Tidal Dilution of the Stockton Regional Wastewater Control Facility Discharge into the San Joaquin River

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Executive Summary

Effluent from the City of Stockton's Regional Wastewater Control Facility (RWCF) is discharged into the San Joaquin River about 1.5 miles upstream of the Deep Water Ship Channel (DWSC). The RWCF discharges an average of about 32 million gallons per day (mgd) (50 cubic feet per second [cfs]) through a 4-foot-diameter discharge pipe into about 15 feet of water. The San Joaquin River channel is about 250 feet wide at the RWCF discharge location.

The RWCF discharge is from a circular pipe, so the well-established equations for describing the performance of a round momentum jet can be applied. The jet dilution equation indicates that dilution increases linearly with distance. An initial mixing zone of about 125 feet radius from the discharge will provide an initial jet dilution of about 7–10 and will only extend halfway across the river channel. The opposite side of the river will not be affected by the effluent plume, thus preserving a zone of passage in the river across from the discharge location.

A box model of this tidal mixing process was developed using 2 rows of river segments that move back and forth with the tidal flow to simulate RWCF discharge and mixing conditions in the San Joaquin River. The 15-minute records of stage and flow from the U.S. Geological Survey (USGS) ultrasonic velocity meter (UVM) tidal flow station, located just upstream of the RWCF discharge, are used in the model. Concentrations on both sides of the river at the discharge location, at upstream river sampling station R2 (located about 1 mile upstream from the discharge), and at downstream river sampling station R3 (located 1.5 miles downstream in the DWSC) are calculated for the month of simulated tidal flows and dilution.

This type of model is sometimes referred to as a *Lagrangian model*, meaning that the boxes move upstream and downstream with the tidal flow past the discharge location. The RWCF discharge into the river segments might be compared to a bulk loader that is pouring material into a train with open cars that move back and forth on the tracks. More material is deposited into the cars that move slowly past the bulk loader

Results from the tidal river box model calculations are described and evaluated in this report. Applications of these tidal mixing model results for estimating maximum expected exposure concentrations in the San Joaquin River are discussed.

Tidal River Flow Conditions

San Joaquin River flow past the RWCF discharge is strongly tidal, with a maximum tidal velocity of about 1 ft/sec at the maximum tidal flow of about 3,000 cfs during peak flood and ebb tides. The RWCF effluent will mix into this tidal movement of San Joaquin River water. As the tidal velocity decreases from the maximum current toward slack, more of the RWCF effluent is discharged into a particular river segment and higher effluent concentrations result. The fluctuating tidal flows will sometimes move water past the RWCF discharge location several times before the net San Joaquin River flow pushes the water into the DWSC.

Lateral mixing is assumed to be proportional to the tidal river flow. A field study was conducted to directly measure the lateral spreading of the effluent ammonia concentrations in the river. The calibrated mixing rate was determined to be 1% of the tidal flow, which is about twice the original assumed mixing rate of 0.5% of the tidal flow. Both lateral mixing rates were simulated to evaluate the sensitivity of the tidal dilution patterns to the assumed lateral mixing rate.

Simulated Effluent Concentrations

Table E1 gives a summary of the simulated, tidally averaged concentrations for the east and west side of the river at the downstream station R3, at the discharge location, and at the upstream station R2, for a range of river flows between 150 cfs and 950 cfs. For example, with a river flow of 150 cfs and with the lateral mixing rate of 1% of the tidal flow, the average concentration at the upstream R2 station was 70 for the west side and 69 for the east side. The average concentrations at the discharge location were 148 on the west side and 122 on the east side. The average concentrations at the downstream R3 station were 205 for the west side and 204 for the east side. These east-side and west-side values are nearly identical at R3, but less than the expected steady-state average of 250.

This difference between the steady-state average of 250 and the simulated values at R3 is a result of the large tidal excursion. The ebb tide flow moves low-concentration water from upstream of the RWCF discharge to a location downstream of the R3 station near the end of the ebb tide. Consequently, the tidally averaged concentration at R3 will be less than the expected steady-state value. Concentrations further downstream, beyond the downstream distance of the tidal excursions, will approach an average of 250 for this assumed river flow of 150 cfs.

Table E1. Average Simulated Concentrations for Range of River Flow and Lateral Mixing Rates at the Downstream R3, Discharge Location, and Upstream R2 Stations

Net River Flow/Mix Rate	Average Dilution	Expected River Concentration	Side of River	Downstream R3 Station	Discharge Location	Upstream R2 Station
150	4	250	East	204	119	66
0.5%			West	205	151	73
150	4	250	East	204	122	69
1.0%			West	205	148	70
450	10	100	East	80	40	27
0.5%			West	82	77	33
450	10	100	East	81	43	29
1.0%			West	81	74	30
950	20	50	East	36	26	11
0.5%			West	39	64	16
950	20	50	East	37	30	13
1.0%			West	38	60	14

Measured Effluent Ammonia Concentrations and Lateral Mixing at High Slack Tide

A field survey of the maximum near-field effluent concentrations and mixing of the effluent across the river was conducted to verify the assumed lateral mixing rate. The concentrations of ammonia at several transects across the river were measured at high slack tide just upstream of the RWCF discharge location. The lateral mixing was expected to mix the west-side and east-side concentrations more completely as the distance upstream increased. Lateral concentration profiles were measured at 100-foot increments for the first 500 feet upstream of the discharge. Subsequent measurements were then made at 500-foot increments. The field survey documented the lateral mixing between the discharge and 2,500 feet upstream. At maximum tidal velocity of about 1 ft/sec, water moves upstream 2,500 feet in about 40 minutes.

The RWCF effluent ammonia concentration was about 25 milligrams per liter (mg/l). The net flow passing Stockton was estimated to be about 1,250 cfs. The RWCF discharge flow was about 35 cfs, so the fully mixed river concentration would average about 0.7 mg/l (i.e., a river dilution of about 35). The near-field ammonia concentration was expected to be somewhat higher, especially during the slack-high- tide event. The jet mixing is expected to always provide a dilution of at least 5 within 125 feet of the discharge pipe, so the maximum river ammonia concentration was expected to be less than 5 mg/l.

The ammonia concentrations were about 0.5–0.75 mg/l higher than the average upstream river concentration of about 1mg/l at all near-field locations. This increase above the river concentration probably resulted from the effluent during the previous tidal cycle. The near-field ammonia concentrations were higher than 1.75 mg/l only at the 10% and 25% lateral stations for transects from 100 feet, 200 feet, 300 feet, and 400 feet upstream. The 1000-foot transect showed some lateral mixing of ammonia to the center (50%) station, raising the center concentration to about 2 mg/l. The ammonia concentrations were not completely mixed across the river at the 1000-foot transect.

The 50% lateral location sample was about the same as the 25% lateral location at the 2,000-foot and 2,500-foot transects. The 75% lateral location sample was within 10% of the average at the 2,500-foot transect. These results indicate that complete lateral mixing requires a distance of about 0.5 miles. These results were used to calibrate the lateral mixing rate used in the box model to be 1% of the tidal flow.

Interpretation of Tidal Mixing Results for Estimating Maximum Exposure Concentrations

The box model predicts maximum instream concentrations at the discharge location during slack tide. As the current increases after slack, the plume will move with the flow and disperse across the river, gradually decreasing in concentration from the slack-tide maximums. An evaluation of maximum 15-minute concentrations under various net flow conditions, ranging from 150 cfs to 950 cfs, indicates that peak river concentrations range from about 30% to 40% of the effluent concentration.

The model predictions can be used to evaluate dilution conditions and dilution credits associated with acute and chronic water quality standards. The hourly maximum concentration predicted by the model is slightly less than the 15-minute peak concentrations, because the slack periods generally do not persist for an hour. Maximum 1-hour average west-side concentration at the discharge location is about 33% effluent at a net flow of 150 cfs. Because the peak hourly concentration does not exceed 33% at any net flow, a dilution credit equal to or greater than 2.0 (i.e., concentration dilution of 3) is appropriate for establishing 1-hour acute limits for the RWCF discharge.

The chronic standard represents a long-term average concentration that is significantly less than the peak concentrations that occur during slack-tide conditions. Over 4 days, a drifting organism will be carried upstream and downstream past the discharge location by the tidal flows. Most of this time will be spent at a concentration that is less than the steady-state average for the net flow condition. Only as the organism is transported downstream past the tidal excursion zone will the organism be exposed to the average concentration expected from the net flow, discharge, and effluent concentration.

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Introduction

Effluent from the City of Stockton's Regional Wastewater Control Facility (RWCF) is discharged into the San Joaquin River about 1.5 miles upstream of the Deep Water Ship Channel (DWSC). The RWCF discharges an average of about 32 million gallons per day (mgd) (50 cubic feet per second [cfs]) through a 4-foot-diameter discharge pipe into about 15 feet of water. The top of the pipe is under only about 5 feet of water at low tide (i.e., 0 feet mean sea level [msl]). The outlet pipe opening is about 25 feet from the west bank of the San Joaquin River. The water depth is a maximum of about 20 feet, with an average depth of less than 15 feet. The San Joaquin River channel is about 250 feet wide at the RWCF discharge location.

A field study of the local mixing of RWCF effluent in the San Joaquin River was performed by Systech Engineering in July 1992 to support the development of the Stockton Water Quality Model (see chapter IV of Philip Williams & Associates 1993). Rhodamine WT dye was released for 1 hour into the RWCF effluent during ebb, low slack, and flood tide conditions. The near-field dye study results are summarized in figure IV-11 of the study report (Philip Williams & Associates 1993).

During all 3 tide conditions, the dye plume was observed to spread only about halfway across the channel. The centerline dilution of the jet was measured at about 10 (dye concentration was about one-tenth of the initial effluent dye value) at stations located

100–150 feet downstream or upstream of the outlet pipe. This observed dye pattern indicates that about 9 parts of river water mixed with 1 part of effluent and moved upstream or downstream in the west side of the river channel.

No dye was observed across the river centerline, indicating that the jet was apparently deflected by the tidal current and all the RWCF effluent was initially distributed in the west side of the river channel. Because the river channel is about 250 feet wide, this observation suggests that initial mixing of the effluent plume will take place within 125 feet across the San Joaquin River and 125 feet upstream or downstream. There will always be a zone of passage along the opposite bank of the river where dilution will be greater and effects from the RWCF effluent will be reduced.

Several U.S. Environmental Protection Agency (EPA) mixing models (e.g., CORMIX) can calculate effluent dilutions at various distances from a specified jet discharge. However, these EPA models only give results for steady-state river conditions; they do not evaluate the effects of a continuous discharge into fluctuating tidal flows. Therefore, a relatively simple box model was developed to evaluate the RWCF effluent dilution patterns as a function of net river flow and measured tidal fluctuations.

A box model of this tidal mixing process was developed using 2 rows of river segments that move back and forth with the tidal flow to simulate RWCF discharge and mixing conditions in the San Joaquin River. The 15-minute records of stage and flow from the U.S. Geological Survey (USGS) ultrasonic velocity meter (UVM) tidal flow station, located just upstream of the RWCF discharge, are used in the model.

The RWCF discharge and concentration is specified and the resulting concentrations in the 2 rows of river segments are calculated for a specified number of tidal cycles (i.e., 30 days). Concentrations on both sides of the river at the discharge location, at upstream river sampling station R2 (located about 1 mile upstream from the discharge), and at downstream river sampling station R3 (located 1.5 miles downstream in the DWSC) are calculated for the month of simulated tidal flows and dilution. Some example results from the tidal river box model calculations are described and evaluated below. Applications of these tidal mixing model results for estimating maximum expected exposure concentrations in the San Joaquin River are discussed.

Momentum Jet Mixing and Dilution

The RWCF discharge is from a circular pipe, so the well-established equations for describing the performance of a round momentum jet can be applied. The momentum jet length scale (Fischer et al. 1979) is calculated to be discharge area $^{1/2}$ (i.e., 3.5 feet for a diameter of 4.0 feet). All jet parameters such as velocity, dilution, and width can be described as functions of this jet-scale length.

The area of the discharge pipe is about 12.5 square feet. With a RWCF discharge of 50 cfs, the initial discharge velocity will be about 4 feet per second (ft/sec) (i.e., 50/12.5). The round jet velocity equation indicates that centerline jet velocity decreases linearly with distance, once the gaussian-shaped velocity distribution is established at a distance of about 7 times the jet length-scale (i.e., 25 feet for the RWCF discharge pipe):

Centerline velocity (ft/sec) =
7 • jet length-scale/distance • initial velocity

The centerline (i.e., maximum) jet velocity is therefore reduced to 2 ft/sec at a distance of 50 feet, 1 ft/sec at a distance of 100 feet, and about 0.5 ft/sec at 200 feet.

The round jet width equation indicates that the width increases with distance:

Jet width = 0.25 • distance

The RWCF jet therefore has a width of about 12.5 feet at a distance of 50 feet and a width of 25 feet at 100 feet. The jet width is equal to the maximum water depth of 20 feet at a distance of about 75 feet. The jet geometry will become distorted as the jet fills the water column.

The jet centerline (i.e., minimum) dilution equation indicates that dilution increases linearly with distance:

Centerline dilution = 0.25 • distance/jet length-scale

The centerline dilution of the RWCF jet is therefore about 3.5 at a distance of 50 feet, about 7 at a distance of 100 feet, and about 10 at a distance of 150 feet. The average dilution in the round jet, with an assumed gaussian distribution of concentration in the jet, would be about 40% higher because the average concentration in a gaussian distribution is about 70% of the centerline concentration.

The zone of maximum effluent concentration will depend on the direction of the discharge jet that is deflected by the tidal flow. However, an initial mixing zone of about 125 feet radius from the discharge will provide an initial jet dilution of about 7–10 and will only extend halfway across the river channel. The opposite side of the river will not be affected by the effluent plume, thus preserving a zone of passage in the river across from the discharge location.

A series of calculations with the CORMIX model were made to verify these basic jet equations for a range of river flow. For example, with no river flow (i.e., slack tide), the simulated RWCF discharge jet moved across the river to the center of the river (125 feet) with a centerline dilution of about 8, meaning that the centerline concentration is about 12.5% (i.e., one-eighth) of the effluent concentration. The average jet concentration should be about 70% of the centerline concentration, or about 9% of the effluent concentration (with an average dilution of 11). The plume will continue to push across the river until it encounters the opposite bank and will begin to recirculate back across the river channel if the slack period lasts for an extended period of time.

With a tidal velocity of 1.0 ft/sec (maximum tidal flow conditions at Stockton), the simulated RWCF discharge jet moves about 120 feet toward the middle of the river before the jet momentum is dissipated. The centerline of the jet has a calculated dilution of 5 at this point, meaning that the centerline concentration is 20% of the effluent concentration. The average jet concentration should be about 70% of the centerline concentration, or about 15% of the effluent concentration (with an average dilution of about 7).

The CORMIX-calculated effluent plume then spreads laterally as it flows downstream (or upstream with the next flood tide). The CORMIX model can only roughly estimate the rate that the effluent will spread across the river and the distance downstream before the effluent will become evenly mixed across the river. An average of the lateral mixing coefficients that have been observed in river mixing studies is used in the CORMIX calculations. The lateral mixing is assumed to be proportional to the downstream tidal river flow.

The lateral mixing (dispersion coefficient) is assumed to be proportional to the shear velocity and depth (Fischer et al. 1979) as referenced by EPA in the *Technical Support Document for Water Quality-Based Toxics Control* (U.S. Environmental Protection Agency 1991):

$$\text{Dispersion coefficient (square feet per second [ft}^2\text{/sec])} \\ = 0.6 \bullet \text{depth (ft)} \bullet \text{shear velocity (ft/sec)}$$

The shear velocity is estimated from the slope and depth as

$$\text{Shear velocity (ft/sec)} = \\ [\text{g (ft/sec}^2) \bullet \text{depth (ft)} \bullet \text{slope (ft/ft)}]^{1/2}$$

where g is the gravitational acceleration (32.2 ft/sec^2).

The slope is estimated from the measured tidal velocity, using the Manning equation, as

$$\text{Slope}^{1/2} = n \bullet \text{velocity} / [1.486 \bullet R^{2/3}]$$

where *n* is the Manning coefficient (0.03) and *R* is the hydraulic radius.

For the river cross section near the RWCF, the hydraulic radius is about 11 feet, so the $R^{2/3}$ term is about 5. For Manning *n* of 0.03 and a depth of 15 feet, the lateral dispersion is proportional to the tidal velocity:

$$\text{Lateral dispersion (ft}^2\text{/sec)} = 0.8 \bullet \text{tidal velocity (ft/sec)}$$

This equation for lateral dispersion is incorporated into the box model. Because the lateral mixing rate is uncertain and a lower mixing will result in higher concentrations in the west side of the river, a range of mixing rates were simulated and compared (U.S. Environmental Protection Agency 1991). A field study was conducted to directly measure the lateral spreading of the effluent ammonia concentrations in the river. The results have been used to confirm the lateral mixing simulated with the model.

Tidal River Flow Conditions

San Joaquin River flow past the RWCF discharge is strongly tidal, with a maximum tidal velocity of about 1 ft/sec. The tidal flow is about 3,000 cfs during peak flood and ebb tides, and the cross-sectional area is about 3,000 square feet at low tide (0 feet msl), and about 4,000 square feet at high tide (4 feet msl). The tidal flows correspond to a tidal excursion (i.e., water movement) that can be tracked back and forth with the tides. The RWCF effluent will mix into this tidal movement of San Joaquin River water. The fluctuating tidal flows will sometimes move water past the RWCF discharge location several times before the net San Joaquin River flow pushes the water into the DWSC. As the tidal velocity decreases from the maximum current toward slack, more of the RWCF effluent is discharged into a particular river segment and higher effluent concentrations result.

These tidal flow conditions can be simulated with a simple box model representation. The river channel is represented by 2 rows of water segments, as illustrated in figure 1. Each water segment (box) has a constant volume of 150,000 cubic feet. The water segments are assumed to move downstream or upstream with the tidal velocity corresponding to the UVM flow measured just upstream of the RWCF. The channel depth and river cross section increases with tidal stage. The channel cross section is 3,000 square feet and is approximately rectangular (i.e., 250 feet wide and 12 feet deep) at a stage of 0 feet msl. The channel cross section increases to 4,000 square feet (i.e., 250 feet wide and 16 feet deep) at a stage of

4 feet msl. A tidal flow of 3,000 cfs corresponds to a velocity of between 1.0 ft/sec and 0.75 ft/sec, depending on the tidal stage.

The box model has 2 rows of segments, so the segment cross section area is half of the river cross section area. The segment width is 125 feet and the length with a stage of 0 feet would be 100 feet. At high stage of 4 feet, the segment length would be 75 feet. At low tide and maximum velocity of 1 ft/sec, the segments are moving past the discharge location at a rate of 1 segment every 100 seconds. In each 15-minute tidal measurement interval (900 seconds), about 9 segments move past the discharge. At slower velocities, fewer segments move past the discharge.

Tidal Mixing of Regional Wastewater Control Facility Discharge

Based on the results of the 1993 dye study and the CORMIX calculations, the effluent is assumed to enter only the nearest (west) river segments if the tidal flow is greater than 0.1 ft/sec (i.e., more than 1 segment moves past the discharge in a 15-minute time step). During relatively stagnant conditions (i.e., slack tide), when the discharge during a 15-minute tidal interval enters a single segment, the effluent plume is assumed to move across the river and enter the east side segment in a recirculation pattern. The effluent flow is mixed completely within the segment volume receiving the discharge. As the segment is transported with the tide, lateral dispersion mixes the contents of the adjacent west and east segments at a rate determined by the tidal velocity. This type of model is sometimes referred to as a *Lagrangian model*, meaning that the boxes move upstream and downstream with the tidal flow past the discharge location. The RWCF discharge into the river segments might be compared to a bulk loader that is pouring material into a train with open cars that move back and forth on the tracks. More material is deposited into the cars that move slowly past the bulk loader.

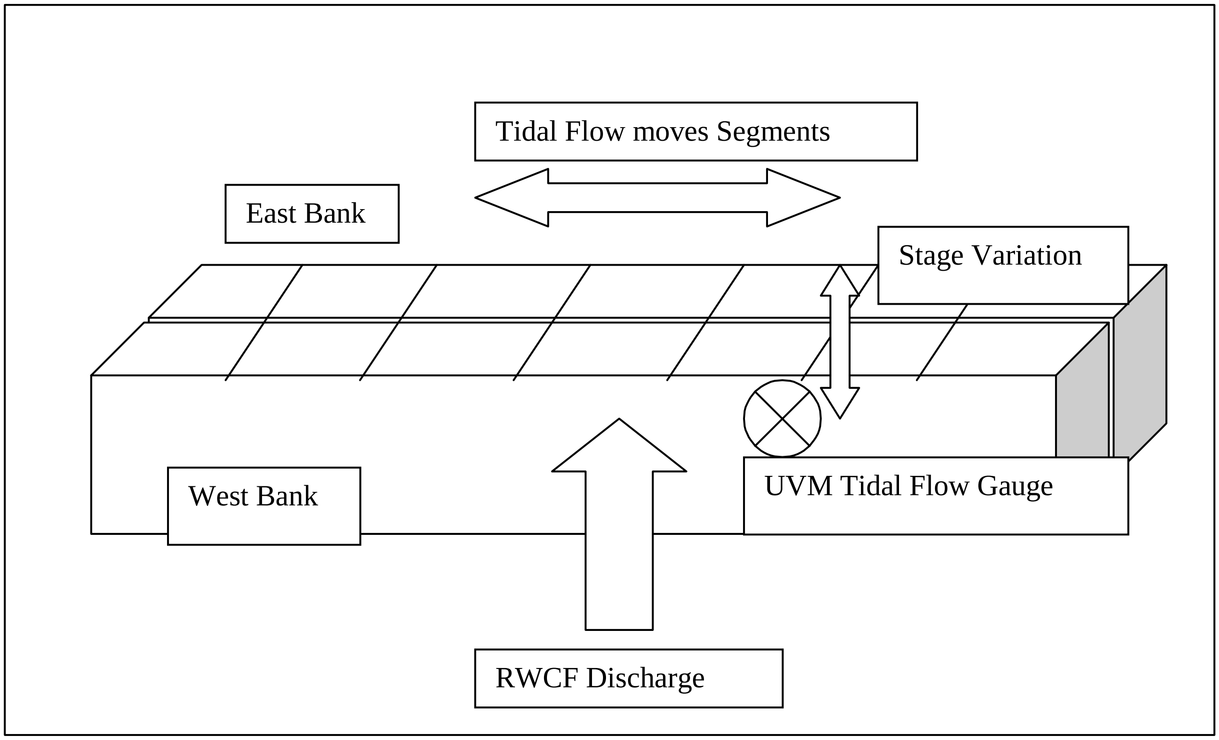


Figure 1
Layout of Box Tidal Flow Model for Evaluating Dilution of RWCF Discharge into the San Joaquin River

For example, with an assumed discharge of 50 cfs and a tidal flow of 1,500 cfs with a stage of 0 feet (low tide), the segment velocity would be 0.5 ft/sec and the effluent would discharge into each segment for about 200 seconds. The effluent volume entering the segment would total 10,000 cubic feet (i.e., 200 sec • 50 cfs) or 6.7% of the segment volume. This would represent a segment dilution of about 15 (150,000/10,000) for this tidal flow. As indicated in the jet analysis, some of this dilution would result from the jet momentum mixing (dilution of about 7–10). The additional dilution results from the nature of the box model that considers each river volume segment to be fully mixed. This assumed mixing within each segment is the main reason for selecting small volume segments and tracking many of them to simulate the full range of concentrations resulting from the dynamic tidal flow conditions.

The amount of lateral river mixing between the segment volumes is specified as a function of the tidal velocity. This mixing will slowly even out the effluent concentrations across the river. The lateral dispersion coefficient can be used to estimate the exchange flow for each pair of segments. The exchange flow is estimated as

Exchange flow (cfs) =
Area • lateral dispersion coefficient/ Length

where length is defined as half the river width (125 feet) and the area is the area between the two segments (i.e., 100 ft length • 15 ft depth). The lateral dispersion coefficient was determined to be 0.8 • tidal velocity (ft/sec), so the lateral exchange flow between segments is about 9.6 times the tidal velocity. This corresponds to a maximum exchange flow of about 10 cfs when the tidal flow is 3,000 cfs (i.e., 0.33% of the tidal flow). For modeling purposes, the lateral mixing rate is specified as 0.5% of the tidal flow as the most likely mixing rate. This assumed mixing rate might be even higher to account for the river bend near the discharge and because the reversing tidal flows are expected to produce more mixing than steady river flows. A lateral mixing rate of 0.5% of the tidal flow is equivalent to mixing about 6% of the segment volumes in each 15-minute time period during maximum tidal flows, which may last for several hours during each tidal cycle.

A field survey was conducted to confirm the assumed lateral mixing rate. Ammonia measurements were taken near opposite banks of the river and from the 25%, 50%, and 75% lateral positions at several stations upstream from the RWCF discharge at high slack tide to track the lateral mixing as the RWCF effluent mixed across the river. The results are described in a later section of this report. The calibrated mixing rate was determined to be 1% of the tidal flow, which is about twice the original assumed mixing rate of 0.5% of the tidal flow. Both lateral mixing rates were simulated to evaluate the sensitivity of the tidal dilution patterns to the assumed lateral mixing rate.

Simulation of Tidal Dilution of Regional Wastewater Control Facility Discharge into the San Joaquin River

Figure 2a shows the tidal flow of water in the San Joaquin River near the RWCF for an example period of 30 days from the September 1999 Stockton UVM measurements. Figure 2b shows the corresponding tidal stage variation during this same 30-day period. The actual tidal flows have been adjusted in the model to give a steady net downstream flow of 150 cfs, which is the estimated lowest likely net river flow passing Stockton. The RWCF discharge of 50 cfs is assumed to be constant during the month of tidal simulation. The long-term average dilution for these flow and discharge conditions would therefore be 4 (i.e., [discharge + river flow] / discharge). The downstream river concentration would be equal to 25% of effluent if this were a steady river discharge situation. The simulated effluent concentration is set at 1,000, so the expected average downstream concentration should be 250 under steady-state conditions.

River concentrations will be highest during an extended period of low net river flow. The tidal flow will mix the effluent into a portion of the river volume that corresponds to the tidal mixing volume (the volume of water moving past the discharge location and receiving some effluent during a tidal cycle). Results from a series of simulations will be shown, for a range of flow from 150 cfs to 950 cfs, to illustrate the increased dilution and reduction in the tidal variations provided by greater net river flows.

Figure 3a shows the simulated location of the discharge relative to the moving river segments corresponding to the tidal flow variations during the month of simulation. Because the net downstream flow is 150 cfs, the location of the RWCF discharge moves to higher segments over time at an average rate of 43 segments per day (1,290 for the month). To avoid having to track so many segments, the downstream segments are dropped from the model at the end of each day (or more often if the river flow is high). These downstream segments do not influence the model results because they have been displaced far downstream from the discharge and lateral mixing is complete by this time. Figure 3b shows the adjusted position; the number of segments being dropped at the end of each day is shown with a + symbol.

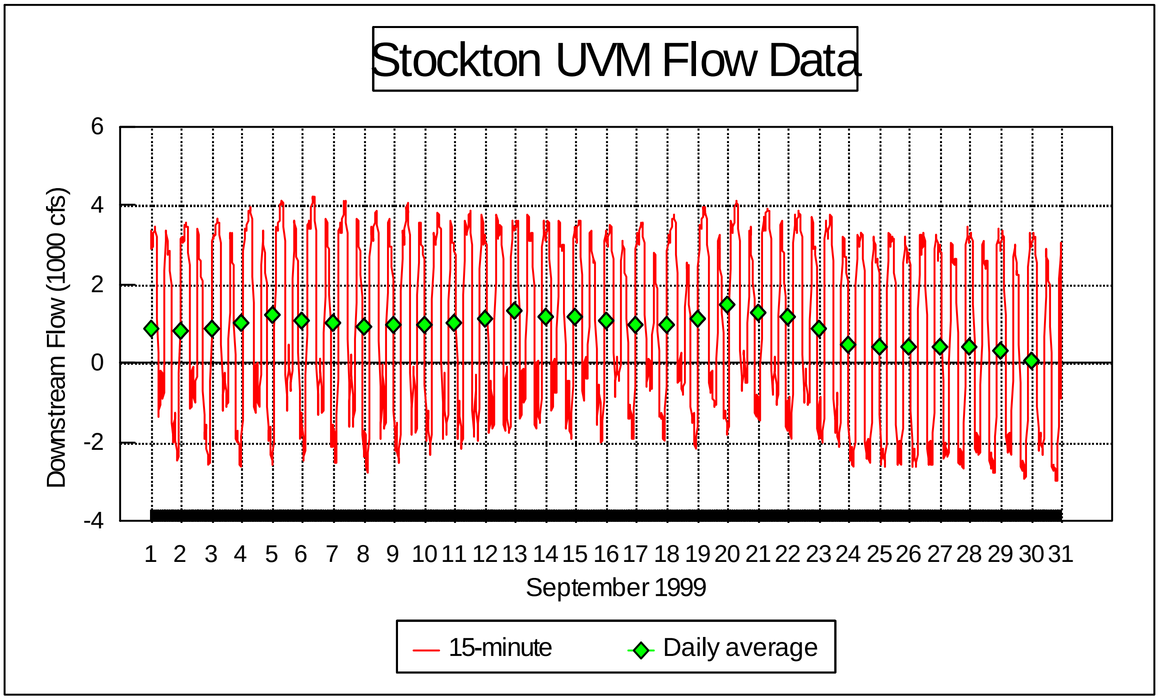


Figure 2a. Tidal Flow at Stockton UVM with Net River Flow of 100 cfs

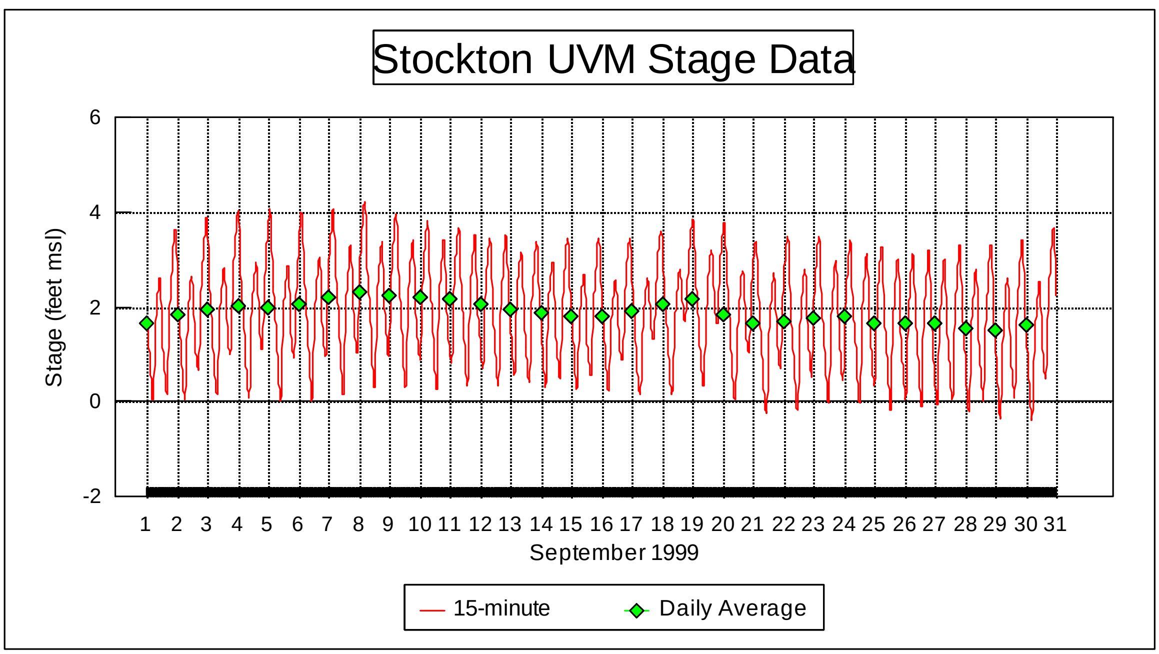


Figure 2b. Tidal Stage Variation at RWCF

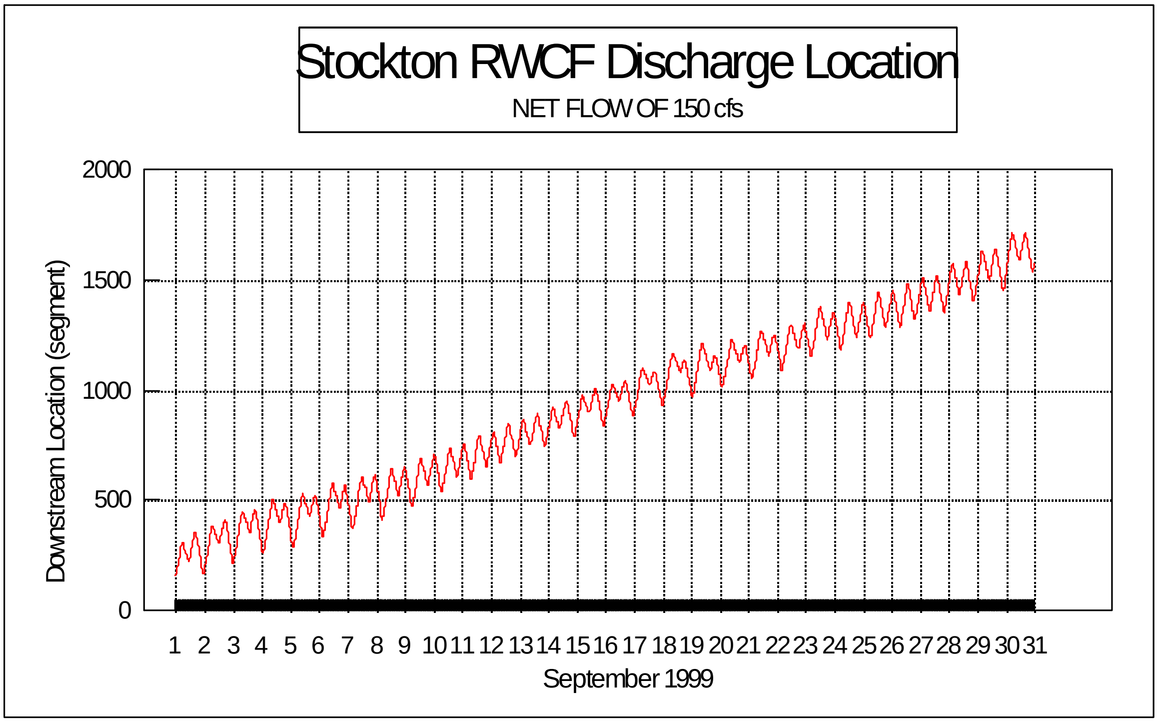


Figure 3a. Tidal Movement of RWCF Discharge with 100 cfs River Flow

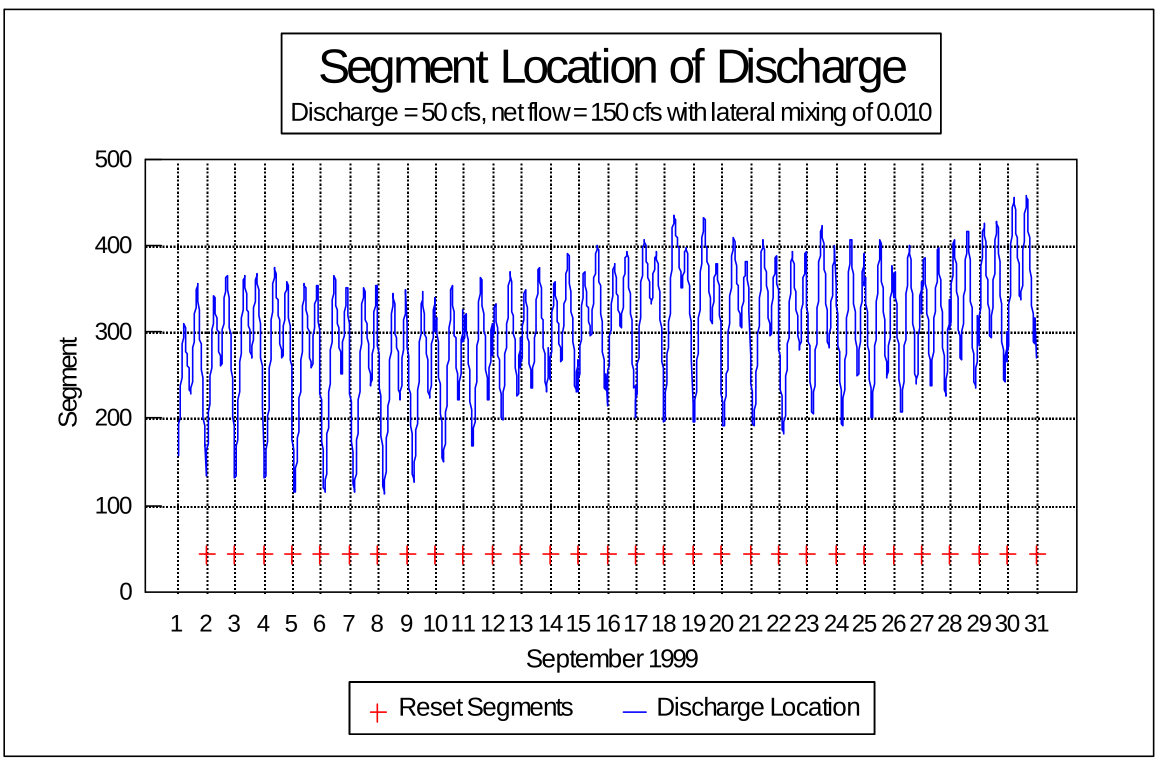


Figure 3b. Adjusted Location of RWCF Discharge Showing Tidal Movement of Segments

The tidal mixing model assumes that the RWCF discharge moves along the row of river segments, adding effluent to the segment volumes. By drawing a horizontal line through the tidal position of the discharge (figure 3a), it is possible to determine the number of times that a water volume will be influenced by the discharge. During periods of low net river flows, tidal flows generally move the water past the RWCF effluent for about 5–7 days. During this time, the water may have effluent added more than 20 discrete times (i.e., during ebb and flood periods of more than 10 tidal cycles). The water will move through the tidal mixing volume faster and have effluent added fewer times at higher river flows.

The difference between the daily maximum and minimum discharge position is an approximation of the tidal mixing volume. Figure 3a indicates that the tidal mixing volume extends about 200 segments, with a corresponding volume of about 1,400 acre-feet (af) (each pair of river segments has a combined volume of about 7 af). The tidal mixing volume changes with the lunar tidal cycle, and is smallest during the middle of the month (i.e., days 10–15) when the neap tides have the smallest tidal excursion (i.e., 2 nearly equal tides each day). The tidal mixing volume is about 150 segments (1,050 af) during this period of minimum tidal fluctuation each month.

River Concentrations with a Net Flow of 150 cfs

Figure 4 shows the simulated river concentrations at the discharge location during the month with an assumed river flow of 150 cfs and a lateral mixing rate of 1% of the tidal flow. Both the west-side and east-side river concentrations are shown as 15-minute values that fluctuate with the tidal flow. The maximum concentrations correspond to periods when the tidal flow velocity is lowest. The maximum west-side concentrations are greatest during the portions of the lunar tidal cycle when the mean tide stage is increasing (i.e., around days 10 and 24). The maximum west-side concentrations range from about 300 to 400, with an assumed effluent concentration of 1,000. The minimum concentrations correspond to periods during the day when the tidal flows are highest. The minimum east-side concentrations correspond to these same periods of maximum ebb (downstream) flow when fresh river water is moving past the discharge. The east-side concentrations are slightly less than the west-side concentrations.

The assumed lateral mixing rate is sufficient to maintain nearly complete mixing across the river with the relatively high tidal flows that are measured in this portion of the San Joaquin River. The greatest differences between the west-side and east-side concentrations occur during the slack high tides.

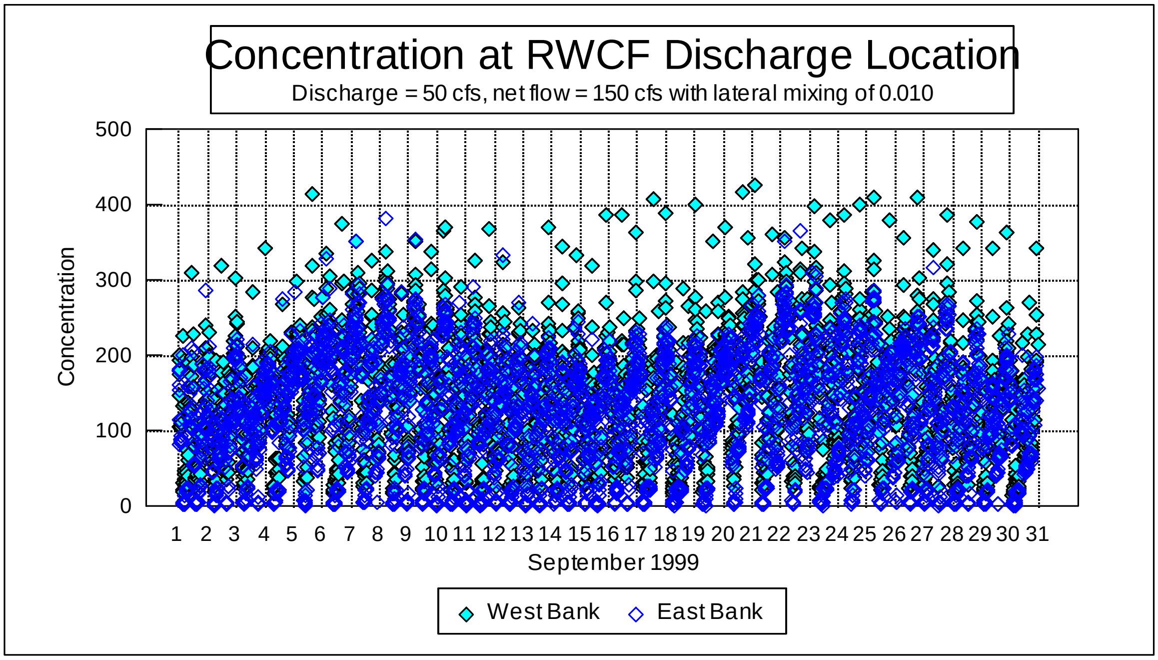


Figure 4. Simulated River Concentration at Discharge Location (East and West Banks) for 150 cfs with lateral mixing of 1% tidal flow

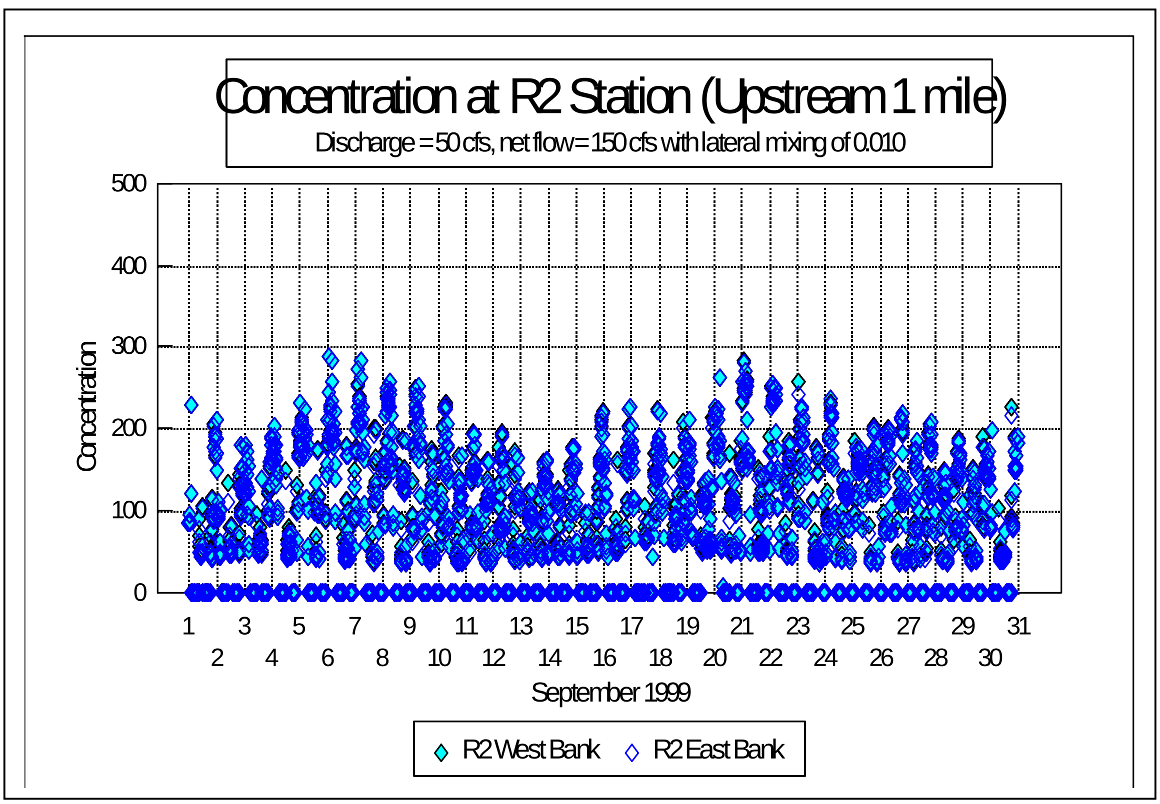


Figure 5. Simulated River Concentrations at Upstream Station R2 (East and West Banks) for 150 cfs with lateral mixing rate of 1% tidal flow

Figure 5 shows the simulated river concentrations at the upstream river monitoring station R2, located about 1 mile upstream of the discharge location. The east-side and west-side concentrations are about the same because of the strong lateral mixing caused by the tidal flows. The maximum west-side concentrations range from about 150 to 300, slightly less than the maximum concentrations at the discharge location. The minimum concentrations correspond to periods during the day when the tidal flows are moving downstream and fresh river inflow is moving past the upstream station.

Figure 6 shows the simulated river concentrations at the downstream river monitoring station R3, located about 1.5 miles downstream from the discharge location. The downstream R3 station is located in the DWSC, where the San Joaquin River channel enters the DWSC. The east-side and west-side concentrations are about the same because of the strong lateral mixing caused by the tidal flows in the river between the discharge and the R3 station. The maximum concentrations range from about 200 to 300, slightly less than the concentrations at the discharge location. The minimum concentrations correspond to water segments that have received slightly less effluent because higher tidal flows moved these segments more rapidly past the discharge location. The minimum concentrations at R3 range from about 100 to 200 during the month.

Table 1 on the following page gives a summary of the simulated, tidally averaged concentrations for the east and west side of the river at the downstream station R3, at the discharge location, and at the upstream station R2. For a river flow of 150 cfs, with the lateral mixing rate of 1% of the tidal flow, the average concentration at the upstream R2 station was 70 for the west side and 69 for the east side. The average concentrations at the discharge location were 148 on the west side and 122 on the east side. The average concentrations at the downstream R3 station were 205 for the west side and 204 for the east side. These east-side and west-side values are nearly identical at R3, but less than the expected steady-state average of 250.

This difference between the steady-state average of 250 and the simulated values at R3 is a result of the large tidal excursion. The ebb tide flow moves low-concentration water from upstream of the RWCF discharge to a location downstream of the R3 station near the end of the ebb tide. Consequently, the tidally averaged concentration at R3 will be less than the expected steady-state value. Concentrations further downstream, beyond the downstream distance of the tidal excursions, will approach an average of 250 for this assumed river flow of 150 cfs. The fluctuations in the daily maximum concentrations shown in figure 6 are the result of variations in the tidal flow patterns (that control the dilution) during the month.

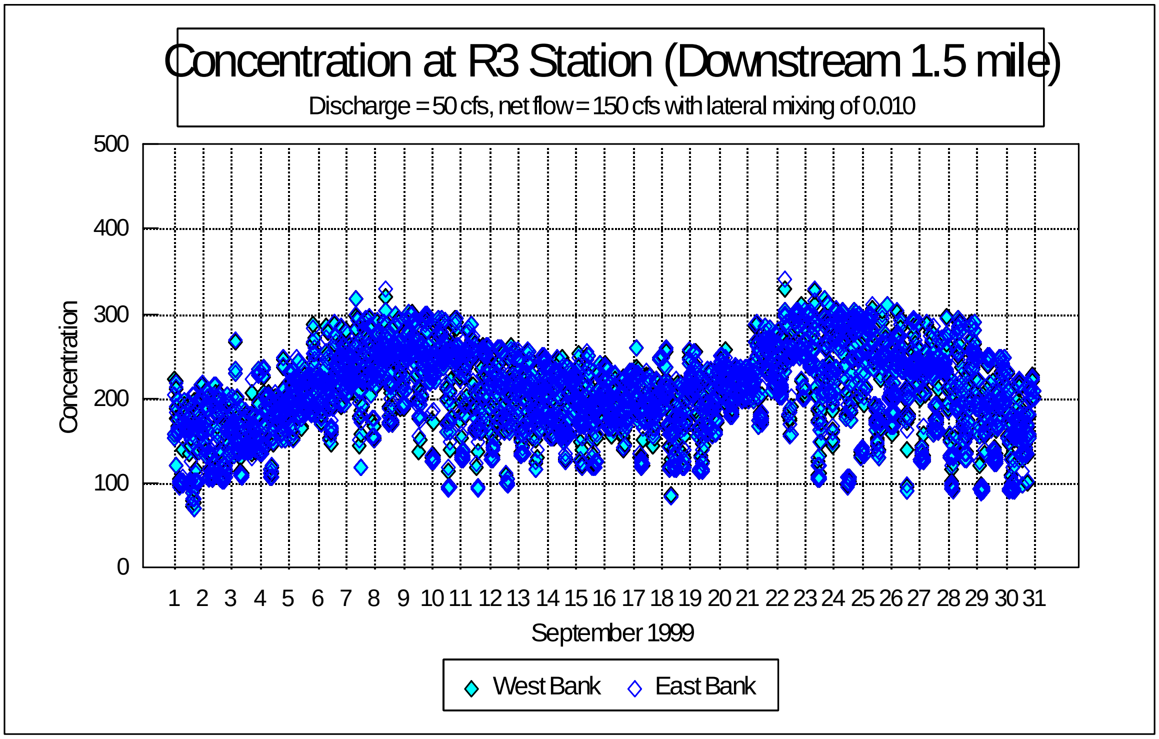


Figure 6. Simulated Concentrations at Downstream R3 Station for 150 cfs

Table 1. Average Simulated Concentrations for Range of River Flow and Lateral Mixing Rates at the Downstream R3, Discharge Location, and Upstream R2 Stations

Net River Flow/Mix Rate	Average Dilution	Expected River Concentration	Side of River	Downstream R3 Station	Discharge Location	Upstream R2 Station
150	4	250	East	204	119	66
0.5%			West	205	151	73
150	4	250	East	204	122	69
1.0%			West	205	148	70
450	10	100	East	80	40	27
0.5%			West	82	77	33
450	10	100	East	81	43	29
1.0%			West	81	74	30
950	20	50	East	36	26	11
0.5%			West	39	64	16
950	20	50	East	37	30	13
1.0%			West	38	60	14

Figure 7 shows the simulated longitudinal profile of river concentration for the west-side segments at the end of each day from day 6 through day 10, with a net river flow of 150 cfs. Segment 1 is the downstream end of the tidal model, and segment 500 is the upstream end.

The RWCF discharge location fluctuates with the tidal flow (see figure 3b) and is generally located between segments 100 and 300, with an average location near segment 265 during these 5 days. The cumulative discharge location during these 5 days is shown by the dots at the bottom of Figure 7 (i.e., each dot represents the cumulative discharge segment location in 10% increments). The river concentrations increase from the upstream edge of the tidal mixing volume (segment 300) to the downstream edge of the tidal mixing volume (segment 100). The river concentrations remain relatively constant downstream of the tidal mixing volume. A downstream river concentration of between 200 and 300 is simulated for these 5 days.

Figure 6 indicates that the maximum concentrations at R3 are increasing during these 5 days because of changes in the spring/neap tidal fluctuations. There are greater longitudinal variations in river concentrations at the upstream end of the tidal excursions. These longitudinal variations are smaller at the downstream end of simulated rows of segments because of lateral mixing and additional effluent discharges into the tidal mixing volume.

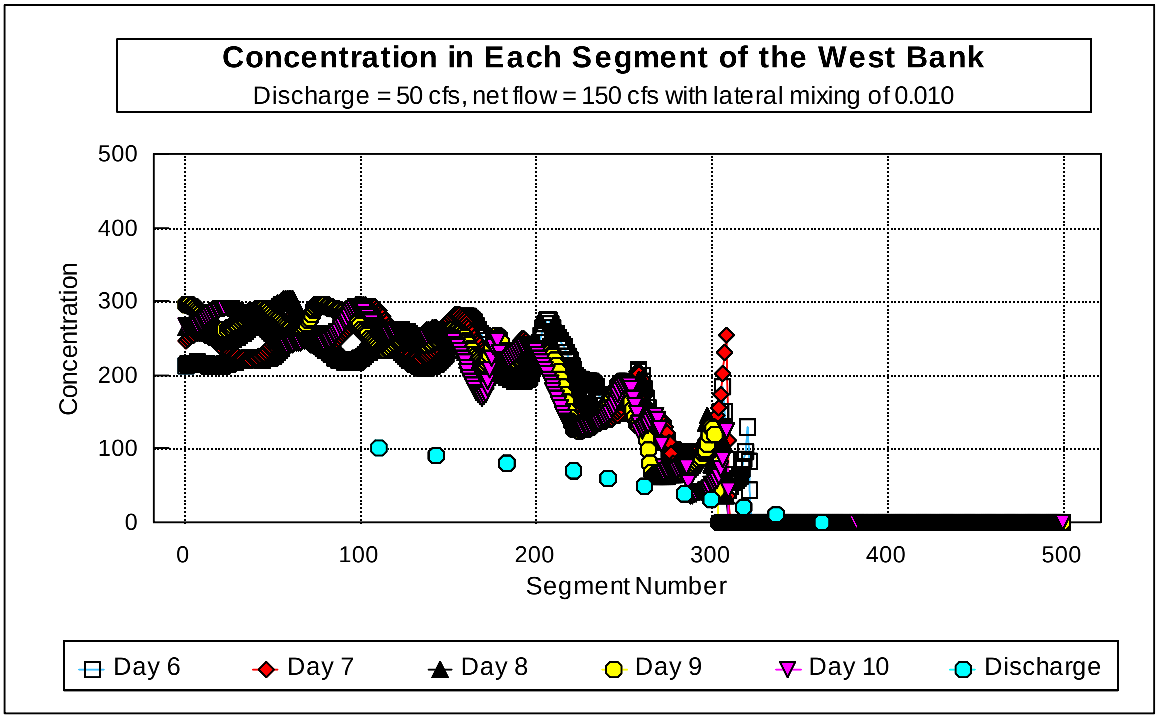


Figure 7. Longitudinal Profile of West Bank River Concentrations for 150 cfs with lateral mixing rate of 1% tidal flow

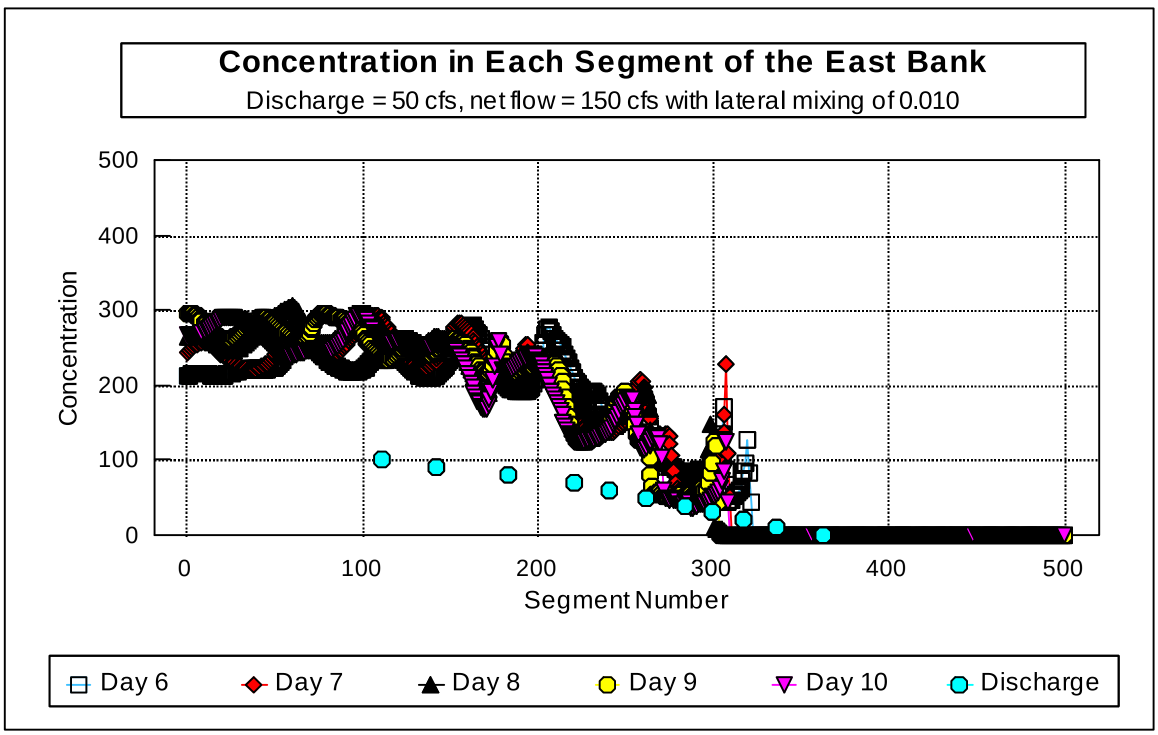


Figure 8. Longitudinal Profile of East Bank River Concentrations for 150 cfs with lateral mixing rate of 1% tidal flow

Figure 8 shows the simulated longitudinal profile of river concentration for the east-side segments at the end of each day from day 6 through day 10, with a net river flow of 150 cfs. The east-side river concentrations increase from the upstream edge of the tidal mixing volume (segment 300) to the downstream edge of the tidal mixing volume (segment 100). The east-side concentrations are only slightly less than the west-side concentrations because of the strong lateral mixing caused by the tidal flows. The river concentrations remain relatively constant downstream of the tidal mixing volume. A downstream river concentration of between 200 and 300 is simulated for these 5 days. The longitudinal concentration pattern generally follows the longitudinal distribution of the discharge location.

River Concentrations with a Net Flow of 150 cfs with Reduced Lateral Mixing

Figure 9 shows the simulated river concentrations at the discharge location with reduced lateral mixing (i.e., 0.5%) to illustrate the sensitivity of the model. Table 1 indicates that the average concentrations for the west side and the east side were 151 and 119, respectively. The east-side concentrations therefore average about 78% of the west-side values. For the higher lateral mixing rate, the east-side concentrations averaged 82% of the west-side values. Both lateral mixing rates provide very high lateral mixing near the discharge location. At this low river flow, the water moving past the discharge location has a cumulative residence time of several days (e.g., 5–7) during which the lateral mixing is working. The effluent is entering only the west side of the river at the discharge location. The lateral mixing creates more uniform concentrations both upstream and downstream of the discharge (see table 1). Lateral mixing is sufficient to produce nearly identical east-side and west-side concentrations at the upstream R2 station for the assumed mixing rate of 1% tidal flow. For the reduced mixing rate of 0.5% tidal flow, the east-side concentrations are about 85% of the west-side concentrations (i.e., 73/86).

Figure 10 shows the simulated river concentrations at the downstream station R3 with reduced lateral mixing (i.e., 0.5%). The R3 station is located about 1.5 miles downstream from the discharge, so the travel time for water to reach R3 is longer and the lateral mixing produces nearly identical east-side and west-side concentrations. The average concentrations for the east and west sides were 204 and 205, respectively. The R3 concentrations were identical to those simulated with the higher lateral mixing rate because both mixing rates were sufficient to produce complete lateral mixing at the R3 station. There are still tidal variations in the simulated concentrations at R3.

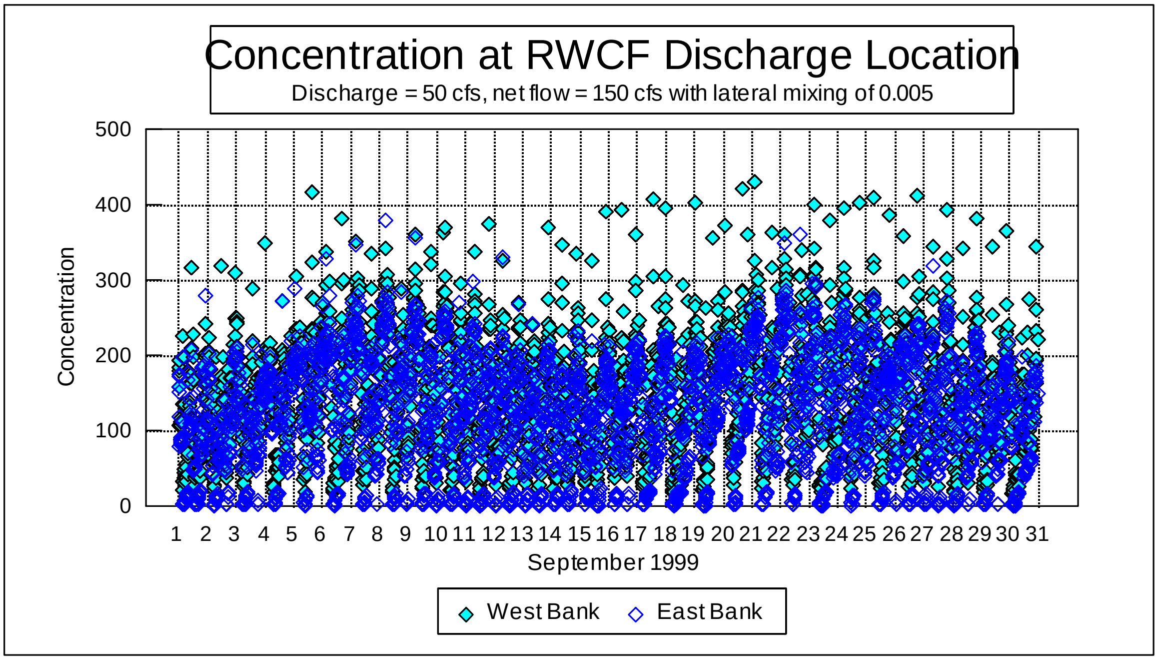


Figure 9. Simulated Concentrations at Discharge for 150 cfs with lateral mixing rate of 0.5% tidal flow

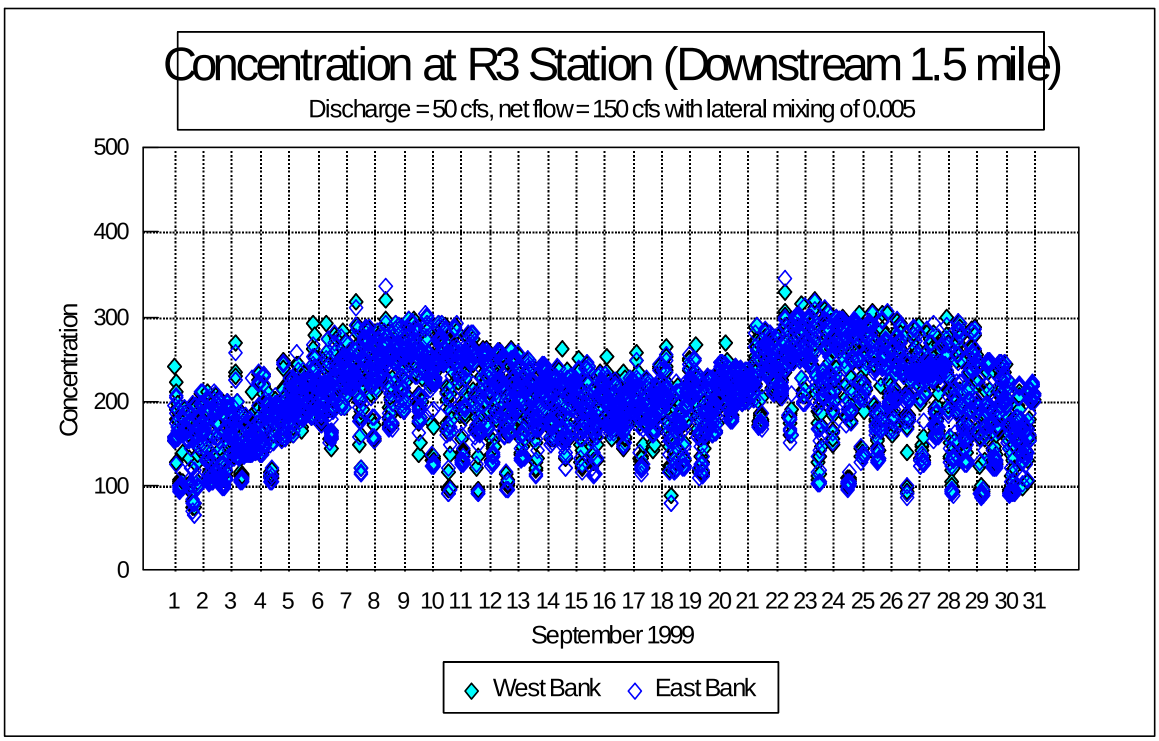


Figure 10. Simulated Concentrations at Downstream Station R3 for 150 cfs with lateral mixing rate of 0.5% tidal flow

Figure 11a shows the daily average east-side and west-side concentrations at the discharge location for the expected lateral mixing of 1.0% with an assumed river flow of 150 cfs. The daily average east-side concentrations average 82% of the west-side concentrations. Figure 11b shows the maximum hourly east-side and west-side concentrations at the discharge location. The maximum hourly values are less than 500, and the hourly maximum on the east side for each day averages about 81% of the hourly maximum on the west side.

Figures 12a and 12b show similar results for the lower lateral mixing rate of 0.5% with an assumed river flow of 150 cfs. The daily average east-side concentrations are about 78% of the west-side concentrations. The hourly maximum east-side concentrations are about 79% of the hourly maximums for the west side. Review of table 1 and these figures suggests that although the lateral mixing rate is somewhat uncertain, it is relatively high and not a strong factor in controlling the simulated concentrations at the discharge location or downstream at station R3. The calibrated lateral mixing rate is 1% of the tidal flow.

River Concentrations with a Net Flow of 450 cfs

Figure 13 shows the west-side and east-side concentrations at the discharge location with a river flow of 450 cfs. This river flow provides a dilution of 10, so the expected average river concentration is 100, with an assumed effluent concentration of 1,000. Table 1 indicates that the average east-side and west-side concentrations at the discharge location are 43 and 74 for a river flow of 450 cfs with a lateral mixing rate of 1% of the tidal flow.

Figure 14 shows the concentrations at the downstream station R3 with a flow of 450 cfs. The average west-side and east-side concentrations were both 81, indicating the effects of the lateral mixing associated with the tidal excursions and the slightly larger downstream flow. The R3 station is located within the tidal excursion zone, and concentrations are less than the expected value of 100 during periods of low tide.

Table 1 indicates that the results of the lower lateral mixing rate (0.5% tidal flow) were very similar for a river flow of 450 cfs. Average simulated concentrations at the discharge location were 40 on the east side and 77 on the west side. Average simulated concentrations at station R3 were 80 on the east side and 82 on the west side.

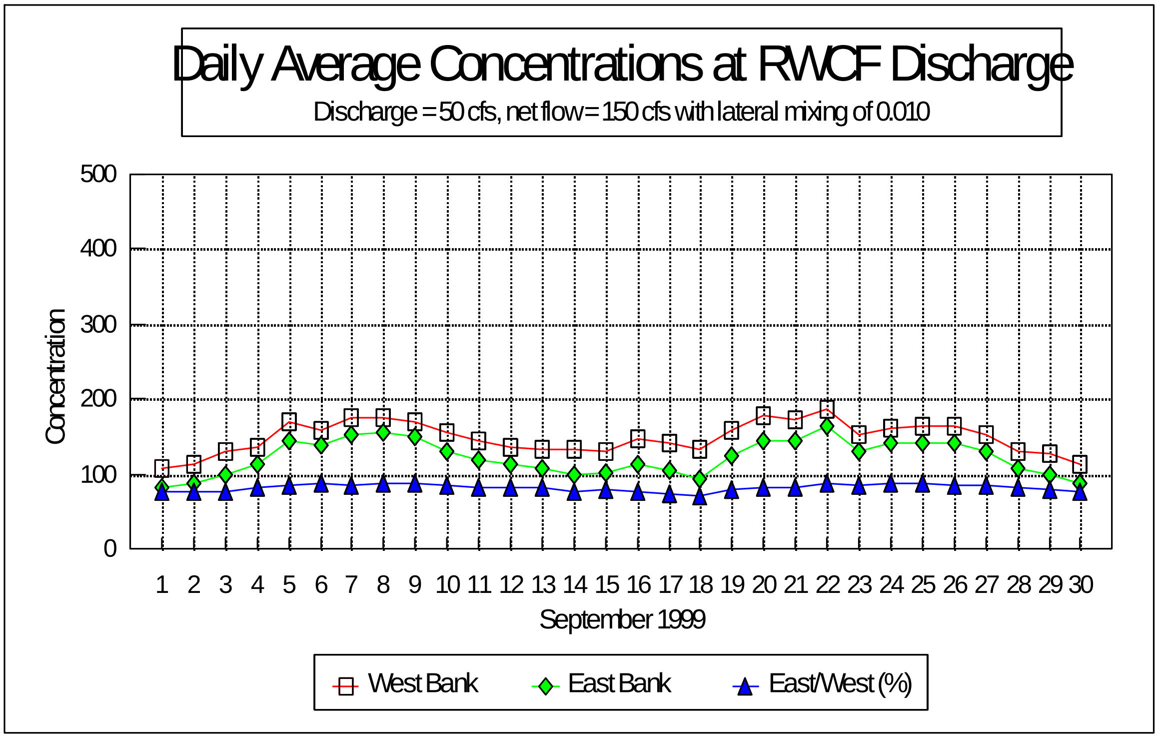


Figure 11a. Average Daily West and East Concentrations at Discharge Location for 150 cfs with Lateral Mixing of 1% Tidal Flow

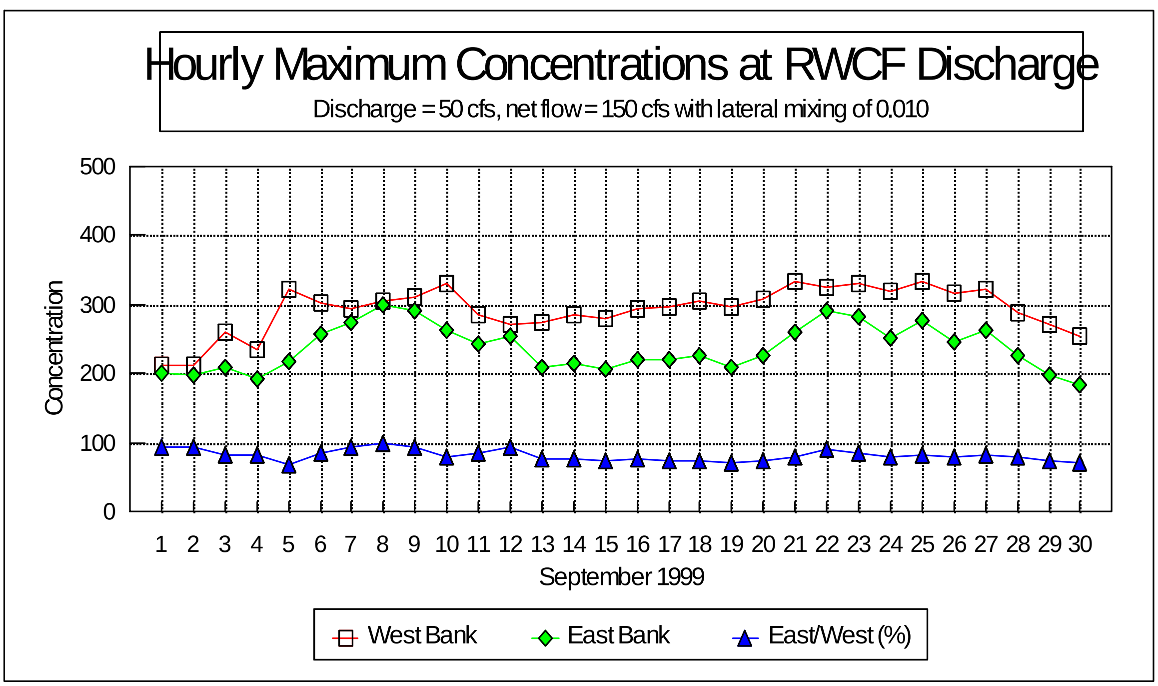


Figure 11b. Hourly Maximum East and West Concentrations at Discharge Location for 150 cfs Flow with Lateral Mixing of 1% Tidal Flow

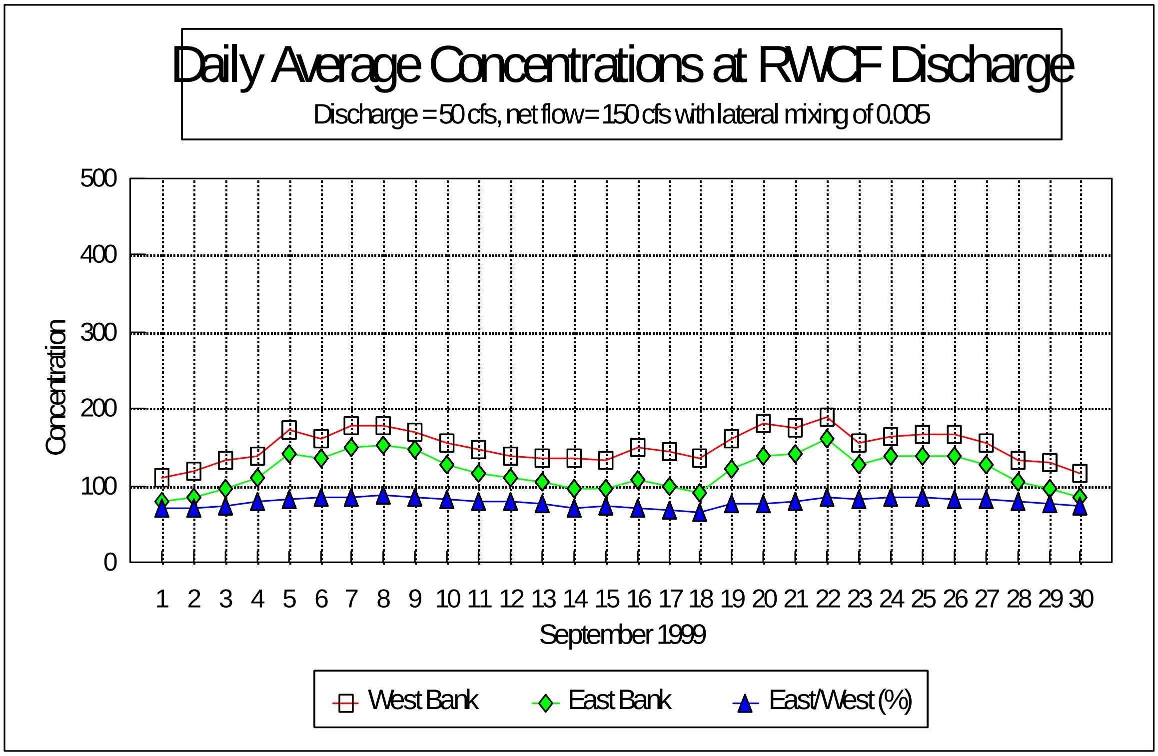


Figure 12a. Daily Average East and West Concentrations at Discharge Location for Flow of 150 cfs with Lateral Mixing of 0.5% Tidal Flow

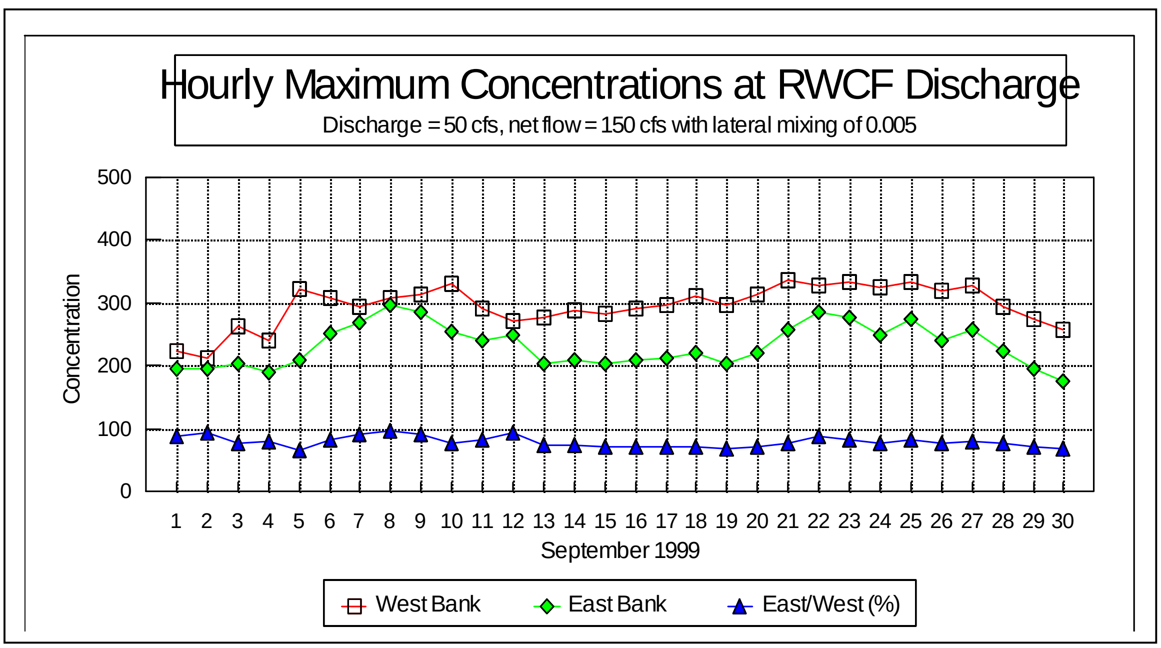


Figure 12b. Maximum Hourly East and West Concentrations at Discharge Location for 150 cfs with Lateral Mixing of 0.5% Tidal Flow

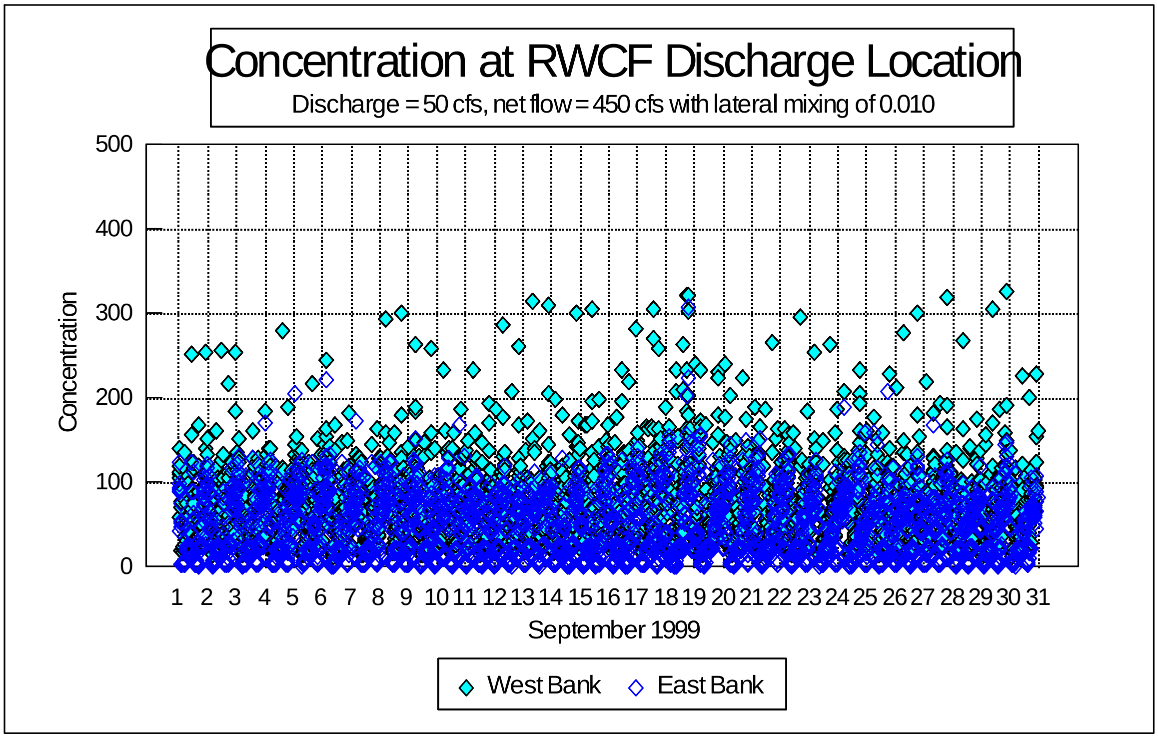


Figure 13. Simulated Concentrations at Discharge Location for 450 cfs with lateral mixing rate of 1% tidal flow

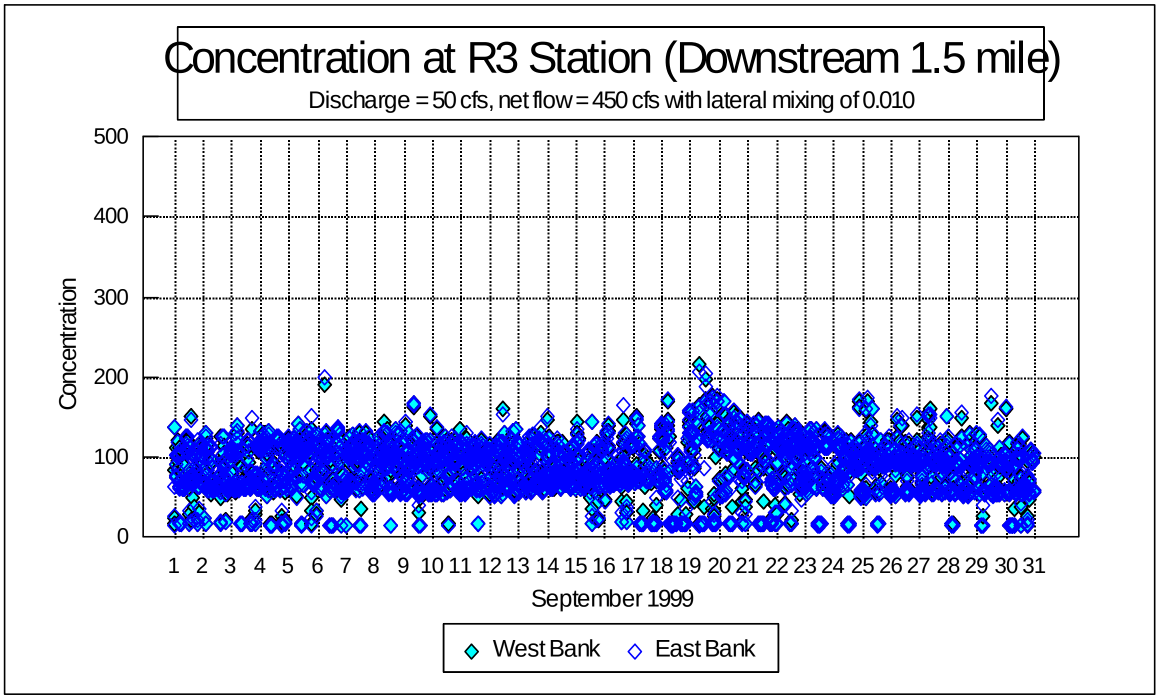


Figure 14. Simulated Concentrations at Downstream R3 Station for 450 cfs with lateral mixing rate of 1% tidal flow

River Concentrations with a Net Flow of 950 cfs

Figure 15 shows the east-side and west-side concentrations at the discharge location with a river flow of 950 cfs. This river flow provides a dilution of 20, so the expected average river concentration is only 50, with an assumed effluent concentration of 1,000. Table 1 indicates that the average east-side and west-side concentrations at the discharge location are 30 and 60 with a river flow of 950 cfs and lateral mixing rate of 1% of tidal flow.

Figure 16 shows the adjusted tidal flows for a net river flow of 950 cfs. Because the flood tide flow currents sometimes nearly equal the net assumed river flow of 950 cfs, there are short periods on several days when flow conditions are relatively stagnant and the maximum 15-minute river concentrations exceed 200 (figure 15). The maximum hourly concentrations were generally less than 250.

Figure 17 shows the concentrations at the downstream station R3 with a flow of 950 cfs. The average east-side and west-side concentrations were 36 and 39, respectively, indicating the effects of the large downstream tidal excursion associated with this high river flow. The rapid movement of water past the discharge location, except during short periods when the river flow balances the flood tide flow (see figure 3a), produces a widely fluctuating concentration pattern in the river downstream of the discharge. Maximum concentrations at R3 exceed 250 for a river flow of 950 cfs when the average is less than 50.

Figure 18 shows the concentrations at the upstream station R2 with a flow of 950 cfs and a lateral mixing rate of 1% of the tidal flow. The average east-side and west-side concentrations were 13 and 14, respectively, indicating the effects of this high river flow. The flood tide flows were not sufficient to move effluent upstream to the R2 station except during the strongest flood tides. The concentrations are often 0 at the upstream R2 station.

Regional Wastewater Control Facility Effluent Concentrations During a Typical Daily Tidal Cycle

Figure 19 shows the simulated concentrations for the west-side and east-side river segments at the RWCF discharge location on September 10, 1999. The measured tidal stage and adjusted tidal flows (i.e., for a 950-cfs daily average net flow) during the day are shown with the solid lines in the 2 panels. The west-side and east-side concentrations, relative to an effluent concentration of 1,000 units, are shown for each 15-minute tidal interval in each panel.

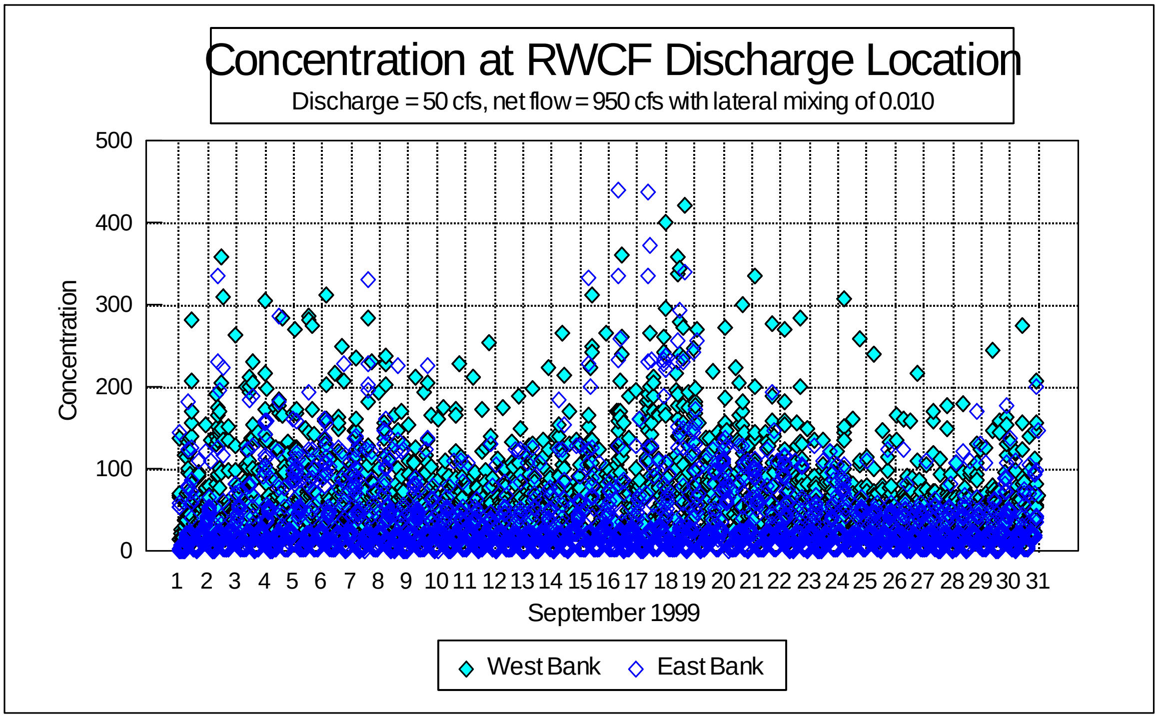


Figure 15. Simulated Concentrations at Discharge Location for 950 cfs with lateral mixing rate of 1% tidal flow

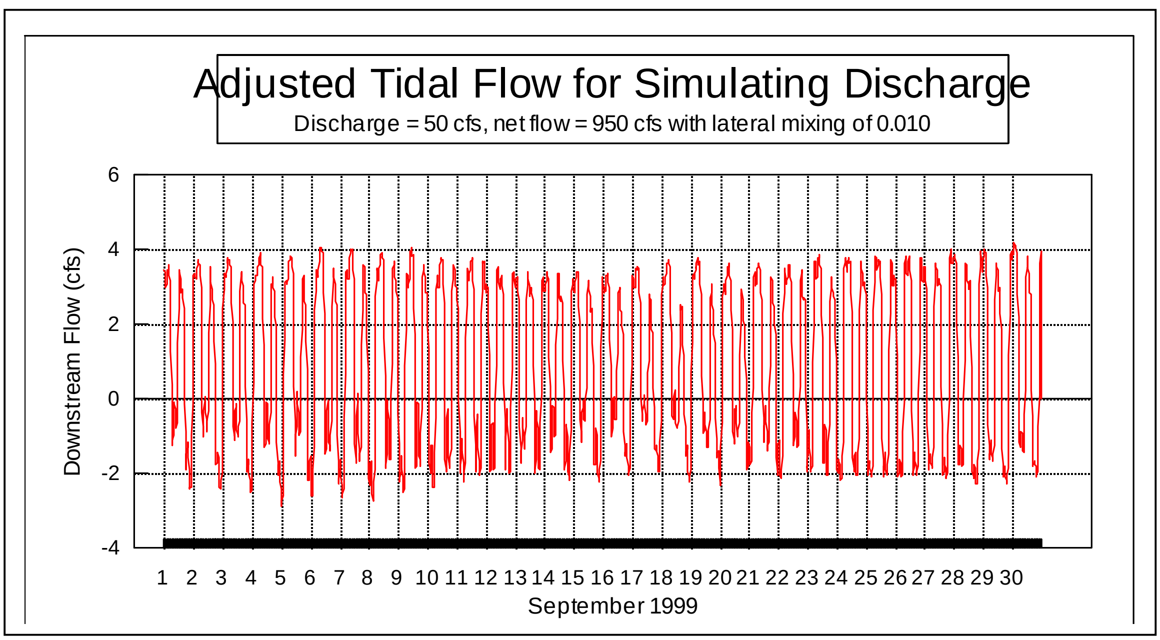


Figure 16. Adjusted Tidal Flow for Simulating Net River Flow of 950 cfs

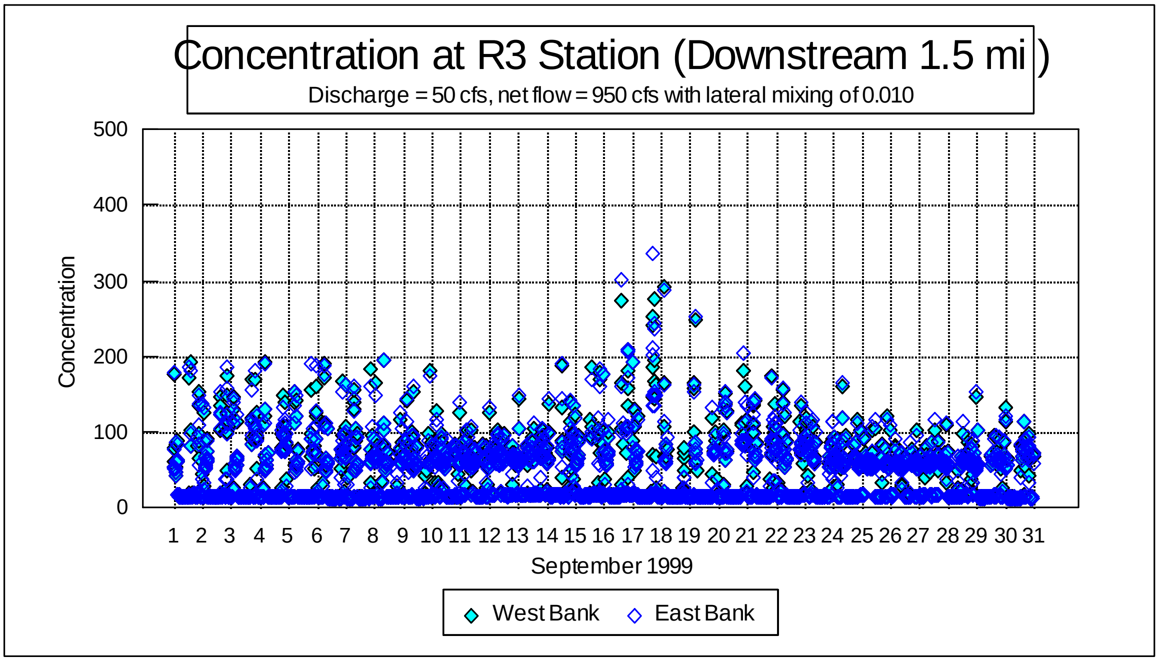


Figure 17. Simulated Concentrations at Downstream Station R3 for 950 cfs with lateral mixing rate of 1% of tidal flow.

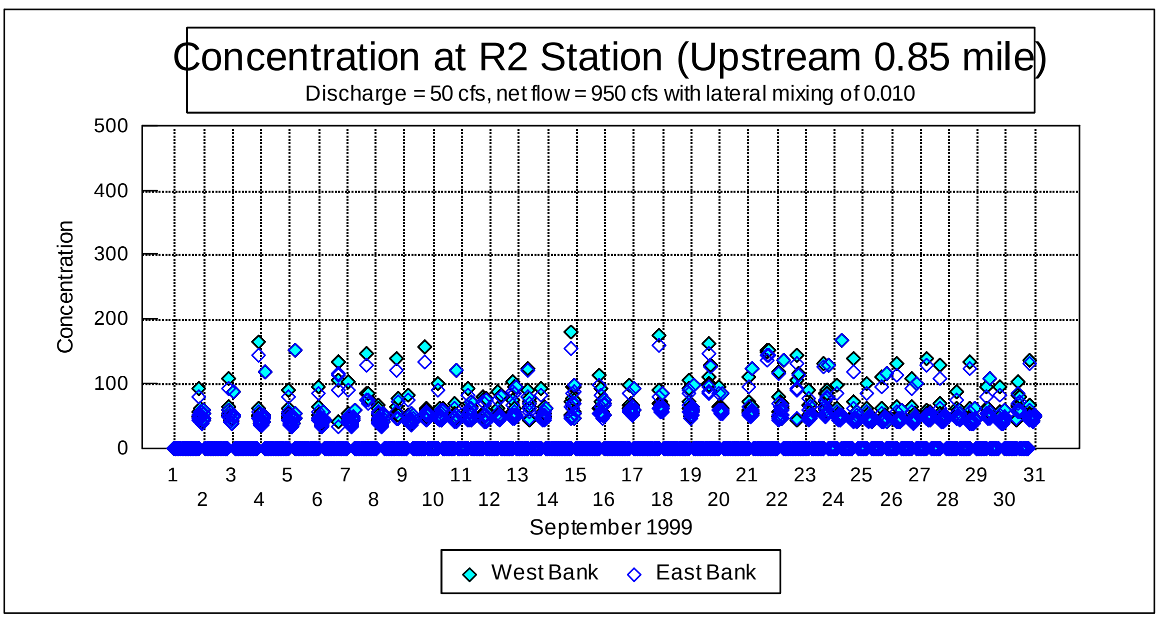
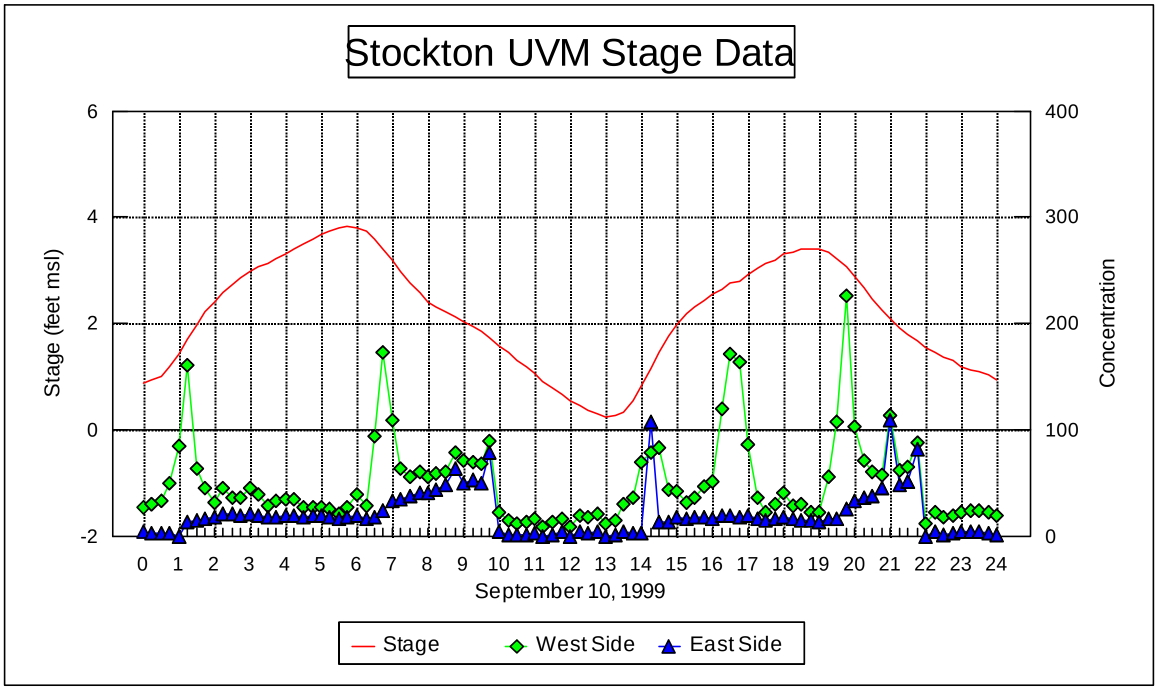


Figure 18. Simulated Concentrations at Upstream R2 Station for 950 cfs with lateral mixing of 1% tidal flow.



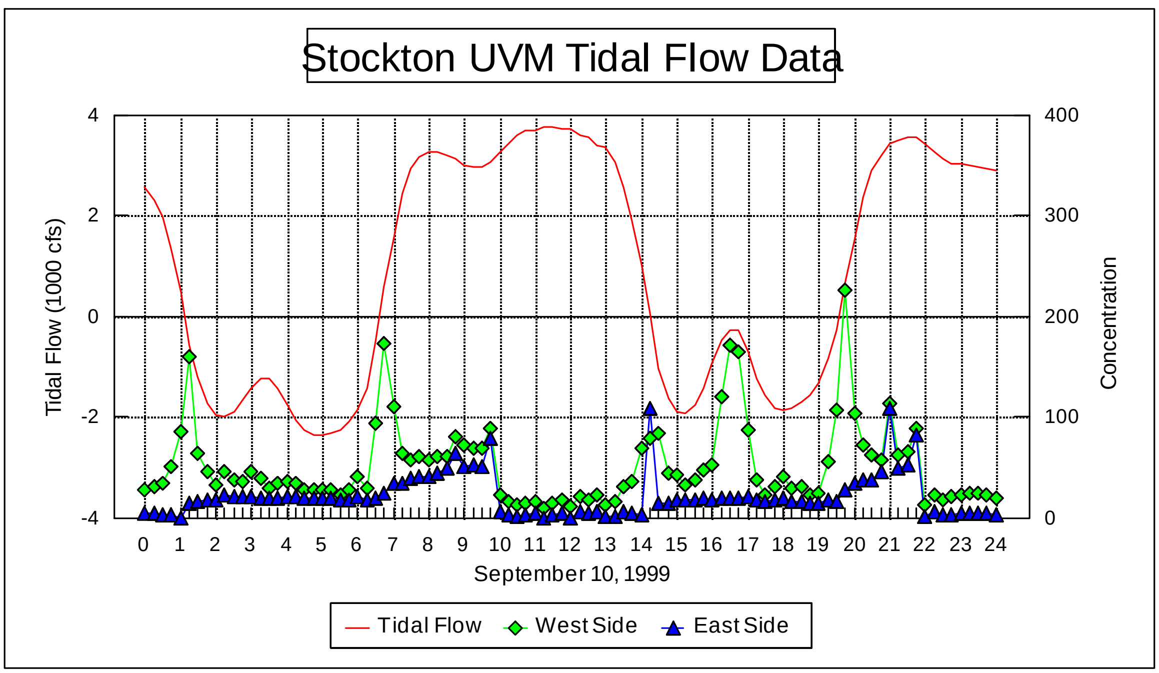


Figure 19. Simulated West and East Bank Concentrations at Discharge Location during Tidal Cycle of September 10, 1999, with Assumed River Flow of 950 cfs

Figure 19 demonstrates the model calculations and illustrates the near-field concentration patterns that result from the constant discharge into the fluctuating tidal flows in the San Joaquin River near Stockton. The selected day (September 10) begins with a low-tide stage of about 1 feet msl, and the tide is rising (flood tide) with a high tide stage of about 4 feet occurring at hour 6. The tidal flow is changing from ebb to flood, and the first slack tide occurs at hour 1. The flood-tide flow is only about 2,000 cfs because it is moving against the assumed river flow of 950 cfs. The upstream tidal flow reverses direction by hour 7 (the second slack tide is about half an hour after high tide) and the ebb-tide flow is 3,000–4,000 cfs because of the assumed river flow of 950 cfs. The falling tide reaches a low-tide stage of 0.3 feet at hour 13. The third slack tide occurs at hour 14 as the tide switches from ebb to flood. The floodflow is less than 1,000 cfs during the afternoon, with the second high-tide stage of 3.5 feet at hour 19. The fourth slack tide occurs at hour 20 and the tide stage declines to about 1.0 feet by the end of the day.

The simulated effluent concentrations on the west side and east side of the river at the RWCF discharge location are the direct result of these fluctuating tidal flows. West-side concentrations are increasing during the first hour as the ebb flow slackens and reverses. A peak concentration is simulated during the slack tide at hour 1. The west-side concentration varies during the flood tide from hour 1 to hour 6 because of the tidal flow velocity and because some of these segments that are moving upstream were already dosed with the effluent during the previous day's ebb tide.

A second peak concentration is simulated at hour 7 during the second slack tide. Concentrations increase until hour 10 because these segments are receiving a third dose of effluent. After hour 10, however, the ebb tide has moved fresh river water downstream past the RWCF discharge. West-side concentrations are low and uniform until the next slack tide at hour 14. The east-side concentrations are 0 during this period because the discharge is assumed to enter only the west side of the river.

The east-side concentration increases slowly between hours 15 and 20 (flood tide) because lateral mixing is moving effluent across the river as these segments are moving upstream. West-side concentrations increase at hour 16 because the measured tidal flows are reduced during the hour. The highest west-side concentrations of the day are simulated at hour 20. Some of the segments moved slowly past the discharge at the end of the flood tide and are then moving past the discharge at the beginning of the ebb tide. The highest west-side concentrations occur during low tidal-flow periods that generally occur during slack tide as the tidal flow changes direction. This change in tidal flow generally takes place 4 times each day, about half an hour after the high tides and the low tides.

There can also be periods of relatively slow moving water during the flood tides, especially if the assumed river flow is relatively high.

The east-side concentrations approach the west-side concentrations after 1–2 hours of tidal flow. This can be seen between hours 6 and 9 and between hours 19 and 22. In both these periods, segments that moved upstream during flood tide have moved downstream past the discharge location during the ebb tide. However, actual mixing may be more rapid because the river bend near the discharge location and the railroad bridge (2 piers) located 500 feet upstream may promote more rapid mixing than the lateral mixing process used in this model.

Simulated Increase in Effluent Concentration During Slack High Tide

Figure 20 illustrates the simulated west-bank concentrations during the high slack-tide event at hour 8 on September 10. The simulated location of the RWCF discharge was moving from right to left past segment 210 at the end of hour 6 (upstream tidal flow) with a concentration of 50 upstream of the discharge and about 25 downstream of the discharge. This indicates that the simulated segment concentrations were increasing by about 25 during this flood-tide period. By the end of hour 7, the RWCF location was at segment 175, and by the end of hour 8, the RWCF was located at segment 165 and the slack tide had occurred, producing a concentration peak of about 250 in 2 segments.

By the end of hour 9, the tide had reversed and was moving downstream, so the location of the RWCF discharge was approaching segment 200. The segment concentrations were about 75 downstream of the RWCF discharge and about 50 upstream, indicating that the effluent concentration in the discharge segment was increasing by about 25 during this ebb tide. This is consistent with an average tidal flow of 2,000 cfs that would provide a dilution of about 40 for the simulated effluent flow of 50 cfs. Each time the tidal flow passes the RWCF discharge location, the river concentration will increase by about 25 (i.e., 1,000/40).

It can be hard to decipher the superposition of concentration patterns caused by several tidal movements together with the net river flow past the discharge location. For example, the peak concentration at segment 275 was produced by the discharge during the previous low-tide slack period. The ebb tidal flow moved the segments downstream, so the simulated location of the RWCF discharge moved to the highest number segments. The number of segments between the peak concentrations that result from the high and low slack tides is about 100 segments (i.e., 275 and 175), representing a distance of about 2 miles. The effluent concentration pattern

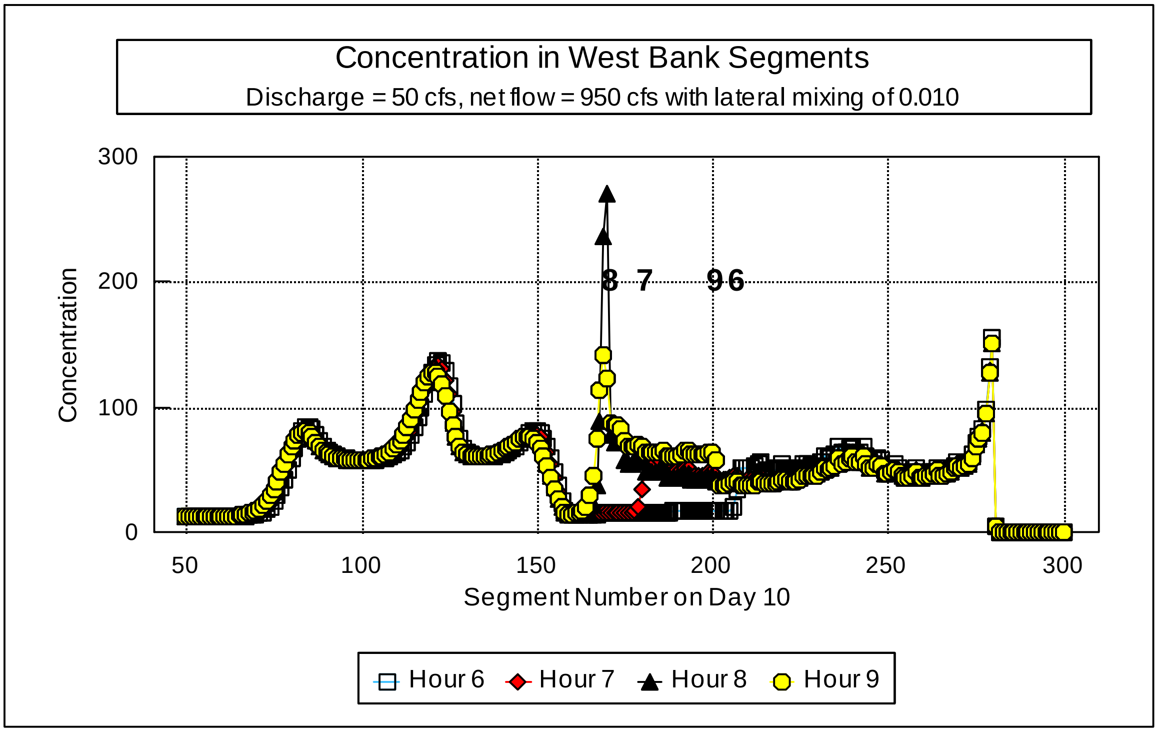


Figure 20. Simulated West Bank Concentrations During High Slack Tide Event on Hour 8 of September 10, 1999

between segments 50 and 150 was the result of the previous day's tidal cycle.

These simulated concentration patterns at the high slack tide during day 10 were similar to the concentrations actually observed during the high-slack-tide field survey described in the next section.

Measured Effluent Concentrations and Lateral Mixing at High Slack Tide

A field survey of the maximum near-field effluent concentrations and mixing of the effluent across the river was conducted to verify the assumed lateral mixing rate. The concentrations of ammonia at several transects across the river were measured at high slack tide just upstream of the RWCF discharge location. The lateral mixing was expected to mix the west-side and east-side concentrations more completely as the distance upstream increased. Lateral concentration profiles were measured at 100-foot increments for the first 500 feet upstream of the discharge. Subsequent measurements were then made at 500-foot increments. The field survey documented the lateral mixing between the discharge and 2,500 feet upstream. At maximum tidal velocity of about 1 ft/sec, water moves upstream 2,500 feet in about 40 minutes.

Figure 21 shows the river in the vicinity of the RWCF discharge pipe and the layout of the sampling transects. The field study plan was to sample water immediately after high slack tide at 5 lateral locations (i.e., west bank, 25%, 50%, 75% and east bank) on transects located 100 feet upstream, 200 feet upstream, 300 feet upstream, 400 feet upstream, and 500 feet upstream. These samples would be used to evaluate the lateral mixing rate in the near-field mixing zone located within 2 river widths (i.e., 500 feet) of the discharge. A similar mixing zone is assumed to occur downstream of the discharge during periods of ebb flow. Survey stakes were placed along the west levee at measured distances upstream of the discharge pipe to denote transect locations. The railroad bridge is located about 400 feet upstream; the State Route 4 bridge (river station R2) is located about 4,500 feet upstream of the RWCF discharge.

Surveys were conducted during 2 consecutive days (January 17 and 18, 2001). Water samples were collected from mid-depth (6–8 feet) and ammonia concentrations were measured using the colorimetric method on both days. Samples for laboratory analysis of ammonia concentrations were also collected on the second day of the survey.

The RWCF effluent ammonia concentration was about 25 milligrams per liter (mg/l). The Vernalis river flow was about 2,500 cfs, so the net flow passing Stockton was estimated to be about

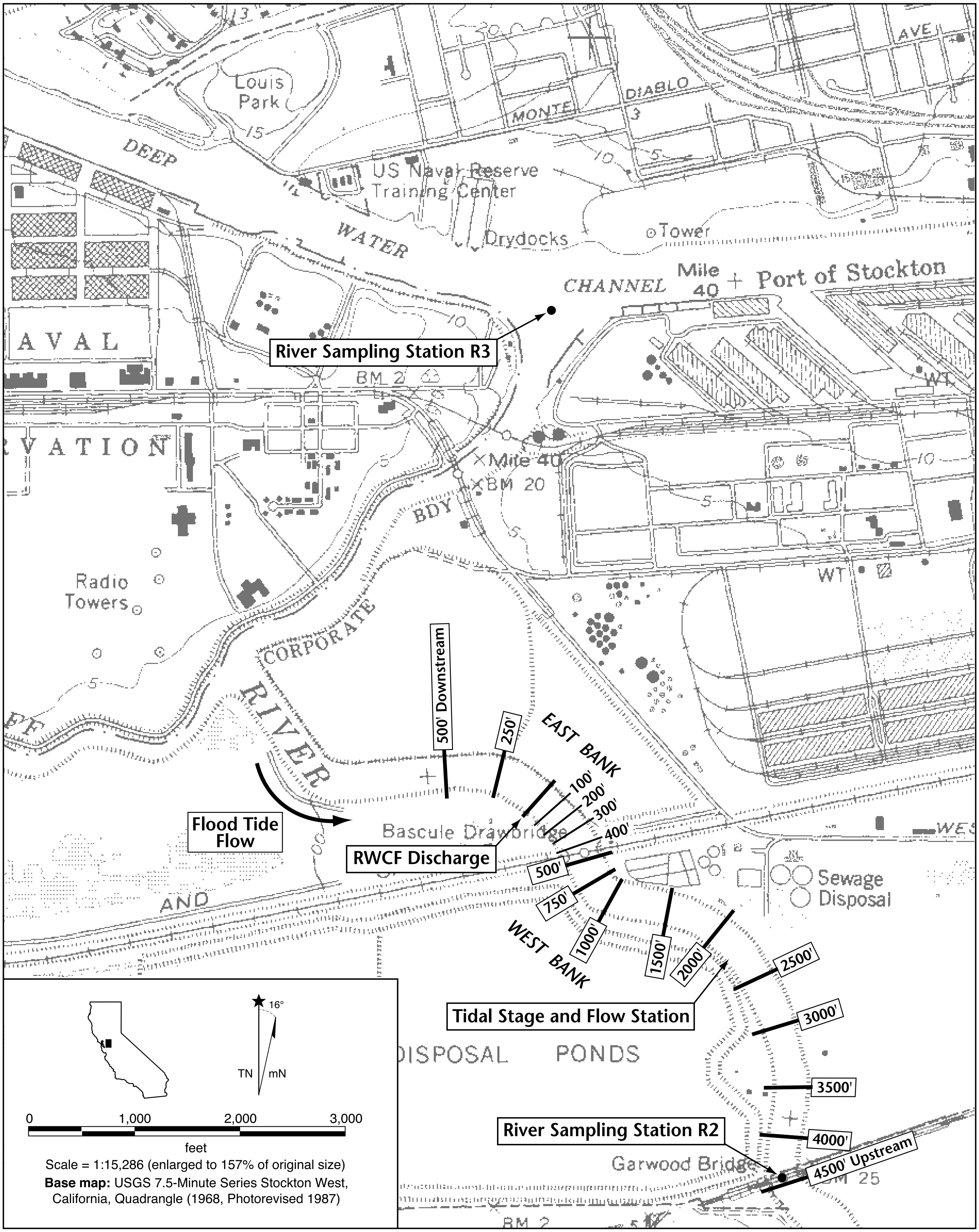


Figure 21. San Joaquin River in the Vicinity of RWCF Discharge with Sampling Locations for Near-Field Mixing Study

1,250 cfs. The RWCF discharge flow was about 35 cfs, so the fully mixed river concentration would average about 0.7 mg/l (i.e., a river dilution of about 35). The near-field ammonia concentration was expected to be somewhat higher, especially during the slack-high-tide event. The jet mixing is expected to always provide a dilution of at least 5 within 125 feet of the discharge pipe, so the maximum river ammonia concentration was expected to be less than 5 mg/l.

Electrical conductivity (EC) measurements were used on the first day to identify the RWCF effluent mixing across the river. However, the difference between the river EC of about 470 µS/cm and the effluent EC of about 1,070 µS/cm was not enough to produce a very distinct lateral gradient of EC values. The initial difference of 600 µS/cm would be reduced to 125 µS/cm with a jet dilution of 5, and the EC difference would be only 60 µS/cm with a river dilution of 10. The highest EC measured at the river transects was 510 µS/cm, indicating a dilution of 15. To reduce the time required to collect the transect samples, EC measurements were not made during the second day of the survey. Continuous monitoring of EC at selected transect locations near the upstream railroad bridge for a 1-month study period might provide additional evidence that the effluent is relatively well mixed.

Tables 2a and 2b give the colorimetric ammonia measurements from the transect samples collected on the 2 days. The pattern of lateral mixing was similar but not identical for the 2 surveys.

Table 2a. January 17, 2001, Sampling Event—High Tide at 12:38 p.m.

		Ammonia (colorimetric) at Sample Point (mg/l)				
Location	Time	West Bank	25%	50%	75%	East Bank
Upstream						
100’	1:45 p.m.	3.54	3.44	3.24	4.68	1.72
200’	1:51 p.m.	3.42	3.18	2.48	1.82	1.66
300’	1:58 p.m.	2.90	2.76	1.80	1.53	1.51
400’	2:06 p.m.	2.48	2.24	1.62	1.83	1.80
500’	2:14 p.m.	2.14	1.84	1.94	1.88	1.62
Downstream						
500’	2:21 p.m.	–	4.62	2.00	2.78	–
1,000’	2:30 p.m.	–	1.78	3.50	4.44	–
Effluent Boil /a/						
0’	2:40 p.m.	7.28	–	–	–	–
0’	2:40 p.m.	9.40	–	–	–	–

Note: /a/ = Replicated samples

Table 2b. January 18, 2001, Sampling Event—High Tide at 1:40 p.m.

		Ammonia (colorimetric) at Sample Point (mg/l)				
Location	Time	West Bank	25%	50%	75%	East Bank
Upstream						
100’	1:45 p.m.	2.72	3.70	1.70	1.84	1.88
200’	1:50 p.m.	3.24	3.78	1.68	1.68	1.61
300’	1:57 p.m.	3.80	3.34	1.59	1.55	1.54
400’	2:05 p.m.	3.50	2.84	1.54	1.56	1.58
750’	2:14 p.m.	3.46	2.44	1.91	1.60	1.56
Mossdale						
	4:20 p.m.	–	–	–	–	1.06

Figure 22 shows the ammonia concentrations (colorimetric method) from the 5 transects at slack high tide on January 17. Ammonia concentrations were highest along the west bank near the discharge, and decreased across the river and upstream of the discharge. The 75% sample from the 100-foot transect was about 1 mg/l higher than the other samples at this transect nearest the discharge, and was the only sample that deviated from the lateral mixing pattern. The ammonia concentrations were fully mixed at the transect located 500 feet upstream from the discharge.

The slack high tide had already occurred (high tide at 12:40 p.m.) when the transect sampling began at 1:45 p.m., and water was moving downstream at a rate of at least 0.5 ft/sec during the 25 minutes that was required to collect these transect samples. This suggests that the 500-foot transect may have moved downstream from 1,500 feet upstream during the sampling event. The mixing distance that was measured during the first day may be much greater than 500 feet. Complete lateral mixing may therefore not occur until a distance greater than 500 feet upstream. The distance required for complete lateral mixing may be as much as 2,500 feet (i.e., 1,500 feet upstream + 1,000 feet back downstream to the 500-foot transect).

Because the tidal flow was already moving downstream when the transects were completed, additional samples were collected 500 feet and 1,000 feet downstream of the discharge. These samples indicated that the river was not yet fully mixed at these downstream locations. There is some indication that the river bend (see figure 21) was causing effluent to be transported across the river, because at the transect 1,000 feet downstream, the 25% sample ammonia was about 2 mg/l but the 75% sample ammonia was 4.5 mg/l. Normally, surface water is found to flow from the inside to the outside of river bends. Researchers observed this phenomenon on the second day when they began drifting across the river in a boat at 1:10 p.m., 30 minutes before high tide. It took about 10 minutes to drift from the west bank, 350 feet downstream of the discharge, to

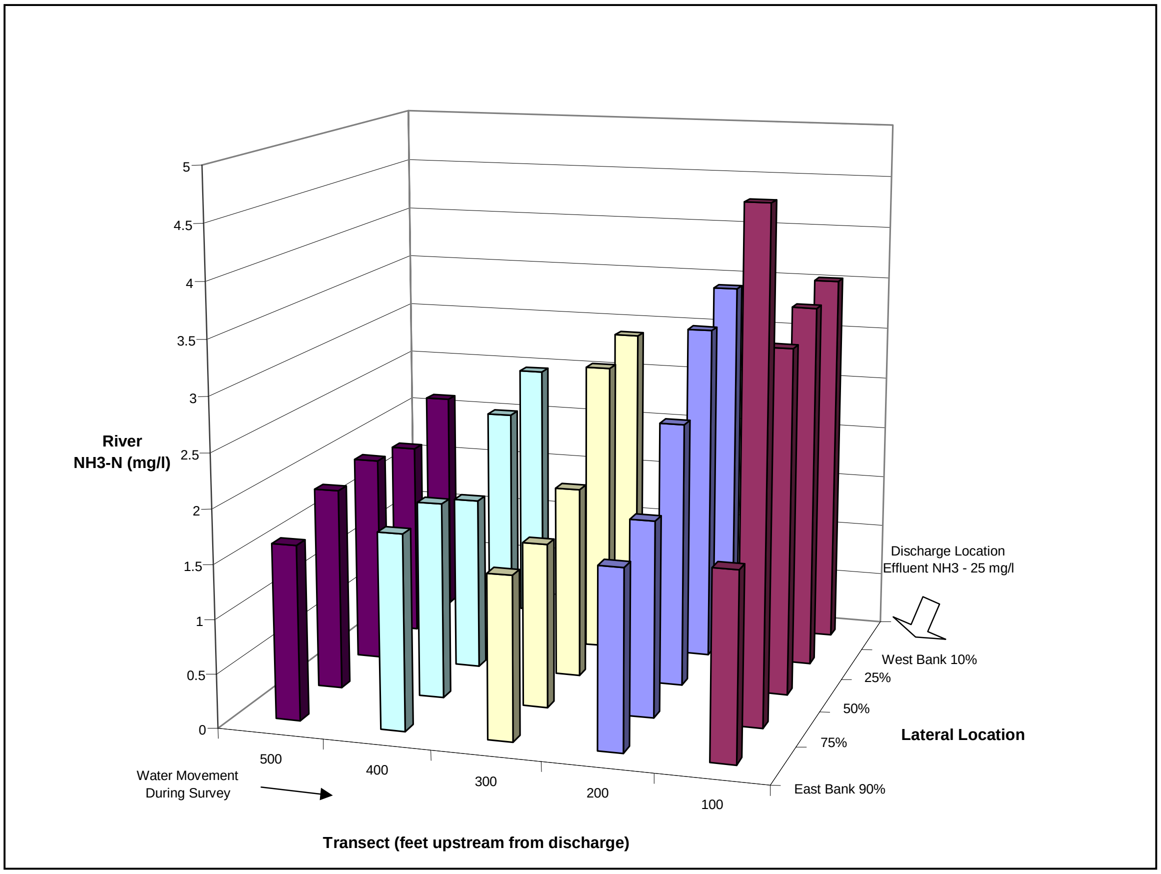


Figure 22. Results of Colormetric Ammonia Concentrations from Near-Field Mixing Study on January 17, 2001

the east bank, opposite the discharge, so the boat traveled 0.5 ft/sec diagonally across the river.

Figure 23 shows the ammonia concentrations (colorimetric method) from the transect samples collected on the second day of the survey, January 18. Collection of samples began at 1:45 p.m., just after high tide. Water bottles were released as drogue floats to track water movement during the sampling event. Sampling of the 5 transects was completed by 2:15 p.m. Water movement averaged about 0.5 ft/sec during the 30 minutes of sampling (moving 900 feet upstream). Because the water movement was still in the upstream direction, the planned transect at 500 feet was moved upstream to 750 feet.

The ammonia concentrations were about 0.5–0.75 mg/l higher than the average background (i.e., Mossdale) river concentration of about 1mg/l at all locations. This increase above the Mossdale river concentration probably resulted from the effluent during the previous tidal cycle. The ammonia concentrations were considerably higher than 1.75 mg/l only at the 10% and 25% lateral stations for transects from 100 feet, 200 feet, 300 feet, and 400 feet upstream. The 750-foot transect showed some lateral mixing of ammonia to the center (50%) station, raising the center concentration to about 2 mg/l. The ammonia concentrations were not completely mixed across the river at the 750-foot transect.

Figure 24 shows the ammonia concentrations (laboratory results) from the second day of the survey. These laboratory ammonia concentrations confirm the colorimetric values. Table 2c on the following page gives the laboratory ammonia results. Laboratory QA/QC results were good for the 3 batches of samples. Laboratory control and matrix spikes were within 10% of expected recovery values. Comparison of the laboratory and colorimetric ammonia values indicates that the colorimetric values were about 10% higher than laboratory values (tables 2b and 2c).

Time series measurements were made at the 100-foot transect at 1:27 and 1:41 p.m. before the transect survey sampling was initiated. The 25% location samples were each 2.9 mg/l; the center and 75% location samples were each 1.8 mg/l. These samples suggest that the downstream water that was moving past the effluent at high tide (but before slack conditions) had an ammonia concentration of 1.8 mg/l and the effluent was increasing the west-side concentration by about 1 mg/l. The sample from the downstream station R3 at 11:55 a.m. of 1.6 mg/l confirms the average ammonia concentration of about 1.4–1.8 mg/l. The upstream river concentration measured at Mossdale on January 18 was 1.0 mg/l. This is a relatively high ammonia concentration that may have been elevated by surface runoff from the previous week's moderate rainfall.

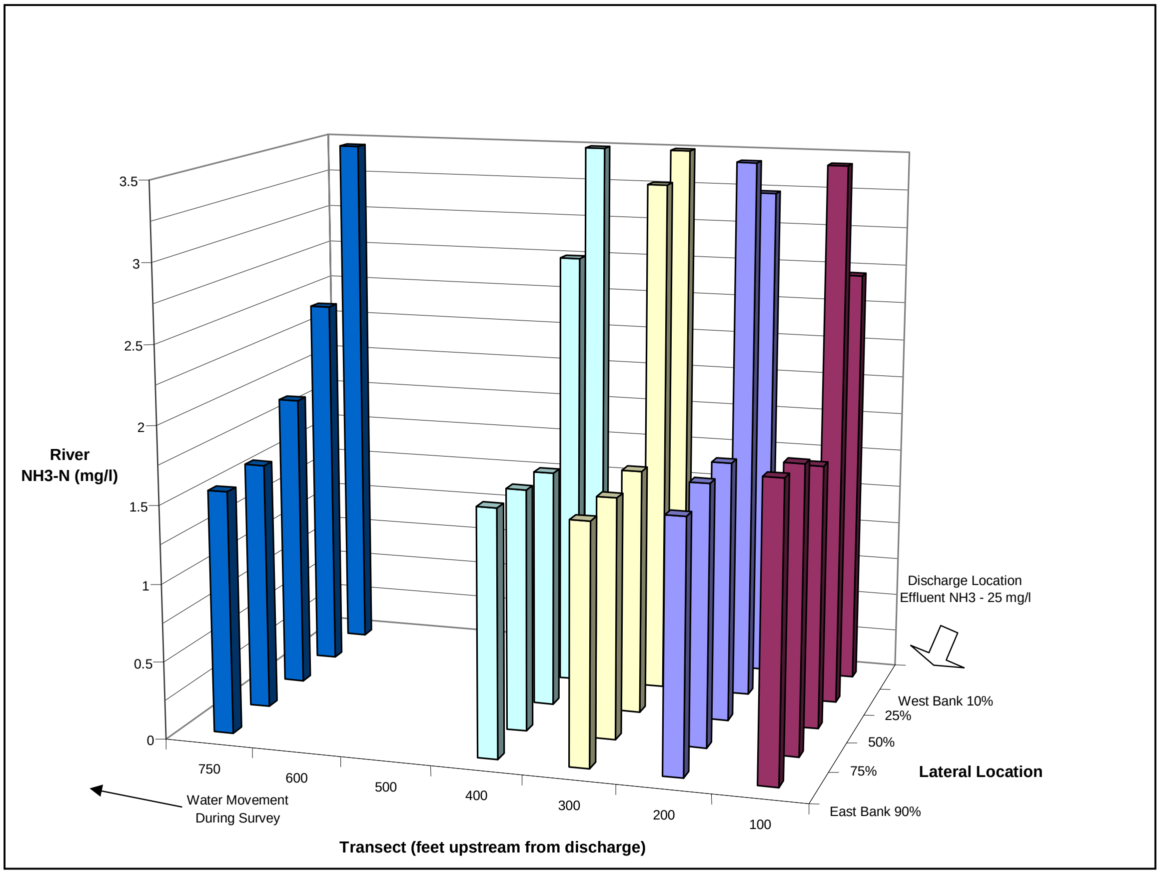


Figure 23. Results of Colormetric Ammonia Concentrations from Near-Field Mixing Study on January 18, 2001

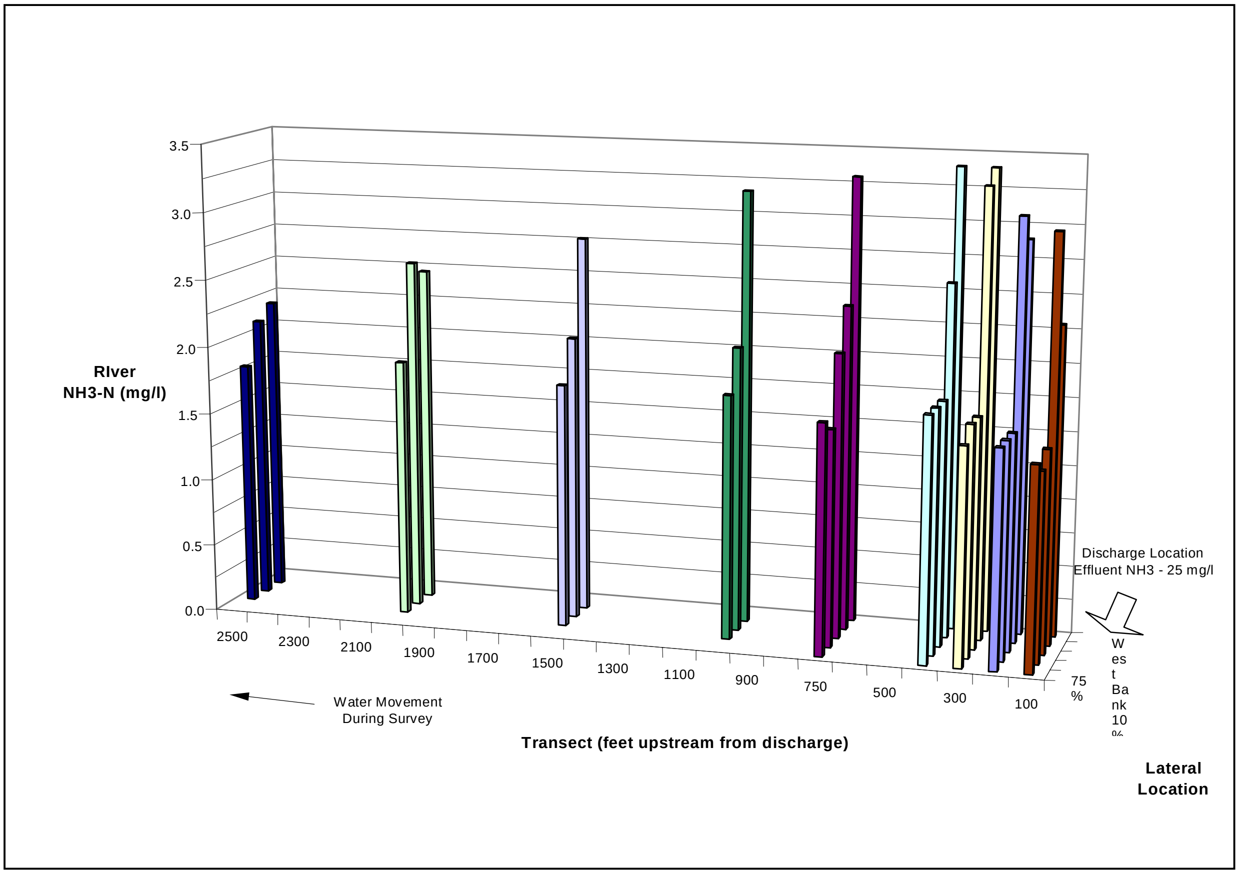


Figure 24. Results of Laboratory Analysis of Ammonia Concentrations from Near-Field Mixing Study on January 18, 2001

Table 2c. January 18, 2001, Sampling Event Laboratory Ammonia Data—High Tide at 1:40 p.m.

		Ammonia at Sample Point (mg/l—EPA 350.2)				
Location	Time	West Bank	25%	50%	75%	East Bank
Upstream Samples						
100’	1:45 p.m.	2.3	3.0	1.5	1.4	1.5
200’	1:50 p.m.	2.9	3.1	1.6	1.6	1.6
300’	1:57 p.m.	3.4	3.3	1.7	1.7	1.6
400’	2:05 p.m.	3.4	2.6	1.8	1.8	1.8
750’	2:14 p.m.	3.3	2.4	2.1	1.6	1.7
1,000’	2:25 p.m.	–	3.2	2.1	1.8	–
1,500’	2:29 p.m.	–	2.8	2.1	1.8	–
2,000’	2:38 p.m.	–	2.5	2.6	1.9	–
2,500’	2:42 p.m.	–	2.2	2.1	1.8	–
Time Series Samples						
100’	1:27 p.m.	–	2.9	1.8	1.8	–
100’	1:41 p.m.	–	2.9	1.8	1.8	–
100’	2:20 p.m.	–	2.9	5.0	3.1	–
Mossdale Sample						
	4:20 p.m.	1.0	–	–	–	–
River Monitoring Location R3 Sample						
	11:55 a.m.	1.6	–	–	–	–

Note:
Laboratory QA/QC procedures were as follows: Three lab batches of 10 samples each. Lab blanks were nondetectable. Lab and matrix spikes were within 90%–110% recovery. Lab duplicates were within 10% allowable tolerance.

The difference between the 2 days appears to be the actual distance that the river water has moved since passing the discharge location. Complete lateral mixing must require at least 1,000 feet. The water collected at the 500-foot transect on the first day may have actually moved 1,500 feet upstream during the 30 minutes after high tide and then moved back downstream 1,000 feet during the 30 minutes after slack tide. The difficulty of sampling during slack tide indicates that the river velocity is reduced only briefly after high or low tide. The river flow reverses within an hour of the high or low tides, and the period of slack current is very short. There is very little opportunity for high effluent concentrations to occur during these short periods of slack tide.

The laboratory samples collected on January18 include transects from 1,000 feet, 1,500 feet, 2,000 feet, and 2,500 feet. The ammonia concentrations determined by laboratory analysis are given in table 2c and illustrated in figure 22. The 50% lateral location sample was about the same as the 25% lateral location at the 2,000-foot and

2,500-foot transects. The 75% lateral location sample was within 10% of the average at the 2,500-foot transect. These results indicate that complete lateral mixing requires a distance of about 0.5 miles. These results were used to calibrate the lateral mixing rate used in the box model to be 1% of the tidal flow.

The maximum ammonia concentrations observed within 500 feet of the RWCF discharge location were about 2.5 mg/l higher than the ammonia concentrations at the east bank. This observation indicates that the effluent experienced an initial dilution factor of 10, which corresponds with previous estimates of jet dilution. The fully mixed ammonia concentrations were approximately 0.7 mg/l greater than the Mossdale concentration, as expected if the net river flow was 1,250 cfs.

Calibration of the Lateral Mixing Rate

The results from the field survey were used to calibrate the model coefficient for lateral mixing. Figure 25 shows the simulated concentrations in the east-side and west-side segments at the end of day 5 for 2 estimates of the lateral mixing rate. Low tide occurred at about 11 p.m., with the discharge location at segment 280 (i.e., segments have moved downstream so the discharge was located in segment 280 at low tide). The flood tide is moving segments upstream, and the discharge is located near segment 225 at midnight of day 5. The west-side concentration was increased from 25 to 75 by the discharge, while the east-side concentration remained at 25.

The top graph of figure 25 shows the simulated results for the original estimate of lateral mixing rate equal to 0.5% of the tidal flow. The east-side and west-side concentrations were not fully mixed, even at segment 275, located about 1 mile upstream of segment 225. The field data from the near-field mixing study indicated that complete mixing occurred more rapidly, and that the west-side and east-side concentrations were fully mixed within a distance of less than 2,500 feet (0.5 mile) from the discharge.

The bottom graph indicates that the higher simulated lateral mixing rate of 1% of tidal flow provided considerably more lateral mixing, with the east-side and west-side concentrations approaching the mixed concentration of about 50 within 25 segments upstream of the discharge. These calibration results suggest that the lateral mixing rate in this portion of the San Joaquin River is approximately 1% of tidal flow. This calibrated lateral mixing rate suggests, in turn, that 20 cfs of water will be exchanging between each pair of model segments during a typical tidal flow of 2,000 cfs. This relatively high lateral mixing rate is consistent with the expected effects of tidal flow conditions and river bends that are located both upstream and downstream of the discharge location. This calibrated rate of

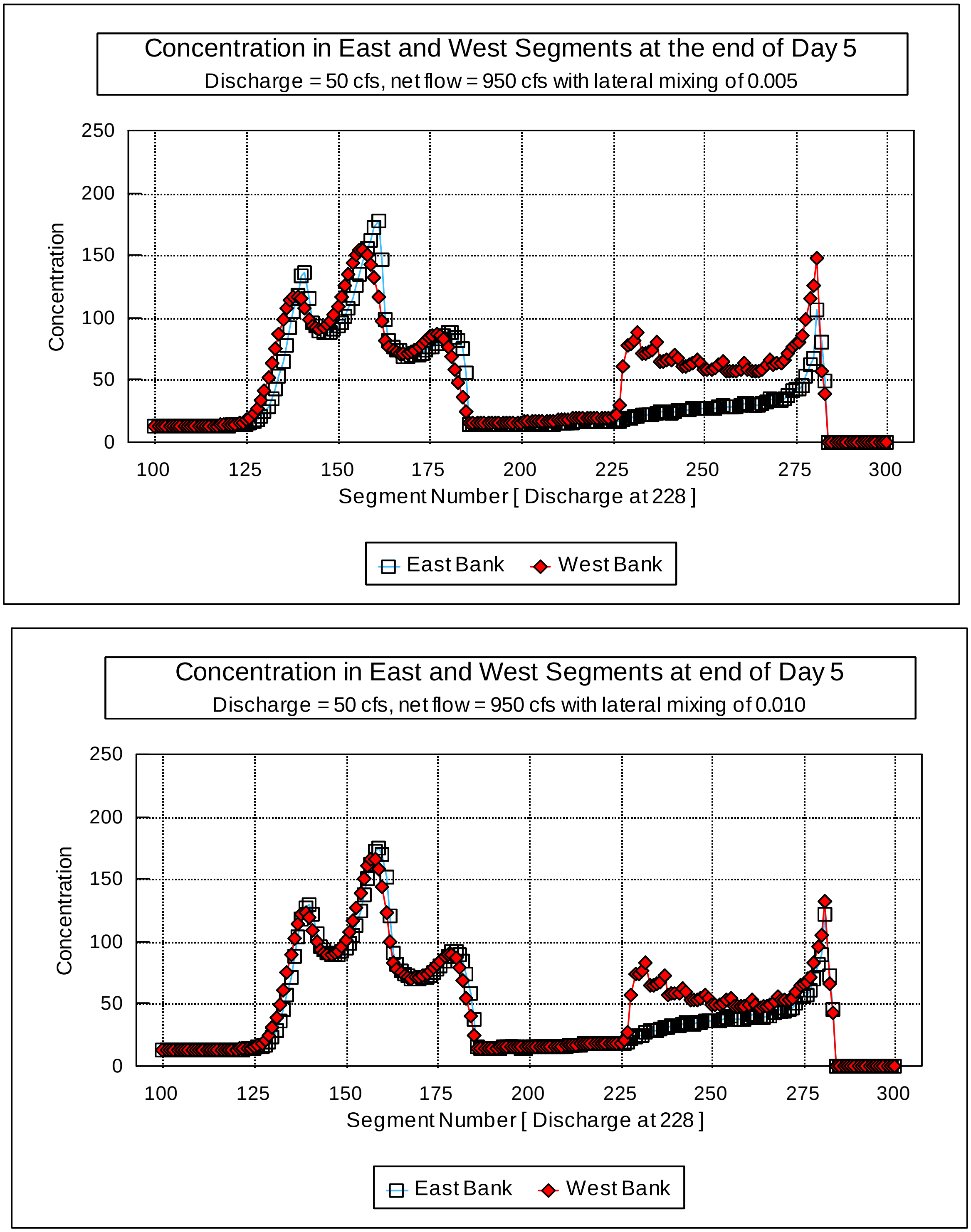


Figure 25. Simulated Concentrations for Lateral Mixing Rates of 0.5 and 1.0 % Tidal Flow

lateral mixing equal to 1% of the tidal flow is the most likely value for accurately simulating the near-field mixing and tidal dilution of the RWCF discharge.

Interpretation of Tidal Mixing Results for Estimating Maximum Exposure Concentrations

Instream sampling indicated that the effluent is diluted significantly as the jet discharge mixes into the tidal flow of the San Joaquin River. Sampling done as part of this study and the dye study conducted in 1993 both indicate that the discharge jet induces mixing at a ratio of 9 parts river water to 1 part effluent (i.e., concentration dilution of 10). The instream effluent concentration is elevated on the west side only, where the outfall pipe is located. As the discharge plume is carried upstream or downstream with the tidal current, the plume mixes across the width of the river until lateral mixing is complete. This process extends over a distance of about 2,500 feet (i.e., about 10 river widths) and may take up to 1 hour to complete.

In general, the Lagrangian box model with 2 lateral segments provided a reasonable simulation of the observed mixing. Model predictions at sampling station R2 (located 0.85 mile upstream of the outfall), using alternative lateral mixing coefficients of 0.5% and 1.0% of the tidal flow, suggested that mixing would be sufficient to reduce the difference between east-bank and west-bank concentrations to less than 10. Instream sampling indicates that lateral mixing is nearly complete within 2,500 feet and that the higher mixing rate of 1% tidal flow is the best estimate of lateral mixing in this portion of the San Joaquin River.

The box model predicts maximum instream concentrations at the outfall during slack tide. Depending upon the period within the spring/neap lunar tidal cycle, the maximum concentrations during slack tides will vary. As the current increases after slack, the plume will move with the flow and disperse across the river, gradually decreasing in concentration from the slack-tide maximums. An evaluation of maximum 15-minute concentrations under various net flow conditions, ranging from 150 cfs to 950 cfs, indicates that peak concentrations range from about 30% to 40% effluent. At low flow (150 cfs), the slack period is of relatively short duration but the background concentration is elevated, giving rise to a peak concentration of 40% effluent (see figure 4). As the net flow increases to 450 cfs, the peak concentration decreases toward 30% (see figure 13). However, at elevated flows of 950 cfs, the net flow works to counteract the flood tide and may prolong the slack tidal flow condition. Consequently, the short-term peak concentration approaches 40% even though the background concentration is reduced significantly (see figure 15).

The model predictions can be used to evaluate dilution conditions and dilution credits associated with acute and chronic water quality standards. Acute water quality standards are defined with averaging periods ranging from 1 hour (applicable to most acute water quality standards) to 3 hours (recommended in the 1999 update for the EPA acute ammonia criteria). Chronic water quality standards are defined with averaging periods ranging from 4 days (most chronic standards) to 30 days (ammonia). Compliance with the appropriate water quality standard may be assessed through consideration of an organism drifting with the plume. Because the model predicts instream concentration on a continuous basis at discrete 15-minute intervals, maximum concentrations corresponding to the specified averaging period may be determined from the 15-minute model results.

At a minimum, the acute standard for many pollutants uses an average exposure over 1 hour. The hourly maximum concentration predicted by the model is slightly less than the 15-minute peak concentrations, because the slack periods generally do not persist for an hour. Figure 11b indicates that the maximum 1-hour average west-side concentration at the discharge location is about 33% effluent at a net flow of 150 cfs. Because the peak hourly concentration does not exceed 33% at any net flow, a dilution credit equal to or greater than 2.0 (i.e., concentration dilution of 3) is appropriate for establishing 1-hour acute limits for the RWCF discharge. The dilution credit appropriate for the 3-hour acute standard (ammonia) would be slightly greater than the 1-hour credit.

The chronic standard represents a long-term average concentration that is significantly less than the peak concentrations that occur during slack-tide conditions. Over 4 days, a drifting organism will be carried upstream and downstream past the discharge location numerous times by the tidal flows. Most of this time will be spent at a concentration that is less than the steady-state average for the net flow condition. Only as the organism is transported downstream past the tidal excursion zone will the organism be exposed to the average concentration expected from the net flow and discharge conditions (see figures 7 and 8). After a few days, the segment will be displaced beyond the influence of the discharge and the exposure concentration will equal the steady-state value.

In summary, the maximum 4-day average exposure concentration will equal the steady-state value for the given net flow condition, but the location for this maximum exposure is considerably downstream of the discharge location. The 30-day average exposure concentration is also equal to the expected steady-state concentration. In either case, the dilution credit can be calculated as the average net river flow divided by the average effluent flow. Both analyses are contingent upon a conservative substance. If decay occurs, the 4-day and 30-day average exposure concentrations could be much less than the steady-state mixed concentration.

If exposure is based on an organism residing in a particular reach of the river, the dilution credit will be significantly greater than that based on a drifting organism (as indicated in table 1) for organisms located within the excursion distance from the outfall. Organisms found downstream of the tidal excursion (e.g., about 2 miles) will be exposed to the expected steady-state concentration.

Summary

A tidal mixing model was developed for the Stockton RWCF to illustrate and evaluate the patterns of tidal dilution that would be expected for a range of river flows considering the actual tidal flow fluctuations measured at the Stockton UVM station.

The tidal flows create more complex dilution patterns than would be expected for a river discharge without the tidal influence that the Stockton RWCF discharge experiences. A little effluent is added to the river by the RWCF discharge as the tidal flows move past the discharge location several times during relatively low river flow (less than 1,000 cfs).

Because river water moves back and forth several times within the tidal mixing zone, the lateral mixing processes maintain relatively well-mixed conditions. At the discharge location, the average daily east-side concentrations are expected to remain within 80% of the west-side concentrations during periods with relatively low river flow (less than 1,000 cfs). The hourly concentrations can be considerably higher than the daily average values on the west side of the river, but the lateral mixing caused by tidal flows will achieve complete lateral mixing within a distance of about 2,500 feet from the RWCF outfall (upstream or downstream).

The maximum concentrations at any selected station will vary during the month because of the variations in tidal fluctuations that limit the tidal mixing zone during days with neap tides (i.e., less tidal variation) and during days when the net tidal movement is slightly upstream (i.e., average tidal stage increase).

The maximum instream effluent concentrations will be no greater than 40% effluent and are expected to occur during slack tide periods when the tidal flow is reduced. This maximum concentration is somewhat independent of the net river flow between 150 cfs and 950 cfs. Average exposure concentrations will approach the expected steady-state fully-mixed condition for averaging periods of 4 days or more.

References

Fischer, H. B., J. Imberger, E. J. List, R. C. Y. Koh, and N. H. Brooks. 1979. *Mixing in inland and coastal waters.* Orlando, FL: Academic Press, Inc.

Philip Williams & Associates, Ltd. 1993. *City of Stockton water quality model, volume I: Model development and calibration.* August. San Francisco, CA. Prepared by Robert Schanz, Philip Williams & Associates, and Carl Chen, Systech Engineering. Prepared for City of Stockton, CA.

U.S. Environmental Protection Agency. 1991. *Technical support document for water quality based toxics control.* Washington, D.C.: Office of Water Enforcement and Permits. EPA/505/2-90-001.