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OFFICE REPORT NOVEMBER 1988

DISSOLVED OXYGEN STUDY

Stockton Deep Water Ship Channel

US Army Corps
of Engineers
Sacramento District

ANNEX A

DISSOLVED OXYGEN STUDY

STOCKTON DEEP WATER SHIP CHANNEL

ABSTRACT

The Corps of Engineers (Sacramento District) has just deepened the Stockton Deep Water Ship Channel from Antioch to Stockton. About a 7-mile reach of this channel near the port of Stockton has experienced dissolved oxygen deficit problems in the past which, along with several other unrelated factors, has hindered the fall season run of salmon on their way to spawn in interior tributaries.

In order to determine how this channel deepening affects dissolved oxygen, the Corps has retained a consultant to perform mathematical modeling studies. The consultant utilized one-dimensional link-node hydrodynamic and water quality models for the predictions. Preliminary work was directed toward calibration and verification of the models, and sensitivity analyses of selected parameters.

Once verification of the models was achieved then dissolved oxygen predictions were made for the previous 30-foot deep channel and the project 35-foot deep channel, for a variety of historical hydrologic and meteorologic conditions. Comparisons were made to determine any decrease in dissolved oxygen concentrations due to the project. The mass of oxygen that would need to be replaced to mitigate for any decrease was determined.

This report presents a summary of the consultant findings. It also presents some additional analyses of data and interpretations of related environmental conditions by the Corps. Additionally, the Corps reviewed previous studies done by others over the past 25 years regarding the dissolved oxygen situation at Stockton, and incorporated salient findings into this report.

NOVEMBER 1988

DEPARTMENT OF THE ARMY
SACRAMENTO DISTRICT, CORPS OF ENGINEERS
SACRAMENTO, CALIFORNIA

SUMMARY

- Dissolved oxygen concentrations in about a 7-mile reach of the Stockton Deep Water Ship Channel at Stockton occasionally fall below the 5 mg/L concentration needed by the salmon run that occurs near the October period. Conditions were worse prior to 1978, which was when tertiary wastewater treatment was added to the City of Stockton's effluent. A substantial oxygen-demanding load still enters the ship channel from upstream river drainage. Reverse flow conditions in the ship channel can occur due to the export pumps of the Federal and State water projects. This has a negative effect on salmon which are trying to swim up-current, and can also have a variable effect on dissolved oxygen conditions. Actions taken over the years to improve dissolved oxygen concentrations at Stockton or to eliminate reverse flow conditions are as follows:

    a. Install tertiary wastewater treatment, by the City of Stockton;
    b. Temporary installations of Old River rock closure to force more flushing flow past Stockton, by California Department of Water Resources;
    c. Occasional injections of up to 60,000 acre-feet of Delta-Mendota Canal water into the Mendota Pool of the San Joaquin River, after Old River closure installed, to provide more flushing flow past Stockton, by U.S. Bureau of Reclamation;
    d. Planning studies for San Joaquin Valley Drain, to remove much irrigation waste loads from San Joaquin River, by Interagency Drainage Committee.

- The Corps project will have an effect upon dissolved oxygen concentrations in the ship channel for the following reasons:

    a. photosynthetic oxygen production will be decreased
    b. atmospheric reaeration will be decreased
    c. hydraulic residence time will be increased

- For the project conditions studied under the upgraded Stockton Regional Wastewater Control Facility operation, the maximum oxygen deficit attributed to channel deepening will be approximately 0.2 mg/L. (For comparative purposes, since 1978 the October dissolved oxygen concentration at Stockton ranges from about 3 mg/L to 7 mg/L.)

- The mass of oxygen needed to mitigate for the above decrease is directly proportional to flowrate. The mass ranges from approximately 625 lbs/day under near zero net flow conditions past Stockton to approximately 2500 lbs/day when the net downstream San Joaquin River flow past Stockton approaches 2000 cubic feet per second.

- The above predictions were assisted through use of one-dimensional link-node hydrodynamic and water quality models. These models were adequate for estimating the effects on dissolved oxygen concentrations when, after calibration and verification was achieved, only channel depth was changed while all other parameters and conditions were held constant to those values obtained in verification. The model is not suitable for absolute predictions at this time.

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STOCKTON DEEP WATER SHIP CHANNEL DISSOLVED OXYGEN STUDY

CHAPTER 1. INTRODUCTION

The Corps of Engineers, Sacramento District (Corps), has just permanently deepened the Stockton Deep Water Ship Channel from Suisun Bay to Stockton. The new depth is 35 feet below mean lower-low water (MLLW), while the previous depth was 30 feet. Additionally, the sedimentation basin, located at the confluence of the San Joaquin River and the ship channel, has been deepened. The new depth is 40 feet below MLLW, and the previous depth was 35 feet.

Since the 1940's the ship channel water in the vicinity of Stockton has been experiencing a summer-fall dissolved oxygen (D.O.) deficit, caused by oxygen-demanding loads entering from several sources. The magnitude of this deficit varies from year to year, depending mostly on flow conditions occurring. When D.O. concentrations become too low, there is a negative effect upon the fall season salmon run.* The channel deepening has some effect on the D.O. deficit condition because of its effect on hydraulic residence time, phytoplankton photosynthesis and respiration, and atmospheric aeration. Quantifying these effects is the purpose of this report.

Originally the Corps was considering a monitoring program to determine the effects of the channel deepening on D.O. However, it was felt that it would be difficult to separate out project effects from those other conditions which affect D.O., such as river phytoplankton loads and flowrates, wastewater inputs, reverse flow conditions, and weather conditions. Also, discrete monitoring programs at this location for D.O. are already conducted by the Department of Water Resources (DWR) and the City of Stockton. The DWR also has a continuous D.O. recorder on the Navy pier at Rough and Ready Island. Thus it was felt that a mathematical modeling effort should be done, where once the model was calibrated and verified all model conditions would be held constant and only channel depth changed. The results would show the project effect upon D.O. A letter was sent from the Corps to the California Department of Fish and Game (CFG) stating that the Corps would proceed with this modeling effort. This report presents the results of that effort.

The following were the specific objectives of this study:

- determine how the vertically-averaged longitudinal D.O. concentration profiles through the ship channel compare for pre-project (30-foot) and project (35-foot) conditions. Make these comparisons for a variety of historical hydrologic years.

- determine the mass of D.O. which would have to be input into the channel to mitigate for any project effects.

* Other conditions are also occuring that can adversely affect the fall salmon run, such as reverse river flow situations and poor quality river water.

CHAPTER 2. BACKGROUND INFORMATION

The San Joaquin River originates as very pure water in the Sierra Nevada Mountains east of Fresno. Its waters are stored behind Millerton Dam, and releases are made for flood control, irrigation, fishery, and recreation purposes as required. After reaching the San Joaquin Valley floor the river flows north, where it enters the Delta area near Mossdale (Figure 1). Along the way the river serves many purposes, and also degrades in quality. It picks up irrigation drainage water with its loads of organic detritus and salts, which contain the phytoplankton stimulants nitrogen and phosphorus. It also picks up some domestic wastewater effluent and nonpoint runoff, which similarly contain nitrogen and phosphorus. In the fall, a salmon run makes its way through the Delta and seeks to migrate up the river and into such tributaries as the Stanislaus, Tuolomne, and Merced Rivers. Some basic requirements those salmon need are a downstream-flowing current against which to swim and sufficient D.O. for breathing.

As the river flows, sunlight penetrates its surface and supplies the energy needed for phytoplankton to grow on the abundant nitrogen and phosphorus present. Large concentrations of phytoplankton have been noted along the river as it approaches the Delta, and an excess of D.O. produced from phytoplankton photosynthesis has occasionally caused supersaturated D.O. conditions.

After entering the tidally-influenced area of the Delta near Mossdale, the river continues its flow toward Stockton. From Mossdale Bridge to Stockton, a distance of 16 miles, stream depth ranges from 5 to 15 feet at mean half-tide (Bain et al, 1968). McCarty (1969) states that the river contains high concentrations of phytoplankton as it approaches Stockton, as a result of nutrient enrichment from land and waste discharge. Substantial man-induced changes in flow conditions occur in this reach. Historically, most of the river water continued on to Stockton, while some small portion of the flow split off and flowed westward in Old River. Today, however, with both the Central Valley Project and the State Water Project exporting water from Old River, a significant portion of the San Joaquin River flow, and sometimes all of its flow, along with some central Delta water, is pulled into Old River and exported south by the drawing action of the massive export pumps.

That portion of the San Joaquin River which does continue its flow to Stockton continues to do so in its natural channel. Once the river enters the Port of Stockton area, however, substantial man-induced changes to its depth have occurred. The approximately 10-foot deep river becomes a 30-foot deep ship channel, which, in fact, has just been permanently deepened to 35 feet by the Corps. The water velocity decreases over natural conditions because of the enlarged cross-sectional area of the ship channel. The water velocity also decreases as the export pumps in Old River draw water away from the San Joaquin River. The water velocity in the area is also affected by the rise and fall of the tide (about 2 feet in the Stockton area). Sunlight penetrates the channel surface, but most of the depth is without sunlight. Vertical mixing from wind action and channel turbulence is decreased by the increased depth. Sedimentation of solid particles increases because of the more

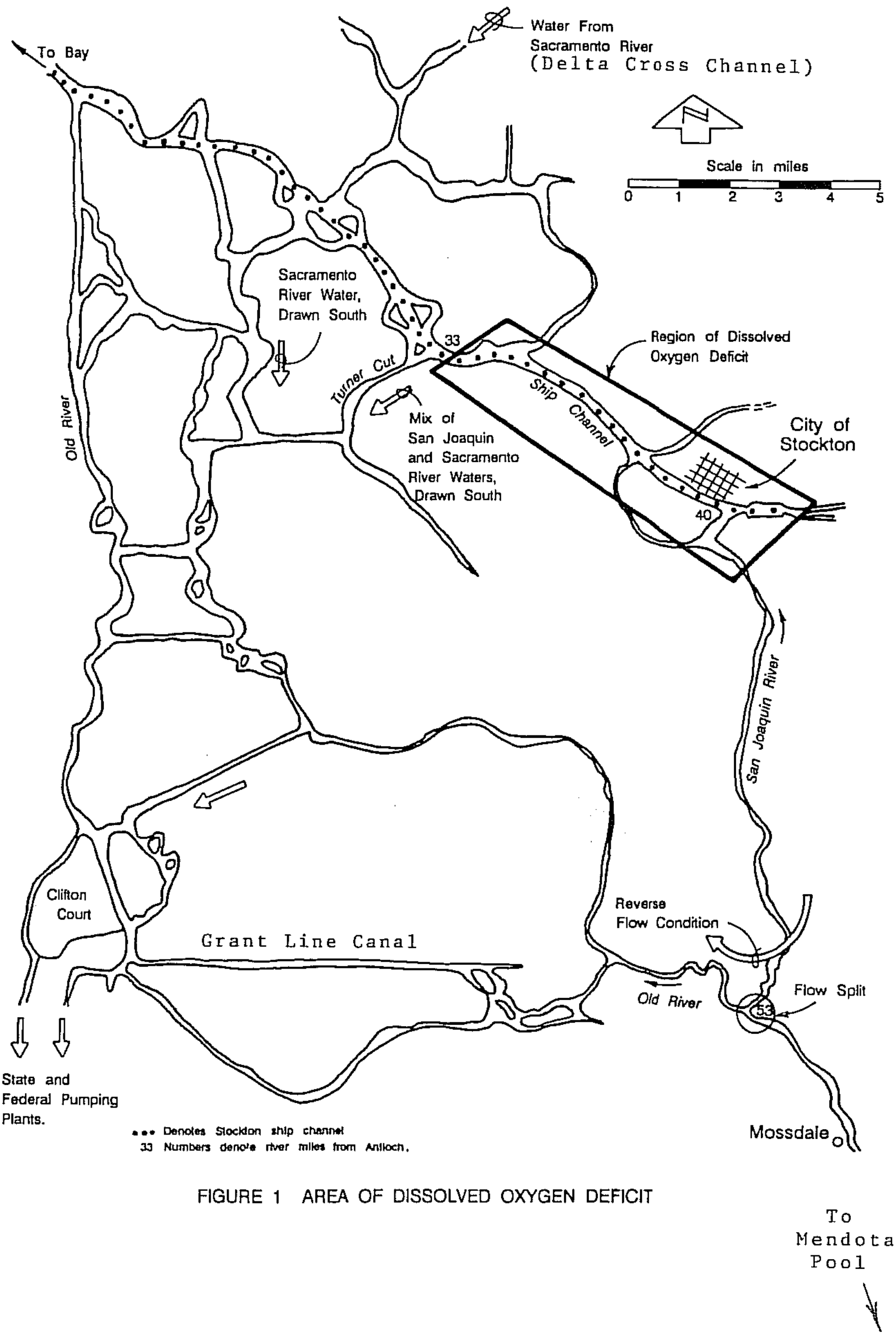


FIGURE 1 AREA OF DISSOLVED OXYGEN DEFICIT

quiescent conditions of the ship channel. Because of this, the Corps has constructed a sedimentation basin at the confluence of the river and ship channel, consisting of a 5-foot deeper cut in the channel bottom extending more than a mile.

There is a dead-ended portion of the ship channel in the port area called the Turning Basin. The only interchange of water here occurs through tidal action. Since some of the river phytoplankton load and city wastewater effluent is transported into this basin during flood tide, and because of the long detention time here, severe D.O. deficits have been measured here. During each ebb tide, some of this low D.O. water is transported back into the ship channel.

The phytoplankton load carried by the river into the ship channel area is affected by the conditions described above. They occupy a water column that is now 35-feet deep rather than 10-feet deep, as the river water becomes mixed with the ship channel water. Thus the phytoplankton in the deeper waters are in an area without adequate sunlight needed for photosynthesis, and the photosynthetic production of oxygen decreases or stops. However, these same phytoplankton continue to utilize oxygen in respiration. As some vertical circulation does occur in the channel (EPA, 1971), most of these deeper phytoplankton do return to the surface waters where photosynthetic oxygen production again picks up. However, they are replaced by other phytoplankton which were at the surface but have now been mixed to the deeper waters. The net effect of all this is that less photosynthetic production of oxygen occurs in the ship channel than occurred in the river, and the deeper the ship channel, the lower the phytoplankton's exposure to sunlighted surface waters as they undergo their vertical circulation.

While the above vertical circulation of phytoplankton occurs, there is still a portion of the phytoplankton which are dying and settling to the channel bottom along with other organic detritus and sand, silt and clay carried from upstream. Bottom-dwelling organisms consume this organic detritus along the channel bottom and consume oxygen in doing so. Some of the organic detritus becomes covered with inorganic sediments and undergoes microbial decay in the absence of oxygen.

Just upstream of the ship channel, the city of Stockton discharges its domestic wastewater effluent into the river. This effluent used to have a large demand upon the D.O. resource of the river, as river bacteria utilized D.O. as they consumed the organic and nitrogenous fractions of the waste load. In 1978 the city added improvements to the treatment process, whereby less organic and nitrogenous load is allowed to be discharged into the river. Non-point urban runoff of unknown magnitude continues to enter the river, and introduces some oxygen-demanding load to the river. All of the above oxygen demand will be satisfied by nature, sooner or later, as the natural processes of stream purification occur. However, the problem at Stockton is that D.O. concentration is desired not to fall below 5 mg/L in the fall, because of the salmon run. Thus, the natural process can be counted on in treating only a portion of the oxygen demanding load in this reach.

If D.O. saturation conditions existed in the water in October, with its temperature range of 16-20°C, the saturation concentration would be

9-10 mg/L. However, the D.O. concentrations in the ship channel fronting Stockton are decreased because of the above oxygen-demanding loads, and occasionally drop below the 5 mg/L desired for the fall salmon run. Prior to upgrading of the city's treatment plant in 1978, the oxygen deficits were more severe. The location of the maximum deficit moves back and forth in the ship channel because of tidal action, and the maximum deficit usually occurs in the period following sunrise, due to the lack of photosynthetic oxygen production over the night time period.

How the action of the export pumps in Old River can draw more San Joaquin River water into Old River was previously described. In fact, with low summer flow in the San Joaquin River and typical summer export rates, the entire flow of the San Joaquin River can be drawn into Old River and, additionally, flow reversal can occur at Stockton to draw that water upstream into Old River and to the pumps. Flow reversals occur in other Delta channels for the same reason, and by this process Sacramento River water is drawn southward through the Delta and to the export pumps. Some of this Sacramento River water is drawn to the vicinity downstream of Stockton (Turner Cut), as shown in Figure 1, and can serve to improve water quality conditions by replacing some of the phytoplankton-laden water there. Since 1964, a program has been worked out by DWR, CFG, and the U.S. Bureau of Reclamation (USBR) to ensure that positive downstream flows occur at Stockton during the fall season (Jones and Stokes, 1972).

The export of water from Old River affects D.O. concentrations in the ship channel near Stockton in several ways, some positive and some negative. Some of the oxygen-demanding load coming down the San Joaquin River is pulled into the Old River, and thus does not enter the ship channel to adversely affect D.O. concentrations there. However, the reduced downstream flow rate into the Stockton area decreases the flushing action and increases the hydraulic detention time there. This allows more ofthe oxygen demand of the load which has already reached Stockton to be exerted there. To increase the river flow rate at Stockton during such times the entrance to Old River is partially blocked by DWR with a rock structure. When this is done sometimes exported water from the Delta Mendota Canal is reintroduced into the river (at Mendota Pool) by USBR to increase river flows past Old River head. This aids the flushing action at Stockton and makes the flow travel in the correct direction for the salmon run, but inputs more of the oxygen-demanding load there. However, as seen from monitoring programs, the net effect has mostly been to improve D.O. conditions.

Thus, the D.O. concentrations in the ship channel at Stockton are affected by a multitude of factors, as shown below:

a. A respiring phytoplankton population in the darker waters;

b. An oxygen demand from non-viable organics and nitrification;

c. A benthic oxygen demand from bottom dwelling organisms and organic decay in the upper sediments;

d. A decrease in atmospheric aeration as channel depths increase;

e. Deepened channels and export rates which can slow the water velocity and allow time for more phytoplankton respiration and other oxygen demand to occur in a shorter channel length;

f. Export rates which affect how much phytoplankton and other oxygen-demanding load enters the ship channel, or how much Sacramento River water is drawn into the area.

The fall season salmon run through the ship channel is affected by several factors, as shown below:

a. Low D.O. concentrations;

b. Flow directions which may be traveling upstream, if Old River rock closure is not in place.

Because of the above D.O. deficit conditions, several monitoring programs have been on-going over the past years. The DWR has a discrete monitoring program for D.O. in the channel during those years when the Old River closure is installed. In this program, the D.O. concentrations are measured at about ten longitudinal sites along the channel, and at top and bottom depths at most sites. Also, the DWR has installed a continuous D.O. recorder on the navy pier at Rough and Ready Island. The City of Stockton has a similar discrete monitoring program as DWR, except the program is on-going every year and is a condition of their wastewater discharge permit. The city monitors many parameters in addition to D.O. The location of these monitoring sites are shown in Figures 2 and 3.

A schematic summarizing how the above processes affect D.O. in the ship channel is shown as Figure 4.

CHAPTER 3. PROCEDURES

The Corps specified the following requirements that were to be achieved in the modeling efforts:

a. Type of models - A one-dimensional link-node hydrodynamic model would be required to determine channel velocities and flowrates during the flood and ebb of the tide. Calibration would be done to tidal stage data. This output would serve on input to a dynamic water quality model. The dynamic water qulaity model would be one-dimensional in the longitudinal direction and represent the channels by a series of continuous flow stirred tank reactors (CFSTR's). The flood and ebb directions of the tide must be accounted for in mass transport considerations, rather than net steady-state downstream flow directions with a dispersion coefficient to account for tidal mixing. The water quality model must be deterministic in obtaining D.O. predictions: that is, the physical, chemical, and biological conditions that affect D.O. must appear in the coupled equations that serve as the model.

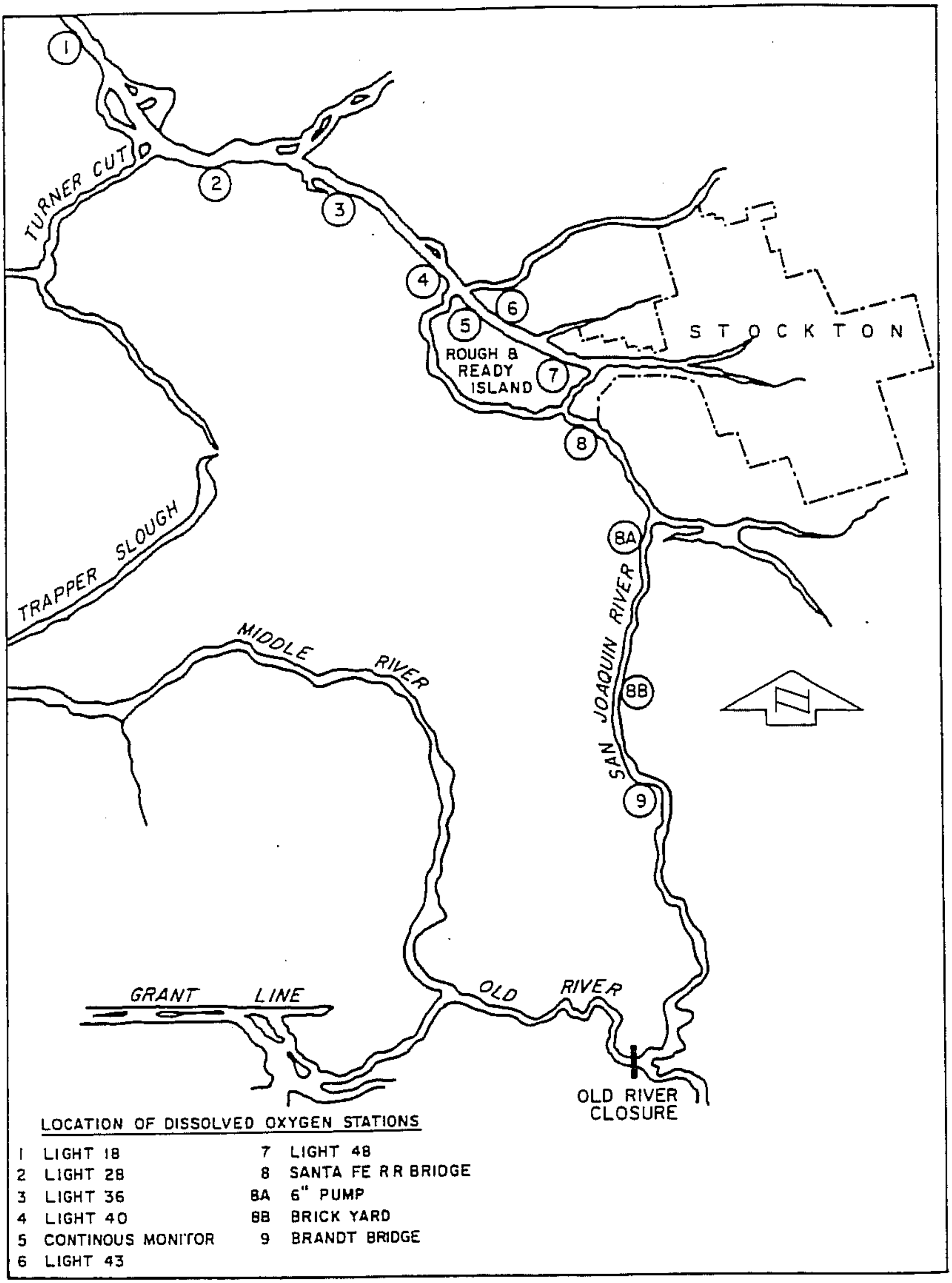


FIGURE 2 CALIFORNIA DEPARTMENT OF WATER RESOURCES DISSOLVED OXYGEN SAMPLING STATIONS AND THE OLD RIVER CLOSURE

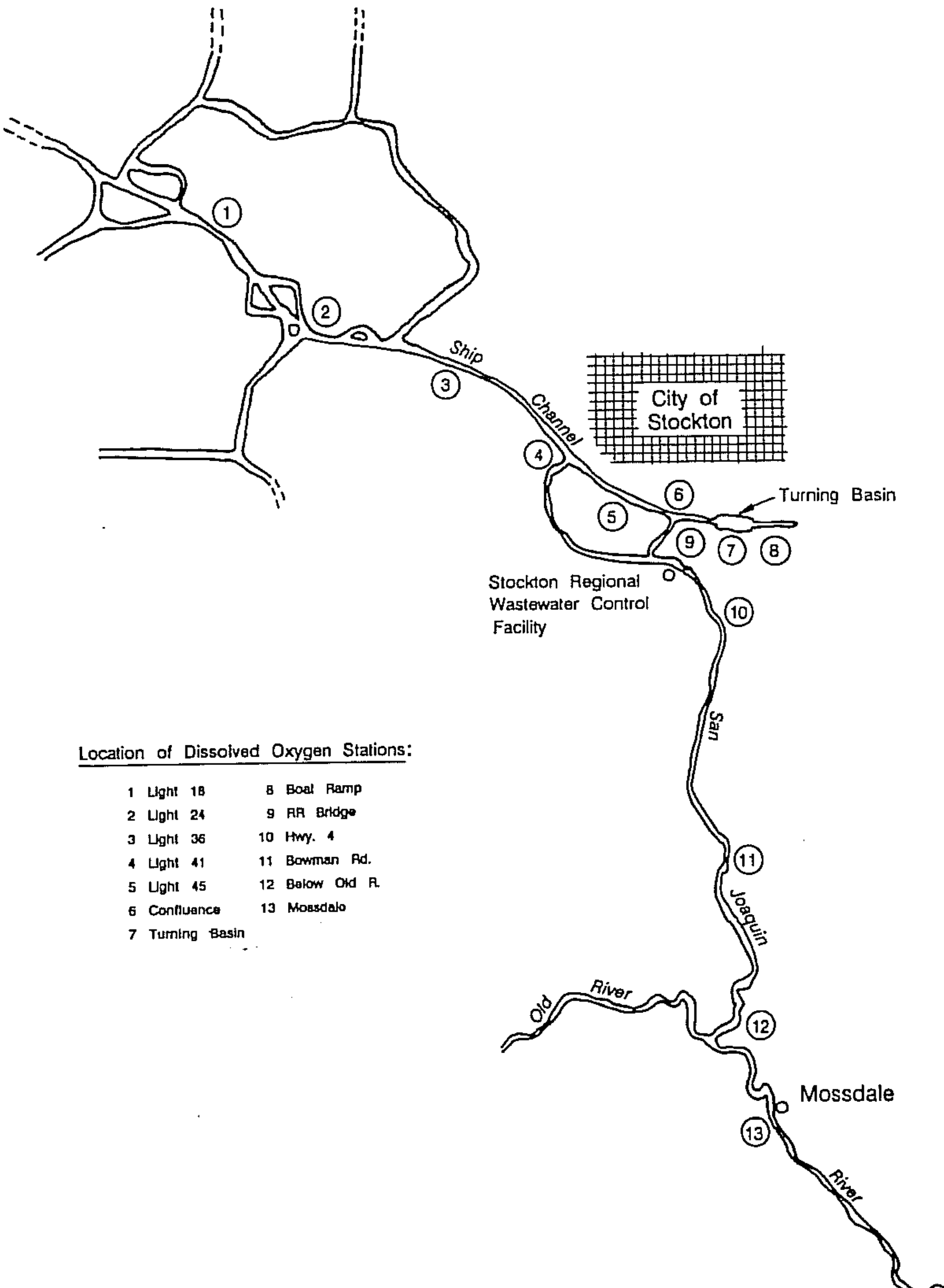
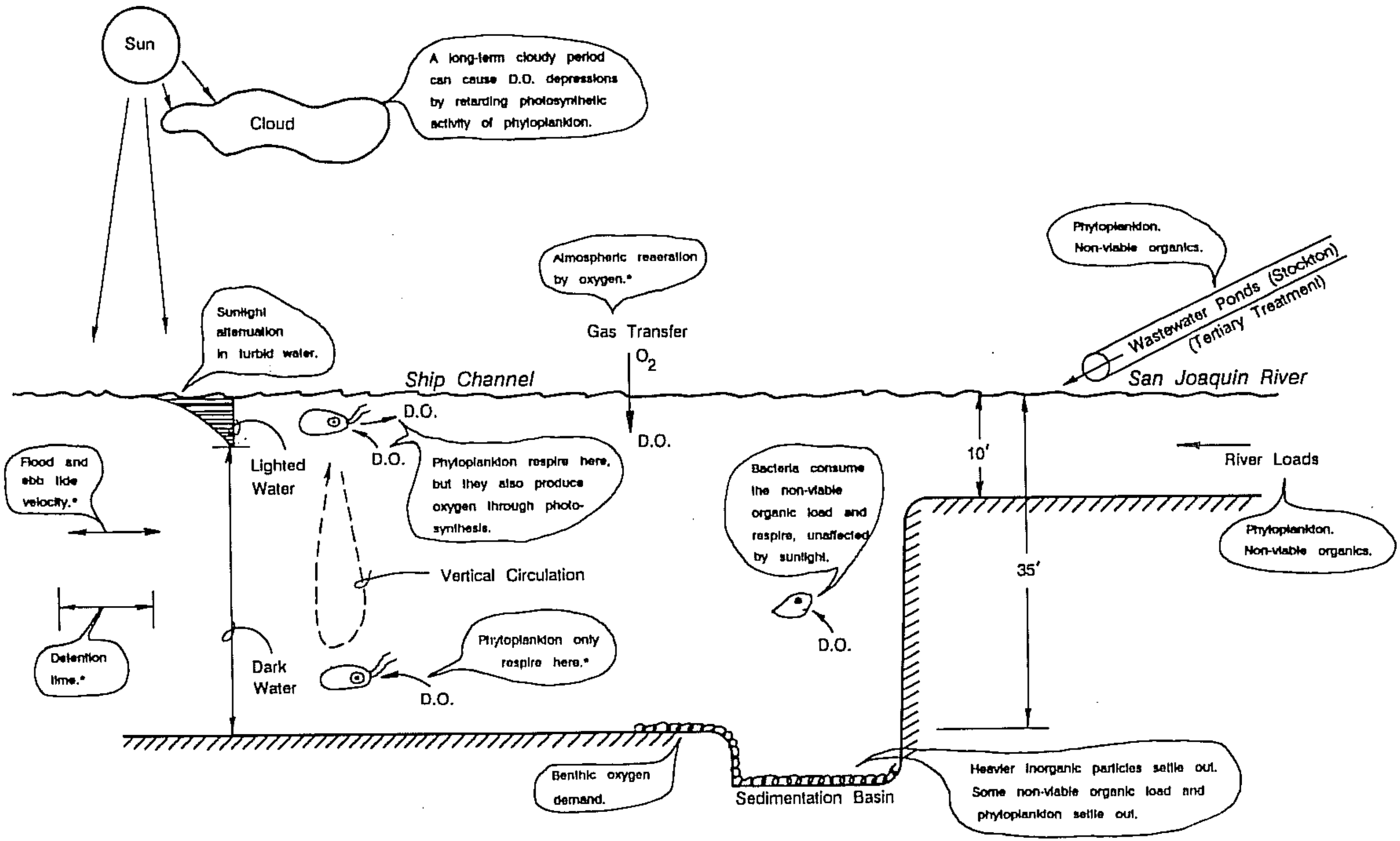


FIGURE 3 CITY OF STOCKTON DISSOLVED OXYGEN SAMPLING STATIONS



* Means affected by project.

FIGURE 4 FACTORS AFFECTING DISSOLVED OXYGEN IN THE SHIP CHANNEL

b. Boundary conditions - The upstream and downstream boundaries must be far enough removed from the Port of Stockton so that inaccuracies in boundary tidal stage conditions or water quality assumptions are not propagated into the port area.

c. Model calibration and verification - A substantial effort would be required in this area, before any project runs were made. Channel soundings were plotted and planimetered to obtain detailed channel cross-section areas. Historic tidal stage data was obtained for many interior Delta sites, for calibration and verification of the tidal hydrodynamic model. Historic water quality data was similarly obtained for inflow and interior Delta sites.

d. Sensitivity analyses - These must be done on selected parameters to see the magnitude of effect they have on the D.O. predictions. For those parameters which have a large effect, additional emphasis should be made to obtain the best data available.

e. Duration of simulations - Water quality simulations should be for about a 3-week period. This is to allow time for the equations to make their predictions so as to move away from any inaccurate assumptions in starting time qualities in each node, and to allow for the long travel time of water quality constituents through the ship channel.

The Corps then retained a consultant, Resources Management Associates of Lafayette, California, to perform the mathematical modeling work. The work was done in two phases. The first phase involved the calibration and verification of the model to the two historic years of 1974 and 1978. These two years represented a year when Old River closure was installed and a year when higher flows made the installation unnecessary. The deepened channel geometry was then superimposed upon the existing channel geometry to determine project effects upon D.O. for these same two years.

The second phase of work was done to check model verification over more years and also to expand the knowledge of project effects over a longer period. In this additional work model verification was done to five more years, and the deepened channel was superimposed upon two more of these additional years. Thus, for the 7 years used in the verification process, 5 years were with the Old River closure installed and 2 years were with it not installed. For the 4 years used in determining project effects, 2 years were with the Old River closure installed and 2 years were with it not installed. For these years, it was also determined how much oxygen would be needed to mitigate for any project effects. The years involved in the total effort are shown in the following tabulation:

Years to which model was verified:	Years to which project effects and the amount of oxygen needed for mitigation were determined:
1972	
1974	1974
1978	1978
1979	1979
1981	
1984	
1985	1985

The mathematical modeling work required the use of two models, one a hydrodynamic model and one a water quality model. The hydrodynamic model is used to determine flowrates, velocities, and tidal stages in the Delta channels, and the water quality model incorporates the flowrates to transport water quality constituents in the channels. As these constituents are transported, the water quality model accounts for the changes that occur to them through biological growths and deaths that may occur, chemical transformations, and other physical, chemical, and biological events occurring.

The hydrodynamic model is a one-dimensional link-node model that represents most of the Delta area upstream of Antioch. The rise and fall of the tide at Antioch, plus the river inflows into the Delta, drive the model. As the historic tide is made to rise at the Antioch node (model input), some of this rising water is made to flow over into the adjacent node through use of a simple hydraulic flow equation, and so on into all nodes. This changes the water elevation in each node. This computation is done every 5 minutes for the entire simulation period. The computed tidal stages are then compared to measured tidal stages at interior Delta locations, to determine how well the predictions are. If the predictions are not satisfactory, then the channel geometries are checked or a coefficient of the hydraulic flow equation is adjusted until satisfactory results are obtained. The above computations are done repetitively every 5 minutes over the entire 25-hour tidal cycle, for all tidal cycles of the simulation period.

The water quality model consists of a series of CFSTR's that represent the nodes of the Delta model. A mass-balance equation for each individual constituent accounts for the changes to it as it flows through each node. Basically, the mass balance equation says that the constituent that flows into a node, plus what grows, decays, or settles in the node, plus what is brought in (or out) by dispersion, is equal to what goes out plus what accumulates in the node if steady-state hydraulic conditions are not occurring. The time period over which the computation is made is 30 minutes. The new concentration of a given constituent is determined in all nodes at the end of the 30 minute period. Then the new concentration of another desired constituent is determined in all nodes for the same time period, and this continues until the new concentrations of all eleven constituents used in the water quality model are accounted for. Then the model advances to the next 30 minute period and the entire procedure repeats. This continues until the entire period desired is simulated.

Efforts were made in the water quality modeling to reduce the adverse effects of numerical dispersion. Numberical dispersion is a term that means that mass (i.e., water quality constituents) is mathematically propelled forward faster than it is carried by the river velocity. This is a result of using the finite difference method for numerical approximation of the mass balance equation or, stated differently, of using a CFSTR to represent a given length of channel. The CFSTR concept assumes instantaneous mixing of constituents as they enter the CFSTR, which in effect propels mass instantaneously from one end of the channel length to the other. This is a necessary evil if one wants to simplify the mass balance differential equation (by removing the delta X term) so as to allow for a solution. There is a way to minimize the effects of numerical dispersion and that is to keep channel lengths short (i.e., CFSTR volumes small), especially in the regions of wastewater inputs. Further away, channel lengths can be increased.

The CFG expressed some concern over the error that might be introduced by numerical dispersion in this modeling study. In an effort to reduce this error, the channel lenghts were shortened in the area between the Stockton RWWCF and Turner Cut. The channel lengths used in this study are as shown in the following tabulation:

Location	Channel lenghts, ft.
San Joaquin River between RWWCF outfall and confluence with Ship Channel	2,500
Turning Basin	3,000
Ship Channel between River Miles 38 and 40	3,500 - 4,000
Ship Channel between Turner Cut and River Mile 38.	5,200

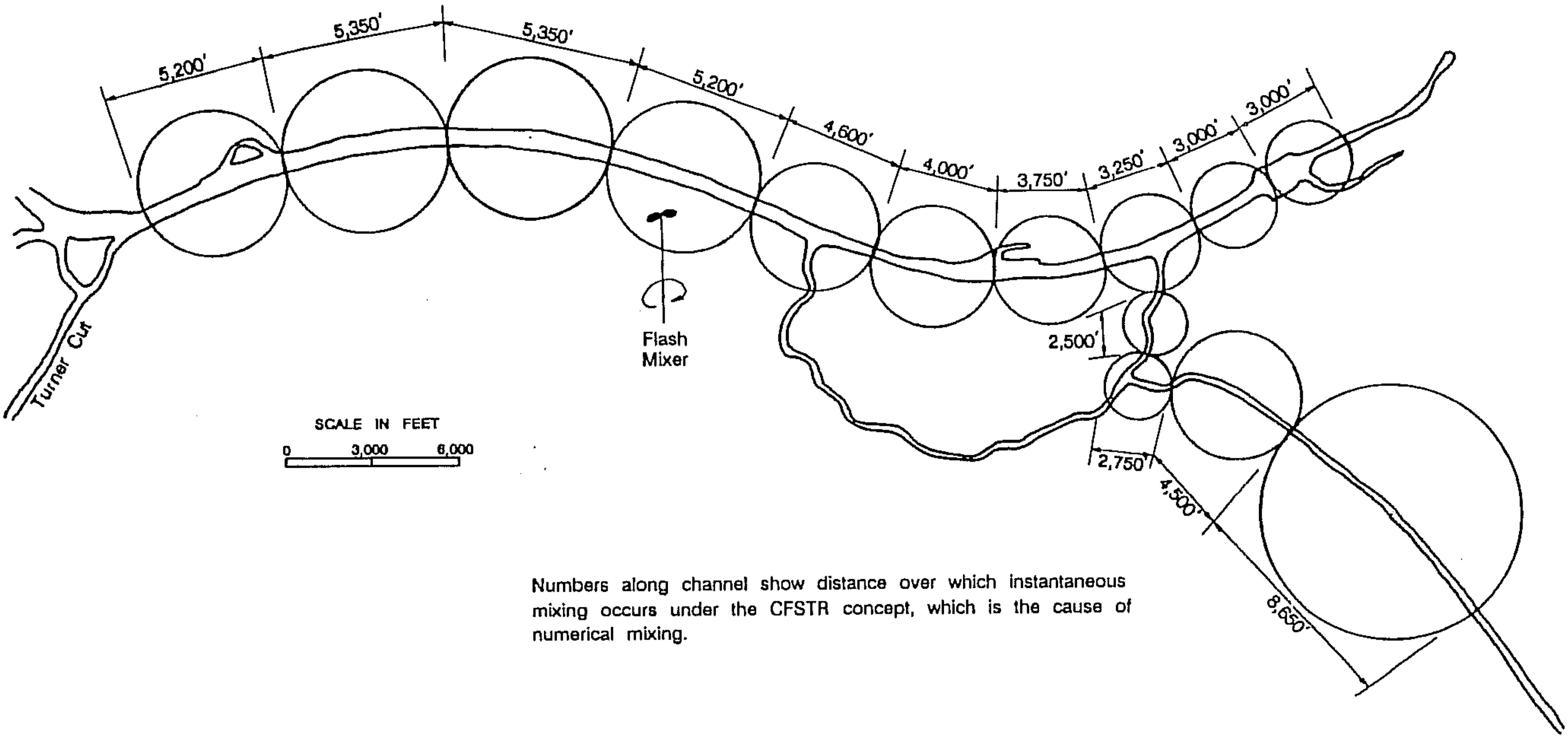
A schematic showing the number of CFSTR's used to represent the ship channel near Stockton is shown in Figure 5A.

The input data to the water quality model is the measured qualities of the river inflow and of the downstream boundary node (as flood tide brings the downstream quality back into our system). The computed water quality is then compared to measured qualities at interior Delta stations obtained from sampling runs. The water quality model has 31 coefficients that account for physical, chemical, and biological changes to constituents, and most of these are not known to a good degree. Thus values are selected from ranges found in the literature, mostly resulting from laboratory work. If computed predictions do not match measured qualities, then an examination must be made of all the items discussed above to see what changes must be made to the model.

The consultant performed sensitivity analyses of several of the parameters used in the water quality model to see which had the most effect and therefore which had to be handled with most scrutiny. The results appear in his phase I report. The parameters used in the sensitivity analysis were as follows:

a. inflow quality
b. depth of sunlight penetration
c. benthic oxygen demand
d. phytoplankton and detritus fluctuations
e. various reaction rate constants

The consultant also looked at how future possible changes to Delta circulation would affect D.O. Such changes would be of interest before any future mitigation efforts for D.O. at Stockton were designed. The changes are shown in the following tabulation:



Numbers along channel show distance over which instantaneous mixing occurs under the CFSTR concept, which is the cause of numerical mixing.

FIGURE 5A SPACING OF CONTINUOUS FLOW STIRRED TANK REACTORS (CFSTR'S) IN THE VICINITY OF STOCKTON.

Scenario Number	Circulation Change
1	Moveable barrier in Sacramento River to force 1000 cubic feet per second (cfs) more through the Delta Cross Channel and into the southern Delta.
2	Installing tide gate in Grant Line Canal and moving State Water Project export intake to the north.
3	Installation of tide gates in Honker Cut, to force more Sacramento River water into Fourteen Mile Slough and thence the San Joaquin River near Stockton.

The Corps obtained the various channel cross-sectional geometries needed for the study. For calibration and verification of the model it was necessary to have the actual geometries as they existed at the time the tidal stages and water quality data was obtained. This data exists as soundings obtained in 1978. For production runs comparing a 30-foot channel to a 35-foot channel, the dredging templates representing these channels were superimposed upon 1982 channel cross-sectional geometries obtained by soundings. The locations where these cross-sections were taken appear in the consultants Phase I report. Each cross-sectional area, at locations approximately one-half mile apart, was plotted and planimetered up to the zero-sounding line. This data, in square-feet, and the cross-section plots, were furnished to the consultant and appear in his Phase I report.

The Corps obtained the tidal stage data from the Department of Water Resources. This data was from many Delta Stations, and either listed the tide heights at 15-minute intervals or else gave the four tide extremes of the day and their corresponding times. The Corps obtained the needed river water quality data from the Environmental Protection Agency's (EPA) STORET system which contained data collected by DWR and USBR, and from the city of Stockton. Data from the Stockton Regional Wastewater Control Facility (RWWCF) effluent was also obtained from the city of Stockton.

From the river water quality and flow data obtained from STORET, the Corps calculated the flow - weighted average concentrations and mass-emission rates of several water quality constituents for the September-October period from 1974-82, less 1977. This was similarly done to the upgraded RWWCF effluent, for the September-October period from 1979-1983. This was done in order to determine the average conditions to expect into the future from these sources of oxygen-demanding and nutrient loads, for use during any Corps mitigation considerations.

The Corps also reviewed past work by other agencies or individuals on the Stockton D.O. problem, and summarizes some of the findings in this report as they relate to channel deepening. This included an analysis of those years and conditions when DWR installed the Old River closure, and the success achieved in this effort.

CHAPTER 4. RESULTS

PAST STUDIES

Several excellent studies were done on the Stockton D.O. problem in the 1960's and early 1970's. Although several things have since changed, such as the upgrading of the Stockton RWWCF, many of the findings of those studies are still applicable and of significance to the Corps project today. Some of the items are presented below because they are related to the coefficients or assumptions used in the modeling effort. Other items are presented because they will be used to gain perspective of the effect caused by the Corps project.

<u>Phytoplankton</u> - The phytoplankton growing in the river are mostly centric diatoms, of genus Cyclotella and Coscinodiscus (Bain et al). The phytoplankton which grew in the wastewater oxidation ponds prior to the 1978 upgrading were mostly greens of genus Scenedesmus (McCarty).

<u>Oxygen demand</u> - McCarty stated that the D.O. deficit at Stockton is primarily from the decomposition of phytoplankton contributed by the river and the wastewater oxidation ponds. A substantial amount of oxygen-demand load is carried into the ship channel. Brown and Caldwell (1970) report that the oxygen demand load carried by the river upstream of the treatment plant is a function of inflow and has varied from 12,800 to 65,000 lbs/day. Jones and Stokes estimated that, prior to treatment plant upgrading, the wastewater effluent had an oxygen demand of 51,000 lb/day. They estimated that, after the plant upgrading, the oxygen demands for years 1980, 1990, and 2000 would be 8,700, 9,500, and 10,300 lbs/day, respectively. McCarty found that the wastewater effluent load decayed in the river at a faster rate than the organic load carried by the river, and thus consumed D.O. faster. Brown and Caldwell reported that in 1970 the urban runoff from the City of Stockton had an oxygen demand of 2,500 lbs/day, and the combined Lincoln Village/Northwest sewage treatment plants discharging into Disappointment Slough had an oxygen demand of 3,000 lbs/day. These plants no longer discharge.

The EPA gives some different figures for the above oxygen-demanding loads. They state that oxygen-demanding load in the ship channel (this is prior to plant upgrading) is 163,000 lbs/day, of which 75% (or 122,000 lbs/day) comes from the wastewater oxidation pond discharge and 25% (or 41,000 lbs/day) comes from the river. Of this pond discharge, one-half, or 61,000 lbs/day, is oxygen-demand due to nitrification.

<u>Sunlight penetration</u> - Bain et al report that in the river from Mossdale to Stockton, the Secchi depth measurements are about 1 foot or less during the summer and fall. He also reports that further downstream in the ship channel the Secchi depth ranges from 1 to 3 feet. The EPA, in a study conducted in September and October 1970, found that the depth to 1% light was 1 meter in the ship channel near Burns Cutoff and 1.5 meters near Light 40. The EPA further states that photosynthetically-effective light is confined to the upper 2 meters in both shallow and deep portions of the San Joaquin River from Mossdale to Antioch.

Vertical mixing - McCarty states that the river above the ship channel has sufficient velocity so that phytoplankton and other particulate matter remain suspended. Vertical mixing decreases in intensity as the river enters the ship channel. Heavier particles transported by the river are thus able to settle in the sedimentation basin constructed at this confluence. However, sufficient vertical mixing does occur in the ship channel to keep phytoplankton suspended. The EPA reports that an extensive series of chlorophyll samples collected in 1967 at Light 40 near the surface, at mid-depth, and near the bottom did not show any consistent pattern of graduation. The EPA states that even in the deep channel phytoplankton populations are fairly well mixed. They state that turbulence, presumably as a result of tidal activity, appears to be sufficient to keep phytoplankton distributed throughout the water column in both shallow and deep water.

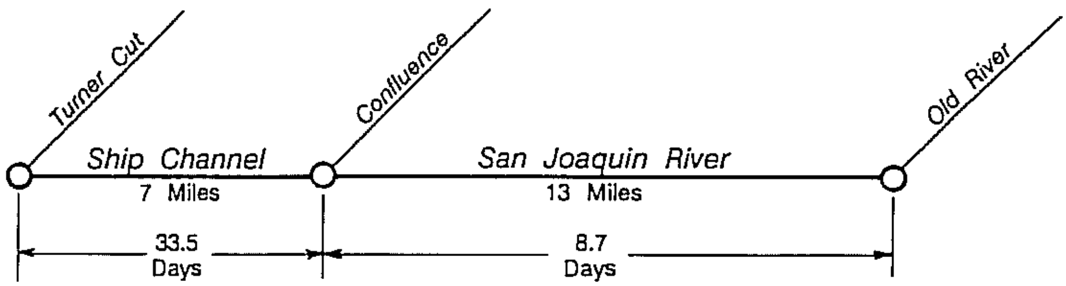
Benthic oxygen demand - Bain et al reported that extensive organic deposits were found in the Turning Basin and sedimentation basin. McCarty reported that the organic particulate matter which settles in the Stockton ship channel can only be a minor contributor to the D.O. deficits which occur. He also reported that the oxygen-demand of this settled organic load proceeds at a slower rate than if the load remained suspended. The CFG (unpublished data, as stated by the EPA, 1971) used a benthic respirometer in situ in 1967 to measure oxygen demand associated with the bottom of the ship channel. Their results indicated a demand of 1 gm/m^2/day. A similar measurement by the EPA in mid-channel below the sedimentation basin failed to indicate a significant demand.

Detention time - The DWR (1964) did dye studies to determine travel times in the river and ship channel. In an analysis of this study for a 200 CFS net downstream flow, Bain et al determined that it took 8.7 days for water in the San Joaquin River to travel the 13 miles from Old River to the confluence with the ship channel, and 33.5 days for this water to travel the 7 miles in the ship channel from the confluence to Turner Cut (Figure 5B).

Self-purification capacity - Brown and Caldwell determined that the reach of ship channel between the Turning Basin and Turner Cut (for the 30-foot deep channel) has a natural purification capacity of 50,000 lbs/day of oxygen demand without causing D.O. concentrations to drop below 5 mg/L.

Old River closure - The effects of the Old River closure on D.O. are determined by a monitoring program conducted by DWR. The results are in the form of longitudinal D.O. profiles for pre- and post-closure periods. These profiles are available from the DWR Central District.

Many of the findings discussed above are presented schematically in Figure 6, and represent very important knowledge or assumptions used in this study.



(From Bain et al, for 200 cfs net downstream flow)

FIGURE 5B COMPARISON OF HYDRAULIC RESIDENCE TIMES IN RIVER VS SHIP CHANNEL

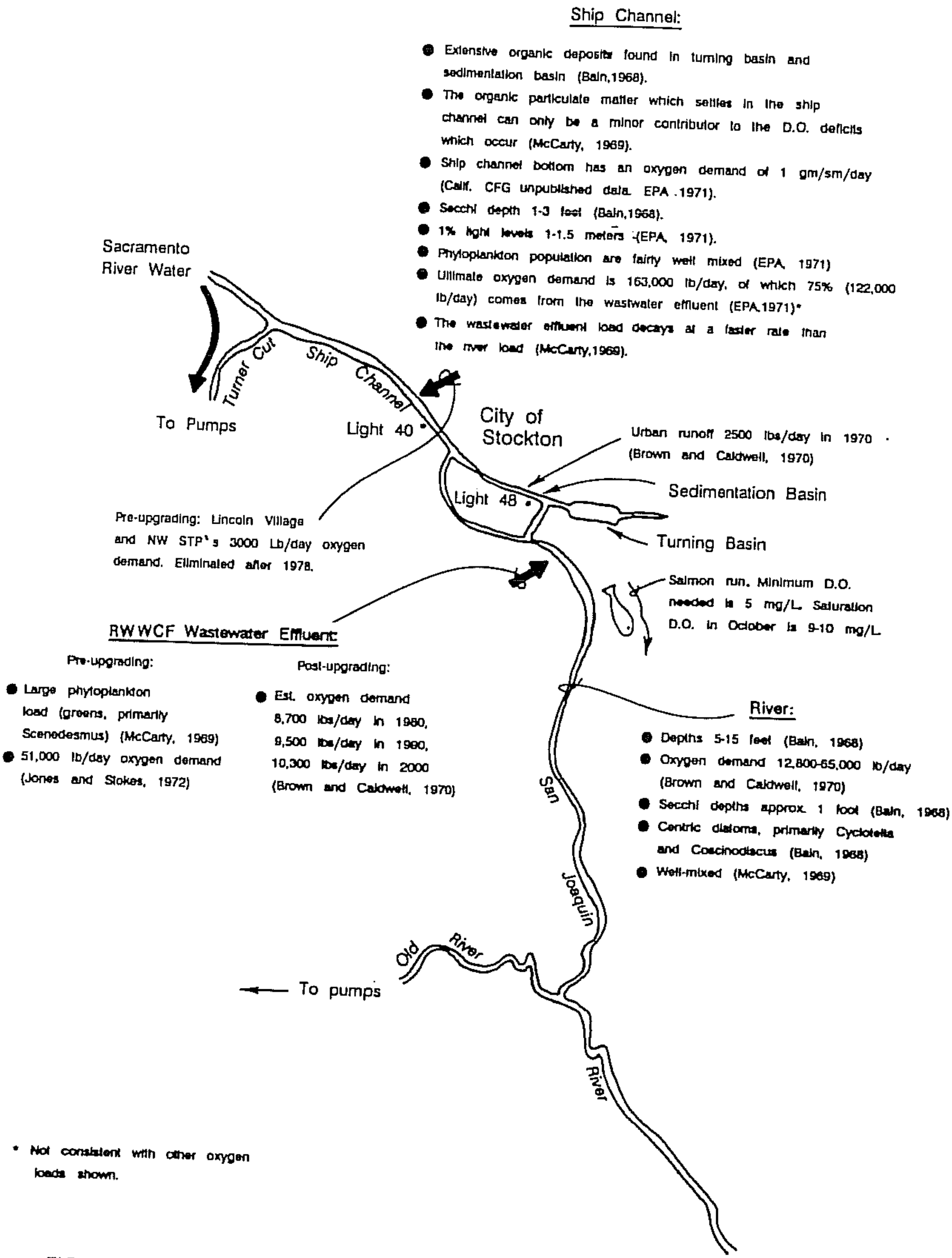


FIGURE 6 SALIENT FINDINGS OF OTHERS RELATED TO CHANNEL DEEPENING AND THE MODELING EFFORT

CORPS EFFORTS

In planimetering the 1982 channel cross-section areas below the zero-sounding line with first the 30-foot dredging template superimposed and then the 35-foot template superimposed, it was found that the project will cause an average increase in cross-sectional area of 11.5%. The percent change for each cross-section is shown in Table 1.

The flow-weighted concentration and mass-emission rate results previously described for the river and the Stockton RWWCF appear in Figures 7 and 8. The percent loss in photosynthetic oxygen production over the daytime period in that width of the channel that has been deepened from 30 to 35 feet is 14%. This is shown in Figure 9. The Corps also reviewed the results of installing the Old River closure, and these are summarized in Table 2.

CONSULTANTS MODELING EFFORTS

The consultant efforts are presented in two reports, entitled "Effects of the Stockton Ship Channel Deepening on Dissolved Oxygen near the Port of Stockton, California", Phase I and Phase II. Copies of these reports are available from the Corp's Hydrology Section.

Verification work on the hydrodynamic model was less extensive than on the water quality model, being done for two different years (1974 and 1978). Verification consisted of comparing predicted tidal stages to measured tidal stages at various interior Delta Stations. Plots of these comparisons are shown in the Phase I report. Comparisons of channel velocity or flowrates are difficult to do because of tidal action, and therefore comparisons are made to stages. These comparisons of tide heights and the times of their occurrences showed that the hydrodynamic model adequately predicted hydraulic conditions. In his work the consultant utilized the actual Clifton Court Forebay operation for water export from the Delta, and accounted for the occasional blockage of Old River in the fall to force more of the San Joaquin River water past Stockton.

Verification work on the water quality model showed that under some conditions the model adequately reproduced measured D.O. concentrations, and at other times it did not. Plots of these comparisons are shown in both the Phase I and II report. The consultant feels that during those times that the net flow past Stockton approaches zero is the condition where verification is not achieved. Unaccounted for local waste loads (i.e. urban runoff) may be one cause of this. In order to strengthen the model in this area, the consultant recommends the following two efforts:

(1) Measure the oxygen-demanding load of local inflows from the city and marina area; and

Table 1. Project changes to Ship Channel cross-section areas.

RIVER MILE	1982 SOUNDINGS TRUNCATED TO 30-FOOT DEPTH SQ. FT. 1,2/	1982 SOUNDINGS TRUNCATED TO 35-FOOT DREDGE SQ. FT. 1,2/	PROJECT INCREASE IN CROSS-SECTION AREA, %
25.5	13,689	14,898	8.8
26.4	23,330	14,555	9.2
27.4	19,482	20,707	6.3
28.5	24,139	25,314	4.9
29.6	11,644	12,819	10.1
30.3	16,580	17,755	7.9
31.6	13,506	14,731	9.1
32.21	11,942	13,127	9.9
32.50	14,124	15,849	12.2
32.97	13,536	14,867	9.8
33.39	13,995	15,391	9.8
33.73	13,301	15,317	15.2
34.03	11,545	13,356	15.7
34.35	12,599	15,098	19.8
34.65	12,713	14,706	15.7
35.03	11,076	12,496	12.8
35.40	12,653	13,799	9.1
35.71	10,600	11,772	11.1
36.02	10,060	11,222	11.6
36.32	9,301	10,915	17.4
36.70	12,482	13,741	10.1
37.00	11,775	12,638	7.3
37.38	11,097	12,565	13.2
37.67	13,364	14,658	9.7
37.98	14,246	15,430	8.3
38.44	14,393	15,741	9.4
38.66	12,452	14,086	13.3
39.04	12,507	13,785	10.2
39.34	12,440 3/	14,090 4/	13.3
39.57	12,260 3/	14,160 4/	15.5
39.87	11,503	13,438	16.8
40.02	11,813	13,549	14.7
40.25	11,636	13,569	16.6
40.48	11,859	13,744	15.9
40.63	32,673	36,987	13.2
40.85	16,291	16,291	0
			11.5% average

1/ Below zero sounding line, which is 2.5 feet above COE datum at Golden Gate (1.1 feet below mean sea level).
2/ Average of double planimetered areas.
3/ Settling Basin depth was authorized at 35-foot depth.
4/ Settling Basin depth is now authorized to 40-foot depth.

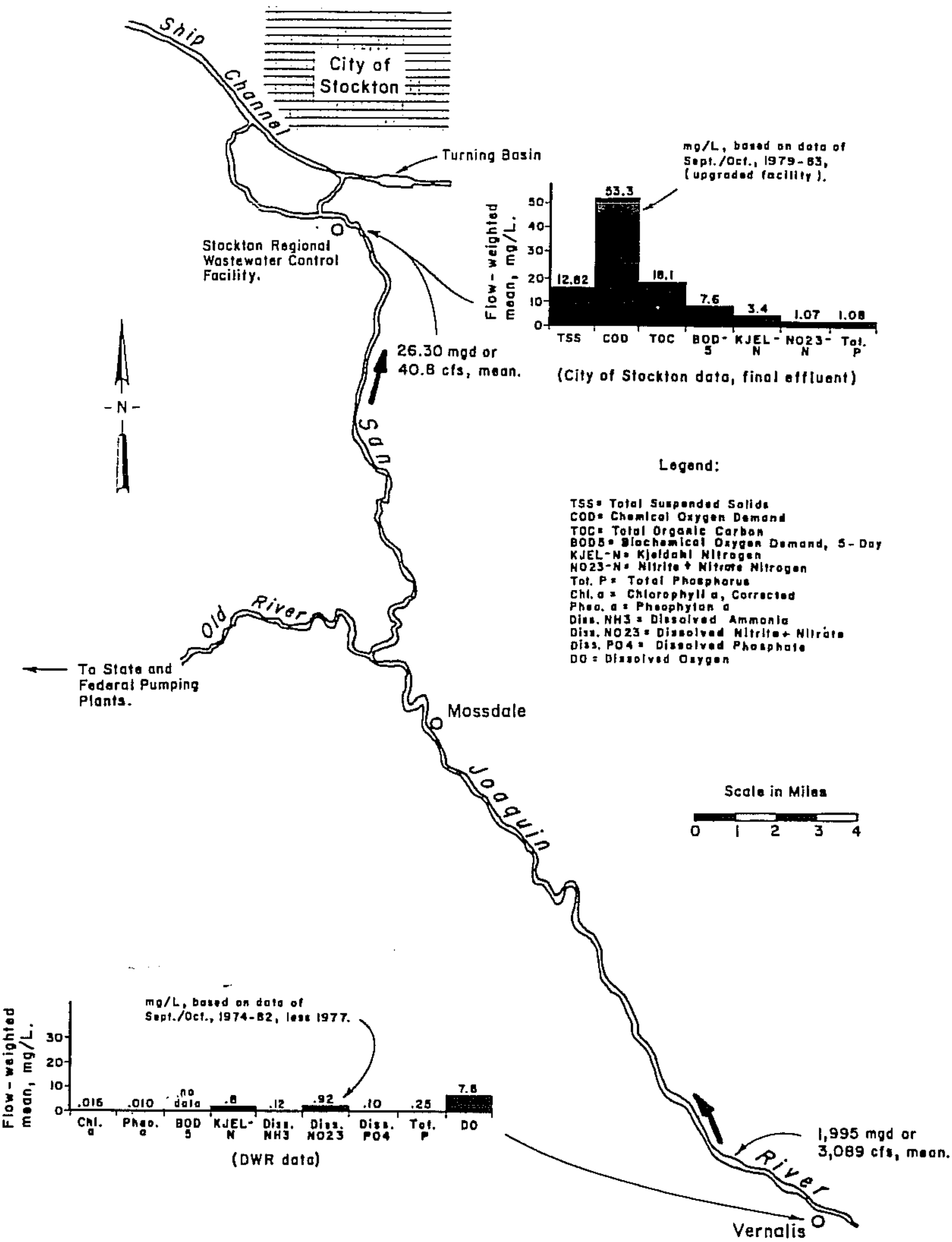


FIGURE: 7 FLOW-WEIGHTED MEAN CONCENTRATIONS, SEPT.-OCT. CONDITIONS.

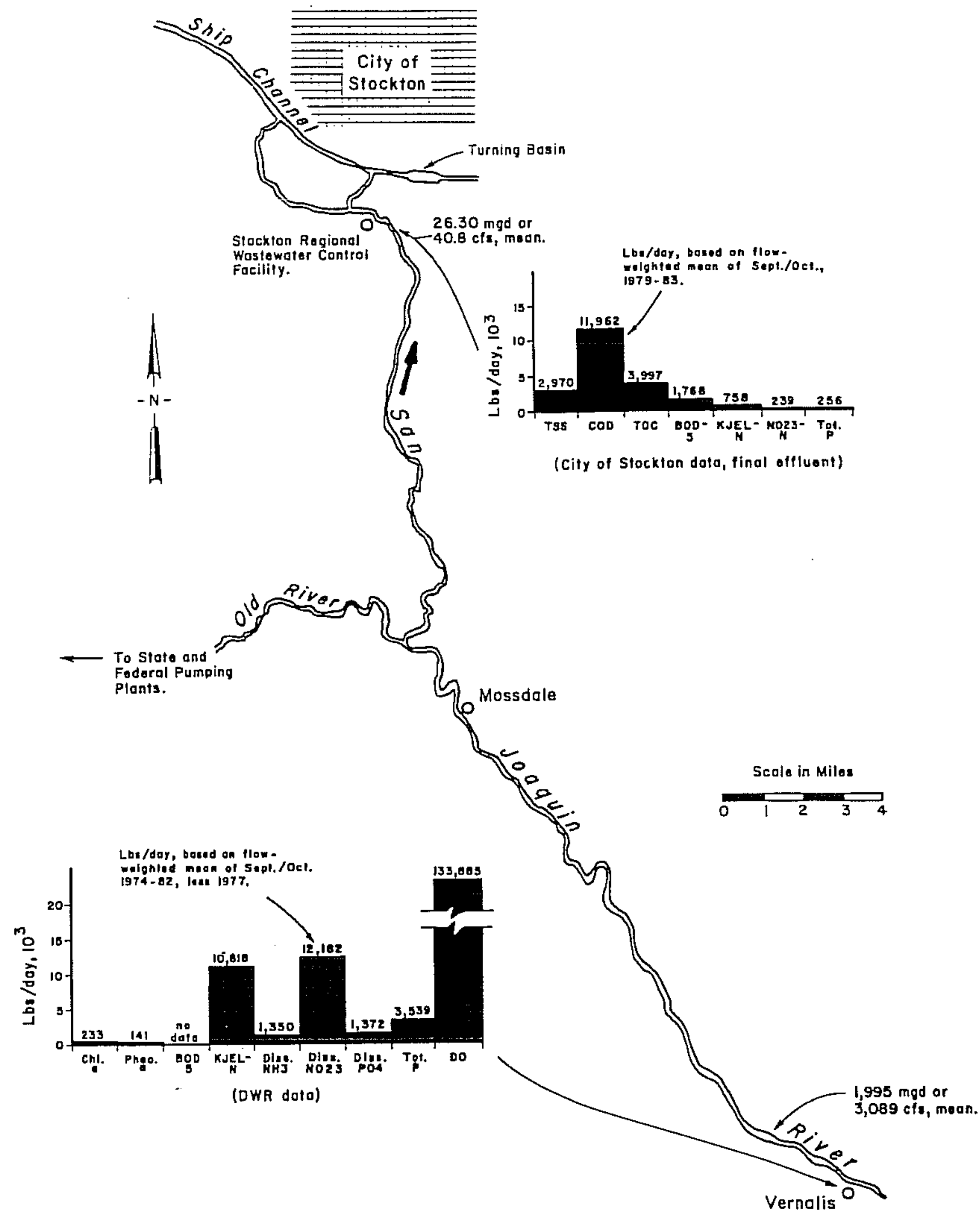


FIGURE: 8 MASS-EMISSION RATES, SEPT.-OCT. CONDITIONS.

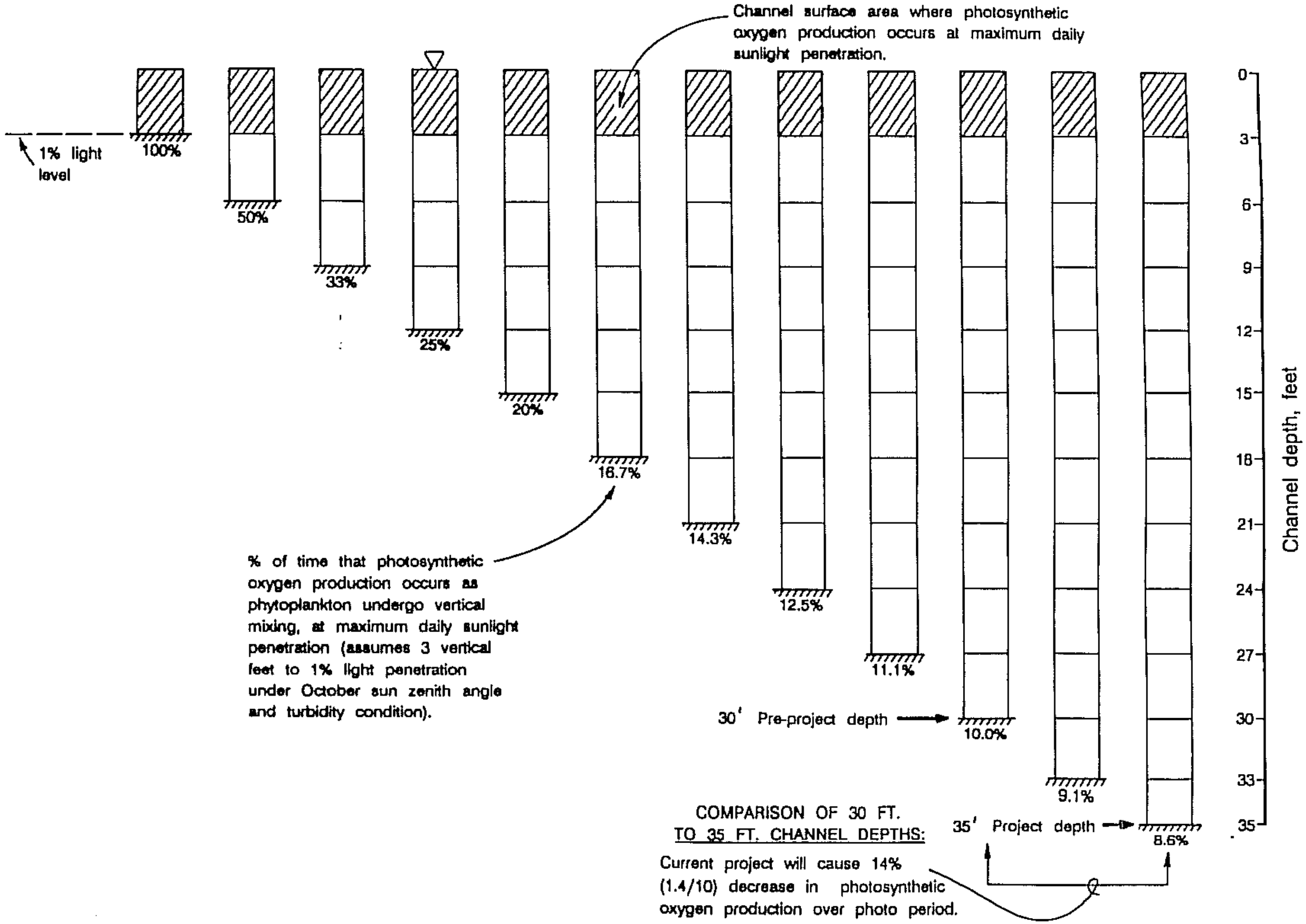
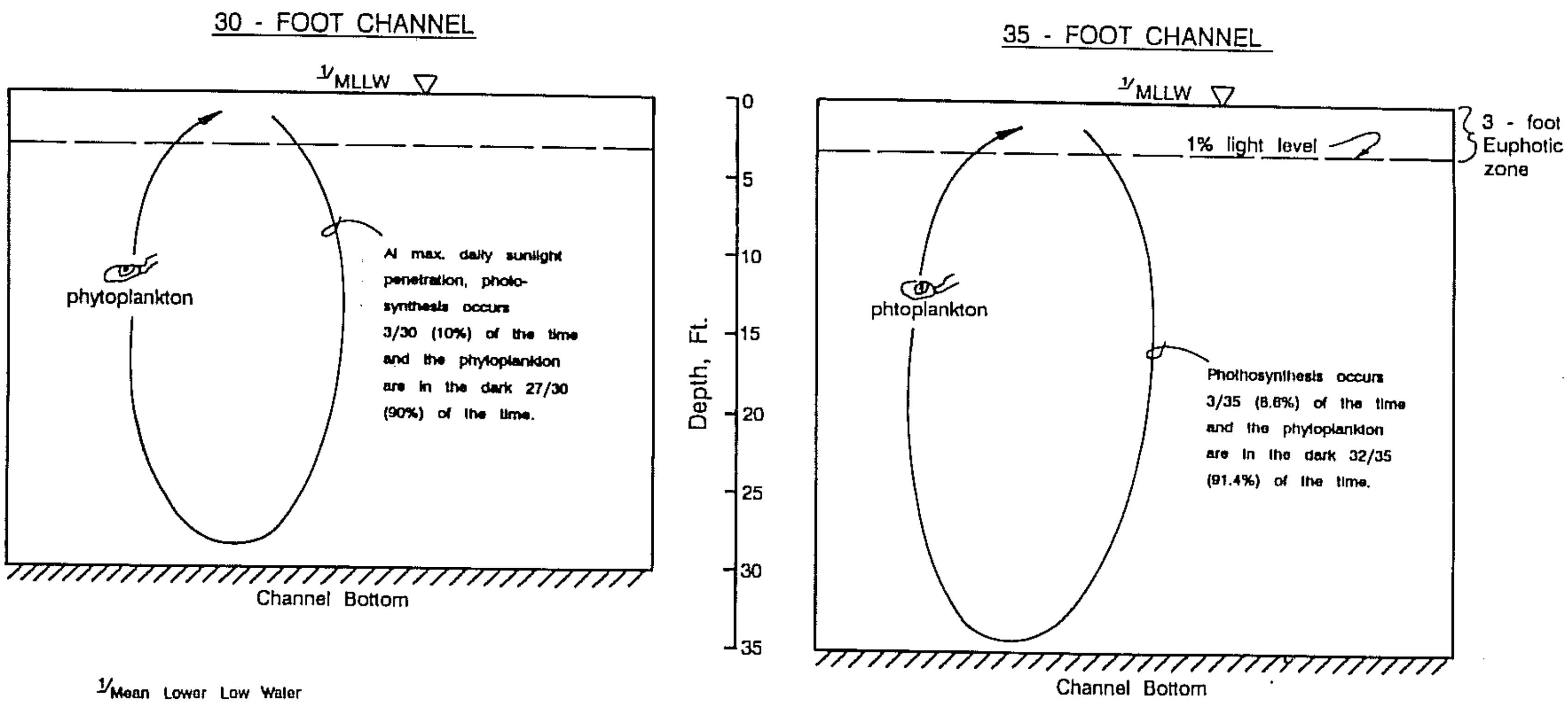


FIGURE 9 HOW PROJECT DEEPENING AFFECTS PHOTOPLANKTON PHOTOSYNTHETIC OXYGEN PRODUCTION.



1/Mean Lower Low Water

Conditions shown occur at maximum daily sunlight penetration, and project effects are only in that portion of the channel cross - section that has been deepened by 5 - feet.

Photosynthetic oxgen production is reduced by 14% (1.4 ÷ 10) over the photo period while phytoplankton respiration remains the same.

FIGURE 9 CONTINUED

TABLE 2. DATES OF OLD RIVER CLOSURE AND SUMMARY OF ITS EFFECTS

Year	Date Installed	Date Removed	Impacts of Closure on D.O. Levels	Remarks
1968	4 Oct	17 Nov		
1969	-	-		
1970	6 Oct	14 Nov		
1971	30 Sept	12 Nov	Dramatic increase	
1972	29 Sept	10 Nov	Increase	Flow augmented by USBR releases from Delta Mendota Canal through the Newman Wasteway.
1973	5 Oct	15 Nov	Gradual increase	*Higher than anticipated flows. Problem with placement of rock on closure. Caused an opening in structure; thus, closure not as effective as planned.
1974	18 Sept	9 Nov	Dramatic increase	Higher than anticipated flows. D.O. levels appeared to vary directly with flow. Reduced number of salmon spawners.
1975	26 Sept	4 Nov	Dramatic increase	Higher than anticipated flows. Reduced number of salmon spawners.
1976	1 Nov	23 Nov	Dramatic increase initially but deterioration with period of fog and overcast.	Access permits initially denied by local agencies. Reduced number of salmon spawners.
1977	27 Oct	5 Dec	Some increase but considerable variability. Desired level could not be maintained.	Access permits initially denied by local agencies. Paradise Cut rock barrier in place on San Joaquin River (drought emergency measure). Low salmon run. Salmon trapped and trucked upstream.
1978	-	-		Flows increased by releasing water upstream and curtailing Federal and State pumping. Steep drop off of D.O. near the turning basin.
1979	1 Oct	29 Nov		
1980	-	-	Above recommended minimum of 5 mg/L	High flows. Cool water temperature.
1981	15 Oct	25 Nov	Increase except for Nov 17-21	Algal bloom in turning basin. Suppression in D.O. in Nov due to precipitation and fog and cloud cover.
1982	-	-		
1983	-	-		
1984	8 Sept	19 Oct		Erosion of right levee embankment adjacent to barrier caused early removal of barrier.
1985	-	-		
1986	-	-		
1987	-	-		

*Higher than anticipated flows seemed to be caused by unanticipated climatic conditions and upstream operations.

(2) Measure currents over a tidal cycle (presumably near the zero net-flow condition) in the port area.* A summary chart of the consultant's verification efforts for the seven years studied appears in Table 3.

The effects of the deepened channel were determined for four years, and showed that the maximum effect of the project was to decrease the D.O. concentrations by 0.2 mg/L, under flow conditions past Stockton ranging from low to high. For mitigation, the higher flowrate will require more oxygen input. The consultant found that the oxygen needed for mitigation ranged from 625 lbs/day under near zero net flow past Stockton to approximately 2500 lbs/day when net flow past Stockton approaches 2000 cfs. A summary of these project effects appears in Table 3.

The consultant was also asked to select a possible future scenario of changes to Delta circulation by the agencies that transport water across the Delta. This was because the Corps is interested in determining if changes by others might alter the D.O. concentrations at Stockton so as to change the scope of any mitigative effort needed. The consultant chose three scenarios to investigate.

The first change to Delta circulation involved a Sacramento River barrier to force 1000 cfs more through the Delta Cross-Channel and into the southern Delta. This had no effect upon D.O. at Stockton, for the historical condition studied of 1985.

The second change involved installation of a barrier in Grant Line Canal and moving the intake of the State pumps to the north in Old River. This had a negative effect upon D.O. at Stockton for the historical conditions studied of 1985, lowering it by 0.8 mg/L and pushing the point of maximum deficit three and one-half miles further downstream.

The third change involved installing tide gates near Honker Cut, to force more of the Sacramento River water that is drawn south to go into 14-mile Slough and then into the San Joaquin River. This had a positive effect in that if raised the minimum D.O. concentration at Stockton by 0.8 mg/L for the historical condition study of 1979.

The consultant performed sensitivity analyses upon six of the parameters that affect D.O. This was done because some of the knowledge on items affecting D.O. is less then exact, and it is desired to know by what relative magnitude each is affecting results. The information on this effort appears in the consultants Phase I report.

* Items (1) and (2) above should only be done if we are trying to improve the predictive accuracy of the model. At this point in time we are not. We only used the model to compare alternatives, not for absolute predictions.

Table 3. Summary of Modeling Results.

Year	Old River Closure in?	Conditions Occurring	Verification: River Mile of maximum Deficit (1)		Verification: Minimum dissolved oxygen conc. mg/L (1)		Results of water quality model verification	Project Effects: Project decrease to D.O. conc. mg/L	Project Effects: Oxygen needed for mitigation lbs/day
			Actual	Predicted	Actual	Predicted			
1972	Y	(a) -10 to 300 cfs (b) 1300 cfs	39/35	39/34	2.2/2.6	2.0/3.2	OK		
1974	Y	(a) 300 cfs (b) 1500 to 2000 cfs	37/30	34/32	2.0/4.5	3.2/3.3	Fair. Magnitude of sag not well produced, but location of maximum deficit was well-predicted.	0.5 (2)	3,400 (2)
1978	N	Stockton flow 700 to 800 cfs, except 4 days 1900 cfs.	35	36	4.0	3.8	OK	0.5 (2)	3,400 (2)
1979	Y	(b) 1300 to 2300 cfs	36	32	5.2	5.2	OK	0.2 (3)	2,500 (3)
1981	Y	(a) -100 to 200 cfs (b) 700 to 1100 cfs	39/30	39/36	4.7/7.0	4.5/5.0	Not good. After closure was put in, predicted D.O. was less than historic by about 2 mg/L, maximum.		
1984	Y	(a) 400 to 500 cfs (b) 1600 to 2200 cfs	36/32	37/30	4.9/4.4	4.7/5.3	OK, except toward end of verification period, as model input quality was not constant.		
1985	N	Stockton flow -60 to 170 cfs.	36	39	5.1	6.0	Not good in downstream areas. Predicted D.O. too high. Possibly an urban runoff input that shows up during stagnant flow conditions	0.2 (3)	625 (3)

(1) Pre-closure / Post-closure.
(2) Historic RWWCF effluent quality used.
(3) Upgraded RWWCF effluent quality used.

(a) Pre-closure flows at Stockton
(b) Post-closure flows at Stockton

CHAPTER 5. DISCUSSION & INTERPRETATION OF RESULTS

PAST STUDIES

The findings of others that diatoms dominate the river upstream of the RWWCF and that greens dominated the RWWCF effluent led to their use in the mathematical model as ALGAE1 and ALGAE2 (as defined in the Consultant's report). That is, the rate coefficients regarding growth, death, and settling selected from the literature were selected for these types of phytoplankton.

Sufficient river inflow data for chlorophyll a was not available in the September-October period of concern to give a good portrayal of phytoplankton loads carried. Several state and federal agencies have an excellent Delta-wide monitoring program underway, but the intensive chlorophyll data needed for this time period in the reach from Mossdale to Turner Cut was not available.

The information on Secchi disk depth in the river of from 1 to 3 feet led to the modeling use of 3 feet for the depth to 1% light. Several authors suggested that benthic oxygen demand of the settled organic detritus would be less than 1 $gm/m^2/day$. This led to sensitivity analyses with the model with benthic oxygen demands ranging from 0 to 1 $gm/m^2/day$.

There appears to be a considerable difference, depending on inflow rate, on the amount of ultimate oxygen demand in the river as it enters the Delta. The amount ranges from a low of 12,800 lbs/day to a high of 65,000 lbs/day. The current amount expected from the RWWCF is about 10,000 lbs/day. Thus, the total oxygen-demanding load available to the ship channel today ranges from about 23,000 lbs/day to 75,000 lbs/day. Compared to these values, the Corps project will have an effect of 625 lbs/day to 2,500 lbs/day. The Corps project does not actually input any oxygen demand into the river. What it does is increase the depth of dark water to cause more phytoplankton respiration to occur over a given distance. It allow more of the non-viable oxygen demand load to be exerted over a shorter length of the ship channel, because of the increased detention time, thereby adding to the maximum oxygen deficit that will occur. It also decreases the atmospheric aeration that will occur, because of the decrease in flood and ebb channel velocities.

If one compares the above maximum oxygen-demanding load today of 75,000 lbs/day available to the ship channel to the Brown and Caldwell estimate of a natural assimilation capacity of 50,000 lbs/day between the Turning Basin and Turner Cut if D.O. is to stay above 5 mg/L, one can see that the potential still exists for D.O. concentrations below 5 mg/L if all of this load is exerted upstream of Turner Cut. Since the pre-1978 maximum oxygen demanding load was 115,000 lbs/day, one can see that at that time there was much more potential to exceed the natural assimilative capacity available.

One early testing result by others that the phytoplankton undergo vertical circulation in the ship channel played an important part in the modeling effort. This allowed the use of one-dimensional modeling to represent the channels. That is, the channels are considered to be vertically and laterally mixed, and the only quality changes occur in the longitudinal direction. Actually, the vertical mixing which occurs is rather weak. Dissolved oxygen data collected in the vertical direction at some sites does show concentrations higher near the surface than near channel bottom. However, there is no evidence of thermal stratification.

CORPS EFFORTS

Change in cross-sectional area and depth.

While deepening the ship channel depth from 30 feet below MLLW to 35 feet below MLLW is a 17% increase in depth over the width of the deepened portion of the channel, it is not the average increase over the width of the entire channel. As stated earlier, planimetering of all pre-project and project cross-section areas showed an average increase in area of 11.5%. Mean depth is the cross-section area divided by the top width of the channel, and since the project does not affect top width the increase in mean depth becomes 11.5% also. This is an important point in this study since the portion of time that phytoplankton photosynthetic oxygen production occurs and the ability of atmospheric reaeration to occur are dependent on channel depth. Thus, the increase in mean depth of the channel is 5 feet x (11.5/17.0) = 3.4 feet, and the project effects upon photosynthetic oxygen production and reaeration will be less than that shown in the figures for 5 feet. Mean channel depth rather than 5 feet was used in the mathematical modeling effort, and so the D.O. predictions are valid for the average channel depth of each node.

Using the above numbers, one sees that the channel velocity for the pre-project channel at any given time of the tidal cycle is $V = Q/A$, and for the project channel is $V = Q/1.115A = 0.89Q/A$. Using this velocity and the deepest depth increase of 5 feet produces a 26% reduction in reaeration capability for the deepest part of the channel, as shown in Figure 10. For the total width of the channel the decrease in reaeration would be less, because the mean depth increase is only 3.4 feet.

Mass emission rates.

The flow-weighted concentrations and mass-emission rates of constituents in the San Joaquin River at Vernalis and in the Stockton RWWCF effluent in recents years was presented in case future mitigative efforts move the Corps to consider these conditions. A discussion of this data as it may affect present-day D.O. in the ship channel follows.

a. San Joaquin River at Vernalis.

(1) <u>Dissolved oxygen</u> - At 7.8 mg/L, the river is not fully saturated with D.O. but experiences a deficit of about 2 mg/L for the water temperature present. Still, a mass of 133,885 lbs/day of D.O. is in the river at this point.

(2) Phytoplankton biomass - Phytoplankton biomass is determined from chloropyll a data, after the pheophyton a correction. Pheophytin a, a common degradation product of chlorophyll a, can interfere with the determination of chlorophyll a because it absorbs light and floresces in the same region of the spectrum as chlorophyll a. The ratio of chlorophyll a to pheophytin a serves as a good indicator of the physiological condition of phytoplankton. Comparisons of this ratio between Vernalis and Buckley Cove show that there is little change in physiological condition between these locations. The American Public Health Association (1985) states that chlorophyll a is about 1.5% of the dry weight of phytoplankton biomass. Thus, the chlorophyll a mass of 233 lbs/day corresponds to a dry weight phytoplankton mass of 15,611 lbs/day in the river at this point. It is this phytoplankton mass, plus that which grows in the river between Vernalis and Stockton, that respires in the darkened waters of the ship channel.

(3) Nitrogenous oxygen demand - Kjeldahl nitrogen consists of organic nitrogen plus ammonia nitrogen. The data shows this amount to be 10,816 lbs/day. Kjeldahl nitrogen serves as an energy source to nitrifying bacteria, which oxidize it to nitrate. This is an oxygen demand. The stoichiometry involved shows that 4.57 lbs. of oxygen are utilized for each pound of Kjeldahl nitrogen oxidized to nitrate. Thus, this amounts to an oxygen demand of 49,400 lbs/day in the river at this point, which is a sizeable demand. This Kjeldahl nitrogen load, besides having the oxygen demand shown above, goes on to stimulate further phytoplankton growth.

(4) Total dissolved nitrogen - There is 10,818 lbs/day of Kjeldahl nitrogen in the river smaple after filtration, and 2,801 lbs/day of dissolved nitrate-nitrogen (0.23 x 12,182 lbs/day), making a total dissolved nitrogen load of 13,619 lbs/day. Thus, there is sufficient nitrogen to stimulate the subsequent phytoplankton crop that occurs downstream. If one assumes that nitrogen represents 10% of pytoplankton biomass, this is sufficient nitrogen to support a maximum phytoplankton crop of 136,190 lbs/day. (Actually, less crop than this will grow, because as the nitrogen is diluted through phytoplankton growth it becomes more difficult to be gained by the phytoplankton cell. Also, self-shading by the phytoplantkon crop may limit growth. Nitrogen fixation is not expected from the type of phytoplankton present.)

(5) Total dissolved phosphorus - There is 548 lbs/day of dissolved orthophosphate-phosphorus (0.40 x 1,372 lbs/day) in the river sample after filtration. Since total phosphorus load is 3,539 lbs/day, it appears that most of the phosphorus is present already bound to participate organic matter. If one assumes that phosphorus represents 1% of phytoplankton biomass, this is sufficient phosphorus to support a maximum phytoplankton crop of 54,800 lbs/day. This indicate that phosphorus may be the limiting nutrient for stimulating further phytoplankton growth in the river below Vernalis.

The above discussion of maximum phytoplankton growth from nitrogen and phosphorus present was only a broad-brush look at the potential for growth, and was done because of an interest in how much phytoplankton crop might respire in the darkened ship channel. The more proper way to determine the phytoplankton crop that would grow would be to do algae growth potential (AGP) studies. If it even becomes desirable to try to improve the D.O. at Stockton by limiting phytoplankton growth in the river, or to reduce trihalomethane precursors in the Delta by limiting phytoplankton growth, then AGP studies for river inflow may become important.

(b) Stockton RWWCF.

(1) Chemical oxygen demand (COD) - The COD test measures the oxygen equivalent of organic matter that can be chemically oxidized. The COD is generally higher than the BOD because more compounds can be chemically oxidized than can be biologically oxidized. The data shows there are 11,962 lbs/day of COD. This represents the maximum amount of oxygen-demand. (The American Public Health Association (1985) states that the COD test does not account for the nitrogenous oxygen demand in the absence of significant concentration of free chlorine ions.) Comparing the 11,962 lbs/day COD to the 1,768 lbs/day BOD shows that most of the organic load is non-biodegradable. (Why is this?) The current oxygen demand is about as designed for by Brown and Caldwell Engineers in the 1978 plant upgrading.

(2) Nitrogenous oxygen demand - The Kjeldahl nitrogen laod of 758 lbs/day converts to an oxygen demand of 3,464 lbs/day (758 x 4.57).

(3) Total organic carbon (TOC) - The TOC test measures the content of organic matter by measuring the amount of organic carbon present. There is a TOC load of 3,997 lbs/day. This is a little confusing, since the total suspended solid load is only 2,970 lbs/day, and carbon is only a fraction of suspended solids. This means most of the TOC is dissolved, and probably should have been removed in secondary treatment.

Effect of channel deepening on sunlight exposure time.

The construction of a ship channel in the San Joaquin River increased the depth of water that was below the sunlight zone. The sunlight zone is where the photosynthetic oxygen production occurs from the phytoplankton, to input D.O. into the water. It has been observed that the crop of phytoplankton undergoes vertical circulation as it moves through the ship channel. Thus the phytoplantkon spend less of their time in the sunlight zone as the channel becomes deeper. For example, for an afternoon sunlight depth of 3 feet, the phytoplankton will spend 20% of their afternoon time in the sunlight zone for a 15 foot channel depth, but only 10% for a 30 foot channel depth. Figure 9 shows this percentage for various channel depths. It shows that by deepening the channel from 30 feet to 35 feet this decreased the photosynthetic oxygen production time by 14% during the daylight hours. When the sunlight depth is less than 3 feet, for example during the morning or late afternoon hours, this 14% reduction still occurs. At night there is no effect, as the entire channel depth is dark. (This is why the least daily D.O. concentration occurs at sunrise, as phytoplankton respiration occurred all night but no photosynthetic oxygen production occurred.) In that width of the channel that is not deepened, there will be no decrease in photosynthetic oxygen production due to the project.

Success of Old River closure.

It appears that for those years in which the Old River closure was installed (Table 2) there was mostly an improvement in D.O. concentrations in the ship channel. Interpretations are presented in Table 2 on the success of the closure in improving the D.O. concentration. The closure also provided for positive net downstream flows during the salmon run. The mathematical modeling effort indicates that on some occasions the closure may not impove D.O., such as when all the river organic load is diverted towards Stockton and low net downstream flows are occurring to allow a long hydraulic residence time at Stockton.

CONSULTANTS MODELING EFFORTS

In discussing the oxygen-demanding load at Stockton, one must be careful not to lump it all together as one similar substance. This load consists not only of live phytoplankton which respire and consume D.O. in the darker waters, but also consists of detritus and some soluble organics and ammonia which are consumed by bacteria which also respire. This latter load is not affected by the amount of light in the water. In the modeling effort these loads were kept separate. The mass of phytoplankton present in the river inflow was determined through use of chlorophyll a data, with the pheophytin correction to remove the degraded portion of chlorophyll a. The corrected chlorophyll a mass is assumed to be 1.5% of the dry weight of the phytoplankton mass (American Public Health Association, 1985), and by this relationship the mass of phytoplankton present was determined and used as model input. The detritus oxygen-demanding load in the river inflow was determined by use of volatile suspended solid data with the phytoplankton mass subtracted out, and this detritus mass was added to in the ship channel by the phytoplankton mass calculated to have settled out there. The ammonia oxygen demand was determined by use of kjeldahl nitrogen data, with the total nitrogenous oxygen demand determined by multiplying this concentration by 4.57 as determined by stoiciometry.

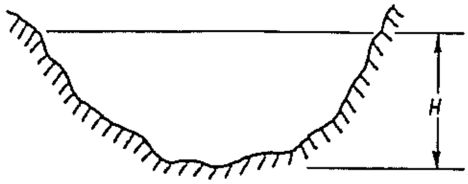
It is felt that the model adequately portrays the change in D.O. concentrations between the 30-foot and 35-foot channel depth, when all other parameters and coefficients in the model are held constant and only depth is changed between the runs. However, as for absolute predictions for a given condition, the model has been shown to make predictions that deviate from measured concentrations under certain conditions. The consultant states that this occurs when net flows past Stockton are low and so that (1) unknown amounts of urban runoff have more of a chance to exert their oxygen demand in the channel, and (2) intertidal flow plays a bigger part in mass-transport and so that any inaccuracies in tidal flow predictions does not transport the constituents correctly. The model does not now account for urban runoff and its oxygen demand.

Results of the modeling effort shows that forcing more of the San Joaquin River flow past Stockton to ensure net downstream flow for the salmon run does not always help the D.O. condition there. There is a trade-off between the increased flow flushing the low D.O. water out of the port area, and the increased phytoplankton and other oxygen-demanding loads that utilize oxygen upon reaching the port area. Looking at historic D.O. profiles obtained by the DWR before and after the Old River closure was put in in past years shows that D.O. was mostly improved with the closure, but not always. However, in some years the closure was assisted by increased flows put into the San Joaquin River by the USBR, using Delta-Mendota Canal water which contains less oxygen-demanding load than the San Joaquin River.

Figures 9 and 10 are schematics showing how the project is assumed to affect phytoplankton photosynthesis-respiration and atmospheric reaeration. If these assumptions are invalid, the model results will be invalid.

It was stated above that mitigation for the project effect could require 625 lbs/day to 2500 lbs/day of oxygen. If oxygen must be added instead to raise the D.O. concentration to the 5.0 mg/L needed by the fishery, substantially more oxygen would be required. For example, in his Phase I work, the consultant determined that for 1978 conditions 7,500 lbs/day of oxygen would be required to raise D.O. concentration from 4.0 mg/L to 5.1 mg/L. This was for a net flow past Stockton of about 800 cfs.

Work is proceeding by DWR (trihalomethane study) on identifying local irrigation return flowrates, locations, and qualities throughout the Delta. These results will assist in making more accurate modeling predictions in the future.



$$K_2 \text{ (base e)} = \frac{(Du)^{1/2}}{H^{3/2}}$$

where K_2 = reaeration coeff(1/day)
u = channel velocity(ft/hr)
H = channel depth(ft)
D = diff. coeff

<u>30-Foot Channel</u>

$$K_2 = \frac{(Du)^{1/2}}{30^{3/2}} = \frac{(Du)^{1/2}}{164} = .0061\ (Du)^{1/2}$$

<u>35-foot Channel</u>

$$K_2 = \frac{(Du)^{1/2}}{35^{3/2}} = \frac{[(D)(0.89u)]^{1/2}}{207} = \frac{0.94(Du)^{1/2}}{207} = .0045(Du)^{1/2}$$

The channel velocity is constantly changing with tidal action, but for that portion of the channel cross-section that has been deepened by 5-feet, the rate of reaeration will be decreased by 26% (.0016/.0061). Those portions of the side channel that are not deepened will not be affected.

The assumption that the O'Connor-Dobbins equation represents reaeration is made here.

FIGURE 10 PROJECT EFFECT ON REAERATION COEFFICIENT

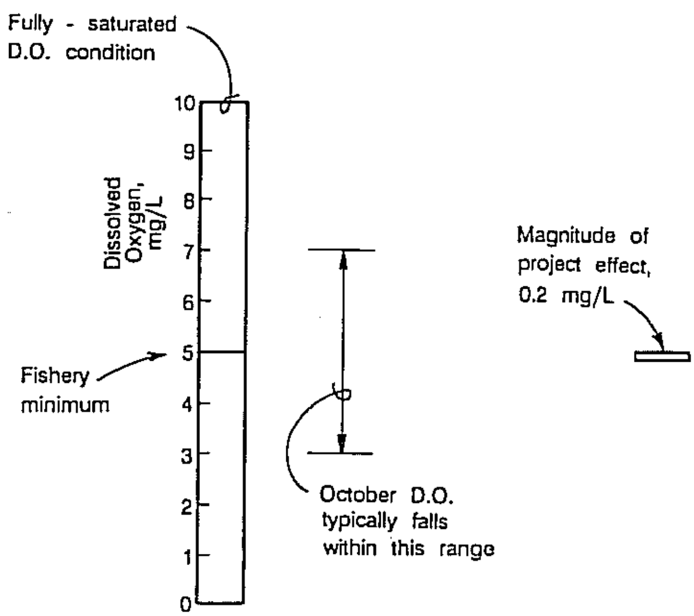


FIGURE 11 COMPARISON OF PROJECT EFFECT TO HISTORIC DISSOLVED OXYGEN CONDITIONS

CHAPTER 6. CONCLUSIONS

The project will have an effect upon D.O. concentrations in the ship channel, for the following reasons:

a. phytoplankton respiration will be increased
b. atmospheric reaeration will be decreased
c. hydraulic residence time will be increased

For the conditions studied under post-Stockton RWWCF operation, the maximum oxygen deficit attributed to channel deepening would be approximately 0.2 mg/L. Figure 11 is a schematic comparing the magnitude of this effect to the historic D.O. concentrations which have occurred under post-RWWCF operation. The mass of oxygen needed to mitigate for the above decrease is directly proportional to flowrate. The mass ranges from approximately 625 lbs/day under near zero net flow conditions past Stockton to approximately 2500 lbs/day when the net downstream San Joaquin River flow past Stockton approaches 2000 cfs.

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ENVIRONMENTAL ASSESSMENT

San Francisco Bay to Stockton Ship Channel: Dissolved Oxygen Mitigation Implementation and Operation

May 1990

1. Introduction. This Environmental Assessment (EA) describes and analyzes the proposed installation of facilities to mitigate reduced dissolved oxygen (DO) levels resulting from dredging of the San Joaquin River in the vicinity of Stockton, California. The ship channel dredging project was described and analyzed in the San Francisco Bay to Stockton (John F. Baldwin and Stockton Ship Channels) Interim General Design Memorandum and Final Environmental Impact Statement. Sacramento District, September 1980. The ship channel dredging occurred between 1984 and 1987. The 1980 EIS documented pre-project channel DO levels and stated that post-dredging monitoring and modeling would document the extent of the dredging caused DO impacts and appropriate remedial action would be implemented. The post project impacts were described in the Dissolved Oxygen Study, Stockton Deep Water Ship Channel. Office Report, Sacramento District, November 1988. This EA document describes the proposed remedial action, alternatives considered, and environmental effects which could occur from the implementation and operation of the remedial action.

2. Proposed DO Mitigation Action. The post-dredging monitoring and modeling effort determined that the project reduced DO levels in the Port of Stockton area by approximately 0.2 milligrams per liter (mg/l). To raise the DO levels in the river, a jet aeration system would be installed on the Stockton Deep Water Ship Channel in the vicinity of Rough and Ready Island (U.S. Naval Communications Station, Stockton) and the San Joaquin River confluence. The facility will be designed and constructed by the Corps of Engineers, with operation and maintenance responsibilities to be assumed by the Port of Stockton.

The confluence site is adjacent to the river reach with the maximum DO deficit and is in an area with depths range from 35 to 45 feet. This facility would pump air and water through a series of submerged nozzles mounted on pilings or the piers. The jet aeration system blows large size air bubbles through a pipe beneath the water. Adjacent to these air pipes are water jets which shear the large bubbles into thousands of smaller bubbles to enhance oxygen transfer efficiency. This also pushes the aerated water laterally into the channel. Tidal flows should mix the aerated water longitudinally through the river reach with reduced DO levels. The system would have a capacity of approximately 3,000 pounds of oxygen per day. The air and water pumps would be located on the adjacent land in a fenced enclosure. The exact facility location will be determined during the design process. The water pump intake will be screened to prevent larval and or juvenile fish from being sucked into the pumps. The screens will utilize a large surface area so that intake flow velocities will be low. The shore-based system eliminates floating equipment that could be damaged by storms, ships, small boats or vandals.

The City of Stockton conducts daily DO monitoring at eight locations in the San Joaquin River between Brandts Bridge (upstream) and Light 18 (downstream) as required by their wastewater discharge permit. When DO levels at any of these monitoring locations drops below 5.0 mg/l, the City of Stockton is required to initiate tertiary treatment at the Stockton Regional Wastewater Control Facility. Because the ship channel dredging reduced DO levels in the channel by approximately 0.2 mg/l, the aeration facility will be operated when any of the DO level monitoring locations drops below 5.2 mg/l during the fall salmon run. DO levels below 5.0 mg/l adversely effect the fall salmon runs which typically occur during September, October or November.

3. <u>Alternatives Considered.</u> The majority of the low DO level problems in the Lower San Joaquin River are related to nutrient rich inflows which feed phytoplankton which in turn consume much of the available oxygen in the water. The major sources of the nutrient rich inflows are from agricultural and urban area runoff and treated sewage effluent. Various alternatives were considered to reduce these inflows. However all source reduction methods were of a large and complex nature requiring multi-agency and multi-jurisdiction programs, not commensurate with the minor DO degradation the dredging has caused. Flushing the lower river with additional "clean water" from New Melones Reservoir was also considered, but was found to be ineffective due to the reverse flow regime caused by the Central Valley and State Water Project export pumping. Thus aeration was selected as the most cost effective and appropriate mitigation method given the minor degradation induced by the dredging project. The types of aeration considered included:

jet aeration
course bubble diffused aeration
mechanical surface aerators
limno-guns
cascade aeration
fine bubble diffused aeration
diffused oxygenation
rotor aerators
fountains

Given cost effectiveness, reliability, minimization of hazards to navigation, and fit to the site considerations, jet aeration was selected as the proposed mitigation method.

4. <u>Environmental Effects of the Proposed Action.</u> The installation and long-term operation of the jet aeration facility are expected to have few negative environmental effects.

Any pumping system such as this has the potential for destroying small fish. The intake structures will be screened and designed so as to minimize inflow velocities which could suck young fish in. The fine bubbles which the system will produce should not impede fish migration or movement. Rough and Ready Island is also outside the area of concern for the threatened Winter Chinook Salmon as identified by the National Marine Fisheries Service.

The underwater air and water pipes will be mounted on pier pilings or other pilings close to shore so as to avoid creating any hazards to navigation or to avoid damage to the aeration system from dragging anchors. This location should not impede shipping activities occurring on the piers.

The Rough and Ready Island and the Port area is an industrial area where the noise of pump and blower operation will be compatible with ambient noise levels. Electric utility service is available in the vicinity to power the pumps and blowers. Approximately 85,000 kilowatt hours of electricity will be consumed by the facility annually.

There are no National Register of Historic Places properties in the Rough and Ready or Port of Stockton area.

5. <u>Coordination.</u> The DO monitoring and modeling report has been reviewed by the agencies listed below. The DO mitigation plan, EA and finding will also be circulated to these agencies for review.

Port of Stockton
City of Stockton
Central Valley Regional Water Quality Control Board
California Department of Water Resources
California Department of Fish and Game
National Marine Fisheries Service
Fish and Wildlife Service
Bureau of Reclamation
Environmental Protection Agency

6. <u>Conclusion.</u> Based upon this analysis, the comments received from the City of Stockton, and the California Department of Water Resources on the draft EA, the installation and operation of the proposed jet aeration facility at the Port of Stockton will result in no significant adverse impacts to the human or natural environments. The installation will improve water quality in the project area. Therefore the preparation of an Environmental Impact Statement will not be required.

DEPARTMENT OF THE ARMY
SACRAMENTO DISTRICT CORPS OF ENGINEERS
650 CAPITOL MALL
SACRAMENTO CALIFORNIA 95814-4794

REPLY TO ATTENTION OF CESPK-PD-R

May 25, 1990

FINDING OF NO SIGNIFICANT IMPACT (FONSI)
San Francisco Bay to Stockton Ship Channel:
Dissolved Oxygen Mitigation Implementation

The U.S. Army Corps of Engineers proposes to install a jet aeration facility on the Stockton Deep Water Ship Channel at the Port of Stockton. This facility will mitigate for an approximate 0.2 milligram per liter reduction in dissolved oxygen (DO) which the ship channel dredging has contributed to. The ship channel dredging project was described and analyzed in the San Francisco Bay to Stockton (John F. Baldwin and Stockton Ship Channels) Interim General Design Memorandum and Final Environmental Impact Statement, September 1980. The EIS stated that post-dredging monitoring would document the dredging caused DO impacts and appropriate remedial action would be implemented.

The facility will be located on the Stockton Deep Water Ship Channel in the vicinity of Rough and Ready Island and the San Joaquin River confluence. This area is adjacent to the river reach with the greatest dissolved oxygen deficit. The jet aerator will pump air bubbles and water out through underwater pipes and be mounted on pilings so as to not create any hazards to navigation. The pump intakes will include fish screens and be designed to achieve low intake velocities in order to prevent sucking in larval or juvenile fish. The facility will be operated and maintained by the Port of Stockton. The facility will be operated whenever the DO levels at any of eight City of Stockton monitoring stations, in the river drop below 5.2 mg/l during the fall salmon run (September-November).

Alternatives considered to improve the dredging induced DO levels in the river included reducing high nutrient agricultural and urban runoff inflows, increasing water releases from upstream reservoirs and directly aerating the area of the river where dredging has reduced the DO levels. Aeration was selected as the most cost effective and appropriate mitigation method given the minor degradation induced by the dredging project.

The installation and operation of the proposed jet aeration facility at the Port of Stockton in the vicinity of Rough and Ready Island will result in no significant adverse impacts to the human or natural environments. The installation will improve water quality in the project area, therefore the preparation of an Environmental Impact Statement will not be required.

Jack A. Le Cuyer
Colonel, Corps of Engineers
District Engineer

July 5, 1990

INCREMENTAL ANALYSIS

DISSOLVED OXYGEN MITIGATION PLAN

SAN FRANCISCO BAY TO STOCKTON DEEP WATER SHIP CHANNEL

1. Inventory and Categorize Resources: Dissolved oxygen (DO) concentrations in about a 7-mile reach of the Stockton Deep Water Ship Channel near the port of Stockton are highly variable and occasionally fall below 5 mg/l. The City of Stockton has been monitoring DO concentrations at several locations over the past several years in connection with operation of their Waste Water Treatment Plant. Over the last two years, DO concentrations have dropped below 5.0 mg/l during the September thru November period for 20 and 34 days per year. DO concentrations have dropped below 5.2 mg/l during this same period for 23 and 35 days per year, respectively.

2. Determine Impacts and Losses: Comments from the California Department of Fish and Game (DFG) on the original 1980 Final Environmental Impact Statement expressed concern on the impact of the channel deepening project upon dissolved oxygen (DO) concentrations in the San Joaquin River (SJR) waters near the Port of Stockton. These waters serve a salmon run during the fall, and at this time it becomes important to hold the minimum DO concentration at 5.0 mg/l.

Channel deepening has three effects that can reduce DO concentrations, as follows:

a. Slightly decreases the volume of channel water that receives sunlight, thereby reducing the photosynthetic production of oxygen that occurs from the phytoplankton;

b. Slightly increases the hydraulic residence time in the port area, so that oxygen consumption by phytoplankton respiration and decay occur over a shorter reach;

c. Slightly decreases the atmospheric re-aeration that can occur in the deeper water.

The Corps and the California Department of Fish and Game (CDFG) concurred that a mathematical modeling study of DO in the San Joaquin River (SJR) would be a suitable effort to determine impacts on DO levels due to channel deepening. Actual DO concentrations in the affected reach were already being monitored by both the California Department of Water Resources (DWR) and the City of Stockton. It was felt that the number of variables affecting DO are so many that separation of impacts due to the channel deepening would be difficult to do solely by analysis of monitoring data. With a calibrated mathematical model all variables can be held constant and only channel depth changed to determine its effects.

The Corps issued a contract to the environmental modeling firm of Resource Management Associates (RMA) to model DO in the SJR. The RMA effort modeled both pre-and post-project conditions. The results indicate that the project deepening under a variety of fall hydrologic conditions would lower DO concentrations by about 0.2 mg/l. This loss amounts to a mass of approximately 625 pounds (lbs.) oxygen/day under near-zero net flow conditions in the project area of SJR to 2,500 lbs. oxygen/day when the net downstream SJR flow in the project area approaches 2,000 cfs.

3. <u>Based on Significance of Losses, Establish Mitigation Objectives</u>: The 0.2 mg/l drop in DO concentrations due to channel deepening is a relatively minor impact, particularly considering the magnitude and variability of other impacts to DO concentrations, e.g. increases to oxygen demand from urban runoff, agricultural drainage, and waste water discharges. The Regional Water Quality Control Board did not formally comment on the mitigation plan nor on the EA which covered the installation of aeration facilities. However, the California Department of Fish and Game identified a particularly critical period when declines in DO concentrations would have impacts on a significant resource. Fishery personnel have stated that during the fall salmon run, it is important to hold the minimum DO concentration at 5.0 mg/l. Low DO concentrations, along with several other unrelated factors, have hindered the fall run of salmon on their way to spawn in interior tributaries. Any impacts which further reduce DO concentrations below the 5.0 mg/l threshold are considered to be significant impacts, requiring mitigation.

Therefore, the mitigation objective is to fully compensate for any decline in DO concentration caused by the deepening project, when the DO falls below the limit of 5.2 mg/l during the fall salmon run. We are utilizing a threshold of 5.2 mg/l rather than 5.0 mg/l to avoid increasing the operation period for the City of Stockton's tertiary treatment plant. We feel this change in threshold will only minimally affect the frequency of operation of both the city's plant and the aeration facilities. Data presented in paragraph 1 support this assumption. As mentioned previously a loss of 2,500 lbs of oxygen per day occurs when flows are 2,000 cfs. However, in order to account for inefficiencies in instream aeration and higher flows than the maximum modeled (i.e. 2000 cfs), the capacity of the aeration facility is set at 3000 lbs oxygen/day.

4. <u>Identify Mitigation Features Responsive to Each Objective</u>:

This analysis is being prepared for only one mitigation objective; i.e. supplying 3000 lbs of oxygen/day to the ship channel. This mitigation could be accomplished by instream aeration or by reducing oxygen demand in the river.

The majority of the low DO level problems in the Lower San Joaquin River are related to nutrient rich inflows, which feed phytoplankton, which in turn consume much of the available oxygen in the water. The major sources of the nutrient rich inflows are from agricultural and urban area runoff and treated sewage effluent. Various alternatives were considered to reduce these inflows. However all source reduction methods were of a large and complex nature requiring multi-agency and multi-jurisdiction programs, not commensurate with the minor DO degradation the project deepening has caused. Flushing the lower river with additional "clean water" from New Melones Reservoir was also considered, but was found to be ineffective due to the reverse flow regime caused by the Central Valley and State Water Project export pumping.

A literature review was performed in an effort to evaluate the various methods for instream aeration. Seven technologies were considered. They are as follows:

1) Rotor aerators
2) Mechanical surface aerators
3) Fine bubble diffused aeration
4) Coarse bubble diffused aeration
5) Diffused oxygenation
6) Sidestream oxygenation
7) Jet aeration

The first four alternatives were rejected. In the following paragraphs the reason for these rejections are outlined.

Rotor aerators require a side channel to be constructed to regulate and control the direction of flow. Also, the mechanism needs protection from wave action. Due to the acquisition of land and construction costs, this alternative was deemed too costly.

In navigable ship channels, mechanical surface aerators are subject to damage in three important ways: 1) by direct collision with ocean going vessels, recreation traffic, or flood debris; 2) through wave action caused by passing ships; 3) by vandalism. They are also unaesthetic in recreational boating areas. Due to these factors, mechanical surface aerators were ruled out as viable alternatives.

Fine and coarse diffused aeration systems require substantial bottom area for placement. They also present a significant maintenance problem due to the ease at which the diffusers become clogged with sediments and debris. They are also vulnerable to damage from maintenance dredging and dragging anchors. Therefore, these systems are not considered feasible or viable alternatives.

5. <u>Determine the Functional Relationship Between Mitigation Features, and Combine Functionally Dependant Features into Separate, Independant Actions</u>: Each of the identified mitigation features are independant actions, separately able to fully mitigate for project impacts.

6. <u>Determine the Cost Effectiveness for Each Functionally Independant Mitigation Management Action for Each Mitigation Objective</u>: In July 1988 a final report was published by a joint venture between Espey, Huston & Associates, Inc., and Pate Engineering. This report analyzed aeration alternatives with equivalent capacities proposed for the Houston Ship Channel in Texas. The alternative chosen from this study was jet aeration. It was chosen from the three remaining alternatives, numbers 5, 6 and 7, based on a cost analysis performed in 1984. These three alternatives and their annual costs, adjusted to 1990 dollars, for the Houston Ship Channel are shown in Table 1. The assumption is made that all components of the cost analysis have appreciated equally and that costs for the Stockton Ship Channel would be proportional.

TABLE 1.

AERATION METHODS:	REMARKS:	ANNUAL COSTS: (1990$)
Jet Aeration	Feasible	94500
Sidestream Oxygenation	Feasible	150200
Diffused Oxygenation	Feasible	185700

For the Stockton Ship Channel, a jet aeration unit capable of producing 3000 lbs. of oxygen per day would have an annual cost (in 1990 dollars, including first costs and annual operation costs) of $34,000, based on two months of operation per year (see attachment A). For comparison sake, operation of the tertiary treatment facilities at the Stockton Waste Water Treatment Plant costs about $11,000 per day (operation costs only). In reality, operation of the tertiary treatment plant to mitigate for impacts due to channel deepening is not a feasible alternative. The plant must operate to mitigate for waste water impacts at the same time the Corps/Port must mitigate for the 0.2 mg/l. Also, during periods of reverse or near stagnant flow in the Port area, due to Delta export conditions, the effect of the Stockton facility does not reach the Port of Stockton.

The jet aeration system blows large-size air bubbles through a pipe beneath the water. Adjacent to these air pipes are water jets which shear the large bubbles into thousands of smaller bubbles to enhance oxygen transfer efficiency. The action of the jet aeration system pushes the aerated water laterally into the channel. This induces horizontal and vertical mixing so that additional benefit is derived from aerated surface water mixed downward. The large air pipes of the jet aeration system result in lower maintenance costs than other aeration systems that directly produce smaller diameter bubbles under the water surface.

7. Arrange Independant Mitigation Features or Actions From Most Cost Effective to Least Cost Effective:

INDEPENDANT MITIGATION FEATURES:	REMARKS:
Jet Aeration	Most Cost Effective
Sidestream Oxygenation	
Diffused Oxygenation	Least Cost Effective

8. Combine the Most Cost Effective Features Into Alternative Plans that Address and Accomplish All Mitigation Objectives: There is no need to combine features as the least cost measure is able to accomplish all mitigation objectives.

9. Provide Information to Support (Justify) the Increased Costs for Adding Each Increment of Management Included in the Recommended Mitigation Plan: The recommended mitigation plan cannot be broken down into increments of management. The Corps proposes to construct one jet aeration facility. Under normal hydrodynamic conditions one site will aerate the reach needing mitigation because of the tidal excursion that occurs in the vicinity of the aeration site. The system will have an oxygenation capacity of 3,000 lbs. oxygen/day, and will be operated during the fall salmon run period (typically September, October and November) whenever DO falls below 5.2 mg/l (see section 3 for an explanation for use of 5.2 rather than 5.0). The aeration facility will be operated and maintained by the Port of Stockton. Assuming an operation period of two months per year, the facility will cost about $11 per year per 1 lb. per day capacity of oxygen production.

APPENDIX A

COST DETERMINATIONS FOR DISSOLVED OXYGEN MITIGATION PLAN AT PORT OF STOCKTON, SAN FRANCISCO BAY TO STOCKTON DEEP WATER SHIP CHANNEL

A. Capital Cost Estimate of Installed Equipment

(FY 1990 Costs - Stockton area)

3000 lbs.oxygen/day Transfer Capacity

1. Aeration Headers Attached to Dock.

Item	Estimated Cost
Aerator Headers 1 header with 24 nozzles each	$55,000
Air & Water Piping	$7,000
Water Pumps: 1-25 HP/4400 gpm pump	$17,000
Blowers: 1-75 HP/ 672 SCFM blower	$14,000
Equipment Installation (40% of above)	$37,000
Aerator Header Support System	$39,000
Pump Backflush System	$13,000
Pump & Blower Freeze Protection	$2,500
Fencing	$6,500
Contingencies (15% of all items)	$28,000
Total Capital Costs	$219,000
	(Current estimate $220,000)

2. Aeration Headers Attached to In-stream Supports, and Protected By Cluster Piles.

Total Capital Costs, from (1) above =	$200,000
Cluster piles, for in-stream protection =	$62,000
Warning Lights and Signs =	$12,000
Contingencies (15% of last two items)	$10,000
Total Capital Costs =	$284,000
	(Current estimate $300,000)

B. Annual Cost Determination

1. Capital cost (if aeration header system is on dock piling)	$219,000
2. Annual operation and maintenance cost(1)	
a. Power ($0.109/kwh (2))	$9,500
b. Maintenance	$4,000
	(Say $14,000)

3. Capital recovery factor
   25 year life, interest rate of 10%, and no salvage, crf = 0.09368

4. Annual cost:	
$219,000 x 0.09368	$20,500
$9,500 + 4,000	$13,500

Total Annual Cost =	$34,000

(1) Based on 2 months per year operation
(2) Phoncon PGE, March 30, 1989.