Issues in Controlling Oxygen Depletion in the San Joaquin River Deep Water Ship Channel: Developing an NPS Nutrient Control Program

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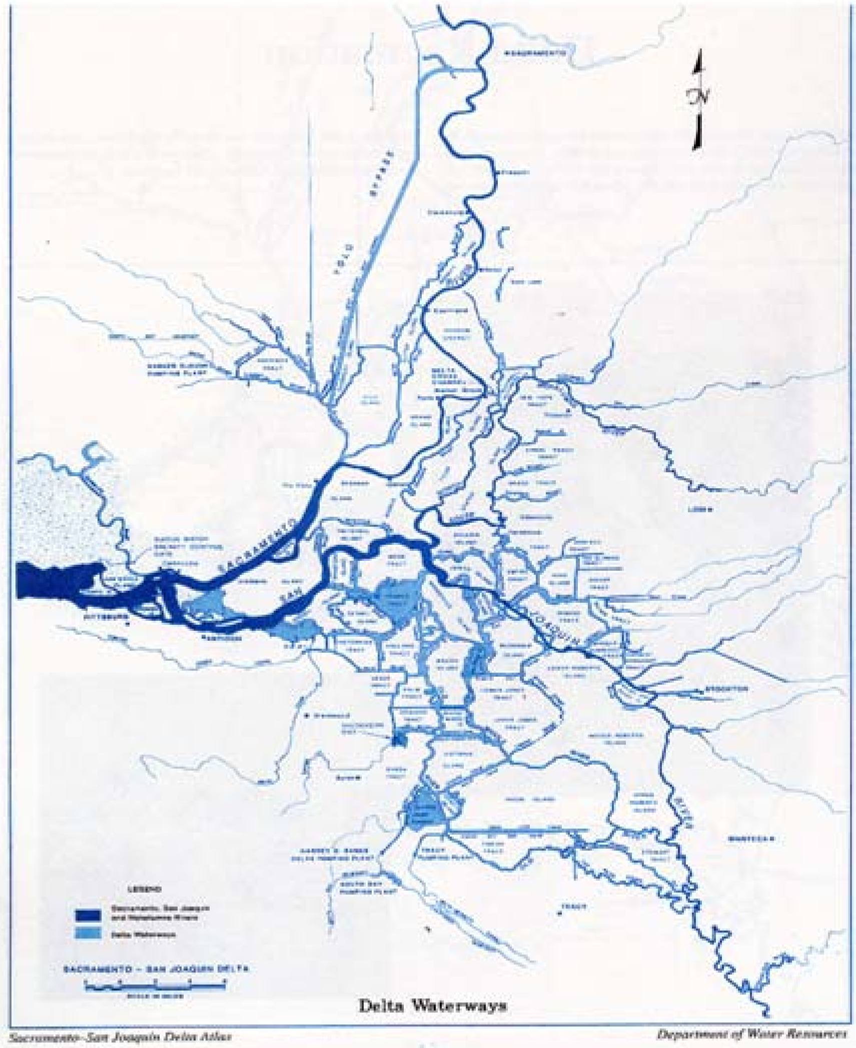
- Characteristics of Low-DO Problem in San Joaquin River(SJR) Deep Water Ship Channel (DWSC)
- Role of NPS Nutrient Sources as Cause of Low DO in DWSC
- Approaches Being Followed to Control Low DO Problem

Upstream SJR Diversions for Southern CA Water Supplies and Central Valley Agriculture Adversely Impact Oxygen Demand Assimilative Capacity



SJR DWSC Watershed:

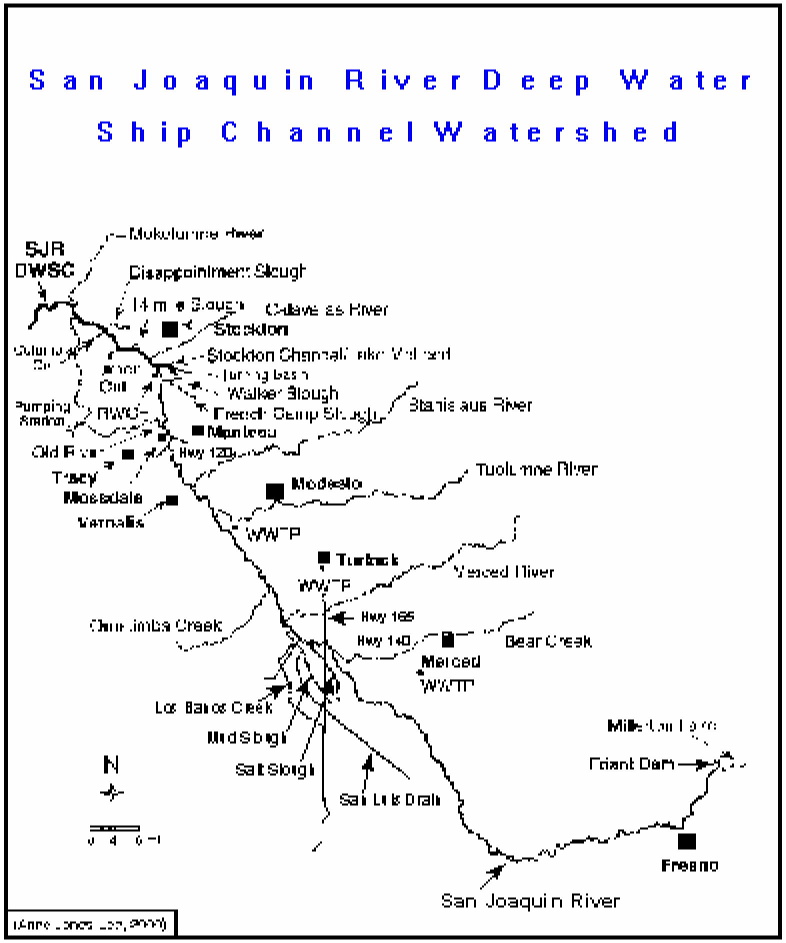
Area: 7,300 mi^2

Intense Agriculture:
- Fruits/Nuts
- Row Crops

Diaries, Feedlots, Ducks

2 Million People
- Increasing 2%/yr

SJR Flow Highly Regulated



SJR DWSC Reach of Concern Is the First 15 miles below Port of Stockton

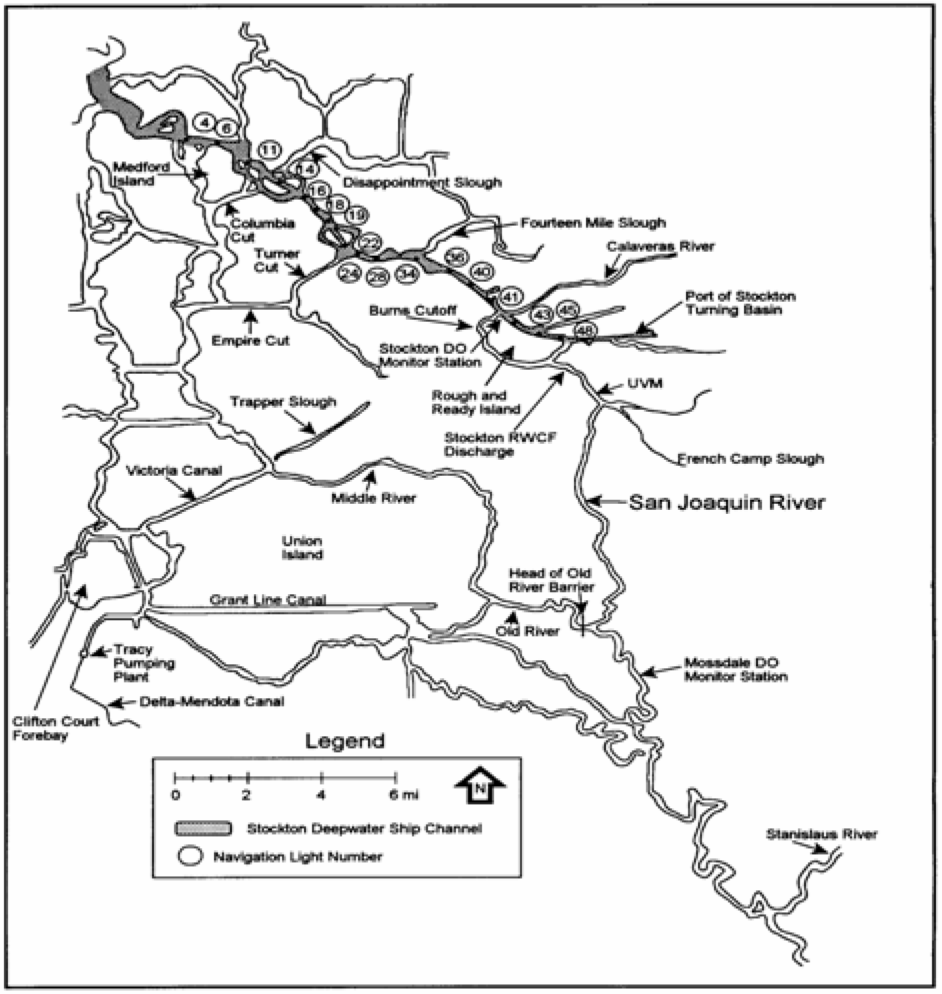
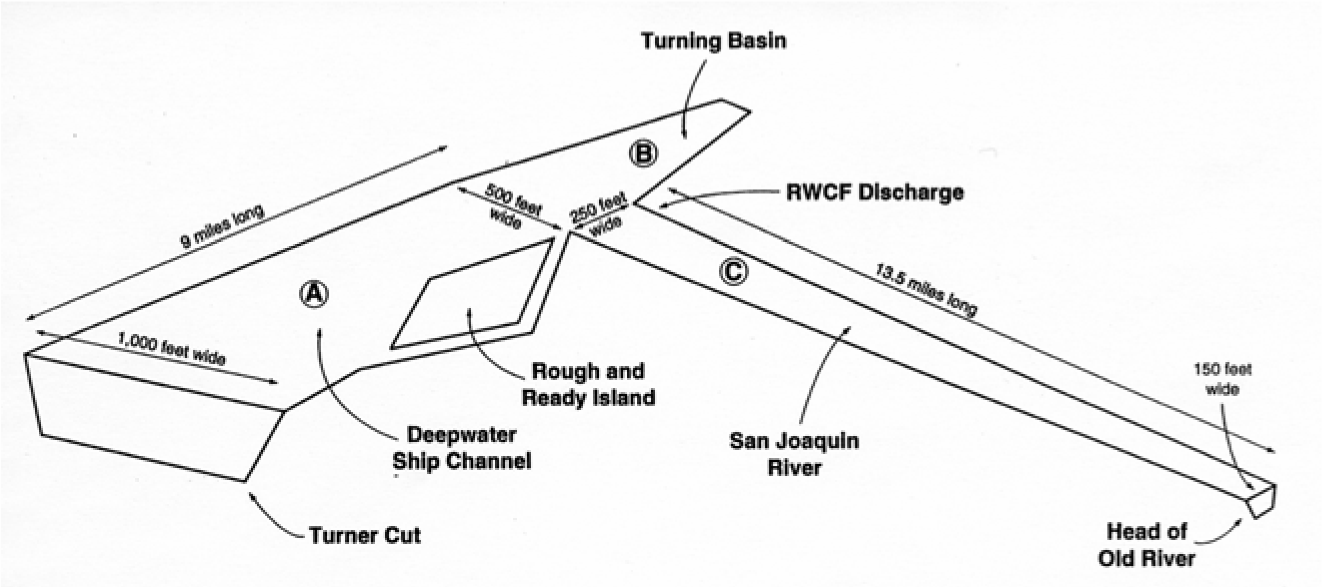


Figure 5
Location of Navigation Lights on the San Joaquin River in the Vicinity of Stockton

Characteristics of the Deep Water Ship Channel (DWSC)



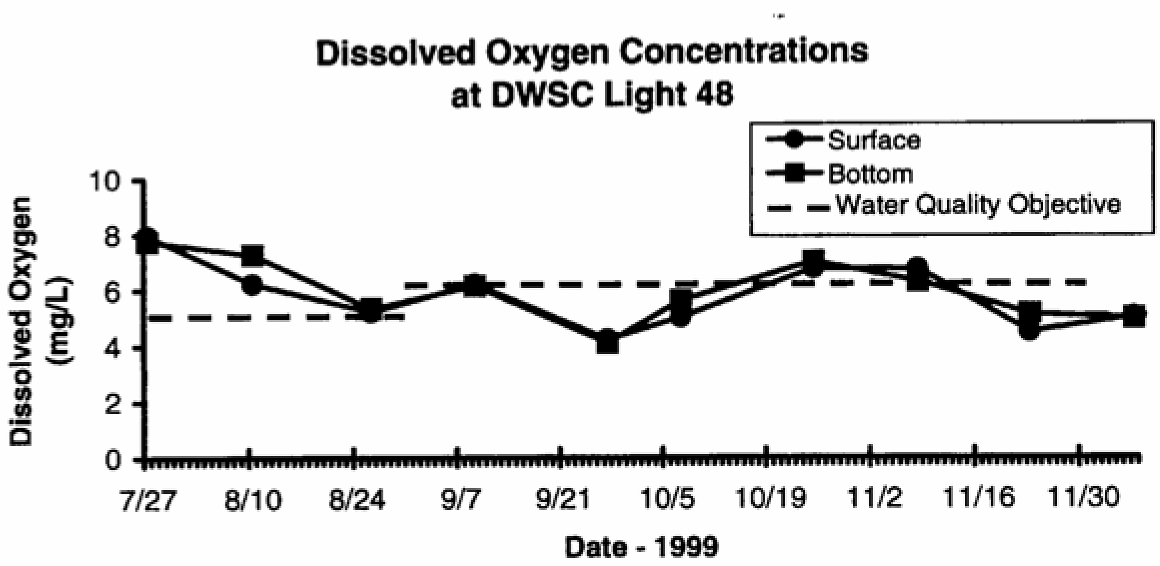
from Jones & Stokes (1998)

Problem

- At Times, Dissolved Oxygen in 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

DWSC DO Data – Summer/Fall 1999

(Adapted from DWR – Lehman, 2000)



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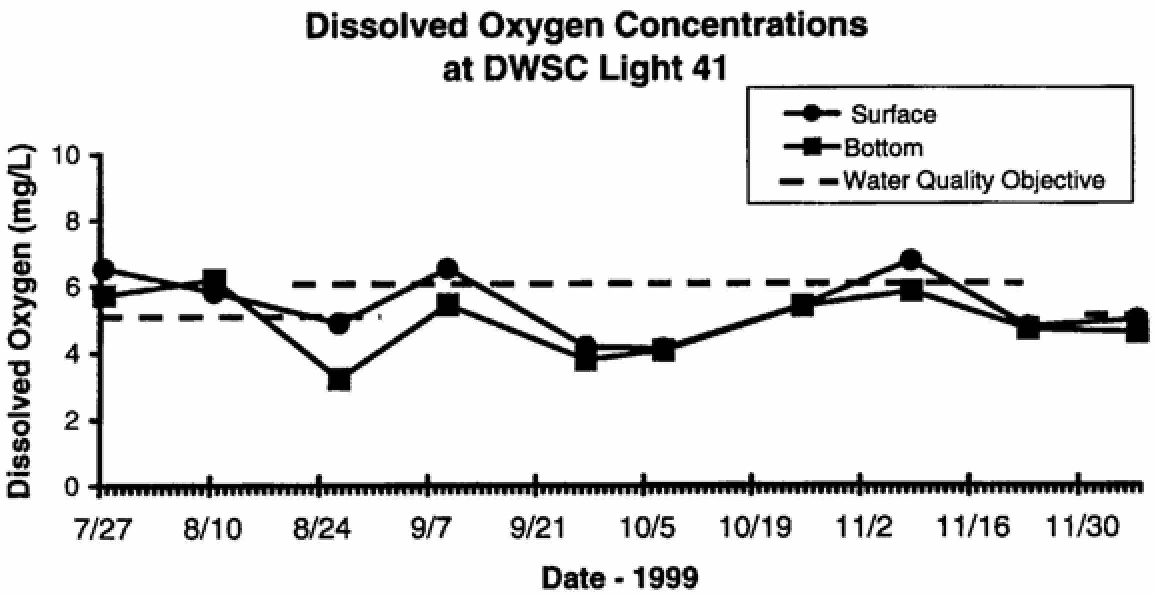

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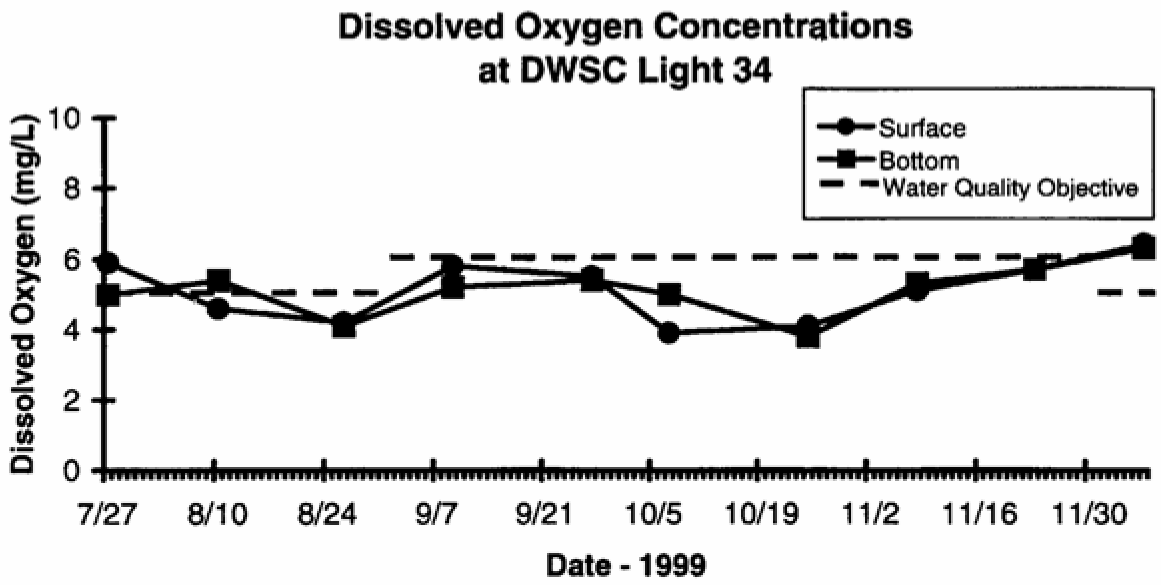

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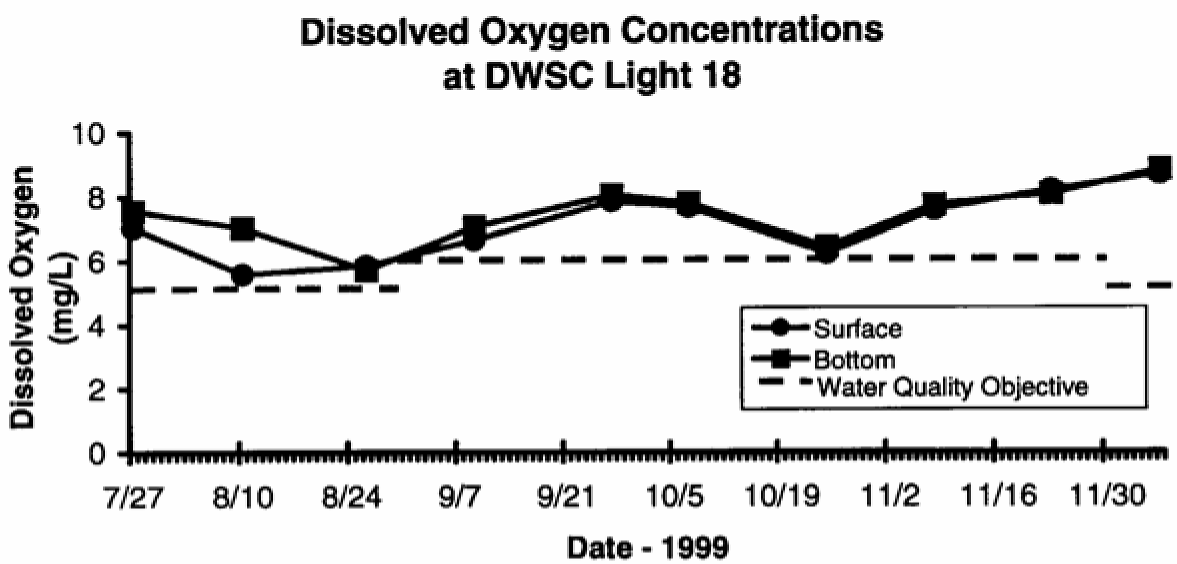


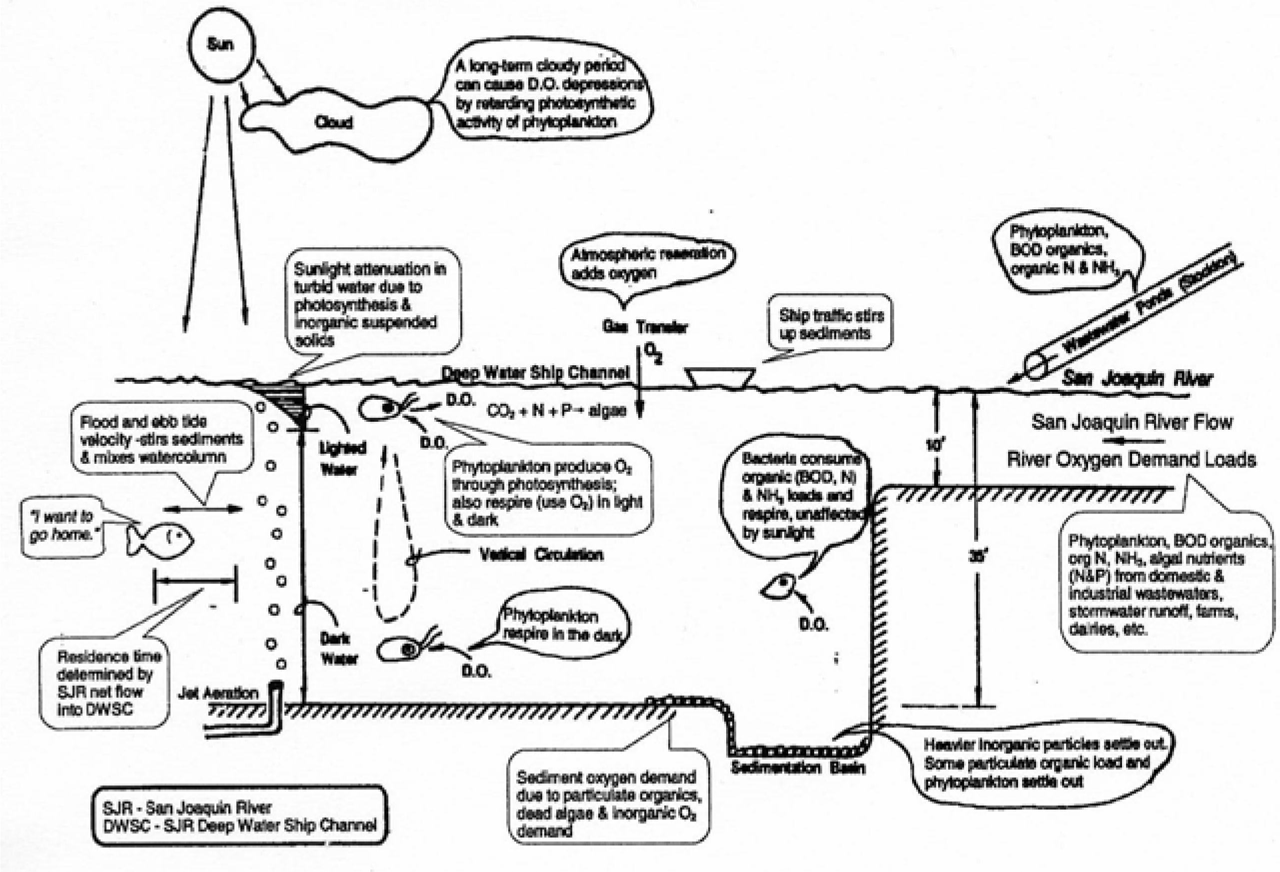
Conceptual Model of SJR DWSC Oxygen Demand Situation

Components

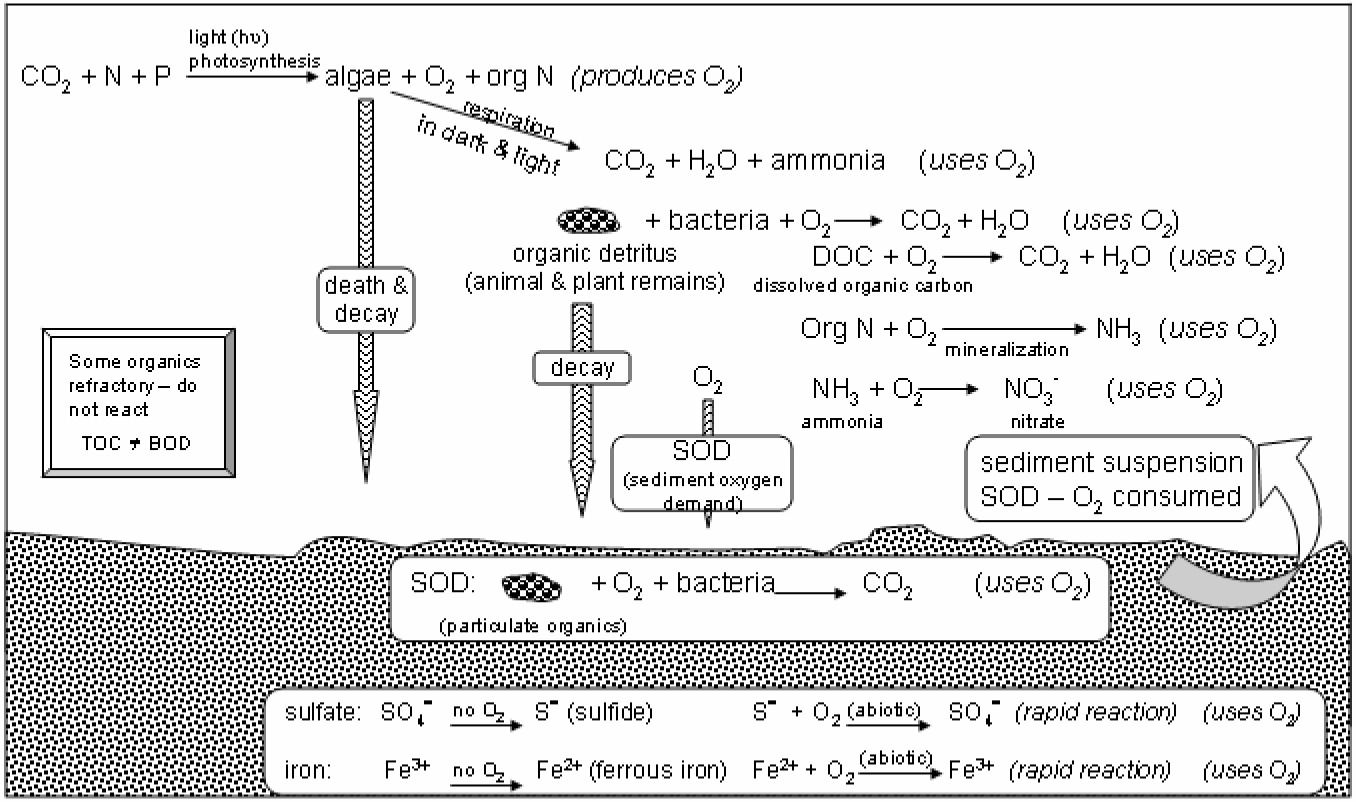
- DWSC Watershed
  - Nutrients, Algae, Non-Algal O_2 Demand Sources
    - Algae Develop in Channels
- DWSC
  - Oxygen Demand Causes and Reactions

Factors Affecting Dissolved Oxygen in DWSC

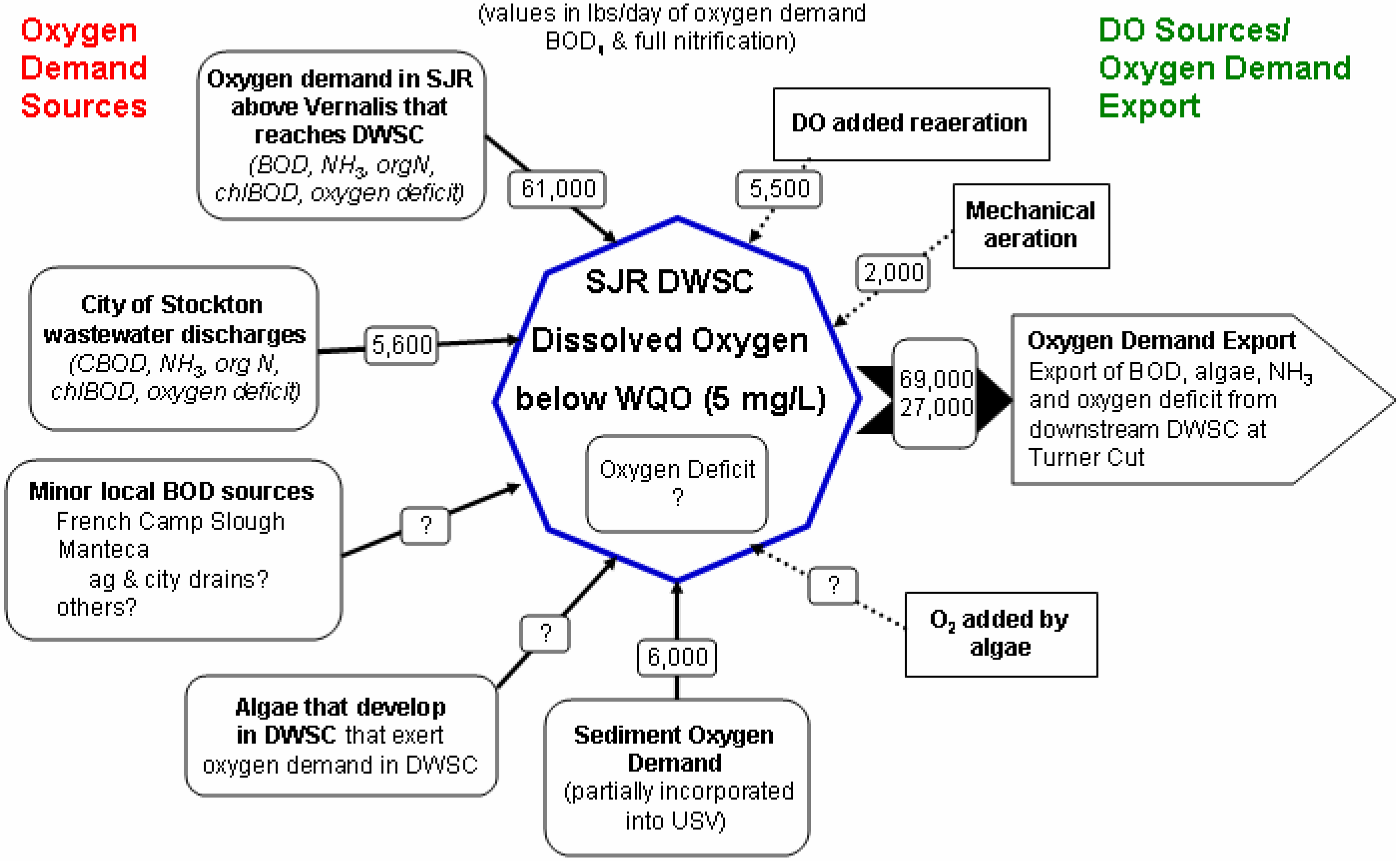
(adapted from COE, 1988)



Algae & Organic Detritus as Sources of Oxygen Demand



Box Model of Estimated DO Sources/Sinks in SJR DWSC August 1999



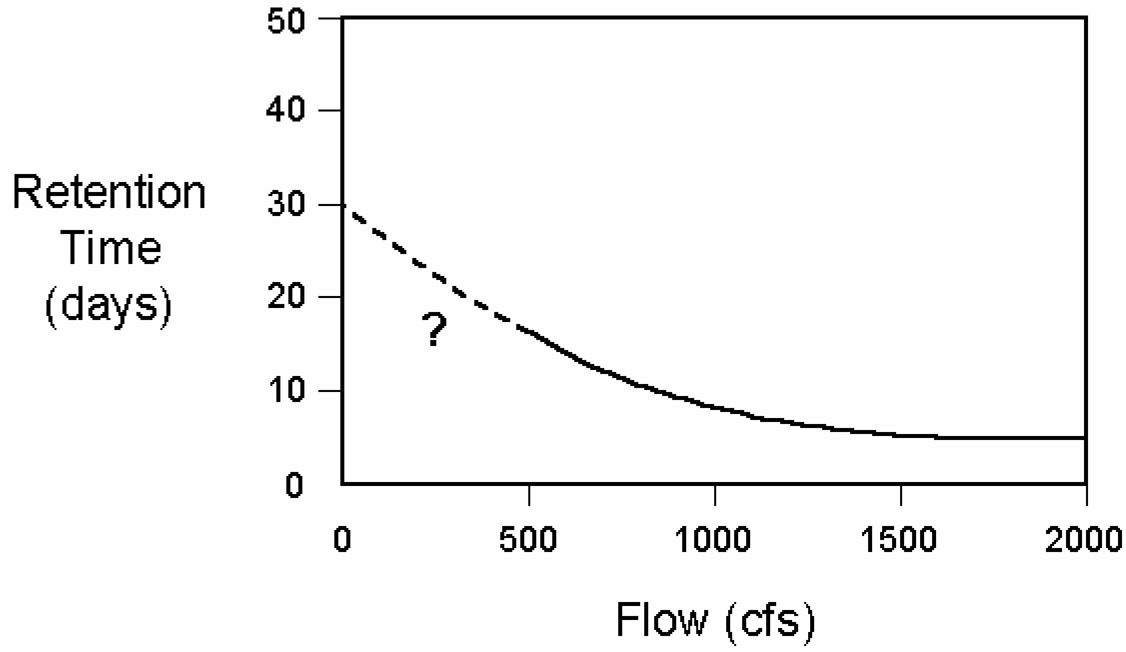
Summer Oxygen Demand Loads Control DO Depletion

- Short Hydraulic Residence Time of DWSC 5 to 20 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 Normally Important Source of Oxygen Demand
    - May Be Important in Late Fall

Box Model Calculations of Oxygen Demand Sources & Sinks for San Joaquin River Summer/Fall 1999

Source	BODu (lbs/day)				
	August	September	October		
SJR DWSC Net Flow (cfs):	~900	~900	150	400	1,000
Upstream of Vernalis	61,000	70,000	6,300	14,130	35,325
City of Stockton	5,600	9,300	12,200	12,000	12,000
Local DWSC	?	?	1,750	1,750	1,750
SOD	6,000	6,000	6,000	6,000	6,000
Aeration(Natural)	5,500	5,500	?	?	?
Aeration(Mech.)	2,000	2,000	?	?	?
DWSC Algae	?	?	?	?	?
Export from DWSC	27,000	27,000	?	?	?

Retention Time in SJR Deep Water Ship Channel (to Turner Cut, including Turning Basin) as a Function of Flow



Role of Sacramento River in DO Depletion in SJR DWSC

- Export Pumping of Delta Water via State & Federal Projects to Central & Southern California Limits Downstream Extent of DO Depletion to Columbia Cut
  - Brings Sacramento River Water Across the SJR DWSC
  - Mixing & Dilution & Advective Transport to Central Delta
  - Does This Create a Low DO Problem in Central Delta?

SJR Flow through DWSC

- Important in Determining DO Depletion in DWSC
- Flow Impacts Hydraulic Residence Time of Water & Oxygen Demand Constituents in Critical Reach of DWSC (first 15 miles)

2,000 cfs	about 5 days
200 cfs	20 – 25 days

- At Low Flow, Much Greater Part of Oxygen Demand Added to DWSC Is Exerted before Dilution by Sacramento River Cross—SJR Channel Flow *en route* to Export Pumps
- SJR Flow through DWSC > 2,000 cfs
  - Few DO Problems
- SJR Flow through DWSC Controlled by
  - SJR Flow at Vernalis
  - Diversion of SJR Flow down Old River
  - Operation of South Delta Channel Barriers
  - State & Federal Export Pumping of Delta Water to Central & Southern California

Responsibility for SJR DWSC DO Depletion below Water Quality Objective

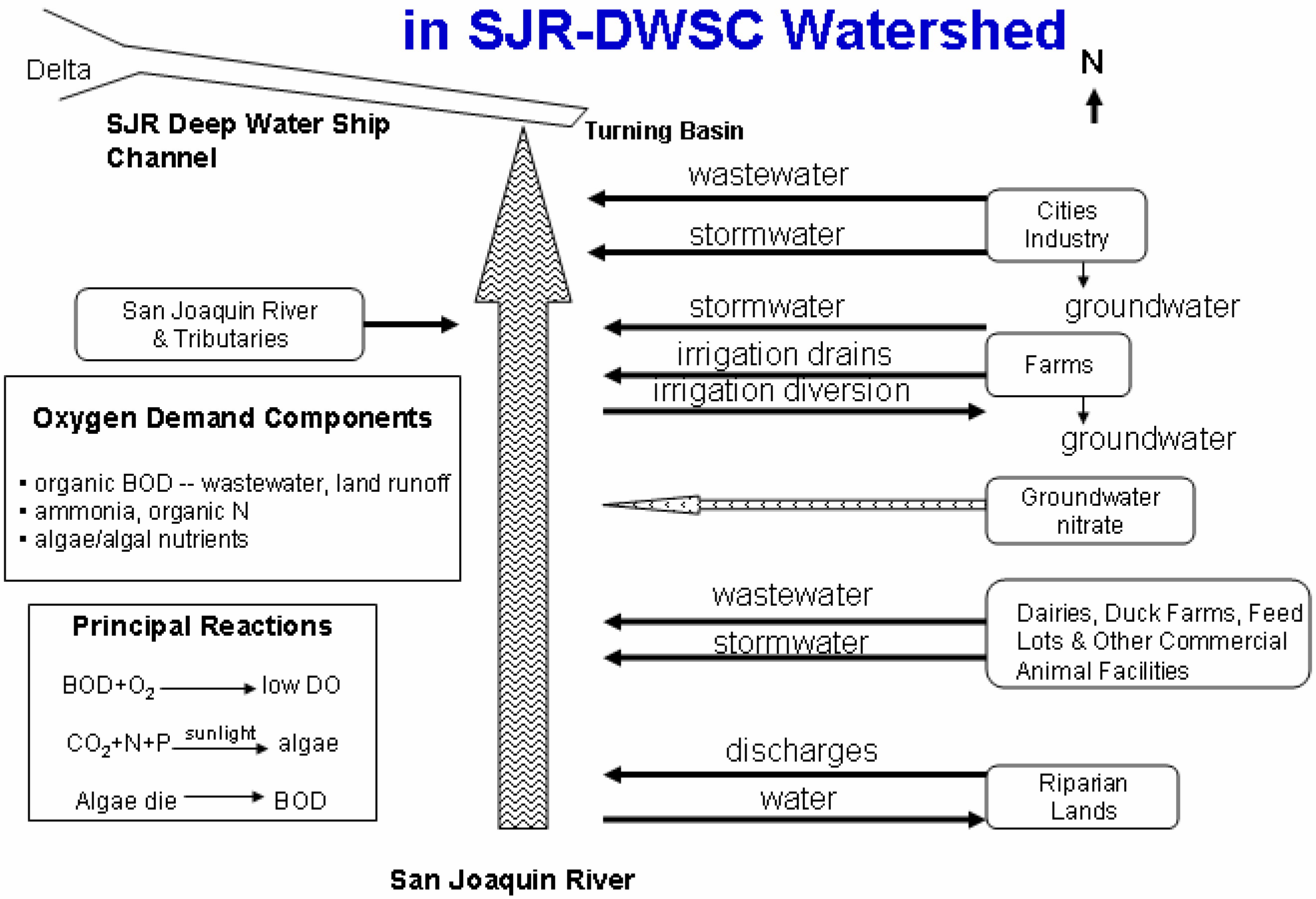
Sources of Oxygen Demand

- 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

Oxygen Demand Sources

- Algae, Other Oxygen Demand Constituents & Nutrients (N&P) from Upstream Tributary Sources Transported Downstream
- Algae Developed in Channels, Creeks, Sloughs & River
  - Doubling Time about 1 to 2 Days in Summer
- Algae & Water Diverted through Abstraction of Irrigation Water
- Water, Nutrients, Algae Added to SJR & Tributaries
- Algae Growth Rate Limited by Light Penetration
  - Surplus Available N & P
- Grazing of Phytoplankton by Zooplankton & Macroinvertebrates
- Non-Algal Oxygen Demand, Detritus, NH_3, Organic N
  - Exert Oxygen Demand in River
- Photosynthesis Produces O_2 in River
  - Excess O_2 in River Lost to Atmosphere

Sources/Sinks of Oxygen Demand in SJR-DWSC Watershed



Reactions Governing Oxygen Demand Dynamics in DWSC Watershed

Growth: Algae + N + P ⇒ More Algae + O_2

Decay: Non-Algal Oxygen Demand ⇒ BOD Exerted in "River" + N + P

Grazing: Algae + "Zooplankton" ⇒ Dead Algae + Oxygen Demand + N + P

SJR Diversion: Algae (Abstraction of Water + Associated Algae) + Other Oxygen Demand ⇒ Reduced Oxygen Demand Load in River

Tributary Input: Water Input (Tributary, River, Creeks + Ag Drains) ⇒ Add Algae + Water, Nutrients + Turbidity ⇒ Increased Algae Concentration/Load or Dilution of Upstream Oxygen Demand/Algae

SJR Scour: Elevated SJR Flow ⇒ Suspended Sediment-Associated Oxygen Demand, Nutrients + Suspended Solids (Turbidity)

Nitrification: NH_3 + OrgN + O_2 ⇒ NO_3^- — ***N-BOD Exerted***

Denitrification: NO_3^- (Low DO near Sediments) ⇒ N_2 — ***N Removal***

Responsibility for SJR 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 SJR 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

Oxygen Demand Constituents

C-BOD — Carbonaceous Biochemical Oxygen Demand

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

N-BOD — Nitrogenous Biochemical Oxygen Demand

$$NH_3 + O_2 \xrightarrow{\textit{Bacteria}} NO_3^{-} \qquad \textit{Nitrification}$$

$$\text{Organic N} \xrightarrow{\textit{Bacteria}} NH_3 \qquad \textit{Ammonification}$$

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

SOD — Sediment Oxygen Demand

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

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

Evaluation of Need for Nutrient Control in SJR Watershed

- Algal Nutrients (N&P) Discharged to SJR & Its Tributaries Important Precursors for Algae-Related Oxygen Demand
- Not All Nutrient Discharges in SJR Watershed of Equal Weight in Contributing to Algal Growth That Leads to Oxygen Demand in DWSC

Algae as Source of Oxygen Demand

$$\underbrace{(CH_2O)_{106}(NH_3)_{16}H_3PO_4}_{\text{Algae}} = 106\ CH_2O + 16\ NH_3 + H_3PO_4$$

$$106\ CH_2O + 106\ O_2 = 106\ CO_2 + 106\ H_2O$$

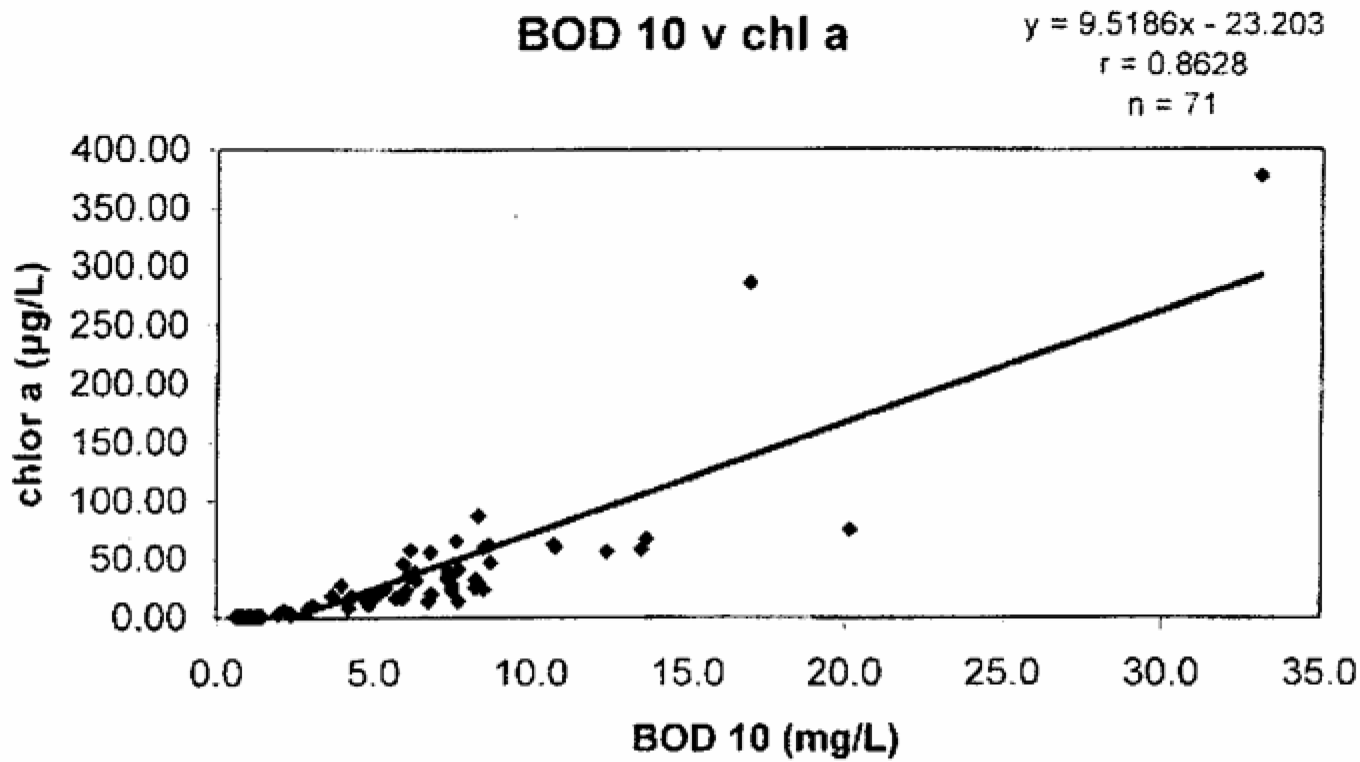
$$16\ NH_3 + 32\ O_2 = 16\ HNO_3 + 16\ H_2O$$

Reactions Added:

$$\underbrace{(CH_2O)_{106}(NH_3)_{16}H_3PO_4}_{\text{Algae}} + 138\ O_2 =$$

$$106\ CO_2 + 122\ H_2O + 16\ HNO_3 + H_3PO_4$$

Algae as a Source of BOD
SJR at Vernalis



Focused Algal Control

- Key Issue to Controlling SJR DWSC Watershed Algae-Caused Oxygen Demand Is:

  Where in SJR Watershed Tributaries Do the Algae That Are the Primary Seed for Algae-Caused Oxygen Demand at Tributary Mouth, Develop ?

  - Understand Whether Control of Nutrient (N or P) at That Location(s) Could Limit Algal Biomass at Tributary Mouth
  - Are There Areas in Tributary Where Focused Nutrient Control Could Reduce Algal Biomass at Tributary Mouth?

Importance of Nutrient Discharge Depends on:

- Rate/Amount of Discharge
- When Discharge Occurs (Summer/Fall; Winter/Spring)
- Distance/Travel Time for Algal Growth from Point of Discharge to DWSC
- Fate (Loss to Atmosphere) of Oxygen Produced with Algal Growth in DWSC & Upstream
- Amount of SJR Water/Algae Diverted to Ag Fields & Down Old River
- Amount of Water/Algae Added to SJR & Its Tributaries That Enters DWSC
- Grazing of Phytoplankton by Zooplankton & "Clams"
- Turbidity – Light Penetration
- Amount of "Surplus" N & P in DWSC
- Amount of Soluble Ortho P & Total P
  - Soluble Ortho P Primary Algal Nutrient

Importance of Nutrient Discharge

- Relationship Among Factors Poorly Understood
  - Need Focused, Detailed Studies of Algal Nutrient Dynamics in SJR Watershed & DWSC
- Essential for Technically Valid Allocation of Oxygen Demand Responsibility
- How Will Regulation Proceed?
  - Will Information Be Developed?
  - Will an Arbitrary Allocation of TMDL Control and Responsibility by Assigned?

Significance of Algal Growth in DWSC to Its Oxygen Resources

- P. Lehman Has Shown, Based on Algal Growth in Laboratory Incubation, There Is Appreciable Algal Development in DWSC
  - Growth in DWSC Could, at Times, Be Equal to Upstream Algal Chlorophyll Loads
- Issue:

  Is Growth of Algae in DWSC a Significant Additional Source of Oxygen Demand That Leads to Increased DO Depletion in DWSC? NO

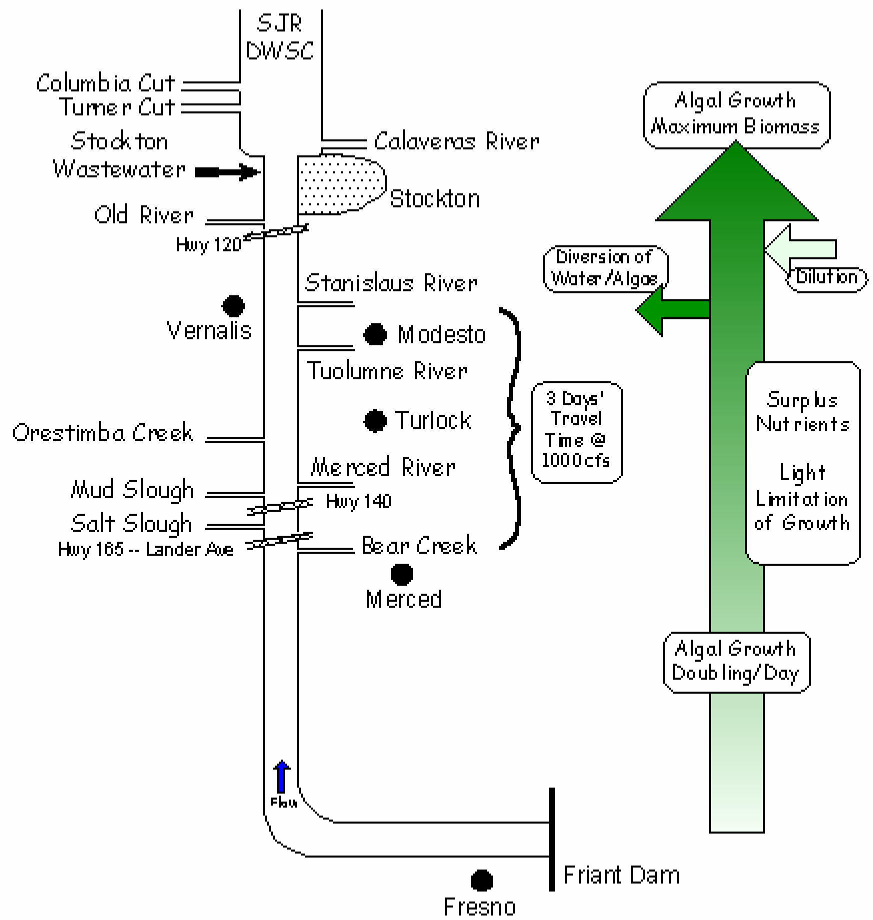
  Algal Growth Occurs with Oxygen Production

  Since DWSC Is Under-Saturated in DO, All DO Produced Is Available to Satisfy Oxygen Demand of Algae Developed in DWSC

What Is Known about Sources of Oxygen Demand?

- In Summer 2000, 50 to 70% of Oxygen Demand in SJR at Vernalis Originated in the Watersheds of Mud & Salt Sloughs and SJR at Landers Ave.
- In Fall 1999, Fall 2000, and Summer 2001, City of Stockton Wastewater Discharges to SJR Were a Significant Source of Ammonia Which Contributed to Oxygen Demand in DWSC

Schematic Representation of Algal Growth in San Joaquin River



Algae Control in Mud & Salt Sloughs & SJR above Lander Ave

- High Concentrations (Loads) of Algae in Mud & Salt Sloughs & SJR above Lander Ave (Hwy 165) Lead to These Areas' Being Significant Sources of Algae-Caused Oxygen Demand in SJR at Vernalis
- Management Issue:

  Summer Conditions Typically Provide Residence Time of Week or More for Nutrient-Rich Water (Sol O-P > 100 µgP/L and NO_3^- + NH_3 > 1 mgN/L) to Develop the Algal Concentrations Found in Mud & Salt Sloughs and SJR at Landers Ave
- Are There Areas in Mud & Salt Sloughs & SJR at Lander Ave Where the Water Could Be Treated with Alum to Remove Sol O-P and Algae to Significantly Reduce the Summer Algal Concentration in the Discharges from Mud & Salt Sloughs and SJR at Lander to San Joaquin River?

Algae Control in Mud & Salt Sloughs & SJR above Lander Ave

- Need to Determine if These Are Locations at Which Alum Could Be Added, or Biological P Removal Could Be Practiced to Significantly Reduce Summer Algal Concentrations in Discharges from Mud & Salt Sloughs and SJR above Lander Ave to San Joaquin River
  - Need to Evaluate Nutrient Concentrations & Algae Sources in Mud & Salt Sloughs and SJR above Landers Ave
  - Need to Define Hydrology (Flow & Residence Times)
  - Need to Be Able to Add Alum & Periodically Remove Alum/ Algae Sludge
    - Must Consider Selenium Concentrations in Sludge & Its Appropriate Management

Management 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
- CALFED Provided $866,000 for Studies in 2000 and $2.5 million/yr for 1 yr to Conduct 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

TMDL Process

- Define Water Quality Problem
- Define Pollutant Sources
- Define TMDL Goal
- Linkage between Sources/Loads of Pollutants & Water Quality Impacts

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Technical TMDL

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Allocation of Responsibility

↓

Implementation of Control Programs

↓

Phase I Monitoring

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Phase II

TMDL Regulatory Issues

- Clean Water Act (CWA) Includes TMDL to Ensure Compliance with Water Quality Standards
- While Conceptually Appropriate, in Practice Requires Adequate Time & Funding to Provide Technical Information Base to Reliably Implement Approach
- Thus Far, US Congress, State Legislators, & Stakeholders Unwilling to Fund Proper CWA Implementation
- SJR Technical Support Funding, While Substantial Owing to CALFED Support, Is Inadequate for Time Allowed
- Funding for TMDL Development & Allocation of Oxygen Demand among Sources Not Adequate to Allow Development of Technically Valid Information Needed to Meet June 2003 Deadline
- Current SJR Steering Committee Stakeholder-Based Approach Not Adequate to Meet Deadlines

Control of Oxygen Depletion

- Increased SJR Flow through DWSC
  - Shorten Hydraulic Residence Time
- Aeration of Channel
  - Funding ?
- Reduce Oxygen Demand Load to DWSC
  - Control C-BOD, N-BOD, Algae
- Allocation of Oxygen Demand Load
  - Based on % Allowed Oxygen Demand Load to DWSC from Each Tributary
    - Will Need to Allocate Oxygen Demand Load within Each Tributary

Channel Aeration

- Likely Need Selective Aeration of DWSC to Eliminate All Low-DO Problems
  - Sidestream with Air or 100% O_2
  - 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 SJR, & Losses, between Vernalis and Channel Point in DWSC
- Impact of SJR Flow at Vernalis and in DWSC on DWSC DO Depletion
- Understanding the Factors Controlling the Impacts of SJR 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

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?

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
- NH_3 Discharged by Stockton Important Source of Oxygen Demand
- 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

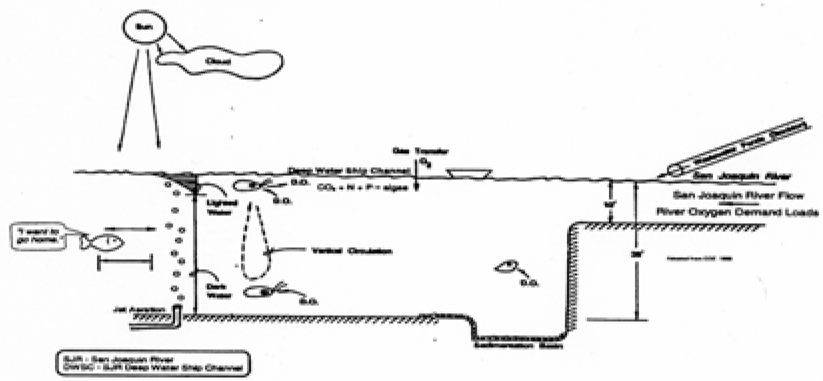
Conclusions

- 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?

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

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August 17, 2000

Further Information

Consult Website of

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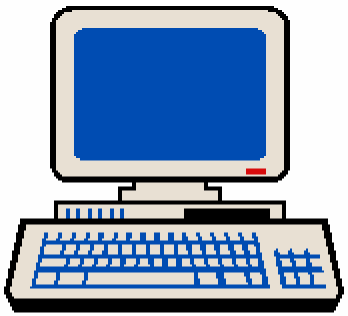

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