Issues in Developing the San Joaquin River, CA
DO TMDL:
Balancing Point and Non-Point Oxygen Demand/Nutrient Control

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Presented at WEF TMDL Science Conference St Louis, MO March 2001

• Characteristics of Low-DO Problem in San Joaquin River (SJR) Deep Water Ship Channel (DWSC)
• Responsible Parties
• Approaches Being Followed to Control Low DO Problem
Biographical Information

BA Degree San Jose State University -- 1955

MSPH University of North Carolina -- 1967

PhD Harvard University -- 1960
    Environmental Engineering/Science

30 years Graduate-Level Teaching and Research in Environmental Engineering/Science
    $6 Million in Research/850 papers and Reports

Full Time Consultant 12 years in:
* Water Supply Water Quality,
* Water and Wastewater Treatment,
* Water Pollution Control,
* Solid and Hazardous Waste Management
Delta Is the Water Supply Source for 20 Million People
SJ R DWSC Watershed:

Area: 7,300 mi²

Intense Agriculture:
- Fruits/Nuts
- Row Crops

Diaries, Feedlots, Ducks

2 Million People
Increasing 2%/yr

SJ R Flow Highly Regulated
SJR DWSC Reach of Concern Is the First 15 mi below Port of Stockton

Figure 5
Location of Navigation Lights on the San Joaquin River in the Vicinity of Stockton
Figure 3 - DWSC DO Data Summer/Fall 1999
Adapted from DWR - Lehman (2000)

Dissolved Oxygen Concentrations
at DWSC Light 48

- Surface
- Bottom
- Water Quality Objective

Dissolved Oxygen (mg/L)

Date - 1999
Figure 3 (continued)

Dissolved Oxygen Concentrations
at DWSC Light 41

- Surface
- Bottom
- Water Quality Objective

Dissolved Oxygen (mg/L)

Date - 1999

7/27 8/10 8/24 9/7 9/21 10/5 10/19 11/2 11/16 11/30
Dissolved Oxygen Concentrations
at DWSC Light 34

- Surface
- Bottom
- Water Quality Objective

Date - 1999
Dissolved Oxygen Concentrations
at DWSC Light 18

Dissolved Oxygen (mg/L)

Date - 1999

Surface
Bottom
Water Quality Objective
Problem

At Times, DO in the San Joaquin River Deep Water Ship Channel Violates Water Quality Objective/Standard

SJR DWSC Placed on 303(d) List of “Impaired” Waterbodies

Requires TMDL to Control Oxygen Depletion below Water Quality Objective by June 2003
Approach

CVRWQCB Organized Stakeholder Process to Develop TMDL for Oxygen Demand Substances and Allocation of Loads among Municipal Wastewater/Stormwater Dischargers, Agriculture Runoff/Tail Water, Dairies, Feedlots, Riparian Wetlands Runoff/Releases

If the Stakeholders Do Not Develop Consensus Allocation of Responsibility by December 2002, CVRWQCB Will Assign Allocation of Load Reduction

CALSEFED Provided $866,000 for Studies in 2000

Applied for $2.5 million/yr for 2 yrs to Conduct the Studies Needed to Develop TMDL and Allocate Responsibility for Control of Low DO in DWSC

Total 3-yr Study Effort in Excess of $6 Million
Issues Report
Discusses the
Issues That Will
Need to Be
Addressed to
Control the Low DO
Problem

Issues in Developing the San Joaquin River
Deep Water Ship Channel DO TMDL

Report to
San Joaquin River Dissolved Oxygen Total Maximum Daily Load
Steering Committee and the
Central Valley Regional Water Quality Control Board
Sacramento, CA

Submitted by
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El Macero, California
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www.gfredlee.com

August 17, 2000
Factors Affecting Dissolved Oxygen in the Ship Channel

- Sunlight attenuation in turbid water due to photosynthesis & inorganic suspended solids
- Atmospheric respiration adds oxygen
- Gas transfer
- Ship traffic stirs up sediments
- Flood and ebb tide velocity stirs sediments & mixes water column
- Vertical circulation

Phytoplankton produce O₂ through photosynthesis; also respire (use O₂) in light & dark
Bacteria consume organic (BOD, N & NH₄) loads and respire, unaffected by sunlight

Phytoplankton, BOD organics, org N, NH₄, algal nutrients (N&P) from domestic & industrial wastewaters, stormwater runoff, farms, dairies, etc.

Heavier inorganic particles settle out. Some particulate organic load and phytoplankton settle out
Algae as a Source of BOD

BOD 10 v chl a

\[ y = 9.5186x - 23.203 \]

\[ r = 0.8628 \]

\[ n = 71 \]
Algae & Organic Detritus as Sources of Oxygen Demand

\[ \text{CO}_2 + \text{N} + \text{P} \rightarrow \text{algae} + \text{O}_2 + \text{org N} \ (\text{produces O}_2) \]

\[ \text{CO}_2 + \text{H}_2\text{O} + \text{ammonia} \quad (\text{uses O}_2) \]

\[ \text{Organic detritus (animal & plant remains)} \]

\[ \text{DOC} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} \quad (\text{uses O}_2) \]

\[ \text{Org N} + \text{O}_2 \rightarrow \text{NH}_3 \quad (\text{uses O}_2) \]

\[ \text{NH}_3 + \text{O}_2 \rightarrow \text{NO}_3^- \quad (\text{uses O}_2) \]

\[ \text{SOD:} \quad + \text{O}_2 + \text{bacteria} \rightarrow \text{CO}_2 \quad (\text{uses O}_2) \]

Some organics refractory – do not react

TOC \neq \text{BOD}

Sulfate:

\[ \text{SO}_4^{2-} \rightarrow \text{S}^- \quad (\text{sulfide}) \]

\[ \text{S}^- + \text{O}_2 \rightarrow \text{SO}_4^{2-} \quad (\text{rapid reaction}) \quad (\text{uses O}_2) \]

Iron:

\[ \text{Fe}^{3+} \rightarrow \text{Fe}^{2+} \quad (\text{ferrous iron}) \]

\[ \text{Fe}^{2+} + \text{O}_2 \rightarrow \text{Fe}^{3+} \quad (\text{rapid reaction}) \quad (\text{uses O}_2) \]
Upstream SJR Diversions for Southern CA Water Supplies and Central Valley Agriculture Adversely Impact Oxygen Demand Assimilative Capacity
Box Model of Estimated DO Sources/Sinks in SJR DWSC August 1999
(values in lbs/day of oxygen demand
BOD, NH₃, org N, chlBOD, oxygen deficit)

Oxygen Demand Sources

City of Stockton wastewater discharges
(CBOD, NH₃, org N, chlBOD, oxygen deficit)
5,600

Minor local BOD sources
French Camp Slough
Manteca ag & city drains?
others?

Algae that develop in DWSC that exert
oxygen demand in DWSC

SJR DWSC
Dissolved Oxygen
below WQO (5 mg/L)

Oxygen Demand Export

Export of BOD, algae, NH₃
and oxygen deficit from
downstream DWSC at
Turner Cut

DO added reaeration
2,000

Mechanical aeration

O₂ added by algae

Oxygen Demand Export

69,000
27,000

Sediment Oxygen Demand
(partially incorporated into USV)

Oxygen Deficit

Oxygen Demand Sources

Oxygen demand in SJR above Vernalis that
reaches DWSC
(BOD, NH₃, orgN, chlBOD, oxygen deficit)
61,000

6,000

Box Model of Estimated DO Sources/Sinks in SJR DWSC August 1999
(values in lbs/day of oxygen demand
BOD, NH₃, org N, chlBOD, oxygen deficit)
**Box Model Calculations of Oxygen Demand Sources & Sinks for San Joaquin River Summer/Fall 1999**

<table>
<thead>
<tr>
<th>Source</th>
<th>BODu (lbs/day)</th>
<th>August</th>
<th>September</th>
<th>October</th>
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<tr>
<td>SJR DWSC Net Flow (cfs):</td>
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<td>~ 900</td>
<td>~ 900</td>
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<td>Upstream of Vernalis</td>
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<td>61,000</td>
<td>70,000</td>
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<td>5,600</td>
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<td>DWSC Algae</td>
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SJ R DWSC Tidal vs Net Flow

Stockton UVM Flow Data, October 1999

Mean Month: 569 cfs
Max Month: 3780 cfs
Min Month: -2920 cfs

Figure 16

- 15-Minute Flow
- Daily Average Flow
Retention Time in SJR Deep Water Ship Channel (to Turner Cut, including Turning Basin) as a Function of Flow
Summer Oxygen Demand Loads Control
DO Depletion

Short Hydraulic Residence Time of the DWSC 5 to 30 days for SJR Flows of 2,000 cfs to 100 cfs

Only Summer Oxygen Demand Loads Important to Summer/Fall DO Depletion

High Winter-Spring Flows/Loads Flush Through the DWSC

Stormwater Runoff Not Important Source of BOD
**Conclusion -- Impact of SJ R DWSC Flow on Low DO**

Diversion of SJ R Flow Upstream of DWSC Increases the Hydraulic Residence Time and Reduces the Oxygen Demand Assimilative Capacity of the DWSC

Flow Diverters Are Responsible Parties in the Low DO Problem
Sources/Sinks of Oxygen Demand in SJR-DWSC Watershed

**Oxygen Demand Components**
- organic BOD -- wastewater, land runoff
- ammonia, organic N
- algae/algal nutrients

**Principal Reactions**
- \( \text{BOD} + O_2 \rightarrow \text{low DO} \)
- \( \text{CO}_2 + N + P \xrightarrow{\text{sunlight}} \text{algae} \)
- Algae die \( \rightarrow \) BOD

**San Joaquin River & Tributaries**
- Turning Basin
  - wastewater
  - stormwater
  - groundwater
  - irrigation drains
  - irrigation diversion
  - groundwater

**Cities Industry**
- groundwater

**Farms**
- groundwater

**Groundwater nitrate**

**Dairies, Duck Farms, Feed Lots & Other Commercial Animal Facilities**
- wastewater

**Riparian Lands**
- discharges
- water
Application of DO Model to Strawman Analysis

Carl W. Chen and Wanteng Tsai
Systech Engineering, Inc.
February 21, 2001
Strawman Deep Scenarios

With DO objective = 5 mg/L, Stockton load = 100% and River load = 100%

- Flow = 250 cfs
- Flow = 500 cfs
- Flow = 750 cfs
- Flow = 1000 cfs
- Flow = 1500 cfs
- Flow = 2000 cfs

Days elapsed from 07/01/99 00:00
Strawman Shallow Scenarios

With DO objective = 5 mg/L, Stockton load = 100% and River load = 100%
Conclusion on the Impact of DWSC Depth

Without the Deep Water Ship Channel, the Low DO Problem Would Not Occur

The Port of Stockton & Those Who Benefit by the Port/Channel Should Be Responsible Parties in Controlling the Low DO Problem
Responsibility for SJ R DWSC DO Depletion below Water Quality Objective

Sources of Oxygen Demand

- NPDES Permittees
  - Municipal and Industrial Wastewater Discharges and Stormwater Runoff – City of Stockton & Other Municipalities
  - Dairies and Other Animal Husbandry Operations, Including Feedlots, Hogs, Horses, Chickens
Responsibility for SJ R DWSC DO Depletion below Water Quality Objective

Sources of Oxygen Demand

• Non-Point Runoff/Discharge of Oxygen Demand
  - Agricultural Lands, Irrigation Drainage, Stormwater Runoff
  - Non-NPDES Permitted Urban Stormwater Runoff
  - Riparian Lands

• Pollution of Groundwater That Leads to Nitrate Discharge to Surface Waters
  - Agriculture
  - Dairies & Other Animal Husbandry Activities
  - Land Disposal of Municipal Wastewaters
  - Urban Areas
Responsibility for SJ R DWSC DO Depletion below Water Quality Objective

DWSC Geometry

• Port of Stockton & Those Who Benefit from Commercial Shipping to Port
  - Channel Depth Impacts Oxygen Demand Assimilative Capacity
• Ship Traffic That Stirs Sediments into Water Column That Increases SOD
Responsibility for SJR DWSC DO Depletion below Water Quality Objective

SJR DWSC Flow

- All Entities That Divert Water from the SJR above the DWSC, as Well as Those That Alter the SJR Flow Pattern through the Delta
  - Municipal and Agricultural Diversions
Responsibility for SJR DWSC DO Depletion below Water Quality Objective

Future Urban Development in Watershed

- How Will Future Development in the SJR DWSC Be Controlled so That the Increased Oxygen Demand and Nutrients Associated with Urban Development Will Not Cause Future Low DO Problems in the DWSC?
Issues in Controlling Algal Biomass as a Means of Reducing Algae-Caused BOD

- Surplus N and P Compared to Algal Needs
- Algal Biomass Controlled by Light Limitation
  - Large Amounts of N or P Control Needed to Limit Algae-Caused BOD
    - 30 to 100 Times Excess N and P
Relationship between Nutrient Concentration and Algal Biomass

Available Nutrient Concentration

Algal Growth

Nutrient-Limited

Not Nutrient-Limited
EFFECT OF NUTRIENTS ON ALGAL GROWTH
(After Ambrose et al., 1993a)
Channel Aeration

• Likely Need Selective Aeration of DWSC to Eliminate All Low-DO Problems
  - Sidestream with Air or 100% O₂
  - Funding – Who Will Pay for It?
    • All Responsible Parties?
Issues That Will Need to Be Addressed

• Export/Loss of BODu, CBOD, NBOD, Algae, N and P between Source (Land Runoff/Discharges) and DWSC

• Assess Additional Oxygen Demand and Nutrient Loads to SJ R between Vernalis and Channel Point in DWSC

• Impact of SJ R Flow at Vernalis and in DWSC on DWSC DO Depletion

• Understanding the Factors Controlling the Impacts of SJ R Flow through DWSC on DO Depletion below WQO’s
Issues That Will Need to Be Addressed

• Understanding Significance of DWSC DO Excursions below 5 mg/L for a Few Hours to a Few Days on the Growth Rates of Fish in DWSC

• Assessing the Significance of DO Depletion below 6 mg/L in Inhibiting Upstream Chinook Salmon Migration

• Cost of Controlling N, P, NBOD, and CBOD from Wastewater, Stormwater Runoff, and Irrigation Return (Tail) Water

• Can a Reliable Oxygen-Demand-Load/DO-Depletion-below-WQO Model for Given SJR DWSC Flow Be Developed That Can Be Used to Establish a Reliable Oxygen Demand TMDL?

• How to Best Manage the Increasing Urbanization (approx. 2%/yr) of the SJR DWSC Watershed with Its Potentially Increased Oxygen Demand Load
Conclusions

• San Joaquin River Deep Water Ship Channel Low DO Problem Is Primarily Due to the Discharge/Release of Aquatic Plant Nutrients That Develop into Algae That Die and Consume Oxygen in the Deep Water Ship Channel

• Oxygen Demand Assimilative Capacity of the San Joaquin River Has Been Greatly Reduced by Construction of the Deep Water Ship Channel

• Upstream Diversions of SJR Flow Exacerbate the DO Depletion Problem
Conclusions

• Nutrient Control from Agricultural, Wetland, and Other Rural Sources Will Not Likely Eliminate the Algal-Related Oxygen Demand So That Violations of the DO Water Quality Objectives Do Not Occur

• A Combination of Instream Aeration, and Nutrient and Oxygen Demand Control Will Be Needed to Control Low DO Problems

• Will It Be Possible to Obtain Financial Support by Water Diverters and Those Who Benefit from the Existence of the Channel to Help Pay for Nutrient Control and Aeration?
Further Information
Consult Website of
Drs. G. Fred Lee and Anne Jones-Lee

http://www.gfredlee.com