San Joaquin River Deep Water Ship Channel Low DO Problem and Its Control

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- Characteristics of SJR DWSC Low DO Problem
  - Occurrence of Low DO
  - Cause of Low DO & Sources of Oxygen Demand
  - Factors Influencing Low DO
- Management Approaches
  - Recommended Approach

(Presented at SETAC World Congress Portland, OR, November 2004, Updated December 2004)

Abstract

San Joaquin River Deep Water Ship Channel Low-DO Problem
- Causes and Remedy -

Dissolved oxygen (DO) concentrations in the seven-mile reach of the San Joaquin River (SJR) Deep Water Ship Channel (DWSC) downstream of the Port of Stockton are chronically below the water quality objectives (WQOs). In addition to being adverse to aquatic life in the DWSC, the low DO is believed to inhibit the homing of the fall-run of Chinook salmon. This has led the California Central Valley Regional Water Quality Control Board to list the DWSC near the Port of Stockton as 303(d) "impaired," which requires the development of a TMDL to control DO depletion to meet the WQOs. Beginning in 1999, about $4 million in studies have been conducted on the occurrence of DO below the WQOs, the factors influencing the depletion of DO below the WQOs, and the sources of oxygen-demand constituents for that critical reach. It has been found that the more than 3-fold greater depth and increased volume of the DWSC compared with the upstream SJR slow the river flow. This reduces the oxygen-demand assimilative capacity of the critical reach of the DWSC by providing more time for the oxygen demand to be exerted there; at times of low SJR flow, the residence time for oxygen demand exertion in the DWSC is almost a month. The flow of the SJR through the DWSC is controlled by reservoir releases and upstream agricultural and domestic water supply diversions. In addition, algae (fed by excessive discharge of algal nutrients from agriculture) that grow in the SJR DWSC watershed die in the DWSC and exert an oxygen demand; ammonia from Stockton domestic wastewater also contributes to the oxygen demand.

Those interests that benefit from the existence of the Port of Stockton/DWSC or the flow diversions, as well as oxygen-demand dischargers are responsible for the impacts of the DWSC dissolved oxygen depletion below the WQOs. The TMDL for solving the SJR DWSC low-DO problem should include:

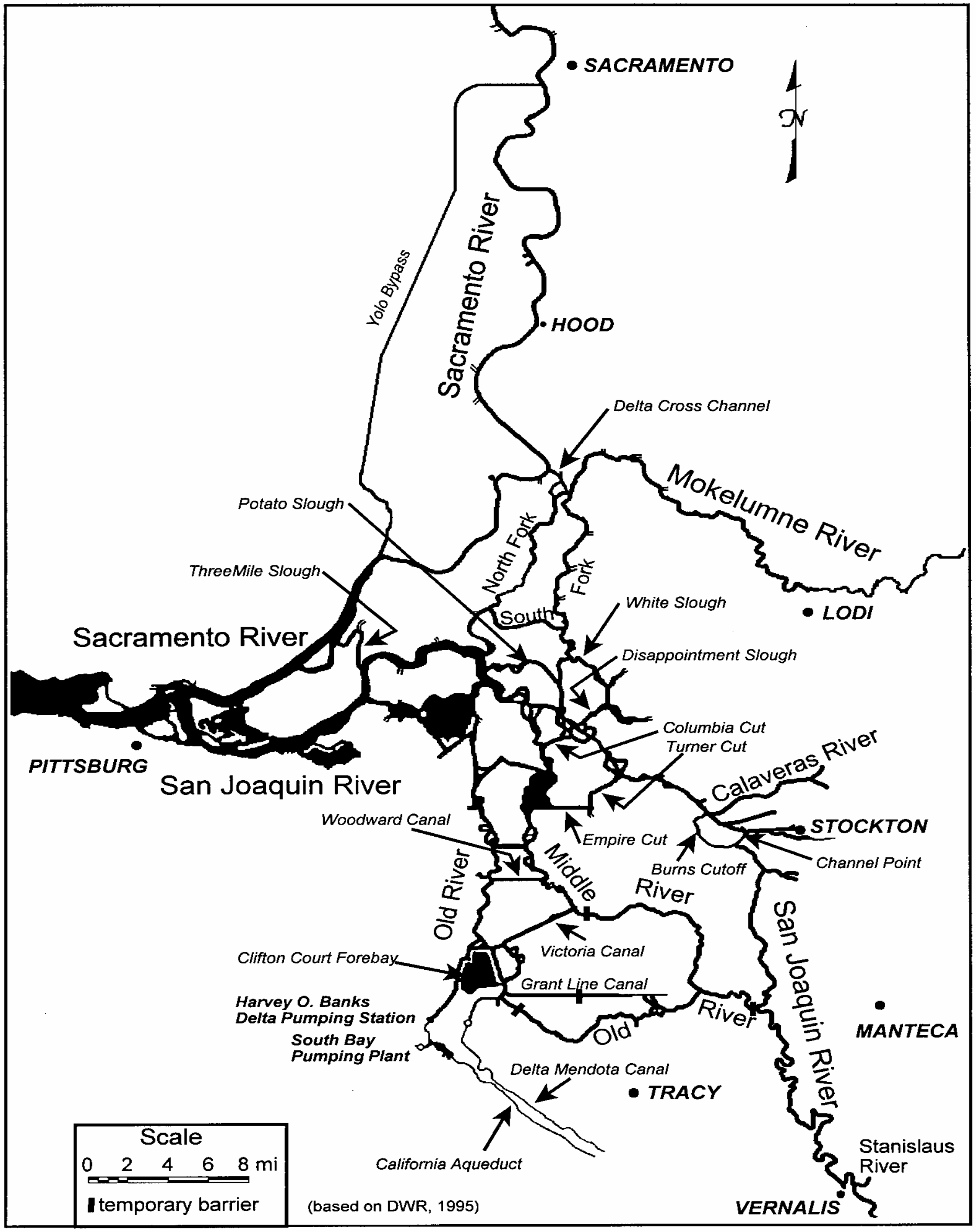
- Maximizing the minimum flow of the SJR through the DWSC,
- Evaluating the cost of aeration of the DWSC at various SJR DWSC flow levels,
- Obtaining federal and other funding to mitigate for the development and maintenance of the DWSC,
- Evaluating the potential for controlling the nutrients within the Mud and Salt Slough watersheds that support the growth of algae in those watersheds that subsequently contribute to the oxygen demand in the DWSC that decreases the DO concentrations below the WQO,
- Controlling the city of Stockton's domestic wastewater ammonia discharges.

Information on each of these aspects is presented, as well as an approach for integrating these components into a TMDL to solve the low-DO problem in the DWSC.

Definitions

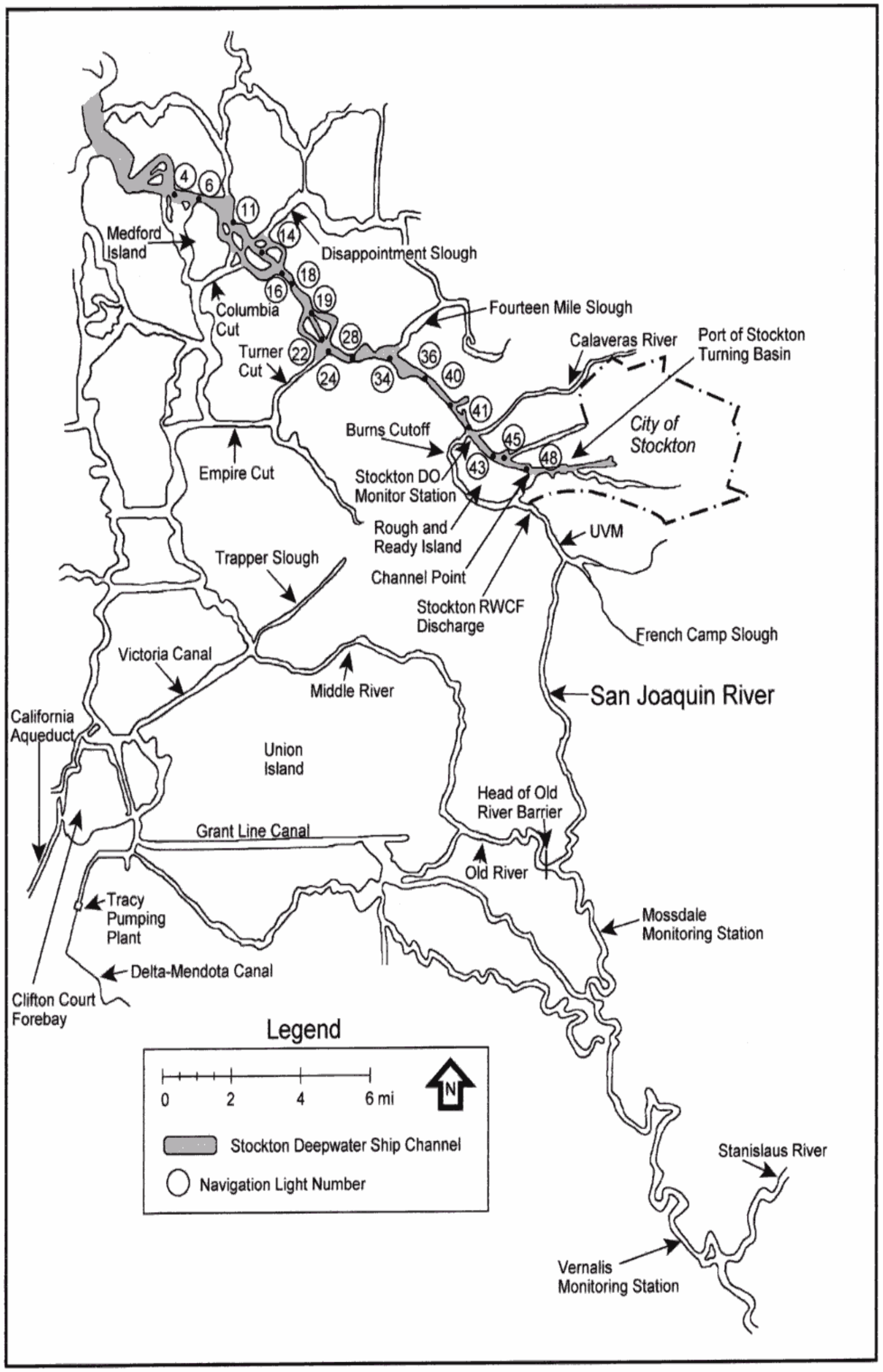
SJR	San Joaquin River
DWSC	Deep Water Ship Channel
DO	Dissolved Oxygen
WQO	Water Quality Objective
CVRWQCB	Central Valley Regional Water Quality Control Board
TMDL	Total Maximum Daily Load
CWA	Clean Water Act
DIP	Delta Improvement Package

Sacramento River San Joaquin River Delta

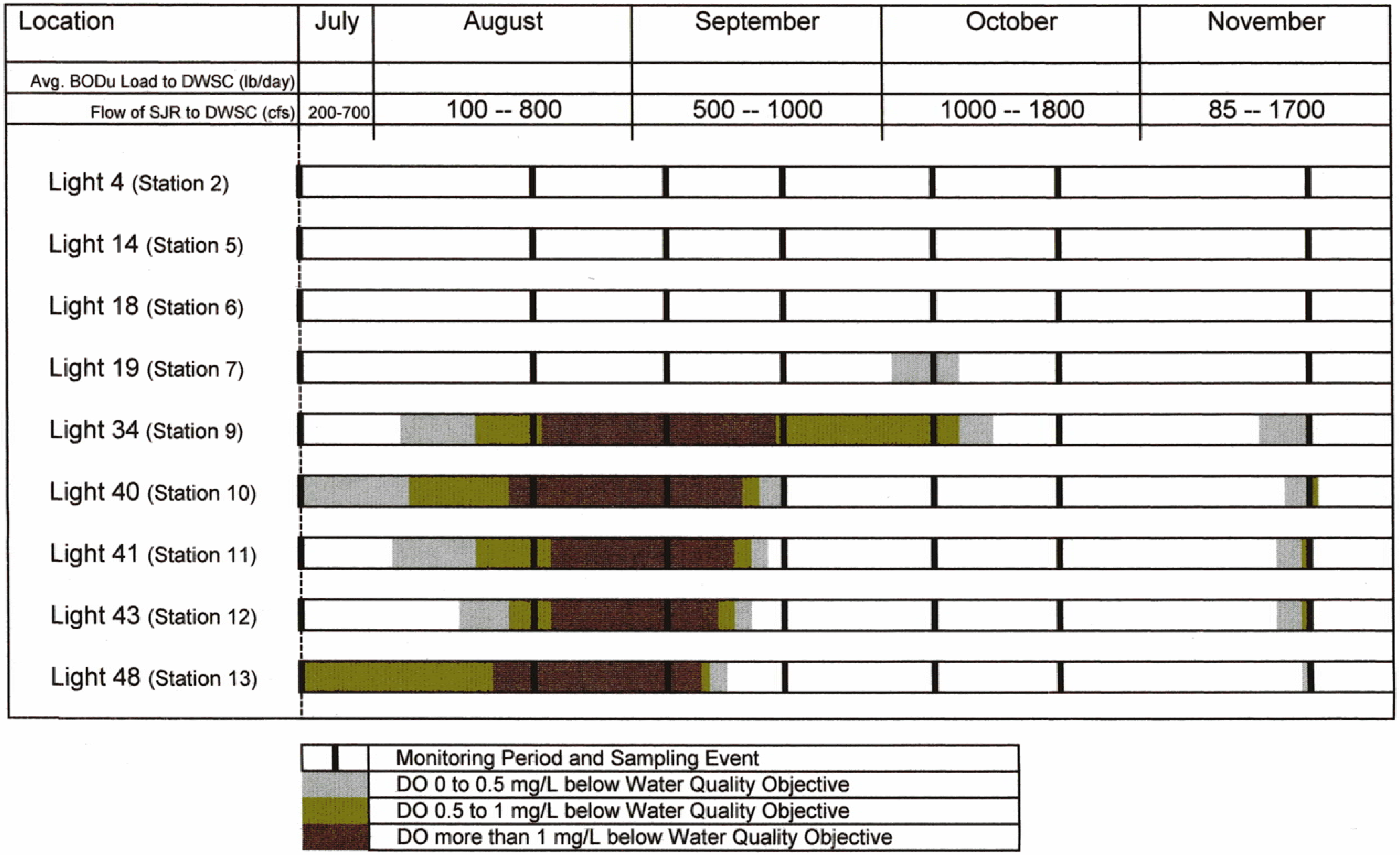


San Joaquin River Deep Water Ship Channel

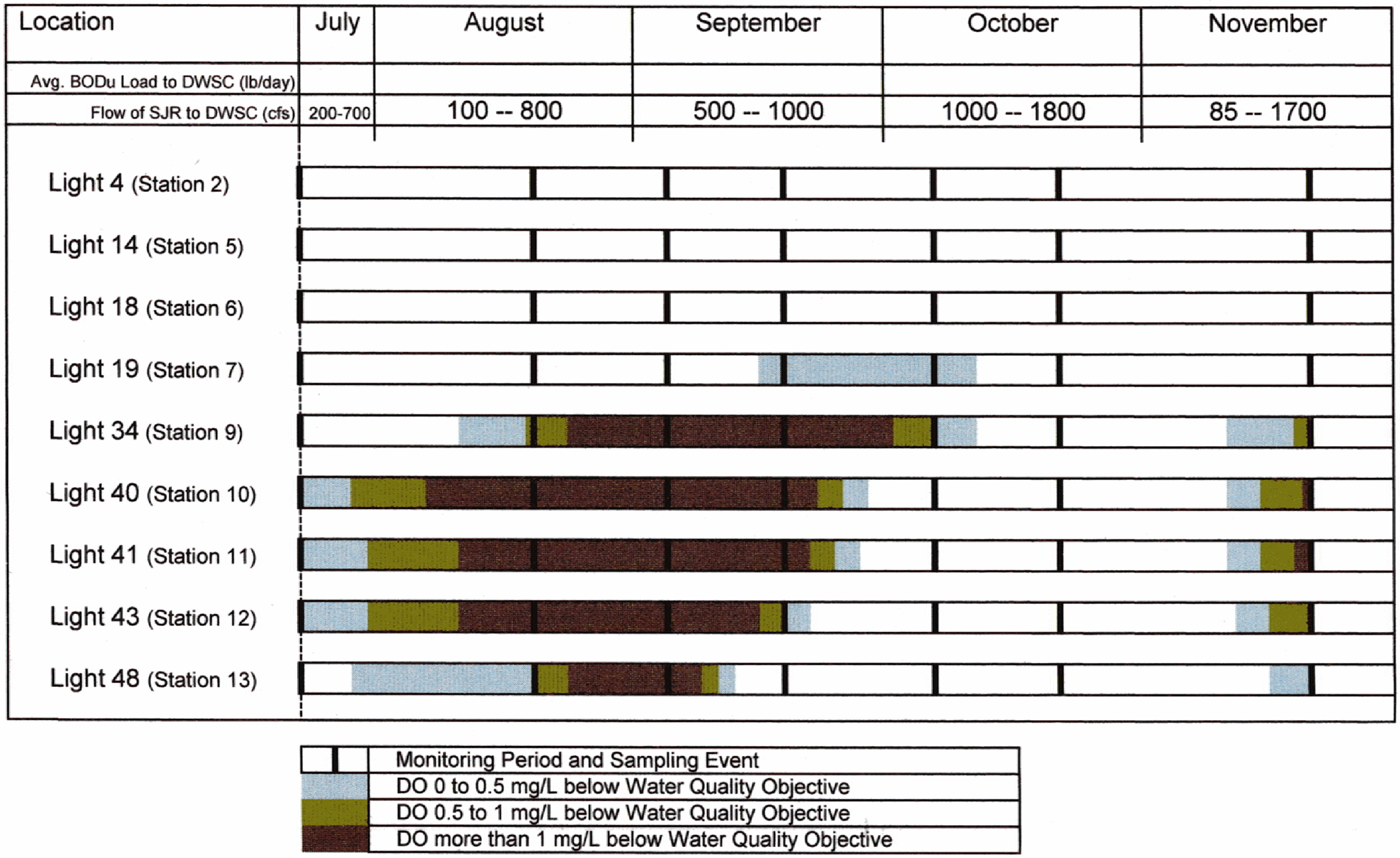
Critical Low-DO Reach



Incidence of Dissolved Oxygen below WQO
Surface Water 2002



Incidence of Dissolved Oxygen below WQO
Bottom Water 2002

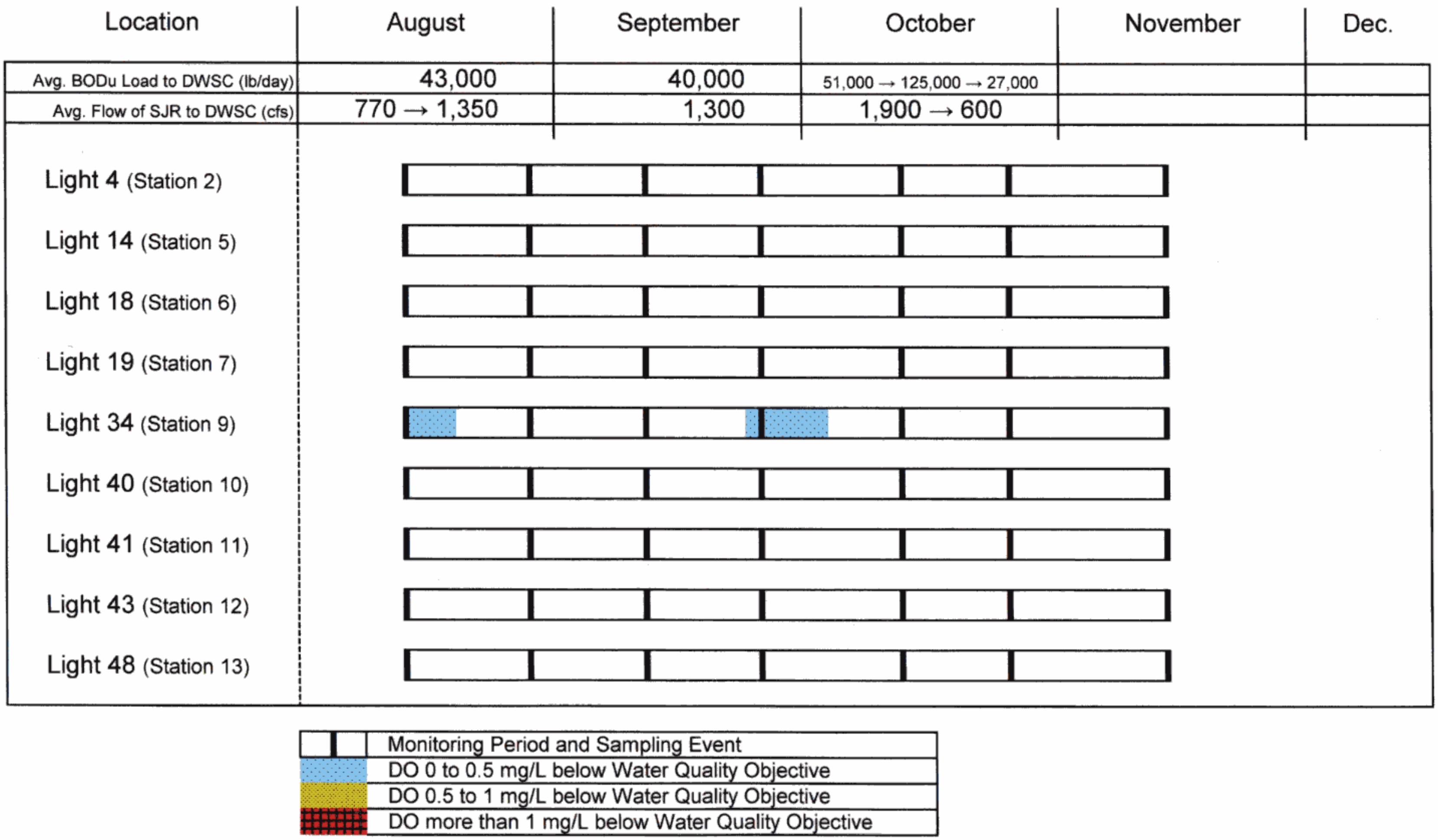


Incidence of Dissolved Oxygen below WQO
Surface Water 2000

Location	August	September	October	November	Dec.
Avg. BODu Load to DWSC (lb/day)	43,000	40,000	51,000 → 125,000 → 27,000		
Avg. Flow of SJR to DWSC (cfs)	770 → 1,350	1,300	1,900 → 600		
Light 4 (Station 2)					
Light 14 (Station 5)					
Light 18 (Station 6)					
Light 19 (Station 7)					
Light 34 (Station 9)					
Light 40 (Station 10)					
Light 41 (Station 11)					
Light 43 (Station 12)					
Light 48 (Station 13)					

- Monitoring Period and Sampling Event
- DO 0 to 0.5 mg/L below Water Quality Objective
- DO 0.5 to 1 mg/L below Water Quality Objective
- DO more than 1 mg/L below Water Quality Objective

Incidence of Dissolved Oxygen below WQO
Bottom Water 2000



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*

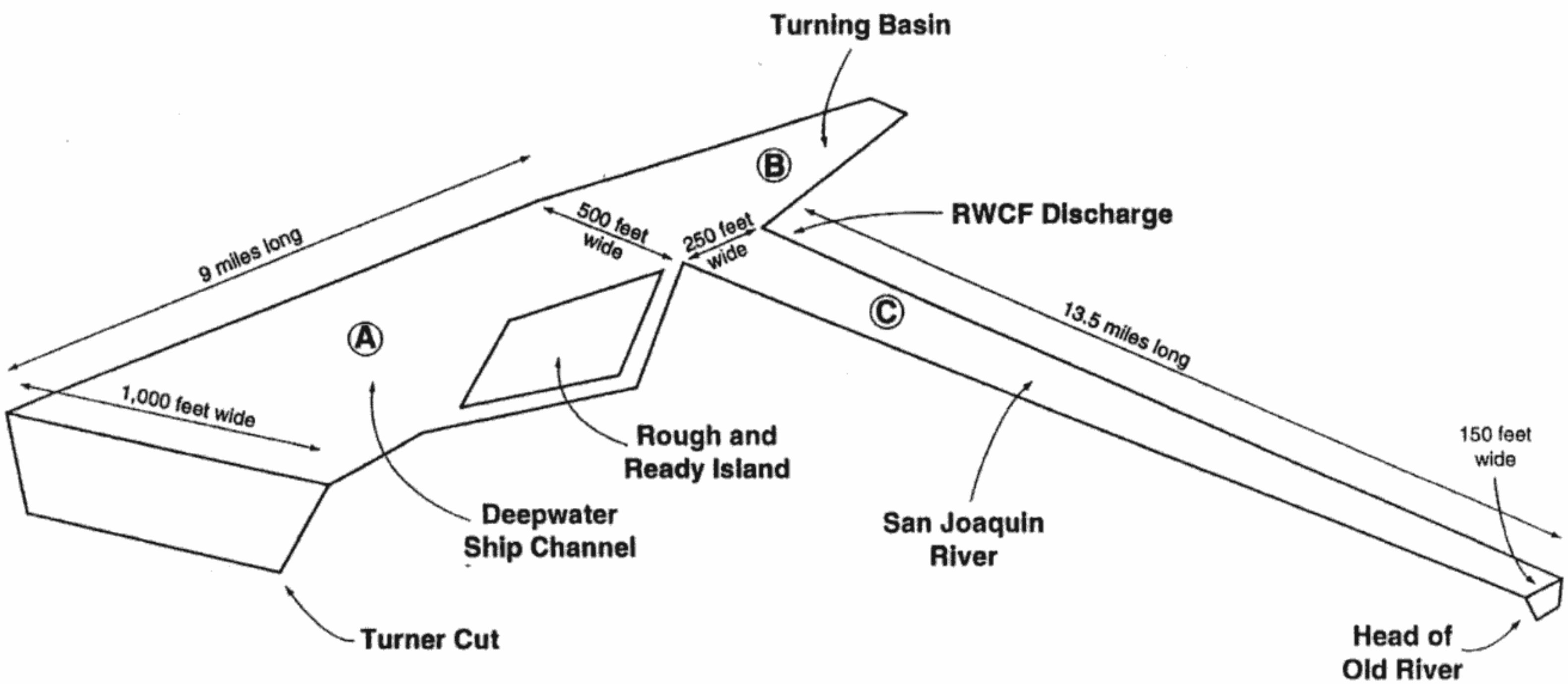
$$\text{Algae} \xrightarrow{\text{Death}} + O_2 \longrightarrow CO_2 + H_2O$$ *Respiration*

SOD — Sediment Oxygen Demand

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

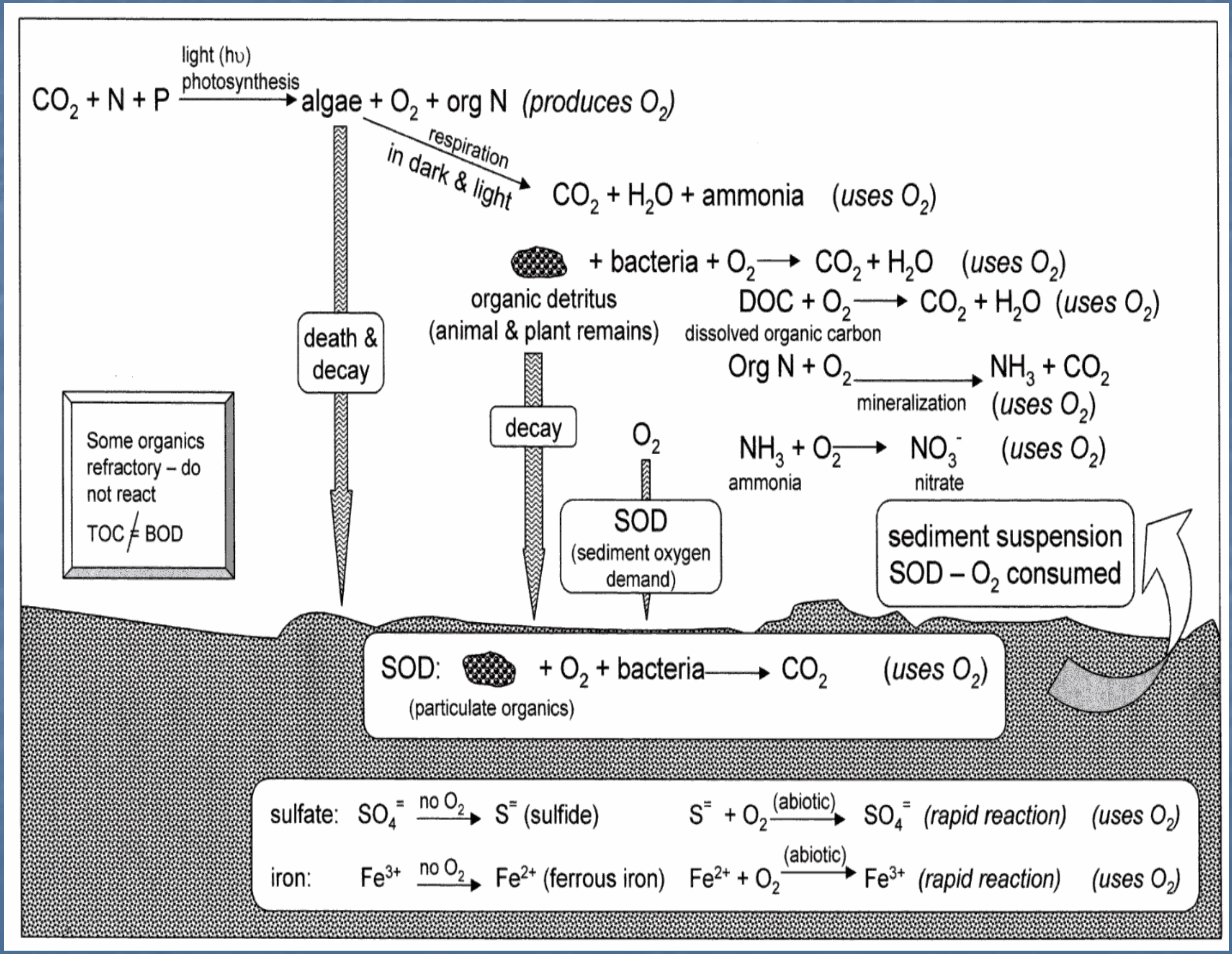
$$\text{Organic} + O_2 \xrightarrow{\text{Biotic}} CO_2 + H_2O$$

Characteristics of the Deep Water Ship Channel (DWSC)



from Jones & Stokes (1998)

Oxygen Demand Reactions and Processes



Nature of Low DO Problem
DWSC First 7 Miles

- DO Less Than Water Quality Objectives
  - Downstream of Port of Stockton
  - Summer, Fall, Some Winters
- Listed by CVRWQCB as CWA Section 303(d) “Impaired”
  - Requires Development of TMDL to Control DO WQO Violations
- Studies Started in 1999 with CALFED Support to Characterize Low DO Problem: Cause, Extent, Magnitude
- 2000 & 2001 Studies Included Upstream Sources of Oxygen Demand in SJR DWSC Watershed
  - > $4 million over 4 years
- Synthesis Report by Lee & Jones-Lee Spring 2003 and Supplements
  - Available from www.gfredlee.com

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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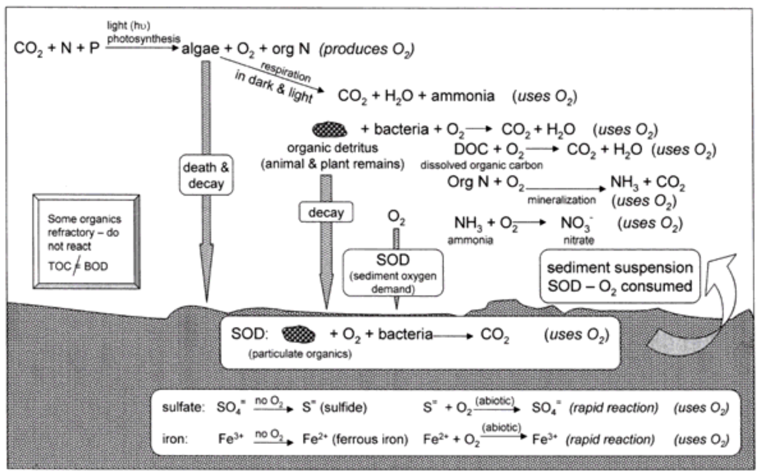


Conceptual Model of DO Depletion Reactions in the SJR DWSC

Report Submitted to
SJR DO TMDL Steering Committee/Technical Advisory Committee
and
CALFED Bay-Delta Program
March 2003

Nature of DWSC Low DO Problem

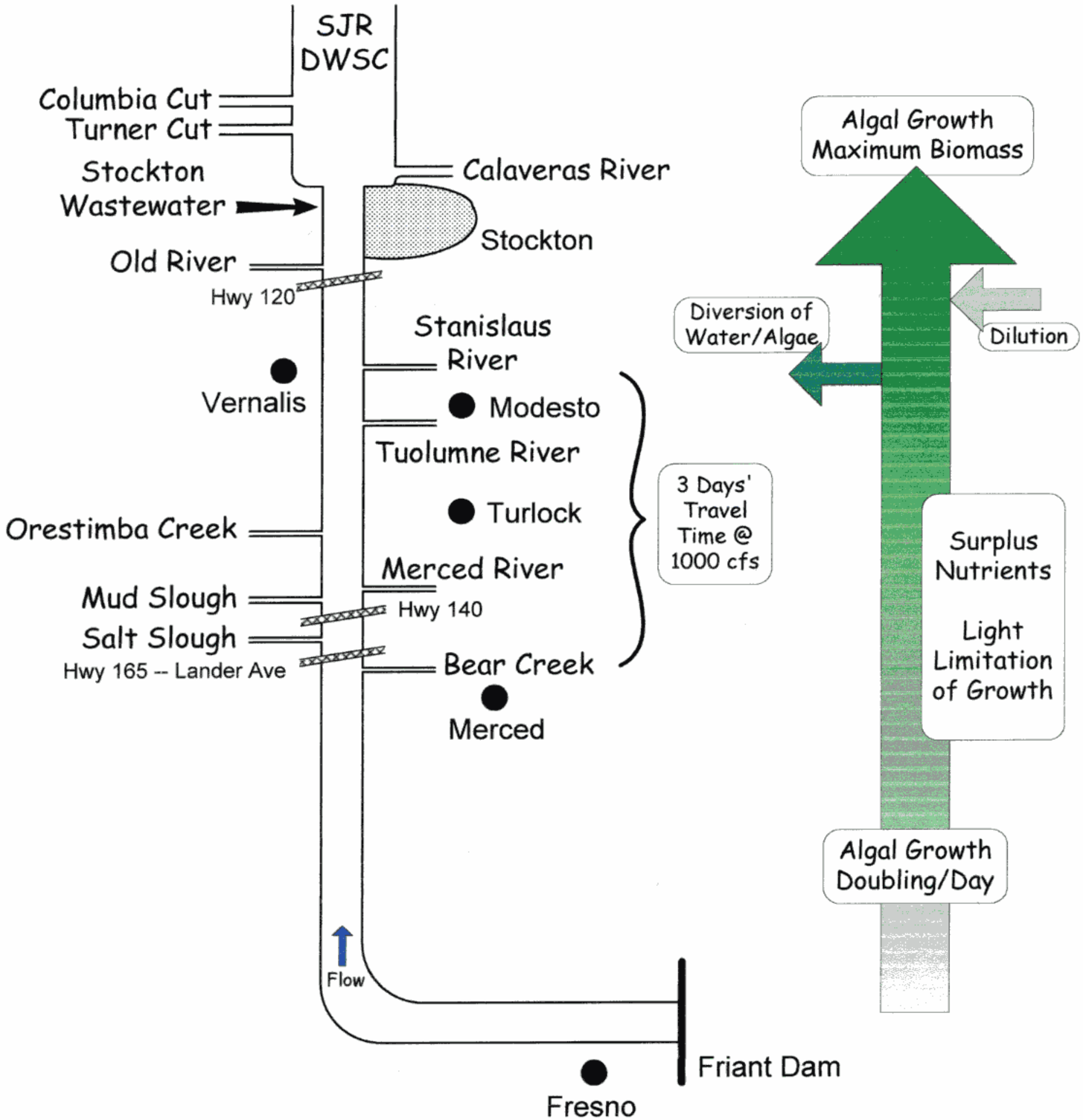
- Problem Only in First 7 Miles of DWSC Downstream of Port of Stockton
  - Downstream Extent Limited by State & Federal South Delta Water Export's Drawing Sacramento River Water to South Delta for Export
- Oxygen Demand Due Primarily to
  - Ammonia in Stockton Wastewater Discharge
    - Nitrification Reactions
  - Algae That Enter DWSC from Watershed, Die & Exert Oxygen Demand during Decomposition

Upstream

Algal

Oxygen

Demand



Non Typical TMDL

- Typical TMDL Involves
  - Defining Sources of Pollutant Loads, and
  - Allocation of Responsibility for Control to the Dischargers of Pollutants

- SJR DWSC DO TMDL Has to Include Impact of
  - Altered SJR Geometry - Development of the DWSC
  - Altered DWSC Oxygen-Demand Assimilative Capacity - Hydromodification of the SJR

Allocation of Responsibility

- Who Has to Pay for Control?
- CVRWQCB – One-Third to Each:
  - Port of Stockton Deep Water Ship Channel
  - Reduced Flows in DWSC by Upstream Diversions
  - Oxygen Demand Loads
- Joint and Several Responsibility – All Are Equally Responsible
  - Work Out Control & Costs among Responsible Parties
- Dischargers Do Not Want to Have to Control Nutrients
  - Be Named Responsible Party
- Irrigation Districts - No SJR Flow/Diversion Alterations Required
  - Water Rights Issues

Impact of Development of DWSC on DO Problem

- SJR Upstream of DWSC
  - Same Algal Oxygen Demand Load/Concentration
  - No Low DO Problem
- DWSC Deeper Than Upstream SJR
  - SJR 8 – 12 ft; DWSC 35 ft
  - Greatly Slows Transport of Oxygen Demand through Channel
    - More Time for Oxygen Demand to Be Exerted
  - If DWSC Not Periodically Dredged, Channel Would Shoal-in
    - Low DO Problem Would Eventually Be Reduced/Eliminated
  - Primary Responsible Party for Low DO Problem
    - Port of Stockton and Those Who Benefit from Maintenance Dredging of DWSC

Nature of DWSC Low DO Problem

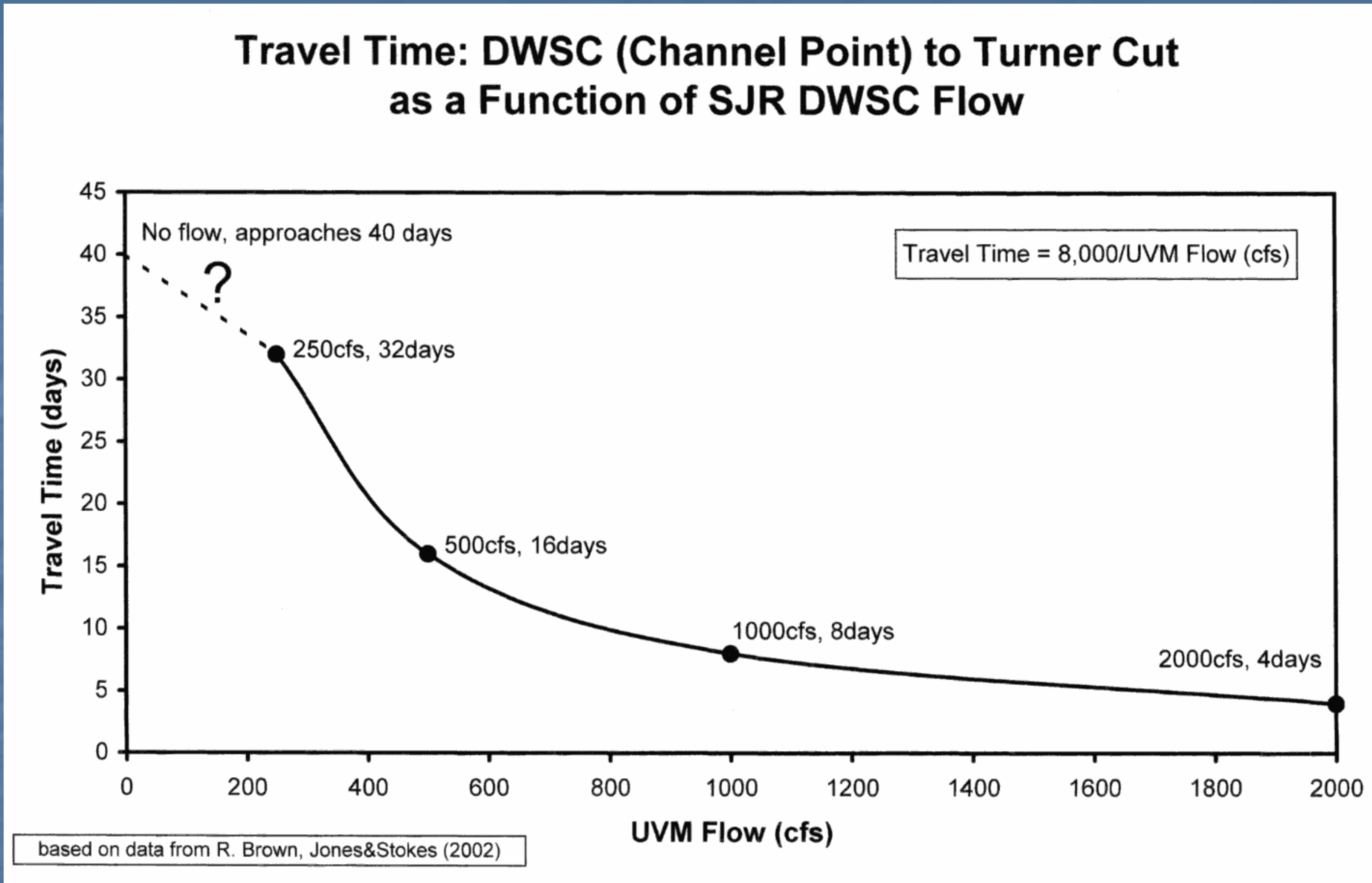
Oxygen Demand Constituents

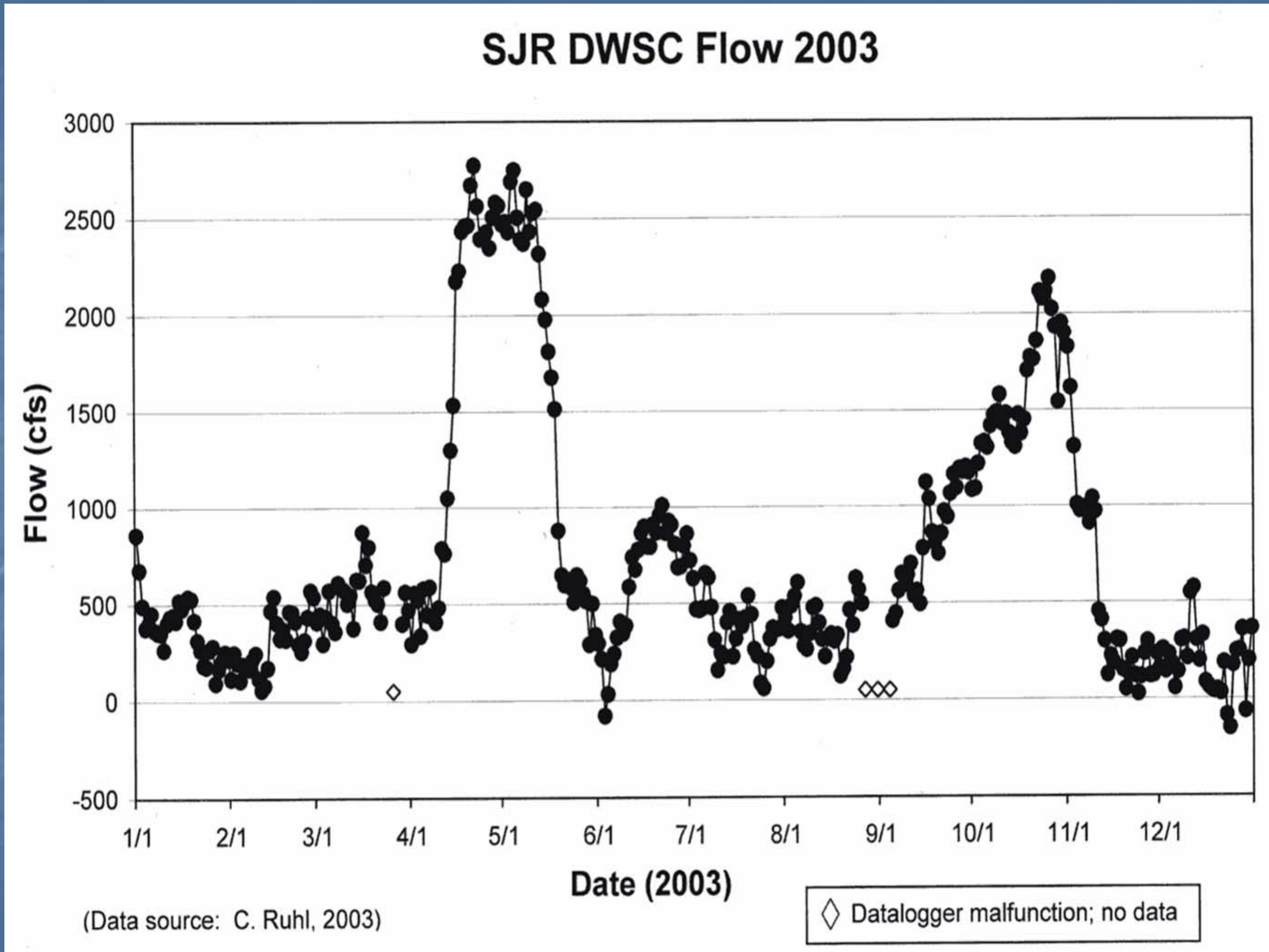
- City of Stockton Wastewater Ammonia
- Algae that Develop Upstream of DWSC

- Relative Significance of Each Source Depends on Flow of SJR through DWSC and Season,
  - Rarely Exceeded 50% of the DWSC Oxygen Demand Load
  - City of Stockton Ammonia Load Depends on Season and other Factors
  - Low SJR DWSC Flow - Low Algae & Possibly Higher Ammonia Loads

Impact of SJR DWSC Flow

- At Higher SJR Flow through DWSC – No Low DO Problem
  - Travel Time of Oxygen Demand through DWSC Too Short for Appreciable Exertion of Oxygen Demand in DWSC
  - DWSC Water Mixes with Sacramento River Water Discharged into Turner Cut
    - Does Not Appear to Cause Low DO in Central Delta, Turner Cut, or Middle River – Needs Study


Travel Time: DWSC (Channel Point) to Turner Cut
as a Function of SJR DWSC Flow
No flow, approaches 40 days
?
Travel Time = 8,000/UVM Flow (cfs)
250cfs, 32days
500cfs, 16days
1000cfs, 8days
2000cfs, 4days
Travel Time (days)
45
40
35
30
25
20
15
10
5
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
UVM Flow (cfs)
based on data from R. Brown, Jones&Stokes (2002)


SJR DWSC Flow 2003
Flow (cfs)
3000
2500
2000
1500
1000
500
0
-500
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
Date (2003)
(Data source: C. Ruhl, 2003)
◊ Datalogger malfunction; no data

Importance of SJR Flow Through the DWSC-

- SJR Flow through DWSC Variable:
  - Negative Flow (Upstream Flow) to Head of Old River to Several Thousand cfs Downstream
    - Depends on Upstream Diversions of SJR Water for Central Valley Irrigation & Domestic Water Supply for Southern CA and Bay Region
- Flow through DWSC >1500 cfs Can Eliminate or Greatly Reduce Magnitude of Low DO Problem
- If Substantial Amount of SJR Vernalis Flow Allowed to Pass through DWSC before Export to Central & Southern CA and Bay Area, Few or No Violations of DO WQOs

Oxygen Demand Sources

- City of Stockton Ammonia Discharge Problem
  - Will Be Greatly Reduced by Advanced Treatment for Ammonia Removal
  - Reduce Ammonia from Current 25 – 30 mg/L to 2 mg/L
    - 2 mg/L Ammonia Monthly Average Can Still Cause Low DO Problems in DWSC under Low-SJR-Flow Conditions
      - Need to Keep SJR DWSC Flows Elevated to Reduce Cost of Aeration to Control Oxygen Demand
- Algae as Source of Oxygen Demand – Difficult to Control
  - Algal Growth Driven by Nutrients from Agricultural Runoff & Discharges in Mud and Salt Slough Watersheds
  - May Not Be Economically Feasible to Significantly Reduce Algal Oxygen Demand Load
    - Must Be Evaluated after Salt Load Control Established

Phosphorus Control

- Typical Deterministic Modeling Predicts That Because of Large-Surplus of Algal-Available N and P, Small Reduction in N and/or P Loads/Concentrations Will Have No Impact on Oxygen Demand Load

- However, Rhine River and OECD Eutrophication Study Results Show That Reduced Phosphorus Loads to Waterbodies with Large Surplus of Available P Resulted in Reduced Algae Biomass and Improved Water Quality

- Impact of P Control Must be Evaluated as Part of Developing SJR DWSC Low DO Control Approach

Nutrient Control Issues

- N vs P, or Both
  - N/P Ratios – Great Surplus of N in SJR DWSC Watershed
    - Must Focus on Potential for P Control
- P Control Goal
  - Not Total Annual P Load
    - Much of P Load Does Not Impact DWSC Low-DO Problem
      - Short Hydraulic Residence Time
  - Focus on P Loads over Limited Periods of Time That Lead to Algae That Cause DO Concentrations < WQO
    - Summer & Fall
    - Most Important: P Loads Entering SJR & Tributaries at Greatest Distance from DWSC
      - Greatest Time for Algal Growth
    - Focus on P Loads That Develop Seed Algae That Lead to High Algal Loads in Upper SJR
      - Must Be Reliably Studied to Develop Credible TMDL

How to Proceed to Develop Nutrient Control Program Evaluation

- Current CBDA-Funded Upstream SJR Studies Do Not Adequately Address Issues of Concern
  - Funds Should be Reprogrammed to Develop Needed Information
- Appoint and Support Independent Advisory Panel to Guide Program Development, Implementation and Reporting
  - Panel Members Should Not be Dischargers, Irrigation Districts or Investigators
    - Avoid Conflict of Interest
  - Consider Both Technical Feasibility of P Control & Costs Associated with Various Degrees of P Control
    - Must Consider How Implementation of Salt TMDL will Impact Oxygen Demand Loads and SJR DWSC Flows

Deficiencies In SJR Oxygen Demand Modeling Effort

- While Deterministic Model May Be Tuned to a Data Set, Such a Tuned Model May Have Limited Predictive Capability for Altered Conditions
  - The Data Set upon Which HydroQual Model Being Tuned to Represent Algal Oxygen Demand in SJR Upstream of the DWSC, May Render Model of Limited Reliability for Conditions That Will Exist When the Salt TMDL Is Implemented
  - Dahlgren Studies on SJR Algal Dynamics (as Presented at SETAC Portland, OR Mtg) Show That the Data Base Developed in the 2000 and 2001 Studies Not Adequate to Develop a Potentially Reliable Model

Suggested Approach for Solving Low DO Problem in SJR DWSC

- Contact US Congressional Delegation in Delta Area
  - Obtain Federal Support for Control as Part of Mitigation of Impact of DWSC Maintenance Dredging on DO Problem
- Work with Those Responsible for Controlling Flow of SJR through DWSC to Maximize Minimum Flow through DWSC
  - Current SJRWQMG and DIP Approaches Not Adequately Addressing This Issue
- Evaluate Potential to Control Sources of Nutrients That Develop into Seed Algae That Cause High Oxygen Demand Loads Discharged by Mud & Salt Sloughs to SJR
- Evaluate Feasibility of Controlling DO Depletion by Aeration
  - Need to Evaluate Possible Secondary Impacts of Aeration & Other Control Approaches – Fish Gas Bubble Disease

Control of Low DO Problem by Aeration of DWSC

- Aeration Can Eliminate Low DO Problem
  - Difficult & Expensive
    - CALFED/CBDA Has $30million to Help Solve the Low DO Problem
    - Need Funding for Operation & Maintenance, Forever
  - Should Work toward
    - Increasing SJR DWSC Flows
    - Eliminating Flow Variability to the Maximum Extent Possible
    - Reducing Oxygen Demand Loads to Reduce the Amount of Money Needed for Aeration

DO Water Quality Objectives & Issues

- 5 mg/L December 1 – August 31
  - US EPA National Criterion
- 6 mg/L September 1 – November 30
  - Block Chinook Salmon Homing – Need Studies to Verify
- DO WQO Applicable at Any Time, Any Place
  - No Averaging (Daily, with Depth)
    - DO Varies as Much as 6 mg/L over Diel Cycle
    - DO near Bottom Typically 1 – 2 mg/L Lower
  - Only 1 DO WQO Violation Allowed Every 3 Yrs
    - Difficult to Achieve
    - Requires Comprehensive DWSC Monitoring Program
      - Currently Proposed Monitoring Not Adequate

Ultimate Control Approaches Depend on Variety of Factors/Policies

- Water Rights Issues
  - Restoration of Flows, Which Causes Water Quality Problem, Allowed in CWA
    - More Than Just meeting SJR Excessive Salt Problem
- Not Being Named Responsible Party
  - Sources of Nutrients Loads That Lead to Algal Oxygen Demand Need to Be Identified & Where Possible, Controlled to Maximum Extent Economical Possible
- SJR Watershed Salt TMDL
  - Upstream SJR Salt Control will Need to be More than Just Meeting 700 µmhos/cm at Vernalis to Protect Agricultural Interests in the South Delta
    - Will Need More SJR Watershed Salt Control Than Being Discussed by SJRWQMG

Problems with Aeration-Only Control

- Turn the SJR DWSC into Treatment Plant for Upstream Oxygen Demand Loads
  - Rapidly Expanding Urban Populations in DWSC Watershed
    - Add Additional Oxygen Demand Loads
    - Increased Water Diversions

Control of Low DO Problem

- Ultimately, Control of the SJR DWSC Low DO Problem Will Likely Determined by Courts
- Role of Technical Information May Be of Limited Importance
  - Often, TMDL Allocation of Responsibility Not Technically Valid
    - Controlled by Politics and Other Factors

Effect of Implementation of Other TMDLs

- Could Greatly Impact Low DO Problem
  - Salt TMDL Implementation Will Likely Greatly Alter Oxygen Demand Loads and Impact Low DO Problem
    - Control of Salt from Mud and Salt Sloughs Will Impact Oxygen Demand (Algae) Discharges to Upstream SJR
      - Will Also Impact SJR DWSC Flows
      - SJR Watershed and Delta TMDLs Could Impact Low DO Problem Management
      - In Accord with HR 2828 CBDA DIP, Attempts to Increase Exports to 8,500 cfs at Banks Will Require Developing Program to Eliminate Water Quality Objective Violations in the Delta
        - This Will Likely Impact Low DO Problem Solution
- Solving the Water Quality and Water Level Problems in the South Delta Will Impact the Solution of the Low DO Problem in the SJR DWSC

Overview of Sacramento-San Joaquin River Delta Water Quality Issues

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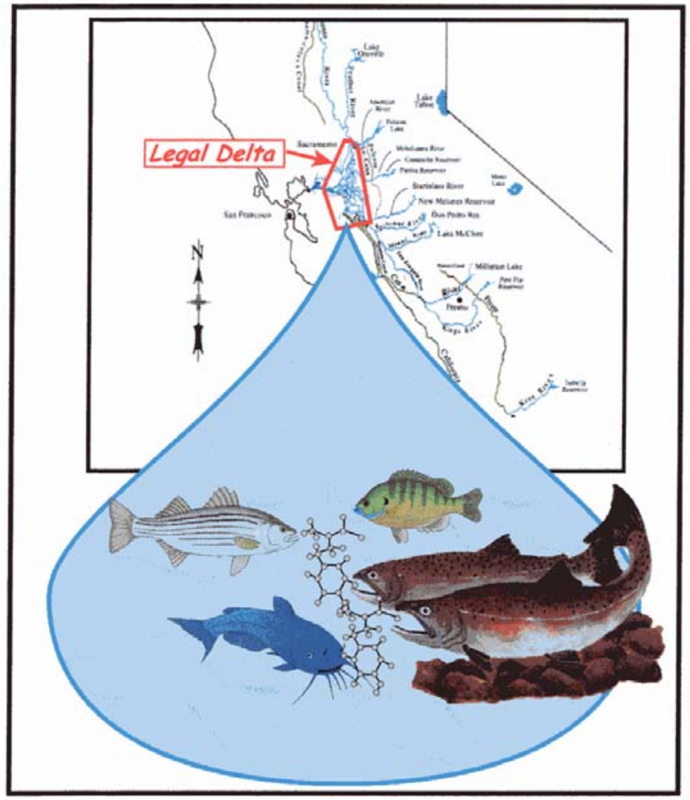

Adapted in part from images in SJRGA (2000)

June 22, 2004

Available on the internet at:
http://www.members.aol.com/apple27298/Delta-WQ-IssuesRpt.pdf

Impact of Export Projects on Water Quality Problems in the DWSC

- Export of South Delta Water by State and Federal Export Projects Is Impacting Water Quality in South and Central Delta
  - Impacting Several Delta TMDLs
  - Will Need to Be Corrected in Accord with HR 2828

Current Investigative Efforts Not Adequate to Meet Information Needs

Issues That Need More Comprehensive Attention:

- SJRWQMG Approach to Controlling Violations of Salt TMDL – Too Limited in Scope
  - Need to Establish EC Objective at SJR Vernalis to Protect Interests of South Delta Irrigated Agriculture
    - 700 μmhos/cm at Vernalis Not Protective of South Delta Ag
    - Will Lead to Violations of EC WQO in South Delta
  - Should Also Consider Impact of Salt & Flow Control on Control of TOC/DOC and Nutrients in SJR Watershed
  - Recirculation of DMC Water to SJR
    - Limited by Pumping Capacity
    - Has Potential Impacts on Fisheries
      - Will Recirculation Lead to New or Enhanced SJR Water Quality Problems/Toxicity?

Current Investigative Efforts Not Adequate to Meet Information Needs

Issues That Need More Comprehensive Attention:

- Must Address Low Water Level & Water Quality Problems in South Delta as Part of Proposed Changes in SJR Flows to Meet TMDL WQOs for Salt
  - DWR Should More Adequately Evaluate Low-Head Reverse-Flow Pumping across South Delta Permanent Barriers
- Should Not Assume That DIP Can Be Implemented to Allow Banks to Export 8,500 cfs as Part of TMDL for Solving Salt Problem in SJR
  - Existing South Delta WQOs/TMDLs Will Be Impacted by Increased Banks Exports
- Should Not Assume That Release of New Melones Water Can Be Changed as Result of Changing DO WQO for Part of Stanislaus River

Current Investigative Efforts Not Adequate to Meet Information Needs

Issues That Need More Comprehensive Attention:

- City of Stockton Wastewater Ammonia Discharges
  - 2 mg/L Monthly Average
  - Can Lead to Violations of DO WQO When SJR DWSC Flow Low
- SWRCB Proposed D1641 Review
  - Scope Too Limited to Address Impact of SJR Flow Diversions on Water Quality Problems in Delta
- DWR SDIP Must Adequately Address Full Range of Water Quality Problems in South Delta and DWSC
- Impact of SJR DWSC Flow on Other Upper DWSC Water Quality Problems Caused by Stockton
  - Must Provide Adequate SJR DWSC Flow for Initial Dilution & Rapid Transport to Turner Cut for Further Dilution by Sacramento River Water

Current Investigative Efforts Not Adequate to Meet Information Needs

Issues That Need More Comprehensive Attention:

- Potential for Aeration with Pure Oxygen to Cause Gas Bubble Disease in Fish
- Proposed DWSC Monitoring of Aeration Inadequate to Detect WQO Violations
- Impact of SJR Flow Diversions on Chemical Signals That Impact Homing/Straying of Chinook Salmon
- Discharges of TOC/DOC from Refuges/Duck Clubs as Influenced by Implementation of Salt TMDL
- Impact of Friant Dam Releases on Flows & Water Quality in SJR at Vernalis

Failure to Adequately & Reliably Address These Issues Could Lead to Litigation That Will Prevent Implementation of SJR DWSC DO TMDL & DWSC Watershed Water Quality Improvements

Further Information

Consult Website of

Drs. G. Fred Lee and Anne Jones-Lee

http://www.gfredlee.com

www.gfredlee.com

Publications on:

- Landfills-Groundwater Quality
- Surface Water Quality
- Hazardous Chemical Sites
- Mine Waste Impacts
- Contaminated Sediment
- Domestic Water Supply
- Excessive Fertilization
- Reclaimed Wastewater
- Watershed Studies San Joaquin River Watershed & Delta
- Stormwater Newsletter

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