

Appendix A

**Tracer Studies of Stormwater Dispersion and
Tidal Exchange in Smith Canal and the
Calaveras River, City of Stockton, California**

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the Calaveras River**

City of Stockton, California

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Introduction

A tracer dye study was performed in Smith Canal and the Calaveras River during August 2003 and February 2004 to evaluate the dispersion of stormwater pollutants and tidal circulation of these embayments with the San Joaquin River. Summer injections of rhodamine WT were conducted near the confluence with the San Joaquin River (i.e., mouth) of each embayment. During the winter, tracer was injected at stormwater pump stations that discharge to these waterways approximately 3 miles upstream of the San Joaquin River. The movement of the tracer plumes was then tracked with a boat-mounted fluorometer and Global Positioning System (GPS). Water quality measurements of dissolved oxygen (DO), electrical conductivity, water temperature, and turbidity were also simultaneously recorded with the tracer monitoring. In addition, long-term biochemical oxygen demand (BOD) kinetic measurements were conducted with water samples collected from the embayments or pump stations during the winter storm event.

Methods and Materials

Tracer Dye Injection

Rhodamine WT dye (Keystone Pacific Division, Santa Fe Springs, CA) was introduced to the Smith Canal and Calaveras River as a conservative tracer during August 2003 and February 2004. The summer releases of tracer to Smith Canal and the Calaveras River occurred on August 6 and August 20, 2003, respectively. Both of the winter tracer injections took place during the afternoon of February 2, 2004, during a storm event. The locations of the tracer injections are shown in Figure 1.

The August 2003 tracer injections were conducted with the diffuser system shown in Figure 2 to provide an initial uniform plug of dye across the width and depth of each waterway. A photograph of the diffuser system and the tracer plume is presented in Figure 3. The February 2, 2004, tracer injections were introduced to Smith Canal and the Calaveras River by direct injection to the stormwater at the Legion Park and Bianchi pump stations, respectively. These pump stations are located at or near the limit of tidal influence for each embayment. In addition, these facilities discharge stormwater runoff from the largest tributary area for each respective waterway within the City of Stockton. The date, injection duration, location, and mass of dye released are listed in Table 1. The dye injection at the Legion Park pump station was accomplished by pumping the dye into the Legion Park pump station stormwater discharge while one of the four natural gas engine-powered pumps (approximate capacity of 25,000 gpm [56 cfs]) was operating simultaneously with the low-flow electric pump (approximate capacity of 5500 gpm [12 cfs]). At the Bianchi pump

station, the dye was pumped into the wet well of the pump station prior to discharge to the Calaveras River.

Table 1. Dates, Times, Locations, Injection Mass for the Dye Releases

Date	Time	Location	Location No.	Mass of Rhodamine WT (g)
August 6, 2003	9:02–9:12 AM	Smith Canal	1	456
August 20, 2003	8:25–8:45 AM	Calaveras River	2	912
August 20, 2003	12:00–12:20 PM	Calaveras River	2	912
February 2, 2004	2:15–2:45 PM	Legion Park Pump Station (Smith Canal)	3	912
February 2, 2004	3:20–3:40 PM	Bianchi Pump Station (Calaveras River)	4	912

The injection of rhodamine WT was accomplished with a Masterflex peristaltic pump (Cole-Parmer Instrument Co., Vernon Hills, IL). The dye was pumped at a concentration of 228 g/L (undiluted 20% dye solution by weight) at a metered flow rate that yielded an initial concentration of approximately 100 µg/L in Smith Canal or the Calaveras River. Dilution was accomplished with either the diffuser system or the stormwater discharge water.

Tracer Dye Concentration Measurements

The concentration of rhodamine WT dye tracer and the corresponding location and depth were measured from an 18-foot aluminum outboard boat in each tidal embayment. A schematic diagram of the monitoring system is shown in Figure 4. The boat speed typically was limited to 2–3 mph during the dye-tracking. The dye concentration was measured with a SCUFA III fluorometer (Turner Instruments, Sunnyvale, CA) calibrated with standards diluted with tributary water collected at a depth of 2 feet prior to the dye injection. A solid secondary standard was also used periodically to check the calibration of the SCUFA. The SCUFA III also measures turbidity and temperature, the two parameters used to adjust the raw fluorescence reading to a tracer concentration. Instrument depth was determined with a 600XL water quality sonde (YSI, Inc., Yellow Springs, OH) fixed to a weighted PVC frame at the same elevation as the SCUFA. The YSI sonde also provided water temperature, DO, and electrical conductivity data. Coordinate locations for each dye measurement were determined by a Garmin GPSMap 238 Sounder (Garmin International, Inc., Olathe, KS) with a 2-second sampling frequency and reported position accuracy of less than 10 ft (position measurements when stationary generally do not vary more than 12 ft). This instrument also measures water depth by sonar with a measured accuracy of approximately 1ft. The four instruments were interfaced to a desktop computer

via serial ports and RS232 communication protocols. Data were collected simultaneously from each instrument every 2 seconds and time-stamped using data acquisition software developed with Matlab (Version 7.0, The MathWorks, Inc., Natick, MA). An example of the initial concentrations measured in the Calaveras River on August 20 after the first dye injection is shown in Figure 5. The dye had spread into about 200 feet of channel and was well-mixed vertically with a maximum concentration of about 100 µg/l.

Water samples were also collected on February 2, 2004, at the locations delineated in Figure 6. Long-term BOD measurements were performed for each of the 10 samples. All water collected for BOD measurements was obtained from mid-depth in the receiving water, except for the Smith Legion Park sample. Water from each station was placed in 300-mL BOD bottles that were maintained in the dark, at 10°C, for 27 days. The DO concentration of the incubated water was periodically quantified using a YSI 55 DO meter (YSI Inc., Yellow Springs, Ohio). Samples were warmed to 20°C prior to measurement.

The bathymetry of Smith Canal and the Calaveras River was also measured along longitudinal and lateral transects. Depth and stage relative to the San Joaquin River stage measured at the Rough and Ready Island monitoring station are reported. The data were adjusted to mean sea level to correspond with the tidal gage records. The data files generated during these studies are extremely large and not included as part of this report. Electronic copies are available by request.

Results and Discussion

Bathymetry

Locations of the bathymetry transects are shown in Figures 7 and 8 for the Calaveras River and Smith Canal, respectively. Lateral transects yielded 12 cross sections for Smith Canal and 21 for the Calaveras River. Jones & Stokes used the bathymetry data in the development of a tidal exchange model. The bathymetry is summarized in Tables 1 and 2 of the main report. The bathymetry data are available in Excel spreadsheet format.

Tracer Dispersion in Smith Canal, August 6–9, 2003

Rhodamine WT was injected into Smith Canal using the boat-mounted diffuser system at approximately 9:00 AM on August 6, 2003, at low-low tide (0.5 foot msl stage) about 1,000 feet upstream from the mouth. Tracking of the dye started immediately and continued throughout the day; however, measurement of the longitudinal distribution of the dye at slack tides was a priority. The timing of the dye release and the slack tide monitoring is presented with the San Joaquin River stage in Figure 9. Measurements on August 8 and 9 were performed only at the low-high slack tide.

Figure 10 presents the movement and dispersion of the tracer within 6 hours of its release on August 6. The 6-hour measurement corresponds to the 3:00 PM low-high slack tide (3.0 feet msl stage) shown in Figure 9. Tidal flows dominate water movement in Smith Canal except during periods of large stormwater inputs. After 6 hours of flood-tide flow, the center of mass of the dye plume (i.e., mode) moved upstream about 5,000 ft, or about one-half the length of Smith Canal. Some dye was measured 7,000 feet upstream from the injection. The dye was spread over about 4,000 feet of the channel. During this tidal floodflow, dispersion reduced the peak concentration from approximately 100 to 5 $\mu\text{g/L}$.

The longitudinal concentration distributions at slack tides are shown in Figure 11 for one 25-hour tidal day. As presented earlier in Figure 10, the extent of the tidal excursion, as determined by the highest concentration located near the center of the dye plume, was about 5,000 ft for the first flood tidal flow. The following weak ebb tide moved the plume downstream only 3,000 ft. The next flood tide returned the plume mode to 5,000 ft upstream of the injection location. After one complete tidal day (LL tide 8-7-04 10:30 AM) the mode of the concentration profile returned to the point of injection, suggesting that no net movement of water occurred in Smith after one tidal day. However, relatively high tracer concentrations near the confluence with the San Joaquin River at low-low slack tide (0.5 foot msl stage) indicate that a significant quantity of dye had flowed into the San Joaquin River. Model calibration and simulations are required to better quantify this exchange of Smith Canal and San Joaquin River water.

Also shown in Figure 11 is an apparent rise in the dye concentration from about 0.8 to 1.5 $\mu\text{g/L}$ between 9,000 and 11,000 ft at the low-low slack tide on August 7. The cause of this increase is unknown, but it is not expected to be associated with the rhodamine WT released on August 6 as elevated dye concentrations did not extend to this reach during the previous high-high slack tide. A possible explanation is the modest rise in turbidity from about 16 to 21 nephelometric turbidity units (NTU); however, sensitivity tests performed with bottom sediments did not yield the same response in dye concentration. Elevated chlorophyll *a* concentrations associated with increased algal productivity in Yosemite Lake is another possible cause. Flow during the ebb tide would move the Yosemite Lake water with elevated algal concentrations into upper Smith Canal. However, sensitivity tests to chlorophyll *a* measurements were not performed to verify this hypothesis.

Shown in Figure 12 are the longitudinal concentration distributions at low-high slack tides from August 6 to August 9. The dye concentration decreases with each day as a result of dispersion and the loss of dye to the San Joaquin River at low-low tides. Also the location of the concentration distribution mode is relatively stationary with a slight upstream shift from 4,000 to 6,000 ft above the August 6 dye injection at low-low slack tide. This upstream migration of the mode appears to be associated with the loss of dye in lower Smith Canal, where exchange with the San Joaquin River is greatest. These data suggest that circulation with the San Joaquin River is significant close to the Smith Canal confluence but is inhibited near Yosemite Lake. The winter dye studies provide

more supporting evidence of this observation, and modeling studies will assist in better quantifying the exchange.

Tracer Dispersion in Calaveras River, August 20–23, 2003

Two injections of rhodamine WT tracer were released to the Calaveras River about 3,000 feet upstream of the confluence with the San Joaquin River on August 20, 2003. Details of the injections are listed in Table 1. As shown in Figure 13, the first tracer injection occurred during the low-low slack tide at 8:30 AM with a stage of about 0.75 foot msl. The second injection occurred after 12:00 PM, but before the low-high tide (2.25 feet msl stage). Similar to the Smith Canal monitoring, tracking of the plume was performed throughout the first day, with longitudinal profiles measured during slack tides. Tracer concentrations were measured at low-high slack tides on August 22 and 23.

The longitudinal concentrations of tracer at low-high slack tide within the first 30 hours are presented in Figure 14. Two injections were conducted on August 20, yielding distinct dye plumes that are visible in the 8–20 19:00 high-low tide data of Figure 14. The second tracer release was performed to provide an additional data set for the water quality model calibration and was conducted about 3.5 hours after the first injection. At the 7:00 PM high-low slack tide, the two plumes are separated by approximately 1,000 ft and have maximum rhodamine WT concentrations of approximately 100 and 15 µg/L. These observations indicate that tidal excursion from the low-low slack tide to the high-low slack tide was approximately 3,500 ft based on the movement of the concentration mode of the first tracer release. The second injection moved upstream approximately 900 ft after 2 hours at low-high tide.

Also visible in Figure 14 is the mixing of the two tracer plumes by 7:00 PM on August 20, approximately 7 hours after the second release. The greatest upstream tidal excursion was measured to be almost 7,000 ft upstream of the injection location during the 1:00 AM high-high tide on August 21. The next measurements were performed at low-low slack tide on August 21, one tidal day after the first tracer release. These data show significant concentrations at the San Joaquin River confluence, approximately 3,000 ft downstream from the dye release. As with Smith Canal, these concentrations near the confluence are caused by the exchange of water between the Calaveras River and the San Joaquin River. Dye entering the San Joaquin River may not return to the Calaveras River on the subsequent flood tide, resulting in a daily loss of dye mass.

The effect of tidal circulation is also evident from the longitudinal concentrations measured at low-high slack tides between August 20 and August 23 as presented in Figure 15. The concentrations of tracer diminish each day as a result of dispersion and losses to the San Joaquin River. The decreasing area under each concentration distribution curve indicates that dye is lost to the San Joaquin River

because of the exchange of the Calaveras and San Joaquin Rivers. Quantification of the circulation associated with these tracer losses will be estimated with modeling efforts performed by Jones and Stokes.

Tracer Dispersion in Smith Canal, February 2–13, 2004

The dye studies in Smith Canal and the Calaveras River were repeated during wet weather conditions on February 2, 2004. The rhodamine tracer was released 2–3 miles upstream from the summer injections to observe the transport characteristics of the dye as it was washed downstream by stormwater discharges from the major pumping stations. The timing of dye releases and measurements performed at high-high slack tides and the tidal stage measured at Rough and Ready Island are presented in Figure 16. As shown in Figure 17, approximately 0.75 inch of precipitation fell in Stockton on February 2. The 2 weeks preceding and following the February 2 event were relatively dry. The cumulative precipitation, tides and the timing of dye releases and measurements are delineated in Figure 18 for February 2 and 3, 2004. The dye was released about 2:12 PM on February 2, 2004 (Table 1). As exhibited in Figure 18, this injection occurred near the high-high slack tide stage measured for the San Joaquin River at Rough and Ready Island. At the time of the 2:15 PM tracer release, approximately 0.6 inch of rain had fallen from the storm, most of which was recorded within 2 hours of the rhodamine release.

As shown in Figure 19, dye was released to the stormwater discharge when flows were approximately 32,000 gpm (71.3 cfs) to Yosemite Lake. These precipitation and flow data were measured by the City of Stockton to fulfill the requirements of their National Pollution Discharge Elimination System (NPDES) Monitoring and Reporting Program for stormwater discharges to surface waters. While light precipitation continued through February 3, stormwater flow was pumped solely with the 5,500-gpm summer pump because the stormwater runoff was not sufficient to activate the large 25,000-gpm pumps at the Legion Park Station. Figure 19 presents the cumulative discharge for the February 2 storm. Approximately 10^6 cubic feet (23 acre-feet) of water was discharged from the pump station before the dye injection. In the 24 hours after the dye injection, another 0.8×10^6 cubic feet (18 acre-feet) of stormwater flushed the dye downstream. This quantity of water is equal to approximately 10% of the water volume of Smith Canal.

Rhodamine WT dye concentrations measured at low-low slack tides from February 2 to February 6 and February 13 are exhibited in Figure 21. The February 2 measurements were conducted approximately 9 hours after the dye release to Yosemite Lake. During this time, the plume had moved approximately 3,500 ft downstream because of the ebb-tidal flow and stormwater inflow shown earlier in Figures 19 and 20. Subsequent measurements of tracer on February 3 through February 6 show a slight movement downstream that appears to be largely associated with dispersion induced by tidal flows. Ten days after the dye release, significant quantities of tracer remain at the upper end of Smith Canal,

indicating that the exchange with the San Joaquin River can be quite limited near Yosemite Lake when flushing stormwater flows have ceased following a storm.

Water quality measurements support these dye observations. The specific conductance, equivalent to electrical conductivity (EC) can also be used to track stormwater discharges and the hydraulic characteristics of Smith Canal. During the February 2 storm, the EC of the San Joaquin River was approximately 850 $\mu\text{mho/cm}$ while the stormwater discharged to Yosemite Lake had an EC value of about 200 $\mu\text{mho/cm}$. As shown in Figure 22, the discharges of low-EC stormwater on February 2 and 3 displaced the higher-EC water originating from the San Joaquin River. Circulation associated with tidal flushing influenced the transport of low-EC stormwater farther down Smith Canal on February 4 and 6. Between February 6 and 13, no precipitation was recorded in Stockton. With the reduction of stormwater discharges to Smith Canal during this dry week, tidal circulation brings more San Joaquin River water into Smith canal as shown, with increasing EC values near the mouth.

DO measurements in Smith Canal provide an indication of its response to the BOD of the stormwater. Figure 23 presents the DO concentrations in Smith Canal during the dye monitoring. Between February 2 and 13, the DO concentration in the San Joaquin River was about 5.5 mg/L. The stormwater discharges contained approximately 8 mg/L of DO. The discharges of stormwater with higher DO concentrations is evident in the February 2 and February 3 measurements shown in Figure 23. However, between February 3 and 4, the DO decreases 1.5 mg/L in the upper Smith Canal. Another 1.0 mg/L decrease in DO is measured a day later. After a week of dry weather, reaeration yielded a DO increase of 1.5 mg/L near Yosemite Lake. This late-season (i.e., cold) storm did not reduce the DO in Smith Canal to below the water quality objective of 5.0 mg/l.

The results of the BOD kinetic tests are presented in Figure 24 for water collected from Smith Canal or the Legion Park pump station discharge on February 2, 2004. The sampling locations were shown earlier in Figure 6. The BOD of all the samples after 27 days was about 13 mg/L. However, the 7-day BOD values for the discharge and the upper Smith Canal are about twice the levels measured near the confluence. These data suggest that for the first 7 days, the rate of DO utilization would be about 0.6–0.7 mg/L per day in the upper Smith Canal. These rates are approximately 50% of the net DO depletion rates shown in Figure 22 for the first 3 days. Modeling studies calibrated with field data may help to resolve these apparent discrepancies.

The linearity of the data shown in Figure 24 indicates that the ultimate BOD may be significantly greater than the 12–14 mg/L measured after 27 days. The slow kinetic rates of decay are probably associated with the low temperature of the water, 10°C, under which the tests were conducted.

Tracer Dispersion in the Calaveras River, February 2–13, 2004

Rhodamine WT was also released to the Calaveras River on February 2, 2004. The tracer was pumped into the wet well of the Bianchi pump station approximately 3 miles upstream of the summer injection location (and 1 mile above the Pershing Road Bridge). Details of the injection and location were described earlier in Methods and Materials. The dye injection started at 3:20 PM, after the peak stormwater runoff inflow had passed through the Bianchi station. The Bianchi pump station outfall is located within the influence of tides on the Calaveras River. As shown in Figure 16, the release of the dye occurred near the high-high slack tide for February 2 (4.5 feet mean sea level stage). Measurements of tracer downstream in the Calaveras River were initiated on February 3 at 12:30 AM, approximately 9 hours after the release of rhodamine WT. The timing of the dye release, initiation of measurements, precipitation, and tides were shown earlier in Figures 16 and 18.

The concentrations of rhodamine WT measured from February 3 to 13 are shown in Figure 25. The February 3 measurements show little evidence of rhodamine up to the Pershing Avenue Bridge (11,500 ft). Shallow water depths above Pershing Avenue prevented safe navigation, and thus dye measurements were not performed upstream of the Pershing Bridge. At the time of the dye release from the Bianchi pump station, no flow was visible in the Calaveras River below the Pershing Bridge. This was largely attributable to the high slack tide conditions at the time of the tracer release. It appears that stormwater inputs and the ebb-tidal flows were insufficient to transport the dye 6,000 feet down the Calaveras to the Pershing Bridge within the 9 hours between injection and measurement. However, on the following day, approximately 34 hours after the release, the plume is quite distinct and was measured at about 11,000 ft above the summer dye injection location. Measurements on the night of February 5 at low-low slack tide indicated that a large flushing flow had passed down the Calaveras River and washed most of the dye out to the San Joaquin River.

This flushing was also evident in the SC data shown in Figure 26. The EC in the Calaveras River increased linearly from about 200 to 800 $\mu\text{mho/cm}$ at the San Joaquin River before the flushing flows down the Calaveras River. However, after the flush of stormwater, the EC of virtually the entire tidal segment of the Calaveras River was approximately 200 $\mu\text{mho/cm}$. The stormwater flush had displaced the more saline water of the San Joaquin River with the lower EC stormwater.

The origin of the flushing water is unknown, but it appears to be associated with stormwater runoff concentrated between Bellota Dam and New Hogan Reservoir. Figure 27 presents a map of the Calaveras River up to New Hogan Reservoir. Under most conditions, the Bellota Dam diverts flow in the Calaveras River to Mormon Slough that in turn flows into the Diverting Canal and then returns to the Calaveras River. Flow gaging stations measure the release from New Hogan Reservoir and the diversion to Mormon Slough at Bellota Dam. These flows are

presented in Figure 28 along with the daily precipitation measured at the Stockton Fire Station. As shown in Figure 28, there was a significant flow at Bellota Dam on February 3 and 4. This flow appeared approximately 24–48 hours after the storm on February 2. The water originated below New Hogan Dam because reservoir releases were relatively constant at about 60 cubic feet per second (cfs) throughout this period.

Figure 29 shows the timing of the February 2 storm, the flow diverted at Bellota Dam, the release of the dye at the Bianchi pump station, and the dye tracking measurements performed in the Calaveras River from February 2 to 6. These data support the dye and SC concentration measurements performed on February 5 and 6. These data indicate there was about a 12-hour lag in the time precipitation was measured in Stockton and the appearance of flow at Bellota Dam. There was also a lag of at least 24 hours between the Bellota flow and the measurement of the dye plume in the Calaveras River on February 4. This second lag appears to be associated with the flow travel time down the Calaveras River, Mormon Slough, and the Diverting Canal. Flows released from Bellota to the Diverting Canal and subsequently back to the Calaveras River may be attenuated significantly. Flow measurements do not exist for the Calaveras River at Stockton; however, model simulations performed by Jones & Stokes suggest that Calaveras River flows reaching Stockton were 30% of the Bellota records.

DO concentrations measured in the Calaveras River during the dye tracking are presented in Figure 30. Prior to the flushing event, the DO concentrations in the Calaveras River were about 6 mg/L except near Pershing Bridge, where it increased to about 9 mg/l. The DO decreased from 9 to 8 mg/L near Pershing Bridge between the nights of February 3 and 4. The high DO in the stormwater released from Bellota Dam is also evident in Figure 30. On February 5 and 6, the DO was elevated to 10 mg/L by the stormwater originating upstream of Bellota Dam. However, 1 week later, exchange with the San Joaquin River and utilization of the BOD in the stormwater resulted in Calaveras River DO concentrations ranging from 5 to 7 mg/L in the area of study.

BOD decay data are presented in Figure 31 for water samples collected from the Calaveras River at the locations shown earlier in Figure 6. These data show much greater variation than the Smith Canal BOD results. BOD was only 2–4 mg/l after 10 days. BOD concentrations after 27 days of incubation, at 10°C, range from 4 to 11 mg/L. In addition, the ultimate BOD may be significantly greater than these values because of the relatively slow rates of decay at this low temperature. First-order curve fits were attempted to estimate decay rates; however, the linear response of the BOD with time yielded poor fits, extremely low decay constants (0.01 to 0.04 1/d), and unrealistically high values of the ultimate BOD.

Conclusions and Recommendations

The summer and winter dye circulation studies performed in Smith Canal and the Calaveras River provide a good set of data for calibrating a water quality model to quantitatively assess stormwater pollutant dispersion, exchange with the San Joaquin River, and stormwater impacts on DO concentration in the receiving waters. The rhodamine WT concentrations and EC measurements can be used to assess the movement of a conservative tracer in these San Joaquin River tributaries. The BOD and DO measurements illustrate the potential effects of the stormwater discharges on the DO concentrations in these tidal embayments.

Qualitatively, the data presented here indicate that a significant exchange of water occurs during each tidal day for the lower reaches of Smith Canal and the Calaveras River. However, the circulation is greatly inhibited in the upper sections of these waterways. For example, pollutants discharged to Yosemite Lake, at the head of Smith Canal, may remain for weeks in the absence of flushing flows.

A delayed flushing of the Calaveras River from stormwater runoff generated above Bellota Dam was observed during the February monitoring. The duration and volume of this flow were sufficient to displace the lower quality urban stormwater and San Joaquin River water from the tidal reach of the Calaveras River. The long residence time of upper Smith Canal could be reduced and significant improvement in water quality could be realized if such flushing was engineered into the hydrology of its watershed. The feasibility of this strategy requires more detailed investigation.

This study provided observations from a single storm event. Conditions during wet weather will vary considerably. Continuous monitoring stations measuring EC, water temperature, and DO would provide a direct assessment of stormwater effects and improve understanding of the hydraulic characteristics of these waterways under a variety of storm conditions. These data would be valuable in calibrating and validating a water quality model that could be used to formulate corrective strategies and in evaluating the benefits from various best management practice actions in the watersheds.