Appendix B

Monitoring of the Aeration Facility Effects and Calculated Dissolved Oxygen Increments in the Stockton Deep Water Ship Channel

Appendix B

Table of Contents

List of Tables and Figures

List of Abbreviated Terms

1988 NAVD	North American Vertical Datum of 1988
Aeration Facility	Stockton Deep Water Ship Channel Dissolved Oxygen Aeration Demonstration Facility
af	acre-feet
cfs	cubic feet per second
CVP	Central Valley Project
DO	dissolved oxygen
DWSC	Deep Water Ship Channel
Ft	feet
ft/sec	foot per second
ft^2	square feet
lb/day	pounds per day
mg/l	milligrams per liter
RRI	Rough and Ready Island
RWCF	Stockton Regional Wastewater Control Facility
SJR	San Joaquin River
SWP	State Water Project
USGS	U.S. Geological Survey

Appendix B
Monitoring of the Aeration Facility Effects and Calculated Dissolved Oxygen Increments in the Stockton Deep Water Ship Channel

The effects of added dissolved oxygen (DO) from the California Department of Water Resources Demonstration (DWR) Aeration Facility (Aeration Facility) on the DO profile in the Stockton Deep Water Ship Channel (DWSC) are tidally controlled. To calculate the DO increments added through the operation of the Aeration Facility, the measured tidal flows and measured 15-minute DO from the monitoring stations are evaluated together. This appendix describes how DWSC tidal flows are measured and how net tidal flows are calculated to estimate the water movement and mixing in the DWSC. It also describes how tidal flows and mixing, together with other natural processes such as surface reaeration, algae growth, and wind mixing, will influence the added DO from the Aeration Facility.

The measured 15-minute DO data from the upstream and downstream monitoring stations are evaluated and compared with calculated DO increments for each station, based on the tidal movement and distance from the Aeration Facility diffuser to the monitoring station. The DO Increment Model was developed to calculate the DO increments in the DWSC. The calculated DO increments can be subtracted from the measured DO to estimate the natural DO conditions in the DWSC. Several model parameters, such as the natural reaeration rate, are uncertain, so the model results for different parameter values were compared to the measured data (i.e., model calibration). The calculations used in the monthly models of 15-minute DO increments are described for the months of June, July, August, and September 2008.

Measured Deep Water Ship Channel Tidal Velocities and Flows

There are three tidal flow measurement stations along the San Joaquin River (SJR) that can be used to estimate the tidal flows and tidal velocities in the DWSC. The SJR at Garwood station has been operated by the U.S. Geological Survey (USGS) with cooperation from the City of Stockton since 1996. The river channel is about 200 feet (ft) wide, the cross section is about 3,000 square feet (ft^2), and the tidal velocities are about 1 foot per second (ft/sec). This tidal flow station has been considered reliable because the measured velocities are relatively high and the tidal velocity measurement includes a large portion of the channel width.

The second tidal flow station is at the Rough and Ready Island (RRI) monitoring location, just downstream of the diffuser. This tidal flow station is operated by DWR and is a more challenging location to measure flow because the channel is so wide (and deep). DWR uses side-scan acoustic Doppler equipment. Because of the equipment design, the velocity measurement extends only about 100 ft into the channel. Based on these measurements, average estimates for upstream and downstream flow velocities for the entire channel are calculated. The measured tidal elevation is used to estimate the cross-sectional flow area, and hence the tidal flow is calculated as the average flow velocity multiplied by the cross-sectional area.

The third tidal flow station is near Lathrop about a mile downstream from the head of Old River. This tidal flow measurement station is operated by DWR and is similar to the Garwood station, with high tidal velocities and a small channel cross section. These tidal flow records generally confirm the Garwood station data.

Figure B-1 shows the tidal elevations measured at these three stations during June–September 2008. The tidal elevations are similar at the RRI and Garwood stations (with slightly less variation at Garwood), but the tidal variation at Lathrop is much less than at RRI or Garwood because Lathrop is about 10 miles upstream of the Garwood station. The minimum elevation at Lathrop was never less than 4 ft, while the minimum elevation at RRI and at Garwood was less than 2 ft on a few days (during the "spring" tide periods with greatest tidal range). The maximum tidal elevation at Lathrop was about 6 ft, while the highest tide at RRI and at Garwood reached almost 7 ft.

The 15-minute elevation changes at the RRI stations are shown at the bottom of Figure B-1. The elevation changes are largest at the end of slack tides (as the tidal flow reverses direction). At low slack tides, water still is coming from upstream as the tidal elevation begins to increase (without much flow resistance), so the tidal flows are converging, and the elevation changes more rapidly. At high slack tide, the upstream flow (negative elevation gradient) no longer is balancing the normal downstream river flow (positive elevation gradient), and the water elevation drops more rapidly. Once the tidal flow becomes established (ebb or flood), the general tidal rise or fall is about 0.15 ft in each 15 minutes (or 0.6 ft per hour). The tidal range of about 3 ft has a very steady rise over a 5-hour period, with a slack tide period of about an hour.

Figure B-2 shows the measured tidal velocities at RRI, Garwood, and Lathrop during June–September 2008. The tidal velocities at Lathrop were the highest, and the RRI velocities were the lowest. The lower velocities are the major reason the tidal flow measurements are more difficult at the RRI station. The cross section sizes at the tidal stations increase slightly with tidal elevation. The channel area can be identified from the tidal velocity and flow measurements by dividing the flow by the velocity. The Lathrop cross-section area is about 1,150 ft^2 at 4 ft elevation to about 1,650 ft^2 at 6 ft, indicating that the channel is about 250 ft wide. The Garwood cross-section area is about 2,900 ft^2 at 3 ft and about 3,500 ft^2 at 6 ft, indicating that the channel is about 200 ft wide. The RRI cross-section area is about 16,500 ft^2 at 3 ft and about 18,500 ft^2 at 6 ft, with a channel width of about 665 ft.

Figure B-3 shows the tidal flows measured at RRI, Garwood, and Lathrop for June–September 2008. The tidal flows at the RRI station are about twice the tidal flows at the Garwood station. The tidal flows at Lathrop are about 25% of the tidal flows at the RRI station. The maximum RRI tidal flows are about 8,000 cubic feet per second (cfs), the maximum tidal flows at Garwood are about 4,000 cfs, and the maximum tidal flows at Lathrop are about 2,000 cfs.

Unfortunately, the RRI tidal velocity and flow data were not reliable in August and September 2008. The Garwood velocities and tidal flows therefore were used for calculating the tidal movements for these months. The tidal flows measured upstream at Garwood were used to estimate the tidal movement at the diffuser by adjusting for the different upstream tidal prism volume. The Garwood tidal flows were doubled because the upstream tidal prism at Garwood is about half the tidal prism volume at RRI. The Garwood tidal flows were increased by the Stockton Regional Wastewater Control Facility (RWCF) discharge flow of approximately 50 cfs.

Estimated Net Flows in the Deep Water Ship Channel

The net (daily average) flows were calculated by averaging the tidal flows from the previous 25 hours (tidal day). Because the net flow patterns measured at these three tidal flow stations or estimated from the Vernalis flows were different, the net flows in the DWSC during June–September 2008 are somewhat uncertain. The Garwood and Lathrop stations are located upstream of the Stockton RWCF discharge of about 50 cfs. Therefore, the net flow in the DWSC is about 50 cfs more than the measured Garwood or Lathrop net flow.

Figure B-4a shows the daily net flows measured at RRI, Garwood, and Lathrop for June 2008. The daily average river flow at Vernalis (upstream of tidal influence) also is shown for comparison. The expected DWSC flows are about 50% of the Vernalis flows during periods of relatively low Central Valley Project (CVP) and State Water Project (SWP) export pumping. The average Vernalis flow for June 2008 was about 1,150 cfs, so the expected DWSC average flow was about 575 cfs. The measured net flows at RRI were highly variable during June 2008. The Garwood net flows in June 2008 ranged from 0 cfs to about 500 cfs and averaged about 250 cfs until June 22, when the station records ended. The net daily flows measured at Lathrop ranged from 100 cfs to about 300 cfs and averaged about 200 cfs for June 2008.

Figure B-4b shows the net daily flow estimates for July 2008. Similar variations in the Garwood and Lathrop stations net flows were measured, but the RRI net flows were highly variable and inconsistent with the Garwood and Lathrop data. The Vernalis flow ranged from 750 cfs to 1,000 cfs, while the Lathrop and Garwood net flows ranged between 0 cfs and 300 cfs, with an average of about 200 cfs. Figure B-4c shows the net flow estimated for August 2008. The Vernalis flows ranged from 750 cfs to 1,000 cfs, while the Lathrop and Garwood net flows ranged from 0 cfs to 400 cfs, with an average of 200 cfs. Figure B-4d shows the net daily flows estimated for September 2008. Vernalis flows again ranged from 750 cfs to 1,000 cfs, while Lathrop and Garwood net flows ranged from 200 cfs to 600 cfs, with an average of about 300 cfs. Because the tidal flows and daily net flows are uncertain, daily net flows of 250 cfs were specified for June–September 2008 for tracking the tidal movement and estimating the added DO increments from the Aeration Facility.

The distance from the inflow of the SJR into the DWSC at mile 40 near Channel Point at Navigation Aid Light (Light) 48 to Turner Cut at mile 32.5 is about 7.5 miles. The low-tide volume in this section of the DWSC is about 14,000 acre-feet (af), so the travel time for a river flow of 1,000 cfs would be 7 days (because 1,000 cfs is about 2,000 af/day). The travel time for a flow of 500 cfs (1,000 af/day) would be about 14 days. The distance from Channel Point at Light 48 to the downstream DO monitoring station at Light 40 (mile 36.3) is about 3.7 miles, and the volume is about 7,000 af. Therefore, the travel time from Channel Point to the Light 40 DO monitoring station is about half of the travel time to Turner Cut. The effects of the added DO from the Aeration Facility are expected to be greatest in this upstream portion of the DWSC, between Light 48 and Light 40.

Tidal Movement of Water in the Deep Water Ship Channel

On ebb tide (downstream movement), some of the added DO from the Aeration Facility diffuser will move past the RRI surface DO monitor located 0.2 mile downstream (1,000 ft) and may move downstream to the Light 42 monitoring station located about 0.7 mile (3,700 ft) downstream of the diffuser or to the Light 40 monitoring station located about 1.6 miles (8,500 ft) downstream. The measured tidal velocity at the RRI station was used to calculate the upstream and downstream movement of water past the diffuser. The water movement during a 15-minute tidal record interval is:

Tidal movement (miles) = tidal velocity (feet per second [ft/sec]) x 900 sec / 5,280 feet per mile [ft/mile]

= 0.17 x tidal velocity (ft/sec)

The maximum tidal velocities at the RRI station are about 0.5 ft/sec (corresponding to a DWSC tidal flow of about 8,000 cfs), so the maximum movement during a 15-minute period is about 0.085 mile (450 ft). Because the diffuser is 200 ft long, some of the DO discharged during a 15-minute period could be spread over a discharge "length" of 650 ft (i.e., diffuser length plus tidal movement). It therefore takes a minimum of 30 minutes for DO from the diffuser to move downstream 1,000 ft to the RRI monitoring station during ebb-tide periods.

Figure B-5a shows the measured RRI tidal elevation and the estimated tidal movement (relative to the RRI station) for June 2008, separated into periods of downstream velocity (i.e., positive velocity during ebb tide) and upstream velocity (i.e., negative velocity during flood tide). The downstream tidal movements are greater because (1) the net flows add to the tidal flows during periods of ebb tides, and (2) the normal tidal variation involves a large ebb-tide variation from higher-high tide to lower-low tide each day. The tidal excursions are greater during spring tide periods and less during ebb tide periods. The maximum downstream movement was about 2.5 miles on several days in June 2008, and the maximum upstream tidal movement was about 1.5 miles on a few days in June 2008. The added DO increments from the Aeration Facility will move upstream to the Light 48 monitoring station only on days with maximum upstream (i.e., flood tide) movement of 1.5 miles, unless there is longitudinal spreading upstream of the diffuser.

Figure B-5b shows the tidal elevation and estimated upstream and downstream RRI tidal movement for July 2008. The patterns of upstream and downstream tidal movement appear very similar to the June 2008 tidal movement patterns. Figure B-5c shows the tidal elevation and estimated upstream and downstream RRI tidal movement for August 2008. Figure B-5d shows the tidal elevation and estimated upstream and downstream RRI tidal movement for September 2008. The upstream and downstream movements for August and September were estimated from the Garwood tidal measurements because the RRI tidal velocities and flows were unreliable (i.e., were out of phase with the tidal elevations). Figure B-6a shows the cumulative tidal movement in the DWSC as calculated from the measured RRI tidal velocities for June 2008. The cumulative movement starts at zero at the beginning of the simulation, which is 5 days prior to the beginning of the month; downstream tidal flow (ebb tide) is positive, and upstream tidal flow (flood tide) is negative. The tidal movement within each day (i.e., back and forth) is about 2–3 miles, suggesting that some added DO from the Aeration Facility will be distributed within this tidal mixing zone each day. The highest mile position each day corresponds to the lower-low tide, when the cumulative water movement (for water that started at the diffuser) is farthest downstream. The lowest mile position each day corresponds to the higher-high tide. All the added DO from the Aeration Facility will be downstream of the diffuser position at lower-low tide each day. At higher-high tide each day, there will be some added DO upstream of diffuser position. The DO increments from the Aeration Facility are estimated by tracking the position of the diffuser, and assuming that an increment of DO was discharged from the diffuser every 15 minutes while the Aeration Facility was operating.

The red line on Figure B-6a indicates the operating schedule during June. The Aeration Facility was operated June 16–20, was turned off over the weekend, was turned on June 23–27, was turned off over the weekend, and was turned on again June 30. The DO increments at any time along the DWSC can be calculated based on the current position of the diffuser and the relative position of the previous diffuser positions (indicating locations of all previous DO increments). For example, Figure B-6b shows the pattern of added DO increments calculated for midnight of June 30, both with and without the reaeration adjustments (described below). The DO increments were highest when the tidal flows moved past the diffuser slowly or received multiple doses from the diffuser. The added DO from the June 16–20 operation would have moved downstream between 3 and 5.5 miles, and the added DO from the June 23–27 operation would have moved downstream between 0.5 and 2.5 miles. The added DO from June 30 would be located upstream of the diffuser because high tide was just after midnight.

Figure B-7a shows the cumulative tidal movement for July 2008. Because the same net flow of 250 cfs was assumed for each day of June and July, the July tidal movement pattern was about the same as for June 2008. Figure B-7b shows the calculated downstream DO increments for July 30. Figures B-8a and B-9a show the cumulative tidal movement patterns for August and September 2008, with net daily flows of 250 cfs simulated for each month. Figures B-8b and B-9b show the calculated downstream DO increments for midnight on August 30 and September 30. Although the downstream tidal movement patterns were similar for these months, the calculated downstream patterns of added DO increments were different because the Aeration Facility was operated for different periods in each of these months.

The tidal movement in the DWSC was calculated from the 15-minute RRI (or Garwood) tidal velocity measurements and was used to calculate the DO increments from the Aeration Facility. The monthly DO increments model of tidal movement and DO increments allowed the daily net flows to be specified to evaluate the effects of higher or lower net flows on the DO increments from the Aeration Facility.

Aeration Facility Dissolved Oxygen Increments

The Aeration Facility diffuser creates near-field jet mixing because the 6-inch-diameter ports discharge water at a velocity of about 3 ft/sec. The diffuser is a 200-ft section of 30-inch-diameter pipe with 80 ports (6-inch-diameter holes) spaced at 2.5 ft along the diffuser pipe. Half the holes are horizontal at a depth of 12 ft below the RRI elevation datum (North American Vertical Datum of 1988 [1988 NAVD]), and half of the holes point down at a 45° angle. With a maximum diffuser flow of 45 cfs, the water velocity in the diffuser pipe is about 10 ft/sec, and the velocity at the ports is about 3 ft/sec. The diffuser port velocity is likely faster at the end of the diffuser nearest the Aeration Facility and decreases toward the far end of the diffuser. Observations of bubbles and a near-field dye study indicate that the discharge is relatively uniform along the first 150 feet of the diffuser.

The diffuser jets mix the discharge with an assumed near-field (i.e., diffuser jet) dilution of about 10 to 1. This suggests that the DO increment in the diffuser (about 30 to 35 milligrams per liter [mg/l] above ambient DO) would be mixed to a near-field DO increment of about 3 mg/l along the diffuser. The maximum DO increments at the RRI station were about 2 mg/l during ebb tides (downstream flow toward the RRI monitoring station), suggesting the dilution from the diffuser jets, as well as the lateral and vertical mixing as the water moved downstream 0.2 mile, was about 15 to 1. This near-field dilution may be lower when a ship is docked at Dock 19 or Dock 20 because the ship hull may partially block the diffuser and limit the near-field dilution and mixing.

The Aeration Facility delivers about 7,500 pounds per day (lb/day) when operated at full capacity, so about 78 lb are discharged from the diffuser during each 15-minute period (with 96 periods per day). As water moves past the diffuser (either upstream or downstream), the diffuser mixes about 1 af of water into the volume moving past the diffuser (i.e., 45 cfs * 900 seconds / 43,560 = 0.93). For a typical tidal flow of 5,000 cfs, the tidal flow volume would be about 103 af in each 15-minute period. The expected DO increment if the added DO was mixed completely with the DWSC flow would be:

Diffuser DO increment (mg/l) = DO (lb) / 2.7 / Volume (af)

The coefficient of 2.7 is the conversion factor. The fully mixed DO increment for a period with tidal flow of 5,000 cfs would be about 0.28 mg/l (dilution of about 125). The mixed DO increment decreases as the tidal flow increases, and would be about half (0.14 mg/l) at the peak tidal flows of about 10,000 cfs. The fully mixed DO increment would be twice as great (0.56 mg/l) for a tidal flow of 2,500 cfs. However, as the tidal flow reaches slack tide conditions (low flow), the jet mixing from the diffuser will maintain a minimum dilution with the DWSC water of about 15, so the highest expected mixed DO increment would be about 2 mg/l even during slack tide conditions. The tidal movement will be very effective in spreading the DO increments over the tidal excursion distance and laterally across the DWSC. (See dye study results in the body of the report.)

The discharge from the Aeration Facility diffuser may not be immediately mixed laterally or vertically, with more of the added DO still near the dock and perhaps more near the surface because of the bubbles remaining in the discharge. Therefore, the RRI surface monitor may indicate a higher DO increment than the fully mixed estimated DO increment. Because the DO monitoring station at Light 43 is on the opposite side of the DWSC from the diffuser, the measured DO increments may be less than expected.

Effects of Flow on the Dissolved Oxygen Increments

The average daily DO increment within the tidal mixing volume can be estimated from the net daily flow and the assumed tidal mixing volume, but the longitudinal distribution of added DO caused by the tidal movement in the DWSC is more complicated to calculate. The longitudinal DO increments will change if the Aeration Facility is operated intermittently with the tidal flow (e.g., on during flood tide) or with a day-night pattern.

The water in the DWSC will be moving downstream with the net daily flow, but the tidal movement will distribute the added DO in a slightly uneven pattern each day. The average daily DO increment that can be added to the DWSC by operation of the Aeration Facility would be:

Average Daily DO increment (mg/l) = Daily DO (lb) / 5.4 / Daily net flow (cfs)

The coefficient of 5.4 is the conversion factor between the three units used in this equation. For example, with the maximum observed Aeration Facility output of 7,500 lb/day, the daily DO increment for a net flow of 500 cfs would be about 2.7 mg/l, if it were evenly distributed in the daily flow volume of 1,000 af. However, because the tidal movement within the DWSC is generally about 1.5 miles from lower-low to higher-high tide, the diffuser will distribute the daily oxygen output within a tidal volume of about 3,000 af. The average DO increment therefore would be about

0.9 mg/l after 1 day of aeration. The net flow of 500 cfs would move the water through the tidal mixing volume of 3,000 af in about 3 days, at which time the downstream DO increment observed at Light 40 (1.5 miles downstream from the diffuser) would be about 2.7 mg/l (i.e., 3 x 0.9 mg/l).

Dissolved Oxygen Increments at the Monitoring Stations

The relative position of each monitoring station and the tidal movement of water in the DWSC are used to determine how many previously discharged DO increments from the diffuser would be in the vicinity of the monitoring stations during each 15-minute interval in the month. This can be imagined as throwing a surface buoy into the water every 15 minutes and tracking the tidal movement of all of the buoys past the DO monitoring stations. The number of buoys within a specified distance (representing the tidal spreading distance) of the station is used to estimate the average DO increment.

The DO monitoring station at Light 48 is located about 1.5 miles upstream of the diffuser. The DO monitoring station at Light 43 is located about 0.2 mile upstream of the diffuser. The RRI monitoring station is located about 0.2 mile downstream of the diffuser, the DO monitoring station at Light 42 is located about 0.7 mile downstream of the diffuser, and the DO monitoring station at Light 40 is located about 1.6 miles downstream of the diffuser.

The initial DO increments from operation of the Aeration Facility will not be uniform along the channel, but longitudinal spreading will occur as the tidal flows move back and forth past the diffuser. This longitudinal spreading will produce a more uniform distribution over time. The DO Increment Model allows the spreading distance to be selected for each station. A longer averaging distance might be used for stations that are located farther away (more spreading time) from the diffuser. It was assumed, based on dye studies, that each 15-minute DO increment would become evenly spread over about 0.5 mile of channel. A spreading distance of 0.5 mile (0.25 mile upstream and 0.25 mile downstream) was used. Spreading distances of 0.25 mile and 1 mile were tested in the DO Increment Modal and did not greatly change the tidal pattern of DO increments.

The DO Increment Model calculations identify the number of times that the previous diffuser position has been at the current relative position of the monitoring stations by counting the times that the diffuser position has been within 0.25 mile of the monitoring station position. For example, if the diffuser was at a cumulative movement position of 7.0 miles at midnight on the 10th of the month, the RRI station would be located at cumulative movement position 6.8 miles (0.2 mile downstream from the diffuser position). A count is made of all previous diffuser positions between 6.55 miles (6.8 – 0.25) and 7.05 miles (6.8 + 0.25). The DO increment at the RRI station is estimated from the 78 pounds of DO from the diffuser during each 15-minute interval and the assumed DWSC volume within each 0.5-mile increment (1,000 af at low tide).

This counting is done in the Microsoft Excel–based DO Increment Model using the function *SUMIF* (range, criteria, sum_range) where the criteria are less than the selected position of the monitor station, plus or minus the selected channel length. Two columns are used to count the number of previous diffuser positions less than 6.55 and less than 7.05 miles. The two counts are subtracted to get the number of times the diffuser was located (and discharged DO increments) within the 0.5-mile increment. This number of diffuser doses then is multiplied by the diffuser DO increment (15-minute dose) to calculate the expected incremental DO concentration at the RRI monitoring station. For example, the DO increment for five previous diffuser position counts within the 0.5-mile volume would be 0.14 mg/l (i.e., 5 counts x 78 lb/1,000 af/2.7).

Loss of Incremental Dissolved Oxygen from Reduced Reaeration

Because the daily source of DO from natural surface reaeration is the reaeration rate times the natural DO deficit, the added DO increments from the Aeration Facility will reduce the DO deficit and thereby reduce the surface reaeration downstream of the diffuser. Therefore, the calculated (or observed) DO increment from the Aeration Facility will decrease downstream with time. The higher the reaeration rate, the faster the DO increment from the Aeration Facility will decrease.

Table B-1 illustrates the effects of different reaeration rates on the remaining DO increment with time. For example, if the reaeration rate was 10% per day (0.10), and the natural DO deficit was 3 mg/l, the daily reaeration gain would be 0.3 mg/l. If the initial added DO increment was 1 mg/l, the daily reaeration gain would be reduced by 0.1 mg/l on the first day. On the second day, the remaining DO increment would be about 0.9 mg/l, and the reaeration rate would be reduced by 0.09 mg/l to 0.81 mg/l. It can be shown that the added DO increment would decrease by the reaeration rate each day. The remaining DO increment after some number of days can be estimated as:

$$\text{Remaining Increment} = \text{Initial Increment} \times [1 - \text{Reaeration Rate (fraction)}]^{\text{days}}$$

Because the travel time since the DO increments were added will be relatively short for the nearby stations, the DO increment will be a higher fraction of the initial DO increment at these nearby locations. There was definitely some reduction in the initial DO increments at downstream DO monitoring stations (Light 42 and Light 40). The DO monitoring indicated that the maximum DO increments were observed at the RRI station, with reduced DO increments at Light 42 and much lower DO increments at Light 40.

The DO Increment Model calculation keeps track of the average travel time for the DO increments and estimates the remaining DO increment from the reaeration rate and the travel time. A comparison of the measured DO data at the five monitoring stations (shown below) indicated that the most likely reaeration rate for the DWSC is between 10% per day (0.1) and 30% per day (0.3). The reaeration rate selected to compare the estimated DO increments at the monitoring stations for the 4 months of operational performance testing was 20% per day (0.2).

Table B-1. Remaining Fraction of Initial Dissolved Oxygen Increment for Various Reaeration Rates

	Reaeration Rate (fraction per day)				
Days	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**
1	0.90	0.80	0.70	0.60	0.50
2	0.81	0.64	0.49	0.36	0.25
3	0.73	0.51	0.34	0.22	0.13
4	0.66	0.41	0.24	0.13	0.06
5	0.59	0.33	0.17	0.08	0.03

Comparison of Measured Dissolved Oxygen and Estimated Dissolved Oxygen Increments

The primary method for testing the performance of the Aeration Facility was the DO monitoring at RRI and two upstream and two downstream stations. YSI sondes were placed at a depth of about 10 ft (at low tide) and recorded 15-minute data. The two upstream stations are at Light 43 (0.2 mile upstream and across the channel from the diffuser) and at Light 48 (1.5 miles upstream and just downstream of the SJR inflow to the DWSC at Channel Point). The RRI station (3-ft depth) is about 0.2 mile downstream, and the downstream stations are at Light 42 (0.7 mile downstream) and Light 40 (1.6 miles downstream).

Monitoring during months without any aeration indicated that there were temporal changes during the month and spatial differences between the DO concentrations measured at these DWSC locations (about 3 miles apart). This confirmed substantial variability in the DO conditions in this upstream portion of the DWSC. The monitoring plan strategy for identifying the effects on the DWSC DO was to operate the Aeration Facility for several days, and then turn the Aeration Facility off for several days, to allow the DWSC to return to natural DO conditions. The results of this on-off operation and monitoring strategy for determining the performance of the Aeration Facility in June, July, August, and September 2008 are described in the following sections.

Initial DO increments refers to the DO changes calculated for the Aeration Facility without any effects from reduced surface reaeration. *Remaining DO increments* refers to the DO changes calculated for the Aeration Facility after the effects from reduced surface reaeration.

June 2008 Dissolved Oxygen Measurements

Dissolved Oxygen at Light 48

Figure B-10a shows the measured DO and the calculated DO increments at Light 48 (1.5 miles upstream) for June 2008. The tidal elevations are shown (shifted up by 3 ft) to indicate periods of high and low tides. The saturated DO concentrations are shown as a blue line, declining from about 9 mg/l to 8.5 mg/l in June, with slightly warming temperatures. The periods of Aeration Facility operation are shown by the red line (at 1 mg/l) near the bottom of the graph. The calculated DO increments at Light 48 station were very small and infrequent because only rarely did the flood tide movement extend 1.5 miles upstream from the diffuser (See Figure B-6a). The measured DO at Light 48 did not show any strong correlation with high tides, which was expected if added DO from the Aeration Facility was reaching Light 48.

The measured DO at Light 48 declined from about 5–6 mg/l early in the month to about 4 mg/l during the first period of aeration testing, and was 3–4 mg/l during the second period of aeration testing during June 23–27. This was assumed to be the natural DO at Light 48 because only small DO increments from the Aeration Facility were calculated to reach this upstream station. However, the Port of Stockton also was operating their water-jet Aeration Facility (2,000 lb/day) and the oxygen gas bubble-hose facility at Dock 13 (2,000 lb/day), which could influence Light 48 DO measurements during ebb tides. The possible effects of these Port of Stockton facilities have not been evaluated in this study. For June and all subsequent months of 2008, the DO concentrations measured at Light 48 were assumed to be the natural DO conditions entering the DWSC from the SJR.

Dissolved Oxygen at Light 43

Figure B-10b shows the measured DO and the calculated DO increments at Light 43 with actual Aeration Facility operation during June 2008. The Aeration Facility was turned on at about noon on Monday, June 16, and operated for 4 days until noon on Friday, June 20. The Aeration Facility was turned on again at about noon on Monday, June 22. The purpose of this pulsed operation was to allow the DO concentrations at the monitoring stations to return to natural conditions during the 3 days when the Aeration Facility was turned off. The calculated DO increments at Light 43 were limited to the periods of higher tidal elevations when tidal flow moved at least 0.2 mile upstream of the diffuser. The initial DO increments calculated without any loss from reaeration effects are shown by the dark blue line. The variations in the initial DO increments were caused by the tidal flows moving upstream past the diffuser during flood-tide movements. The red line shows the calculated remaining DO increments with the estimated loss from reaeration effects. The DO Increment Model used a reaeration rate 20% per day (0.2) as the most likely value after comparing the measured and estimated natural DO from each station for the 4 months of operational performance testing.

The maximum calculated initial DO increments at Light 43 were 2–3 mg/l during short periods of highest tide (elevation of more than 8 ft on graph) when water moved upstream past the diffuser. It took about 2 days of Aeration Facility operation for the maximum DO increments to appear at Light 43, and the DO calculated increments were almost gone on the third day of non-operation (see June 22 and June 29). With the assumed reaeration rate of 20% per day, the remaining calculated DO increments at Light 43 were only a little less than the initial DO increments because the average travel time of the added DO increments at Light 43 was generally less than 2 days (travel time shown with light blue dots). The calculated remaining DO increments at Light 43 were generally 1–2 mg/l. There were no calculated DO increments at Light 43 during low tides when all of the added oxygen moved downstream of the diffuser.

The natural DO pattern at Light 43 was estimated by subtracting the calculated remaining DO increments from the measured DO. The estimated natural DO at Light 43 decreased to 4–5 mg/l during both periods of Aeration Facility operation. The measured DO remained above 5 mg/l on June 22 and June 29 (after 3 days of non-operation), suggesting that the calculated remaining DO increments were perhaps too great at Light 43. The difference between the calculated DO increments and the measured DO might be caused by incomplete mixing across the channel, because Light 43 is located on the opposite side of the channel from the diffuser.

Dissolved Oxygen at Rough and Ready Island

Figure B-10c shows the measured DO and the calculated DO increments at the RRI station (0.2 mile downstream) with actual Aeration Facility operation during June 2008. The highest DO concentrations (almost at DO saturation) were measured during the ebb tides on June 17–20 and June 24–27 during Aeration Facility operation. The calculated initial DO increments at the RRI station were lowest during low tide when tidal flow had moved water from upstream of the diffuser past the RRI station. The maximum calculated initial DO increments were about 3 mg/l on a few days. It took about 3 days of Aeration Facility operation for the maximum DO increments to appear at the RRI station, and most of the calculated DO increments were gone on the third day of non-operation (June 22 and June 29). The calculated remaining DO increments were about 2 mg/l while the Aeration Facility was operated and decreased to less than 1 mg/l during the period the Aeration Facility was shut off because the travel time of the oxygen increments increased to more than 3 days.

The natural DO pattern at RRI was estimated by subtracting the calculated remaining DO increments from the measured DO. The estimated natural DO at RRI decreased to about 4 mg/l during both periods of Aeration Facility operation. The measured DO was above 5 mg/l on June 22 and June 29, suggesting that the calculated DO increments at RRI were too large. The daily variation (from algal photosynthesis) was less than 1 mg/l for June 1–16 and on June 29 while the Aeration Facility was not operated. This suggests that the majority of the large variations in DO were caused by tidal variations. However, the calculated DO increments did not always match the observed DO pattern at the RRI station.

Dissolved Oxygen at Light 42

Figure B-10d shows the measured DO and the calculated DO increments at Light 42 (0.7 mile downstream) with actual Aeration Facility operation during June 2008. The initial calculated DO increments at Light 42 were similar to those calculated for the RRI station. However, the tidal variations in the DO increments were reduced because some added DO from the diffuser was in the vicinity of Light 43 most of the day. The calculated remaining DO increments were usually less than 2 mg/l. There may be more lateral and longitudinal spreading at this station because the tidal movements have more time to spread the added DO.

Dissolved Oxygen at Light 40

Figure B-10e shows the measured DO and the calculated DO increments for Light 40 (1.6 miles downstream) with actual Aeration Facility operation during June 2008. The measured DO at Light 40 showed very small increases during periods of Aeration Facility operation. A delay in the DO increments at Light 40 was expected, but very little of the DO increments observed at RRI and Light 42 was measured at Light 40. The maximum calculated initial DO increments at Light 40 were about 3 mg/l, reflecting the full mixing of the added DO with the net flow of 250 cfs. The calculated DO increments at Light 40 were reduced during some periods of low tide when less DO was added to the water. The calculated initial DO increments were at least 4 days out-of-phase with the on-off operations because of the travel time delay to Light 40, and the calculated DO increments were highest during the 3 days of non-operation. The calculated remaining DO increments were a maximum of about 2 mg/l on the fourth day of operation and declined to less than 1 mg/l after 3 days of non-operation.

Figure B-10f shows a comparison of the calculated initial and remaining DO increments at Light 40 for conditions of higher flow (500 cfs rather than 250 cfs) and a faster reaeration rate (30% per day rather than 20% per day). The higher flow reduced the initial DO increments to about 2 mg/l and reduced the tidal variations in the calculated DO increments. The higher flows allowed the on-off signal to become stronger at Light 40, and the calculated DO increments were much less after 3 days of non-operation (June 22 and June 29). The higher flow reduced the travel time and would have allowed more of the initial DO increments to remain at Light 40, but the increased reaeration rate reduced the initial DO increments to less than 1 mg/l on the fourth day of operation and to less than 0.5 mg/l after 3 days of non-operation.

This alternative set of DWSC conditions was calculated at Light 40 to demonstrate that there may be several flow and reaeration rates that would give similar results at the DO monitoring stations. The net flow of 250 cfs with a reaeration rate of 20% per day for June 2008 was selected as the best overall match of the measured DO and estimated DO increments and natural DO concentrations during the on-off operations from June 16 to June 30.

July 2008 Dissolved Oxygen Measurements

Dissolved Oxygen at Light 48

Figure B-11a shows the measured DO and the calculated DO increments at Light 48 for July 2008. The calculated DO increments at Light 48 were small and infrequent because only rarely did the flood tide movement extend 1.5 miles upstream from the diffuser. The Aeration Facility was operated with a weekly on-off schedule during July 2008. The measured DO at Light 48 generally varied between about 4 mg/l and 6 mg/l during the month. This was assumed to be the natural DO at Light 48 because no added DO increments reached this upstream station, although the Port of Stockton was operating the water-jet aeration and the oxygen gas bubble-hose facilities at Dock 13. The natural DO deficit for July varied from about 2 mg/l to 3 mg/l. The DWSC net flows were adjusted to 250 cfs for each day of July 2008.

Dissolved Oxygen at Light 43

Figure B-11b shows the measured DO and the calculated DO increments at Light 43 with actual Aeration Facility operation during July 2008. The measured DO increased to about 7 mg/l during periods of Aeration Facility operation. The calculated DO increments at Light 43 were limited to periods of higher tidal elevations, when tidal flow moved at least 0.2 mile upstream of the diffuser. The maximum calculated initial DO increments at Light 43 were about 3 mg/l during periods of high tide after several days of Aeration Facility operation. It took about 3 days of Aeration Facility operation for the maximum DO increments to appear at Light 43, and the DO calculated increments were not quite gone on the third day of non-operation. With the assumed reaeration rate of 20% per day, the remaining DO increments at Light 43 were less than about 2 mg/l. The natural DO pattern at Light 43 was estimated by subtracting the calculated remaining DO increments from the measured DO. The estimated natural DO at Light 43 was about 5–6 mg/l throughout July but was greater than 6 mg/l in the first week and lower than 5 mg/l during the third week of operation in July 2008. The calculated DO increments varied with the tides more than the measured DO at Light 43.

Dissolved Oxygen at Rough and Ready Island

Figure B-11c shows the measured DO and the calculated DO increments at the RRI station with actual Aeration Facility operation during July 2008. The highest DO concentrations were measured during the ebb tides on days with Aeration Facility operation. The maximum measured DO was greater than DO saturation during operations. The maximum calculated initial DO increments were greater than 3 mg/l during the higher tides on the fourth day of Aeration Facility operation. The remaining DO increments were about 2 mg/l on the second to fourth days of operation because the travel time (i.e., age) of the DO increments at the RRI station was less than 2 days. The remaining DO increments decreased to about 1 mg/l during the period the Aeration Facility was shut off.

The estimated natural DO at RRI decreased to less than 5 mg/l during periods of Aeration Facility operation. The measured DO was about 6 mg/l on days without Aeration Facility operation, with a daily variation (from algal photosynthesis) of less than 1 mg/l. This again suggests that the majority of the large variations in DO at RRI were caused by tidal movement of the DO increments. The calculated DO increments did not match the observed DO pattern at the RRI station for July 2008, perhaps because RRI measured greater DO increments during ebb tides before the DO was fully mixed across the channel.

Figure B-11d shows the calculated DO increments at the RRI station with a higher longitudinal spreading distance of 1 mile rather than 0.5 mile. The tidal variations in the DO increments were reduced slightly by this increased longitudinal averaging. However, the tidal movement of water past the diffuser was not changed, so the variations in the DO increments caused by the ebb and flood tide were not modified. The DO increment calculations do not appear to be sensitive to the longitudinal spreading. The major differences between the measured and calculated DO increments at the RRI station were probably caused by incomplete lateral mixing between the diffuser and the RRI surface measurements.

Dissolved Oxygen at Light 42

Figure B-11e shows the measured DO and the calculated DO increments at Light 42 with actual Aeration Facility operation during July 2008. The measured DO increased only about half as much as at RRI during Aeration Facility operation in July 2008. The initial DO increments at Light 42 were similar to those calculated for the RRI station, with a maximum of 3–4 mg/l on the fourth day of aeration. The estimated DO increments were more uniform with less tidal variation because most of the DO increments were measured at Light 43, and only the lowest tides would move water from upstream of the diffuser past Light 43. However, because the travel time was longer than at the RRI station, the remaining DO increments were about 2 mg/l after the third day of operation and decreased to about 1 mg/l after 3 days of non-operation. Therefore, the remaining DO increments at Light 43 were less than 1 mg/l on the first and second day of aeration each week. The estimated natural DO pattern at Light 43 was about 4.5 to 5.5 mg/l during most of July 2008. The measured DO decreased to about 5.5 mg/l while the Aeration Facility was shut off, suggesting that the calculated remaining DO increments at Light 43 may have been a little too high. A slightly higher reaeration coefficient might have better matched the natural DO of about 5.5 mg/l.

Dissolved Oxygen at Light 40

Figure B-11f shows the measured DO and the calculated DO increments for Light 40 with actual Aeration Facility operation during July 2008. The measured DO at Light 40 was very uniform at about 6–7 mg/l during July 2008, with daily increases of about 1 mg/l from algal photosynthesis or reaeration effects during low tides. Very little of the DO increments observed at RRI and Light 42 was measured at Light 40. The maximum initial DO increments at Light 40 were about 3–4 mg/l, reflecting the full mixing of the added DO with the net flow of 250 cfs. It took about 5 days for the maximum DO increments to appear at Light 40, so the calculated DO increments were highest during the 3 days of non-operation each weekend. The estimated natural DO at Light 40 was less than 5 mg/l during the weekend periods, suggesting that the calculated remaining DO increments at Light 40 were too large.

Figures B-11g and B-11h show the calculated DO increments at Light 42 and Light 40 with an increased reaeration rate of 30% per day (instead of 20% per day). The remaining DO increments at Light 42 were reduced by about 0.5 mg/l, and the remaining DO increments at Light 40 were reduced by about 1 mg/l. The estimated natural DO at Light 42 and Light 40 remained at about 5 mg/l during July 2008. The higher reaeration rate reduced the calculated effectiveness of the Aeration Facility at these downstream locations during these low-flow conditions because the travel time to Light 42 was about 3 days and the travel time to Light 40 was more than 5 days.

The basic strategy of evaluating the Aeration Facility performance by DO monitoring of pulsed operations was not as effective at the downstream stations during low-flow conditions because DO increments from the diffuser required more days to be transported past Light 40. The effects of the pulsed operation at the downstream stations would be stronger (more complete separation) if the Aeration Facility were operated for a week and then not operated for a week. This change in the operational performance testing (i.e., longer pulses) therefore was used in August.

August 2008 Dissolved Oxygen Measurements

Dissolved Oxygen at Light 48

Figure B-12a shows the measured DO and the calculated DO increments at Light 48 for August 2008. The Aeration Facility was operated for three periods during August, with a 4-day period of August 4–8, and two longer periods of August 12–19 and August 26–September 5 to give a better separation between Aeration Facility operations and natural DO conditions. The measured DO at Light 48 generally varied between about 5 mg/l and 7 mg/l during the month. There was a daily variation of about 1 mg/l, with some days of 2 mg/l that may have been caused by algal photosynthesis. The daily pattern was partially masked by the random fluctuations of about 1 mg/l. The net daily flow was assumed to be 250 cfs, and the natural DO deficit at Light 48 in August 2008 was 2 mg/l.

Dissolved Oxygen at Light 43

Figure B-12b shows the measured DO and the calculated DO increments at Light 43 with actual Aeration Facility operation during August 2008. The measured DO was more than 7 mg/l, approaching the saturated DO concentration (8 mg/l), during periods of Aeration Facility operation. The DO increments at Light 43 were limited to the periods of higher tidal elevations when tidal flow moved at least 0.2 mile upstream of the diffuser. It took about 3 days of Aeration Facility operation for the maximum DO increments of about 3 mg/l to appear at Light 43, and the DO increments were gone on the third day of non-operation. With the assumed reaeration rate of 20% per day, the remaining DO increments at Light 43 were less than 2 mg/l during operation. The estimated natural DO at Light 43 was 5–6 mg/l throughout August. The measured DO at Light 43 did not have as strong a tidal variation as the calculated DO increments.

Dissolved Oxygen at Rough and Ready Island

Figure B-12c shows the measured DO and the calculated DO increments at the RRI station with actual Aeration Facility operation during August 2008. The highest DO concentrations (some above DO saturation) were measured during the ebb tides of days with Aeration Facility operation. The maximum initial DO increments were about 4 mg/l during the higher tides after the fourth day of Aeration Facility operation. The remaining DO increments were about 2 mg/l after the third day of operation. The remaining DO increments decreased to about 1 mg/l during the period the Aeration Facility was shut off because the travel time of the oxygen increments increased to more than 3 days. The estimated natural DO at RRI decreased to about 5 mg/l during periods of Aeration Facility operation. The measured DO on days without Aeration Facility operation was 5–6 mg/l with a daily variation (from algal photosynthesis) of 1–2 mg/l. This suggests that the majority of the large variations in DO at RRI were caused by tidal movement of the added DO increments. The DO increments did not always match the observed DO pattern at the RRI station for August 2008 because of tidal movement of the near-surface DO increments during ebb tides past the RRI surface monitor before the DO was fully mixed across the channel.

Dissolved Oxygen at Light 42

Figure B-12d shows the measured DO and the calculated DO increments at Light 42 with actual Aeration Facility operation during August 2008. The measured DO at Light 42 increased less than at RRI because the Light 42 measurements are taken 10–15 ft below the surface and because more complete mixing was likely at Light 42. The initial DO increments at Light 42 were similar to those calculated for the RRI station, with a maximum of 3–4 mg/l on the fourth day of aeration and on high tide elevations on days between Aeration Facility operations. The tidal variations in the DO increments were reduced because most of the added DO was measured at Light 42, and only the lowest tides would move water from upstream of the diffuser past Light 42. The travel times during operation varied from about 1 day at low tides to about 4 days at high tides. Because the travel time was longer than at the RRI station, the remaining DO increments were smaller, about 1–2 mg/l. The estimated natural DO pattern at Light 42 was about 5–6 mg/l during periods of operation and matched the measured DO of about 6 mg/l during periods of non-operation, suggesting that the calculated DO increments were accurate at Light 42.

Figures B-12e and B-12f show the measured DO and the calculated DO increments for Light 42 with two different reaeration rates, to illustrate the effects of the reaeration rate on the remaining DO increments and the estimated natural DO. Figure B-10e shows the effects of a lower reaeration rate of 10% per day. The remaining DO increments were higher at about 2.5 mg/l. The estimated natural DO concentrations at Light 42 for this low reaeration rate therefore were lower (about 4–5 mg/l) during operation. The remaining DO increments apparently were too high with this lower reaeration rate. Figure B-9f shows the effects of a higher reaeration rate of 30% per day. The remaining DO increments were about 1.5 mg/l. The estimated natural DO increments for this higher reaeration rate therefore were higher (about 6–7 mg/l) during operation. The remaining DO increments with an aeration rate of 20% best matched the measured DO during periods of non-operation.

Dissolved Oxygen at Light 40

Figures B-12g and B-12h show the measured DO and calculated DO at Light 40 with two different reaeration rates, 20% per day and 30% per day, for August 2008. The measured DO at Light 40 was about 6–7 mg/l during August 2008, with the highest DO about 4–5 days after the Aeration Facility operation began. The highest DO was associated with the lowest tides, when DO increments had the shortest travel times from the diffuser (about 3 days). Much lower DO increments were measured at Light 40 compared to those observed at RRI and Light 42. The reaeration rates of 20% per day and 30% per day appear to provide similar estimates of the DO increments and natural DO concentrations at Light 40. The estimated natural DO concentrations at Light 40 varied from about 5 to 6 mg/l during August 2008.

Because the reaeration rate cannot be measured directly, the results from the DO Increment Model were used to calibrate the natural reaeration rate. Comparison of the calculated natural DO concentrations for three reaeration rates suggests that 10% per day is too low and 30% per day is too high; therefore, a reaeration rate of 20% per day appears to provide the best match with the measured natural DO during periods without Aeration Facility operation.

September 2008 Dissolved Oxygen Measurements

Dissolved Oxygen at Light 48

Figure B-13a shows the measured DO at Light 48 for September 2008. Saturated DO increased from 8 to 8.5 mg/l as temperatures decreased in September. The DO concentrations at Light 48 increased from 6 mg/l to 7 mg/l from September 4 to September 8, perhaps corresponding to the period of Aeration Facility operation of September 1–5. The DO at Light 48 increased from about 6 mg/l on September 15 to more than 7 mg/l during September 20–30, and was almost at DO saturation on September 23–26. These peak DO concentrations appear to correspond to the period of Aeration Facility operation of September 16–26. However, the estimated DO increments at Light 48 were small because the tidal movement did not extend upstream 1.5 miles on most days. This apparent influence of the Aeration Facility on the Light 48 DO concentrations was not observed as strongly in the previous 3 months of operational performance testing.

Dissolved Oxygen at Rough and Ready Island

Figure B-13b shows the measured DO and calculated DO at the RRI station with an assumed flow of 250 cfs for September 2008. The RRI station measured the highest DO concentrations during periods of Aeration Facility operation because it is located just 0.2 mile downstream of the diffuser. The measured DO increments may be higher than the fully mixed DO increments. The measured DO was above saturation for parts of the day September 2–6 and again September 23–26 during Aeration Facility operation. With a reaeration rate of 20% per day and a DO deficit of 2 mg/l, the calculated DO increments varied about 1–2 mg/l during periods of Aeration Facility operation. However, the measured DO increments at RRI appeared to be greatest at the beginning of ebb tides (with tidal elevations above 7 ft on graph). This suggests that the surface DO increments measured at RRI were higher because they were not fully mixed as they passed the RRI station on ebb tides.

Dissolved Oxygen at Light 43

Figures B-13c and B-13d show the measured DO and the calculated DO increments at Light 43 (0.2 mile upstream, across channel) with assumed net flows of 250 cfs and 500 cfs. A flow of 250 cfs produced maximum DO increments (without reaeration effects) of about 3 mg/l at Light 43, while a flow of 500 cfs reduced the maximum DO increments to about 2 mg/l at Light 43. With a DO deficit of 2 mg/l and a reaeration rate of 20% per day, the remaining DO increments fluctuated with tidal movement from 0 mg/l during low tide elevations to about 2 mg/l at high tide elevations for a net flow of 250 cfs. With a flow of 500 cfs, the upstream movement was reduced, and the maximum DO increments at Light 43 were about 1.5 mg/l. The measured DO at Light 43 did not have as much tidal or daily variation as the calculated DO increments, perhaps because the initial DO increments did not mix across the channel until after tidal mixing for more than a day. Flows of 250 cfs and 500 cfs both gave natural DO concentrations that remained above 6 mg/l, which was the measured DO between the periods of Aeration Facility operation. Therefore, DWSC flows of between 250 cfs and 500 cfs would give similar calculated DO increments at Light 43.

Dissolved Oxygen at Light 42

Figures B-13e and B-13f show the measured DO and the calculated DO increments and natural DO concentrations at Light 42 (0.7 mile downstream) with assumed net flows of 250 cfs and 500 cfs.

The measured DO at Light 42 approached saturated DO from September 1 to September 5 (after 5 days of operation) and September 24–26 (after 8 days of operation). A flow of 250 cfs produced maximum DO increments of about 3–4 mg/l at Light 42, and a flow of 500 cfs produced maximum DO increment of about 2.5 mg/l at Light 42. With a reaeration rate of 20% per day, the remaining DO increments fluctuated from 1 mg/l during high tide elevations (longest travel times) to about 2 mg/l at middle tide elevations (shortest travel times) with a net flow of 250 cfs.

With a flow of 500 cfs, the travel times were reduced, and the remaining DO increments at Light 42 were about 1.5 mg/l. The measured DO at Light 42 did not have much tidal or daily variation when the Aeration Facility was not operating, but the tidal variation of DO was about 2 mg/l during operation. The highest DO increments were associated with ebb tides and middle tide elevations, corresponding to the full Aeration Facility increment with a travel time of 1–2 days. The natural DO patterns at Light 42 calculated with flows of 250 cfs and 500 cfs both remained above 6 mg/l, which was the measured DO between periods of Aeration Facility operation. The estimated natural DO patterns at Light 42 were about 6–7 mg/l during periods of operation and matched the measured DO of about 6–7 mg/l during periods of non-operation. The remaining DO increments were similar because the reduced initial increments for a flow of 500 cfs were balanced by the longer travel times for a flow of 250 cfs, giving nearly identical remaining DO increments of about 1.5–2 mg/l at Light 42.

Dissolved Oxygen at Light 40

Figures B-13g and B-13h show the measured DO, the calculated DO increments, and natural DO concentrations at Light 40 with net flows of 250 cfs and 500 cfs. A flow of 250 cfs produced maximum initial DO increments of about 4 mg/l at Light 40, and a flow of 500 cfs reduced the maximum initial DO increments to about 2 mg/l at Light 40. With a reaeration rate of 20% per day, the calculated remaining DO increments at Light 40 fluctuated with tidal movement from 0.5 to 1 mg/l as the travel time varied from 3 to 6 days with a flow of 250 cfs. With a flow of 500 cfs, the travel times were reduced, and the remaining DO increments at Light 40 were about 1–1.5 mg/l. The measured DO at Light 40 did not have much tidal or daily variation when the Aeration Facility was not operating, but the tidal variation of DO was about 1 mg/l during operation (highest at low tide elevations, short travel time). The estimated natural DO patterns at Light 40 were similar, ranging from 5 mg/l to 7 mg/l during the month and suggesting that the calculated DO increments with flows of 250 cfs and 500 cfs were both possible.

As was discussed previously for other months, a higher reaeration rate can balance a higher net flow to give similar remaining DO increments at downstream stations. Therefore, the combination of net flow uncertainty and reaeration rate uncertainty may prevent a single best match or calibration for the DO increment calculations for the DWSC. Nevertheless, for these 4 months of operational performance testing in 2008 with DWSC flows between 250 cfs and 500 cfs, reaeration rates between 20% per day and 30% per day provide similar reasonable matches with the measured DO increments and natural DO patterns at the five DO monitoring stations.

Conclusions from Dissolved Oxygen Monitoring

The primary method for testing the performance of the Aeration Facility was the DO monitoring at the existing RRI station and at two upstream and two downstream stations that were installed by DWR for Aeration Facility performance testing. The RRI station has a 3-foot-deep floating DO sensor and is closest to the diffuser, about 0.2 mile downstream. The other installed DO monitoring stations have DO probes located at a depth of about 10–15 feet. The DO monitoring station at Light 48 is located about 1.5 miles upstream from the diffuser, and the station at Light 43 is about 0.2 mile upstream from the diffuser. The DO monitoring station at Light 42 is about 0.7 mile downstream from the diffuser, and the station at Light 40 is about 1.6 miles downstream from the diffuser.

Monitoring during months without any aeration confirmed substantial variability in the natural DO concentrations measured at the DWSC locations upstream and downstream of the diffuser. The monitoring plan strategy for identifying the effects of the added DO from the Aeration Facility on the DWSC DO (i.e., performance) was to operate the Aeration Facility for several days, and then turn it off for several days, to allow the DWSC to return to natural DO conditions.

The DO monitoring indicated that the maximum DO increments were observed at the RRI station, which was expected because of its location just 1,000 feet downstream of the diffuser on the same side of the channel. The calculated DO increments at RRI were larger than the fully mixed DO increments that were observed farther downstream at Light 42 and Light40.

The measured DO increments at Light 42 (0.7 mile downstream) were likely the best indication of the fully mixed added DO from the Aeration Facility. Much lower DO increments are measured at Light 40 because it is farther downstream (1.6 miles downstream of the diffuser). By the time added DO from the diffuser reaches Light 40, reduced surface reaeration in the DWSC has reduced the added DO effects, making it difficult to discern the effects of the Aeration Facility. Upstream, the calculated DO increments at Light 48 station were small and infrequent because only rarely does the flood tide movement extend 1.5 miles upstream from the diffuser. It takes about 2–3 days of Aeration Facility operation for the maximum DO increments to appear at Light 43, located just 0.2 mile upstream but across the DWSC from the diffuser.

Therefore, each of the four DO monitoring stations installed by DWR to test the performance of the Aeration Facility provided valuable information for the assessment. Light 48 provided measurements of the upstream conditions, largely unaffected by the Aeration Facility. Light 43 provided an indication of the lateral spreading of the added DO from tidal movement, showing a gradual DO increase during operation of the Aeration Facility. RRI provided a clear signal during operational periods, with a very large DO increment during all ebb tides when the Aeration Facility was operated. Light 42 provided the best estimate of the average (fully mixed) added DO increment in the DWSC from the Aeration Facility. The downstream DO monitoring station at Light 40 provided a very strong tidal signal during Aeration Facility operation, with a relatively large DO increment at low tide and a much smaller DO increment at high tide.

Tidal Elevation at RRI, Garwood, and Lathrop

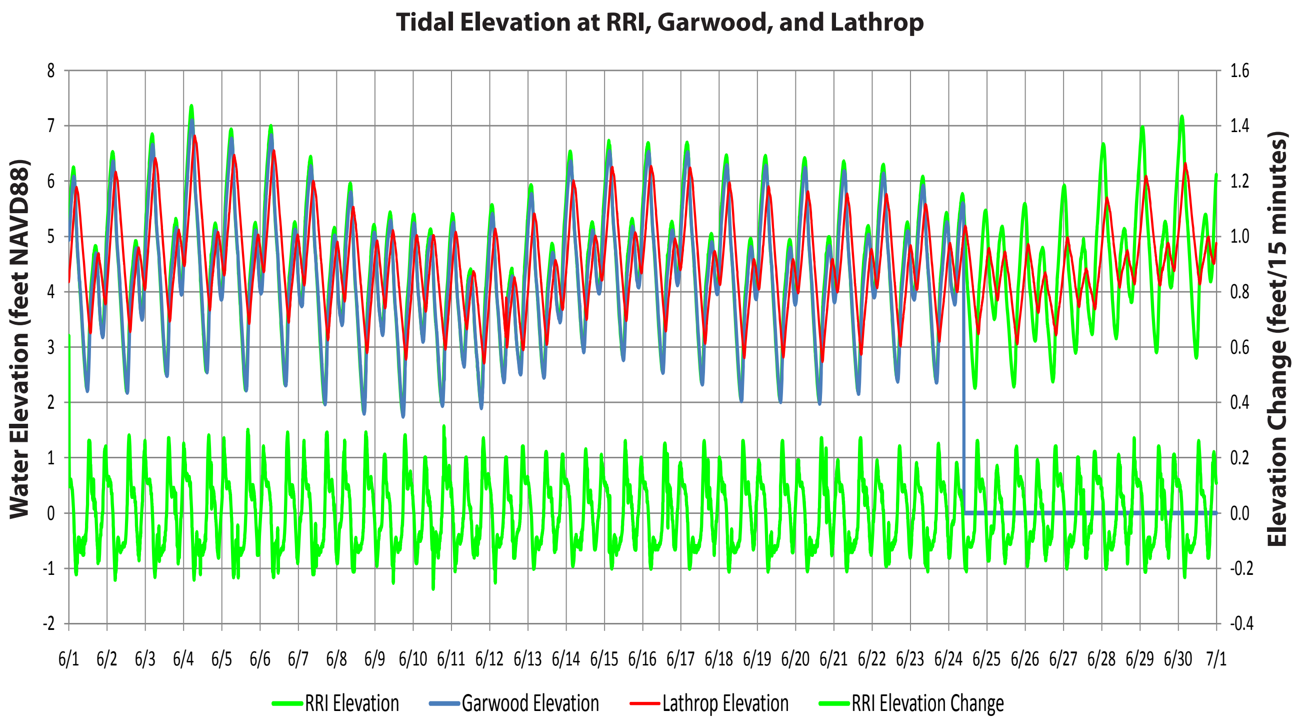

Figure B-1a: Measured Tidal Elevation at RRI, Garwood, and Lathrop Stations for June 2008.

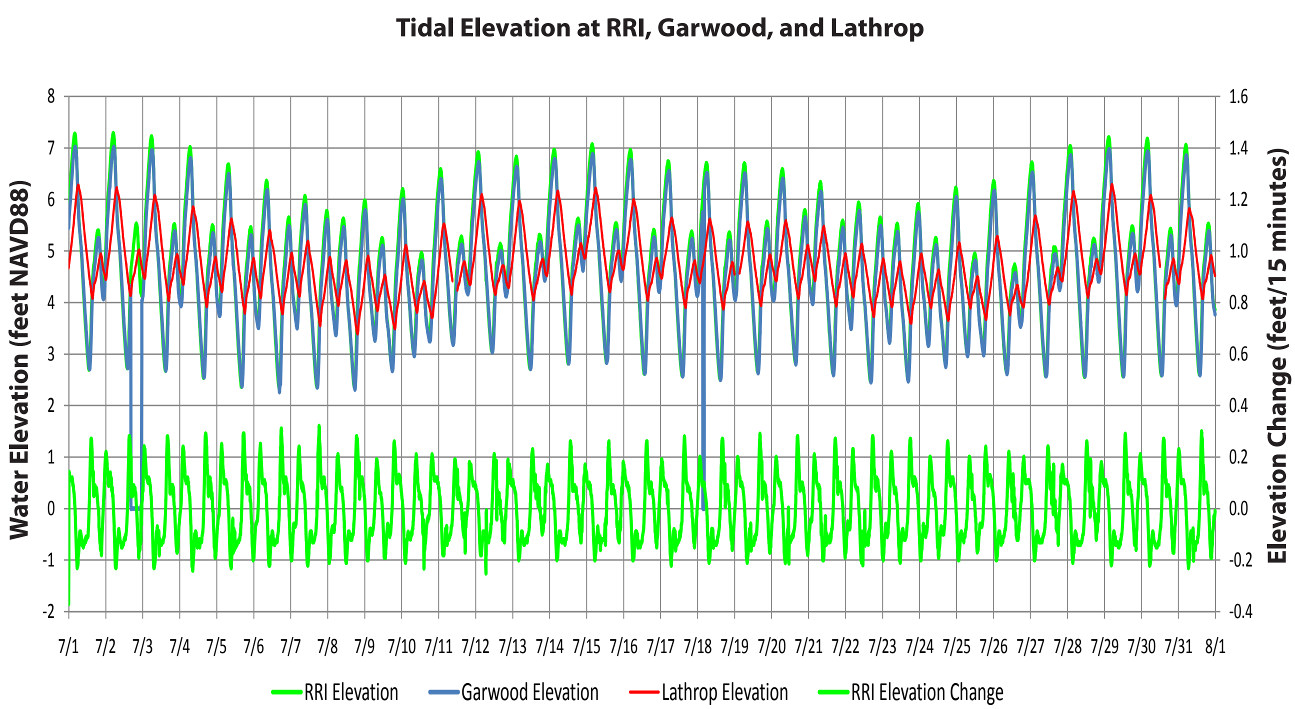

Figure B-1b: Measured Tidal Elevation at RRI, Garwood, and Lathrop Stations for July 2008.

Graphics/Projects/00902.08 TO-I Operation and Technical Support/2008 Operation Report/Appendix A (03-09) SS

ICF INTERNATIONAL

Figure B-1

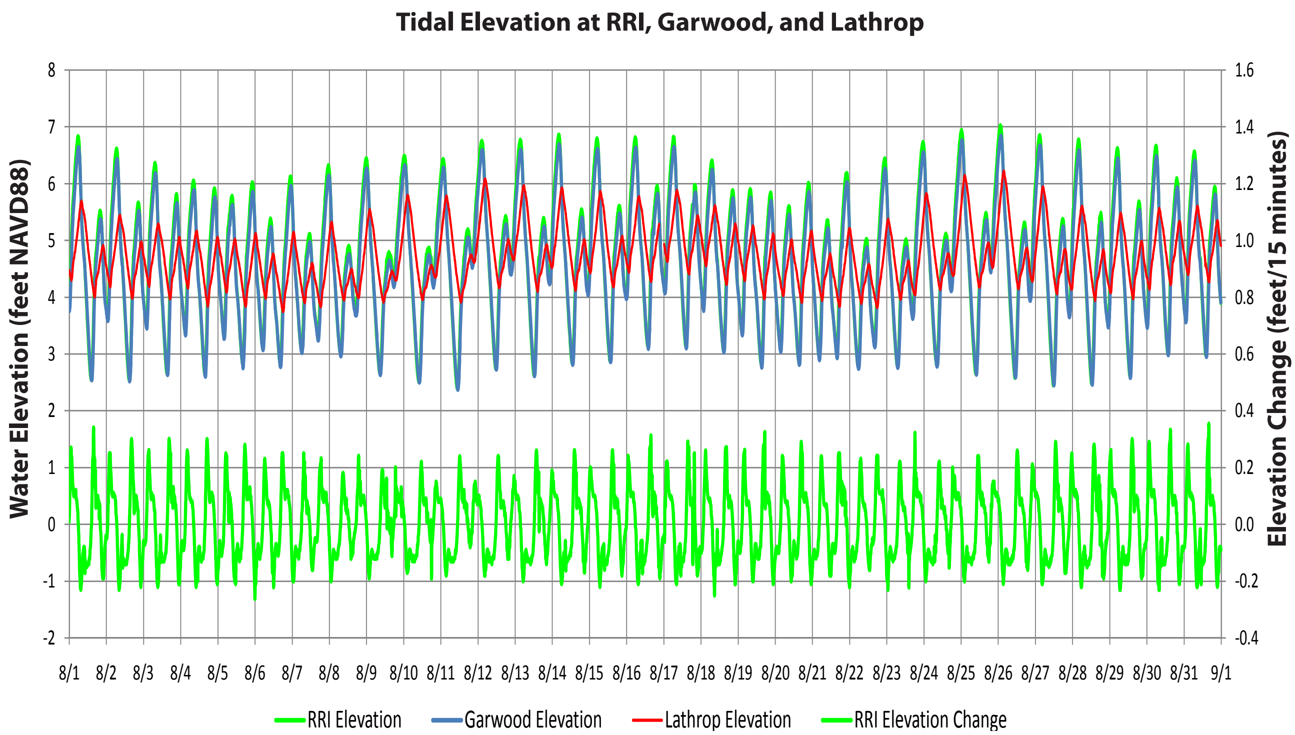

Figure B-1c: Measured Tidal Elevation at RRI, Garwood, and Lathrop Stations for August 2008.

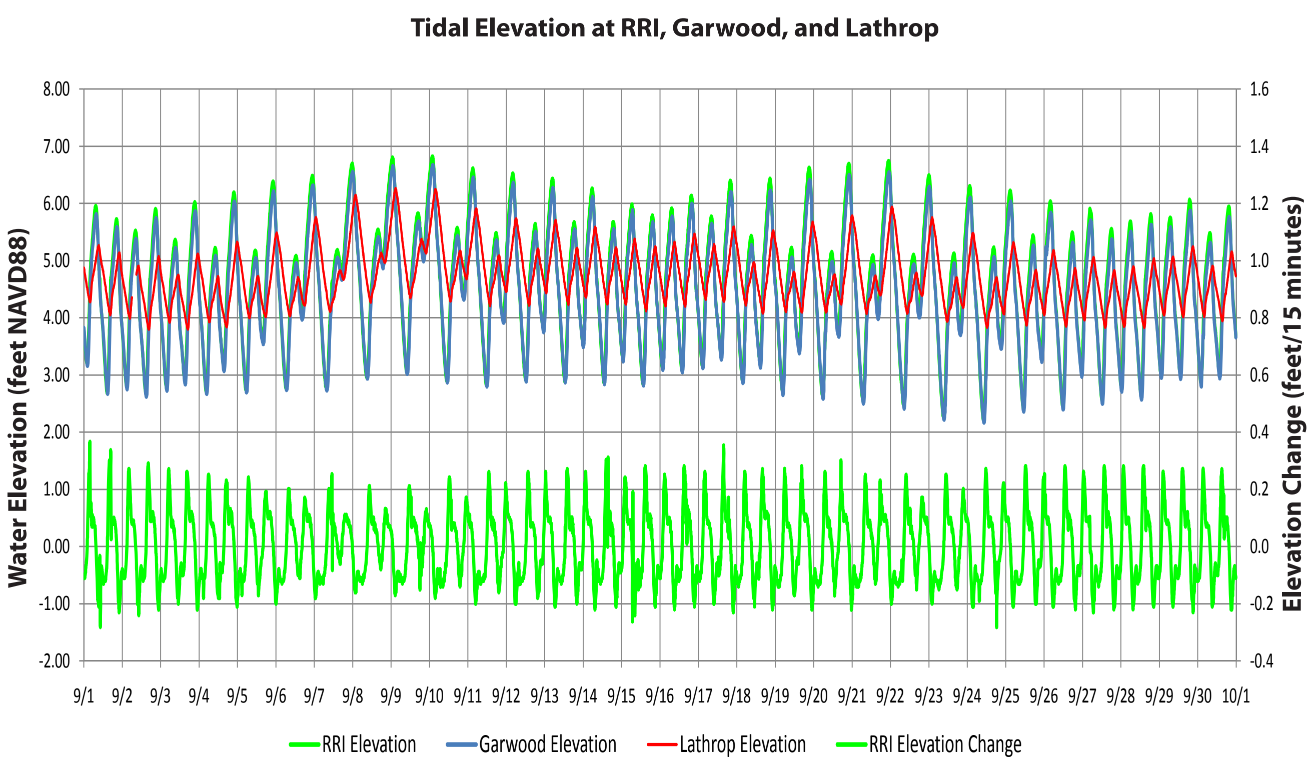

Figure B-1d: Measured Tidal Elevation at RRI, Garwood, and Lathrop Stations for September 2008.

Figure B-1 (continued)

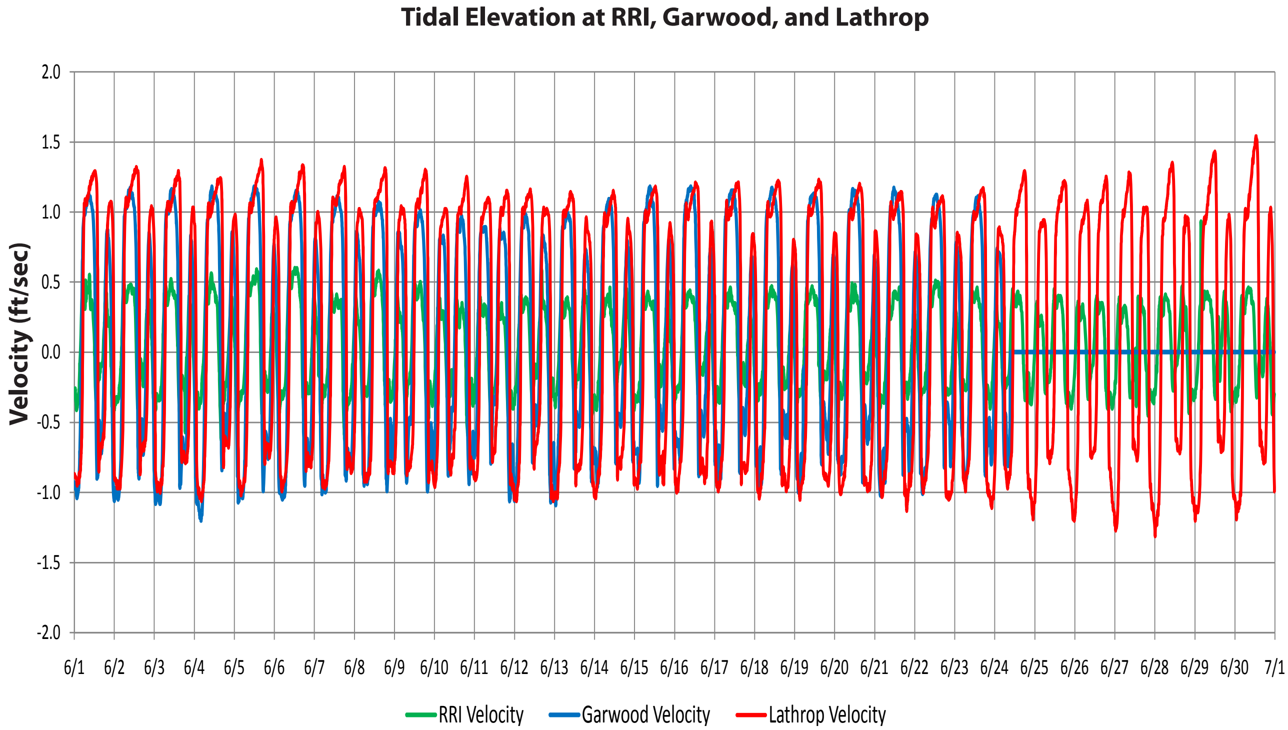

Figure B-2a: Measured Tidal Velocity at RRI, Garwood, and Lathrop Stations for June 2008.

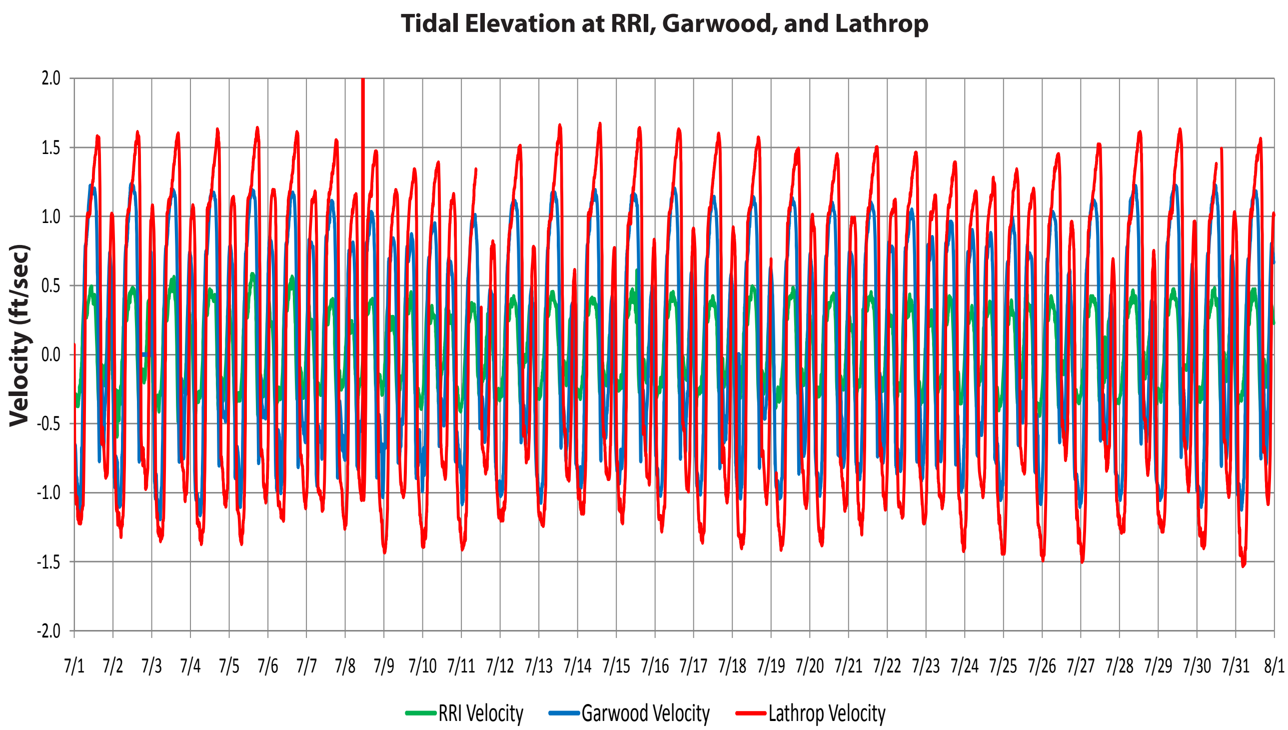

Figure B-2b: Measured Tidal Velocity at RRI, Garwood, and Lathrop Stations for July 2008.

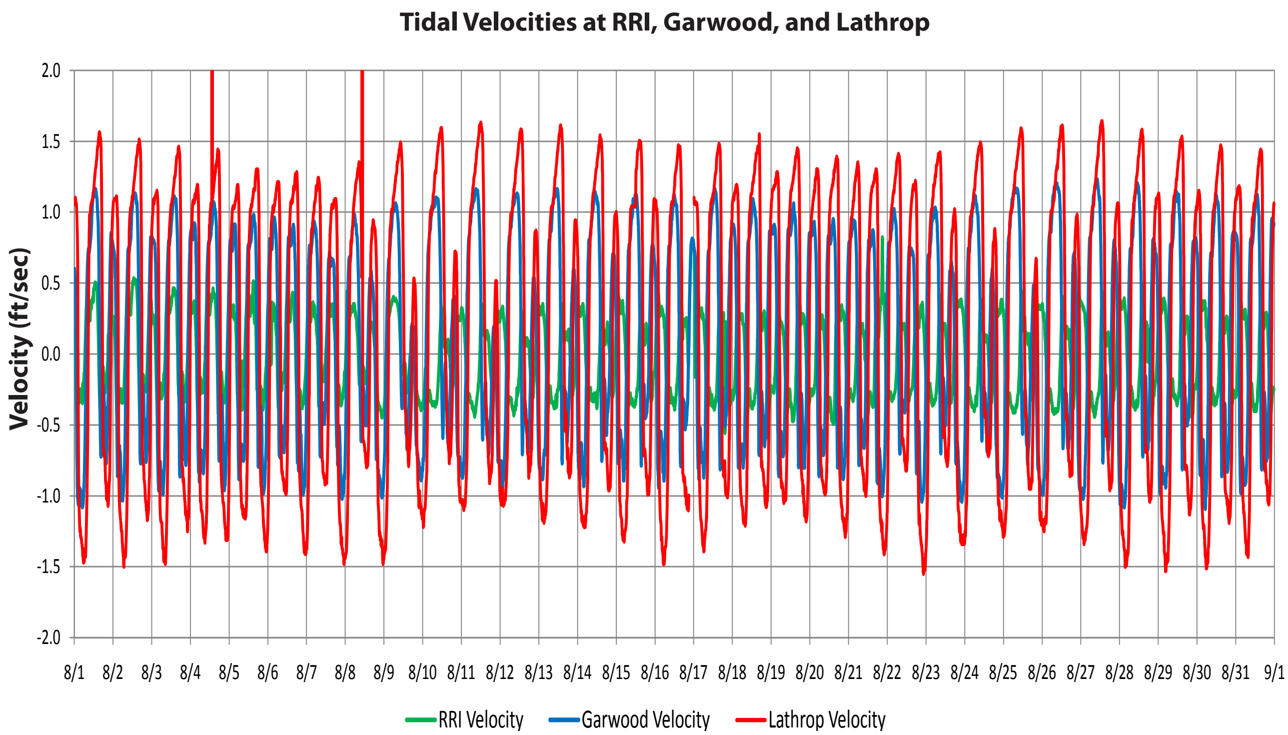

Figure B-2c: Measured Tidal Velocity at RRI, Garwood, and Lathrop Stations for August 2008.

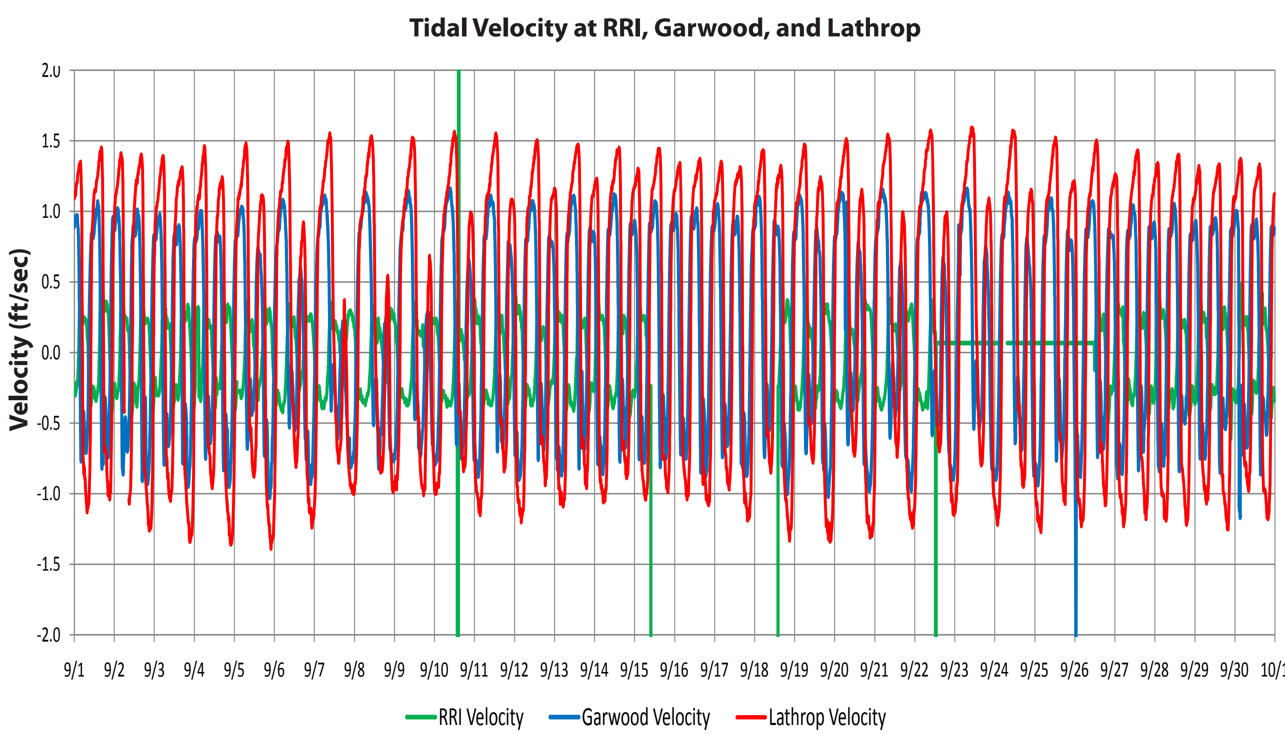

Figure B-2d: Measured Tidal Velocity at RRI, Garwood, and Lathrop Stations for September 2008.

ICF INTERNATIONAL

Figure B-2 (continued)

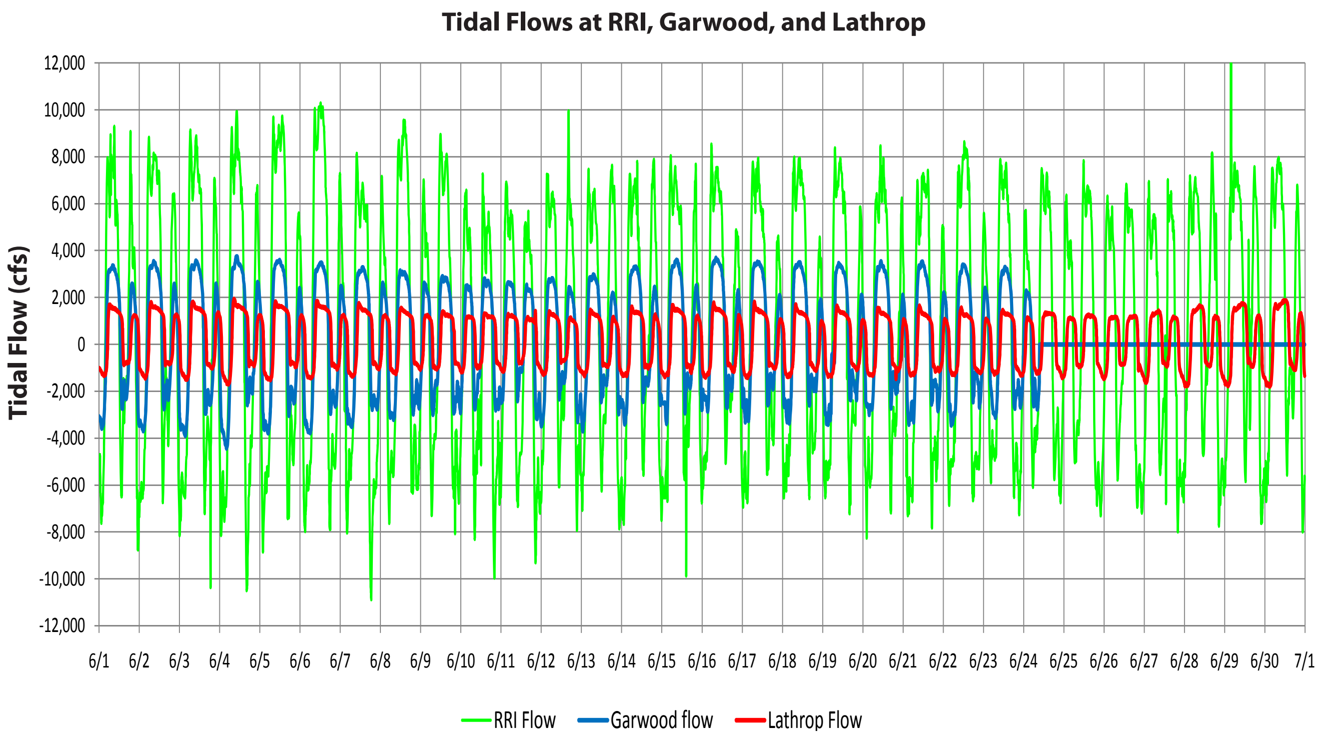

Figure B-3a: Measured Tidal Flows at RRI, Garwood, and Lathrop Stations for June 2008.

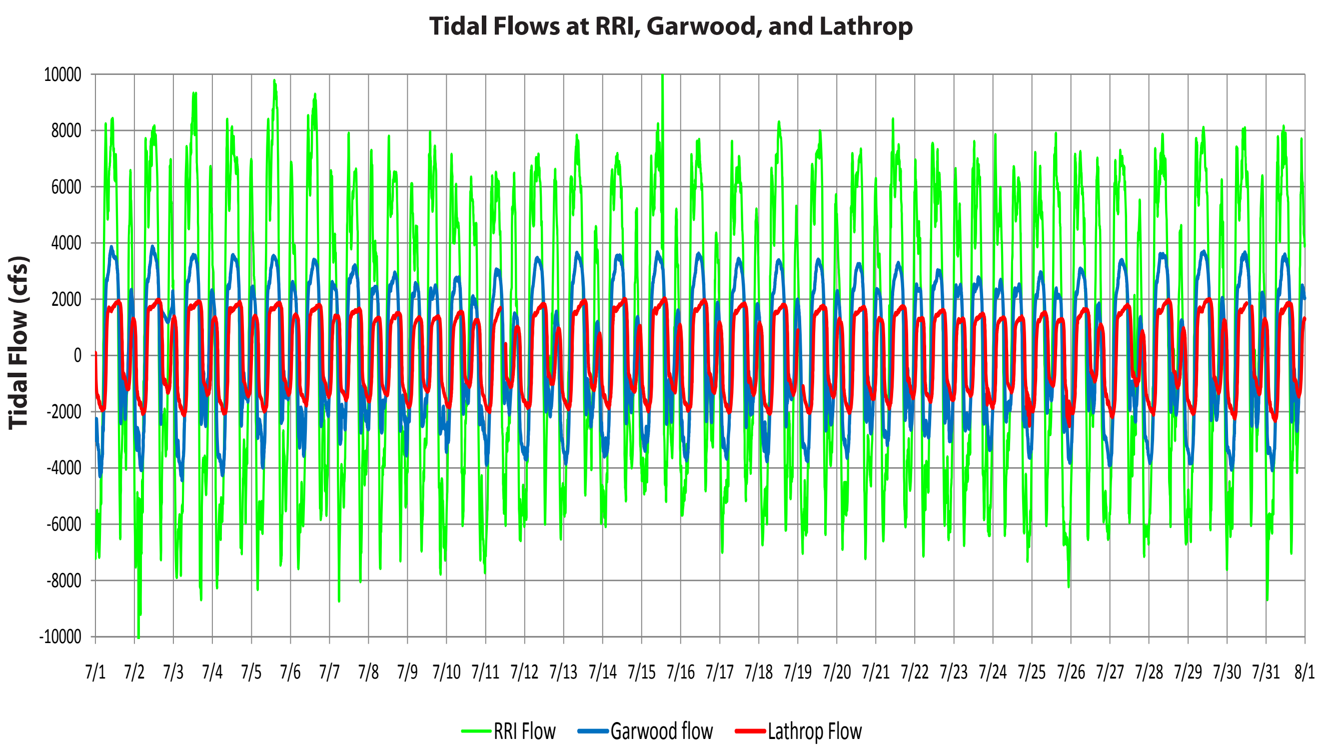

Figure B-3b: Measured Tidal Flows at RRI, Garwood, and Lathrop Stations for July 2008.

Graphics/Projects/00902.08 TO-I Operation and Technical Support/2008 Operation Report/Appendix A (03-09) SS

ICF INTERNATIONAL

Figure B-3

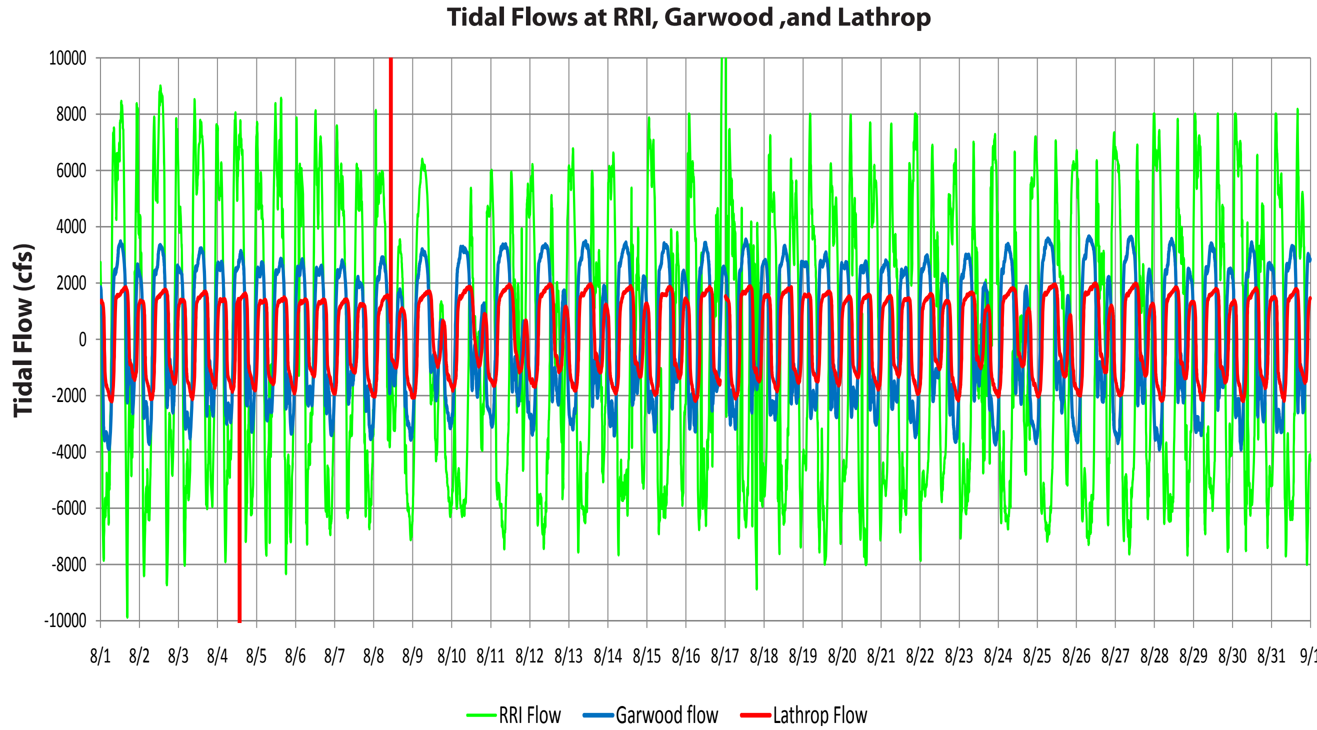

Figure B-3c: Measured Tidal Flows at RRI, Garwood, and Lathrop Stations for August 2008.

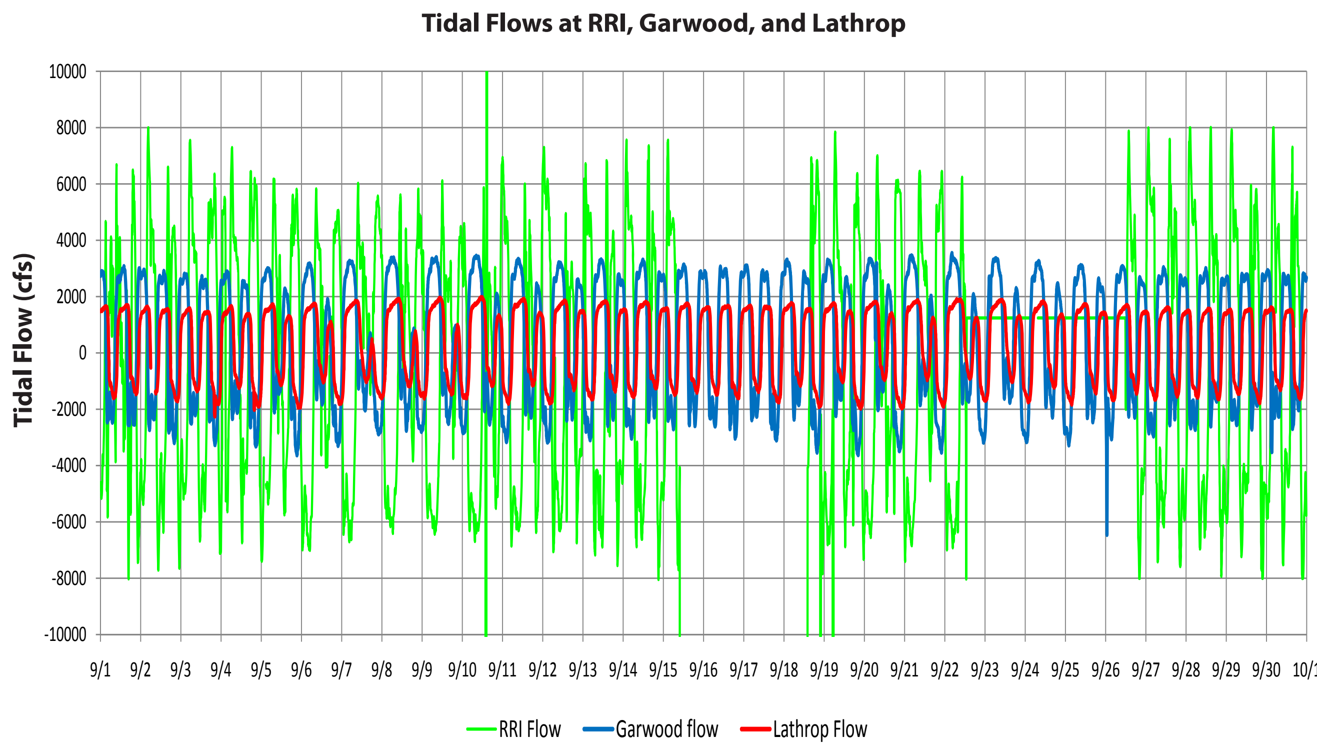

Figure B-3d: Measured Tidal Flows at RRI, Garwood, and Lathrop Stations for September 2008.

ICF INTERNATIONAL

Figure B-3 (continued)

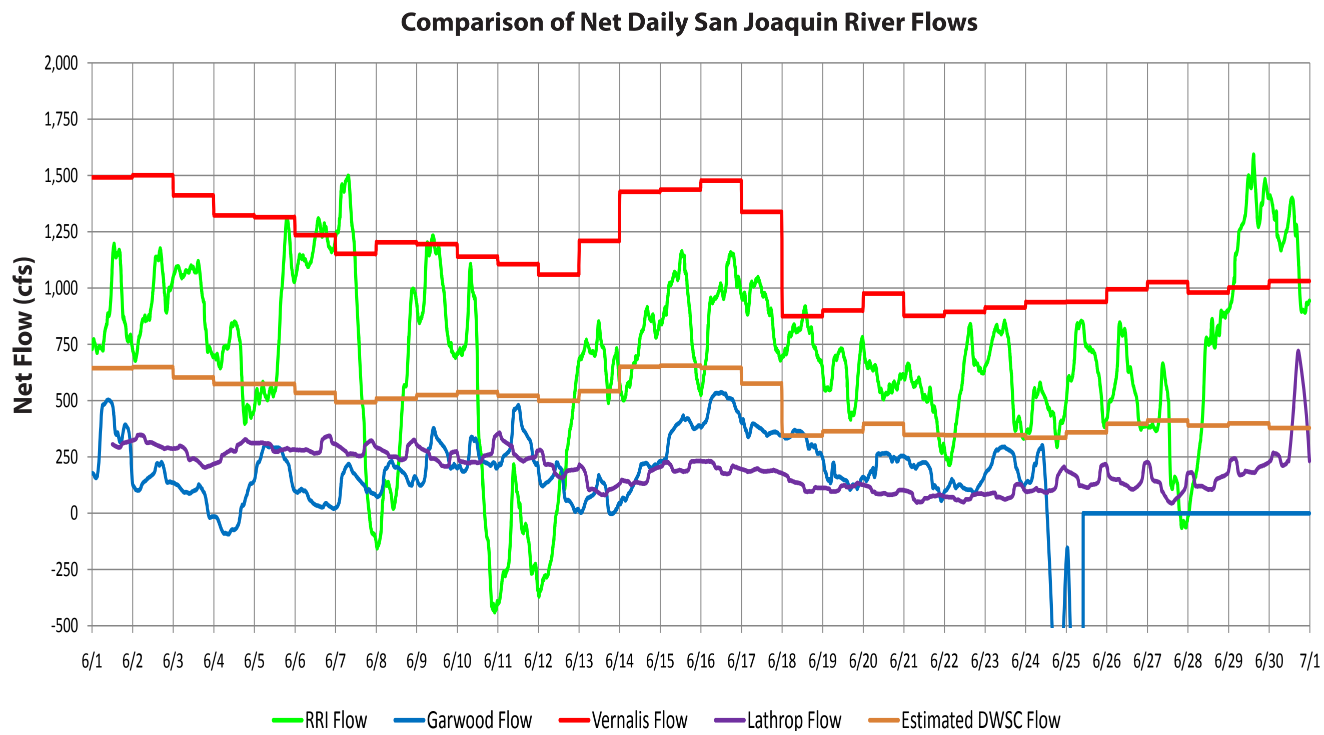

Figure B-4a: Net Daily San Joaquin River Flows at RRI, Garwood, and Lathrop Compared to Vernalis for June 2008.

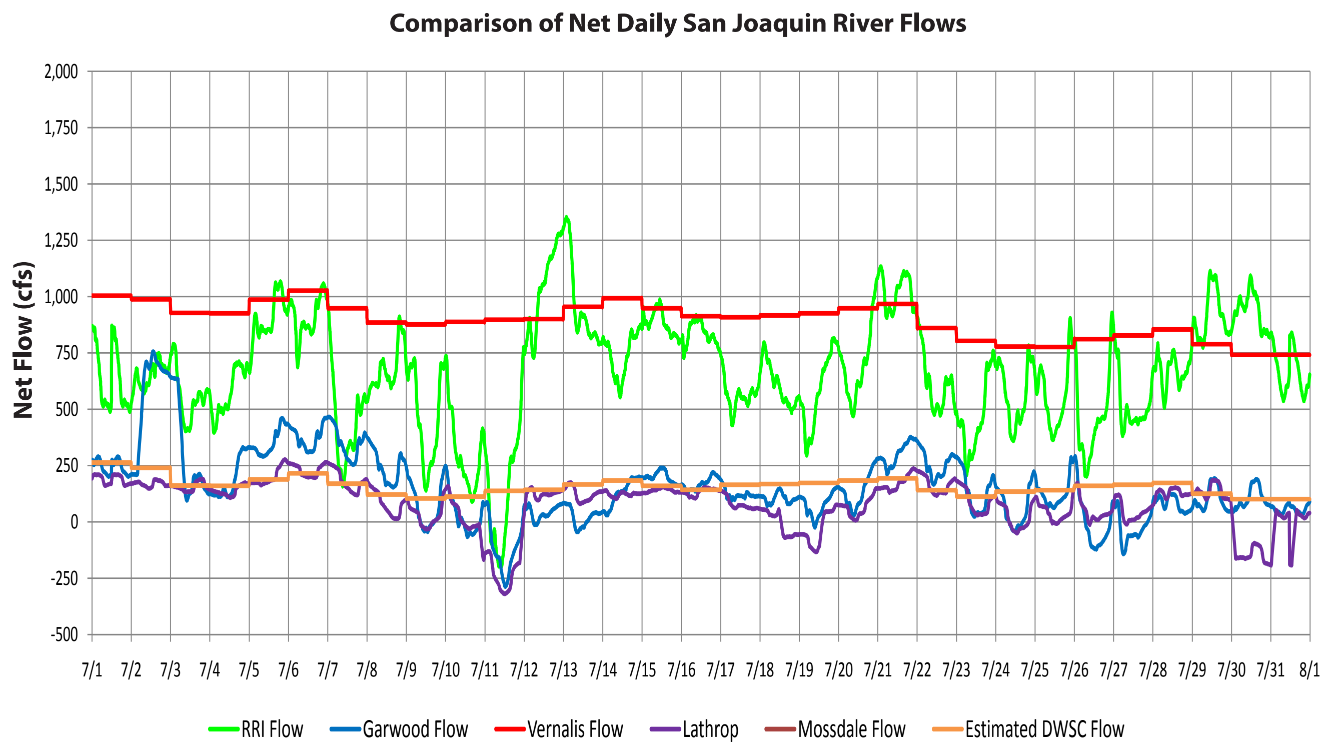

Figure B-4b: Net Daily San Joaquin River Flows at RRI, Garwood, and Lathrop Compared to Vernalis for July 2008

Graphics/Projects/00902.08 TO-I Operation and Technical Support/2008 Operation Report/Appendix A (03-09) SS

ICF INTERNATIONAL

Figure B-4

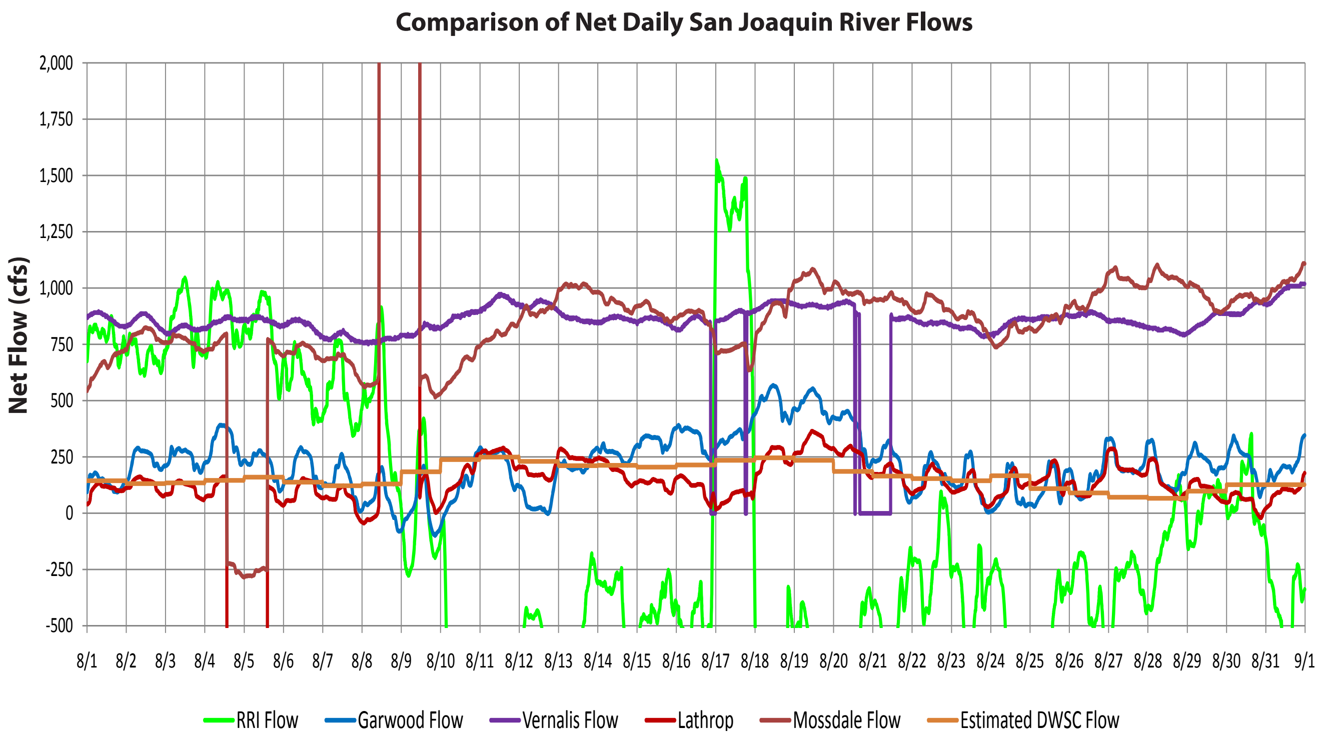

Figure B-4c: Net Daily San Joaquin River Flows at RRI, Garwood, and Lathrop Compared to Vernalis for August 2008.

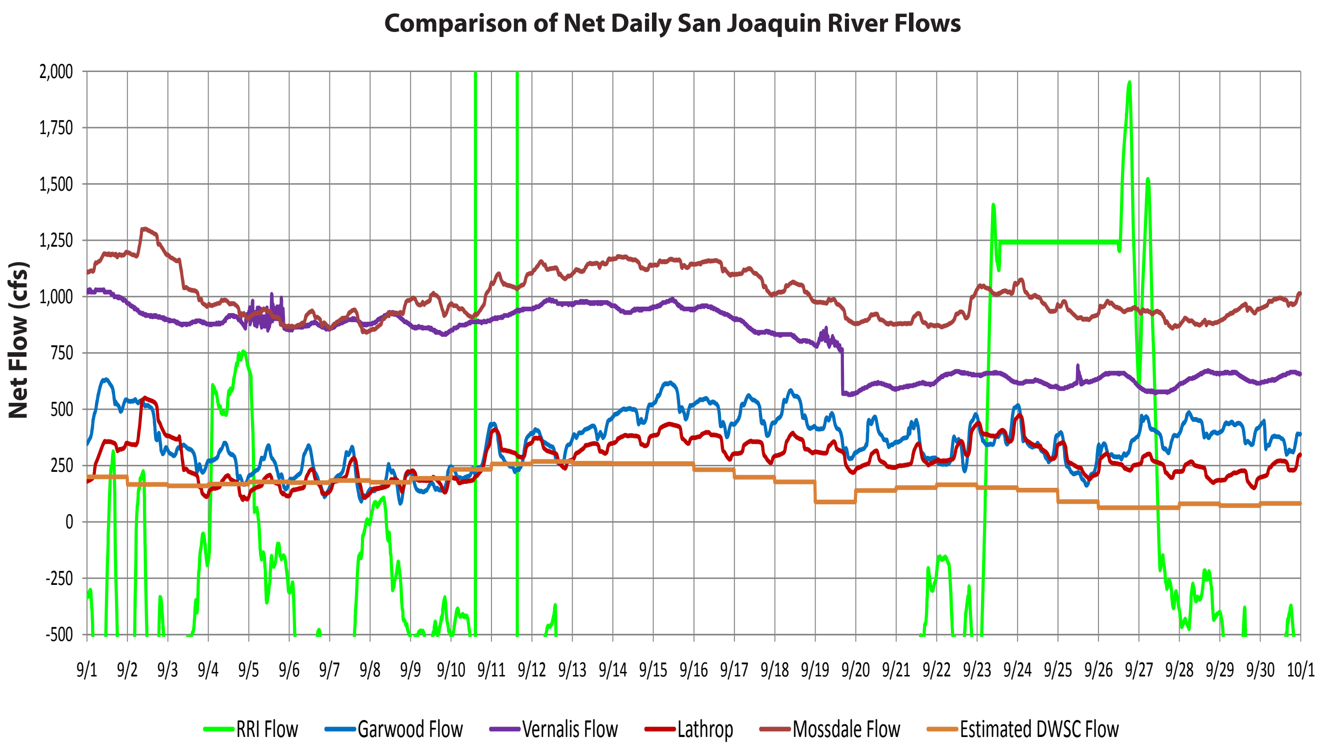

Figure B-4d: Net Daily San Joaquin River Flows at RRI, Garwood, and Lathrop Compared to Vernalis for September 2008.

Graphics/Projects/00902.08 TO-I Operation and Technical Support/2008 Operation Report/Appendix A (03-09) SS

ICF INTERNATIONAL

Figure B-4 (continued)

Tidal Elevation and Tidal Movement at RRI

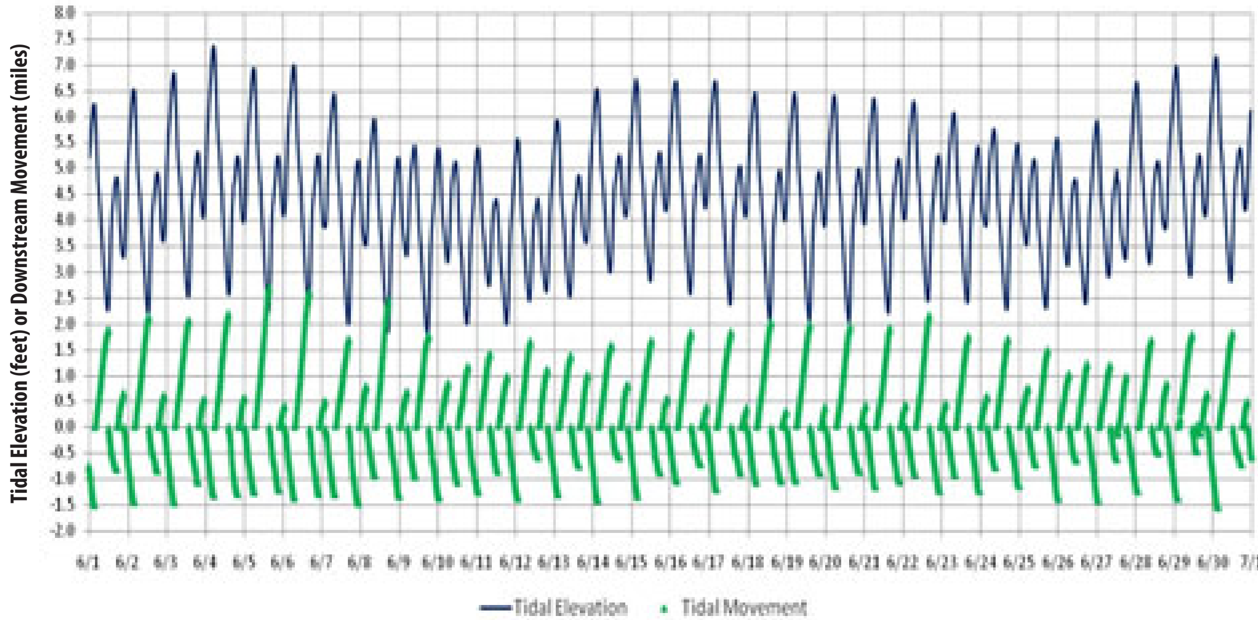

Figure B-5a: Tidal Elevations and Tidal Movement Calculated for the RRI Station for June 2008.

Tidal Elevation and Tidal Movement at RRI

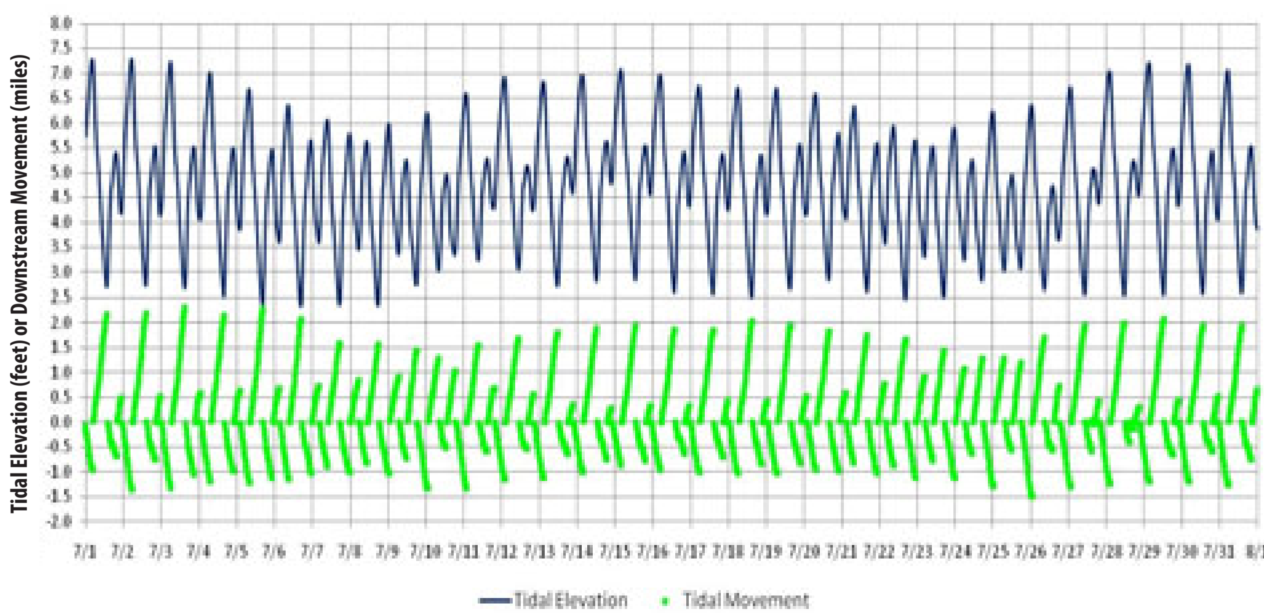

Figure B-5b: Tidal Elevations and Tidal Movement Calculated for the RRI Station for July 2008.

ICF INTERNATIONAL

Figure B-5

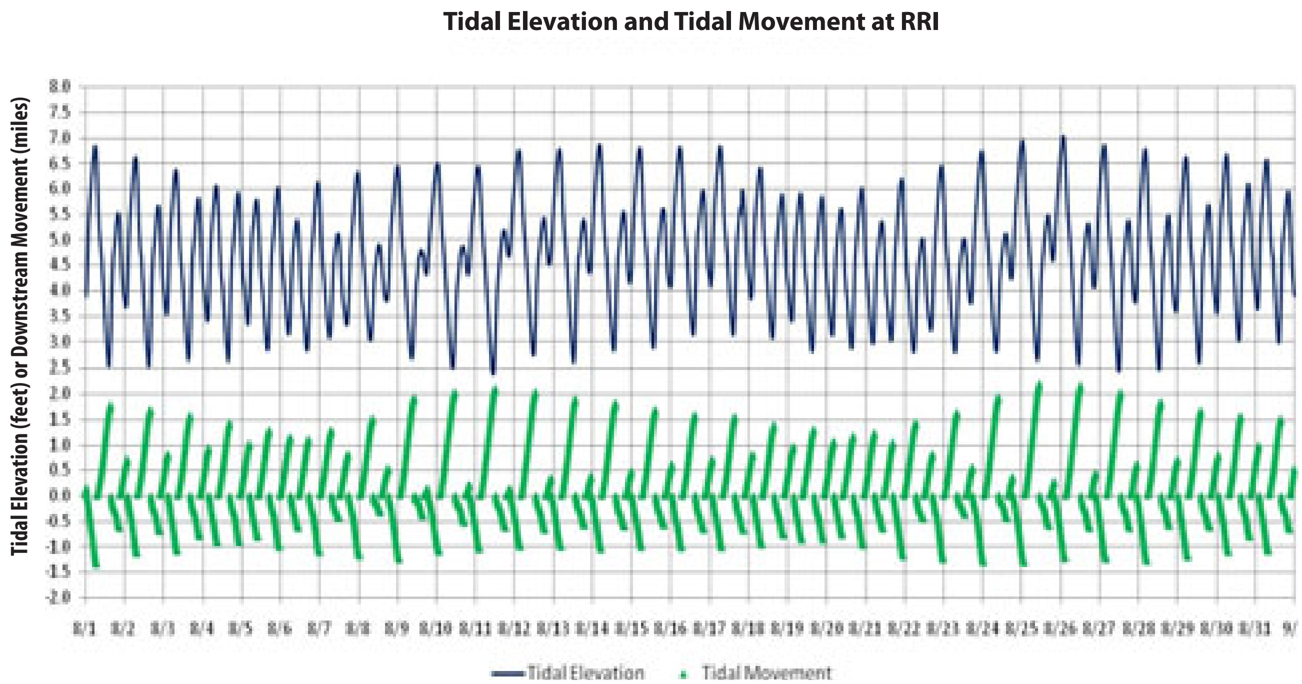

Figure B-5c: Tidal Elevations and Tidal Movement Calculated for the RRI Station for August 2008.

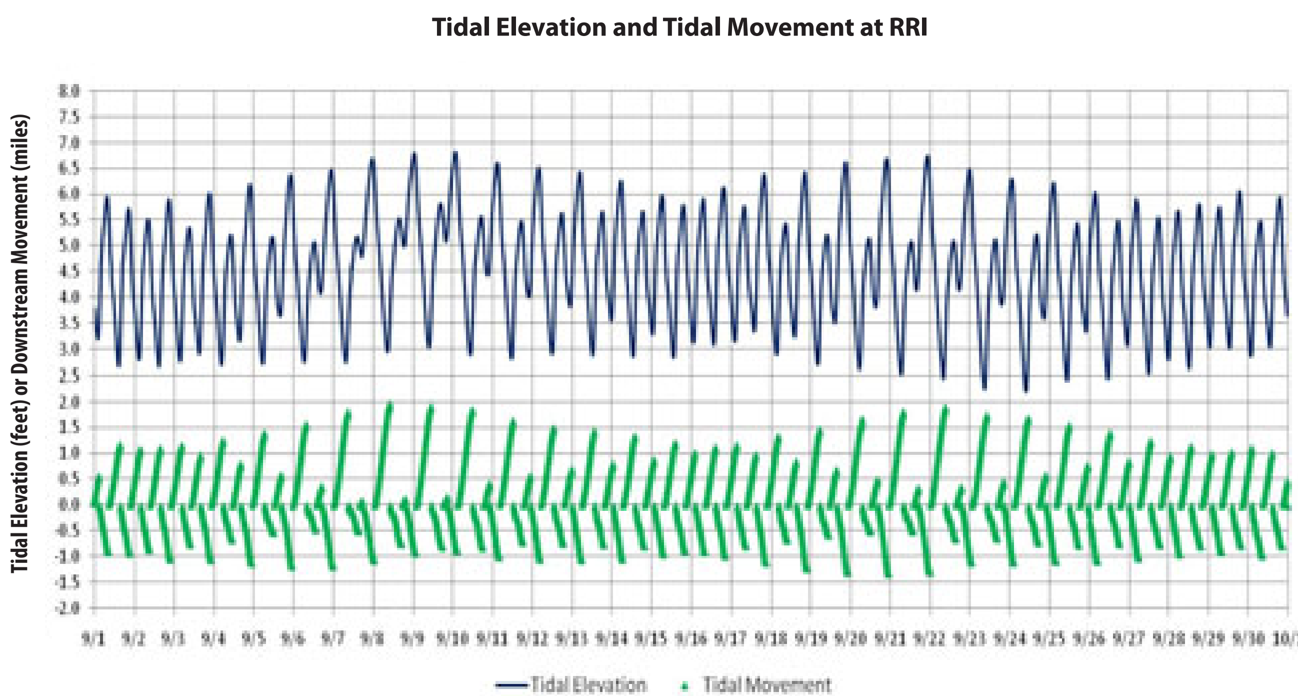

Figure B-5d: Tidal Elevations and Tidal Movement Calculated for the RRI Station for September 2008.

Figure B-5 (continued)

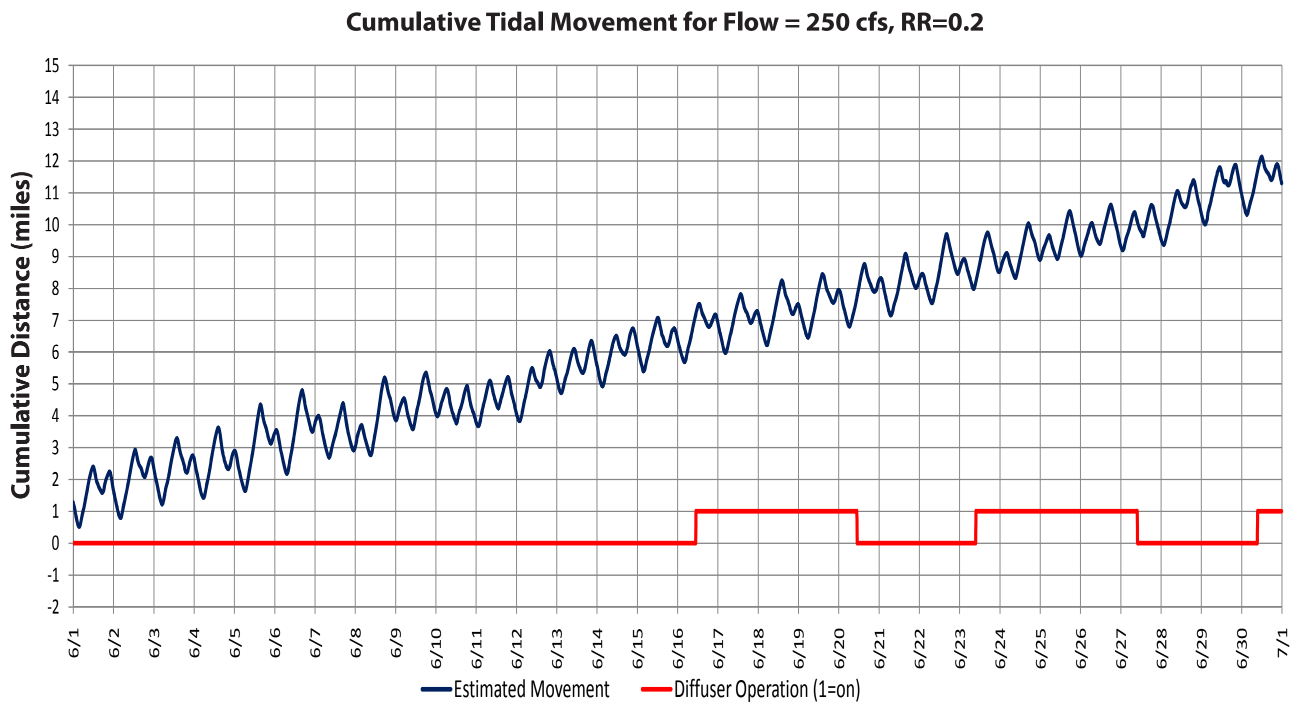

Figure B-6a: Downstream Tidal Movement with Flow of 250 cfs for June 2008.

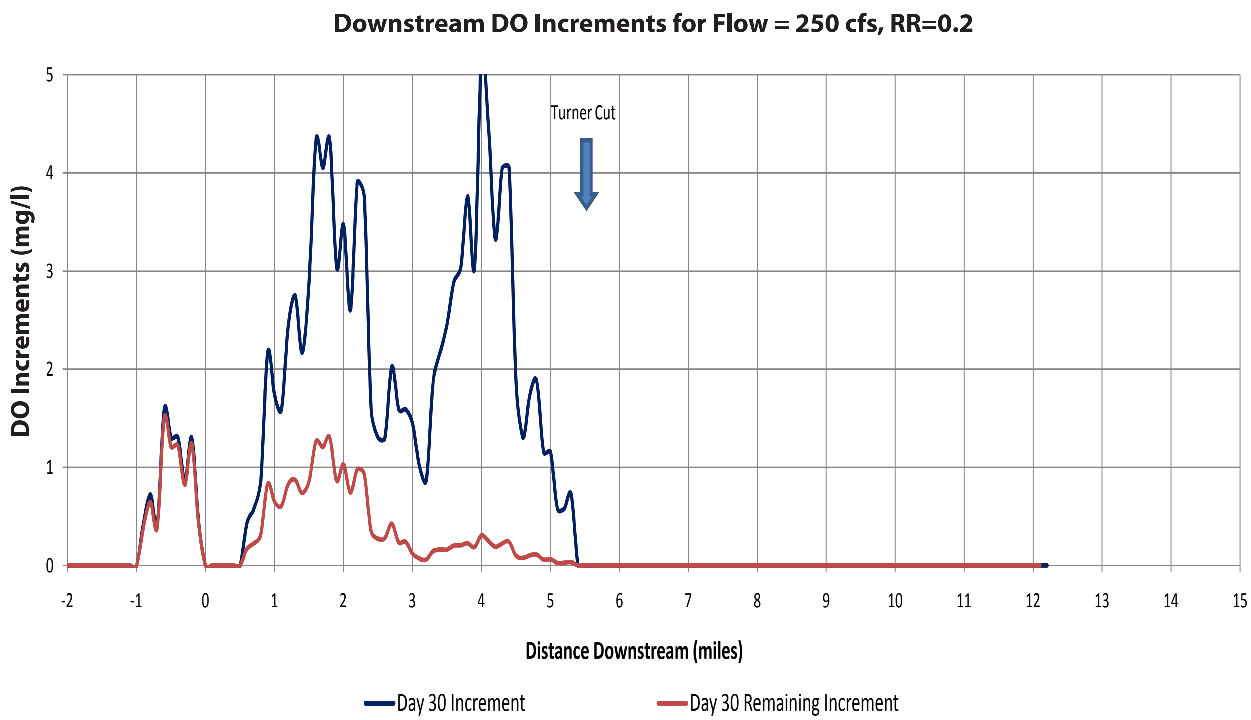

Figure B-6b: Longitudinal DO Increments with Flow of 250 cfs for June 2008.

Graphics/Projects/00902.08 TO-I Operation and Technical Support/2008 Operation Report/Appendix A (03-09) SS

ICF INTERNATIONAL

Figure B-6

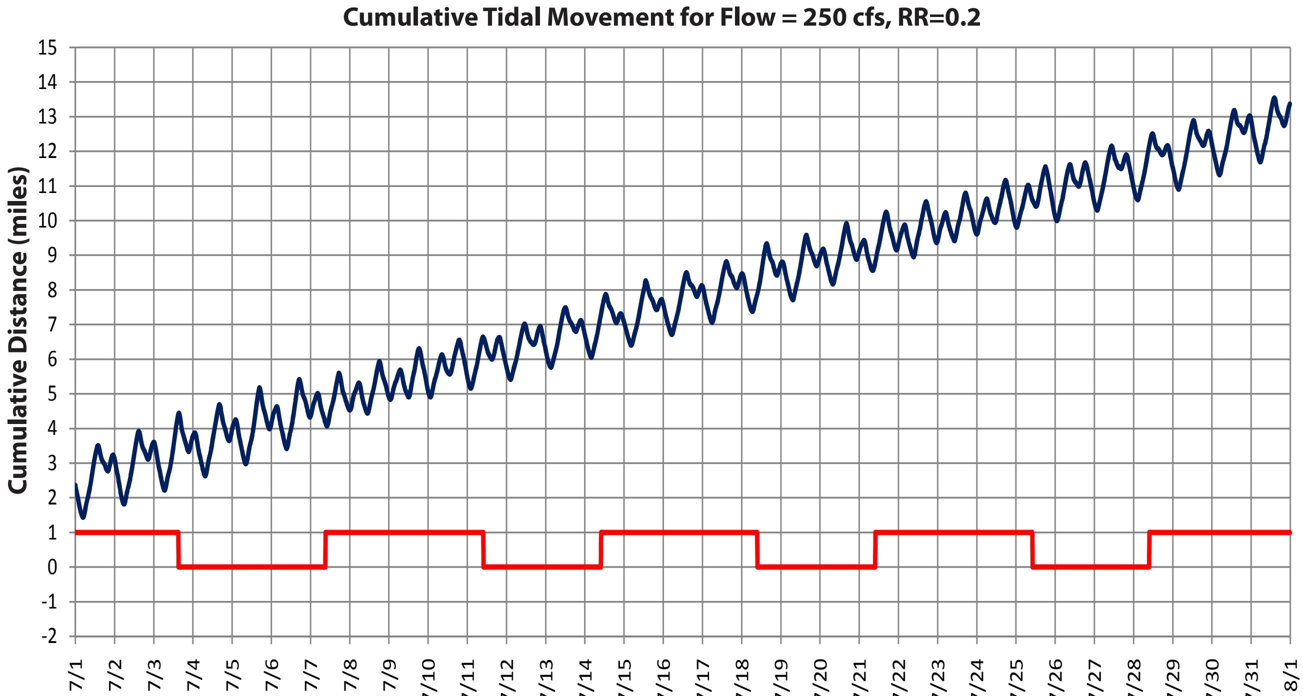

Figure B-7a: Downstream Tidal Movement with Flow of 250 cfs for July 2008.

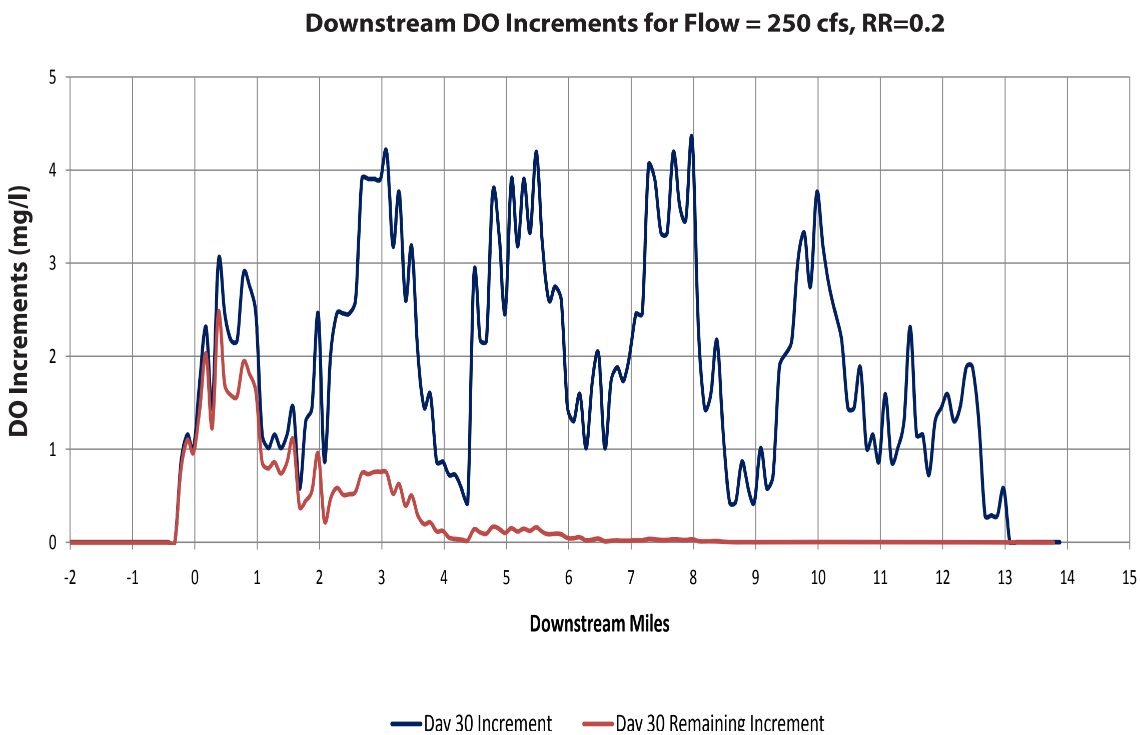

Figure B-7b: Longitudinal DO Increments with Flow of 250 cfs for July 2008.

Graphics/Projects/00902.08 TO-I Operation and Technical Support/2008 Operation Report/Appendix A (03-09) SS

ICF INTERNATIONAL

Figure B-7

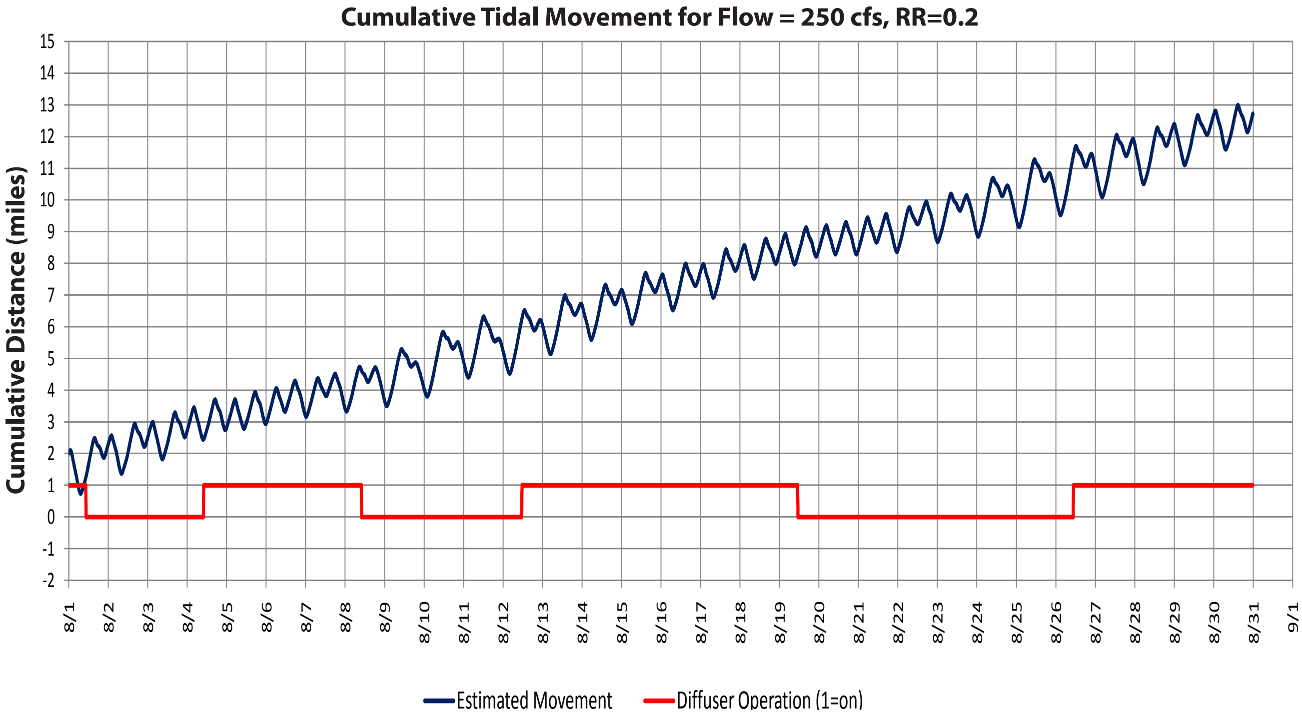

Figure B-8a: Downstream Tidal Movement with Flow of 250 cfs for August 2008.

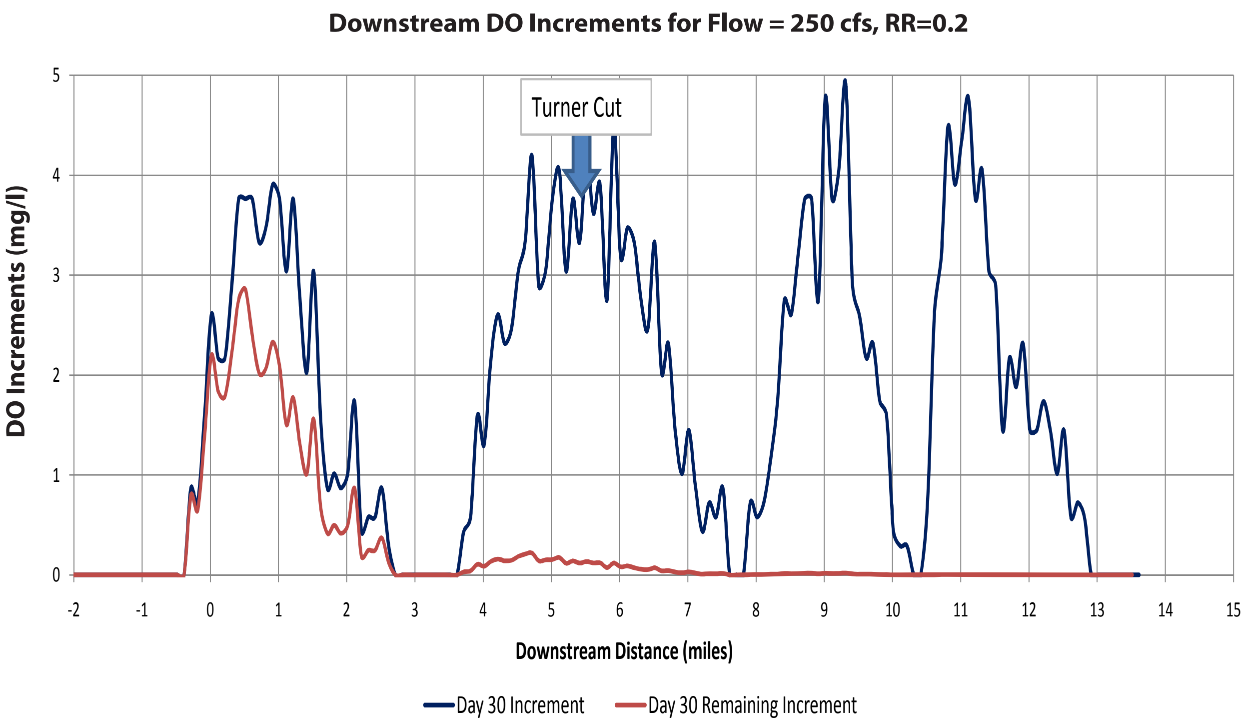

Figure B-8b: Longitudinal DO Increments with Flow of 250 cfs for August 2008

Graphics/Projects/00902.08 TO-I Operation and Technical Support/2008 Operation Report/Appendix A (03-09) SS

ICF INTERNATIONAL

Figure B-8

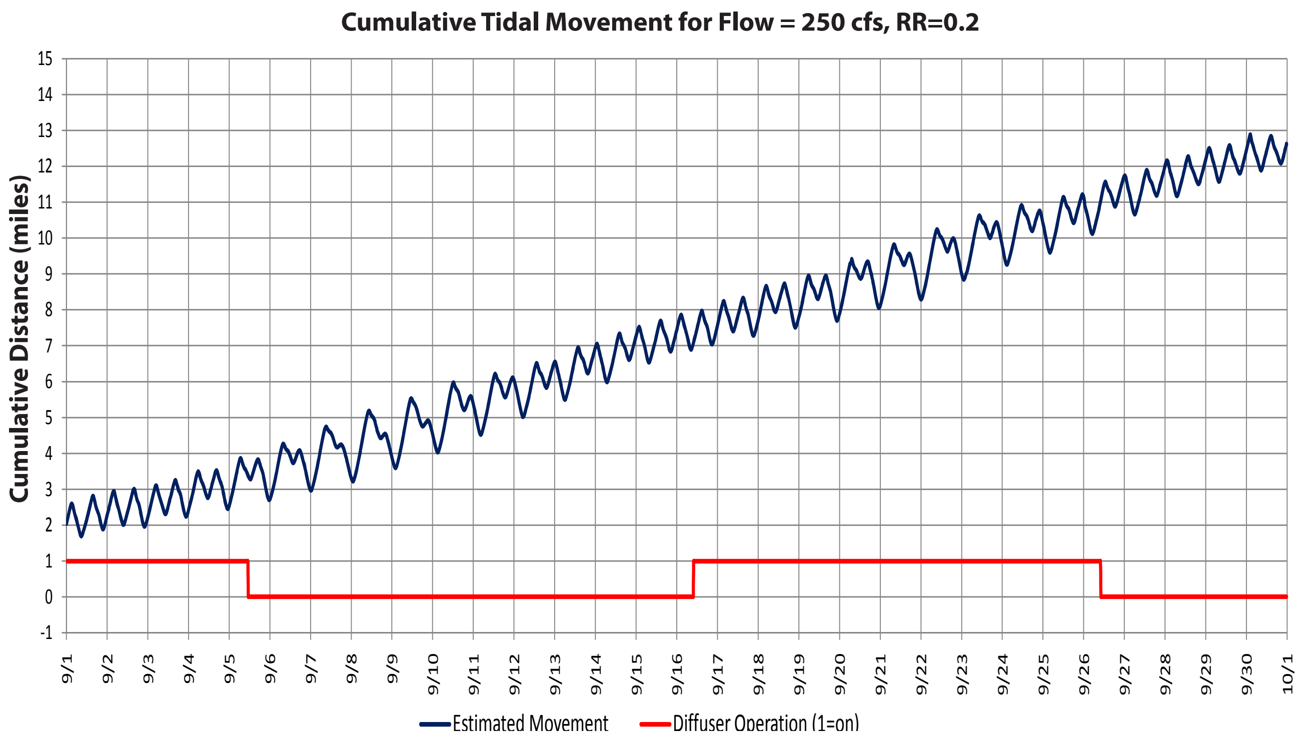

Figure B-9a: Downstream Tidal Movement with Flow of 250 cfs for September 2008.

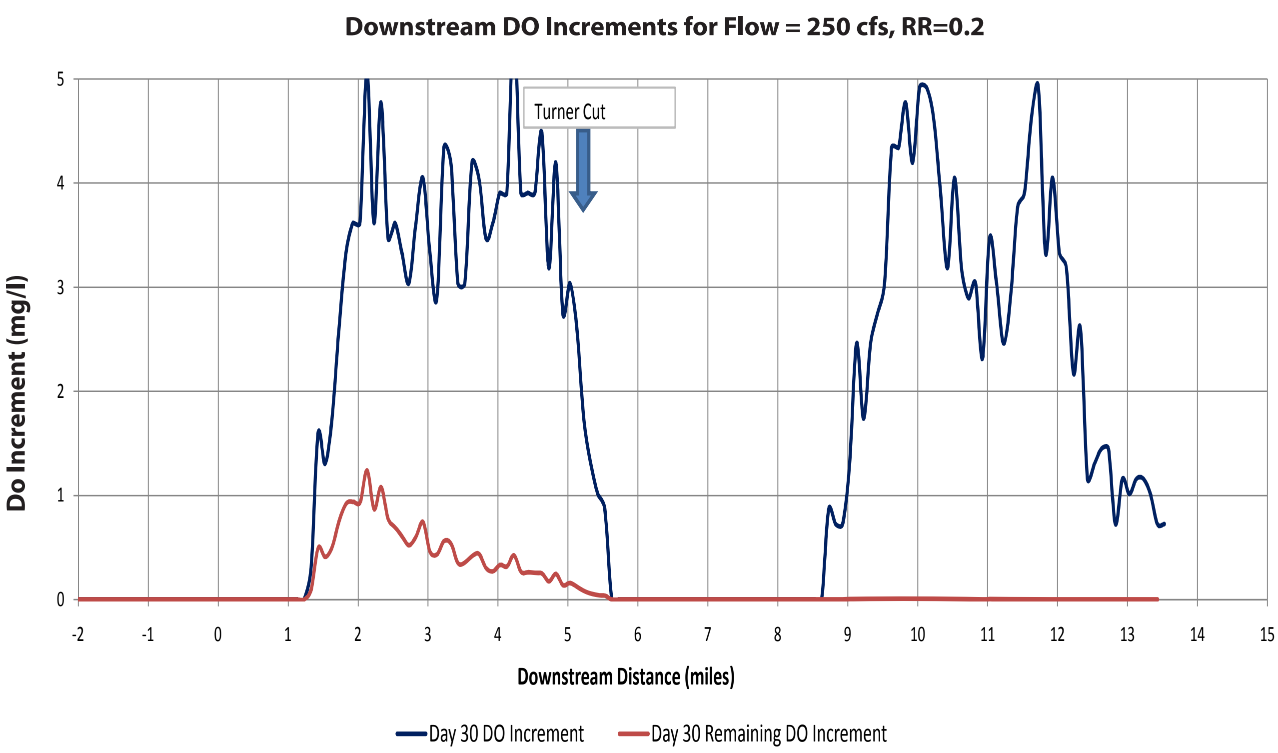

Figure B-9b: Longitudinal DO Increments with Flow of 250 cfs for September 2008.

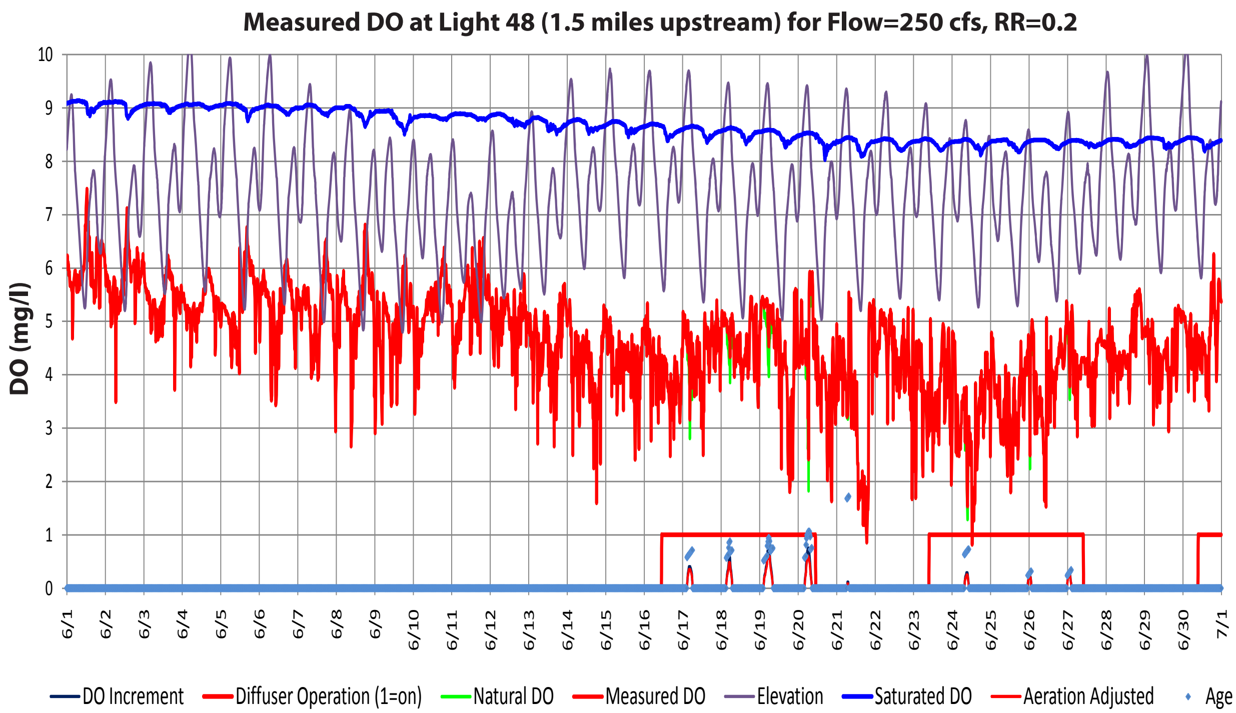

Figure B-10a: Measured DO at Light 48 with Calculated DO Increments from the Diffuser for June 2008.

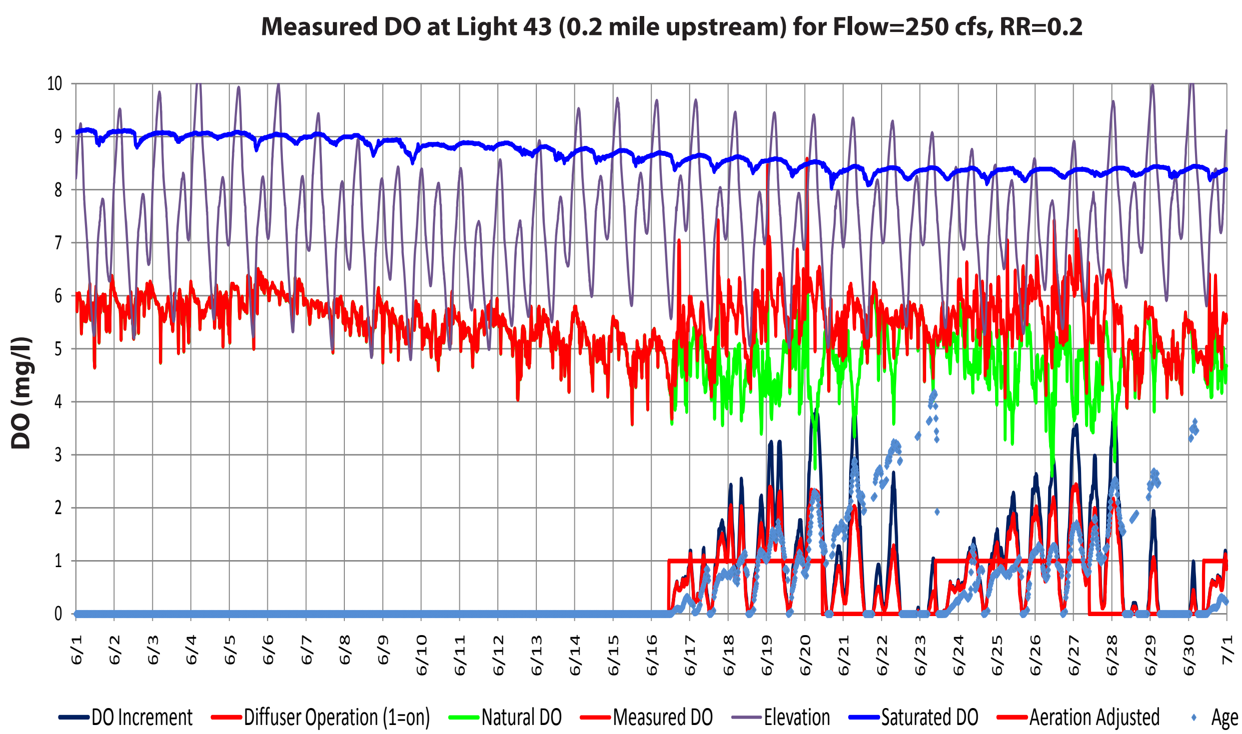

Figure B-10b: Measured DO at Light 43 with Calculated DO Increments from the Diffuser for June 2008.

Graphics/Projects/00902.08 TO-I Operation and Technical Support/2008 Operation Report/Appendix A (03-09) SS

ICF INTERNATIONAL

Figure B-10

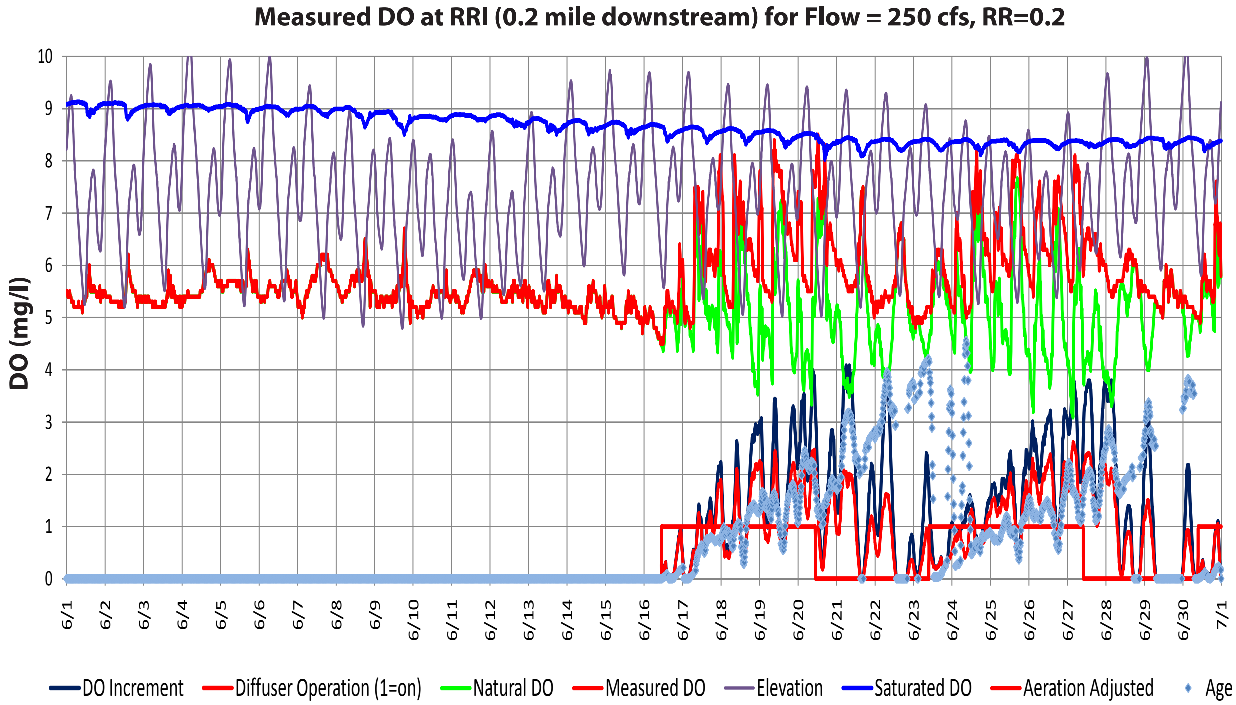

Figure B-10c: Measured DO at RRI with Calculated DO Increments from the Diffuser for June 2008.

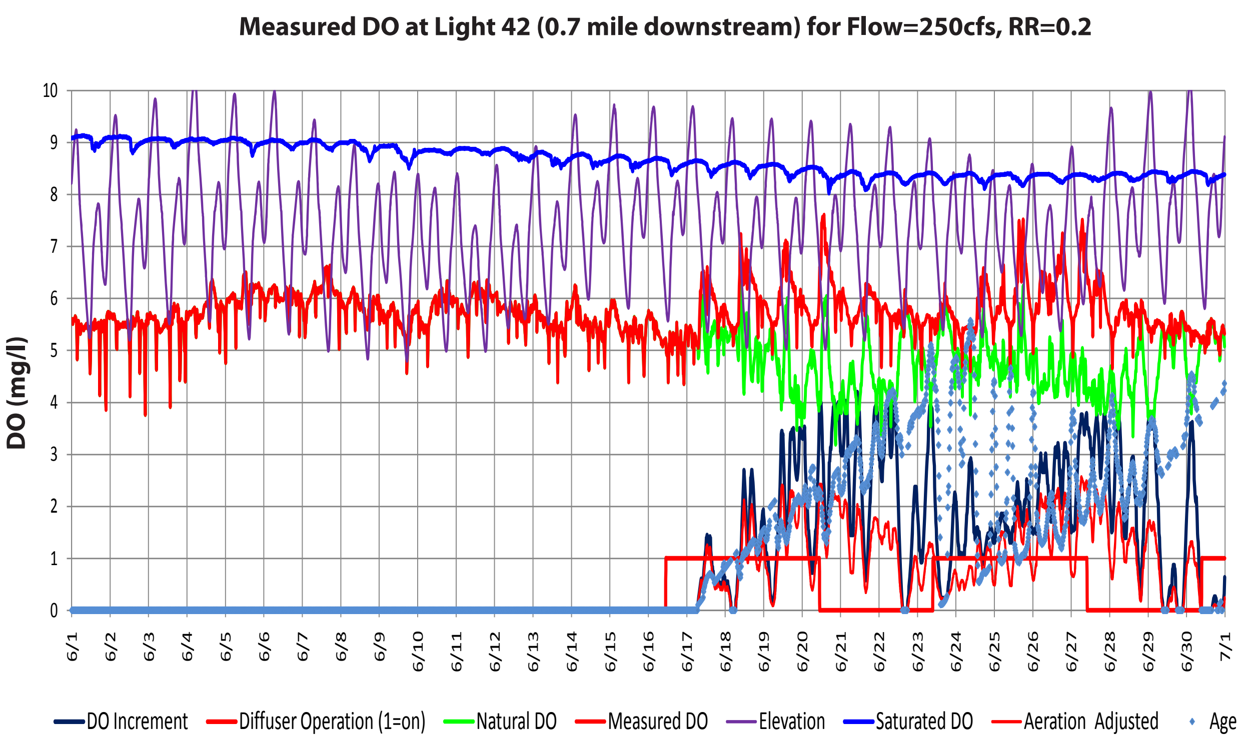

Figure B-10d: Measured DO at Light 42 with Calculated DO Increments from the Diffuser for June 2008.

ICF INTERNATIONAL

Figure B-10 (continued)

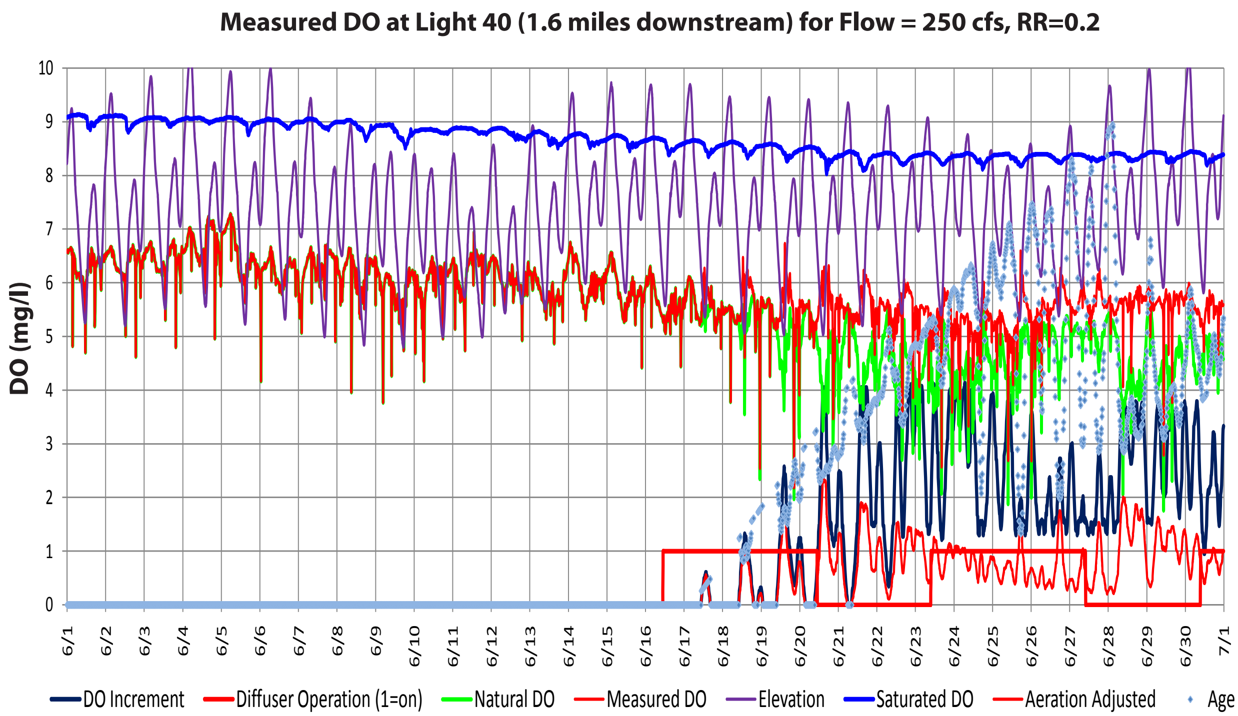

Figure B-10e: Measured DO at Light 40 with Calculated DO Increments from the Diffuser for June 2008.

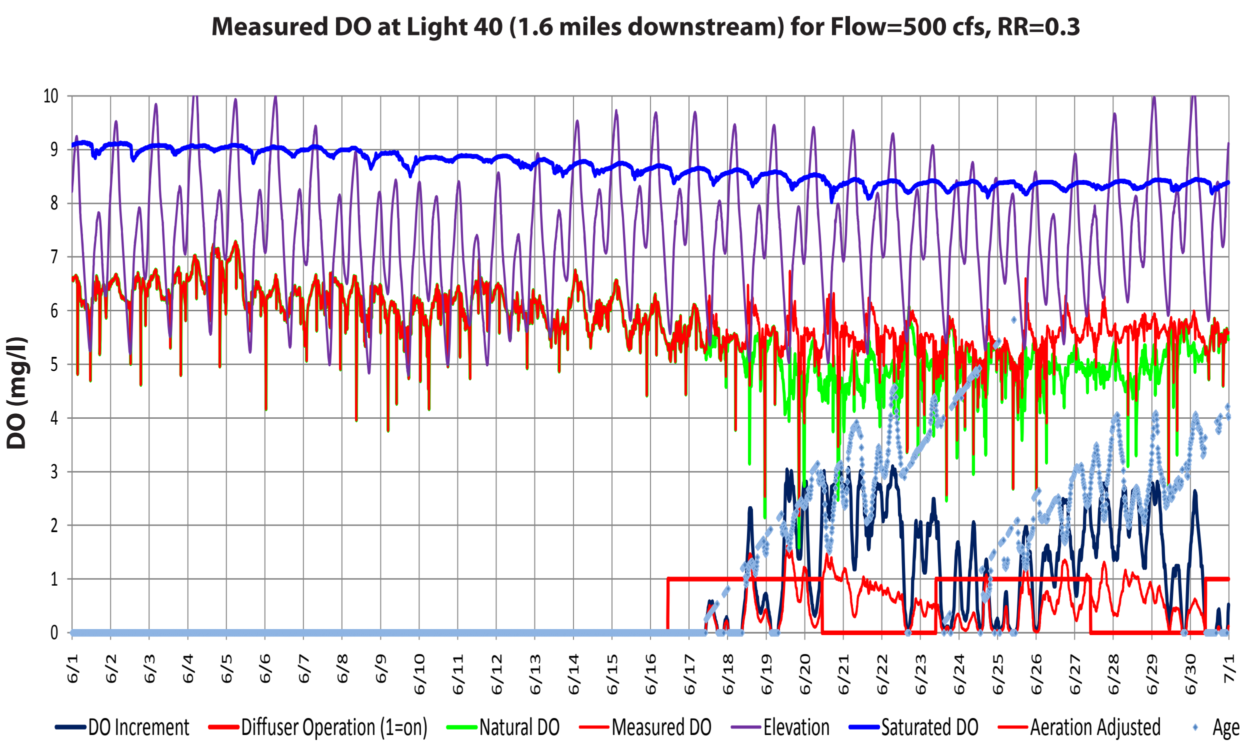

Figure B-10f: Comparison of Calculated DO Increments at Light 40 with Higher Flow (500 cfs) and Higher Reaeration Rate (0.3 day-1) for June 2008.

Graphics/Projects/00902.08 TO-I Operation and Technical Support/2008 Operation Report/Appendix A (03-09) SS

ICF INTERNATIONAL

Figure B-10 (continued)

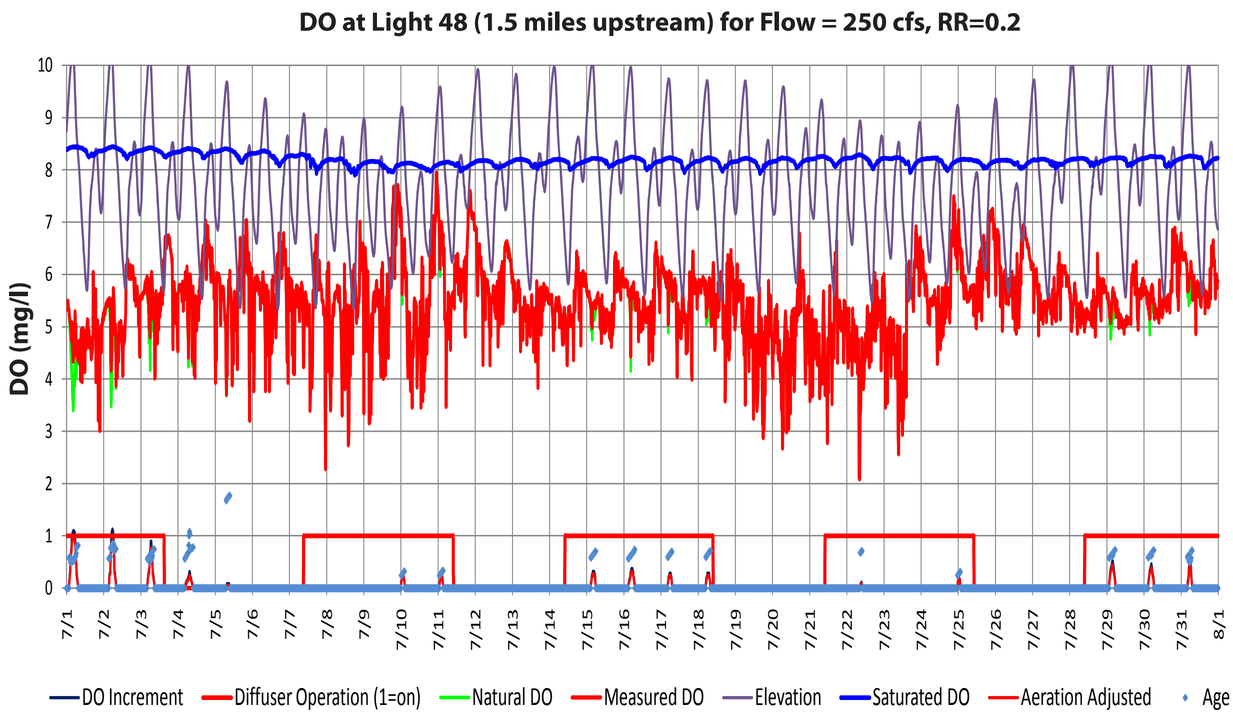

Figure B-11a: Measured DO at Light 48 with Calculated DO Increments from the Diffuser for July 2008.

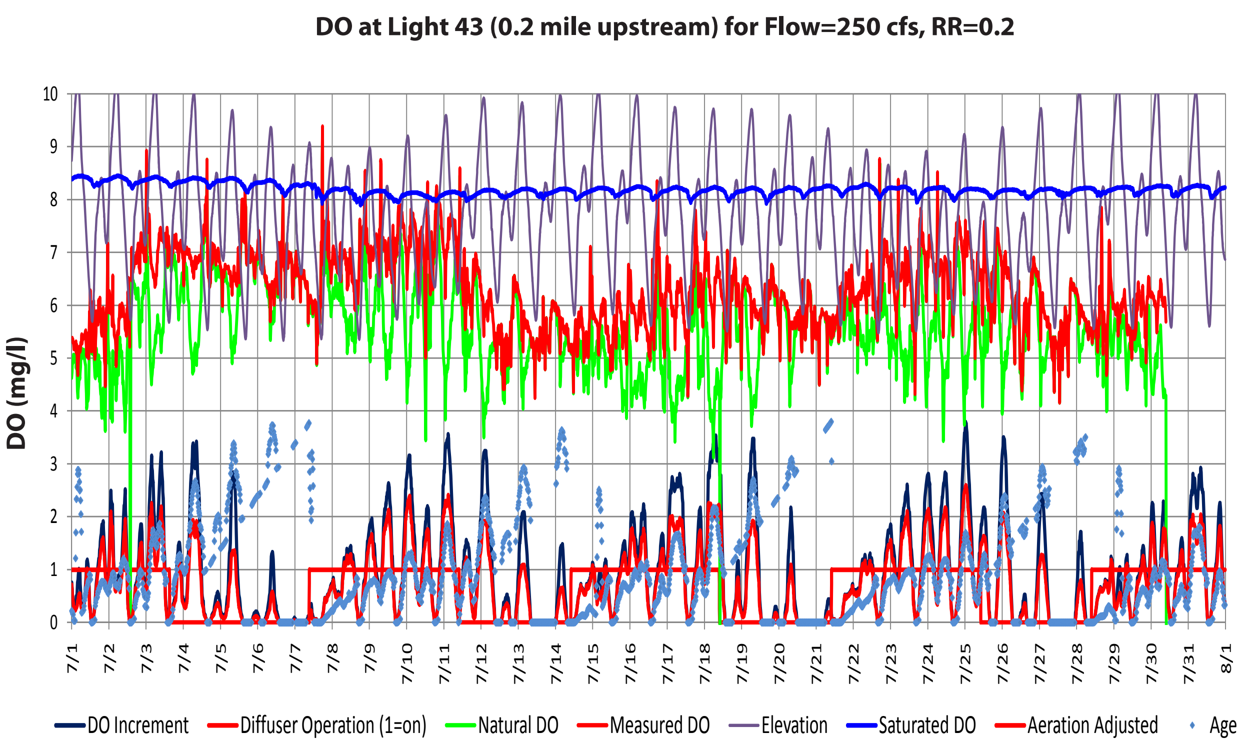

Figure B-11b: Measured DO at RRI with Calculated DO Increments from the Diffuser for July 2008.

Graphics/Projects/00902.08 TO-I Operation and Technical Support/2008 Operation Report/Appendix A (03-09) SS

ICF INTERNATIONAL

Figure B-11

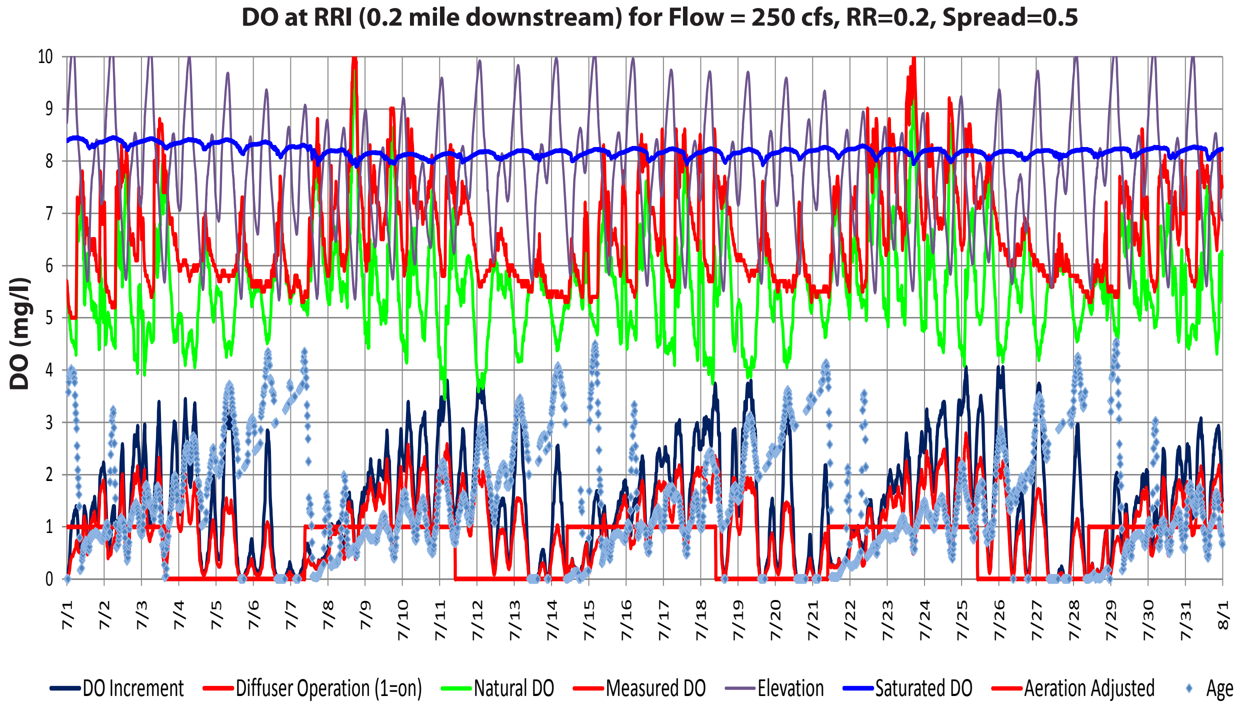

Figure B-11c: Measured DO at RRI with Calculated DO Increments from the Diffuser for July 2008.

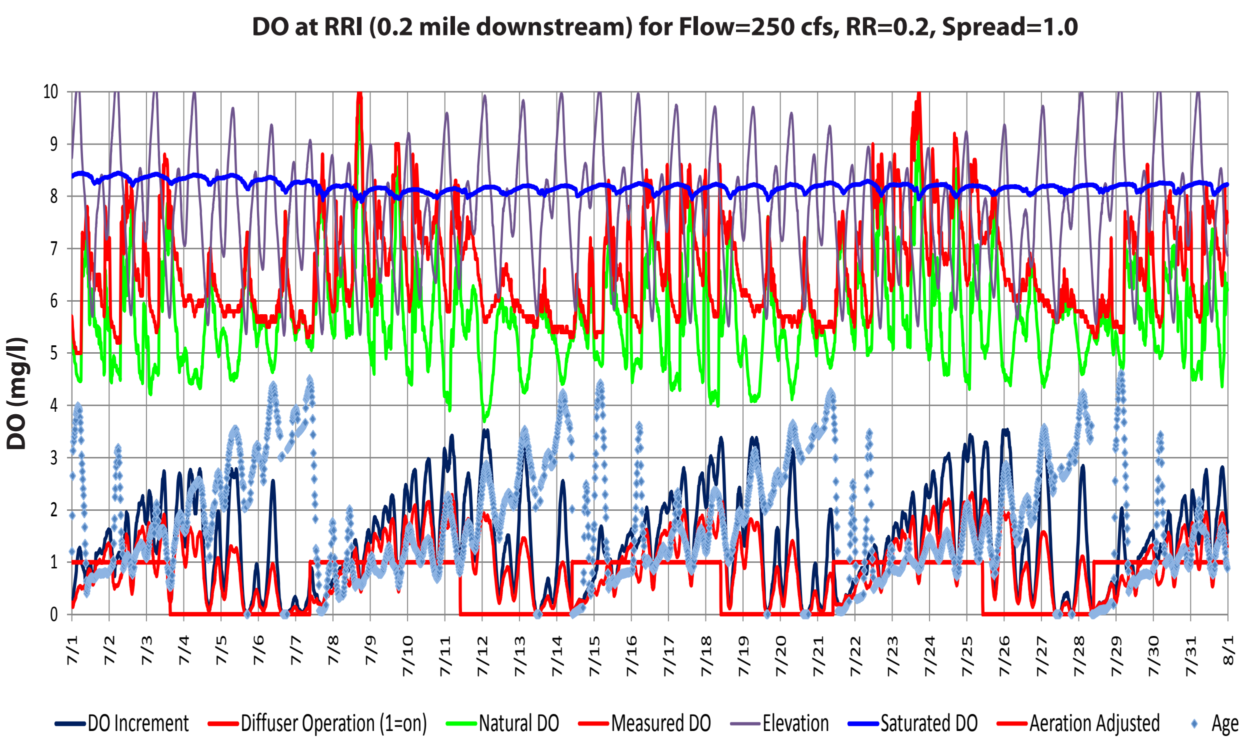

Figure B-11d: Comparison of Calculated DO Increments with Increased Spreading (1.0 mile) at RRI for July 2008.

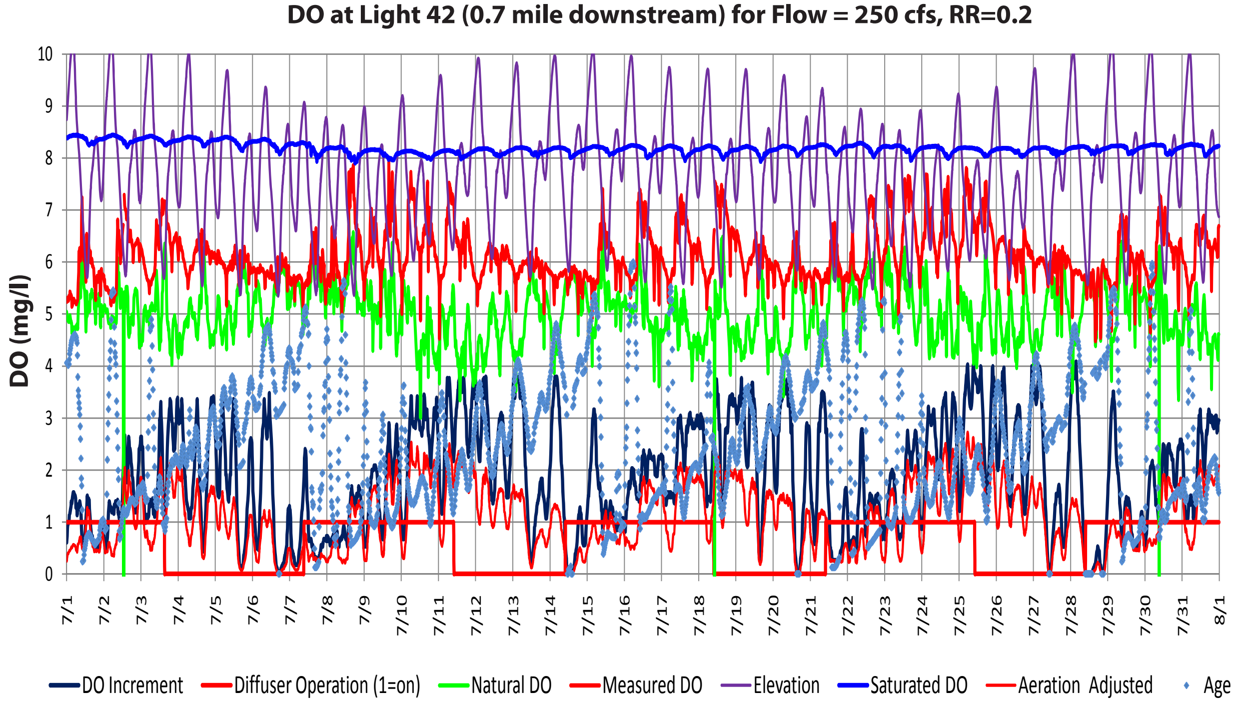

Figure B-11e: Measured DO at Light 42 with Calculated DO Increments from the Diffuser for July 2008.

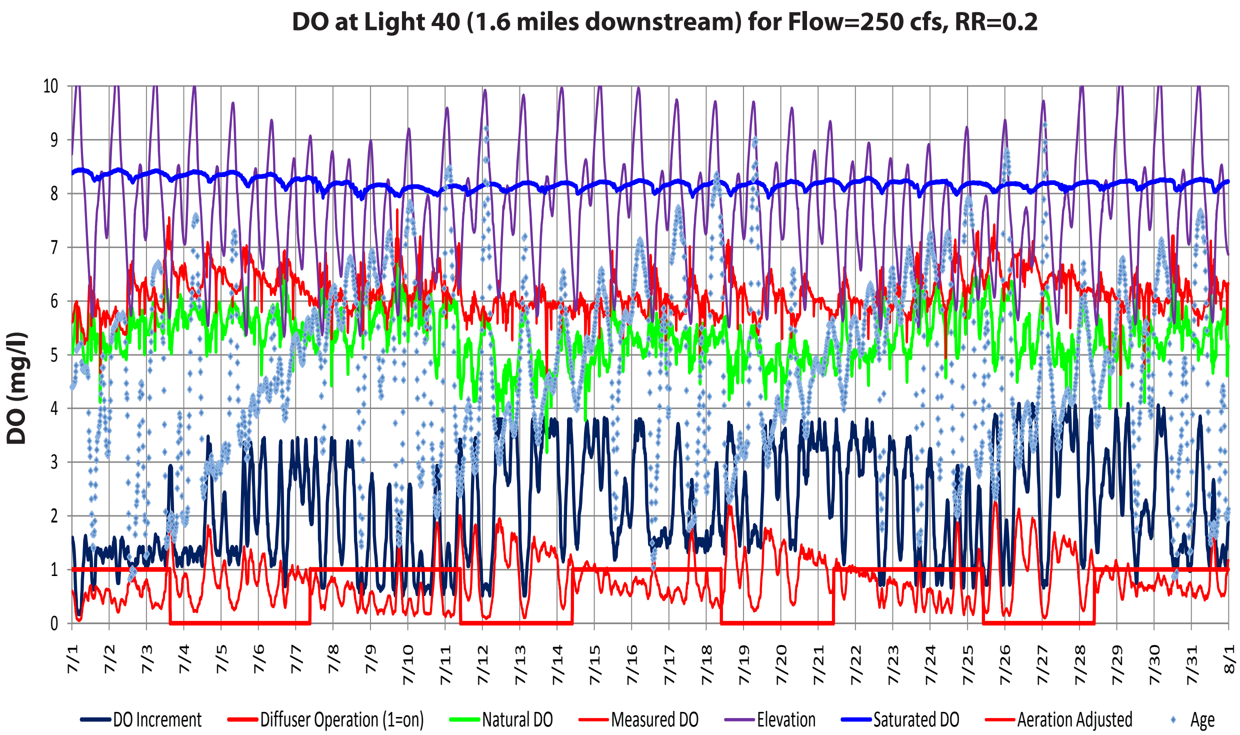

Figure B-11f: Measured DO at Light 40 with Calculated DO Increments from the Diffuser for July 2008.

ICF INTERNATIONAL

Figure B-11 (continued)

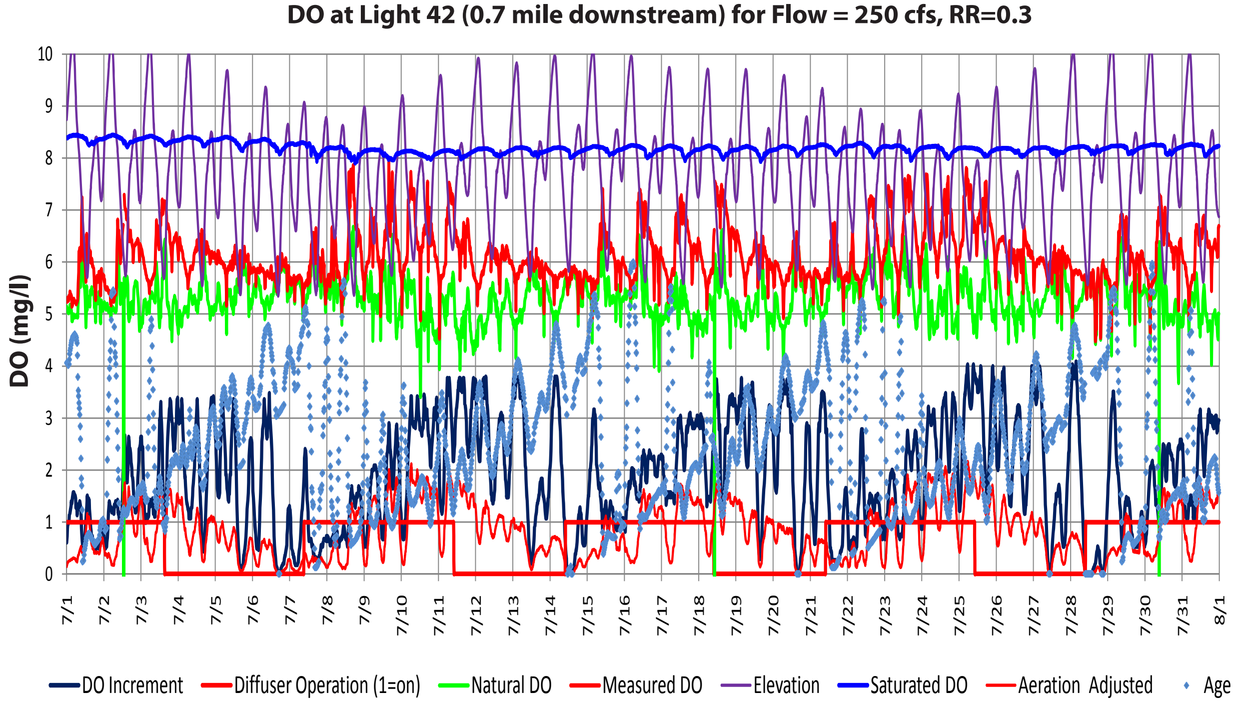

Figure B-11g: Calculated DO Increments at Light 42 with Reaeration Rate of 30% per day for July 2008.

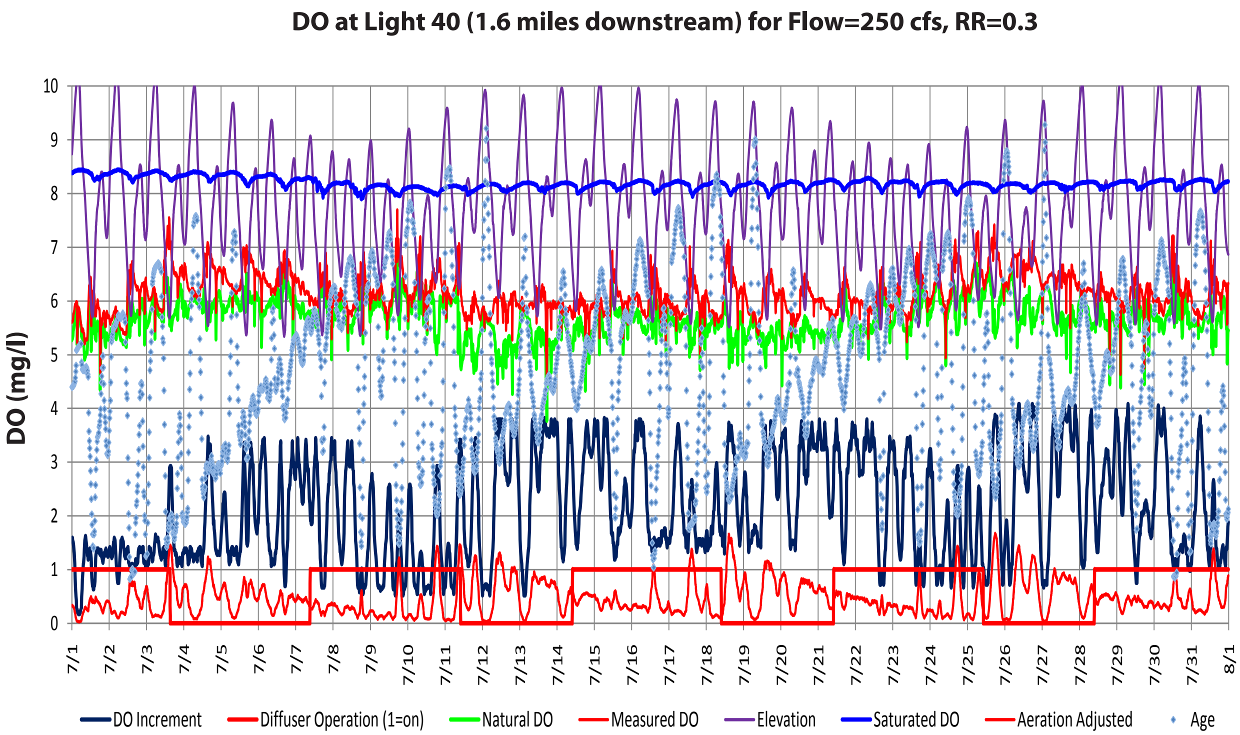

Figure B-11h: Calculated DO Increments at Light 40 with Reaeration Rate of 30% per day for July 2008.

ICF INTERNATIONAL

Figure B-11 (continued)

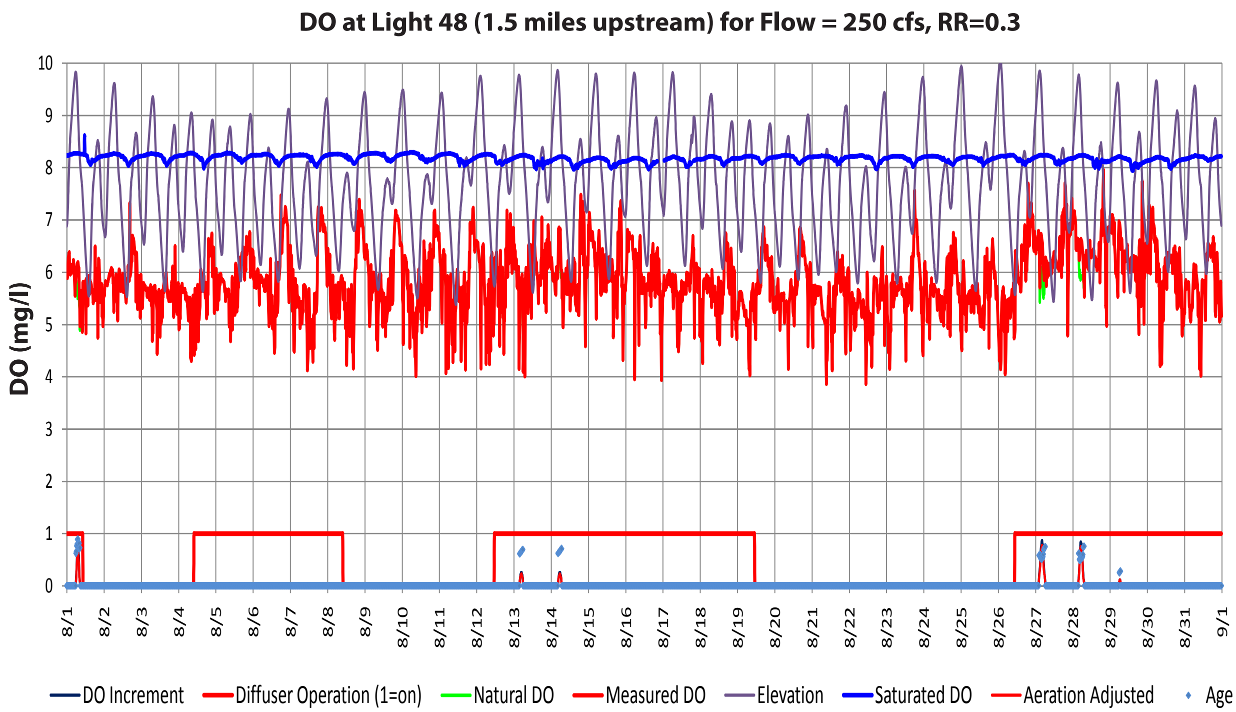

Figure B-12a: Measured DO at Light 48 with Calculated DO Increments from the Diffuser for August 2008.

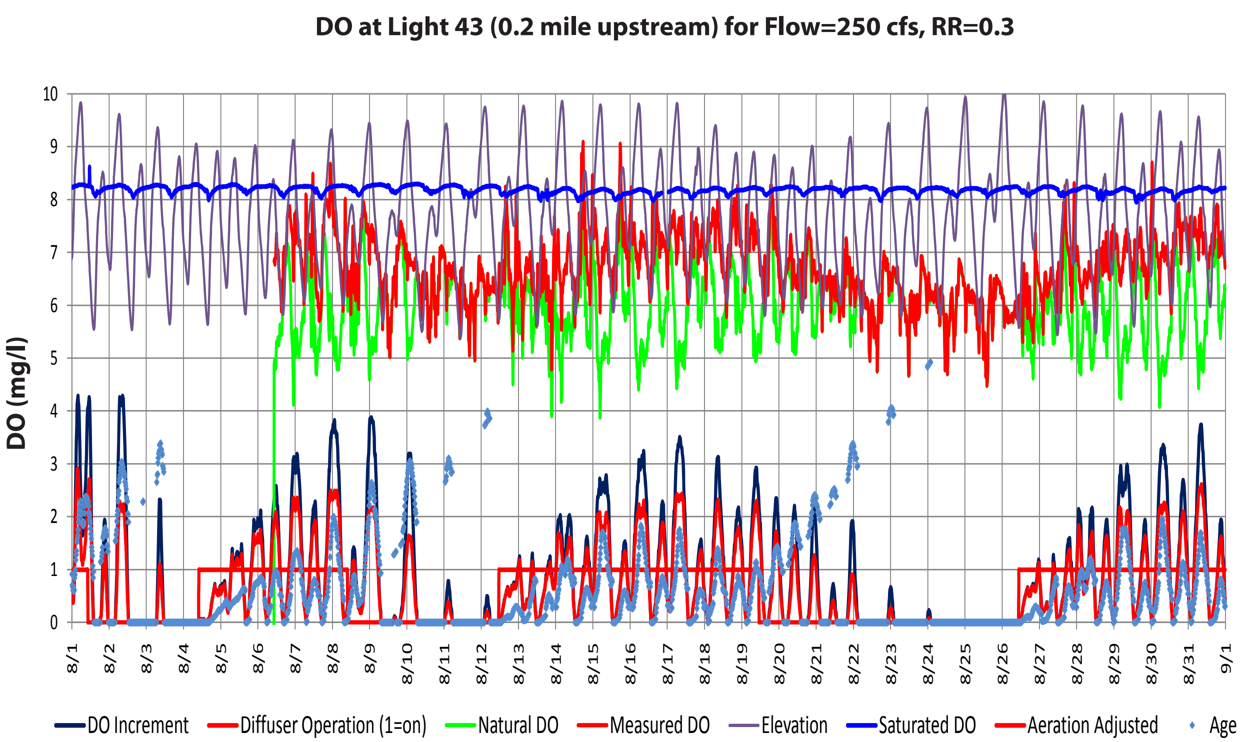

Figure B-12b: Measured DO at Light 43 with Calculated DO Increments from the Diffuser for August 2008.

Graphics/Projects/00902.08 TO-I Operation and Technical Support/2008 Operation Report/Appendix A (03-09) SS

ICF INTERNATIONAL

Figure B-12

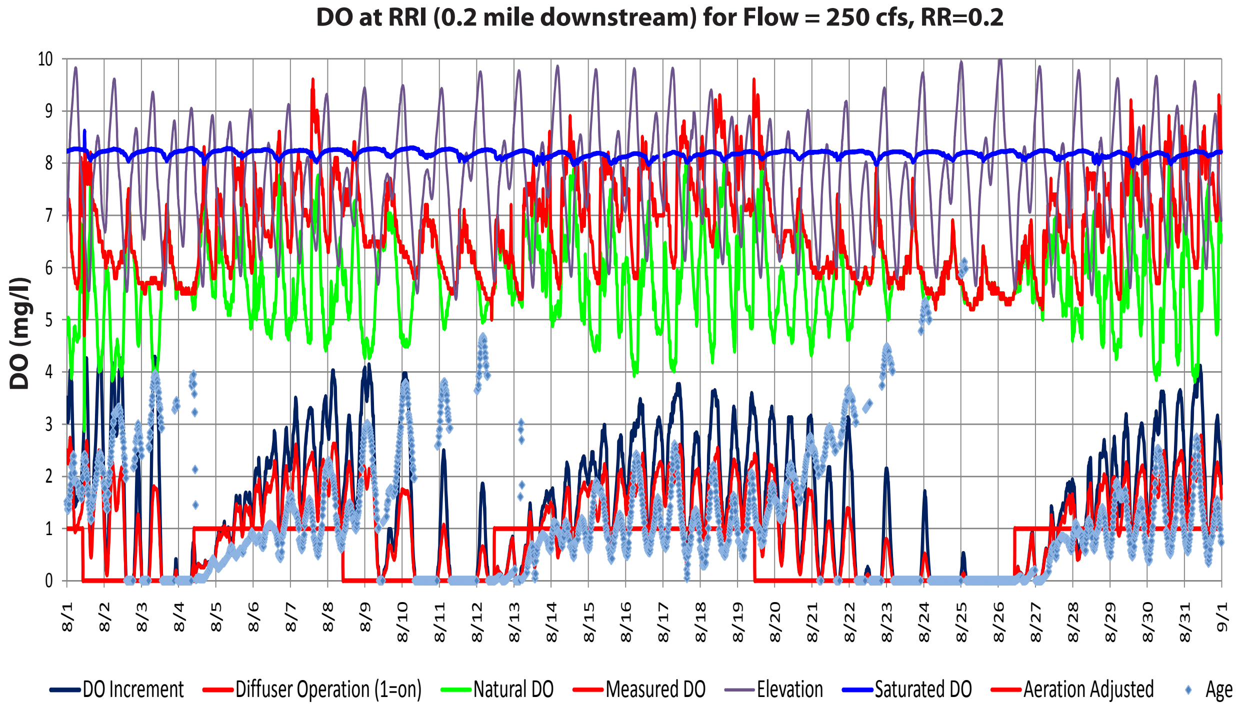

Figure B-12c: Measured DO at RRI with Calculated DO Increments from the Diffuser for August 2008.

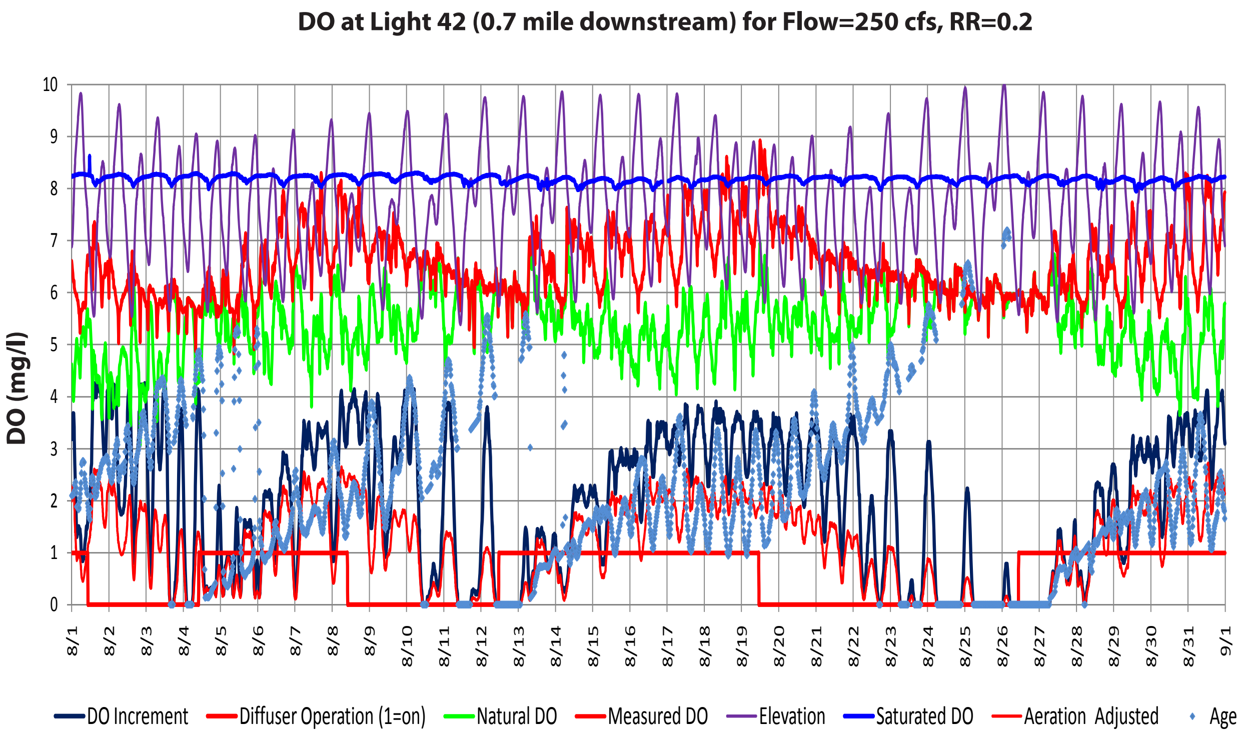

Figure B-12d: Measured DO at Light 42 and Calculated DO Increments with Reaeration of 0.2 day-1 for August 2008.

Graphics/Projects/00902.08 TO-I Operation and Technical Support/2008 Operation Report/Appendix A (03-09) SS

ICF INTERNATIONAL

Figure B-12 (continued)

DO at Light 42 (0.7 mile downstream) for Flow = 250 cfs, RR=0.1

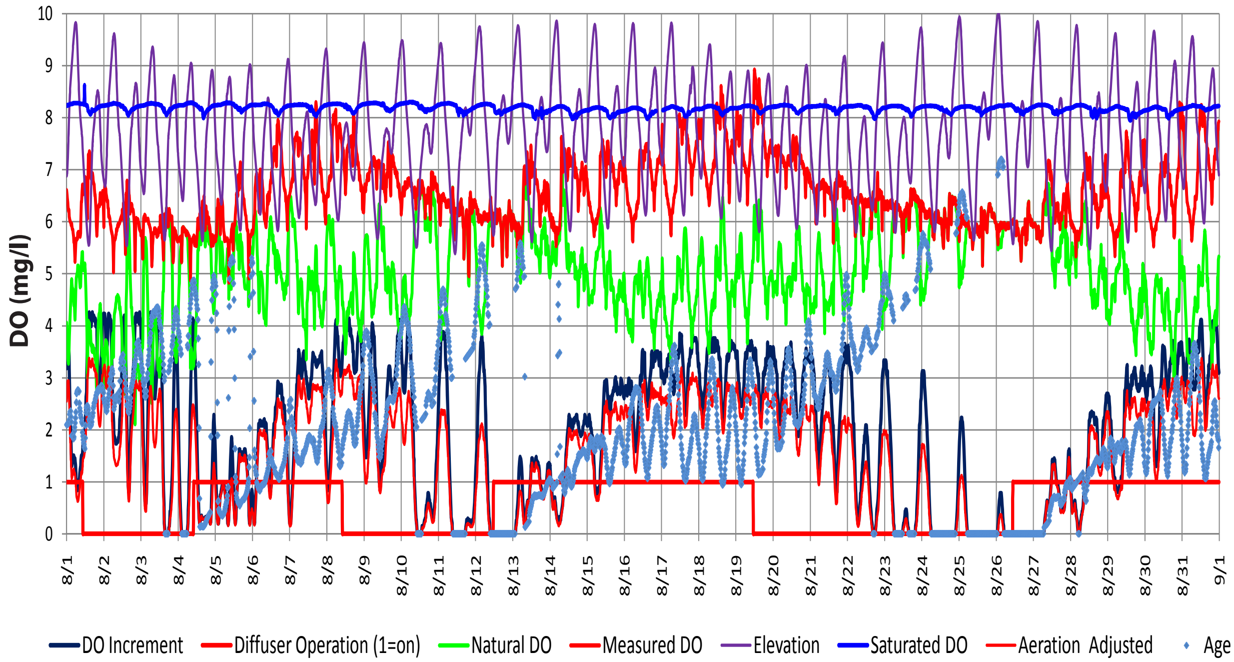

Figure B-12e: Comparison of DO Increments at Light 42 with Reaeration of 0.1 day-1 for August 2008.

DO at Light 42 (0.7 mile downstream) for Flow=250 cfs, RR=0.3

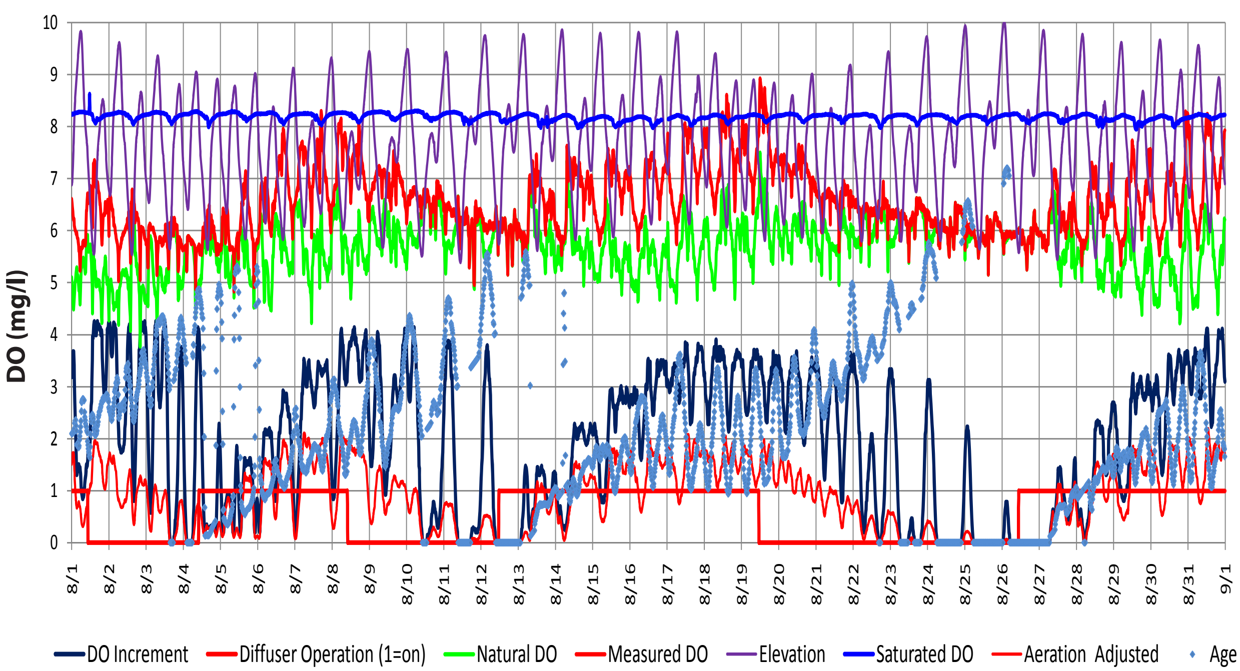

Figure B-12f: Comparison of DO Increments at Light 42 with Reaeration of 0.3 day-1 for August 2008.

Graphics/Projects/00902.08 TO-I Operation and Technical Support/2008 Operation Report/Appendix A (03-09) SS

ICF INTERNATIONAL

Figure B-12 (continued)

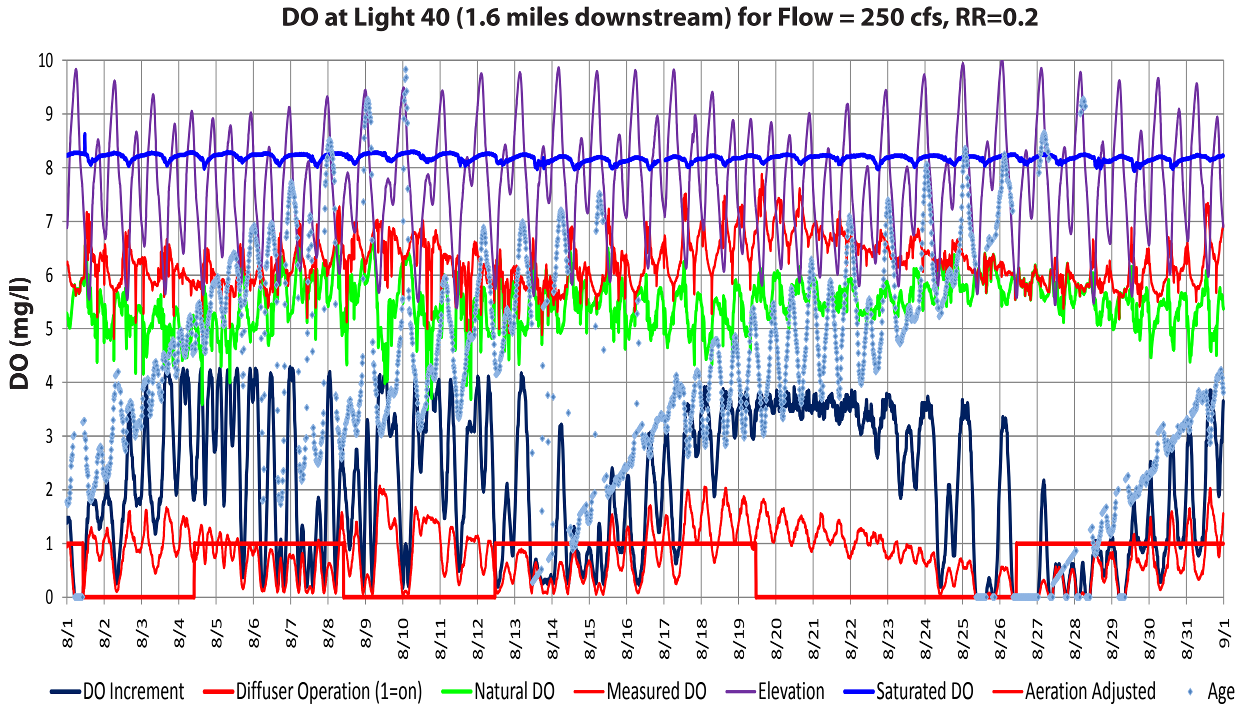

Figure B-12g: Measured DO at Light 40 and DO Increments with Reaeration of 0.2 day-1 for August 2008.

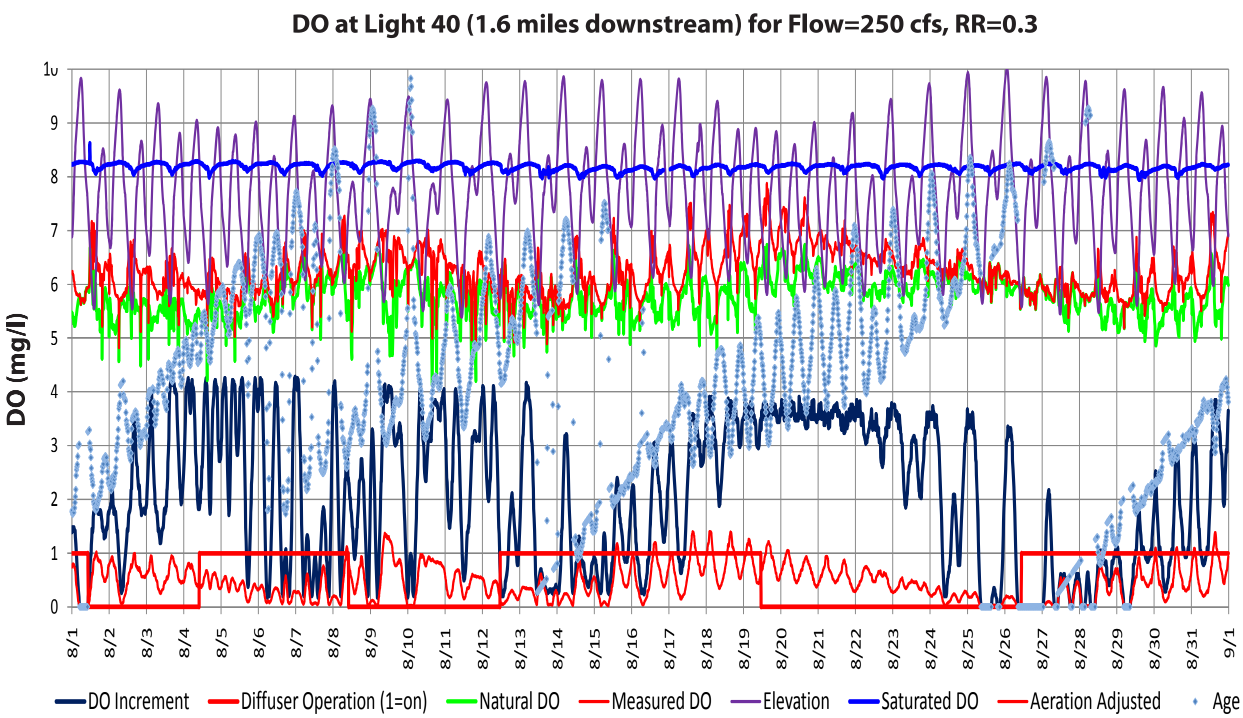

Figure B-12h: Comparison of DO Increments at Light 40 with Reaeration of 0.3 day-1 for August 2008.

ICF INTERNATIONAL

Figure B-12 (continued)

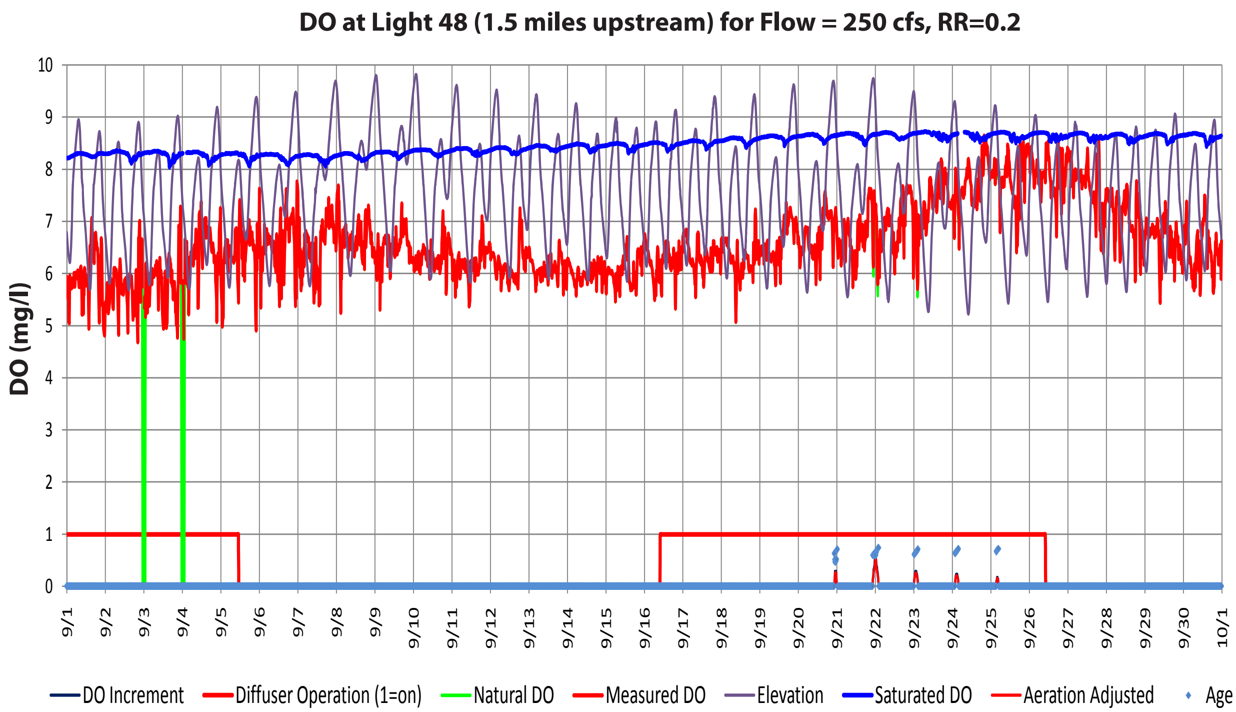

Figure B-13a: Measured DO at Light 48 and Calculated DO Increments for September 2008.

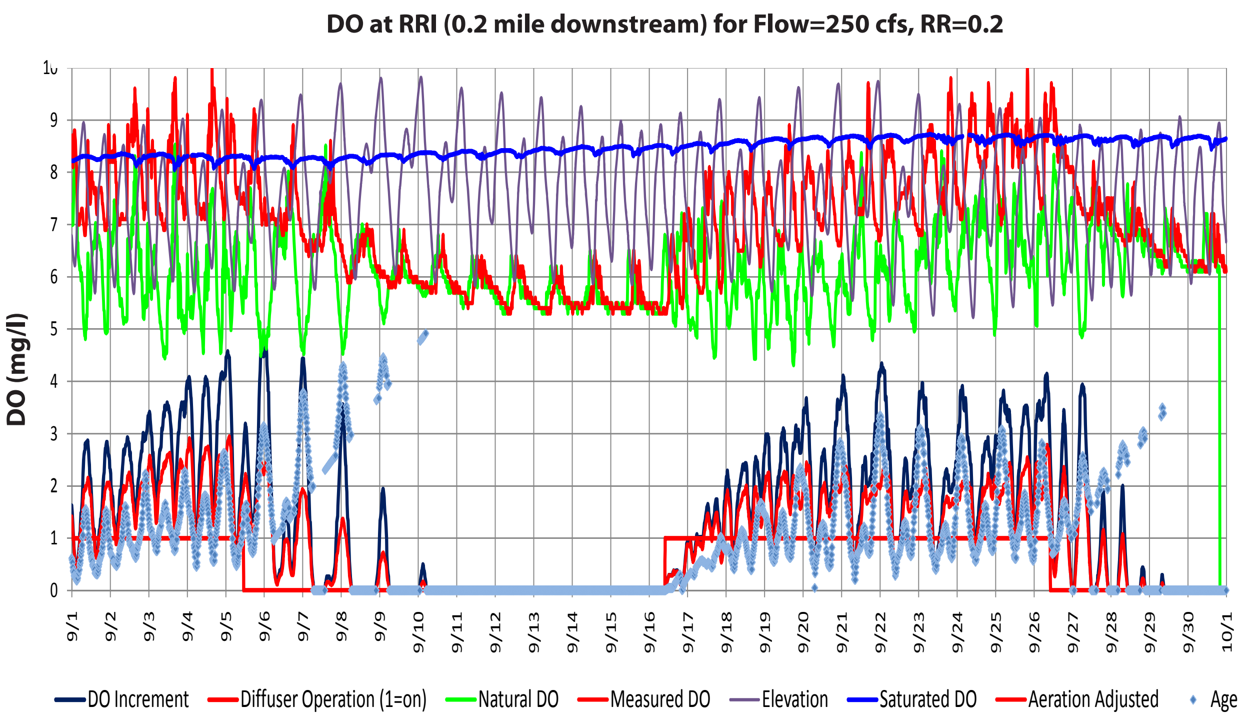

Figure B-13b: Measured DO and Calculated DO Increments at RRI with Flow of 250 cfs for September 2008.

ICF INTERNATIONAL

Figure B-13

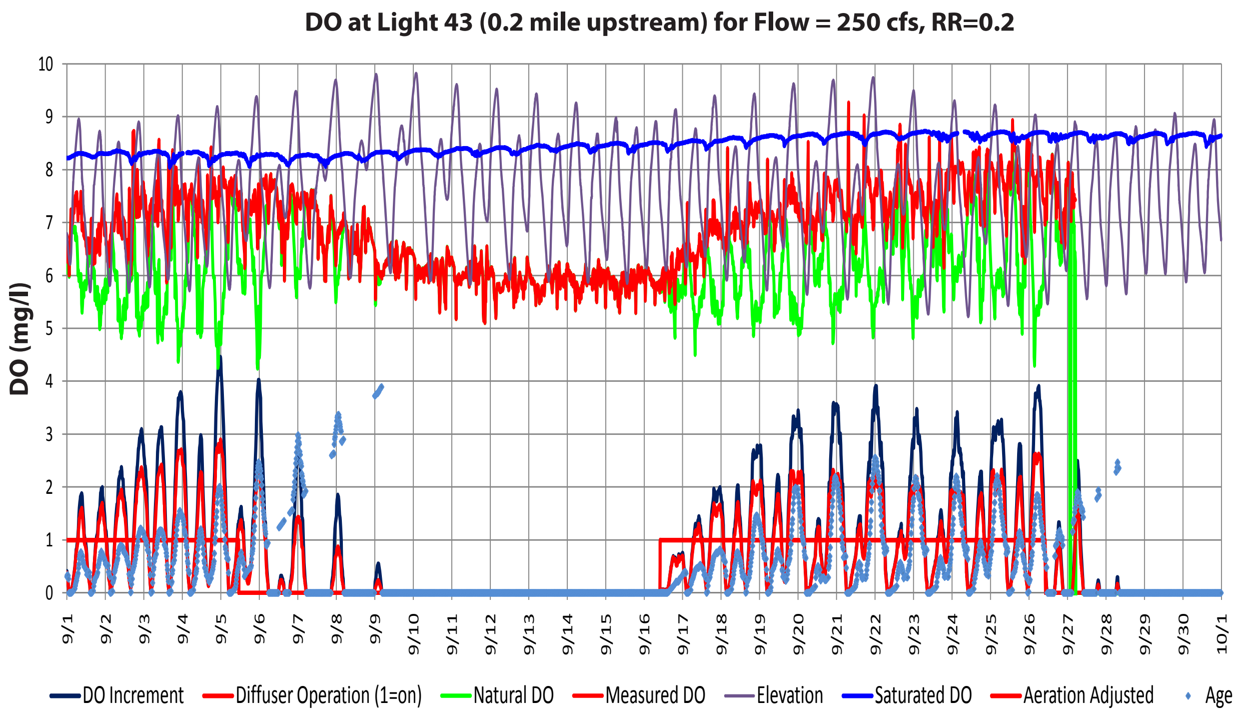

Figure B-13c: Measured DO at Light 43 and DO Increments with Flow of 250 cfs for September 2008.

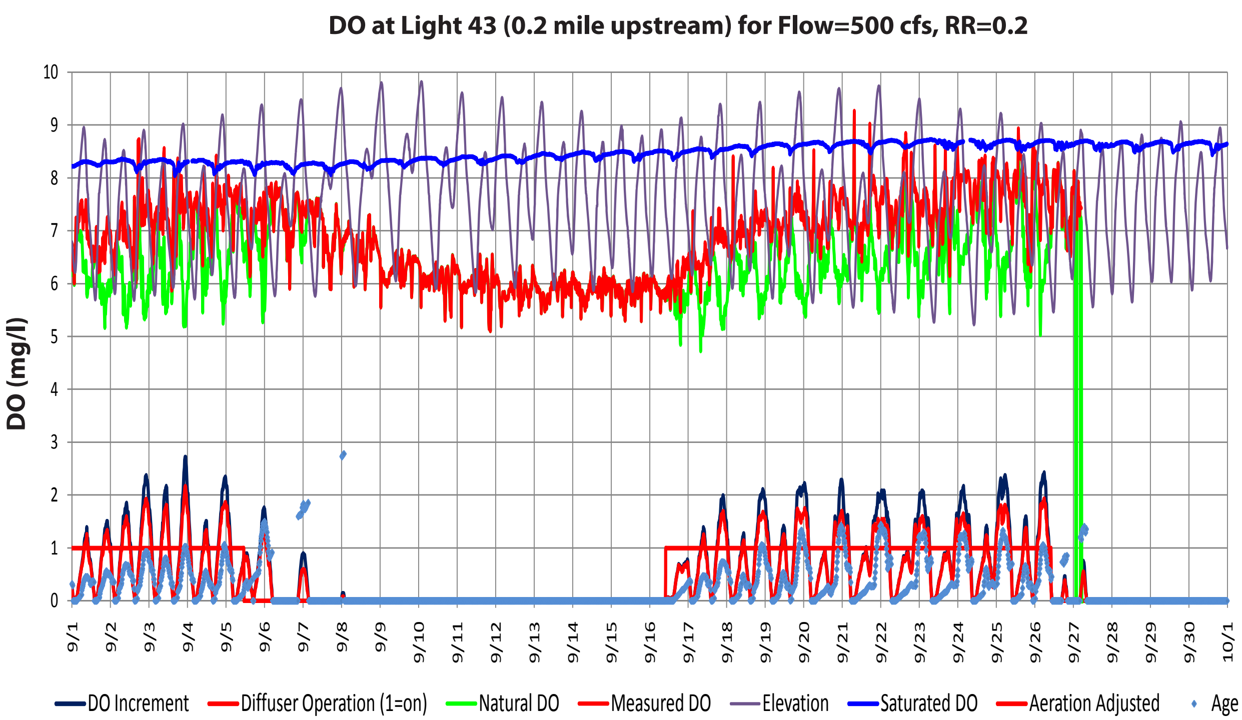

Figure B-13d: Measured DO at Light 43 and DO Increments with Flow of 500 cfs for September 2008.

Graphics/Projects/00902.08 TO-I Operation and Technical Support/2008 Operation Report/Appendix A (03-09) SS

ICF INTERNATIONAL

Figure B-13 (continued)

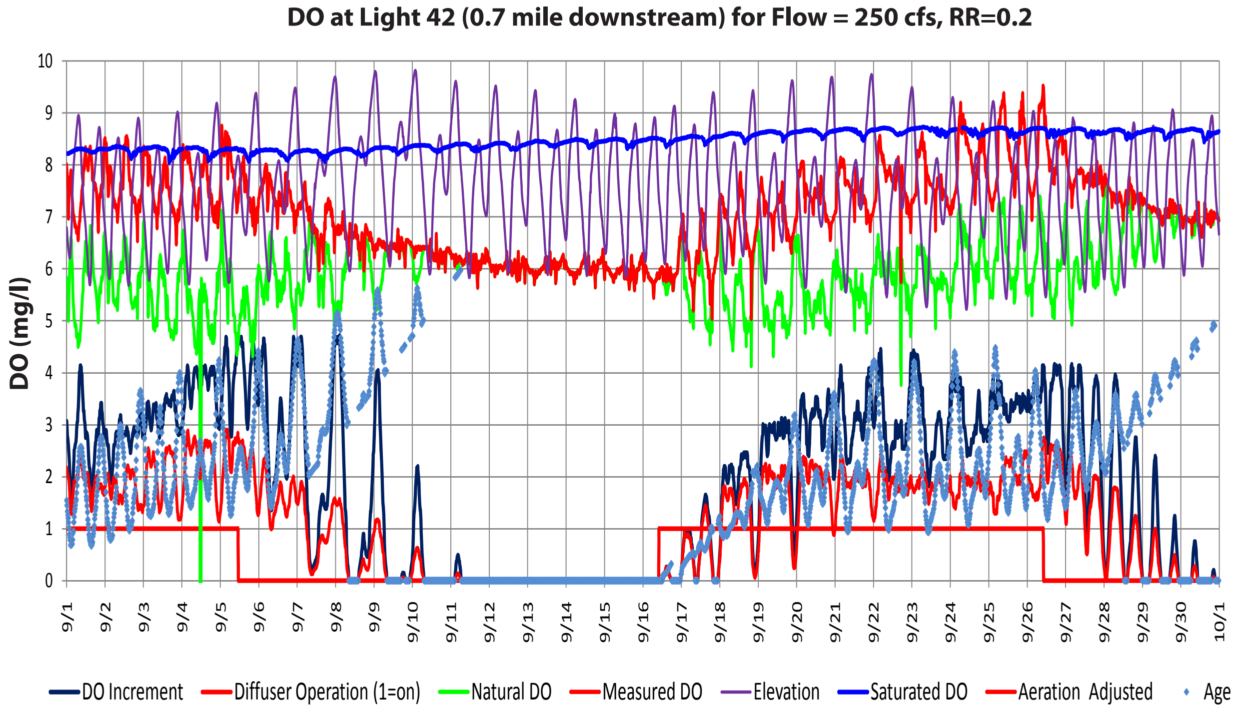

Figure B-13e: Measured DO at Light 42 and DO Increments with Flow of 250 cfs for September 2008.

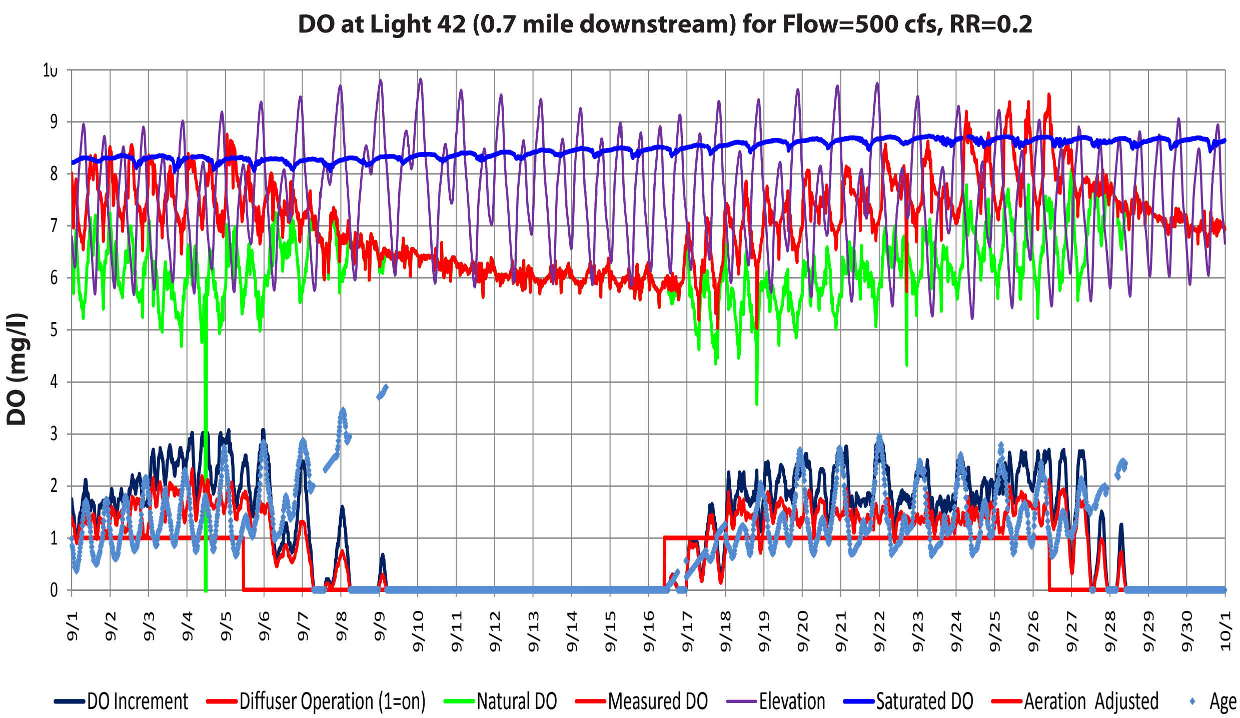

Figure B-13f: Measured DO at Light 42 and DO Increments with Flow of 500 cfs for September 2008.

Figure B-13 (continued)

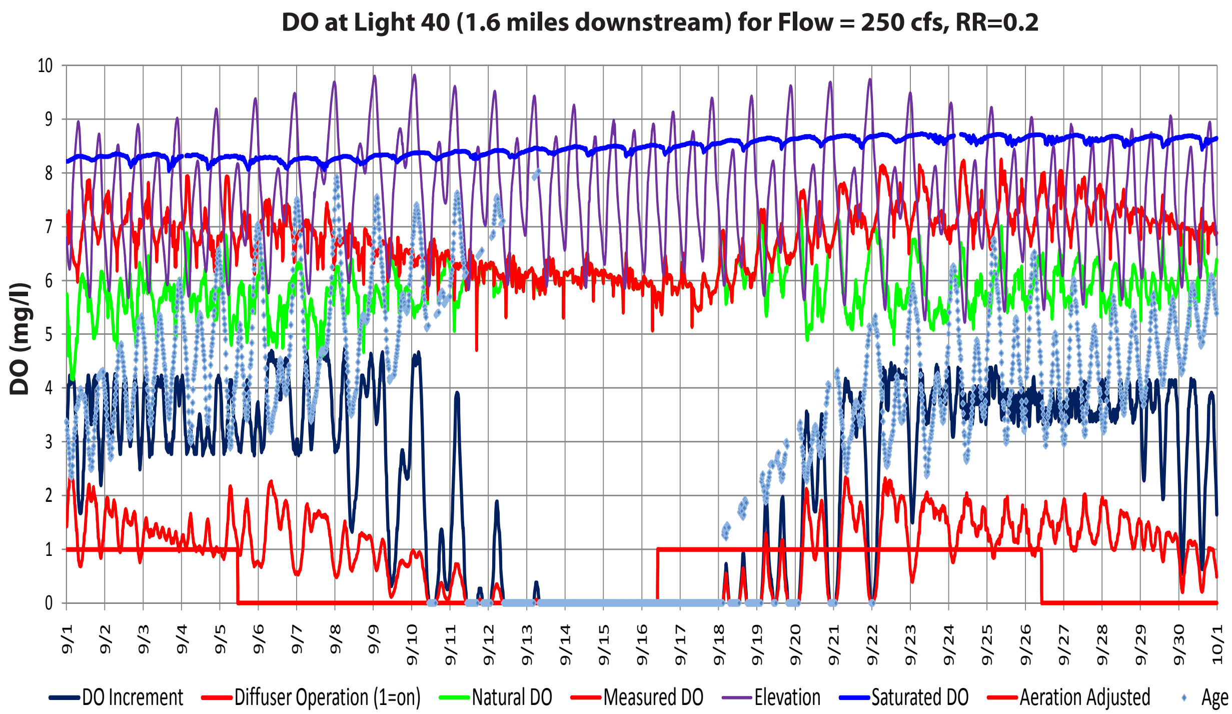

Figure B-13g: . Measured DO at Light 40 and DO Increments with Flow of 250 cfs for September 2008.

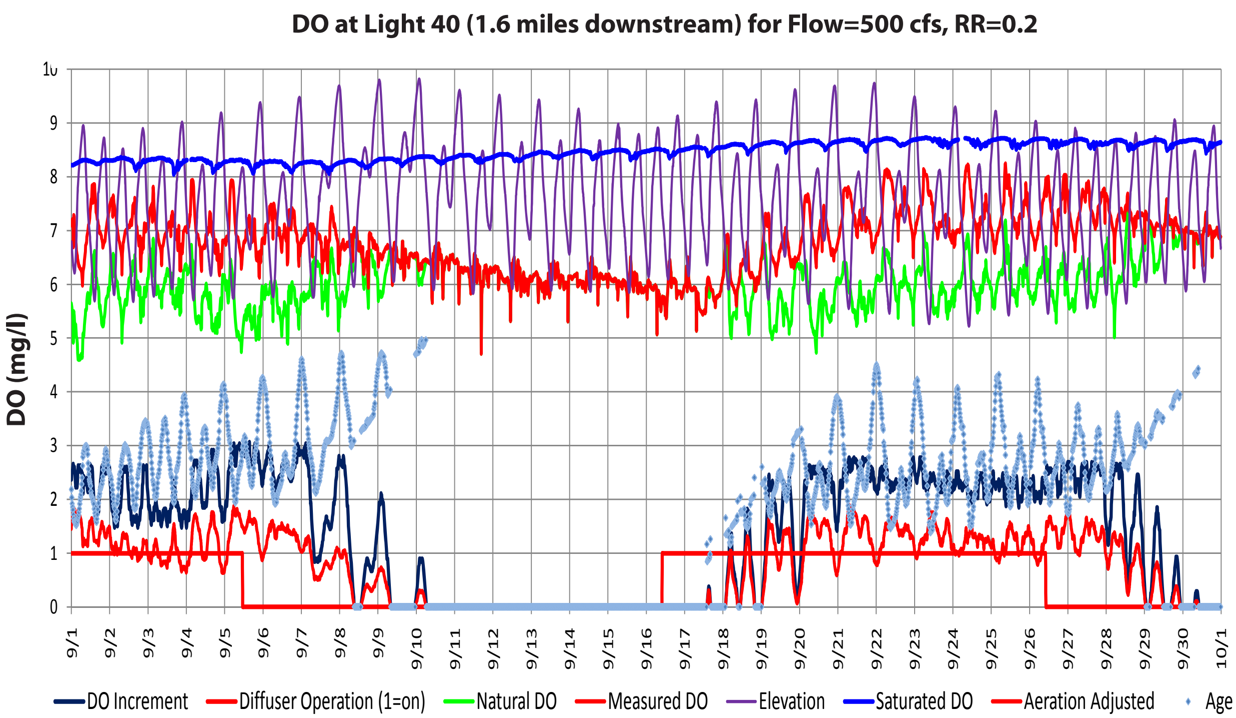

Figure B-13h: Measured DO at Light 40 and DO Increments with Flow of 500 cfs for September 2008.

Figure B-13 (continued)