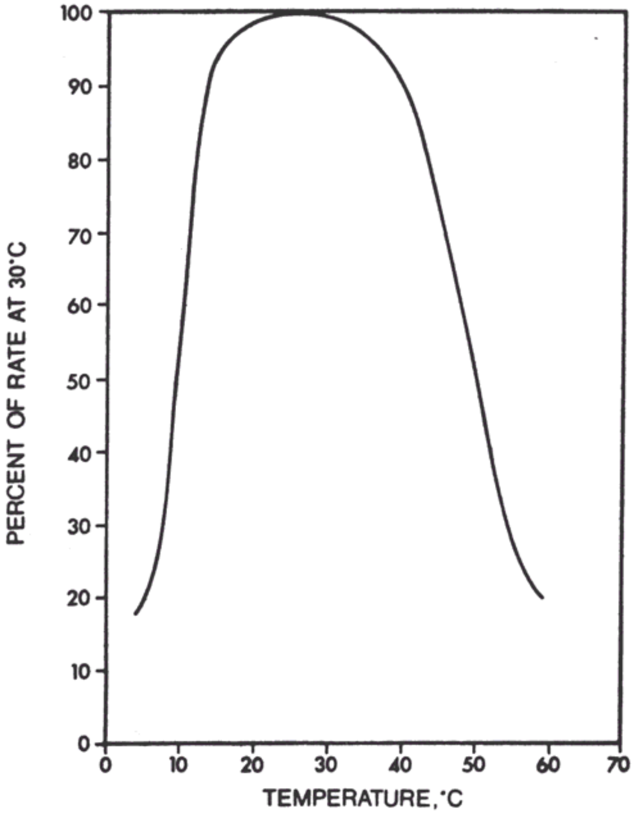
There are a variety of factors that are known to influence the growth of the nitrifying bacteria, *Nitrobactor* and *Nitrosomonas*, that can influence the conversion of ammonia to nitrite and nitrate. Trace metals such as copper are known to be important in this reaction in natural water systems. Bowie, *et al*. (1985) list such factors as pH, temperature, ammonia and nitrite concentrations, DO concentrations, suspended solids and organic and inorganic compounds, as influencing the nitrifications that could impact the measurement of NBOD in the BOD test and the exertion of oxygen demand in the SJR and DWSC. The growth of these bacteria is known to be highly temperature-dependent at low temperatures, where nitrification takes place at slow rates at temperatures below about 10ºC.

Figure 15 presents information on the effect of temperature on nitrification, from Bowie, *et al.* (1985). Examination of this figure shows that, in the temperature range of about 20 to 40ºC, the rates of nitrification are relatively independent of temperature. However, at 15ºC, the nitrification rate has decreased to 95 percent of this rate, while at 10ºC, the rates decrease to about 56 percent of the 20-30ºC value. Examination of the RRI temperature monitoring over the past couple of years shows that the winter temperatures are on the order of 50ºF, or 10ºC. The lowest value over the past three years was 8ºC. These results indicate that the rate of nitrification of ammonia in the DWSC during the winter will be significantly less than in the summer, and may, under the extreme low temperatures that have been observed, cease almost entirely.

An issue of particular importance is an understanding of the role of the city of Stockton's ammonia discharges during the late fall and winter as a cause of the low DO that has been found in the DWSC during this period. For example, as discussed below, in 2002 the City was discharging 22 mg/L ammonia nitrogen during February and March, when there were DO WQO violations in the DWSC. At that time, the temperature of the DWSC at the RRI station was about 12ºC. At this temperature, the rate of nitrification would be expected to be about 70 percent of the typical summer values. As a result, ammonia discharged during late fall and winter when the temperatures of the DWSC are low would be expected to persist (less nitrification) in the DWSC to a greater extent than in the summer.

Gallagher of HydroQual (pers. comm., 2002) noted that, at times, nitrification takes place at a higher rate than would be expected. The conditions that cause these higher rates of nitrification are not understood, and it is unclear whether this type of situation occurs in the DWSC. It is evident that much greater emphasis should be placed on understanding the role of ammonia as a cause of oxygen depletion in the DWSC. Litton (pers. comm., 2003) is, at the time of development of this write-up, conducting studies to better understand the role of ammonia as a cause of low DO in the DWSC during late January through early March 2003. A discussion of his preliminary results is included in a subsequent section of this report.

Figure 15
Effect of Temperature on Nitrification
as Reported by Borchardt (1966), from Bowie, *et al.* (1985)



Box Model Calculations

Lee and Jones-Lee (2000a,b; 2001), as part of developing the "Issues" report, presented "box model" calculations of the oxygen demand loads to the DWSC, and some of the factors influencing oxygen depletion within the DWSC. This analysis supported the previous conclusions of Brown and Caldwell (1970), McCarty (1969) and Jones & Stokes (1998) that the primary source of oxygen demand for the DWSC was algae developed in the SJR upstream of the DWSC. Lee and Jones-Lee reported that the upstream of Vernalis oxygen demand loads found during August and September 1999 were on the order of about 60,000 to 70,000 lb/day BOD_u, which were about 10 times the city of Stockton loads of oxygen demand to the SJR just upstream of the DWSC. However, in October 1999, with reduced algal growth in the SJR upstream of Vernalis associated with reduced light duration and cooler temperatures, the upstream algal oxygen demand load decreased to about 10,000 lb/day BOD_u, and the city of Stockton wastewater load increased to about the same value – i.e., the two were about equal. The increase in the city of Stockton load was associated with the City's discharge of significantly elevated concentrations of ammonia in its wastewater effluent.

The 2000 and 2001 studies conducted by the TAC were designed to develop data that could be used to further examine oxygen demand load sources, with particular reference to the city of Stockton wastewaters and the upstream sources. Tables 3, 4 and 5 present the results of box model calculations of oxygen demand sources for the DWSC based on the studies conducted in 1999, 2000 and 2001. Appendix F presents backup information on the basis for developing the estimated loads presented in these tables. Table 6 provides information on how the values in each of the columns of Tables 3, 4 and 5 have been developed. A discussion of the columns in these tables follows.

The city of Stockton used an analytical method for measuring ammonia with a detection limit of about 0.2 mg/L for ammonia N, and for organic N of about 0.5 mg/L N. These detection limits resulted in many of the SJR and DWSC ammonia and organic nitrogen concentrations being reported as "non-detect." Frequently, based on Dahlgren's data, the concentrations of these two parameters were just below the City's detection limits. For the purposes of the calculations presented in this report, it was assumed that "less than" values for ammonia and organic nitrogen were one-half of the detection limit. This approach probably underestimates the ammonia and organic N concentrations in the SJR and the DWSC samples to some extent, since half of the detection limits is typically, where data were available from Dahlgren, less than the concentrations measured by Dahlgren. This problem did not occur with the city of Stockton's effluent measurements since the concentrations were almost always above the analytical method detection limit.

The estimated oxygen demand loads at Mossdale are based on a city of Stockton-measured BOD_5 in mg/L, times the UVM flow of the SJR through the DWSC plus the city of Stockton wastewater flow in cfs, times 3, times 5.4, as shown in equation (2):

$$BOD_u \text{ (load to the DWSC)} = BOD_5 \text{ in mg/L (at Mossdale)} \times 3 \times 5.4 \times \text{(SJR DWSC flow in cfs+ city of Stockton wastewater flow)} \tag{2}$$

Table 3
DWSC Estimated Oxygen Demand Loads and Deficits
1999

Date	Flow (cfs)	Travel Time (days)			DO Deficit at Mossdale (lb/day)	Loads (BOD_u)						DO Deficit at R7 (lb/day)
		Mossdale to Channel Pt	Channel Pt to Turner Cut	Mossdale to Turner Cut		Mossdale + City (lb/day)	% City	Turner Cut (lb/day) (Calc.)	R7 (lb/day) (Meas.)	Sum of Deficits Below WQO (lb)	Oxygen Demand Exerted in DWSC (lb/day)	
8/24	850	1.8	9.4	11.2	0	64,226	18.5	26,544	66,096	16,300	-18,394	16,524
8/31	1,024	1.5	7.8	9.3	2,765	64,984	18.3	31,216	66,355	14,540	-20,725	19,354
9/07	1,022	1.5	7.8	9.3	+ 4,967	120,350	14.7	57,812	102,650	28,170	-1,064	18,764
9/14	1,157	1.3	6.9	8.2	+ 625	130,160	13.6	68,045	153,696	59,470	-49,777	26,241
9/21	1,135	1.3	7.0	8.3	2,452	146,109	12.1	75,668	154,451	32,680	-32,245	23,903
9/28	395	3.8	20.3	24.1	2,133	45,856	38.6	6,803	31,355	53,960	8,955	5,546
10/05	494	3.0	16.2	19.2	4,001	64,013	43.7	13,961	30,411	76,340	23,732	9,870
10/19	623	2.4	12.8	15.2	1,009	72,407	38.7	21,739	84,778	78,430	-31,211	18,840
10/26	592	2.5	13.5	16.0	3,516	75,952	36.9	21,351	76,723	57,340	-17,394	16,623

Table 4
DWSC Estimated Oxygen Demand Loads and Deficits
2000

Date	Flow (cfs)	Travel Time (days)			DO Deficit at Mossdale (lb/day)	Loads (BOD_u)						DO Deficit at R7 (lb/day)
		Mossdale to Channel Pt	Channel Pt to Turner Cut	Mossdale to Turner Cut		Mossdale + City (lb/day)	% City	Turner Cut (lb/day) (Calc.)	R7 (lb/day) (Meas.)	Sum of Deficits Below WQO (lb)	Oxygen Demand Exerted in DWSC (lb/day)	
6/20	1,202	1.2	6.7	7.9	+ 11,034	92,731	9.7	49,395	19,472	0	56,383	16,876
6/27	652	2.3	12.3	14.6	+15,492	50,193	17.9	15,795	10,562	5,360	30,477	9,154
7/11	634	2.4	12.6	15.0	+ 8,217	52,600	6.3	16,092	16,433	790	26,581	9,586
7/18	662	2.3	12.1	14.4	+ 11,082	49,415	6.7	15,845	18,231	9,290	21,890	9,294
7/25	770	1.9	10.4	12.3	+ 6,237	60,680	5.4	22,829	13,721	5,150	35,732	11,227
8/01	759	2.0	10.5	12.5	+ 12,296	47,806	12.6	17,817	19,673	10,930	15,017	13,116
8/08	837	1.8	9.6	11.4	+ 10,396	42,610	14.1	17,282	16,271	10,180	13,684	12,655
8/15	725	2.1	11.0	13.1	+ 11,354	45,933	13.1	16,333	14,094	3,440	19,311	12,528
8/22	1,251	1.2	6.4	7.6	+ 2,702	46,532	12.9	25,496	24,319	0	5,325	16,888
8/29	1,447	1.0	5.5	6.5	+ 3,126	57,571	10.4	34,330	18,753	0	17,721	21,097
9/12	1,277	1.2	6.3	7.5	+ 11,723	54,237	31.3	29,999	10,344	0	28,722	15,171
9/19	1,224	1.2	6.5	7.7	+ 8,592	60,623	28.0	32,907	29,743	10,490	12,373	18,507
9/26	1,372	1.1	5.8	6.9	+ 4,445	54,785	31.0	31,760	11,113	0	32,559	11,113
10/03	1,201	1.2	6.7	7.9	5,188	79,186	36.1	42,182	9,728	17,530	48,705	20,753
10/17	2,141	0.7	3.7	4.4	3,468	80,626	35.5	56,941	17,342	0	25,131	38,153
10/24	2,416	0.6	3.3	3.9	11,742	153,845	18.6	112,814	19,570	0	106,878	27,397
10/31	573	2.6	14.0	16.6	5,260	55,520	51.5	14,891	--	0	55,520	--

Table 5
DWSC Estimated Oxygen Demand Loads and Deficits
2001

		Travel Time (days)				Loads (BOD_u)						
Date	Flow (cfs)	Mossdale to Channel Pt	Channel Pt to Turner Cut	Mossdale to Turner Cut	DO Deficit at Mossdale (lb/day)	Mossdale + City (lb/day)	% City	Turner Cut (lb/day) (Calc.)	R7 (lb/day) (Meas.)	Sum of Deficits Below WQO (lb)	Oxygen Demand Exerted in DWSC (lb/day)	DO Deficit at R7 (lb/day)
6/12	674	2.2	11.9	14.1	+ 10,191	68,578	17.2	22,407	24,021	4,840	35,458	9,099
6/19	610	2.5	13.1	15.6	+ 12,188	69,116	17.1	20,174	10,277	23,570	45,992	12,847
6/26	746	2.0	10.7	12.7	+ 8,057	67,392	17.5	26,649	7,614	38,220	47,290	12,488
7/10	622	2.4	12.9	15.3	+ 10,748	74,981	15.3	22,301	13,099	27,380	53,485	8,397
7/17	657	2.3	12.2	14.5	+ 3,903	56,202	20.5	17,853	14,581	17,670	29,204	12,417
7/24	618	2.4	12.9	15.3	+ 13,683	51,546	22.3	15,331	9,711	30,310	32,825	9,010
7/31	599	2.5	13.4	15.9	+ 4,528	48,374	23.8	13,727	7,957	27,280	29,419	10,998
8/07	577	2.6	13.9	16.5	+ 623	45,603	46.7	12,346	4,674	1,720	32,516	8,413
8/14	583	2.6	13.7	16.3	+ 2,833	61,912	34.4	17,080	17,000	17,430	35,782	9,130
8/21	626	2.4	12.8	15.2	2,366	44,625	47.7	13,398	11,865	26,070	22,619	10,141
8/28	634	2.4	12.6	15.0	1,027	39,787	53.5	12,172	18,487	28,120	7,606	13,694
9/11	610	2.5	13.1	15.6	988	50,763	28.0	14,817	13,143	19,030	30,044	7,576
9/18	792	1.9	10.1	12.0	0	61,672	23.0	23,865	45,805	47,370	-385	16,252
9/25	1,143	1.3	7.0	8.3	6,789	64,195	22.1	33,246	38,885	42,940	-1,230	26,540
10/02	785	1.9	10.2	12.1	4,663	68,010	34.6	26,072	34,717	32,950	16,337	16,956
10/16	1,279	1.2	6.3	7.5	6,907	58,724	40.0	32,481	67,754	0	-29,750	20,720
10/23	2,068	0.7	3.9	4.6	15,634	67,052	35.0	46,473	68,008	0	-31,107	30,151

Table 6
Explanation of the Origin of the Columns in Tables 3, 4 and 5

Column Heading	**Explanation**
Flow (cfs)	UVM flow (measured or estimated) of SJR through DWSC
Travel Time (Mossdale to Channel Pt)	Estimated Travel Time from Mossdale to Channel Pt. for the flow indicated based on Figure 6
Travel Time (Channel Pt to Turner Cut)	Estimated Travel Time from Channel Pt. to Turner Cut (i.e., 7 miles of the DWSC) for the flow indicated based on Figure 7
Travel Time (Mossdale to Turner Cut)	Sum of Travel Time (Mossdale to Channel Pt) + Travel Time (Channel Pt to Turner Cut) for the flow indicated
DO Deficit at Mossdale	Amount of DO deficit below water saturation measured at Mossdale on the dates sampled
Loads (Mossdale + City)	Sum of the BOD_u estimated at Mossdale for the date indicated + Average daily BOD_u contributed by the City for that month
% City	Percent of the “Mossdale + City” BOD_u loads contributed by the City
Turner Cut (Calc.)	Estimated residual BOD_u load at Turner Cut, based on the “Mossdale + City” BOD_u loads × the exponential decay of the BOD_u loads: $BOD_t = BOD_u \times e^{-kt}$, where BOD_t = BOD ultimate at time t, BOD_u = BOD ultimate, k = BOD rate constant = 0.094/day, t= time of measurement, which is the estimated travel time from Mossdale to Turner Cut
R7 (Meas.)	BOD_u load measured at Turner Cut on the date sampled. This is the residual load, which is equal to the load that will be exported from the DWSC.
DO Deficit at R7	DO deficit below saturation measured at Turner Cut on the date sampled. This is the DO deficit below saturation that will be exported from the DWSC at Turner Cut.
Sum of Deficits Below WQO	Sum of the masses of DO deficits below the WQO applicable to the date sampled (5 or 6 mg/L), for each segment of the DWSC between Channel Pt and Turner Cut, which equals the sum for all segments of the (volume of the segment times its DO deficit below WQO) on the date sampled.
Oxygen Demand Exerted in DWSC	Total “Mossdale + City” BOD_u loads to the DWSC minus the R7 (Meas.) plus the DO Deficit at R7. This column represents the amount of BOD_u load added to the DWSC from upstream sources, minus (the oxygen demand BOD_u exported from the DWSC plus the oxygen deficit exported from the DWSC at Turner Cut).

The factor of 3 in equation (2) was used to convert the BOD_5 to an estimated BOD ultimate (BOD_u). This factor is based on the results of Litton (2003) and Lehman (2002), who reported that nitrification-inhibited BOD_5 measurements showed that 40 to 60 percent of the BOD_5 was due to carbonaceous BOD, with the remainder due to nitrogenous BOD. A 50-percent split between the two forms of BOD was used in these calculations. Based on samples taken from the SJR and the DWSC, Litton (2003) concluded that the $CBOD_5$ should be multiplied by 2.5 to convert to $CBOD_u$, and the $NBOD_5$ should be multiplied by 3.5 to convert to $NBOD_u$. With a 50-50 split between CBOD and NBOD, multiplying the measured BOD_5 by 3 yields an estimate of the sum of the $CBOD_u$ and $NBOD_u$. The factor of 5.4 converts all the units to lb/day.

During the study period (August, September and October 1999, and June through October 2000 and 2001), 43 sampling runs were made by the City, in which measurements were made of a variety of parameters at about a dozen locations in the DWSC and the SJR upstream of the DWSC. The data have been presented by the city of Stockton (Jones & Stokes, 2000, 2001, 2002). A summary of selected parts of these data is presented in Appendix F. The average BOD_5 measured by the City at Mossdale during the summer and fall, from August 1999 through October 2001, was 3.7 mg/L. The range was from 1.3 to 7.0 mg/L, with values less than about 2 mg/L occurring in October. The average sum of the chlorophyll *a* plus pheophytin *a* was about 64 µg/L during the three summer/fall periods. Again, the low values occurred in October. Based on the data presented in Appendix E, a BOD_5 value of 5 mg/L corresponds to a measured value of about 100 µg/L of chlorophyll *a* plus pheophytin *a*. As discussed above, the primary source of BOD at Mossdale was algae that developed in the SJR upstream of this location.

Examination of Tables 3, 4 and 5 shows that the average flow of the SJR through the DWSC during the summer/fall 1999, 2000 and 2001 was about 930 cfs. The flows ranged from a low of 395 to a high of 2,416 cfs. Many of the values are in the range of 600 to 1,200 cfs. The average flow of 930 cfs yields an average travel time between Channel Point and Turner Cut of 8.6 days.

The city of Stockton oxygen demand loads are based on measured concentrations of $CBOD_5$ using a nitrification-inhibited BOD_5 measurement, times 2.5 to calculate the $CBOD_u$, plus the ammonia plus organic nitrogen concentration measured in the effluent times 4.57 (to convert ammonia nitrogen concentrations to $NBOD_u$). The concentrations of $CBOD_u$ plus $NBOD_u$ were multiplied by the City's effluent flow and 5.4 to calculate the total BOD_u load contributed by the City's wastewater discharges to the SJR just upstream of where the SJR enters the DWSC at Channel Point. The City's average effluent flow to the SJR during the summer and fall 1999, 2000 and 2001 was 42 cfs. The average for the summer/fall $CBOD_5$ during the study period was 5.3 mg/L. The average effluent NH_3 was 12 mg/L N with a monthly average range of about 3 to 25 mg/L N. The average organic N was 3.2 mg/L with a monthly average range of 1.7 to 4.5 mg/L N. The monthly average planktonic algal chlorophyll *a* in the City's wastewater effluent was 23 µg/L with a monthly average range of 5 to 41 µg/L during the summer/fall of the three-year study period.

The nitrification-uninhibited BOD_5 of the City's effluent was 7 mg/L. However, it was found in this review that the BOD_5 value is not a reliable indication of the BOD_u since it did not properly account for the NBOD in the sample. Brown (pers. comm., 2002) suggested that this value is low since there may not be sufficient assimilatable organic carbon in the BOD bottle to enable the nitrifying bacteria to oxidize the ammonia in the sample.

The sum of the Mossdale average monthly oxygen demand load plus the city of Stockton average monthly oxygen demand load is presented in Tables 3, 4 and 5, as the "Mossdale + City" column. The average load over the three summer/fall periods is 86,000 lb/day, with the City's contribution to this load averaging about 25 percent of the total load. During the study period, the City's percent contribution to the total load of BOD_u to the DWSC ranged from about 5 percent to about 54 percent. The City's $CBOD_u + NBOD_u$ loads ranged from about 3,000 lb/day to 30,000 lb/day during the summer/fall months. During the winter/spring, the City's contribution of $CBOD_u + NBOD_u$ loads can be as much as 37,000 lb/day. Normally, but not always, the SJR flow through the DWSC during the late winter and spring is considerably elevated compared to the summer/fall. The organic nitrogen $NBOD_u$ loads during the summer/fall ranged from about 2,000 to almost 5,000 lb/day. The remainder of the $NBOD_u$ load is due to ammonia.

Lehman (2002) has concluded that the city of Stockton's ammonia discharges are likely a major cause of DO depletion in the DWSC. According to Lehman (pers. comm., 2002), oxygen demand in the DWSC was primarily caused by nitrogenous BOD (NBOD) that reached up to 85 percent of the oxygen demand in the DWSC at Rough and Ready Island in 2000 and 2001. Lehman (2002) further reported that the total and nitrogenous BOD in the DWSC was associated with ammonia concentrations that varied directly with ammonia discharged from the Stockton wastewater treatment plant in both 2000 and 2001.

The CVRWQCB (2002a) has adopted a revised NPDES wastewater discharge permit for the city of Stockton that limits the monthly average ammonia concentration in the effluent to 2 mg/L for aquatic life toxicity reasons. The permit has been appealed to the State Board by the city of Stockton. If the permit is upheld, then the oxygen demand load reduction would result in up to a 20,000 lb/day BOD_u reduction during the time that the city of Stockton's wastewaters contain 20 or more mg/L ammonia N. This reduction will be most significant during the fall months, when the City's effluent tends to contain on the order of 20 mg/L ammonia N, and when the SJR DWSC flow is reduced to a few hundred cfs during October/November when the upstream algal load of BOD_u is reduced. The city of Stockton's revised NPDES permit is not based on the potential for ammonia discharged by the City to be an oxygen demand source in the DWSC. It is based on the CVRWQCB's findings that the City's wastewater discharges of ammonia at times could be in excess of the US EPA (1999a) revised water quality criteria for ammonia. In 1999 the US EPA revised its ammonia criteria to reflect new information that indicated that ammonia is not as toxic to fish as originally thought. The US EPA is now allowing a longer-term (monthly) ammonia concentration averaging period in implementing the water quality criteria than has been used in the past.

Examination of Tables 3, 4 and 5 for the total load (Mossdale + City) shows that this load, at times, especially under elevated SJR flows through the DWSC, can be as much as 150,000 lb/day BOD_u. For example, on October 24, 2000, with an SJR DWSC flow of 2,416 cfs, the total estimated load was 153,800 lb/day BOD_u. It is of interest that a 1 mg/L difference in BOD_5

measured at Mossdale translates to about 16,200 lb/day of BOD_u at a flow of 1,000 cfs. Therefore, small changes in the measured BOD at Mossdale can cause substantial changes in the measured oxygen demand load (BOD_u) added to the DWSC at Channel Point.

Mossdale could be exerted in the SJR between Mossdale and Channel Point. Tables 3, 4 and 5 present the estimated travel times between these two points as a function of the flows that were measured during the study period based on the relationships presented in Figures 6 and 7. Typically, there is a 1- to 2.5-day travel time between Mossdale and Channel Point, provided that the UVM flows are above about 600 cfs. With SJR DWSC flows on the order of about 400 cfs, there is about a 4-day travel time between Mossdale and Channel Point. Several investigators (Lehman, 2002; Litton, 2003; Van Nieuwenhuyse, 2002) have indicated that the algae present at Vernalis appear to be healthy; however, when they enter the tidal reach of the SJR, which occurs between Vernalis and Mossdale, they become distressed and start to die. It appears, therefore, that a several-day travel time between Mossdale and Channel Point is sufficient time for some of the BOD measured at Mossdale to be exerted by the time it reaches Channel Point. This would be particularly important under UVM SJR DWSC flows less than about 500 cfs.

An attempt was made to examine the changes in BOD_5 between Mossdale and Channel Point by comparing the BOD_5 measured at Mossdale to the BOD_5 measured at Channel Point (R3) (see Appendix F). The average BOD_5 at Mossdale over the study period was 3.7 mg/L. The average BOD_5 at Channel Point was 3.6 mg/L, with a range from 1.4 to 9.5 mg/L. While individual sampling runs show increases or decreases between the two locations, on the average, there is no change in the BOD_5 between Mossdale and Channel Point. It appears that, while some of the BOD present at Mossdale is exerted in the SJR by Channel Point, the amount exerted is compensated for by the additional BOD load added by the City just upstream of Channel Point. Also, there would be some algal growth in the SJR between Mossdale and Channel Point, which would add BOD to the SJR at Channel Point.

A comparison between the dissolved oxygen concentrations found at Mossdale and saturation values for the measured temperature shows that, frequently, the waters at Mossdale are supersaturated with respect to DO by, at times, as much as 4 mg/L. Occasionally, DO may be undersaturated by 0.5 to 1 mg/L. However, at Channel Point, the summer/fall average DO during the study period was 5.8 mg/L, which, on the average, was about 2.7 mg/L under saturation. While the City's effluent, which enters the SJR just upstream of Channel Point, is usually undersaturated with respect to DO by about 0.5 to 1.7 mg/L, the City's effluent flow of about 40 to 50 cfs is such that the effluent undersaturation does not affect the DO saturation of the SJR with SJR DWSC flows of about 200 or more cfs. Litton (pers. comm., 2002) has reported that the DO in the SJR near where the city of Stockton discharges its wastewater effluent is typically at saturation. Since this location is about two miles upstream of Channel Point, it does not appear that the DO concentrations several mg/L below saturation normally found at Channel Point are due to BOD exertion in the SJR upstream of the DWSC. Litton has indicated he believes that the average 2.7 mg/L DO undersaturation at Channel Point during the summer/fall study period is due to mixing of low-DO water within the DWSC with the SJR water.

Tables 3, 4 and 5 present (in the column labeled "Sum of Deficits Below WQO") the amount of oxygen in pounds that would need to be added to the DWSC to eliminate violations of the water quality objective at various locations in the DWSC between Channel Point and Turner Cut. These values are based on the City's mid-depth measurements of dissolved oxygen at each of the sampling stations (R3 to R7). This DO was compared to the water quality objective (5 or 6 mg/L, depending on the month). Based on the information provided by Brown (2002a) on the volume of the DWSC associated with each sampling station segment and the measured DO concentrations relative to the WQO, the total magnitude of the oxygen demand deficit was computed. The oxygen demand deficits for the segments were summed, and the values entered into Tables 3, 4 and 5 for the dates of the individual sampling runs. Examination of these tables shows that, while there were a number of sampling runs made in 2000 where there were no deficits below the WQO, in 1999 over 78,000 lb of oxygen would be needed to satisfy the WQO deficit that occurred on October 19. Similarly, on September 18, 2001, approximately 47,000 lb of oxygen would be needed to satisfy the DO deficit below the water quality objective. The overall average WQO deficit for the three-year study period was 20,000 lb.

The average DWSC DO deficit below saturation for 1999 was 3.7 mg/L. In 2000 it was 2.7 mg/L, and in 2001, 3.2 mg/L. With a DWSC volume on the order of 15,000 ac-ft and a 3 mg/L deficit below water saturation, 120,000 lb of DO deficit frequently exists in the DWSC during the summer/fall months. Since the water at Mossdale is saturated with respect to DO, a considerable part of the oxygen demand associated with the Mossdale + City's load is exerted in reducing the DWSC DO concentrations to or below the water quality objective.

Tables 3, 4 and 5, column "DO Deficit at R7," presents the DO deficit from saturation exported load measured at Turner Cut. The "DO Deficit at R7" column is the amount of DO deficit that is being exported to the Central Delta by the Sacramento River cross-SJR DWSC flow caused by the State and Federal Projects' pumping to Central and Southern California. This deficit also represents oxygen that was used in the DWSC to satisfy BOD that was not compensated for by atmospheric surface aeration and algal photosynthesis. The average DO deficit exported from the DWSC at Turner Cut was about 16,000 lb/day with a range of about 5,000 to 38,000 lb/day. As discussed above, the atmospheric oxygen reaeration, with a 4 mg/L deficit from saturation, is about 4,500 lb/day.

Examination of Table 3, which presents the deficits for 1999, shows that the average DO deficit below the water quality objective in the DWSC during August through October was 46,000 lb. Table 4 shows that the average deficit, for those sampling runs where there was a deficit below the water quality objective, was about 8,000 lb during 2000. Table 5 shows that, during 2001, the average deficit, for those sampling runs were there was a deficit below the water quality objective, was 22,000 lb. The magnitude and location of these deficits within the DWSC is shown previously in Figure 9 (Hayes cruise data). Examination of this figure shows that 1999 had much greater deficits in terms of magnitude and extent than were found in 2000 and 2001. The Figure 9 data was based on the Hayes cruises, while Tables 3, 4 and 5 were based on the data collected by the city of Stockton.

The column labeled "R7 BOD_u loads (Meas.)" is the amount of BOD_u exported form the DWSC at Turner Cut. The average BOD_u export for the study period was about 34,400 lb/day. This is the BOD_u load that enters the Central Delta via Columbia Cut and Turner Cut. The sum of the R7 BOD_u export and the R7 DO deficit (average 16,000 + 34,400 lb/day) is the total oxygen demand load to the Central Delta. At times, in excess of 157,000 lb/day of oxygen deficit below saturation is exported into the Central Delta. As discussed by Lee and Jones-Lee (2000a) there is no information on DO depletion problems in the Central Delta in Columbia Cut, Turner Cut or Middle River below where these two channels mix with Middle River (see Figures 1 and 2).

The column presented in Tables 3, 4 and 5 labeled "Oxygen Demand Exerted in DWSC" is an assessment of the difference between the BOD_u added to the DWSC (Mossdale + City), minus the sum of the DO deficit from saturation at R7 and the oxygen demand exported from the DWSC ("R7 (Meas.)" column). The negative values shown in the "Oxygen Demand Exerted in DWSC" column represent a net production of oxygen demand in the DWSC compared to the Mossdale + City load. For 1999 the excess oxygen demand present at R7 (Turner Cut), compared to the load, represented as much as 50,000 lb/day. Typically in 1999, there was more oxygen demand plus DO deficit exported from the DWSC than added to it from upstream loads. Some of this difference could be related to the sampling frequency and the fact that there is often a one- to two-week lag between a measured Mossdale plus City load and when the residual load reaches R7. Probably the greatest cause of the differences relates to the approach used for calculations of loads, and potential problems in reliably measuring the BOD of algae and the nitrification reactions.

Examination of the data for 2000 and 2001 (Tables 4 and 5) shows that for positive values there was a reduction in the oxygen demand loads present at R7, compared to the load derived from the City and present in the SJR at Mossdale, that ranged from about 5,000 to about 107,000 lb/day. There were no negative values (net oxygen demand production in the DWSC) in the "Oxygen Demand Exerted in DWSC" column for 2000 (Table 4), and the negative values in this column for 2001 (Table 5) were in late September and October. The October data for all three years are different from the summer data. This may be related to the decrease in algal load in the SJR at Mossdale and the increase in the City's ammonia discharges.

Brown, on behalf of the city of Stockton (Jones & Stokes, 2000, 2001, 2002) has examined the ratio of the city of Stockton measured concentrations of electrical conductivity, chloride, BOD, ammonia, organic nitrogen, chlorophyll *a*, pheophytin *a* and several other constituents present at R3 (Channel Point) and R7 (just upstream of Turner Cut). In the three years, as expected, the ratios of the average concentration of electrical conductivity and chloride at R3 and R7 were 1.0. This indicates that these constituents were conservative in the passage through the DWSC and that there were no major additions or dilutions between R3 and R7.

In 1999 the overall average BOD_5 ratio showed no change between the two locations, while in 2000 and 2001 the overall average BOD_5 at R7 was 0.53 and 0.6 times the overall average BOD_5 at R3, respectively. Based on the information presented in Appendix F, the overall ratio of BOD_u at Turner Cut to BOD_u at Channel Point over the three years of study was 0.68. In 1999 the ammonia R7 to R3 ratio was 0.4, while in 2001 it was 0.3. The overall average Kjeldahl nitrogen ratio in 1999 was 0.6, and in 2001, was 0.7. The concentrations of ammonia and Kjeldahl nitrogen in the DWSC during 2000 (which was a high-flow year) were less than the detection limit used by the City.

In 1999 the R7 to R3 overall average ratio for chlorophyll *a* and pheophytin *a* was 0.8 and 0.6, respectively, while in 2000 it was 0.6 and 0.4, respectively. In 2001, it was 0.85 and 0.45, respectively. These results show that, in general, the concentrations of oxygen-demanding constituents (BOD, ammonia/organic nitrogen and chlorophyll *a*/pheophytin *a*) decreased down the DWSC. However, there were times where, on an individual day, the concentrations of BOD and planktonic algae increased between R3 and R7. This would indicate that during certain times there was an apparent increase in the concentration of algae down the DWSC.

The "Turner Cut (Calc)" column is the calculated residual oxygen demand that should be present at R7, assuming that the total BOD_u load decays in accord with Litton's (2003) first-order rate constant of 0.094 per day. This BOD_u decay relationship is shown in equation (3).

$$L_t = BOD_u \times e^{-kt} \qquad (3)$$

Where

L_t = BOD ultimate at time t in mg/L
BOD_u = BOD ultimate in mg/L
k = BOD rate constant = 0.094/day
t = time of measurement in days

Based on the total BOD_u (Mossdale + City) added to the DWSC and the travel time from Channel Point to Turner Cut for the City's sampling run, the "Turner Cut (Calc)" is developed. This column is an estimate of the BOD_u that would be expected to be present at Turner Cut if the only factor influencing BOD removal was its decay in accord with the first-order relationship that typically describes BOD exertion. A comparison of this column with the "R7 Meas." column shows that sometimes there is more BOD_u measured at Turner Cut than would be expected. The three-year average Turner Cut calculated is about 29,000 lb/day with a range of 7,000 to 113,000 lb/day, while the three-year average measured BOD_u at Turner Cut was 34,400, with a range of 5,000 to 154,000. This positive difference could be due to algal growth in the DWSC. Negative R7 measured values compared to the calculated values could reflect the loss of algae and detritus that is removed by settling in the Channel. There is no apparent pattern in the data as to the cause of the excess or negative differences.

Brown, on behalf of the city of Stockton (Jones & Stokes, 2000, 2001, 2002) has examined the overall vertical gradient ratios of constituents in the DWSC during the three years of study. In general, the overall average vertical gradient ratios for most dissolved constituents between the surface and near-bottom waters during the summer/fall over the three years was about 1.0, indicating that, overall, most of the time, the concentrations of temperature, pH, BOD, phosphorus, electrical conductivity, nitrate and chloride in the surface waters are similar to those near the bottom. This means that, with respect to these parameters, the DWSC at any station along the DWSC is vertically well-mixed.

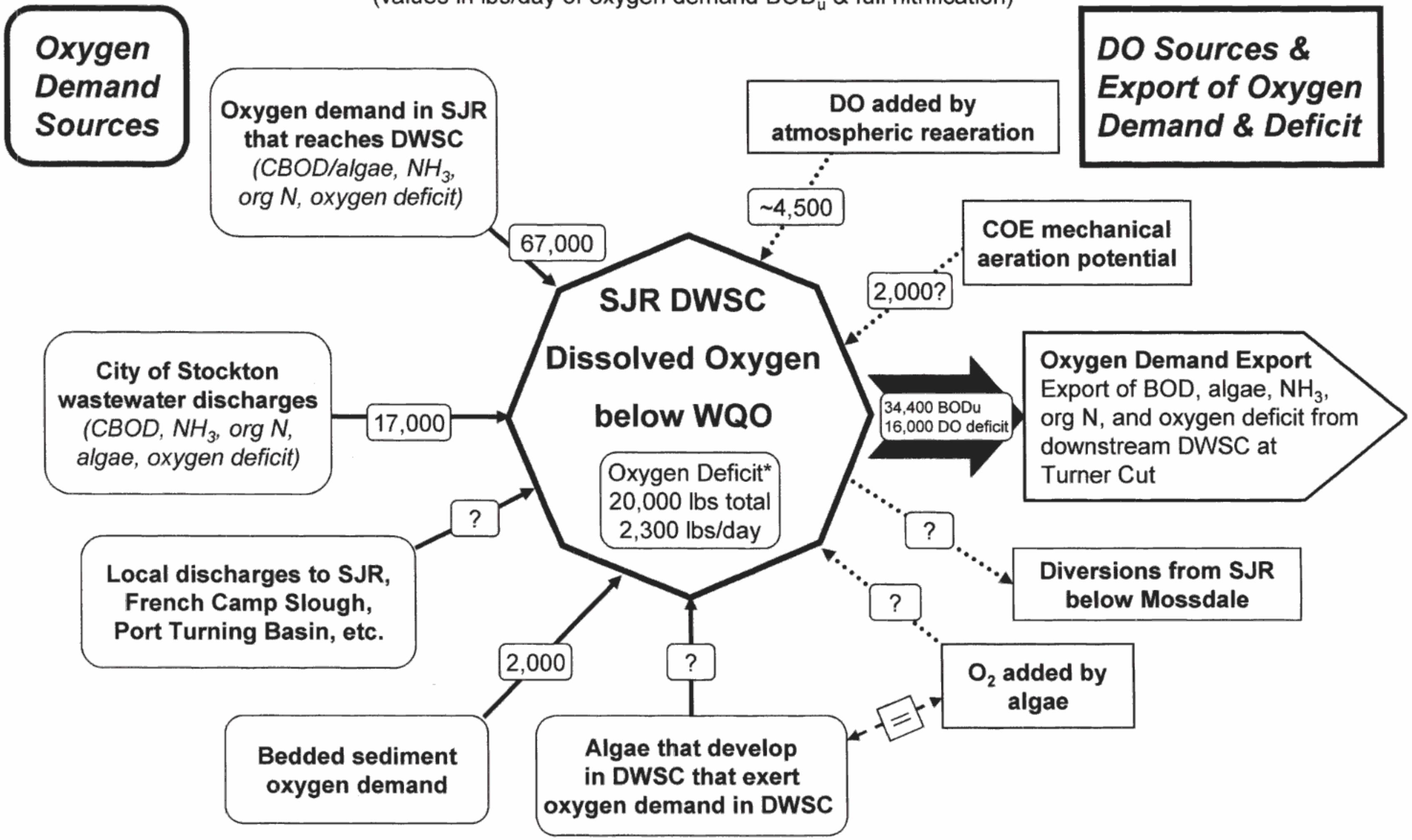
There were, however, some important differences between the surface and bottom, especially with respect to particulate constituents such as total suspended solids (TSS), volatile suspended solids (VSS), turbidity, chlorophyll *a* and pheophytin *a*. The near-bottom waters tended to have higher concentrations of particulates. This is in accord with Litton's (2003) finding that the tidal currents in the DWSC are sufficient to suspend sediments into the near-bottom waters. Brown also reported that the DO near the bottom was almost always less than that at the surface, by as much as 0.5 to several mg/L. This is apparently due to the algal photosynthetic production of oxygen in the near-surface waters and the suspended sediment oxygen demand in the near-bottom waters.

While there is not a permanent density (temperature) difference between surface and bottom waters, it appears that there may not be sufficient vertical mixing in the DWSC to fully mix the water column each day. Evidently, the tidal currents do not induce full vertical mixing in the DWSC. Examination of the RRI daily temperature data for 2000 and 2001 and 2002 (not presented in this report, available from http://cdec.water.ca.gov/cgi-progs/queryF?s=rri&d= now&span=12hours) shows that, typically, there is a 1 to as much as 4 ºF diel temperature change in the near-surface waters of the DWSC. The highest temperatures are recorded about 4:00 pm, with the lowest temperatures occurring in early morning. This situation reflects a surface water warming that leads to a temporary stratification of the water column, with the cooling that occurs in late afternoon/evening associated with mixing of the water column and loss of heat through the surface to the atmosphere.

Mass Balance Evaluation. Figure 16 presents a diagram of the three-year summer/fall average loads of oxygen demand 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. This diagram is based on the average of 43 city of Stockton sampling runs during August-October 1999 and June-October 2000 and 2001. This figure shows that on the average during the summer and fall the oxygen demand (BOD_u) load at Mossdale added to the DWSC is on the order of 67,000 lb/day. The city of Stockton on average adds about 17,000 lb/day of BOD_u. The upper end of Litton's measurements of sediment oxygen demand was about 2,000 lb/day, for a total average oxygen demand load of about 86,000 lb/day BOD_u.

One of the sources of oxygen demand to the DWSC that has not been adequately characterized is discharges from local sloughs (tidal drainage ways) that are connected to the SJR downstream of Mossdale or directly to the DWSC and the Turning Basin from the city of Stockton. In June 2001, members of the TAC, as part of the Quinn/Tulloch agricultural diversion/discharge studies, toured French Camp Slough by boat and visually observed that the waters in the Slough contained high planktonic algal chlorophyll *a* in the surface water, and the mid-bottom to bottom waters had low DO, indicating that there was considerable biological activity occurring in French Camp Slough. Since French Camp Slough is tidal, there is some exchange between French Camp Slough and the mainstem of the SJR on each tidal cycle. As a result, additional algal loads could be added to the SJR that are developed within French Camp Slough. Further, low-DO

Figure 16. Box Model of Estimated DO Sources/Sinks in SJR DWSC
(SJR DWSC Flow: 930 cfs; Travel Time: 8.6 days)
(values in lbs/day of oxygen demand BOD_u & full nitrification)



* Total oxygen deficit below oxygen saturation ≈ 120,000 lbs; 14,000 lbs/day

waters from French Camp Slough could be mixed into the waters of the SJR, contributing to an oxygen deficit.

As discussed by Lee and Jones-Lee (2000a), based on the limited data collected by King (2000), French Camp Slough is a potentially significant source of oxygen demand when the SJR flow through the DWSC is a few hundred cfs. The oxygen demand in French Camp Slough could arise from upstream French Camp Slough sources of agricultural runoff and wastewater discharges from dairies, as well as algal growth within the Slough. During October 1999, based on limited data, it was estimated that French Camp Slough was adding about 1,700 lb/day of BOD_u to the SJR downstream of Mossdale.

The city of Stockton has a number of tidal sloughs that connect directly to the SJR, the Port of Stockton Turning Basin or the DWSC. These include Mosher Slough, Five-Mile Slough, Smith Canal, Calaveras River, Walker Slough and Mormon Slough. Generally, water quality in these sloughs is poor during the summer, where low DO concentrations exist at mid-depth and near the bottom. Further, there can be appreciable algal concentrations in the surface waters. There is tidal exchange of waters between these sloughs and the SJR/DWSC. The tidal exchange could bring some additional oxygen demand load into the SJR and DWSC from these sloughs. However, based on the limited net flow, it is expected to be of minor significance. The amount of oxygen demand loads from these tidal sloughs has not been quantitatively evaluated. A subsequent section discusses the potential significance of city of Stockton stormwater runoff-associated oxygen demand on DO in these tidal sloughs and its potential impact on the DO resources of the DWSC.

Another source of oxygen demand materials (algae) is the Port of Stockton Turning Basin and the waters between the Turning Basin and McLeod Lake (see Figure 3). The channel between the Turning Basin and McLeod Lake develops large populations of algae, which, through tidal action, are to some extent transported into the DWSC and thereby mixed with SJR DWSC water. Further, studies on the Turning Basin have shown that it tends to have higher concentrations of algae and lower concentrations of DO in the bottom waters than at Channel Point in the DWSC. At this time, the impact of the Turning Basin and the upstream channel to McLeod Lake on DWSC water quality has not been quantified.

Atmospheric reaeration adds about 4,500 lb/day and the Corps of Engineers' mechanical aerator at Channel Point has a potential of adding about 2,000 lb/day of dissolved oxygen to the DWSC waters. This aerator is only operated some of the time when there is a DO deficit in the DWSC during the late summer and fall. It is not operated during the early to mid-summer. Further, Brown (2003) reported that the COE aerator operates at less than its design capability.

The algae that develop in the DWSC represent a potential oxygen demand that is compensated for by the oxygen they produce in photosynthesis. However, as discussed above, there likely is a separation of the photosynthetically produced oxygen and the DWSC-produced algal oxygen demand as a result of the algae and detritus derived from the algae settling and adding to the near-bottom oxygen demand. The photosynthetically produced oxygen remains in the water column, reducing the magnitude of water column oxygen deficit.

Assuming that surface reaeration adds 4,500 lb/day of DO to the DWSC and assuming that the COE aerator is not operating, it is estimated that the total oxygen demand sinks are about 70,900 lb/day. This value is compared to the oxygen demand load of 86,000 lb/day. There is about a 15,100 lb/day difference. This difference is well within the reliability of oxygen demand measurements at Mossdale, in the City wastewater discharges and the measurements made at R7 near Turner Cut. At the average flow of the SJR DWSC of 930 cfs, a one mg/L error in BOD_5 measurement translates to about 15,000 lb/day BOD_u. Considering all the approximations and assumptions used to make these estimates there is remarkable agreement (e.g., within about 25 percent) between the three-year summer/fall average loads and sources/sinks of DO in the DWSC.

Figure 16 shows a potential loss of oxygen demand from the SJR between Mossdale and Channel Point, due to agricultural diversions of irrigation water. According to Quinn/Tulloch (2002) it is estimated that the maximum diversions during the May through August irrigation season would be about 500 cfs. Again, these diversions are likely to be the most significant during the times when the SJR DWSC flow is a few hundred cfs or less, which would occur during periods of drought and/or when essentially all of the SJR flow at Vernalis is diverted into Old River for export to Central and Southern California.

Table 7 summarizes the oxygen demand, sinks/exports of oxygen demand and oxygen deficit for the DWSC.

Table 7
Average Mass Balance of Oxygen Demand Loads and Sinks

Oxygen Demand Loads	**lb/day**	
BOD_u Load in the SJR at Mossdale	67,000	
BOD_u Load – City of Stockton	17,000	
Oxygen Demand Exerted by Bedded Sediments	2,000	
Total		86,000
Oxygen Demand Sinks and DO Sources	**lb/day**	
Atmospheric Reaeration	4,500	
COE Mechanical Aeration (potential)	2,000	
BOD_u Exported at Turner Cut	34,400	
DO Deficit Exported at Turner Cut	16,000	
DWSC O_2 Deficit Below Saturation	14,000	
Total		70,900
Mass Balance Difference		15,100 lb/day

On the average about 50,400 lb/day of BOD_u and oxygen deficit below saturation are exported from the DWSC at Turner Cut. The total average oxygen deficit from the applicable WQO is about 20,000 lb which, when divided by the average travel time between Channel Point and Turner Cut of 8.6 days based on an average SJR DWSC flow of 930 cfs, translates to an average 2,300 lb/day oxygen deficit. This is an estimate of the average amount of aeration that is needed to eliminate the DO deficit below the current water quality objective. The total oxygen deficit during the summer and fall for all three years below saturation is about 120,000 lb or 14,000 lb/day.

Examination of the data presented in Tables 3, 4 and 5 shows that in 1999 there were several days where on the order of 75,000 lb of oxygen deficit occurred in the DWSC. In 2001, there were several days where there was on the order of 50,000 lb of oxygen deficit. Dividing the deficit found by the hydraulic travel time for the sampling run shows that the greatest deficits found during the three years of study would require the addition of about 6,000 lb/day of DO to eliminate violations of the WQO. The actual amount of aeration that will be needed will be greater than the projected amount in order to cover the inefficiency of various types of aerators.

The CVRWQCB staff (Gowdy and Foe, 2002) have proposed that, during the initial phase of TMDL implementation, the water quality target for DO concentration for the daily minimum seven-day running average be set at 5 mg/L with no value less than 3 mg/L. This target will require less aeration than that projected in the above calculations since this interim target would allow deviations from the current water quality objective of 6 mg/L during the period September 1 through November 30. With a DWSC volume of 18.3 x 10^9 liters (15,400 ac-ft), 1 mg/L of DO deficit represents about 40,000 lb of oxygen demand. Decreasing the WQO from 6 to 5 mg/L during September, October and November will decrease the deficit below the WQO during the initial implementation phase of the TMDL by about 40,000 lb/day. Examination of the "Sum of Deficit Below WQO" column in Tables 3, 4 and 5 shows that during 1999, using the 5 mg/L WQO rather than the 6 mg/L WQO applicable during September through November, two of the nine city sampling runs (on 9/7 and 9/21) would not have shown a violation of the WQO.

Following the same approach for fall 2000 shows that there would have been no WQO violations during this period. However, there were several WQO violations of up to about 11,000 lb during the summer months when the WQO was 5 mg/L. During 2001 all but two of the WQO violations during September and October would have disappeared if the interim proposed 5 mg/L DO objective were used rather than the 6 mg/L value. There were WQO violations in the summer that would have to be addressed by aeration/oxygen demand load control. This analysis does not consider the proposed daily minimum seven-day running average allowed violation of the 5 mg/L interim DO WQO so long as the DO does not decrease below 3.0 mg/L. Considering the running daily minimum seven-day average approach would further reduce the number of WQO violations during the summer and fall.

Overall, based on box model calculations, it appears that on the average, supplemental aeration on the order of several thousand lb/day of oxygen added to the DWSC would be adequate to satisfy the oxygen demand that exists in the DWSC to meet the proposed interim target WQO. There are situations where much larger amounts of DO will be needed to prevent DO depletion below the proposed interim DO WQO and the current CVRWQCB WQO.

Need for Further Data Evaluation. The relationship between SJR DWSC flow, oxygen demand load and DO depletion in the Deep Water Ship Channel, in the flow range of 600 to 1,500 cfs, is not obvious. However, as shown in Figure 9, when the SJR DWSC flow is above about 2,000 cfs the DO depletion problems are essentially eliminated, and it is likely that aeration would not be necessary to meet the WQO during these higher flows. The week-to-week variation is sufficiently complex so that an adaptive management approach will have to be used to learn how to best aerate the DWSC to meet the WQO. Pilot aeration studies will need to be conducted for several years to determine how best to aerate the DWSC in the most cost-effective manner. This issue is discussed further below.

Further analysis of the existing database for the SJR and its tributaries is needed as time and funds permit. The additional data review should include an examination of the estimates of oxygen deficit in the DWSC based on the DWR Hayes cruises. These cruises provide information on DO depletion below the water quality objective and saturation for surface and bottom waters at several locations in the DWSC since 1983. In addition, detailed review of the city of Stockton data is needed to examine on a sampling-run-by-sampling-run basis the internal consistency of the measured concentrations of BOD, ammonia and chlorophyll *a* from Mossdale to Turner Cut. This examination will help to determine if there are any spurious data points at Mossdale or Turner Cut which cause the results of the box model calculations for a particular sampling run location to be out of line from other runs and what would be expected. Particular attention should be given to the changes in chlorophyll *a* down the DWSC which would explain the high BOD_u load being exported from the DWSC at certain times.

One of the issues that needs to be addressed in more detail is the influence of Mossdale to Channel Point travel time as a function of DWSC flow to determine if the variability in response is related to the lag time between when oxygen demand loads are assessed at Mossdale and when the responses to these loads occur at Turner Cut. There is need to consider load-response relationships in the DWSC from a Lagrangian transport of oxygen demand loads through the SJR upstream of the DWSC and within the DWSC perspective. Under low flow conditions there can be as much as two weeks' difference between when a total oxygen demand load to the DWSC, as calculated at Mossdale, is fully expressed in DO depletion, residual oxygen demand load and DO deficit export at Turner Cut. If there are significant changes in flow during this period then these would reflect a change in travel time which could cause deviations in the oxygen demand load DO depletion response relationship found for a particular city of Stockton sampling run.

A critical evaluation needs to be made as to whether, under low SJR DWSC flow conditions of less than about 600 cfs, the City's wastewater discharge pattern, where no discharges occur on weekends and where elevated discharges occur during the early part of the following week, is responsible for some of the variability in the oxygen demand-load response relationships that have been found in the data that have been collected over the past three years. The issue of concern is whether the sampling locations near Turner Cut represent water that originally has reduced City oxygen demand load because it was originally discharged to the SJR on a weekend, or whether it has an elevated load compared to the rest of the week because it was discharged during an elevated City discharge period. While there is expected considerable tidally-induced longitudinal mixing within the DWSC, it is not clear that the longitudinal mixing that occurs is sufficient to eliminate the influence of the variable discharge pattern that occurs in the City's wastewater effluent, on the data collected at various locations along the DWSC.

A similar issue relates to the variability of the planktonic algal loads at Mossdale compared to the average loads used to examine load-response relationships in the box model calculations. Lehman (2002) has reported, based on continuous monitoring of planktonic algal chlorophyll *a* at Mossdale, that the chlorophyll *a* concentrations at Mossdale are highly variable from day to day. Since the BOD load at Mossdale is related to the algal load, the week to every two week average concentrations used in the box model calculations in Tables 3, 4 and 5 do not reflect the higher frequency variability that is occurring in the BOD load to the DWSC. There is need to better characterize the variability of the BOD loads at SJR Mossdale and, for that matter, the city of Stockton's loads to the DWSC on a daily basis and then follow the fate of these loads and their impacts on DO depletion in the DWSC over the week to two weeks that a particular load introduced at Mossdale and by the City takes to get to Turner Cut. As part of this pattern there is need to understand the role of the tidally-induced longitudinal mixing within the SJR and DWSC which would tend to smooth out the high-frequency variability in the oxygen demand loads to the DWSC.

An issue that needs to be examined is whether variable amounts of erosion from the SJR watershed upstream of Vernalis could lead to variable amounts of algal growth in the SJR due to increased or decreased light penetration. The highly variable planktonic algal chlorophyll *a* reported by Lehman (2002) for the Mossdale sampling station indicates the algal biomass moving down the SJR is patchy. This patchiness may be related to algal discharge patterns in the headwaters as well as variable amounts of suspended sediment which influences algal growth in the SJR tributaries as well as the SJR. The data needs to be examined with respect to whether there is an inverse relationship between planktonic algal chlorophyll *a* and inorganic turbidity found in the samples.

An evaluation should be made of the expected decay (nitrification) of ammonia in the DWSC to Turner Cut based on a first-order rate process for the ammonia present at Channel Point. Deviations from the expected concentrations may be an indication of the amount of ammonification of organic nitrogen that is occurring in the DWSC. In addition, there is need to examine in detail the DWSC vertical profile data collected by the city of Stockton, G. Litton and P. Lehman. This may help assess the representativeness of surface and bottom water DO measurements collected by Hayes and the mid-depth DO measurements collected by the city of Stockton in characterizing the DO deficit at any location and time. A review of the raw data collected by Lehman needs to be conducted for information that they provide on these issues. This additional data review may help elucidate why, under certain conditions, there are significant deviations from the "average" that has been developed from the three summers of data collected in 1999, 2000 and 2001.

Review of the 2002 Data. While the CALFED-supported Directed Action project monitoring of the SJR and the DWSC ended in the fall of 2001, R. Dahlgren from the University of California, Davis, continued to collect data on the SJR and its tributaries during 2002. The CVRWQCB provided support so that the water samples collected from the SJR at Mossdale, Vernalis and

Maze could be analyzed for BOD during the period June 2002 through the present (March 2003). The Mossdale data are presented in Appendix F, Table F-7 and Figure F-1. These data have been used to estimate the BOD load at Mossdale that occurred during 2002. Because of the high variability in the flows of the SJR into the DWSC during most months, the high, average and low daily flow were used to compute the estimated BOD_u loads at Mossdale. The average was the arithmetic average of the daily average UVM flows for the month. The SJR DWSC flow values were obtained from examination of each month's daily flows, as reported by C. Ruhl of the USGS for the UVM. These data are presented in Table 8.

The city of Stockton is required to monitor its wastewater effluent for oxygen demand constituents. The data for 2002 are presented in Appendix F, Table F-8. These data have been used to compute monthly box-model-like calculations for 2002, using the approach described above. The results of these calculations are presented in Appendix F, Table F-9, and in Table 8 below.

Examination of Table 8 shows that during any month in 2002 the range of total BOD_u loads to the SJR/DWSC was large. The low-flow values were from 20 to 70 percent of the high-flow values during the month. Since in many months the flows were highly variable from day to day, the oxygen demand loads to the DWSC were also highly variable. This type of data review shows why examination of the average BOD_u loads to the DWSC for the month may not correlate well with the oxygen depletion during the month. It is evident that the BOD_u load DO depletion response relationship for the DWSC must be examined on a much shorter timeframe than monthly, or even biweekly, averages.

Comparing the 2002 BOD_u load at Mossdale plus the City's BOD_u load to corresponding times during 2001 and 2000 shows that 2002 had higher oxygen demand loads. Table F-7 presents the planktonic algal chlorophyll data for 2002 as measured at Mossdale. A comparison between the planktonic algal chlorophyll plus pheophytin for 2000 and 2001, compared to 2002, shows that higher planktonic algal chlorophyll concentrations were present in 2002. It should be noted, however, that the 1999, 2000 and 2001 chlorophyll data presented earlier in this report, made available by the City, were based on an acetone extraction method (APHA, *et al.*, 1998), while the Dahlgren data presented for 2002 (Table F-7) were based on an alcohol extraction method. It has been found that the alcohol extraction method yields slightly greater chlorophyll concentrations than the acetone extraction method. This difference, however, is not sufficient to account for the increased chlorophyll found during 2002, compared to previous years.

Table 8 shows that the percent of the total oxygen demand load contributed to the DWSC by the City ranged in 2002 from about 30 to near 90 percent on days when there was low flow of the SJR through the DWSC. There was a short period during 2002 when the calculated SJR ammonia concentration below the City's wastewater treatment plant discharge was over 11 mg/L ammonia N. As discussed below, the extreme low SJR DWSC flows that occurred during 2002 resulted in there being very little SJR water to dilute the City's effluent ammonia, causing elevated concentrations of ammonia in the DWSC during the low-flow events when the City was discharging elevated ammonia.

Table 8
Estimated Oxygen Demand Loads for the DWSC during 2002

Month	DWSC Flow (cfs)			Mossdale				Stockton Total BOD_u (lb/day)	Total (Mossdale + City) BOD_u (lb/day)			Percent City Contribution to Total BOD_u		
	Low	Ave	High	BOD_5 (mg/L)	BOD_u (lb/day)				Low Flow	Ave Flow	High Flow	Low Flow	Ave Flow	High Flow
					Low Flow	Ave Flow	High Flow							
Jan 2002	-54	1002	3953	-	-	-	-	-	-	-	-	-	-	-
February	194	387	719	-	-	-	-	27,810	-	-	-	-	-	-
March	305	588	1060	-	-	-	-	31,723	-	-	-	-	-	-
April	258	616	2452	-	-	-	-	9,906	-	-	-	-	-	-
May	339	1558	2320	-	-	-	-	8,895	-	-	-	-	-	-
June	87	584	896	5.2	11,625	53,492	79,775	8,978	20,603	62,470	88,753	44	14	10
July	193	430	772	7.2	29,510	57,154	97,044	10,886	40,396	68,040	107,930	27	16	10
August	39	353	861	7.2	10,730	47,356	106,609	21,042	31,772	68,398	127,651	66	31	16
September	512	759	1005	4.6	42,551	60,957	79,289	41,704	84,255	102,661	120,993	49	41	34
October	978	1342	1834	4.2	70,081	94,848	128,323	41,562	111,643	136,410	169,885	37	30	24
November	85	814	1737	3.2	7,465	45,256	93,105	49,754	57,219	95,010	142,859	87	52	35
December	161	462	1182	3.6	12,889	30,443	72,433	48,602	61,491	79,045	121,035	79	61	40
Jan 2003	94	377	859	3.6	8,981	25,486	53,596	40,875	49,856	66,361	94,471	82	62	43

\- Data not available

BOD_u load to DWSC = BOD_5 (Mossdale) * 5.4 * (SJR DWSC Flow + City Flow) * 3

Table 9 presents information on the percent of the total oxygen demand load to the DWSC that is due to the city of Stockton wastewater discharges. During 1999 through 2002 the city of Stockton's average monthly oxygen demand load to the DWSC ranged from about 6 to 62 percent, with many values in the 15 to 40 percent range. The higher oxygen demand loads were associated with the periods of time when the City was discharging ammonia at concentrations from 25 to 30 mg/L N and when the SJR flow through the DWSC was on the order of a few hundred cfs -- i.e., when the upstream SJR algal associated BOD load was reduced.

The impact of the oxygen demand BOD_u load is related to the rate of exertion of the type of load -- i. e., algae versus ammonia. While ordinarily the carbonaceous BOD (algae) and nitrification are modeled with rate constants of about 0.1 per day, if enhanced nitrification occurs, the percent of the total oxygen demand load ($TBOD_u$) that leads to DO values below the WQO due to the city of Stockton wastewater ammonia would be greater than that indicated in Table 9. This issue is discussed further below.

From a review of the previous years' data it is evident that the DO depletion in the DWSC is governed not only by the total BOD_u load, but also by the travel time between Channel Point and Turner Cut – i.e., the period of time over which this load can be exerted prior to its dilution /export into the Central Delta.

Examination of the SJR DWSC flow data for 2002 (see Appendix B) shows that there were several periods, including recently, when the SJR DWSC flow was only a few hundred cfs, with several occasions with the SJR DWSC flow less than 100 cfs. As reported in the "Issues" report, low flows are associated with low DWSC DO, where the low flows result in longer travel times from Channel Point to Turner Cut (critical reach) and thereby enable a greater exertion of the BOD load that is discharged to the DWSC.

In order to examine the impact of SJR DWSC flow on travel times, the monthly travel times were examined for the 2002 DWSC low flow conditions (see Table 10, "Longest"). The travel times presented in Table 10 have been computed based on the USGS SJR DWSC (UVM) flows provided by C. Ruhl of the USGS, and the equations provided by R. Brown, discussed previously. It has been found that for most months in 2002 there was a period when the travel time from Channel Point to Turner Cut was over 20 days. During some months there were days when the estimated travel time was over 30 days. According to R. Brown, his equations are applicable for travel times only up to about 30 days.

Table 10 also presents the Mossdale to Channel Point travel times. There were a number of days during 2002 when this travel time was in excess of 10 days. The Table 10 "Shortest" travel times represent the situations associated with the highest SJR DWSC flow that occurred during the month. Therefore, the range of travel times that occurred during the month is from the "Shortest" to the "Longest" travel times presented in the table. It is evident that, because of the extreme variability of flow that occurred in 2002 (and in some months in other years, as shown in Appendix B), the travel times of the oxygen demand load through the critical reach of the DWSC are highly variable.

Table 9
Relationship between SJR DWSC Flow, Total BOD_u Load to DWSC and Percent of Total BOD_u Load Contributed by the City of Stockton

	1999			**2000**			**2001**			**2002**		
	DWSC Flow (cfs)	**$TBOD_u$ Load (lb/day)**	**Percent City**	**DWSC Flow (cfs)**	**$TBOD_u$ Load (lb/day)**	**Percent City**	**DWSC Flow (cfs)**	**$TBOD_u$ Load (lb/day)**	**Percent City**	**DWSC Flow (cfs)**	**$TBOD_u$ Load (lb/day)**	**Percent City**
June				927	71,462	14	677	68,362	17	584	62,470	14
July				689	54,232	6	624	57,776	20	430	68,040	16
August	937	64,605	18	1004	48,090	13	605	47,982	46	353	68,398	31
September	927	110,619	20	1291	56,548	30	848	58,877	24	759	102,807	41
October	570	70,791	41	1583	92,294	35	1377	64,595	36	1342	136,282	30
November	-	-	-	-	-	-	-	-	-	814	95,155	52
December	-	-	-	-	-	-	-	-	-	462	79,637	62

\- Data not available

Table 10
SJR Vernalis and DWSC Flows and Travel Times in 2002

Month	SJR Vernalis Flow (cfs)		DWSC Flow (cfs)		Old River Flow* (cfs)		Travel Time** (days)				
	Low	High	Low	High	Low	High	Mossdale to Channel Point		Channel Point to Turner Cut		
							Longest	Shortest	Longest	Shortest	Old River Flow= 0
January	1800	6000	(-54)***	3953	1854	2047	(-)***	0.4	(-)***	2	4.4
February	1800	2000	194	719	1606	1281	7.7	2.1	41	11	4.4
March	1900	2300	305	1060	1595	1240	4.9	1.4	26	7.5	4.2
April	1750	3100	258	2452	1492	648	5.8	0.6	31	3.3	4.6
May	2000	3600	339	2320	1661	1280	4.4	0.6	24	3.4	4.0
June	1300	1600	87	896	1213	704	17.2	1.7	92	8.9	6.1
July	1200	1500	193	772	1007	728	7.8	1.9	41	10.4	6.7
August	1050	1400	39	861	1011	539	38.5	1.7	205	9.3	7.6
September	1000	1400	512	1005	488	395	2.9	1.5	16	8	8
October	1400	2700	978	1834	422	866	1.5	0.8	8.2	4.4	5.7
November	1500	2100	85	1737	1415	363	17.6	0.9	94	4.6	5.3
December	1500	3000	161	1182	1339	1818	9.3	1.3	50	6.8	5.3
Jan 2003	1700	2000	94	859	1606	1141	16	1.7	85	9.3	4.7

* Does not consider irrigation diversions between Vernalis and the DWSC, which are estimated to be on the order of 100 cfs (Quinn and Tulloch, 2002)

** Calculated based on R. Brown's equations: Mossdale to Channel Point Travel Time = 1500/UVM Flow (cfs)
Channel Point to Turner Cut Travel Time = 8000/UVM Flow (cfs)

*** Net Flow on this day of the month was upstream

- Not Computed

Source: USGS (2003)
http://waterdata.usgs.gov/ca/nwis/dv/?dd_cd=04_00060_00003&format=img&site_no=11303500&set_logscale_y=1&begin_date=20011224)

An issue of particular concern is when elevated SJR flows rapidly decrease, such as occurred at the end of May 2002 and in mid-November 2002. Under these conditions the DWSC receives a high oxygen demand load, followed by a period of low flow and, therefore, significant time to exert the influence of this load on DO in the DWSC.

Table 10 also presents the USGS measured flows of the SJR at Vernalis for 2002. This information was obtained from the USGS website. This information has been used to estimate the amount of the SJR flow at Vernalis that has been diverted down Old River. It was found that from 30 to as much as 96 percent of the lowest monthly SJR flow at Vernalis was diverted into Old River. It has been found that if the SJR Vernalis flow was not allowed to flow down Old River – i e., allowed to go down the SJR into the DWSC – the 2002 worst-case monthly travel times from Channel Point to Turner Cut would be reduced from 20-30 days to 4-8 days (see the rightmost column of Table 10).

According to A. Hinojosa (pers. comm., 2003) of DWR Delta Operations and Maintenance, during the period when the Head of Old River rock barrier is in place, it is estimated that about 60 percent of the SJR Vernalis flow is diverted down Old River through the culverts in the barrier. It is evident that in 2002 the percentage of the SJR Vernalis flow that was diverted into Old River when the Head of Old River barrier was in place was often greater than the 60 percent value.

The flow of the SJR at Vernalis for the past 12 years was obtained from the USGS website. Table 11 presents a listing of the lowest SJR Vernalis flows for each of the years and the month when these low flows occurred. All other flows during the year were above this value. A comparison of the low flows at Vernalis with those of the SJR DWSC shows that the lowest SJR DWSC flows occurred at the same time as when the SJR at Vernalis flow was lower. While many times a low SJR flow at Vernalis persisted for several weeks, there were occasions when a low flow at Vernalis occurred for only a few days. This situation caused a dip in the SJR DWSC flow and a corresponding increase in the travel time between Channel Point and Turner Cut.

It is evident that some of the lowest SJR flows (and, therefore, the longest travel times through the critical reach of the DWSC) are a result of short-term flow manipulations that occur upstream of Vernalis. From the information available, it appears that those who control the flow of the SJR at Vernalis through upstream releases and diversions, need to exercise greater control of rapid short-term decreases in the SJR at Vernalis flow, in order to avoid the short-term longer travel times through the critical reach of the DWSC.

If the February 2003 SJR flow at Vernalis had been prevented from going into Old River and allowed to proceed down the SJR to the DWSC, the estimated over-30-day travel time for water to go from Channel Point to Turner Cut would have been reduced to about 5 days. Decreasing the travel time to a few days would, based on past data, essentially eliminate the February 2003 low-DO problem in the DWSC. Rather than having a long, thin lake where the BOD associated with the upstream algae and the City's ammonia have ample time to be exerted in the 30-plus-day travel time, the critical reach of the DWSC would be converted to a riverine system with a 5-

Table 11
SJR Historical Low Flows at Vernalis

Year	Low Flow (cfs)	When Measured
1987	1200	December
1988	1000	October
1989	1000	August
1990	700	September
1991	440	September
1992	400	June-August
1993	1000	January
1993	1500	July-August
1994	750	September
1995	1300	January
1996	1900	January, July-August
1997	1800	July-August
1998	1900	January
1999	1600	December
2000	1700	January, August
2001	1300	July-September
2002	1000	August-September
2003 (Jan - Feb)	1700	January

Source USGS (2003)

day travel time, where most (over 50 percent) of the oxygen demand load to the DWSC would be diluted by the cross-SJR channel flow of the Sacramento River at Columbia Cut before it could be exerted in the DWSC. This could significantly improve the 0 mg/L DO concentration that was repeatedly present in mid-February 2003 in the surface waters at the RRI monitoring station.

One of the consequences of the current flow control approach where a large part of the SJR flow at Vernalis is sucked down Old River by the State and Federal Projects is that the flow in the DWSC is reduced to a very low level resulting in high ammonia in the DWSC. During 2002 there was a period when the calculated ammonia in the DWSC was over 11 mg/L N. There were several periods when the City's wastewater effluent, when diluted by the DWSC flow, was above 5 mg/L N. One of the issues that is not being adequately considered is that the combination of high ammonia and low DO leads to higher toxicity than ammonia alone. This issue is not addressed in the current US EPA water quality criteria for ammonia. Further discussion of ammonia as a source of oxygen demand is presented in a subsequent section.

In the past, the SJR DO TMDL Steering Committee and TAC have discussed the possibility of increasing the flow of the SJR through the DWSC. The issue that should be addressed is how to prevent the diversion of the SJR Vernalis flow down Old River. A review of the SJR flows at Vernalis over the past 9 years shows that if the SJR Vernalis flow was allowed to pass through the DWSC before export from the South Delta, the longest Channel Point to Turner Cut travel time would be about 8 days with the worst-case conditions in many years being 4 to 6 days.

Achieving this travel time would greatly reduce to essentially eliminate in some years the low-DO problems in the DWSC.

During the late 1980s and early 1990s drought years, the flow of the SJR at Vernalis was at times reduced to less than 1,000 cfs, which results in an 8-day travel time through the critical reach. Therefore, during drought years there still will be longer travel times through the critical reach of the DWSC (Channel Point to Turner Cut) where additional control of the oxygen demand loads and aeration would be needed.

From the current information, 1,800 cfs is the flow through the DWSC that yields the travel time needed to significantly reduce the exertion of the oxygen demand load in the critical reach of the DWSC. As discussed previously, there is need to evaluate the consequences of diverting the DWSC high flow oxygen demand load into the Central Delta, especially through Turner Cut. This evaluation will need to be made since even under the current SJR diversions into Old River there are times when high oxygen demand loads are added to the Central Delta.

Some of the issues that need to be considered/evaluated in connection with greatly restricting SJR Vernalis flow into Old River include the following.

Advantages

- Reduce occurrences of DO WQO violation in the DWSC and thereby achieve greater aquatic life protection in the DWSC.
- Reduce salt recirculation for the Federal Project waters.
- Reduce cost of control of the low-DO problem in the DWSC.
- Better home water signal for fish homing to upstream eastside rivers.
- Cooler waters in the DWSC.
- Reduce the oxygen demand load and debris to the South Delta.
- Will not affect the ability to divert SJR water upstream of the DWSC and within the South Delta to Central and Southern California.

Potential Problems

- The flow control system at the Head of Old River would need to be constructed to manage the flow down Old River to the minimum necessary without leading to an increased threat of flooding.
- Potential fisheries impacts need to be investigated.

- There is need to evaluate the impact of reducing the SJR flow into Old River on South Delta channel water quality. The purpose of the diversions of SJR flow down Old River is primarily to provide water for South Delta irrigation and recreation. It also helps to flush the South Delta water quality impacts of local South Delta discharges.

It would, therefore, be essential that any significant reduction of SJR flow into the South Delta through Old River be compensated for by increased flow of Sacramento River water into the South Delta from Middle River. There is need to evaluate how best to cause the higher-quality Sacramento River water on its way to the Projects' export pumps to, in part, pass through the South Delta channel. If this can be achieved in association with reduced SJR flow into Old River, then the water quality in the South Delta could be significantly improved, since the relatively poor water quality of the San Joaquin River would no longer be diverted into the South Delta, and the South Delta local discharges would be diluted/flushed by higher-quality Sacramento River water.

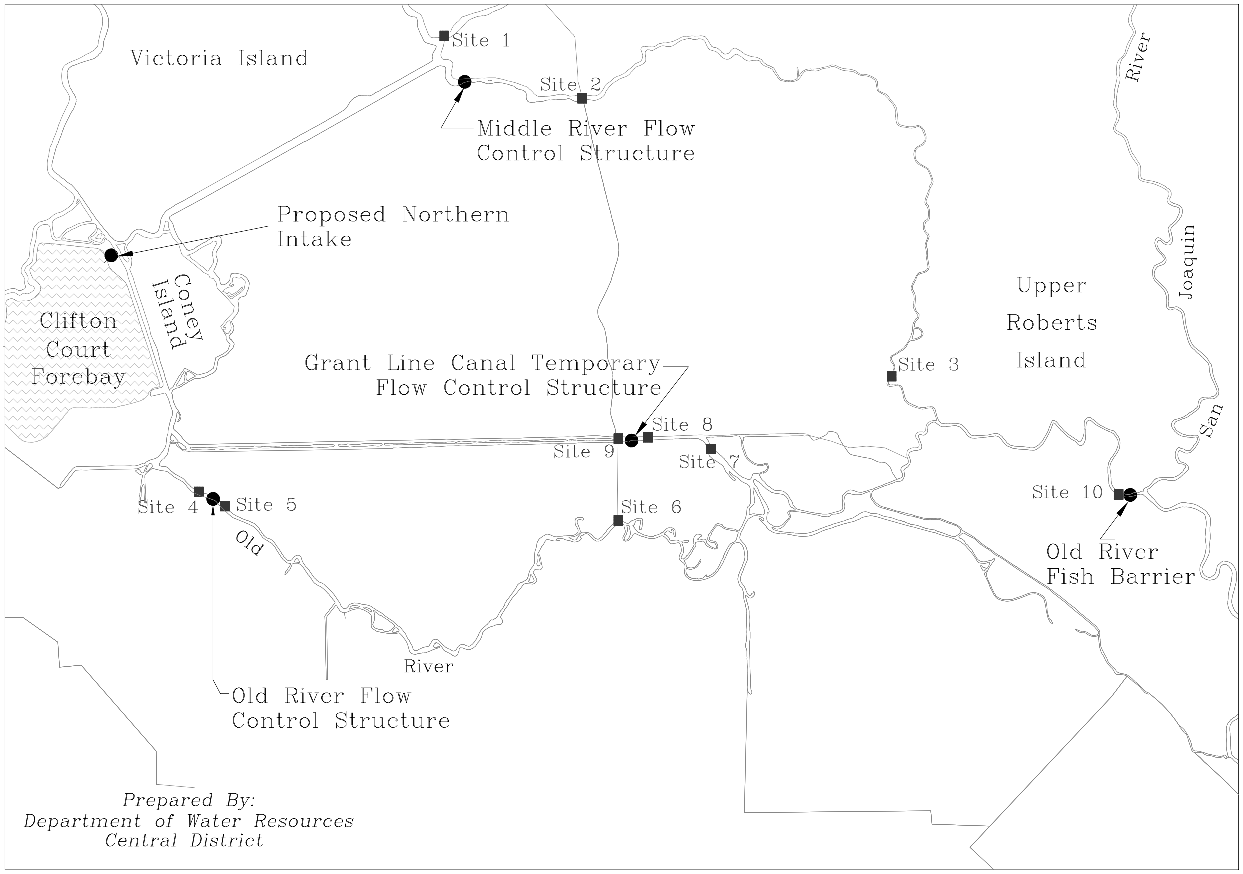
It is recommended that a high priority be given to exploring keeping a greater fraction of the SJR at Vernalis flow in the SJR channel rather than allowing it to be diverted into the Old River Channel. Appendix G presents responses to a request for comments that was submitted to the SJR DO TMDL Steering Committee on this proposal to severely limit the amount of SJR at Vernalis water that is diverted down Old River.

DO-Related South Delta Water Quality Issues. Since two of the South Delta channels (a 15-mile stretch of Old River and 9.7 miles of Middle River) have been found to experience dissolved oxygen concentrations below the water quality objective of 5 mg/L, resulting in their being listed on the SWRCB's recently-adopted (February 4, 2003) updated 303(d) list (http://www.swrcb.ca.gov/rwqcb5/programs/tmdl/303dupdate.pdf), information was obtained on the recent years' water quality characteristics of the South Delta channels. The listed cause of the low DO for both of these listings is "hydromodifications."

DWR maintains water quality monitoring stations in the South Delta as part of their barrier operations. According to S. Philippart of DWR (pers. comm., 2003), discrete water quality data are available for 10 sites from March 26 through December 3, 2002. Water quality measured at the discrete sites include water temperature, dissolved oxygen, specific conductance, turbidity, gage height, ammonia, nitrite-nitrate, dissolved organic nitrogen, ortho-phosphate, chlorophyll *a*, and pheophytin *a*. Figure 17 presents a map of the South Delta showing the location of these discrete monitoring stations. Philippart made available the discrete sampling station data for 2001 and 2002.

Also available are continuous water quality data for five sites (Middle River at Howard Road, Middle River at Undine Road, Old River near Head, Old River at the Tracy Wildlife Association, and Old River at Delta Mendota Canal) from June 4, 2002 through the present, recording water temperature, dissolved oxygen, pH, specific conductivity, and turbidity. A sixth site was added in January 2003 in the Middle River about 0.5 mile downstream of the Tracy Road Bridge.

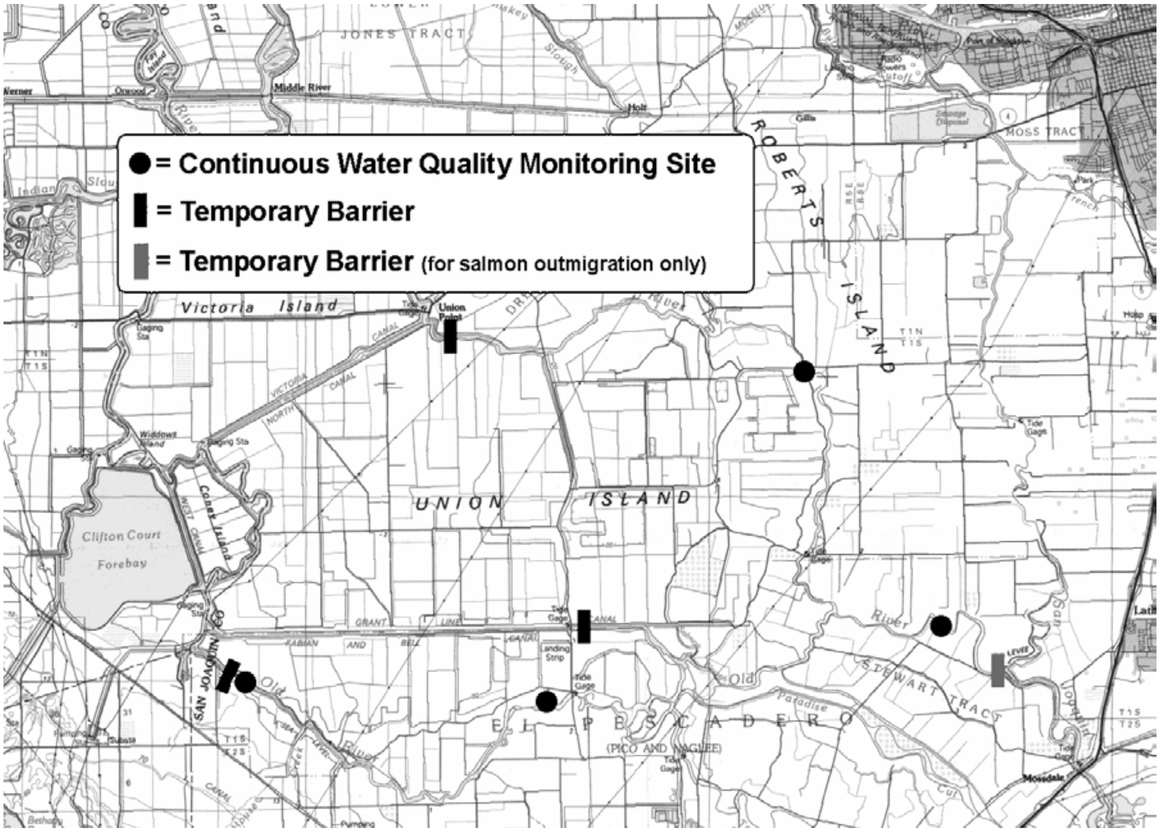
Figure 17
Map of South Delta Showing DWR Discrete Water Quality Monitoring Stations



Site	Location
1.	Middle River @ Union Point
2.	Middle River @ Tracy Blvd
3.	Middle River @ Undine Road
4.	Old River Downstream of DMC Barrier
5.	Old River Upstream of DMC Barrier
6.	Old River @ Tracy Blvd
7.	Grant Line Canal @ Doughty Cut
8.	Grant Line Canal Above Barrier
9.	Grant Line Canal @ Tracy Blvd
10.	Old River @ Head

Figure 18 presents a map of the South Delta showing the location of these continuous monitoring stations.

Figure 18
Map of South Delta Showing DWR Continuous Water Quality Monitoring Stations



According to S. Philippart (pers. comm., 2003),

> *"Yellow Springs Instruments 6600 "sondes" (continuous multi-parameter water quality monitoring instruments) were operated during the year to gather data at five sites in the South Delta. Three monitoring sites were located on the Old River: one on a pump platform just upstream of the barrier near the Delta Mendota Canal (DMC), one on a private boat dock at the Tracy Wildlife Association, and one on a pump-platform approximately two miles downstream of Old River at Head. The fourth site was located on a pump platform in the Middle River just upstream of the Howard Road Bridge crossing. In 2002, a fifth monitoring site located on a pump platform in the Middle River just upstream of the Undine Road Bridge crossing was added. Sampling at Undine Road did not begin until June 4, 2002. Sampling in the Old River at Head did not commence until July 10, 2002. There is no data for any of the stations from about October 2, 2001 - June 4, 2002 because of staff limitations. There are certain sections where data may have been deleted or are missing, which is either because of probe malfunctions or the data was found to be inadmissible because of biological fouling on the probes."*

A review of the 2-week grab sample data (not presented, available from S. Philippart) from the Head of Old River station for 2001 and 2002 shows that there were no DO concentrations below the 5 mg/L WQO. Chlorophyll *a* concentrations at this station in 2001 during the summer ranged up to 65 µg/L on July 17, 2001, while in June through September 2002 there were several samples taken at this location which had chlorophyll *a* concentrations above 100 µg/L. These high chlorophyll concentrations are expected since the water at this location is SJR water.

At Old River at Tracy Road during 2001 there were four sampling events during the summer with DO concentrations less than 5 mg/L. During 2002 there were five sampling events during the summer with DO concentrations less than 5 mg/L. The chlorophyll *a* concentrations at this location during both years frequently were above 20 µg/L, with one value in 2002 exceeding 60 µg/L. Chlorophyll *a* samples above about 30 µg/L are generally considered to be representative of excessive algal growth, where, with low inorganic turbidity, the waters might be called "pea soup green."

Biweekly grab samples taken from the Old River at Delta Mendota Canal (DMC) upstream of the barrier during 2001 showed several samples with DO concentrations below the 5 mg/L WQO, with a low of 4 mg/L in 2001. While there were many summer 2002 samples taken from this station with DO concentrations less than the 5 mg/L DO WQO, on September 24, 2002, this station recorded a DO concentration of 2.7 mg/L. Chlorophyll *a* concentrations measured at this station during both 2001 and 2002 were generally less than 10 µg/L.

At the monitoring station located at Old River at DMC downstream of the barrier, during 2001 there were a couple of occasions when the DO was just under the WQO. In 2002, many of the summer values measured at this station were less than 5 mg/L, and a low value of 2.1 mg/L was recorded on September 24, 2002. The chlorophyll *a* concentrations measured at this location during both 2001 and 2002 were generally less than 10 µg/L during the summer and fall, with the exception of October and November 2002, when the chlorophyll *a* concentration was above 20 µg/L.

Grant Line Canal is sampled at Tracy Road. In 2001 there were two DO values less than the 5 mg/L objective. Six sampling days had DO concentrations less than 5 mg/L in 2002, with a low value of 3.4 mg/L that occurred on October 10, 2002. Chlorophyll *a* concentrations at this location during 2002 were highly variable, with some values in excess of 50 µg/L.

Doughty Cut above Grant Line Canal had one DO value less than the 5 mg/L objective, which occurred on June 26, 2001. In 2002 a value of 3.4 mg/L was found on October 8 at this station. The chlorophyll *a* concentrations at this location were frequently above 20 µg/L, with a value as high as 107 µg/L recorded during 2002.

Middle River at Union Point in 2001 and 2002 did not show any DO violations below the WQO, and typically the chlorophyll *a* concentrations for both years were less than 3 µg/L.

Middle River at Tracy Road during 2001and 2002 did not show any DO violations below the WQO. The chlorophyll *a* concentrations at this location typically were less than 5 µg/L.

Middle River at Undine Road in 2001 showed only one DO concentration below the WQO, which occurred on August 8, 2001. There were no violations of the WQO during 2002 at this location. However, chlorophyll *a* concentrations at this location in both years were frequently above 20 µg/L, with some values as high as 70 µg/L.

Overall, it can be concluded, based on grab samples taken at the 10 DWR sampling stations in the South Delta, that several of the South Delta channels occasionally experience DO concentrations below the 5 mg/L WQO during the summer and fall months. It is expected that continuous recording of DO, which would include early morning measurements, would show a greater number of DO violations than was found with grab sampling. Some locations experience high levels of planktonic algal chlorophyll. The algal nutrient concentrations found in the waters at these sampling stations generally indicated that, given sufficient time, substantial algal populations could develop in these waters.

S. Philippart provided data for the five DWR continuous monitoring stations. These data are recorded at 15-minute intervals. Examination of these data (not shown, available from S. Philippart) shows that, at Old River at Tracy Wildlife Association in early June 2001, there was about a three-day period when the early morning DO concentrations were below the 5 mg/L WQO, with a low value of 3.6 mg/L. The afternoon values were typically on the order of 12 mg/L at this station during this period. From June 22 through June 30, 2001, there was a period of early morning DO concentrations as low as 1.4 mg/L at this location. In early July, early morning DO was recorded as low as 1.65 mg/L. There were also periods of several weeks in July 2001 when the DO did not drop below the WQO. In August 2001 there were a number of days when the low DO for the day was less than 3.0 mg/L, with an extreme low of 1.05. There were substantial periods during the late summer when the DO meter at this location was not working.

There was a period in early June 2002 when the DO concentrations were less than 5 mg/L at the Old River at Tracy Wildlife Association station, with a low of 4.08 mg/L. In mid-June 2002, early morning DO concentrations of less than 0.5 mg/L were recorded, while on the same day the afternoon values were on the order of 14 mg/L. Much of July at this station had DO concentrations above 5 mg/L. There was a period in August when the DO concentrations were recorded as low as 1.1 mg/L. These periodic early morning low DO concentrations continued through September and October 2002. It is evident that the high algal concentrations present in the waters at the Old River at Tracy Wildlife Association were causing marked diel variations in DO, with early morning extreme lows of a few mg/L. Thus far in 2003, all recorded DO values have been above the 5 mg/L WQO at this location.

DWR maintains a Head of Old River monitoring station about 2 miles downstream from the head. In September and October 2001 there were early morning DO concentrations as low as 3.2 mg/L at this station. There were substantial periods in 2002 when the DO meter was not working at this location. When the meter was working, all reported DO concentrations were greater than 5 mg/L during the summer. However, a 3.5 mg/L DO concentration was reported in late October. In January 2003, all DO values were up around 9 to 10 mg/L.

At the Old River at Delta Mendota Canal station, there were some DO values less than 5 mg/L but greater than 4 mg/L in early July 2001. The same situation occurred in August. In September 2001 at this station there were periods of a week or more when the DO concentrations were less than 4 mg/L. During June 2002 there were several days when the early morning DO values were just less than the WQO of 5 mg/L. In July 2002 there were several days when the early morning DO concentrations were on the order of 2 to 3 mg/L. There were periods in August of DO concentrations less than 3 mg/L, with some extreme lows of 0.7 mg/L. The same pattern occurred in September, with low DO values on the order of 0.7 mg/L. DO values less than 4 mg/L were recorded in October and November 2002. In December and thus far in 2003, all DO values have been above the 5 mg/L WQO at this station.

The DWR continuous monitoring station for Middle River at Undine Road showed all DO values above 5 mg/L in 2002. There were substantial periods, however, when the DO meter was not working at this location. All 2003 DO values thus far have been above the 5 mg/L WQO.

At the Middle River at Howard Road station, some DO values less than 5 mg/L but greater than 4 mg/L were recorded in June 2002. In July an early morning DO value of 2.3 was recorded.

It is evident that there are locations on Old River and, at times, on Middle River where the DO concentrations in the summer-fall are less than the 5 mg/L WQO in the early morning hours. This dataset demonstrates the importance of discrete sampling of DO in the early morning hours in order to detect WQO violations.

It is of interest to find that all of the 2003 South Delta channel DO data reported thus far are above the 5 mg/L WQO. This indicates that the high algal concentrations that are associated with the extreme low DO values in the Deep Water Ship Channel during January and February 2003 are not occurring in South Delta waters. The difference may be that the DWSC is receiving a substantial ammonia load from the city of Stockton, which is leading to the DWSC low DO conditions that occurred between mid-January and early March 2003.

The city of Tracy discharges its secondarily treated domestic wastewaters to Old River just upstream of Sugar Cut. According to Kummer (pers. comm., 2003) of the CVRWQCB, Tracy's wastewater discharge average flow is about 11 cfs, with an average BOD_5 of 7 mg/L and, during November 2002, ammonia of 16 mg/L N. This amounts to about 4,000 lb/day of $NBOD_u$ contributed by Tracy in November, with a total BOD_u of about 5,000 lb/day. Kummer indicated that Tracy is applying for an expansion of its NPDES permitted discharge, which would allow a total effluent flow of 23 cfs. As part of this expansion, Tracy will be practicing tertiary treatment, with nitrification to remove ammonia and denitrification to remove nitrate.

Because of the current 303(d) listing of two of the South Delta channels for DO violations, at some unspecified time in the future, under the current regulatory requirements TMDLs will need to be developed to control the DO water quality objective violations. This situation could be of significance to SJR upstream of Vernalis nutrient dischargers, as well as local South Delta nutrient dischargers, since it appears that the DO violations are likely due to excessive amounts of algae in the South Delta channels.

There are a number of other water quality issues in the South Delta that will need to be addressed, including excessive salt, pesticide-caused aquatic life toxicity and excessive bioaccumulation of organochlorine pesticides and PCBs in fish tissue. Any program designed to change the flow patterns through the South Delta, including the installation of the permanent barriers, should include a detailed evaluation of how the altered flow will impact South Delta water quality.

Evaluation of the Oxygen Demand Significance of the City's Ammonia Discharges. The box model calculations indicated that the city of Stockton's ammonia discharges contribute about 10 to as much as about 90 percent of the oxygen demand (BOD_u) load to the SJR just upstream of the DWSC. The issue of primary concern is how much of the ammonia-associated oxygen demand load is exerted between the point of its discharge by the City and Turner Cut. It is the exertion of this oxygen demand load plus the exertion of the residual Mossdale oxygen demand load that leads to the low DO concentrations that violate the WQO. As discussed above, typical modeling of nitrogenous BOD (NBOD) and carbonaceous BOD (CBOD) utilizes a first-order rate constant of about 0.1 per day. Litton (2003), discussed below, reported that the rate constants for CBOD and NBOD are about 0.11 and 0.076 per day, respectively. These values were derived, however, from the nitrification-inhibited BOD tests and, therefore, may be in error.

Litton (pers. comm., 2003) has indicated that he is currently conducting BOD tests on DWSC and SJR water in which he is examining the rates of nitrification based on measurements of the nitrate buildup and ammonia disappearance in the tests. As discussed above, this is the recommended approach for evaluating CBOD and NBOD in a sample. Litton indicated that, during the low flow periods of the SJR through the DWSC that occurred in mid-February, he found a significantly elevated rate of nitrification, compared to that expected based on the typical rate constant of 0.1 per day. However, with increasing flows of the SJR through the DWSC, which began to occur in late February 2003, the enhanced rate of nitrification disappeared. He indicated that he will be preparing a report on these issues in the near future.

Table 12 presents information on the potential significance of the rate constant on the nitrification of ammonia in the DWSC. The uppermost part of the table presents the expected $NBOD_u$ that would be present at Turner Cut as a function of the $NBOD_u$ concentrations at Channel Point and the estimated travel time between Channel Point and Turner Cut with the 20°C rate constant of 0.1 typically used in nitrification modeling.

The middle part of the table presents the expected $NBOD_u$ that would be present at Turner Cut with a "winter" rate constant of 0.05 per day. The 0.05 rate constant is obtained from Figure 15,

Table 12
Ammonia Oxidation in DWSC

NBOD$_u$ Residual at Turner Cut at Temperature of 20 ˚C (k = 0.1)

Ammonia Concentration at Channel Pt (mg/L)		0.5	1.0	2.0	3.0	5.0
NBOD$_u$ at Channel Pt (mg/L)		2.3	4.6	9.1	13.7	22.8
Travel Time (days)	5	1.4	2.8	5.5	8.3	13.8
	10	0.85	1.7	3.3	5.0	8.4
	15	0.51	1.0	2.0	3.0	5.1
	20	0.31	0.62	1.2	1.8	3.1
	25	0.19	0.38	0.75	1.1	1.9
	30	0.11	0.23	0.45	0.68	1.1

NBOD$_u$ Residual at Turner Cut at Temperature of 10 ˚C (k = 0.05)

Ammonia Concentration at Channel Pt (mg/L)		0.5	1.0	2.0	3.0	5.0
NBOD$_u$ at Channel Pt (mg/L)		2.3	4.6	9.1	13.7	22.8
Travel Time (days)	5	1.8	3.6	7.1	10.7	17.8
	10	1.4	2.8	5.5	8.3	13.8
	15	1.1	2.2	4.3	6.5	10.8
	20	0.85	1.7	3.3	5.0	8.4
	25	0.66	1.3	2.6	3.9	6.5
	30	0.51	1.0	2.0	3.0	5.1

NBOD$_u$ Residual at Turner Cut – "Enhanced" (k = 0.5)

Ammonia Concentration at Channel Pt (mg/L)		0.5	1.0	2.0	3.0	5.0
NBOD$_u$ at Channel Pt (mg/L)		2.3	4.6	9.1	13.7	22.8
Travel Time (days)	5	0.19	0.38	0.75	1.1	1.9
	10	0.015	0.031	0.061	0.092	0.15
	15	0.001	0.003	0.005	0.008	0.013
	20	< 0.001	< 0.001	< 0.001	< 0.001	0.001
	25	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
	30	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

$NBODu_t = NBODu * e^{-kt}$

where a 10ºC rate is about 50 percent of the 20ºC rate. This rate constant is based on the temperatures that have been measured in the DWSC at the RRI monitoring station during 2002. As shown in Table 13, during the winter the temperatures in the DWSC are on the order of 10ºC.

Table 13
2002 DWSC Monthly Temperature Ranges at RRI

Month	ºF		ºC	
	Low	High	Low	High
January	47	54.2	8	12
February	47	57	8	14
March	56.5	63	14	17
April	61	63	16	17
May	59	75	15	24
June	73	77	23	25
July	77	80	25	27
August	76	79	24	26
September	73	76	23	24
October	61	72	16	22
November	56	60	13	16
December	48	56	9	13

Annual Range 8 – 27 ºC
Diel Range in Surface Water ~ 3 ºF

The bottom part of Table 12 presents the expected $NBOD_u$ that would be present at Turner Cut with an "enhanced" rate constant of 0.5 per day. The 0.5 "enhanced" rate constant was somewhat arbitrarily selected, although rate constants of this magnitude have been reported. Bierman (pers. comm., 2003) stated in response to a question on enhanced nitrification rates,

> *"I do know that HydroQual, Inc. developed a hydrodynamic and water quality model for the Delaware River:*
>
> > *HydroQual, Inc. 1998. Development of a Hydrodynamic and Water Quality Model for the Delaware River. Prepared for Delaware River Basin Commission, 25 State Police Drive, West Trenton, New Jersey 08628. Project No. DRBC0030.*
>
> *Page 7-13 of that report contains the following:*
>
> *'The nitrification rate, Kn, varied spatially with the River divided into three nitrification zones: zone 1 (RM 133 to 110) with Kn = 0.1/day, zone 2 (RM 110-83) with Kn = 1.0/day and zone 3 (RM 83-48.5) with Kn = 0.5/day. The assignment of the nitrification rate to each zone was guided by the fit of the model to the ammonia and nitrite + nitrate data.'*
>
> *The City of Philadelphia lies between RMs 110 and 90. RM 50 is approximately 10 miles downstream of the Chesapeake and Delaware Canal. The HydroQual nitrification*

> *rates for zones 2 and 3 seem very high but I do not know the full reasons for these choices."*

It is evident that it is possible that much higher nitrification rates could at times be occurring in the DWSC than would be predicted based on a 0.1 per day rate constant. Examination of Table 12 shows that, for the 20ºC conditions, travel times between Channel Point and Turner Cut on the order of 15 to 20 days allowed substantial exertion of the NBOD in the critical reach of the DWSC. As expected, at 10ºC the rate of nitrification is significantly slowed down, so that less of the NBOD present at Channel Point would be exerted by Turner Cut. However, under the "enhanced" rates of oxidation assumed, even an ammonia concentration of 5 mg/L N at Channel Point ($NBOD_u$ of 22.8 mg/L) is substantially exerted in 10 days, and most of it is exerted in 5 days. From the information available, to the extent that enhanced nitrification occurs, the city of Stockton's ammonia discharges could be an even greater source of oxygen demand for DO depletion below the WQO in the critical reach of the DWSC.

The results presented in Table 12 demonstrate the importance of reliably determining the *in situ* nitrification rate constants under the various conditions that exist in the summer, fall and winter. Because of its potential problems, the inhibited BOD test should not be used for this purpose. Instead, the approach recommended by Standard Methods (APHA, *et al.*,. 1998) that was recently used by Litton, involving the measurements of ammonia and nitrate during the course of the test, should be used. These rates should then be compared to the results of field studies of ammonia disappearance within the Channel. Through this approach, an assessment can be made of the significance of ammonia discharges to the SJR DWSC causing or contributing to DO concentrations below the water quality objective.

In addition to the city of Stockton's domestic wastewaters being a source of ammonia for the SJR DWSC, there are other sources, including the decay of algae, wastewaters from dairy and animal husbandry areas, and upstream domestic wastewater discharges to the SJR during the late fall and winter. Based on the city of Stockton's NPDES reports to the CVRWQCB, an estimate can be made of the concentrations of ammonia that could occur in the SJR due to the City's wastewater discharges. These estimates are presented in Table 14.

The calculated ammonia concentrations shown in Table 14 are based on city of Stockton's reported average ammonia effluent concentration for the month and Stockton's average monthly wastewater flow reported to the CVRWQCB. The City's wastewater flow and the UVM-measured lowest daily SJR DWSC flow for the month are added to give the flow into which the ammonia load is discharged. Since the flow of the SJR past the City's wastewater discharge is tidal, the flows that are available for dilution of the City's effluent ammonia and other constituents are dependent on a variety of factors, such as the duration of the low net flow of the SJR past the City's wastewater discharge point, that must be evaluated to determine the magnitude of the dilution that is available for the City's effluent at any particular time. The calculations in Table 14 assume that the SJR flow at the point of the City's discharge does not contain any significant ammonia concentration. During the past several years, the ammonia in the SJR upstream of the City's discharge has typically been on the order of a few tenths of a milligram per liter N.

Table 14
2002 Calculated Ammonia Concentration in the SJR, Based on Lowest Monthly SJR DWSC Flow and Stockton's Wastewater Ammonia Concentration and Flow

Month	Stockton Ammonia Effluent Average Concentration (mg/L N)	Stockton Average Monthly Flow (cfs)	DWSC Lowest Daily Flow (cfs)	Calculated Ammonia Concentration in SJR (mg/L N)
January	-	-	-	-
February	22.0	39	194	3.7
March	22.7	43	305	2.8
April	4.3	43	258	0.6
May	2.0	58	339	0.3
June	2.6	51	87	0.96
July	2.3	60	193	0.5
August	10.8	53	39	6.2
September	23.9	59	512	2.5
October	27.1	52	978	1.4
November	27.9	59	85	11.4
December	26.6	60	161	7.2

- Data not available

The lowest SJR DWSC flows can be subject to error, due to the fact that the UVM measurements are attempting to discern a net downstream flow of 100 or so cfs against a background tidal flow of 2,000 to 4,000 cfs. While the absolute UVM flows of a few hundred cfs or less are somewhat in question, there is no question about the fact that the SJR flows through the DWSC are at times low, resulting in higher travel times through the critical reach of the DWSC, as well as higher ammonia concentrations in the DWSC arising from the City's ammonia discharges to the SJR.

As shown in Table 14, the City's wastewater effluent ammonia concentrations during late spring through mid-summer 2002 were 2 to 4 mg/L N. Starting in September through early winter, the ammonia concentrations were 25 to as much as 28 mg/L N. This is the typical ammonia discharge pattern that has been experienced for a number of years. As noted above, during 2001 this typical pattern was not followed, in that the City had high ammonia discharges during the summer, as well.

The City does not discharge wastewaters on weekends. Therefore, there will be about a 2-day period each week when the ammonia concentrations in the SJR just below the City's discharge will be lower than during the rest of the week. At times, the City's wastewater discharges are higher on Mondays, when they initiate discharges for the week. This will give an ammonia concentration in the SJR below the City's discharge (and, likely, at Channel Point) which is variable, depending on the day of the week and tide stage.

According to Litton (pers. comm., 2003), he expects that tidally induced longitudinal dispersion in the SJR below the City's discharge and near Channel Point will smooth out the impacts of the variable ammonia concentrations due to the City's wastewater discharge pattern on SJR and DWSC ammonia concentrations near Rough and Ready Island, although these effects may still be discernible near Channel Point.

It is also important to understand that, because of tidal excursions in the SJR near the point of wastewater discharge, at times under flood tides, the City's wastewater discharge to the SJR occurs into SJR water that has already received a wastewater effluent discharge associated with the previous flood tide. Because of the variable concentrations of ammonia and other constituents discharged by the City, the variable concentrations of oxygen demand (algae) and the variable SJR flow through the DWSC, there is need to conduct Lagrangian studies in which water masses present at Mossdale are followed (monitored) to Turner Cut under various flows, days of the week, City ammonia discharge concentrations, Mossdale BOD/algae concentrations, and seasons.

While there is no doubt that when the City discharges high concentrations of ammonia in its wastewater effluent under low SJR DWSC flow conditions the City's discharge is a major cause of low DO in the DWSC, there is need for additional investigation of the significance of the City's ammonia discharges as a cause of DO water quality objective violations in the DWSC under lower effluent ammonia discharge concentrations and elevated SJR DWSC flows.

Sources of Oxygen Demand

Gronberg, *et al*. (1998) and Kratzer and Shelton (1998) provide information on the environmental setting of the San Joaquin River basin. The SJR watershed consists of over 7,000 square miles in the Central San Joaquin Valley of California below the eastside reservoirs. The total watershed, which includes the Sierra-Nevada mountains above the reservoirs is estimated to be 13,536 square miles. It is bounded on the east by the Sierra-Nevada mountains, and on the west by the Coast Range mountains. It extends north from Fresno to the Sacramento-San Joaquin River Delta (see Figure 3). The eastside rivers (Merced, Tuolumne and Stanislaus Rivers), including the San Joaquin River, which drain the western slopes of the Sierra-Nevada mountains, are the primary sources of water for the SJR. This section presents a summary of the current understanding of the sources of oxygen demand for the SJR upstream of Mossdale.

Significance of SJR Upstream of Mossdale Oxygen Demand Loads. Lee and Jones-Lee (2000a) presented a conceptual model of the sources and sinks of oxygen demand in the SJR DWSC watershed. Figures 19 and 20 present the primary components of this conceptual model. Oxygen-demanding substances are contributed to the SJR upstream of Mossdale by irrigation tailwater and subsurface drain water associated with high water tables, domestic and industrial wastewaters, discharges/runoff from riparian lands (such as wetlands) and stormwater runoff from various types of land use.

Figure 19
Sources/Sinks of Oxygen Demand in SJR-DWSC Watershed

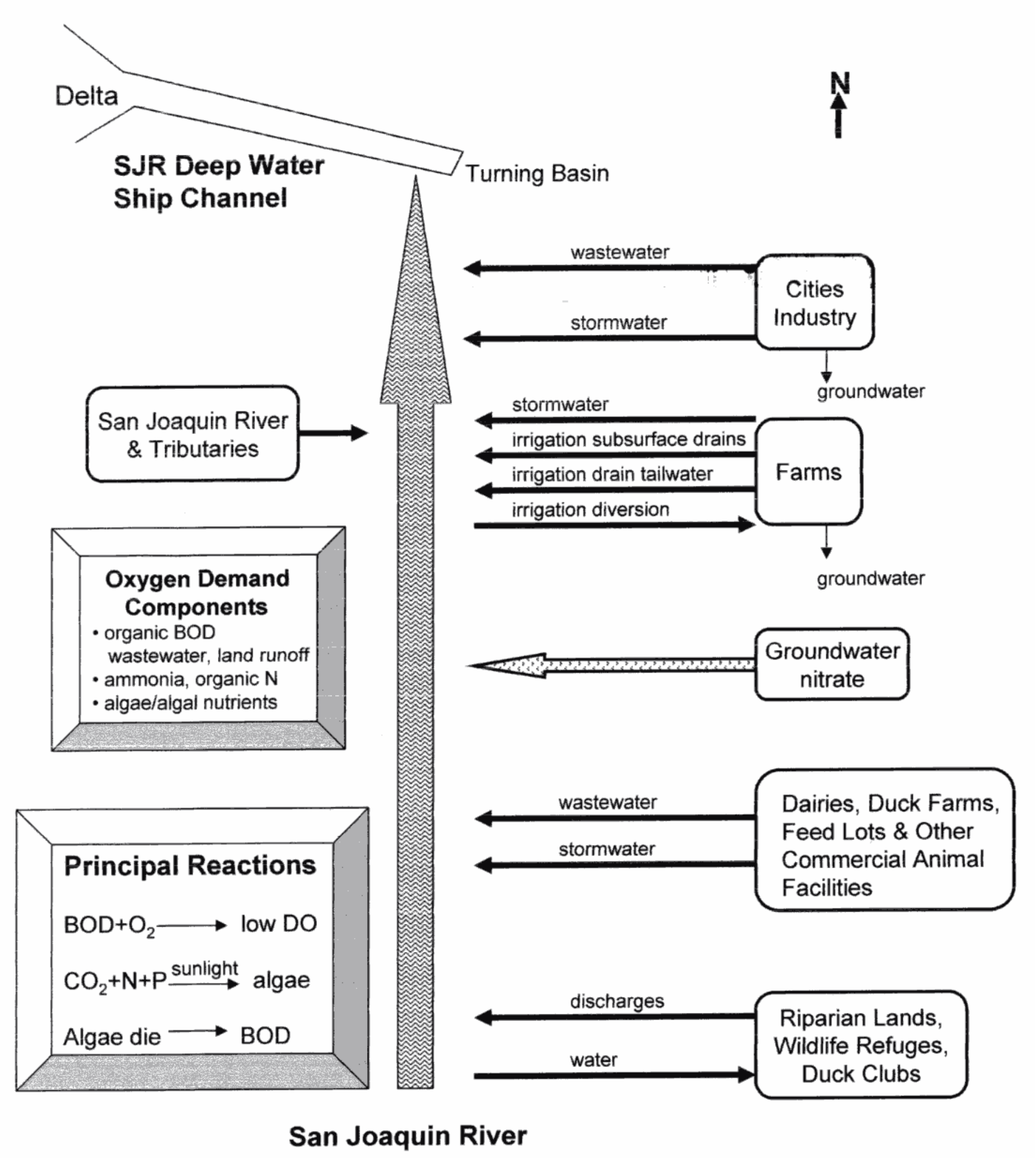
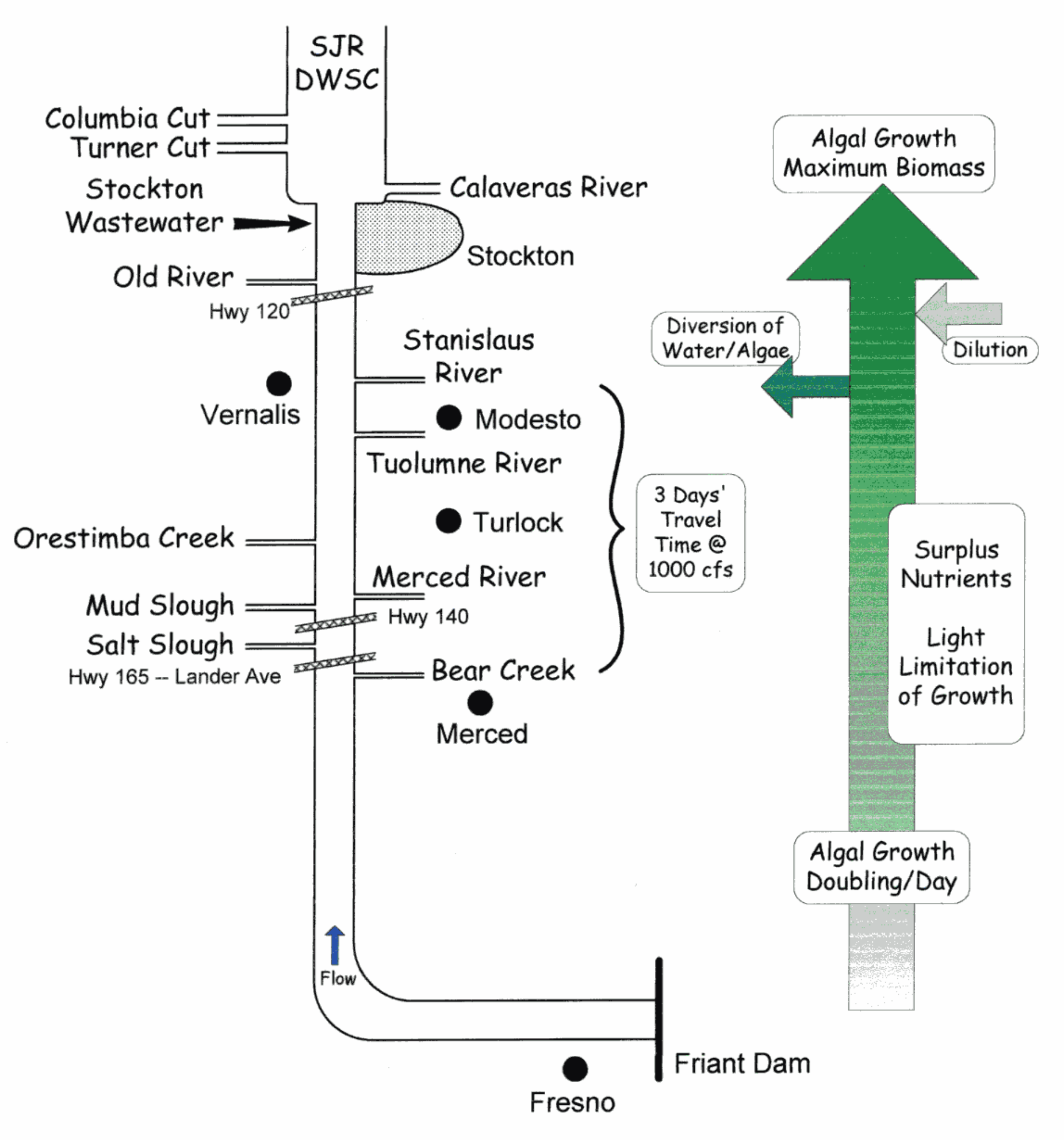


Figure 20
Schematic Representation of Algal Growth in San Joaquin River



During 2000 and 2001 the US Geological Survey, under the leadership of C. Kratzer and P. Dileanis, and R. Dahlgren from the University of California, Davis, conducted monitoring of the SJR and many of its tributaries upstream of Mossdale. The concentrations of a variety of water quality parameters, such as BOD, chlorophyll *a*, various chemical constituents, etc., were monitored in these programs. While, at this time, no reports are available covering the results of this monitoring, the data have been made available for use in the SJR DO TMDL project. These data were used by Foe in developing the Strawman analysis of "upstream" oxygen demand loads and sources from the SJR watershed. Typically these data were collected every two weeks and covered the period from June through mid- to late October.

The Dahlgren studies were part of a project sponsored by the US Fish and Wildlife Service devoted to understanding nutrient dynamics in the Sacramento and San Joaquin River watersheds. Dr. Dahlgren assisted the SJR DO TMDL effort by making his data available prior to their publication. Dahlgren and Kratzer/Dileanis collected samples at the mouths of the major tributaries to the SJR upstream of Vernalis and at various locations within the SJR, including Mossdale. At these same sampling locations flow measurements were already available, or were made at the time of sampling.

Strawman Analysis. Foe, *et al*. (2002) reported a strong correlation between the concentration of chlorophyll *a* and pheophytin *a* in the SJR at or near Vernalis and the BOD measured in the same samples. The summer pattern of estimated BOD based on chlorophyll *a* and pheophytin *a* measurements and the dissolved oxygen concentrations at the Rough and Ready Island monitoring station were nearly inverse of each other, indicating that high chlorophyll *a* and pheophytin *a* loads (BOD loads) were likely responsible for lower DO concentrations at the Rough and Ready Island monitoring station.

Seasonal algal concentration patterns at Mossdale and upstream in the SJR showed that peak chlorophyll *a* concentrations in the River were consistent from where Mud and Salt Sloughs enter the SJR to Mossdale. Further, the highest concentrations of chlorophyll *a* were found in the Mud and Salt Slough and SJR upstream of Lander Avenue discharges to the SJR and downstream in the SJR to Mossdale. These results indicate that the eastside rivers (Merced, Tuolumne and Stanislaus Rivers) and other tributaries are not major sources of planktonic algal chlorophyll *a* downstream of Mud and Salt Sloughs for the SJR. In fact, the major river inputs would tend to lower the SJR concentrations of chlorophyll *a*, due to a dilution effect.

Foe*, et al.* (2002) developed an algal growth model for the SJR from the Mud and Salt Slough discharges to the SJR, to Maze Boulevard, which is just upstream of Vernalis. This model showed that there was an apparent doubling of the algal population down the SJR every one and a half to three days. According to Kratzer and Biagtan (1997), the normal travel time between Mud and Salt Slough discharge points and Vernalis during the summer is about three days. The Foe, *et al.* (2002) estimated growth rate is in accord with what would be expected based on normal rates of algal growth in a severely light-limited system such as occurs in the mainstem of the SJR.

P. Dileanis (2002) provided a work-up of the USGS (Kratzer/Dileanis) and Dahlgren chlorophyll *a* and pheophytin *a* data. Figures 21 and 22 present plots of these data for representative sampling runs during the study period. These data show, as reported by Foe, *et al.* (2002) in the Strawman analysis, that high concentrations of planktonic algal chlorophyll *a* are present in the SJR and the Mud Slough watershed near where Mud and Salt Sloughs enter the SJR in the upper part of the Valley (below the reservoirs) watershed. It is also evident that the concentrations of chlorophyll *a* found in the SJR from near where Mud and Salt Sloughs enter (i.e., SJR at Merced River, which is just downstream of where Mud and Salt Sloughs enter the SJR) are already elevated.

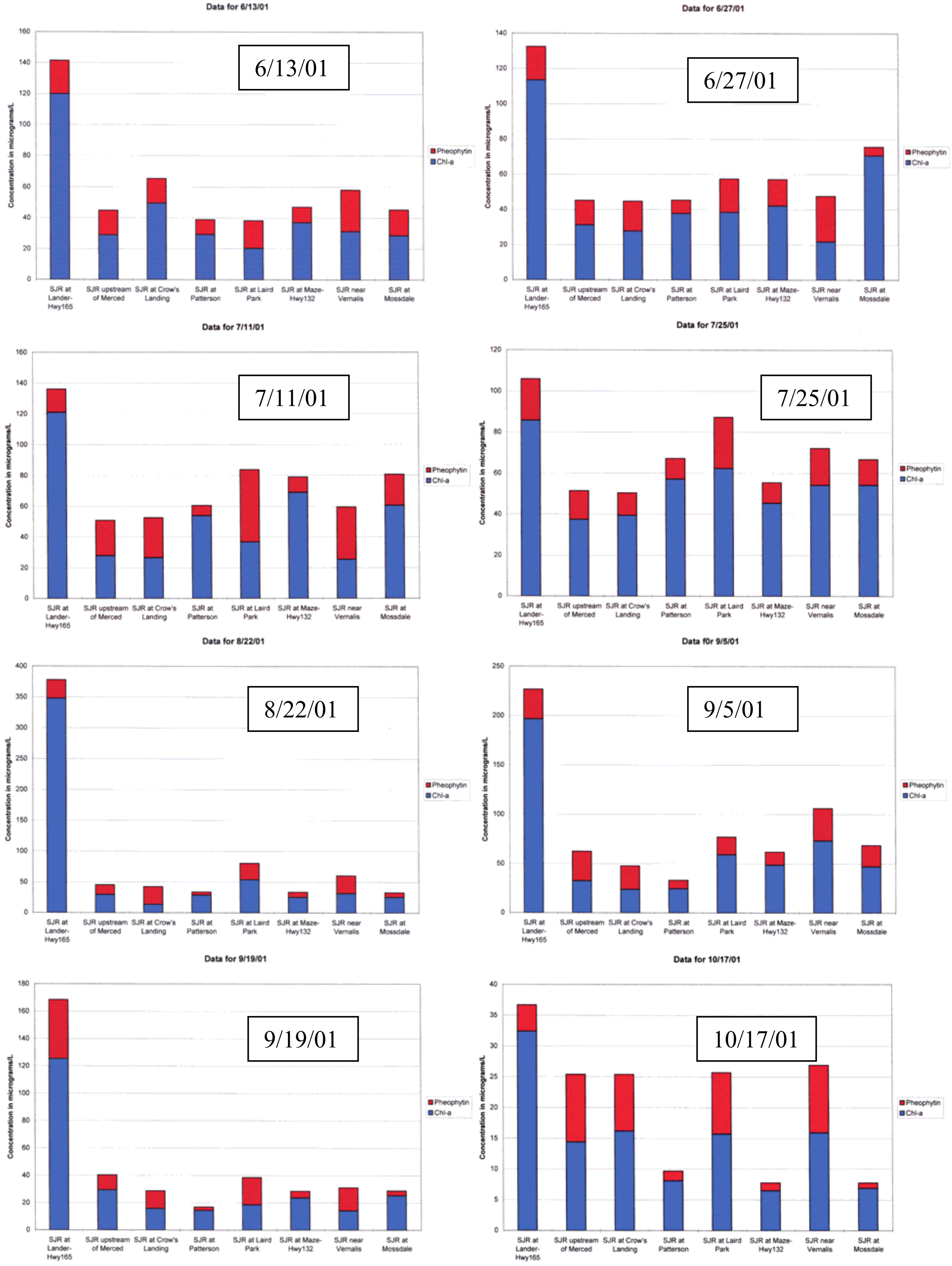
For many of the sampling runs, the concentrations tend to remain essentially constant down the SJR to Vernalis/Mossdale, or increase somewhat down the River. This pattern, which occurred in both 2000 and 2001, demonstrates that there is appreciable algal growth in the SJR from the Mud and Salt Slough area to Vernalis/Mossdale. This growth is evidenced by the fact that the eastside rivers (Merced, Tuolumne and Stanislaus Rivers) contribute substantial amounts of low-chlorophyll *a* water to the SJR, which do not significantly dilute the planktonic algal chlorophyll *a* concentrations in the SJR.

Table 15 presents the average flows of the SJR and its major tributaries during the summer/fall 2000 and 2001. The high flows that sometimes occur at the beginning of June or in late October were not included in the average. The average flows listed are the flows that are transporting the oxygen demand load that is present at Mossdale. As shown in Table 15, the SJR and several of its major tributaries during the summer 2000 tended to have about twice the flow of the summer 2001. During 2001 the measured flows upstream of Patterson add to a total flow of 358 cfs while the flow of SJR at Patterson was measured at 644 cfs. Adding the flow of the Tuolumne River to the SJR Patterson flow gives a total of 957 cfs which compares to the measured SJR at Maze flow of 939 cfs. Adding the Stanislaus River flow of 448 cfs to the SJR Maze flow of 939 cfs yields 1,387 cfs, which compares quite favorably to the measured SJR Vernalis flow of 1,380 cfs.

Examination of the flows in the SJR during 2000, which was a wetter year, shows that the sum of the SJR Patterson measured upstream flows was 422 cfs while the SJR at Patterson had a flow of 785 cfs. The SJR Maze measured flow was 1,610 cfs while the sum of the Tuolumne River and the SJR Patterson flows was 1,609 cfs. The measured Vernalis flow was 2,286 cfs and the sum of the SJR Maze and the Stanislaus River flows was 2,047 cfs. Part of the difference between measured and expected flows relates to agricultural diversions and discharges. This issue is discussed below.

Table 15 also contains the estimated BOD_u loads for each of the major tributaries and along the SJR upstream of Mossdale. These loads were calculated based on the measured summer average BOD_{10} concentrations reported by Foe, *et al.* (2002) in the Strawman analysis, multiplied by the summer average flows at each of the measuring points, times 0.65 to convert BOD_{10} to BOD_5, times 3.0 to convert BOD_5 to ultimate BOD, times 5.4 to convert the units to lb/day.

Figure 21
Representative Planktonic Algal Chlorophyll *a* in San Joaquin River Summer/Fall 2001 (from Dileanis, 2002)



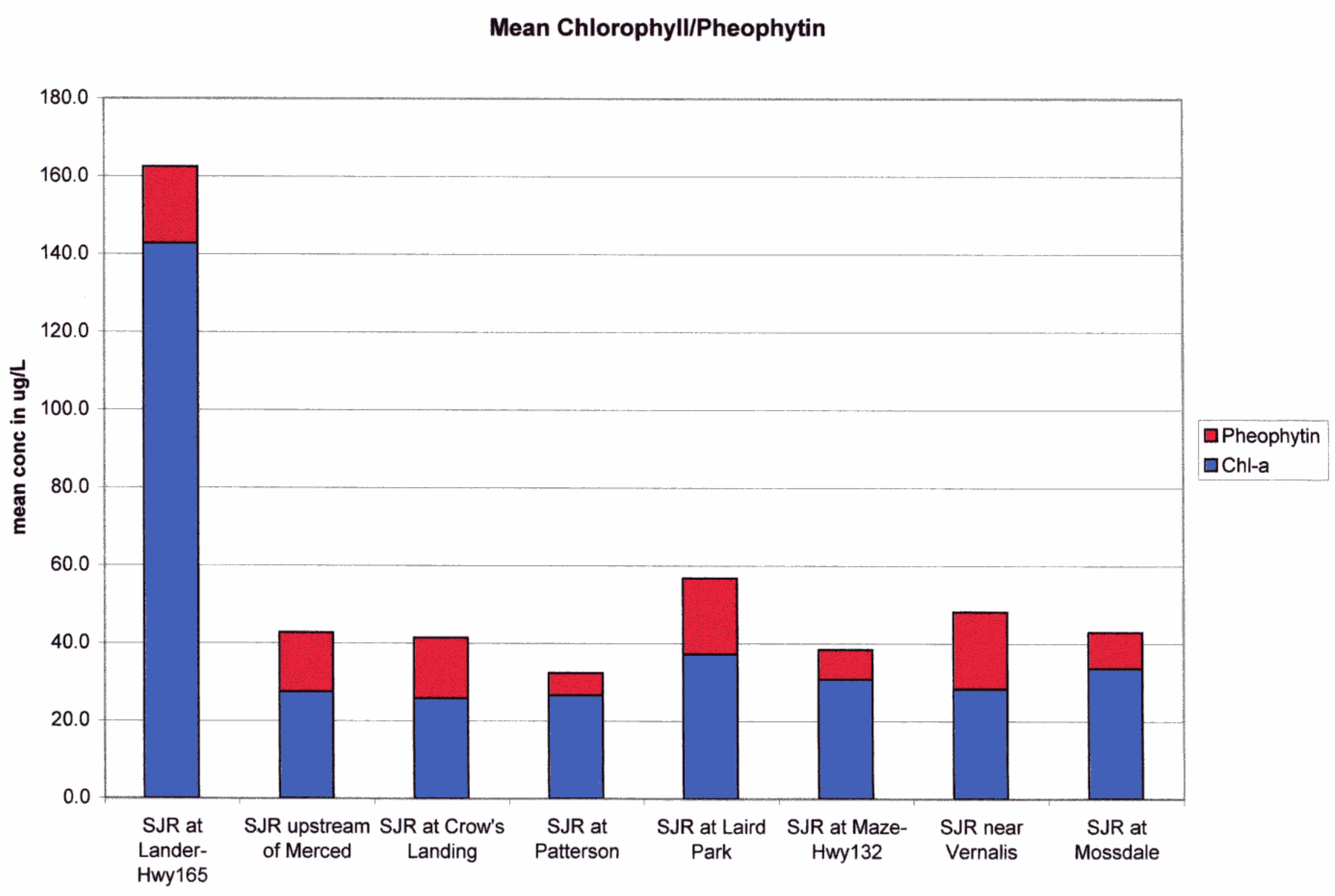


Figure 22. **Mean Chlorophyll *a*/Pheophytin *a* in San Joaquin River – Summer/Fall 2001**
(from Dileanis, 2002)

Table 15
Estimated Average Summer Flow of the SJR and Major Tributaries

Location	Summer* Ave Flow (cfs)		2000 Ave BOD_u Load (lb/day)	2001 Ave BOD_u Load (lb/day)
	2000	2001		
SJR Lander	25	9	4,580	2,274
Salt Slough	150	134	8,845	5,221
Mud Slough	61	84	6,166	7,253
Merced River	186	131	1,959	1,379
SJR Patterson	785	644	52,903	44,079
Tuolumne River	824	313	8,677	3,625
SJR Maze	1,610	939	72,899	59,326
Stanislaus River	437	448	5,522	3,774
SJR Vernalis	2,286	1,380	108,322	63,938
SJR Mossdale	2,286	1,380	120,358	93,001

* Flow data based on Appendix A from Foe, *et al.* (2002) Strawman Report.

As evidenced from this table, the SJR at Lander Avenue coupled with Salt and Mud Sloughs' discharges add substantial BOD_u to the SJR. This is manifested as 40,000 to 50,000 lb/day of BOD_u in the SJR at Patterson. At the SJR at Maze, the BOD_u increased to 60,000 to 73,000 lb/day. At Mossdale, there is further increase to 90,000 to 120,000 lb/day of BOD_u. The eastside rivers (Merced, Tuolumne and Stanislaus), which are major contributors of flow, are not major sources of BOD_u. These results are in agreement with the above-discussed findings that the measured BOD is correlated with planktonic algal chlorophyll *a* and that the eastside rivers are not major sources of phytoplankton for the SJR.

McGahan (pers. comm., 2002) has questioned the cause of the significant increase in the planktonic algal chlorophyll *a* and BOD_u loads that occurs between the discharges of Mud and Salt Sloughs and the SJR at Lander, and the SJR at Patterson. This issue has been reviewed further, with respect to whether there are significant additional sources of algae/BOD between the Mud/Salt Slough discharges and the SJR at Patterson. It was found that Los Banos Creek discharges into Mud Slough downstream from where Mud Slough gaging and monitoring has been conducted. Therefore, Los Banos Creek is a potential source of algae and BOD to Mud Slough that is not reflected in the Mud Slough loads.

Dahlgren (2002) collected samples of Los Banos Creek during the summer 2000. It was found that the average planktonic algal chlorophyll *a* in the Creek waters during the summer was about 11 µg/L, while at the same time, Mud Slough planktonic algal chlorophyll *a* averaged 45 µg/L. Quinn (pers. comm., 2002) estimates that the summer (June through September) average flow of Los Banos Creek is about 9 cfs. Based on this information, Los Banos Creek is not a major contributor to the planktonic algal loads and their associated BOD to the SJR upstream of Patterson.

Dileanis (pers. comm., 2002) of the USGS has provided estimates of the chlorophyll *a* plus pheophytin and BOD_{10} added to the SJR during 2001 between where the Merced River enters the

SJR and the SJR at Patterson. One sample per month was taken from the three tributaries that discharge to the SJR between the Merced River and the SJR at Patterson (Harding Drain, Orestimba Creek and Spanish Grant Drain) during the period July through October 2001. Using an average of the USGS data for 2001 for each of these tributaries between July and October, it is estimated that about 10,000 lb of BOD_u were contributed by these tributaries to the SJR at Patterson. Therefore, the increase in BOD_u between the Mud and Salt Slough discharges and Patterson due to algal growth in the SJR and other sources of BOD is about 34,000 lb of BOD_u. This compares to a summed load of about 16,000 lb of BOD_u from Mud Slough, Salt Slough, SJR at Lander Avenue and the Merced River. Therefore, the BOD_u load between the upstream tributary discharges (Mud and Salt Sloughs) and Patterson about doubled in the summer/early fall of 2001.

Dileanis (pers. comm., 2002) has indicated that the travel time of the SJR from Highway 165 (Lander Avenue) to Patterson is about 50 hours (about 2 days). This is based on the dye-tracer studies of Kratzer and Biagtan (1997). They indicated that the flow of the SJR at the time of their dye-tracer studies was in the range of 1,000 to 2,000 cfs at Vernalis. They further indicated that the travel times in this flow range were not highly dependent on SJR flow. Foe (pers. comm., 2002) has estimated the travel times during the summer 2001 between Salt Slough's discharge to the SJR and Patterson as 1.7 days, Mud Slough and Patterson as 1.1 days, and the SJR at Lander Avenue and Patterson as 1.8 days. He points out that the gaging stations on Mud and Salt Sloughs are upstream of the discharge point to the SJR, and therefore there could be another half a day or so travel time within the tributaries before reaching the SJR. Quinn (pers. comm., 2002) indicates that the distance between the Mud Slough gage and the discharge to the SJR is less than six miles. Further, he indicates that the stream gage on Salt Slough at Highway 165 is even closer to the SJR. He stated that, except under backwater conditions, it is unlikely the travel time from the gage to the SJR is more than 12 hours. It is evident that there is from 1.5 to 2 days' travel time between where Mud and Salt Sloughs discharge to the SJR, and SJR at Patterson. Bowie, *et al.* (1985) have indicated that a review of the literature on algal doubling times in laboratories and waterbodies shows that the range is from about 0.2 to 3, with many doubling times on the order of 1 to 2 days. Since Foe, *et al.* (2002), found an apparent doubling time for algae in the upper SJR of about 38 to 47 hours (1.6 to 2 days), it is apparent that the increase in BOD_u between Mud and Salt Slough and the SJR at Lander Avenue discharges and that found at the SJR at Patterson can readily be accounted for based on algal growth and the inputs from other tributaries between these two locations, with algal growth being the dominant cause of the increased algae and BOD in the SJR at Patterson.

Based on the information provided by Dileanis (pers. comm., 2002), it is found that the ratio of BOD_{10} to planktonic algal chlorophyll *a* for Orestimba Creek and Spanish Grant Drain is significantly different than this same ratio for Harding Drain. Harding Drain has a much higher BOD to chlorophyll *a* ratio than Orestimba Creek and Spanish Grant Drain. This indicates that Harding Drain, which represents about 80 percent of the total BOD load from these three tributaries, has other causes of BOD than planktonic algae. This might be expected, based on the fact that Harding Drain receives city of Turlock domestic wastewaters, which contain CBOD and ammonia. Further, there are upstream dairies that could be contributing wastewaters to Harding Drain. There is need to further investigate the sources of BOD in Harding Drain.

The summer 2000 flows, which were approximately twice the flows in 2001, contained increased BOD_u as measured along the River and at Mossdale. The comparison between the BOD_u measured at Mossdale for 2000 and 2001 of 120,000 and 93,000 lb/day, respectively, with the three years' summer average of the city of Stockton's BOD data collected at Mossdale (67,000 lb/day) (Figure 16), shows a substantial difference between the two values. This difference is a result of the Figure 16 box model calculations being based on the use of flow of the SJR into the DWSC to estimate the Mossdale load that reaches the DWSC from upstream sources. The Table 15 values, however, use the Vernalis flow to estimate the total load at Mossdale. The difference between the two is the amount of the load that is diverted down Old River below Mossdale.

The potential significance of summer irrigation return flows has been examined by Foe, *et al.* (2002). According to Foe, *et al*., during the study period summer irrigation return flows were about 20 percent of the flow at Vernalis. In 2000 Foe, *et al.,* used chlorophyll *a* concentrations from Orestimba Creek as representative of algal concentrations from irrigation return flows. In 2001 the USGS measured chlorophyll *a* at a number of sites in the Central Valley including Orestimba Creek. Statistically, all of the westside tributaries had about the same concentrations of planktonic algal chlorophyll *a* as Orestimba Creek. Foe, *et al.* (2002) conclude that the data from Orestimba Creek is broadly representative of agricultural irrigation tailwater returns.

When the average Orestimba chlorophyll *a* concentration is multiplied by 20 percent of the flow at Vernalis the calculated load of algae and their associated BOD is not a significant part of the total load measured in the SJR at Vernalis. Multiple regression of all the data collected from SJR tributaries shows that ammonia, DOC, etc., are important in explaining tributary-to-tributary variations in chlorophyll *a* and BOD. However, examination of the data collected at Mossdale shows that the concentrations of chlorophyll *a* and pheophytin *a* are the only significant factors causing oxygen demand. Foe (pers. comm., 2002) interprets this to mean that the BOD constituents from other sources of BOD in the tributaries have been largely oxidized by the time they arrive at Mossdale, leaving algae as the primary source of BOD at Mossdale.

One of the issues of particular concern is the role of growth of algae in the SJR between where Mud and Salt Sloughs discharge to the SJR and Mossdale. If there was no growth of algae in the SJR between where Mud and Salt Sloughs enter the SJR and Vernalis/Mossdale, then the eastside rivers would dilute the planktonic algal chlorophyll *a* present in the River. However, it appears, from the chlorophyll *a* concentrations found along the SJR, that the amount of growth that occurs about equals the amount of low-algal water added from the eastside rivers during the summer and early fall months. This finding supports the Foe, *et al.* (2002) algal growth model discussed in the Strawman, which shows that there was an apparent doubling of the algal populations in the SJR every day and a half to three days during the study period.

Hutton (2002) conducted modeling studies of flow and algal growth dynamics in the SJR upstream of Mossdale in which the DWR DSM2 flow model was expanded to include a water quality component. This modeling was to be done in cooperation with CALFED-funded HydroQual modeling. The results of this modeling have been delayed due to contracting problems between CALFED and HydroQual. According to Hutton (2002), the purpose of his 2001 studies was,

> *"to develop a 'stand-alone' version of the DSM2 model for the upper San Joaquin River (SJR). This stand-alone model, herein referred to as the San Joaquin River Simulation Model (SJRSM), was developed, tested and furnished to the Technical Advisory Committee and is much faster and easier to use than the complete DSM2 model. In addition to simulating hydrodynamics and salt transport, SJRSM allows for the simulation of dissolved oxygen, temperature, and other non-conservative constituents in the San Joaquin River upstream of Vernalis. It is anticipated that HydroQual, Inc., as part of the 2002 directed action studies, will conduct the necessary calibration and validation to simulate these water quality constituents."*

As a result of Hutton terminating his association with DWR, the responsibility for this modeling has now been assumed by Rajbhandari.

While the box model calculations by Foe, *et al.* (2002) of algal concentrations/oxygen demand along the SJR between the Merced River and Mossdale describe the situations that have occurred during the summer/fall 2000 and 2001, this approach does not provide the information needed to predict how altering the oxygen demand/algal concentrations in the SJR upstream of the Merced River will impact the oxygen demand load that enters the DWSC. This information is essential to reliably predicting how control of algae and other oxygen demand constituents in the Mud and Salt Slough watersheds as well as in the SJR upstream of Lander Avenue will impact the oxygen demand loads that enter the DWSC. The DWR HydroQual modeling effort has the potential of providing this type of information.

The SJR chlorophyll pattern (see Figure 21) that evolved from both the Foe, *et al.* (2002) Strawman analysis and the USGS/UCD data presented by Dileanis (2002) of the mainstem and tributary monitoring of the SJR during the summer/fall 2000-2001 is one of Mud and Salt Sloughs, as well as the SJR at Lander Avenue discharging (containing) high concentrations of planktonic algae. The planktonic algae measured as chlorophyll *a* is correlated with the BOD of the sample. These algae develop in the Mud and Salt Slough and SJR upstream of Lander Avenue watersheds based on nutrients discharged to the tributaries within the watershed. As the waters in the SJR travel over the three-or-so-day travel time from Mud and Salt Slough discharge points just upstream of where the Merced River enters the SJR to Vernalis/Mossdale, there is additional algal growth based on the algal populations that are present in the headwaters near where Mud and Salt Sloughs enter the SJR. The net result is that from 50 to at times as much as 80 percent of the planktonic algae and BOD at Mossdale has its origin in the discharges from Mud and Salt Sloughs and the SJR at Lander Avenue.

As discussed below, during the irrigation season (May through September), part of the algal load present in the SJR upstream of Vernalis is diverted by the 30 or so percent of the SJR agricultural diversions (reported by Quinn and Tulloch, 2002). These diversions change the total load of algae at various locations in the SJR by removing total algal load from the River. They do not change the concentrations of algae in the River. The eastside rivers add low-algal water to the SJR, and thereby increase the total flow of the SJR. The additions tend to dilute the planktonic algal concentrations in the SJR from those present just upstream of where an eastside river enters the SJR; however, since the mixture of the eastside rivers coupled with the upstream SJR waters still contain significantly surplus available forms of nitrogen and phosphorus derived from upstream sources, there is substantial growth of planktonic algae in the SJR.

Since the eastside rivers during the summer and fall tend to be low in turbidity (suspended solids), they would tend to dilute the turbidity within the SJR, thereby promoting algal growth in the SJR because of the potential for increased light penetration below where the eastside rivers enter the SJR. At this time, the potential role of the low turbidity in the eastside rivers in allowing greater algal growth is an issue of concern. Dileanis (pers. comm., 2002) has indicated that he is investigating this area and will report on it at a later time. His initial findings include that the Secchi depth (a measure of light penetration) in the SJR increases from the Merced River location to Vernalis. The suspended solids in the River decrease from the Mud and Salt Slough discharge area to Vernalis. This increased water clarity would likely be due to the input of low turbidity water from the eastside rivers that would tend to reduce the light limitation governing algal growth in the SJR, promoting even greater growth of algae than that which occurs in the upstream parts of the SJR near the Merced River.

<u>IEP Database Statistical Analyses</u>. Van Nieuwenhuyse (2002) conducted a statistical analysis of the 19 years of data that have been collected as part of the Interagency Ecological Program (IEP) monitoring of the Delta and its tributaries, to evaluate the effects on Delta water quality of South Delta water exports to Central and Southern California. This compliance monitoring program was started in 1983. It has consisted of detailed monitoring of certain parameters at selected locations, such as the continuous monitoring station on the SJR at the northern end of Rough and Ready Island. There has also been monthly sampling of the water near this location for a variety of parameters, including planktonic algal chlorophyll *a*. In addition, there has been monitoring of the SJR at Vernalis. This database is almost unequaled for long-term record of water quality monitoring of waterbodies in California. The database used by Van Nieuwenhuyse (2002) is an independent database from that used by Foe, *et al.* (2002) in the Strawman analysis and by Dileanis (2002) in developing Figures 21 and 22.

Van Nieuwenhuyse (2002) examined all data collected in the IEP monitoring program that are potentially relevant to the DO depletion situation in the SJR DWSC. This included the winter/spring data, as well as the summer/fall data. The parameters on which he focused were those that are potentially influential in causing DO depletion within the DWSC. These include planktonic algal chlorophyll *a* at Vernalis, the city of Stockton's reported ammonia discharges to the SJR just upstream of the DWSC, and planktonic algal concentrations present in the SJR just downstream of Rough and Ready Island. He also used the Rough and Ready Island continuous monitoring data to examine the DO depletion that occurs at this location. These data were used as an index to minimum DO concentrations that occur throughout the DWSC.

As discussed elsewhere in this Synthesis Report, the DO monitoring that occurs at the DWR Rough and Ready Island continuous monitoring station provides a reasonable assessment of the DO depletion that occurs in the DWSC near Rough and Ready Island with respect to the upper part of the water column. It does not properly reflect the magnitude of DO depletion that occurs near the bottom of the DWSC. Further, the DWR monitoring station has been found (see Stringfellow, 2001) to underestimate to some extent the DO concentrations in the surface waters in the DWSC at the monitoring station location. The magnitude of this underestimation will likely depend on time of day, tidal stage, algal biomass and sunlight intensity. It also does not reliably address the situations where, during higher flows of the SJR through the DWSC, the point of maximum DO depletion occurs further downstream of Rough and Ready Island. These issues are discussed further by Foe, *et al.* (2002) and elsewhere in this Synthesis Report, with particular reference to the monitoring that has been conducted by DWR in the Hayes cruises.

One of Van Nieuwenhuyse's (2002) conclusions is that there is a strong negative correlation between DO concentrations at Rough and Ready Island (from the IEP database) and the planktonic algal chlorophyll *a* that is present in the SJR at Vernalis. This conclusion is the same as that reported by Foe, *et al.* (2002).

Van Nieuwenhuyse (2002) found that ammonia loading from the city of Stockton was not significantly correlated with minimum DO; its effect only became apparent once the variation due to other factors had been accounted for. This partial effect was negative. Also, his analysis indicated that minimum DO increased with flow at Vernalis; however, increasing SJR at Vernalis flow did not perform as well as reducing ammonia loading as a way to reduce the amount of aeration required to meet a 5 mg/L DO water quality objective. Reducing ammonia also performed much better than reducing upstream algal biomass. These findings would seem to contradict the results of the last three years' studies by the TAC, especially the box model results and the Chen-Systech model results.

Van Nieuwenhuyse (2002) investigated, using statistical evaluation techniques, the potential impacts of altering various factors that influence low DO in the DWSC. He found that the best performing alternative would be to impose a 2 mg/L NH_4 N effluent limit on the city of Stockton's wastewater treatment facility and to cut in half the upstream chlorophyll concentration at Vernalis. According to his analysis, by adopting this approach the low-DO problem in the DWSC could essentially be controlled using just point and nonpoint source pollution control methods. He noted, however, that no realistic combination of management alternatives is likely to guarantee year-round compliance with a 5 mg/L DO objective. Consequently, artificial aeration will probably be required during some months of most years. He stated that management scenarios that include reduction of ammonia loading may benefit salmon more than other management actions because reducing ammonia loading would shift the timing of maximum DO deficits from fall to summer. Under the current situation, the City's high ammonia loads typically occur each fall at a time that is of critical importance to the fall run of Chinook salmon through the DWSC to their home stream waters.

Leland, *et al.* (2001) reported on the distribution of algae in the San Joaquin River relative to nutrient supply, salinity and other factors. They found that the phytoplankton in the San Joaquin River were primarily centric diatoms, and indicated that the growth of these phytoplankton was found to be limited more by light and flow regime than nutrient supply. Lehman (2002) has reported that the SJR upstream of Vernalis frequently shows substantial changes in the types of algae that are present in the River over short periods of time. These changes may be due to variable inputs of upstream water from the Mud and Salt Slough and SJR at Lander Avenue watersheds, which contain different types of algae that are manifested in the SJR as patches of a certain type of algae that are carried downstream.

Additional information on phytoplankton dynamics and planktonic algal chlorophyll *a* in the Delta has been provided by Ball (1987). Further, Jassby and Cloern (2000) have presented a review of the significance of organic matter, which is principally algal and other sources, as part of the trophic structure of the Delta. Woodard (2000) has reviewed the TOC and DOC data that have been collected over the years in the tributaries to the Delta and within the Delta. These various studies point to the SJR upstream of Mossdale as being an important source of organic carbon for the Delta, and show that an appreciable part of this organic carbon is in the form of algae and algal remains (detritus).

Urban Stormwater Runoff as a Source of Oxygen Demand for the DWSC. In the Lee and Jones-Lee (2000a) "Issues" report and initial draft of this report, issues were raised about the potential significance of urban stormwater runoff as a source of oxygen demand for the DWSC during the fall. At the time of preparation of those reports, information was not available on the amounts of oxygen demand and the frequency and magnitude of storms that typically occur in the fall that can contribute to the low-DO episodes that occur in the San Joaquin River Deep Water Ship Channel. DO depletion problems below the water quality objective have been found in every month. They occur most frequently during the summer and fall, up through late November and early December. While the summer months and early fall are typically periods of no precipitation, there are storms that lead to substantial runoff during mid- to late fall that would be contributing urban stormwater runoff-derived constituents to the San Joaquin River and/or the Deep Water Ship Channel. Recently, as part of another TMDL effort (Lee and Jones-Lee, 2002b), the authors have had the opportunity to gain background information on summer-fall precipitation events in the Stockton area, as well as the magnitude of BOD and nutrients present in urban stormwater runoff from Stockton. This section summarizes the findings with respect to the estimated magnitude of oxygen demand loads from the city of Stockton that could be occurring in a fall stormwater runoff event.

Studies across the country, as well as in Stockton and in Sacramento, have found that urban stormwater runoff typically contains from 10 to 15 mg/L of BOD_5. City of Stockton 1992-1997 data had a median event mean concentration of BOD_5 of 14 mg/L (Stockton, 1998). From the information provided by the city of Stockton (2000) to the CVRWQCB in its annual NPDES stormwater runoff water quality monitoring reports, it is found that a 0.54-inch storm over a 2-day period produced 485,000 cf of runoff from 533 acres. This translates to about 1.4×10^7 L of runoff from 533 acres. The monitored area consisted of 533 acres (2.2×10^6 m^2) of residential area. Therefore, the runoff from a 2-day, half-inch storm contains about 1.3 x 10^{10} mg of BOD_5. This translates to a BOD_5 export coefficient of 93 mg BOD_5/m^2 of runoff area.

According to the city of Stockton website, the City occupies 56 sq mi. There are 2.6 x 10^6 m^2 per sq mi; therefore, the city of Stockton occupies 1.4 x 10^8 m^2. If it is assumed that all of Stockton's area exports BOD_5 at about the same rate as the monitored areas, a half-inch storm would contribute about 1.3 x 10^{10} mg BOD_5/stormwater runoff event or about 1.3 x 10^4 kg, which is 2.9 x 10^4 lb BOD_5/stormwater runoff event discharged to the DWSC.

Using a factor of 2.5 to convert BOD_5 to BOD_u, 7.3 x 10^4 lb of BOD_u could be added to the DWSC by a stormwater runoff event from the city of Stockton.

The city of Stockton stormwater runoff has been found to contain about 0.6 mg/L of ammonia nitrogen and 2.2 mg/L of total Kjeldahl nitrogen. Using a factor of 4.5 to convert organic and ammonia nitrogen to ultimate oxygen demand ($NBOD_u$), and assuming that 1 mg/L of the Kjeldahl nitrogen could be converted to nitrate in the DWSC upstream of Turner Cut, it is found that the $NBOD_u$ from the nitrogen in stormwater runoff would amount to about 4 x 10^3 kg of $NBOD_u$ or 8.8 x 10^3 lb of $NBOD_u$ added to the DWSC in a half-inch stormwater runoff event. One mg/L was used rather than 2.2 mg/L, since the BOD_5 measurements included some of the nitrogenous BOD.

Therefore, on the order of 81,000 lb of total BOD_u could be added to the DWSC associated with a half-inch stormwater runoff event in the city of Stockton. Actually, the amount would be larger than this since scour within the storm sewers and within the drainage channels (sloughs) would contribute additional oxygen demand load to the DWSC.

As discussed above, during the fall, based on the 1999-2001 monitoring conducted by the city of Stockton, the combined city of Stockton wastewater and SJR Mossdale BOD_u load to the DWSC was on the order of 50,000 to 80,000 lb/day of BOD_u.

The conclusion is that fall stormwater runoff events in the city of Stockton have the potential to add a significant amount of BOD_u to the DWSC. It is concluded that event-based sampling of the DWSC should occur in the fall just prior to and for about two weeks following stormwater runoff events to determine if the pulse of BOD added to the DWSC by the stormwater runoff event causes significant additional DO depletion. This problem would be more acute during lower SJR flow through the DWSC, where the residence time for BOD exertion would be longer. There would be need to consider whether a half-inch or so storm would significantly change the hydraulic residence time of the DWSC. Further, runoff from upstream areas could contribute additional BOD load to the DWSC following a rainfall runoff event.

Precipitation in Stockton. The city of Stockton website, www.stockton.org, contains a link to NOAA "Climate Summary for Stockton." This summary indicates that on the average September has 0.3 in of precipitation with a maximum of 3.0 in. In October the mean precipitation is 0.7 in with a maximum of 2.2 in. In November the mean precipitation is 1.8 in with a maximum of 6.2 in. Therefore, in some years there are rainfall runoff events in the fall that could transport substantial oxygen demand load to the DWSC from Stockton and from upstream urban and other sources.

DeltaKeeper Dissolved Oxygen Study 2002-2003**.** During the fall of 1996 and the fall and winter of 1999-2000, DeltaKeeper collected dissolved oxygen (DO) data on several City of Stockton waterways. DeltaKeeper data from 1999-2000 and 1996 show low-DO problems in Stockton sloughs in those years. A review of the DeltaKeeper data shows that 24-48 hours following a rain event, DO concentrations in Stockton waterways frequently drop below the 5 mg/L aquatic life water quality objective contained in the Basin Plan. Chen and Tsai (1999) conducted a study of dissolved oxygen in Smith Canal (a Stockton slough) after stormwater runoff events. The study showed that during or soon after a stormwater runoff event, the water in Smith Canal was significantly impacted; DO levels dropped to approximately 1mg/L about two days after initiation of the event.

During the fall and winter of 2002-2003, beginning with the first storm event on November 6, DeltaKeeper collected dissolved oxygen data on seven Stockton waterways. In October and early November 2002 baseline data were collected for five consecutive days at the seven study sites. Baseline data were collected mainly during low outgoing tides and occasionally at high tide. Storm runoff event data collection commenced the first day of a rain event and monitoring continued for 5 to 10 consecutive days at each site or until DO readings rebounded. Storm event data was collected at low (ebb) tide at each site and also at high tide at one or two of those sites during 2 to 3 days of the sampling period.

DeltaKeeper dissolved oxygen sampling sites during 2002-2003

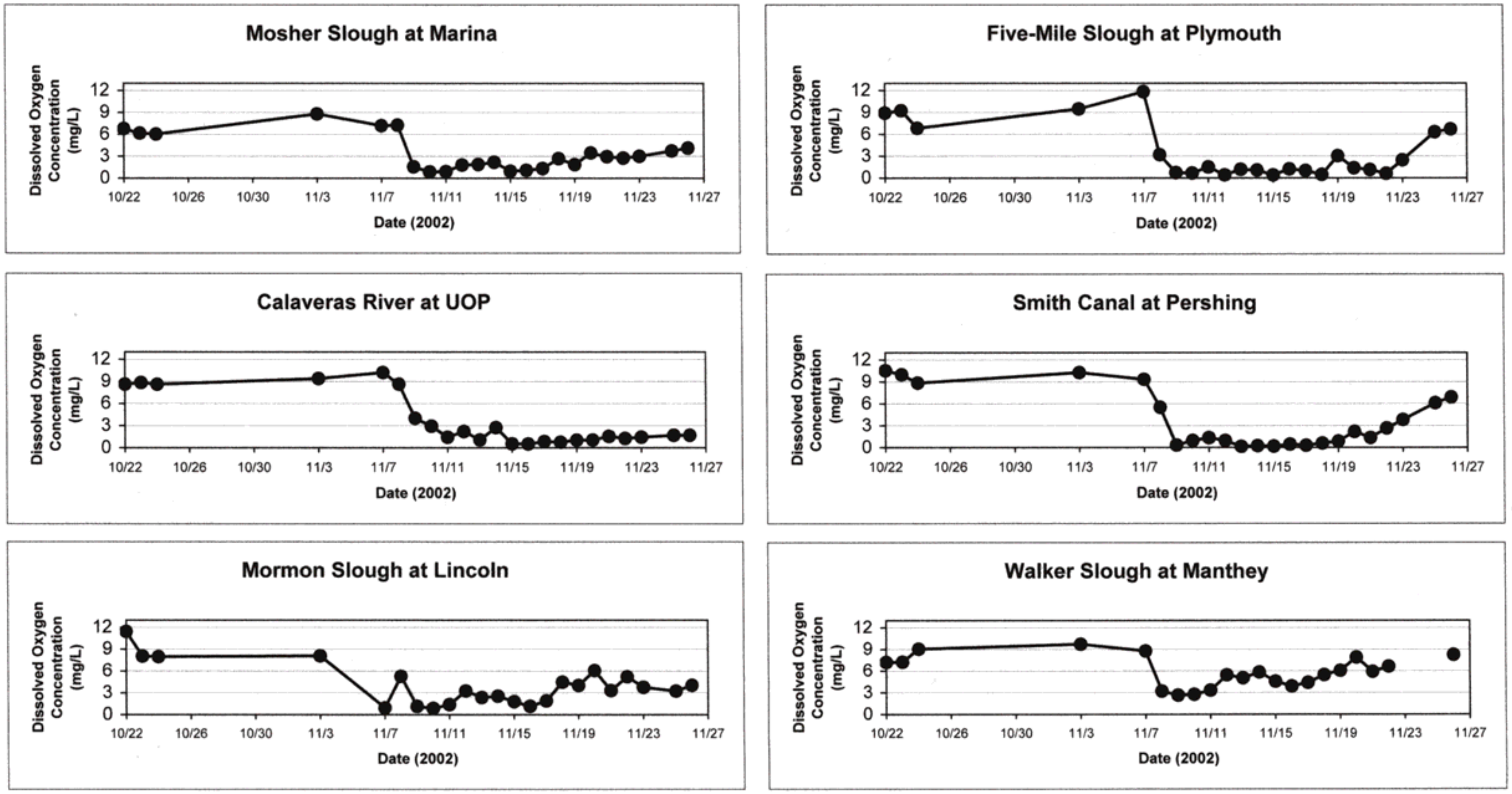
1) Mosher Slough - Mariners Drive bridge at I-5
2) Bear Creek – at Laughlin Park levee
3) Five Mile Slough - at Plymouth Road bridge
4) Calaveras River – at UOP footbridge
5) Smith Canal at Pershing Ave. bridge
6) Mormon Slough – at Lincoln Street bridge
7) Walker Slough – at Manthey Road bridge and at I-5

Monitoring was performed by DeltaKeeper staff and/or trained certified volunteers. Field parameter measurements were made using the Hach portable turbidimeter and one of the YSI 600xls, or Hydrolab Surveyor 4 multimeters. All sampling crews followed the safety precautions and sample collection protocol outlined in the QA/QC. Multimeters and the turbidimeter were calibrated daily during the sampling period prior to each sampling run. The multimeters' DO membranes were changed after each sampling trip and recalibrated no less than 12 hours later (after the membrane had had a chance to soak in deionized water). Multimeters were calibrated in the field at each sampling site. Once each month, multimeters were also calibrated using the azide modification of the Winkler method contained in the LaMotte dissolved oxygen titration kit. The data collected in the 2002 city of Stockton studies are presented in Figure 23.

Figure 23

Dissolved Oxygen Concentrations in Stockton Waterways 2002 (outgoing tide) (mg/L)

	Oct 22	Oct 23	Oct 24	Nov 2-4	Nov 7	Nov 8	Nov 9	Nov 10	Nov 11	Nov 12	Nov 13	Nov 14	Nov 15	Nov 16	Nov 17	Nov 18	Nov 19	Nov 20	Nov 21	Nov 22	Nov 23	Nov 25	Nov 26
Mosher Slough at Marina	6.78	6.16	6.04	8.81	7.2	7.28	1.57	0.86	0.91	1.8	1.88	2.2	0.96 1.23 (incoming tide)	1.09	1.33	2.68	1.86	3.47	2.95	2.77	3.01	3.73	4.13
Five-Mile Slough at Plymouth	8.92	9.25	6.84	9.48	11.84	3.21	0.74	0.68	1.51	0.42	1.17	1.09	0.4	1.24	1.02	0.47	3.03	1.38	1.14	0.63	2.47	6.31	6.71
Calaveras River at UOP	8.63	8.85	8.61	9.4	10.21	8.63	4	2.93	1.44	2.22	1.08	2.75	0.54 0.36 (incoming tide)	0.53	0.86	0.77	1.03	1.05	1.55	1.28	1.43	1.69	1.7
Smith Canal at Pershing	10.54	9.99	8.85	10.27	9.34	5.52	0.33	0.96	1.34	0.96	0.15	0.23	0.18 0.23 (incoming tide)	0.45	0.3	0.59	0.86	2.17	1.35	2.64	3.8	6.1	6.9
Mormon Slough at Linclon	11.44	8.04	7.97	8.08	0.92	5.26	1.15	0.87	1.38	3.26	2.36	2.54	1.79	1.16	1.9	4.48	4.02	6.06	3.32	5.21	3.76	3.24	4.04
Walker Slough at Manthey	7.21	7.25	9.05	9.72	8.78	3.2	2.65	2.76	3.34	5.46	5.04	5.85	4.56	3.89	4.39	5.47	6.07	7.9	5.91	6.63			8.25



On 17 November 02, DO in the Calaveras River upstream at the diverting canal at Fremont Street and #126 was 8.56 mg/L while DO at the UOP footbridge was 0.86 mg/L.
Note: Daily dissolved oxygen concentrations at DWR's Mossdale gage have consistently been above criteria while concentrations at DWR's Rough & Ready Island gage have been
Source: W. Jennings (2002)

There is a consistent pattern for each of the sampling locations, where prior to the stormwater runoff beginning on November 6, the DO concentration was 6 to about 10 mg/L. Following the stormwater runoff the DO rapidly decreased to about 1 to 3 mg/L. As shown in Figure 23 the DO did not return to prior to the storm concentration for several days to several weeks. Associated with the decrease in DO there were severe fish kills in several of the Stockton waterways. Appendix D presents the DWR RRI monitoring data for 2002 through early 2003. Examination of these data shows that, following the large storm in early November 2002, which produced substantial urban runoff from the city of Stockton to the DWSC, the DO concentrations in the DWSC decreased to about 3 mg/L (see the November 2002 data in Appendix D). Prior to the storm, the RRI DO was 7.5 to about 9 mg/L. The RRI measured DO did not return to concentrations above the WQO until mid-December 2002. Examination of the DWR continuous monitoring data collected at Mossdale showed the low-DO water was not being transported down the SJR following the storm. It appeared that the storm-associated DWSC low DO concentrations were of local origin to the DWSC.

Upstream Oxygen Demand Stormwater Runoff Sources. The studies of Kratzer and Biagtan (1997) indicate that stormwater runoff from the cities in the SJR DWSC watershed could reach the DWSC in several days after the rainfall runoff event. Part of the oxygen demand in stormwater runoff from upstream cities will add to the BOD load of the DWSC. The same situation also applies to stormwater runoff from other areas such as where municipal, commercial, dairy, feedlot, industrial, and/or agricultural wastes are deposited on land that are subject to stormwater runoff. The amount of the BOD load that reaches the DWSC depends on the flow of the tributaries and the SJR which, in turn, impacts to some extent the travel time from where the stormwater runoff occurs to the DWSC.

An area of particular concern as a source of oxygen demand during stormwater runoff events for the DWSC is French Camp Slough. French Camp Slough receives urban, commercial and industrial runoff. This issue is reviewed by Lee and Jones-Lee (2000a).

In addition to the impact of the stormwater-runoff-derived BOD on the DWSC there can also be impacts on the tributary's DO. A common problem that occurs associated with stormwater runoff is low DO following a rising hydrograph. The increased flow leads to increased velocity in the stream which leads to scour of stream sediments and the suspension of inorganic oxygen demand.

It is concluded that urban stormwater runoff in Stockton and other municipalities and from other sources could contribute sufficient oxygen demand to the DWSC to contribute to DO depletion in the DWSC. This is a topic area that needs attention during Phase I of the TMDL, in order to evaluate the need to control BOD and other oxygen demand constituents in stormwater runoff from urban and other land to prevent DO depletion below the water quality objective.

SJR Water Diversions. The SJR DWSC monitoring data collected over the years in the Hayes cruises, the data collected in the past three years as part of the CALFED-supported studies, and the water quality modeling data discussed above and below have all shown that flow of the SJR through the DWSC is a dominant factor in influencing DO depletion in the DWSC. Decreases in flow of the SJR through the DWSC increase the hydraulic residence time of oxygen-demanding substances in the critical reach of the DWSC, thereby decreasing the oxygen demand assimilative capacity of the DWSC. SJR flows through the DWSC in excess of about 2,000 cfs would largely, if not completely, eliminate the DO violations below the water quality objective in the DWSC. The flow of the SJR through the DWSC is highly dependent on upstream reservoir releases of water and upstream diversions of water. All water diversions and managed shifts from summer flow to spring flow that decrease the flow of the SJR through the DWSC during the summer and fall below about 2,000 cfs contribute to the low-DO problem in the DWSC. There are basically two types of diversions that need to be considered. One of these is headwater/upstream diversions, and the other is diversions that take place within the Valley floor.

There are several major upstream diversions, such as the CVP at Friant Dam, the city of San Francisco and various irrigation districts, that are potential contributors to the low-DO problem. The effects of the CVP on the southern Delta water supply are discussed in a report (WPRS, 1980). At this time there is an inadequate understanding of the impact of these upstream diversions on the flow of the SJR through the DWSC during the summer and fall months and therefore the magnitude of the DO depletion below the WQO associated with these diversions.

The federal Central Valley Project (CVP) and State Water Project (SWP) export through the Delta-Mendota Canal and California Aqueduct, respectively, up to about 11,000 cfs of South Delta water to Central and Southern California. The export pumps artificially change the flows in the South Delta which results in more of the San Joaquin River going through Old River. These Old River diversions can significantly reduce the SJR flow through the DWSC, thereby directly contributing to the low-DO problem in the DWSC during the summer and fall.

In addition to diversion of SJR and its tributary waters, which reduces the flow of the eastside rivers into the SJR, there are appreciable diversions of the SJR along its length from the Merced River to the DWSC. Quinn and Tulloch (2002) have reported on their assessment of these diversions. They report that during 1999, 2000 and 2001, the Patterson Irrigation District, West Stanislaus Irrigation District, El-Solyo Water District and Banta Carbona Water District divert about 500 cfs from the SJR during the months of May through August. The Patterson diversion is located near Patterson, California, about 1,000 ft downstream of the SJR Patterson gage. The West Stanislaus Irrigation District intake is located between Patterson, California, and where the Tuolumne River discharges to the SJR. The El-Solyo intake is located just downstream of the SJR Maze gage. The Banta Carbona Water District intake is located between Vernalis and Mossdale.

During the summer the three upstream of Vernalis diversions divert an average of about 400 cfs. In September, the total irrigation/water districts' diversion of water decreased to about 188 cfs, while in October, diversions amounted to about 50 cfs. With a SJR flow at Vernalis during the same period of about 1,000 to 2,000 cfs, the irrigation districts' diversions diverted between 25 and 50 percent of the SJR flow at Vernalis/Mossdale. Some of this diverted irrigation water is returned to the SJR in tailwater returns. Quinn and Tulloch (2002) estimate that during July the irrigation return waters to the SJR represent about 60 cfs, which is about 15 percent of the water diverted.

Quinn (pers. comm., 2002) indicated that the CVRWQCB estimates the groundwater inflow to the SJR to be about 4.7 cfs/mile. Therefore, in the SJR reach from Patterson to Vernalis (about 15 river miles) the groundwater would add about 70 cfs to the SJR flow. Additional information on the quantity and quality of groundwater inflow to the SJR has been provided by Phillips, *et al.* (1991).

If it is assumed that the SJR water that is diverted contains about 6 mg/L of BOD_{10}, the total BOD load removed from the SJR by the agricultural diversions is about 31,500 lb/day. This represents a substantial reduction in the total BOD_u load that is diverted from the SJR by agricultural diversions. Therefore, the agricultural irrigation diversions are detrimental to the DO problem within the DWSC to the extent that these diversions reduce the flow of the SJR through the DWSC. However, these agricultural diversions are beneficial to the DO problem in the DWSC as a result of removing a substantial algal (BOD_u) load from the DWSC.

Upstream Wastewater Sources. The oxygen demand loads of the city of Stockton's discharge of about 45 cfs of treated domestic wastewaters to the SJR just upstream of where the SJR enters the DWSC have been quantified. Of particular importance is the City's discharge of elevated concentrations of ammonia which can exert a significant oxygen demand in the DWSC. There are, however, a number of upstream of Mossdale municipal and commercial/industrial wastewater sources that have the potential to add oxygen demand to the SJR and thereby, increase the DO depletion problem in the DWSC. Quinn and Tulloch (2002) have reviewed the existing information on these sources.

With the exception of Manteca (6 mgd) and Turlock (10.4 mgd), the CVRWQCB NPDES wastewater discharge permits for municipal and industrial discharges in the SJR watershed above Vernalis generally prohibit wastewater discharges to the SJR and its tributaries during the summer and early fall. According to Tulloch (pers. comm., 2002), Los Banos and Merced wastewaters do not reach the SJR because of agricultural diversions or infiltration. Modesto's NPDES wastewater discharge permit requires that it discharge its wastewaters to land irrigation systems during the summer and early fall. These land irrigation systems do not have direct discharge to the SJR or its tributaries. There may, however, be groundwater transport of nutrients, especially nitrate, from the wastewater irrigation areas to the SJR or its tributaries during the summer months.

Tracy discharges its wastewaters to the South Delta, which at this time do not enter the SJR DWSC. That situation could change if the reverse-flow pumping of South Delta waters into the SJR via Old River is initiated. Further, according to Foe (pers. comm., 2002), Lathrop and Mountain House have proposed NPDES wastewater discharge permits. Mountain House would discharge to Old River, while Lathrop would discharge to the SJR upstream of the DWSC.

As with agricultural land stormwater runoff, the lack of rainfall during the summer and early fall prevents stormwater runoff from municipal and industrial areas in the SJR watershed from being a major contributor to summer and fall loads of oxygen demand materials to the SJR and its tributaries. As discussed above, however, mid-fall rain could transport oxygen demand materials from municipal and industrial wastewater management areas in stormwater runoff that could add to the mid- to late fall low-DO problems in the DWSC.

Generally, it can be concluded that since the large municipalities in the SJR watershed upstream of Vernalis, such as Modesto and Merced, do not discharge domestic wastewaters to the SJR or its tributaries during the summer and early fall months, these municipalities are not major direct causes of the summer/fall low-DO problem in the DWSC. However, the wastewater discharges from these cities may contribute to the low-DO problem at other times of the year.

Significance of the Mud and Salt Slough and SJR Upstream of Lander Avenue Watersheds. Evaluation of the data collected in the summer/fall of 2000 and 2001 of the SJR upstream of Vernalis has shown that two of the SJR tributaries, Mud Slough and Salt Slough, and the SJR upstream of Lander Avenue (Highway 165) are the primary sources of algae that ultimately, after several days of transport with additional growth in the SJR, lead to the high algal related oxygen demand that causes DO depletion below the water quality objective in the DWSC. At times, up to about 80 percent of the oxygen demand load to the DWSC at Mossdale is derived from these three sources.

McGahan (pers. comm., 2002) has provided the following information on the Mud and Salt Slough and SJR upstream of Lander Avenue watersheds. The "Grassland Drainage Area" is only a small portion of the watershed that discharges out Mud and Salt Slough into the San Joaquin River. The Grassland Drainage Area is a 97,000-acre agricultural area with 40,000 acres of subsurface drains that discharges out the San Luis Drain. All of this flow goes into Mud Slough, along with other flows outside of the Grassland Drainage Area. Flows from the Grassland Drainage Area in water year 2000 were 31,260 acre-feet. The total flows from Mud and Salt Slough were 235,490 acre-feet. The Grassland Drainage Area therefore discharged 13 percent of the flow from these two combined sites, and this does not include the flow contribution from the San Joaquin River at Lander Avenue (Hwy 165).

The Mud and Salt Slough watersheds are an important source of other pollutants, including selenium, boron, and salt (TDS). According to McGahan (pers. comm., 2002), the flows from the Grassland Drainage Area have been reduced significantly (47 percent from historical flows) due to the current selenium reduction program over the last five-year period. It will be important in developing the TMDLs to manage the water quality problems in discharges from the Mud and Salt Slough watersheds to integrate the various control programs for selenium, boron and TDS with nutrient/algae control programs so that they do not exacerbate the low-DO problem in the DWSC.

Thus far, studies conducted by Stringfellow and Quinn (2002) within the Mud and Salt Slough watersheds during the summer/fall 2000 have shown that the primary source of algal nutrients (nitrogen and phosphorus compounds) that lead to high algal concentrations/loads at the mouths of Mud and Salt Sloughs where they enter the SJR, is water derived from agricultural activities. These studies show that, at least during the summer/fall of 2001, the public and private wildlife refuges were not major sources of nutrients and algae compared to the agricultural drain waters during the summer months.

Johnston, *et al.* (1965) made measurements of the nitrogen and phosphorus content of tile drainage waters in the San Joaquin Valley near Fresno, California. While the purpose of their study was to investigate the losses of fertilizer, it provides information on the potential for tile drain waters to serve as a source of nutrients which can lead to algal growth problems and thereby development of oxygen demand in the waters downstream of the tile drains. Johnston, *et al.*, studied tile drains from 11 systems on the west side of the San Joaquin Valley, including seven in Fresno, three in Merced and one in Stanislaus County. Based on the study of a number of different tile drain systems, Johnston, *et al.*, reported that the nitrogen content of the drainage effluent ranged from 2 to 14 mg/L N. The phosphorus concentrations in tile drain water ranged from 0.053 to 0.23 mg/L P.

While Johnston, *et al.*, characterized the phosphorus losses as small compared to the fertilizers applied, the concentrations of both N and P in the tile drain waters are sufficient to represent a potentially significant source of nutrients which would stimulate the growth of algae. This particular situation is of concern in the Mud and Salt Slough watershed areas, where discharges from the tile drains potentially represent a starting point for the development of the algae that become the important seed to cause Mud and Salt Sloughs to have high concentrations of algal-derived oxygen demand.

Kratzer and Shelton (1998) reviewed the studies conducted in the late 1980s on the sources of nutrients and suspended sediment in the surface waters of the San Joaquin River watershed. They reported that the approximate nutrient concentrations in agricultural irrigation tailwater (surface return flow) were nitrate at 6 mg/L N, ammonia at 0.1 mg/L N, orthophosphate at 0.2 mg/L P and total phosphorus at 0.4 mg/L P. Subsurface agricultural drainage (tile drains) was reported by Kratzer and Shelton, based on the California Department of Water Resources (1975) report, to contain nitrate at 25 mg/L N, ammonia at 0.2 mg/L N, orthophosphate at 0.05 mg/L P and total phosphorus at 0.1 mg/L P. These results are in general agreement with those reported by Johnston*, et al.* (1965). It is evident that agricultural tailwater and tile drain water can contain sufficient N and P to stimulate substantial growth of planktonic algae. The Mud and Salt Slough watershed tailwater and tile drain water will need to be investigated with regard to their contribution of nutrients that stimulate the growth of algae in the headwaters of the Mud and Salt Slough watersheds, that in turn lead to the high concentrations of algae and BOD at the point where Mud and Salt Sloughs discharge to the SJR.

Eastside Rivers. The Tuolumne, Stanislaus, and Merced Rivers (eastside rivers), bring high-quality Sierra Nevada mountain-derived waters into the SJR. These eastside rivers have been found to have a low algal and oxygen demand content. The addition of eastside river water to the SJR in the summer and fall can be a major asset to controlling the low-DO problem in the

DWSC, since this low algal content water dilutes the high algal content water of the SJR, and thereby reduces the concentration/load of oxygen demand to the DWSC.

Water Quality Modeling

Several modeling approaches have been used in this study of oxygen demand sources and their impacts on the DO in the DWSC. They include spreadsheet mass-balance box-model calculations, which relate oxygen demand loads to DO deficit in the DWSC. The results of these box model calculations were presented above. A similar box-model approach was used by Foe, *et al.* (2002) to determine the major sources of oxygen demand that enter the SJR upstream of Mossdale. Further, statistical evaluation of the 19-year IEP database has been conducted by Van Nieuwenhuyse (2002). The results of his studies have been presented above. Also, an estimate has been made of the expected algae and BOD concentrations in the DWSC that should be present if all of the algae within the DWSC developed in the DWSC. These results are presented in a subsequent section.

Evaluation of Oxygen Demand Rate Constants. Litton (2001, 2003) and Foe, *et al*. (2002) have conducted long-term BOD tests. Litton (2003) has used these results to characterize the BOD exertion during the BOD test. Typically, the BOD reaction is formulated as a first-order exponential reaction, where the instantaneous rate of BOD decay is proportional to the BOD remaining in the sample. This relationship is described by Chapra (1997), Thomann and Mueller (1987) and Bowie*, et al*. (1985), and is shown in equation (4).

$$dL/dt = -kL \tag{4}$$

Where L is the amount of BOD remaining to be oxidized.

This equation integrates to

$$L = L_0 \times e^{-kt}$$

Where L_0 is the initial amount of BOD in the sample at the beginning of the test, and
k is the BOD exertion rate constant, with units of "per day."

Litton (2003) has indicated that the ratio of BOD_u to BOD_5 is

$$BOD_u/BOD_5 = 1/(1 - e^{-k \times 5}) \tag{5}$$

Where BOD_u is the ultimate (long-term) BOD in the sample.

Litton's 2001 BOD exertion rate constants and associated multipliers are shown in Table 16.

Table 16
2001 Mean and Standard Deviation of the First-Order BOD Decay Constants at 20ºC

Location	k at 20ºC (d^{-1})		BOD_u/BOD_5
	mean	std. dev.	
	BOD / CBOD / NBOD	BOD / CBOD / NBOD	BOD / CBOD / NBOD
San Joaquin River	0.087 / 0.11 / 0.057	0.019 / 0.022 / 0.017	2.8 / 2.4 / 4.0
DWSC	0.094 / 0.11 / 0.076	0.034 / 0.023 / 0.038	2.7 / 2.4 / 3.2

From Litton (2003)

According to Litton, a reasonable BOD_u/BOD_5 multiplier for the DWSC 2001 data is estimated to be 2.75 at 20ºC. The multiplier for CBOD is 2.4, which was estimated from nitrogen-inhibited BOD bottle data.

Chen and Tsai (2002), in their Chen-Systech model of the DWSC, have reported using a BOD_5 decay constant of 0.1 per day, a BOD_u to BOD_5 ratio of 2.54, an ammonia decay constant of 0.05 per day and a DO to ammonia ratio of 4.57. According to Bowie, *et al.* (1985), the Chen and Tsai values are typical of what are normally used in oxygen demand modeling. They are, however, somewhat higher than those found by Litton for the SJR and the DWSC during 2001. It is unclear at this time if the differences are sufficient to cause significant deviations between the loads of oxygen demand to the DWSC and the DO responses found, compared to those predicted by the Chen and Tsai modeling.

Since the BOD measurements are made at 20ºC, there is need to correct the rate of BOD exertion for the impact of temperature on this rate. Normally, the impact of temperature on BOD rate constants is corrected through equation (6):

$$k_T = k_{20}\theta^{(T-20)} \tag{6}$$

Where k_T is the rate constant at temperature T,
k_{20} is the rate constant at 20ºC, and
θ is an empirical coefficient.

The typical value of θ used in BOD modeling is 1.047. Since temperatures as high as 28ºC are sometimes found in the DWSC, a 20ºC 0.1 rate constant becomes 0.144 at 28ºC. As a result, a BOD_u of 10 mg/L at Channel Point would exert over a 10-day period about 6.3 mg/L of oxygen demand at 20ºC, while at 28ºC, the BOD exerted would be 7.5 mg/L. Since most of the time during the summer there is not an eight-degree temperature differential between 20ºC and the DWSC temperature, the magnitude of temperature impact on BOD exertion in the DWSC is a fraction of a mg/L.

As discussed above, there is concern that assessing the BOD of algae in a five-day test may underestimate the long-term BOD of the water. Fitzgerald (1964) reported that assessing the BOD of algae often shows a significant lag between the start of the test and the initiation of oxygen depletion. Fitzgerald's studies showed that this lag-time was the period of time over which the algae die in the BOD bottle. Fitzgerald found that algae that have been held in the dark have the potential to immediately start photosynthesis upon exposure to light. The lag period during which algae die can be several days to several weeks, depending on the type of algae and other factors. Examination of the long-term BOD tests that Litton (2001, 2003) and Foe*, et al.* (2002) conducted showed a smooth regression from the beginning of the test – i.e., no lag.

Deterministic Modeling of Oxygen Demand Load-Response Relationships for the DWSC. The DWSC and the SJR, almost to Vernalis, are part of a freshwater tidal system where tidal flows, ranging from 2,000 to about 4,000 cfs, occur through the DWSC each day. In addition, there is the downstream flow of the SJR through the DWSC which can range from a negative (upstream to Old River) flow to a few thousand cfs downstream. This creates a complex flow system that must be properly modeled in order to assess the impacts of altered oxygen demand load from various sources on DO depletion in the DWSC.

In the mid-1990's, the city of Stockton contracted with Systech Engineering (Dr. Carl Chen) to develop a model that could be used to predict the impact of the City's domestic wastewater discharges to the SJR, just upstream of the DWSC, on the dissolved oxygen resources within the DWSC. The city of Stockton model (Schanz and Chen, 1993; Chen and Tsai, 2002) of the SJR, near the DWSC and the DWSC, is a deterministic model that describes the tidal and net SJR flow through the DWSC and attempts, through a set of differential equations, to describe the processes that govern DO depletion in the DWSC as a function of oxygen demand loads. This model was reviewed by the US EPA (1999b) and found to be of appropriate structure. With the initiation of these DO TMDL studies, the Chen model was modified so that it more appropriately matched the DO depletion found in the summer/fall 1999 studies. Chen and Tsai (2002) have reported on the modeling results obtained during the TAC studies. Generally, there was some agreement with the general trends between the measured DO depletion at various times and locations in the DWSC and the Chen model simulations of the DO during the summer/fall 1999. There were also some deviations between the tuned model simulation results and the field data to which the model was tuned.

The improved Chen model, developed to simulate the 1999 data, was used to simulate the dissolved oxygen conditions in the DWSC found during the summer/fall 2000. Again, the model which had been tuned to 2000 results showed some similarity between the simulated values and the measured values. However, in both 1999 and 2000, there were times when there was relatively poor agreement between the modeled simulated results and the DO within the DWSC. Similar problems occurred for other modeled constituents, such as nitrogen and phosphorus compounds, planktonic algal chlorophyll *a* and several other parameters.

In winter 2001-2002, CALFED approved a limited amount of funds to support Chen to use his current model to predict DO depletion in the DWSC, compared to the actual depletion that occurred in the summer/fall 2001. Brown (2002b) reviewed the ability of the Chen and Tsai model to simulate the DWSC 2001 conditions. Brown concluded,

> *"These sensitivity results suggest that the model needs additional calibration of the algae growth, decay and settling processes that occur between Mossdale and the DWSC. Similarly, the VSS settling and re-suspension processes that occur between Mossdale and the DWSC need additional calibration. Model simulations of the moderate decline in algae, VSS, and DO concentrations between R3 and R5 appear to be much closer to the measured data.*
>
> *The Stockton DWSC water quality model is our most useful existing tool for integration and systematic analysis and evaluation of alternative management actions. The existing model should continue to be used to increase our understanding of the DWSC water quality processes. The model equations and coefficient values have been improved from the original model developed in 1993 for the City of Stockton. However, additional simulations and integration of results from recent experiments performed by the CALFED funded projects (e.g., Litton, 2003 and Lehman, 2002) should be made. The recent peer review panel wondered why the existing model was not being used to provide integration of field data and analysis of potential management actions. The existing water quality model should be used until a more comprehensive alternative model is available."*

There is considerable discussion in the modeling literature about how models should be evaluated and used in water quality management programs. Chapra (2002), Reckhow and Chapra (1983) and Oreskes*, et al*. (1994) have provided information on this issue that is pertinent to the development and evaluation of models that can be used in the SJR DO TMDL.

In the original CALFED proposal submitted in January 2001 to support the summer/fall 2001 studies, funding was budgeted to expand the Chen modeling of the DWSC through the use of a real-time or near real-time forecasting modeling approach. From information that was to be developed through the monitoring program of the loads of oxygen demand present at Mossdale from SJR upstream sources and discharged to the SJR by the city of Stockton, studies were to be conducted to determine whether the Chen model properly predicted the DO depletion that was occurring in the DWSC. Since this was to be a forecasting modeling approach, discrepancies between the predicted DO depletion and the measured DO depletion were to be used to modify the Chen model to more properly simulate the field observations. Through this interactive forecasting modeling approach, it was felt that by the fall 2001, a somewhat better simulation of DO depletion for certain oxygen demand loads would be achieved. Unfortunately, the CALFED Science Program chose not to support further work with the refinement of the Chen model during the summer/fall 2001. This means that little progress has been made in modeling oxygen demand load to the DWSC DO response in the DWSC during 2001 and 2002. As discussed in a subsequent section, the external peer reviewers concluded that the Chen modeling approach originally proposed by the TAC in the 2001 Directed Action project should have been supported and should be activated.

One of the issues of concern to the CALFED Science Program management and their peer review panel that reviewed the SJR Low-DO Directed Action proposal submitted in January 2001, was the belief that DO depletion in the DWSC could not be adequately modeled with a one-dimensional model of the Chen model type. Since, at times, there is short-term stratification that occurs within the DWSC, which is apparently related to somewhat lower dissolved oxygen in the near-sediment waters, it was suggested that the modeling of oxygen demand load DO depletion in the DWSC must be done with a two-dimensional model. It appears, however, that the Science Program peer review panel/management did not adequately consider the transitory nature of the stratification that occurs, and that its impact represents only a small part of the DWSC volume that is of concern with respect to DO depletion within the DWSC. Further, it is clear from the data available that the vertical stratification that has been found, particularly with respect to particulate matter in the DWSC (see Jones & Stokes, 2000, 2001, 2002), is not related to thermal stratification. It appears that this lack of vertical mixing is related to inadequate tidal turbulence to cause the water column to fully mix.

CALFED has been in the process of contracting with HydroQual, a water quality consulting modeling firm in New Jersey, and Monismith, *et al.* (2001) of Stanford University, University of California, Davis, and USGS, to develop two-dimensional or, in the case of Monismith, *et al.*, three-dimensional models of oxygen demand DO depletion for the DWSC. After a year and a half, the contracts have still not been finalized.

An important component of the HydroQual modeling is the interactions with DWR (formerly Hutton, now Rajbhandari) in modeling the algae and oxygen demand loads that develop in the SJR upstream of Mossdale. As described by Hutton (2002), the HydroQual modeling will be coupled to the DWR DSM2 model, which will enable tracking of algae and oxygen demand in the SJR from where Mud and Salt Sloughs enter the SJR to Mossdale. This modeling effort could be of value in helping to evaluate how altering algae and oxygen demand loads present in the SJR upstream of the Merced River would affect algae and oxygen demand loads in the SJR at Mossdale. As discussed elsewhere in this report and by Foe, *et al.* (2002), while, at this time, it appears that there is good correlation between algae and oxygen demand loads in the SJR upstream of the Merced River that, when considering algal growth and diversions downstream of the Merced River, correlates with the algae and oxygen demand loads at Mossdale, the coupling between the upstream of Merced River and Mossdale loads of oxygen demand and algae is not fully defined. The HydroQual/DWR DSM2 modeling has the potential of addressing this issue.

Rajbhandari (2001) of the Department of Water Resources is developing a modification of the DSM2 model for prediction of DO depletion in the DWSC. Further work on this model is being conducted by DWR.

A factor that influences the reliability of simulating DO depletion in the DWSC from the measured oxygen demand loads is that the various investigators, such as two different groups in DWR and the city of Stockton, who have been making measurements of DO and other parameters in the DWSC during the summer and fall, sometimes show differences between each of their measured values at approximately the same time and location. A comparison of the city of Stockton with the Hayes cruise DO measurements in the summer/fall of 2000 showed that the city of Stockton and the DWR Hayes monitoring of the DWSC DO were consistently about a mg/L different at about the same time and location. The Hayes DO measurements were about a mg/L higher than the city of Stockton DO measurements. This difference occurred in the DO 5 to 6 mg/L range, which is the critical range for these measurements. The mg/L difference in this range could be the difference between violating or not violating the water quality objective.

In an effort to determine if there was a systematic error between the city of Stockton and the Hayes cruise data DO measurements, a special QA/QC study on DO measurements was conducted in the summer 2001. These results, as reported in a subsequent section, do not show such an error. The differences between the 2000 Hayes cruise data and the city of Stockton measurements of DO are apparently related to the fact that the city of Stockton DO measurements are made at mid-depth, while the Hayes cruise data measurements are made near the surface and near the bottom. Frequently the DWSC surface DO concentrations are a mg/L or more higher than at mid-depth. The Chen and Tsai (2002) model results predict a mid-depth DO, and should agree with the city of Stockton measurements, and be somewhat different than the surface water DO measurements made during the Hayes cruises.

It is also not clear whether the problems with the Chen-Systech model being able to be tuned to the whole dataset for a particular situation are due to the variability of the input parameters or fundamental problems with the modeling processes. It is apparent that, in order to potentially make the modeling effort more reliable, a much more comprehensive monitoring program of the oxygen demand loads to the DWSC and the DO responses to these loads as a function of parameters that influence responses must be obtained. There is need to plan the monitoring program for the Phase I implementation, to develop the database needed so that, during Phase I, the modeling can be improved. Of particular concern is the need to increase the frequency of monitoring from the current grab sample every two weeks to at least a sample every week and, in some cases, twice a week. Further, there is need to conduct a number of diel studies of the water column at various locations within the SJR upstream of the DWSC and, especially, within the DWSC.

An issue of particular concern to many of the stakeholders in the SJR DWSC watershed, who potentially face spending large amounts of funds to control the oxygen demand problem, is whether the current Chen model is sufficiently reliable to provide guidance on how best to manage the low-DO problem in the DWSC. If the TMDL allocation shows that the agricultural interests in the Mud and Salt Slough watersheds need to reduce their nutrients that become algae at the mouths of these sloughs by a certain amount, say 25 percent, is this estimate reliable plus or minus five percent, 20 percent or 50 percent? At this time, an answer to this issue is not available.

Lee and Jones-Lee (2000a), in their discussion of the modeling in their "Issues" report, emphasized the importance of the model being expanded to include addressing low-DO episodes. At this time, the Chen model more or less predicts a mid-depth DO in the water column. While under certain conditions, it is possible to tune the model so that the data points and the simulation match fairly well, at other times the simulation does not match the data well. Part of this is due to the scatter in the data. Another part is due to the inability of the model to properly track constituents such as ammonia and organic nitrogen. Lee and Jones-Lee (2000a) recommended that an effort be devoted to examining the relationship between the average concentration of DO in the water column predicted by the model and the excursions above and below this prediction, based on actual data obtained at various locations in the DWSC. This recommended evaluation was not funded by CALFED and, therefore, has not been done, with the result that the model has not yet addressed a number of major issues in properly simulating DO in the DWSC water column and at various locations in the DWSC.

Now that the CVRWQCB staff have proposed a Phase I TMDL implementation target, the modeling should be designed to make predictions of how altered loads achieve that target, at all locations and times where low DO occurs in the Deep Water Ship Channel. The modeling needs to be expanded to stations nearer Turner Cut, since at times, especially under high flow, the maximum oxygen depletion is shifted downstream to the Turner Cut region.

Another issue that needs to be addressed is whether the vertical stratification of particulate oxygen demand that occurs near the surface and bottom and the DO depletion that often occurs near the bottom can be modeled within the financial resources that are available for data gathering. The existing database is not adequate to build a model that has potentially reliable predictive capability in addressing these issues.

It is important to understand that the proposed HydroQual model will not likely eliminate many of the significant problems that are found with the Chen model, since the database upon which to build the HydroQual model to address issues of concern, does not exist. Further, because of the way the funding has developed, there will be limited (if any) additional data collected which can be input to the HydroQual model. As a result, the HydroQual model will likely provide little in the way of improvement in predictive capability over the current Chen model. This will result in the Phase I TMDL and its allocation having to be based largely on the Strawman analysis and intuition about what the members of the SJR DO TMDL Steering Committee feel may be occurring in the Deep Water Ship Channel with respect to oxygen demand load DO response relationships.

Application of the Streeter-Phelps Model. As part of the Strawman analysis, Foe, *et al*. (2002) have applied the Streeter-Phelps equation/model to helping to understand DO depletion in the DWSC. Information on this modeling approach is available from Chapra (1997), Thomann and Mueller (1987) and Bowie, *et al.* (1985). This equation relates the oxygen demand load to a riverine waterbody to the DO depletion that will occur downstream of the introduction of the load. It is traditionally used to predict the impact of domestic wastewater discharges of BOD on the DO concentrations in a river. The original Streeter-Phelps equation is a simplistic model, which incorporates dissolved oxygen depletion due to a BOD load with reaeration of the waterbody through atmospheric surface aeration. These two processes are modeled as first-order processes, where the rate of BOD exertion is proportional to the BOD concentration, and the rate of reaeration is proportional to the oxygen deficit from saturation. The typical oxygen profile downstream of a BOD load is a curvilinear relationship, where at the minimum DO, the rate of DO depletion equals the rate of reaeration. This point is referred to as the point of inflection in the DO sag relationship.

Foe, *et al.* (2002) used the unmodified Streeter-Phelps model to examine how much of the oxygen demand DWSC depletion data could be explained by these fundamental mechanisms. Once it was shown that these two fundamental mechanisms explain much (but not necessarily all) of the observed DO trends in the DWSC, the model was used to perform a sensitivity analysis of how changing major input variables would affect these trends. The Streeter-Phelps model was intended to be more illustrative than predictive, but in spite of this, it generates estimates of theoretical reaeration requirements similar to those of the box model calculations presented above and Brown's (2003) estimates. Considering only these basic mechanisms, the following observations and suggestions for further studies have been provided by Gowdy (pers. comm., 2002).

- Incoming DO and BOD concentrations at Channel Point were observed to be a function of flow. Whereas theory would suggest no improvement of minimum DO at the inflection point at higher flows (with fixed input variables), the fact that incoming BOD_u and DO improve at higher flows may explain the observed DO improvement at the inflection point. This theoretical explanation may suggest that further study of the relationships between incoming BOD_u and DO versus flow would be important in understanding how flow appears to improve DO conditions in the DWSC.

- Initially, increasing flow theoretically increases the reaeration rate requirements as more DO deficit is brought into the system per unit time. After reaching a maximum, the reaeration requirements begin to decrease until they are eliminated at high flows. Considering the equation,

  Reaeration rate (lb/day) = flow (cfs) * Δ DO mg/L * 5.4 conversion,

  the rate at which increased flow brings in more DO deficit (initial rise in reaeration requirements) is eventually overcome by the rate of improvement of DO at the inflection point as flow increases (causing the subsequent decrease in reaeration requirements). Improving the understanding of these reaeration requirements as a function of flow will be important in evaluating aeration alternatives and their relationship to other flow and load control alternatives.

- Theoretically the DO deficit and associated reaeration requirements to mitigate it are sensitive to BOD_u and temperature. Future monitoring programs need to measure these variables carefully. This sensitivity also suggests a priority on studies aimed at understanding temperature and incoming BOD_u and DO.

Foe, *et al.* (2002) used the unmodified Streeter-Phelps model to examine how the point of inflection in the DWSC would change with changes in flow of the SJR through the DWSC. The changes in flow affect the travel time of the oxygen demand constituents through the critical reach of the DWSC. Using the flow-travel time relationship developed by Brown (2002a), as shown in Figure 7, and the city of Stockton's measured BOD concentrations at Channel Point, as well as the DO deficit from saturation measured at this location, Foe, *et al.* (2002) calculated the location of the point of inflection for DO depletion in the DWSC. In order to make the unmodified Streeter-Phelps equation fit the observed data, based on city of Stockton monitoring and the DWR Hayes cruises, Foe, *et al.* (2002) found it necessary to use a BOD exertion rate constant of 0.25 per day. This is over 2.6 times the BOD exertion rate constant measured by Litton (2003) of 0.094 per day.

As discussed by Bowie, *et al.* (1985), Chapra (1997) and Thomann and Mueller (1987), many of those who utilize the Streeter-Phelps equation have found it necessary to incorporate a variety of other factors in order to be able to reliably simulate DO depletion downstream of a BOD source. Of particular importance in many situations is sediment oxygen demand, algal growth/ photosynthesis and respiration, temperature and, in some systems, particulate BOD settling. The unmodified Streeter-Phelps equation used by Foe, *et al.* (2002) does not include a variety of factors that are known to influence DO concentrations in the DWSC. Litton (2003) has reported that a significant part of the BOD removal in the DWSC is related to particulate BOD settling and the suspension of particulate BOD near the sediment water interface.

One of the observations made by Foe, *et al.* (2002) utilizing the unmodified Streeter-Phelps relationship is that, on the average, the BOD_5 concentrations measured by the City at Channel Point are lowered by 0.06 mg/L for each hundred cfs increase in SJR flow through the DWSC.

Foe, *et al.* (2002) indicated that the point of inflection for the oxygen sag curve occurred 0.2 to 0.3 mile further downstream with each hundred cfs increase in SJR flow through the DWSC. In a comparison between their Streeter-Phelps-predicted point of inflection with its actual location, based on city of Stockton and DWR cruise data, showed that the predicted point was consistently about 2.5 miles further upstream than it actually occurred.

Foe, *et al.* (2002) examined the effect of changing the temperature on the oxygen profiles simulated from the unmodified Streeter-Phelps. Overall, Foe, *et al*. (2002) found that higher temperatures tend to cause greater DO depletion at the point of inflection.

Using the unmodified Streeter-Phelps approach for a 10 to 13 mg/L BOD_u and a flow of 1,000 cfs, Foe, *et al.* (2002) predicted that the DWSC will need between 3,300 and 8,500 lb/day of additional DO, respectively, to avoid violations of the water quality objective. These amounts are in general agreement with the three-year average conditions (2,300 lb/day) that were found in the box model calculations presented previously. Further, they are in general agreement with, but somewhat lower than, Brown's (2003) estimate of needed aeration (10,000 lb/day).

Estimating Algal Growth within the DWSC. There is concern about the potential influence of algae that develop in the DWSC on oxygen depletion in the DWSC. Lehman, *et al.* (2001) reported that the increase in algal biomass in the DWSC was up to 100 kg chlorophyll *a* per day

(220 lb/day), and that, at this rate, the DWSC algal biomass development is similar to the upstream daily loads of algal biomass to the DWSC. It is of interest to evaluate the expected growth of algae in the DWSC based on its morphological, hydrological and nutrient characteristics. An estimate of this growth can be obtained from the Vollenweider-OECD eutrophication modeling results reported by Jones and Lee (1986) and Lee and Jones-Lee (2002a). Based on empirical data collected from over 750 waterbodies located throughout the world, it is possible to estimate the amount of algae that should develop in the DWSC. This estimate is based on a normalized available phosphorus load to the DWSC, considering its morphology (mean depth) and hydrology (hydraulic residence time). This normalized phosphorus load translates to an average in-waterbody phosphorus concentration. The average available phosphorus concentration in the DWSC during the summer months is about 0.1 mg/L P. Using the Jones-Lee and Lee updated relationship between normalized phosphorus load and planktonic algal chlorophyll *a*, it is found that the DWSC should develop about 10 to 15 µg/L of chlorophyll *a* by the time the water reaches Turner Cut, when the SJR flow through the DWSC allows at least a 10-day travel time between Channel Point and Turner Cut.

Examination of the city of Stockton data for station R7 (just upstream of Turner Cut) shows that frequently during the summer/fall of 2000 and 2001, the planktonic algal chlorophyll *a* at this location is from 5 to 17 µg/L – i.e., in the range of the expected planktonic algal chlorophyll *a* based on Vollenweider-OECD modeling results. This concentration of planktonic algal chlorophyll *a* translates, according to the relationship shown in Appendix E, to 1 to 2 mg/L BOD_5. These are the typical concentrations of BOD_5 measured by the city of Stockton during 2000 and 2001 at Turner Cut. Therefore, it can be concluded that the DWSC is growing algae in accord with the growth of algae that typically occurs in waterbodies located throughout the world.

Assuming 1 mg/L BOD_5 in the DWSC due to in-Channel algal growth and the DWSC volume, it is found that algal growth in the DWSC could represent on the order of 120,000 lb of BOD_u. Using a 10-day travel time through the DWSC, the algal growth would amount to about 12,000 lb/day of BOD_u. It is evident that the primary source of oxygen demand for the DWSC, when the city of Stockton's discharges contain a few mg/L ammonia N, is upstream sources of algae, since on the average the algal BOD_u loads to the DWSC are on the order of 67,000 lb/day at Mossdale.

An issue that needs to be considered in applying the Vollenweider-OECD eutrophication modeling approach to the DWSC is that significant new algal biomass in the DWSC arising from algal growth would be primarily found in the lower parts of the DWSC near Turner Cut. It is the experience of the authors that long, thin waterbodies like the DWSC should be modeled with a "plug-flow" modeling approach, where maximum algal biomass will occur at the downstream end of the waterbody. While this approach is appropriate for most long, thin waterbodies, the tidal flows in the DWSC would lead to increased longitudinal dispersion and would therefore tend to smooth out variable loads to the DWSC. The net result is that most of the algal growth that occurs in the DWSC is likely exported from the DWSC to the Central Delta at Turner Cut and Columbia Cut.

It is important to recall that any algal growth that occurs in the DWSC is accompanied by oxygen production, where, unless the surface waters of the DWSC become oversaturated with respect to DO and there is loss of the photosynthetically produced oxygen to the atmosphere, the oxygen produced by the algal growth is available to satisfy the oxygen demand associated with it. Typically, the near-surface waters of the DWSC are found to be undersaturated with respect to dissolved oxygen. A possible exception could occur in late afternoon, during periods of intense photosynthesis in the upper one to two feet of the DWSC. Further studies are needed to determine if there are periods during the afternoon when there is short-term supersaturation of DO in the surface waters of the DWSC.

An issue that has not been addressed in these studies, as well as in the modeling, is the potential for zooplankton and clam grazing of algae that could significantly impact phytoplankton concentrations. Since zooplankton grazing can significantly impact phytoplankton populations over short periods of time, it is possible that some of the unexplained changes in concentrations of phytoplankton in the SJR upstream of the DWSC and within the DWSC could be due to zooplankton and clam grazing of phytoplankton. Litton (pers. comm., 2002) has reported seeing evidence for the potential significance of declining chlorophyll *a* concentrations between Mossdale and the DWSC being due to zooplankton grazing. He also found large numbers of zooplankton in his sediment traps located in the DWSC during algal bloom conditions. Litton (pers. comm., 2002) has reported that there are large numbers of clams in the DWSC sediments near Turner Cut. Current measurements and modeling have not measured or incorporated the potential for zooplankton and clam grazing of phytoplankton as a factor that could influence phytoplankton populations in the SJR upstream of the DWSC and within the DWSC. This grazing could be an important reason for some of the significant decreases in phytoplankton that have been observed in the DWSC. As discussed herein, these decreases are also due to settling in the water column.

Since there are pulses of pesticide-caused zooplankton toxicity present in the SJR and DWSC, it is possible that pesticides discharged from agriculture in irrigation tailwater and discharged from urban areas in stormwater runoff to the SJR and the DWSC influence zooplankton populations, which in turn influence phytoplankton populations. These situations could explain some of the changes in phytoplankton concentrations that are found in the SJR and DWSC.

South Delta Barrier Modeling Results

During the course of the study, it became evident that the operation of the South Delta channel barriers (see Figure 5) was important in influencing the amount of SJR flow at Vernalis that was diverted into Old River for export to Central and Southern California versus allowed to continue down the SJR into the DWSC. The South Delta has three main channels which convey water from the SJR through Old River to the State and Federal Project export pumps in the South Delta. These channels have rock barriers installed each spring to help control water levels within these channels. CALFED, as part of the Record of Decision, is obligated to replace the temporary rock barriers with permanent mechanical barriers. Hildebrand (pers. comm., 2001) suggested to the SJR DO TMDL Steering Committee and TAC that it may be possible to provide additional water to the SJR DWSC by auxiliary low-head, reverse-flow pumping of South Delta water over the permanent barriers.

In order to investigate this situation, one of the CALFED 2001 Low-DO Directed Action component projects was devoted to modeling water flow through the South Delta in order to assess the feasibility of the use of auxiliary flow pumps across South Delta flow barriers to increase the flow of the SJR through the DWSC. Rajbhandari, *et al.* (2002) has issued a report on this modeling effort. The results indicate that it is potentially technically and economically feasible through low-head, reverse-flow pumping across the permanent barriers to add substantial South Delta water to the SJR via Old River that would pass through the DWSC.

The modeling has shown that the auxiliary reverse-flow pumping would significantly improve the relatively poor water quality that now exists in the South Delta, associated with the temporary rock barriers creating relatively stagnant waterbodies in some of the channels. The improvement in water quality would arise from the fact that the reverse-flow pumping over a permanent barrier would largely pump high-quality Sacramento River water that is diverted from its course toward being exported to Central and Southern California via the State and Federal Projects. At this time, during the summer, the water in the South Delta is largely San Joaquin River water which has high algal concentrations and experiences DO concentrations below the water quality objective.

One of the potential benefits of low-head reverse-flow pumping across the South Delta barriers is the ability to stabilize the flow of the SJR through the DWSC. Flow stabilization would eliminate some of the significant changes in SJR flow through the DWSC that, under certain conditions, can lead to severe DO depletion. Further, stabilized flow would be an asset to managing aeration in the DWSC.

There are a number of issues that need to be addressed before the reverse-flow pumping approach could be adopted. These include the potential impacts of the approximately 200 cfs of agricultural drain water that is discharged to the South Delta each summer from agricultural activities in the South Delta. This agricultural drain water would contain a number of potential pollutants that could cause adverse impacts on water quality in the South Delta and the SJR below where Old River intersects with the SJR. Also of concern is that the city of Tracy currently discharges its domestic wastewaters to a South Delta channel. Other developing cities will likely propose to follow a similar approach. The municipal wastewater loads to the South Delta could cause significant water quality problems in the South Delta. There is need for a multi-year water quality monitoring/modeling project to evaluate the potential water quality problems associated with the reverse-flow pumping of water across the permanent barriers when they are installed.

QA/QC Issues

One of the issues of concern in a study of this type is the reliability of the database developed, upon which management decisions involving expenditures of large amounts of funds will be based. Each of the PIs generating data in this study followed standard QA/QC procedures for their respective organizations. Duplicate samples, spikes and in some cases, split sample comparisons were made. Some of the PIs have reported the results of the QA/QC program in their data reports. In general it is believed that the data generated in this study is neither worse nor better than the typical water quality data generated in studies of this type.

In an attempt to try to address two specific QA/QC issues, the project PI, G. F. Lee (2001a), organized a proposed QA/QC program, which was to enable the investigators making similar measurements to compare the results. A study of this type on DO measurements was conducted in July 2001 at the DWR Rough and Ready Island station. The results of this study have been reported by Stringfellow (2001). His report and other information on the QA/QC program are available on the SJR TMDL website, www.sjrtmdl.org. The DO measurements made by the various investigators all agreed with each other, as well as agreed with the DWR Rough and Ready Island monitoring station results. It became clear that, at least under those conditions, the various investigators could measure DO reliably.

Another parameter of particular concern with respect to reliability of measurements, is the planktonic algal chlorophyll *a*. During the July 2001 QA/QC study at Rough and Ready Island, each of the investigators making chlorophyll *a* measurements were to make measurements from a single sample. As of this time, the results of these measurements have not been reported. It has been found, however, that Dahlgren of the University of California, Davis, used a different chlorophyll *a* extraction procedure using methanol than the other investigators who extracted the chlorophyll *a* with acetone. Dahlgren is not part of the TAC studies and therefore, has not been involved with the TAC in planning, implementing and reporting of the results. He has, however, significantly contributed to this project through making his data available prior to their publication.

DO Water Quality Objectives

As discussed by Lee and Jones-Lee (2000a), there has been considerable discussion about the appropriate dissolved oxygen water quality objective for the Deep Water Ship Channel (DWSC) that will protect the beneficial uses of the DWSC, upstream waters and the Delta without unnecessary expenditures for DO depletion control. The current Central Valley Regional Water Quality Control Board Basin Plan objective (CVRWQCB, 1994) for dissolved oxygen is that the concentration of DO at any location in the Deep Water Ship Channel between Channel Point and Disappointment Slough shall not be less than 6 mg/L between September 1 and November 30, and 5 mg/L between December 1 and August 31. Gowdy and Foe (2002) have recently reviewed the origin of these objectives. The 5 mg/L WQO is similar to, but not the same as, the US EPA's national water quality criterion for DO (US EPA, 1986, 1987). The current US EPA national water quality criterion for DO allows for averaging and for low DO concentrations to occur near the sediment water interface. The 6 mg/L WQO was adopted to protect the fall run of Chinook salmon migration through the DWSC to their upstream home waters. The DO TMDL target for the DWSC is an extremely important value that could influence large expenditures for oxygen demand constituent control in the watershed, aeration of the DWSC and/or enhanced flow of the SJR through the DWSC.

Gowdy and Foe (2002) have proposed that the TMDL would be implemented with a phased approach, where during the initial phase, the following issues will be addressed:

- *"further development of source and linkage analysis to refine allocations of responsibility and source control measures;*
- *study of the effectiveness of initially implemented alternatives in meeting the interim DO performance goal;*
- *design of improvements to implemented initial phase alternatives as necessary to meet final Basin Plan DO objective; and*
- *an examination of the technical basis for the Basin Plan DO objective and, if appropriate, modification of the objective through the required State and Regional Board processes."*

They indicate that the number of TMDL phases and specific actions in each phase will be defined as part of the TMDL implementation plan that will be developed after June 2003. Gowdy and Foe (2002) did not define the length of the initial phase of the TMDL.

During the initial phase of the TMDL implementation, Gowdy and Foe (2002) have proposed as the interim DO water quality target that,

> *"Between June 1 and November 30 dissolved oxygen shall not be less than 5.0 mg/l measured as a 7-day mean of daily minimums, with no daily minimum below 3.0 mg/l. The Basin Plan objective of 5.0 mg/l will be applicable between December 1 and May 31."*

The current Basin Plan dissolved oxygen objective will be the final target unless changed by a Basin Plan amendment before then.

A review of the DWR Rough and Ready Island monitoring station DO data during 2002 (see Appendix D, Figure D-1) shows that it will be difficult to achieve the proposed interim DO target. Substantial aeration will be needed to eliminate the long periods of RRI DO below 5 mg/L.

There is some controversy about the appropriateness of the proposed interim minimum DO target of 3 mg/L. Several individuals (J. Stuart of NMFS and W. Jennings of DeltaKeeper) have indicated to the authors that the interim minimum DO of 3 mg/L is not likely protective of aquatic resources in the DWSC. It is suggested by the authors that this value should be raised to at least 4 mg/L as the minimum that can occur at any time and location. Hicks*, et al.* (1991) have provided information on the effects of dissolved oxygen on salmonids. However, the focus of their discussion is on the impacts of low DO on salmonid habitat for reproduction. Other than the Hallock, *et al.* (1970) study, there appears to be little information in the literature on the effects of low DO concentrations impacting salmonids reaching their home stream waters.

Seager, *et al*. (2000) have investigated the effects of short-term oxygen depletion on fish. They exposed trout and roach to low-DO pulses of one, six or 24 hours of DO concentrations of 4.0

and 5.5 mg/L at frequencies of once or twice a week over 75 days. Their results indicate that for a given duration of low-DO exposure, there is a narrow threshold concentration range above which mortality does not occur and below which mortality rapidly occurs. Post-exposure examination of the fish indicated no significant effects of low-DO concentrations above the critical level. There were no significant effects on growth rates or other fish characteristics. Based on a review of the literature (see Lee and Jones-Lee, 2000a), the CVRWQCB's proposed interim TMDL target would not be expected to significantly adversely impact the aquatic life resources of the DWSC. It would be protective of fish and other aquatic life from death caused by low DO.

During the final phase of the TMDL implementation, which could be from five to 10 years after June 2003, the DO TMDL target would become the CVRWQCB water quality objective. It is possible that, by the time the final phase of the TMDL implementation is initiated, the CVRWQCB water quality objective for the DWSC may be changed from the current 5 mg/L during December 1 through August 31 and 6 mg/L between September 1 through November 30. Also, rather than the current absolute minimum of no exceedance of these objectives, a daily averaging of the DO concentrations, reflecting photosynthetically caused diel variations in DO, where early morning concentrations in the surface waters are significantly lower for a few hours than late afternoon concentrations, would be used in assessing compliance with the water quality objective. This approach is acceptable to the US EPA and is the approach followed in a number of states (Delos, 1999).

Another possible change in the current CVRWQCB DO water quality objective that is acceptable by the US EPA and many states is an allowance of DO depression near the bottom, reflecting the effect of the sediment oxygen demand associated with eutrophic waters. Highly fertile waterbodies throughout the world, which have excellent fisheries, routinely experience DO depletions near the sediments.

From a review of how the 6 mg/L water quality objective was developed for the DWSC (see Gowdy and Foe, 2002, and Lee and Jones-Lee, 2000a), it can be concluded that changing the 6 mg/L objective to the US EPA national water quality criterion of 5 mg/L is likely technically justified. The California Department of Fish and Game studies reported by Hallock, *et al.* (1970) concluded that DO concentrations less than 5 mg/L could potentially inhibit upstream migration of the fall run of Chinook salmon through the DWSC. However, as they point out, it was not clear whether this inhibition was due to high water temperatures and/or loss of home stream water signal during the same time the DO was less than 5 mg/L.

Another issue of concern is whether DO depletions below the 6 mg/L concentration near the bottom waters, but above this value in the mid-water column and surface waters, are inhibitory to Chinook salmon migration to home stream waters during the fall. There is need for further studies to understand the role of DO concentrations less than 6 mg/L as a migratory barrier to the fall run of Chinook salmon. As part of gaining acceptance for stakeholders' expenditures of funds to control the low-DO problem in the DWSC, it will be important to justify the significant additional expenditure for aeration or oxygen demand constituent control from the watershed based on appropriately conducted studies that show the fall run of Chinook salmon through the DWSC is in fact inhibited by DO concentrations less than 6 mg/L.

In December 2001, the State Water Resources Control Board held a workshop devoted to discussion of the current understanding of the recovery of the Chinook salmon and other anadromous fish populations in Central Valley waterbodies. This workshop was attended by G. F. Lee. About 10 years ago, the fisheries' managers and the State Water Resources Control Board established a 10-year goal of doubling the anadromous fish populations in the Central Valley. At this meeting a variety of factors were discussed by the participants as potentially impacting the success of increasing the anadromous fish populations. DO was not one of the parameters mentioned by any of the participants. It appears that the "experts," as well as those responsible for managing/enhancing the anadromous fish populations, consider a variety of other factors, including water temperature, habitat, water diversions, ocean harvesting, etc., as more important than dissolved oxygen water quality objective violations in the Deep Water Ship Channel. Based on discussions at the workshop, the interaction of these various factors is poorly understood. Further, it is not clear that the populations of many of the anadromous fish have changed significantly since the enhancement program was initiated approximately 10 years ago.

A major factor influencing the populations of anadromous fish is the available flows and, in particular, wet and dry years. This greatly complicates understanding the changes that have taken place in the anadromous fish populations, since the initial baseline period was during a drought period, and the last few years have been fairly wet years. There seemed to be general consensus at this workshop that everything should be left alone in order to allow another 10 years or so to see if the enhancement programs that are in place are, in fact, significantly enhancing the populations. This could be an impetus for not changing the 6 mg/L DO water quality objective to 5 mg/L, even though the 6 mg/L is not based on a technically valid assessment of the effect of DO on Chinook salmon migration through the DWSC.

Implications of Technical Studies for Managing the DWSC Low-DO Problem

The results of the three-year technical studies of the DWSC and its watershed provide useful information on the technical allocation of responsibility for control of the low-DO problem that occurs in the DWSC. A summary of these issues is presented below.

Port of Stockton. As discussed above, if the Deep Water Ship Channel had not been constructed and the SJR downstream of the Port of Stockton had the same depth as upstream, there would be few, if any, low-DO problems in the seven miles of the SJR upstream of Turner Cut. The "Port of Stockton" is responsible for the existence of the Deep Water Ship Channel, and therefore, has a responsibility for controlling low DO in the Deep Water Ship Channel by helping fund oxygen demand control programs and/or aeration. Since the maintenance of the Deep Water Ship Channel by the US Army Corps of Engineers is mandated by Congress as part of a national program for dredged channel maintenance, and since continued maintenance of this Channel continues to contribute to the low-DO problem in the DWSC, the Corps of Engineers/US Congress could have considerable responsibility for helping to solve the low-DO problem in the DWSC.

If the DWSC were not maintained it would shoal (become shallower) within a few years. This would eventually lead to increased oxygen demand assimilative capacity as the volume and residence time of the DWSC, between Stockton and Turner Cut, decreases. Eventually, the SJR downstream of Stockton would have the same ability to transport high algal oxygen demand loads as now occurs upstream of the Port. The CVRWQCB staff have indicated that the Port and its stakeholders could likely find that their need to obtain maintenance-dredging permits from the Central Valley Regional Water Quality Control Board could be used to help convince the Port and its stakeholders that they need to become a responsible stakeholder to help correct the problem caused by the creation of the Port and its associated Deep Water Ship Channel. This in turn could lead to causing Congress to fund, as part of the annual maintenance dredging appropriation, corrective measures for the low-DO problem.

There is precedent for this in that, as part of deepening the Deep Water Ship Channel from 30 to 35 feet, which took place several years ago, the Corps of Engineers installed an aeration system near Channel Point for the purpose of correcting the loss of oxygen demand assimilative capacity associated with channel deepening (see discussion by Nichol and Slinkard, 1999; US EPA, 1971; USA COE, 1988). The Sacramento Corps District is responsible for operation and maintenance of this aeration system. Basically, there is need for Congress to make the funding available to address the larger picture associated with ongoing navigational depth management of the first seven miles of the DWSC below the Port of Stockton.

Supplemental Aeration. As part of gaining permission from the CVRWQCB to deepen the DWSC from 30 to 35 feet, the Corps of Engineers installed two jet aerators at the Port of Stockton. According to Foe (pers. comm., 2002), the agreement between the Corps and the CVRWQCB requires that the Corps operate the aerators when the DO falls below 5.2 mg/L anywhere in the DWSC as measured by the city of Stockton weekly monitoring runs between September 1 and November 30. These aeration devices were designed to compensate for the increased oxygen demand caused by the increased depth of the water column in the DWSC. However, they were not evaluated with respect to whether the design characteristics were, in fact, achieved. It has been found by Brown (2003) that one of the aerators is operating at about 80 percent and the other is operating at about 25 percent of design.

Brown (2003), as part of his component project of the Directed Action project, tested an oxygen bubble diffuser device that would operate in just 25 feet of water at the edge of the DWSC (under the Rough & Ready Island dock). According to Brown, the oxygen bubble device is a diffuser at one end of a U-shaped pipe (horseshoe) that is called a “mounted oxygen bubble injector” (MOBI). The oxygen bubbles from a diffuser located at the bottom of the riser tube create a flow of upwelling water. The gas that is not dissolved rises to an exhaust spout at the top of the U-pipe and might be pumped back into the diffuser to dissolve more of the oxygen gas supplied. Good performance was measured with the 20-inch diameter test version, with a 20 percent transfer efficiency that would deliver about 125 lb/day of DO. Brown indicated that the full-size devices (36-inch diameter) should deliver 500 lb/day, so about 20 of the full-size devices would be needed to supply the 10,000 lb/day of oxygen needed in the DWSC to satisfy the oxygen deficit below the WQO.

Brown (2003) conducted a preliminary review of the major aeration technology for rivers and lakes. He reported that several methods appear to be economical and feasible for controlling the DO depletion below the WQO in the DWSC. Each of the most promising devices for pilot scale testing was compared for likely oxygen bubble or aeration efficiency. Brown recommends that the most effective devices for transferring DO from oxygen or air bubbles in only 25 feet of water should be field tested in the DWSC and compared with the MOBI device. Brown indicated that soaker hose bubble diffusers and submerged chambers (Speece Cone) are the most likely devices for solving the low-DO problem in the DWSC.

Brown (2003) stated that several aeration and oxygenation techniques appear to be feasible and economical for the DWSC, with a depth constraint of 25 feet, and without interfering with ship traffic. He estimates that the cost of adding oxygen to a waterbody is on the order of about \$0.10/lb. He indicated that the cost for aeration or oxygen bubble devices to eliminate the DO problem in the DWSC is likely to be less than \$2.5 million dollars, with annual operating expenses of less than \$500,000.

Brown (2003) investigated water temperature measurements at several depths at the Rough & Ready Island water quality station during the summer of 2002. These data indicate that diel stratification during the afternoon in the DWSC occurs on most days and may influence the near-surface algal photosynthesis and surface aeration, and may also isolate the surface layer from the majority of the DWSC.

Brown (2003) indicated that lateral mixing across the DWSC may prevent aeration or oxygen injection devices that are located under the Port of Stockton Rough and Ready Island dock from effectively increasing DO throughout the DWSC. A dye study was conducted in cooperation with Dr Gary Litton (Civil Engineering, UOP) to measure the lateral and vertical spreading of dye that was injected into the MOBI device along the Rough & Ready Island dock. Lateral mixing of the dye was nearly uniform at the end of a full 24-hour tidal cycle. The normal tidal movement is about 5 miles in the vicinity of the Rough & Ready Island station, and this apparently provides sufficient energy to laterally mix the DWSC. Brown concluded that aeration or oxygen injection devices can be located along the Rough & Ready Island dock and increase DO throughout the DWSC.

As discussed above in the “Box Model Calculations” section, based on the last three years’ data, on average about 2,300 lb/day of DO needs to be added to the DWSC to prevent DO depletion below the water quality objective. There are times, however, when much larger amounts of oxygen will be needed. Considering the worst-case conditions for DO depletion below the WQO found in the box model calculations for data collected over the past three years, on the order of about 6,000 lb/day of DO would be needed to keep the DWSC from violating a WQO. Using the unmodified Streeter-Phelps approach for a 10 to 13 mg/L BOD_u and a flow of 1,000 cfs, Foe, *et al.* (2002) predicted that the DWSC will need between 3,300 and 8,500 lb/day of additional DO, respectively, to avoid violations of the water quality objective. Brown (2003), using a different approach for calculating oxygen deficit below the water quality objective, indicated that in 2001 an aeration device that delivered 10,000 lb/day of DO would satisfy the DO deficit during the summer. He concludes that about the same amount would likely have been needed in 1999 and 2000. The amount of aeration needed to meet the WQO will be dependent on the SJR DWSC flow, where increased flow will require greater amounts of aeration. Further, increased flow will affect the locations where aerators should be placed.

At this time, there is need for a comprehensive engineering evaluation of the use of aeration to control the low-DO problem in the DWSC. This evaluation should lead to several years of large-scale pilot studies to examine the technical feasibility and associated costs of using one or more aeration approaches to solve the low-DO problem in the DWSC. Eventually, through the pilot studies, it will be possible to design, construct and operate an aeration system to control the low-DO problem to meet the interim and final TMDL DO target. It is likely that aeration will be part of an overall management plan which will utilize a combination of upstream oxygen demand load control, managed SJR flow through the DWSC and selective aeration of the DWSC to control the low-DO problem. Additional information on the recommended pilot aeration studies is provided in a subsequent section.

South Delta Barrier Reverse-Flow Pumping. At this time, the barriers in the South Delta are manually operated. CALFED has committed to the installation of automatic tidal barriers, which are reported to better manage flows in the South Delta channels, to eliminate the low water levels that occur now, associated with export pumping of South Delta water to Central and Southern California. As discussed above, it has been proposed that the operation of the barriers can be conducted in such a way as to increase the flow of the SJR through the DWSC. Hildebrand (pers. comm., 2002) proposed that barrier operations, coupled with low-head, reverse-flow pumping over the barriers, can be conducted in such a way as to export water from the South Delta into the SJR via Old River. This, in turn, would shorten the hydraulic residence time of oxygen-demanding materials added to the DWSC, potentially resulting in less DO depletion in the DWSC. It has been found by Rajbhandari, *et al.* (2002) that low-head, reverse-flow pumping is technically feasible in providing South Delta water to the SJR DWSC. There are, as discussed above, a number of issues that need to be addressed in connection with developing this proposed approach to helping solve the low-DO problem in the DWSC.

The Strawman results from Foe, *et al.* (2002), as well as the observations made from the Hayes cruise data on the impact of flow on the low DO in the DWSC over the past 15 years, and the box model calculations presented herein, have raised questions about the ability of supplemental flow to the DWSC to control the low-DO problems. There is no issue that SJR flows greater than about 2,000 cfs through the DWSC will control the low-DO problem in the first seven miles below the Port of Stockton in the DWSC by exporting the oxygen demand loads into the Central Delta before they can be exerted in the DWSC. At this time there is not a readily discernable relationship between SJR flow through the DWSC between about 500 and 1,500 cfs and DO depletion in the DWSC. While the Chen and Tsai (2002) modeling presents a generalized relationship between SJR DWSC flow and DO depletion in the DWSC, the DWSC monitoring data, such as those presented herein based on the city of Stockton's monitoring as well as those developed in the Hayes cruises, raise questions about the reliability of the Chen model results. This is an issue that has not been resolved at this time.

The Rajbhandari, *et al.* (2002) modeling has predicted that reverse-flow, low-head pumping over the permanent South Delta barriers would improve water quality in the South Delta as a result of introducing Sacramento River water into the South Delta. It is desirable that the supplemental flow into the SJR should be of a low oxygen demand content and thereby dilute the oxygen demand in the SJR waters that enter the DWSC. While this appears to be feasible, there are other South Delta water quality issues that are not well understood. There are a number of South Delta water quality issues that need to be addressed before the barrier reverse-flow pumping approach can be adequately evaluated. There is need for further studies on the hydraulics of the South Delta, with particular reference to how the permanent barriers would impact the water quality that is occurring in the South Delta and the quality of water that would be exported from the South Delta to the SJR via Old River.

Mud and Salt Slough and SJR Upstream of Lander Avenue Watersheds. The significance of the Mud and Salt Slough and SJR upstream of Lander Avenue watersheds as a source of algae/oxygen demand material for the DWSC could require that stakeholders in these watersheds develop control programs that can control the growth of algae in the Sloughs' watersheds and the SJR upstream of Lander Avenue. The Mud and Salt Slough watersheds are already under regulatory constraints for control of selenium. According to McGahan (pers. comm., 2002), the regulatory controls have resulted in a reduction of selenium loads discharged by Mud Slough by 56 percent over the last five years. The flow from the Mud Slough watershed has been reduced by 47 percent during this period. The Mud and Salt Slough watersheds will also likely come under regulatory control of total salt (TDS) and boron (CVRWQCB, 2002b). Further, it is possible that, as a result of the TMDL to control oxygen demand loads in the SJR watershed, the discharges of nutrients in the Mud and Salt Slough watersheds, as well as to the SJR upstream of Lander Avenue, that lead to the development of algae that cause violations of the DO water quality objective in the DWSC, will need to be reduced/controlled.

The algae control program should be designed to reduce the algal-related oxygen demand loads that enter the SJR from Mud and Salt Sloughs and the SJR upstream of Lander Avenue that cause/contribute to DO depletions below the WQO in the DWSC, as opposed to nutrient control programs that are arbitrary, across-the-board nutrient reductions irrespective of their contributions to the water quality problem. Thus far, nutrient control programs that have been developed across the US do not incorporate the information needed to cost-effectively control the nutrient sources and amounts to achieve the desired water quality without excessive expenditures for nutrient control. As discussed by Lee (2001b), a technically valid, cost-effective nutrient control approach requires a good understanding of nutrient and algal growth dynamics from where the nutrients are first discharged until the algae enter the DWSC and cause DO depletion below the WQO.

At this time there is a limited understanding of the specific sources of nutrients in the Mud and Salt Slough and SJR upstream of Lander Avenue watersheds that develop into algae that grow to a sufficient extent, within the Mud and Salt Slough watersheds as well as the SJR upstream of Lander Avenue watershed, to lead to high algal concentrations/loads in the SJR upstream of where the Merced River enters the SJR. It is the growth of algae, based primarily on the nutrients derived from these watersheds, that ultimately becomes the high algal-caused oxygen demand loads that have been found in the SJR at Mossdale. The initial focus of the Mud and Salt Slough and SJR upstream of Lander Avenue watersheds' oxygen demand load control program should be on gaining an understanding of algal growth dynamics and nutrient sources in these watersheds, focusing on the headwater areas of the watersheds. This understanding can then potentially be used to control the algal populations that are present in the SJR upstream of where the Merced River enters the SJR.

SFEI (2002) has published the 1999-2000 annual report for the Grassland Bypass Project. This report contains information pertinent to monitoring within the Mud and Salt Slough watersheds. At this time, there is extensive monitoring being conducted for temperature, pH, EC, TSS, selenium, boron, sediments, selenium uptake by biota, and aquatic life toxicity to fish larvae, zooplankton and algae. As recommended by the SJR DO TMDL Steering Committee (Lee, 2001c), the current monitoring program in the Mud and Salt Slough watersheds needs to be significantly expanded to include the various forms of nitrogen and phosphorus compounds that serve as algal nutrients, as well as planktonic algal chlorophyll *a*, pheophytin *a* and BOD. Further, each of the subwatersheds within the Mud and Salt Slough and SJR at Lander Avenue watersheds should be monitored for some of these parameters, as well as flow, at various locations to define the specific sources of nutrients and algae that ultimately become the high concentrations at the mouths of Mud and Salt Sloughs and in the SJR at Lander Avenue. The needed studies will require several years of detailed, selective monitoring in the Mud and Salt Slough and SJR upstream of Lander Avenue watersheds to develop an information base on which to begin to formulate potential oxygen demand control programs. Guidance on the needed studies is provided in a subsequent section of this report.

It should be understood, as discussed by Lee (2001b), that controlling algal nutrients (nitrogen and phosphorus) from agricultural activities will be difficult and could be quite expensive compared to the profit margins that many parts of agriculture are experiencing today. Lee and Jones-Lee (2002a,b; 2003b) reviewed the literature summarizing the experience of nutrient control programs from agricultural sources in other parts of the country, such as in the Great Lakes region and in the Chesapeake Bay watershed. Sharpley (2000) and Logan (2000) have summarized the experience of attempting to control algal nutrients in agricultural runoff in the Chesapeake Bay and the Lake Erie watersheds. As summarized by Lee (2001b), the nutrient control programs that have been conducted over the past 15 to 20 years in these areas have thus far failed to be highly effective in controlling nitrogen and phosphorus inputs to these waterbodies. It has been reported by Sprague, *et al.* (2000) that the major ag-derived nutrient reductions that have occurred in the Chesapeake Bay watershed are associated with the cessation of agricultural activities in parts of the watershed.

Lee (2001b) has reviewed many of the issues that need to be considered in developing a technically valid, cost-effective algae/nutrient control program in the SJR watershed. As he discussed, the approach should focus on controlling the nutrients that are specifically responsible for the algal biomass (BOD load) that causes DO depletion below the water quality objective in the DWSC. From the information available, it is concluded that available algal phosphorus control in the Mud and Salt Slough headwaters could have the potential of limiting algal growth in these waters and thereby reducing the biomass of algae that are discharged by these tributaries to the SJR. Stringfellow and Quinn (2002) and Foe, *et al.* (2002) have reported that the concentrations of algal available phosphorus in Mud Slough near its mouth where it joins with the SJR, are sufficiently depressed to be near algal growth-rate limiting. If that situation can be promoted throughout the Mud and Salt Slough watersheds, as well as the SJR upstream of Lander Avenue, then the algal seed which ultimately develops into a large algal biomass at Mossdale could potentially be controlled sufficiently to reduce the algal-caused oxygen demand that enters the DWSC.

Stringfellow and Quinn (2002) reported that algal growth in the San Luis Drain, which is a concrete-lined channel that carries agricultural drain water from the 97,000-acre Grassland Drainage Area to Mud Slough, shows a doubling in algal biomass in about one to two days. This is in accord with the expected algal growth under light-limited conditions. It is also similar to the apparent algal doubling rates reported by Foe, *et al.* (2002). There is an important difference between the Foe, *et al.* (2002) doubling rates and those of Stringfellow and Quinn in that the Stringfellow and Quinn doubling rates are the true doubling rates while the Foe doubling rates reflect the algal doubling but also water diversions and tributary discharge of low algal water to the SJR. The Foe, *et al.* (2002) doubling rates are not true doubling rates but are the apparent doubling rates reflecting changes in the hydrologic characteristics of the SJR.

In conducting a nutrient control program in the Mud and Salt Slough and SJR upstream of Lander Avenue watersheds, it would be important to focus on algal nutrients such as nitrate and soluble ortho P, and not total P. Lee, *et al.* (1980) have reported that large amounts of the agriculturally derived phosphorus in stormwater runoff is often in particulate forms, where most of the phosphorus is not available to support algal growth. This situation may not apply to ag-derived tailwater and subsurface drain water. Lee and Jones-Lee (2002a,b; 2003b) have discussed nutrient control issues associated with agricultural sources. These discussions provide information pertinent to the control of nutrients and algae in the Mud and Salt Slough and SJR upstream of Lander Avenue watersheds.

Allocation of Oxygen Demand Loads in Subwatersheds. It is possible that the CVRWQCB will assign allowable oxygen demand loads to each of the SJR tributaries as part of implementation of the TMDL. It will then become the responsibility of the stakeholders in each SJR tributary watershed, as well as those that discharge directly to the SJR in agricultural drains, to develop approaches for controlling their oxygen demand discharges to meet the CVRWQCB-allowed oxygen demand load from a tributary. It will likely require several years of study and considerable funding before an allocation of responsibility for control of oxygen demand sources that occur at the tributary's point of discharge to the SJR can be developed. Only when this information is available and is implemented into a management plan, can there begin to be effective control of oxygen demand sources within the SJR DWSC watershed. The initial phase of the DO TMDL implementation plan will need to be devoted largely to gaining an understanding of oxygen demand sources and their potential control within each of the SJR tributaries' watersheds. It will be important in developing these programs to be certain that the control of oxygen demand in the watershed is appropriately tied to oxygen demand that leads to DO depletion below a WQO within the DWSC, and not directed to control of oxygen demand from sources that do not lead to low-DO problems in the DWSC.

As mentioned previously, at this time there is inadequate understanding of how a change in the oxygen demand load discharged to the SJR or one of its tributaries will impact the oxygen demand load in the SJR at Mossdale. The DWR HydroQual modeling (discussed above) could provide information on this issue as it relates to discharges to the SJR by the tributaries. There will be need to extend this modeling into the subwatersheds in order to evaluate how controlling nutrients/algae within any part of a subwatershed would impact DO depletion in the DWSC below the WQO.

Agricultural Diversions. Agricultural diversions of SJR water along its course between where Mud and Salt Sloughs enter the SJR and the DWSC can, during the irrigation season, divert significant amounts of water and associated oxygen demand for irrigation. This tends to reduce the magnitude of the Mud and Salt Slough and SJR upstream of Lander Avenue oxygen demand loads that ultimately reach the DWSC. As discussed above, a significant part of the algal oxygen demand load present in the SJR upstream of the Merced River never reaches the SJR at Mossdale because of agricultural diversions of irrigation water. There is need to improve the ability to assess the magnitude of agricultural diversions along the SJR as part of assigning responsibility for oxygen demand loads in the SJR at Mossdale.

One of the most significant diversions of SJR water occurs into Old River, where the waters are exported via the State and Federal Projects to Central and Southern California. At times, most of the water in the SJR that reaches Old River is diverted into Old River for export. This diversion, while reducing the magnitude of the algal related oxygen demand loads that are present in the SJR at Mossdale that reach the DWSC which is beneficial to the DWSC, adversely impacts the flow of the SJR through the DWSC, thereby increasing the hydraulic residence time of the residual oxygen demand loads to the DWSC. The low flow conditions of a few hundred cfs of SJR flow through the DWSC, compared to about 600 to 2,000 cfs that typically occurred during the 1999, 2000 and 2001 study period and including the 2002 data, resulted in some of the most significant oxygen depletions in the DWSC found during the studies. DO concentrations of about 2 mg/L were found in late September/early October 1999, associated with one occasion of this type. The diversion down Old River associated with the removal of the Grant Line barrier resulted in a high algal load being introduced into the DWSC just prior to the reduced flow through the DWSC. As a result, the algae present in this pre-diversion flow had an extended period of time to exert their oxygen demand, resulting in very low DO concentrations occurring in the DWSC. Other examples of low flows resulting in severe oxygen depletion in the DWSC occurred in 2002 and 2003, as discussed above. It will be important to stabilize the flow of the

SJR through the DWSC so that major changes in flow, especially dramatic decreases from over 1,000 cfs to a few hundred cfs such as occurred in late September 1999 and late May-early June 2002, are avoided. Further, stabilized flow will enhance the ability to manage aeration of the DWSC.

Eastside Rivers. An increase in flow of eastside rivers (Tuolumne, Stanislaus, and Merced Rivers) into the SJR can be a major factor in reducing the oxygen demand derived from the Mud and Salt Slough and SJR upstream of Lander Avenue watersheds that leads to low-DO problems in the DWSC. This is a result of diluting the elevated SJR algal concentrations that are present upstream of where the eastside rivers enter the SJR. Further, additional eastside river flow would decrease the travel time of the oxygen demand loads through the DWSC. This conclusion is particularly important since, as discussed by Lee and Jones-Lee (2000a), the San Joaquin River watershed is predicted to double in population over the next 20 years. Such doubling can only occur if additional water supplies are developed to serve this population. It appears now that there would likely be opposition to the use of any eastside river water to serve as a domestic supply for any new populations or any additional growth in the Central Valley or in the San Joaquin River watershed because of the potential adverse impacts on the flow of the eastside rivers to the SJR.

Issues that Need to be Resolved

There are a number of key issues that evolve from the conceptual models for the sources and impacts of oxygen demand on the DO resources of the SJR DWSC that need to be resolved. With respect to the constituents responsible for the DO depletion in the DWSC, the key issue is identifying the constituents primarily responsible for DO depletion below water quality objectives in the DWSC. Of equal importance is the origin of these constituents, their respective loads and how reducing these loads will improve water quality in the DWSC.

Oxygen Demand Dynamics in the SJR DWSC Watershed. A major issue that needs to be addressed in formulating a technically valid, cost-effective DO depletion control program for the DWSC is an understanding of the dynamics of oxygen demand development and changes in the oxygen demand that occur in the SJR during transport to the DWSC. As discussed herein, this understanding of the dynamics of oxygen demand development, transport and fate upstream of the DWSC must be addressed for the various seasons (monthly), especially during the late spring, summer and fall. In addition, since the studies of the past three years were conducted during wet-year periods, they may not be fully applicable during dry years. There is need to consider how the wet-year versus dry-year conditions within the SJR watershed influence oxygen demand dynamics within the DWSC watershed.

An issue that will need to be considered in developing nutrient control programs within the SJR watershed is the potential adverse impact of such programs on the fisheries resources of the Delta. Lee and Jones (1991) have shown that there is a direct relationship between fish production in waterbodies and their nutrient loads. Since there is an interest in improving the fisheries of the Delta, controlling nutrient inputs to the Delta from its tributaries could prove to be detrimental to Delta fisheries. This issue will need to be evaluated as part of any nutrient management program within the Delta and its tributaries.

City of Stockton Wastewater Discharges. The wastewater discharges from the city of Stockton are, at times, potentially significant sources of oxygen demand for the DWSC. In addition to the residual BOD present after treatment, the wastewaters, at times, can contain high concentrations of algae that develop in the City's treatment ponds. While at times the City filters its effluent to remove many of the algae, at other times discharges of algae occur. This adds to the algal load within the DWSC which could be significant during low SJR DWSC flow. Another factor to consider with the City's wastewater discharges is that they are not constant, but are often shut off over the weekends, and then are allowed to occur again on Monday. This discharge pattern could be influencing the oxygen depletion within the upper parts of the DWSC, especially near Channel Point. The impacts of this discharge pattern on DO depletion in the DWSC need to be evaluated.

The CVRWQCB has adopted a revised NPDES wastewater discharge permit for city of Stockton which will limit the amount of ammonia discharged to the SJR because of the potential for these discharges to cause toxicity to aquatic life. There is need to evaluate the degree of control that the City must exercise to control ammonia-caused significant oxygen demand that influences DO depletion in the DWSC.

DO "Crashes" in the DWSC. One of the most significant issues that will need to be understood is the origin of the DO "crashes," where, for what appears to be short periods of time, unusually low DO occurs at certain locations in the DWSC. At times there will be short-term DO depletions to relatively low levels -- i.e., 2 mg/L. These DO crashes are particularly significant since they may ultimately become the controlling DO depletions that must be managed. At this time, the causes of the DO crashes are not understood.

Some of the factors that may be responsible for the DO crashes include unusually high short-term oxygen demand loads or other factors, such as decreased light penetration associated with increased turbidity or color, that influence how oxygen demand discharged to the DWSC influences DO depletion within the DWSC. There is need for intensive field studies involving more frequent monitoring of sources and DO depletion than has been conducted in the past three years. Such studies should be designed to understand and thereby control the DO crash episodes that occur occasionally in the DWSC.

As discussed above, there are a number of issues related to the variability of the oxygen demand loads present in the SJR at Mossdale and discharged by the City to the SJR upstream of Channel Point in influencing the variability of oxygen depletion measured a week to two weeks later at various locations in the DWSC. A Lagrangian approach needs to be adopted where load-response relationships are examined at various locations within the DWSC as a function of travel time to the location of interest. This approach needs to consider the tidal-induced longitudinal mixing that occurs within the DWSC that would smooth the variable load inputs to the SJR to minimize the variability in oxygen depletion and exported loads of oxygen demand and oxygen deficits at Turner Cut. This will require more frequent sampling at various locations within the DWSC to determine the variability in DWSC response parameters to upstream oxygen demand loads. At this time, this issue has not been addressed.

DO Depletion within the South and Central Delta. At times, large amounts of oxygen demand are delivered to the South Delta through the diversion of SJR water into Old River. As discussed herein there are significant DO depletions below the water quality objective in the South Delta. These DO depletions appear to be due to the presence of large populations of algae and their photosynthetic/respiration activity. The role of SJR-derived algae versus those that develop in the South Delta, in causing the DO concentrations to fall below the WQO, is not understood. Also, the influence of the city of Tracy's wastewater discharges on South Delta water quality needs to be evaluated.

Another factor is how these DO depletions in the South Delta will be influenced by the installation and operation of the permanent barriers that CALFED is proposing to install in the South Delta. Also of concern is the influence of the proposed increased export of South Delta water through the State and Federal Projects, which again will cause manipulations of the oxygen demand and flows in the SJR down Old River and through the DWSC. Any major changes in the flow patterns from what exist now need to be carefully evaluated before the changes take place, to be certain that the problems that now occur because of diversions and export pumping of water from the Delta do not make the DO depletion problem in the SJR worse than it already is.

Under high flow conditions of the SJR through the DWSC, appreciable amounts of oxygen demand in the form of algae and, at times, nitrogenous BOD are diverted into the Central Delta through the cross-SJR DWSC flow of the Sacramento River that arises from the export pumping of South Delta waters to Central and Southern California. No work has been done thus far on the DO depletions in the Central Delta. Studies need to be conducted before any plan to modify the SJR flow through the DWSC is implemented through the discharge of South Delta water through the DWSC. This proposed flow management plan also needs to be evaluated with respect to the quality of the water that would be discharged to the SJR DWSC from the South Delta via Old River.

Oxygen Demand Dynamics between Mossdale and Channel Point. Foe, *et al.* (2002), as part of the Strawman analysis, have addressed the issue of whether there are unusual or unexpected changes in oxygen demand that occur between the SJR at Mossdale and the DWSC at Channel Point. Confusing information has been presented on this issue, where claims of large amounts of oxygen demand disappearance occurred in this reach of the San Joaquin River. There are questions, however, about the reliability of that assessment, based on the ability to reliably conduct a mass balance in the tidal part of the DWSC at Channel Point. Measurements at Channel Point reflect dependence on tidal stage and direction, inputs from the SJR DWSC downstream of this location, inputs from the upstream SJR and inputs from the Port of Stockton's Turning Basin. The Turning Basin has significantly different surface and bottom water characteristics than the main body of the DWSC near Rough and Ready Island. Channel

Point is an extremely difficult area to properly monitor and understand factors influencing algae and oxygen demand concentrations in samples taken from this location. In order to properly characterize the concentrations of constituents at Channel Point, an extensive sampling and flow measurement program far beyond those that have been conducted thus far is needed to be able to reliably claim that there are unexpected or unusual concentrations of oxygen demand constituents in samples taken from Channel Point.

Foe, *et al.* (2002) have shown that the changes that occur in oxygen demand between Vernalis and Mossdale are in accord with what would be expected, where there is increased algal growth in the SJR between these two locations. Quinn and Tulloch (2002) have pointed out that there is a major agricultural diversion (Banta Carbona) of SJR water between Vernalis and Mossdale. According to Quinn (pers. comm., 2002) during July 2001, the Banta Carbona diversion represented about 200 cfs. This water district, therefore, has the potential to divert a substantial part of the oxygen demand load present in the SJR at Vernalis and thereby reduce the total load that is present at Mossdale.

As shown in Figure 7, at 1,000 cfs of SJR flow through the DWSC there is about a 1.5-day travel time between Mossdale and Channel Point, while at 600 cfs the travel time between these two points is about 2.5 days. During a one- to two-day travel time between Mossdale and Channel Point, significant changes in the oxygen demand, algae, etc., would not be expected. However, under SJR DWSC flows of a few hundred cfs, such as frequently occurred in 2002, much longer travel times exist between Mossdale and Channel Point, during which major changes in the algal population and oxygen demand load constituents can occur. This is an area that needs intensive study.

Overall, it does not appear that under SJR DWSC flows above about 600 cfs there is any unusual behavior of oxygen demand loads present at Vernalis that cause the concentrations at Mossdale, or for that matter at Channel Point, to be significantly different from what is expected. This may not be the case, however, under extreme low flows of less than 500 cfs.

Development of a TMDL and Its Technical Allocation

As discussed above, the studies and information reported herein are part of support of a short-timeline TMDL development program, where the CVRWQCB must develop a technical TMDL for submission to the US EPA in June 2003. These studies were designed to support the SJR DO TMDL Steering Committee in the development of a management plan that could be submitted to the CVRWQCB in December 2002 for control of the low-DO problem in the DWSC. As discussed in Appendix A, for a variety of reasons, the results of the studies fell short of achieving the originally established objectives. Further, the Steering Committee failed to develop the implementation plan by the December 2002 deadline. This has resulted in the situation where the CVRWQCB staff have had to assume the responsibility for development of an implementation plan which will be incorporated into a Basin Plan Amendment that will be initiated in June 2003. The CVRWQCB staff (Foe, 2002; CVRWQCB, 2003) have provided their current approach for conducting the initial phase of the TMDL (Phase I), which includes the development and implementation of the Phase I TMDL implementation plan.

It is the authors' conclusion, based on their experience in working on similar problems in other areas, that there is an adequate information base now to establish a preliminary Phase I TMDL of oxygen demand and to allocate the oxygen demand load responsibility for the discharge of oxygen-demanding constituents that influence DO depletion in the DWSC, to the SJR DWSC tributary mouths. Substantial additional work will need to be done during Phase I to refine the TMDL, especially under altered meteorological/hydrological conditions, and to improve on the predictive capability of the city of Stockton/Chen model to define the occasional excursions of DO below the normal DO depletion in what are characterized as "crashes."

The 2000 and 2001 monitoring has defined the magnitude of the loads of oxygen demand from each of the major tributaries to the SJR and the changes in these loads along the SJR from the Mud and Salt Slough area down to Mossdale. Therefore, at least during moderately wet years, the expected oxygen demand loads at various locations within the SJR watershed above Mossdale, have been defined at the major tributary mouths. The magnitude of the loads will likely vary somewhat from year to year and especially during drought years. However, the overall conclusions, with respect to Mud and Salt Sloughs and the SJR upstream of Lander Avenue being dominant sources of oxygen demand, will not likely change. The Central Valley Regional Water Quality Control Board can allocate oxygen demand loads to the mouths of the major tributaries to the SJR until such time as detailed oxygen demand load studies have been conducted in each of the major tributary watersheds.

Technical Allocation of Oxygen Demand Load. The discussion presented herein on a suggested allocation approach is based on the information available on technical issues. This is, therefore, a technically-based allocation approach. TMDL allocations of responsibility, however, are often based on other social, political, and other factors. It has been the authors' experience that frequently the actual allocation for responsibility, and therefore funding to correct the problem, largely ignores technical information and is based primarily on political or other non-technical issues. This situation has been repeatedly found to lead to some stakeholders having to pay far more for correcting the water quality problems than their technical responsibility indicates.

The CVRWQCB (2003) staff have recently released their proposed allocation of responsibility for solving the DO problem in the DWSC. Their proposed approach allocates the responsibility one-third to DWSC geometry, one-third to water diversions, and one-third to oxygen demand constituent loads. The staff indicated that studies conducted during Phase I of the TMDL will be used to refine this allocation. In mid-March 2003 the CVRWQCB at a SJR DO TMDL workshop accepted the staff's recommended approach for the initial allocation of oxygen demand loads and a TMDL Phase I phased approach involving additional studies to refine this allocation. The information provided below is pertinent to conducting these studies and the refinement of this allocation.

In order to develop a technical allocation of the responsibility for control of the low-DO problem in the DWSC it is necessary to develop a common currency where the responsible parties for this problem (the Port of Stockton, upstream of DWSC water diverters, and oxygen demand dischargers) and their responsibility for the low DO problem can be equated. A common currency can be developed based on the dollars needed to eliminate a pound of oxygen deficit below the WQO. As demonstrated by the Chen modeling discussed above (see Figures 14a and 14b), it is possible to equate the depth of the DWSC as well as SJR flow diversions to an oxygen deficit. Similarly, it is possible to equate an oxygen demand constituent load from a source to an oxygen demand deficit below the WQO in the DWSC. Through additional studies and refined modeling conducted during the Phase I TMDL implementation, it would be possible to establish the relationship between continued existence of the DWSC, water diversions and the discharge of oxygen demand constituent loads to the dollars needed to aerate the DWSC to control DO depletion below the WQO in the DWSC. Further, through the studies discussed herein, it would be possible to relate the cost of controlling a pound of oxygen demand load discharged from a particular source, such as the upstream watershed agriculture and managed wetlands, to eliminating a pound of DWSC DO deficit.

There are several major issues that must be resolved in order to establish the technical allocation of oxygen demand load control among the sources of oxygen demand. The most important of these issues is the responsibility that the Port of Stockton and those who benefit by the continued existence of the Port/DWSC will assume/be assigned in helping to pay for correcting the DWSC low-DO problem. This responsibility can be implemented by payments to a fund to help cover the cost of aeration and/or oxygen demand constituent source control. The allocation of the use of these funds could be developed by a stakeholder advisory committee that would be approved by the CVRWQCB. It is important to understand that there is an interrelationship between flow and aeration, where, with higher flows, more aeration is needed, up to a flow above which there is no deficit in the critical reach of the DWSC.

Another non-oxygen-demand constituent load factor that is important to allocation of oxygen demand constituent loads is the upstream of the DWSC diversions of SJR flow that could pass through the DWSC if the upstream diversion did not occur. The impact of these diversions can be translated to aeration/oxygen demand constituent control costs, in terms of reduced oxygen demand loads that could occur if the upstream diversions did not occur through the approach suggested by Chen discussed above.

The third oxygen demand allocation issue that needs to be resolved is the residual oxygen demand load that the city of Stockton will be allowed to discharge to the SJR just upstream of the DWSC. The primary constituents of concern are ammonia and organic nitrogen. It is suggested that the initial allowed oxygen demand load for the city of Stockton wastewater discharges be set at the current carbonaceous BOD and organic NBOD loads. The ammonia loads should be set at the loads that occur with the current effluent flows and a 2 mg/L ammonia N effluent concentration. Basically the suggested allowed city of Stockton oxygen demand load should be set at the current CVRWQCB revised NPDES permit conditions.

The fourth issue of primary concern in the traditional TMDL load allocation is the upstream of the DWSC algal/BOD_u load that leads to DO concentrations in the DWSC below the WQO. In traditional TMDLs, the load allocation would be based on a fixed percentage reduction of nutrients from all sources without regard to the importance of the overall nutrient load or specific loads to the water quality problem. While this approach may be appropriate for some situations, it is not a technically valid approach for controlling low DO that occurs in the DWSC since substantial parts of the nutrient loads discharged to the SJR and its tributaries do not develop into algae that impact the DWSC DO resources. The oxygen demand source studies that have been conducted identified Mud Slough, Salt Slough and the SJR upstream of Lander Avenue as the primary sources of algae that contribute to low DO in the DWSC. Each of these waterbodies' watersheds could be assigned an oxygen demand discharge load, in proportion to their average algal/BOD loads during the summer and early fall. Based on the information presented in Table 15, the summer average BOD_u load from the three SJR tributary upstream watersheds is distributed among the watersheds as follows: Mud Slough 40 percent, Salt Slough 40 percent and SJR Lander 20 percent. These percentages could be used to apportion the responsibility for the SJR upstream discharges of oxygen demand load control.

A review of the SJR upstream oxygen demand loads for the summers of 2000 and 2001 shows that the Merced River contributes an oxygen load to the upper SJR. Considering the BOD_u loads during 2000 and 2001 including the Merced River discharged loads yields an average responsibility for Mud Slough of 37 percent, for Salt Slough of 36 percent, for SJR Lander of 18 percent and for Merced River of 8 percent. These percentages could change as the 2002 data that R. Dahlgren has collected in 2002 are made available and reviewed. While no SJR upstream BOD measurements were made in 2002, the chlorophyll and pheophytin data that were collected can be converted to equivalent BOD concentrations based on the 2000 and 2001 data.

Table 15 shows that the Tuolumne River and Stanislaus River contributed in 2000, 8,677 and 5,522 lb/day of BOD_u to the SJR, respectively, while in 2001 the respective contributions from these two lower SJR tributaries were 3,625 and 3,774 lb/day of BOD_u. These BOD_u loads, as well as those from the Merced River, are different from the upper watershed loads in that they are associated with lower concentrations of BOD_u and higher tributary flows. Typically the Tuolumne River and Stanislaus River BOD concentrations are about one-fifth to one-tenth of the Mud and Salt Slough concentrations. Further, they are discharged lower down the SJR and therefore there is less time for algal growth in the SJR before they reach the DWSC. The BOD concentrations found in these rivers at the point that they discharge to the SJR are typical of ambient water concentrations for non-polluted/non-nutrient-enriched situations. It will likely be difficult to control the BOD of these river waters much below their current concentrations. While not computed, because of the shorter travel times, the coupling between the discharged BOD loads and the resulting load from these loads at Mossdale could be on the order of 2 to 1 or 3 to 1. It is recommended that the initial upstream BOD load control program focus on the upper SJR watershed tributaries because of the large coupling factor. It is suggested that the BOD load sources in the Tuolumne River and Stanislaus River watersheds be determined to see if there are readily controllable sources of BOD.

The allocation of oxygen demand load among stakeholders within a particular tributary watershed will require several years of detailed monitoring within the subwatershed, coupled with developing a subwatershed stakeholder structure that would enable the stakeholders in a subwatershed to work together to develop an allocation process which could control the oxygen demand loads from their respective sources to meet the allocated load at the tributary discharge point to the SJR. The development of this information is at least several years away. The TMDL will need to be conducted in a phased approach where the first phase will be largely devoted to obtaining additional information on the specific sources of oxygen demand in the Mud and Salt Slough, SJR upstream of Lander Avenue and the Merced River watersheds and their potential for economical control.

An issue that is important to formulating an oxygen demand control program from the Mud and Salt Slough and SJR upstream of Lander Avenue watersheds is the coupling of a reduced amount of algal related oxygen demand discharged by the upstream waterbodies to the SJR, to the oxygen demand reductions that will occur at Mossdale. While it is clear from the data that the two are coupled, the studies thus far have not defined the details of this coupling. This information may evolve from the HydroQual or other modeling that is currently being developed.

A preliminary allocation of responsibility for oxygen demand load reduction from the SJR upper watersheds could be developed based on examining the coupling of the total BOD_u loads discharged by these upper watershed tributaries and the BOD loads found at Mossdale. Table 17 presents information that is used to establish the coupling between the sum of the average of the BOD loads from the upper watersheds to the SJR and the BOD loads in the SJR at Mossdale.

Table 17
Coupling Upstream SJR BOD_u Loads to SJR Mossdale BOD_u Loads
(Includes Mud and Salt Sloughs, SJR Lander and the Merced River)

Year	Average Summer Sum of the Upstream BOD_u Loads (lb/day)	Average Summer SJR 2000 Mossdale BOD_u Loads (lb/day)	Ratio of Mossdale BOD_u Load to Sum of Upstream BOD_u Loads
2000	21,550	120,358	5.6
2001	16,127	93,001	5.8

Based on this approach there is an about 1 to 6 coupling of the upstream BOD_u load to the SJR by the upper watersheds to the SJR and the Mossdale BOD_u loads. One lb/day of BOD_u load discharged by the upper watersheds to the SJR results in 6 lb/day BOD_u load at Mossdale. This coupling applies to the summer conditions which include the irrigation diversions and the algal growth that occurs during the two summers for which there are data. This coupling will likely change in the fall when the irrigation diversions no longer occur and the growth of algae is slowed due to lower temperatures and reduced sunlight duration.

The monitoring and HydroQual modeling studies conducted during the Phase I TMDL will better define the coupling in upper watershed oxygen demand loads discharged to the SJR from Mud and Salt Sloughs, SJR at Lander Avenue, and the Merced River and the BOD loads that are found in the SJR at Mossdale.

In order to establish the allowed SJR upper watershed oxygen demand loads, it is necessary to establish the coupling between SJR Mossdale BOD_u loads and allowed oxygen depletion in the DWSC that does not cause a WQO violation. Tables 3, 4 and 5 present the information to establish a preliminary estimate of this coupling, where the total BOD_u load (Mossdale plus City) to the DWSC and the oxygen deficit that occurred for various total BOD_u loads to the DWSC during the summer and fall of 1999, 2000 and 2001 for the monitoring runs that were conducted by the city of Stockton are compared. Table 18 presents a summary of these data.

Table 18
Relationship between Total BOD_u Load to the DWSC and the Oxygen Deficit in the DWSC

Date	Flow (cfs)	Mossdale + City (lb/day)	Sum of DO Deficits below WQO (lb)	DO Deficit (lb/day)	Ratio of Total BOD_u to Deficit below WQO
1999					
8/24/99	850	64,226	16,300	1,734	37
8/31/99	1,024	64,984	14,540	1,864	35
9/07/99	1,022	120,350	28,170	3,612	33
9/14/99	1,157	130,160	59,470	8,619	15
9/21/99	1,135	146,109	32,680	4,669	31
9/28/99	395	45,856	53,960	2,658	17
10/05/99	494	64,013	76,340	4,712	14
10/19/99	623	72,407	78,430	6,127	12
10/26/99	592	75,952	57,340	4,247	18
2000					
6/20/00	1,202	92,731	0	-	-
6/27/00	652	50,193	5,360	436	115
7/11/00	634	52,600	790	63	835
7/18/00	662	49,415	9,290	768	64
7/25/00	770	60,680	5,150	495	122
8/01/00	759	47,806	10,930	1,041	46
8/08/00	837	42,610	10,180	1,060	40
8/15/00	725	45,933	3,440	313	147
8/22/00	1,251	46,532	0	-	-
8/29/00	1,447	57,571	0	-	-
9/12/00	1,277	54,237	0	-	-
9/19/00	1,224	60,623	10,490	1,614	38
9/26/00	1,372	54,785	0	-	-
10/03/00	1,201	79,186	17,530	2,616	30
10/17/00	2,141	80,626	0	-	-
10/24/00	2,416	153,845	0	-	-
10/31/00	573	55,520	0	-	-

Table 18 (continued)

2001					
6/12/01	674	68,578	4,840	407	168
6/19/01	610	69,116	23,570	1,799	38
6/26/01	746	67,392	38,220	3,572	19
7/10/01	622	74,981	27,380	2,122	35
7/17/01	657	56,202	17,670	1,448	39
7/24/01	618	51,546	30,310	2,350	22
7/31/01	599	48,374	27,280	2,036	28
8/07/01	577	45,603	1,720	124	368
8/14/01	583	61,912	17,430	1,272	49
8/21/01	626	44,625	26,070	2,037	22
8/28/01	634	39,787	28,120	2,232	18
9/11/01	610	50,763	19,030	1,453	35
9/18/01	792	61,672	47,370	4,690	13
9/25/01	1,143	64,195	42,940	6,134	10
10/02/01	785	68,010	32,950	3,230	21
10/16/01	1,279	58,724	0	-	-
10/23/01	2,068	67,052	0	-	-
Overall Box Model (Figure 16)	930	84,000	20,000	2,300	36

- No deficit on that day

Table 18 shows that the DWSC DO deficit ranged from 0 to 8,619 lb/day, with the overall average for the three years of 2,300 lb/day (see Figure 16). The ratio of total BOD_u load to DWSC DO deficit (when there was a deficit) ranged from 10 to 835 with an average of 75. This coupling can be used to estimate the allowed combined city of Stockton BOD_u loads to present DO depletion below the WQO for a given SJR DWSC flow through the DWSC. No relationship was seen in these data between the SJR DWSC flow and the magnitude of this ratio.

Each mg/L of DO deficit in the DWSC is equivalent to 40,000 lb of oxygen. The DWSC during the summer typically has an oxygen assimilative capacity of about 3.5 mg/L times 40,000 lb, without violating the DO WQO. This is based on the difference between the oxygen saturation value of 8.5 mg/L and the WQO, assuming a temperature of 25ºC in the DWSC.

Nine out of the 43 sampling events conducted by the City during the three years of study found no DO deficit measured in the DWSC. These nine runs occurred when the SJR DWSC flow was above 1,200 cfs. There were two sampling runs during the study period when SJR DWSC flow was above 1,200 cfs and there was a measured deficit. The two occasions when DO deficits were found during a high SJR DWSC flow occurred during a major algal bloom in the DWSC. It appears from these data that a SJR DWSC flow above about 1,200 cfs pushes the minimum DO sag downstream to eliminate any DO deficits upstream of Turner Cut.

The data in Table 18 were examined for a possible unusual influence of the city of Stockton ammonia discharges that resulted in a measured elevated ammonia concentration at Channel Point. In general, it is found that low ratios of Mossdale load to DWSC DO deficit were associated with elevated concentrations of ammonia at Channel Point. This could be an indication of enhanced ammonia nitrification, which would cause greater DO deficits than predicted based on the sum of the Mossdale and City BOD_u loads being exerted under normal rates of nitrification.

Special consideration will need to given to stormwater runoff situations where stormwater runoff from Stockton and other near-DWSC watershed communities has the potential to add substantial oxygen demand to the lower SJR and directly to the DWSC. In some years, one or more storms occur in the fall that could be a factor that leads to low DO in the DWSC. There is need to give special consideration to oxygen demand load conditions and their allocation to sources during rainfall runoff conditions that occur each fall.

The amount of the allowed upstream constituent oxygen demand load can be adjusted to the extent that the Port of Stockton and water diverters assume or are assigned responsibility for affecting the oxygen demand assimilative capacity of the DWSC. Since the water diversions also remove oxygen demand from the SJR, it will be important to weight the effect of the water diversions on decreasing the oxygen demand assimilative capacity versus the decreased oxygen demand of algae that occurs as a result of the diversions.

The initial phase of the TMDL will need to be devoted to pilot studies of aeration of the DWSC to control the low-DO problem. Particular attention will need to be given to how best to provide the needed oxygen at least cost. In addition, an engineering evaluation of the potential to achieve at least control of flow, if not enhanced flow, of the SJR through the DWSC will need to be conducted during the initial phase of the TMDL implementation.

This initial phase of the TMDL implementation will likely require about five years. At that time, with continued substantial support of ongoing studies specifically directed toward evaluating the implementation of control programs, it should be possible to formulate a low-DO management program for the DWSC which would represent the final phase of the TMDL.

Summary of the Proposed Oxygen Demand Load Allocation Process. The proposed approach for technical allocation of oxygen demand (OD) loads/factors that leads to DO concentrations in the DWSC below the water quality objective follows traditional TMDL allocation approaches of determining, for selected SJR DWSC flow regimes (50 to 500, 500 to 1000, 1000 to 1500, 1500 to 2000 and above 2000 cfs), the DO deficit that has occurred or would likely occur during June, July, and August; September; and October and November. These oxygen deficits can then be translated to reduced oxygen demand loads to the DWSC during each of the seasons for each of the months. No attempt is being made at this time to suggest the magnitude of the couplings that would be used in an initial allocation approach of oxygen demand loads for the winter DO depletion problems since the situations that have occurred in past winters, especially 2003, need to be investigated to better understand the factors involved.

Under the suggested preliminary allocation approach, the city of Stockton would be allowed an oxygen demand load equivalent to its current CBOD and organic nitrogen NBOD and ammonia-related load that would occur under the current 2 mg/L N wastewater effluent limitation. The City's load would become an important part of the total load beginning in September when the ammonia concentration in the City's effluent normally increases above about 2 mg/L N.

The remainder of the oxygen demand load not accounted for by the City's allowed loads would be assigned to the Mud/Salt Slough, SJR Lander Avenue and Merced River watersheds, in proportion to their average monthly contributions during 2000 and 2001. This could be modified when the 2002 data that have been collected by R. Dahlgren are reviewed. With the cessation of irrigation in August, it may be necessary to increase the coupling factor between the Mossdale load and upstream algal loads due to lack of irrigation diversion of the algal loads in the SJR.

Under this allocation process, the stakeholders in these watersheds would have the responsibility to control oxygen demand loads discharged by the watershed to the SJR to achieve the allowed discharge load, assuming a direct proportionality coupling between what has been discharged in the past and the SJR loads that occur at Mossdale. For now, none of the other tributaries to the SJR would be assigned a responsibility for load control. That could change in the future as additional information is developed.

The Port of Stockton's responsibility would be developed based on the extent that the Port of Stockton is assigned or assumes responsibility for the hydromodification that has occurred associated with the development of the Deep Water Ship Channel and its continued existence. This responsibility could be manifested in the form of a commitment for funding to pay for oxygen demand constituent control of the upper watershed loads and/or aeration. The allowed loads from the upstream watersheds could be reduced proportional to the funding made available by the Port to cover, in part, its and its benefactors' responsibility for the DO problem in the Deep Water Ship Channel. If state or federal funds can be obtained by the Port and its stakeholders to help pay for oxygen demand constituent control and/or aeration, those funds would be part of the Port's satisfying its responsibility.

Similarly, if the diverters of water that cause a decreased flow in the SJR through the DWSC during June through March, assume a financial responsibility proportional to the costs of aeration or oxygen demand constituent control to achieve a certain reduction in oxygen deficit related to the decreased flow that occurs as a result of upstream diversions, the amount of oxygen demand constituent control that would have to be practiced by the SJR upstream watershed stakeholders could be reduced proportionate to the flow diverter-assumed responsibility. It is important to note that while there are some who claim that the Clean Water Act does not allow the assignment of a responsibility for hydromodification as an allocation of equivalent load, there are a number of senior US EPA staff (A. Strauss (2002) of the US EPA Region 9, and B. Zander (2002) of the US EPA Region 8) who have indicated that hydromodifications could lead to an assignment of responsibility to water diversions or other water modifications that contribute to a TMDL problem.

The adoption of the suggested technical allocation approach should stimulate the upstream watershed stakeholders to pursue the determination of the potential economic feasibility of controlling algal growth during the summer and fall months that leads to low DO in the DWSC. Studies conducted during the Phase I TMDL will better define the impacts of algal-related oxygen demand and ammonia-related oxygen demand on the DO deficit in the DWSC, as well as the translation factor between algal oxygen demand discharge at the mouths of the three upstream watersheds and the loads that arrive at Mossdale. Also a better understanding will be achieved of how the measured Mossdale load during any month translates to a DWSC load under the low flow conditions.

In three to five years, as part of completion of Phase I of the TMDL, it will be possible to refine this allocation approach to take into account the new information that is developed during Phase I. Ultimately, a Phase II allocation of responsibility will be developed and implemented that should begin to effectively solve the low-DO problem in the DWSC.

Guidance on Monitoring Program during Phase I TMDL Implementation

With the development of the first phase of the TMDL implementation program, there will be need to establish a long-term monitoring program designed to assess the effectiveness of the implementation program and, most importantly, to continue to gather information on the factors controlling the development of oxygen demand in the SJR DWSC watershed and depletion of DO in the Deep Water Ship Channel. A specific project should be developed which reviews the existing data on the characteristics of the oxygen demand loads, their sources and the impacts on DO resources within the DWSC for the purpose of developing a TMDL Phase I monitoring program. The objectives of this program should be clearly defined. It should be designed and developed with adequate funding to meet the appropriate objectives.

Lee and Jones-Lee (2002c) have recently completed comprehensive guidance for conducting nonpoint source water quality monitoring and evaluation programs. They point out that many so-called water quality monitoring programs fail to develop reliable assessments of the current water quality of the waterbody being monitored. Their review should be consulted and followed in the development and implementation of the TMDL Phase I program. In particular the following issues should be addressed in developing the TMDL monitoring program.

Organizing a Water Quality Monitoring Program. The development of a comprehensive nonpoint source water quality monitoring program involves consideration of each of the following:

- Clearly establish the objectives of the monitoring program.
- Understand the nature of "water quality," water quality concerns, beneficial uses, and their assessment for the waterbodies of concern.
- Select the parameters to be measured and justify potential significance of each parameter selected.

- Examine previous studies to understand variability in each area of the waterbody to be monitored.
- List factors that can influence results of the monitoring program and how they may influence the results.
- Determine the level of confidence at which the objective is to be achieved.
- For each area of each waterbody to be monitored, determine the number and location of samples to be collected.
- If no data are available from previous studies or if existing data are inadequate to define variability and other characteristics needed to establish a reliable monitoring program, conduct a pilot study of representative areas to define the characteristics of the area that are needed to develop a reliable water quality monitoring program.
- If the purpose of the monitoring program is to determine changes in water quality characteristics, select the magnitude of change that is to be detected and design the monitoring program accordingly.
- Select sampling techniques and methods of analysis to meet the objectives and level of confidence desired.
- Verify that analytical methods are appropriate for each area of the waterbody and at various seasons.
- Conduct studies to evaluate precision of sampling and analytical procedures and technique, reliability of preservation, and variability of the system.
- Critically examine the relationship between present and past studies.
- Determine how the data will be analyzed, with respect to compliance with Basin Plan objectives, using existing data or synthetic data that is expected to be representative of the site.
- Screen/evaluate data as they are collected.
- Analyze, interpret and store data, and report on the results of the analysis and interpretation.

Information on each of these areas is presented in the Lee and Jones-Lee (2002c) report.

The San Joaquin River DO TMDL Phase I will require intensive monitoring/evaluation of various parameters within the Deep Water Ship Channel (DWSC) and upstream of the DWSC as well as in the Central and South Delta. There are several purposes for monitoring of the DWSC. These include evaluating the effects of the experimental aeration program. Another purpose is to further define the magnitude of oxygen demand loads of various types and from various sources, and the resultant dissolved oxygen (DO) depletion within the DWSC. The DWSC monitoring should be primarily devoted to evaluating the factors influencing DO depletion, such as the relative contributions of ammonia versus carbonaceous BOD in the form of algae, the role of short-term thermal stratification in influencing DO depletion, the role of sediment suspension as a cause of DO depletion in the near-bottom waters of the channel, and the impact of SJR flow through the DWSC on DO depletion and the location of maximum DO deficit.

Further, there will be need for monitoring/evaluation in several of the major tributaries to the SJR, especially the Mud and Salt Slough watersheds and the SJR upstream of Lander Avenue.

The purpose of this watershed monitoring is to determine the specific sources of nutrients/algae that lead to the elevated algal concentrations that are found at the mouths of Mud and Salt Sloughs and in the SJR at Lander Avenue. Also there is need to evaluate the relationship between and oxygen demand load added to the upper part of the SJR watershed and the amount of the load that reaches the DWSC. The SJR monitoring program will need to focus on the oxygen demand loads and factors influencing the transport and transformation of these loads from the Mud and Salt Slough discharge points to the DWSC. This monitoring will be a key part of providing the information needed for the HydroQual modeling of oxygen demand that is added to and transported by the SJR upstream of the DWSC. Further, special-purpose monitoring/evaluation will need to be conducted between Vernalis/Mossdale and the DWSC (Channel Point) to resolve issues pertinent to the fate of oxygen demand in this reach of the river.

In addition, during the TMDL Phase I, there will be need for monitoring/evaluation in the Central Delta, to determine whether high SJR DWSC flow transports sufficient oxygen demand into the Central Delta through Turner Cut and Columbia Cut to cause low-DO problems in these Cuts or Middle River. Also, there will be need to further characterize the water quality in the South Delta and, especially, the factors influencing this water quality, as part of determining the potential impacts of using low-head, reverse-flow pumping across one or more permanent barriers in the South Delta in order to supplement flow in the SJR downstream of Old River.

The TMDL Phase I proposed monitoring/evaluation studies should be designed to fill information gaps and provide the information base needed for the California Environmental Quality Act (CEQA) review that will need to be conducted as part of adopting the final DWSC low-DO management program. This program should be conducted to provide specific information that is needed to finalize the TMDL that will be developed at the end of Phase I.

Support of Aeration Studies. One of the primary areas of emphasis for the Phase I TMDL is that of gaining an understanding of the amount of aeration and how best to apply it to prevent DO, during Phase I, from going below the interim target of a seven-day running average of 5 mg/L, with no value less than 3 mg/L. As formulated now, these requirements will apply at all times and all locations. In order to determine if the requirements are met, a comprehensive monitoring program will need to be conducted. While some insight has been gained into when and where DO values in the channel are less than these values, it is not possible at this time to do more than generally predict when dissolved oxygen concentrations less than these values will occur at a particular location.

There is a substantial amount of DO data on the Deep Water Ship Channel that have only been partially analyzed with respect to the factors controlling DO depletion below the interim DO water quality goals. The first step in the Phase I aeration monitoring program should be a detailed review of the existing data, where an attempt should be made to utilize the existing information and the characteristics of the DWSC to predict the magnitude of DO depletion at various locations, especially in the early morning hours when the DO tends to be the least in the near-surface waters, and apparently at any time (although this has not been confirmed) when the DO is least in near-bottom waters.

Previous studies have shown that elevated SJR flow through the DWSC tends to push the point of minimum DO further down the channel to and below Turner Cut. There is need to better understand this relationship. Of particular interest is the relationship between the planktonic algal chlorophyll and ammonia loads to the DWSC, and the position of the maximum DO depletion. Ultimately, this initial review of the existing database should focus on developing a mass balance model that can be used to predict where DO deficits of a certain magnitude would occur in the DWSC.

It may be possible, through the use of an expanded Chen model, to predict DO depletion at various times and locations in the DWSC as a function of the factors controlling the exertion of oxygen demand in the DWSC. Eventually, the Chen model will need to be expanded so that a relationship between the currently predicted average DO in the water column to the near-surface and near-bottom DO can be predicted. In order to do this, the Chen model will need to be verified that it can, in fact, reliably predict DO depletion at various locations and times given the loads of oxygen demand, flow, and other conditions that are known to influence DO depletion, as presented in the 43 city of Stockton monitoring runs that took place from 1999 through 2001. This evaluation of the Chen model should be conducted as soon as CALFED can make funds available for this purpose. If this model is found to be reliable, it will be useful in establishing the experimental aeration program and its associated monitoring. This approach is in accord with the CALFED external Peer Reviewers' comments discussed below.

Once the initial aeration unit(s)'s placement has been worked out and it (they) are ready to be operated, then monitoring of DO should be conducted at critical locations within the DWSC in such a way as to examine how the aeration influences the DO depletion that would be occurring in its absence. By varying the magnitude and location of aeration, and specifically choosing conditions of high and low chlorophyll loads and high and low ammonia loads as a function of SJR DWSC flows and season (summer versus fall), it should be possible to gain considerable insight into how the DWSC responds to various factors that influence DO depletion and how aeration can be used to correct DO depletions below the initial target and then the ultimate (projected final) DO water quality objective. Further information on the potential cost of aeration should become available from these studies.

By the end of the first year of the Phase I TMDL, sufficient knowledge on the various issues pertinent to managing DO depletion through aeration as a function of parameters that influence DO depletion should have been gained so that a proactive monitoring/modeling program can be established where, through continuous measurements of chlorophyll at Mossdale, flow of the SJR through the DWSC at the UVM, city of Stockton ammonia loads, water temperature, turbidity, coupled with Chen or some other model, it will be possible to predict the magnitude and location of DO depletion within the DWSC. A detailed monitoring program of DO depletion within the DWSC will need to be conducted to develop and then implement this proactive monitoring approach. By the third year of Phase I, this proactive monitoring should be developed sufficiently so that it becomes a reliable tool upon which to base aeration operations, such as when to turn on the aerators, where to locate them, etc.

It is expected that the funding of the monitoring associated with the experimental aeration will involve at least one crew with a boat that, from late May through at least mid-November, can be on the water making selected measurements. It will be important to have DWR continue to operate the continuous fluorometer at Mossdale and at the Rough and Ready Island monitoring station. These fluorometers, however, may need to be upgraded to provide more reliable results, as influenced by temperature and turbidity, than is apparently being achieved now with the current instrumentation. Also, turbidity measurements should be made at these locations, as well as diel (day/night) DO and electrical conductivity. In addition, arrangements should be made to work with the USGS to get a continuous realtime read-out on the UVM monitoring of the net SJR flow through the DWSC. The operation of this TMDL Phase I monitoring/evaluation program should be guided by a small expert panel, who would critically review the data as they are generated and make recommendations on changes in the program.

Monitoring/Evaluation of Oxygen Demand Loads for the Mainstem of the SJR Upstream of the DWSC. The monitoring of the SJR during 2000-2001 by Kratzer and Dileanis, and Dahlgren has provided a database upon which Chris Foe has developed the Strawman analysis of upstream of the DWSC oxygen demand/algae sources. This analysis shows that substantial oxygen demand is added to the SJR upstream of where the Merced River enters the SJR. At times, as much as 90 percent of the oxygen demand load present in the SJR at Mossdale can be attributed to the discharge of algae to the SJR by the Mud and Salt Slough watersheds and the watershed upstream of Lander Avenue (upstream watersheds).

There is appreciable growth of algae and, therefore, an increase in oxygen demand load along the SJR to Vernalis/Mossdale. While the box model mass balance approach has provided some insight into the dynamics of oxygen demand in the SJR upstream of Mossdale, there is need to refine this understanding so that it is possible to relate oxygen demand loads that enter the SJR at any location to the amount of that load that increases in magnitude due to algal growth and decreases due to agricultural irrigation diversions and death of the algae as well as their predation.

HydroQual, under a proposed contract with CALFED, is to develop a model of oxygen demand dynamics for the SJR from the upper reaches of the river to the DWSC. This model will initially make use of the existing Kratzer/Dileanis and Dahlgren databases. There will be need, however, for considerable additional special-purpose monitoring of the SJR oxygen demand loads and the factors influencing these loads at various locations within the SJR, the SJR at Highway 165 (Lander Avenue) and the DWSC. This monitoring will need to take place over a several-year period and be closely integrated with the HydroQual modeling efforts. All of the parameters that are thought to potentially impact oxygen demand load at various locations in the SJR upstream of the DWSC will need to be monitored, including flow of the mainstem and tributaries at various locations, planktonic algal chlorophyll and pheophytin, zooplankton, turbidity, magnitude of irrigation diversions and tailwater returns, etc.

One of the primary objectives of the HydroQual modeling should be to develop an oxygen demand load-response model of the SJR upstream of the DWSC, which considers the various factors which influence how algal loads and water added to the SJR at various locations and water diversions influence the amount of oxygen demand from upstream sources that enter the DWSC. While the current information shows that there is a coupling between the magnitude of oxygen demand loads discharged to the SJR from the Mud and Salt Slough watersheds and the SJR at Lander Avenue watershed, and the magnitude of the oxygen demand load at Mossdale, it may not be possible, with the current information base, to predict the magnitude of decreased upstream load needed to achieve a certain decrease in oxygen demand load that reaches the DWSC. The ultimate goal of the modeling/monitoring should be the development of these relationships with sufficient reliability to have confidence that if the agricultural and managed wetlands interests in the Mud and Salt Slough and SJR upstream of Lander Avenue watersheds are told that they need to reduce the magnitude of their oxygen demand load that develops at the mouths of these tributaries by a certain amount to achieve the desired oxygen demand load to the DWSC, they will be confident that their efforts will achieve the desired oxygen demand load to the DWSC reduction.

One of the issues that will need to be addressed to begin to understand the reported changes in algal types that occur in the SJR upstream of Vernalis is a comprehensive monitoring program at various locations in the SJR to determine the numbers and dominant types of planktonic algae present in the SJR. Since the travel times through the SJR are such that it is not possible to grow new populations of algae so that the planktonic algal chlorophyll that is present does not change to any significant extent as the water moves down the SJR to the DWSC, there is need to understand why the algal types apparently change rapidly in the SJR at a particular location upstream of Vernalis. It is possible that these apparent changes relate to different water masses with different algal content being discharged by Mud Slough or Salt Slough or developed in the SJR upstream of Lander Avenue, which enter the SJR as patches that are carried down the SJR to the DWSC. The SJR monitoring program should be designed to address this issue.

It is likely that several Lagrangian-type studies, using dye tracers, will need to be conducted in the SJR between the Merced River and Mossdale in order to establish/verify that the processes that govern the changes in oxygen demand that have been observed along the River are understood and can be quantified.

There has been some controversy about the fate of algae and oxygen demand in the reach of the SJR between Vernalis/Mossdale and Channel Point. It is unclear whether the controversy is related to inadequate sampling by some investigators to properly characterize oxygen demand loads at Channel Point or is related to processes that influence oxygen demand loads that occur between these two locations. The flow pattern at Channel Point is extremely complex, controlled by tides, net downstream SJR flow, and the mixing with the Port of Stockton Turning Basin waters. Since each of these sources has a different oxygen demand content that is varying hour by hour and with depth, especially for the Turning Basin, attempting to obtain reliable mass fluxes at Channel Point requires a much more comprehensive monitoring program than has been conducted thus far. Consideration should be given to adding one or more additional monitoring stations between Mossdale and Channel Point to better characterize the concentrations of constituents in this reach of the River. It has been suggested that possibly a monitoring station at Bowman Avenue should be added.

It is possible that under conditions of low SJR flow into the DWSC there could be appreciable BOD removal between Mossdale and Channel Point. Under conditions of normal SJR flow through the DWSC of 500 or more cfs, the travel times in this reach are too short to allow for major changes in algal types or algal biomass (through either growth or death). It will likely be necessary to conduct Lagrangian-type studies, using dye tracers, to follow several dye releases made at Mossdale, in order to determine whether there is anything occurring to oxygen demand/algae other than what would be expected based on travel time and algal growth and death dynamics by the time the water reaches Channel Point.

Comments on San Joaquin Valley Drainage Authority Proposal, "Monitoring and Investigations of the San Joaquin River and Tributaries Related to Dissolved Oxygen," dated March 13, 2003

As part of developing a monitoring program to provide additional information on nutrient and algal sources and algal population dynamics within the SJR DWSC watershed, several individuals who have been associated with the SJR DO TMDL previous studies began work in the fall 2002 to develop a SJR DWSC watershed monitoring program that would be submitted as a Directed Action proposal to be funded by CALFED. This monitoring program was to be conducted through and in support of agricultural interests in the SJR DWSC watershed. Lee (2003a) provided comments on the significant technical deficiencies in the January 2003 draft proposed monitoring program. Similar comments on deficiencies in this program were provided by Foe (2003). The Lee and Foe comments are available from the SJR TMDL website (www.sjrtmdl.org). On March 18, 2003, the San Joaquin Valley Drainage Authority made available, through the SJR DO TMDL website (www.sjrtmdl.org), a research proposal entitled, "CALFED Directed Action Proposal for Monitoring and Investigations of the San Joaquin River and Tributaries Related to Dissolved Oxygen." This proposal was not provided to the SJR DO TMDL Steering Committee prior to submission. The Steering Committee, however, without reviewing the proposal, approved its submission to CALFED.

As discussed below, the proposal submitted to CALFED has significant deficiencies compared to the needed studies. Many of these deficiencies were pointed out to the upstream monitoring stakeholder group in an initial review of the preliminary draft proposal. Since the deficiencies were not addressed in the final proposal, either a supplemental proposal will need to be submitted to CALFED to address these deficiencies or CALFED will need to require that the proposal be significantly modified from that submitted, in order to provide the Phase I TMDL information that should be developed in an upstream monitoring program. Key issues of concern with respect to the adequacy of the March 13, 2003, proposal in providing the needed information for the Phase I TMDL are summarized below. More detailed information on these issues is available from Lee (2003b).

These comments on the SJR upstream studies that should be conducted during Phase I of the SJR DO TMDL are based on the author's review of the data that have been generated in the SJR and DWSC studies beginning in 1999 and continuing through 2002. They are also based on over 40 years of professional experience in developing water quality data that are to be used in a regulatory program. As discussed in the comments on the draft proposal, many of the problems in the proposed monitoring program reflect a lack of review of the May 2002 draft Synthesis Report and the supplements to that report that have been made available to the SJR DO TMDL Steering Committee. It is essential that the upstream monitoring program be developed based on a comprehensive review of the information that is presented in the May 2002 draft Synthesis Report and its supplements and the reports that serve as a basis for this report, as well as the information that is available in the literature that is pertinent to these issues.

One of the fundamental problems with the upstream monitoring proposal submitted to CALFED is that the objectives of the proposal are not in tune with developing the information in a timely manner that is needed in the Phase I TMDL effort. Much of the over-$6-million proposal is focused on developing information that appears to be designed to evaluate the reliability of the previous monitoring studies and the conclusions that have been developed from them with respect to the primary sources of oxygen demand in the SJR DWSC watershed. The conclusions that Mud and Salt Sloughs and the SJR at Lander Avenue are the primary sources of algae that lead to the high algal oxygen demand loads that are discharged to the DWSC is not an issue that needs further investigation. Additional studies are not going to change this conclusion.

The objectives of the upstream monitoring program should be focused on the following areas:

- *Developing the data that is needed for reliable modeling of the relationships between Mud and Salt Slough and SJR at Lander Avenue algal oxygen demand loads and the oxygen demand loads that enter the DWSC.*

  It is understood that the CALFED HydroQual modeling contract is still a viable contract, where the contracting problems are being resolved. Under these conditions the focal point of the upstream monitoring/evaluation studies should be to develop the data needed by HydroQual to be able to relate Mud and Salt Slough and SJR at Lander Avenue oxygen demand loads to oxygen demand loads that reach the DWSC. There should be no need for $826,250 of additional funding for Task 6-Modeling, so long as the HydroQual modeling contract is a potentially viable contract. Under these conditions, as suggested previously in the author's recommended upstream monitoring discussed elsewhere in this report, HydroQual staff should meet with those developing the upstream monitoring and others interested and knowledgeable, to define the data needed to develop and use the HydroQual modeling results to define the relationships between oxygen demand loads discharged to the SJR by the upstream watersheds and those that reach the DWSC.

  One of the major deficiencies with the proposed monitoring program is the failure to include zooplankton and other organism grazing of algae in the SJR. Without this information the modeling will have a major information gap which can readily cause it to be an unreliable tool for relating changes in upstream oxygen demand loads to those discharged to the DWSC.

  The Task 4 monitoring effort needs to be reorganized to focus more on support of the modeling. As discussed in the comments on the initial draft proposal, the two-week summer/fall sampling frequency and the monthly winter sampling frequency adopted by Stringfellow, *et al.*, ignore the substantial database that exists which shows that major changes in load characteristics can occur between sampling events that will not be defined with these sampling frequencies. Examination of the existing database associated with the most significant DO depletion that has occurred in the DWSC during the period mid-January 2003 through early March 2003 shows that sampling a month apart could readily have missed characterizing the loads and conditions that influenced this low-DO episode.

Further, it is well known from past studies that there are pulses of oxygen-demanding materials, inorganic turbidity and/or color of a few days to a week or so in duration that influence DO in the DWSC. Sampling the SJR upstream of the DWSC at two-week intervals is not adequate to define these situations. In order to properly develop the modeling, it is necessary that a much higher frequency sampling be developed, of no greater than one week at the fixed sampling locations. The proposed SCUFA approach for continuous monitoring of a few selected parameters will not adequately address this issue. In addition, if there is to be a distinction between summer and winter sampling frequency, there is need to start the "summer" monitoring program in May in order to ascertain the loads of oxygen demand materials and their sources that lead to the low DO that has occurred for several years in early June. Further, the "winter" monitoring must be continued through March, since DO problems have been encountered during November, December, January and February in recent years.

- *Sources and fate of oxygen demand between Vernalis and Mossdale, and Mossdale and the DWSC.*

  Task 8-Linkage of the upstream monitoring proposal that is to be conducted by Dr. G. Litton is an important component project that should be supported.

Component projects that should not be included in the proposal include the following:

- Task 5-Algal Growth and Task 7-BOD Characterization, which have a combined budget of approximately $1.5 million, should be deleted from these studies since, as discussed in comments on the draft proposal, the proposed algal growth dynamic studies and the attempts to determine the source of the oxygen demand constituents based on isotopic analysis will not yield reliable, useful information for the Phase I TMDL effort. It appears that the authors of the isotopic studies do not understand that there is a significant discrepancy between total organic carbon or dissolved organic carbon and oxygen demand. The issue is not, as proposed, the upstream origin of the TOC measured at a particular location in the SJR. As discussed in the author's comments on the initial draft proposal, since it is not possible to measure the isotopic composition of the oxygen demand constituents in a sample, it is not possible to reliably use this approach to determine the origin of the oxygen demand that is measured at a particular location in the SJR. Even if it were possible to make this distinction, this information would not be of any significant value in the TMDL effort beyond what is already known. The same situation applies to the origin of the nutrients. These issues are already defined, based on past monitoring studies.

  As previously discussed, the laboratory studies on algal growth dynamics proposed in both the draft and final proposal will provide little or no useful information for the Phase

I TMDL. Stringfellow, as the lead PI on Task 5, is still attempting to prove that heavy metals or nutrient limitations, etc., play a major role in oxygen demand development in the SJR watershed. The existing data clearly demonstrate that algae are growing in the SJR watershed and its tributaries at the rate expected, and that this growth is not controlled by nutrient concentrations or heavy metals.

Deleting Task 5 and Task 7 from the project will free up about $1.5 million that can be used to beef up Task 4 monitoring to include a more appropriate frequency of sampling and to expand on a new task (Task 10) to address one of the most important issues that should be developed as a result of the upstream monitoring/evaluation studies. Both Foe (2003) and Lee (2003a) have commented on the draft proposal on the failure of Stringfellow*, et al.*, to include studies devoted to understanding algal growth dynamics in the headwaters of Mud and Salt Sloughs and the SJR at Lander Avenue. As discussed elsewhere in this report and as was made available to the SJR DO TMDL Steering Committee last summer, one of the most important issues that needs to be addressed in the upstream monitoring/evaluation is developing an understanding of the potential for controlling the seed algae that lead to the high algal BOD concentrations that occur in the Mud and Salt Slough discharges to the SJR and in the SJR at Lander Avenue. There is need for the stakeholders in the upper parts of these watersheds to immediately begin to evaluate whether they can develop control programs that would lead to reduced algal-caused BOD loads being discharged to the SJR. This information, along with cost information for potential control programs, must be developed during the Phase I TMDL. Information in this area will be needed to reliably define the potential to economically control some of the oxygen demand loads from these watersheds. Without this information the TMDL Phase II decisions on the control of oxygen demand in these watersheds will have to be made without adequate information.

At the recent CVRWQCB workshop, the Board supported the staff's approach that control of oxygen demand sources in the upper SJR watershed is a high priority for investigation. Special-purpose studies of the type discussed in this report need to be conducted over the next three years to evaluate the potential for oxygen demand control in these watersheds.

Monitoring Parameters and Analytical Methods

BOD measurements are only an **estimate** of oxygen-demanding materials. BOD data should be examined with their potential reliability in mind. NBOD measurements are highly questionable, since the approach used to estimate NBOD, through an inhibited BOD test, is well known to be unreliable. These issues are discussed elsewhere in this Synthesis Report.

Total organic carbon is not a major component of oxygen demand. In the SJR upstream setting, there is no relationship between TOC and BOD. Much of the TOC present in these waters is refractory and has no effect on oxygen demand.

The orthophosphate measurements should be specified to be soluble orthophosphate and properly labeled. Further explanation needs to be provided on what is meant by phosphorus will be determined by *"... Ascorbic Acid Method (adapted from SM 4500-P-E)...."* There is need to examine the details of that modified method to be sure that it is reliable. Mention is made in this paragraph that ammonia is to be determined by Nessler's method. Nessler's method is not necessarily reliable for ammonia, and must be used carefully.

The continuous monitoring of *in situ* fluorescence as a measure of algae is not necessarily reliable. There are many factors that influence the relationship between *in situ* fluorescence and algal biomass. While some of the currently available equipment for *in situ* fluorescence measurement of chlorophyll corrects for some of these factors to some degree, it does not totally correct for the problems.

The proposal states that, *"Maintenance of the SCUFA consists of visits every two weeks to clean the optics and casing, check calibration using a solid calibration standard,...."* The solid calibration standard approach is not a reliable approach for calibrating chlorophyll in waters like those of the SJR and its tributaries. The calibration must be checked against samples taken where extractive chlorophyll measurements are made. This calibration should be made weekly for at least a year, until it is demonstrated that the variety of conditions that can influence planktonic algal chlorophyll measurements by *in situ* fluorescence measurements are appropriately compensated for by the equipment available. A solid calibration standard will not properly address this issue. The proposal also mentions the use of data from the Mossdale DWR chlorophyll monitoring system. The chlorophyll unit at that location has not been working for some time.

Recommended Approach for SJR Upstream Watershed Monitoring

Chris Foe's Strawman analysis of the data generated by Kratzer/Dileanis and Dahlgren showed that, during the summer/fall 2000 and 2001, the Mud and Salt Slough and the SJR upstream of Lander Avenue (Highway 165) watersheds (upstream watersheds) were major sources of planktonic algae, which were highly correlated with BOD measurements. At times, up to about 90 percent of the algae/BOD present in the SJR at Mossdale had its origin in the three upstream watersheds. It is estimated that the algae that are discharged from these watersheds will approximately double in load by Mossdale. It is also estimated that during the May through September irrigation season, on the order of 40 percent of the algae that are discharged to the SJR from these watersheds are diverted from the SJR by agricultural irrigation diversions. This means that the additional algal growth in the SJR from where the Merced River enters the San Joaquin River to Mossdale approximately balances the algae diverted from the SJR by irrigation diversions.

Between the Merced River and Vernalis, the eastside rivers discharge low chlorophyll/BOD water to the SJR. As discussed above, since the chlorophyll concentrations in the SJR remain relatively constant, algae growth in the SJR downstream of the eastside river discharges allows the chlorophyll to remain constant.

While some studies were conducted during the summer 2001 on the potential sources of oxygen demand within parts of the upstream watersheds, these studies did not provide the information needed to begin to effectively understand the specific origin of the algae within the watersheds that become the source of the high oxygen demand load (algae) at the mouths of Mud and Salt Sloughs and in the SJR at Lander Avenue. There is need to conduct detailed monitoring/ evaluation studies in these three watersheds to determine the principal sources of nutrients that lead to algal growth from their point of discharge to the mouths of the primary tributaries where they discharge to the SJR.

Comprehensive monitoring of nutrient dynamics and algal growth dynamics within the upstream watersheds will need to be undertaken. These studies should be conducted for several years in order to examine the year-to-year variability that can occur in nutrient releases from agricultural areas, wetland areas, and other areas and algal growth. Ultimately, these studies should develop sufficient information so that a model of algal growth dynamics in each of the watersheds can be developed which has sufficient reliability so that a prescribed reduction in the amount of algal biomass that occurs at the mouths of the sloughs and the SJR at Lander Avenue can be translated into a prescribed reduction in the input of nutrients that lead to algal growth in each of the watersheds. Ultimately, the models of each of these watersheds should be coupled with the HydroQual modeling of the mainstem of the SJR.

It is expected that understanding nutrient sources that are primarily responsible for leading to the high algal biomass at the mouths of the sloughs and the SJR at Lander Avenue could lead to one or more control options. These could include nutrient control through changes in farming practices, water management, and/or treatment of the discharge waters with a chemical such as aluminum sulfate which can precipitate phosphorus and remove algae from the water.

Part of the studies should include investigation of the relationship between the amount of phosphorus control needed to reduce the algal biomass that develops in the water to the desired degree. Studies during the summer 2001 demonstrated that the phosphorus concentrations near the mouth of Mud Slough, where it discharges to the SJR, were approaching algal growth-rate-limiting concentrations. This appears to be related to algal growth within the San Luis Drain, which is incorporating the available phosphorus into algal biomass. Through understanding algal growth dynamics and nutrient sources it may be possible to enhance this process in the Mud Slough watershed and promote the development of this process in the SJR upstream of Lander Avenue and within the Salt Slough watershed. One of the primary values of these studies will be to gain an understanding as to whether there is a significant potential to cost-effectively reduce the oxygen demand loads that enter the DWSC from upstream sources.

Basically, there is need to determine the specific source of soluble orthophosphate and nitrate plus ammonia that cause the waters just downstream of the point of discharge to contain nitrogen and phosphorus above about 20 µg/L P and 100 µg/L N. These concentrations of N and P, given sufficient time, can develop into substantial algal concentrations. Typically, with algae doubling at the rate of one to two days, about four to five days travel time would be needed from the point of nutrient release from the field to the mouths of the tributaries to develop the algal biomass (concentration/load) that has been found at the mouths of the tributaries.

As part of the SJR DO TMDL, there is need to conduct studies in each of these watersheds to follow algal growth dynamics, nutrient dynamics, and the hydrology of the flow regimes that exist in each part of each watershed. This will require an extensive chemical constituent monitoring and stream gaging program. As a minimum, there is need to establish representative sampling locations in each of the watersheds and their subwatersheds where stream gaging and sample collection can take place beginning about May 15 through November 15. The location of monitoring stations will be established by an upstream monitoring advisory panel. Special-purpose sampling should also be conducted during rainfall runoff events that occur in the fall where several samples during the event are taken during the rise and fall of the hydrograph. The recent finding of significant DO depletion problems in the DWSC which are attributable to algal blooms that are derived in part from the upstream SJR will require that the monitoring programs be expanded into and through the winter low flow period, such as through March. Further, since ultimately these watersheds will also be subject to nutrient control to meet chemically based numeric nutrient water quality objectives, it would be highly desirable to conduct this monitoring program year round. The parameters that should be monitored at weekly intervals at each sampling location include the following. (Background information on issues that should be considered in establishing this monitoring program is provided in Lee and Jones-Lee, 2002c,d.)

Field Measurements

pH,
temperature,

Secchi depth,
the presence of floating algal scum,
unusual color, such as that associated with wetlands' releases,
estimated flow and water velocity at time of measurement,
time of sample collection.

Special Field Studies
At about monthly intervals, diel (day/night) measurements should be conducted over one day for DO and pH and other parameters needed to conduct the "Flowing Water Productivity Measured by Oxygen Method," as set forth on page 10-37 of Standard Methods, APHA, *et al.* (1998). Generally, this will require measurements of DO and pH every 2 to 3 hours at representative monitoring stations in each of the upstream watersheds. Samples for chemical analysis of the water for many of the parameters listed below should also be taken at early morning and late night.

Laboratory Measurements
In general, the analytical methods for the following parameters are those listed in Standard Methods, APHA, *et al*. (1998) or those listed by the US EPA (see the Agency's website for the latest guidance). Note: some of the specific methods for a particular parameter in Standard Methods are not suitable for these measurements. The specific analytical methods used should be approved by the SJR TMDL Steering Committee Upstream Watershed Advisory Subcommittee that should be appointed to guide the upstream monitoring.

total phosphorus, with a quantitation limit of 10 μg/L P,
soluble orthophosphate with a quantitation limit of 5 μg/L P,
ammonia, with a quantitation limit of 0.1 mg/L N,
organic nitrogen, with a quantitation limit of 0.5 mg/L N,
nitrate plus nitrite, with a quantitation limit of 0.1 mg/L N,
electrical conductivity at 20 or 25 degrees C,
planktonic algal chlorophyll *a*, using acetone extraction,
planktonic algal pheophytin *a*,
turbidity,
color (true and apparent),
BOD_{10},
total suspended solids (TSS),
total dissolved solids,
alkalinity,
dominant types of algae and zooplankton.

Lee and Jones-Lee (2002c,d) provide information on the constituents that are of potential concern as water pollutants in the Central Valley. As discussed there could be about 15 potential pollutants for which there is need for monitoring/evaluation information. The full suite of potential parameters should be monitored at selected locations in the SJR DWSC watershed. Lee and Jones-Lee (2002d) should be consulted for further information on these issues.

Evaluation of the Reliability of *in situ* Fluorometric Chlorophyll Analysis

It has been found that measurement of chlorophyll at biweekly intervals is not frequent enough to define the oxygen demand load in the SJR and its tributaries. There is need to make more frequent analysis of chlorophyll in order to estimate the BOD load present at the location and time of measurement. This is leading to the use of continuous *in situ* or sidestream fluorometric chlorophyll measurements, where a fluorometer is suspended in the waterbody or the water is pumped to a fluorometer. The authors have considerable experience with fluorometric measurement of chlorophyll. Great caution should be exercised in accepting the fluorometric measurement of chlorophyll as reliable. Fluorometric chlorophyll measurements are subject to a number of interferences that cause the measurement to be unreliable. Because of the well known unreliability of fluorometric chlorophyll measurements, those using fluorometric chlorophyll measurements must frequently prove that these measurements are reliable. Failure to do so can readily lead to generation of large amounts of unreliable oxygen demand load data that will lead to unreliable assessment of oxygen demand loads. Of particular concern are turbidity and color. While fluorometric chlorophyll measurements can be reliably made in waters with constant low levels of turbidity, in waters with high concentrations of turbidity and especially variable turbidity, the fluorometer must be frequently (weekly) calibrated by measuring the chlorophyll using acetone extraction methods such as in Standard Methods (APHA, *et al.*, 1998) on samples of the water which have been subjected to fluorometric measurements. The approach advocated by some instrument manufacturers of calibrating the fluorometer with standard purchased chlorophyll is not adequate for addressing the problems of variable turbidity and other factors that influence reliable fluorometric measurement of chlorophyll.

Biostimulation Studies

Since there is a potential for the control of algae in the upstream watersheds through limiting the phosphorus concentrations in the waters in which the algae develop, it is of interest to explore potential benefits of removing phosphorus from the water on reducing the algal growth in the water. As a special-purpose study at selected locations within each of the watersheds at about monthly intervals, a biostimulation algal productivity study could be conducted. In general, the approach followed is that set forth in Standard Methods, APHA, *et al.* (1998) Section 8111 pg. 8-42 Biostimulation (Algal Productivity).

Filtered samples of the water to be tested are treated with aluminum sulfate (alum) to remove phosphorus by coprecipitation. It is suggested that sufficient alum be added to reduce the soluble orthophosphate of the sample by 25, 50, and 75 percent of the original value. In general, follow the procedures in section 8111 F Inoculum and 8111 G Test Conditions and Procedures. To each sample an inoculum of *Selenastrum capricornutum* is added. After about one week, measure the algal biomass in the sample using one of the procedures set forth in Standard Methods, such as chlorophyll.

Since alum additions to a water sample may also remove essential trace elements, a duplicate set of experiments should be conducted where phosphorus is added back in the amount removed by alum treatment to determine if essential trace elements/compounds were also removed. If the alum-treated phosphorus-added samples do not develop about the same algal biomass, then add the trace element cocktail specified in Standard Methods to the alum-treated samples and the untreated sample to determine if the alum removed an essential trace element that is present in the cocktail.

Standard QA/QC Program

Follow US EPA standard QA/QC procedures for replicate and spike samples. In addition, split samples and known standard samples which are not identified as splits should be sent to the laboratory. Lee and Jones-Lee (2002c) have discussed that the standard QA/QC procedures do not prevent unreliable data from being produced in a water quality monitoring program. As they discuss there are a variety of factors that can cause unreliable data to be generated even with strict following of US EPA standard QA/QC procedures. The investigators for a project have the responsibility of conducting the studies needed to verify that the data generated are reliable.

Data Management and Evaluation

The monitoring program should be an "active" monitoring program, where a panel of experts would review the data as soon as they are available and make recommendations and modifications to the monitoring program as needed (see Lee and Jones-Lee, 2002c).

In establishing the upstream watershed monitoring program, the SJR TMDL Steering Committee Upstream Watershed Advisory Subcommittee, guiding the upper watershed monitoring, should (prior to initiating the program) develop a set of synthetic data that they feel would be representative of the data that are likely to be generated in the study. These data should be used by this panel to develop a data analysis/interpretation to ascertain whether all of the information needed to interpret the data is being collected. This exercise should be repeated at about monthly intervals using the data that have been collected during the previous month.

Horne (2002) suggested, as part of the peer review of the SJR DO TMDL CALFED Directed Action project, that constructed wetlands in the Mud and Salt Slough watersheds could potentially be effective in removing nitrogen from these waters before their discharge to the SJR upstream of the Merced River. Enhanced constructed wetlands have been effective in reducing nitrogen loads to the upper Santa Ana River near Riverside, California. Since there are already substantial wetlands in this area, it may be possible to utilize some of these wetlands, plus additional constructed wetlands, for nitrogen removal through enhanced denitrification of nitrate. This would have to be done, however, in such a way as to not adversely impact the wildlife habitat of the federal and state refuges and private duck clubs. The purpose of this effort would be to reduce the nitrate concentrations in the upstream tributaries to the SJR so that further growth of algae within the SJR is nitrogen-limited. Phase I TMDL studies should include at least a preliminary evaluation of this approach. If it appears feasible, then a pilot study should be considered/conducted.

South Delta

During the summer and fall, when the San Joaquin River is diverted down Old River into the South Delta, there is an appreciable oxygen demand load discharged to the South Delta that develops upstream of Vernalis. Further, there is an oxygen demand load added to the South Delta from the growth of algae within the South Delta derived from nutrients in the SJR diverted into the South Delta, in domestic wastewater inputs from Tracy, CA, and in South Delta agricultural tailwater. During the summer there is about 200 cfs of agricultural tailwater discharged to the South Delta channels. As discussed above, these oxygen demand loads cause, at times, severe DO depletion in the South Delta below the water quality objective. As a result of the 303(d) listing of Old River and Middle River as impaired due to low DO, there will be need to correct this problem. At this time, the potential significance of oxygen demand loads derived from upstream of Vernalis versus those that are derived from in-South Delta sources, has not been evaluated. With CALFED's commitment to construct and operate permanent operable barriers within the South Delta by 2007, it is likely that there will be appreciable changes in the oxygen demand loads and the oxygen depletion problem that is occurring in the South Delta associated with the development of the permanent barriers. There is need to significantly expand the DWR monitoring of South Delta waters to develop the information base that can be used to understand the conditions that lead to low DO in South Delta channels and how the installation/ operation of the permanent barriers will influence these situations. The development of the South Delta monitoring program will require some preliminary studies to gain better insight into the conditions that lead to low DO in the South Delta channels.

Central Delta

The studies that have been conducted on DO depletion within the SJR DWSC have shown that, at times, especially under conditions of high SJR flow through the DWSC, there is appreciable oxygen demand exported from the DWSC into the Central Delta. This export occurs to some extent at Turner Cut, but principally takes place at Columbia Cut. It is due to the strong cross-SJR DWSC flow of the Sacramento River water down Disappointment Slough, across the DWSC, into Columbia Cut, associated with the export pumping of South Delta water for the State and Federal Projects. While it is generally believed that there is substantial dilution of the exported SJR water from the DWSC at Columbia Cut by the Sacramento River, there are potential conditions where sufficient oxygen demand could be added to the Central Delta to cause DO depletion in some areas and at some times below the 5 mg/L water quality objective. As part of the SJR DO TMDL and, especially as related to attempts to increase the flow of the SJR through the DWSC to reduce the oxygen depletion that occurs in the DWSC, thereby increasing the oxygen demand load to the Central Delta, there is need to determine whether there are low-DO problems occurring in the Central Delta due to the export of the SJR DWSC water into that area. This information will be needed as part of gaining CEQA approval of any program that would increase the flow of SJR water through the DWSC.

It is proposed that a team of experts guide the development of a highly focused monitoring program that is specifically designed to examine worst-case conditions for DO depletion in the Central Delta associated with the export of SJR DWSC waters into this area that contain significantly elevated concentrations of oxygen demand in the form of algae and/or ammonia/organic nitrogen. This monitoring program, like other monitoring programs, should be conducted on an active basis, where, as the data are generated, they will be reviewed, and further monitoring runs will be conducted to specifically address issues that arise from the previously collected data.

Impact of DO Concentrations on DWSC Chinook Salmon Migration and Aquatic Life Habitat

An issue that needs to be resolved is the appropriate dissolved oxygen concentration that will prevent inhibition of the fall run of Chinook salmon migration through the DWSC to their home waters. There is need to conduct studies over a several-year period to determine whether the 6 mg/L DO water quality objective adopted by the State Water Resources Control Board is technically justified. The Department of Fish and Game studies, conducted in 1970, concluded that the DO in the DWSC should be above 5 mg/L to avoid inhibition of Chinook salmon migration through the DWSC due to low-DO. These studies need to be updated.

Another area that needs attention during the Phase I TMDL is the need to establish the 5 mg/L minimum DO water quality objective as being applicable to all locations and times within the DWSC. The US EPA and a number of states allow averaging of the diel (day/night) DO. Further, they allow lower DO in the near-bottom waters of some waterbodies. An issue that needs to be resolved is whether following this approach would be significantly detrimental to the aquatic life resources of the DWSC and, for that matter, the South Delta.

A review of the appropriate DO water quality objective for the DWSC should be conducted which may conclude that there is need for studies to examine how DO values less than 6 mg/L, between September 1 and November 30, impact Chinook salmon migration through the DWSC. Also, the water quality and the aquatic life resource impacts of an average diel DO and a lower DO in the near-bottom waters of the DWSC should be evaluated.

Alternative Approaches for Solving the DWSC Low-DO Problem

Presented below are several alternative approaches that have been suggested that should be considered and, if found appropriate, evaluated to help solve the low-DO problem in the DWSC. Information on several of these approaches will be needed as part of the CEQA alternatives evaluation that will be associated with the final TMDL for solving the low-DO problem in the DWSC.

Impact of Continued Operation of the Port of Stockton on the DO Problem in the DWSC

The previous studies have determined that, without the existence of the Port of Stockton and its associated Deep Water Ship Channel, there would be few, if any, DO depletion problems below the water quality objective in the DWSC. This situation causes the Port of Stockton and those who benefit from the Port to be one of the, if not the, primary responsible party for the DO problem in the DWSC. Since the continued existence of the Port is of economic value to a variety of entities within the Central Valley, especially in the San Joaquin River watershed, it is appropriate to examine the economic and other consequences of terminating the existence of the Port of Stockton as a deep water ship port and thereby allow the DWSC to fill in. In time, the DWSC would become shallower and ultimately, shoal in sufficiently so that the DO depletion problems in the DWSC would be greatly reduced. It is suggested that an economic study be conducted of the value of the Port to stakeholders in the region and its cost in terms of controlling the low-DO problem in the DWSC.

Altered Flow of the SJR past Rough and Ready Island

It has been suggested by representatives of the Port of Stockton that Burns Cutoff, which connects to the SJR just upstream of Channel Point and flows on the westside of Rough and Ready Island, could be used as a channel that would carry SJR water around Rough and Ready Island and thereby discharge the oxygen demand loads in the SJR that enter the DWSC several miles downstream of Channel Point. The waters in Burns Cutoff could be aerated and thereby reduce the oxygen demand load that now enters the DWSC at Channel Point. The aeration of Burns Cutoff could be done in such a way as to eliminate the interference with ship traffic. It has been suggested that there may be need for a lock on the SJR at Channel Point to allow small boat traffic to pass from the DWSC into the SJR and to divert SJR water into Burns Cutoff. It is suggested that an engineering study of the potential use of Burns Cutoff as an alternative low flow summer channel for routing and aerating the SJR water and its associated oxygen demand load into the DWSC downstream of Rough and Ready Island be conducted.

Purchase of Eastside River Water to Supplement SJR Flow through the DWSC

The SJR watershed eastside rivers have been found to provide high quality low oxygen demand water to the SJR and to the DWSC to the extent that the eastside river water is allowed to pass into the DWSC -- i.e., is not diverted down Old River. To the extent that these rivers discharge to the SJR during the summer and fall, this discharge reduces the travel time through the DWSC and therefore the oxygen deficits that occur within the DWSC. It has been found that SJR DWSC flows above about 2,000 cfs do not cause DO depletion problems in the DWSC even though there are elevated oxygen demand loads entering the DWSC associated with these flows.

The travel times of the SJR water through the critical reach of the DWSC (Channel Point to Colombia Cut) are sufficiently short under the elevated flows so that there is not time for the oxygen demand to be exerted in this reach.

The export pumping of water from the South Delta by the State and Federal Projects eliminates the downstream extent of the DO depletion problem below the water quality objective to upstream of Colombia Cut. It has been suggested that a possible approach for reducing the DO depletion problem within the DWSC would be to purchase New Melones Reservoir water for the specific purpose of increasing the SJR flow through the DWSC. This approach would tend to overcome the impacts of the diversion of SJR water upstream of the DWSC that now contributes to low flow conditions within the DWSC. Information on the potential for increased summer/fall flow of the eastside rivers into the SJR DWSC could be evaluated as part of the CEQA evaluation of alternative approaches for solving the low-DO problem in the DWSC. This evaluation would need to consider potential redirected effects of eastside river flow through the DWSC.

Implementation of the Evaluation/Monitoring Program

It has been suggested that a workshop be organized which would have two purposes. One of these would be to present, discuss, and refine the monitoring/evaluation programs that would be conducted during the TMDL Phase I. The second would be to review and discuss the alternative approaches for solving the low-DO problem discussed above. This workshop should be held over at least 1, and possibly, 1.5 to 2 days.

The workshop could be sponsored by CALFED where all interested parties would have the opportunity to present their views on solving the low-DO problem in the DWSC. A report to CALFED, the Steering Committee/stakeholders, and the CVRWQCB would evolve from the workshop which would present the general characteristics of the Phase I monitoring/evaluation program. This workshop could lead to the development of a number of Steering Committee subcommittees that would become responsible for further refinement of specific components of the Phase I monitoring/evaluation program. The Steering Committee subcommittees could then become the responsible entities for developing the details and shepherding the development and implementation of each of the components of the monitoring/evaluation program. These subcommittees would work with the contracting entity responsible for actually implementing the specific components of the monitoring/evaluation program and report to the Steering Committee, CALFED, and the CVRWQCB on their activities.

External Peer Review Issues

This section of this report presents information pertinent to the external peer review of the CALFED-supported Directed Action studies of the low-DO problem in the SJR DWSC and information on the sources of oxygen demand from its watershed.

Peer Review Questions for the San Joaquin River Deep Water Ship Channel Dissolved Oxygen TMDL

Presented below is information that was provided to the external peer review panel in connection with preparing for the peer review that took place in June 2002. The overall goal of the external peer review held in June 2002 was to help the Steering Committee/stakeholders and CALFED evaluate the adequacy of the technical information base upon which the TMDL analysis and stakeholder allocations of loads/responsibilities would be developed. These questions were developed by CALFED and the Steering Committee. The italicized sections represent the authors' (Lee and Jones-Lee) discussion of the issues raised by the question.

1. Overall Understanding

Is there adequate understanding of responsible constituents and conditions that lead to violations of DO water quality objectives in the San Joaquin River (SJR) Deep Water Ship Channel (DWSC) to develop the initial phase of a technically valid, cost-effective management plan for eliminating the DO water quality objective violations that occur in the DWSC each summer/fall?

If not, what are the major information gaps that need to be filled before it will be possible to formulate an appropriate management plan for controlling the low-DO conditions in the DWSC?

In addressing these questions it is important to consider the framework in which the peer review, these studies, the past studies and the TMDL implementation will take place. As discussed herein, the Central Valley Regional Water Quality Control Board must, in June 2003, develop the first phase of a TMDL designed to control the DO depletion in the Deep Water Ship Channel. While the first question, devoted to "Overall Understanding," asks whether there is adequate information to proceed with this effort, it is important to understand that there are information gaps in a number of areas, which are discussed in the synthesis report. However, sufficient information has been gained during the three years of studies to identify the primary approaches that can be used to solve the low-DO problem."

2. Modeling

a) Has the dynamic and mass balance box modeling of the oxygen demand load-DO depletion in the DWSC adequately defined the impact of the loads of oxygen demand constituents (carbonaceous BOD and nitrogenous BOD including algae, ammonia and organic N) derived from upstream of the DWSC and within the DWSC on DO depletion in the DWSC?

b) Will the existing models allow reliable forecasts of the implications of different management actions? Do the models help us understand the causes of the low DO?

c) If not, how should the modeling be expanded/changed to address areas of inadequate modeling capability?

d) Do the present studies differentiate the roles of flow, tidal exchange, basin morphometry and organic matter input (or its precursors) adequately? What additional studies are necessary to allow such differentiation?

With respect to the second question (devoted to "Modeling"), part "a," at this time there is a fair understanding of the relationships between carbonaceous and nitrogenous BOD as a cause of DO depletion. We do not have a good handle on the organic nitrogen component of BOD at this point, although, with additional review of the existing data, we will likely be able to provide that information. With respect to "b," we are not in a position to forecast the implications of different management options. At this point, the existing, as well as the proposed, modeling effort will not provide the information needed to make reliable forecasts. There will be need to follow an adaptive management approach. With respect to "c," the issue is not the modeling, but the database from which the models are to be developed. With respect to "d," we are not able to differentiate the roles of flow, tidal exchange, basin morphometry and organic matter input adequately at this time. Modeling will not solve this problem. While five years of detailed studies might provide additional insight into these issues, it will be more cost-effective to start the implementation process, where we are specifically focusing on developing information for implementing each of the proposed approaches for managing the DO problem.

3. Allocation of Oxygen Demand Load

a) What SJR subwatersheds should be studied and what should be measured? Do we have enough information to determine where (what subwatersheds) load reduction feasibility studies should be conducted?

b) Is there sufficient data and analysis to determine whether load reduction upstream could benefit, though possibly not solve on its own, the low-DO problem in the DWSC? How much reduction in what substance would reduce the load entering the SJR from that watershed and how much would that reduction result in improved DO conditions in the DWSC?

c) Is there sufficient data and analysis to determine how much upstream load reduction would result in what level of DO improvement under different flow conditions?

With respect to the third question, "Allocation of Oxygen Demand Load," at this point the allocation of the oxygen demand load will be to the Mud Slough, Salt Slough and SJR upstream of Lander Avenue watersheds, as well as to the city of Stockton. With respect to parts "b" and "c," we are not in the position yet to predict how altering oxygen demand loads in any of these watersheds will affect the DWSC.

4. DO Concentration Goal

Is the interim TMDL Phase I minimum DO concentration goal proposed by the CVRWQCB staff appropriate? If not, what should the Phase I minimum DO concentration goal be?

With respect to the fourth question ("DO Concentration Goal"), since this is essentially the same as the US EPA's recommended "Gold Book" DO goal, it is appropriate as a Phase I target. During this phase there will be need to determine what should be the appropriate DO concentration goal/water quality objective for the final phase of the TMDL.

5. Flow

Is there sufficient data and analysis to determine how increases or decreases in flows from different sources affect DO conditions? If not, what studies and monitoring should be undertaken?

With respect to the fifth question on "Flow," there is insufficient information at this time to predict how changing the flow in the range from about 500 to 1,500 cfs will impact DO. Further data review of the existing database may help in this area.

6. Aeration Questions

a) Are estimates correct for the amount of aeration that would be needed in the DWSC under different flows? How broad should the range of estimates be to ensure that if aeration occurred within those parameters, the performance goal milestones would be met?

b) Is there sufficient data and analysis to be able to develop a DWSC monitoring program during pilot aeration?

c) Is there sufficient data and analysis to be able to predict how much aeration will be needed under different flow conditions? Is this important to know before beginning pilot aeration and monitoring studies?

With respect to the sixth question on "Aeration," the estimated oxygen deficits are dependent on a number of factors which range from a few thousand pounds of oxygen needed per day to several tens of thousands of pounds of oxygen needed. There is need to start comprehensive field studies which can be used to examine how effective aeration, practiced to various degrees at various locations, is in controlling the DO problem. With respect to "b," there is sufficient information available to develop the first phase of a monitoring program to investigate aeration. This monitoring program would be an adaptive management program which should be adjusted during the course of these studies. Item "c" relates flow to aeration. At this point there is insufficient understanding of the two to be able to directly couple flow to aeration, although estimates can be made which can then be evaluated in the pilot studies.

7. DWSC Geometry Questions

a) Would there be a significant DO problem if the DWSC weren't there and the river remained at its historic depth through this reach?

b) Do we know enough to fairly predict how additional channel deepening will affect DO conditions in the DWSC?

With respect to the seventh question ("DWSC Geometry"), there is no issue about whether the DO problem would be there if there were no DWSC. With respect to "b," we are not in a position to reliably predict how additional Channel deepening will affect DO conditions. We know it will be in the wrong direction. However, the magnitude of impact is not known.

Responses to the CALFED Low-DO Directed Action Project External Peer Review Panel's Overall Comments

On June 11 and 12, CALFED conducted an external peer review of the CALFED Low-DO Directed Action Project of the 2001 studies and the previous two years' studies. On July 11, 2002, the Peer Review panel's (PR) July 1, 2002, report was made available for review. In accord with the CALFED/NFWF contract, the component project PIs were to provide a written response to each of the PR comments as part of submitting their final reports. Also the overall project PI (G. F. Lee) was to address the general PR comments. This section of the report provides the responses to the PR general comments.

The Peer Reviewers are to be thanked for the time and effort they made in conducting this peer review. Their comments reflect a critical review of the large amount of information that has been developed for the approximately $3 million of CALFED support that has been made available over the past three years. The Peer Reviewers' comments are presented below in italics with the responses following the PR comments. The italicized sections below are the peer reviewers' comments.

Appropriate DO Target

The PR comments,

"… it is important to identify an appropriate DO target that would be protective of aquatic organisms in the SJR DWSC system. First it is necessary to determine the ecological groups and life stages that may be impacted by low DO concentrations (just migrating fish or also benthic/aquatic invertebrates?). The next step would be to determine protective DO thresholds, and how compliance should be defined spatially and temporally."

This is an important issue that has been of concern over the past three years. The issue of appropriate DO water quality objectives for solving the low-DO problem in the DWSC is an issue that has been discussed extensively amongst several of the participants in the studies. The Lee and Jones-Lee (2000a) "Issues" report contains considerable discussion of this issue. This discussion is based on Dr. Lee's experience in developing water quality criteria, including specifically being involved in DO criteria. There are appropriate questions about the need for the

6 mg/L DO objective for protection of Chinook salmon migration that has been established by the State Water Resources Control Board for the reach of the DWSC between Channel Point and Turner Cut during September 1 through November 30.

In developing the original recommended peer review panel members, a proposed panel member, Dr. Alan Mearns, was selected and initially agreed to be a participant in this peer review effort. His PhD dissertation and professional work since then has included considerable attention on the effect of DO on Chinook salmon physiology. Unfortunately, Dr. Mearns found that he could not participate in this peer review, with the result that this left a gap in the peer review process. Efforts are being undertaken to correct this situation through supplemental review of the low-DO project target objectives by Dr. Chris Foe and Mark Gowdy of the CVRWQCB. The issues that need to be addressed include:

- The appropriateness of the 6 mg/L DO objective adopted by the State Water Resources Control Board and the CVRWQCB for the DWSC to protect Chinook salmon homing migration during the fall.
- The need for a 5 mg/L DO objective that is applied without averaging with respect to time of day and location within the DWSC. Of particular concern are excursions which lead to low-DO concentrations in the near-surface waters that occur only in the early morning, related to the diel photosynthetic cycle, and the excursions below 5 mg/L in the near-bottom waters.

Data Gaps and Need for Improved Teamwork

The PR makes the recommendation that,

"*A comprehensive analysis of all current data has not yet been completed. The investigators need the opportunity to exploit historical and new data to:*

- *Refine conceptual models of sources and causes of the DO problem*
- *Identify high priority data gaps*
- *Design a road map for filling those data gaps*

This can best be accomplished by extending contracts and funding expressly for this purpose. In addition, the hiring of a facilitator to improve teamwork and help all parties understand where the data needs are will assist the investigators to fully exploit the data."

Data Gaps. The peer review panel's primary recommendations, as represented by the three bulleted items above, are all important issues that need to be addressed in the near future. Considerable discussion has already taken place on these issues with regard to further defining the sources and causes of the DO problem, identifying high-priority data gaps, and designing appropriate programs to fill the existing data gaps to develop a technically valid, cost-effective program for solving the low-DO problem in the DWSC. As discussed in the May 2002 draft Synthesis Report, the timeframe governing the development of reports for the peer review panel precluded a comprehensive review of the large amount of data that have been collected. It is concluded, however, that simply extending all current PI contracts and adding funding may not be the appropriate approach to follow in filling data gaps.

The approach that is planned involves first identifying the major data gaps for which there is immediate need for additional data as part of the implementation of Phase I of the TMDL. Next, there is need to determine how best to proceed to fill these data gaps. This is a decision that will be made by the Steering Committee and CALFED. While there are a number of interesting scientific issues associated with the low-DO problem in the DWSC, many of these are not high priority to solving the low-DO problem. It is important to focus CALFED's financial resources on the highest priority items needed to proceed with the Phase I TMDL. As it stands now, there are few data gaps that need to be immediately filled in order to proceed with the Phase I TMDL. Many of the key data gaps can, in fact, be addressed during Phase I. The key data gap issues are discussed below.

As a followup to the peer review workshop, and in response to a request made by Barbara Marcotte, G. F. Lee has developed a draft write-up of the overall monitoring/evaluation approach that should be developed for each of the major areas in which there is need for additional information. This write up is presented in a subsequent section.

Improving Teamwork. Considerable effort has been devoted to correcting the lack of teamwork and the lack of responsiveness to contractual requirements by component project PIs as required by CALFED, the Steering Committee, the overall project PI, and the CVRWQCB staff. The inability to achieve an integrated teamwork approach has been a serious problem throughout the three years of study. Considerable efforts were made as part of developing the 2001 Directed Action project to address this problem. While some improved teamwork was achieved through these efforts, a variety of factors have prevented achieving a highly coherent investigative team. Hiring a facilitator, *per se*, as recommended by the peer review panel, will not solve this problem.

One of the key issues that played a major role in failing to achieve an integrated team approach was CALFED's problems with issuing contracts in a timely manner. Another factor that played a role was CALFED's approach toward funding the modeling effort. As originally designed in the CALFED proposal, the primary integrating effort for the 2001 studies was the realtime forecasting modeling approach, where all data were to be fed into the model as they were generated. This, in turn, was to lead to an integrated team approach for review and recommendations for modifications of the study program. Unfortunately, CALFED chose not to support this approach, with the result that the binding component (the model) of the 2001 studies was lost, and still has not been effectively started.

PR Response to Question 1 on Adequacy of Existing Understanding

"There was general agreement among the reviewers that the data have established that there is a strong correlation between flow rates and dissolved oxygen levels. However, the roles of loadings of various types and sources of oxygen-demanding materials are not well understood.

Dr. Chapra suggests that an analysis of Stockton discharge records be performed to construct a multi-year time series of flow and discharge concentrations of several key variables."

As discussed in the May 2002 draft Synthesis Report and by Dr. Foe in the Strawman analysis (Foe, *et al*., 2002), the overall aspects of the relationship between types and sources of oxygen demand loads to the DWSC are understood with respect to the role of upstream planktonic algae and the city of Stockton's ammonia loads. How flow affects these loads in the 500 to 1,200 cfs range of SJR flow through the DWSC is not well understood at this time. It is concluded by the authors, however, that further studies of the type that have been conducted in 2000 and 2001 will not likely provide the information needed, and that an experimental aeration approach, coupled with appropriate modeling and monitoring, will provide this information.

Following the peer review workshop, G. F. Lee prepared a preliminary proposal to CALFED and the CVRWQCB devoted to supporting the PR's comments of using the Chen model to further elucidate the DO depletion issues in the 500 to 1,200 cfs range of SJR flow through the DWSC. This proposal specifically focused on evaluating the ability of the existing Chen model, without additional coefficient tuning, to predict the characteristics of the DWSC for each of the 43 monitoring runs that the city of Stockton made in 1999, 2000 and 2001, relating the oxygen demand load in the form of algae/BOD at Mossdale and ammonia loads from the city of Stockton to DO depletion at Channel Point, Rough and Ready Island and near Turner Cut. It was decided that this model evaluation should be done by the Regional Board staff, rather than the modelers. As of this time, CALFED has not made the funds needed to proceed with this evaluation available to the Regional Board.

If the current Chen model can properly track the results of the 43 monitoring runs without coefficient adjustment, then considerable confidence will be gained in the use of this model to evaluate the effects of flow and various load types and sources on DO depletion at various times and locations within the DWSC. If the model cannot make these predictions reliably, then there is need for further work on the model before any refinements can be made in the understanding of DO depletion versus oxygen demand load types and sources. Subsequent to developing these comments, Brown (2002b) provided comments (discussed above) which indicate that the model needs additional work to improve its ability to simulate DO depletion for various conditions that are encountered in the DWSC.

PR-Identified Data Needs

"Preliminary identification of data needs includes:

- *Continuous measurements of flow, DO, and representative measurements of phytoplankton, zooplankton, nutrients and other oxygen-affecting substances. These should be collected within the DWSC, upstream of the DWSC at Mossdale, and far upstream from one or more significant tributaries. These are critical for new modeling work as well as for quantifying the driving forces into the SJR and on to the DWSC."*

G. F. Lee's monitoring/evaluation program guide that has been developed and is presented above specifically addresses these issues.

- *"Information on critical levels of DO in water (and location) for various organisms of interest, both aquatic and benthic."*

The recommended DO target and objectives review mentioned above will address these issues.

- *"Information on the importance of thermal stratification in the DWSC."*

G. F. Lee's monitoring/evaluation program guide addresses this issue.

- *"Information on flow augmentation resulting from permanent tidal barriers in the Delta. These would factor into a major hydrodynamic change in the SJR/DWSC system. There is a need for a better hydrologic budget for better modeling of the upper SJR system."*

Further studies on the low-head pumping as a means of supplementing the SJR flow through the DWSC are being planned. These studies will include an expansion of the current South Delta modeling to include water quality issues. Further, G. F. Lee's monitoring/evaluation program guide discusses the general characteristics of the South Delta monitoring program that will be needed to provide the information needed to gain approval for the low-head, across-the-barriers pumping program.

- *"Data on certain high-priority watersheds within the upper watershed (to support development of control actions). This should include data on BOD loading from upstream wetlands."*

The characteristics of the specific upstream watershed monitoring have been developed in G. F. Lee's monitoring/evaluation program guide.

- *"Data to resolve disagreement on the causes of DO depletion in the DWSC (upstream algae versus local ammonia inputs)."*

The specific program to address the conflict between Lehman and the other investigators on the importance of city of Stockton ammonia discharges as a cause of low DO in the DWSC, even when the city's ammonia load is low, will first be addressed in the review of the Chen model's ability to predict the DWSC conditions during the 43 city of Stockton monitoring runs. Follow-up studies will be defined at that time.

- *"Characterization of the dynamics between Mossdale and the DWSC, including the effects of zooplankton and especially macrobenthic grazing on algae levels."*

The oxygen demand dynamics in the reach of the SJR between Mossdale and Channel Point is a specific study area in the G. F. Lee monitoring/evaluation program guide.

- *"Information on species variation of the algal load along the SJR, which will demonstrate whether upstream algal inputs act as a seed population, or whether a new algal community develops. This distinction has a large impact on the eventual algal load into the DWSC."*

Algal dynamics in the SJR upstream of Mossdale and between Mossdale and Channel Point are proposed to be examined by G. F. Lee during the follow-up monitoring/evaluation program.

PR Monitoring Recommendations

PR comment:

> *"General additional monitoring recommendations include the following:*
>
> - *Extend monitoring upstream*
> - *Install more probes to adequately define temporal and spatial variation in DO, conductivity, temperature, turbidity, and pH*
> - *Continue "synoptic surveys" (Hayes cruises, etc.)"*

All of these issues have been addressed in the G. F. Lee proposed monitoring/evaluation program guide.

PR comment:

> "*It is important to coordinate all data collection activities with modeling needs. If the monitoring and research proceed without input from the modelers, there would be a risk of obtaining information that could be incompatible with the model structure (i.e., its kinetic representation, as well as its temporal and spatial resolution)."*

The peer review panel support of the approach that was originally proposed in the CALFED Directed Action proposal submitted in January 2001 to closely integrate monitoring/evaluation with modeling is important to achieving this integration. If the realtime forecasting modeling approach that was proposed in January 2001 had been supported by CALFED, it is believed that a much better understanding of the processes responsible for DO depletion in the DWSC would be available now. It is planned, through the experimental aeration studies, to closely integrate modeling with monitoring and evaluation. These issues have been discussed by G. F. Lee in his monitoring/evaluation program guide.

The monitoring/evaluation program guide specifically addresses the need to establish a monitoring program that will provide the HydroQual modeling effort with the necessary data. It will be important for CALFED to establish a framework where an integration of the monitoring/evaluation with the modeling can be achieved. This framework does not exist at this time. The upstream modeling of the SJR that is being planned is still not integrated with the CALFED-supported monitoring and evaluation that has been conducted over the past three years on the DWSC and its tributaries.

PR Comments on Future Monitoring and HydroQual Modeling

> "*This is particularly critical if the actual allocations in the TMDL will be generated by the HydroQual model. Considering the short time frame, the team cannot afford unnecessary research or data collection that (1) measures the wrong processes or variables, and (2) do not address the proper space and time scales.*"

Those responsible for working with CALFED and the Steering Committee in organizing future studies are keenly aware of the need to focus on data collection needed to support the HydroQual model with specific studies designed to provide the information needed to properly develop this model. As discussed above, a key component of this will be CALFED's ability to integrate the current HydroQual modeling with Phase I monitoring and evaluation. The G. F. Lee monitoring/evaluation program guide specifically addresses this issue.

PR Comments on Question 2 on Modeling

> *"The 1-D model or other suitable model can and should be used to obtain a version of the oxygen mass balance for the DWSC that accounts for all of the different information (primary productivity, respiration, sedimentation rates and SOD) and resolves the ammonia controversy or better exposes basis for differing opinions. Use of the 1-D model can accomplish this in a relatively short period of time."*

As discussed above, G. F. Lee's proposal to use the Chen model to address these issues is being planned. The first phase, which can be initiated as soon as CALFED support is available, will be devoted to an evaluation of the ability of the Chen model to properly track the conditions that were found in the 43 city of Stockton monitoring runs. Of particular concern is the role of the city of Stockton ammonia discharges on DO depletion in the DWSC.

PR comment:

> *"The application of a statistical model to long term data is promising and should be pursued. There are problems with the existing statistical model that must be resolved to make it a valuable tool for analysis."*

Discussions will be held with E. Van Nieuwenhuyse and CALFED about refining the statistical modeling as an independent approach.

Ammonia Issues

PR comment:

> *"Ammonia concentrations in the DWSC are high. This deserves serious attention. Analysis of Stockton Regional Wastewater Control Facility (RWCF) effluent data needs to be performed to verify the occurrence and completion of nitrification."*

The issue of the importance of the city of Stockton ammonia as a cause of low DO is an issue that has been of concern. One of the issues that will need to be addressed with future funding is the potential benefits of the CVRWQCB's requirements of limiting the city of Stockton's wastewater discharges to a monthly average of no more than 2 mg/L ammonia nitrogen in affecting DO depletion in the DWSC. The issue that needs to be resolved is whether the 2 mg/L ammonia discharge limit, which was based on toxicity issues and not DO depletion issues, is adequate to control significant oxygen depletion due to the ammonia discharged by the City to the DWSC.

Upstream Oxygen Demand Source Issues

PR comment:

> *"The evidence identifies Mud and Salt Sloughs as the primary subwatersheds for examining possible load reduction. However, the ultimate worth of any such reductions needs to be considered more thoroughly. There might be gains in water quality, but it is not clear at this point that they would be significant with respect to the ultimate goal."*

One of the primary areas of emphasis discussed in G. F. Lee's monitoring/evaluation program guide is the need for detailed watershed studies of Mud and Salt Sloughs, as well as the SJR upstream of Lander Avenue, to understand algal growth dynamics and, especially, whether there is potential for controlling the algal biomass generated within these watersheds that reaches the SJR at the tributary mouths. In addition, as part of the HydroQual modeling, it is proposed that an evaluation be conducted of how altering the algal loads that are discharged by these three watersheds to the SJR influences the oxygen demand loads that reach the DWSC. Through these studies, it should be possible to understand the coupling between upstream algal/BOD loads and DO depletion in the DWSC. Based on this understanding, it should be possible then to evaluate the cost-effectiveness of any upstream nutrient/algal control programs on the DO depletion problem within the DWSC.

Further DO Objective Compliance Issues

PR comment:

> "*It is likely that the interim DO objective can be achieved, but a variety of control measures may be required rather than a single one. In addition, the feasibility of achieving this objective depends on how compliance is defined spatially and temporally."*

The experimental aeration program that was proposed by the CVRWQCB/Steering Committee that will be conducted during Phase I will provide information on the ability of aeration to achieve the interim, as well as the final, DO target/objective.

PR comment:

> *"The relationship between flow and DO conditions has been described in general terms. Further statistical analysis of historical data, as well as refinement of the Systech model would be useful, as stated in Dr. Jassby's comments (Appendix E)."*

The experimental aeration studies will yield further insight into the relationship between SJR flow through the DWSC and DO depletion for a given oxygen demand load. By conducting the aeration/monitoring studies at different flows, it will be possible to gain insight into this relationship. Further, it may be possible to alter the flow through the DWSC, through discharges down Old River, to help in gaining this understanding.

PR comment:

> *"There is a need to develop information on various aeration schemes/technologies, including performance of science-based demonstrations at pilot scale. Cost/benefit data are also needed."*

Task 5 of G. F. Lee's component project for the current CALFED Low-DO Directed Action project provided funds that were used by URS Corporation to develop an overall recommended approach that is acceptable to the Steering Committee and CALFED for conducting the experimental aeration studies. As planned now, these studies will provide the information suggested by the PR that will enable CALFED and the Steering Committee/CVRWQCB to determine the appropriate use of aeration as a means of controlling the low-DO situation in the DWSC. It should be noted that, while the focus of the Phase I TMDL will be on aeration, considerable additional information will be gathered during Phase I on other means of controlling the low-DO problem. There seems to be general agreement that it will be a combination of approaches that will ultimately solve the low-DO problem.

PR comment:

> *"The Systech model results show that the channel deepening has had a strong influence on DO conditions. There is some question as to how the geometry of the DWSC affects the settling and resuspension of sediments and oxygen demanding particulate matter. There is also a question as to the thermal stratification that occurs in the DWSC and what effect this has on the DO at various depths."*

The issue of how depth of the channel influences DO is an issue that will be addressed as further work with the Systech (Chen) model is undertaken, once it has been verified that the model can reliably track DO depletion under various conditions. There will be need for CALFED to better integrate its modeling efforts with the DWSC studies than has been done thus far if there is going to be a better understanding of how thermal stratification and depth of channel affects settling and resuspension within the channel, as they relate to DO depletion.

Comments on Dr. J. Cloern's "Minority View" on Structural Solutions for the DO Problem in the DWSC

J. Cloern, in his discussion as a "minority view," has misinterpreted the US EPA's Clean Water Act requirements for controlling water quality problems through load reduction. The US EPA (2002) Region 9 has indicated in recent communications that solving the problem does not necessarily mean that there has to be a load reduction. Solving the problem can be accomplished by other means. While, typically, TMDLs are solved through pollutant load reductions, this does not mean that other approaches are not acceptable. It is suggested that pollutant load reduction should be accomplished where it is technically and economically feasible. This approach especially needs to be supported with respect to future agricultural and urban development within the SJR DWSC watershed. Aeration should ultimately be used to control DO depletion problems where load control is not feasible. As planned now, the initial focus on aeration represents a learning process that has substantial promise for controlling low-DO situations in the DWSC. While aeration is being evaluated, work will be done on controlling oxygen demand loads to the DWSC.

Dr. Chapra

Dr Chapra's Specific Comment:

> *"Action Item: An analysis of Stockton discharge records should be performed to construct a multi-year time series of flow and discharge concentrations of several key variables including nitrogen species (not only ammonia, but also organic nitrogen), $CBOD_u$ and dissolved oxygen. One goal of this analysis would be to accurately characterize the seasonal trends of ammonia discharge from the pond* [city of Stockton wastewater effluent pond]. *In particular, the analysis should establish the timing of the rise in ammonia discharge that occurs in the fall and the subsequent reductions that would occur in the spring."*

The nitrogen dynamics in the City's wastewater effluent ponds needs to be better understood, although this situation is likely to change with the Regional Board's revised NPDES permit, which limits the ammonia discharge to a monthly average of 2 mg/L ammonia nitrogen.

Dr. Chapra's Specific Comment:

> *"Action Item: Available time series data collected with data sondes should be systematically analyzed to ascertain the magnitude and frequency of low dissolved oxygen conditions during the winter. The first goal would be to evaluate whether winter low oxygen episodes are a significant recurring phenomenon. If so, an initial evaluation of possible causes should be performed. For example, the correlation of low oxygen with low flow should be analyzed."*

While it has been understood that there are low-DO problems in the DWSC at other times of the year, the initial emphasis in the TMDL is on the Chinook salmon fall run situation. Recently, Dr. Foe and Mr. Gowdy have indicated that the TMDL issues will need to be expanded to include other times of the year when DO depletion below the water quality objective occurs. This will include the need to conduct studies in the winter and spring. Further work will need to be done to begin to plan the necessary studies to understand the low-DO conditions that occur during the winter and spring.

During the course of the current studies, it was realized that low-DO concentrations were occurring throughout the summer. This caused the investigators to expand their work to include sampling during June and July.

Dr. Chapra's comment:

> *"Study and observation are needed in a number of areas:*
>
> *Further rate experiments should be conducted to quantify the rate constants for nitrification, plant growth and respiration. In particular, there is a major discrepancy between model and bottle estimates of productivity (Chen and Tsai, Lehman). As Chen*

> *and Tsai point out, bottle rates can reflect artifacts due to the enclosure process. On the other hand, the order of magnitude discrepancy that presently exists seems too large. A simple test of Lehman's rate would be developed by using her rate in the Chen and Tsai model to assess the impact on the oxygen calibrations. Another approach would be to compare model predictions of diurnal oxygen swings with measurements on the river. HydroQual should be consulted to solicit their ideas for process studies to strengthen their model development."*

Discussions will be held to determine how best to proceed to resolve the differences between the Chen and Tsai estimates of productivity, and those of Lehman.

Dr. Chapra's comment:

> *"I was surprised at how little the Systech model was referenced during our workshop. Although it could certainly be improved (by improved data and rate measurements), it is a technically sound tool for making initial assessments."*

As discussed above, the lack of use of the Systech (Chen) model during the 2001 studies, related to CALFED's decision not to fund the proposed use of this model during these studies, has left a substantial gap in the information base, which hopefully can now be corrected.

Dr. Ritter

Dr. Ritter's comment:

> *"Based upon what is known and what the uncertainties are in what is causing the oxygen depletion it is recommended*
>
> a. *Further research be conducted on more accurately delineating the major sources of oxygen demanding material that are causing the oxygen depletion in the DWSC.*
> b. *A more detailed analysis of historical data from the DWSC, San Joaquin River and Stockton wastewater treatment plant discharges.*"

Dr. Ritter's recommendations are in line with what is being planned in further work on the low-DO problem in the DWSC. This work includes more accurately delineating the major sources of oxygen demand and, if funds are made available, a more detailed review of the existing database. The approach to these issues has been summarized above.

Dr Ritter's comment:

> *"It is important to go ahead with the development of the more sophisticated models. This should give us a better understanding of the dynamics of the system and be able to evaluate management alternatives more accurately. In order for the more complex models to be of any use, it is very important to collect more data."*

Dr. Ritter's comments that there is need to go ahead with the more sophisticated modeling effort, and that this will require collection of additional data, are in line with what is planned. However, as discussed above, the integration of the "more sophisticated modeling" and additional data collection will need to be achieved, since at this time this approach is not well defined.

Dr. Ritter's comment:

> *"There is disagreement among the scientists as to the major causes of DO depletion in the DWSC. There is a need to reduce the uncertainty in the causes and sources of DO depletion before load reduction studies are conducted. To reduce the uncertainty, the principal investigators need to collect more data and do a more thorough analysis and synthesis of historical data."*

Dr. Ritter's comment about the disagreement among the scientists as to the major causes of DO depletion in the DWSC needs to be reviewed in terms of the situation. While, based on the peer review workshop, it is possible for a peer review panel member to come away with the conclusion that this issue is a major issue that needs to be resolved, the facts are that Drs. Brown, Litton, Foe, Mr. Gowdy and Dr. Lee are in agreement that algae from upstream sources are a major cause of oxygen demanding loads that lead to oxygen depletion in the DWSC below the WQO. At times, when the City's ammonia discharges are significantly elevated and the SJR DWSC flow is low, the City's ammonia can contribute significantly to the DO depletion problem. On the other hand, Lehman asserts, based on a statistical evaluation rather than a deterministic evaluation used by the others, that ammonia is the dominant factor causing DO depletion. The data do not support her position. There is no question that ammonia is an important factor when the flows of the SJR through the DWSC are low, and especially in the fall when the algal BOD load is reduced. As discussed herein, caution should be exercised in using statistical approaches to try to determine cause and effect. This has and can readily lead to erroneous conclusions on the importance of a particular situation. The proposed use of the Chen model to establish the impact of ammonia versus algal loads on the DO depletion problem should provide considerable information pertinent to resolving the relative significance of ammonia versus algae as a cause of the DO depletion problem in the DWSC.

Dr. Ritter's comment:

> *"There is enough data available to determine which of the tributaries are the major sources of oxygen demanding material that is transported into the San Joaquin River channel. What is not known with certainty is what are the causes of the oxygen demanding material in the subwatersheds of the tributaries."*

Dr. Ritter's comments about there being enough data to show that the oxygen demand materials are derived from certain tributaries of the SJR and that we do not understand the sources of oxygen demand within the tributary watersheds, where he supports the need for further studies, is in accord with the planned activities.

Dr Ritter's comment:

> *"There is a need to collect more data in this flow range with continuous DO, temperature and flow rate at various points within the system and to obtain accurate measurements of BOD loads to determine the relationship between flow rate, DO and BOD loads to the DWSC with more certainty."*

Dr. Ritter's recommendations regarding the need to collect more data on various parameters in the flow range of greatest interest are in accord with what is being planned. As indicated above, an overall monitoring/evaluation program guide has been developed. This work will likely be done during the Phase I TMDL.

Dr. Ritter's comment:

> *"CALFED should go ahead with a pilot scale aeration demonstration. It is recommended an RFP be developed for the aeration demonstration and the proposals be evaluated by a peer group of scientists and engineers. There is also a need to develop detailed cost/benefit data for different aeration schemes."*

Dr. Ritter's recommendation for CALFED to go ahead with the support of a pilot aeration demonstration is in accord with the planned approach. The pilot (or experimental) aeration program will be a key component of the Phase I TMDL.

Dr. Ritter's comment:

> *"It is fairly clear how the DWSC increases the hydraulic residence time and affects the DO conditions in the DWSC. There is some question how the geometry of the DWSC affects the settling and resuspension of sediments and oxygen demanding particulate matter. There also is a question to the thermal stratification that occurs in the DWSC and what effect this has on the DO levels at various depths."*

Dr. Ritter's comments regarding how the geometry of the DWSC affects settling and resuspension of the sediments and oxygen-demanding particulate material is an important issue that will need to be considered in future studies, especially as it relates to the potential for deepening the DWSC that the Port of Stockton has recently proposed. His recommendation on thermal stratification is in accord with planned studies.

Dr. Jassby

Dr. Jassby did not attend the Peer Review workshop or participate in the PR discussion of issues. He provided specific comments on several of the component project reports. The issues raised in these comments will be addressed by the component project PIs. He comments,

> "*c) Information gaps*
>
> - *There is still much uncertainty on the fate of river loads downstream of Mossdale but upstream of the DWSC. It would still be helpful, as suggested in the last review panel, to establish stations between Mossdale and Channel Point that evaluated changes in both the total BOD load and the relative role of different constituents (algal-derived materials, ammonium, other refractory and labile detrital organic matter). This would also help to address Dr. Lehman's contention that river loads are much more refractory than expected.*
> - *A better estimate of river loads into the DWSC is necessary. At the very least, a station several miles upstream of the RWCF outfall would be more appropriate than Channel Point or Mossdale when using discrete measurements. For chlorophyll,*

> *continuous flow and fluorescence monitoring should enable load estimates at any point."*

Dr Jassby's recommendations on adding monitoring stations between Mossdale and Channel Point will be considered in the development of the Phase I TMDL. Sampling in this area is much more expensive because of the tidal flow in this region, which results in having to take many more samples to obtain reliable results. The reason that sampling has not been conducted in this area in the past is based on funding limitations.

- *"A related issue is the role of primary consumers. It is still important, as noted in the last review panel, to find out what role primary consumers are playing in the DWSC as well as between Mossdale and Channel Point. Because primary producers are so variable (especially* Corbicula fluminea*, a major macrobenthic filter-feeder in the Delta), this information is essential to calibrating a reliable simulation model, as well as to understanding BOD changes downstream of Mossdale."*

Consideration is being given to quantification of zooplankton and macrobenthic organism grazing as a factor in controlling phytoplankton populations as part of the future monitoring/ evaluation program that is being developed.

- *"There is a very large body of historical evidence (DWR, DFG, and USBR datasets) that can be brought to bear on some of the questions here and that remains unexploited. Historical data analysis and time series or other statistical models offer a cost-effective addition to this project that could produce results in a timely manner with respect to the TMDL timelines. Moreover, they offer a long-term, data based perspective to the results generated by other types of analyses and models. Agreement between such different approaches gives us a much higher degree of confidence in the conclusions. Disagreement subjects all approaches to a more rigorous examination."*

To the extent that Dr. E. Van Nieuwenhuyse is involved in these studies in the future, he could address these issues. Note: Dr. E. Van Nieuwenhuyse was not part of the CALFED-supported team of investigators. He has followed closely the reporting on the studies that have been done and, on his own initiative without CALFED support, provided a statistical evaluation of the IEP database pertinent to the DO depletion problem. His future involvement will be dependent on the arrangements that he makes with his employer – USBR – and CALFED, for support if needed, as well as the time he has available for activities of this type.

Dr. Jassby's comment:

> *"I do, however, feel that it would be worthwhile to emphasize a few of the points that bear on future research and mitigation strategies:*
>
> *1. The role of river loading from upstream in controlling DWSC DO levels is uncertain. The research to date has made a strong case for the role of channel*

> *dredging, RWCF wastewater discharge and river flow. But some of the best guesses that have been brought to bear on the importance of river loading are contradictory. Resolving the relative importance of river loading should be a research priority, whether it involves additional field measurement or analysis of existing data."*

The statement with respect to the uncertainty in the role of river loading only relates to Lehman. The other investigators, who have all independently examined this issue, are in agreement with respect to the relative significance of upstream river loading versus city of Stockton ammonia. Basically, the issue focuses on the use of a questionably reliable statistical approach to infer cause and effect, versus a deterministic approach based on measured rates and concentrations of constituents. This issue will be addressed and resolved as part of the future studies.

> *"2. Given the uncertainty regarding river loading, the most important known load is from RWCF wastewater. Even if river loading proves to be relatively important, wastewater contributions will remain significant. Improving wastewater effluent quality is therefore at this point the most likely way to reduce TMDLs to the system, and at any time an effective way to reduce TMDLs to the system."*

As discussed above, the issue of the future City's ammonia discharges is under review. As now currently required under the recently-adopted NPDES permit for the City's wastewater discharges to the SJR just upstream of the DWSC, the ammonia loads to the SJR during times of elevated concentrations in the effluent will be reduced by a factor of about 10.

Dr. Jassby commented on the title of the Synthesis Report, indicating that this report goes beyond a "synthesis" of the other component project PIs' studies. The Synthesis Report has always been designed to present an integration of the CALFED component project PIs' findings, as well as information from the literature and G. F. Lee's experience/expertise in the topic areas covered by the report. To address this issue, the title of the Synthesis Report has been expanded to include "discussion." Further, the scope of the Synthesis Report has been further discussed in the beginning of the Preface. Considerable work has been done by G. F. Lee and A. Jones-Lee during the fall and winter of 2002–2003, devoted to additional examination of the SJR DWSC 1999 through 2001 data, and the presentation and discussion of the 2002 data. The title has been broadened to include mention of the 2002 data review.

Dr. Horne

Dr. Alex Horne was unable to attend the Peer Review panel workshop. He provided comments that focused on his recommended approach to solve the low-DO problem in the DWSC. He strongly supports channel aeration as the initial means of controlling low DO in the DWSC. He also supports the use of constructed wetlands to control upstream nutrient loads. G. F. Lee's proposed monitoring/evaluation program guide includes exploratory studies on the potential to use naturally occurring and/or constructed wetlands in the Mud and Salt Slough watersheds to remove the nitrogen loads to the SJR upstream of where the Merced River enters the SJR.

Scope of Work for SJR DWSC Aeration Project

Under contract to G. Fred Lee & Associates/NFWF/CALFED, URS Corporation developed a Scope of Work and Schedule to conduct an aeration project as part of the Phase I SJR DO TMDL project. This Scope of Work and Schedule was reviewed and approved by the SJR DO TMDL Steering Committee. According to the URS write-up,

> "*The San Joaquin River Deep Water Ship Channel Demonstration Aeration Project Scope of Work focuses on development and implementation of a demonstration aeration system as one approach to increase the DO concentrations in the DWSC. In addition to the engineering design elements, this Scope of Work includes associated monitoring, modeling, and environmental permitting.*
>
> *The SJR DO TMDL will be implemented using a phased approach to solve the DO problem in the DWSC. The first phase of the TMDL will have two main objectives with the first objective being to continue to acquire the information necessary to understand the mechanisms that both create oxygen demanding substances in the upper watershed and cause excess oxygen demand in the DWSC. This information will be required to develop the permanent solutions in the final TMDL phase. The second objective is to ensure that the Regional Board's interim DO performance goal is met in the DWSC while these studies continue. The projects making up this first phase of the TMDL will consist of an aeration demonstration project and associated performance monitoring in the DWSC, and a set of studies in portions of the watershed upstream of the DWSC (not addressed as part of this Scope of Work). Phase I is expected to be implemented for a period of approximately five years. The final TMDL phase will consist of the alternatives analysis required by the National Environmental Protection Act (NEPA) and/or the California Environmental Quality Act (CEQA), followed by design, implementation and long-term* operation *and maintenance of the selected permanent solutions designed to meet the final Basin Plan DO objectives.*
>
> ***Interim Performance Goal***
> *The Phase I interim performance goal proposed by the RWQCB is applicable to all locations within the DWSC between Channel Point and Disappointment Slough, but is not applicable to the Turning Basin or local tributary channels. Between June I and November 30, the goal is to ensure that no 7-day mean of daily DO minimums is below 5 mg/L, and that no single daily DO minimum is below 3 mg/L. Between December 1 and May 31, the goal is to ensure that no daily minimum is below 5 mg/L. This performance goal is not a formal water quality objective, but a milestone to measure progress towards meeting the proposed long-term objectives. Attainment of this performance goal would begin to provide a base level of protection for beneficial uses. This interim performance goal will be the basis for selection and design of the demonstration aeration project.*
>
> *This Scope of Work lays out the steps that must be completed in order to plan, design, install, and operate the aeration demonstration project. The purpose of the aeration demonstration project is to meet the Regional Board's proposed interim DO performance goal during Phase*

I of the TMDL implementation. It will also provide for data collection and analysis aimed at improving the understanding of the mechanisms causing the DO deficit within the channel. This information will assist in the evaluation of cost/benefit and NEPA/CEQA alternatives required to develop the permanent solutions in the final TMDL implementation phase.

The aeration demonstration project is envisioned to be a multi-year effort. The first step will be to perform a feasibility study to determine the preferred location, size, and type of aeration technology to be demonstrated. One or more pilot aeration alternatives may be tested and/or evaluated as part of the feasibility study. This will be followed by planning, design and construction of the selected full-scale demonstration project. The demonstration project will be operated and monitored with the following goals:

- *collect data on aeration system efficiency and cost-effectiveness in meeting DO water quality objectives;*
- *use the aerators in an experimental mode to quantify the relative importance and interrelationship of the various oxygen consuming mechanisms in the DWSC;*
- *provide the aquatic resources in the DWSC with increased DO concentrations while collection and evaluation of data continue;*
- *collect data to evaluate effects of aeration on the river environment."*

URS (2002) has provided detailed information on the development of the aeration demonstration project.

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Appendix A
Organization of the Studies

(Note: the figures and references mentioned in this appendix are in the report text)

The CVRWQCB (SWRCB, 1999b), as part of developing an approach for controlling the low-DO problems in the DWSC, provided the opportunity for the stakeholders (dischargers of oxygen demand constituents, entities whose activities influence the oxygen demand assimilative capacity of the DWSC, environmental groups and others) to develop an allocation of responsibility for solving the low-DO problem. The stakeholders organized the SJR DO TMDL Steering Committee. The Steering Committee organized a Technical Advisory Committee (TAC).

In the spring of 1999, members of the TAC submitted a proposal to CALFED to fund the initial phase of a study designed to determine the causes of low DO in the DWSC and factors influencing low DO. CALFED approved an $860,000, one-year study of the low-DO problem in the DWSC that was to take place during the summer/fall 2000. In the summer of 1999, the TAC, with Sportfishing Protection Alliance litigation settlement funds from the City of Turlock, City of Stockton funds and some advanced funding from the CALFED grant (that was approved, but not yet funded), initiated studies on the DWSC and the SJR at Vernalis (see Figures 2 and 3) for the purpose of determining whether the loads of oxygen-demanding materials entering the DWSC during the summer and fall were derived from "local" sources, such as the City of Stockton's wastewater discharges, or were derived from oxygen-demanding constituents present in the SJR at Vernalis. Previous studies (McCarty, 1969; Brown and Caldwell, 1970; Jones and Stokes, 2000) had concluded that algae in the SJR derived from upstream of Vernalis were a major source of oxygen demand that caused low DO in the DWSC.

In the fall of 1999, the CVRWQCB developed a contract with Dr. G. F. Lee to develop an "Issues" report (Lee and Jones-Lee, 2000a) that was to summarize the key findings from the summer 1999 studies and present recommendations for future studies. The Steering Committee's original plan called for the summer 1999 component project PIs to make available a draft report of the results from their summer (August and September) studies that could be used as the basis for developing the Issues report. The Issues report was published in mid-August 2000. The Issues report, which is available from the SJR DO TMDL website (www.sjrtmdl.org), provides a comprehensive discussion of issues pertinent to understanding and managing the low-DO problem in the DWSC, based on the knowledge available through the spring 2000. The Issues report is an important background document to this Synthesis Report. Dr. G. F. Lee has published several supplemental discussions of issues pertinent to managing the low-DO problem in the DWSC (Lee and Jones-Lee, 2000b, 2001). These are available from his website, www.gfredlee.com, and the SJR DO TMDL website.

In the spring of 2000, an external peer review of the draft reports based on the summer 1999 studies was conducted. The peer reviewers' comments are available from the SJR DO TMDL website. Also, at the same time, the TAC developed a followup proposal to CALFED to obtain additional funding for further studies that would be conducted in the summer/fall 2001, of the oxygen demand problem in the DWSC. This proposal represented an unprioritized collection of TAC members' proposed studies. CALFED Science Program's review of this proposal concluded that it should not be funded, since it lacked organization, detail on some studies, and integration of the proposed studies. In the fall of 2000, Dr. G. F. Lee was asked by the Steering Committee to develop a Directed Action proposal to CALFED to fund a comprehensive, integrated study. CALFED imposed a $2 million, one-year limitation on this proposal. This proposal was submitted in January 2001, and approved by CALFED (with modifications) in April 2001. Dr. G. F. Lee was named the principal investigator (PI) coordinator for the 2001 studies.

There was inadequate time between authorization to proceed with the development of the Directed Action proposal and when the proposal had to be submitted to CALFED to conduct a proper in-depth review of each of the proposed component projects that were to be submitted to CALFED for support of 2001 studies. The projects were reviewed to stay within the $2-million, CALFED-imposed limit, and those submitted in the spring proposal which did not fit the primary objectives of defining sources and loads of oxygen-demanding materials and their impacts were deleted from the proposal.

While the funding of the 2001 studies was approved by CALFED in the spring 2001, it was late summer before some of the component project PIs could establish contracts with CALFED to purchase equipment, etc., needed to fully implement the proposed studies. There were significant contracting problems between CALFED and some of the 2001 component project organizations, such as the California Department of Water Resources (DWR), some of which were not resolved until January 2003.

Dr. P. Lehman was the coordinating PI for the summer/fall 2000 CALFED-supported studies. The CALFED contract for these studies called for an external peer review to take place in the spring 2001. This peer review did not take place, as a result of the situation where many of the PIs for the component projects had not developed draft reports covering the results of their summer/fall 2000 studies.

The original plan for developing the final scopes of work for the 2001 studies called for the component project PIs for the year 2000 studies to have their near-final draft reports completed in early spring 2001, so that adjustments could be made in the 2001 scopes of work to reflect the information gained in 2000. This approach could not be followed, since many of the component project PIs for the year 2000 studies did not complete their draft reports until the summer 2001, after the 2001 studies had already been initiated.

In May 2000, the Steering Committee asked Dr. G. F. Lee to become Chair of the TAC. He was supported in this position for one year by funds derived from the city of Stockton. These funds were exhausted the end of May 2001, and no additional funding was made available for a TAC Chair. Between June 2001 and March 2002, the TAC operated without a Chair. K. Wolf, facilitator for the SJR DO TMDL project, served as the "pseudo" TAC Chair, organizing the meetings that were not devoted to 2001 studies, such as the internal and external peer review of the year 2000 studies. Those parts of the TAC meetings devoted to 2001 studies were organized by Dr. G. F. Lee. In April 2002 Tom Quasebarth, with support from the city of Modesto, assumed the TAC Chair position.

In accord with the contractual arrangements with CALFED for the 2001 studies, an external peer review of the 2001 studies was to take place in early March 2002. The component project PIs for the 2001 studies agreed in their contractual arrangements with CALFED to submit final draft reports covering data collected in the summer 2001 studies through September 30, 2001, by December 31, 2001. However, none of the component project PIs met this deadline. As a result, the external peer review of the 2001 studies had to be postponed until mid-June 2002. Further, as a result of the lack of external peer review of the summer/fall 2000 studies, the external peer review of these studies was to be combined with the external peer review of the 2001 studies.

As part of organizing the external peer review of the 2001 studies, the TAC agreed to conduct a comprehensive internal peer review of the 2001 studies. This internal (TAC) peer review was to serve as the basis for coordinating and integrating the results of the component projects. The internal peer review was, by TAC decision, a limited-scope peer review, which took place in March 2002. The initial draft -- and, to the extent completed, final -- reports for the 1999, 2000 and 2001 studies were posted on the SJR TMDL website (www.sjrtmdl.org). The internal peer reviewers' comments are also posted with these reports.

The original plan for followup to the 2001 studies, which involved completion by December 31, 2001, of final draft reports covering the data collected through September 30, 2001, followed by an internal peer review in February 2002, and an external peer review in March 2002, was to set the stage for continued funding from CALFED for studies that would be conducted in the summer of 2002. However, since the final draft reports were not received in time to conduct the external peer review in March, and since CALFED Science Program (Marcotte, pers. comm., 2002) would not provide additional funding without external peer review, there was no possibility of any significant follow-on studies in the summer 2002 to fill information gaps.

The CVRWQCB, as part of formulating the TMDL development plan, established December 31, 2002, as the date by which the Steering Committee must submit an implementable management plan for controlling the low DO in the DWSC. Failure to meet this deadline would mean that the CVRWQCB staff would be required to formulate a management plan (technical TMDL and its allocation of responsibility) by the end of June 2003. These deadlines have been a major driving force in establishing the short turnaround times between conducting studies, developing final reports and having these reports externally peer-reviewed. The fact that the originally planned summer 2002 studies did not take place, because of the delayed external peer review, meant that the information base available in April 2002 was essentially the information base that was available for the Steering Committee and the CVRWQCB to formulate a TMDL of allowable oxygen demand loads and the allocation of responsibility for controlling these loads or factors influencing the oxygen demand assimilative capacity of the DWSC.

The May 2002 draft Synthesis Report was designed to serve as the primary reference point for the external peer review of the 1999, 2000 and 2001 studies. While the 1999 studies were previously externally peer-reviewed, the peer review took place, in some cases, on preliminary draft reports. Further, there was need to review the 1999 studies with reference to the 2000 and 2001 studies, since all three years showed markedly different DO depletion patterns in the DWSC.

The initial framework for the June 2002 external peer review was developed by Lee with the assistance of Foe. In February 2002 CALFED developed a contract with URS to assume the responsibility for conducting the June 2002 external peer review. The external peer review of the current information base is critical for CALFED and the stakeholders to assess the adequacy of the current information base in defining the causes of oxygen demand that lead to DO concentrations below the WQO in the DWSC, factors influencing the oxygen demand assimilative capacity of the DWSC, and the sources of oxygen demand constituents that lead to low DO in the DWSC. As part of developing the peer review, a set of draft questions that the stakeholders and CALFED wished to have the peer reviewers address was developed. The questions are available from the SJR DO TMDL website (www.sjrtmdl.org) and in this report.

One of the chronic problems that has existed in these studies is that PIs for component projects of the studies failed to meet the deadlines that they agreed to meet as part of the scope of work for the funding that they or their agency received. As of the time of development of the final Synthesis Report in mid-March 2003, K. Jacobs and C. Kratzer have not submitted a draft report and P. Lehman only submitted a preliminary draft report of the 2000 and 2001 data that she collected. N. Quinn collected considerable data after he submitted his draft report for the peer review. As of March 21, 2003, he has not submitted these data and his final report which includes a discussion of these data. As a result of several of the PIs for component projects failing to meet their contract requirements for submitting the final project report by even four months after the due date, this Synthesis Report has had to be completed without having available for review the final reports for several of the component projects.

Each of the component project PIs were required, in accord with their project scopes of work, to submit all data collected, to K. Jacobs for posting on the IEP database. In July 2002 the project PI, G. F. Lee, contacted each component project PI to determine if all the data they had collected were submitted, were posted correctly, and were in a retrievable form. Several of the PIs did not respond to the request for this information, with the result that it is not clear at this time that all the data collected in 1999, 2000 and 2001 with CALFED support have been posted on the IEP database in a retrievable form.

In June 2002 CALFED permitted G. F. Lee to rebudget “administrative” funds from his component project for further work on review of previously collected data. Subsequently in early July, B. Marcotte of CALFED requested that these funds not be used for data review, but instead be used for developing Phase I TMDL monitoring programs that could be supported by CALFED. Lee, with review by Foe, developed this monitoring/evaluation program guidance, which is available on the SJR DO TMDL website and presented in this report. This monitoring guidance was submitted to the SJR DO TMDL Steering Committee email lists for their review and comment.

Beginning in October 2002, without additional support, Lee and Jones-Lee initiated a review of the potential significance of urban stormwater runoff as a source of oxygen demand for the DWSC. In November 2002, associated with a stormwater runoff event, low-DO conditions were encountered in city of Stockton sloughs and creeks, and within the DWSC. This led to a review of the DWR Rough and Ready Island continuously recorded DO data for all of 2002 that is presented in this report. In addition, the extremely low DO conditions that occurred in the DWSC in late January and February 2003 have been presented in this report. Further, as Dr. Dahlgren's 2002 data on BOD and chlorophyll at Mossdale became available in January 2003, and the city of Stockton's wastewater effluent characteristics data for 2003 became available from the CVRWQCB, Lee and Jones-Lee used these data to estimate oxygen demand loads for the DWSC. This information is presented in this report.

Appendix B
SJR DWSC Flows during 1999, 2000 and 2001

Values Compiled or Estimated by R. Brown (pers. comm., 2002), Jones & Stokes

Blue values are interpolated, for all years

Date	**SJR at Stockton UVM Flow 1999 cfs**	**SJR at Stockton UVM Flow 2000 cfs**	**SJR at Stockton UVM Flow 2001 cfs**	**SJR at Stockton UVM Flow Low Estimate 2001 cfs**	**SJR at Stockton UVM Flow High Estimate 2001 cfs**	**SJR at Stockton UVM Flow Estimate 2001 cfs**
1-Jan	1680	457	414	343	580	**414**
2-Jan	1660	528	426	396	612	**426**
3-Jan	1640	500	367	332	565	**367**
4-Jan	1670	344	188	263	515	**188**
5-Jan	1660	150	134	251	507	**134**
6-Jan	1610	284	90	288	529	**90**
7-Jan	1520	200	173	515	681	**173**
8-Jan	1390	272	318	758	854	**318**
9-Jan	1200	263	616	886	963	**616**
10-Jan	1030	298	602	964	1014	**602**
11-Jan	930	183	710	1073	1127	**710**
12-Jan	1040	440	910	1172	1228	**910**
13-Jan	1060	171	939	1081	1193	**939**
14-Jan	946	203	979	1032	1171	**979**
15-Jan	833	230	839	911	1088	**839**
16-Jan	874	608	912	767	979	**912**
17-Jan	989	849	765	780	951	**765**
18-Jan	1170	947	671	1025	1090	**671**
19-Jan	1340	1029	627	1005	1085	**627**
20-Jan	1720	946	596	1023	1098	**596**
21-Jan	2420	887	518	806	947	**518**
22-Jan	2850	986	342	521	748	**342**
23-Jan	2540	958	233	463	704	**233**
24-Jan	3700	1235	288	368	641	**288**
25-Jan	4390	1596	430	436	691	**430**
26-Jan	4750	1934	413	385	686	**413**
27-Jan	4420	1656	583	942	1100	**583**
28-Jan	4510	1559	995	1039	1189	**995**
29-Jan	4350	1548	965	998	1146	**965**
30-Jan	4010	1513	858	927	1077	**858**
31-Jan	3950	1847	755	858	1013	**755**

1-Feb	4390	675	696	691	889	696
2-Feb	3870	535	534	654	853	534
3-Feb	3310	291	445	629	825	445
4-Feb	3040	508	364	598	797	364
5-Feb	3210	443	320	590	790	320
6-Feb	3320	577	161	563	771	161
7-Feb	3390	382	453	580	779	453
8-Feb	4250	316	433	534	746	433
9-Feb	4990	363	288	524	739	288
10-Feb	5950	346	347	501	729	347
11-Feb	6920	209	517	744	919	517
12-Feb	7330	1224	842	768	974	842
13-Feb	7880	1813	1005	869	1092	1005
14-Feb	8200	2810	1068	1045	1236	1068
15-Feb	8240	4615	963	970	1188	963
16-Feb	7700	5152	914	1089	1282	914
17-Feb	7220	5224	853	1129	1301	853
18-Feb	6980	5986	856	1073	1247	856
19-Feb	7020	6544	746	1051	1228	746
20-Feb	7160	6618	905	1038	1213	905
21-Feb	7410	6808	1002	1010	1182	1002
22-Feb	7700	6359	882	1164	1336	882
23-Feb	8190	7018	1389	1284	1473	1389
24-Feb	7870	7616	1905	1334	1618	1905
25-Feb	7040	8060	2783	1568	1846	2783
26-Feb	6520	7132	2770	1804	2089	2770
27-Feb	6140	6614	2420	1912	2119	2420
28-Feb	5850	6841	2174	1715	1925	2174
29-Feb		8013				
1-Mar	5710	7903	1933	1498	1720	1933
2-Mar	5420	7935	1716	1262	1489	1716
3-Mar	5100	7103	1438	1162	1384	1438
4-Mar	5140	6914	1037	1088	1316	1037
5-Mar	4870	6900	1853	1130	1375	1853
6-Mar	4590	7703	2548	1612	1860	2548
7-Mar	4350	8534	2970	2449	2569	2970
8-Mar	4050	7874	2813	2375	2501	2813
9-Mar	3810	7856	2440	2400	2546	2440
10-Mar	3860	7821	2305	2331	2492	2305
11-Mar	4000	7666	2149	2065	2224	2149
12-Mar	4200	7481	1785	1575	1803	1785
13-Mar	4260	7401	1358	1426	1642	1358
14-Mar	4090	7275	1225	1271	1487	1225
15-Mar	3980	6923	1116	1133	1342	1116
16-Mar	3970	6441	1010	1114	1299	1010
17-Mar	3680	6267	937	1057	1242	937
18-Mar	3510	5987	812	1010	1190	812
19-Mar	3450	5364	735	970	1152	735

20-Mar	3510	5084	616	935	1120	616
21-Mar	3420	5224	537	922	1105	537
22-Mar	3320	4441	554	870	1052	554
23-Mar	3180	3771	618	803	1002	618
24-Mar	2980	3461	528	737	946	528
25-Mar	2890	3433	652	726	943	652
26-Mar	2730	3331	598	664	861	598
27-Mar	2800	3194	524	506	697	524
28-Mar	2670	2969	433	480	676	433
29-Mar	2540	2694	457	509	696	457
30-Mar	2430	2485	495	544	720	495
31-Mar	2330	2357		528	704	444
1-Apr	2190	2183	392	513	687	392
2-Apr	2080	1842		586	753	594
3-Apr	1850	1521		582	748	797
4-Apr	2020	1286	999	542	701	999
5-Apr	1770	1216	377	603	731	377
6-Apr	1820	1110	550	745	842	550
7-Apr	2000	1009	709	893	980	709
8-Apr	2230	864	899	929	1042	899
9-Apr	2560	1016	794	962	1063	794
10-Apr	2460	1067	776	775	920	776
11-Apr	2780	1169	742	756	904	742
12-Apr	2930	1723	708	763	911	708
13-Apr	3030	2210	711	794	931	711
14-Apr	2990	2935	689	778	919	689
15-Apr	2870	4446	703	786	925	703
16-Apr	2800	5412	715	839	971	715
17-Apr	2770	6024	652	714	853	652
18-Apr	2860	6639	460	711	826	460
19-Apr	2960	6811	481	747	867	481
20-Apr	2950	6222	1135	1694	1722	1135
21-Apr	2830	5825	1971	2254	2272	1971
22-Apr	2930	5940	2148	2339	2358	2148
23-Apr	3060	6031	1966	2297	2315	1966
24-Apr	2900	6083	1849	2290	2308	1849
25-Apr	3080	5886	2426	2779	3225	2426
26-Apr	3080	5763	3091	3269	4141	3091
27-Apr	2860	5494	3260	3298	4177	3260
28-Apr	2840	5310	3429	3355	4249	3429
29-Apr	2980	5062		3354	4248	3801
30-Apr	3130	5165		3269	4141	3705
1-May	2980	5024		3323	4209	3766
2-May	2940	4952		3337	4227	3782
3-May	3060	4760		3388	4291	3839
4-May	3280	4636		3326	4213	3770
5-May	3190	4684		3322	4208	3765
6-May	3080	4867		3318	4202	3760

7-May	3160	5028		3314	4197	3755
8-May	3060	5276		3349	4242	3795
9-May	3190	5520		3326	4212	3769
10-May	3220	5498		3110	3939	3524
11-May	3040	5487		3129	3963	3546
12-May	2810	5199		3145	3983	3564
13-May	2940	4927		3245	4110	3677
14-May	3070	4992		3391	4295	3843
15-May	3300	4670		3345	4237	3791
16-May	3190	4137		3383	4285	3834
17-May	2770	3954		3374	4274	3824
18-May	2110	3544		3419	4331	3875
19-May	1790	2866		3226	4086	3656
20-May	1620	1883		2894	3665	3279
21-May	1520	1626		2486	3149	2818
22-May	1360	1505		2092	2650	2371
23-May	1400	1377		1822	2308	2065
24-May	1560	1357	2012	**1229**	**1791**	**2012**
25-May	1320	1707	1378	637	1274	**1378**
26-May	1230	1625		624	1249	936
27-May	1300	1543		625	1249	937
28-May	1300	1483		644	1289	967
29-May	1290	1169		652	1304	978
30-May	1030	1130		615	1229	922
31-May	1130	956		596	1191	893
1-Jun	1040	1077		597	1193	895
2-Jun	1170	1167		571	1142	856
3-Jun	1490	1269		555	1111	833
4-Jun	1600	1310	677	564	1129	**677**
5-Jun	1640	1420	661	558	1116	**661**
6-Jun	1680	1387	783	542	1083	**783**
7-Jun	1780	1233	662	541	1082	**662**
8-Jun	1670	1440	581	541	1082	**581**
9-Jun	1540	1580	698	541	1082	**698**
10-Jun	1480	1604	718	541	1082	**718**
11-Jun	1380	1642	611	515	1030	**611**
12-Jun	1490	1688	700	483	966	**700**
13-Jun	1590	1724	639	480	959	**639**
14-Jun	1590	1511	563	475	949	**563**
15-Jun	1620	1093	455	462	925	**455**
16-Jun	1720	846	281	473	946	**281**
17-Jun	1620	684	1000	487	973	**1000**
18-Jun	1570	1019	754	479	959	**754**
19-Jun	1590	1003	576	442	883	**576**
20-Jun	1710	754	547	413	826	**547**
21-Jun		757	557	422	844	**557**
22-Jun		667	556	418	835	**556**
23-Jun		765	622	392	783	**622**

24-Jun		699	768	422	844	**768**
25-Jun		936	843	457	914	**843**
26-Jun		708	825	455	909	**825**
27-Jun		615	860	444	889	**860**
28-Jun	1240	588	835	443	885	**835**
29-Jun	1100	503	759	453	907	**759**
30-Jun	973	673	629	446	892	**629**
1-Jul	883	691		446	893	670
2-Jul	923	479		431	862	647
3-Jul	987	629		418	836	627
4-Jul	1200	527		404	807	605
5-Jul	1310	505		421	842	631
6-Jul	1100	485		419	837	628
7-Jul	1090	662		407	814	611
8-Jul	813	717		422	844	633
9-Jul	673	744		435	869	652
10-Jul	782	590		433	866	649
11-Jul	900	650		404	809	607
12-Jul	839	561		387	775	581
13-Jul	701	758		411	823	617
14-Jul	563	775		421	841	631
15-Jul	658	659		446	892	669
16-Jul	816	724		480	959	720
17-Jul	825	759		464	929	697
18-Jul	830	719		437	874	656
19-Jul	840	597		408	815	612
20-Jul	824	515		412	824	618
21-Jul	706	664		404	809	607
22-Jul	665	776		425	850	638
23-Jul	601	925		444	887	666
24-Jul	777	788		413	825	619
25-Jul	762	677		391	782	586
26-Jul	729	648		406	812	609
27-Jul	688	817		402	803	603
28-Jul	810	760		391	782	586
29-Jul	854	856		412	824	618
30-Jul	892	943		432	865	648
31-Jul	875	882		408	816	612
1-Aug	1100	860		404	808	606
2-Aug	1090	621		371	742	556
3-Aug	982	456		376	752	564
4-Aug	918	697		381	761	571
5-Aug	811	877		397	794	595
6-Aug	845	1022		420	841	630
7-Aug	767	999		407	814	611
8-Aug	906	767		381	763	572
9-Aug	971	616		358	715	536
10-Aug	795	741		351	703	527

11-Aug	972	839		372	745	558
12-Aug	972	841		395	789	592
13-Aug	911	819		406	812	609
14-Aug	936	776		391	781	586
15-Aug	1100	680		389	778	584
16-Aug	1050	612		388	776	582
17-Aug	798	583		380	760	570
18-Aug	757	767		404	808	606
19-Aug	825	1015		439	878	659
20-Aug	812	1279		443	886	665
21-Aug	792	1228		417	835	626
22-Aug	895	1085		403	806	605
23-Aug	787	1179		412	824	618
24-Aug	912	1537		402	804	603
25-Aug	902	1436		411	823	617
26-Aug	892	1498		446	893	670
27-Aug	771	1664		459	919	689
28-Aug	909	1562		443	886	664
29-Aug	1170	1356		424	848	636
30-Aug	1250	1285		401	803	602
31-Aug	1180	1314		387	774	581
1-Sep	925	1257		371	742	557
2-Sep	859	1469		413	825	619
3-Sep	873	1472		474	948	711
4-Sep	972	1592		436	872	654
5-Sep	1200	1563		387	775	581
6-Sep	1080	1398		376	752	564
7-Sep	1010	1301		403	806	604
8-Sep	900	1068		416	833	625
9-Sep	990	1198		434	868	651
10-Sep	1000	1352		439	877	658
11-Sep	1080	1402	762	421	842	**762**
12-Sep	1190	1324	761	398	795	**761**
13-Sep	1310	1184	871	377	753	**871**
14-Sep	1240	1110	835	384	767	**835**
15-Sep	1180	1145	817	404	809	**817**
16-Sep	1100	1658	925	417	834	**925**
17-Sep	1000	1557	904	419	838	**904**
18-Sep	1000	1260	773	419	838	**773**
19-Sep	1070	919	645	399	797	**645**
20-Sep	1410	675	598	392	784	**598**
21-Sep	1250	921	879	412	824	**879**
22-Sep	1200	1581	1829	404	809	**866**
23-Sep	880	1699	853	412	824	**853**
24-Sep	459	1738	1137	429	857	**1137**
25-Sep	430	1728	1120	425	851	**1120**
26-Sep	426	1321	921	426	851	**921**
27-Sep	425	1118	1000	421	842	**1000**

28-Sep	454	1216	934	424	847	**934**
29-Sep	344	786	1030	435	869	**1030**
30-Sep	230	699	1060	449	898	**1060**
1-Oct	269	637		454	907	680
2-Oct	348	402		425	850	638
3-Oct	535	803		399	797	598
4-Oct	496	1170		390	781	585
5-Oct	559	1522		403	805	604
6-Oct	538	1414		**781**	**1098**	940
7-Oct	534	1670		1160	1391	1275
8-Oct	546	1852		1231	1477	1354
9-Oct	512	1843		1186	1423	1304
10-Oct	585	2027		1175	1410	1293
11-Oct	509	2319		1144	1373	1258
12-Oct	697	2459		1110	1332	1221
13-Oct	611	2310		1124	1349	1449
14-Oct	454	2081		1161	1393	1480
15-Oct	481	2079		1152	1382	1452
16-Oct	631	2107		1132	1358	1393
17-Oct	655	1934		1136	1364	1459
18-Oct	689	1879		1189	1427	1565
19-Oct	776	2094		1284	1541	1656
20-Oct	703	2259		1385	1661	1740
21-Oct	606	2474		1580	1895	1943
22-Oct	552	2580		1882	2258	2321
23-Oct	524	2452		1887	2264	2282
24-Oct	710	2464		1924	2309	2460
25-Oct	612	2301		1992	2390	2416
26-Oct	548	2315		2088	2506	2486
27-Oct	584	2326		2078	2493	2469
28-Oct	613	2435		2146	2575	2608
29-Oct	660	2348		2042	2450	2547
30-Oct	575	2209		1858	2229	2354
31-Oct	506	2140		1698	2038	2144
1-Nov	594	2040		1643	1972	2122
2-Nov	490	1878		1650	1980	2078
3-Nov	501	1948		1593	1912	1983
4-Nov	516	1794		1521	1825	1886
5-Nov	458	1762		1484	1781	1665
6-Nov	536	1660		1455	1746	1573
7-Nov	519	1752		1438	1725	1629
8-Nov	493	1493		1520	1824	1776
9-Nov	485	1487		1519	1823	1762
10-Nov	363	1390		1523	1827	1728
11-Nov	375	1449		1580	1895	1906
12-Nov	398	1425		1624	1949	1797
13-Nov	356	1268		1662	1994	1906
14-Nov	289	1341		1639	1967	1857

15-Nov	449	1372	1634	1960	1795
16-Nov	352	1353	1639	1967	1788
17-Nov	548	1412	1649	1978	1728
18-Nov	413	1507	1621	1945	1789
19-Nov	362	1517	1599	1919	1802
20-Nov	321	1534	**1042**	**1292**	1705
21-Nov	304	1545	485	665	1824
22-Nov	336	1547	467	646	1764
23-Nov	215	1484	448	626	1628
24-Nov	236	1382	372	572	1622
25-Nov	236	1312	437	627	1861
26-Nov	140	1367	433	615	1577
27-Nov	194	998	443	620	1475
28-Nov	286	362	398	590	1167
29-Nov	185	68	635	755	1155
30-Nov	280	555	837	892	1171
1-Dec	345	534	811	867	1110
2-Dec	227	551	812	876	1245
3-Dec	305	576	893	950	1188
4-Dec	243	554	788	873	1217
5-Dec	185	584	472	662	1032
6-Dec	122	421	273	534	1012
7-Dec	91	310	279	544	1064
8-Dec	209	282	287	547	1238
9-Dec	84	246	248	514	973
10-Dec	229	237	221	484	890
11-Dec	489	264	217	475	867
12-Dec	360	210	178	446	949
13-Dec	506	290	162	431	893
14-Dec	555	362	147	414	759
15-Dec	518	342	103	383	704
16-Dec	446	404	73	353	793
17-Dec	438	351	49	328	761
18-Dec	393	546	48	327	791
19-Dec	416	340	63	333	746
20-Dec	420	342	48	327	798
21-Dec	321	253	116	394	956
22-Dec	397	264	155	435	971
23-Dec	372	283	196	476	1091
24-Dec	367	266	144	427	1032
25-Dec	289	299	112	393	971
26-Dec	235	303	101	379	1015
27-Dec	316	257	70	351	826
28-Dec	219	226	69	351	810
29-Dec	175	243	241	519	1016
30-Dec	111	273	823	1105	1908
31-Dec	140	280	1591	1885	2930

For this estimate:

Low Estimate

Red	= (0.5 - 0.075*(Pumping/Vernalis Flow))*Vernalis Flow
Purple	= 0.75*Vernalis Flow
Black	= 0.30*Vernalis Flow
Orange	= 0.75*Vernalis Flow

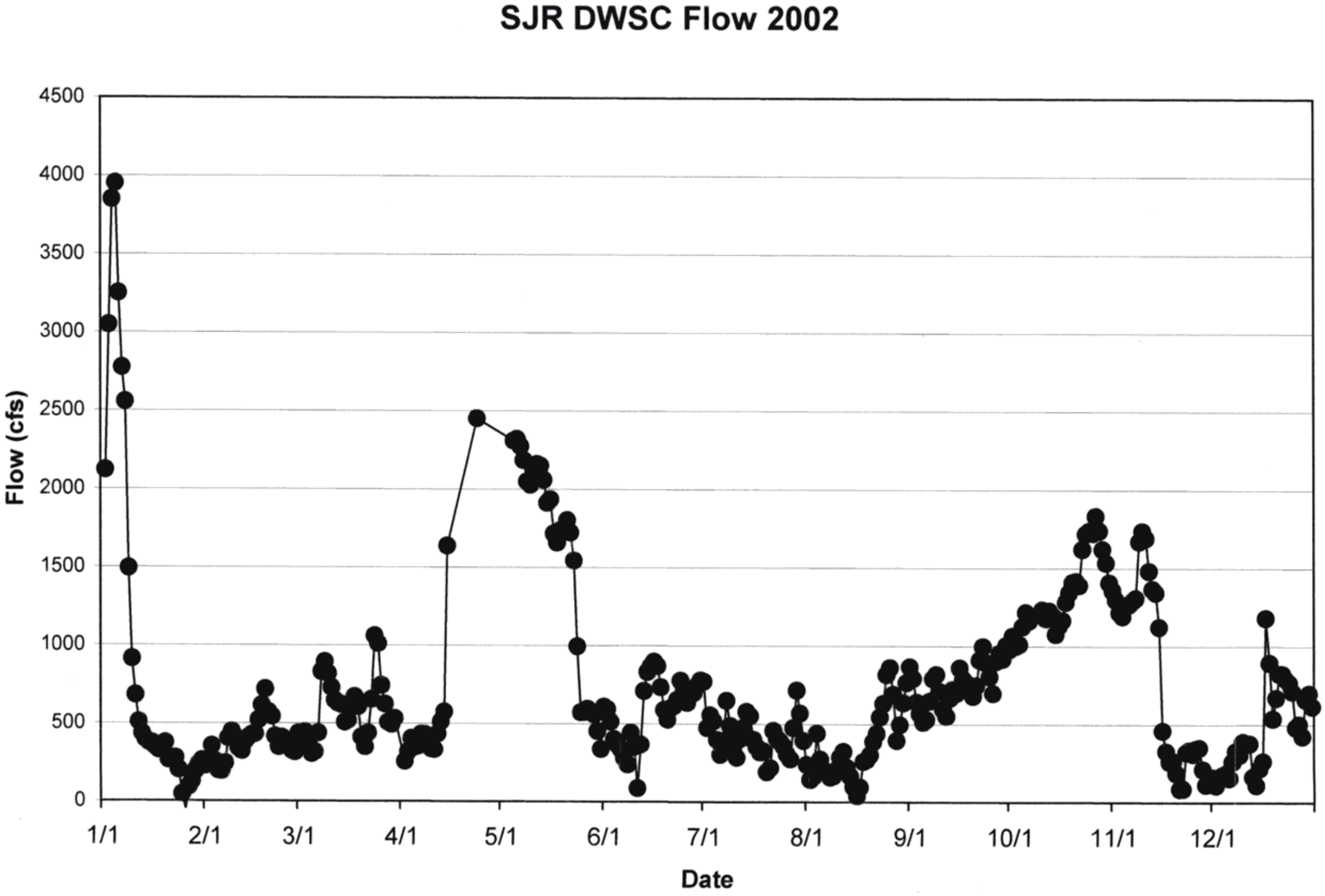
High Estimate

🟦	= (0.5 - 0.05*(Pumping/Vernalis Flow))*Vernalis Flow
	= 0.95*Vernalis Flow
	= 0.60*Vernalis Flow
	= 0.90*Vernalis Flow

For this estimate:

Black	values are the actual UVM data
Green	values are an average of the high and low estimate
Pink	values are the Vernalis - Old River flows

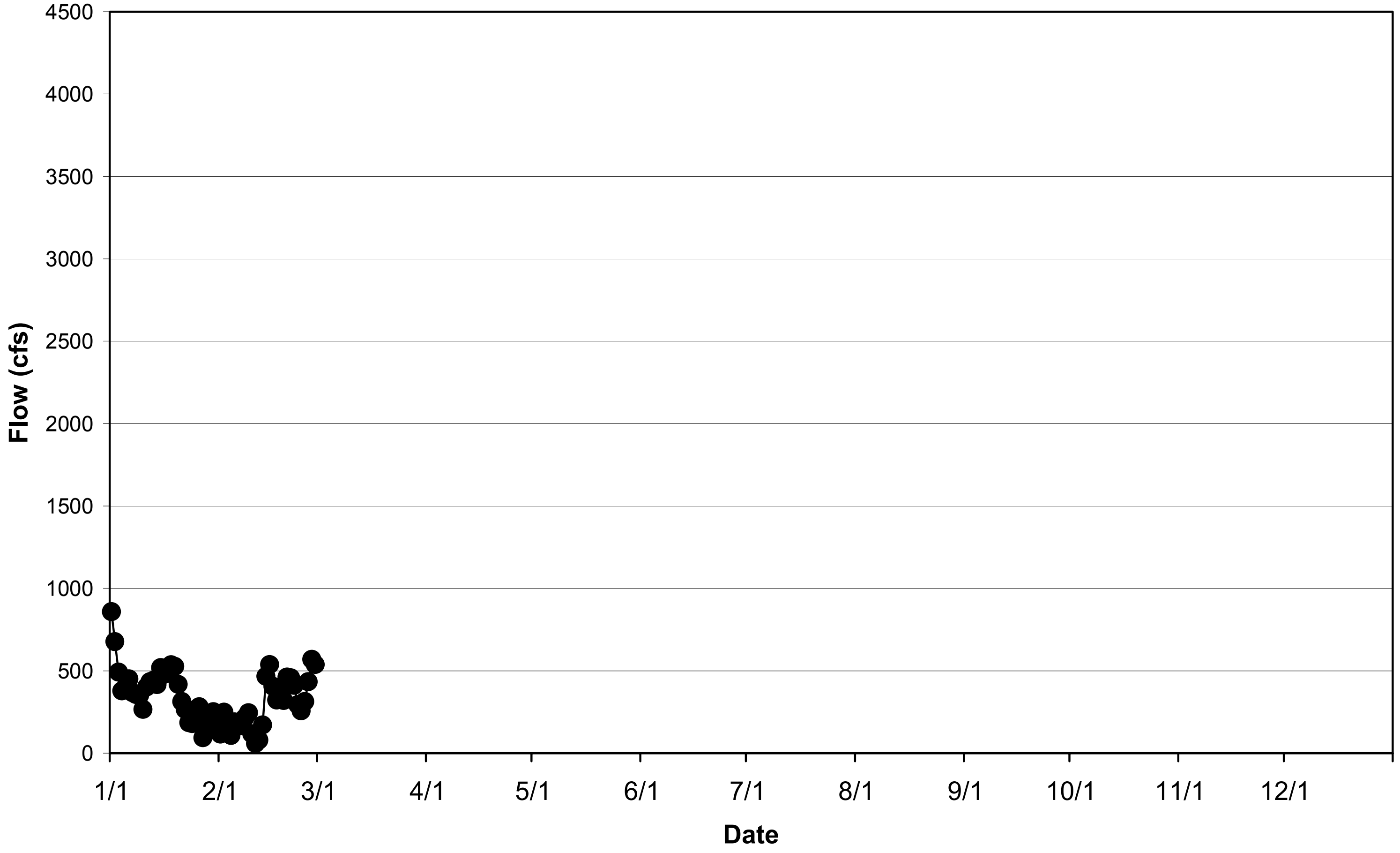
Figure B-1



(Source: C. Ruhl of the USGS (pers. comm., 2003)

Figure B-2

SJR DWSC Flow 2003



(Source: C. Ruhl of the USGS (pers. comm., 2003)

Appendix C - Hayes Cruise Data 1995-2002

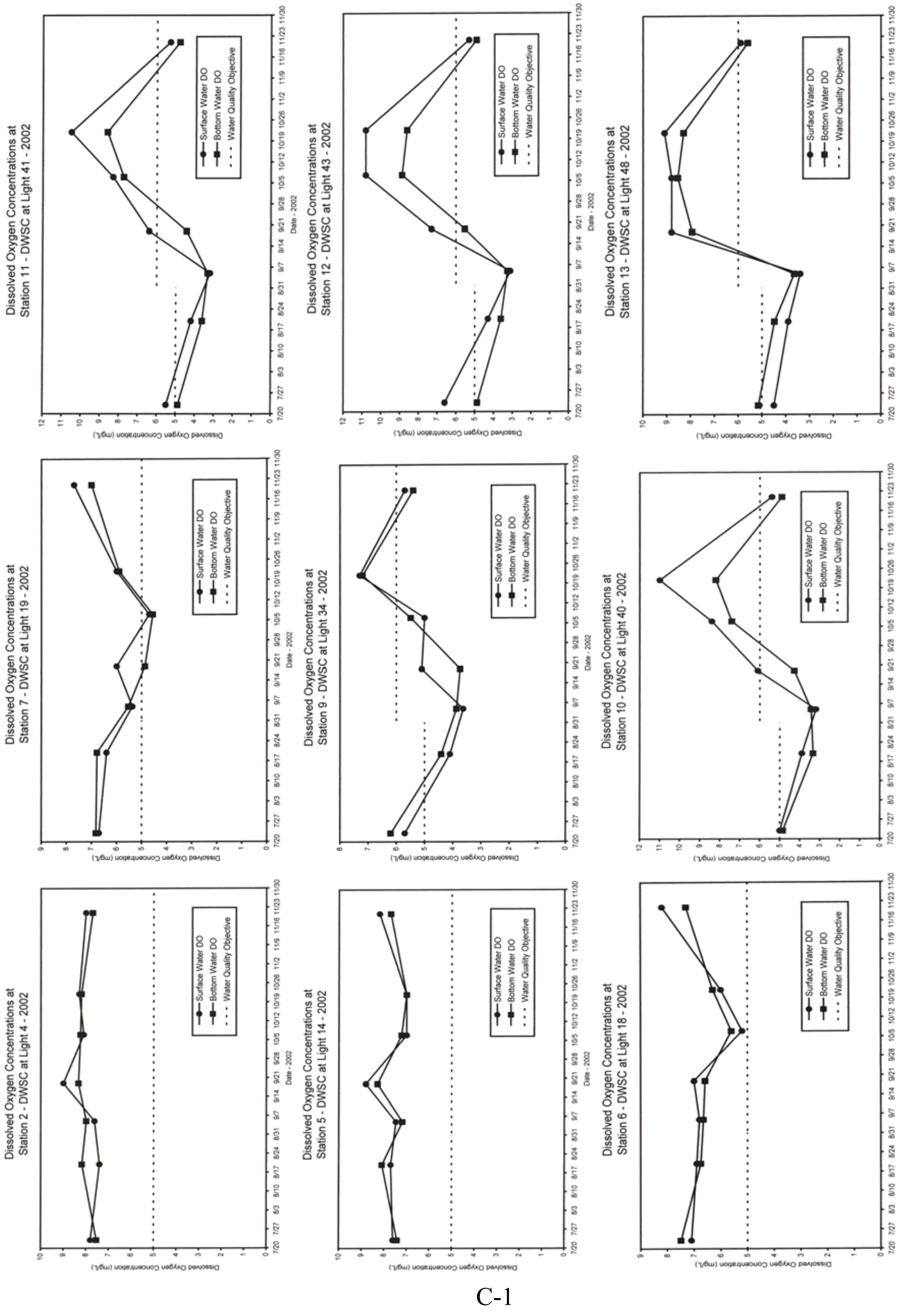


Figure C-1. Dissolved Oxygen Concentrations at Selected DWSC Stations July 23 – November 21, 2002

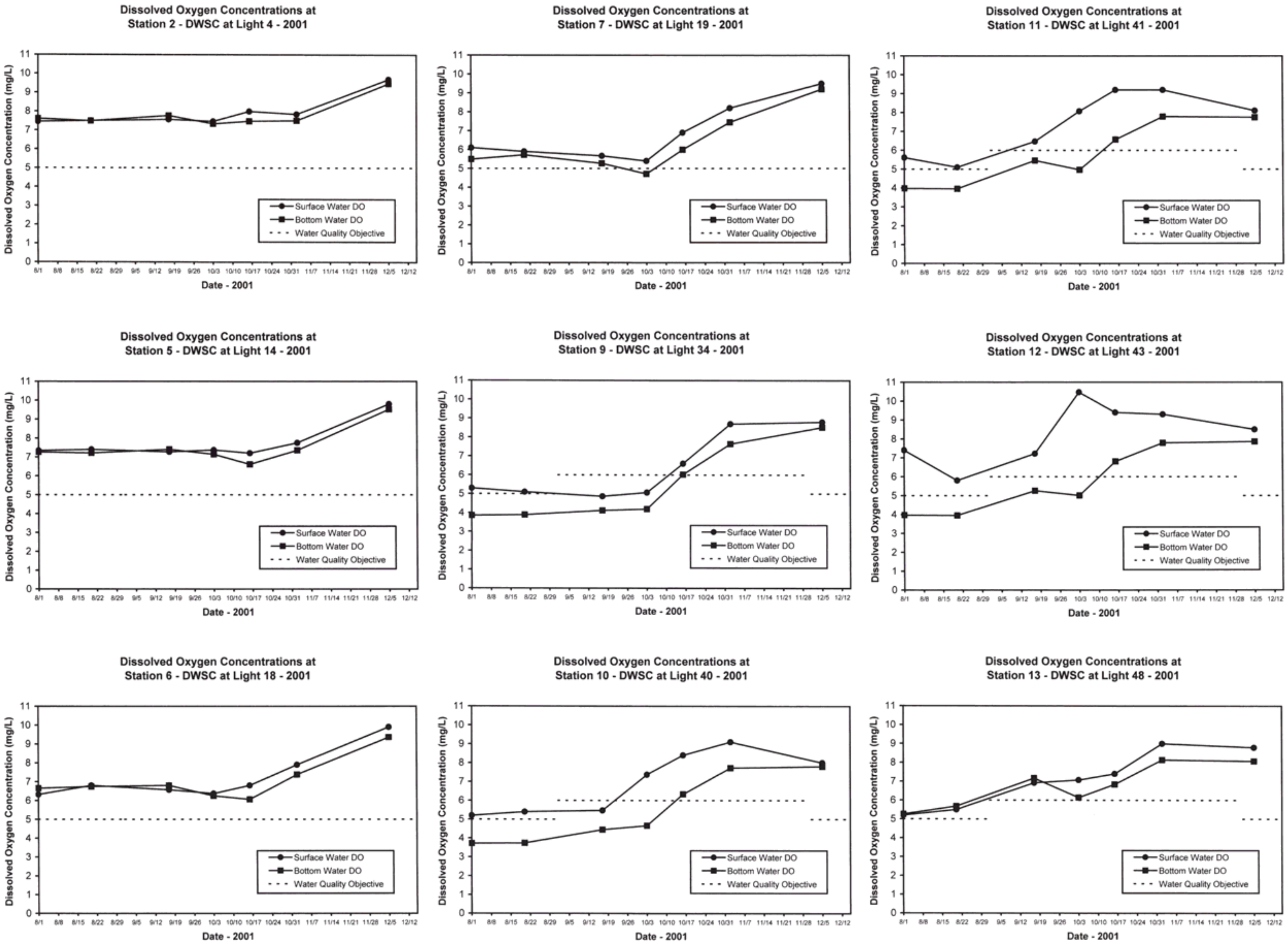


Figure C-2. Dissolved Oxygen Concentrations at Selected DWSC Stations August 1 – December 15, 2001

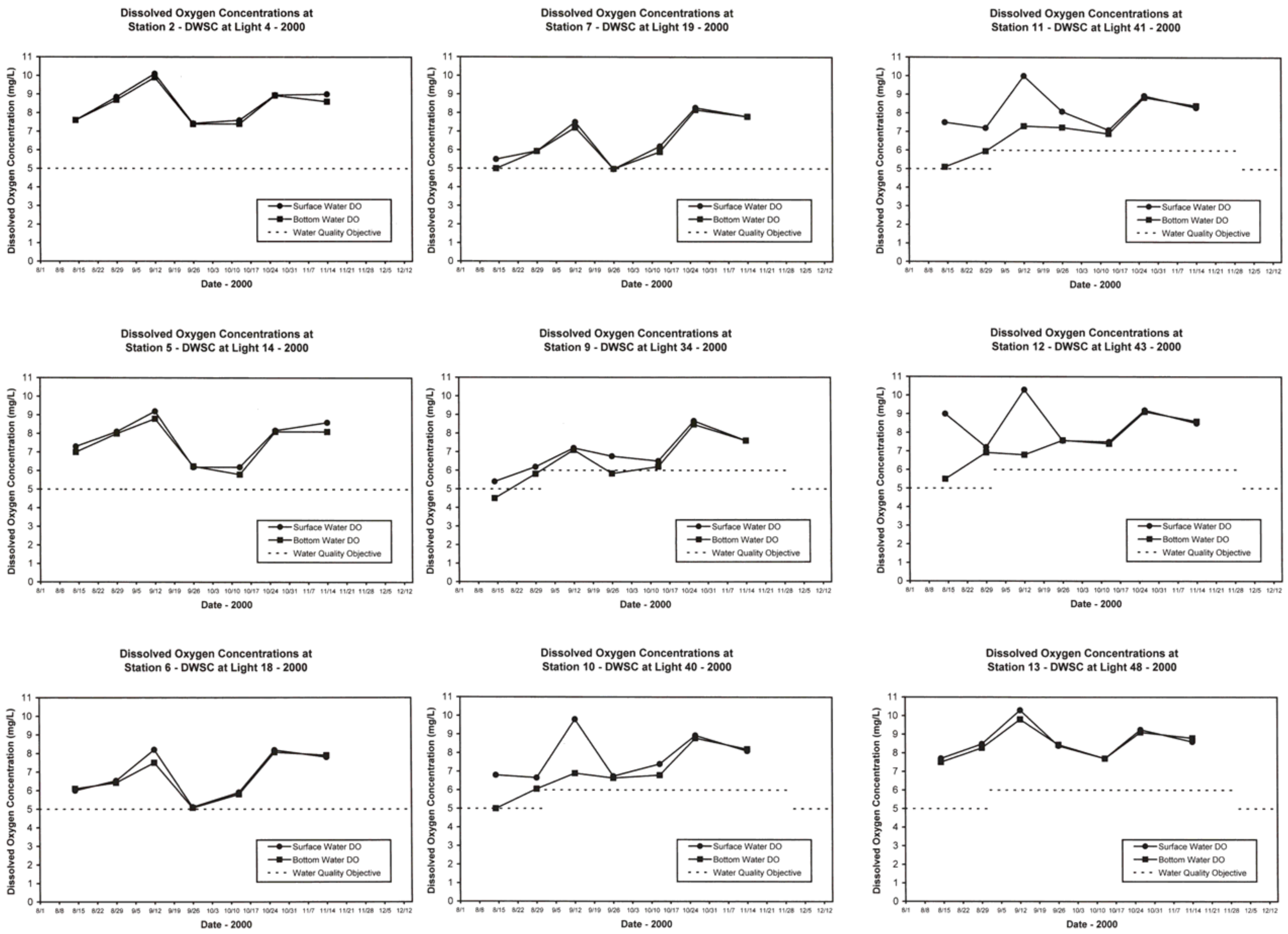


Figure C-3. Dissolved Oxygen Concentrations at Selected DWSC Stations August 1 – December 15, 2000

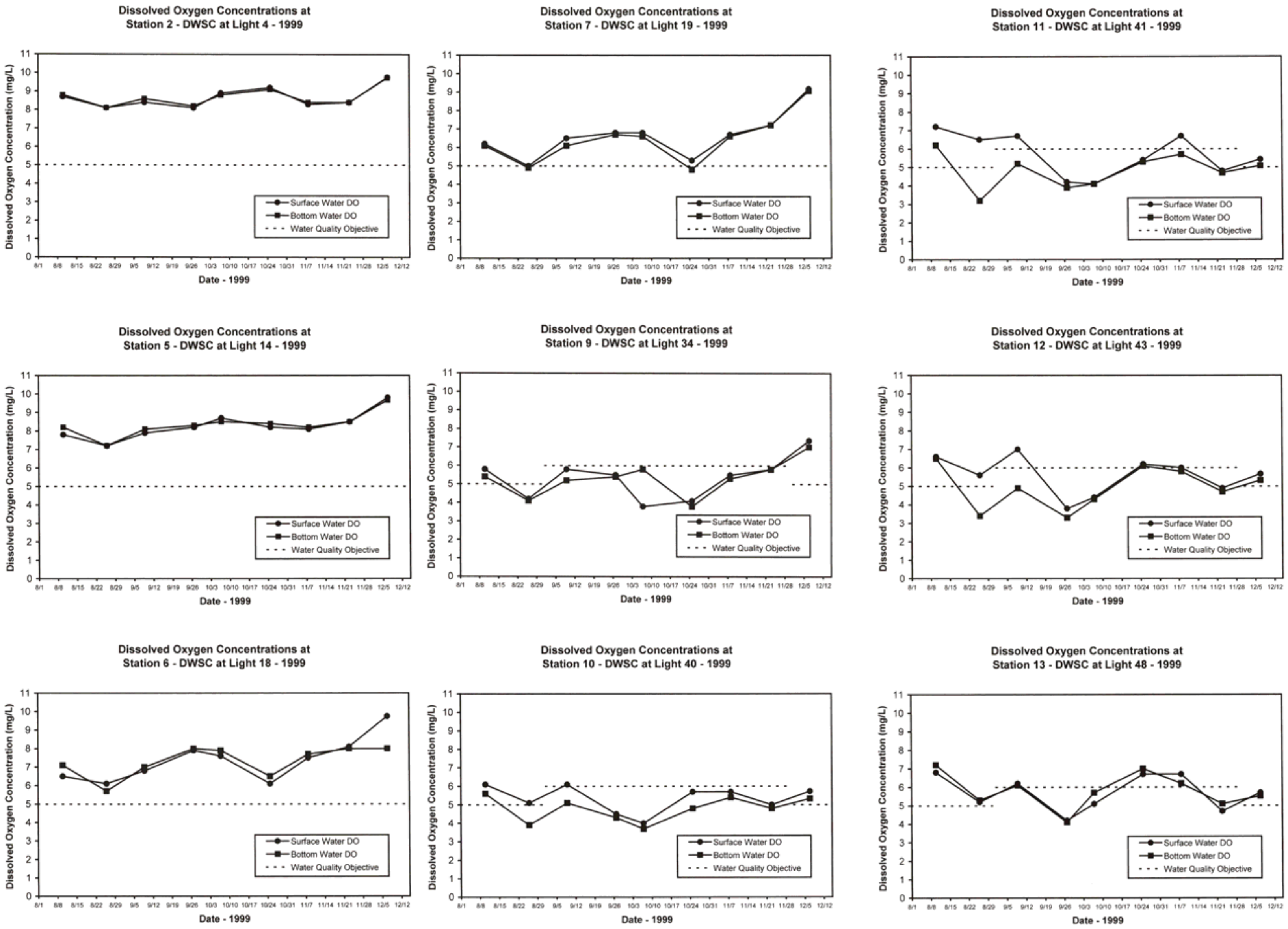
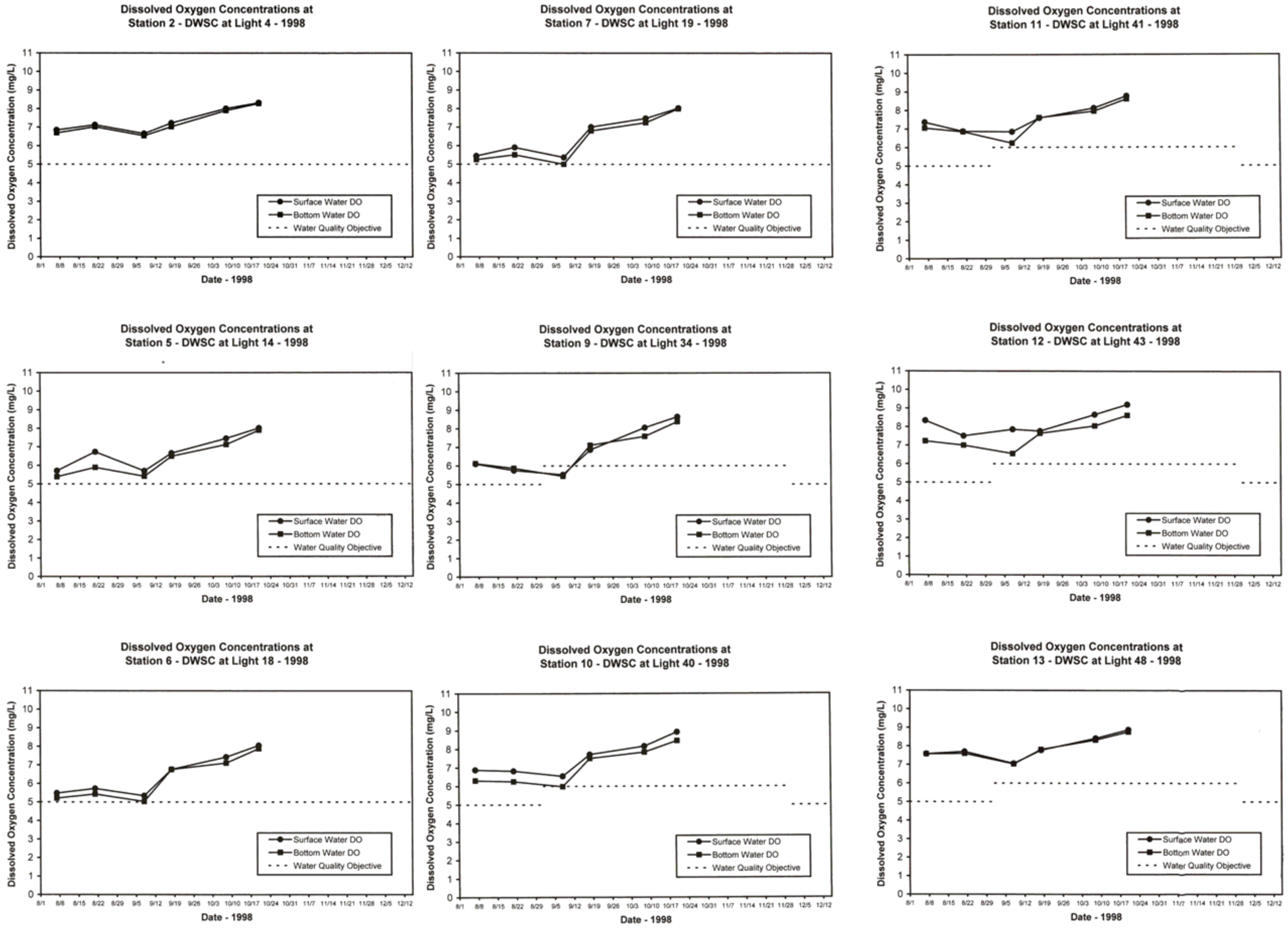


Figure C-4. Dissolved Oxygen Concentrations at Selected DWSC Stations August 1 – December 15, 1999


Dissolved Oxygen Concentrations at Station 2 - DWSC at Light 4 - 1998

Dissolved Oxygen Concentrations at Station 7 - DWSC at Light 19 - 1998

Dissolved Oxygen Concentrations at Station 11 - DWSC at Light 41 - 1998

Dissolved Oxygen Concentrations at Station 5 - DWSC at Light 14 - 1998

Dissolved Oxygen Concentrations at Station 9 - DWSC at Light 34 - 1998

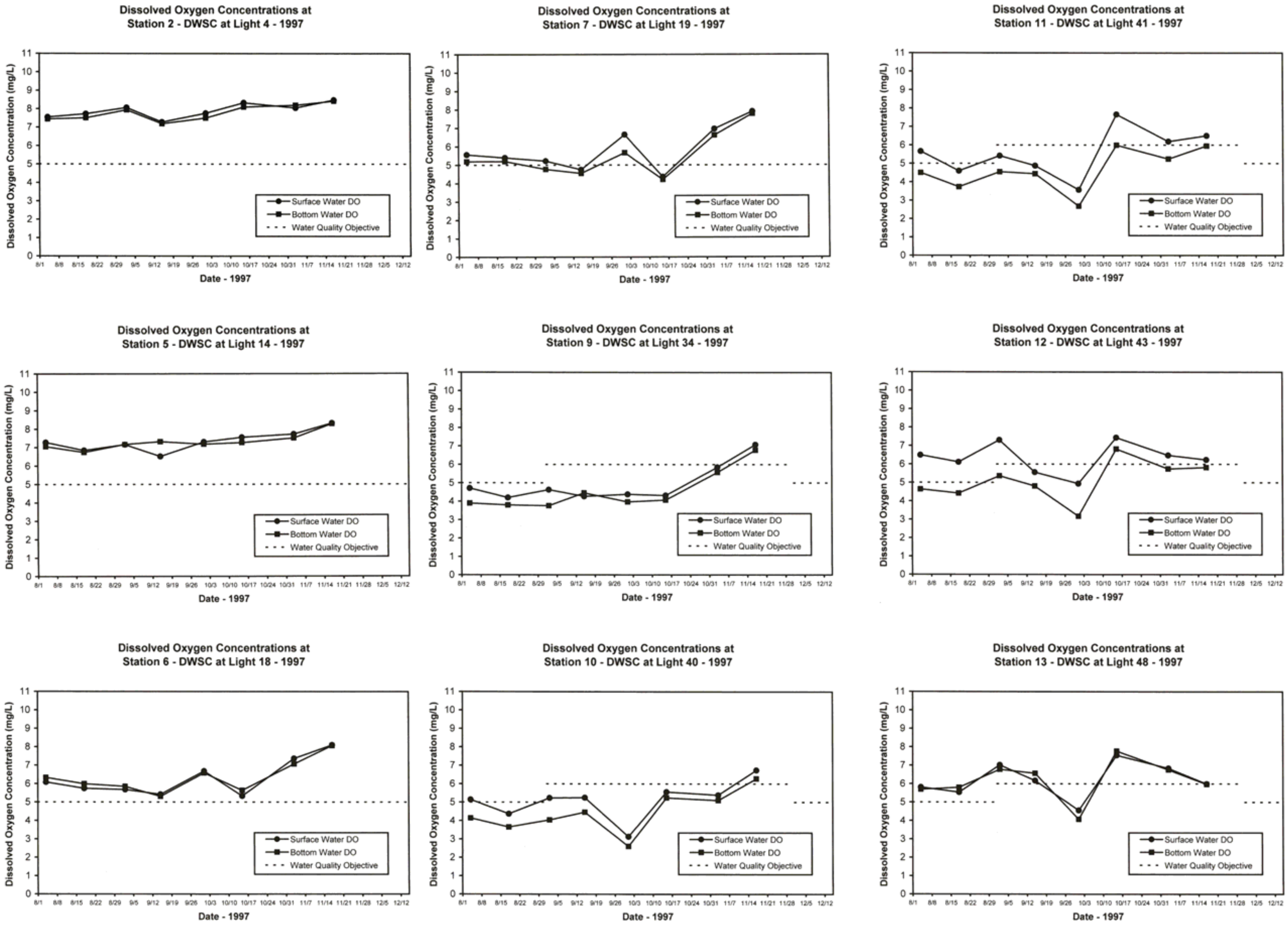
Dissolved Oxygen Concentrations at Station 12 - DWSC at Light 43 - 1998

Dissolved Oxygen Concentrations at Station 6 - DWSC at Light 18 - 1998

Dissolved Oxygen Concentrations at Station 10 - DWSC at Light 40 - 1998

Dissolved Oxygen Concentrations at Station 13 - DWSC at Light 48 - 1998

Figure C-5. Dissolved Oxygen Concentrations at Selected DWSC Stations August 1 – December 15, 1998



Dissolved Oxygen Concentrations at Station 2 - DWSC at Light 4 - 1997

Dissolved Oxygen Concentrations at Station 7 - DWSC at Light 19 - 1997

Dissolved Oxygen Concentrations at Station 11 - DWSC at Light 41 - 1997

Dissolved Oxygen Concentrations at Station 5 - DWSC at Light 14 - 1997

Dissolved Oxygen Concentrations at Station 9 - DWSC at Light 34 - 1997

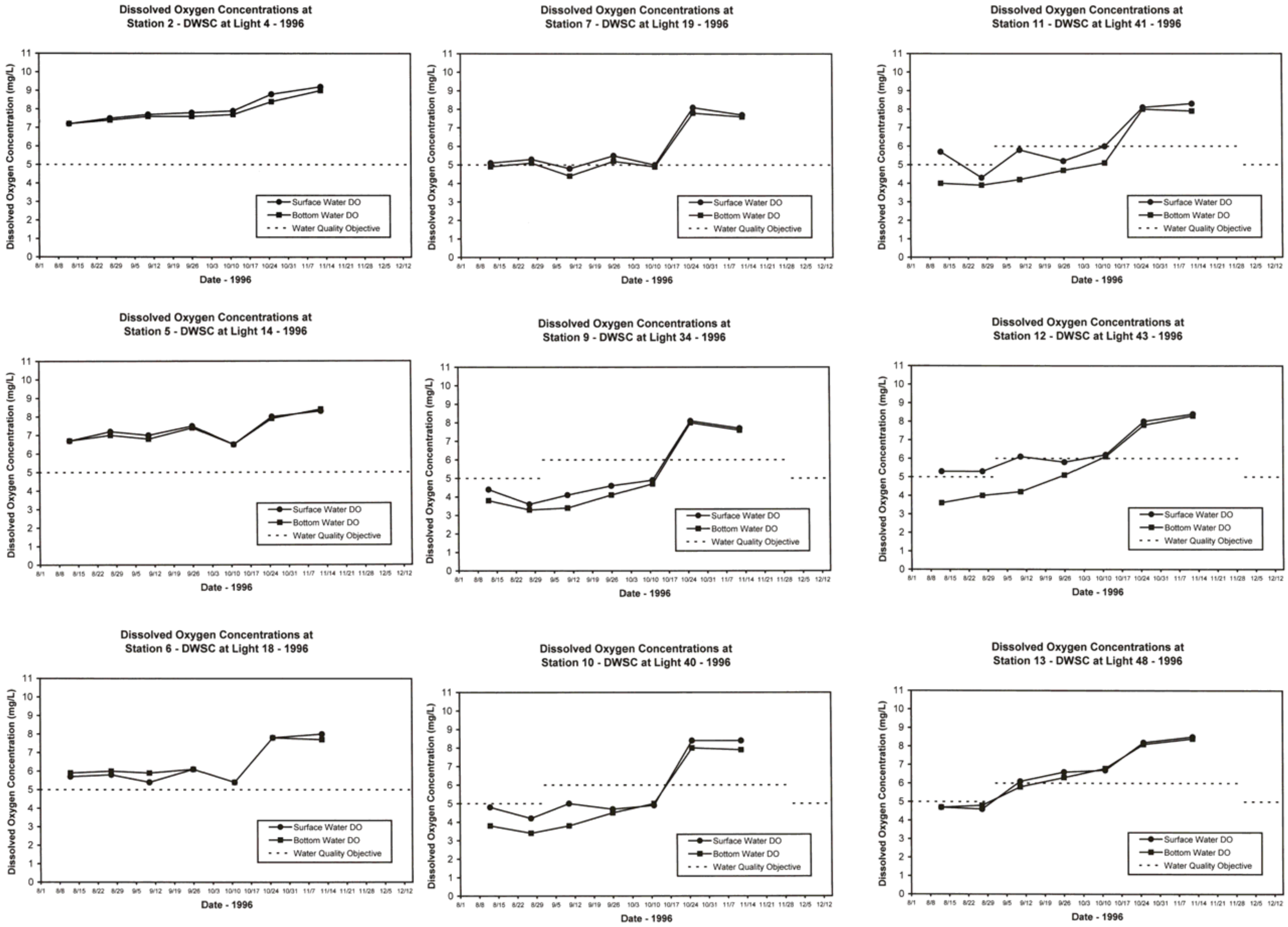
Dissolved Oxygen Concentrations at Station 12 - DWSC at Light 43 - 1997

Dissolved Oxygen Concentrations at Station 6 - DWSC at Light 18 - 1997

Dissolved Oxygen Concentrations at Station 10 - DWSC at Light 40 - 1997

Dissolved Oxygen Concentrations at Station 13 - DWSC at Light 48 - 1997

Figure C-6. Dissolved Oxygen Concentrations at Selected DWSC Stations August 1 – December 15, 1997



Dissolved Oxygen Concentrations at Station 2 - DWSC at Light 4 - 1996

Dissolved Oxygen Concentrations at Station 7 - DWSC at Light 19 - 1996

Dissolved Oxygen Concentrations at Station 11 - DWSC at Light 41 - 1996

Dissolved Oxygen Concentrations at Station 5 - DWSC at Light 14 - 1996

Dissolved Oxygen Concentrations at Station 9 - DWSC at Light 34 - 1996

Dissolved Oxygen Concentrations at Station 12 - DWSC at Light 43 - 1996

Dissolved Oxygen Concentrations at Station 6 - DWSC at Light 18 - 1996

Dissolved Oxygen Concentrations at Station 10 - DWSC at Light 40 - 1996

Dissolved Oxygen Concentrations at Station 13 - DWSC at Light 48 - 1996

Figure C-7. Dissolved Oxygen Concentrations at Selected DWSC Stations August 1 – December 15, 1996

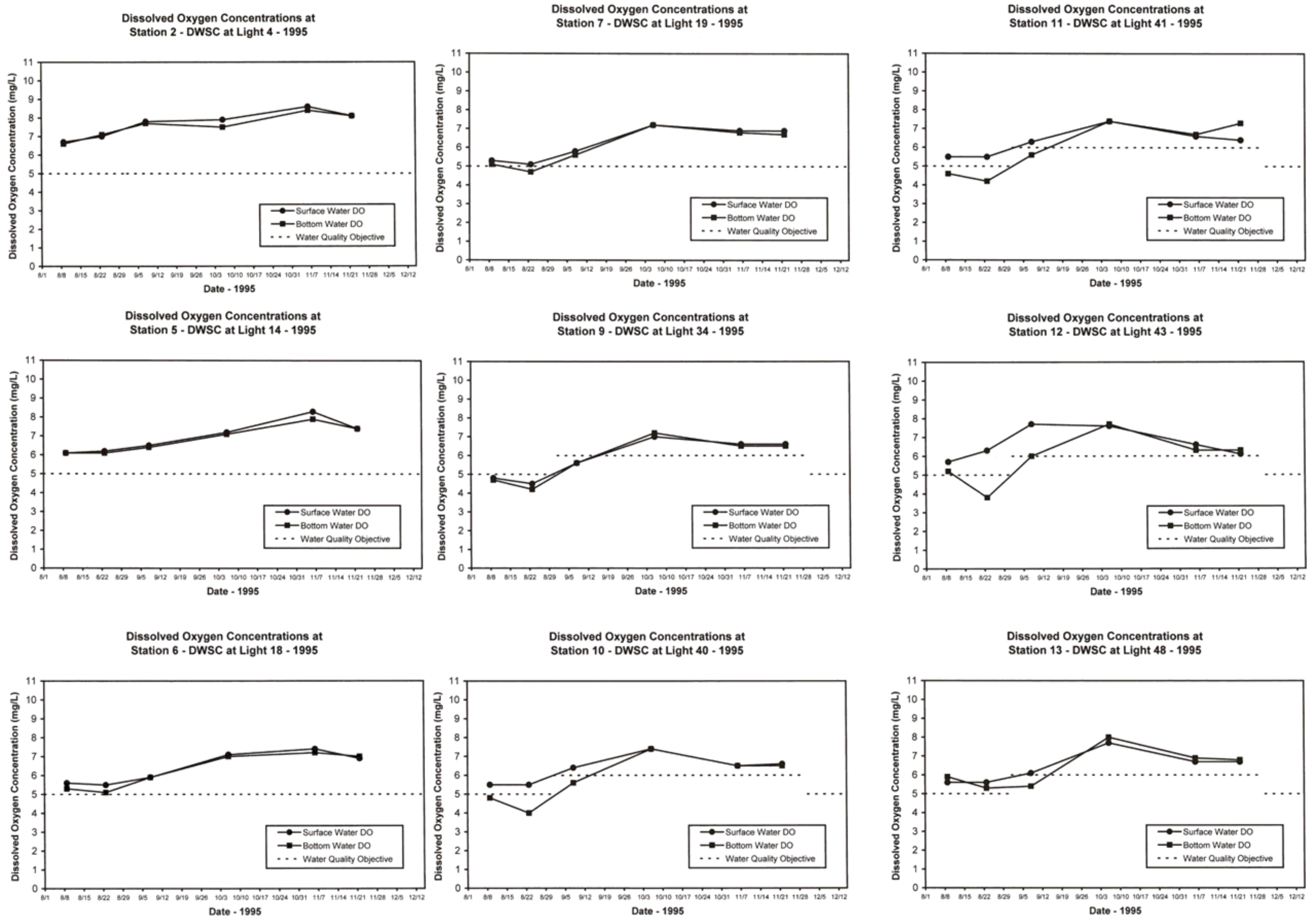


Figure C-8. Dissolved Oxygen Concentrations at Selected DWSC Stations August 1 – December 15, 1995

Appendix D
DWR RRI Monitoring Station DO Data for 2002-2003

Figure D-1 presents a series of monthly plots of dissolved oxygen concentrations, as measured by the DWR Rough and Ready Island continuous DO monitor for 2002 and thus far in 2003. These data were obtained from the following website:
http://cdec.water.ca.gov/cgi-progs/queryF?s=rri&d=now&span=12hours

This monitor measures DO inside of a perforated sampling well, which measures a somewhat integrated sample of about the upper third of the DWSC water column at the point of measurement. DO values in the surface waters would be expected to be higher, and DO values near the bottom could be considerably lower than those reported by the station. Further, the DO concentrations measured at this location are not necessarily the worst-case conditions for the DWSC, especially under elevated SJR DWSC flows, where the point of minimum DO occurs further downstream, near Turner Cut.

The Figure D-1 plots have a number of general features, such as periodic spikes, which relate to calibration of the instrument. These spikes do not reflect DO concentrations. Further, in examining these monthly plots it is important to note that they are not all to the same ordinate scale. The abscissa scale has been converted from the DWR CDEC presentation of hour of the day, to day of the month.

It is important to note that DWR indicates that all CDEC data are provisional, and have not been screened for unreliable/questionable values. The issue of particular concern is whether there was drift in the DO readings which are corrected through the weekly calibration. If, associated with a calibration spike, there is a change of the DO reading on each side of the spike, then the readings on the left of the spike (before calibration) need to be adjusted for the calibration change.

In discussing these data, it is important to consider the SJR flow through the DWSC, since flow information can help in the interpretation of the DO depletion data. The flow data are presented in Figures B-1 and B-2 in Appendix B. In January 2002, the DOs were between 6 and 7 mg/L through the first 10 days, then dropped down to about 5 mg/L by mid-month. During this period the SJR flow through the DWSC ranged from 2,000 to 4,000 cfs during the first few days of the month, then rapidly dropped by mid-month to about 400 cfs. DO concentrations were between 5 and 6 mg/L for the remainder of the month, during which time the flows were less than 250 cfs.

In February 2002, the DOs dropped to about 4 mg/L beginning about the 5th of the month, and stayed between 4 and 6 mg/L for the rest of the month. During this time the SJR DWSC flows were generally less than 500 cfs, with a short period of flows mid-month of 600 cfs. Therefore, there were significant water quality objective violations during February 2002. These violations continued into March 2002, until about the eighth of the month when the DO began to increase gradually up to between 6 and 8.5 mg/L. During this time the SJR DWSC flows were variable, ranging from about 300 cfs at the first of the month up to 900 cfs by the second week, down again to a low of 400 cfs, back over 1,000 cfs during the last week, and then back down to 500 cfs. The DO depletion during the spring for a given flow condition would be expected to be somewhat different than summer-fall, since normally the winter-spring period has lower algal growth and biomass. While this is the normal expected situation, as discussed below, this is not the situation that was encountered during January and February 2003, when a large algal bloom occurred during mid-winter.

In April 2002 there were some DO values down to about 5 mg/L; however, all the values for the month were above the water quality objective. Again the latter part of the month had a major increase in DO, to around 10 mg/L. During this time the Vernalis Adaptive Management Program (VAMP) was initiated, where by mid-April the flows rapidly increased to over 2,000 cfs.

A review of the Rough and Ready Island (RRI) CDEC dissolved oxygen data shows that during May 2002 the DO generally ranged from about 6.6 mg/L to about 10.5 mg/L. There were no recorded violations of the DO water quality objective during this period. The VAMP flow was in effect from April until about the last week of May, when the flows decreased to about 600 cfs.

During the latter part of June 2002 there was a period when the DO at the Rough and Ready Island station was as low as 3.4 mg/L. Generally it was between 5 and 8 mg/L. During this time the SJR DWSC flows were highly variable, where at the beginning of the month the flows were about 400 cfs, decreased to about 50 cfs by the second week, increased rapidly to 900 cfs, and finished the month at about 600 cfs.

The July DO data, as measured at the Rough and Ready Island monitoring station showed a low DO of 1.9 mg/L occurring around the end of July, while much of the month had DOs less than the water quality objective of 5 mg/L. There are also marked diel variations in DO during mid- to late July, ranging from about 3 to 10 mg/L during the diel cycle. This diel pattern persisted through the rest of the month, with typical mornings, through most of the day, having DOs less than the water quality objective of 5 mg/L. During July, except for a couple of days, the SJR DWSC flows were less than 500 cfs, with a low value occurring during the third week of about 150 cfs.

During August, except for the diel peaks that occurred on several days, the DO was less than the 5 mg/L WQO. There were some values on the order of 1 mg/L. The SJR DWSC flows during the first part of August were in the range of 200 to 400 cfs, with a low value of about 50 cfs occurring mid-month. From that point, there was a steady increase in flow to about 900 cfs.

During September the DOs measured at Rough and Ready Island station, with the exception of diel peaks that occurred on a couple of days, were all less than the water quality objective of 6 mg/L, with many values on the order of 2 to 4 mg/L. SJR DWSC flows during September started at about 500 cfs, and gradually increased to about 1,000 cfs by the end of the month.

During October 2002 the DO at the beginning of the month was 2 mg/L. By mid-month it was generally above the 6 mg/L WQO. The increasing SJR DWSC flow trend noted for September continued through October, beginning with a flow of about 900 cfs at the first of the month, increasing to a high of about 1,800 by the third week. The DO readings during the first week or so of October may be somewhat low due to drift problems, as evidenced by the increase at the calibration mark that occurred on the sixth of the month.

At the beginning of November the DOs were generally between 7 and 9 mg/L. At the end of the first week there was a major rainfall runoff event in the San Joaquin River watershed, and the DO began to drop, in a steady decline to the end of the month, when the DO was 3.5 mg/L. The SJR DWSC flows at the beginning of November were about 1,200 cfs. During the first week there was an increase to about 1,700 cfs, and then a rapid drop in flow by the third week down to about 100 cfs.

DO measurements at the beginning of December were between 3 and 4 mg/L. By mid-month they increased to between 5 and 6 mg/L, and they stayed in that range through the end of the month. The DO water quality objective during this time was 5 mg/L. The SJR DWSC flows at the beginning of December were about 100 cfs, and remained below 400 cfs until mid-month, when there was a rapid increase to about 1,200 cfs. For the rest of the month, the flow was greater than 500 cfs.

A review of the 2002 data shows that monitoring load parameters such as ammonia and chlorophyll at Mossdale must be done more frequently than every two weeks as has been done in the past. Weekly measurements or even twice-a-week measurements would be more appropriate. Otherwise, biweekly measurements could totally miss a major algal pulse that passes through the DWSC, which would lead to high diel DO swings and substantial oxygen demand loads. Further, more frequent monitoring of the SJR DWSC loads and within the DWSC needs to be conducted during times such as in 2002 when there are rapid changes in the flow of the SJR through the DWSC.

January-February 2003

Examination of Figure D-1 for the January through mid-March 2003 RRI DO data shows that the DO at the beginning of January was about 6 to 7 mg/L. There was a steady decrease during January, reaching 2 mg/L by the end of the month. As shown in Figure D-1 for February 2003, the DO concentrations at the RRI station during the early part of the month were between 2 and 3 mg/L, with a small diel change. By about February 10, the DO concentrations were reading zero or near-zero each morning, through about February 20. According to Jennings (pers. comm., 2003) these extremely low DO values were associated with a fish kill. Around February 20, the DO concentrations began to rise slightly, so that by the end of the month, they were at 1.8 mg/L. In the first 12 days of March, the DO concentrations continued to steadily increase, so that by the 12th, the DO in the early morning was 5.4 mg/L. As a result, there was a period from January 13 through the first ten days or so of March, when the DO concentrations were in violation of the 5 mg/L WQO.

As shown in Figure B-2, beginning about January 20, through mid-February, SJR flows through the DWSC were on the order of less than 100 to a couple of hundred cfs. By mid-February they jumped back up to about 500 cfs, and then bounced around 250 to 500 cfs for the rest of the month. These low flows appear to be contributing to the severe low DOs that were found in the DWSC during February 2003. During the low-DO period in February 2003 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.

Examination of the Rough and Ready Island chlorophyll measurements during February 2003 (data not included, but available from the RRI station CDEC website, http://cdec.water.ca.gov/cgi-progs/queryF?s=rri&d=now&span=12hours) shows that, at the beginning of the month, the daily chlorophyll measurements were around 10 to 15 units (µg/L?). There was a steady increase until about February 17, where the peak value was 60 units. After that, it decreased to about 25 units by the end of February. During March, the chlorophyll values at the RRI station were in the range of 20 to 25 units. In January, the chlorophyll values were on the order of 7 to 10 units.

The city of Stockton wastewater effluent ammonia concentrations for November 2002 through January 2003 values averaged about 26 mg/L ammonia N. According to Litton (pers. comm., 2003), the city of Stockton's wastewater ammonia concentrations for February were similar to those that have been discharged for November through January. It appears that the combination of low SJR flows through the DWSC and elevated city of Stockton wastewater ammonia discharges led to the severe DO depletions during February 2003. Coincidentally, a large algal bloom occurred in the DWSC during the low-DO episode. Litton indicates that the SJR upstream of the DWSC did not have high algal concentrations and that the algal bloom was local to the DWSC.

Figure D-1
Dissolved Oxygen Concentrations at the RRI Monitoring Station
During 2002 - 2003

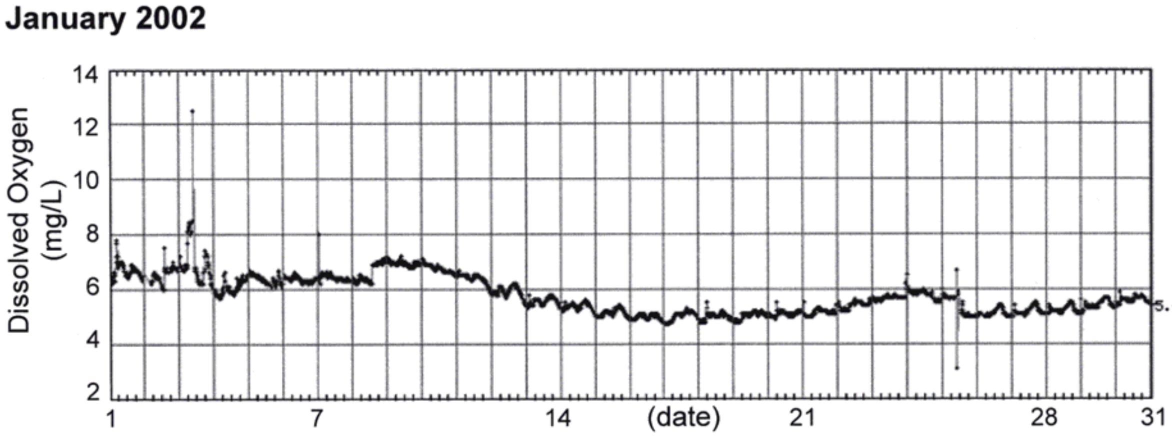
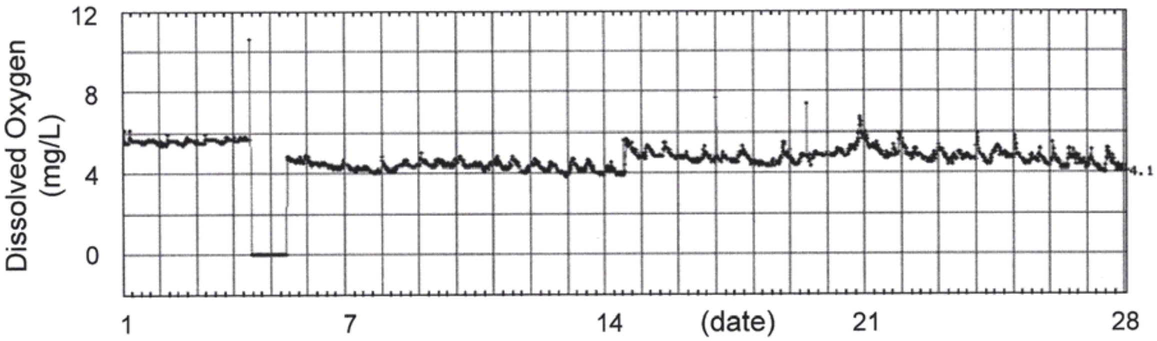
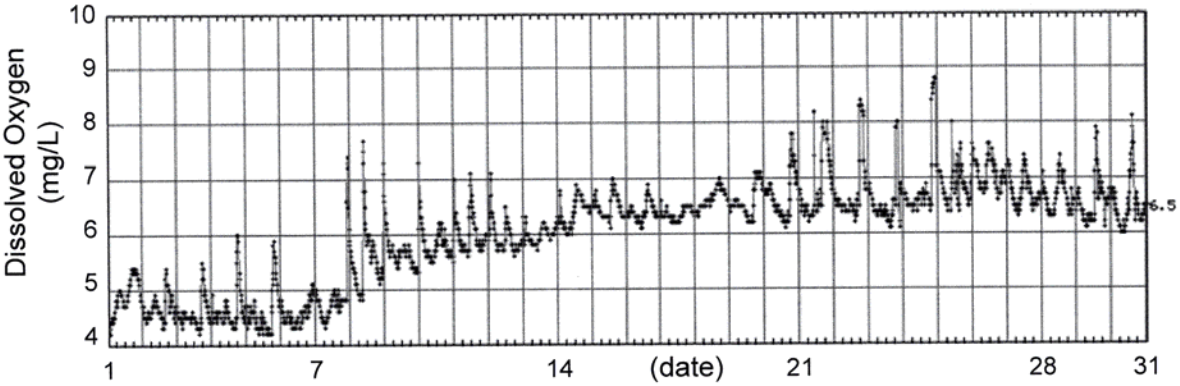


Figure D-1 (continued)

February 2002



March 2002



April 2002

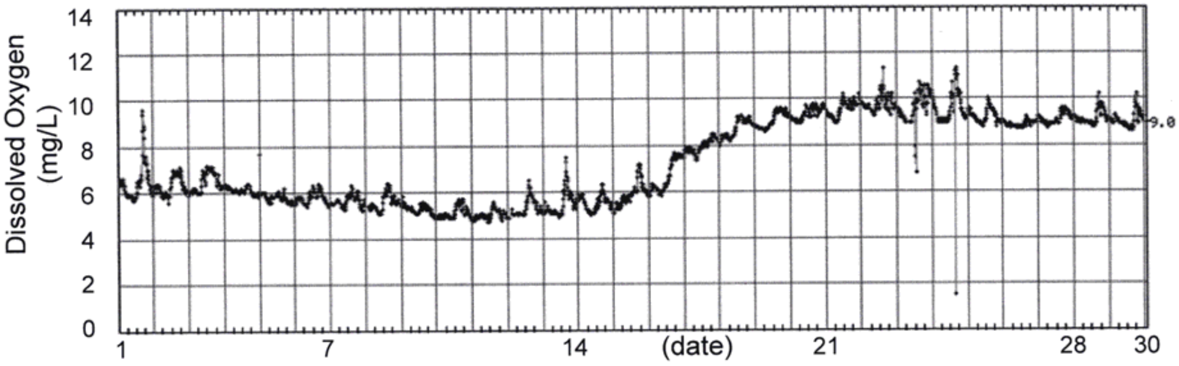
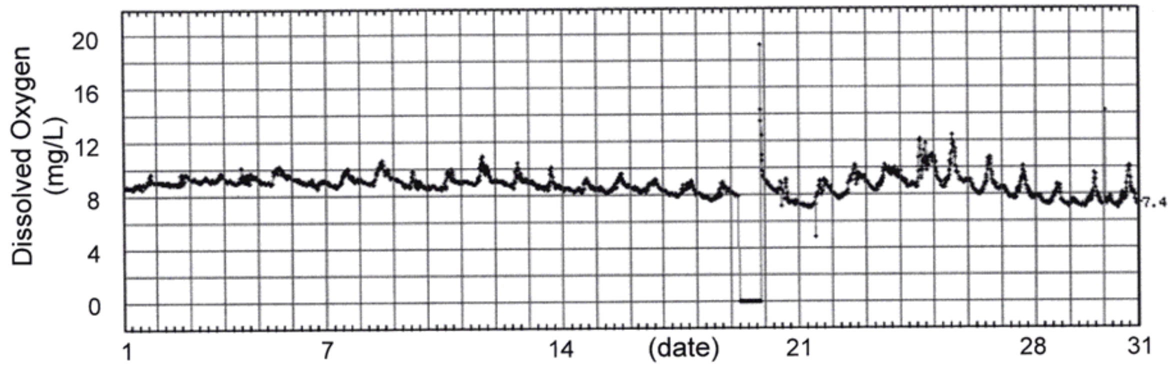
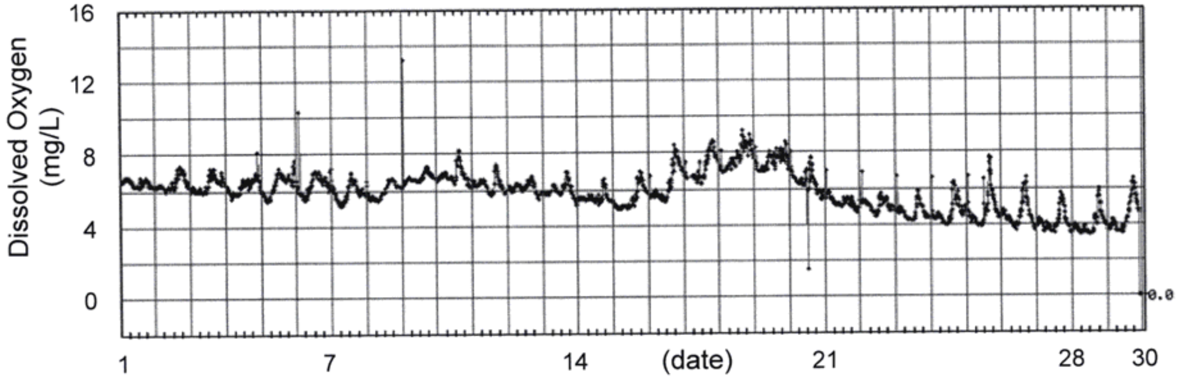


Figure D-1 (continued)

May 2002



June 2002



July 2002

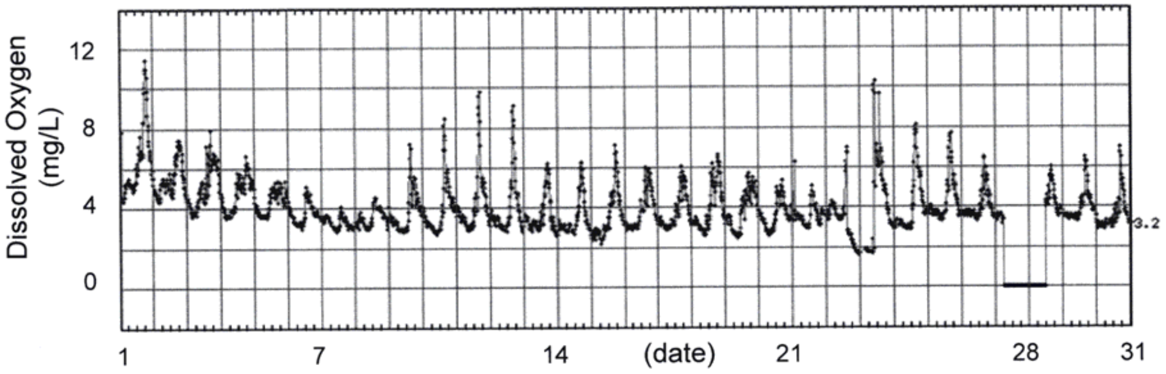
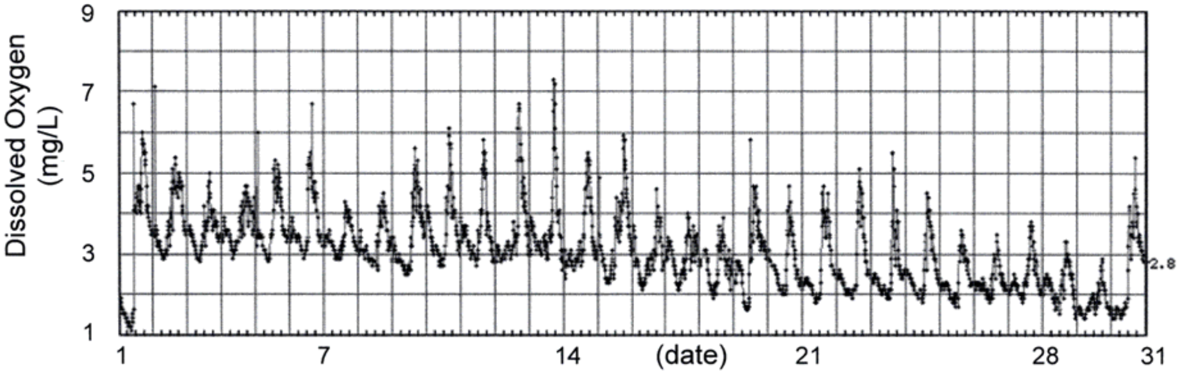
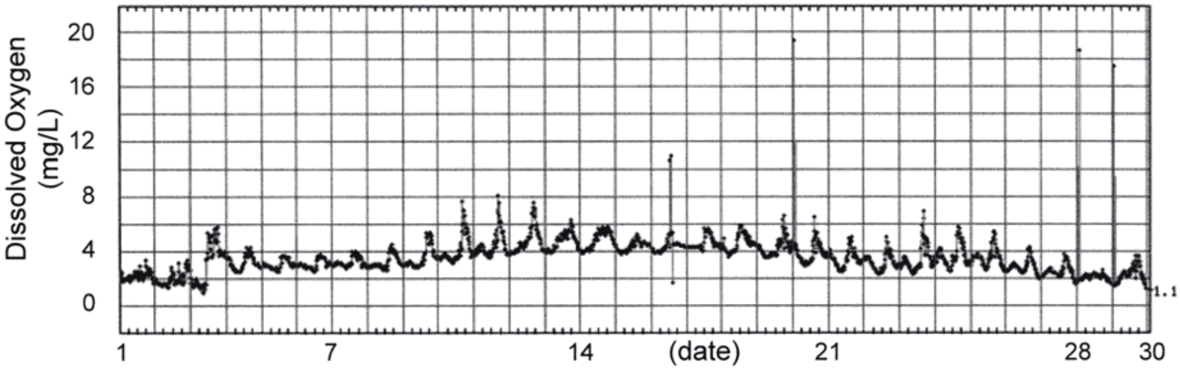


Figure D-1 (continued)

August 2002



September 2002



October 2002

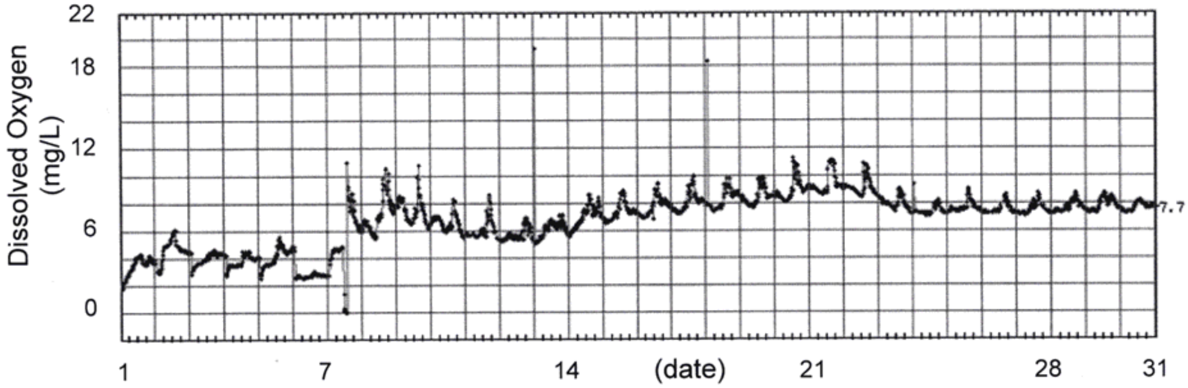
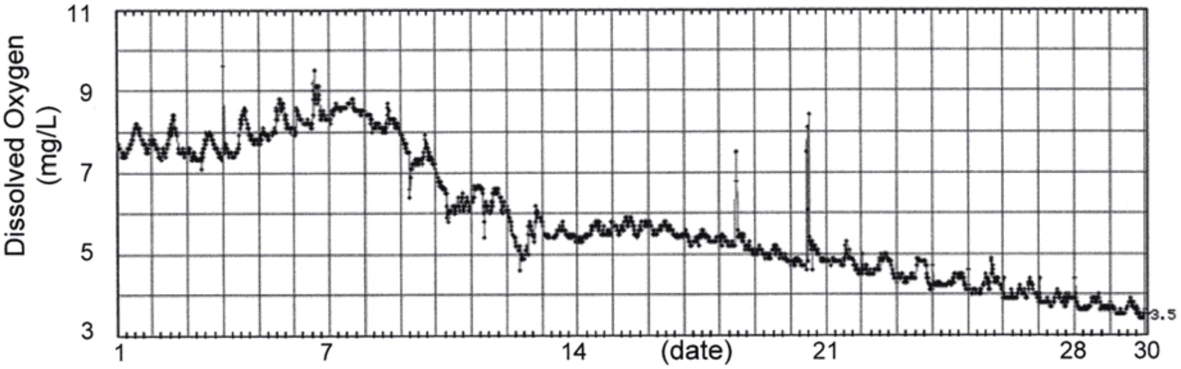
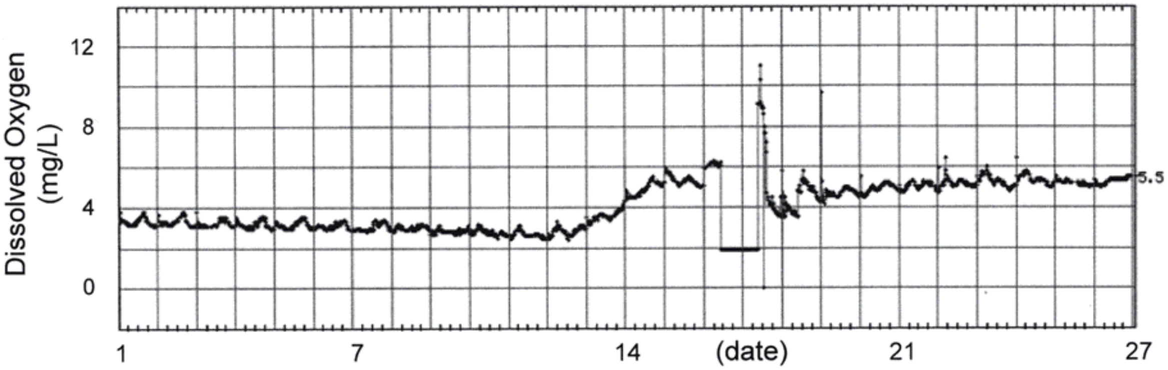


Figure D-1 (continued)

November 2002



December 2002



January 2003

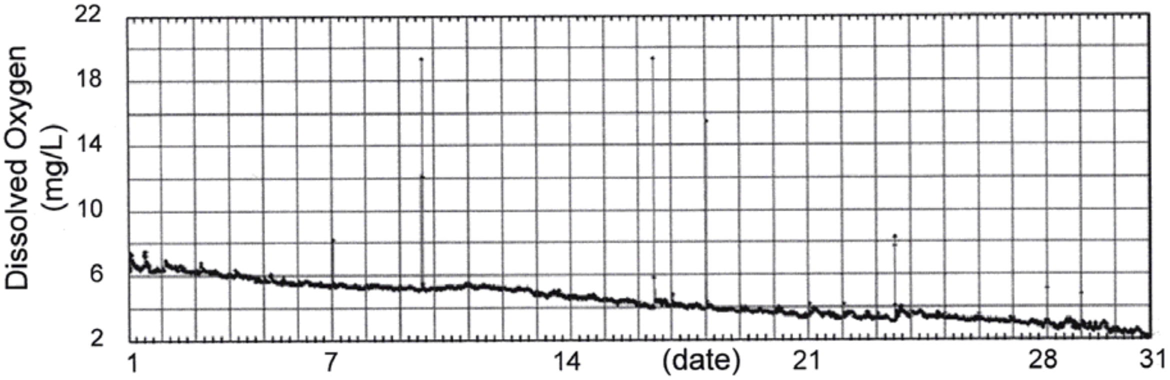
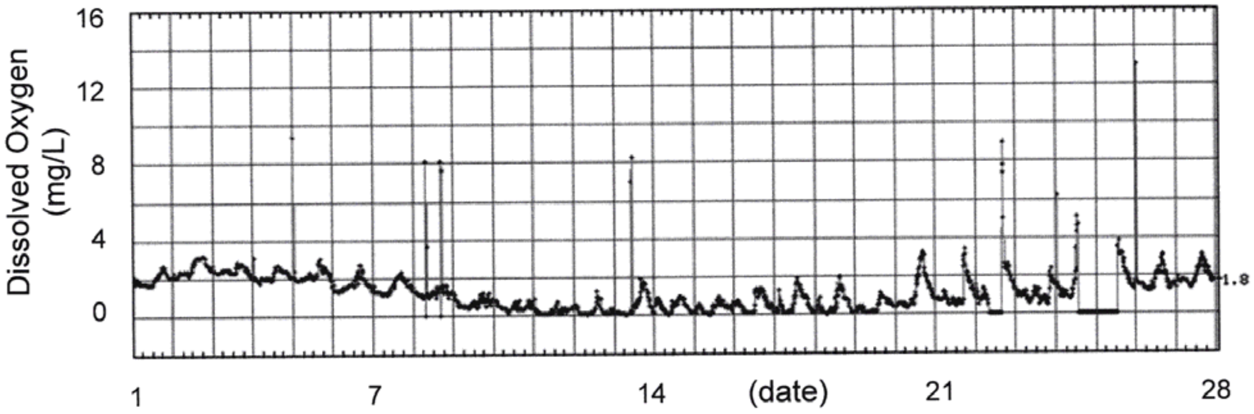
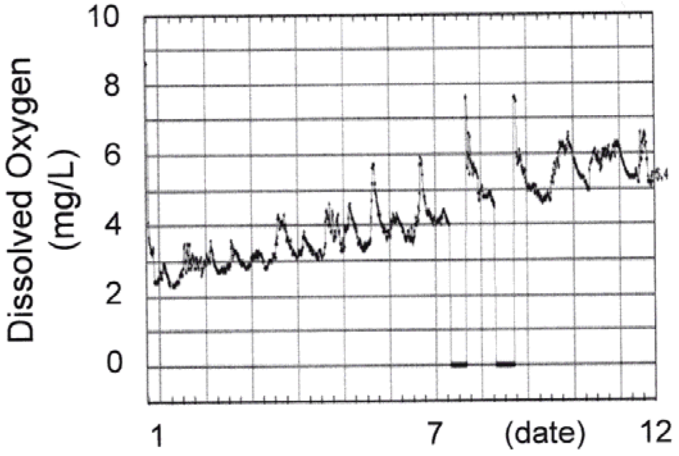


Figure D-1 (continued)



February 2003



March 2003

Appendix E
Relationship between BOD_5 and Chlorophyll *a* Plus Pheophytin *a*

Based on the studies of Foe, *et al*. (2002) and Dahlgren (2002), which show that there is a relationship between oxygen demand in the SJR and the planktonic algal chlorophyll *a*, it is of interest to examine the city of Stockton data for 1999, 2000 and 2001 for the relationship between BOD_5 and the sum of the chlorophyll *a* and pheophytin *a*. Using the sum of the chlorophyll *a* and pheophytin *a* as a potential estimate of oxygen demand is based on the results of Foe, *et al*. and Dahlgren. Brown (pers. comm., 2002) supports this approach.

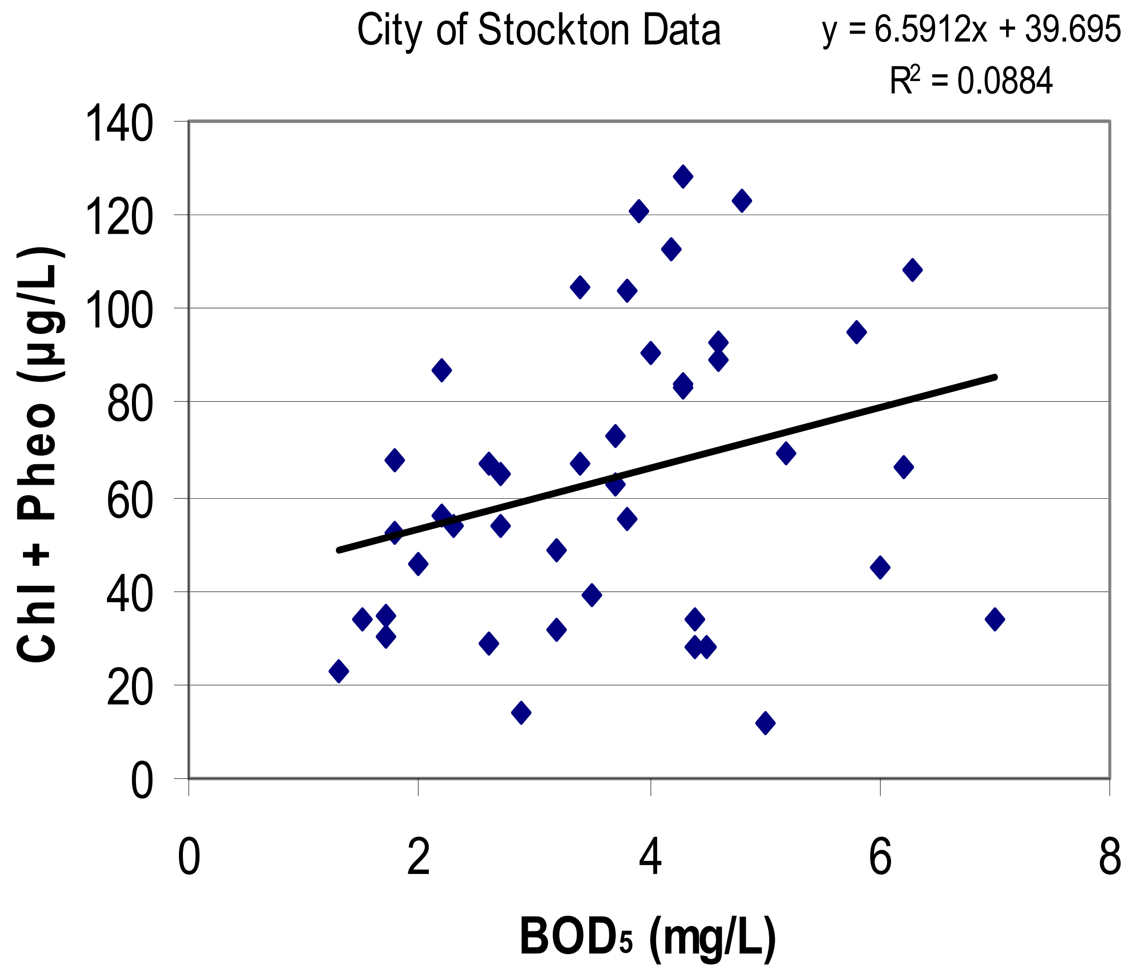
The city of Stockton BOD_5 versus the sum of chlorophyll *a* and pheophytin *a* data obtained at Mossdale for 1999, 2000 and 2001 are plotted in Figure 1. As shown, there is little or no relationship between the measured BOD_5 and the sum of the chlorophyll *a* and pheophytin *a*. However, examination of the data shows that the data points on the right side of the plot, which have high BOD but lower chlorophyll *a*, were all obtained in 1999. The removal of the 1999 data from this plot (see Figure 2) significantly improves the relationship between the measured BOD at Mossdale and the sum of the chlorophyll *a* plus pheophytin *a*.

In order to examine the BOD, chlorophyll *a* and pheophytin *a* relationships for the DWSC, the data obtained by the city of Stockton during 1999, 2000 and 2001 for stations R3 and R7 were used. This relationship is shown in Figure 3. As shown, there is no relationship. However, as occurred at Mossdale, all of the higher BOD values with lower chlorophyll *a* – i.e., the points above about 5 mg/L BOD_5 – were obtained in 1999. Removal of the 1999 data, and replotting just the 2000 and 2001 data (see Figure 4) significantly improves the relationship between BOD_5 and the sum of the chlorophyll *a* plus pheophytin *a*.

One of the reasons why the BOD could be elevated for a given chlorophyll *a* would be increased concentrations of ammonia. Examination of the 1999 data, particularly at station R3, tends to show a higher ammonia concentration than was found in 2000. However, in 2001 the ammonia concentrations at R3 were, in general, similar to those in 1999. It does not appear that the differences between the BOD, chlorophyll *a* plus pheophytin *a* obtained in 1999 compared to those found in 2000 and 2001 were due only to ammonia. According to L. Huber of the city of Stockton, the same laboratory made the measurements of chlorophyll *a* all three years; however, different laboratories made measurements of BOD in all three years. At this time, it is not clear why there are such differences between the 1999, 2000 and 2001 data for the relationship between BOD and the sum of the chlorophyll *a* plus pheophytin *a*.

Figure 1

Mossdale BOD_5 vs. Chlorophyll + Pheophytin 1999, 2000, 2001



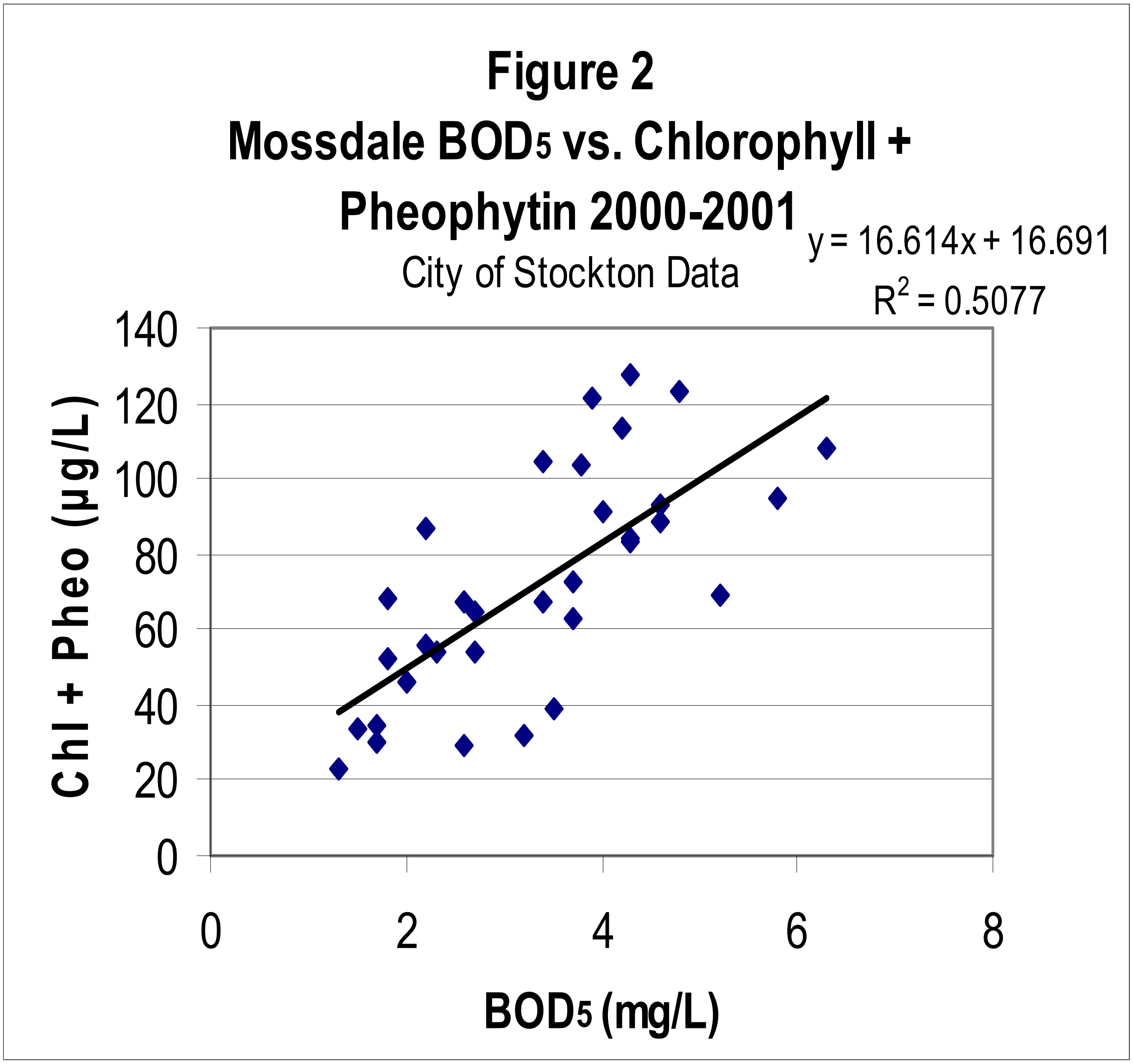


Figure 2
Mossdale BOD5 vs. Chlorophyll + Pheophytin 2000-2001
City of Stockton Data

Figure 3
DWSC (Stations R3 and R7) BOD_5 vs. Chlorophyll + Pheophytin
1999, 2000, 2001
City of Stockton Data

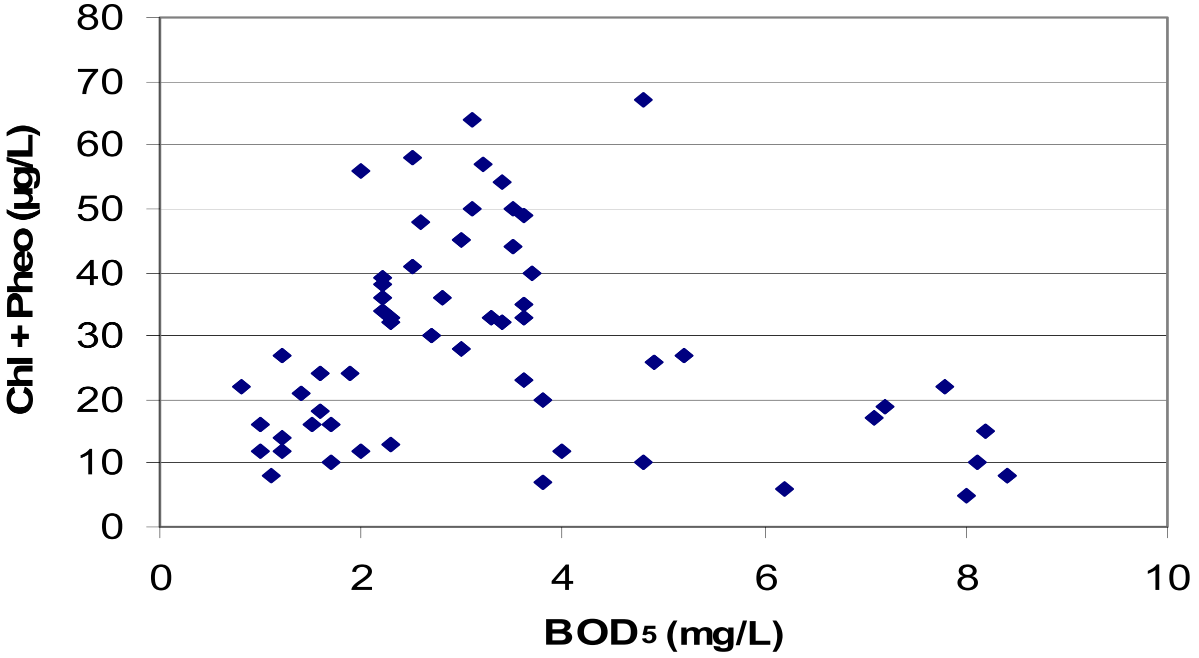
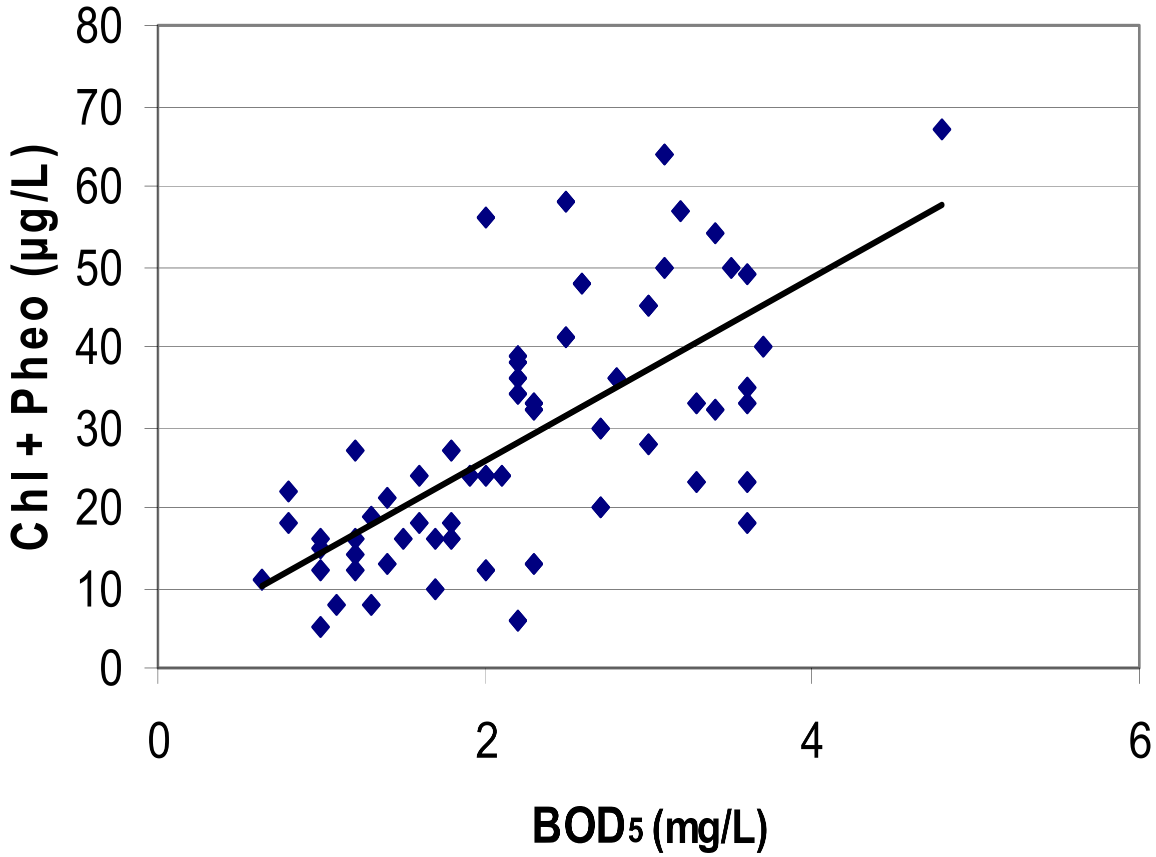


Figure 4

DWSC (Stations R3 and R7) BOD5 vs. Chlorophyll + Pheophytin

2000-2001

City of Stockton Data



Appendix F – Backup Information for Box Model Calculations
Approach for Calculating Oxygen Demand Loads

The city of Stockton sampling of the DWSC and upstream in the SJR data for 1999, 2000 and 2001 were used to calculate estimated oxygen demand loads at Mossdale, city station R3 (Channel Point) and city station R7 (just upstream of Turner Cut). The SJR DWSC flows for each of the sampling dates were estimated, based on the information provided by R. Brown, as the average of the SJR UVM flows into the DWSC. The flows just before and just after the sampling date were averaged, and that flow was used for that sampling date for the Mossdale, Channel Point and Turner Cut locations. The BOD concentration data for Mossdale was only a single value in the water column. For stations R3 and R7, in some years samples were collected from surface and bottom, and in 2001 they were collected from surface, mid and bottom. The available water column data were averaged at each sampling station and date to provide an average concentration of BOD, ammonia and organic nitrogen. The chlorophyll *a* and pheophytin *a* data were summed at each depth for each sampling location, and the average of the water column (from the data available) was used to compute an average concentration for that location and date.

For DO concentrations, the City only made measurements at mid-depth. This was the DO reported for the station. The DO saturation values were obtained from a table provided by Standard Methods (APHA, *et al.*, 1998), for the mid-depth temperatures provided by the City for the location for the sampling event. The BOD_u was obtained by multiplying the BOD_5 by 3. This is the approach that was recommended by G. Litton (pers. comm., 2002), based on his site-specific data collected in 1999, 2000 and 2001, which relates the BOD_5 measured in a standard bottle test to the ultimate BOD for the carbonaceous and nitrogenous fractions. The loads of various parameters were estimated through the relationship of the concentration in mg/L times 5.4 times the average SJR DWSC flow for the sampling event.

The BOD_{10} values were converted to BOD_5 by multiplying by 0.65. This is the value that was found by Foe, *et al.* (2002) to relate these two BOD measurements.

The DO deficit loads were estimated based on the difference between the observed mid-depth oxygen and the saturation value. The DO deficit loads were estimated based on the difference times 5.4 times the flow for the sampling event. The travel times were based on information provided by R. Brown, based on the SJR DWSC flow and the geometry of the Deep Water Ship Channel between Channel Point and Turner Cut, and the SJR between Mossdale and Channel Point (Figure 7).

The loads for the city of Stockton wastewater discharges were based on information provided by the city of Stockton, as developed by R. Brown on behalf of the City. The values provided in the report were checked against the original data. The organic nitrogen BOD_u for 1999 and 2000 was added to the information provided by the City for the carbonaceous and nitrogenous BOD. R. Brown's calculations (on behalf of the City) of oxygen demand in the City's wastewater discharges were based on the carbonaceous BOD developed in a nitrification-inhibited BOD test times 2.5 to estimate the total carbonaceous BOD. The nitrogenous BOD was estimated based on the ammonia concentration times 4.57, to obtain the $NBOD_u$. The City's data were presented on an average per-month basis. The monthly values were used to estimate the City's contribution for each of the sampling dates for the sampling of the DWSC and SJR upstream of Channel Point.

Table F-1
1999 Mossdale

Date	Flow (cfs)	DO (mg/L)			Temp (°C)	BOD$_5$ (mg/L)	BOD$_u$ (mg/L)	NH$_3$-N (mg/L)	Org-N (mg/L)	Chlorophyll *a* and Pheophytin *a* (µg/L)		
		Meas.	**Sat.**	**Delta**						**Chlor.**	**Pheo.**	**Sum**
8/24	850	8.2	8.2	0	25.4	3.8	11.4	< 0.2	0.8	19	36	55
8/31	1,024	8.1	8.6	0.5	22.4	3.2	9.6	< 0.2	0.7	22	27	49
9/07	1,022	9.5	8.6	+ 0.9	23.0	6.2	18.6	< 0.2	0.6	24	44	66
9/14	1,157	8.7	8.6	+ 0.1	22.4	6.0	18.0	0.2	0.6	18	27	45
9/21	1,135	8.5	8.9	0.4	21.2	7.0	21.0	0.3	0.8	20	14	34
9/28	395	8.1	9.1	1.0	20.0	4.4	13.2	0.2	0.7	20	14	34
10/05	494	8.0	9.5	1.5	18.5	4.5	13.5	< 0.2	0.7	15	13	28
10/19	623	9.5	9.8	0.3	16.2	4.4	13.2	0.2	0.6	20	8	28
10/26	592	8.2	9.3	1.1	16.4	5.0	15.0	0.2	0.6	6	6	12

Table F-1 (continued)
1999 Station R3

Date	Flow (cfs)	DO (mg/L)			Temp (ºC)	BOD_5 (mg/L)	BOD_u (mg/L)	NH_3-N (mg/L)	Org-N (mg/L)	Chlorophyll *a* and Pheophytin *a* (µg/L)		
		Meas.	Sat.	Delta						Chlor.	Pheo.	Sum
8/24	850	4.7	8.3	3.6	24.6	3.5	10.5	0.2	0.6	8	36	44
8/31	1,024	4.8	8.6	3.8	23.9	3.8	11.4	0.5	0.6	8	12	20
9/07	1,022	5.5	8.6	3.1	23.1	7.1	21.3	0.4	1.2	8	9	17
9/14	1,157	5.3	8.6	3.3	22.6	7.8	23.4	0.4	0.6	6	16	22
9/21	1,135	6.0	8.8	2.8	21.4	7.2	21.6	0.7	1.1	3	16	19
9/28	395	3.8	8.7	4.9	22.1	9.5	28.5	1.0	1.3	4	12	16
10/05	494	4.4	9.1	4.7	20.9	5.2	15.6	1.8	2.0	12	15	27
10/19	623	5.9	9.5	3.6	18.1	8.4	25.2	0.7	1.0	3	5	8
10/26	592	6.1	9.5	3.4	17.6	8.1	24.3	1.2	1.5	4	6	10

Table F-1 (continued)
1999 Station R7

Date	Flow (cfs)	DO (mg/L)			Temp (ºC)	BOD_5 (mg/L)	BOD_u (mg/L)	NH_3-N (mg/L)	Org-N (mg/L)	Chlorophyll *a* and Pheophytin *a* (µg/L)		
		Meas.	Sat.	Delta						Chlor.	Pheo.	Sum
8/24	850	4.6	8.2	3.6	24.7	4.8	14.4	< 0.2	0.7	4	6	10
8/31	1,024	4.7	8.2	3.5	24.7	4.0	12.0	0.2	< 0.5	2	10	12
9/07	1,022	5.1	8.5	3.4	23.5	6.2	18.6	0.2	0.5	4	2	6
9/14	1,157	4.3	8.5	4.2	23.7	8.2	24.6	0.2	0.6	6	9	15
9/21	1,135	4.7	8.6	3.9	22.9	8.4	25.2	0.4	0.6	2	6	8
9/28	395	6.0	8.6	2.6	22.4	4.9	14.7	< 0.2	0.5	4	22	26
10/05	494	5.1	8.8	3.7	21.5	3.8	11.4	< 0.2	0.4	3	4	7
10/19	623	3.5	9.1	5.6	20.0	8.4	25.2	< 0.2	0.4	7	1	8
10/26	592	4.1	9.3	5.2	19.0	8.0	24.0	0.2	< 0.5	3	2	5

Table F-2
2000 Mossdale

Date	Flow (cfs)	DO (mg/L)			Temp (ºC)	BOD$_5$ (mg/L)	BOD$_u$ (mg/L)	NH$_3$-N (mg/L)	Org-N (mg/L)	Chlorophyll *a* and Pheophytin *a* (µg/L)		
		Meas.	Sat.	Delta						Chlor.	Pheo.	Sum
6/20	1,202	10.0	8.3	+ 1.7	24.6	4.3	12.9	0.3	< 0.5	55	29	84
6/27	652	12.4	8.0	+ 4.4	6.4	3.9	11.7	< 0.2	< 0.5	81	40	121
7/11	634	10.7	8.3	+ 2.4	24.5	4.8	14.4	< 0.2	< 0.5	87	36	123
7/18	662	11.6	8.5	+ 3.1	23.3	4.3	12.9	< 0.2	< 0.5	85	43	128
7/25	770	9.8	8.3	+ 1.5	24.6	4.6	13.8	< 0.2	< 0.5	55	34	89
8/01	759	11.0	8.0	+ 3.0	26.6	3.4	10.2	< 0.2	< 0.5	56	49	105
8/08	837	10.6	8.3	+ 2.3	24.3	2.7	8.1	< 0.2	< 0.5	55	10	65
8/15	725	11.2	8.3	+ 2.9	25.1	3.4	10.2	< 0.2	< 0.5	59	8	67
8/22	1,251	8.9	8.4	+ 0.4	23.4	2.0	6.0	< 0.2	< 0.5	35	11	46
8/29	1,447	9.1	8.7	+ 0.4	21.9	2.2	6.6	< 0.2	< 0.5	61	26	87
9/12	1,277	10.4	8.7	+ 1.7	22.2	1.8	5.4	< 0.2	< 0.5	43	25	68
9/19	1,224	9.8	8.5	+ 1.3	23.4	2.2	6.6	< 0.2	< 0.5	43	13	56
9/26	1,372	9.4	8.8	+ 0.6	21.3	1.7	5.1	< 0.2	< 0.5	21	14	35
10/03	1,201	8.0	8.8	0.8	21.3	2.6	7.8	< 0.2	< 0.5	20	9	29
10/17	2,141	9.2	9.5	0.3	18.1	1.5	4.5	< 0.2	< 0.5	18	16	34
10/24	2,416	9.2	10.1	0.9	14.8	3.2	9.6	< 0.2	< 0.5	12	10	22
10/31	573	8.5	10.2	1.7	14.3	2.9	8.7	0.3	< 0.5	8	6	14

Table F-2 (continued)
2000 Station R3

Date	Flow (cfs)	DO (mg/L)			Temp (°C)	BOD_5 (mg/L)	BOD_u (mg/L)	NH_3-N (mg/L)	Org-N (mg/L)	Chlorophyll *a* and Pheophytin *a* (µg/L)		
		Meas.	Sat.	Delta						Chlor.	Pheo.	Sum
6/20	1,202	6.3	8.1	1.8	25.4	4.8	14.4	0.2	0.6	33	34	67
6/27	652	6.2	8.1	1.9	26.2	3.1	9.3	< 0.2	< 0.5	32	32	64
7/11	634	4.9	8.3	3.4	24.4	3.0	9.0	< 0.2	< 0.5	30	15	45
7/18	662	5.4	8.3	2.9	24.4	3.5	10.5	< 0.2	< 0.5	30	20	50
7/25	770	6.3	8.1	1.8	25.9	3.0	9.0	< 0.2	< 0.5	19	26	45
8/01	759	6.4	8.0	1.6	27.0	2.5	7.5	< 0.2	< 0.5	41	17	58
8/08	837	5.4	8.1	2.7	25.4	2.2	6.6	< 0.2	< 0.5	12	27	39
8/15	725	6.2	7.9	1.7	25.7	2.2	6.6	< 0.2	< 0.5	18	16	34
8/22	1,251	6.7	8.5	1.8	23.6	2.2	6.6	< 0.2	< 0.5	22	16	38
8/29	1,447	7.3	8.6	1.3	23.1	2.2	6.6	0.2	< 0.5	20	16	36
9/12	1,277	7.4	8.6	1.2	22.7	2.6	7.8	< 0.2	< 0.5	24	24	48
9/19	1,224	7.5	8.6	1.1	22.7	2.3	6.9	< 0.2	< 0.5	10	22	32
9/26	1,372	8.3	8.7	0.4	21.9	2.3	6.9	0.5	0.7	26	7	33
10/03	1,201	6.2	8.8	2.6	21.6	1.9	5.7	0.8	2.4	12	12	24
10/17	2,141	7.4	9.5	2.1	18.2	2.0	6.0	< 0.2	< 0.5	4	8	12
10/24	2,416	8.3	9.9	1.6	15.3	2.3	6.9	< 0.2	< 0.5	8	5	13
10/31	573	8.0	10.3	2.3	14.2	1.7	5.1	0.3	0.9	4	6	10

Table F-2 (continued)
2000 Station R7

Date	Flow (cfs)	DO (mg/L)			Temp (°C)	BOD_5 (mg/L)	BOD_u (mg/L)	NH_3-N (mg/L)	Org-N (mg/L)	Chlorophyll *a* and Pheophytin *a* (µg/L)		
		Meas.	Sat.	Delta						Chlor.	Pheo.	Sum
6/20	1,202	5.7	8.3	2.6	24.6	1.0	3.0	< 0.2	0.8	8	4	12
6/27	652	5.3	7.9	2.6	25.7	1.0	3.0	< 0.2	< 0.5	6	10	16
7/11	634	5.5	8.3	2.8	25.0	1.6	4.8	< 0.2	< 0.5	12	12	24
7/18	662	5.7	8.3	2.6	24.3	1.7	5.1	< 0.2	< 0.5	10	6	16
7/25	770	5.5	8.2	2.7	25.4	1.1	3.3	< 0.2	< 0.5	4	4	8
8/01	759	4.8	8.0	3.2	26.5	1.6	4.8	< 0.2	< 0.5	10	8	18
8/08	837	5.3	8.1	2.8	26.1	1.2	3.6	< 0.2	< 0.5	10	4	14
8/15	725	5.0	8.2	3.2	25.5	1.2	3.6	< 0.2	< 0.5	10	2	12
8/22	1,251	5.8	8.3	2.5	25.1	1.2	3.6	< 0.2	< 0.5	17	10	27
8/29	1,447	5.9	8.6	2.7	23.2	0.8	2.4	< 0.2	0.4	12	10	22
9/12	1,277	6.4	8.6	2.2	22.4	1.5	4.5	< 0.2	< 0.5	12	4	16
9/19	1,224	5.6	8.4	2.8	23.7	1.5	4.5	< 0.2	< 0.5	7	9	16
9/26	1,372	7.0	8.5	1.5	23.5	1.5	4.5	0.2	< 0.5	14	7	21
10/03	1,201	5.5	8.7	3.2	22.5	1.5	4.5	< 0.2	< 0.5	6	2	8
10/17	2,141	6.2	9.5	3.3	18.2	1,5	4.5	0.2	0.5	6	5	11
10/24	2,416	7.6	9.7	2.1	16.5	1.5	4.5	< 0.2	< 0.5	8	6	14
10/31	573	--	--	--	--	--	--	--	--	--	--	--

Table F-3
2001 Mossdale

Date	Flow (cfs)	DO (mg/L)			Temp (°C)	BOD_5 (mg/L)	BOD_u (mg/L)	NH_3-N (mg/L)	Org-N (mg/L)	Chlorophyll *a* and Pheophytin *a* (µg/L)		
		Meas.	**Sat.**	**Delta**						**Chlor.**	**Pheo.**	**Sum**
6/12	674	11.4	8.6	+ 2.8	23.0	5.2	15.6	< 0.1	0.57	51	18	69
6/19	610	11.8	8.1	+ 3.7	26.0	5.8	17.4	0.91	2.30	58	37	95
6/26	746	10.6	8.6	+ 2.0	22.8	4.6	13.8	0.11	1.40	78	15	93
7/10	622	11.5	8.3	+ 3.2	25.1	6.3	18.9	0.35	1.20	80	28	108
7/17	657	9.6	8.5	+ 1.1	23.4	4.2	12.6	0.13	0.90	58	55	113
7/24	618	12.2	8.1	+ 4.1	26.1	4.0	12.0	0.16	1.40	69	22	91
7/31	599	9.7	8.3	+ 1.4	24.9	3.8	11.4	0.81	1.50	49	55	104
8/07	577	8.3	8.1	+ 0.2	26.4	2.6	7.8	0.55	1.30	20	47	67
8/14	583	9.3	8.4	+ 0.9	23.9	4.3	12.9	0.78	1.60	58	25	83
8/21	626	7.9	8.6	0.7	23.5	2.3	6.9	0.11	0.96	24	30	54
8/28	634	7.9	8.2	0.3	25.6	1.8	5.4	< 0.1	0.82	28	24	52
9/11	610	8.3	8.6	0.3	22.5	3.7	11.1	1.00	1.50	44	29	73
9/18	792	8.6	8.6	0	23.0	3.7	11.1	0.61	1.70	33	30	63
9/25	1,143	7.8	8.9	1.1	21.0	2.7	8.1	0.57	1.40	25	29	54
10/02	785	7.6	8.7	1.1	21.9	3.5	10.5	0.59	1.50	23	16	39
10/16	1,279	8.1	9.1	1.0	20.0	1.7	5.1	0.71	1.20	15	15	30
10/23	2,068	8.3	9.7	1.4	16.9	1.3	3.9	< 0.1	0.37	11	12	23

Table F-3 (continued)
2001 Station R3

Date	Flow (cfs)	DO (mg/L)			Temp (ºC)	BOD$_5$ (mg/L)	BOD$_u$ (mg/L)	NH$_3$-N (mg/L)	Org-N (mg/L)	Chlorophyll *a* and Pheophytin *a* (µg/L)		
		Meas.	Sat.	Delta						Chlor.	Pheo.	Sum
6/12	674	5.2	8.5	3.3	23.8	3.6	10.8	0.44	0.46	14.3	9.1	23.4
6/19	610	5.1	8.2	3.1	25.5	3.6	10.8	0.52	1.04	25.7	9.5	35.2
6/26	746	3.8	8.2	4.4	25.3	3.0	9.0	0.90	1.50	21.0	6.6	27.6
7/10	622	4.2	8.0	3.8	26.6	2.7	8.1	0.28	0.98	9.7	20.2	29.9
7/17	657	5.5	8.4	2.9	24.0	3.4	10.2	0.73	1.55	16.2	37.7	53.9
7/24	618	4.0	8.3	4.3	24.8	1.4	4.2	0.85	1.50	2.5	18.7	21.2
7/31	599	4.3	8.3	4.0	24.8	2.5	7.5	0.72	1.25	8.9	32.3	41.2
8/07	577	4.9	8.2	3.3	25.5	2.8	8.4	0.85	1.40	10.7	25.7	36.4
8/14	583	6.1	8.3	2.2	24.8	3.1	9.3	0.94	1.40	18.3	31.3	49.6
8/21	626	4.8	8.2	3.4	25.1	3.6	10.8	1.05	1.75	16.0	17.3	33.3
8/28	634	4.5	8.2	3.7	24.9	3.4	10.2	0.36	1.20	17.0	15.3	32.3
9/11	610	6.2	8.5	2.3	23.2	3.7	11.1	0.36	1.20	14.0	26.3	40.3
9/18	792	5.9	8.6	2.7	22.6	2.0	6.0	0.62	1.65	13.0	42.7	55.7
9/25	1,143	6.3	8.6	2.3	22.6	3.2	9.6	0.33	1.20	17.0	40.0	57.0
10/02	785	6.5	8.7	2.2	22.0	3.6	10.8	0.58	1.65	25.7	23.3	49.0
10/16	1,279	6.9	9.1	2.2	19.5	3.3	9.9	2.10	2.35	13.4	20.0	33.4
10/23	2,068	6.8	9.4	2.6	18.3	1.8	5.4	0.33	0.78	12.3	14.3	26.6

Table F-3 (continued)
2001 Station R7

Date	Flow (cfs)	DO (mg/L)			Temp (ºC)	BOD_5 (mg/L)	BOD_u (mg/L)	NH_3-N (mg/L)	Org-N (mg/L)	Chlorophyll *a* and Pheophytin *a* (µg/L)		
		Meas.	Sat.	Delta						Chlor.	Pheo.	Sum
6/12	674	6.0	8.5	2.5	23.8	2.20	6.60	0.20	0.48	3.9	2.2	6.1
6/19	610	4.3	8.2	3.9	25.3	1.04	3.12	0.24	0.46	3.6	1.6	5.2
6/26	746	5.2	8.3	3.1	24.6	0.63	1.89	0.14	0.60	7.9	3.5	11.4
7/10	622	5.7	8.2	2.5	25.5	1.30	3.90	0.18	0.44	4.8	3.4	8.2
7/17	657	4.8	8.3	3.5	24.7	1.37	4.11	0.18	0.55	6.0	7.2	13.2
7/24	618	5.6	8.3	2.7	24.7	0.97	2.91	0.21	0.47	7.9	7.2	15.1
7/31	599	4.9	8.3	3.4	24.7	0.82	2.46	0.28	0.70	9.6	8.9	18.5
8/07	577	5.4	8.1	2.7	25.7	< 1	1.50	0.28	0.71	5.9	10.1	16.0
8/14	583	5.3	8.2	2.9	25.2	1.80	5.40	0.16	0.86	6.2	9.9	16.1
8/21	626	5.2	8.2	3.0	24.9	1.17	3.51	0.14	0.78	5.5	10.8	16.3
8/28	634	4.2	8.2	4.0	25.2	1.80	5.40	< 0.1	0.88	11.7	6.8	18.5
9/11	610	6.3	8.6	2.3	23.2	1.33	3.99	< 0.1	0.70	4.4	14.9	19.3
9/18	792	4.8	8.6	3.8	23.0	3.57	10.71	0.09	0.68	2.0	16.3	18.3
9/25	1,143	4.4	8.7	4.3	22.2	2.10	6.3	0.30	0.84	8.8	15.7	24.5
10/02	785	4.7	8.7	4.0	22.3	2.73	8.19	0.16	1.08	2.3	17.3	19.6
10/16	1,279	6.1	9.1	3.0	19.9	3.27	9.81	0.59	1.04	6.4	16.3	22.7
10/23	2,068	6.4	9.1	2.7	19.5	2.03	6.09	0.24	0.50	11.0	13.3	24.3

Table F-4
1999

Date	Flow (cfs)	Mossdale (lb/day)					Station R3 (lb/day)					Station R7 (lb/day)				
		DO Deficit	BOD_u	NH_3 $NBOD_u$	KJ $NBOD_u$	Chlor + Pheo	DO Deficit	BOD_u	NH_3 $NBOD_u$	KJ $NBOD_u$	Chlor + Pheo	DO Deficit	BOD_u	NH_3 $NBOD_u$	KJ $NBOD_u$	Chlor + Pheo
8/24	850	0	52,326	2,098	18,879	252	16,524	48,195	4,195	16,781	202	16,524	66,096	2,098	16,781	46
8/31	1,024	2,765	53,084	2,527	20,216	271	21,012	63,037	12,635	27,797	111	19,354	66,355	5,054	11,372	66
9/07	1,022	+ 4,967	102,650	2,522	17,655	364	17,108	117,550	10,088	40,353	94	18,764	102,650	5,044	17,655	33
9/14	1,157	+ 625	112,460	5,710	22,842	281	20,618	146,199	11,421	28,552	137	26,241	153,696	5,710	22,842	94
9/21	1,135	2,452	128,709	8,403	30,810	208	17,161	132,386	19,607	50,417	116	23,903	154,451	11,204	28,010	49
9/28	395	2,133	28,156	1,950	8,773	73	10,452	60,790	9,748	22,420	38	5,546	31,355	975	5,849	55
10/05	494	4,001	36,013	1,219	9,753	75	12,538	41,615	21,944	46,326	72	9,870	30,411	1,219	6,095	19
10/19	623	1,009	44,407	3,075	12,300	94	12,111	84,778	10,762	26,136	27	18,840	84,778	1,537	7,687	27
10/26	592	3,516	47,952	2,922	11,688	38	10,869	77,682	17,531	39,445	32	16,623	76,723	2,922	6,574	16

Table F-5
2000

Date	Flow (cfs)	Mossdale (lb/day)					Station R3 (lb/day)					Station R7 (lb/day)				
		DO Deficit	BOD$_u$	NH$_3$ NBOD$_u$	KJ NBOD$_u$	Chlor + Pheo	DO Deficit	BOD$_u$	NH$_3$ NBOD$_u$	KJ NBOD$_u$	Chlor + Pheo	DO Deficit	BOD$_u$	NH$_3$ NBOD$_u$	KJ NBOD$_u$	Chlor + Pheo
6/20	1,202	+11,034	83,731	8,899	16,315	545	11,683	93,468	5,933	23,730	435	16,876	19,472	2,966	26,697	78
6/27	652	+15,492	41,193	1,609	5,632	426	6,690	32,743	1,609	5,632	225	9,154	10,562	1,609	5,632	56
7/11	634	+ 8,217	49,300	1,565	5,476	421	11,640	30,812	1,565	5,476	154	9,586	16,433	1,565	5,476	82
7/18	662	+11,082	46,115	1,634	5,718	458	10,367	37,535	1,634	5,718	179	9,294	18,231	1,634	5,718	57
7/25	770	+ 6,237	57,380	1,900	6,651	370	7,484	37,422	1,900	6,651	187	11,227	13,721	1,900	6,651	33
8/01	759	+12,296	41,806	1,873	6,556	430	6,558	30,740	1,873	6,556	238	13,116	19,673	1,873	6,556	74
8/08	837	+10,396	36,610	2,066	7,229	294	12,203	29,831	2,066	7,229	176	12,655	16,271	2,066	7,229	63
8/15	725	+11,354	39,933	1,789	6,262	262	6,656	25,839	1,789	6,262	133	12,528	14,094	1,789	6,262	47
8/22	1,251	+ 2,702	40,532	3,087	10,805	311	12,160	44,586	3,087	10,805	257	16,888	24,319	3,087	10,805	182
8/29	1,447	+ 3,126	51,571	3,571	12,498	680	10,158	51,571	7,142	16,069	281	21,097	36,162	3,571	17,855	172
9/12	1,277	+11,723	37,237	3,151	11,030	469	8,275	53,787	3,151	11,030	331	15,171	31,022	3,151	11,030	110
9/19	1,224	+ 8,592	43,623	3,021	10,572	370	7,271	45,606	3,021	10,572	212	18,507	29,743	3,021	10,572	106
9/26	1,372	+ 4,445	37,785	3,386	11,850	259	2,964	51,121	16,929	40,630	244	11,113	33,340	6,772	15,236	156
10/03	1,201	5,188	50,586	2,964	10,373	188	16,862	36,967	23,711	94,842	156	20,753	29,184	2,964	10,373	52
10/17	2,141	3,468	52,026	5,284	18,492	393	24,279	69,368	5,284	18,492	139	38,153	52,026	10,567	36,985	127
10/24	2,416	11,742	125,245	5,962	20,868	417	20,874	90,020	5,962	20,868	170	27,397	58,704	5,962	20,868	183
10/31	573	5,260	26,920	4,242	7,777	43	7,117	15,780	4,242	16,969	31	--	--	--	--	--

Table F-6
2001

		Mossdale (lb/day)					**Station R3 (lb/day)**					**Station R7 (lb/day)**				
Date	**Flow (cfs)**	**DO Deficit**	**BOD_u**	**NH_3 $NBOD_u$**	**KJ $NBOD_u$**	**Chlor + Pheo**	**DO Deficit**	**BOD_u**	**NH_3 $NBOD_u$**	**KJ $NBOD_u$**	**Chlor + Pheo**	**DO Deficit**	**BOD_u**	**NH_3 $NBOD_u$**	**KJ $NBOD_u$**	**Chlor + Pheo**
6/12	674	+10,191	56,778	832	10,312	251	12,011	39,308	7,319	14,970	85	9,099	24,021	3,327	11,310	22
6/19	610	+12,188	57,316	13,699	48,322	313	10,211	35,575	7,828	23,484	116	12,847	10,277	3,613	10,538	17
6/26	746	+ 8,057	55,592	2,025	27,799	375	17,725	36,256	16,569	44,183	111	12,488	7,614	2,577	13,623	46
7/10	622	+10,748	63,481	5,372	23,792	363	12,763	27,206	4,298	19,341	100	8,397	13,099	2,763	9,517	28
7/17	657	+ 3,903	44,702	2,108	16,700	401	10,289	36,188	11,836	36,967	191	12,417	14,581	2,918	11,836	47
7/24	618	+13,683	40,046	2,440	23,792	304	14,350	14,016	12,963	35,840	71	9,010	9,711	3,203	10,371	50
7/31	599	+ 4,528	36,874	11,974	34,147	336	12,938	24,260	10,643	29,121	133	10,998	7,957	4,139	14,486	60
8/07	577	+ 623	24,303	7,832	26,343	209	10,282	26,173	12,103	32,038	113	8,413	4,674	3,987	14,097	50
8/14	583	+ 2,833	40,612	11,222	34,242	261	6,926	29,278	13,524	33,666	156	9,130	17,000	2,302	14,675	51
8/21	626	2,366	23,325	1,699	16,530	183	11,493	36,508	16,221	43,256	113	10,141	11,865	2,163	14,213	55
8/28	634	1,027	18,487	782	13,612	178	12,667	34,921	5,632	24,408	111	13,694	18,487	782	14,551	63
9/11	610	988	36,563	15,054	37,634	240	7,576	36,563	5,419	23,484	133	7,576	13,143	753	11,290	64
9/18	792	0	47,472	11,922	45,149	269	11,547	25,661	12,118	44,367	238	16,252	45,805	1,759	15,050	78
9/25	1,143	6,789	49,995	16,078	55,568	333	14,196	59,253	9,308	43,157	352	26,540	38,885	8,462	32,156	151
10/02	785	4,663	44,510	11,430	40,488	165	9,326	45,781	11,236	43,200	208	16,956	34,717	3,100	24,022	83
10/16	1,279	6,907	35,224	22,410	60,286	207	15,195	68,375	66,283	140,456	231	20,720	67,754	18,337	51,448	157
10/23	2,068	15,634	43,552	2,552	21,434	257	29,035	60,303	17,777	56,648	297	30,151	68,008	12,248	37,765	271

Table F-7
2002 Data for SJR at Mossdale

Month	BOD_{10} (mg/L)	BOD_5 (mg/L)	Chlorophyll* *a* (µg/L)	Pheophytin* *a* (µg/L)
January	-	-	3.04	1.41
February	-	-	6.31	1.68
March	-	-	6.73	3.62
April	-	-	12.6	4.10
May	-	-	33.6	6.35
June	8	5.2	109	25.0
July	11	7.2	114	30.8
August	11	7.2	120	34.6
September	7	4.6	83.7	43.1
October	6.5	4.2	-	-
November	5	3.2	-	-
December	5.6	3.6	-	-

* Chlorophyll and pheophytin data are provisional, and under review

\- No data available

$BOD_5 = BOD_{10} * 0.65$

Source: R. Dahlgren (pers. comm., 2003)

Table F-8
City of Stockton Wastewater Treatment Plant Effluent Characteristics, 2002
Monthly Averages

Month 2002	Flow (cfs)	$CBOD_5$ (mg/L)	Ammonia (mgN/L)	Organic N (mgN/L)	Nitrate (mgN/L)	Nitrite (mgN/L)
January	-	-	-	-	-	-
February	39	8.4	22	2.3*	-	-
March	43.5	8.4	22.7	2.3*	-	-
April	43	5	4.3	2.3*	-	-
May	58	3.5	2	2.3	7.9	0.04
June	51	3.9	2.6	2.4	5.2	0.07
July	60	4.3	2.3	2.7	1.1	0.056
August	53	4	10.8	3.1	<0.2	0.06
September	59	4.1	23.9	2.5	<0.2	0.12
October	52	4	27.1	3.1	<0.2	0.04
November	59	4.7	27.9	3.7	<0.2	0.04
December	60	3.7	26.6	4.2	0.3	0.06
Jan 2003	52	4.3	24.9	4.6	<0.4	0.09

- No data available

* Estimated value

Source: J. Marshall, CVRWQCB (2003)

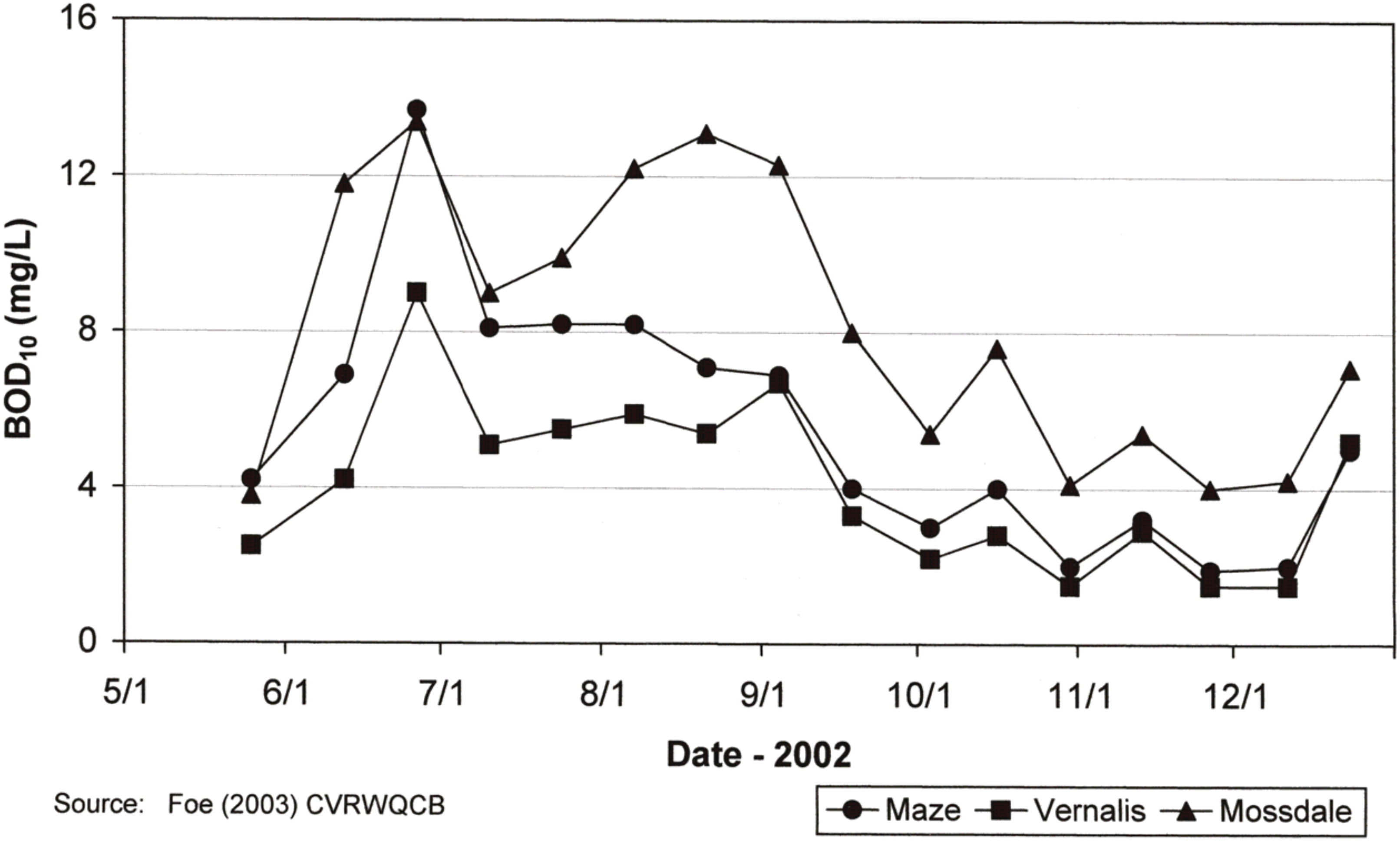
Table F-9
2002 City of Stockton BOD_u Loads

Month	$CBOD_5$ (mg/L)	$CBOD_u$ (lb/day)	NH_3 + OrgN (mg/L N)	$NBOD_u$ (lb/day)	Total BOD_u (lb/day)
January	-	-	-	-	-
February	8.4	4,423	24.3	23,387	27,810
March	8.4	4,876	25.3	26,847	31,723
April	5.0	2,902	6.6	7,004	9,906
May	3.5	2,740	4.3	6,155	8,895
June	3.9	2,685	5.0	6,293	8,978
July	4.3	3,483	5.0	7,403	10,886
August	4.0	2,862	13.9	18,180	21,042
September	4.1	3,266	26.5	38,584	41,850
October	4.0	2,808	30.1	38,626	41,434
November	4.7	3,744	31.7	46,155	49,899
December	3.7	2,997	31.2	46,197	49,194

$NBOD_u$ = (NH_3 + OrgN) * 4.57 * City Flow * 5.4
Total $CBOD_u$ = $CBOD_5$ * 5.4 * City Flow * 2.5

Figure F-1

BOD_{10} in Lower San Joaquin River - 2002



Source: Foe (2003) CVRWQCB

Appendix G
Responses to Request for Comments on Impact of Minimizing SJR Vernalis Diversion down Old River

Subj:	**Re: Effects of SJR Flow Down Old River on DWSC DO**
Date:	2/10/2003 4:51:57 PM Pacific Standard Time
From:	Jherrlaw
To:	Gfredlee

Dear Dr. Lee:

The questions and suggestions you raise run into long standing water rights issues. Absent the export pumps for the state and federal projects, the flow of the San Joaquin River would naturally split at the point where Old River breaks off from the main stem. Approximately half of the flow would go each way. The export pumps draw water toward themselves by lowering the water levels in the immediate vicinity, which causes the surrounding waters to flow towards the low spot. The net effect is that not only is Sacramento water drawn to the export pumps, but local waters also are drawn directly to the pumps, including the flows from Old River. When the exports are in excess of the Vernalis flow, most if not all (depending on tides) of the San Joaquin River is drawn through the South Delta to the pumps.

This additional flow does not help local diversions because the lowered water levels remain a function of the export pumps. Absent a decrease or shut down of the export pumps, this condition will continue. In the discussions between SDWA, DWR and USBR, it was decided that the only way to mitigate this lowered water level problem (there is also a quality problem) was to trap the incoming high tides when necessary and isolate the trapped tidal water from the export pumps. This action, depending on flow and tides, also results in more if not all of the flow of the San Joaquin River going down the main stem to the DWSC. This action also results from the installation and operation of the HOR barrier.

However, the HOR barrier, by cutting off San Joaquin River flow exacerbates the lowered water level problems in the South Delta because the export pumps continue to operate. To address this, the relevant parties have agreed to allow flow through the HOR when necessary to meet local diversion needs.

At this time, the tidal barriers are only allowed to operate from (approx) April through November. Any proposal to operate the HOR outside of its currently authorized time frame (April - June and September - October) would have the same effect of exacerbating the lowered levels in the South Delta if the tidal barriers are not also functioning. Hence, we don't want to cure the DO problem by making the water level problem worse.

Proposing to alter Sacramento and San Joaquin River flows to help meet the DO objective makes sense, but will be strongly opposed by DWR, USBR, and their contractors. Current modeling indicates that the projects are incapable of meeting all their obligations, and therefore any proposed allocation of flows for DO will end up shorting some other use.

Given the above, Alex has proposed additional pumping over the tidal barriers (to increase the amount of water trapped behind them). Such an action would provide additional DWSC flow, while not affecting the total amount of water in the system or exports. Once the water flows through the DWSC it meets the cross-Delta flow and can head for the export pumps. This has the same effect as your proposal to pull more water to the pumps but also takes care of the local diverters.

Without having and numbers for support, I conclude that the operation of the export pumps is just as responsible for the DO sags as is the DWSC. The Regional Board should, as part of their TMDL, request the SWRCB use its water rights authority to make the projects mitigate their effects on DO.

Hope this helps,
JOHN HERRICK

JOHN HERRICK
Attorney at Law
4255 Pacific Avenue, Suite 2
Stockton, CA 95207
(209) 956-0150
(209) 956-0154 FAX

Subj: **Re: Effects of SJR Flow Down Old River on DWSC DO**
Date: 2/10/2003 11:14:01 PM Pacific Standard Time
From: DeltaKeep
To: G. Fred Lee
CC:

Fred: As I observed, you've suggested an elegant, intelligent and sensible approach. Beyond that, you're probably right. The only downside I can see is that it would entail a replumbing of the Central Valley and a massive water rights proceeding. As John points out, DWR, the Bureau and contractors would likely come unglued. I suspect that DFG, NMFS and USFWS might also find themselves mainlining malox. A potential solution might be to dredge Old and Middle Rivers and Grantline Canal and pump Sacramento River water into the South Delta for recirculation (not sure tidal flow would be sufficient). Entrainment is a likely problem. Water quality might be (and who is going to pay for the baseline monitoring?). The comparative costs of aeration might seem like chump-change. The obvious solution is to eliminate the Friant Kern canal. Alternatively, shut down the pumps and let the folks down south drink Gatorade. I believe a global solution that includes a tweaking of the HOR barrier, aeration, load reductions, a cap on diversions/loads and the tagging of all responsible parties with the responsibility for solving the problem would move us incrementally in the direction of a solution. I agree with John that the pumps should mitigate. I would be remiss if I neglected to mention that we still believe that pumping from the South Delta into the San Joaquin would require a permit. I really enjoyed reading your "Effects" paper. You have likely glimpsed what the rest of us haven't yet perceived. By the way, DO at R&R has rebounded all the way up to 0.4 mg/l. Cheers! Bill

Subj: **Re: Effects of SJR Flow Down Old River on DWSC DO**
Date: 2/11/2003 5:19:35 PM Pacific Standard Time
From: hildfarm@gte.net
To:
Gfredlee@aol.com, Deltakeep@aol.com, jherrlaw@aol.com
CC: FoeC@rb5s.swrcb.ca.gov, GowdyM@rb5s.swrcb.ca.gov
File: **RonOttbarriersandfish.doc** (26112 bytes) DL Time (26400 bps): < 1 minute
Sent from the Internet (Details)

TO: Fred, John, and Bill

FROM: Alex Hildebrand

Thank you, Fred, for your 2/10 e-mail re flow down Old River. We are sending a copy of a recent e-mail to Ron Ott which also addresses keeping Vernalis flow out of Old River and even augmenting flow into the DWSC by reversing flow from Old River into the San Joaquin for fishery benefit. This is physically entirely feasible and is what I have urged for some time as a way to address various problems.

I have read John and Bill's comments. Hopefully my e-mail to Ron Ott responds in some degree to their comments. Perhaps a four-way conference call on the issue would be useful.

With regards to all three of you,

Alex
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February 6, 2003

To: Ron Ott ronott@water.ca.gov

From: Alex Hildebrand hildfarm@gte,net
Phone (209) 823-4166
Fax (209) 825-6180

Dear Ron:

This e-mail is to explain in somewhat greater detail the suggestion I made on January 29 for an alternate way to dispose of fish that are screened at the export facilities. You pointed out that better screening of fish will have limited value if we don't also reduce the mortality of screened fish during the process of returning them to the Delta. You also discussed the difficulty resulting from debris at the screens. A substantial portion of that debris derives from the San Joaquin River.

Background
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I will first outline the future South Delta hydraulics on which the fish disposal system would be superimposed. The preferred alternative in the SDIT EIR will provide for three permanent tidal barriers to protect the South Delta's in-channel water supply from the drawdown of water levels and the lowering of water quality caused by export pumping. These barriers will operate on an as needed basis all year around. There will also be an operable barrier at the head of Old River (HOR) that will be operated from approximately April 15 to May 15 and again in October and November for protection of San Joaquin salmon. When the HOR barrier is operating, most of the water, fish, and debris in the San Joaquin River will be routed past Stockton to the central Delta. When the HOR barrier is open, the three tidal barriers will do almost the same thing providing that all three are operated. They will not all three be needed to protect the in-channel water supply when Vernalis flows are substantial, but they could be most of the time. When the inflow to Old River is less than the local diversions upstream of the barriers, enough water has to flow into the channels from the downstream side during the flood tide so that the barriers can capture it to maintain water level through the low tide. When export operations substantially reduce the high tide level during the conditions of low Vernalis flow, this high tide fill up of channels does not occur, and the deficit then has to be made up by using a low lift, fish friendly pump to pump upstream over one of the barriers.

Alternate method for disposal of screened fish

The purpose of the above description is to explain why the facilities will be available and could be operated to maintain a net daily flow up through Old River into the San Joaquin during dry year and typical summer San Joaquin River flow conditions. This would keep San Joaquin fish and debris from being drawn through Old River and Grantline Canal to the export pumps. It would also permit a continuous piping of screened fish to the east side of the Grantline Canal barrier to flow to the central Delta via Old River and the San Joaquin River. The fish would then never be concentrated or handled as they are for trucking and at the point of truck discharge.

It is true that some of these fish may get drawn back to the pumps from the central Delta. However, modeling has shown the velocity of flow from the central Delta toward the pumps is small compared to the tidal flows in the central Delta. They have also shown that most of the dissolved materials, such as salt, in the San Joaquin River do not end up at the export pumps if they are first conveyed to the central Delta.

Every method of conveying screened fish will have pros and cons. However, I believe this method deserves consideration.

February 23, 2003

To:	Kirk Rodgers	krodgers@mp.usbr.gov
From:	Alex Hildebrand	hildfarm@gte.net Phone (209) 823-4166 Fax (209) 815-6180
cc:	Dianna Jacobs	dkjacobs@dfg.ca.gov
	Tim Quinn	tquinn@mwdh2o.com
	Ron Ott	ronott@water.ca.gov
	Chris Foe	foec@rb5s.swrcb.ca.gov
	Fred Lee	Gfredlee@aol.com
	John Herrick	jherrlaw@aol.com

During the South Delta Fish Forum meetings there has been extensive discussion of the difficulty of screening and preserving fish at the export facilities. The situation differs from major screening operations elsewhere because the screens are at an hydraulic “dead end”. This precludes flushing screened fish past the screens and exacerbates serious problems caused by drawing trash to the screens.

At the January 29 meeting I suggested a possible method of preserving screened fish by discharging them on a continuous basis upstream of the three anticipated permanent South Delta tidal barriers, and moving them to the central Delta via Old River and the San Joaquin River. This concept was further explained in my February 6 e-mail to Ron Ott which is attached hereto.

At the February 18 meeting I suggested that by taking that proposal a step further we could avoid the “dead end” problem most of the time. Any way of addressing the fish-screening problem will have pros and cons. On the pro side, this concept would incidentally also substantially reduce the trash problem, and the difficulty of meeting salinity and dissolved oxygen requirements in South Delta channels and the dissolved oxygen standard in the Stockton Ship Channel, and would reduce salinity in the DMC and the main stem of the San Joaquin River.

This e-mail responds to your request for a written explanation of this concept. I won’t repeat the background provided in the e-mail to Ron Ott.

The concept includes moving the CVP intake to Clifton Court and putting an additional tide gate south of the Clifton Court intake. Screened water would then be taken into Clifton Court during the flood tide. At that time all tide gates would be open. The screened fish and trash would be swept on past the screens by the water needed to fill up many miles of South Delta channel. The tide gates would all be closed during the ebb tide so that screened fish would not be drawn back to the screens.

During the ebb tide the intake of water to Clifton Court would be reduced or eliminated. Any fish that are screened during the ebb tide would be held until they could be added to the bypass flow during the next flood tide.

During low Vernalis flow and low local agricultural diversions (such as all this winter) there will be tidal pumping of water up through the head of Old River and thence down the San Joaquin to the central Delta if all tidal barriers are operated. As Vernalis flows increase, the water stage at the head of Old River increases. When the Vernalis flow is too high for tidal pumping it will be necessary to augment the water stage upstream of the barriers in order to maintain the daily flow up through the head of Old River. This would be done with one or more low-lift, fish-friendly pumps at one or more of the tidal barriers. (Some such pumping will be needed even without this proposed concept when low Vernalis flow, high local diversions, large drawdown of high tide levels by export pumping, and low natural tides combine to create the conditions which we apparently had last July).

As Vernalis flows increase further it will be necessary to use a second stage of low head booster pumping over a barrier at the head of Old River. When the Vernalis flow exceeds about 6000 cfs (which is not much of the time), it will not be possible to reverse flow in Old River. However, the fish could then be flushed downstream instead of upstream past the screens at times when the flow into Clifton Court is less than the flow down Old River.

Water quality benefits related to this concept were mentioned above but will not be explained here because they are not the focus of this forum. There are obviously many details that need to be examined and modeled. However, the benefit of reducing the “dead end” problem should justify examination of a concept that may reduce that problem. This is particularly true if it can be done while also benefiting rather than exacerbating some serious water quality problems.

I urge you and your co-chairs to arrange to have these concepts evaluated.

Attachment

Subj: **Re: Effects of SJR Flow Down Old River on DWSC DO**
Date: 2/14/2003 10:24:11 AM Pacific Standard Time
From: Jherrlaw
To: FoeC@rb5s.swrcb.ca.gov
CC:
DeltaKeep, Gfredlee, hildfarm@gte.net, GowdyM@rb5s.swrcb.ca.gov

Dear Chris:

Neither Alex or I remember any study which measured the "natural" split of flows where Old River breaks off from the main stem. The 1980 Report on the Effects of the CVP on the Delta may have that info included in its calculations, but it may not be apparent even to the educated eye. [I will forward you a copy of that Report as it shows what the projects do to the water levels, circulation, flows and quality in the South Delta.] Alex believes that if the Report has the info, it may not be up to date in light of subsequent changes.

Your next question dealt with exporter preference to water going down Old River or being forced towards the Central Delta. We must make a distinction between federal and state contractors. The Exchange contractors receive their water through the DMC which takes water from the federal pumps. It is these pumps which would take in most of the San Joaquin flows when no HOR or tidal barriers are installed or operated. Hence, their water quality would get worse at those times the San Joaquin has poor quality. They therefore, like all DMC users, should prefer that less water be allowed to go down Old River.

Southern Cal gets its water from the state pumps which fill Clifton Court Forebay which feeds the California Aqueduct. These pumps get much less of the San Joaquin flow when barriers are absent due to their location and the hydraulics of the Sacramento water getting to both the state and federal pumps. Barrier modeling shows that use of the tidal barriers in some summer months (actually during poor quality times) can slightly raise the TDS of the water at Clifton Court even after it has been diluted in the Central Delta. As I recall, its only by a few parts. They therefore would prefer the water go down Old River under those limited circumstances. However, DWR, as the proponent of the tidal barrier project concludes this increase in TDS under the limited circumstances is insignificant. Contra Costa, which has a diversion downstream (north) of the state pumps, disagrees and doesn't want a 5 parts or less increase at their diversion.

That's a long explanation/guess at what other might prefer. I will pull the old MOU and fax it to you. JOHN

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