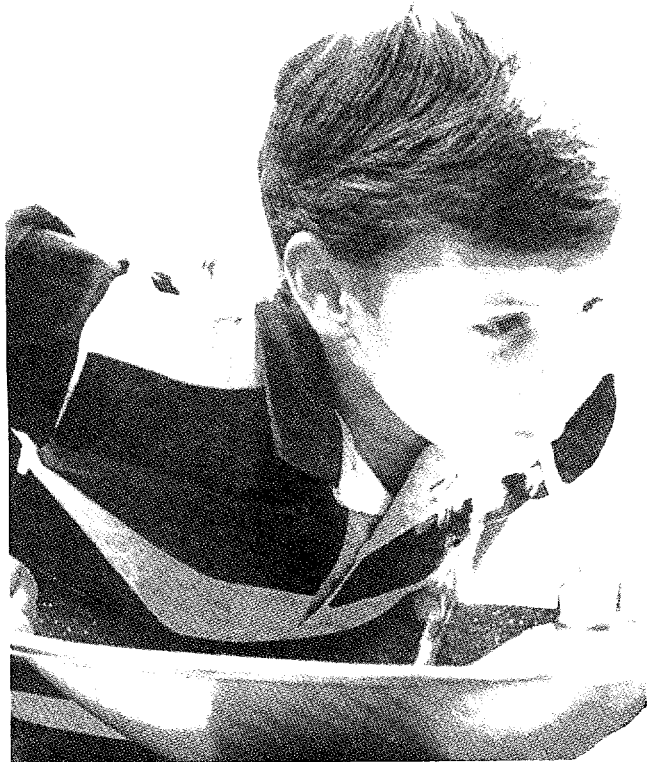
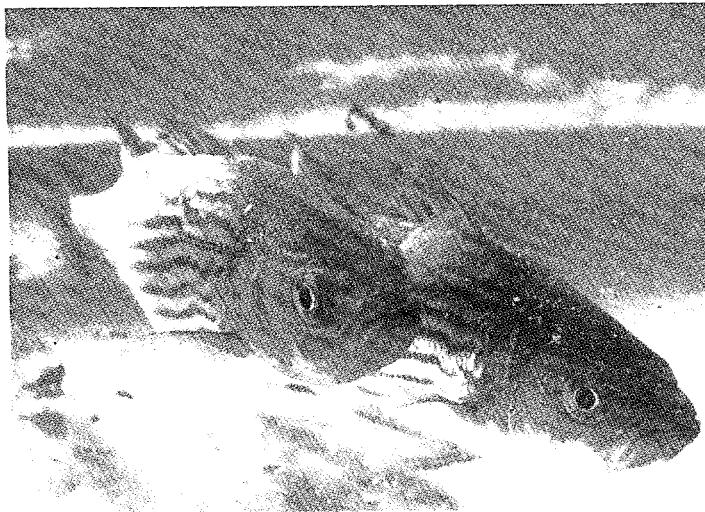


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DELTA



CALIFORNIA URBAN WATER AGENCIES

May 1993

THE DELTA

OVERVIEW OF THE SACRAMENTO-SAN JOAQUIN DELTA

May 1993

prepared for

California Urban Water Agencies

Alameda County Water District
Contra Costa Water District
East Bay Municipal Utility District
Los Angeles Department of Water and Power
Metropolitan Water District of Southern California
Municipal Water District of Orange County
Orange County Water District
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The information in this report does not necessarily represent the views of the governing bodies of the CUWA member agencies.

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FOREWORD

California Urban Water Agencies (CUWA) is an organization of the largest urban water providers in California. Its member agencies serve water to metropolitan areas comprising about two-thirds of the state's nearly 32 million population. CUWA was formed to work on statewide water supply issues. Among those concerns is the health and effective management of the Sacramento-San Joaquin Delta.

All California water professionals and public officials recognize that the Delta is the essential hub of the State's largest and increasingly interdependent water storage and transport systems. Virtually all agree with Governor Wilson's April 1992 overview of the importance of the Delta and his comment that the Delta is broken and we must fix it—in an environmentally sensitive and responsible manner.

CUWA believes that an essential first step in developing a supportable plan to fix the Delta is understanding its problems. Much has happened in the last few years to alter and amplify Delta issues. Facts and figures on Delta problems need continuous updating. Water management consultant and researcher B.J. Miller assisted CUWA in preparation of this overview of the Delta. The assignment was to produce a comprehensive but readable, uncomplicated but accurate compendium of Delta issues. CUWA is pleased to offer this overview to all who want to further their understanding of the Delta.

California Urban Water Agencies

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INTRODUCTION

The Sacramento-San Joaquin Delta (Delta) is a complex region. It is the center of California's water system. Water projects serving much of the state use water that would otherwise flow into the Delta. The two largest of these projects draw water directly from the Delta. Populations of some fish that migrate through and live in the Delta are at all-time recorded lows as a result of several factors, including water project operations. Some solutions to fishery problems threaten the water supplies of cities and farms because of the constraints they impose on water project operations. From any perspective, Governor Pete Wilson's pronouncement of April 6, 1992, 'The Delta is broken.' (Wilson 1992) appears valid. In fact, it appears to have been an understatement. Many water experts on all sides of the issue think that if Delta problems can be solved, California's water problem can be solved. If Delta problems cannot be solved, then California faces continuing fishery and water supply problems.

As California struggles with and fights over the Delta, information accumulates. Understanding of Delta problems improves.

In addition, the environmental protection rules evolve and constrain the options. Endangered species are designated. Their protection is uncompromising. Drinking water requirements become more stringent, causing water quality imperatives to emerge.

New information and new rules change our perspectives of the Delta. In 1982 there was a statewide referendum on a comprehensive package of water legislation. (Senate Bill 200) The package included the Peripheral Canal, a large canal around the periphery of the Delta. The legislative package was defeated. The major concern was that with the Peripheral Canal, damaging amounts of water would be exported from the Delta.

Of the water users who get water from the Delta, most supported the legislation. Ironically, some of them opposed it. They thought that environmental protections in the legislation were too stringent.

Now, ten years later, water users see the issue more broadly. Delta fishery problems are water supply problems. Water will have to be diverted from the Delta in a more environmentally benign way. Protecting the reliability of current supplies is at least as important as getting more water. Opportunities for water marketing, a revolutionary idea in 1982, focus on the Delta. Drinking water quality, barely mentioned ten years ago, is a primary consideration.

Because Delta issues are complex and because so much about the Delta has changed, California Urban Water Agencies has sponsored this overview report. Some of the member agencies of CUWA obtain water diverted directly from the Delta. Others use water diverted from tributaries to the Delta. Policy positions on the Delta vary among the CUWA members. Therefore, this report simply sets forth what is known about the Delta, what is uncertain about the Delta, and what the logical implications are, based on the generally accepted knowledge and uncertainties.

This report draws heavily on the work of many researchers, especially information submitted in recent hearings before the State Water Resources Control Board. Experts on all sides of the issue provided comments and reviewed drafts. However, the information and conclusions herein are the responsibility of the author.

CONCLUSIONS

A crisis is at hand in the Delta. Fishery problems are more serious than ever. One species, the Winter-run salmon, has been listed for protection under both the federal and state Endangered Species Acts. The Delta smelt has recently been listed under the federal act. Petitions have been filed for two more species (NHI 1992), and petitions have been prepared for another two (personal communication, G. Thomas and P. Moyle 1992). By the end of next year, as many as six fish that live in or migrate through the Delta could be on the threatened or endangered list.

The state and, especially, the federal endangered species acts are uncompromising. Listed species

must be protected. Their recovery must be ensured. Use of water upstream of the Delta and exports from the Delta could be severely curtailed. Already, in the Spring of 1992, when Winter-run salmon were found in the Delta, state and federal water deliveries had to be cut by 250,000 acre-feet (DWRc 1992), in addition to the severe cuts already imposed due to the sixth year of an historic drought.

Recently, The Central Valley Project Improvement Act, Title XXXIV of Public Law 102-575, was passed. It gives fish and wildlife protection equal footing with agricultural and urban water supply as primary purposes of the Central Valley Project, which delivers about 20 percent of the water used in the state. The law allocates some 800,000 acre-feet per year to Central Valley fish and wildlife. Much of that allocation will no doubt be used to reduce exports from the Delta.

With the listing of several endangered species, environmental protection will strongly influence water project operations. Water supply will be secondary. In any irreconcilable conflict between water users and endangered species, water users will lose.

Fish are not the only problem in the Delta. About 20 million people in California get at least part (in some places, all) of their drinking water from the Delta. (DWR 1990) From a drinking water quality standpoint, the Delta is the worst major source of urban water in the state. Federal drinking water standards are becoming more and more stringent. (Means et al 1993, Pontius 1993) Urban users of Delta water face expenditures ranging from hundreds of millions to over three billion dollars of capital cost (to say nothing of the cost of operating and maintaining the water treatment facilities) for uncertain compliance with these new standards. (Pirnie 1992, MWD 1992, MWD/JMM 1991)

The third great problem in the Delta is levee stability. Most of the Delta is below sea level. (DWRb 1987) The islands of the Delta are really holes. Delta soils, especially the rich peat soils, oxidize and blow away as they are tilled in farming.

(SLC 1991) The levees, originally built with hand labor when the Delta was a marsh, were never intended to withstand the pressures they are subjected to today. Earthquake experts say that the Bay-Delta area may be entering a new, several-decade period of earthquake activity after about 70 years of quiescence. (USGS 1990, CSUH 1992) There is a better than two-thirds chance of a major earthquake near the Bay-Delta area in the next 30 years. (USGS 1990, CSUH 1992) Much of the Delta is underlain with soils that could liquefy during an earthquake. (DWRc 1992) Some of the levees themselves are made of liquefiable soils. (DWRc 1992) The peat soils may serve to lessen the liquefaction (DWRc 1992), but a substantial risk remains. East Bay Municipal Utility District has recently had an assessment made of the chances of liquefaction of soils along its aqueduct route through the southern Delta. At one third of the locations, the chances were at least 90 percent that liquefaction would occur sometime in the next 30 years. (Earth Sciences Associates 1992) Liquefaction means levee failure. Levee failure means islands flooding with salty water from San Francisco Bay. Salty water means export shutdown and the use of precious stored water to flush out the Delta if, in fact, it could be flushed out. Salty water in the southern Delta may have to be pumped out.

So, not only are current supplies immediately threatened by fish problems. Earthquake damage to the low-lying Delta presents another, longer-range threat.

But is this really that serious? After all, is this not the era of water transfers in California? If the Delta water supplies are cut back, can't the truly deficient water users buy the water they need? Can't they bank wet period water for later use in dry years? Maybe banking and transfers will help some, but as this report describes, the Delta fishery problems may not allow much water to be transferred or banked. Thirsty parts of the state could buy the water, but they cannot deliver it because of the problems in the Delta. After all, the Delta is at the head end of the major canals that could deliver the water to the buyers. No Delta exports?—Then little water transfers and water banking.

How can the Delta problems be solved? Some would suggest that flow is the answer—Simply put more water into the Delta and/or export less out, and the problems will be solved. Of course, that does nothing for the earthquake problem. It might help the drinking water quality problem some, but it does not eliminate it. (personal communication, E. Means MWD 1993) Most importantly, it does not solve the fishery problem, not without cutting the exports by 50 to 60 percent during dry periods, thereby creating water shortages in every year of less than normal precipitation and severe water shortages in dry years.¹

Those experts who have studied the Delta and who have a clear understanding of its problems generally agree on one thing: If the fishery, drinking water quality, and levee stability problems are to be solved without causing severe water shortages, improvements must be made in the way water moves across and is exported from the Delta. However, many of these same experts are also concerned about how the water projects would be operated if such improvements were made. It may be difficult to conceive of conditions getting worse in the Delta, but some people fear this could happen if Delta improvements were made and, then, the water projects were mis-operated.²

Therefore, if Delta improvements are to be made, there must be guarantees against mis-operation. One could argue that such guarantees already exist in the combined form of the Endangered Species Acts, the recently passed Central Valley Project Improvement Act, and other environmental protections such as the authority of the State Water Resources Control Board, the Corps of Engineers, and the U.S. Environmental Protection Agency. The Endangered Species Act alone requires uncompromising protection and

recovery of its protected species. Nevertheless, operational guarantees specific to Delta improvements may be necessary.

What form could such guarantees take to give them permanence? A two-tiered form has been developed by a committee of environmental and water rights attorneys. The two tiers are: A multi-party contract, including at least one private party to prevent state legislative overturn, and federal legislation backing up the contract. (NHI 1991)

To summarize, the Delta problems are now more serious than anyone anticipated. The fishery problem cannot be solved solely by providing more flow. Even a serious (and unavoidably inadequate) attempt to do so would provoke severe water shortages for cities and farmers. Nor can the drinking water quality and levee stability problems be solved by providing more flow. Improvements in the way water moves across and is exported from the Delta will be needed to solve these problems and to ensure a reliable supply of good quality water for those parts of the state that depend on water from the Delta. Proper operation of such improvements should be guaranteed. The means to provide such guarantees has been developed and will be discussed later in this report.

¹ As this paper is being written, the State Water Resources Control Board is considering whether to act on draft Decision 1630, which would modify the existing Delta standards to protect fish. The draft of D-1630 reallocates an average of about 660,000 acre-feet per year from agricultural and urban use to the protection of fish, based on revisions to the draft as proposed by the State Board. That decision is not analyzed in this paper because Water Board deliberation on the draft decision is proceeding as this paper is being written. However, it should be noted that D-1630, as proposed in draft form, is only a first step in solving the fishery problems in the Delta. As concluded in this paper, much more water would be required to approach that, and, still, fishery problems would remain. In other words, the adoption of D-1630 in any form similar to the draft of D-1630, does not indicate that the fishery and water supply problems of the Delta can be solved without Delta improvements which would correct the way water moves across and is exported from the Delta.

² 'Mis-operated' in this context means that Delta water facilities would be operated primarily to benefit water users to the detriment of the Delta environmental values or vice versa.

THE MOVEMENT OF WATER IN THE DELTA

The Sources of Water

All of the Delta issues are inextricably bound up with the way water moves into and out of the Delta. This section briefly describes that movement. Please refer to Figure 1 for an overview.

Water moves into the Delta from four major sources. Fresh water enters from the Sacramento River on the north, the San Joaquin River on the south, and east side streams. In addition, salty water tends to move in from the west with the tides, from Suisun and Honker Bays, the northern reach of the San Francisco Bay system.

The Delta is a tidal region. Each 24.8 hours, the tides cause water to move into and out of the Delta twice. The tides cause a five- to eight-mile, back and forth movement of water in the western part of the Delta. The average flow into the Delta on the flood (incoming) tide is about 150,000 cubic feet per second. About six hours later, the flow reverses as the ebb (outgoing) tide begins, and water flows out of the Delta at about 150,000 cubic feet per second. (personal communication, E. Winkler DWR, based on internal DWR memorandum 1992)

The movement of fresh water through the Delta from upstream is, in a sense, superimposed on these tidal flows. Typical flows of fresh water are much less than flows caused by tides. The average Delta outflow, for example, is only about 30,000 cfs. (DWRb 1992) Delta outflow in the summers of dry years can be as low as 3,000 cfs.³ (DWRb 1992)

Most of the fresh water comes from the Sacramento River. In an average year the Sacramento River contributes about 85 percent of the fresh water to the Delta, and the San Joaquin River contributes about 10 percent. Streams on the east side, including the Mokelumne River, provide

the rest. The Sacramento River's contribution can increase to almost 90 percent in dry years and drop to about 70 percent in wet years. (DWRb 1992)

What follows immediately below is a description of what might be termed the 'current understanding' of water movement in the Delta. A later section discusses new studies and theories that may change this understanding.

The Current Understanding of Water Movement in the Delta

The Tides and Fresh Water Flow

The flows induced by the incoming and outgoing tides are thought to cancel each other out. That is, the water is assumed to simply slosh in five to eight miles and then slosh out five to eight miles, with no net movement occurring. While fresh water flows are small relative to tidal flows, they are important because they are the source of net movement of water. In addition, they are the means by which things dissolved in or floating in the water move from place to place in the Delta. Salt, for example, is dissolved in the water. Fish eggs and larvae are planktonic; that is, they drift with the water. So are the small plants and animals on which fish feed. For this reason, non-tidal flows have received the most attention.

Calculation of Delta Outflow

Because of the large tidal flows, non-tidal flows cannot be measured easily. For example, if a current meter is put at the confluence of the Sacramento and San Joaquin Rivers, at the western end of Sherman Island, it will record the very large tidal flows. Net Delta outflow is barely detectable, and certainly not measurable to any degree of accuracy. Sophisticated sonar meters and computer analysis of the resulting data are required for accurate measurement, and, so far, such meters have not been proven to work in that part of the Delta.

³ This superimposition can be thought of as a person on a train, walking from the front to the back of the train. The train is on a six-mile track. The train runs back and forth on this track, making two trips per day. In the middle of each run, the train's speed reaches, say, 85 miles per hour. The person is walking about 5 mph. The train is the tidal motion of 150,000 cfs. The person represents the flow of fresh water, the non-tidal flows, in this case about 10,000 cfs. The person eventually gets to the back of the train and jumps off (into San Francisco Bay), but there is a lot of disruption during the trip. For this analogy to be more applicable, the person would have to be continually trading body parts for train parts, representing the mixing of incoming fresh water and water moving in the Delta due to the tides.

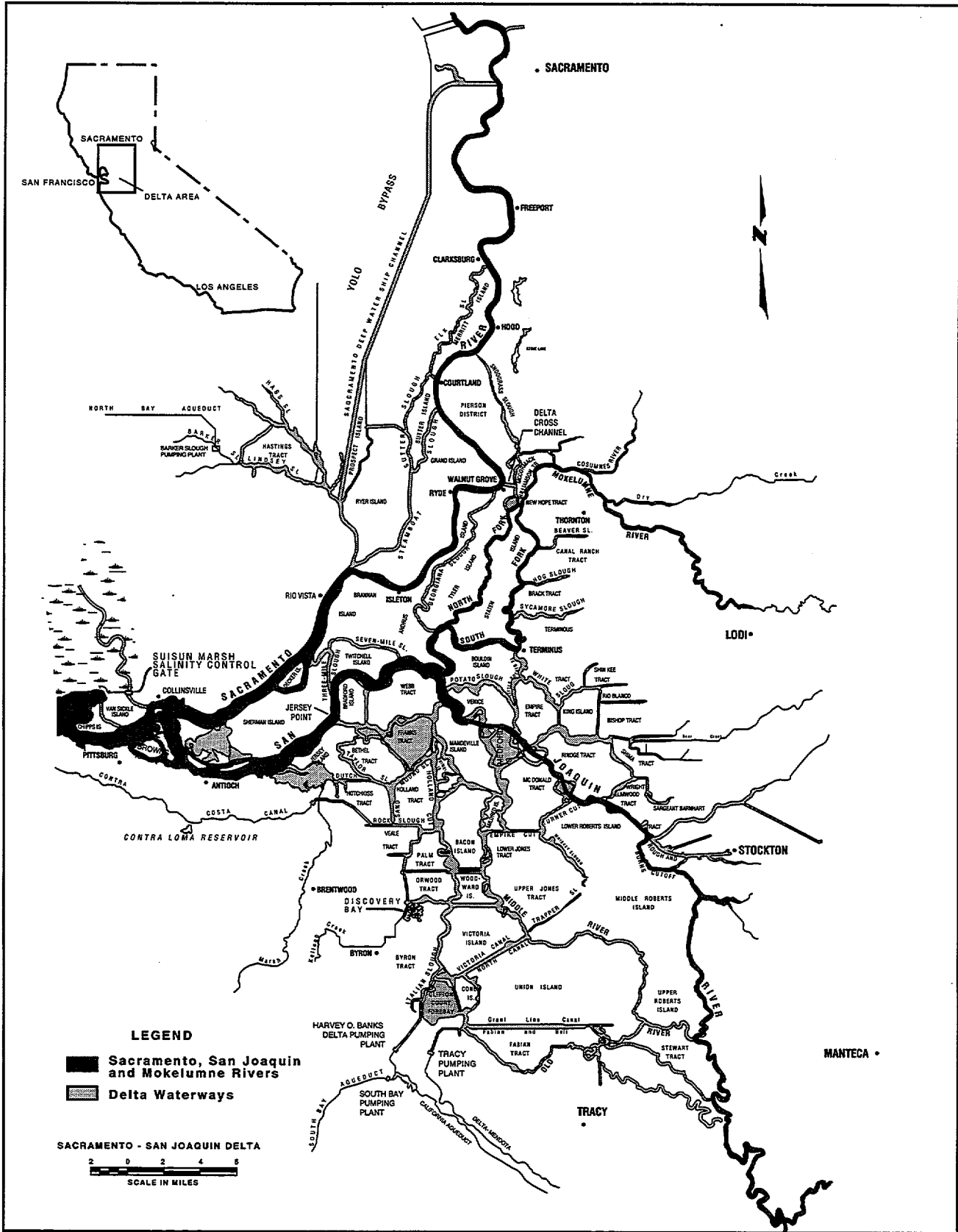


Figure 1. The Delta

Therefore, for many years, the non-tidal flow rates have been calculated. (DWRb 1992) The bases of this calculation are Delta inflows (primarily the Sacramento and San Joaquin Rivers and other east side streams and rivers), which are measured; precipitation, which is measured; exports from the Delta, also measured; and the diversions and discharge of water by agriculture in the Delta. The calculation looks like this:

Table 1
Calculation of Delta Outflow
IN minus OUT equals DELTA OUTFLOW

San Joaquin River	Exports from the Delta
Sacramento River	Banks (state) Pumping Plant
East Side Streams	Tracy (federal) Pumping Plant
Precipitation	Contra Costa Water District
Drainage from Delta croplands	Diversions for Delta crop irrigation

Drainage and diversions for Delta croplands are not measured. There are few meters on the hundreds of diversion and drainage points in the Delta. Instead, these drainage and diversion flows are calculated. The calculation is based on historical records of the types of crops grown in the Delta. The calculated values vary throughout the year, but the same values are used for each day of every year. Obviously, some error is introduced by these estimates. They are generally thought to be accurate enough to calculate flow rates averaged over a period of at least two weeks. However, they are still not accurate for estimating daily flow rates. (personal communication, F. Chung DWR 1992)

Calculation of Reverse Flow

The southern Delta is of particular concern. The large export pumping plants are there. This pumping can cause water in southern Delta channels to flow upstream. This phenomenon is known as 'reverse flows.' Actually, as it has come to be used, the term 'reverse flows' refers to upstream flow in the lower San Joaquin River. If the flow is upstream there, due to export pumping, then it is likely that flow will be upstream in many of the southern Delta channels.

The net flow in the lower San Joaquin River cannot be measured with conventional current meters because of the large tidal flow rates. Therefore, just as for Delta outflow, the flow in the lower San Joaquin River (Jersey Point to the confluence with the Sacramento River) is calculated ignoring the effects of tides. In that regard, the calculation is similar to that for Delta outflow.

The first step is to draw an imaginary line around the southern Delta, as shown on the map on the following page, Figure 2. Then, the calculation described above is repeated, with two important modifications:

Water from the Sacramento River enters the southern Delta primarily via the Mokelumne River. Water gets into the Mokelumne River via the Delta Cross Channel or Georgiana Slough.

Only about 65 percent of Delta agricultural lands are in the southern Delta. Therefore, net use by agriculture and precipitation for the total Delta must be reduced by 35 percent.

Surprisingly, the amount of water entering the southern Delta from the Sacramento River through the Delta Cross Channel or Georgiana Slough does not depend on the amount of water being exported from the southern Delta. The pumps are simply too far away to affect water levels there. (personal communication, F. Chung DWR 1992) The Cross Channel Gates are the major determinant. The Cross Channel was built years ago by the federal government to allow water to flow more directly from the Sacramento River to the export pumps. According to relationships developed by the State Department of Water Resources, when the Cross Channel Gates are open, about 30 percent of the water from the Sacramento River, plus about 2100 cubic feet per second, is diverted south to the San Joaquin River through the Cross Channel and Georgiana Slough. With the Cross Channel closed, about 15 percent of the Sacramento River, plus about 1,000 cubic feet per second, is diverted south into the lower San Joaquin River through Georgiana Slough alone. (DWRb 1992) For example, if the flow in the Sacramento River is 20,000 cubic feet per second and the Cross Channel Gates are open,

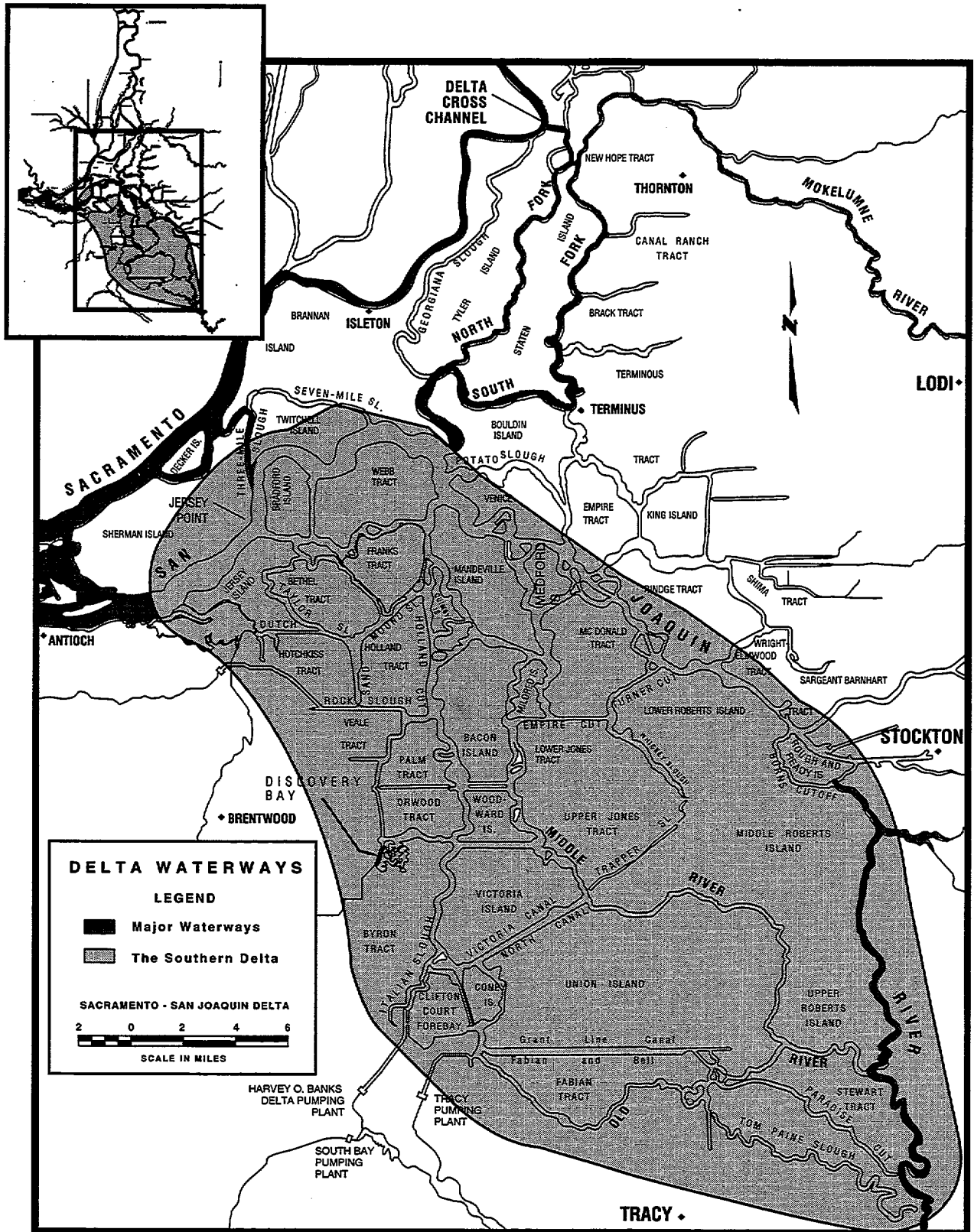


Figure 2. The Southern Delta

the flow of water from the Sacramento River to the lower San Joaquin River is 30 percent of 20,000, which is 6,000; plus 2,100, for a total of 8,100 cubic feet per second, 40 percent of the Sacramento River flow. With the Cross Channel Gates closed, the corresponding flow would be 4,000 cubic feet per second or about 20 percent of the Sacramento River flow.

With these modifications, the previous table becomes:

Table 2
Calculation of Reverse Flows
(Flow in the Lower San Joaquin River)
IN minus OUT equals NET FLOW IN THE
LOWER SAN JOAQUIN RIVER

San Joaquin River	Exports from the Delta
East Side Streams	Banks (state) Pumping Plant
65% Precipitation	Tracy (federal) Pumping Plant
65% of Drainage from Delta croplands	Contra Costa Water District
Sacramento River: Cross Channel open: 30% Sac. R. flow + 2,100 cfs Cross Channel closed: 15% Sac. R. flow + 1,000 cfs	65% of Diversions for Delta crop irrigation

If the net calculated flow in the lower San Joaquin River is negative, then 'reverse flows' are said to exist. Note, however, that even if the flow in the lower San Joaquin River is positive, that is, downstream, that does not mean that reverse flows do not exist in channels close to the export pumps. The alleged significance of reverse flows, as calculated above for the lower San Joaquin River, is that they indicate the widespread occurrence of upstream flows toward the export pumps, over much of the southern Delta.

The Significance of Calculated Reverse Flows

Several important conclusions can be drawn about this table, that is, about conditions leading to the existence of calculated reverse flows:

Closing the Delta Cross Channel⁴ cuts the flow

from the Sacramento River into the southern Delta by about half.

With the Cross Channel Gates closed, for every additional 1,000 cubic feet per second of flow in the Sacramento River, only about 200 to 300 cubic feet per second more Sacramento River water gets into the southern Delta. In other words, with the Cross Channel Gates closed, if calculated reverse flows are to be avoided in the lower San Joaquin River, putting more water down the Sacramento River does not do much good.

On the other hand, if calculated reverse flows are to be avoided, curtailing exports or increasing the flow in the San Joaquin River has direct, one-for-one benefits. Assume that no calculated reverse flows are allowed, that is, the flow in the lower San Joaquin River can be no less than zero. Assume that the Cross Channel Gates are closed. Exports from the Delta must be low enough to bring the above calculation into balance (in = out, for the southern Delta). Then, if exports are to be increased by 1,000 cubic feet per second, flows in the San Joaquin River must be increased by 1,000 cubic feet per second or flows in the Sacramento River must be increased by about 3,000 to 5,000 cubic feet per second! Of course some combination of increases would be possible.

The combination of Cross Channel Gate closures and prohibitions on calculated reverse flows amounts to severe curtailments of export pumping.

Using actual flow data, it is fairly easy to calculate how much the total of export curtailments and extra San Joaquin River flow would have to be to eliminate calculated reverse flows. For the first five years of the recent drought (October, 1986, through September, 1991⁵) the amount of water would be in the range of 3.5 to 4.0 million acre-feet per year.⁶ That is about 1.6 to 1.9 million acre-feet per year more than the entire flow in the San

⁴ The reason to close the Cross Channel is explained later. The brief explanation is that by closing the Cross Channel, fewer fish are diverted out of the Sacramento River into the Central Delta where their mortalities are higher.

Joaquin River system without any dams or irrigated agriculture.⁷ (Miller 1992)

Put another way, eliminating calculated reverse flows from February through June under the assumptions noted in the footnote below, would require eliminating all water use from streams tributary to the San Joaquin River and curtailing Delta exports by 25 to 30 percent of the current average annual demand for those exports. If all of the water was made up from exports, then exports would have had to be cut by 50 to 60 percent relative to the current demands.

Carriage Water

There is one other important idea that derives from this current understanding of water movement in the Delta. This is the concept of 'carriage water.' Calculated reverse flows have been thought to draw salty water back up into the southern Delta. If this is true, then extra water must be released down the Sacramento River to hold the salty water back. So, for every 1,000 cubic feet per second of exports, from 300 to 700 extra cubic feet per second must be released from upstream reservoirs to flow down the Sacramento River and 'carry' the 1,000 cubic feet per second to the export pumps without contamination by intruding salty water.

This carriage water can be viewed as a 'duty' on water purchased north of the Delta for export out of the southern Delta. If 100 acre-feet is to be delivered south of the Delta, at least 140 acre-feet must be purchased and released into the Sacramento River north of the Delta if the Cross Channel Gates are open. If the Cross Channel Gates are closed, much more water must be purchased and released for the same 100 acre-foot delivery south of the Delta.

⁵ The water year runs from October 1 through the following September 30. For example, water year 1987, the first year of the drought, began on October 1, 1986, and ended on September 30, 1987.

⁶ This calculation is based on 'dayflow' data from the Department of Water Resources during the first five years of this drought. (DWRB 1992) Assume that the Delta Cross Channel and Georgiana Slough would be closed from February 1 through June. Assume that no calculated reverse flows should occur in the San Joaquin River at Jersey Point from February 1 through June (that is, the calculated flow would never fall below '0' in the San Joaquin River at Jersey Point). Assume current annual demands for water exported from the Delta, about 3.0 million acre-feet for the Central Valley Project and about 3.5 million acre-feet for the State Water Project. As an alternative, assume that the calculated flow in the San Joaquin River at Jersey Point was never allowed to fall below 1,000 cfs from February 1 through June.

⁷ In California water jargon this is known as the 'unimpaired' flow.

Summary of the Current Understanding of Water Movement in the Delta

In summary, in accordance with the current understanding of water movement in the Delta, the key area of concern is the western and southern Delta. In particular, the phenomenon of calculated reverse flows now appears to dominate the flow issue. Calculated reverse flows are aggravated by exports from the Delta and diversions onto Delta islands. Calculated reverse flows are mitigated by having the Cross Channel Gates open so that more water can get from the Sacramento River to the San Joaquin River via the Mokelumne River. Calculated reverse flows are also mitigated by increased flows in the San Joaquin River or by curtailing exports or both.

However, as discussed above, calculated reverse flows cannot be eliminated by providing more flow into the Delta or by curtailing exports, not without wiping out much of the agricultural use of water on the east side of the San Joaquin Valley or by having dry year water shortages of 25 to 60 percent for exports from the Delta.

Recent Insights into Water Movement in the Delta

Recent work has just begun to suggest that the actual movement of water in the Delta may be quite different than the current understanding described above. Some of the ideas are new. Others are revisited. All of this work is related to the effect of tides and involves three phenomena:

- Tidal pumping through Threemile Slough
Longitudinal dispersion

- Filling and draining of the Delta on the neap-spring lunar cycle.

It is also possible that wind and barometric pressure may be important, but analysis of these effects has not been done.

Tidal Pumping through Threemile Slough

Threemile Slough is the upstream boundary of Sherman Island. Water moves from the Sacramento River to the San Joaquin River via Threemile Slough. This occurs by a phenomenon known as 'tidal pumping.' Please refer to Figure 3 (based on information in CCWD 1992 and personal communication, G. Gartrell and A. Nelson CCWD 1993):

Consider the end of an ebb (outgoing) tide, shown in panel #1. Lower salinity water has been drawn from the interior part of the Delta toward the western part of the Delta.

The flood (incoming) tide begins, as shown in panel #2.

Water is pushed up the Sacramento and San Joaquin Rivers by the incoming tide, and water levels are rising in both rivers.

However, as can be seen from a map of the Delta, the incoming tide does not have as far to go to reach the Sacramento (northern) end of Threemile Slough as the San Joaquin (southern) end. So, as shown in panel #3, the water level will be higher sooner at the northern end than at the southern end of Threemile Slough.⁸

Therefore, during the flood tide, water will flow from the Sacramento River to the San Joaquin River. This will be lower salinity water, drawn out of the Delta on the ebb tide. The average flow in Threemile Slough during the flood tide has been estimated at 10,500 cubic feet per second. (DWR 1962)

The flood tide ends (panel #4) and the ebb tide begins.

The opposite effect occurs. The water level drops faster at the northern end of Threemile

Slough than at the southern end.

Water flows from the San Joaquin River to the Sacramento River, as shown in panel #5. Again, the rate of flow is in the range of 10,500 cubic feet per second.

Because the flood tide has tended to move saltier water into the Delta, the water flowing north through Threemile Slough tends to be saltier than the water pumped south through Threemile Slough on the flood tide. This is shown as 'higher salinity water' on panel #6.

The net effect of this tidal pumping is to move high quality (that is, low salinity) water from the Sacramento River to the San Joaquin River.

This tidal pumping can offset the effects of reverse flows, at least as far as salinity goes. That is, the salinity increase that would occur because of reverse flows can be offset by the net amount of fresh water pumped into the San Joaquin River from the Sacramento River by tidal pumping through Threemile Slough. In fact, tidal pumping through Threemile Slough is great enough to prevent salinity increases in the San Joaquin River regardless of how much water is exported from the southern Delta, provided that flows in the Sacramento River are high enough to maintain low salinity at the Sacramento River end of Threemile Slough. (personal communication, G. Gartrell and A. Nelson CCWD 1993)

Also, water does not simply flow through Threemile Slough on the flood tide at exactly the same rate as on the ebb tide. There can be net flow in one direction or the other. A few measurements of net flow have been made. These measurements show that there can be net flow south, from the Sacramento to the San Joaquin River of almost 2,000 cubic feet per second. (DWR 1962) The rate of flow is determined by the strength and other characteristics of the tides.

Calculated values of reverse flows, as described in the last section, are typically in the range of 1,000

⁸ Other factors besides the distance can be important, factors such as the depth and width of the rivers and the shape of the river bottoms.

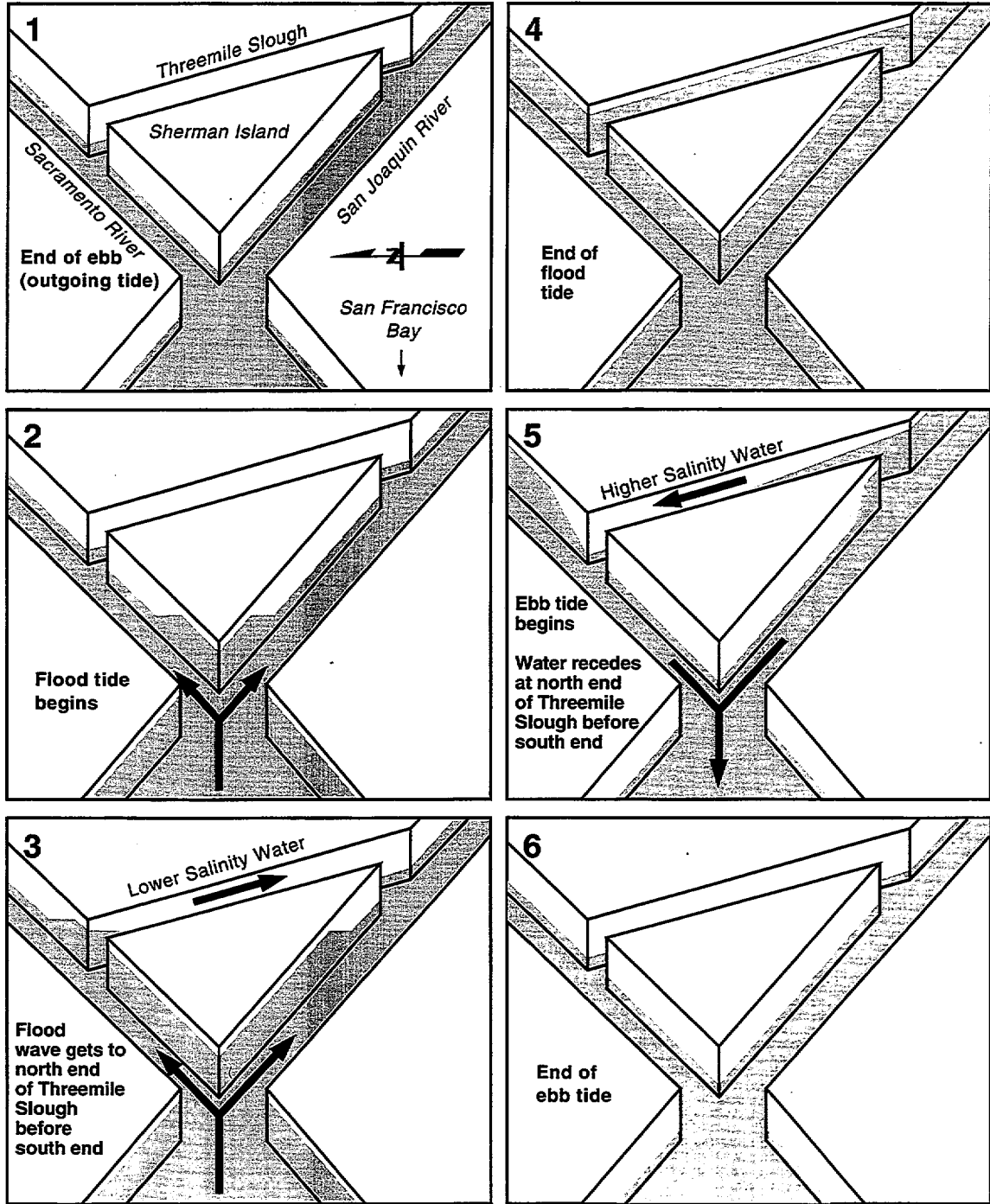


Figure 3. Tidal Pumping Through Threemile Slough

to 2,000 cubic feet per second. Large reverse flows are typically about 4,000 cubic feet per second. Net flow through Threemile Slough is not included in the calculation of the flow in the lower San Joaquin River. If it were included, it appears that the calculation would reveal that reverse flows were not occurring during much of the time when they are now calculated to occur.

If the net flow through Threemile Slough were included in the calculation of flows in the lower San Joaquin River, and if the calculation did not reveal that reverse flows were occurring, it would not mean that reverse flows were not occurring anywhere in the southern Delta. It would mean that reverse flows were not occurring in the lower San Joaquin River and that reverse flows were probably confined to channels closer to the export pumps.⁹

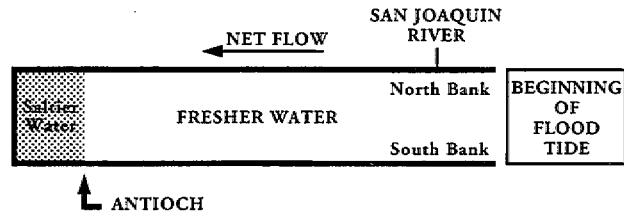
Longitudinal Dispersion

Consider a situation when water is flowing downstream in the lower San Joaquin River (that is, no reverse flows). If the downstream flow is not great, salty water will be intruding upstream. How is this possible? How does salty water move upstream against the prevailing downstream flow of fresh water? The answer is, 'Longitudinal dispersion.' It can be explained as follows:

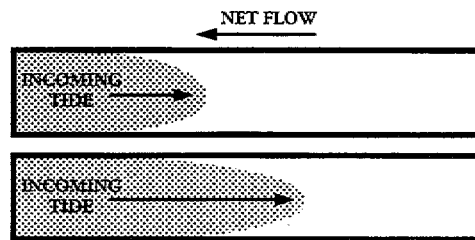
The twice-daily flood and ebb tides move water back and forth about five to eight miles past a particular point on the shore. (CCWD, 1992) The water does not move as a plug. The sides and bottoms of the channels exert a drag on the water near the sides and bottom.¹⁰ Therefore, water in the center of the channel moves faster and farther

on each flood and ebb tide than water near the sides or bottom.

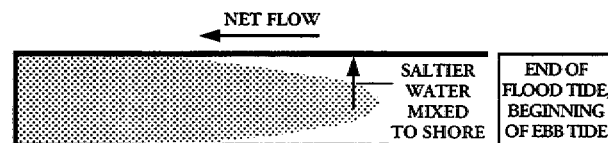
Now consider some salty water just offshore of Antioch on the lower San Joaquin River at the beginning of the flood (incoming) tide.



The salty water in the center of the San Joaquin River moves farther upstream than the water near the sides and bottom.



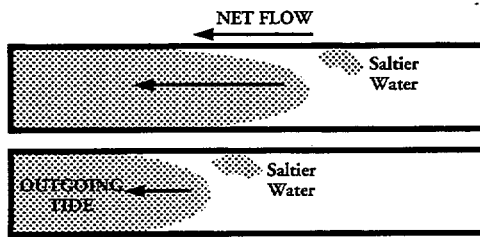
At the end of the flood tide, some of this salty water that has moved far upstream can get mixed over to the sides of the river.



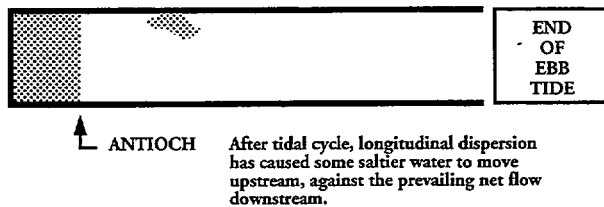
⁹ A significant, albeit incidental, point arises from consideration of tidal pumping through Threemile Slough. Mathematical models are used to estimate the amount of water that can be exported from the Delta without violating legal requirements. The current requirements (Decision 1485 of the State Water Resources Control Board) include salinity standards in the western Delta, but no requirements for calculated reverse flows. The models now being used do not consider the 'freshening' of the San Joaquin River due to tidal pumping through Threemile Slough. Therefore, these models overestimate the amount of water required to flow out of the Delta to meet the salinity standards in the western Delta, and the models under-estimate the amount of water that can actually be exported without violating the standards. (personal communication, F. Chung and E. Winkler DWR, A. Nelson CCWD, G. Link Water Resources Management, consultants 1993) The error could be as much as several hundred thousand acre feet per year. (G. Link Water Resources Management, consultants 1993) The new draft decision by the State Water Resources Control Board (D-1630) includes the calculated flow at Jersey Point as a requirement. Reverse flows are not allowed for much of the year. This calculated standard applies for both the model estimates and the actual operation of the export projects. Therefore, the error in the model estimates does not occur when allowable exports are estimated for D-1630 requirements. Therefore, any model comparisons of the effect of D-1630 relative to D-1485 underestimate the effect by as much as several hundred thousand acre feet per year.

¹⁰ This drag can be seen when molasses is poured from a jar. The molasses that is near or in contact with the glass moves much more slowly than the molasses on the top of the pour. If this example is troubling because of the changing direction of the molasses, try the experiment by piling molasses behind a vertical piece of glass on an inclined cutting board. Remove the glass and watch the molasses on top tumble over the molasses near the cutting board. The cutting board exerts a drag on the molasses in contact with it.

Then, on the ebb (outgoing) tide, this salty water will not move as far downstream as Antioch.



So, at the end of one tidal cycle (one flood and one ebb) some salty water will have moved upstream, despite the fact that the net flow was downstream.



Likewise, some fresher water will have moved downstream much farther than the net flow could have taken it.

This net movement of salty water (or particles suspended in the water, such as fish eggs) resulting from the tidal flows combined with some mixing across the channel and from top to bottom, is longitudinal dispersion.

Preliminary analyses suggest that longitudinal dispersion is far more important than net flow in moving salt and other things that drift with the water, including fish eggs and larvae. (CCWD 1992) As an example of such analyses, consider typical calculated reverse flows of 1,000 to 4,000 cubic feet per second (upstream). This rate of flow is only 1 to 3 percent of the average tidal flow. In other words, during any flood or ebb tide, the tides are moving the water 30 to 100 times as far as calculated reverse flows are. This difference in movement, coupled with the mixing between the center of the channel and the sides and bottom,

suggests that longitudinal dispersion is the dominant mechanism by which salt, fish eggs and larvae, and other particles, suspended in the water, move in the western Delta, rather than any net flow, including calculated reverse flows.

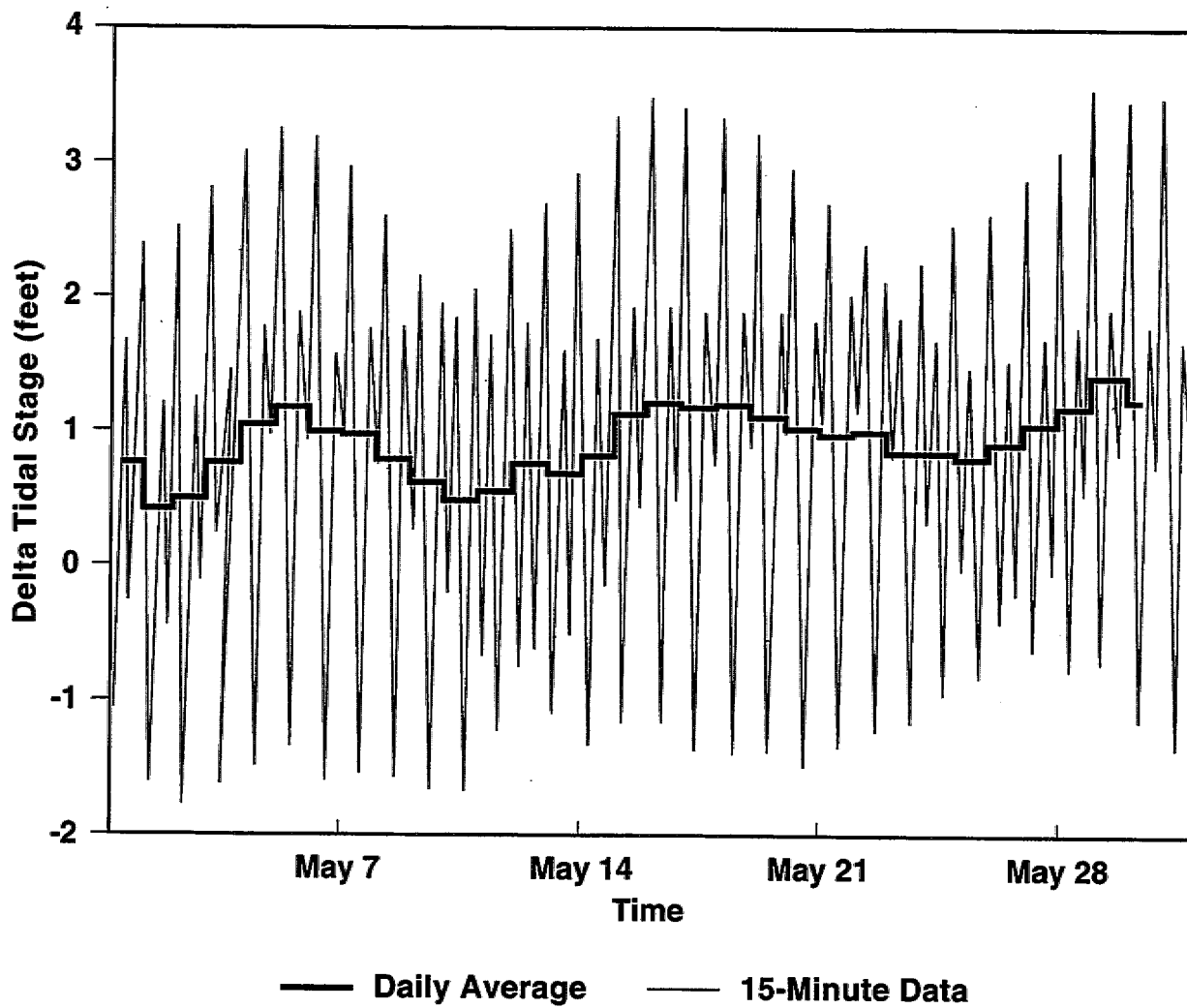
The Filling and Draining of the Delta on the Lunar Cycle

In addition to the twice-daily (actually, every 24.8 hours) flood/ebb tide cycle, another tidal cycle occurs. This is the lunar cycle. It is about 28 days long. At the full moon and the new moon, the gravitational pull of the sun and the moon are reinforcing one another, and the tides are stronger. These stronger tides are called spring tides. Slightly more than seven days after the new and full moons, the gravitational pulls of the sun and moon cancel each other somewhat, and the tides are weaker. These weaker tides are called neap tides. So, every 28 days, beginning with the new moon, there are four seven-plus day periods, first of spring tides, then neap tides, then spring tides, then neap tides. (Conomos 1979)

In the Delta, during the spring tides, the average water depth is as much as one foot more than the average water depth during the neap tides. (personal communication, G. Gartrell CCWD and F. Chung DWR 1993) Figure 4 shows this variation in water depth in the Delta. In other words, the Delta is filling every seven-plus days, then draining during the following seven-plus days. The surface area of the water in the Delta is about 50,000 acres (personal communication, F. Chung DWR 1992) Therefore, about 50,000 acre-feet (50,000 acres times one foot) moves into the Delta during the spring tide and about 50,000 acre-feet moves out on the neap tide.¹¹ The induced flow (or change in what otherwise would be the downstream flow) is about 3,500 cubic feet per second, averaged over a single spring or neap tide period.

Of the total 50,000 acres of Delta water surface, more than 80 percent appears to be in the southern

¹¹ Actually, what may be happening is that water flowing into the Delta is piling up on the spring tide and rushing through the Delta on the neap tide. The effect is the same, to cause the downstream flow to be less than predicted by the reverse flow calculation on the spring tide and more than predicted on the neap tide.



The daily average values are illustrative only. They illustrate the rising and falling of water levels in the Delta during the lunar cycle. Even without the daily average values, the trend can be clearly seen in the maximum and minimum values of the 15-minute data, which are actually recorded at water level stations in the delta.

Figure 4. Average Daily Water Elevations in the Delta, May 1988

Delta. Therefore, the neap-spring cycle is inducing changes in the calculated value of reverse flow by about 3,000 cubic feet per second, averaged over a seven-day neap or spring part of the lunar cycle. It is causing calculated reverse (upstream) flows to increase during the spring tides and decrease during the neap tides.

The actual effect of the neap-spring cycle is more complex than described here, involving wave motions requiring computer simulation to produce precise estimates. However, the simple analysis set forth immediately above is sufficient to indicate that the neap-spring tidal cycle significantly changes the concept of reverse flows as calculated by a simple water balance. The neap-spring cycle must be accounted for when calculating reverse flows, especially on a daily basis.

Summary

The current understanding of water movement in the Delta incorporates the concept of reverse flows. Reverse flows are calculated. Calculated reverse flows are thought to be indicative of the net flow of water in the lower San Joaquin River. Calculated reverse flows are the most important regulatory requirement now being imposed on water projects in the Delta. The combination of limitations on calculated reverse flows and requirements to close the Delta Cross Channel Gates results in severe curtailments of exports from the southern Delta, including exports to the Contra Costa Water District.

However, preliminary work on tidal phenomena suggest that the movement of water may be substantially different than implied by calculated reverse flows. Therefore, the movement of salt and fish eggs and larvae may also be different. If this is true, then the use of calculated reverse flows as a means of regulating water exports and improving the fishery is questionable.

DELTA FISHERY

Population Trends in Key Species

There are concerns about species of fish that reside in or migrate through the Delta. As shown on Figure 5, populations of a number of these species have fallen since the late 1970's to low levels. (DFGa,c,d,e, 1992, Hymanson 1993, IESP 1987, USFWS 1992) These species include:

- Winter-run salmon (migrant)
- Longfin smelt (resident)
- Spring-run salmon (migrant)
- Splittail (resident)
- Delta smelt (resident)
- San Joaquin River Fall-run salmon (migrant)
- Green sturgeon (migrant)

In addition, there is concern about striped bass. Adult populations have fallen from levels of two decades ago. (DFGa,b 1992) In addition, the index of abundance of small striped bass, about 1.5 inches long, has fallen dramatically from the 60 to 100 range to values of less than ten in the last few years. (DFGa,b 1992)

In addition to fish, there are other problem species, ones that make up part of the food chain for fish. The graphs in Figure 6 show the declines in phytoplankton and zooplankton, small plants and animals, respectively, near the base of the food chain. (Hymanson 1993, Orsi 1993)

Factors Causing the Fishery Problems

The questions is: Why have these declines occurred and how can they be reversed?

A popular version of the answer to this question is that the water projects have been the sole significant cause and that undoing the water projects is the way to reverse the problems. For example, the State Department of Fish and Game has proposed a mathematical model for striped bass abundance that includes water project operations as the only controllable factor of importance. (DFGa 1992) The model has been severely criticized on statistical grounds. (DWRd) However, this model, at least in its conceptual form, has been popularized

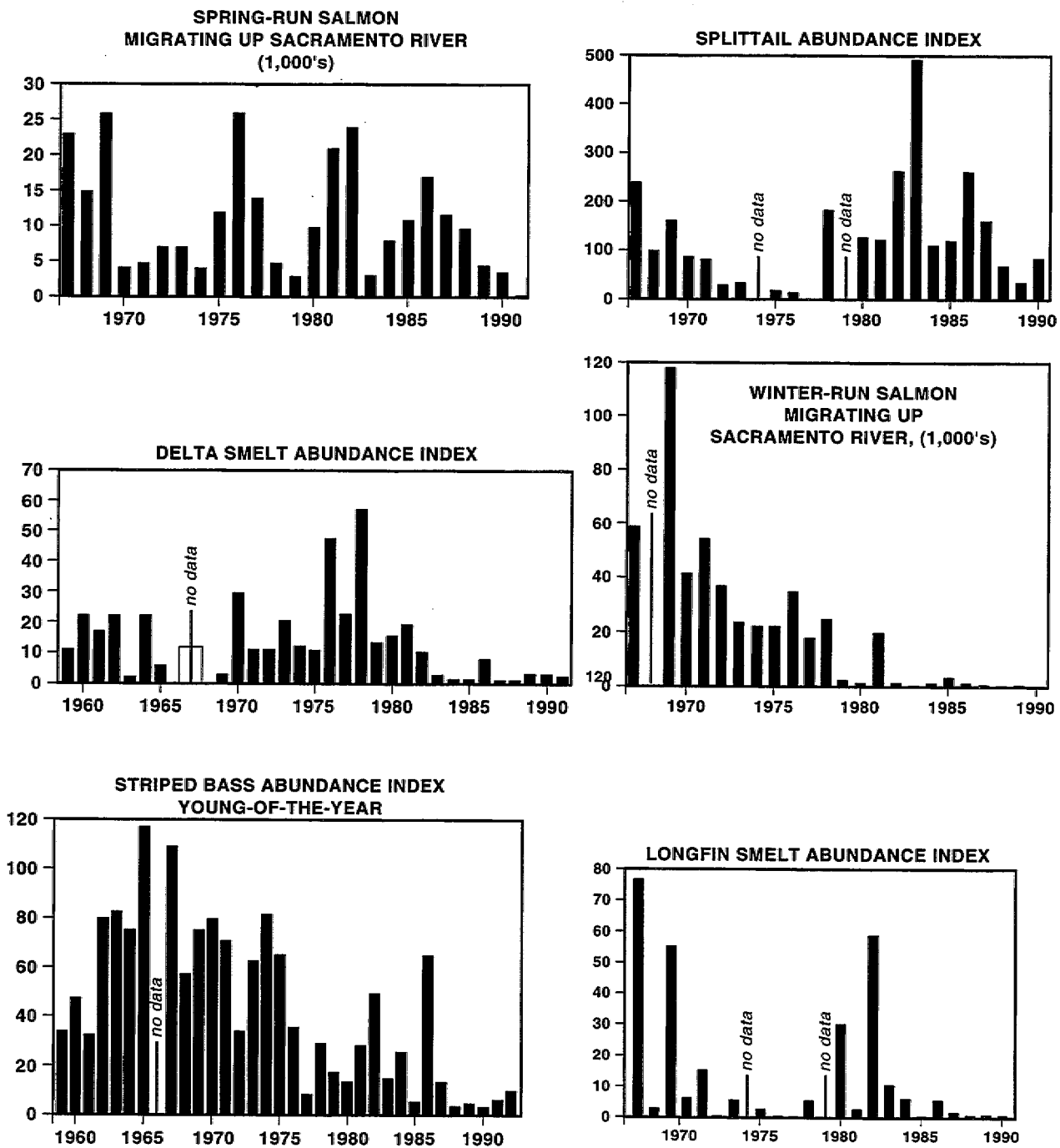
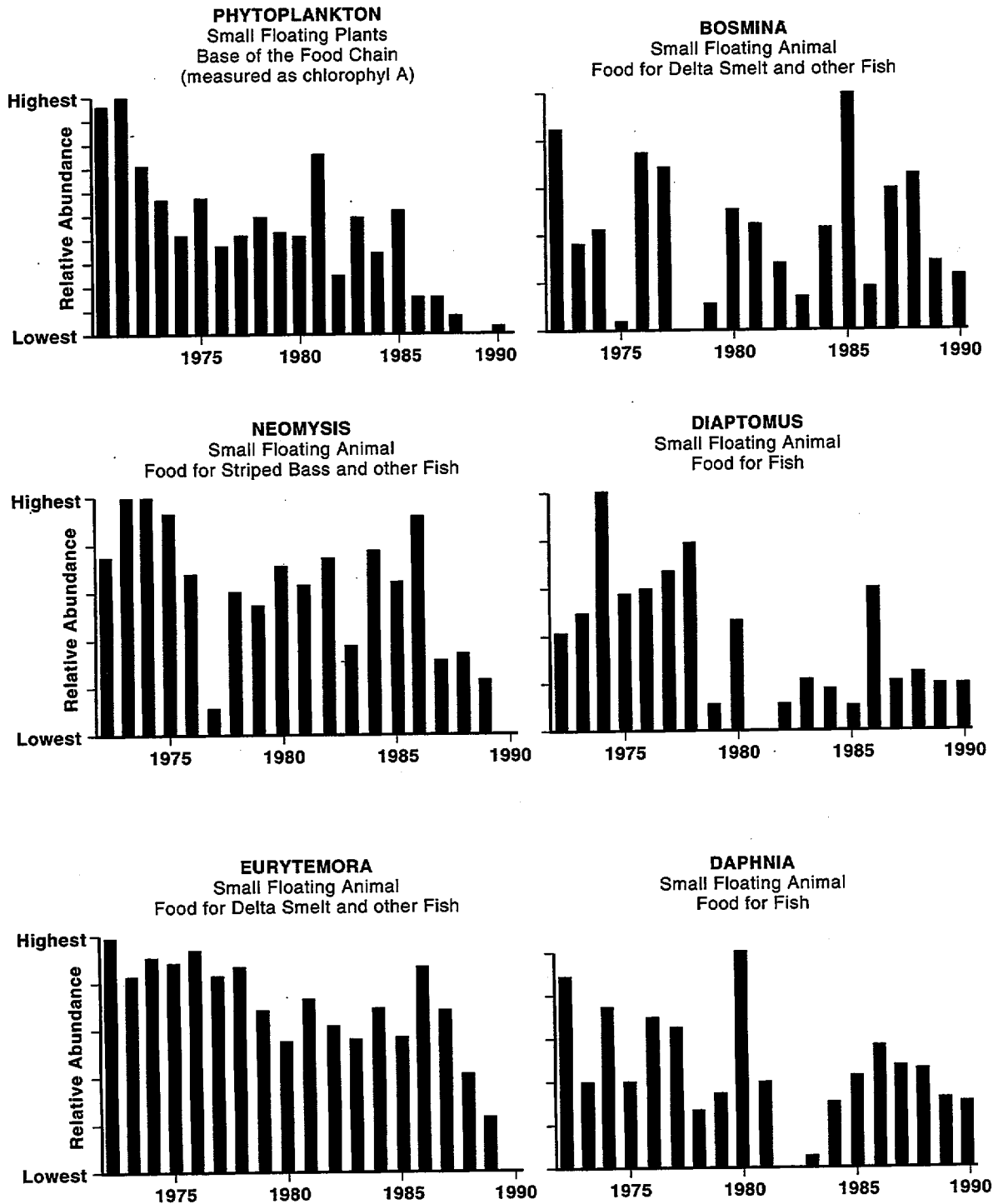


Figure 5. Trends in Abundance of Selected Fish



These charts depict the relative abundance of microscopic plants (phytoplankton) and animals (zooplankton). The data have been transformed by removing the variations attributable to the time of the year and the salinity. So, they represent the declines that may have occurred in addition to the changes in salinity caused by the combined effect of the drought and diversions of water from upstream or from the Delta. In addition, the data have been transformed by taking their logarithms, so the declines are actually much greater than shown. For example, the 1989 abundance of Eurytemora was actually about one tenth that in 1988.

Figure 6. Declines in Food Chain Organisms

by the news media and strongly promoted by various interest groups. In the absence of any alternative model, conceptual or otherwise, it has gained considerable prominence.

Role of the Water Projects in Delta Fishery Problems

The water projects have had serious effects on the fisheries. Please refer to the simplified schematic of the Delta shown on the Figure 7.

Water project operations have several effects in the Delta on the fishery¹² These effects fall into three categories, Delta inflow, Delta outflow, and intra-Delta effects. They are described and sub-categorized below:

A. Delta inflow: This refers to the amount of water flowing into the Delta from the Sacramento and San Joaquin Rivers. Delta inflow is important because it provides homing water for upstream migrating fish. It also carries fish eggs and larvae downstream from spawning areas and assists in the outmigration of young migrants. Delta inflow also carries detritus and other important food for fish.

B. Delta outflow: Delta outflow controls the salinity of the western Delta and downstream areas. It controls the location of the entrapment zone, an area where fish and their food are entrapped by the complex mixture of fresh and salty water. Delta outflow moves fish eggs and larvae and young fish out of the Delta into Suisun and Honker Bays. This is important in its own right. Also, such movement tends to carry species away from the influence of the Delta export pumps.

C. Intra-Delta Effects: This refers to the various effects of water projects within the Delta. Intra-Delta effects can be sub-categorized as follows:

1. Main stem diversions: These are the re-routings of water from the Sacramento and San Joaquin (i.e., main stem) Rivers. These diversions remove outmigrating fish from their normal routes

and move them into inhospitable parts of the Delta.

a. Delta Cross Channel and Georgiana Slough: Main stem diversions from the Sacramento River take place through the Delta Cross Channel and Georgiana Slough. At least 15 percent of the river flow branches off through Georgiana Slough and, when the Cross Channel Gates are open, at least another 15 percent is diverted through the Cross Channel. (DWRb 1992) Fish that are diverted suffer higher mortalities in the Central and Southern Delta than if they continued their normal migration down the Sacramento River. (USFWSa 1992) As discussed earlier, these diversions, while bad for fish migrating in the Sacramento River, are thought to be good in the sense that they offset reverse flows that would otherwise occur in the lower San Joaquin River.

b. Old and Middle Rivers: When the export pumps are operating, water is drawn into Old and Middle Rivers. Fish migrating in the San Joaquin River are also diverted from their normal migration routes to the pumps, where mortalities are higher. (personal communication, P. Chadwick DFG 1991)

2. Reverse Flows: When Delta inflows are low and Delta exports are high, reverse flows can occur, as shown on Figure 8. (DWRb, 1992) Reverse flows are thought to disrupt migration patterns, cause fish and fish eggs and larvae to move toward the export pumps, and may impede the natural movement of species downstream into Suisun and Honker Bays. (DWRa 1987) However, as described in the previous section on water movement in the Delta, there are several significant questions about the significance of reverse flows in the lower San Joaquin River.

3. Other Flow Modifications: Besides reverse flows, water project operations can cause the rates of flow through some Delta channels to increase. This can have adverse effects on the production of species at the bottom of the food chain. (Brown 1992)

4. Direct Losses at the Pumping Plants: This

¹² Water projects and other factors also have effects upstream of the Delta on fish that migrate through the Delta. For example, dams block access to and prevent replacement of spawning gravels. Upstream diversions can kill fish on their way to and from spawning areas. Spawning areas can be altered or destroyed by activities not related to water project operations, such as gravel mining.

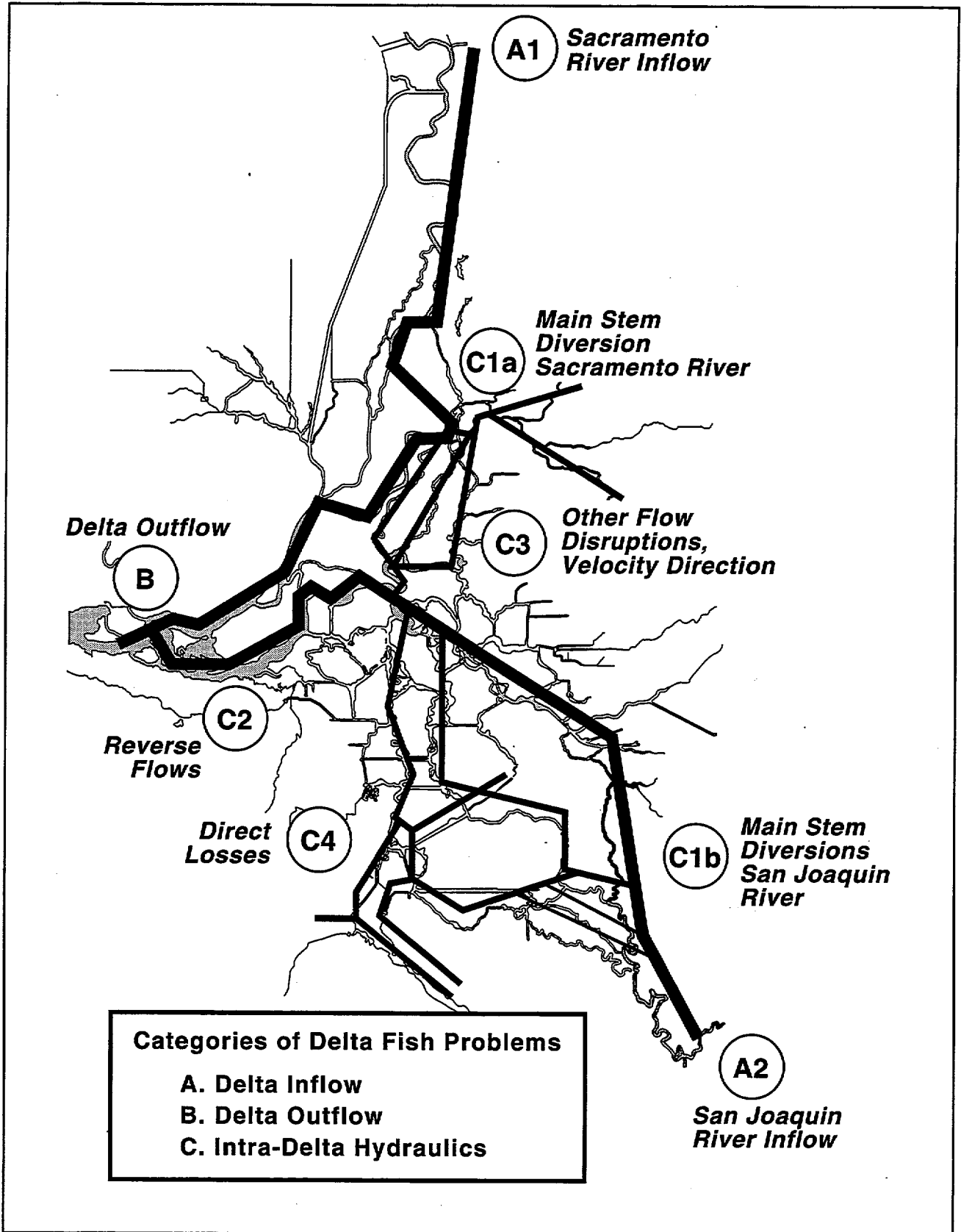


Figure 7. Categories of Delta Fish Problems

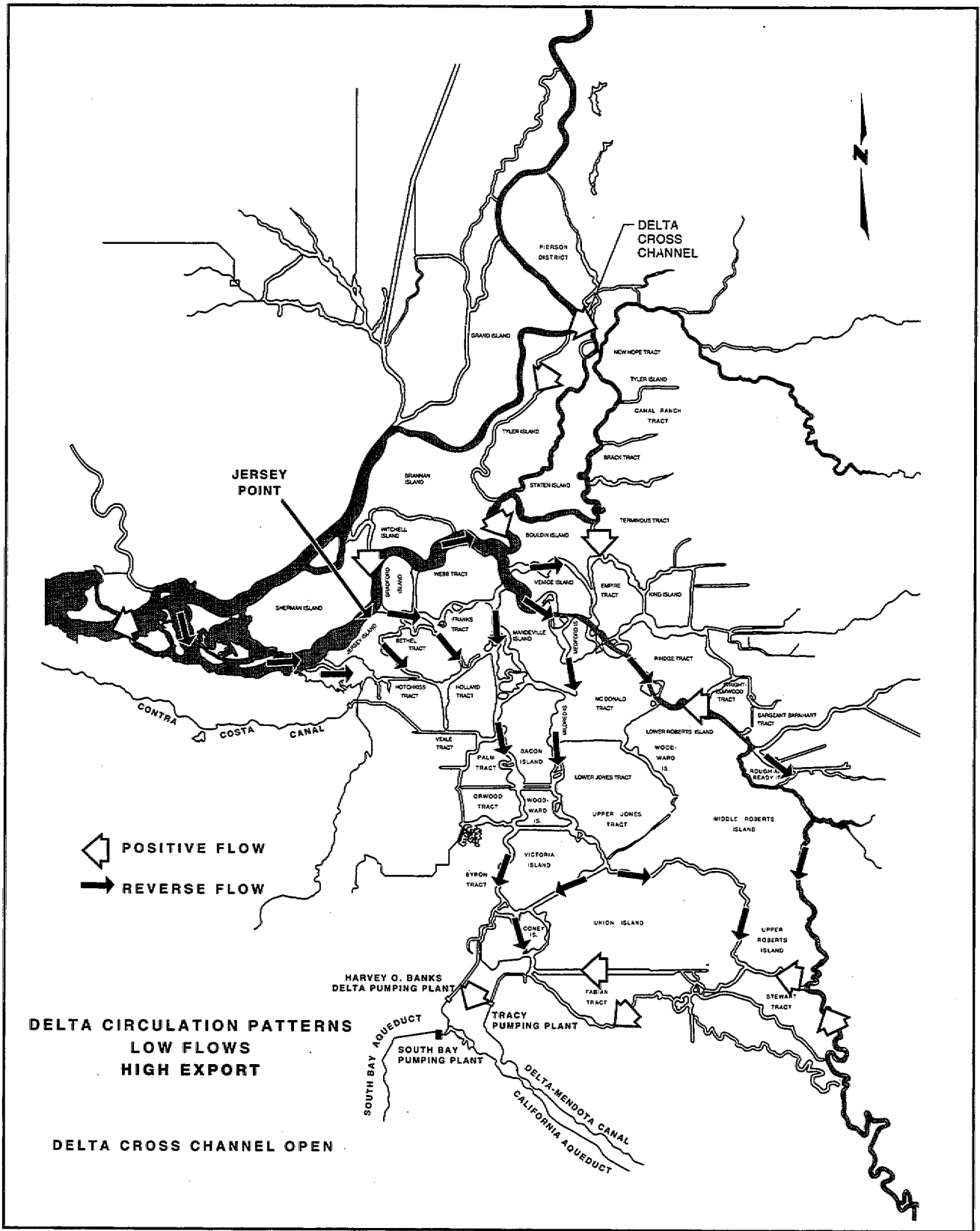


Figure 8. Reverse Flows

includes losses of fish and fish eggs and larvae that occur at or very near the export pumps. Species can be pumped out of the Delta or killed on the fish screens. Fish that are salvaged can die from being handled in the process of capturing and trucking them downstream. However, the greatest loss is predation.¹³ In fact, at Clifton Court Forebay predation can account for almost 70 percent of the direct losses of striped bass at the pumps. (Brown 1992)

Of these categories of problems, the intra-Delta problems are generally thought to be the most critical. (personal communication, R. Brown DWR 1992) In fact, one of the reasons the other problems, Delta inflow and outflow, are so important is because of their mitigating or aggravating effect on the intra-Delta problems. For example, higher Delta outflows are not only important in their own right, as a means of controlling salinity in the western Delta, for example. Delta outflow is also important to move species away from the influence of the export pumps. (personal communication, R. Brown DWR 1992)

Other Factors Causing the Fishery Problems

It is clear that a number of factors in addition to the water projects have affected the Delta fishery and its supporting food chain. These factors and a brief description of their effects are listed below:

A. Introduced species: Table 3 is a partial list of organisms introduced into the San Francisco Bay-Delta system. (Brown 1992) Figure 9 shows the introduction of new, bottom-dwelling mollusks (clams, oysters, mussels, etc.) in the San Francisco Bay system. (Brown 1992) *Potamocorbula amurensis* is particularly notable. It was accidentally introduced in 1986 from the ballast water of an Asian ship. These active, bottom-dwelling, thumbnail-sized, filter-feeding clams are being found at densities of 20,000 per square meter on the

bottom of Suisun Bay. Figure 10 shows the spread of this clam. (Carlton et al 1990, Hymanson 1991) As shown in Figure 11, other fish have been introduced. (DFG midwater trawl data) Some of these compete with and some prey on species already in the Bay-Delta system. As a result of these introduced species and other factors, including, in some cases, water project operations, there have been significant changes in the food chain as shown in Figure 6. (Hymanson 1993, Orsi 1992)

Data collected at the state pumping plant in the southern Delta reveal that in 1991, 60 percent of all species collected were non-native and, of all fish collected, 96 percent were non-native. At the federal pumping plant, 98 percent of the fish were non-native. (personal communication, David Kennedy DWR) Scientists at the U.S. Geological Survey have stated that in no part of the Bay Delta system is the dominant species native. (personal communication, S. Luoma USGS 1991)

B. The current drought: This six-year drought is comparable to the 1928-1934 drought, previously estimated to have a return frequency of 200 to 400 years.¹⁴ (Roos 1992 and personal communication, Roos 1992) It is a highly unusual event. Even without any water projects, this drought would have had an adverse effect on fish.

C. Pollution: Studies have shown an excellent correlation (better than with water project operations) between rice herbicide pollution and the survival of young striped bass during the period of 1973 through 1988. (Foe 1989, Bailey 1992) Other studies have shown significant adverse effects of pollutants on fish, including analyses of the occurrence of pollutants in the organs of striped bass. (Brown et al 1987, Cashman et al 1992, Bennett et al 1990)

D. Poaching: Estimates of poaching place the take on undersized striped bass at more than 500,000 per year as well as tens of thousands of adult striped bass. That would make the losses due

¹³ Agreements have been executed for mitigation of these direct losses at both the state and federal pumping plants. The state agreement has been in effect since 1986. It calls for cooperative measures to eliminate losses. Also, for unavoidable losses, the State Water Project must pay into a fund used by the Department of Fish and Game to carry out fish enhancement projects and to produce fish in hatcheries to build up the population.

¹⁴ Now that two such droughts have occurred within six decades, this return frequency will have to be re-examined.

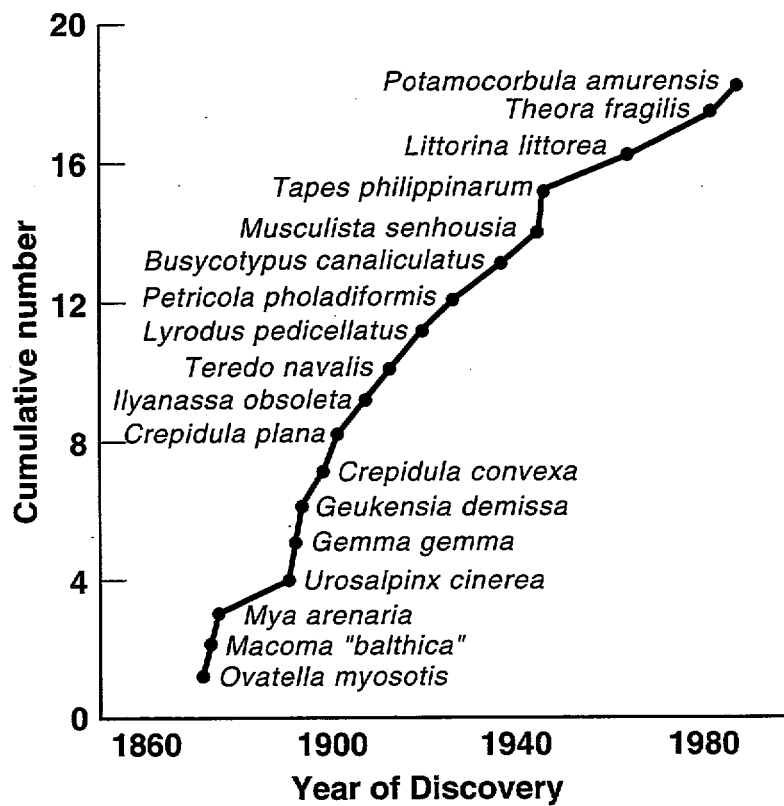
Table 3.
General Characteristics of Introduced Organisms in San Francisco Bay

Common Name- (Scientific Name)	Descriptor	Date of Introduction	Origin	Mode of Introduction	Economic/Ecologic Impact
Isopod (<i>Sphaeroma quoyanum</i>)	Pillbug	1850-90	Australasia	Shipping	Bores and weakens dikes and banks
Eastern Oyster (<i>Crassostrea virginica</i>)	Oyster	1869	Atlantic	Intentional/Railroad	Commercial aquaculture
American Shad (<i>Alosa spadissima</i>)	Fish	1871	Eastern No. Am.	Intentional/Railroad	Commercial/sport fishery
Gribbles (<i>Limnoria spp.</i>)	Pillbug	1873	Unknown	Shipping	Destruction of wood structures
Soft Shell Clam (<i>Mya arenaria</i>)	Clam	1874	Atlantic	Accidental with oysters	Sport fishery
Striped Bass (<i>Monroe saxatilis</i>)	Fish	1879	Eastern No. Am.	Intentional/Railroad	Commercial/sport fishery
Shipworm (<i>Teredo navalis</i>)	Boring Clam	1913	Atlantic	Shipping	Destruction of wood structures
Japanese Oyster (<i>Crassostrea gigas</i>)	Oyster	1930	Japan	Intentional/Shipping	Commercial aquaculture
Japanese Littleneck (<i>Tapes japonica</i>)	Clam	1946	Japan	Accidental with oysters	Sport fishery
Asian Clam (<i>Corbicula fluminea</i>)	Clam	1946	SE Asia	Ballast water or intentional	Commercial fishery. Fouls freshwater canal
Yellowfin Goby (<i>Acanthogobius flavimanus</i>)	Fish	1963	Japan	Ballast water	Competes with native fish for food
Copepod (<i>Orthona davisae</i>)	Zooplankton	1966	Japan	Ballast water	Unknown
Snail (<i>Littorina littorea</i>)	Snail	1968	Atlantic	On algae used pack eastern lobster	Unknown
Copepod (<i>Sinocalanus doerrii</i>)	Zooplankton	1978	China	Ballast water	May compete with or prey upon other zooplankton
Copepod (<i>Limnorchthona sinensis</i>)	Zooplankton	1979	China	Ballast water	Unknown
Clam (<i>Theora fragilis</i>)	Clam	1982	Japan	Ballast water	Unknown
Amphipod (<i>Gammarus daiberi</i>)	Amphipod	1983	Eastern No. Am.	Unknown	Consumed by striped bass
Asian Clam (<i>Potamocorbula amurensis</i>)	Clam	1986	Asia	Ballast water	Alters food chain
Crustacean (<i>Hemieucon hinumensis</i>)	Crustacean	1986	Japan	Ballast water	Unknown
Copepod (<i>Pseudodiaptomus maninus</i>)	Zooplankton	1986	Japan	Ballast water	Additional food source for fish
Copepod (<i>Pseudodiaptomus forbes</i>)	Zooplankton	1987	Asia	Ballast water	Additional food source for fish
Snail (<i>Malanoides tuberculata</i>)	Snail	1988	Unknown	Unknown*	Unknown
Polychaete (<i>Potamilla sp.</i>)	Worm	1989	Unknown	Unknown**	Unknown
European Green Crab (<i>Carcinus maenas</i>)	Crab	1991	Atlantic	Unknown	Voracious predator of mollusks
Polychaete (<i>Spionid sp.</i>)	Worm	1991	Unknown	Unknown	Unknown

*Reported to have a nearly worldwide distribution.

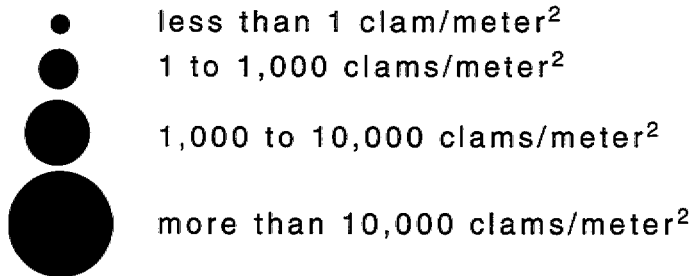
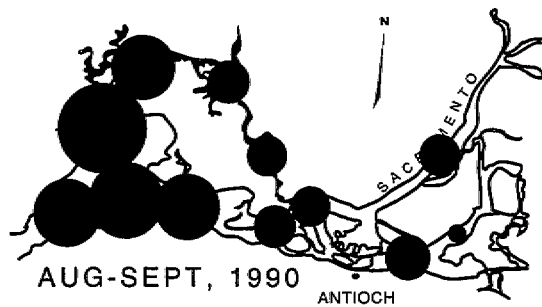
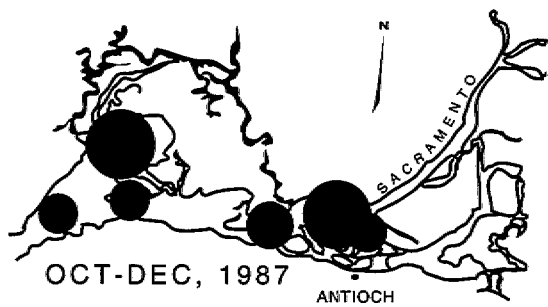
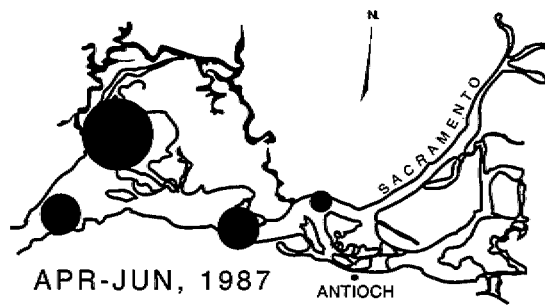
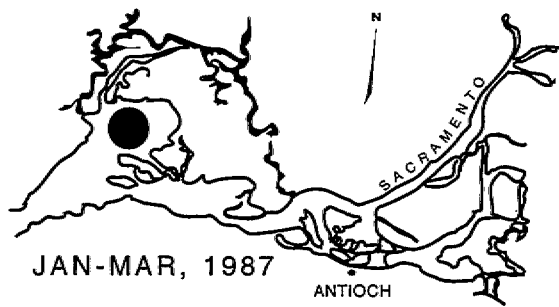
**May be new to science.

SOURCE: Adapted from information compiled by F. Nichols and J. Thompson, U.S. Geological Survey.



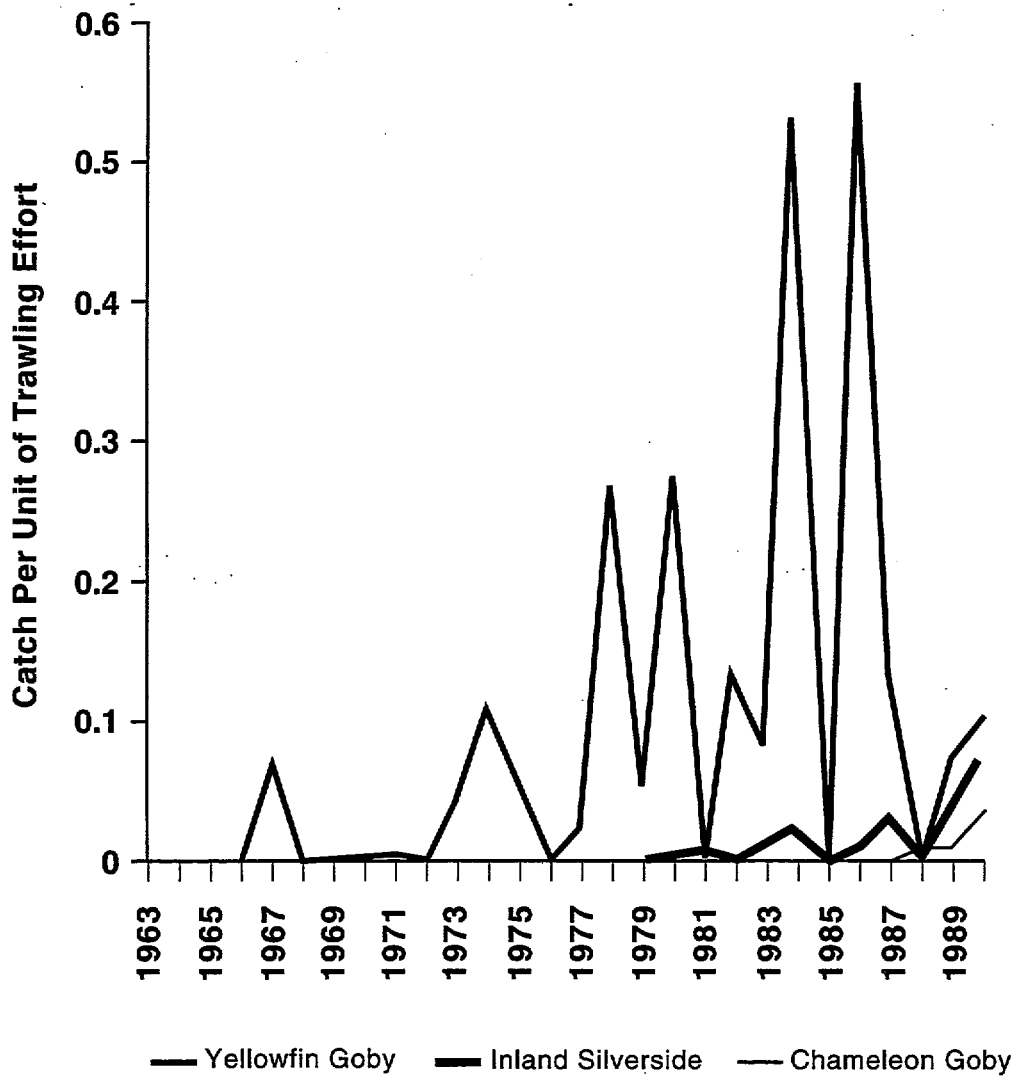
Source: F. Nichols and J. Thompson. U.S. Geological Survey

Figure 9. Introduced Mollusks in San Francisco Bay



This clam was introduced into the Bay-Delta system from the ballast water of a ship, probably in late 1986. It spread rapidly, reaching concentrations of more than 20,000 per square meter. It has changed the ecosystem in the northern reach of the San Francisco Bay from pelagic (floating) to benthic (bottom). The six years following its introduction were all drought years. There is some question whether this clam will persist in wetter years. So far, in March of 1992, the clams are present but relatively dormant, awaiting the return of saltier water later in the year. The clams have not spread into the Delta, reaching only as far as shown on the last map. They are apparently limited by fresh water or competition with fresher water clams.

Concentration of the Asian Clam, *Potamocorbula Amurensis*, on the Bottom of Suisun Bay and the Western Delta



Yellowfin Goby and Chameleon Goby prey on Delta smelt.
 Inland silverside competes with Delta smelt for food.

Figure 11. Introduced Fish Data from Midwater Trawls

to poaching considerably higher than the losses at the State Water Project pumping plant in the Delta. (Brown 1992)

E. Delta agricultural diversions: Studies are now in progress to get better estimates of these losses. Various estimates in the past indicate that the losses due to agricultural diversions in the Delta are comparable to the losses at the state and federal Delta pumping plants. (Brown 1992)

F. Over-fishing: Recreational and, where allowed, commercial fishing cause substantial losses of various species, especially those that spend much of their adult lives in the ocean. (Brown 1992) Fishermen counter that their take is regulated and that the relative significance of fishing harvest would not be so great if other factors, especially the water projects, had not caused the population levels to be so low.

There is limited information on the relative importance of these factors. There is evidence that water project operations have certainly been an important factor. The projects are exporting more water from the Delta, and, in combination with the drought, these exports result in lower flow rates of water into the western Delta and San Francisco Bay and, of course, greater fish losses at the export pumps.

It seems likely that several other factors have had significant effects on the fishery. If this is true, then the fishery problems are attributable to all of these factors, including water project operations. However, common opinion holds that the water projects are the sole significant cause of fishery problems. This assumption, once made, becomes relatively easy to confirm, ironically, because it is incorrect. Consider this example.

Assume that three factors have caused the fishery decline: water project operations, introduced species, and illegal fishing. Further assume that someone sets out to demonstrate that only one factor, water project operations, is to blame. So, correlations are made between, say, Delta exports and fish abundance. Exports have increased; fish abundance has declined; good correlations are

found. The conclusion is drawn: Delta exports have caused the decline because the correlations are so good. However, the reason the correlations are so good is because the other two factors drove the abundance down. So, the greater the influence of other, ignored factors, the more likely they will continue to be ignored, once the incorrect assumption is made that they should be ignored.

Carrying this example one step further, one might logically, but incorrectly, assume that the fishery problems could be solved solely by modifying water project operations. So, the exports are reduced. Some improvement results, but not as much as expected. The logical but incorrect conclusion would be to further reduce exports—After all, they are the sole significant cause of the problem, are they not?

An alternative conceptual model of the fishery problems would include all relevant factors. Each factor would be assessed relative to all the other factors. Such a model does not exist, and little work has ever been done to construct such a model.

DELTA DRINKING WATER QUALITY

Background

About 20 million people in California get at least part of their drinking water from the Delta. (DWR 1990) These people live in Napa, Solano, Contra Costa, Alameda, and Santa Clara Counties as well as Bakersfield and the six counties that make up the South Coastal Plain, Ventura, Los Angeles, Orange, San Diego, Riverside, and San Bernardino.

The Delta used to be a marsh. (SLC 1991) Over many years, the marsh vegetation grew, died, and decomposed. The dead vegetation accumulated, layer upon layer, to the point where its decomposition consumed all of the oxygen in the layers, so the decomposition (actually, oxidation) was not complete. This partially decomposed vegetation became peat. The layers of peat are more than 20 feet thick in the central part of the Delta. Peat soils are organic, meaning, among other things

that their decomposition (or oxidation) is incomplete. (DWRe 1992) This turns out to be a very important feature of the Delta peat soils, both for drinking water quality and for levee stability, as discussed in the next section.

Urban water agencies must comply with federal and state drinking water standards. Two categories of federal standards present special problems for urban users of Delta water. (Means et al 1993) One category concerns the disinfection of water, that is, the addition of disinfectants to kill disease-causing agents. The most effective disinfectants are strong oxidizing agents, typically compounds containing chlorine. Household bleach is a strong oxidant and good disinfectant and contains chlorine compounds.

The other category is disinfection byproducts. Disinfection byproducts are produced when disinfectants react chemically with other compounds in the water. Several of these disinfection byproducts are suspected carcinogens. The federal government has announced plans to make current standards for these byproducts more stringent and to set standards for new disinfection byproducts. (Means et al 1993, Pontius 1993)

Now, there is a limit of 100 part per billion (ppb) for only one group of disinfection byproducts, trihalomethanes. (Means et al 1993) The federal Environmental Protection Agency plans to set new, probably more stringent, standards for trihalomethanes by mid-1995. (Means et al 1993) They may also set standards for organic carbon content and other disinfection byproducts, including bromate and haloacetic acids.¹⁵ (Personal communication, Means MWD 1992)

The disinfection standards are also becoming more stringent. To comply with these changing standards, urban water agencies must provide more effective disinfection. The typical way to do this is to add more disinfectant.

However, if more disinfectant is added, more disinfection byproducts are produced, making it

more difficult to comply with the potentially more stringent disinfection byproduct standards.

The Special Problems in the Delta

Water from the southern Delta presents special problems for urban users. Delta water contains relatively high concentrations of two constituents that can react with disinfectants to produce disinfection byproducts.

The first of these is a broad class of constituents known as organics. A significant amount of these organics derives from the partially decomposed peat soils of the Delta. When Delta lands are farmed, water from surrounding channels is applied to Delta lands. The water passes through the organic soils, dissolving organic matter as it does so. The excess water, not used by the crops, is discharged back into the Delta channels at numerous points and in large quantities (see Figure 12, taken from DWRb 1987) This drainage water typically has very high concentrations of dissolved organic matter. Delta farming operations contribute about half of the organic matter dissolved in water exported from the Delta. (personal communication, Means MWD 1992)

This situation has spawned a policy debate. Urban users of exported water say that Delta agricultural drainage is polluting their water supply. Delta farmers say they are doing no such thing. They contend that they are only adding organic matter to Delta waters; the urban water users are creating the problem by adding disinfectants to the water and producing disinfection byproducts. Water users counter that pollution or not, agricultural drainage is impairing their legitimate beneficial use of Delta waters.

Water entering the Delta from the Central Valley also contains organic matter. This organic matter derives from natural plant decay, weathering of soils in the Central Valley, and from farming operations.

¹⁵ In December of 1992 the New Jersey Department of Health in cooperation with the federal Center for Disease Control announced the results of a several-year study of the relationship between birth defects and disinfection byproducts. The study showed a statistical correlation between a higher incidence of birth defects and the presence of disinfection byproducts in drinking water. As the study directors stress, statistical correlations do not necessarily indicate a cause and effect relationship. The results are only indicative of the need to investigate this relationship further.

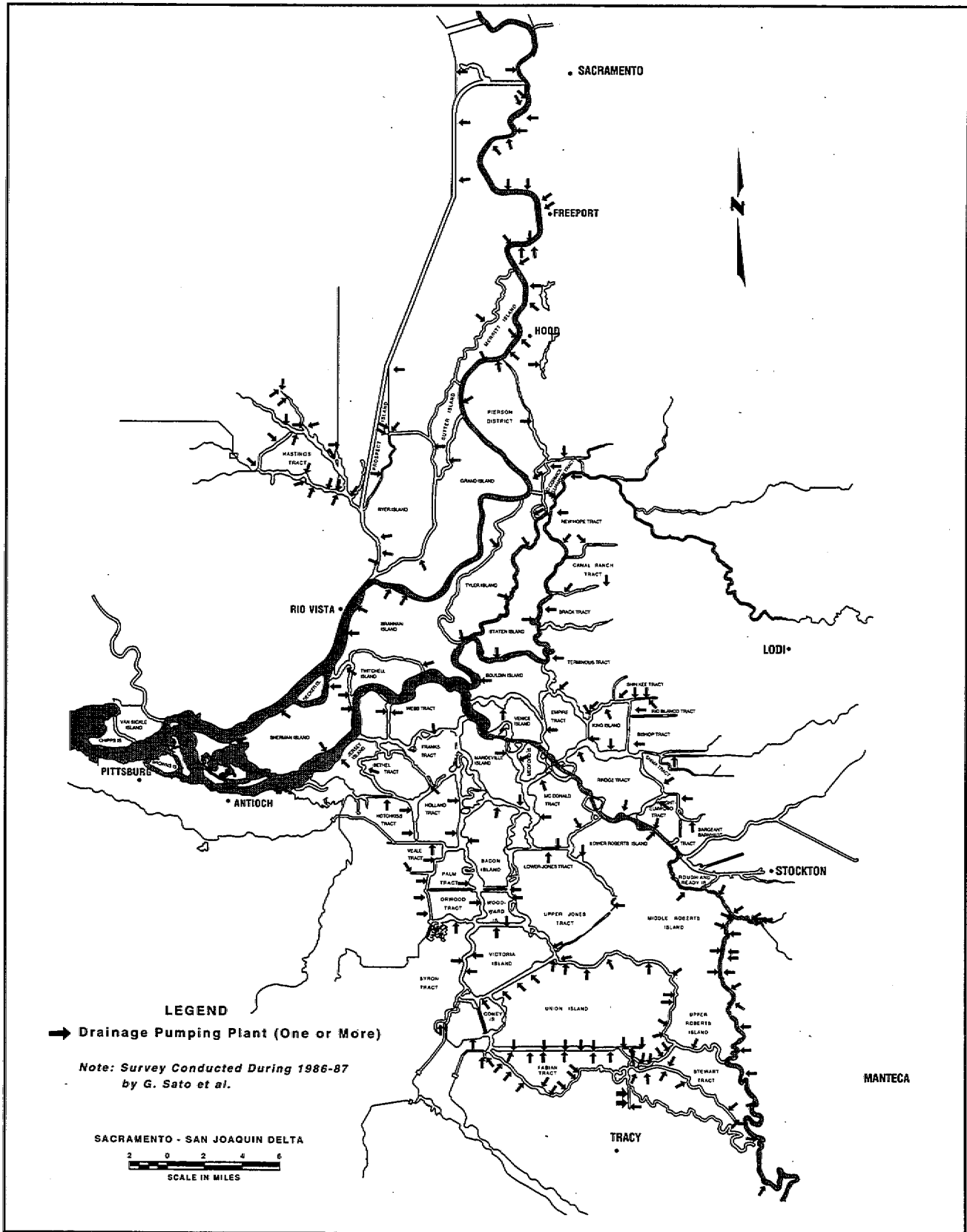


Figure 12. Agricultural Drains in the Delta

The concentration of organics in Delta exports is already causing problems for urban users. They have had to change methods of disinfection to stay under the 100 ppb standard for trihalomethanes. One of the promising new methods of disinfection is the use of ozone, a powerful oxidizing agent. However, ozone is not without its problems, which leads to the second constituent of concern, bromide.

Bromide naturally occurs in small quantities in sea water and, therefore, in the waters of San Francisco Bay. Tidal effects, especially longitudinal dispersion, tend to move some of this salty water toward the export pumps. When this happens, exported water can contain higher concentrations of bromide. Bromide reacts with chlorine to form an intermediate product which, in turn, reacts with organic matter in the water to produce a particular type of trihalomethanes known as brominated trihalomethanes. These trihalomethanes have a higher cancer risk than other forms of trihalomethanes. (Means et al 1993) Ozone also reacts with bromide to produce bromate. Bromate, like the trihalomethanes, is a suspected carcinogen. (Means et al 1993) There is no drinking water standard for bromate now, but one is anticipated in the next several years. (Means et al 1993)

Summary

Urban users of Delta water are caught between a rock and a hard place. The rock is the increasingly stringent disinfection standards. The hard place is the potential for a more stringent standard for trihalomethanes plus new standards for other disinfection byproducts, especially bromate.

For the time being, urban users must deal with the poor quality water exported from the southern Delta. They will have to add new water treatment processes to comply with the new standards. For the Metropolitan Water District of Southern California alone, this new treatment will cost from several hundreds of millions of dollars up to several billion dollars in capital cost (not including the higher cost to operate and maintain these treatment plants), depending on how stringent the new standards are. Also, there is no certainty that water treatment alone could insure compliance with standards in the

future. (personal communication, J. Gaston, CH2M/Hill 1992) For urban water users, the quality of Delta water presents a major concern—the prospect of having to significantly increase water rates to pay for treatment that will not provide certainty that future standards can be met.

For these reasons, urban water users are strongly motivated to improve the quality of water exported from the Delta.

LEVEE STABILITY

Background

As shown in Figure 13 most of the Delta is below sea level. The water in Delta channels is at or higher than sea level. The many tracts of land named islands are, in fact, holes, some as deep as 20 feet below sea level. (DWRb 1987)

Beginning in about the middle of the last century, when the Delta was still a marsh, levees were built around the islands, the standing marsh vegetation was burned, and the Delta was converted into highly productive farmland. (SLC 1991) The peat soils are excellent for farming, but tilling them exposes the peat to oxygen in the air. When this happens, the peat soils oxidize (that is, the incomplete oxidation of the old marsh vegetation is completed) and literally blow away. Consequently, the level of land in the peaty areas continues to drop. (DWRa 1987)

The levees were not originally constructed to hold back 10 to 20 feet of water pressure, the difference between the water level in the channels and the elevation of the land surface inside the levees. (DWR 1978)

Flooding of Delta islands has occurred in the past (see Figure 14, taken from DWRb 1987) When a levee fails, the island fills up with water. The intruding water tends to be salty because it is drawn from San Francisco Bay. If several islands flooded, especially ones in the western Delta, water quality would be degraded to the point where Delta exports would have to be shut down until the salty water

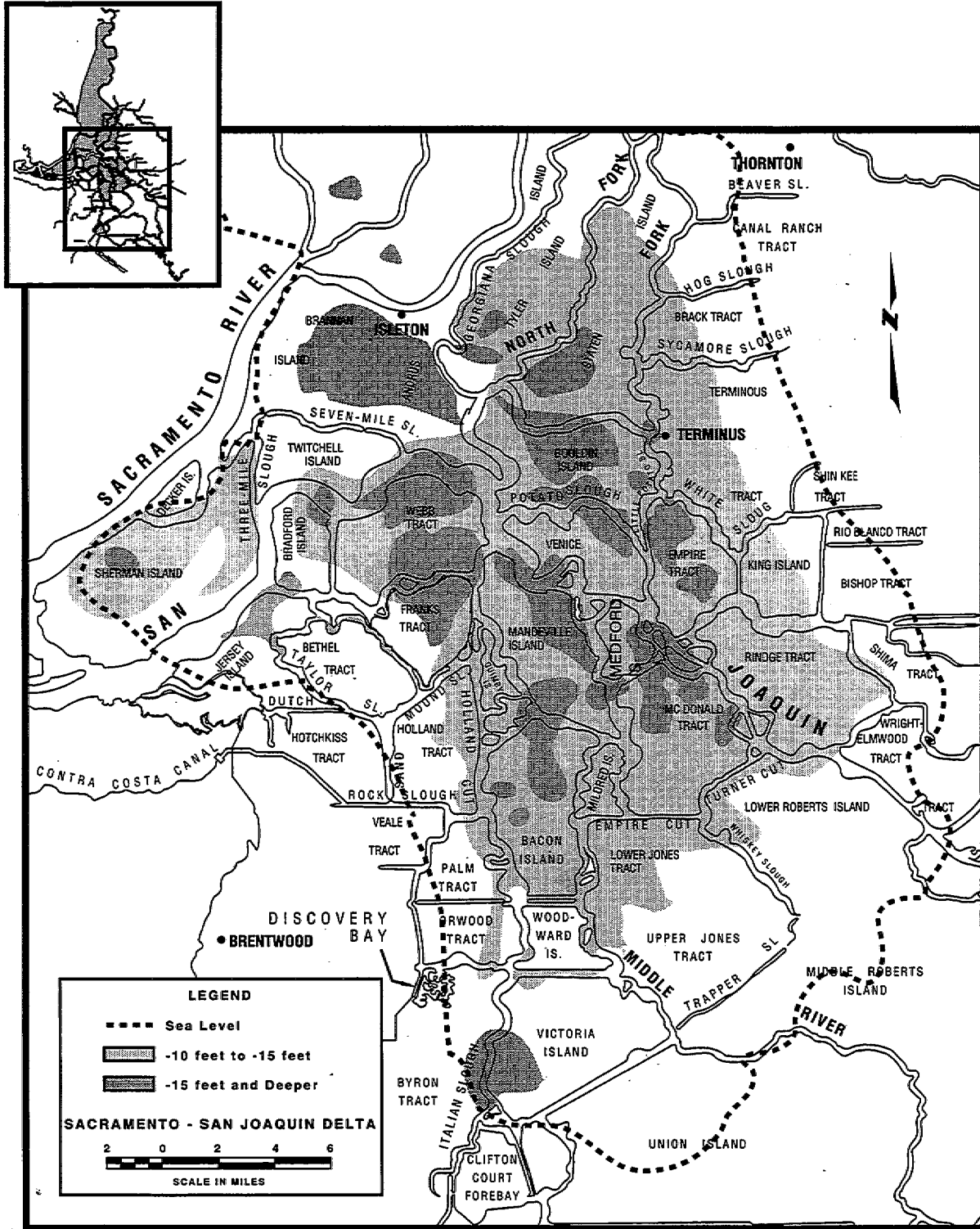


Figure 13. Delta Lands Below Sea Level

could be flushed out of the Delta. (personal communication, J. Cox DWR 1991)

In 1988, the state legislature passed The Delta Flood Protection Act. This act provides money for local Delta agencies to maintain the 75 percent of the levees not maintained by the state or federal governments. (Senate Bill 34) Work is progressing under that program. Levees are being strengthened to the point where the chance of normal flooding due to high fresh water flows into the Delta would be lessened.

However, there are potentially greater problems with levee stability in the Delta than normal flooding, namely, the earthquake problem. The levee maintenance program is only incidentally addressing this problem. The likelihood of seismic failure of levees has been a concern for some time. It was raised most pointedly in 1991 by the Association of California Water Agencies (ACWA). ACWA carried out a public relations program intended to inform the public about problems in the Delta, one of which was the threat of levee failure due to earthquakes.

At that time the State Department of Water Resources was engaged in a study of this issue. ACWA's efforts were judged by some to be premature, pending the outcome of the Department of Water Resources work.

The first phase of the Department of Water Resources studies has been completed. At the same time, the East Bay Municipal Utility District had commissioned independent seismic studies of their Mokelumne Aqueduct. (ESA 1992) This aqueduct crosses the southern Delta (see Figure 15, taken from DWRb 1987) and supplies about 95 percent of the water supply for 1.2 million people in Oakland, Berkeley, and surrounding communities. In addition, other studies on earthquake risk have continued in the aftermath of the Loma Prieta

earthquake in 1989.

Facts and Uncertainties

At this time there does not appear to be a consensus on the seriousness of the threat presented by earthquakes to the Delta and to water supplies exported from the Delta. Listed below are the generally agreed upon facts and points of uncertainty:

There are a number of active faults near the Delta, the San Andreas being the most distant (see Figure 16, taken from DWR 1992). There is some question as to whether an earthquake on this fault could significantly affect the Delta. (DWR 1992) Certainly, earthquakes on faults closer to the Delta could have serious effects. There may be a fault passing directly under the Delta, but there is little evidence that this fault is active enough to be of concern. (DWR 1992)

The probability of a major earthquake¹⁶ on one of these faults (not including the fault beneath the Delta but including the San Andreas Fault) is more than two chances in three sometime within the next 30 years. (USGS 1990, CSUH 1992)

A major earthquake near the Delta could produce ground shaking in the Delta that could cause liquefaction¹⁷ of liquefiable soils.¹⁸ (DWR 1992)

Much of the Central Delta and portions of the southern Delta are underlain with soils that have a moderate or high potential for liquefaction. (DWR 1992) Some of the soils used for levee construction are also liquefiable. (personal communication, R. Volpe ESA and W. Lettis W. Lettis and Assoc. 1991)

¹⁶ Magnitude 7.0 or greater. The Loma Prieta earthquake had a magnitude of 7.1.

¹⁷ Liquefaction means just what it says: Some soils that are normally solid can, if shaken, become liquid. You can visualize the phenomenon as follows: Picture sandy soil, saturated with water. That is, the sand particles are resting against each other, but the small spaces between the sand particles are filled with water. If the sand is shaken, the particles can become temporarily dislodged from each other. The particles are now suspended in the surrounding water instead of enclosing it, and the sand behaves like a liquid.

¹⁸ Studies done for East Bay Municipal Utility District indicate that there is 90+ percent chance that liquefaction would occur sometime in the next 30 years at one third of the locations analyzed along their aqueduct where it crosses the southern Delta. (ESA 1992)

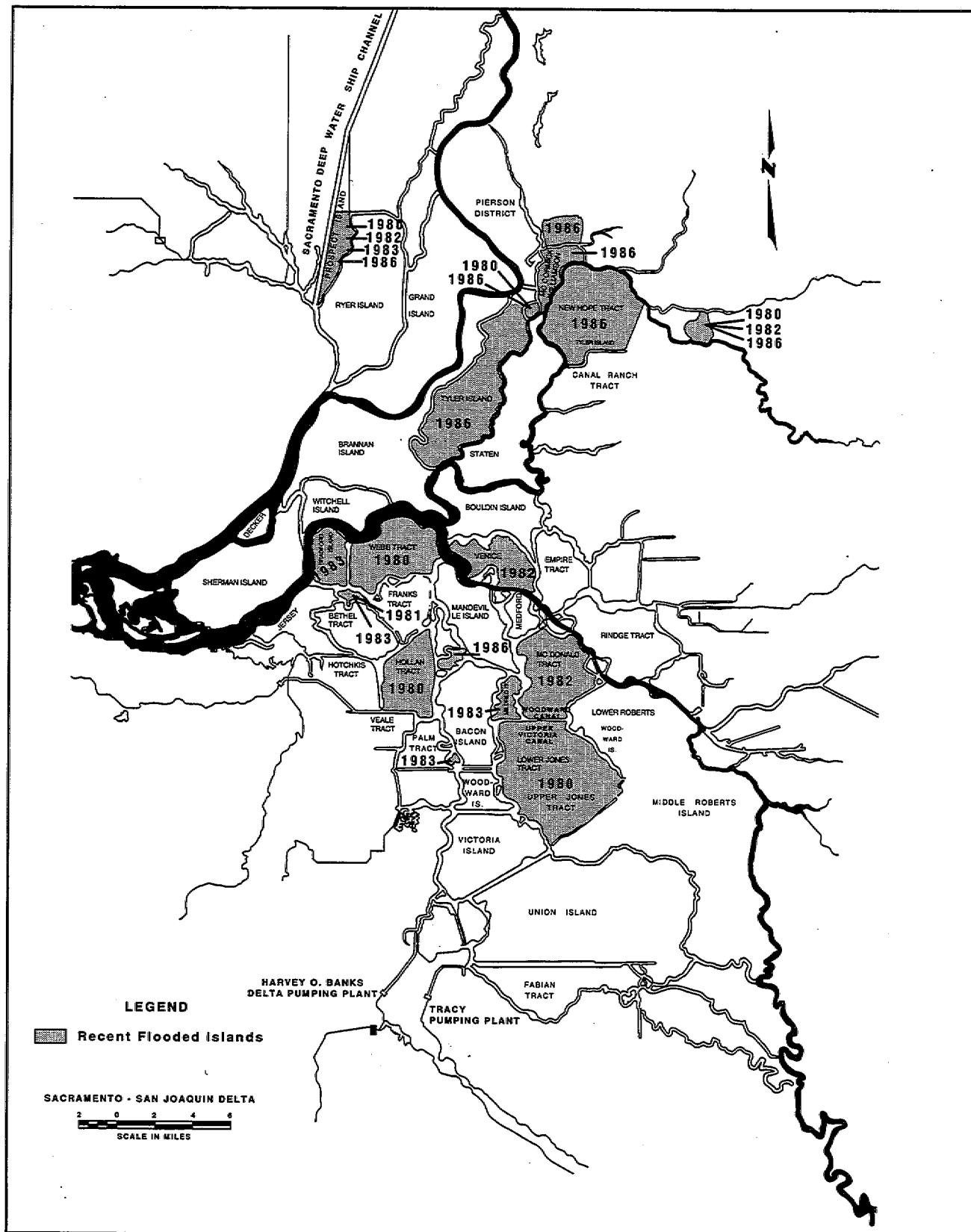


Figure 14. Recent Instances of Flooding of Delta Islands

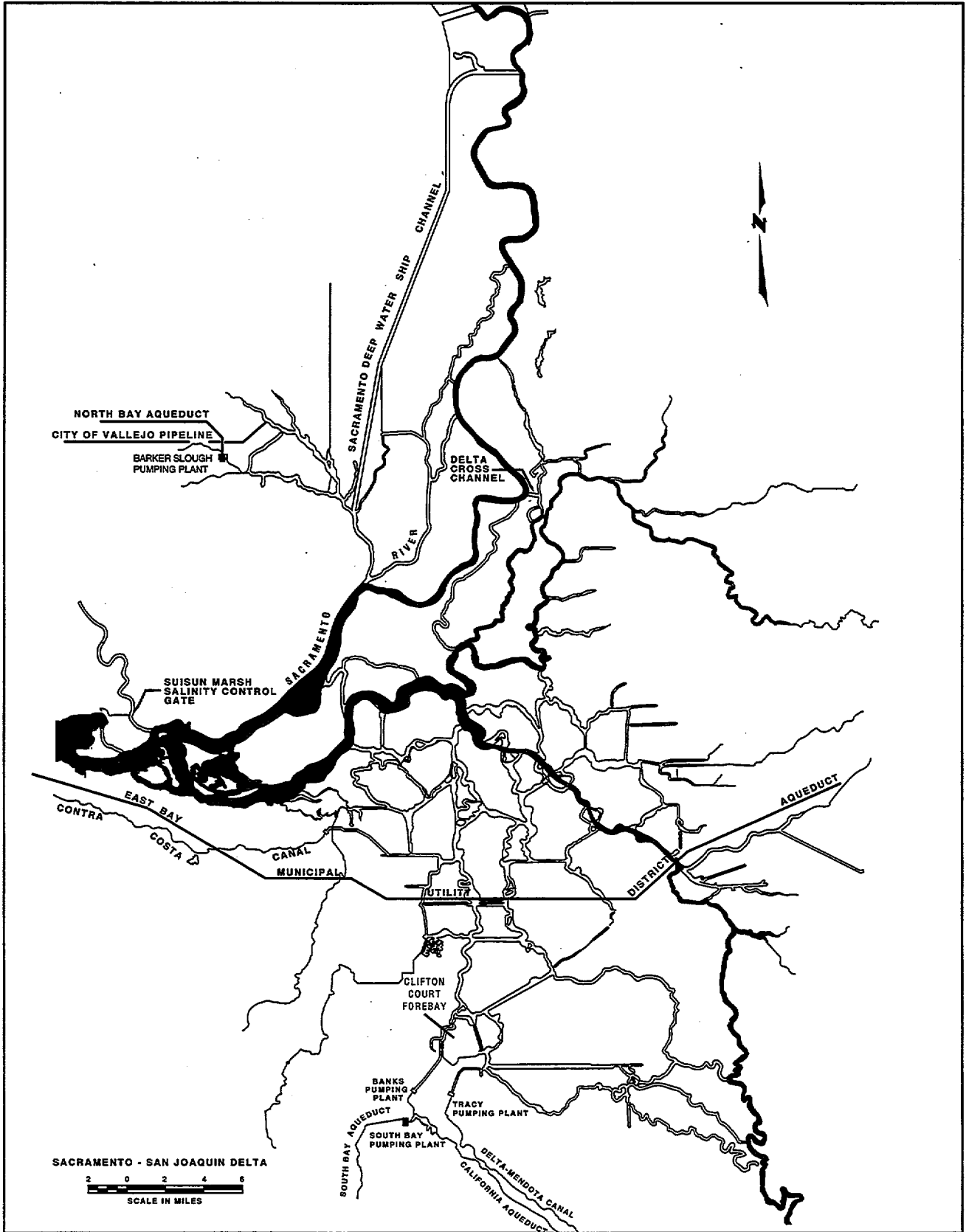


Figure 15. Delta Water Facilities

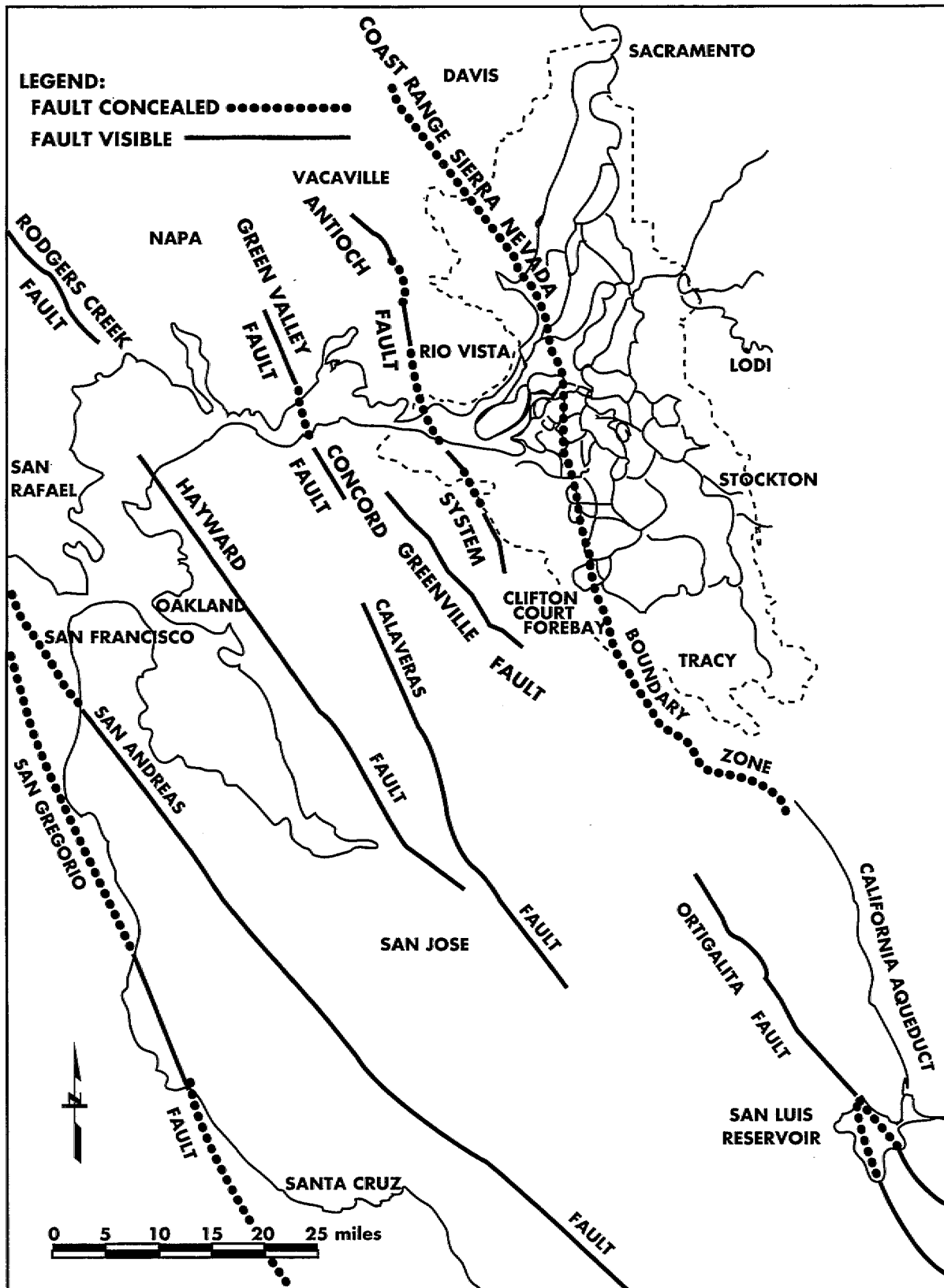


Figure 16. Faults Near the Delta

Much of the Delta is also underlain with peaty soils. (DWR 1992) There is uncertainty how peat soils would react in an earthquake. They may serve to attenuate the deep ground shaking, thereby lessening the damaging shaking that occurs near the surface of the ground. In this case, the chances of liquefaction would be lessened. On the other hand, peaty soils may amplify the deep ground shaking. In this case, liquefaction and considerable damage could be expected.¹⁹ (ESA 1992)

There has been little damage in the Delta from earthquakes in the recent past. (DWR 1992) However, during the period when the Delta has existed as we know it today (leveed islands, since the mid-1900's), there have been few earthquakes on faults near the Delta (from San Andreas east). In the eight decades from 1830 to 1910 there were 18 earthquakes of magnitude 6.0 or larger, 8 of magnitude 6.5 or larger, and 3 of magnitude 7.0 or larger, including the 1906 earthquake of 8.3 magnitude. From about 1910, there were no earthquakes of magnitude 6.0 or larger until 1979. Since 1979, there have been four earthquakes of magnitude 6.0 or larger, including the Loma Prieta earthquake (magnitude 7.1, October, 1989). (USGS 1990)

It appears that the region has entered a period of increased earthquake activity. (USGS 1990, CSUH 1992)

The epicenter of the Loma Prieta earthquake was as close to the southern Delta as it was to the Marina District in San Francisco and the Cypress Freeway Structure in Oakland. Significant damage occurred in these Bay Area locations. No such damage occurred in the southern Delta. (DWR 1992)

However, the damage that occurred in the Bay Area during the Loma Prieta earthquake may have been in part the result of peculiar deep rock formations that bounced the earthquake

energy waves up into the Bay Area. Therefore, the southern Delta may not be less vulnerable to damage from significant ground shaking. (personal communication, W. Lettis, W. Lettis and Associates 1992)

If there were failure of a number of levees during an earthquake, flooding of several islands could occur. Such flooding would draw salty water into the Delta unless freshwater flows into the Delta were high at the time. Exports would be interrupted until the salty water could be flushed out. If the damage occurred when reservoir levels were down, valuable stored water supplies could be used up to accomplish this flushing. It could take months to selectively patch up the Delta levees and flush out the salts. (personal communication, J. Cox DWR 1991)

The Alternative Conclusions

The question is what should be done with this information and the uncertainties. One school of thought would be to do nothing until these uncertainties have been resolved and there is certainty that significant damage would occur with a reasonably high probability.

Another school of thought is that more than enough information is available to raise serious concerns about the security of Delta export supplies with respect to earthquake damage. If this school of thought were to prevail, three conclusions would logically follow:

All water agencies that rely heavily on exports from the Delta should have contingency plans in the event of a several-month interruption in exports from the Delta.

Provisions should be made to move wet period water out of the Delta in an environmentally benign manner and store it south of the Delta as an emergency supply. Water stored north of the Delta could be used to help flush out the Delta.

¹⁹ Not all peat soils are the same. Some peat soils in the Delta are fibrous. These soils should attenuate deep ground shaking. Other peat soils are more like muck. These peat soils could amplify deep ground shaking and may themselves liquefy.

The intakes for the export pumps should be moved so as to reduce the risk of export interruptions due to earthquake damage to Delta levees.

CONSTRAINTS ON WATER TRANSFERS AND WATER BANKING

Most water users and environmentalists seem to agree on the desirability of water transfers and water banking.²⁰ However, the Delta fishery problems present serious constraints to these options. This section describes these constraints.

Why is the Delta so important to transfers and banking? First, consider water banking.

Water Banking

There are three essential conditions for banking water:

Excess water, that is, water in excess of the needs of other water users and of the environment.

Storage, a place to put the water. Now, in California this probably means reservoirs on dry streams or use of groundwater basins.

A means of taking control of and moving the water to storage. If storage reservoirs cannot be built on live streams, there would have to be pumping and conveyance facilities to move the water from where it occurs to where it can be stored. In addition, these pumping and conveyance facilities must not already be filled up with water for other purposes.

The Delta is the downstream point for the entire Central Valley. The Delta is where the excess water shows up. The Delta is also the head end of the two canals that serve much of the populated area of the state, the Bay Area²¹ and Southern

California. Therefore, the most likely place to bank water from is the Delta.

Does water show up in excess amounts in the Delta? Yes, without question, as Figure 17 shows. Notice the large peaks that occur in some years. To put these peaks in perspective: A peak of 250,000 cfs for three days is equal to 25 percent of the total annual urban water use in the state. During the 1980's there were eight such peaks.

Banking possibilities out of the Delta have been analyzed. (Miller 1991) Even assuming very high environmental requirements for Delta outflow, large amounts of water are available for banking out of the Delta. For example, assume that water were only banked during November through February and only when Delta outflows were over 60,000 cfs. In the 1980's there would have been enough water to bank so that the bank could have been drawn down at the rate of three to four million acre-feet per year for that decade or almost 10 million acre-feet per year in the first four years of the 1987-92 drought. This would have required a storage reservoir near the Delta and use of the full capacity at the Delta export pumps when water was available to be pumped. The point is that water is available in the Delta for banking, if there were a means to move the water from the Delta in an environmentally benign manner and if there were a place to store it.

Is there a place to store the water? Yes, some facilities already exist, and more storage is planned. Now, there is San Luis Reservoir and the Kern Water Bank, a groundwater storage project. Offstream storage is being planned at Domenigoni Valley Reservoir in southern California and at Los Vaqueros Reservoir in Contra Costa County. Los Banos Grandes Reservoir is being planned for the west side of the San Joaquin Valley, just south of San Luis Reservoir and along the route of the Delta-Mendota Canal and the California Aqueduct. San Diego County has begun investigations for more reservoir storage. So, there is already some capacity

²⁰ 'Water Transfers' means the purchase of water from one user for transfer and use by another user. 'Water banking' means the capture of a fraction of water available during periods of high flows and banking of that water for later use. Both are means of producing more water for critical needs, including environmental needs, in an environmentally benign way.

²¹ Even San Francisco and those parts of the Bay Area served by the San Francisco system would have to rely on an intertie with the South Bay Aqueduct, part of the California Aqueduct system, to obtain transferred water. Of course, that water would have to be exported from the Delta.

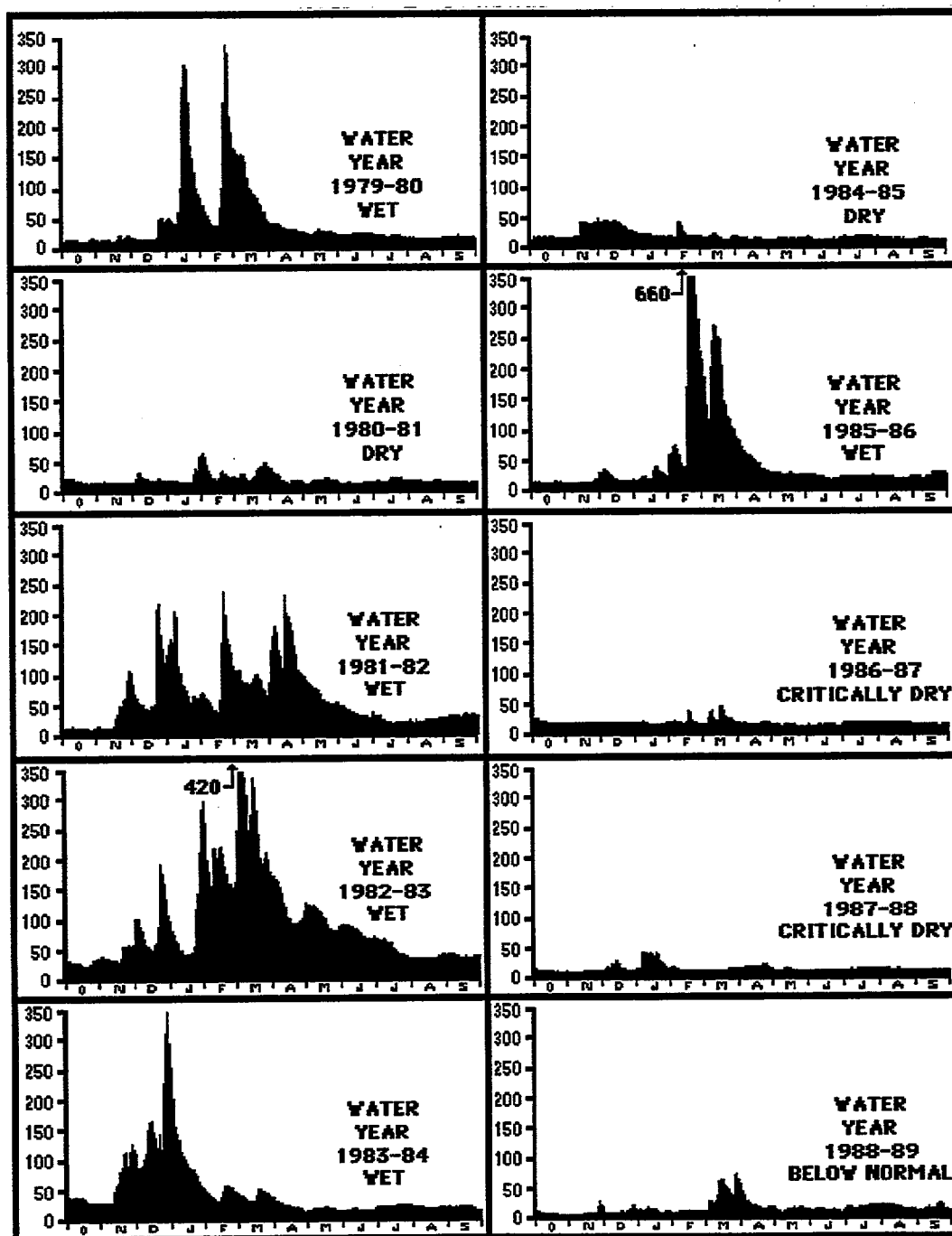


Figure 17. Delta Inflow in the 1980's
(1,000's of cubic feet per second)

and more is being planned.

Is there the means to move the water out of the Delta to these storage facilities?

Here is where the Delta fishery problem becomes important.

Because the export pumps are located in the part of the Delta where fish are spawning and migrating and because operation of the pumps draws fish from other parts of the Delta, the worse the fish problem, the greater the need to curtail these exports. More export curtailments means less time when water can be exported out of the Delta. The less water that can be exported out of the Delta, the greater the pressure to use the pumps (and downstream canals) at their maximum capacity when curtailments are not in effect, just to satisfy normal demands for exported water. Therefore, the less capacity there would be for banking water.²² Before considering this problem in more detail, consider the situation for water transfers.

Water Transfers

The figure on the next page (Figure 18) shows the major areas of the state that would probably want to buy water and the areas from which water might be bought. As this figure shows, the Delta is involved in almost all of these transfers.²³ In fact, it is likely that only those transfers between southern California and agencies in the southeastern part of the state, the ones receiving water from the Colorado River, would not involve the Delta. Also, note that many of these transfers involve increasing the amount of water exported from the Delta. Such increases may not be allowed because of the fishery problems.

So, for both water banking and water transfers, the Delta is key.

²² As an example, the State Water Contractors, who purchase water exported from the Delta, have expressed serious concern about the continuing expense of proceeding with plans for additional water storage south of the Delta in view of proposed or actual new constraints on Delta exports.

²³ Note that some of these transfers would have to occur by exchange. Exchanges are common in California water but require some explanation to those who may not be familiar with them. For example, a Bay Area water agency could obtain water from a Colorado River user by paying that user to give their water to the Metropolitan Water District of Southern California who would, in turn, give up an equal amount of their export from the Delta to the Bay Area agency. Incidentally, water can be 'backed up' from, say, the Colorado River into a northern California reservoir like Lake Shasta by these types of exchanges. So, there is considerable flexibility in the system and many opportunities—if the Delta problem can be overcome.

The Fishery Constraints

Figure 19 shows potential fishery constraints on water project operations in the Delta. This figure shows the constraints that have been or could be imposed based on the opinions of fishery biologists. (personal communication, L. Miller and D. Sweetnam DFG, R. Brown DWR, C. Hanson fishery biologist consultant 1992) Not all of these requirements are yet in effect. The Winter-run salmon has been listed under both the state and federal Endangered Species Acts, and the Delta smelt under the federal act. Another four species could be listed within the next two years. Note that the curtailments would be more serious in dry years.

In the case of endangered species, fishery biologists' opinions carry considerable weight, and there is little consideration of the social and economic effects of measures to protect the fish. For non-endangered species, such as striped bass, some balancing can occur between fishery requirements and agricultural and urban water needs.

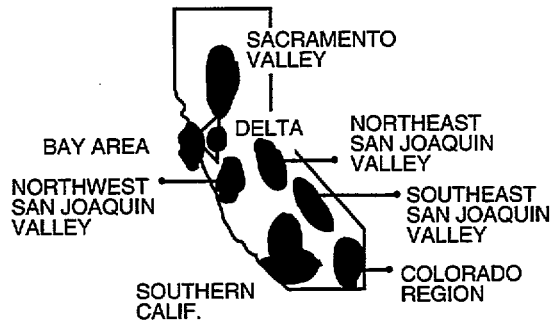
The X's mean that operations are eliminated or curtailed. For example, an X over the Delta export arrow means that Delta exports must be reduced during that month. A + means flow must be increased.

Recall that any time the Cross Channel is closed, reverse flows are calculated to occur, even with little export pumping, unless flows in the San Joaquin River are high.

The following conclusions can be drawn from the chart:

Now, the combined protections for the Winter-run salmon and other salmon and striped bass can result in export curtailments in all years.

The recent listing of the Delta smelt as a



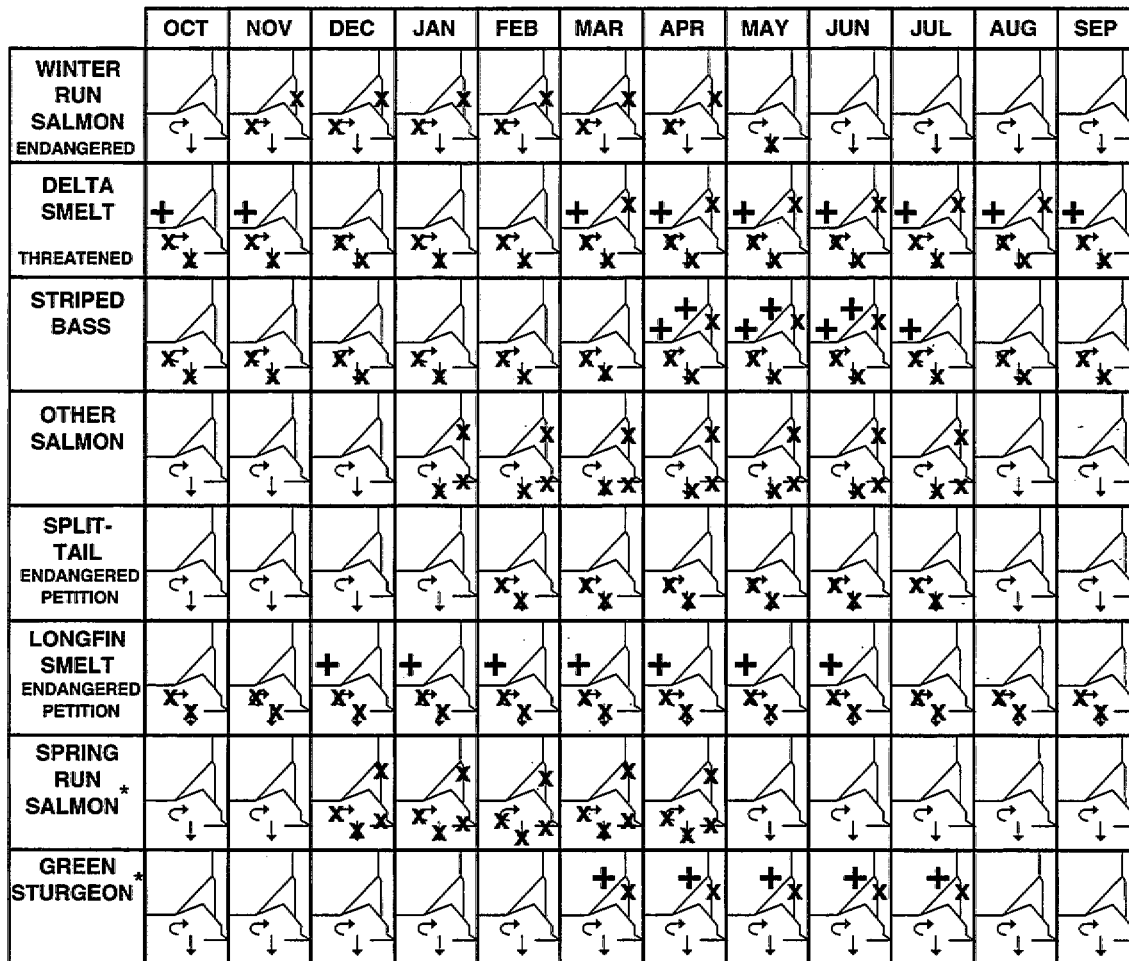
SELLER

	SACRAMENTO VALLEY	DELTA	NE S.J. VALLEY	SE S.J. VALLEY	NW S.J. VALLEY	COL. REGION
BAY AREA	down Sac. R. export <u>extra</u> amount from Delta	export <u>extra</u> amount from Delta	down S.J. River, export <u>extra</u> amount from Delta	trade with Delta exporter, export same amount from Delta	export same amount from Delta	by exchange from So. CA., export same amount from Delta
NW S.J. VALLEY	down Sac. R. export <u>extra</u> amount from Delta	export <u>extra</u> amount from Delta	down S.J. River, export <u>extra</u> amount from Delta or divert from S.J. River	trade with Delta exporter, export same amount from Delta		by exchange with So. CA. export same amount from Delta
SO. CALIF.	down Sac. R. export <u>extra</u> amount from Delta	export <u>extra</u> amount from Delta	down S.J. River, export <u>extra</u> amount from Delta	trade with Delta exporter, export same amount from Delta	export same amount from Delta	export less from Delta

"Export extra amount" means that the transfer would increase the amount of water exported from the Delta.

"Export same amount" means that the transfer was from one export user to another, so the same amount of water would be exported from the Delta as would have been transported without the transfer.

Figure 18. Importance of the Delta to Water Transfers



*Petitions to list these species as endangered have been prepared but not yet filed.

+ INCREASED FLOW

X NOT ALLOWED OR ALLOWED BUT LIMITED

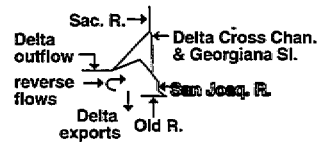


Figure 19. Fishery Constraints on Water Project Operations in the Delta

threatened species is likely to make the curtailments even more stringent.

Listing of the Longfin Smelt could, again, increase the stringency of curtailments in excess of those required for the Delta smelt.

Because these requirements are most stringent in dry years, when water transfers are needed, they are serving, and will continue to serve, as severe constraints on water transfers.

Listing of the Spring-run salmon could provoke requirements for additional flows down the San Joaquin River. At first thought this might seem to improve the possibilities for Delta exports. However, it is likely that stringent export curtailments would be necessary to avoid drawing the outmigrating Spring-run salmon to the pumps.

Recent Actions to Address Fishery Problems

In the last several years, much has happened to address the fishery problems in the Delta. The Winter-run salmon was listed as an endangered species by the National Marine Fisheries Service. As already mentioned, stringent measures were taken to protect this fish, including export curtailments.²⁴ These export curtailments are continuing each year and will do so until the population has recovered.

The Delta smelt has recently been listed, and this will prompt more serious curtailments of exports. Other species, including the Longfin smelt, are likely to be listed, prompting still more serious curtailments of exports.

Meanwhile, The Central Valley Project Improvement Act is beginning to take effect with its requirement to dedicate about 800,000 acre-feet per year of water for fish and wildlife plus additional amounts if needed to fulfill broader objectives of the act (doubling natural populations of salmon, for

example). It is likely that much of that water would be taken in the form of Delta export curtailments. Such curtailments may at least partially overlap those required to protect endangered species.

The State Water Resources Control Board is deliberating on a new water rights decision for the Delta (D-1630). In its draft form, this decision would curtail exports relative to what is allowed now. Again, some of these export curtailments would overlap those mentioned above.

The federal Environmental Protection Agency has announced its intention to attempt to increase further its influence over the California water allocation process.²⁵ Acting under its water quality authority, EPA has threatened to set its own water quality standards for the Delta and for San Francisco Bay if the State Water Resources Control Board does not set standards considered by EPA to be sufficient to provide long term protection of fish. One of these water quality standards would be for salinity in the western Delta. This standard could only be met by having more water flow out of the Delta to San Francisco Bay, thus potentially further limiting Delta exports.

EPA's attempt to extend its influence over the California water allocation process would no doubt provoke litigation that would take some time to resolve. However, even if the state prevails in such litigation, all of the requirements mentioned above under other authorities would still take effect.

In addition, victory by the state (or some other event, for that matter) could provoke federal legislation to provide additional protections for the environmental resources of San Francisco Bay and the Delta. There would probably be considerable support for such action at the federal level.

The trend is clear—There will be increasingly stringent curtailments of water project operations, directed not only at Delta exports but also to the

²⁴ These curtailments can occur directly or through the combination of prohibitions on calculated reverse flows and requirements to close the Delta Cross Channel.

²⁵ EPA already has some authority over water allocation by virtue of its ultimate approval authority for permits required for any construction activities in navigable waters. These permits are issued by the federal Corps of Engineers. Such permits already limit the amount of water that can be exported from the Delta.

release into the Delta of water that would otherwise be stored and used upstream. Such steps cannot be completely effective in solving the fishery problems, even with severe curtailments on water project operations.

Responses to the Fishery Curtailments on Water Project Operations

Now, the most important aspects of the response to Delta fishery problems consist of the following:

Requirements that blanket several months, for example, closure of the Cross Channel or prohibitions on calculated reverse flows for November through April.

General parameters, for example, calculated reverse flows, a parameter that includes Delta exports, San Joaquin River flows into the Delta, and Sacramento River flows that are diverted into the Central Delta.²⁶

Non-water-using improvements such as rehabilitation of upstream spawning beds and screening of some diversions.

Establishment of funds collected by surcharges on water sales, with the money going to fund environmental improvements or to purchase water for environmental use.

These first two responses listed above, blanket requirements for general parameters, are especially burdensome for the water projects. Therefore, considerable attention is being directed at other ideas that would both protect the fish and avoid serious water shortages. These are discussed below.

The Detailed Analysis Approach

This approach was first described in Department of Water Resources testimony to the State Water Resources Control Board. (DWRa 1992) So far, this approach has yielded valuable information that could allow fishery improvement without reallocating large amounts of water from urban and agricultural use to the environment.

The method consists of successively more specific analyses of fishery problems until the particular underlying mechanisms are identified. Then, specific measures can be taken to address the specific causes of the problem. Often this approach provides better solutions and saves water.²⁷

Two examples illustrate this approach.

Example 1: It has been clear for years that Delta export pumps have considerable damaging effect on fish. At first, prevailing opinion held that the pumps' major effect was to export eggs, larvae, and small fish out of the Delta ('entrainment') and to kill slightly larger fish on the fish screens. Further studies have revealed that for striped bass, entrainment and screening losses account for only about 25 percent of the mortality of 'yearling equivalents'²⁸ at the state pumping plant. Predation by larger fish, including striped bass, in Clifton Court Forebay is estimated to account for almost 70 percent of the yearling equivalent mortality (adapted from Brown 1992). Therefore, it would appear that much of the direct losses at the state pumping plant could be avoided by controlling predation rather than solely by further, drastic curtailments of exports.

Example 2: In 1987, studies revealed that flows in the Sacramento River appeared to have a marked effect on the mortality of young, out-migrating

²⁶ The State Water Resources Control Board's draft decision D-1630 does provide for real time monitoring for the presence of significant numbers of fish or fish eggs and larvae as a basis for closing the Cross Channel Gates. However, the endangered species requirements that supersede the Board's decision call for blanket closures for several months.

²⁷ This approach contrasts sharply with the more popular and easily understood approach of seeking only broad apparent causative factors for fishery problems. Examples of such broad factors would be 'Delta exports' or 'Delta inflow,' both of which can often be correlated with declining fish populations, just as can other variables, like the rising stock market or the increasing number of ethnic conflicts in the world.

²⁸ A yearling equivalent is one, year-old fish. This measure is useful because, obviously, it is much worse to kill one year-old fish than one fish egg. Because of the high natural mortalities of early life stages, many, many eggs equal one, year-old fish.

salmon. These studies implied that much higher river flows would improve salmon survival. More detailed studies revealed that flow in the Sacramento River was not the real factor. The real factors were water temperature and diversions from the Sacramento River through the Delta Cross Channel and Georgiana Slough. Both of these factors are affected by river flow. However, water temperature in the Sacramento River can best be improved by installing a multi-level outlet at Lake Shasta Dam (so cool water could be released from near the bottom of the reservoir). The diversion problem could be attacked by closing the Delta Cross Channel Gates and, possibly, putting a barrier across Georgiana Slough when out-migrating salmon are present. Here again, what appeared initially to be a problem solvable only by large effects on agricultural and urban water supplies turned out to be better solved by other, less-water-costly means.

Real Time Monitoring

This approach consists of establishing a comprehensive, reliable system of monitoring throughout the Delta and upstream. The monitoring system would detect the presence of different life stages (eggs, larvae, smolts, etc.) of different species of fish. When these species were present, water project operations would be altered to protect the species. When they were not present, water projects would be operated to reflect that fact.

Real time monitoring is already being carried out. A system has been developed to determine when striped bass eggs and larvae are drifting down the Sacramento River toward the Cross Channel. In addition, other monitoring is now being carried out in, upstream, and downstream of the Delta. However, current programs suffer from lack of funding and could be improved. Water project operators have considerable incentive to support such improvements.²⁹ Of course, the reliability of real time monitoring systems would have to be demonstrated, especially in the case of endangered species where the law is very strict about 'taking' and where the number of fish to detect is small.

Nevertheless, real time monitoring holds considerable promise.

Fish Screening and Repulsion

There is also considerable and growing interest in methods to keep fish away from dangerous areas, such as the export pumps, Delta agricultural diversions, or, in the case of outmigrating fish in the Sacramento River, the Cross Channel and Georgiana Slough. Advances continue to be made in the design and operation of fish screens. (personal communication, C. Hanson fishery biologist consultant 1993) Sonic and electrical repulsion systems have been installed at several locations in this country, including the confluence of the San Joaquin and Merced Rivers. (personal communication, C. Hanson fishery biologist consultant 1993)

Screening and repulsion of fish also holds considerable promise for fish protection in the near term.

Refinement of Regulatory Parameters

Particular attention is being paid to the accuracy and relevance of calculated reverse flows. This subject was discussed in a previous section of this report on the movement of water in the Delta. Suffice it to say that any parameter of such importance to the water supply of the state should be subject to rigorous analysis, better modeling, and improved understanding.

IMPLICATIONS OF THE FISHERY PROBLEMS FOR OTHER DELTA PROBLEMS

The Drinking Water Quality Problem

It is possible that curtailments on Delta exports coupled with other requirements to put more water into the Delta could improve the drinking water quality problem somewhat. These curtailments ought to decrease seawater intrusion into the Delta,

²⁹ For example, the value of water exported by the federal pumping plant at Tracy ranges up to about \$800,000 per day based on the cost of an alternative groundwater supply whose use would be limited and temporary.

thereby lowering the bromide levels in exported water. However, the large contributions of organic matter from Delta and upstream agriculture would still remain.

This kind of improvement could, in fact, have been implemented years ago by the urban water users. Of course, it would have required that they suffer the accompanying water shortages. Given a choice between the expense of treating poor quality Delta water and the threat of water shortages, urban water users would almost always choose to pay for treatment. However, in the case of trihalomethanes and other, even-more stringent requirements now being formulated, the cost is very high, perhaps billions of dollars, and there is no assurance that continued compliance with drinking water standards could be achieved.

The Levee Stability Problem

The current trend in water project curtailments does nothing for the basic levee stability problem, that of having the water supply intakes for much of the state at sea level and protected only by levees susceptible to seismic failure or to rupture for other reasons, such as high water levels in the Delta. In fact, the levee stability problem is becoming more serious because the fishery requirements reduce the amount of water storage south of the Delta, where it would be needed to offset any cutoff in exports from the Delta. Water storage south of the Delta is the key to responding to the failure of Delta levees. Water stored north of the Delta would also be needed to flush out the salty water that would rush into the Delta if levees failed. (The requirements for Winter-run salmon do require that more water be held in storage in Shasta Reservoir north of the Delta, but it must be released at times favorable to the fish.) Water stored south of the Delta would be the emergency supply until Delta exports could resume.

The Problems of Water Supply Reliability and Constraints on Water Banking and Water Transfers

The increasingly serious measures to solve the fishery problems will markedly aggravate the

problems of water supply reliability and place more constraints on water banking and transfers. In other words, these two problems will become more serious in the near future even if the state had above normal precipitation for all the years until improvements can be made in the way water moves across and is exported from the Delta.

IMPROVEMENTS IN THE WAY WATER MOVES ACROSS AND IS EXPORTED FROM THE DELTA

The Need

Clearly, there must be improvements in the way water moves across and is exported from the Delta. Otherwise, while measures can be taken to protect fish, the fishery problems cannot be completely solved, and all the other problems grow much worse, with the possible exception of the drinking water quality problem, where some improvement can be expected at the price of large sums of money and increased water shortages. If such improvements are ever seriously considered, it would appear that there must be some system of guarantees that the improvements would be used for their intended purpose.

Guarantees of Proper Use of Improvements in the Way Water Moves Across and is Exported from the Delta

The real question concerns the form (as opposed to the substance) of such guarantees—How would they be put into place?

During the Three-Way Water Agreement Process, a special committee of environmental and water rights attorneys and others addressed this general issue, the form of Delta environmental guarantees. (NHI 1991) They ruled out state legislation and amendment of the state constitution as insufficient. State legislation and the state constitution could be changed if sufficient political power could be mustered. Such guarantees must provide protection against future overturn by those populous areas of the state that receive water from the Delta, namely, the South San Francisco Bay

Area (everything south of Hayward), much of the San Joaquin Valley, and Southern California. Constitutional guarantees of environmental protection were part of the legislative package that contained the Peripheral Canal and was defeated in a statewide referendum in 1982. Opponents of the Peripheral Canal argued that constitutional amendments were really not guarantees.³⁰

Considering all of this, the committee came up with a two-tiered set of guarantees:

Tier 1: A multi-party contract among San Francisco Bay, Delta and northern California interests and water project operators, including at least one private party.³¹ The private party(s) would insulate the contract against state legislative modification.

Tier 2: Federal legislation. Various possibilities exist here. The point would be to create a backup set of guarantees.

To weaken or do away with such guarantees, Delta export interests would not only have to break the contract, they would also have to convince members of Congress from the rest of the nation, as well as the President of the United States, that the environmental protections for the most important estuary on the west coast should be relaxed so that more water could be exported.

One might argue that the formidable and mounting array of environmental protections will soon amount to guarantees equivalent in form to those described above. However, if additional guarantees are required, the two-tiered, multi-party contract/federal legislation approach would appear to offer the most promise.

³⁰ Interestingly, much of the financial support for the 1982 campaign opposing the Peripheral Canal came from San Joaquin Valley agricultural interests who thought the environmental guarantees were too stringent.

³¹ 'Private party' means an organization that is not a creature of the state legislature. A contract among only water agencies and resource agencies (for example, the state Departments of Water Resources and Fish and Game) could be overturned by the state legislature because the existence and functions of these agencies are determined by the legislature.

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