

**Downstream Tidal Exchange
in the Deep Water Ship Channel
near Turner Cut**

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Executive Summary

This is the interim draft report for this CALFED Directed Action 2001 Project. Some of the modeling tasks have not yet been completed. These preliminary results have been summarized to provide the SJR DO TMDL Steering Committee and Technical Advisory Committee information that may improve the analyses and evaluations leading to the initial TMDL for DO in the SJR by the end of 2002. The full report will be completed and submitted to CALFED in June 2002.

Measurements of electrical conductivity (EC) were used to determine the tidal excursion of water in the DWSC near Turner Cut. Historical measured EC at the City of Stockton river stations were used to estimate the upstream mixing of low salinity Sacramento River water moving across the Delta in the SJR channels (i.e., Columbia Cut and Turner Cut). The tidal exchange of this water into the DWSC near Turner Cut was calculated as a function of Delta export pumping and SJR flow through the DWSC near Stockton.

The tidal flow measurements at the DWR Rough & Ready Island station and at the USGS Stockton RWCF station were compared and evaluated. The tidal flow and mixing within the DWSC was described. The Stockton water quality model will be calibrated to match these observed tidal mixing and exchange characteristics. Results from DWR's Delta hydrodynamic model DSM2 will be compared to the Stockton water quality model flow and mixing simulations.

The downstream tidal exchange at Turner Cut is minimum and dominated by the net downstream flow whenever DWSC flows are greater than 500 cfs. The downstream tidal exchange provides a benefit by increasing DO in the DWSC downstream of Rough & Ready Island (i.e., City of Stockton stations R6 and R7) only when the DWSC net flow is less than 500 cfs. There is never enough tidal exchange at Turner Cut to increase DO concentrations at R5 (near the Rough & Ready DO monitoring station).

The dye studies that were originally proposed to evaluate this tidal mixing and exchange near Turner Cut were not conducted. Preliminary analysis of historical data from the City of Stockton river sampling stations and DWR's longitudinal DO surveys revealed that the electrical conductivity (EC) of the SJR provided a natural tracer that would more clearly illustrate the tidal exchange near Turner Cut.

Introduction

The strong tidal flows in the Deep Water Ship Channel (DWSC) near Stockton create a significant exchange of water between the San Joaquin River downstream of Turner Cut and the upstream portion of the DWSC where low Dissolved Oxygen (DO) concentrations are generally observed. This tidal exchange reduces the residence time of water in the downstream portion of the DWSC between the DWR Rough & Ready DO monitor (SJR mile 37.5) and Turner Cut (SJR mile 32.5). The tidal exchange is reduced and becomes less important at higher SJR flows (i.e., greater than 500 cfs) when the DWSC residence time to Turner Cut is already short (i.e., less than 15 days). The tidal exchange may be influenced by the magnitude of south Delta export pumping and agricultural diversions that increase the net flow from the lower San Joaquin River (SJR) into Turner Cut and south in Middle River towards Victoria Cut and the export pumping plants on Old River.

The tidal exchange near Turner Cut may reduce the BOD concentrations and increase the DO concentrations in the downstream portion of the DWSC because the water from the Sacramento River that is moving across the Delta has a much higher DO concentration and a much lower BOD concentration. The tidal exchange may reduce the residence time of water and the subsequent DO depletion from BOD decay in this portion of the DWSC. This tidal exchange is difficult to characterize in the Stockton water quality model because of the downstream boundary near Columbia Cut and because the net flows into Turner Cut are not simulated (Schanz and Chen, 1993). The DWR DSM2 model includes the entire Delta and this tidal exchange is more easily calculated, but may not be properly calibrated. Results from both models will be compared for a range of SJR flows and export pumping. A simplified spreadsheet model will also be used to demonstrate the response of the DWSC EC values to various tidal flow and exchange conditions.

The Stockton water quality model assumes a specific tidal exchange rate at the downstream boundaries of the model that is located near Columbia Cut. The simulated tidal exchange removes water from the downstream end of the DWSC and replaces it with "boundary water" having a lower BOD and a higher DO concentration (specified as model input). The model was calibrated with salinity (EC) at the downstream portion of the DWSC that was measured in 1990 and 1991. This simulated tidal exchange rate, however, is uncertain and was further verified in this study with longitudinal EC measurements near Turner Cut.

A dye study was originally planned to measure the tidal exchange near Turner Cut, but has been replaced with a series of longitudinal electrical conductivity (EC) measurements in the vicinity of Turner Cut. The EC of the Sacramento River water is generally about 150 uS/cm. As this water flows across the Delta in the SJR channels, the EC increases to about 250 uS/cm near the mouth of the Mokelumne River (i.e., San Andreas Landing EC station). The EC of the SJR river water in the DWSC is generally between about 500 uS/cm and 750 uS/cm during the irrigation season of April through August. The salinity objective at Vernalis is 700 uS/cm from April through August. This allows the tidal

mixing of these two sources of water to be directly observed along the DWSC in the vicinity of Turner Cut without the release of dye. The mixing of the dye within the DWSC would have been extremely complex. The dye was to be released as a longitudinal line, upstream of Turner Cut. The interpretation of the tidal exchange from the measured longitudinal dye profiles as the dye moved downstream towards Turner Cut would have been somewhat difficult. The dye would be spreading from longitudinal mixing as well as moving downstream and into Turner Cut with each tidal cycle. It would be difficult to separate the longitudinal mixing rate upstream of Turner Cut from the slightly increased tidal exchange caused by the tidal flows into Turner Cut.

Background Information

Figure 1 shows a map of the DWSC between Stockton and Columbia Cut. The locations of the City of Stockton river sampling stations are indicated. The geometry of the DWSC upstream of Turner Cut is very important background information because it controls the movement of water through the DWSC and the tidal flows within the DWSC. The residence time is controlled by the volume, and the tidal flows are controlled by the tidal stage variations and the surface area of the DWSC and the tidal portion of the SJR located upstream of the DWSC (i.e., between the DWSC and Mossdale).

Table 1 gives the surface widths (i.e., area) and cross-sectional areas (i.e., volumes) of the DWSC from the upstream end (i.e., turning basin) at SJR mile 41 to Turner Cut (SJR mile 32.5). The total surface area is about 725 acres at an elevation of 0 feet mean sea level (msl) and about 750 acres at an elevation of 4 feet msl. The DWSC between the turning basin and Turner Cut has a volume of about 15,000 acre-feet at an elevation of 0 feet msl and a volume of 18,000 acre-feet at an elevation of 4 feet msl. This geometry is estimated from a combination of USGS quad maps, and the specified model geometry in the Stockton Water Quality model and in the DWR DSM2 model (i.e., Cross-Section Development Program).

The measured tidal flows at the USGS Stockton tidal flow station and the DWR Rough & Ready tidal flow station reflect the upstream "tidal prism" that is defined as the difference in upstream volume between low tide and high tide. Assuming a flat surface elevation at high and low tide, the net upstream movement of water past one of these tidal stations must be equal to the upstream area times the change in tidal stage. The volume of water flowing past a tidal flow gage during one flood-tide period is:

$$\text{Tidal Volume (acre-feet)} = \text{tidal stage change} * \text{upstream area (acres)}$$

Based on the tidal flow records and this tidal volume estimate, the SJR surface area upstream of the USGS Stockton UVM station is estimated to be about 400 acres. For a 3-foot tidal stage change, the tidal volume is 1,200 acre-feet. This volume corresponds to an average flow of about 2,400 cfs during the 6-hour flood-tide period (i.e., $\text{flow (cfs)} = \text{AF} * 43,560 / [6 * 3600]$). Based on the tidal flow records, the surface of the DWSC and the SJR upstream of the DWR Rough & Ready tidal station is about 850 acres, so the effective tidal area of the DWSC (between the UVM station and the Rough & Ready station) is about 450 acres. For a 3-foot tidal stage change, the tidal volume at the Rough & Ready station is about 2,550 acre-feet (i.e., 3 feet * 850 acres). This represents an average flow of about 5,100 cfs during the 6-hour flood-tide period. The additional DWSC surface area between the Rough & Ready station and Turner Cut is about 450 acres. Therefore, the expected tidal flow at Turner Cut would be about 3,900 acre-feet (i.e., 3 feet * 1,300 acres). This represents an average flow of about 7,800 cfs during the 6-hour flood-tide period.

This relatively large tidal flow moving past Turner Cut may produce a considerable exchange between water from the DWSC upstream of Turner Cut and water from downstream of Turner Cut that may originate from the Sacramento River. This exchange was observed as dilution of the DWSC salinity (i.e., EC) between the City of Stockton sampling station R5 (SJR mile 37.5) near the Rough & Ready DO monitor, station R6 (SJR mile 35.5), and station R7 (SJR mile 32.5) at Turner Cut. The salinity gradient in this portion of the DWSC has been measured for many years by the City of Stockton NPDES compliance sampling program. EC measurements during the low flow periods of 1990 and 1991 will be examined to determine the combined effects of net SJR flow and downstream tidal exchange on the EC gradient in this portion of the DWSC.

The flows in 1990 and 1991 were very low, with Vernalis flows of about 500 cfs measured during the summer months. Flows at Vernalis are generally expected to be higher than this in the future (because of the EC objective of 700 uS/cm). Conditions observed in 1990 and 1991 represent worse flow conditions than expected in the future.

Vernalis flows in the summer of 2000 were about 2,000 cfs and flows during the summer of 2001 were about 1,500 cfs. To understand the salinity gradient near Turner Cut, the net SJR flow past Stockton and the net flow into Turner Cut must be evaluated. Both of these may be influenced by the south Delta export pumping. The tidal flows in the DWSC (relatively constant) and the upstream SJR salinity (i.e., Mossdale EC) and the downstream SJR salinity (i.e., San Andreas Landing EC) must also be considered.

Approach and Methods

Measurements of tidal stage, velocity, and flow at the DWR Rough & Ready Island station as well as the tidal stage and flows measured at the USGS UVM station at the Stockton Regional Wastewater Control Facility (RWCF) discharge, located 1.5 miles upstream of the DWSC were described and compared. The tidal flows and velocities that are expected near Turner Cut were estimated and discussed. Some USGS tidal flow measurements in the SJR downstream of Turner Cut and in Turner Cut during 1997 are shown to confirm these estimates. This tidal flow information was then used to characterize the strength of the tidal exchange (i.e., mixing) within the portion of the DWSC between R5 and Turner Cut.

Tidal hydrodynamics (tidal flow and mixing) govern the exchange of water between the DWSC and Turner Cut (leading to Middle River and other south Delta channels). The tidal exchange of water near Turner Cut may reduce the residence time of water within the portion of the DWSC between R5 and R7 and may limit the effects from decay of algae and other organic materials (i.e., BOD). Particulate resuspension and transport is also influenced by tidal flows within the DWSC. The downstream tidal exchange was evaluated from measured longitudinal salinity (i.e., EC) gradients to confirm the assumed mixing in this portion of the DWSC for a range of relatively low SJR flow conditions.

These effects of the tidal exchange on salinity were evaluated with the measured salinity gradient between the City of Stockton sampling station R5 (SJR mile 37.5) near the Rough & Ready DO monitor, station R6 (SJR mile 35.5), and station R7 (SJR mile 32.5) at Turner Cut. The salinity gradient in this 5-mile portion of the DWSC has been measured for many years by the City of Stockton NPDES compliance sampling program. EC measurements during the low flow periods of 1990 and 1991 were examined to determine the combined effects of net SJR flow and downstream tidal exchange on the EC gradient in this portion of the DWSC.

Additional longitudinal EC profiles were measured during October 2001 to provide greater detail in the salinity gradient near Turner Cut. Measurements at high tide and low tide confirmed the tidal excursion near Turner Cut. Because DWSC flows during the period of these EC measurements were greater than 1,000 cfs, the salinity gradient was generally located downstream of Turner Cut. This confirms that the downstream tidal exchange will not effect DO concentrations upstream of Turner Cut if the DWSC net flow is greater than 1,000 cfs.

Comparison of results from the DWR DSM2 Delta hydrodynamic and water quality model will be used to further understand the tidal flow and mixing patterns in the DWSC near Turner Cut. Results from the EC measurements and the analytical particle tracking studies will be incorporated into the boundary condition exchange rate for the Stockton Water Quality Model that has been used in the TMDL load allocation and implementation evaluations. A simplified spreadsheet model of the DWSC tidal flow and mixing rates will be used to illustrate the response of the salinity gradient between

R5 and Turner Cut to a range of SJR net flows, Turner Cut net flows, and assumed tidal mixing rates (i.e., fraction of tidal flow).

Results

USGS Stockton UVM Tidal Flows

The USGS Stockton tidal flow station was installed during the summer of 1995 in cooperation with the City of Stockton to provide direct measurements of the tidal flow near the Stockton RWCF discharge. The USGS tidal flow station provides 15-minute records of stage, velocity, and flow. These records have been evaluated to determine the net daily flows and the average tidal flows that correspond to the tidal prism volume upstream of the UVM station. The net daily flow can be subtracted from the 15-minute tidal flow records to generally evaluate the average tidal flows. This separation of the tidal flow from the net daily flow is most accurate during periods of relatively low net flow.

Figure 2 shows the 15-minute tidal stage and flow records from the Stockton UVM station for September 1999. The daily average stage and net daily flows are shown with the dots. The net daily flow was about 1,000 cfs during September 1999. The 28-day lunar cycle produces some relatively high tides (i.e., spring tides) and some relatively lower tides (i.e., neap tides). Generally, however, the tidal stage change during a tidal cycle averages about 3 feet at the Stockton UVM tidal flow station.

The tidal stage change produces the water surface slope that drives the tidal flows. The tidal flow is positive (i.e., downstream) during falling tides (i.e., "ebb tides", stage decreasing). The tidal flow is negative (i.e., upstream) during rising tides (i.e., "flood tides", stage increasing). There is generally a delay between the high or low tide stage and the reversal of the flow because the momentum of the water must be overcome. This time delay at the Stockton UVM station is about an hour (Jones & Stokes, 2001).

Figure 3 shows the 15-minute tidal volumes at the Stockton UVM station for the first 7 days of September 1999. The net daily flow has been subtracted from the tidal flow records and the flows are converted to volumes (AF). The tidal stage changes have been calculated from the tidal stage records. The average tidal stage change is 5.7 feet for September 1999. The average positive and negative tidal volumes are about 2,300 AF per day for September 1999. This indicates that the upstream tidal prism surface area is about 400 acres.

Figure 3 also indicates that the tidal flows at the Stockton UVM station are relatively complex. These data do not resemble a smooth sinusoidal pattern. The geometry of the SJR channel connected to the DWSC and to the Head of Old River creates a non-symmetrical tidal stage and flow pattern. However, the average tidal volume is generally described as the tidal stage change times an upstream area of about 400 acres.

The tidal excursion at a station is estimated by comparing the tidal volume between low tide and high tide (i.e., upstream surface area * tidal stage change) to the channel cross-section of the station. The tidal excursion is therefore:

$$\text{Tidal Excursion (miles)} = \frac{\text{Upstream Area (acres)} * \text{Stage Change (feet)}}{\text{Cross-section (square feet)} * 43,560 / 5,280}$$

$$\text{Excursion (miles)} = 8.25 * \text{Surface Area} * \text{Stage} / \text{Cross-section Area}$$

For a 3 foot change in stage between high and low tide, the tidal excursion distance is about 2.8 miles (based on cross-sectional area). This is the approximate distance from the highway 4 bridge to the DWSC. Some effluent from the Stockton RWCF moves upstream 2.8 miles between low tide and high tide.

DWR Rough and Ready Tidal Flows

The DWR Rough & Ready tidal flow station was installed during the summer of 2000 and 2001 as part of the intensive data collection effort for the SJR DO TMDL study program. The DWR tidal flow station was evaluated to determine the net daily flows and the average tidal flows that correspond to the tidal prism volume upstream of the Rough & Ready gage.

Figure 4 shows the 15-minute tidal stage and flow records from the Stockton UVM station for September 2000. The daily average stage change and the net daily flows are shown with the dots. The net daily flow was about 1,500 cfs in September 2000. The 28-day lunar cycle includes some relatively high tides and some relatively lower tides. Generally, however, the tidal stage change during a day (approximately two 12.5-hour tidal cycles) is about 6 feet at the Rough & Ready tidal flow station.

Figure 5 shows the 15-minute tidal volumes at the Rough & Ready tidal station for the first 7 days of September 2000. The net daily flow has been subtracted from the tidal flow records and the flows are converted to volumes (AF). The tidal stage changes have been calculated from the tidal stage records. The average daily positive and negative tidal stage change is 5.7 feet for September 2000. The average positive and negative tidal volumes are about 4,600 AF per day for September 2000. This indicates that the upstream tidal prism surface area is about 850 acres.

Figure 5 also indicates that the tidal flows at the Rough & Ready station are relatively symmetrical. The time delay between a stage change and a tidal flow is smaller at the Rough & Ready station located in the wide and deep DWSC than at the Stockton UVM station located in the relatively narrow and shallow SJR channel upstream of the DWSC. The average tidal volume each 15-minutes is generally well described as the tidal stage change times an upstream area of about 850 acres.

The tidal excursion between low and high tides (i.e., 3 feet stage change) at the Rough & Ready station is about 1.25 miles. Water quality measurements at the Rough and Ready station will include water from a 1.25 mile longitudinal reach, between low tide and high tide. Water quality measurements at low tide will represent water that will move 1.25

miles upstream of the station at high tide. Water quality measurements at high tide will represent water that will move 1.25 miles downstream of the station at low tide. Grab samples from R5 will therefore represent a 1.25-mile length of the DWSC, centered at the Rough & Ready station, if the tidal stage is not considered in the timing of samples.

Tidal Flows in the SJR upstream of Turner Cut

The DWSC tidal flows near Turner Cut can be estimated from the combination of the Rough & Ready tidal flows and the additional surface area between the Rough & Ready station and Turner Cut. Table 1 indicates that the surface area of the DWSC between the Rough & Ready tidal station and Turner Cut is about 450 acres. There may be slightly more tidal surface area associated with Fourteen-mile Slough. The combined upstream tidal surface area is therefore about 1,300 acres at Turner Cut. Assuming an average tidal stage change of about 3 feet, the tidal volume at Turner Cut is about 3,900 AF. The average tidal flow is therefore about 7,800 cfs during the two 6-hour ebb tides (downstream flow) and 7,800 cfs during the two 6-hour flood tides (upstream flow). This is a considerable tidal flow moving back and forth near Turner Cut.

The tidal excursion (average distance between high tide and low tide) near Turner Cut can be estimated by dividing the tidal volume by the cross-sectional area near Turner Cut. The DWR bathymetric data for the Delta indicate that the DWSC cross-section near Turner Cut has an area of about 16,000 square feet. The average tidal excursion at Turner Cut is therefore expected to be about 2.0 miles.

Measured Tidal Excursion at Turner Cut

Longitudinal EC profiles were measured at high and low tides on October 15, 2001 and October 26, 2001. The distance between the location of the salinity gradients is a direct measurement of the tidal excursion corresponding to the tidal stage changes on these two days. Figure 6 shows the measured tidal stage during October 2001 at Venice Island, located on the SJR downstream of Columbia Cut. The high and low tidal stages on the days of the tidal excursion surveys are listed. The measured low tide on October 15 was 0.05 feet msl and the measured high tide was 2.83 feet msl, giving a tidal stage change of about 2.8 feet. The low tide on October 26 was -0.57 feet msl and the high tide was 2.38 feet msl, giving a tidal stage change of about 3.0 feet.

Figure 7 shows the surface and bottom EC measurements from October 15 and October 26, 2001. The longitudinal separation of the EC gradients measured at low and high tides on these two days was about 3 miles. This is greater than the estimated tidal excursion of 2.0 miles near Turner Cut for a 3-foot stage change.

The location of the high tide EC gradient on both days is just downstream of Turner Cut (SJR mile 32.5). Because there is a substantial tidal flow into Turner Cut, this tidal volume moving into Turner Cut must be added to the calculated tidal volume for the

DWSC at Turner Cut to match the 3.0 mile tidal excursion measured downstream of Turner Cut.

USGS Tidal Flows in SJR and in Turner Cut

Tidal flows were measured by USGS with portable (temporary) ADCP (acoustic-doppler current profiler) equipment from May through July 1997, as part of dye studies and flow evaluations of the Head of Old River fish protection barrier and agricultural barriers in the south Delta (Oltmann 1998). Tidal flows were measured in the SJR downstream of Turner Cut and in Turner Cut itself. Subtracting the Turner Cut tidal flow from the SJR tidal flow provides an estimate of DWSC tidal flows upstream of Turner Cut.

Figure 8 shows the measured tidal flows in the SJR downstream of Turner Cut and in Turner Cut during May 1997. The Turner Cut flow was subtracted from the SJR tidal flow to estimate the DWSC tidal flow just upstream of Turner Cut. The tidal flows in Turner Cut indicated that an average net flow of 800 cfs was moving upstream (i.e., negative) from the DWSC towards Middle River and the south Delta pumping plants near Tracy. The tidal flow in Turner Cut (after subtracting the net flow) during the month of May 1997 averaged 3,500 cfs during flood-tide periods and 3,500 cfs during ebb-tide periods (i.e., tidal volume of 1,750 AF during each 6-hr flood or ebb tide). The upstream tidal area for an assumed average 3-foot stage change is therefore about 585 acres.

This additional tidal volume would increase the tidal excursion downstream of Turner Cut to be about 0.8 miles. The expected tidal excursion downstream of Turner Cut is therefore about 2.8 miles. The EC measurements at high and low tides on October 15, 2001 and October 26, 2001 generally confirm this estimate of the tidal excursion just downstream of Turner Cut. An additional 100 acres of Fourteen-mile Slough surface area would increase the expected tidal excursion at Turner Cut to exactly 3 miles.

Turner Cut Net Flows

Figure 9 shows the simulated Turner Cut net daily flow results from the RMA Delta hydrodynamic model for a range of San Joaquin River and Delta export pumping conditions. The DWR DSM2 model is expected to give similar results. The San Joaquin River flow does not appear to have much effect on the net Turner Cut flows. The Turner Cut flow appears to be about 10% of the total export pumping. This suggests that about 10% of the net flow moving towards the export pumping plants travels through Turner Cut. These results from the RMA hydrodynamic model indicate that higher export pumping will draw more water from the lower end of the DWSC and may therefore increase the tidal exchange rate.

The USGS tidal flow measurements in May 1997 indicated a net upstream flow of about 800 cfs in Turner Cut. The combined export pumping was about 3,000 cfs for May 1997. This suggests that the Turner Cut flow was about 25% of the total exports. This is higher

than the RMA model indicated. The Head of Old River barrier was installed until May 15, 1997. This may partially explain the higher fraction of the export flow moving down Turner Cut.

The tidal flow from the DWSC upstream of Turner Cut is expected to be approximately one half of the net daily flow into Turner Cut, because half of the water would originate from the DWSC upstream of Turner Cut and half would originate from the SJR downstream of Turner Cut. The tidal exchange flow originating upstream of Turner Cut would therefore be about 500 cfs (1000 acre-feet per day) when Turner Cut net flow was 1,000 cfs, corresponding to Delta export pumping of 10,000 cfs (relatively high pumping-typical of summer conditions).

DWSC Residence Time with Tidal Exchange

This tidal exchange rate caused by the net flow into Turner Cut would reduce the residence time in the DWSC upstream of Turner Cut expected from considering the SJR net flow and the DWSC volume. The travel time from Rough & Ready Island (R5) to Turner Cut would be reduced by the tidal exchange of water moving into Turner Cut.

For example, Table 1 suggests that the travel time between Rough & Ready and Turner Cut (with a volume of 10,000 AF) would be about 10 days with a net SJR flow of 500 cfs. The additional tidal exchange of water caused by a Turner Cut net flow of 1,000 cfs would reduce the travel time from 10 days to 5 days (i.e., effective outflow of 1,000 cfs). The effects of the tidal exchange at Turner Cut would be greatest within the tidal excursion distance (i.e., within 1.85 miles) upstream of Turner Cut and would not be expected to substantially influence DWSC water quality upstream of R6.

Periods with lower SJR flows would be expected to have the greatest influence from this downstream tidal exchange near Turner Cut. The effects from this tidal exchange would be expected to be much less when the SJR net flow was 1,000 cfs. These were the conditions measured in October 2001. Very little dilution of the EC gradient was measured upstream of Turner Cut.

Measured EC Gradients Between River Stations R5 and R8

The historical EC measurements from City of Stockton river sampling stations during the low flow periods of 1990 and 1991 illustrate the effects of the tidal exchange near Turner Cut on DWSC water quality. Table 1 indicates that station R8 is located at SJR mile 30.5, 2 miles downstream of Turner Cut. Station R7 is located at SJR mile 32.5, at Turner Cut. Station R6 is located at SJR mile 35.5, 3 miles upstream of Turner Cut. Station R5 is located at SJR mile 37.5, 5 miles upstream of Turner Cut.

Figure 10 shows the measured EC data during 1990 and 1991. The SJR flow at Vernalis was about 1,000 cfs during the July through September period when weekly EC

measurements were taken in the DWSC. The daily average EC at the DWR Rough & Ready water quality station, located near station R5, was about 800 uS/cm at the beginning of July, and dropped to 500 uS/cm in August, and then increased to 800 uS/cm by the end of September. The station R5 EC values follow the Rough & Ready measurements.

The EC values at R8 were about 300 uS/cm less than the R5 EC data throughout the summer. The R7 (Turner Cut) EC values were about equal to the R8 EC values. The R6 EC data was generally closer to the R5 value than to the R7 value. During August of 1990 the R6 EC was about mid-way between the R5 and R7 values, indicating that the area of interchange between the two water types was upstream of Turner Cut. Although the DWSC flows were not measured, the Vernalis flow of 1000 cfs suggests that the DWSC flow might have been only 250 cfs (i.e., 25% of Vernalis). On September 10, 1990 the HOR barrier was installed and the DWSC flows likely increased to at least 75% of the Vernalis flows. The EC values at R6 increased to the EC measurements at R5 during September, suggesting that the effects of tidal exchange at Turner Cut were reduced as the flow increased above 500 cfs.

The data from 1991 is similar. The station R5 EC data follows the Rough & Ready daily average EC measurements. The R8 and R7 EC data are always lower than the R5 data, suggesting that a longitudinal EC gradient existed somewhere between R5 and R8. The R7 data is generally the same as the R8 values, suggesting that the EC gradient was upstream of Turner Cut. SJR flow at Vernalis was only 500 cfs during the summer of 1991. Nevertheless, the EC data from R6 was generally closer to the R5 values than the R7 values. This suggests that even during periods when the DWSC flows must have been less than 250 cfs, the tidal exchange was only moderately diluting the EC gradient between Turner Cut and the Rough & Ready EC monitor. The HOR barrier was installed on September 9, 1991. The EC at station R6 increased to about the EC at R5, suggesting that the flow of about 500 cfs was enough to move the EC gradient caused by tidal exchange at Turner Cut to a location somewhat downstream of R6 (within 3 miles of Turner Cut).

Figure 11 shows the EC measurements from 2000 and 2001. During 2000 the SJR flow at Vernalis was greater than 2000 cfs. Only small differences in EC values were measured between R5 and R7. The major drop in EC was consistently downstream of Turner Cut at R8. EC measurements in 2001 showed a similar location for the EC gradient.

The tidal exchange from Turner Cut is not expected to influence DO concentrations at station R5 because the EC gradient has never been observed to extend this far upstream from Turner Cut. The DO concentrations at station R6 (SJR mile 35.5) can be slightly influenced if the DWSC flow is less than 500 cfs. No effects are expected upstream of Turner Cut if the flow is greater than 750 cfs.

DWSC Geometry for Modeling Tidal flows, Excursions, and Travel Time

The geometry of the DWSC influences all of the tidal flow parameters and travel time calculations used in modeling and interpreting observed water quality patterns in the DWSC. The surface area can be seen on maps of the Delta channels, but it is more difficult to visualize the cross sections of the channel. DWR maintains a GIS database of available geometry measurements (surveys) for the Delta channel sections, called the Cross-section development program.

Figures 12 to 15 show several representative sections along the DWSC. These cross-section areas are listed in Table 1. Figure 12 shows the section for the Turning Basin that is upstream of the SJR channel entrance to the DWSC. The width is about 1,100 feet, because tug-boats turn the ships around in the turning basin. The maximum depth of the turning basin is about 40 feet and the average depth is about 35 feet. The cross-section area is 37,000 ft² at a water elevation of 0 feet. The DWSC section along Rough & Ready Island is shown at the bottom of Figure 12. This section has a width of about 700 feet, with a maximum depth of 35 feet. The cross-section area is about 16,000 ft² at an elevation of 0 feet. There is a slightly more shallow area on the right side (i.e., 200 feet wide) that is outside of the navigation channel.

Figure 13 shows the channel section at the Rough & Ready tidal flow and water quality station. It is very similar to the section shown at the bottom of Figure 12. The width of the channel is about 700 feet and the depth is 35 feet, and the area is about 17,000 ft² at an elevation of 0 feet. The channel between Rough & Ready and Turner Cut is shown at the bottom of Figure 13. The channel is slightly narrower at this location (approximately 400 feet wide), but is still 35 feet deep. The cross section area at this location is about 12,000 ft² when the water elevation is at 0 feet msl.

Figure 14 shows channel sections of the Deep Water Ship Channel upstream and downstream of Turner Cut. The section upstream of Turner Cut (at the top of Figure 14) is approximately 700 feet wide with about 100 feet of the width representing a relatively shallow area on the right bank. The depth of this section is about 37 feet and the cross-sectional area at a water level of 0 feet msl is approximately 16,000 ft². The section of the Deep Water Ship Channel located downstream of Turner Cut (bottom of Figure 14) is similar to the one upstream of Turner Cut. It is approximately 600 feet wide, 35 feet deep, and has a cross section area of about 16,000 ft² at 0 feet msl.

Figure 15 shows the two side channels, Fourteen-Mile Slough and Turner Cut itself. Fourteen-Mile Slough is much smaller than the Deep Water Ship Channel. The section shown in Figure 15 is only 400 feet wide, less than 10 feet deep, and has an area of only 2,000 ft² when the water elevation is at 0 feet msl. The section of Turner Cut shown at the bottom of Figure 15, while narrower (about 250 feet wide), has about twice the area (4,000 at 0 feet msl) than Turner Cut because of its greater depth (approximately 22 feet).

These channel cross-sections illustrate the general shape of the DWSC. It is a relatively simple channel shape, but exhibits relatively complex water quality patterns. The volume

characteristics can be accurately measured and is already included in the Stockton water quality model and the DSM2 model. The interaction of the DWSC geometry with the tidal flows, SJR flows, temperature stratification, salinity gradients, and side channels make this a complex hydrodynamic environment. Adding the settling and resuspension of organic particles and the growth and decay of algae, and nitrification of ammonia, and decay of both dissolved and particulate organic materials creates a very complicated "reactor". Accurately describing the downstream tidal exchange effects will provide another step in adequately understanding and managing this portion of the Delta.

References

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