# Appendix D
# Suspended Sediments Model
# Methods and Results

# Contents



## Tables



## Figures

# Attachments

# Abbreviations and Acronyms

| | |
|---|---|
| CalSim II | California Simulation Model II |
| cfs | cubic feet per second |
| Delta | Sacramento-San Joaquin River Delta |
| DMC | Delta-Mendota Canal |
| mg/L | milligram(s) per liter |
| $N/m^2$ | Newton(s) per square meter |
| SJR | San Joaquin River |
| TSS | total suspended sediments |
| Wasteway | Newman Wasteway |

# Appendix D
# Suspended Sediments Model Methods and Results

## D.1 Background and Purpose

### D.1.1 Background

Delta-Mendota Canal (DMC) is a 117-mile-long canal located in the San Joaquin Valley of Central California. It is part of the Bureau of Reclamation's Central Valley Project, which primarily supplies irrigation water to farmers located in the San Joaquin Valley. The DMC starts at pumping facilities located in the Sacramento-San Joaquin Delta (Delta) and runs parallel to the California Aqueduct along the western border of the San Joaquin Valley. After reaching the San Luis Reservoir, the DMC deviates towards the east and eventually empties into the San Joaquin River (SJR) near the town of Mendota at Mendota Pool (**Figure D-1**).

Newman Wasteway (the Wasteway) was built as an emergency spillway from the DMC to the SJR that can be used to drain the DMC rapidly if the need arises. The Wasteway is located near the town of Newman and empties into the SJR about 1 mile upstream of the confluence of the SJR and Merced River. The Wasteway has a total length of 8.2 miles including 5 sets of culverts; the upper 1.5 miles are concrete-lined and the remainder is earth-lined. The Wasteway's design capacity is 4,300 cubic feet per second (cfs). **Figure D-2** shows the Wasteway near its confluence with the SJR.

### D.1.2 Purpose

DMC-Newman Wasteway is one of the conveyance facilities chosen to study the feasibility of recirculating water between the Delta and the SJR to improve the water quality and increase fisheries flows in the SJR.

In the years prior to the study, the release gate located at the confluence of the DMC and the head of the Wasteway has been routinely opened to allow flows up to 500 cfs to flow through the gate to flush out accumulated sediment. During this maintenance process, the gate is only open for a few minutes. Aside from the maintenance flushing, the Wasteway has lain relatively dormant and experienced the buildup of debris and sediment throughout its approximately 7-mile earth-lined section. During Recirculation Pilot Studies, elevated turbidity was observed at the discharge point of the Wasteway where it meets the SJR (shown on **Figure D-3)**. Discharging recirculation flows through the Wasteway may result in increased erosion, and turbidity, and total suspended solids (TSS). The purpose of the study described in this appendix is to determine the erosion rates and sediment concentrations in the Wasteway and SJR for various flowrates that could be experienced during recirculation events.

The goal of the analysis is to develop a relationship between flow in the Wasteway and TSS in the Wasteway and in the SJR downstream from the Wasteway. The measured data from the two pilot studies (Bureau of Reclamation 2005, 2007) could be used to develop a relationship directly but the pilot study data do not cover as wide a range of flow as necessary for the analysis of the alternative plans. The method used in the analysis described below is therefore meant to provide a rational approach to extend the relationship beyond the range represented by the measured data.

## D.2 Modeling Analysis

Three simple spreadsheet-level models were developed to estimate the erosion rates of sediment in the Wasteway and the corresponding TSS concentrations in the SJR. One model (HEC-RAS) is used to develop a relationship between flow in the Wasteway and the TSS concentration in the discharge from the Wasteway into the SJR. The second model is used to predict the transport of that sediment downstream and to provide an estimate of the average concentration of TSS in the Wasteway plume in the SJR between the Wasteway and the mouth of the Tuolumne River. The third model calculates the lateral distribution of TSS contributed by the Wasteway in the SJR at specified locations. This section of the report describes the development of these models.


**Figure D-1. Suspended Sediment Analysis Extent**

**Figure D-2. Newman Wasteway near the Confluence with the San Joaquin River**

**Figure D-3. Turbidity at the Mouth of Newman Wasteway**

### D.2.1 Newman Wasteway Erosion Rates

The erosion rate in the Wasteway is a function of the shear stress on the Wasteway bed due to the flow of water in the Wasteway and soil properties of the sediment making up the bed. The model to develop a relationship between flow and erosion rates (and TSS) in the Wasteway is based on the commonly used relationship that assumes that the erosion rate is proportional to the excess shear stress:

$$\mathrm{E} = k\rho_s(1-\theta)(\tau-\tau_c) \quad \text{(D-1a)}$$

Or

$$C_{TSS} = E/Q \quad \text{(D-1b)}$$

Where:

E = erosion rate (kg/s)

Q = flow rate ($m^3/s$)

$C_{TSS}$ = suspended sediment concentration ($kg/m^3$)

k = erodibility coefficient ($m^3/N/s$)

$\tau_c$ = critical shear stress (Newtons per square meter [$N/m^2$])

$\tau$ = effective shear stress ($N/m^2$)

$\rho_s$ = particle density (assumed equal to 2,650 $kg/m^3$)

$\theta$ = porosity (assumed equal to 0.30)

The erodibility coefficient and the critical shear stress are a function of the soil type and condition. The effective shear stress is a function of the flow rate in the Wasteway. The selection of these parameters is described below.

#### *Effective Shear Stress*

The effective shear stress ($\tau$) in Equation D-1 was calculated using the U.S. Army Corps of Engineers (2006) HEC-RAS model V4.01. HEC-RAS is a one-dimensional hydraulic model that calculates water surface elevations given river cross sections and flow rates. Wasteway cross sections were obtained from the DMC-Newman Wasteway as-builts obtained from Bureau of Reclamation (1956). The reach was modeled from the beginning of the Wasteway to the confluence with the SJR including five culverts. The model consisted of two typical cross sections, the first representing the concrete-lined trapezoidal channel and the second the earth-lined section. The as-builts were compared to present-day photos of the site, and the presence of a low-flow channel along the earth-lined section was noted and incorporated into the HEC-RAS model. The model was then run for a range of flow rates, and shear stresses along the right, left, and center of the channel were calculated. **Figure D-4** shows a typical cross section for the earthen section of the canal. The low-flow channel seen on **Figure D-5** was added to the Wasteway based on photos of the Wasteway and is not on the as-built drawings.

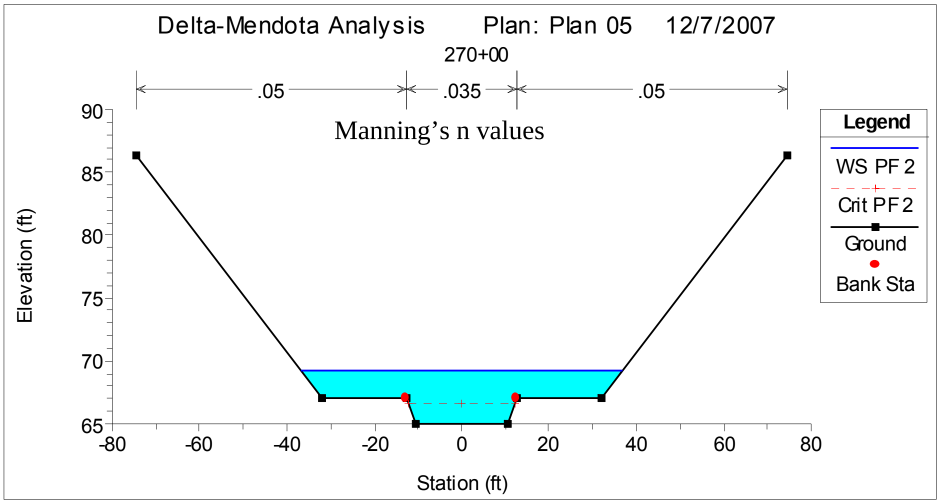



**Figure D-4. Typical HEC-RAS Model Cross Section**

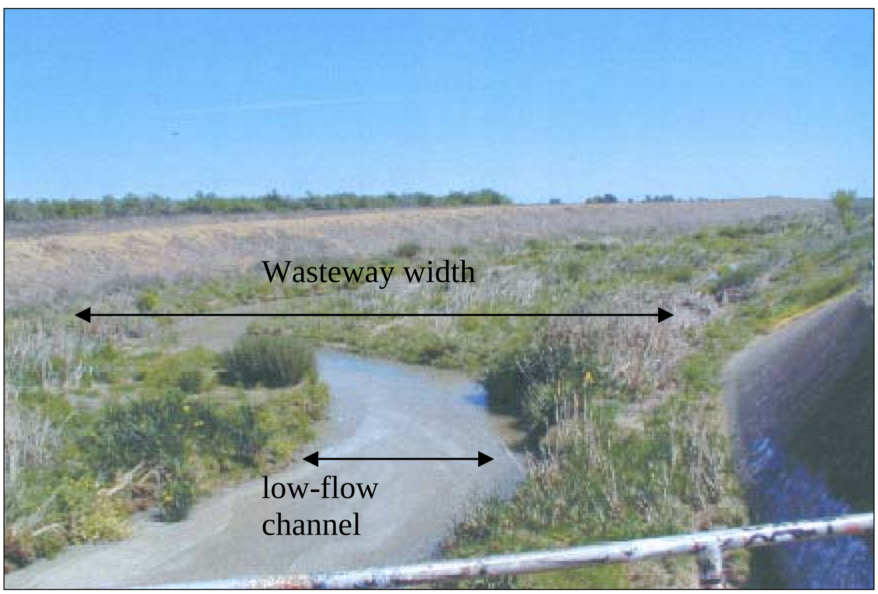



**Figure D-5. Newman Wasteway Showing Low-Flow Channel**

The HEC-RAS model was used to simulate a range of flows from 10 to 2,000 cfs, which covers the range of flows that are being considered for recirculation. **Figure D-6** shows representative water-surface profiles for the range of the flows likely to occur during recirculation. The profile is generally flat except near the culverts where the slope of the water surface profile sharply increases, due to the relatively steep slope on the culverts (between 7 and 8%) relative to the channel (< 1%). Most of the elevation lost between the DMC and the SJR is lost in the culverts. In HEC-RAS effective shear stress is calculated as:

$$\tau = \kappa\delta RS \qquad \text{(D-2)}$$

Where:

$\kappa$ = reduction factor for narrow channels (unitless)

$\tau$ = bed shear stress ($N/m^2$)

$\delta$ = specific weight of water (unitless)

R = hydraulic radius, which is equal to the flow area divided by the wetted perimeter. For wide channels it is equal to the depth of water.

S = slope of the water surface elevation (m/m)

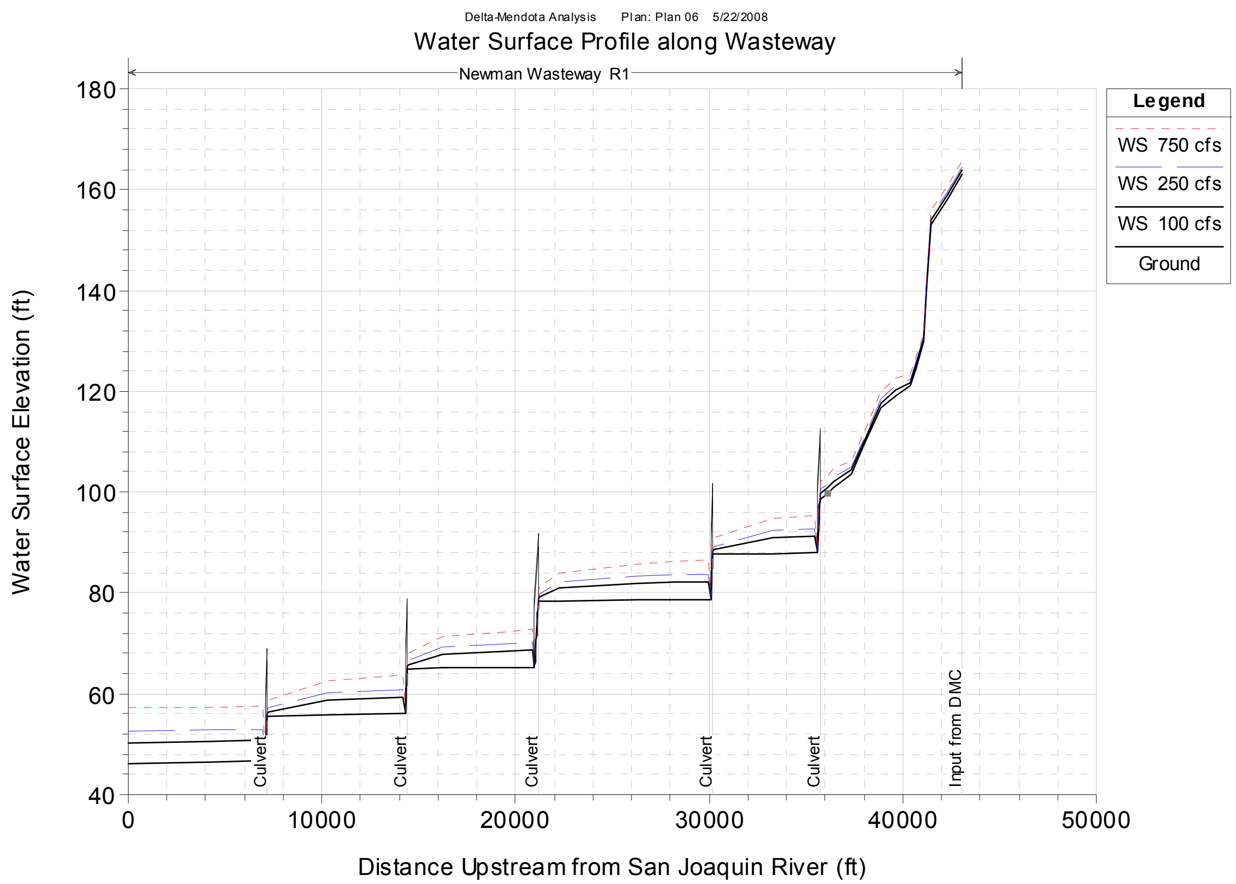



**Figure D-6. Water Surface Profiles in Newman Wasteway Calculated from HEC-RAS Model for the Range of Flows Being Considered for Recirculation**

A summary of the HEC-RAS results is provided in **Attachment D1** of this appendix. The results indicate large shear stresses just upstream of the culverts, due to the increased water surface slope. These values are excessively large and may cause significant erosion during the first instances of high flows. However, given the grade control at the culverts, the total long-term scour will be limited.

### *Critical Shear Stress and Erodibility*

Hanson and Simon (1999) used an in-situ submerged jet-testing apparatus to develop a relationship between the erodibility coefficient and critical shear stress based on soil type. **Figures D-7 and D-8** show the relationship developed by Hanson and Simon. The best-fit relationship developed by Hanson and Simon is:

$$k=0.2/\sqrt{\tau_c} \qquad \text{(D-3)}$$

**Equation D-3** was used with the pilot study data to develop the relationship between erosion and flow for the Wasteway.

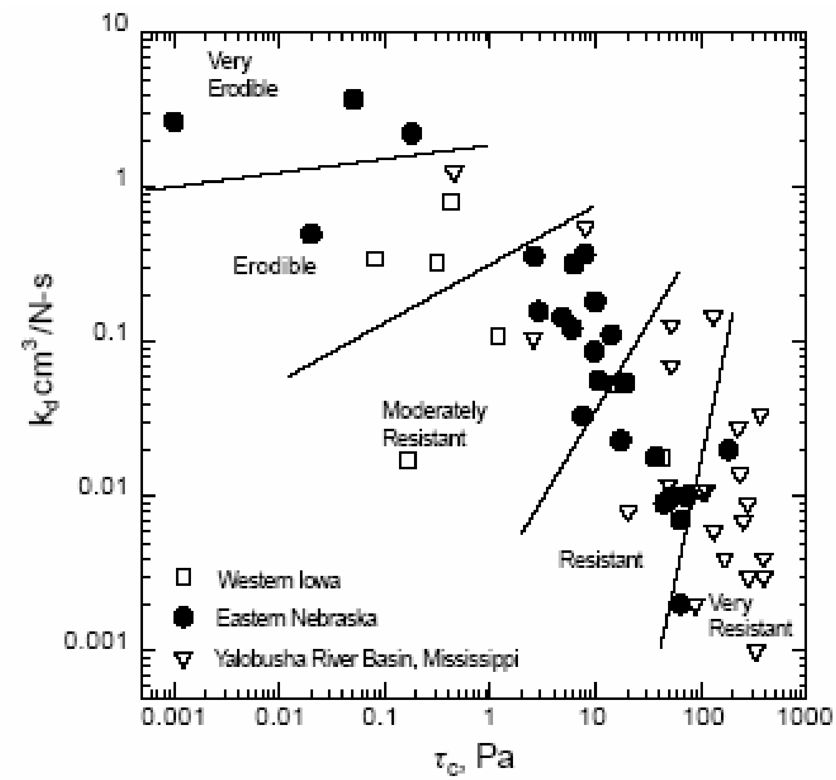



**Figure D-7. Data from Hanson and Simon (1999) Showing the Relationship Between Critical Shear Stress and Erodibility Coefficient (note: kd is equivalent to k in Equation D-3)**

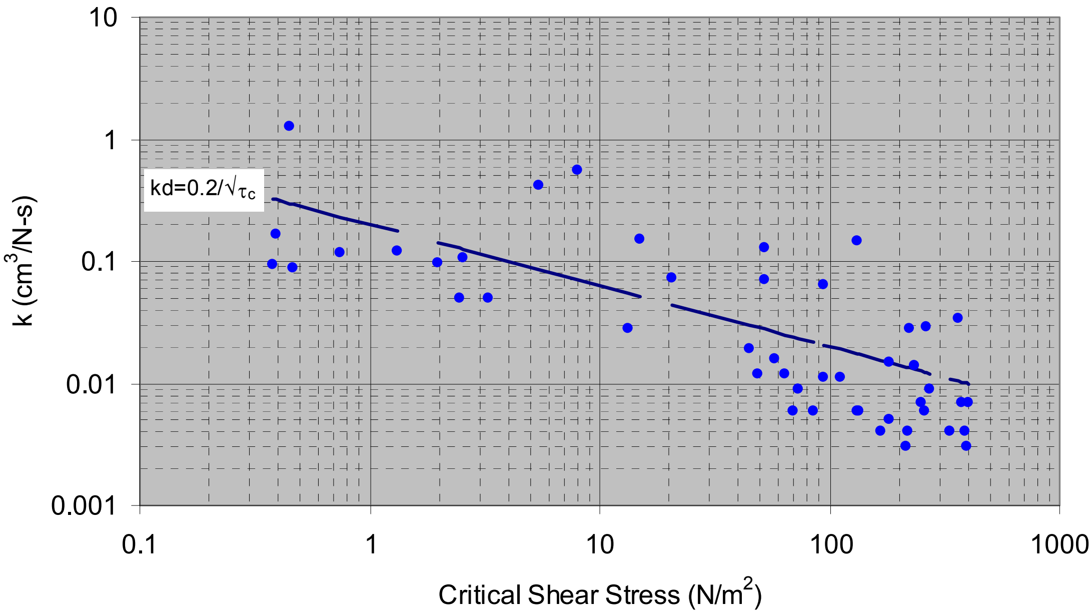



**Figure D-8. Data from Hanson and Simon (1999) Showing the Relationship Between Critical Shear Stress and Erodibility and the Data Used to Develop the Relationship**

Two pilot study datasets are available for calibration/validation of the erosion model (Equation D-1). The Recirculation Report (Bureau of Reclamation 2005) provides measured flow rates and corresponding measured TSS concentrations for the pilot study conducted during the period August 19 through 23, 2004, with one additional sample collected on August 30. The flow in the Wasteway was increased from near zero to about 250 cfs during the first 30 hours of the study and was approximately constant from then on. The flow was measured approximately once per day with more frequent measurements collected during the ramp-up period. TSS samples were collected approximately every 6 hours. Digital data were not available for the 2004 pilot study. Flow rates were estimated from Figure 12 and TSS data from Table 14 in the Recirculation Report (Bureau of Reclamation 2005). **Figure D-9** shows the data collected in the 2004 pilot study and **Table D-1** shows the data used from the 2004 pilot study.

The second dataset was collected during the second pilot study conducted from August 15 through September 12, 2007. However, large gaps exist in the TSS data: only one sample was collected during a 5-day gap between August 17 and 22, and no samples were collected during a 3-1/2 day gap between August 24 and 28 and a 7-day gap between August 28 and September 4. During other times, TSS data were collected about every 6 or 12 hours. In addition, the flow rate was not constant during the period, but varied from less than 10 to 180 cfs. However, the flow rate was maintained at about 40 cfs for much of the nonramping periods. The flow rate was increased twice during the study. The flow was ramped up from 40 to 114 cfs and back down again from August 22 to 24 and was ramped up to 180 cfs and back down again from September 4 to 7. During these two periods the data indicated that the flow was not held constant, but varied continuously. **Figure D-10** and **Table D-2** show the data from the 2007 pilot study.

For the 2004 pilot study, the flow was constant throughout most of the study so all the data could be used for calibration; however, since the flow data have very little variability, the data provide little information on how TSS varies with flow rate. However, the data do indicate that TSS can be highly variable even if the flow rate is relatively constant. From August 20 through 23 the flow was approximately constant but the TSS varied by about a factor of about 2 (from 113 to 227 milligrams per liter [mg/L]). Because the flow was variable during the 2007 pilot study, only sets of TSS and flow data that were collected within 2 hours of each other were used in the analysis.

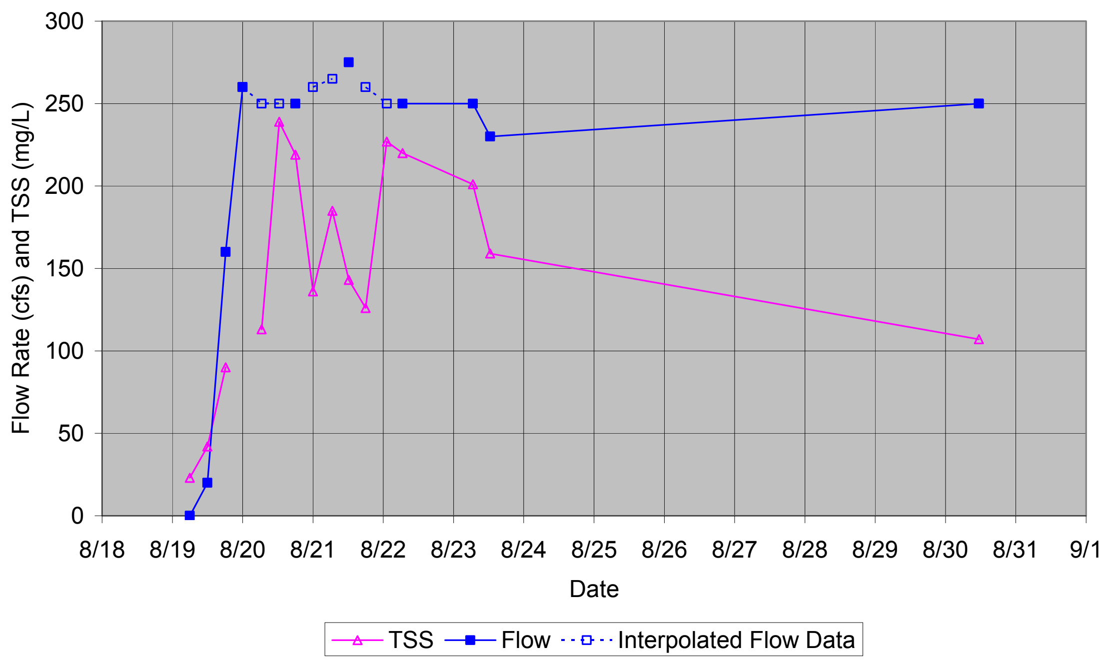



**Figure D-9. Flow and TSS Measured in Newman Wasteway During the 2004 Recirculation Pilot Study**

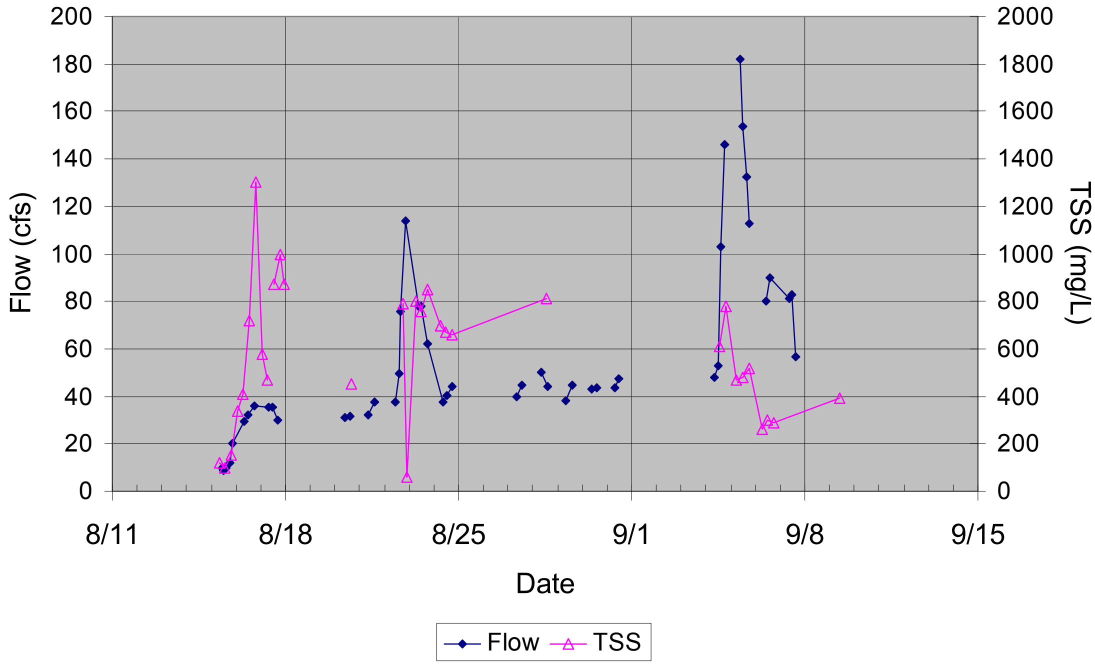



**Figure D-10. Flow and TSS measured in Newman Wasteway Near the Confluence with the San Joaquin River for the 2007 Recirculation Pilot Study (at Milepost 6.88)**

**Table D-1. TSS Concentrations Used for Erosion Study from 2004 Pilot Study**

| Date and Time | Flow (cfs) | TSS (mg/L) |
|---|---|---|
| 8/19/04 6:00 | 0 | 23 |
| 8/19/04 12:00 | 20 | 42 |
| 8/19/04 18:10 | 160 | 90 |
| 8/20/04 18:00 | 250 | 219 |
| 8/21/04 12:15 | 275 | 143 |
| 8/22/04 6:35 | 250 | 220 |
| 8/23/04 6:40 | 250 | 201 |
| 8/23/04 12:30 | 230 | 159 |

*Source: Bureau of Reclamation (2005), Table 14 and Figure 12*

**Table D-2. Measured Flow and TSS in Newman Wasteway Collected During the 2007 Pilot Study**

| Collection Date and Time | Flow (cfs) | TSS (mg/L) |
|---|---|---|
| 8/15/07 8:00 | 10.02 | 120 |
| 8/15/07 13:00 | 9.325 | 99 |
| 8/15/07 19:00 | 16.025 | 150 |
| 8/16/07 7:00 | 29.32 | 410 |
| 8/16/07 13:00 | 32.41 | 720 |
| 8/16/07 19:00 | 35.87 | 1300 |
| 8/17/07 7:00 | 35.62 | 470 |
| 8/17/07 13:00 | 35.46 | 870 |
| 8/20/07 16:00 | 31.78 | 450 |
| 8/22/07 18:00 | 94.835 | 790 |
| 8/22/07 22:00 | 114.15 | 61 |
| 8/23/07 12:00 | 77.85 | 760 |
| 8/23/07 18:00 | 61.87 | 850 |
| 8/24/07 12:00 | 40.51 | 670 |
| 8/24/07 18:00 | 44.11 | 660 |
| 8/28/07 13:00 | 44.2 | 810 |
| 9/4/07 13:00 | 53.1 | 610 |
| 9/4/07 19:00 | 146.32 | 780 |
| 9/5/07 12:00 | 153.94 | 480 |
| 9/5/07 18:00 | 112.69 | 520 |

*Source: 2007 Pilot Study (Bureau of Reclamation 2007)*

The flow rates during the 2004 pilot study were higher than the flow rates during the 2007 pilot study but the TSS concentrations were significantly lower, which is counter-intuitive since it is expected that erosion rates would increase as flow rates increase. It is possible that conditions changed between the two studies such that more erodible material was available during the 2007 pilot study than was available during the 2004 study (for example if a large storm event deposited a layer of erodible silt and clay in the Wasteway between pilot studies). However, regardless if soil conditions changed between pilot studies it is expected that TSS would increase with flow rate during a given pilot study. The relationship between flow and TSS based on the data obtained from the pilot studies are shown on **Figure D-11**. It is possible that for high flows (e.g., above 500 cfs) the two datasets could have converged, but no data are available to support this speculation. The calculations for the results shown on **Figure D-11** are provided in **Attachment D-1**.

Neither dataset is very robust with respect to developing a relationship between flow and TSS. The flow rate and TSS concentration were both relatively constant during the 2004 pilot study except during the first 12 hours when the flows were ramped up. This resulted in essentially three datapoints to develop a relationship from (20, 160, and 250 cfs). During the 2007 pilot study the flow was more variable (though lower); only four flow rates/TSS datapoints with flows greater than 100 cfs were recorded (see **Table D-2**). However, the data indicate that TSS is independent of flow for flows above about 20 cfs. Over the range of flows from 30 to 180 cfs TSS varied from about 400 to above 900 mg/L with no relationship to flow rate, again counter-intuitive since erosion rate generally increases with flow rate.

The data from both studies were used to estimate the critical shear stress by using **Equations D-1b** and **D-3** and calculating the critical shear stress for each measured TSS and flow combination, which assumes that the eroded sediment is uniformly mixed into the water column. The shear stress was calculated using the HEC-RAS model for the measured flow rate,  leaving the critical shear stress as the only unknown between **Equations D-1** and **D-3**. The data indicate relatively high TSS even for low flows. Depending upon the pilot study the TSS is around 40 to 100 mg/L for a flow of only 10 cfs. For this low-flow rate the HEC-RAS model indicates a channel shear stress of between 0.2 and 0.3 $N/m^2$ for most of the Wasteway, indicating that the critical shear stress is smaller than these values. **Equations D-1** and **D-3** were applied to each datapoint individually and the results extrapolated down to zero cfs. **Figure D-12** shows the results using the 2004 and 2007 datasets. The results of this analysis indicate a critical shear stress of about 0.2 $N/m^2$, representative of erodible to slightly resistant material.

When hydraulic conditions are such that a sediment particle is on the threshold of becoming entrained, the particle is said to be in a state of incipient motion. The incipient motion of a particle can be determined by numerous relationships. One of the most common methods uses the Shields Parameter, or Shields Curve, as shown on **Figure D-13** (ASCE 1975). Above the line shown on the figure particles are in motion; below the line particles are stable.

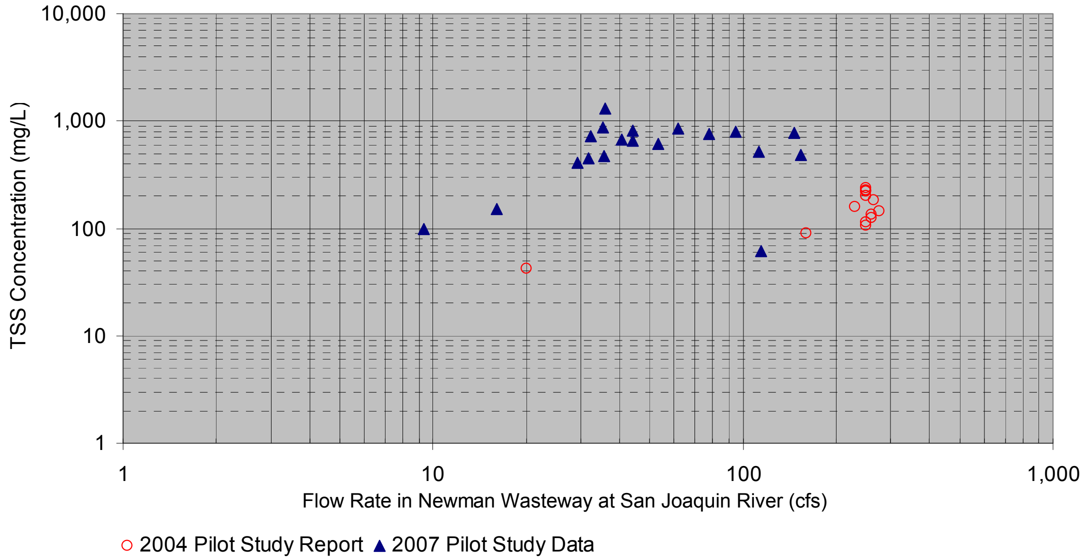



**Figure D-11. Observed Variation in TSS Concentration with Flow Rate in Newman Wasteway at the San Joaquin River for 2004 and 2007 Pilot Studies**

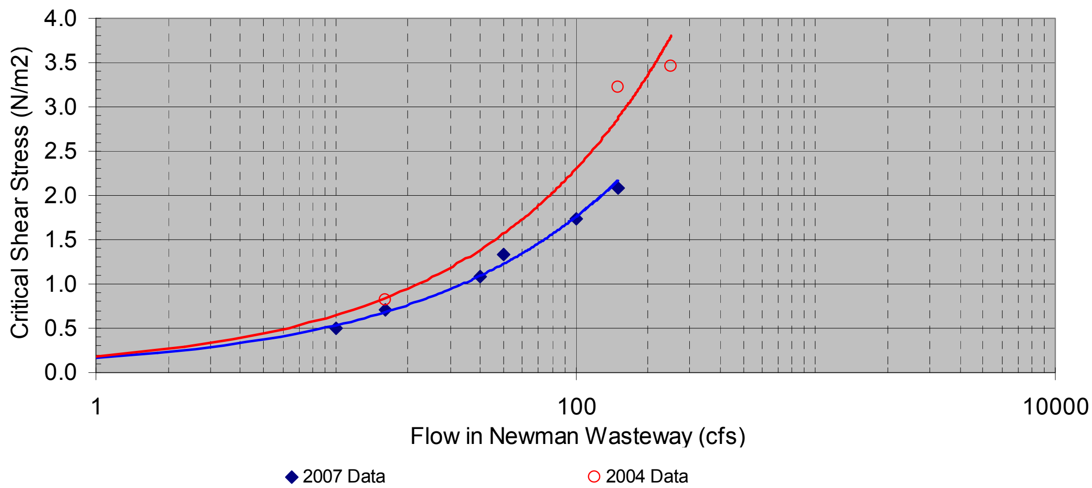



**Figure D-12. Estimation of Critical Shear Stress for Erosion**

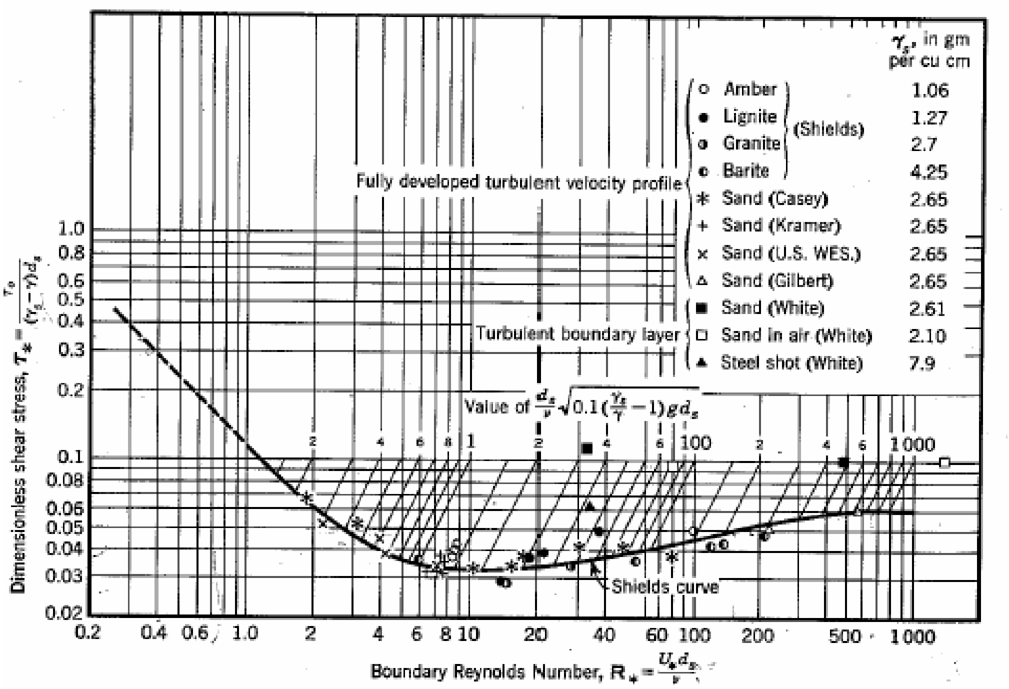



**Figure D-13. Shields Diagram (ASCE 1975)**

**Equations D-4, D-5,** and **D-6** (U.S. Army Corps of Engineers 1989) were developed to evaluate the Shields relation analytically for a range of particle diameters and for various hydraulic conditions.

$$\tau^{*} = 0.22\beta + 0.06x10^{-7.7\beta} \qquad \text{(D-4)}$$

$$\beta = \left( \frac{1}{\nu} \sqrt{\frac{\gamma_s - \gamma}{\gamma} g d^{3}} \right)^{-0.6} \qquad \text{(D-5)}$$

$$\tau_c = \tau^{*}(\gamma_s - \gamma)d \qquad \text{(D-6)}$$

Where:

τ* = dimensionless shear stress

γ = specific weight of water

γs = particle specific weight

ν = kinematic viscosity

G = acceleration of gravity

D = particle diameter

Using the Shields diagram a critical shear stress of 0.2 $N/m^2$ corresponds to a particle size of about 380 microns or a fine to medium sand. Based on the sediment data collected during the 2007 pilot study, over 95% of the bed sediments in the Wasteway are smaller than this size and are therefore erodible.

Typically, when using **Equation D-1** both the critical shear stress and the erodibility are constants, based on soil properties, which is the basis for Hanson and Simon's results shown on **Figure D-7**. The data from each pilot study were used to estimate the erodibility using a critical shear stress of 0.2 $N/m^2$ (as opposed to using **Equation D-3**). A "best fit" value for erodibility was calculated using data from each of the pilot studies by adjusting the value of erodibility until the difference between the measured and predicted TSS was minimal. **Figure D-14** presents the results. The results are unusual in that the TSS concentration does not vary significantly with flow rate, due to the small values of erodibility required to match the measured data. A value of 0.002 $cm^3/N/s$ was used for the 2004 data and 0.0085 $cm^3/N/s$ was used for the 2007 data. These values are typical for erosion of resistant soils (see **Figure D-7**). The maximum flow rate from the pilot studies was about 250 cfs released during the 2005 study. In concept if the correct values for erodibility and critical shear stress are used in **Equation D-1,** the results from this study should apply to flow rates larger than observed during the pilot studies. However, given the discrepancies between the two pilot study results and the unusual results obtained from the pilot studies (little relationship between flow and TSS), the model results should be extrapolated with caution and additional data, at higher flow rates, should be obtained.

To test the sensitivity of the erodibility to the choice of critical shear stress the same analysis was conducted using a critical shear stress of 0.50 $N/m^2$ (the value estimated for the smallest observed flow rate). This test had no significant effect on the erodibility. Note that typically the critical shear stress and erodibility should be compatible with each other; that is, a soil that is easy to erode will erode at a high rate (large erodibility) and a soil that is difficult to erode will erode at a low rate (low erodibility). The results from fitting the model to the pilot study data do not follow this pattern. The soils in the Wasteway are fairly easy to erode, as evidenced by the high TSS concentrations for even low-flow rates. However, as the flow rate increases the TSS does not increase, indicating that the soil does not erode at a high rate.

In general, shear stress increases as flow squared, so the volume of material eroded should increase faster than the flow rate; thus, the TSS increases with increasing flow. However, shear stress was calculated from the HEC-RAS model, which results in a slower rate of increase in shear stress since the depth of water is also increasing with flow. The counter-intuitive results of the model, i.e., the TSS decreases as flow increases for flows above about 250 cfs, are due to the sediment source becoming limiting at high flows. For long-term releases and/or releases at high flow rates after vegetation is scoured out, the sediment source may not be limiting, in which case the TSS concentration would increase with increasing flow. For this report a constant value of concentration was used for flow above 200 cfs equal to the maximum calculated value of 131.5 mg/L. This assumption should be reviewed after more data are collected.

During application of the recirculation project, the flow released down the Wasteway could vary from about 150 to almost 2,000 cfs and could be held constant for several weeks or more. The pilot study conducted in 2004 more closely matches the actual prototype conditions. During the 2007 pilot study the flow was varied often, and when held constant was held at only about 40 cfs, far below the flows that will be used in the prototype conditions. Therefore, the results from the 2004 study were used in sediment analysis.

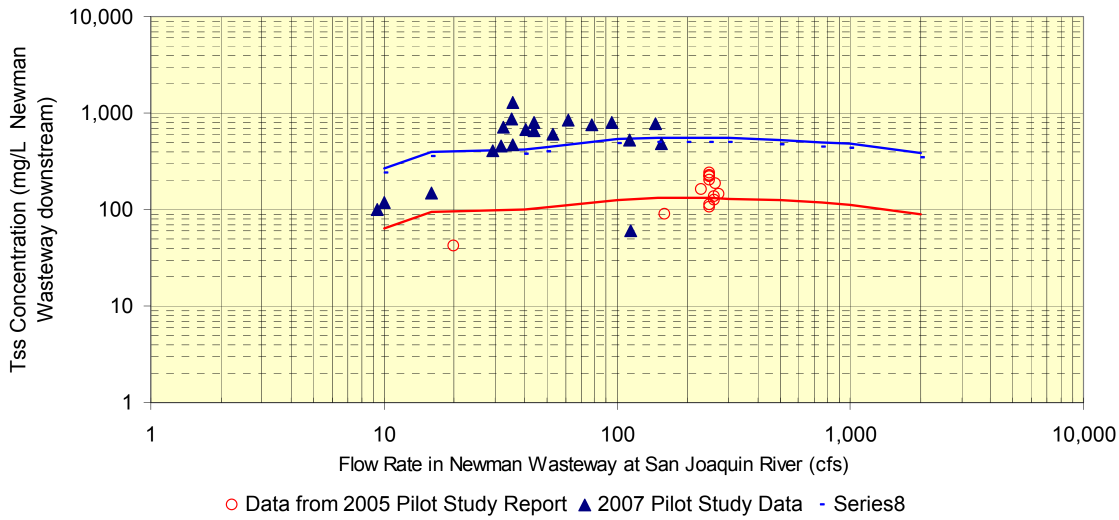



**Figure D-14. Variation in TSS Concentration in Newman Wasteway at the San Joaquin River for 2004 and 2007 Pilot Studies and Predicted Values using Equation D-1 with Best Fit Parameters**

**Table D-3** presents the erosion rates, TSS concentration, and flow rates modeled in the Wasteway. The erosion rate was calculated using **Equation D-1** written in the form:

$$\frac{E}{\rho_s(1-\theta)} = k(\tau - \tau_c) \qquad \text{(D-1c)}$$

Where E is now a volume erosion rate in units of $m^3/s$. Dividing by the surface area of the Wasteway results in the values shown in **Table D-3**.

**Table D-3. Estimated TSS Concentrations and Erosion Rates for the Range of Flows Expected for Recirculation**

| Flow Rate (cfs) | Concentration (mg/L) | Erosion Rate (inches/day) |
|---|---|---|
| 10 | 63.2 | 4.81E-04 |
| 16 | 93.8 | 1.14E-03 |
| 40 | 99.1 | 3.01E-03 |
| 50 | 104.5 | 1.39E-03 |
| 100 | 125.3 | 3.34E-03 |
| 150 | 130.7 | 5.22E-03 |
| 200 | 131.5 | 7.01E-03 |
| 250 | 131.5 | 8.70E-03 |
| 300 | 131.5 | 1.03E-02 |
| 500 | 131.5 | 1.64E-02 |
| 750 | 131.5 | 2.34E-02 |
| 1000 | 131.5 | 2.98E-02 |
| 2000 | 131.5 | 4.79E-02 |

Estimates calculated from HEC-RAS Analysis (critical shear stress = 0.20 $N/m^2$, erodibility = 0.0020 $m^3/N/s$, based on 2004 pilot study)

## D.2.2 Average Plume Concentration in the San Joaquin River

Sediment that is eroded from the Wasteway will be discharged into the SJR and transported downstream. Two simple models were developed, one to estimate the average TSS concentration in the sediment plume generated by the Wasteway discharge and the second to estimate the lateral profile of TSS concentration across the SJR at a given location. This section of the report describes the assumptions used in these analyses.

A simple mass balance model was developed to estimate the average TSS concentration in the plume downstream of the Wasteway discharge. The mass balance is based on **Equation D-7**:

$$C_d = \frac{C_w Q_w + C_{sjr} Q_{sjr} f}{Q_w + Q_{sjr} f} \quad \text{(D-7)}$$

Where:

$C_d$ = average TSS concentration in the plume downstream of the confluence with the Wasteway (mg/L)

$C_w$ = TSS concentration in the Wasteway at its mouth (mg/L)

$C_{sjr}$ = TSS concentration in the SJR above the confluence with the Wasteway (mg/L)

$Q_w$ = flow in the Wasteway (cfs)

$Q_{sjr}$ = flow in the SJR above the confluence with the Wasteway (cfs)

f = fraction of the SJR occupied by the Wasteway plume (ft/ft)

TSS concentration in the Wasteway at its mouth ($C_w$) is predicted by the erosion model described in **Section D2.1**, based on the recirculation flow rate predicted to occur for each alternative plan during the time period evaluated. The flows in the Wasteway and the SJR ($Q_w$ and $Q_{sjr}$) were predicted for each recirculation alternative plan using California Simulation Model II (CalSim II) listed and discussed in **Appendix A**. The TSS concentration in the SJR above the confluence ($C_{sjr}$) was estimated as equal to the average TSS concentration measured monthly by the Central Valley Regional Water Quality Control Board at Fremont Ford Station from 2000–2006.

The fraction of the river width occupied by the Wasteway plume just below the Wasteway discharge was estimated by assuming that the Wasteway discharge acts as a simple jet discharging into a river. In this case the jet (i.e., Wasteway discharge) extension into the river is a multiple of the crossflow length scale before it is bent downstream. The crossflow length scale is defined as (Fisher et al. 1979):

$$l_c = \sqrt{D_w W_w}\,\frac{u_o}{V_{sjr}} \qquad \text{(D-8)}$$

Where:

$l_c$ = cross-flow length scale (feet)

$D_w$ = depth of the water in the Wasteway (feet)

$W_w$ = width of the Wasteway (feet)

$u_o$ = velocity in the Wasteway (ft/s)

$V_{sjr}$ = velocity in the SJR (ft/s)

Results from Muppidi and Mahesh (2005) for round jets into a crossflow indicate the discharge has started to turn towards the direction of flow in the river when $l_c$ exceeds 1 and is mostly turned in the direction of the river flow within 2 to 3 times the crossflow length scale. This conclusion is consistent with results on jet trajectory provided in Chu and Jirka (1986). A value of 3 times $l_c$ was used in the calculations to be conservative since it will result in a plume from the Wasteway that occupies the largest portion of the river.

$$b = 3l_c \qquad \text{(D-9)}$$

where b is the width of the source of sediment in the SJR at the confluence with the Wasteway (i.e., distance the Wasteway discharge extends into the SJR). The fraction of the SJR that is occupied by the Wasteway plume just below the Wasteway (f in Equation D-7) is then $b/W_{sjr}$, where $W_{sjr}$ is the width of the SJR.

The velocity and width of flow in the Wasteway were calculated by the HEC-RAS model described in **Section D2.1**. To use the results in the spreadsheet model a curve was fit to the results derived from the HEC-RAS model. The derived curves are shown on **Figure D-15**. The equations used are shown in **Table D-4**.

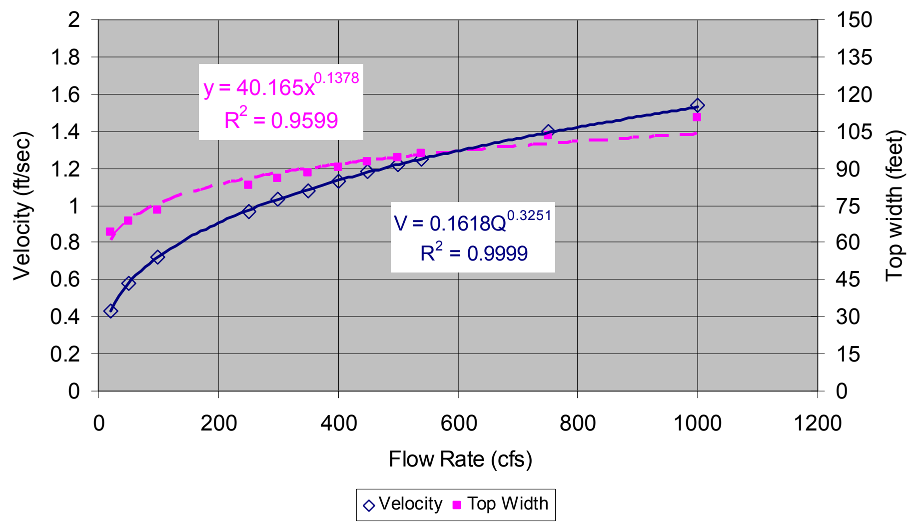



**Figure D-15. Velocity and Width at the Mouth of Newman Wasteway Based on HEC-RAS Model Output**

**Table D-4. Equations Used in Model of Sediment Transport in the San Joaquin River**

| Parameter | Equation | Source |
|---|---|---|
| Velocity in the Wasteway | $u_o = 0.1618 Q_w^{0.3251}$ | Developed using HEC-RAS results |
| Width of flow in the Wasteway | $W_w = 40.165 Q_w^{0.1378}$ | Developed using HEC-RAS results |
| Width in the SJR above Merced River | $W_{sjr} = 32.626(Q_{sjr} + Q_w)^{0.235}$ | Based on Data from Fremont Ford Gauge |
| Depth in the SJR | $D_{sjr}=0.1206(Q_{sjr} + Q_w)^{0.4921}$ | Based on Data from Fremont Ford Gauge |
| Velocity in the SJR | $V_{sjr} = 0.3639 Q_{sjr}^{0.2034}$ | Based on data measured at Newman Gauge |
| Width of SJR below Merced River | $W_n=25.05Q^{0.293}$ | Based on Newman Gauge since 2005, earlier values indicated narrow river |
| Width of the plume in the SJR | $L = b\sqrt{1+\frac{24\varepsilon_t x}{V_{sjr} b^2}}$ | Grace (1978) |
| Lateral dispersion coefficient | $e_t = C_k D u^*$ | Fisher et al. (1979) |
| Shear velocity | $u^* = \sqrt{gDs}$ | Fisher et al (1979) |
| Settling velocity | $V_s= \frac{gd^2(\gamma_p - 1)}{18\nu}$ | Thomann and Mueller (1987) |
| Distance for complete mixing | $L = 0.4 V_{sjr} W_n^2 / e_t$ | Fisher et al. (1979) (assumes a point source so may overestimate distance) |
| Decay rate | $k=V_s/D$ | |

**Table D-4. Equations Used in Model of Sediment Transport in the San Joaquin River**

| Parameter | Equation | Source |
|---|---|---|
| Variable definitions | $u_o$ = velocity in Wasteway<br>$Q_w$ = flow in Wasteway<br>$Q$ = flow in SJR below Merced confluence<br>$W_w$ = width of Wasteway<br>$W_{sjr}$ = Width of the SJR<br>$D_{sjr}$ = Depth of the SJR<br>$V_{sjr}$ = velocity in the SJR<br>$L$ = width of plume in SJR<br>$\varepsilon_t$ = lateral dispersion coefficient<br>$x$ = distance downstream<br>$C_k$ = factor to account for meandering,<br>= 0.6 if sinuosity <1.3<br>= 1 if 1.3 < sinuosity < 1.6<br>= 2 if sinuosity > 1.6<br>$b$ = width of plume at its source<br>$u^*$ = shear velocity<br>$g$ = gravitational acceleration<br>$D$ = depth of water<br>$s$ = slope of river<br>$Vs$ = particle settling velocity<br>$d$ = particle diameter<br>$g$ = specific weight of particle of particle<br>$\nu$ = kinematic velocity | |

The average depth in the Wasteway was calculated from the flow, width, and velocity to maintain consistency between the flow parameters in the Wasteway.

$$D_w = \frac{Q_w}{W_w}\frac{1}{u_o} \qquad \text{(D-10)}$$

The width and velocity of the SJR ($W_{sjr}$ and $V_{sjr}$) were estimated from data on flow rate, velocity, width, and average cross-sectional area in the SJR measured by the U.S. Geological Survey since early in the 20$^{th}$ century. These data were used to develop relationships between the flow in the SJR and the velocity, width, and depth. The equations used in the analysis were based on Newman Gauge because of its distance from the Wasteway. The equations used in the analysis are shown in **Table D-4**. They are based on the data measured from 2000 through 2007. The curves derived are shown on **Figures D-16, D-17, and D-18**. A curve developed from the data collected at the U.S. Geological Survey gauge at Fremont Ford located just above 6 miles upstream of the Wasteway is also included on some figures for comparison.

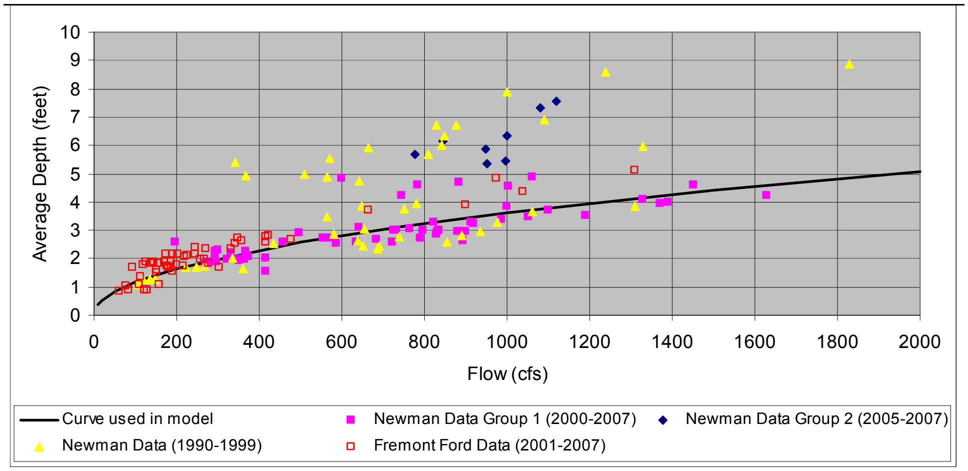



**Figure D-16. Regression Used to Estimate Depth in the San Joaquin River**

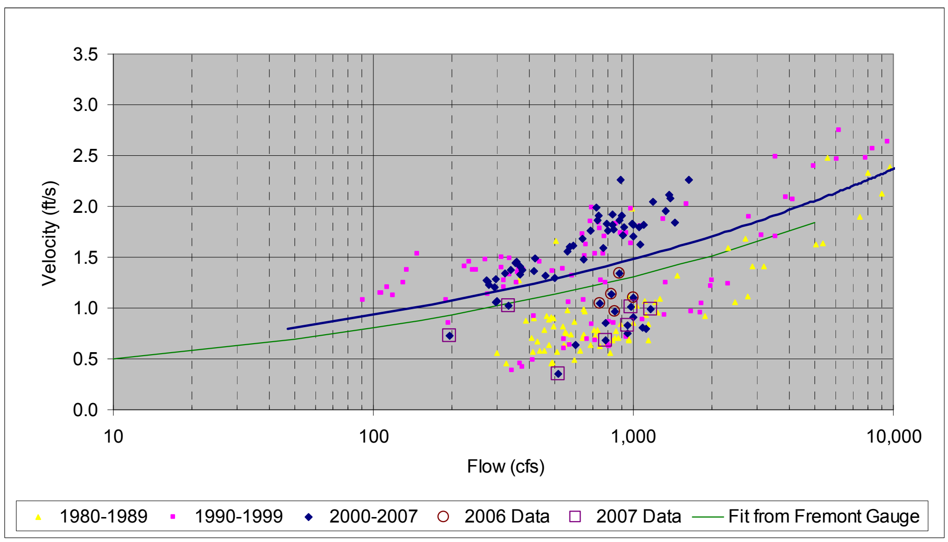



**Figure D-17. Velocity in the San Joaquin River at Newman Gauge**

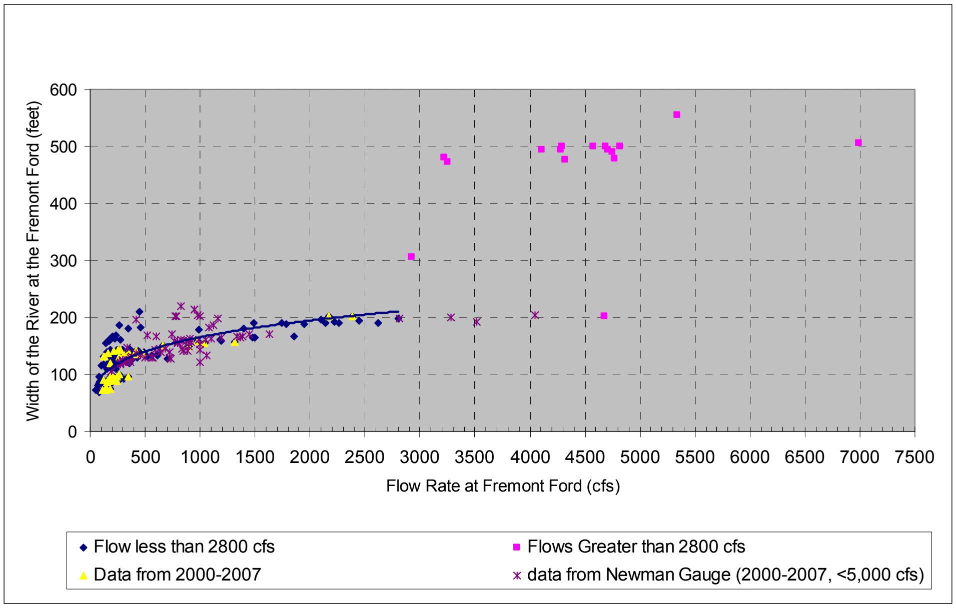



**Figure D-18. Average Width of the San Joaquin River Measured at Fremont Ford Gauge for U.S. Geological Survey Data Collected between 1976 and 2007**

The velocities measured in the 1980s were lower than most of the velocities measured in the 2000 to 2007 period. However, the velocities measured during the period from 2005 to present were grouped with the 1980 data. Most of the data from the 1990s to 2005 are grouped together, indicating that more than one low-flow channel may be occupied by the SJR. Since future conditions are unknown, both groups of data collected from 2000 to present were kept together. The equations used for the width, depth, and velocity in the SJR are based on all data available from 2000–2007, and are shown in **Table D-4**.

The width of the plume (used to calculate parameter f in Equation D-7) was calculated using the Brooks model for dispersion of a finite length line source (as reported in Grace 1978 and Socolofsky and Jirka 2002) for locations downstream of the confluence with the Wasteway.

For homogeneous turbulence (dispersion = constant) the concentration in the SJR from the Brooks model is:

$$\frac{C(x,y)}{C_o} = \frac{e^{\frac{kx}{Vsjr}}}{2}\left(erf\left(\frac{y+\frac{b}{2}}{2}\sqrt{\frac{V_{sjr}}{e_t x}}\right) - erf\left(\frac{y-\frac{b}{2}}{2}\sqrt{\frac{V_{sjr}}{e_t x}}\right)\right) + C_b/C_0 \qquad \text{(D-11)}$$

Where: (note any consistent set of units is acceptable)

C(x,y) = concentration at location x,y (mg/L)

$C_0$ = concentration of the source; for the SJR transport $C_o$ equals $C_d$ from **Equation D-7** (mg/L)

$C_b$ = background concentration; equivalent to $C_{sjr}$ for the SJR upstream of the Merced River (mg/L)

k = decay rate (1/s)

y = lateral distance from center of source b (feet)

x = distance downstream (feet)

b = width of the source (feet)

$e_t$ = dispersion coefficient ($ft^2/s$)

$V_{sjr}$ = velocity in the SJR (ft/s)

It is assumed in **Equation D-11** that the distribution of concentration across the plume has a normal or Gaussian profile. The width of the plume is assumed to be equal to:

$$L(x) = 2\sqrt{3}\sigma \qquad \text{(D-12)}$$

where σ is the standard deviation of the Gaussian profile. A width equal to **Equation D-12** has 91.7% of the mass within the plume. In terms of the parameters used in the analysis, the width of the plume is equal to (Grace 1978):

$$L = b\sqrt{1 + \frac{24 e_t x}{V_{sjr} b^2}} \qquad \text{(D-13)}$$

The f term in **Equation D-7** is then:

$$f = L/W_{sjr} \qquad \text{(D-14)}$$

where $W_{sjr}$ = width of the river (feet)

Below the confluence of the Merced River and the SJR, the procedure for calculating the average TSS concentration in the plume is the same as above. However, the parameters used are representative of the conditions below the confluence with the assumption that the plume is fully mixed across the SJR just above the confluence. Although the TSS concentration may not be completely uniform across the SJR, the plume under almost all cases that were evaluated was predicted to occupy the entire SJR width. With this assumption, the width of the source (variable "b" in Equations D-11 and D-12) is replaced with the width of the SJR above the confluence. The other variables in Equations D-11 and D-12 are then calculated using information from below the confluence (e.g., velocity, width, depth).

The sediment contributed by the Wasteway was assumed to settle as it is transported down the SJR. Note that no settling was assumed to occur in the Wasteway, it was assumed that all sediment eroded in the Wasteway would discharge to the SJR. To the extent that sediment does resettle in the Wasteway the concentrations predicted by the model would be overestimates. The fraction of sediment that settles was calculated using Equation D-15 below:

Fraction settled = $e^{-kx/v}$ (D-15)

Where:

k = decay rate (1/s)

= $V_s/D_{sjr}$

$V_s$ = settling velocity (ft/s)

$D_{sjr}$ = depth of river (feet)

x = distance downstream (feet)

The settling velocity was calculated using Stokes Law (Thomann and Mueller 1987):

$$V_s = gd^2 \frac{(\gamma_p - 1)}{18\upsilon} \quad \text{(D-16)}$$

Where:

g = acceleration due to gravity ($ft/s^2$)

d = particle diameter (ft)

$\gamma_p$ = specific weight of particle, assumed to be 2.65

ν = kinematic viscosity ($ft^2/s$)

$V_s$ = settling velocity (ft/s)

Because the objective of this analysis is to estimate the changes in the TSS concentrations in the SJR due to recirculation, the model does not explicitly account for settling or resuspension of the sediment that would already be present in the SJR in the absence of recirculation (represented by the $C_{sjr}$ term in Equation D-7 and the TSS concentration in the Merced River). Essentially, it is assumed that the rates of settling and resuspension are in steady state conditions for the reach of the SJR evaluated, with no net settling or resuspension of sediment contributed. If it is assumed that the sediment contributed by the Wasteway settles (and not the sediment already in the SJR) and no additional sediment is eroded by the SJR, the concentration of sediment in the SJR would eventually decrease below "baseline" concentrations due to dilution from the Wasteway (i.e., the water is "clean" after all the sediment has settled out). This scenario is not realistic, so it was assumed that sufficient sediment would erode in the SJR due to the extra flow from the Wasteway such that the concentration in the SJR would not go below the concentration in the SJR above the confluence with the Wasteway.

It was assumed that the sediment leaving the Wasteway consisted of two particle sizes, silts and clays, as any sand that eroded would likely settle out quickly. To determine the median size and percentage of each size class to be used in the model, two surface sediment samples were collected in the Wasteway on October 17, 2007. The first sample, DMC-1, was taken at Milepost 6.88, just above the last drop structure in the Wasteway. The second sample, DMC-2, was taken further upstream at Milepost 6.25. Results of the sediment sampling analysis are provided in **Table D-5**. The estimated median sizes of silt and clay particles, 11.5 and 1.5 μm, respectively, were used in the model. It was assumed that silt would comprise 85% and clay would comprise 15% of the suspended sediment (silt and clay fraction), based on the proportion present in the samples collected.

#### *Lateral Concentration Profile in the San Joaquin River*

The lateral concentration of TSS in the SJR was calculated using the Brooks model as shown in **Equation D-11**.

For the analysis results presented below it was assumed that only the sediment contributed by the Wasteway was able to settle, not the sediment in the SJR or the Merced River. Therefore, instead of calculating the actual concentration in the river using **Equation D-11** the model was used to calculate the excess TSS concentration above a background value $C_b$ in **Equation D-11**. The value of $C_b$ is $C_{sjr}$ above the confluence with the Merced River and the concentration in the Merced River ($C_m$) below the confluence.

The Brooks model (**Equation D-11)** assumes constant parameters but the parameters are different above and below the confluence with the Merced River (e.g., velocity and dispersion coefficient). To account for this difference, model parameters (e.g., velocity, dispersion coefficient) representative of the river above the confluence were used for locations above the confluence, and parameters representative of the river below the confluence were used when calculating the lateral concentration for locations below the confluence with the Merced River. Since the model assumes constant parameters, for locations below the confluence the origin for the analysis (i.e., the point distances are measured from) was moved to the confluence. The value for $C_o$ in this case is the concentration at the Merced confluence rather than at the Wasteway confluence.

The value of $C_o$ in **Equation D-11** is typically a constant. However, because only the sediment contributed by the Wasteway was allowed to settle, the value of $C_o$ was adjusted at each distance from the Wasteway such that the average excess concentration (that is the concentration in the SJR contributed by the

Wasteway) calculated using **Equation D-11** equaled the average excess concentration calculated as described in **Section D2.2**.

The Brooks model, **Equation D-11**, assumes infinite room for the plume to expand. In the case of the SJR, the dispersion of the plume is restricted by the river banks. This restriction is accounted for by assuming an “image” source exists opposite each river bank at an equal distance from the bank as the real source (Fisher et al. 1979). This “image” source results in zero flux of sediment at each bank thus restricting the dispersion of sediment to between the two river banks.

# D.3 Results

## D.3.1 San Joaquin River Average River TSS Concentration

Five different water year types are modeled for the DMC Recirculation Plan Formulation Report for existing conditions and future levels of development for the alternative plans (A1, A2, B1, B2, C, and D) and for no project conditions (the No-Project Alternative and the No-Action Alternative). Water year types include Wet, Above Normal, Below Normal, Dry, and Critical. Water quality data for Water Years 1997 through 2006 were grouped by water year type.

The San Joaquin River Index from the California Department of Water Resources was used to determine water year types. The reconstructed San Joaquin Valley Index classifies Water Years 1901 through 2007. Official San Joaquin Valley Index water year classifications occur from 1995 through 2007 (California Department of Water Resources 2007). Based on the index, selected water years were classified as Critical, Dry, Below Normal, Above Normal, or Wet.

Flow output from the SJR CalSim II model (**Appendix A** of the Plan Formulation Report) was used as the input flow data for the TSS models. CalSim II flow output is in a monthly time step, with April and May flow separated into pulse and nonpulse time periods. The CalSim II flow output includes existing conditions (the No-Project Alternative), future conditions (the No-Action Alternative), and all alternative plans under a future level of development (A1, A2, B1, B2, C, and D). For the TSS model, representative years were selected for each water year type (1993, 1963, 2003, 2002, and 1992, which correspond to Wet, Above Normal, Below Normal, Dry, and Critical, respectively). These years were selected as representative because recirculation flow was modeled by CalSim II to occur in these years under the future level of development. Only those time periods for which recirculation was predicted to occur under at least one alternative plan were modeled.

**Table D-6** summarizes the time periods, inputs and results for No-Action Alternative and each alternative plan modeled. The inputs include the flow and TSS concentrations in the Wasteway, SJR, and the Merced River. The results include the estimated TSS concentrations at the confluence of the Wasteway and the SJR ($C_o$), immediately downstream of the Wasteway confluence (100 feet), immediately above and below the confluence of the Merced River (6,500 and 7,000 feet, respectively), the fully mixed concentration downstream of the Merced River (distance varies), and the concentration at the confluence of the Tuolumne River (165,000 feet) (locations shown on **Figure D-1**). Also presented in **Table D-6** are the calculated distances downstream where the SJR is fully mixed (the TSS contributed by the Wasteway is uniformly distributed across the SJR), the fraction of initial silt and clay particles remaining in the water column at the Tuolumne River, as well as the calculated percent of total sediment contributed by recirculation that would remain in the SJR at that same point.

**Table D-5. Particle Size Distribution of Silt and Clay in Newman Wasteway Samples DMC-1 and DMC-2**

| | | phi Size | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | <-1 | -0.5 | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 | 4.5 | 5 | 5.5 | 6 | 6.5 | 7 | 7.5 | 8 | 8.5 | 9 | 9.5 | 10 | 10.5 | 11 | 11.5 | >12 |
| | | Microns | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | >2000 | 1410 | 1000 | 710 | 500 | 354 | 250 | 177 | 125 | 88.4 | 62.5 | 44.2 | 31.3 | 22.1 | 15.6 | 11.1 | 7.8 | 5.5 | 3.9 | 2.8 | 1.95 | 1.38 | 0.98 | 0.69 | 0.49 | 0.35 | <0.24 |
| **Sample ID** | **Lab Rep.** | coarse sand | coarse sand | med sand | med sand | med sand | med sand | fine sand | very fine sand | very fine sand | very fine sand | very fine sand | very fine sand | course silt | course silt | course silt | silt | fine silt | very fine silt | very fine silt | clay | clay | clay | clay | clay | clay | clay | clay |
| DMC-1 | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.69 | 2.85 | 6.53 | 8.94 | 9.51 | 8.93 | 8.34 | 8.23 | 8.34 | 8.21 | 7.93 | 6.42 | 4.74 | 3.06 | 2.43 | 1.50 | 0.89 | 0.88 | 0.85 | 0.57 | 0.15 | 0.00 |
| DMC-1 | 2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.97 | 3.43 | 7.16 | 9.55 | 9.87 | 8.89 | 8.03 | 7.86 | 7.98 | 7.87 | 7.59 | 6.16 | 4.56 | 2.96 | 2.35 | 1.45 | 0.87 | 0.84 | 0.81 | 0.55 | 0.15 | 0.00 |
| DMC-1 | average | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.83 | 3.14 | 6.85 | 9.25 | 9.69 | 8.91 | 8.19 | 8.04 | 8.16 | 8.04 | 7.76 | 6.29 | 4.65 | 3.01 | 2.39 | 1.48 | 0.88 | 0.86 | 0.83 | 0.56 | 0.15 | 0.00 |
| DMC-2 | 1 | 0.00 | 0.00 | 0.00 | 0.05 | 1.06 | 5.21 | 13.05 | 15.88 | 12.97 | 8.73 | 6.05 | 4.82 | 4.51 | 4.45 | 4.32 | 4.29 | 3.77 | 3.09 | 2.20 | 1.84 | 1.17 | 0.72 | 0.68 | 0.65 | 0.45 | 0.03 | 0.00 |
| Estimated Median Grain Size (microns) | | NA (sand fraction not used in model) | | | | | | | | | | | | 11.5 | | | | | | | 1.5 | | | | | | | |
| Percent of Total | | 57% | | | | | | | | | | | | 36% | | | | | | | 6.30% | | | | | | | |
| Percent of Silt+Clay Fraction | | NA (sand fraction not used in model) | | | | | | | | | | | | 85% | | | | | | | 15% | | | | | | | |

### Table D-6. Summary of Inputs and Results for Each Alternative Plan Modeled

| Description of Alternative Plans | | | | Newman Wasteway Inputs | | San Joaquin River Inputs | | Merced River Inputs | | Results | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Water Year | Representative Year | Month | Alternative Plan | Flow Rate | TSS Conc. | Flow Rate | TSS Conc. | Flow Rate | TSS Conc. | TSS Conc. in SJR at NWW Mouth | TSS Conc. Below Conflu-ence of NWW (100 ft) | TSS Conc. Above Merced Confluence (6,500 ft) | TSS Conc. Below Conflu-ence of Merced (7,000 ft) | TSS Conc. at Tuolumne River (165,000 ft) | TSS Conc. Fully Mixed after Merced | Distance Downstream Fully Mixed | Fraction Clay Remaining at Tuolumne River | Fraction Silt Remaining at Tuolumne River | Percent of Wasteway Sediment Remaining In Water Column at Tuolumne River |
| | | | | Qw | Cw | Qsjr | Csjr | Qm | Cm | Co | | Cabv | | | Cmf | | | | (31.23 Miles) |
| | | | | cfs | mg/L | cfs | mg/L | cfs | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | miles | | | % |
| Wet | 1993 | March | NAA,A1,A2 | 0 | 0 | 1316 | 58 | 438 | 11 | 58 | 58 | 58 | 49 | 47 | 47 | 4.61 | NA | NA | NA |
| | | | B1,B2 | 332 | 132 | 1316 | 58 | 438 | 11 | 101 | 90 | 70 | 60 | 49 | 60 | 4.64 | 0.88 | 0.00 | 13 |
| | | | C | 471 | 132 | 1316 | 58 | 438 | 11 | 103 | 95 | 74 | 64 | 50 | 65 | 4.65 | 0.88 | 0.00 | 13 |
| | | | D | 469 | 132 | 1316 | 58 | 438 | 11 | 103 | 95 | 74 | 64 | 50 | 65 | 4.65 | 0.88 | 0.00 | 13 |
| | | April 1-15 | NAA,A1,A2,B1,B2 | 0 | 0 | 731 | 71 | 7 | 14 | 71 | 71 | 71 | 70 | 70 | 70 | 4.46 | NA | NA | NA |
| | | | C | 1908 | 132 | 731 | 71 | 7 | 14 | 122 | 121 | 112 | 112 | 86 | 114 | 4.68 | 0.91 | 0.00 | 14 |
| | | | D | 1907 | 132 | 731 | 71 | 7 | 14 | 122 | 121 | 112 | 112 | 86 | 114 | 4.68 | 0.91 | 0.00 | 14 |
| | | May 16-31 | NAA,A1,A2,B1,B2 | 0 | 0 | 479 | 79 | 65 | 5 | 79 | 79 | 79 | 70 | 70 | 70 | 4.41 | NA | NA | NA |
| | | | C,D | 335 | 132 | 479 | 79 | 65 | 5 | 118 | 113 | 96 | 88 | 74 | 93 | 4.49 | 0.81 | 0.00 | 12 |
| Above Normal | 1963 | Feb | NAA,A1,A2,B1,B2 | 0 | 0 | 1343 | 60 | 410 | 15 | 60 | 60 | 60 | 52 | 50 | 50 | 4.61 | NA | NA | NA |
| | | | C | 473 | 132 | 1343 | 60 | 410 | 15 | 104 | 96 | 76 | 66 | 52 | 67 | 4.65 | 0.89 | 0.00 | 13 |
| | | | D | 472 | 132 | 1343 | 60 | 410 | 15 | 104 | 96 | 76 | 66 | 52 | 67 | 4.65 | 0.89 | 0.00 | 13 |
| | | March | NAA | 0 | 0 | 691 | 58 | 469 | 11 | 58 | 58 | 58 | 43 | 39 | 39 | 4.54 | NA | NA | NA |
| | | | A1,B1 | 1019 | 132 | 691 | 58 | 469 | 11 | 116 | 114 | 98 | 81 | 49 | 82 | 4.64 | 0.88 | 0.00 | 13 |
| | | | A2,B2,C | 1016 | 132 | 691 | 58 | 469 | 11 | 116 | 114 | 98 | 81 | 49 | 82 | 4.64 | 0.88 | 0.00 | 13 |
| | | | D | 1009 | 132 | 691 | 58 | 469 | 11 | 116 | 114 | 97 | 81 | 49 | 82 | 4.64 | 0.88 | 0.00 | 13 |
| | | May 16-31 | NAA,A1,A2,B1,B2 | 0 | 0 | 706 | 79 | 272 | 5 | 79 | 79 | 79 | 61 | 58 | 58 | 4.51 | NA | NA | NA |
| | | | C | 830 | 132 | 706 | 79 | 272 | 5 | 119 | 117 | 104 | 90 | 66 | 92 | 4.61 | 0.87 | 0.00 | 13 |
| | | | D | 827 | 132 | 706 | 79 | 272 | 5 | 119 | 117 | 104 | 90 | 66 | 92 | 4.61 | 0.87 | 0.00 | 13 |
| | | June | NAA,A1,A2 | 0 | 0 | 464 | 100 | 460 | 8 | 100 | 100 | 100 | 64 | 54 | 54 | 4.50 | NA | NA | NA |
| | | | B1,B2,C,D | 828 | 132 | 464 | 100 | 460 | 8 | 126 | 125 | 118 | 92 | 62 | 91 | 4.61 | 0.86 | 0.00 | 13 |
| Below Normal | 2003 | Feb | NAA | 0 | 0 | 601 | 60 | 287 | 15 | 60 | 60 | 60 | 48 | 45 | 45 | 4.49 | NA | NA | NA |
| | | | A1,A2 | 526 | 132 | 601 | 60 | 287 | 15 | 113 | 109 | 88 | 73 | 51 | 77 | 4.57 | 0.84 | 0.00 | 13 |
| | | | B1 | 550 | 132 | 601 | 60 | 287 | 15 | 114 | 109 | 89 | 74 | 52 | 78 | 4.57 | 0.85 | 0.00 | 13 |
| | | | B2,C,D | 663 | 132 | 601 | 60 | 287 | 15 | 115 | 112 | 92 | 78 | 53 | 82 | 4.59 | 0.86 | 0.00 | 13 |
| | | March | NAA,A1,A2,B1,B2 | 0 | 0 | 479 | 58 | 243 | 11 | 58 | 58 | 58 | 44 | 43 | 43 | 4.46 | NA | NA | NA |
| | | | C | 613 | 132 | 479 | 58 | 243 | 11 | 116 | 113 | 93 | 78 | 51 | 83 | 4.56 | 0.84 | 0.00 | 13 |
| | | | D | 674 | 132 | 479 | 58 | 243 | 11 | 117 | 114 | 95 | 80 | 52 | 85 | 4.57 | 0.85 | 0.00 | 13 |
| | | April 1-15 | NAA,A1,A2,B1,B2 | 0 | 0 | 364 | 71 | 150 | 14 | 71 | 71 | 71 | 55 | 54 | 54 | 4.40 | NA | NA | NA |
| | | | C | 960 | 132 | 364 | 71 | 150 | 14 | 123 | 122 | 111 | 100 | 69 | 105 | 4.58 | 0.86 | 0.00 | 13 |
| | | | D | 973 | 132 | 364 | 71 | 150 | 14 | 123 | 122 | 111 | 100 | 69 | 105 | 4.58 | 0.86 | 0.00 | 13 |

**Table D-6. Summary of Inputs and Results for Each Alternative Plan Modeled**

| Description of Alternative Plans | | | | Newman Wasteway Inputs | | San Joaquin River Inputs | | Merced River Inputs | | Results | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Water Year | Representative Year | Month | Alternative Plan | Flow Rate | TSS Conc. | Flow Rate | TSS Conc. | Flow Rate | TSS Conc. | TSS Conc. in SJR at NWW Mouth | TSS Conc. Below Conflu-ence of NWW (100 ft) | TSS Conc. Above Merced Confluence (6,500 ft) | TSS Conc. Below Conflu-ence of Merced (7,000 ft) | TSS Conc. at Tuolumne River (165,000 ft) | TSS Conc. Fully Mixed after Merced | Distance Downstream Fully Mixed | Fraction Clay Remaining at Tuolumne River | Fraction Silt Remaining at Tuolumne River | Percent of Wasteway Sediment Remaining In Water Column at Tuolumne River |
| | | | | Qw | Cw | Qsjr | Csjr | Qm | Cm | Co | | Cabv | | | Cmf | | | | (31.23 Miles) |
| | | | | cfs | mg/L | cfs | mg/L | cfs | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | miles | | | % |
| | | May 16-31 | NAA,A1,A2,B1,B2 | 0 | 0 | 462 | 79 | 264 | 5 | 79 | 79 | 79 | 56 | 52 | 52 | 4.46 | NA | NA | NA |
| | | | C | 520 | 132 | 462 | 79 | 264 | 5 | 120 | 117 | 102 | 81 | 58 | 85 | 4.55 | 0.83 | 0.00 | 12 |
| | | | D | 519 | 132 | 462 | 79 | 264 | 5 | 120 | 117 | 102 | 81 | 58 | 85 | 4.55 | 0.83 | 0.00 | 12 |
| | | June | NAA,A1,A2 | 0 | 0 | 346 | 100 | 165 | 8 | 100 | 100 | 100 | 72 | 70 | 70 | 4.40 | NA | NA | NA |
| | | | B1,B2 | 493 | 132 | 346 | 100 | 165 | 8 | 126 | 124 | 115 | 95 | 77 | 100 | 4.51 | 0.81 | 0.00 | 12 |
| | | | C,D | 1032 | 132 | 346 | 100 | 165 | 8 | 128 | 127 | 122 | 109 | 83 | 111 | 4.58 | 0.86 | 0.00 | 13 |
| Dry | 2002 | Feb | NAA | 0 | 0 | 637 | 60 | 307 | 15 | 60 | 60 | 60 | 48 | 45 | 45 | 4.50 | NA | NA | NA |
| | | | A1,A2,B1 | 494 | 132 | 637 | 60 | 307 | 15 | 112 | 107 | 86 | 71 | 51 | 75 | 4.57 | 0.84 | 0.00 | 13 |
| | | | B2,C,D | 495 | 132 | 637 | 60 | 307 | 15 | 112 | 107 | 86 | 71 | 51 | 75 | 4.57 | 0.85 | 0.00 | 13 |
| | | March | NAA,A1,A2 | 0 | 0 | 577 | 58 | 249 | 11 | 58 | 58 | 58 | 46 | 44 | 44 | 4.48 | NA | NA | NA |
| | | | B1,B2,C,D | 462 | 132 | 577 | 58 | 249 | 11 | 112 | 107 | 85 | 71 | 50 | 76 | 4.55 | 0.84 | 0.00 | 13 |
| | | April 1-15 | NAA,A1,A2,B1,B2 | 0 | 0 | 263 | 71 | 98 | 14 | 71 | 71 | 71 | 55 | 55 | 55 | 4.34 | NA | NA | NA |
| | | | C | 1150 | 132 | 263 | 71 | 98 | 14 | 126 | 125 | 117 | 109 | 78 | 113 | 4.58 | 0.87 | 0.00 | 13 |
| | | | D | 1224 | 132 | 263 | 71 | 98 | 14 | 126 | 125 | 118 | 111 | 79 | 114 | 4.59 | 0.87 | 0.00 | 13 |
| | | May 16-31 | NAA,A1,A2,B1,B2 | 0 | 0 | 332 | 79 | 221 | 5 | 79 | 79 | 79 | 53 | 49 | 49 | 4.41 | NA | NA | NA |
| | | | C | 497 | 132 | 332 | 79 | 221 | 5 | 122 | 120 | 105 | 82 | 57 | 88 | 4.52 | 0.81 | 0.00 | 12 |
| | | | D | 525 | 132 | 332 | 79 | 221 | 5 | 122 | 120 | 106 | 83 | 58 | 89 | 4.52 | 0.82 | 0.00 | 12 |
| | | June | NAA,A1,A2 | 0 | 0 | 296 | 100 | 178 | 8 | 100 | 100 | 100 | 68 | 66 | 66 | 4.39 | NA | NA | NA |
| | | | B1,B2,C,D | 313 | 132 | 296 | 100 | 178 | 8 | 125 | 123 | 112 | 86 | 70 | 92 | 4.47 | 0.77 | 0.00 | 12 |
| Critical | 1992 | March | NAA,A1,A2,B1,B2,C | 0 | 0 | 454 | 58 | 298 | 11 | 58 | 58 | 58 | 43 | 40 | 40 | 4.46 | NA | NA | NA |
| | | | D | 408 | 132 | 454 | 58 | 298 | 11 | 114 | 109 | 86 | 67 | 45 | 72 | 4.54 | 0.82 | 0.00 | 12 |
| | | April 1-15 | NAA | 0 | 0 | 248 | 71 | 203 | 14 | 71 | 71 | 71 | 48 | 45 | 45 | 4.38 | NA | NA | NA |
| | | | A1,B1 | 178 | 131 | 248 | 71 | 203 | 14 | 116 | 111 | 87 | 62 | 49 | 69 | 4.43 | 0.72 | 0.00 | 11 |
| | | | A2,B2,C | 564 | 132 | 248 | 71 | 203 | 14 | 123 | 121 | 107 | 86 | 56 | 93 | 4.51 | 0.81 | 0.00 | 12 |
| | | | D | 549 | 132 | 248 | 71 | 203 | 14 | 123 | 121 | 107 | 85 | 56 | 93 | 4.51 | 0.81 | 0.00 | 12 |
| | | April 16-30 | NAA,A1,A2,B1,B2 | 0 | 0 | 248 | 71 | 203 | 14 | 71 | 71 | 71 | 48 | 45 | 45 | 4.38 | NA | NA | NA |
| | | | C,D | 562 | 132 | 248 | 71 | 203 | 14 | 123 | 121 | 107 | 86 | 56 | 93 | 4.51 | 0.81 | 0.00 | 12 |
| | | May 1-15 | NAA,A1,A2 | 0 | 0 | 230 | 79 | 143 | 5 | 79 | 79 | 79 | 52 | 50 | 50 | 4.35 | NA | NA | NA |
| | | | B1,B2 | 450 | 132 | 230 | 79 | 143 | 5 | 124 | 122 | 108 | 85 | 60 | 95 | 4.48 | 0.79 | 0.00 | 12 |
| | | | C,D | 476 | 132 | 230 | 79 | 143 | 5 | 124 | 122 | 109 | 87 | 61 | 96 | 4.48 | 0.79 | 0.00 | 12 |
| | | May 16-31 | NAA,A1,B1 | 0 | 0 | 230 | 79 | 143 | 5 | 79 | 79 | 79 | 52 | 50 | 50 | 4.35 | NA | NA | NA |

**Table D-6. Summary of Inputs and Results for Each Alternative Plan Modeled**

| Description of Alternative Plans | | | | Newman Wasteway Inputs | | San Joaquin River Inputs | | Merced River Inputs | | Results | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Water Year | Representative Year | Month | Alternative Plan | Flow Rate | TSS Conc. | Flow Rate | TSS Conc. | Flow Rate | TSS Conc. | TSS Conc. in SJR at NWW Mouth | TSS Conc. Below Conflu-ence of NWW (100 ft) | TSS Conc. Above Merced Confluence (6,500 ft) | TSS Conc. Below Conflu-ence of Merced (7,000 ft) | TSS Conc. at Tuolumne River (165,000 ft) | TSS Conc. Fully Mixed after Merced | Distance Downstream Fully Mixed | Fraction Clay Remaining at Tuolumne River | Fraction Silt Remaining at Tuolumne River | Percent of Wasteway Sediment Remaining In Water Column at Tuolumne River |
| | | | | Qw | Cw | Qsjr | Csjr | Qm | Cm | Co | | Cabv | | | Cmf | | | | (31.23 Miles) |
| | | | | cfs | mg/L | cfs | mg/L | cfs | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | miles | | | % |
| | | | A2,B2,C | 516 | 132 | 230 | 79 | 143 | 5 | 124 | 123 | 110 | 89 | 62 | 97 | 4.49 | 0.80 | 0.00 | 12 |
| | | | D | 503 | 132 | 230 | 79 | 143 | 5 | 124 | 123 | 110 | 88 | 62 | 97 | 4.49 | 0.80 | 0.00 | 12 |
| | | June | NAA | 0 | 0 | 219 | 100 | 146 | 8 | 100 | 100 | 100 | 66 | 63 | 63 | 4.35 | NA | NA | NA |
| | | | A1,A2,B1,B2, C,D | 164 | 131 | 219 | 100 | 146 | 8 | 124 | 121 | 109 | 76 | 66 | 84 | 4.41 | 0.70 | 0.00 | 10 |
| | | Oct | NAA,A1,A2,B 1,B2,C | 0 | 0 | 184 | 80 | 208 | 12 | 80 | 80 | 80 | 49 | 44 | 44 | 4.36 | NA | NA | NA |
| | | | D | 155 | 131 | 184 | 80 | 208 | 12 | 120 | 116 | 95 | 61 | 47 | 68 | 4.41 | 0.68 | 0.00 | 10 |

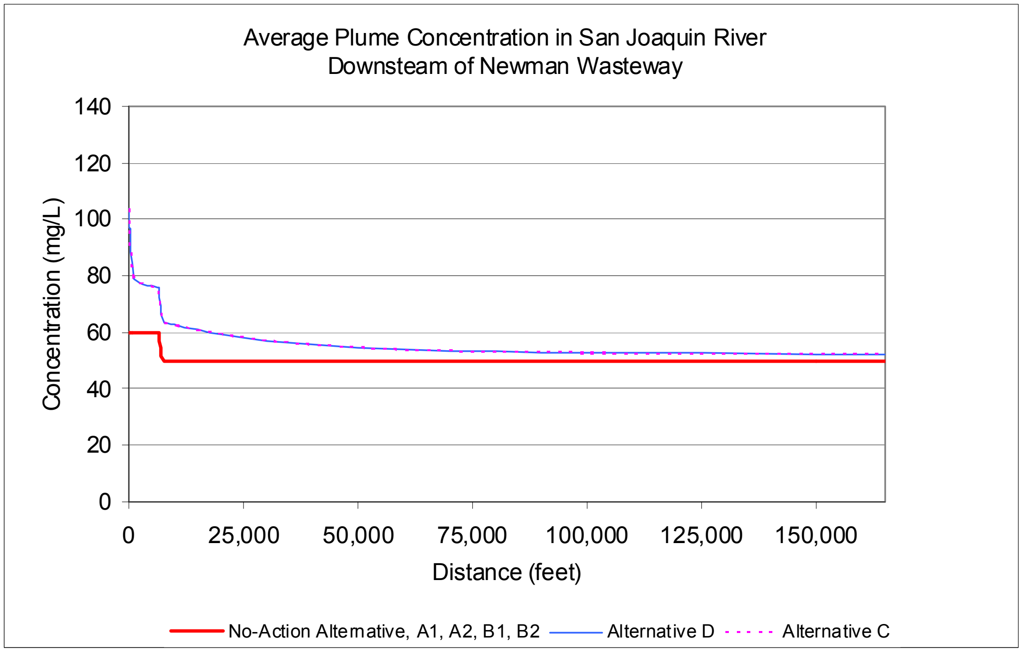
NAA = No-Action Alternative

The initial TSS concentration in the SJR plume ($C_0$) resulting from recirculation ranged from 101 mg/L (Alternatives B1 and B2, March, Wet water year) to 128 mg/L (Alternatives C and D, June, Below Normal water year). The distance downstream where the system becomes completely mixed after inputs from both the Wasteway and the Merced River varies little between alternative plans or from No-Action Alternative conditions. The distance ranges from 4.34 to 4.68 miles downstream from the Wasteway.

The average plume concentration results for the 24 time periods modeled are also presented in **Attachment D2** as a set of graphs. **Figure D-19** shows an example graph found in **Attachment D2**. All graphs follow the same general trends as discussed below, with some variation in the magnitude of TSS concentrations. Each graph represents TSS concentrations as a function of distance downstream from the Wasteway (0 foot) to the Tuolumne River (165,000 feet).

As can be seen in the representative graph on **Figure D-19**, the simulations consists of three zones. For the No-Action Alternative and the alternative plans where no recirculation occurs during the relevant time period, the TSS concentration in the first zone, between the confluence of the SJR and the Wasteway (0 foot) and the Merced River (6,500 feet), remains constant. The second zone, downstream of the confluence with the Merced River, has an approximately 1,000-foot-long mixing zone where the SJR and Merced River converge. In the third zone, downstream of the mixing zone, the TSS concentration is again constant reflecting the fully mixed concentration in the SJR.

For each alternative plan where recirculation occurs during the time period, a similar pattern is observed; however, in the zone between the confluences of the SJR with the Wasteway and with the Merced River a steep decline in TSS concentration occurs, followed by a zone of mixing with the Merced River, and lastly a zone where the TSS concentration slowly decreases due to settling of sediments contributed from the Wasteway. In all cases, the TSS concentration in the SJR modeled for alternative plans where recirculation occurs remains higher than that modeled under the No-Action Alternative all the way to the Tuolumne River.




| Above Normal Feb - 1963 | | Initial | Upstream SJR | | Merced | |
|---|---|---|---|---|---|---|
| Scenario | Recirc. Flow (cfs) | Conc. In SJR at Newman (mg/L) | Flow (cfs) | Initial Conc. (mg/L) | Flow (cfs) | Initial Conc. (mg/L) |
| No-Action Alternative | 0 | 60 | 1343 | 60 | 410 | 15 |
| Alternative A1 | 0 | 60 | 1343 | 60 | 410 | 15 |
| Alternative A2 | 0 | 60 | 1343 | 60 | 410 | 15 |
| Alternative B1 | 0 | 60 | 1343 | 60 | 410 | 15 |
| Alternative B2 | 0 | 60 | 1343 | 60 | 410 | 15 |
| Alternative C | 473 | 104 | 1343 | 60 | 410 | 15 |
| Alternative D | 472 | 104 | 1343 | 60 | 410 | 15 |

**Figure D-19. Representative Graph of Modeled TSS Concentrations Downstream from Newman Wasteway in the San Joaquin River**

The first zone of steep concentration decline is where the silt-sized particles eroded in the Wasteway settle out. Although it varies by alternative plan (due to the different river velocities), most of the silt particles settle out before the confluence with the Merced River. These particles are estimated to constitute 85% of the sediment eroded in the Wasteway. After mixing with the Merced River, another zone of gradual concentration decline occurs. At this point, the remaining sediment left in suspension is mainly clay; therefore, the decrease in concentration is gradual. Due to this condition, by the time the flow reaches the Tuolumne River, 68 to 91% of the original clay fraction in the Wasteway sediments remains in the water column, which represents 10 to 14% of the sediment eroded from the Wasteway. The difference between alternative plans is mainly due to the recirculation flow rate since high flow rates will discharge a high mass of sediment that will take longer to settle out and be conveyed farther downstream (due to the increased velocity in the SJR).

### D.3.2 San Joaquin River Lateral TSS Concentrations

The lateral dispersions of the Wasteway plume for the both the highest and lowest flows through the Wasteway for each scenario are described below. The graphs are presented in **Attachment D3** with an example presented below for April 1993, a Wet water year (**Figure D-20**). Graphs of lateral concentrations were created for four distances downstream of the Wasteway along the SJR and presented on each figure. The distances include 100 feet downstream from the Wasteway, just above the confluence of the Merced River (6,500 feet downstream), just below the confluence with the Merced River (7,000 feet downstream), and just above the confluence of the Tuolumne River (165,000 feet). Each graph depicts the TSS concentration as a function of distance across the width of the SJR for the No-Action Alternative and each alternative plan.

All of the graphs presented in **Attachment D3** follow similar trends, with differences in the magnitude of predicted TSS concentrations. One hundred feet downstream from the Wasteway, the TSS concentration for each alternative plan has a maximum near the western or southern river bank and the concentration tapers off to the No-Action Alternative concentration towards the opposite bank as the plume has not fully mixed with the SJR (**Figure D-20a**). At 6,500 feet, the TSS plume from the Wasteway for all alternative plans where recirculation was predicted to occur has almost completely mixed laterally across the SJR and is higher than the No-Action Alternative concentration for the entire distance across river (**Figure D-20b**). Just below the confluence with the Merced River (7,000 feet), the effect of the inflow from the Merced River can be seen (**Figure D-20c**). The concentration on the left bank is the concentration from the SJR, while at the right bank it is close to the concentration in the Merced River. **Figure D-20d** presents the TSS concentration at the Tuolumne River (165,000 feet).

The results indicate that the sediments coming out of the Wasteway would be almost completely mixed with the SJR by the confluence with the Merced River, after which small changes in TSS concentration would be observed across the SJR until it is fully mixed.

### D.3.3 Limitations and Uncertainty

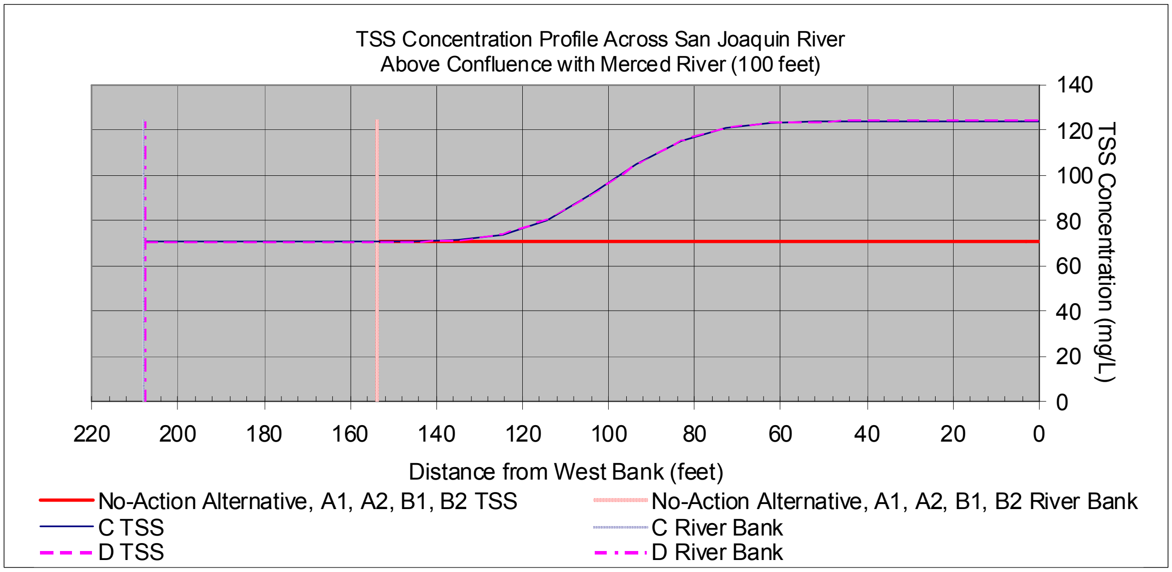
The above analysis is based on a limited set of data collected in 2004 and 2007. The conditions under which the data were collected may not be representative of the conditions that will exist during periods of recirculation. Conditions that may differ from those that occurred during the pilot studies include:

- Recirculation could result in periods of sustained high flows in the Wasteway. These high flows will likely change the morphology of the

Wasteway, especially the early releases, which could affect the TSS level observed in the Wasteway discharge.

- Except for the approximately 250 cfs release during the 2004 studies, most of the other data collected during the pilot studies were collected during periods of changing flows and at flows smaller than 250 cfs. Predictions above the pilot study flow rates are more uncertain than those for flows less than 250 cfs.
- Under current conditions limited releases occur to the Wasteway. As a result, beaver dams and other flow obstructions exist in the Wasteway that may not exist if the Wasteway was used as a conveyance for recirculation on a regular basis. Failure of these structures can cause changes in TSS that may not be well represented by the current model.
- The Wasteway is presently heavily vegetated with a meandering low-flow channel. Sustained high flows will likely straighten the flowpath and scour out much of the vegetation. This process will expose more sediment to erosion and may result in higher TSS concentrations than were observed in the 2004 pilot study during the period of sustained flow and used for calibration to the model.
- Several feet of sedimentation have potentially been in the Wasteway since it was constructed. If recirculation becomes a frequently used management tool, much or all of the deposited sediment may erode exposing the original bed of the channel. This bed may have different erosion characteristics than the deposited sediment.
- Two pilot studies were conducted. The two studies were conducted under different flow conditions and resulted in very different and inconsistent results.

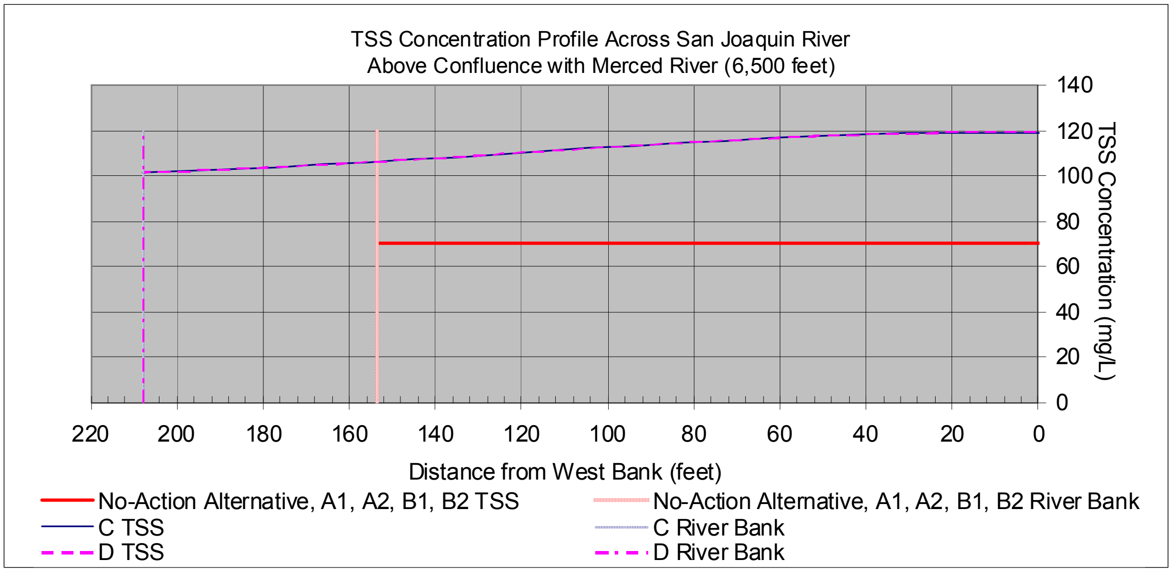
Because of the above limitations, the analysis presented in this report should be revisited when more data become available. The new data may indicate the need to change the parameters used in the model.




Wet April 1993

| Scenario | Recirc. Flow (cfs) | Initial Source Concentrations (mg/L) | | | Concentration in SJR at 100 ft (mg/L) | |
|---|---|---|---|---|---|---|
| | | SJR at Newman | Upstream SJR | Merced River | West Bank | East Bank |
| No-Action Alternative | 0 | 0 | 71 | 14 | 71 | 71 |
| Alternative A1 | 0 | 0 | 71 | 14 | 71 | 71 |
| Alternative A2 | 0 | 0 | 71 | 14 | 71 | 71 |
| Alternative B1 | 0 | 0 | 71 | 14 | 71 | 71 |
| Alternative B2 | 0 | 0 | 71 | 14 | 71 | 71 |
| Alternative C | 1908 | 132 | 71 | 14 | 124 | 71 |
| Alternative D | 1907 | 132 | 71 | 14 | 124 | 71 |

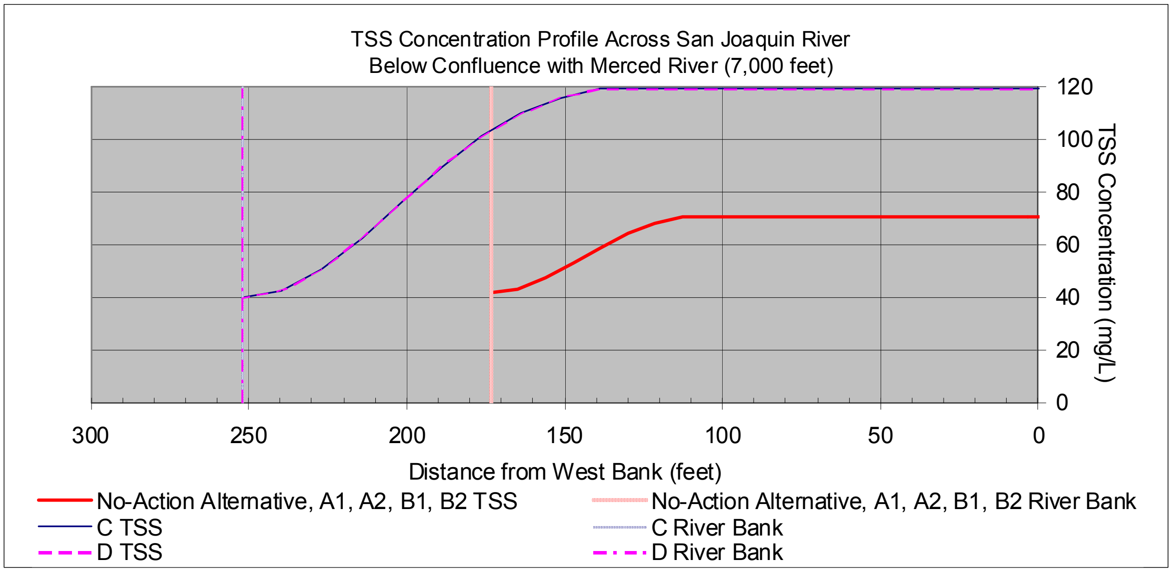
**Figure D-20a. Lateral Profile Across the San Joaquin River at 100 feet Downstream of Newman Wasteway for Wet Water Year April (1993)**




Wet April 1993

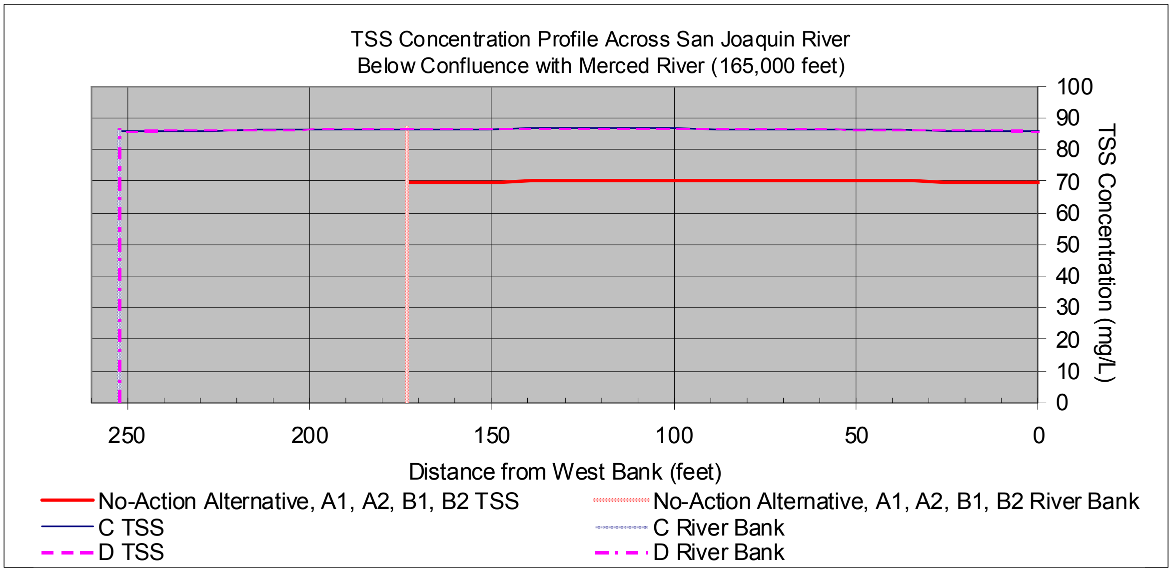
| Scenario | Recirc. Flow (cfs) | Initial Source Concentrations (mg/L) | | | Concentration in SJR at 6,500 ft (mg/L) | |
|---|---|---|---|---|---|---|
| | | SJR at Newman | Upstream SJR | Merced River | West Bank | East Bank |
| No-Action Alternative | 0 | 0 | 71 | 14 | 71 | 71 |
| Alternative A1 | 0 | 0 | 71 | 14 | 71 | 71 |
| Alternative A2 | 0 | 0 | 71 | 14 | 71 | 71 |
| Alternative B1 | 0 | 0 | 71 | 14 | 71 | 71 |
| Alternative B2 | 0 | 0 | 71 | 14 | 71 | 71 |
| Alternative C | 1908 | 132 | 71 | 14 | 119 | 101 |
| Alternative D | 1907 | 132 | 71 | 14 | 119 | 101 |

**Figure D-20b. Lateral Profile Across the San Joaquin River at 6,500 feet Downstream of Newman Wasteway at Merced Confluence for Wet Water Year April (1993)**




| Wet April 1993 | | Initial Source Concentrations (mg/L) | | | Concentration in SJR at 7,000 ft (mg/L) | |
|---|---|---|---|---|---|---|
| **Scenario** | **Recirc. Flow (cfs)** | **SJR at Newman** | **Upstream SJR** | **Merced River** | **West Bank** | **East Bank** |
| **No-Action Alternative** | 0 | 0 | 71 | 14 | 71 | 42 |
| **Alternative A1** | 0 | 0 | 71 | 14 | 71 | 42 |
| **Alternative A2** | 0 | 0 | 71 | 14 | 71 | 42 |
| **Alternative B1** | 0 | 0 | 71 | 14 | 71 | 42 |
| **Alternative B2** | 0 | 0 | 71 | 14 | 71 | 42 |
| **Alternative C** | 1908 | 132 | 71 | 14 | 119 | 40 |
| **Alternative D** | 1907 | 132 | 71 | 14 | 119 | 40 |

**Figure D-20c. Lateral Profile Across the San Joaquin River at 7,000 feet Downstream of Newman Wasteway for Wet Water Year April (1993)**




Wet April 1993

| Scenario | Recirc. Flow (cfs) | Initial Source Concentrations (mg/L) | | | Concentration in SJR at 165,000 ft (mg/L) | |
|---|---|---|---|---|---|---|
| | | SJR at Newman | Upstream SJR | Merced River | West Bank | East Bank |
| No-Action Alternative | 0 | 0 | 71 | 14 | 70 | 69 |
| Alternative A1 | 0 | 0 | 71 | 14 | 70 | 69 |
| Alternative A2 | 0 | 0 | 71 | 14 | 70 | 69 |
| Alternative B1 | 0 | 0 | 71 | 14 | 70 | 69 |
| Alternative B2 | 0 | 0 | 71 | 14 | 70 | 69 |
| Alternative C | 1908 | 132 | 71 | 14 | 86 | 86 |
| Alternative D | 1907 | 132 | 71 | 14 | 86 | 86 |

**Figure D-20d. Lateral Profile Across the San Joaquin River at 165,000 feet (31 miles) Downstream of Newman Wasteway at the Tuolumne River for Wet Water Year April (1993).**

## D.4 Summary and Conclusions

The discharge of recirculation water through the Wasteway will cause erosion of the sediments in the Wasteway and the discharge of the sediment into the SJR. Samples of surface sediments collected in the Wasteway indicate that most of the suspended sediment leaving the Wasteway will consist of silt-sized particles with about 15% clay size particles.

The sediment discharged from the Wasteway into the SJR will increase the sediment load and the TSS concentration in the SJR. The predicted increase in the average plume concentration of TSS in the SJR just below the Wasteway confluence varies from about 21 to 59 mg/L (or 21 to 95% increase compared to no recirculation). Initially, the increased concentration will be mostly near the left bank but will quickly disperse across the entire SJR. By the time the plume reaches the confluence with the Merced River, the concentration in the SJR will be relatively uniform. Also, most of the silt particles will have settled out, resulting in an increase in average plume TSS concentration in the SJR above the Merced confluence of between 9 and 39 mg/L (or 9 to 67% increase compared to no recirculation).

The Merced River has very low TSS concentrations. Below the Merced River confluence, this condition results in a sharp gradient in TSS between the left side of the SJR, which is primarily SJR water, and the right side of the SJR, which is primarily Merced River water. However, the suspended sediment will disperse across the SJR so that within a few thousand feet below the confluence with the Merced River (the exact distance depends upon the SJR flow rates) the TSS concentration is more uniform. The concentration will then slowly return to the ambient conditions as the clay particles contributed by the Wasteway settle out. However, by the time the added sediment reaches the Tuolumne River, the model predicts that TSS concentrations under all recirculation scenarios will remain higher than predicted concentrations assuming no recirculation.

The predicted increase at the Tuolumne River ranges from 2 to 22 mg/L, or 4 to 41% increase compared to no recirculation. The greatest differences at Tuolumne River are predicted to occur when both the SJR and Merced River flows are relatively low and recirculation flow from the Wasteway is relatively high. For example, the increase of 22% was predicted to occur during the first half of April in 2002, when the modeled Merced River flow rate ($Q_m$) is 98 cfs, the SJR flow rate ($Q_{sjr}$) is 263 cfs, and the recirculation flow rate ($Q_w$) is 1,150 cfs.

In a given water year, the largest increases in TSS were consistently predicted to occur in March. Conversely, the smallest increases during periods when recirculation would occur were predicted to occur in June.

The calculation of sediment contributed by the Wasteway to the SJR was based upon data collected during the 2004 pilot study. The data from the 2004 and 2007 studies were inconsistent with each other and with data commonly encountered in similar studies. Data from additional pilot studies should provide information that may help resolve these inconsistencies and improve the ability to predict the sediment load contributed by the Wasteway.

## D.5 References

American Society of Engineers (ASCE). 1975. *Sedimentation Engineering*. ASCE Manuals and Reports on Engineering Practice 54. Vito A. Vanoni, Editor. ASCE Headquarters, New York, NY.

Bureau of Reclamation. 1956. Delta-Mendota Canal: Newman Wasteway As-built. April.

———. 2005. Recirculation Pilot Study Final Report. Mid-Pacific Region, Sacramento, CA. June.

———. 2008. *Recirculation Pilot Study Draft Report*. Mid Pacific Region, Sacramento, CA. June.

California Department of Water Resources. 2007. Available online at http://cdec.water.ca.gov/cgi-progs/iodir/wsihist.

Chu, V.H., and G.H. Jirka.1986. Surface buoyant jets and plumes. *Encyclopedia of Fluid Mechanics*, Chapter 25. Houston, TX: Gulf Publishing Company.

Fisher, H.B., E. . List, R.C.Y. Koh, Jorg Imberger, and Norman H. Brooks 1979. *Mixing in Inland and Coastal Waters*. New York, NY: Academic Press.

Grace, RA. 1978. *Marine Outfall Systems, Planning, Design, and Construction*. Englewood Cliffs, NJ: Prentice-Hall, Inc.

Hanson, G.J., and A. Simon. 1999. *Erodibility of cohesive streambeds in the loess area of the Midwestern USA. Hydrological Processes* 15(1): 23-38.

Muppidi, Summan, and Krishnan Mahesh. 2005. Study of trajectories of jets in crossflow using direct numerical simulations. *Journal of Fluid Mechanics* 530: 81-100.

Socolotsky, S.A., and G.H. Jirka. *Environmental Fluid Mechanics Part 1: Mass Transfer and Diffusion*. 2nd Edition. Engineering Lectures, Institut fur Hydromechanik Universitat Kalsruhe, Germany.

Thomann, R,. and JA. Mueller. *Principles of Surface Water Quality Modeling and Control*. New York, NY: Harper Collins Publishers.

U.S. Army Corps of Engineers. 1989. *Sedimentation Investigation of Rivers and Reservoirs.* Engineering Manual 1110-2-4000.

———. 2008. *HEC-RAS River Analysis System, User's Manual, Version 4.0*. Hydrologic Engineering Center. Model V4.01. March.

Whitehouse, R.J.S., R.L. Soulsby, W. Roberts, and H.J. Mitchener. 1999. *Dynamics of Estuarine Muds. A Manual for Practical Applications*. HR Wallingford Group Limited. Howbery Park, Wallingford, England