Managing Oxygen Demand in the San Joaquin River Deep Water Ship Channel, CA

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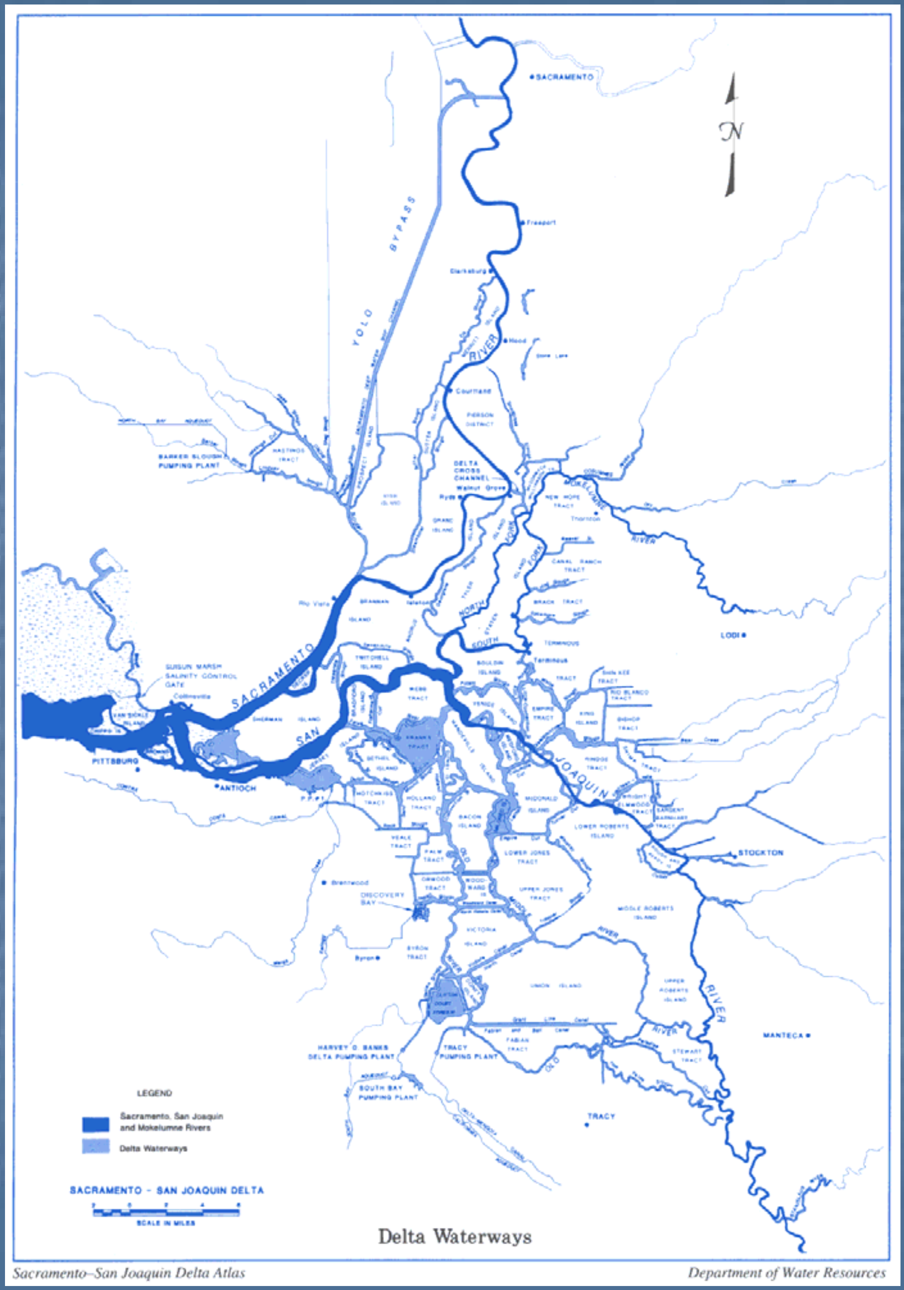
- Nature of Low DO Problem in San Joaquin River Deep Water Ship Channel
- Causes of the Problem
- Approaches Being Evaluated to Control DO Water Quality Objective Violations

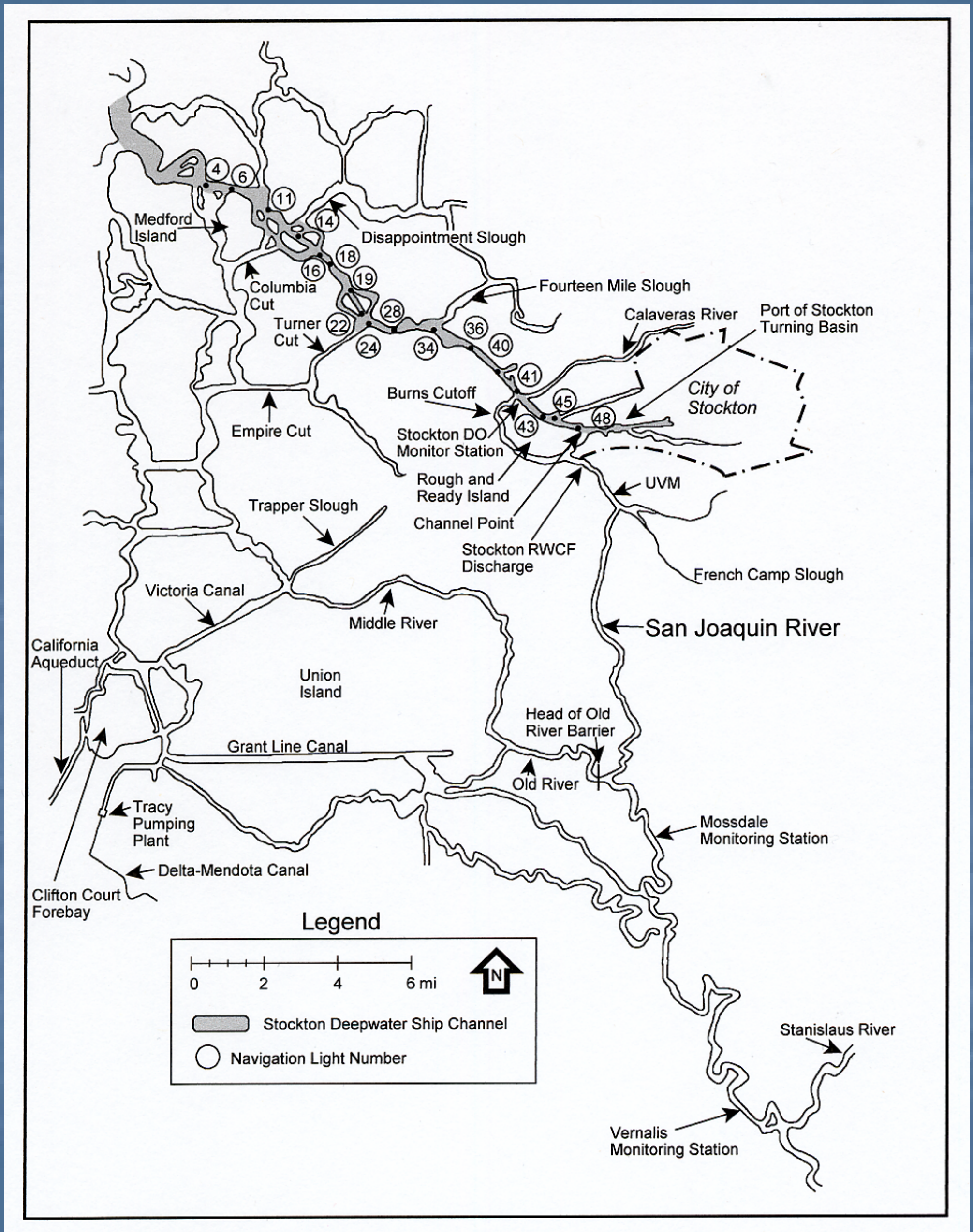
Abbreviations:

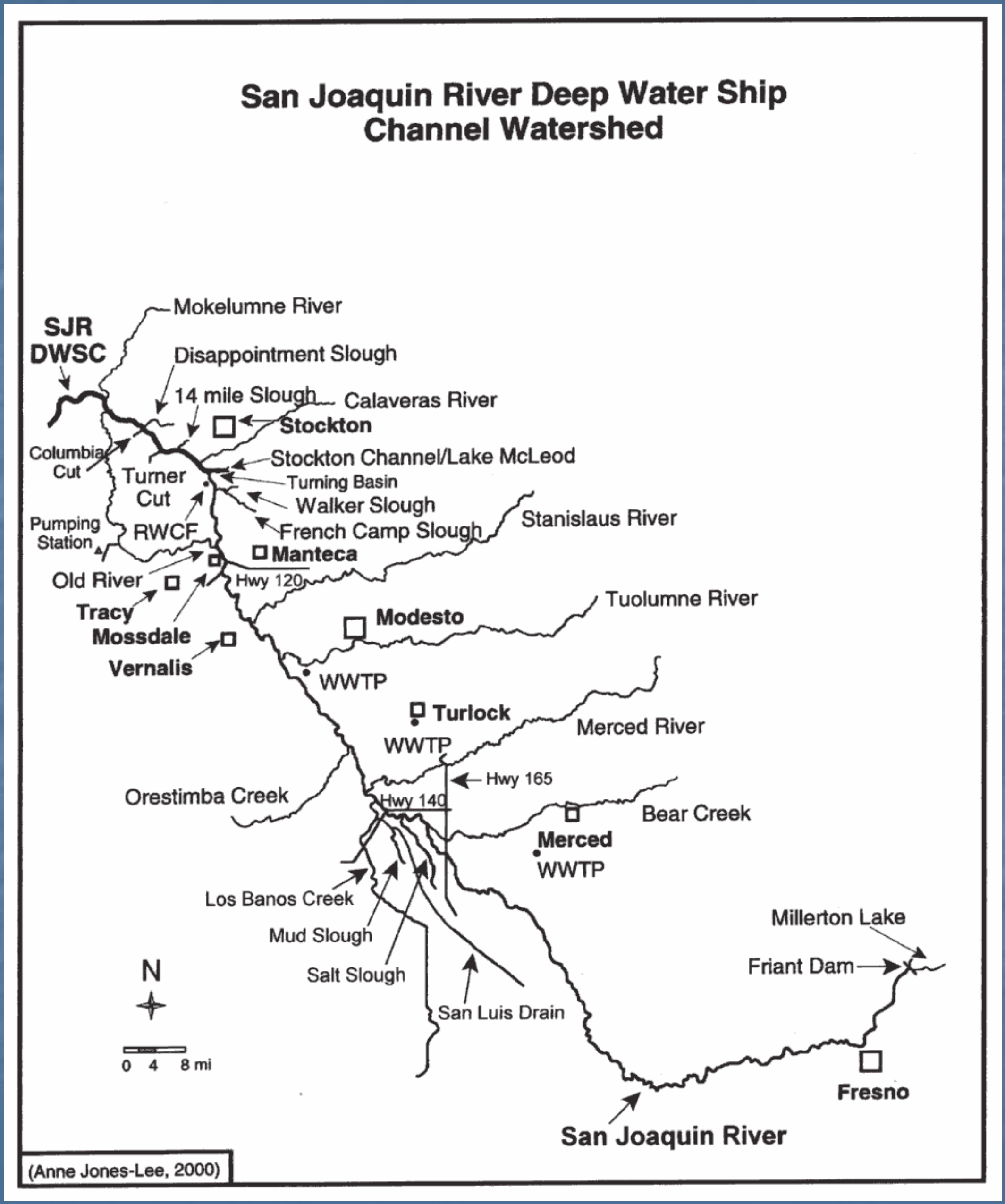
DO	Dissolved Oxygen	DWSC	Deep Water Ship Channel
SJR	San Joaquin River	TMDL	Total Maximum Daily Load
CBDA	CA Bay Delta Authority (formerly CALFED)	WQO	Water Quality Objective
		DWR	CA Dept of Water Resources



San Joaquin – Sacramento River Delta

SJR Deep Water Ship Channel

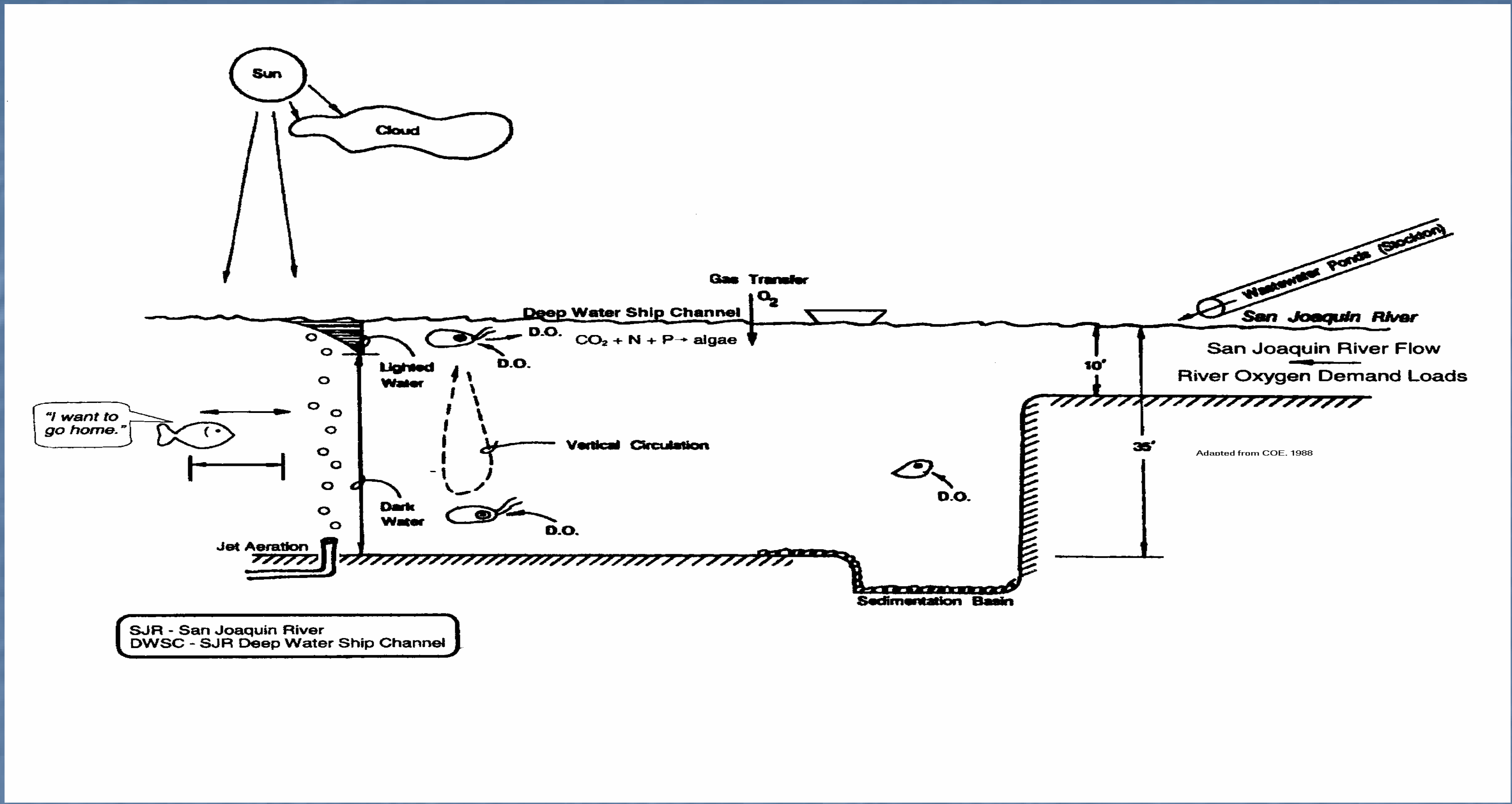




San Joaquin River DWSC Watershed

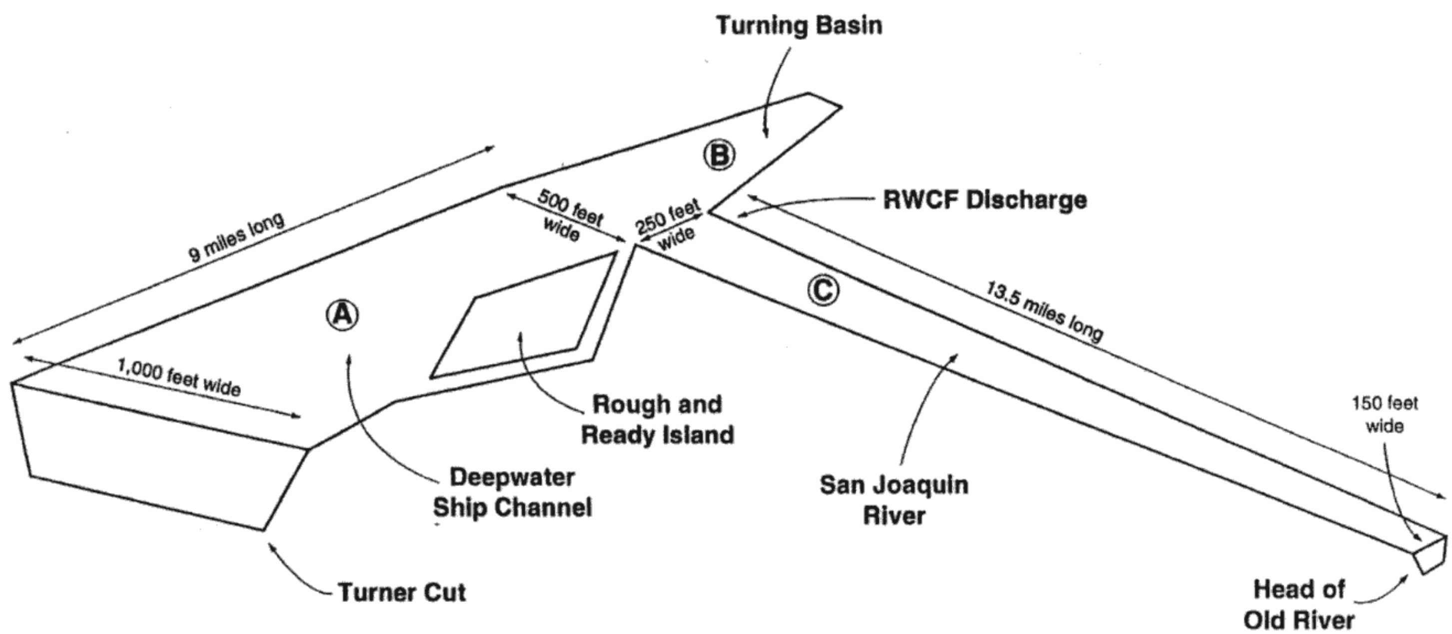
Studies

- ~ $4 million over 4 yrs Devoted to SJR DWSC & Watershed
  - 12 Investigators
  - Lee & Jones-Lee Developed Synthesis Report of Those Studies 280-page Summary of Findings -- March 2003
- Summer 1999, Studies Initiated of DWSC
  - DO Depletion in DWSC
  - Oxygen Demand Load to DWSC
- Summers 2000 & 2001
  - Additional Studies of DWSC & SJR Watershed Sources of Oxygen Demand
- Summers 2002 & 2003
  - Review of USGS & DWR Data by G.F. Lee
  - Focused on Impact of SJR Flow on DO Depletion



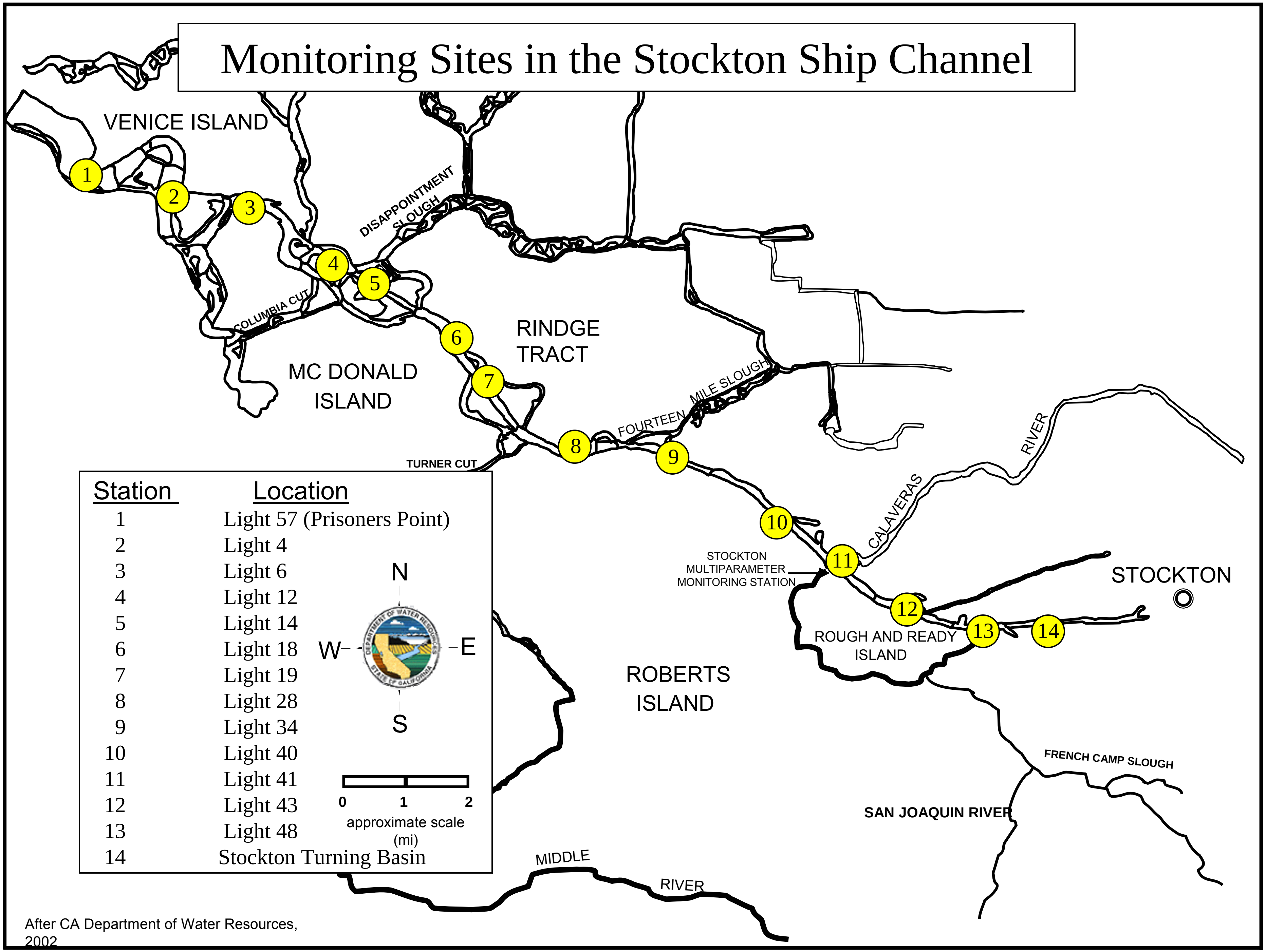
The Low-DO Setting

Characteristics of the Deep Water Ship Channel (DWSC)



from Jones & Stokes (1998)

Monitoring Sites in the Stockton Ship Channel

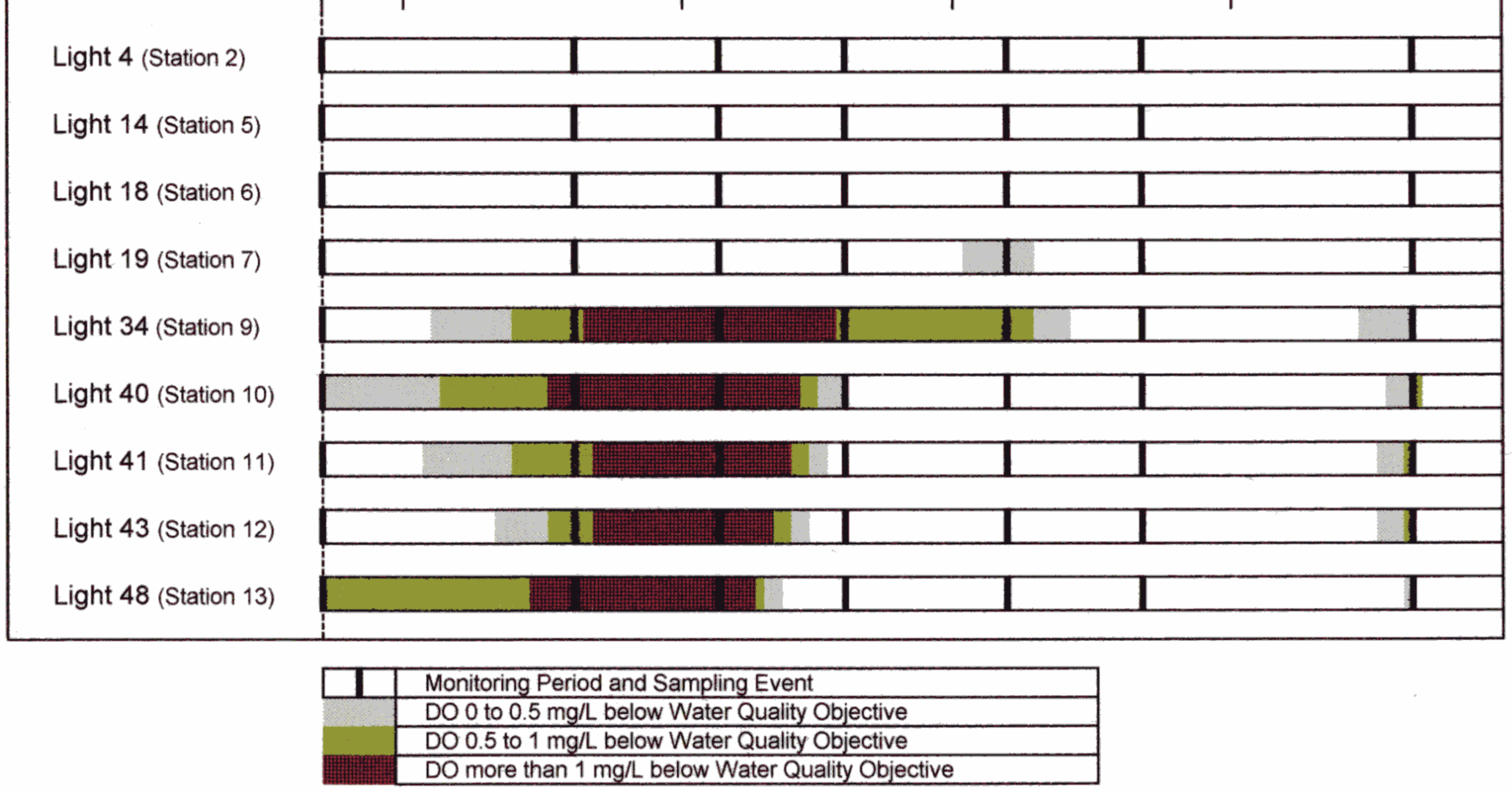


Station	Location
1	Light 57 (Prisoners Point)
2	Light 4
3	Light 6
4	Light 12
5	Light 14
6	Light 18
7	Light 19
8	Light 28
9	Light 34
10	Light 40
11	Light 41
12	Light 43
13	Light 48
14	Stockton Turning Basin

After CA Department of Water Resources, 2002

Incidence of Dissolved Oxygen below WQO
Surface Water 2002

Location	July	August	September	October	November
Avg. BODu Load to DWSC (lb/day)	68,000	68,000	103,000	136,000	95,000
Flow of SJR to DWSC (cfs)	193-772	39 -- 861	512 -- 1005	978 -- 1834	85 -- 1737

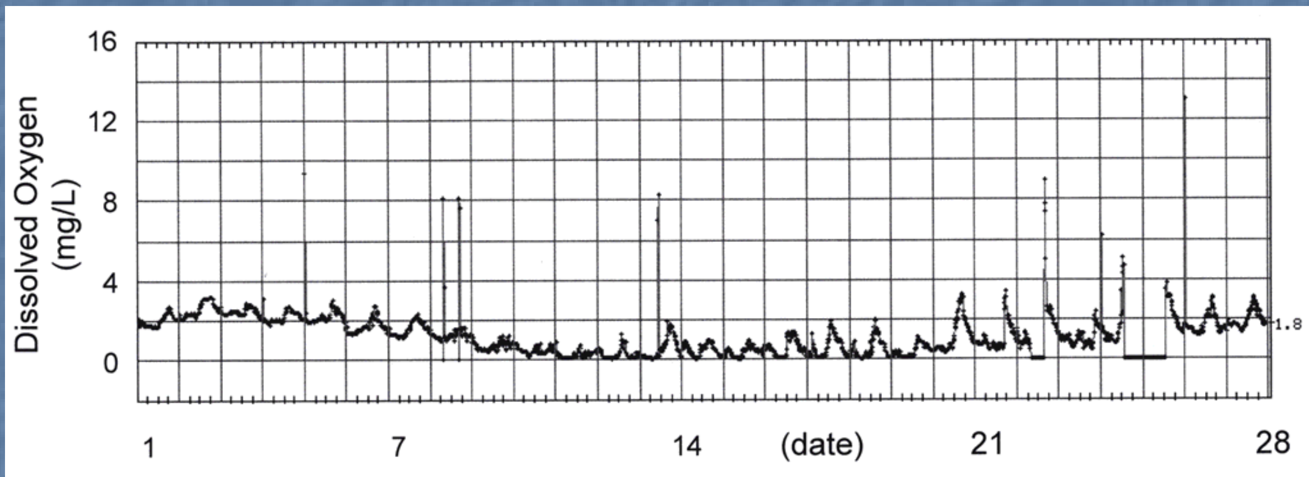


Incidence of Dissolved Oxygen below WQO
Surface Water 2000

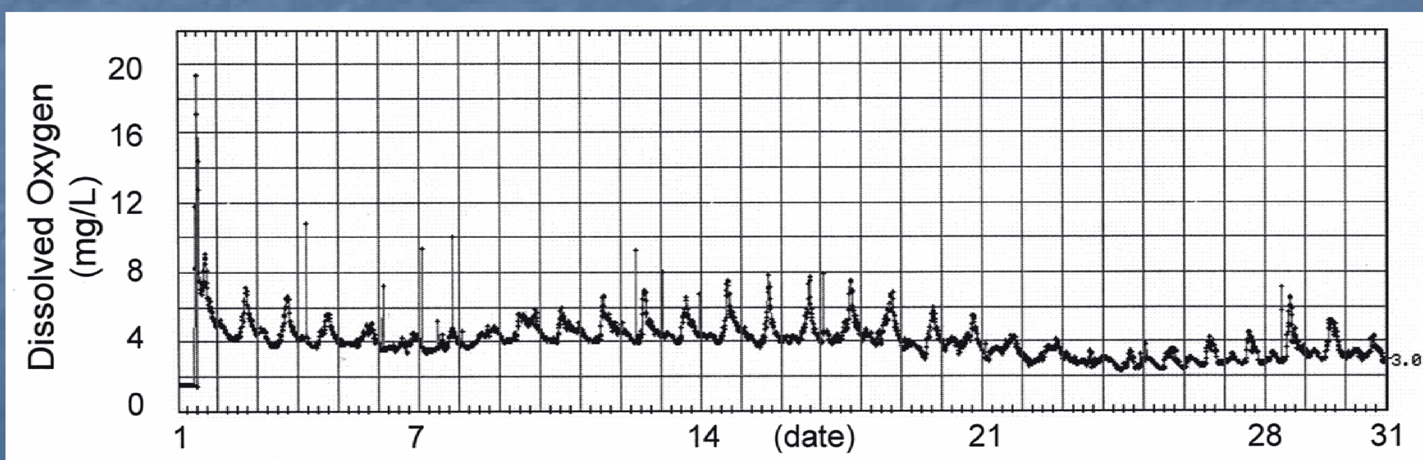
Location	August	September	October	November	Dec.
Avg. BODu Load to DWSC (lb/day)	43,000	40,000	51,000 → 125,000 → 27,000		
Avg. Flow of SJR to DWSC (cfs)	770 → 1,350	1,300	1,900 → 600		
Light 4 (Station 2)					
Light 14 (Station 5)					
Light 18 (Station 6)					
Light 19 (Station 7)					
Light 34 (Station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

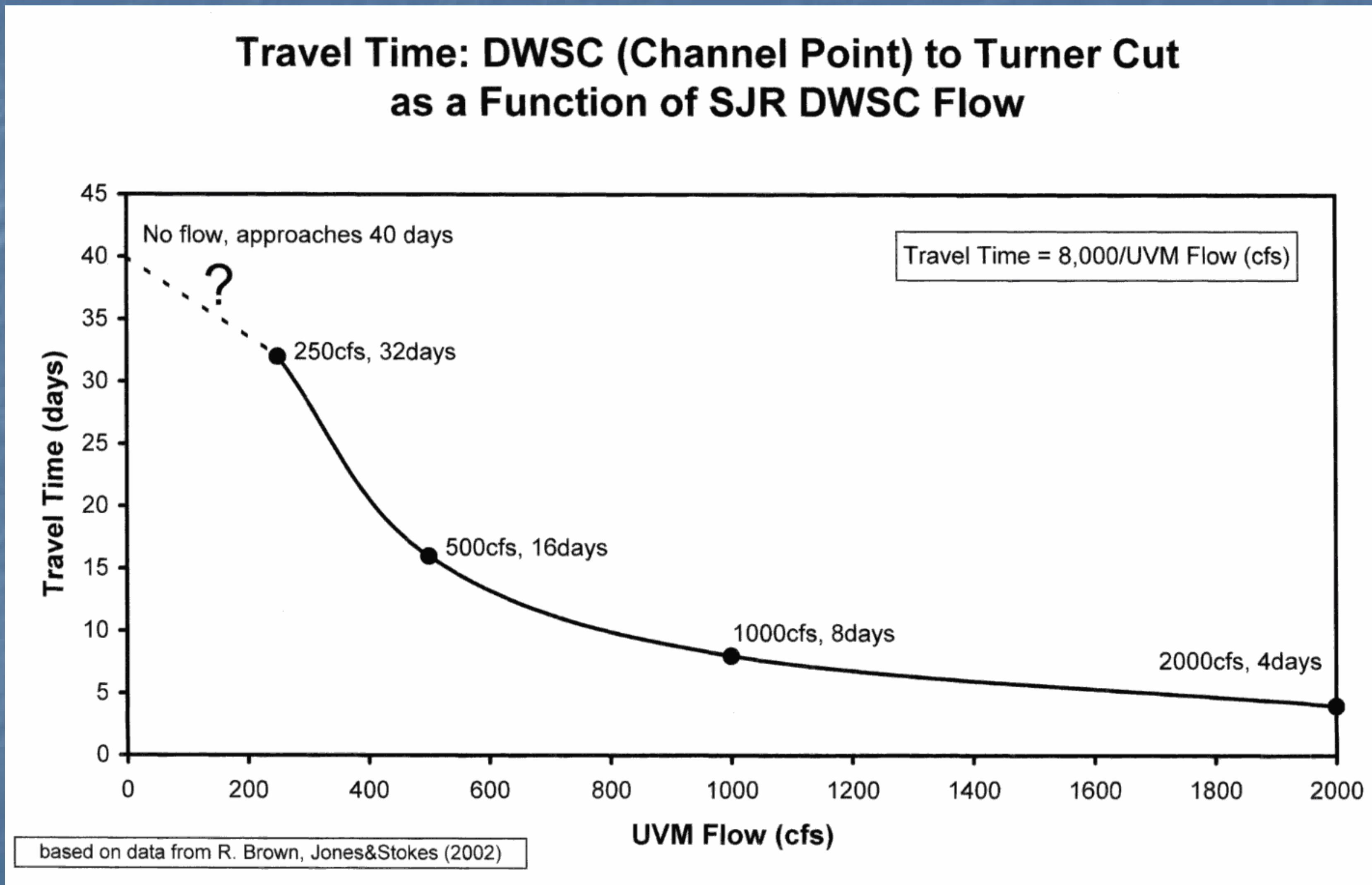
In February & July 2003 When SJR DWSC Flow Was ~ 100 cfs, DWSC Surface Water DO near Rough & Ready Island Was at or near 0 mg/L for Several Days to > 1 wk



February



July


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)
0
5
10
15
20
25
30
35
40
45
0
200
400
600
800
1000
1200
1400
1600
1800
2000
UVM Flow (cfs)
based on data from R. Brown, Jones&Stokes (2002)

Oxygen Demand Constituents

C-BOD — Carbonaceous Biochemical Oxygen Demand

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

N-BOD — Nitrogenous Biochemical Oxygen Demand

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

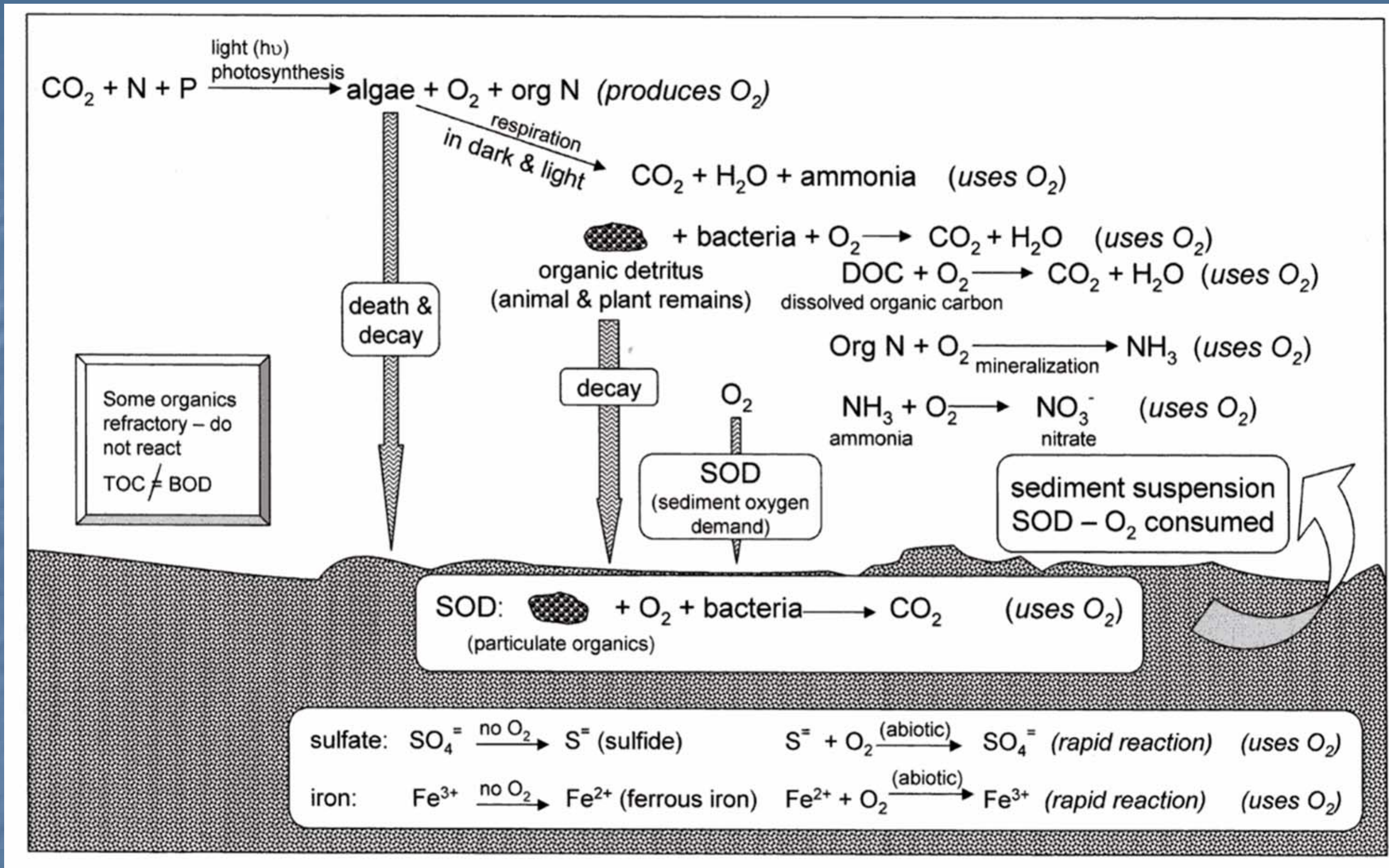
$$\text{Organic N} \xrightarrow{\textit{Bacteria}} NH_3$$ *Ammonification*

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

SOD — Sediment Oxygen Demand

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

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

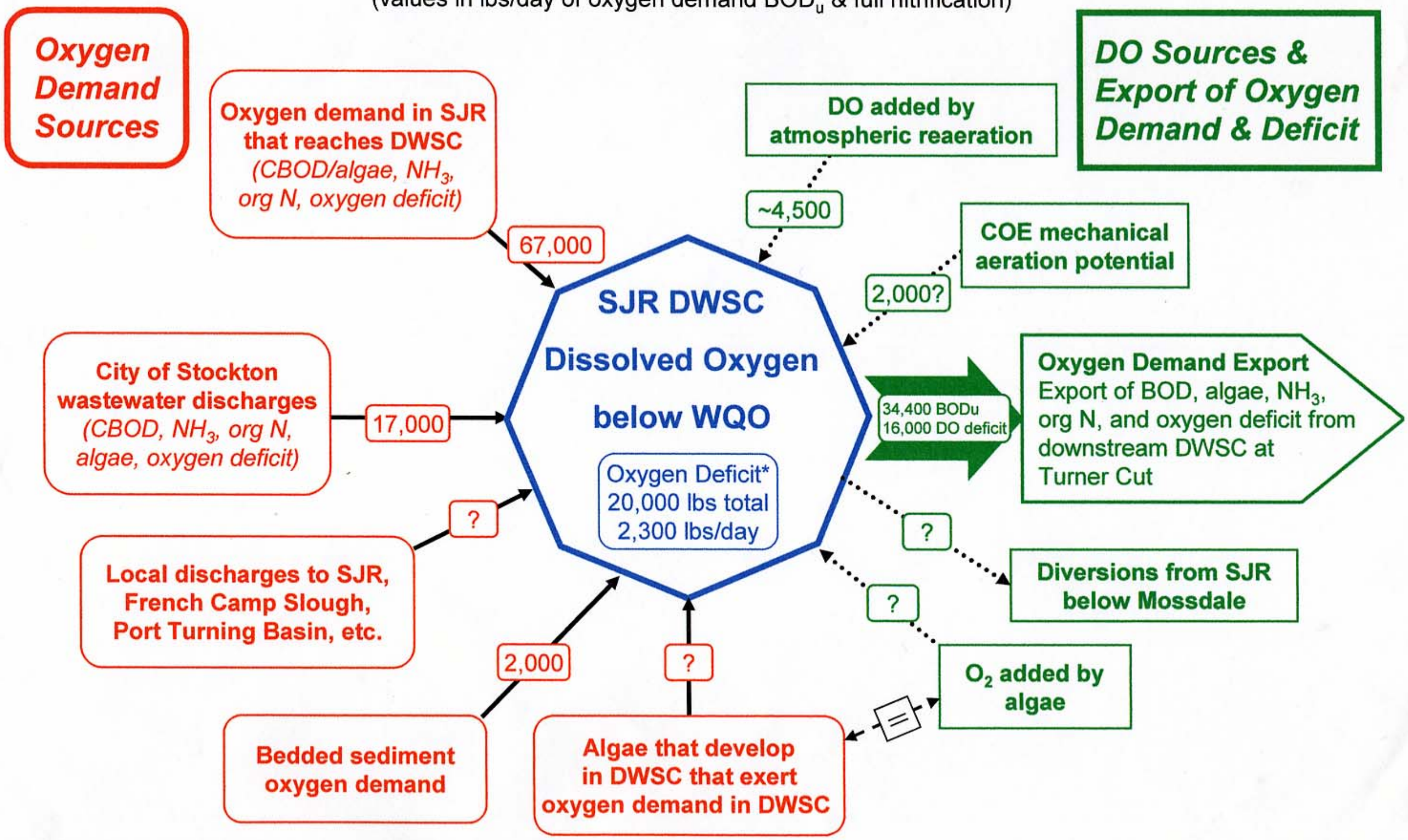


Oxygen Demand Processes

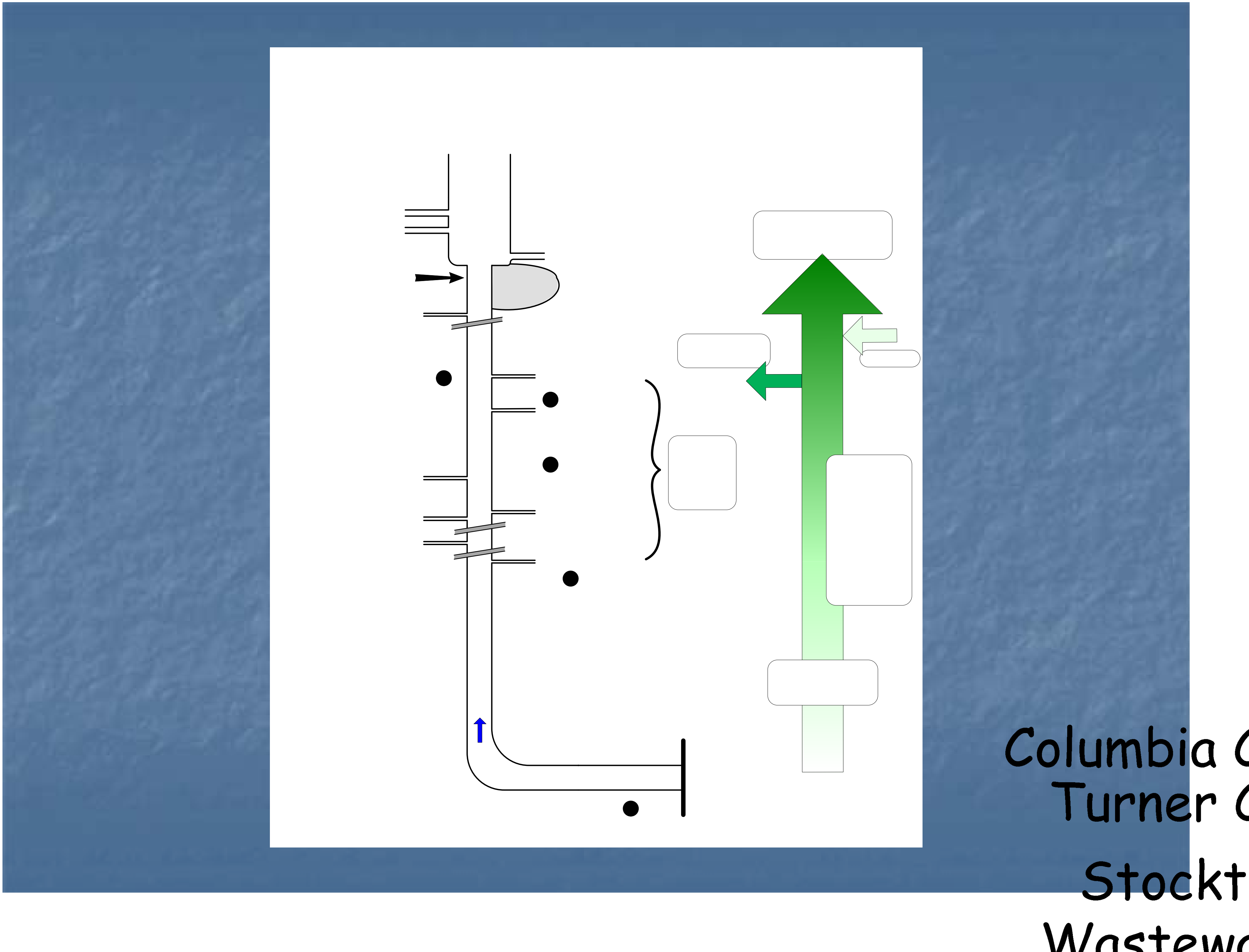
Figure 15. Box Model of Estimated DO Sources/Sinks in SJR DWSC "Average" Summer/Fall 1999—2001

SJR DWSC Flow: 930 cfs; Travel Time: 8.6 days

(values in lbs/day of oxygen demand BOD_u & full nitrification)

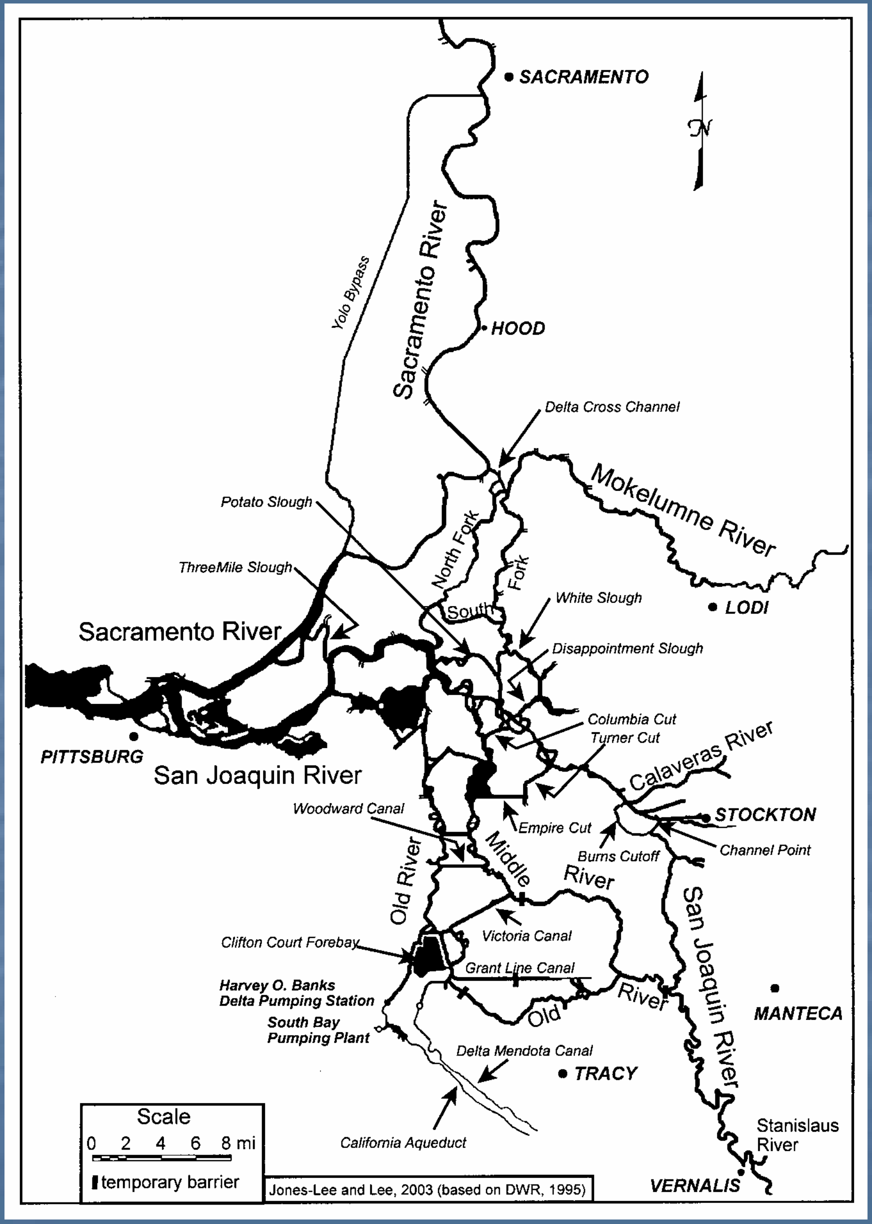


* Total oxygen deficit below oxygen saturation ≈120,000 lbs; 14,000 lbs/day


Columbia C
Turner C
Stockt
Wastewa

Impact of SJR DWSC Flow on Occurrence of DO WQO Violations

- Examination of Occurrence of DO WQO Violations & SJR DWSC Flows Shows
  - Severely Low DO When Flow of SJR through DWSC < ~500 cfs
  - Violations Rare When SJR DWSC Flow > ~1,500 cfs
- Most Low-DO Problems Would Not Occur If SJR DWSC Flow Was Kept >1,500 cfs
  - Additional Flow Typically Available at SJR Vernalis



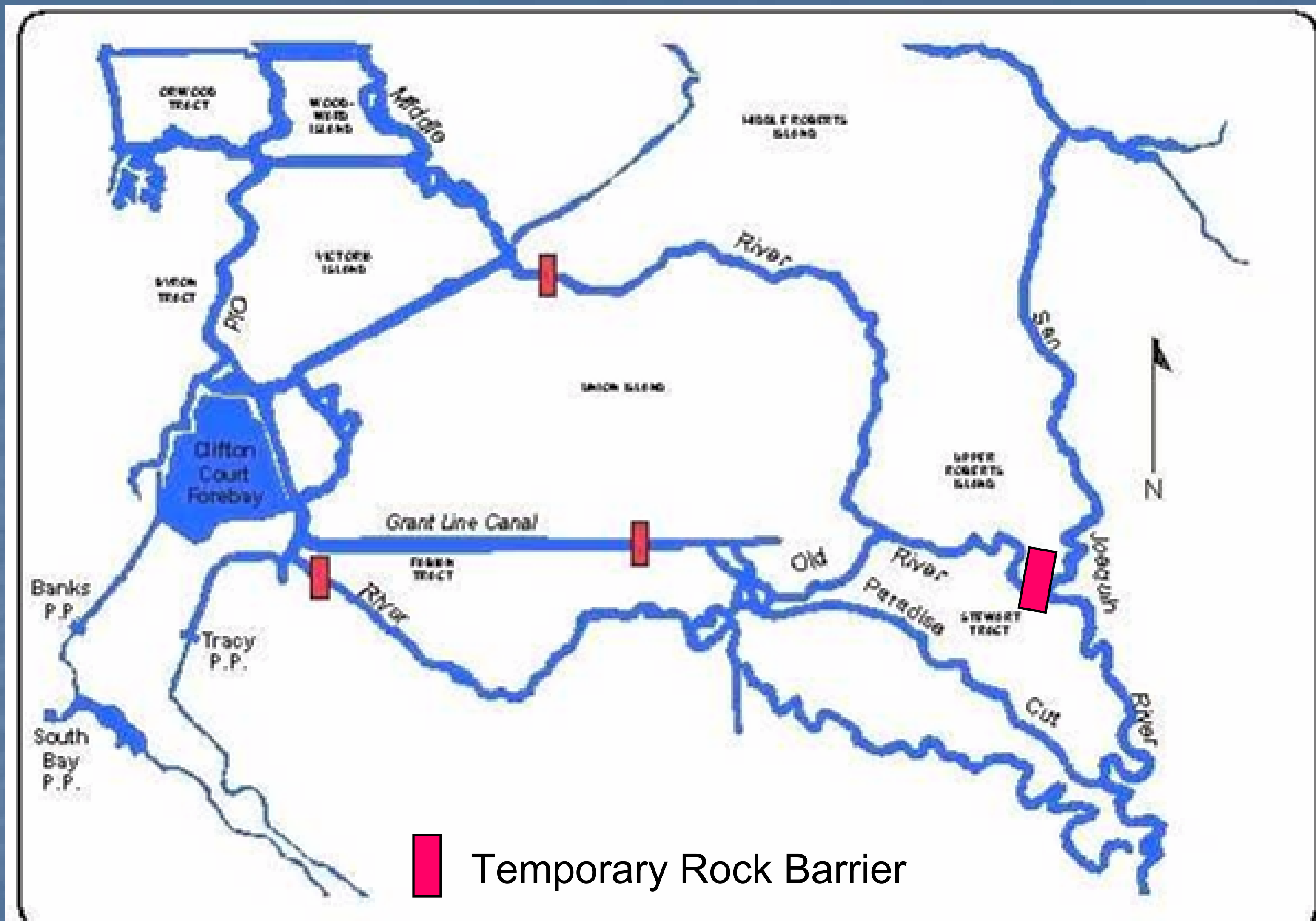
Sacramento — San Joaquin River Delta

Delta Flow Patterns

- State & Federal Projects Export ~ 10,000 to 13,000 cfs of South Delta Water to Central & Southern CA, and to San Francisco Bay Region
  - Since Early 1990s, Summer & Fall SJR Flow at Vernalis Has Been ~ 1,500 to 2,000 cfs
    - All of SJR Vernalis Water Taken by
      - Federal Export Project at Tracy Pumps
      - by Delta Agriculture
  - Remainder of Water Exported from South Delta Is Sacramento River Water Drawn to South Delta by Federal & State Project Pumps
    - A 10,000 cfs “River” of Sacramento River Is Drawn South through Central Delta

Impact of Delta Export Projects on the SJR DWSC Low-DO Problem

- The State and Federal South Delta Water Export Projects Bring Large Amounts of Sacramento River to the South Delta
- Limits the Extent of the Low DO Problem in the DWSC to upstream of Columbia Cut
  - The Large Amount of Sacramento River Water Dilutes the SJR DWSC Residual Oxygen Demand at Turner Cut and Columbia Cut



South Delta Channels and Barriers

South Delta Issues

- State & Federal Water Export Projects Have Caused Several Water Quantity and Water Quality Problems in South Delta
  - Export Projects Lower Water Levels in South Delta Channels by Pumping More Water from South Delta Than Is Supplied
    - Interferes with Agricultural Irrigation & Recreation
  - Created Water Quality Problems
    - Low DO in South Delta Channels
    - Poor Circulation
- Problems Must Be Controlled through Installation of Permanent, Operable Barriers in South Delta
- Reverse Low-Head Pumping across Permanent Barriers Could Solve South Delta Low-DO and Water Level Problems

Delta Food Web Issues

- Delta Aquatic Food Web Is Carbon-Poor
  - Low Primary Production of Assimilatable Carbon
  - Few Algae in North, Central & Western South Delta
    - Drawing of Sacramento River Water to South Delta Pumps by State & Federal Export Projects Leads to Low Algal Growth
    - Limited Light Penetration Due to Turbidity & Color
    - Excessive Growths of Vascular Plants– Hyacinth & Egeria
- Should Explore Use of Algae Developed in SJR Watershed to Help Support Food Web of Central Delta
  - DWSC Low-DO Problems Can Be Solved & Allow Algae Developed in SJR DWSC & Watershed to Enter Central Delta via Turner Cut & Columbia Cut
- In Some Years (e.g., 1998, 2000) SJR DWSC Flow >1,500 cfs,
  - Few Low-DO Problems in DWSC
  - No Major Water Quality Problems in Delta

Responsible Parties for Low-DO Problem

- Port of Stockton & All Who Benefit from It
- Water Diverters That Decrease Flow of SJR through DWSC That Leads to DO Concentrations below WQO
- City of Stockton Wastewater Discharges, Especially Ammonia
- Upstream Agriculture That Discharges Nutrients (N & P) That Develop into Algae That Contribute to DO WQO Violations
  - Not All N & P Discharges Contribute to Low-DO Problems
- CVRWQCB Adopted a "Three-Legged Stool" Concept
  - Port, Water Diverters & Oxygen Demand Loads Initially All Considered Equal Contributors

Approaches for Solving DWSC Low-DO Problem

- CA Legislature Provided $40 million to Solve Low-DO Problem
  - Administered by CBDA (CALFED) with Guidance by CVRWQCB
  - How to Best Use Funds?
- Approaches
  - Allow DWSC to Fill In — Stop Dredging DWSC
    - What Is Benefit of Port to Area?
  - Increase Flow of SJR through DWSC
    - Purchase Eastside River Water to Supplement SJR Flow through DWSC
    - Reverse-Head Pumping over Permanent South Delta Barriers
      - Technically Feasible & Economically Viable with Funding as Part of Solving South Delta Problems Caused by State & Federal Export Projects

Approaches for Solving DWSC Low-DO Problem

- Control City of Stockton Wastewater Ammonia
  - Nitrification of Wastewater Effluent
    - CVRWQCB NPDES Wastewater Discharge Limit for Ammonia 2 mgN/L Monthly Average
- Aeration of DWSC
  - Under Current Oxygen Demand Loads & SJR Flows, Could Need as Much as 10,000 lb O_2/day on Some Days
    - Reduce Aeration Costs by Increasing SJR DWSC Flow & Oxygen Demand Loads. Key Issues:
      - Who Will Operate & Manage Aeration System
      - Who Will Pay for Ongoing Operation & Maintenance of Aeration System?
        - Responsible Parties ?

Approaches for Solving DWSC Low-DO Problem

- Control of Upstream Algal Oxygen-Demand Load
  - Require Upstream Agricultural Interests to Control Their Nutrient Loads to SJR That Lead to Algae-Derived Oxygen Demand Loads That Cause DO WQO Violations
    - Difficult to Achieve
    - May Not Be Achievable While Maintaining Economically Viable Agriculture
    - Detrimental to Delta Aquatic Food Web
- CVRWQCB Conducting a Phase I TMDL to Evaluate Options
  - 5-year Program to Be Completed by 2008?
  - Funded by CBDA (CALFED)

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- Also see ***www.gfredlee.com*** in the San Joaquin River Watershed Section

Abstract

The San Joaquin River (SJR) is one of the major rivers in California. Its watershed consists of over 15,000 sq km of some of the most productive agricultural areas in the world. The river from the city of Stockton to San Francisco Bay, CA, a distance of about 100 km, has been dredged to form a Deep Water Ship Channel (DWSC) with a large ship navigation depth of about 12 m. The first 15 km of the DWSC experiences dissolved oxygen (DO) depletion below the water quality standard/objective (WQO). This has led to the need to develop a total maximum daily load (TMDL) of oxygen-demanding substances to eliminate the violations of the DO WQO. Approximately $4 million of studies of the SJR DWSC watershed conducted over the past four years has shown that the primary cause of oxygen demand (OD) is algae that are produced in the SJR upstream of the DWSC. Planktonic algal chlorophyll has been found to be proportional to BOD. Three small upstream watersheds are responsible for up to 90% of the algal BOD that leads to low DO in the DWSC. The nutrients that serve as the basis for the algal growth are derived from irrigated agriculture tailwater and farm field subsurface drainwater discharges. Also at times the city of Stockton domestic wastewaters ammonia can be a significant oxygen demand cause of the low DO problem in the DWSC.

The existence of the DWSC is a major cause of the DO depletion below the WQO. The SJR upstream of the DWSC is 2 to 3 m deep and does not experience low DO problems, even though it has the same algal BOD loads as the DWSC. The DWSC changes the characteristics of the SJR from a shallow, rapidly moving river to a long, thin tidal freshwater “lake,” where the algae, upon entering the channel, die due to limited light penetration, and exert a water column oxygen demand. Further, upstream water diversions associated with urban and agricultural water development projects divert SJR water that would normally flow through the DWSC. These diversions lead to lower flow through the DWSC, which results in longer residence times in the critical reach of the DWSC and, therefore, greater time for algal oxygen demand exertion.

The State of California has appropriated $40 million to solve the low-DO problem in the DWSC. An evaluation is being conducted on aeration of the DWSC to help eliminate the DO WQO violations. Also efforts are being made to increase the flow of the SJR through the DWSC through the use of operable South Delta flow barriers and low head reverse head pumping of water over the barriers into the South Delta and SJR. There is a conflict between the attempts to try to control the algae that develop in the SJR watershed and the allowing these algae to enter the Central Delta under high SJR DWSC flow conditions and thereby serve as a source of carbon for the Delta aquatic food web A discussion of the nature of this problem and the ongoing development of management approaches are presented.

KEYWORDS: algae, oxygen demand, dissolved oxygen depletion, dredged navigation channel, management program, TMDL, agriculture nutrient releases, Sacramento and San Joaquin River Delta

Further Information

Consult Website of

Drs. G. Fred Lee and Anne Jones-Lee

http://www.gfredlee.com

Surface and Groundwater Quality Evaluation and Management
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http://www.gfredlee.com

Dr. G. Fred Lee and Dr. Anne Jones-Lee have prepared professional papers and reports on the various areas in which they are active in research and consulting including domestic water supply water quality, water and wastewater treatment, water pollution control, and the evaluation and management of the impacts of solid and hazardous wastes. Publications are available in the following areas:

- Landfills and Groundwater Quality Protection
- Water Quality Evaluation & Management for Wastewater Discharges
  - Stormwater Runoff, Ambient Waters and Pesticide Water Quality Management Issues, TMDL Development, Water Quality Criteria/Standards Development and Implementation
- Impact of Hazardous Chemicals—Superfund
  - LEHR Superfund Site Reports to DSCSOC
  - Lava Cap Mine Superfund Site Reports to SYRCL
  - Smith Canal
- Contaminated Sediment—Aquafund
  - BPTCP, Sediment Quality Criteria
- Mine Waste Management
- Domestic Water Supply Water Quality
- Excessive Fertilization/Eutrophication, Nutrient Criteria
- Reuse of Reclaimed Wastewaters
- Watershed-Based Water Quality Management Programs:
  - Sacramento River Watershed Program
  - Delta—CALFED Program
  - Upper Newport Bay Watershed Program
  - San Joaquin River Watershed DO and OP Pesticide TMDL Programs