# Jordan River Summer 2014 Synoptic Survey and QUAL2Kw Model Validation Report

**Utah Division of Water Quality**

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## AUTHOR

Nicholas von Stackelberg, Utah Division of Water Quality



## ACKNOWLEDGEMENTS

This project was a joint effort between the Utah Division of Water Quality (UDWQ), the Jordan River-Farmington Bay Water Quality Council (JRFBWQC) and the water reclamation facilities that discharge to the Jordan River. Data collection was conducted by numerous staff with UDWQ and JRFBWQC under the lead of Suzan Tahir with UDWQ. Logistical support was provided by staff with South Davis Sewer District. Sample analysis services were provided by the laboratories at Central Valley Water Reclamation Facility and South Valley Water Reclamation Facility. Carl Adams, Jodi Gardberg, and Suzan Tahir with UDWQ and Theron Miller with JRFBWQC provided technical review comments on a draft version of this report. This document was reviewed by management at UDWQ.


## CORRECTIONS

Corrections were made to page 17 and Table 4 in June 2017.

# Executive Summary

A QUAL2Kw water quality model of the Jordan River was previously built and calibrated to support the TMDL for dissolved oxygen, temperature, and total dissolved solids. For the purposes of developing an independent data set to validate the model, a synoptic survey along the Jordan River, State Canal and lower Mill Creek was conducted by Utah Division of Water Quality and Jordan River/Farmington Bay Water Quality Council staff between July 22 and August 7, 2014. Sampling included deployment of continuous water quality sondes and collection of grab samples at various locations throughout the river in order to characterize the chemistry, suspended sediments, nutrients, organic matter, and algae. Due to precipitation during the sampling period, only the samples collected prior to July 28 were used for the model validation.

In order to validate the model, the conditions during the synoptic survey were simulated and compared to observed results. The calibrated rate parameters were not adjusted during the model validation. Limited modifications were made to the structure of the calibrated model, including extension of the model down State Canal at Burnham Dam, addition of three point sources to the State Canal, and addition of the Jordan Basin Water Reclamation Facility.

Following are the key findings from the synoptic survey and model validation:

1. Large diel dissolved oxygen (DO) ranges, indicators of high levels of primary production, were observed in the upper Jordan River between the Narrows and 3300 South. The level of productivity did not appear to be significantly impacted by the discharge from the water reclamation facilities (Jordan Basin, South Valley, and Central Valley).

2. Confirmation of a high assimilation rate of orthophosphate and nitrate downstream of South Valley Water Reclamation Facility, which was also observed during previous synoptic surveys. The cause of this phenomenon warrants further investigation.

3. DO excursions below the minimum DO criteria in the lower Jordan River were observed both during dry periods, and during and immediately following storm events. The storm event on July 29-30 resulted in very low DO at Center Street and near anoxic conditions at Burnham Dam. Review of continuous DO data from the permanent sonde stations confirms this phenomenon of acute DO excursions associated with storm events.

4. The model performance during validation was generally good for many constituents, including specific conductivity, temperature, total suspended solids, total nitrogen, total phosphorus; however, pH was generally over-predicted throughout the Jordan River, ammonia assimilation was over-predicted and DO diel range was under-predicted in the upper Jordan River, and DO was over-predicted in the lower Jordan River.

5. Dissolved metal concentrations were generally low in the Jordan River, with the exception of exceedances of water quality criteria observed for lead during dry weather and iron during wet weather.

Based on the findings of this study and other related studies, the following recommendations for modeling eutrophication in the Jordan River are made.

Although pH and ammonia assimilation were generally over-predicted in the model, these inaccuracies are offsetting with regard to compliance with ammonia criteria, as elevated pH results in lower ammonia criteria and higher assimilation results in lower ammonia concentrations. Therefore, the model represents the best available tool currently available and is considered suitable for application to the wasteload allocation for the Jordan River POTW permit renewals in 2015 and 2016.

However, for application of the model to the TMDL for DO, the recommendation is to transition the steady-state QUAL2Kw model to a dynamic modeling platform. The limitations of the steady-state model include an inability to link sources of organic matter to low DO in the lower Jordan River and an inability to simulate acute DO excursions during storm events, both of which will be necessary to determine the TMDL. One option that should be considered would be to build an EPA WASP model of the Jordan River and link it to the existing HSPF model of the Jordan River watershed within Salt Lake County. The new dynamic model would require calibration, which should be conducted in consultation with the modeling workgroup associated with the TMDL, as was done for the original calibration.

Following are additional recommendations for improving the modeling of eutrophication in the Jordan River and State Canal for the purposes of the wasteload allocation and TMDL:

1. Revisit the calibration of selected parameters related to simulating benthic algae growth, as well as pH and ammonia decay and plant uptake, particularly in the upper Jordan River.

2. Evaluate potential enhancements to the model to improve simulation of sediment oxygen demand, including specification of decay rate parameters.

3. Improve understanding and simulation of scour of benthic algae from the upper Jordan River during storm events and at senescence, and subsequent deposition in the lower Jordan River.

4. Conduct another synoptic survey during the non-irrigation season, when the Jordan River is not influenced by releases from Utah Lake. The data set in part could be used to validate the model during the clear phase of the river.

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The purpose of this report is to summarize the objectives, methods and results from the synoptic survey conducted on the Jordan River in the summer of 2014 and validation of the Jordan River QUAL2Kw model. The report includes conclusions and recommendations for model refinement.

## Background

The Jordan River flows approximately 52 miles from Utah Lake to its terminus at Burton Dam. At Burnham Dam, some of the Jordan River flow is diverted to the State Canal, which flows approximately 3.5 miles to its terminus at the Farmington Bay Waterfowl Management Area. The Utah Pollution Discharge Elimination System (UPDES) discharge permits for five publicly owned treatment works (POTW) that discharge to the Jordan River, State Canal and Mill Creek immediately upstream of the confluence with the Jordan River expire in 2015 and 2016. The Jordan River is covered under a Total Maximum Daily Load (TMDL) for organic matter that addresses impairment for low dissolved oxygen (Cirrus Ecological Solutions and Stantec Consulting 2013). A QUAL2Kw water quality model of the Jordan River was built and calibrated to support the TMDL (Stantec 2010; UDWQ 2010).

## Goals and Objectives

The following objectives were established for conducting the synoptic survey:

1. Collect a validation data set for the Jordan River QUAL2Kw model in support of the wasteload allocation (WLA) for the Jordan River UPDES permit renewals and Phase 2 of the TMDL for dissolved oxygen.

2. Conduct sampling at additional in-river sites and tributaries to improve characterization of pollutant loads to the river and fate and transport within the river, including dissolved oxygen dynamics throughout the river.

3. Collect data to support extending the model down the State Canal and up Mill Creek, and the addition of the Jordan Basin Water Reclamation Facility (WRF) and South Davis Sewer District's North Wastewater Treatment Plant (WWTP).

4. Sample for metals at selected river sites and sources, which had not been done in previous synoptic surveys of the Jordan River.

5. Enhance stakeholder collaboration and cooperation with the POTWs, who assisted with data collection and sample analysis.

# METHODS

## SAMPLING

Synoptic sampling was conducted along the Jordan River between July 22 and August 7, 2014. Sampling was completed according to the procedures in *Field Data Collection for QUAL2Kw Model Build and Calibration Standard Operating Procedures Version 1.0* (UDWQ 2012).

Sampling was conducted by three crews comprised of UDWQ and Jordan River-Farmington Bay Water Quality Council staff. Samples were collected at 20 sites along the Jordan River and at 25 significant tributaries and point sources (Table 1). Continuous data sondes were deployed at 25 of the sites (Table 1), of which 8 were long term stations and 17 were short term deployments. The sondes measured a varying set of parameters that included: temperature, specific conductivity, dissolved oxygen, pH, turbidity, chlorophyll *a*, and fluorescent dissolved organic matter (FDOM).

Grab water quality samples were collected at the same time as when the continuous data sondes were deployed on 7/21 and 7/22, and also on 7/30 when the sondes were checked and redeployed. Due to precipitation and storm flows, no water quality samples were collected when the sondes were removed on 8/6 and 8/7.

At those sites with suitable substrate and water depth, benthic algae samples were collected following Utah Comprehensive Assessments of Stream Ecosystems (UCASE) protocols (UDWQ 2014).

The samples were analyzed at the Central Valley Water Reclamation Facility's environmental laboratory for the constituents listed below. Benthic and free floating chlorophyll *a* were analyzed at the South Valley Water Reclamation Facility's environmental laboratory.

Constituents analyzed include:

1. Chemistry
    a. Alkalinity (ALK)
    b. Bicarbonate (HCO3)
    c. Calcium (Ca)
    d. Carbon Dioxide ($CO_2$)
    e. Carbonate ($CO_3$)
    f. Hydroxide (OH)
    g. Magnesium (Mg)
    h. Specific Conductivity (SC)
    i. Total Dissolved Solids (TDS)
2. Biochemical Oxygen Demand
    a. Biochemical Oxygen Demand 5-day ($BOD_5$)
    b. Soluble Carbonaceous Biochemical Oxygen Demand 5-day ($SCBOD_5$)
3. Nutrients
    a. Ammonia (NH3-N)
    b. Nitrite (NO2-N)
    c. Nitrate (NO3-N)
    d. Total Kjeldhal Nitrogen (TKN)
    e. Orthophosphate (PO4)
    f. Total Phosphorus (TP)
4. Solids
    a. Total Suspended Solids (TSS)
    b. Turbidity (TURB)
    c. Volatile Suspended Solids (VSS)
5. Algae
    a. Phytoplankton Chlorophyll a (PHYTO CHLA)
    b. Benthic Chlorophyll a (BENTHIC CHLA)
6. Metals (Dissolved) [sampling for metals done at selected sites]
    a. Aluminum (Al)
    b. Arsenic (As)
    c. Cadmium (Cd)
    d. Chromium (Cr)
    e. Copper (Cu)
    f. Iron (Fe)
    g. Lead (Pb)
    h. Mercury (Hg)
    i. Molybdenum (Mo)
    j. Nickel (Ni)
    k. Selenium (Se)
    l. Silver (Ag)
    m. Zinc (Zn)

A multi-parameter water quality probe was also used to measure temperature, pH, conductivity, and dissolved oxygen while collecting samples at each of the sites.

Table 1: Sampling sites

| # | Site ID | Type | Site Name | River Mile | Sonde Type[1] | Sonde Parameters[2] | Flow[3] |
|---|---|---|---|---|---|---|---|
| 1 | 4994790 | RIVER | JORDAN R AT UTAH L OUTLET U121 XING | 52.88 | LT | TMP, SC, DO, DOSAT, PH, CHLA, TURB, FDOM | MEASURED |
| 2 | 4994720 | RIVER | JORDAN R AT NARROWS - PUMP STATION | 43.19 | ST | TMP, SC, DO, DOSAT, PH, CHLA, TURB | DWR |
| 3 | 4994730 | RIVER | JORDAN NARROWS BL TURNER DAM PUMP HOUSE | 43.00 | | | DWR |
| 4 | 4994600 | RIVER | JORDAN R AT BLUFFDALE ROAD XING | 39.21 | ST | TMP, SC, DO, DOSAT, PH | MEASURED |
| 5 | 4994520 | RIVER | JORDAN R AT BANGERTER HIGHWAY XING | 37.84 | ST | TMP, SC, DO, DOSAT, PH | MEASURED |
| 6 | 4994530 | SOURCE | JORDAN BASIN WRF | 37.10 | ST | TMP, SC, DO, DOSAT | WWTP |
| 7 | 4994111 | SOURCE | CORNER CANYON CREEK AT RAILROAD CROSSING | 36.47 | | | MEASURED |
| 8 | 4994112 | SOURCE | RIVERBEND GOLF COURSE RETURN | 35.67 | | | MEASURED |
| 9 | 4994490 | RIVER | JORDAN R AT 12600 S XING | 35.48 | ST | TMP, SC, DO, DOSAT, PH, CHLA, TURB | MEASURED |
| 10 | 4994420 | SOURCE | MIDAS CREEK ABOVE JORDAN RIVER | 32.99 | | | MEASURED |
| 11 | 4994114 | SOURCE | WILLOW CREEK ABOVE JORDAN RIVER | 32.12 | | | MEASURED |
| 12 | 4994370 | RIVER | JORDAN R AT 10600 S | 32.00 | | | MEASURED |
| 13 | 4994115 | SOURCE | DRY CREEK ABOVE JORDAN RIVER | 30.14 | | | MEASURED |
| 14 | 4994270 | RIVER | JORDAN R AT 9000 S XING | 29.58 | ST | TMP, SC, DO, DOSAT, PH, CHLA, TURB | MEASURED |
| 15 | 4994116 | SOURCE | 9000 SOUTH CONDUIT | 29.58 | | | SLCO |
| 16 | 4994190 | SOURCE | BINGHAM CREEK AT 1300 WEST | 28.09 | | | MEASURED |
| 17 | 4994170 | RIVER | JORDAN R AT 7800 S XING AB S VALLEY WWTP | 27.78 | ST | TMP, SC, DO, DOSAT | MEASURED |
| 18 | 4994160 | SOURCE | SOUTH VALLEY WWTP | 27.28 | ST | TMP, SC, DO, DOSAT | WWTP |
| 19 | 4994118 | SOURCE | NORTH JORDAN CANAL RETURN AT RURAL ROAD W | 27.03 | | | MEASURED |
| 20 | 4994100 | RIVER | JORDAN R AT 6400 S XING (WINCHESTER) | 26.28 | ST | TMP, SC, DO, DOSAT, PH, CHLA, TURB | MEASURED |
| 21 | 4993590 | SOURCE | LITTLE COTTONWOOD CK AT 360 W 4900 S | 23.24 | ST | Sonde missing. | SLCO |
| 22 | 4993470 | RIVER | JORDAN RIVER AT 4500 S XING | 22.62 | ST | Sonde missing. | MEASURED |
| 23 | 4992970 | SOURCE | BIG COTTONWOOD CK AB JORDAN R AT 500 W 4200 S | 22.12 | ST | TMP, SC, DO, DOSAT | SLCO |
| 24 | 4992880 | RIVER | JORDAN R AT 3300 S XING | 19.95 | LT | TMP, SC, DO, DOSAT, PH, CHLA, TURB, FDOM | MEASURED |
| 25 | 4992480 | SOURCE | MILL CREEK ABOVE CONFLUENCE JORDAN RIVER | 18.83 | ST | TMP, SC, DO, DOSAT | MEASURED |
| 26 | 4992500 | SOURCE | CENTRAL VALLEY WWTP | 18.83 | ST | TMP, SC, DO, DOSAT, PH | WWTP |
| 27 | 4992505 | SOURCE | MILL CK. AB CENTRAL VALLEY WWTP OUTFALL | 18.83 | ST | TMP, SC, DO, DOSAT | SLCO |
| 28 | 4994119 | SOURCE | 900 WEST DRAIN (MILL CREEK) | 18.83 | | | MEASURED |
| 29 | 4992390 | SOURCE | DECKER LAKE OUTFLOW ABOVE JORDAN RIVER | 18.58 | | | MEASURED |
| 30 | 4992320 | RIVER | JORDAN R 1100 W 2100 S | 17.52 | LT | TMP, SC, DO, DOSAT, PH, CHLA, TURB, FDOM | USGS |
| 31 | 4992290 | RIVER | JORDAN R AT 1700 S | 16.71 | ST | TMP, DO, DOSAT | USGS |
| 32 | 4992070 | SOURCE | 1300 SOUTH CONDUIT (TRI-CREEK) | 15.72 | | | MEASURED |
| 33 | 4992040 | SOURCE | 900 SOUTH DRAIN (TRI-CREEK) | 14.85 | | | MEASURED |
| 34 | 4992050 | RIVER | JORDAN R AT 800 S AB DRAIN OUTFALL | 14.60 | LT | TMP, SC, DO, DOSAT, PH, CHLA, TURB, FDOM | MEASURED |
| 35 | 4991920 | SOURCE | NORTH TEMPLE CONDUIT (CITY CREEK) | 13.48 | | | MEASURED |
| 36 | T13B | SOURCE | FOLSOM AVENUE DRAIN | 13.36 | | | MEASURED |
| 37 | 4991900 | RIVER | JORDAN R AT 300 N | 12.43 | LT | TMP, SC, DO, DOSAT, PH, CHLA, TURB, FDOM | SLCO |
| 38 | 4991820 | RIVER | JORDAN R AT CUDAHY LANE AB S DAVIS S WWTP | 6.84 | LT | TMP, SC, DO, DOSAT, PH, CHLA, TURB, FDOM | DWR |
| 39 | 4991810 | SOURCE | S DAVIS S WWTP | 6.71 | ST | TMP, SC, DO, DOSAT, PH, TURB | WWTP |
| 40 | 4990890 | RIVER | JORDAN R AB BURNHAM DAM AND STATE CANAL | 3.54 | LT | TMP, SC, DO, DOSAT, PH, CHLA, TURB, FDOM | MEASURED |
| 41 | 4994121 | SOURCE | A1 DRAIN AT LEGACY PARKWAY FRONTAGE ROAD | 0.99 | | | MEASURED |
| 42 | 4990790 | RIVER | STATE CANAL 100FT ABOVE SOUTH DAVIS NORTH WWTP | 0.68 | LT | TMP, SC, DO, DOSAT, PH, CHLA, TURB, FDOM | MEASURED |
| 43 | 4990780 | SOURCE | S DAVIS N WWTP | 0.59 | ST | Sonde failed. | WWTP |
| 44 | 4994124 | SOURCE | MILL CREEK (DAVIS COUNTY) | 0.31 | | | MEASURED |
| 45 | 4990720 | RIVER | STATE CANAL AT S BRIDGE FARMINGTON BAY WMA | 0.00 | ST | TMP, SC, DO, DOSAT, PH | MEASURED |

1: LT, long term station; ST, short term deployment
2: CHLA, chlorophyll a; DO, dissolved oxygen; DOSAT, dissolved oxygen saturation; FDOM, fine dissolved organic matter; PH, pH; SC, specific conductivity; TURB, turbidity
3: DWR, Division of Water Rights; SLCO, Salt Lake County; WWTP, Wastewater Treatment Plant

At sampling sites without a permanent stream flow gauge, flow rate was measured using a Handheld Acoustic Doppler Velocimeter (FlowTracker) at wadeable sites and using a Q-boat (StreamPro ADCP) at nonwadeable sites (Table 1). Flow rates for diversions were obtained from the Utah Division of Water Rights distribution records.

The sampling to support the QUAL2Kw model validation was intended to occur during dry, steady state flow conditions. A brief thunderstorm occurred at 5:00 PM on 7/20/2014 (Table 2), which was considered to have cleared the system and to have a negligible effect on the sampling and sonde deployment that was initiated on 7/21/2014. It was planned that the sondes would be retrieved and a second sample would be collected the following week starting on 7/28/2014. However, it rained on 7/28, 7/29 and 7/30, and it was decided to collect a storm sample at selected sites and to leave the sondes in place for another week. It rained again on 8/4, 8/5, 8/6, and 8/7, and it was decided to retrieve the sondes and not collect another storm sample.

Table 2: Daily weather summary at NWS Salt Lake City International Airport weather station

| Date | Precipitation (in) | Temperature (deg F) | |
|---|---|---|---|
| | | Min | Max |
| 7/18/2014 | 0 | 71 | 96 |
| 7/19/2014 | 0 | 70 | 96 |
| 7/20/2014 | 0.13 | 73 | 94 |
| 7/21/2014 | 0 | 68 | 96 |
| 7/22/2014 | 0 | 63 | 98 |
| 7/23/2014 | 0 | 73 | 103 |
| 7/24/2014 | 0 | 78 | 93 |
| 7/25/2014 | 0 | 64 | 92 |
| 7/26/2014 | 0 | 66 | 94 |
| 7/27/2014 | 0 | 65 | 99 |
| 7/28/2014 | 0.04 | 77 | 92 |
| 7/29/2014 | 0.11 | 66 | 76 |
| 7/30/2014 | 0.02 | 65 | 82 |
| 7/31/2014 | 0 | 62 | 85 |
| 8/1/2014 | 0 | 66 | 91 |
| 8/2/2014 | 0 | 67 | 94 |
| 8/3/2014 | 0 | 67 | 93 |
| 8/4/2014 | 0.04 | 64 | 86 |
| 8/5/2014 | 0.19 | 66 | 83 |
| 8/6/2014 | 0.13 | 63 | 84 |
| 8/7/2014 | 0.01 | 58 | 81 |
| 8/8/2014 | 0 | 63 | 88 |
| 8/9/2014 | 0 | 65 | 89 |
| 8/10/2014 | 0 | 61 | 92 |

## Stream Metabolism

Whole stream metabolism methods were used to estimate average daily reaeration rate ($k_a$), gross primary production (GPP), and ecosystem respiration (ER) at selected sampling stations during the dry period. The River Metabolism Analyzer (RMA.xls Version 2.3 Beta 5.1), developed and maintained by the Washington State Department of Ecology, estimates stream metabolism utilizing four methods. The only results presented in this report are from the one-station inverse model method (van de Bogert et al. 2007) that is solved in RMA using a genetic algorithm.

## Model Validation

The synoptic data set was used to validate the Jordan River QUAL2Kw model that was originally calibrated in 2010 for the TMDL (Stantec 2010; UDWQ 2010).

The following modifications were made to the structure of the calibrated model:

1. The calibrated model terminated at Burton Dam. For the model validation, the model was broken at Burnham Dam (1.7 miles upstream from Burton Dam) and extended down the State Canal to the Farmington Bay Waterfowl Management Area (3.5 miles downstream of Burnham Dam).
2. Three point sources were added to the State Canal reach of the model: A-1 Drain, South Davis Sewer District's North Wastewater Treatment Plant, and the outlet channel from Bountiful Pond (Mill Creek and Stone Creek).
3. The Jordan Basin Water Reclamation Facility, which was constructed and put into operation since 2010, was added as a point source to the Jordan River.

The purpose of the model validation was to evaluate the calibrated model performance with an independent data set. Therefore, no model parameters were adjusted during the model validation. The model was populated with the data from the synoptic survey and simulated results were compared to observed results for each of the constituents.

The primary measures of model performance included: 1.) graphical comparisons between simulated and observed mean, minimum and maximum daily concentrations for each water quality constituent; and 2.) statistical calculation of standard error, or root mean square error (RMSE), and coefficient of variation of the RMSE (CVRMSE). The RMSE is the square root of the variance between the simulated and observed concentration. The CVRMSE is the ratio of the RMSE to the observed mean concentration (reported in %).

The Jordan River TMDL QUAL2Kw model was intended to simulate dry, steady state conditions in the river, and is not able to simulate storm flows as currently configured. Therefore, only sampling results from the dry period (7/21 – 7/27) were utilized for the model validation.

# RESULTS AND DISCUSSION

## MODEL VALIDATION

Table 3 summarizes the model validation error for selected constituents.

Table 3: Absolute and relative error of the daily concentrations from all sampling stations.

| Constituent | Units | RMSE | CVRMSE |
|---|---|---|---|
| Temperature Mean | deg C | 1.0 | 4.5% |
| Temperature Min | deg C | 1.2 | 5.7% |
| Temperature Max | deg C | 1.3 | 5.3% |
| Conductivity | µmhos | 166.2 | 8.6% |
| Inorganic Suspended Solids | mg/L | 16.7 | 34.2% |
| TSS | µg/L | 16.8 | 28.7% |
| DO Mean | mg/L | 0.8 | 13.2% |
| DO Min | mg/L | 1.5 | 31.9% |
| DO Max | mg/L | 2.7 | 29.1% |
| CBOD | mg/L | 3.3 | 74.1% |
| Organic Nitrogen | µg/L | 581.9 | 49.1% |
| Ammonia | µg/L | 157.2 | 64.3% |
| Nitrate | µg/L | 491.8 | 22.4% |
| Total Nitrogen | µg/L | 931.0 | 25.7% |
| Organic Phosphorus | µg/L | 82.8 | 160.1% |
| Inorganic Phosphorus | µg/L | 240.8 | 48.0% |
| Total Phosphorus | µg/L | 171.7 | 31.0% |
| Phytoplankton | µg/L | 13.2 | 63.8% |
| Detritus | mg/L | 10.3 | 133.1% |
| Alkalinity | mg/L | 51.0 | 20.8% |
| pH | | 0.5 | 6.5% |

The flow regime for the period 7/21-7/27 was typical for the Jordan River during the irrigation season with mid-summer dry conditions. The majority of the flow that was released from Utah Lake was diverted to the irrigation canals at Turner Dam (Narrows) and Joint Dam (Figure 1). Downstream of Joint Dam, flows slowly built up from groundwater discharge, tributary inflow and wastewater treatment plants up to the Surplus Canal. Over half the flow was diverted at the Surplus Canal, with the remainder (~160 cfs) delivered to the lower Jordan River (LJR). At Burnham Dam, approximately 42 cfs were diverted down the State Canal to Farmington Bay Waterfowl Management Area. The observed and simulated specific conductance matched well (Figure 2) with a CVRMSE of 8.6% (Table 3), which provided some confirmation that the flow balance in the model was reasonable (less than 10% error overall).

The mean daily water temperature and diel range matched fairly well between the model and observed (Figure 3), with a CVRMSE of 4.5% (Table 3). Water temperature affects kinetic rates and shading affects the amount of incoming solar radiation at the water surface.

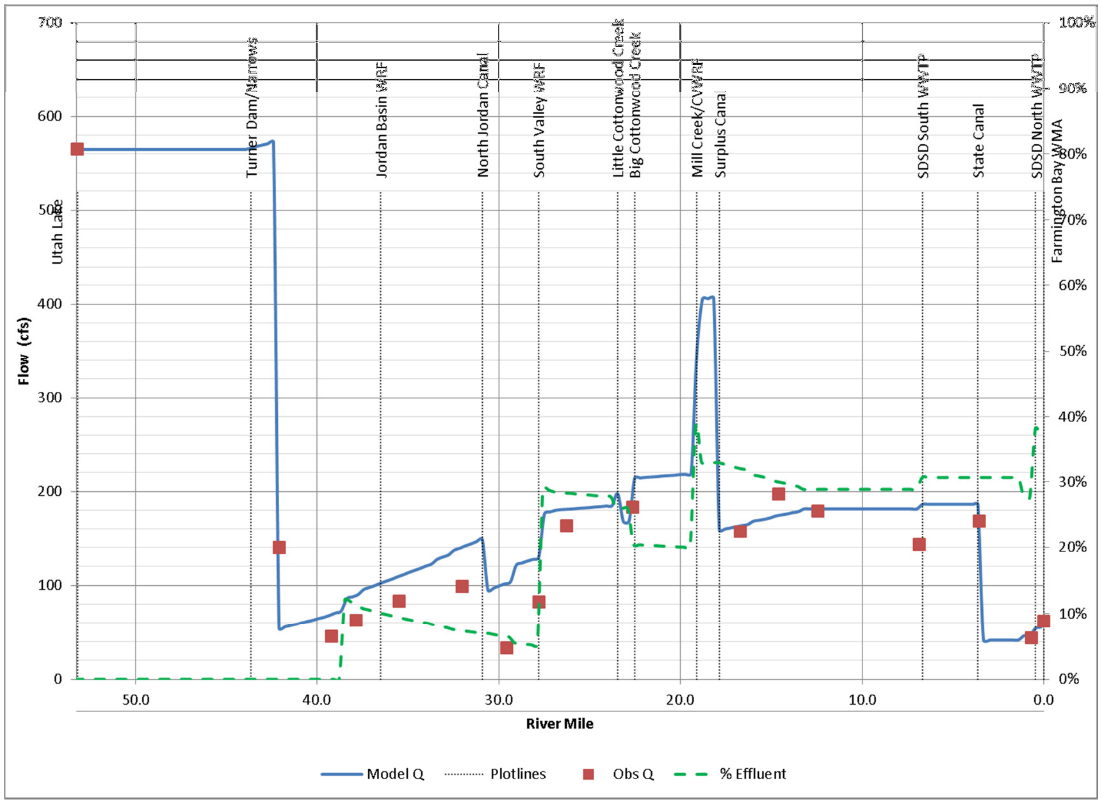


Figure 1: Flow rates during synoptic survey dry period

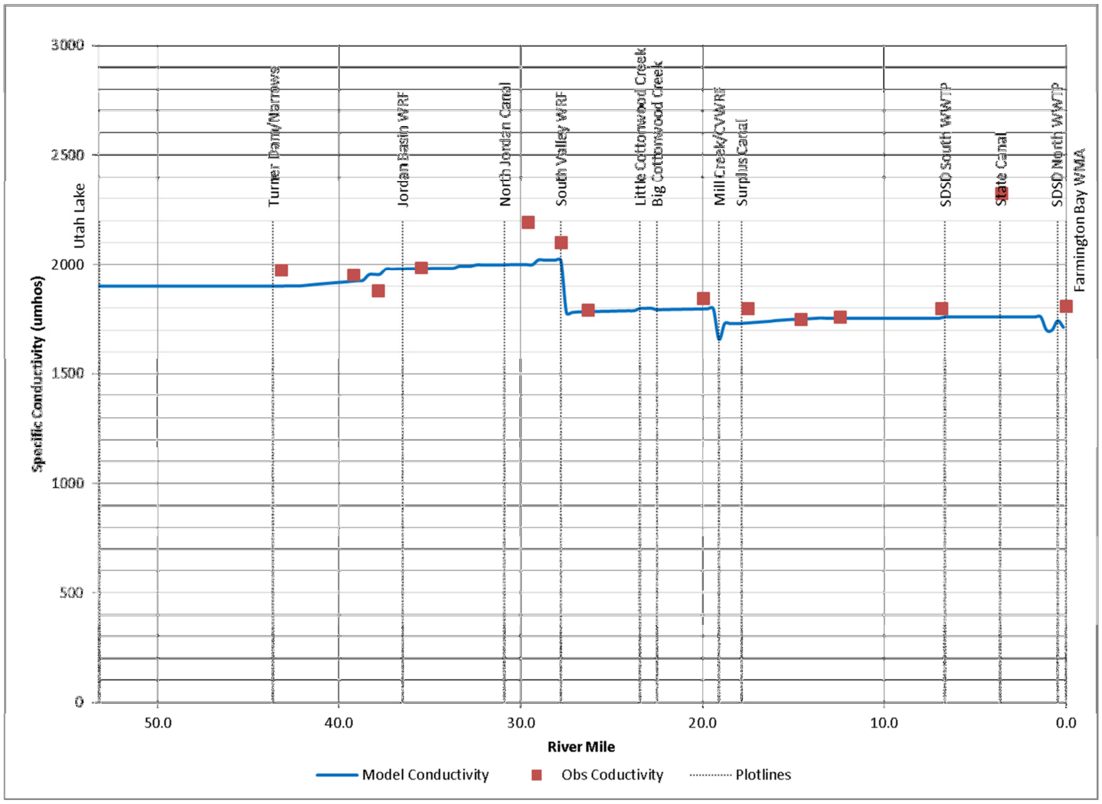


Figure 2: Specific conductivity during synoptic survey dry period

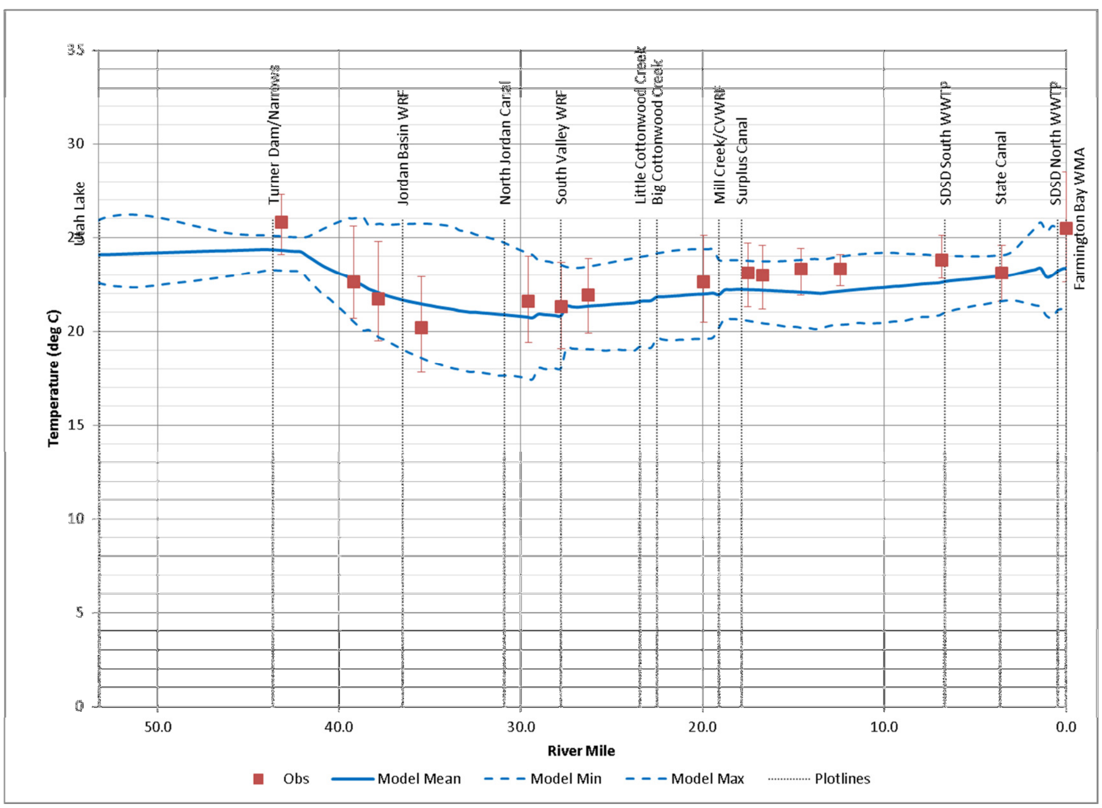


Figure 3: Water temperature during synoptic survey dry period

Although observed concentrations of ammonia in the upper Jordan River (UJR) were low, the model over-predicted ammonia assimilation as evidenced by the lower predicted ammonia concentration as compared to observed (Figure 4). Ammonia concentrations remained relatively elevated throughout the LJR as compared to the UJR, which the model generally under-predicted. Nitrate was generally well simulated by the model (Figure 5), whereas total nitrogen was over-predicted in the UJR (Figure 6). The model represented the total phosphorus concentration trends well, with some variation between observed and predicted concentrations (Figure 7). A rapid assimilation of nitrate and orthophosphate occurred downstream of South Valley WRF; this phenomenon was previously observed and warrants additional evaluation.

The pH was over-predicted in the model through-out much of the river (Figure 8), which is perhaps attributable to a high assumed pH for groundwater inputs (8.0). The acute and chronic ammonia water quality criteria are dependent on pH, with higher pH resulting in lower criteria.

The mean DO was under-simulated between 12600 South and Surplus Canal, and over-predicted in the LJR (Figure 9). In addition, the diel DO range was significantly under-simulated by the model in the UJR, which in turn is an indicator that primary productivity associated with phytoplankton and benthic algal growth was under-represented. The predicted phytoplankton matched the observed well in the UJR (Figure 10), which indicates that benthic algal growth is largely the reason for the under-prediction in primary productivity. The observed phytoplankton continuously lowered from Utah Lake to Burnham Dam, which is consistent with Rushforth and Rushforths' (2009) findings of the dominance of open-water genera in Jordan River phytoplanktonic samples. In the calibrated model, benthic algal growth is constrained by the bottom algae coverage parameter, which was set to 80%.

The observed soluble carbonaceous BOD was highly variable within short distances in the river (Figure 11), which is impossible to replicate with a mechanistic model with uniform decay rate. The predicted sediment oxygen demand (SOD) used the prescribed SOD in the calibrated model plus the SOD generated through diagenesis during the simulation period (Figure 12). Since measurements of sediment oxygen demand (SOD) were not made during the synoptic period, the mean of chamber measurements made from 2009-2013 are shown for reference (Hogsett 2015).

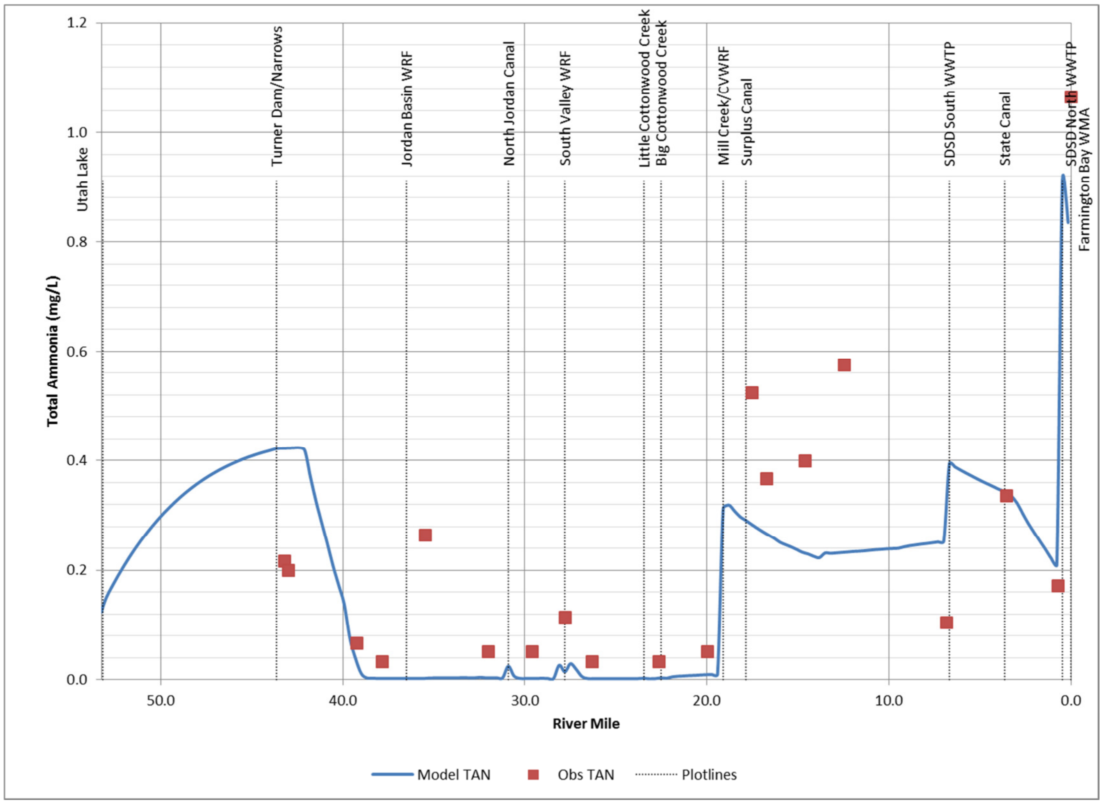


Figure 4: Total ammonia profile during synoptic survey dry period

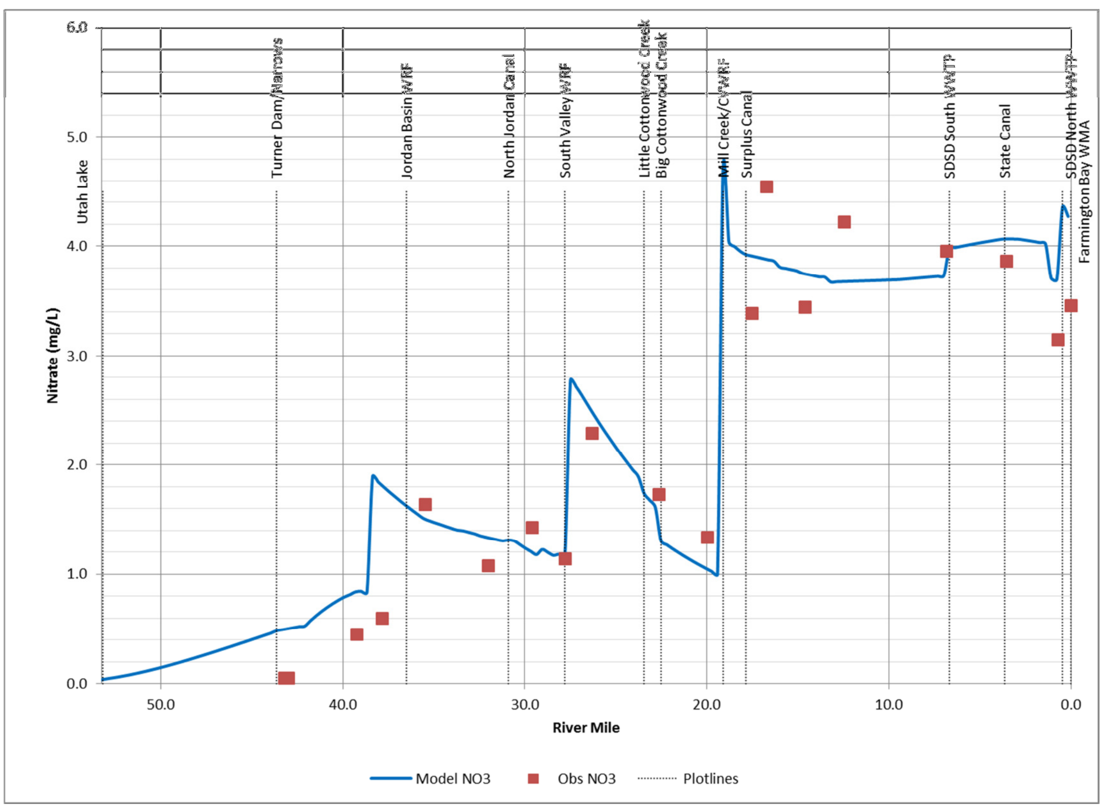


Figure 5: Nitrate/nitrite profile during synoptic survey dry period

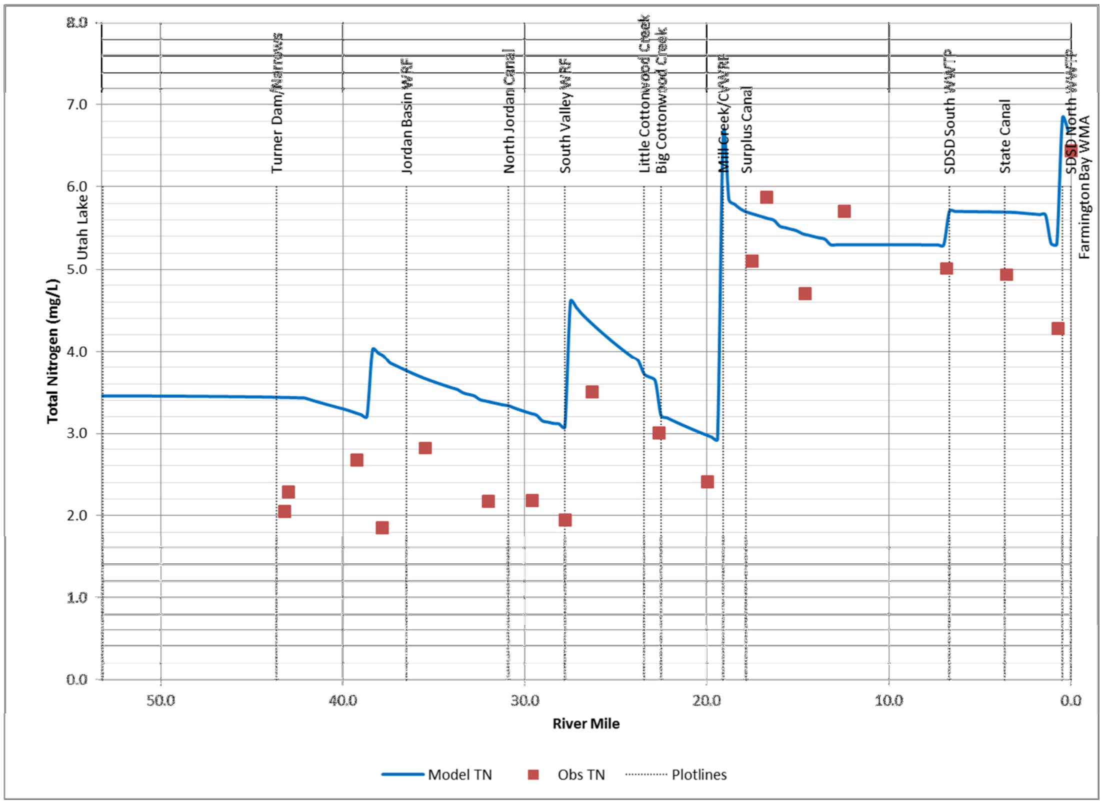


Figure 6: Total nitrogen profile during synoptic survey dry period

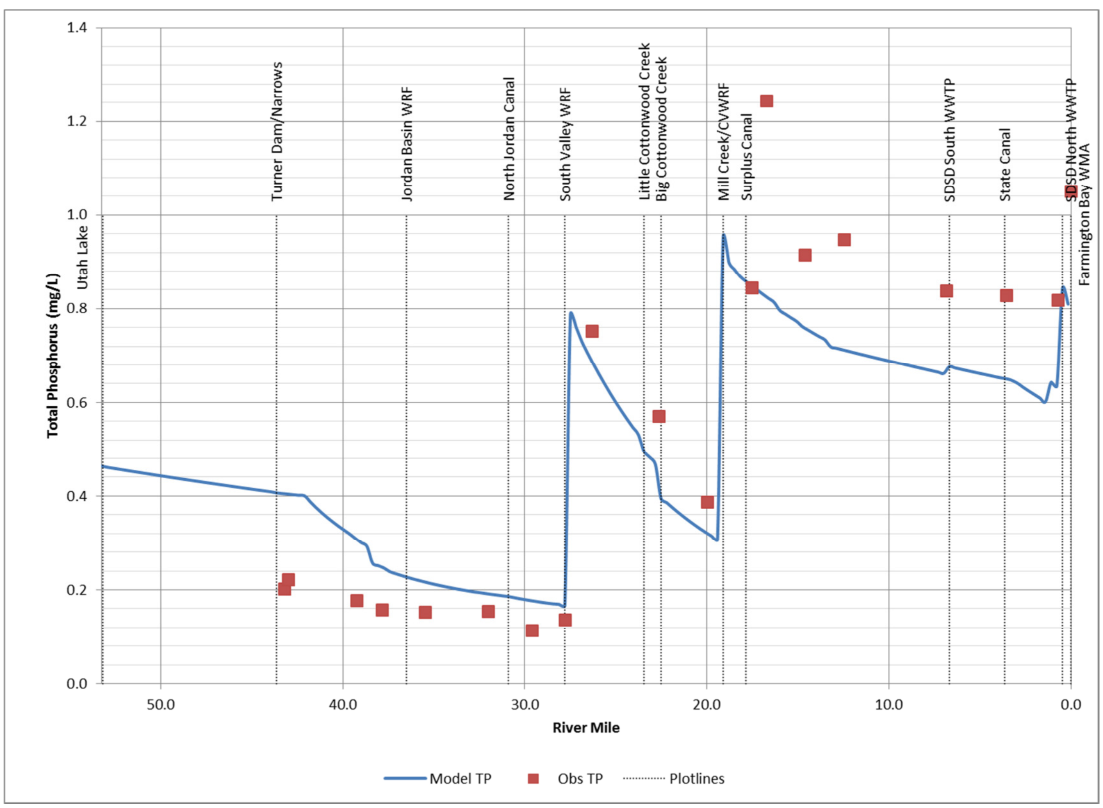


Figure 7: Total phosphorus profile during synoptic survey dry period

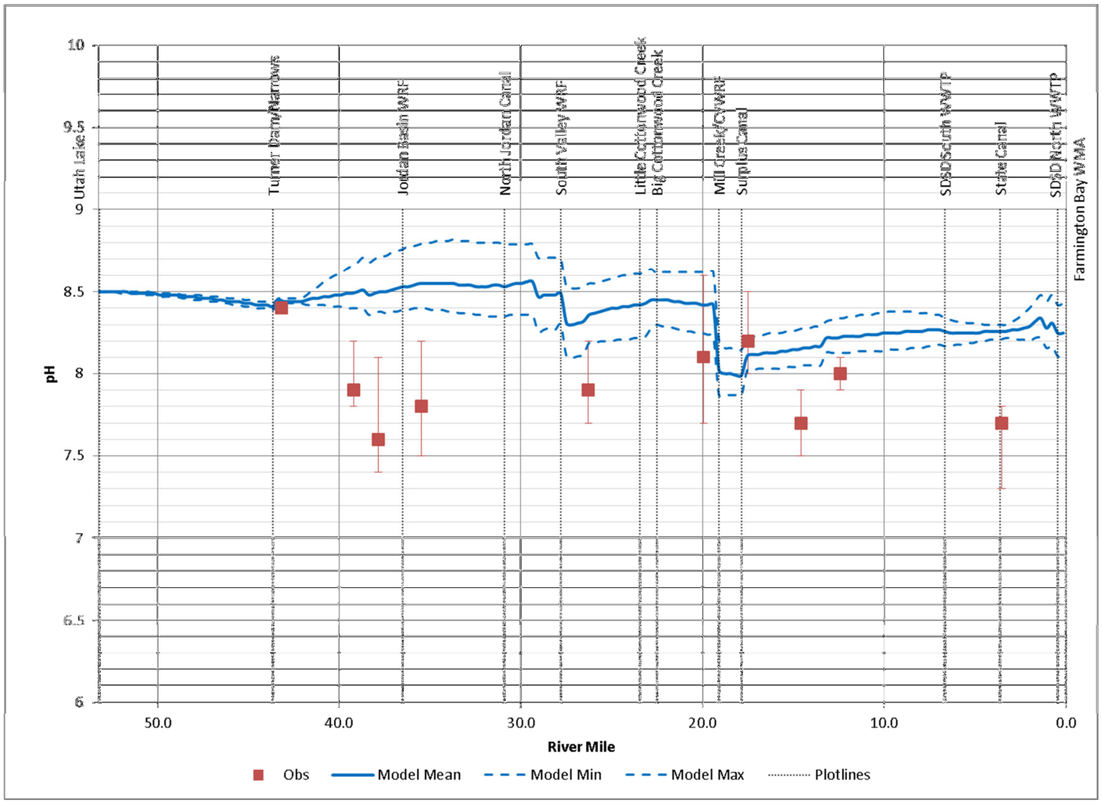


Figure 8: pH profile during synoptic survey dry period

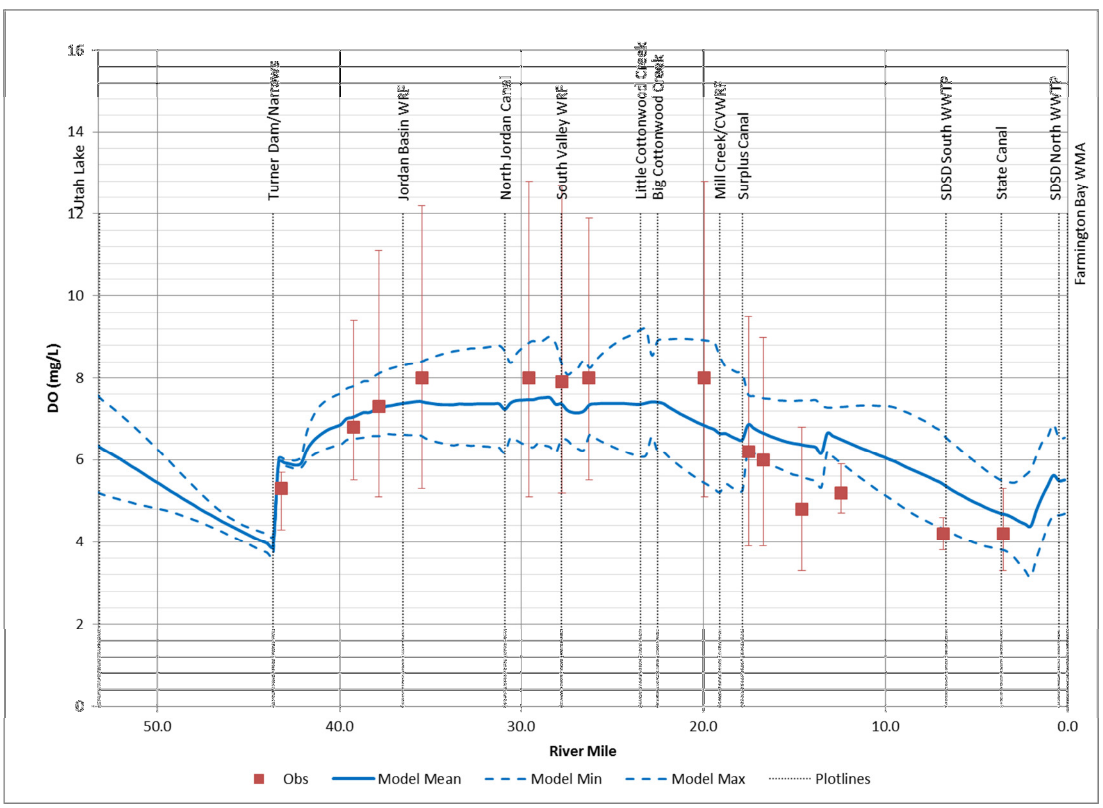


Figure 9: Dissolved oxygen profile during synoptic survey dry period

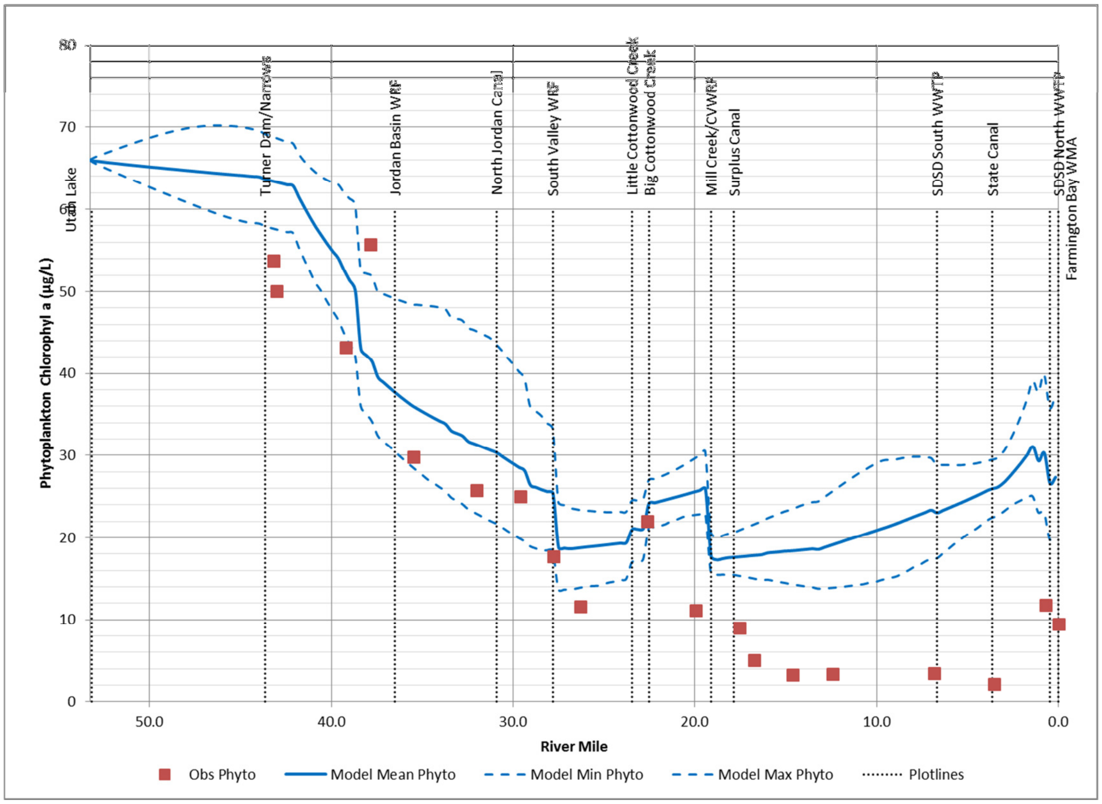


Figure 10: Phytoplankton chlorophyll a profile during synoptic survey dry period

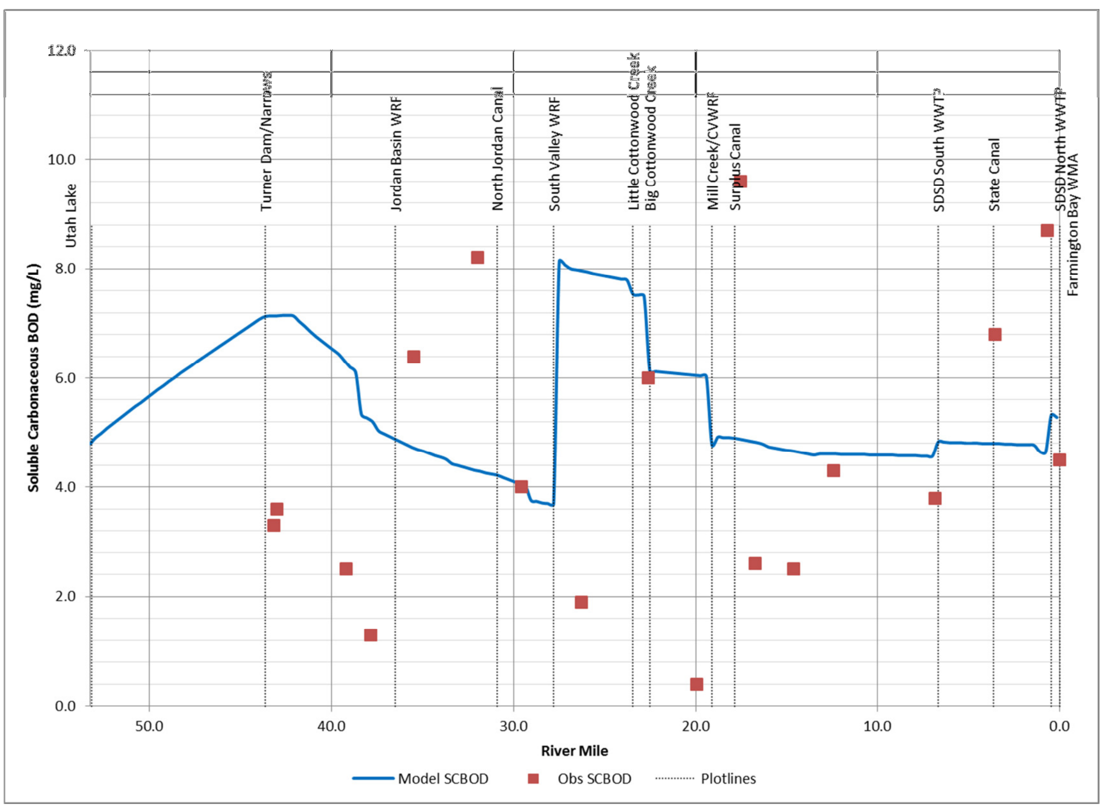


Figure 11: Soluble carbonaceous BOD profile during synoptic survey dry period

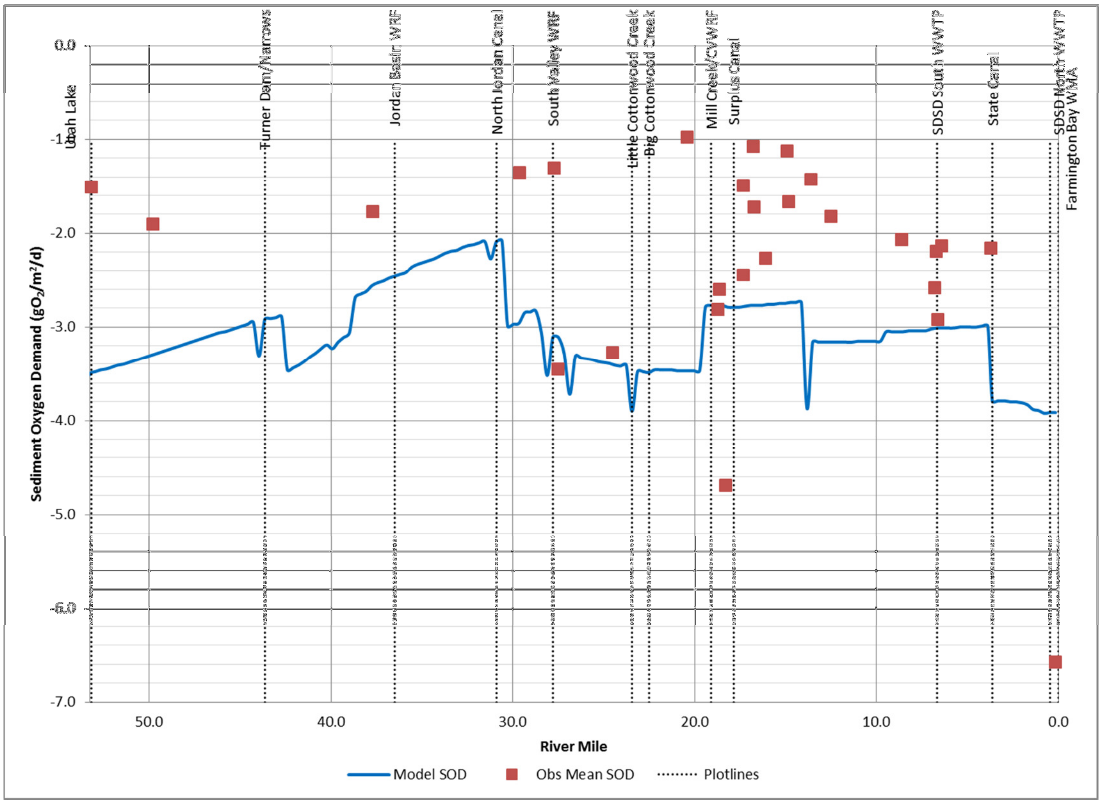


Figure 12: Sediment oxygen demand profile in QUAL2Kw model

[Note: Observed Mean SOD from chamber measurements made 2009-2013 (Hogsett 2015)]

## Continuous DO

At the Narrows sampling site, the DO diel range was relatively small and variable, indicating limited primary productivity in the uppermost reach of the Jordan River (Figure 13). The DO diel range progressively increased from the Narrows, through Bluffdale Road and Bangerter Highway, to 12600 South. The Jordan Basin WRF effluent enters the Jordan River between Bangerter Highway and 12600 South; however, only a small increase in primary productivity occurred between these sampling sites. In the absence of fish early life stages, the minimum and 7-day average DO criteria for 3A cold water fishery (4.0 mg/L and 5.0 mg/L, respectively) were met at each of the sites below the Narrows; however, with fish early life stages present, the criteria were met at none of the sites (8.0 mg/L and 9.5 mg/L, respectively).

As has been observed previously at the permanent DO stations, storm flows cause a temporary reduction of the DO minima and diel range during and immediately after the event. The reduction in the DO diel range is evidence of a disruption to the algal productivity in the river during the storm event, potentially as a result of growth inhibition due to increased turbidity and/or periphyton biomass removal due to scour from increased flow velocities. Interestingly, the algal growth rebounded and the DO diel range was greater after than before the 7/28-7/29 storm event (Figure 13).

Before the 7/28-7/29 storm, the diel DO was similar between 12600 South and 7800 South (Table 4), whereas after the storm, algal productivity was inhibited downstream of 9000 South (Figure 14). In the absence of fish early life stages, the minimum and 7-day average DO criteria for 3A cold water fishery were met at each of the sites; however, with fish early life stages present, the criteria were met at none of the sites.

The DO diel range was similar at 7800 South and 3300 South (Table 4), while slightly inhibited immediately downstream of South Valley WRF at 6400 South (Figure 14). The addition of Little Cottonwood Creek (no data) and Big Cottonwood Creek appeared to have little influence on the DO at 3300 South. In the absence of fish early life stages, the minimum and 7-day average DO criteria for 3A cold water fishery were met at each of the sites above Little Cottonwood Creek; however, with fish early life stages present, the criteria were met at none of the sites.

Both the DO minima and diel ranges were lower at 2100 South as compared to 3300 South (Figure 16). The minimum DO criteria (4.5 mg/L May through July and 4.0 mg/L August through April) were violated on seven consecutive days at 2100 South. The river slope transitions from a transport reach to a depositional reach downstream of 3300 South in the vicinity of the confluence with Mill Creek. The substrate consists of finer materials that are less suitable for periphyton colonization, and the deposition of organic matter from upstream results in enhanced sediment oxygen demand.

The DO diel range was progressively reduced from 2100 South to Center Street just above South Davis Sewer District's South WWTP (Figure 17). The DO minima before the 7/28-7/29 storm at 800 South were lower than at 300 North and Center Street. The minimum DO criterion was violated at all of the sites, while the 7-day average DO criterion was violated at 800 South, 300 North, and Center Street. Note that the 7-day average DO criterion of 5.5 mg/L only applies from May through July, per UAC R317-2-14, Table 2.14.5.

The primary productivity was enhanced at Burnham Dam as compared to Center Street (Figure 18). The sonde data was too spotty in the State Canal to make inferences. The minimum DO criterion was violated at all of the sites. The 7-day average DO criterion was violated at Center Street and Burnham Dam, which nearly went anoxic at these two locations during the storm.

During the 7/28-7/29 storm event, the DO progressively lowered in the river as the flow moved downstream (Figures 14-18), which would suggest a cumulative response to urbanization and stormwater runoff in the valley. It has been shown that stormwater runoff has elevated levels of dissolved organic carbon (DOC), which is readily degradable and can immediately depress DO in the river (Richardson 2014). In the LJR, the effect of the storm was even more pronounced due to several additional contributing factors. The channel below the Surplus Canal is a low gradient, depositional reach with high levels of decomposing organic matter and low atmospheric reaeration (Hogsett 2015), both of which result in a lower DO baseline condition prior to the storm. In addition, a majority of the upstream flow is diverted at the Surplus Canal, resulting in lower base flows and a higher proportion of stormwater from tributary storm drains in the LJR, which enhances the effect of the readily degradable DOC.

Table 4: Dissolved oxygen (mg/L) daily mean, minimum, maximum, and diel range at selected sampling stations.

| Date | Mean | | | | Minimum | | | | Maximum | | | | Diel Range | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 12600 S | 7800 S | 3300 S | 2100 S | 12600 S | 7800 S | 3300 S | 2100 S | 12600 S | 7800 S | 3300 S | 2100 S | 12600 S | 7800 S | 3300 S | 2100 S |
| 7/22/2014 | 8.1 | 8.0 | 8.1 | | 5.6 | 5.3 | 5.2 | | 12.4 | 12.9 | 12.9 | | 6.8 | 7.6 | 7.6 | |
| 7/23/2014 | 8.0 | 7.8 | 7.6 | 6.0 | 5.3 | 5.1 | 5.1 | **4.0** | 12.0 | 12.5 | 12.2 | 9.1 | 6.7 | 7.5 | 7.1 | 5.1 |
| 7/24/2014 | 7.6 | 7.8 | 8.0 | 6.2 | 5.0 | 5.2 | 5.1 | **4.0** | 12.2 | 12.2 | 13.0 | 9.6 | 7.2 | 7.0 | 7.9 | 5.6 |
| 7/25/2014 | 8.2 | 8.1 | 8.1 | 6.4 | 5.5 | 5.3 | 5.1 | **3.9** | 12.4 | 13.1 | 13.0 | 9.8 | 6.9 | 7.8 | 7.9 | 5.9 |
| Dry Mean | 8.0 | 7.9 | 8.0 | 6.2 | 5.3 | 5.2 | 5.1 | **3.9** | 12.2 | 12.7 | 12.8 | 9.5 | 6.9 | 7.5 | 7.6 | 5.5 |
| | | | | | | | | | | | | | | | | |
| 7/26/2014 | 8.3 | 7.7 | 7.7 | 6.3 | 5.6 | 5.3 | 5.1 | **3.9** | 12.8 | 11.4 | 12.2 | 9.7 | 7.3 | 6.1 | 7.1 | 5.8 |
| 7/27/2014 | 8.2 | 7.7 | 7.8 | 6.2 | 5.4 | 5.4 | 5.2 | **4.0** | 13.2 | 11.8 | 12.2 | 9.5 | 7.9 | 6.5 | 7.0 | 5.6 |
| 7/28/2014 | 7.3 | 7.1 | 6.9 | 5.4 | 5.2 | 5.3 | **3.8** | **2.9** | 12.2 | 11.2 | 11.5 | 8.5 | 7.1 | 5.9 | 7.7 | 5.6 |
| 7/29/2014 | 6.3 | 5.9 | 5.8 | 4.3 | 5.1 | 5.0 | 5.0 | **3.4** | 8.9 | 7.0 | 6.7 | 5.3 | 3.7 | 2.0 | 1.7 | 1.8 |
| 7/30/2014 | 7.8 | 6.7 | 6.7 | 5.6 | 5.2 | 5.7 | 6.0 | 4.7 | 12.2 | 8.5 | 8.1 | 6.8 | 7.0 | 2.8 | 2.2 | 2.1 |
| 7/31/2014 | 6.1 | 7.3 | 7.4 | 6.5 | 5.6 | 6.1 | 6.1 | 5.1 | 8.9 | 9.9 | 9.6 | 8.7 | 3.3 | 3.8 | 3.5 | 3.7 |
| 8/1/2014 | 11.5 | 8.5 | 7.7 | 6.9 | 5.9 | 6.2 | 6.0 | 5.0 | 15.1 | 10.1 | 10.9 | 9.9 | 9.2 | 3.9 | 5.0 | 4.9 |
| 8/2/2014 | 8.4 | 7.2 | 7.5 | 6.4 | 5.3 | 5.4 | 5.8 | 4.8 | 14.6 | 10.2 | 10.6 | 9.1 | 9.3 | 4.8 | 4.9 | 4.3 |
| 8/3/2014 | 8.2 | 6.7 | 7.2 | 6.0 | 5.4 | **1.7** | 5.6 | 4.5 | 13.7 | 10.3 | 10.9 | 8.8 | 8.4 | 8.6 | 5.3 | 4.4 |
| 8/4/2014 | 8.3 | 6.5 | 6.6 | 5.4 | 5.2 | 5.7 | 5.7 | 4.7 | 14.1 | 8.1 | 7.7 | 6.5 | 8.9 | 2.5 | 2.1 | 1.8 |
| 8/5/2014 | 5.2 | 5.9 | 6.5 | 5.2 | 4.5 | 5.7 | 5.5 | 4.2 | 7.2 | 6.6 | 7.8 | 6.5 | 2.7 | 0.9 | 2.3 | 2.3 |

Value in **bold red** text indicate a violation of instantaneous minimum DO criteria.

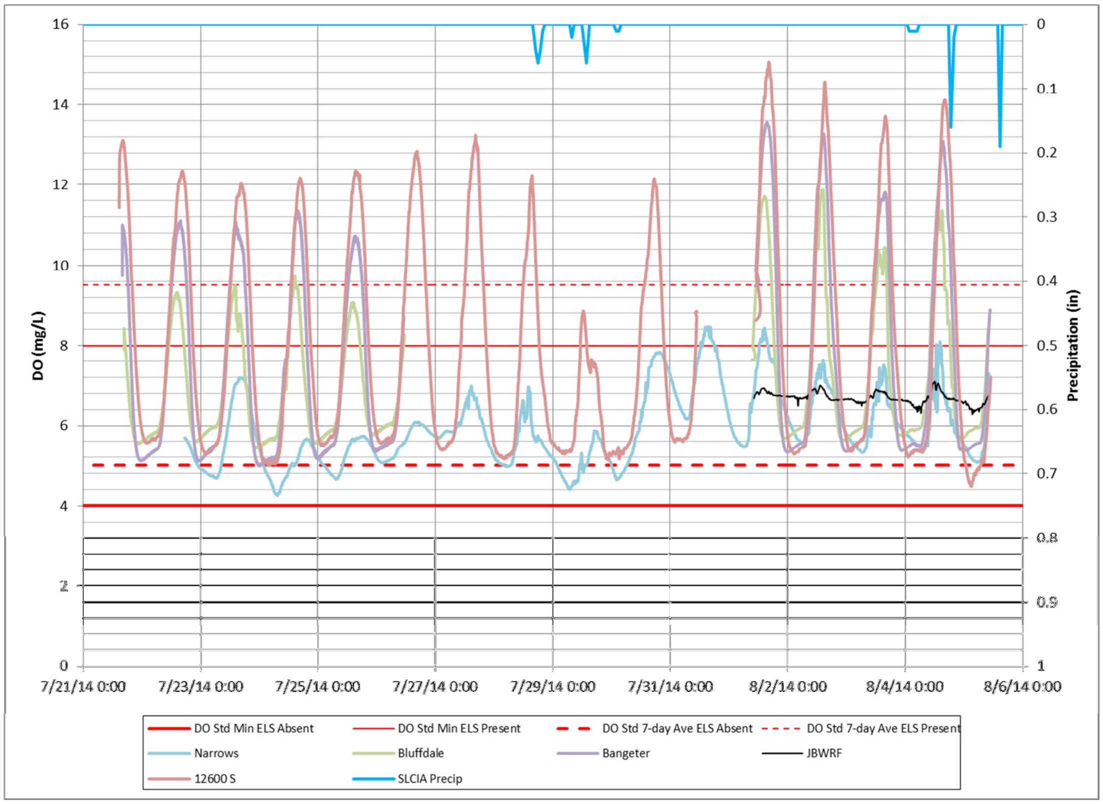


Figure 13: Continuous dissolved oxygen from Narrows to 12600 South

[Note: DO criteria shown for 3A waters; does not apply to Narrows site.]

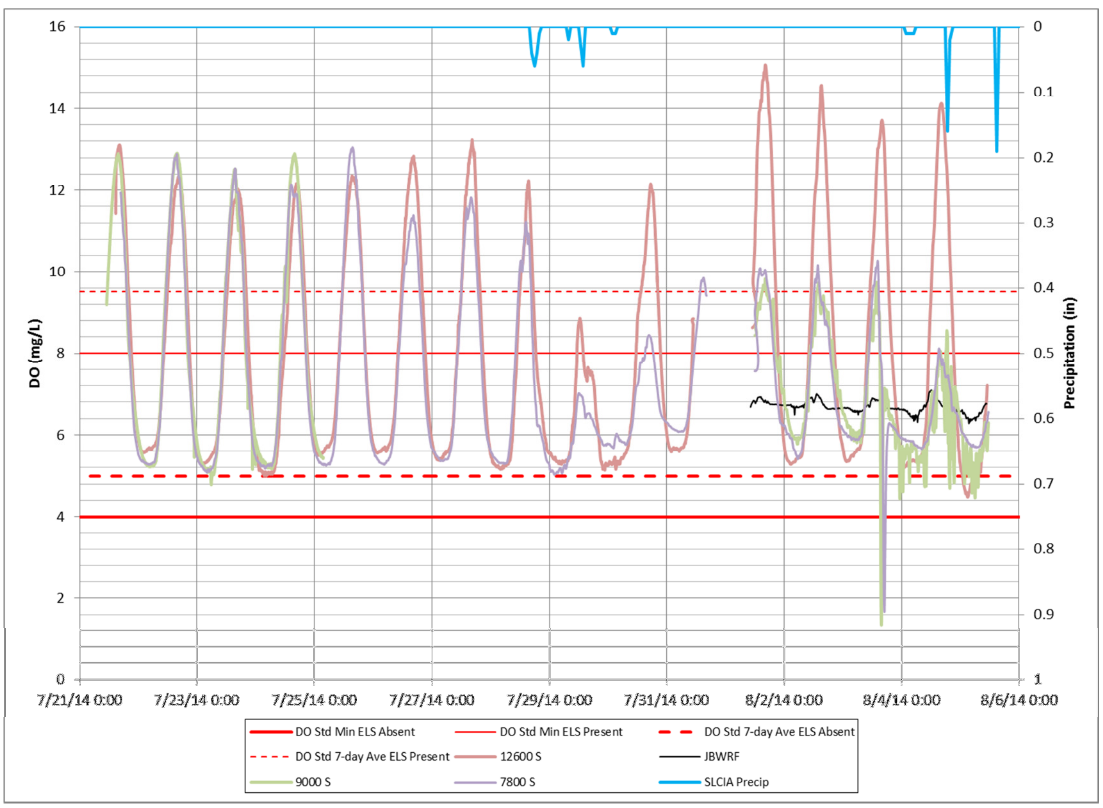


Figure 14: Continuous dissolved oxygen from 12600 South to 7800 South

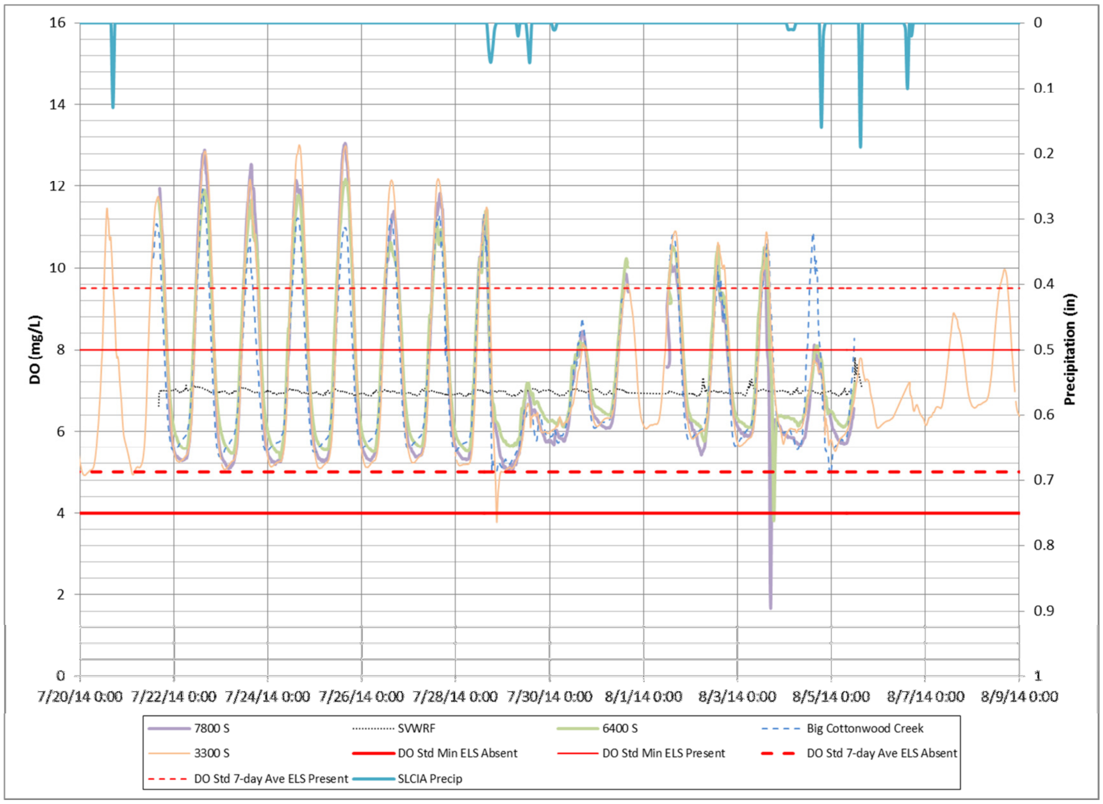


Figure 15: Continuous dissolved oxygen from 7800 South to 3300 South
[Note: DO criteria shown for 3A waters; does not apply to 3300 South site]

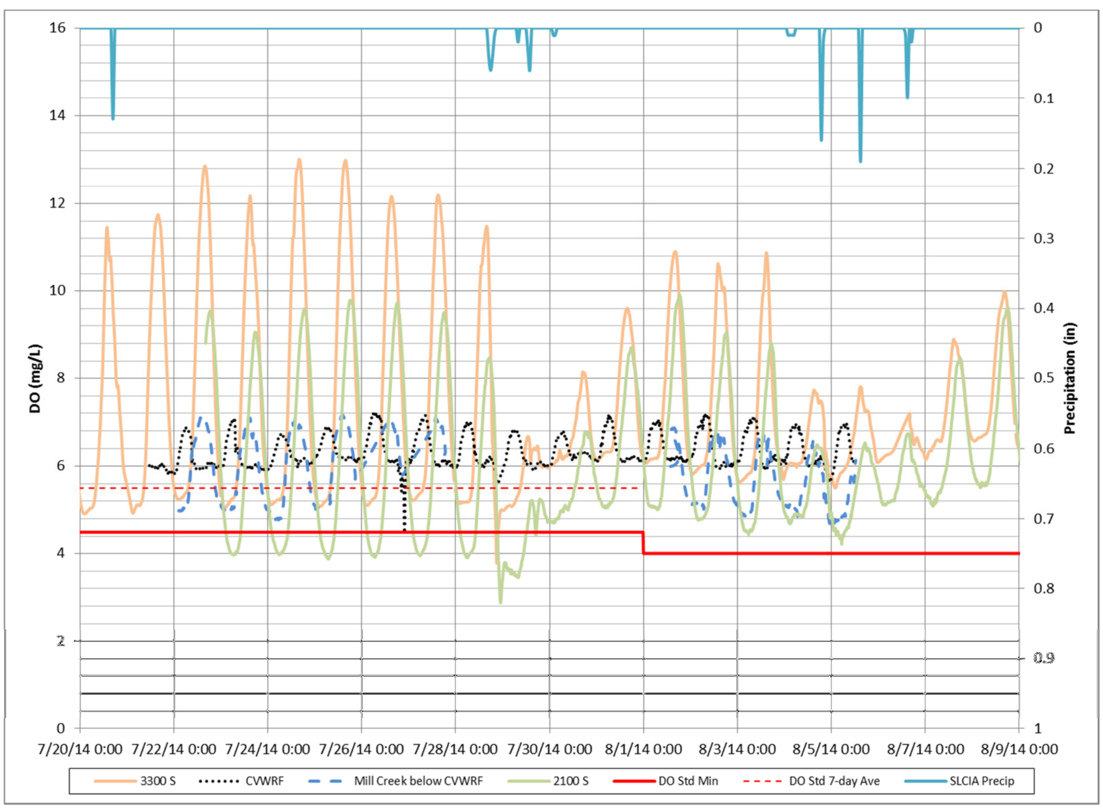


Figure 16: Continuous dissolved oxygen from 3300 South to 2100 South

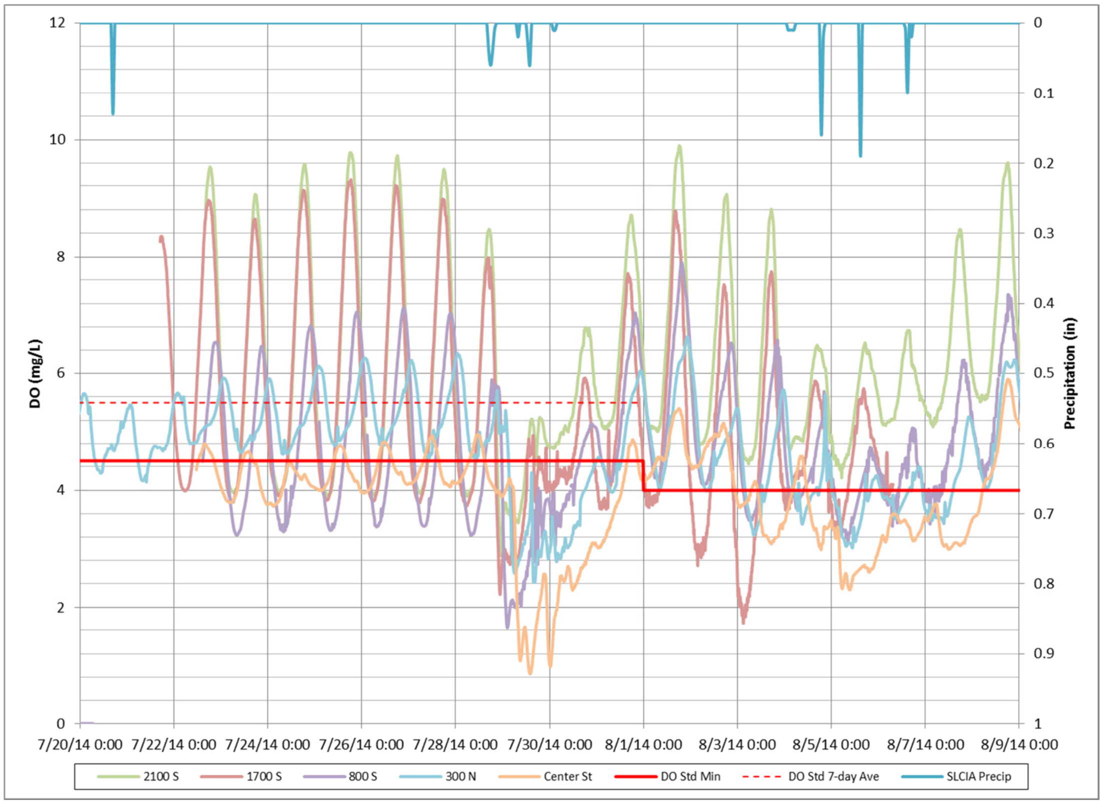


Figure 17: Continuous dissolved oxygen from 2100 South to Center Street (Cudahy Lane)

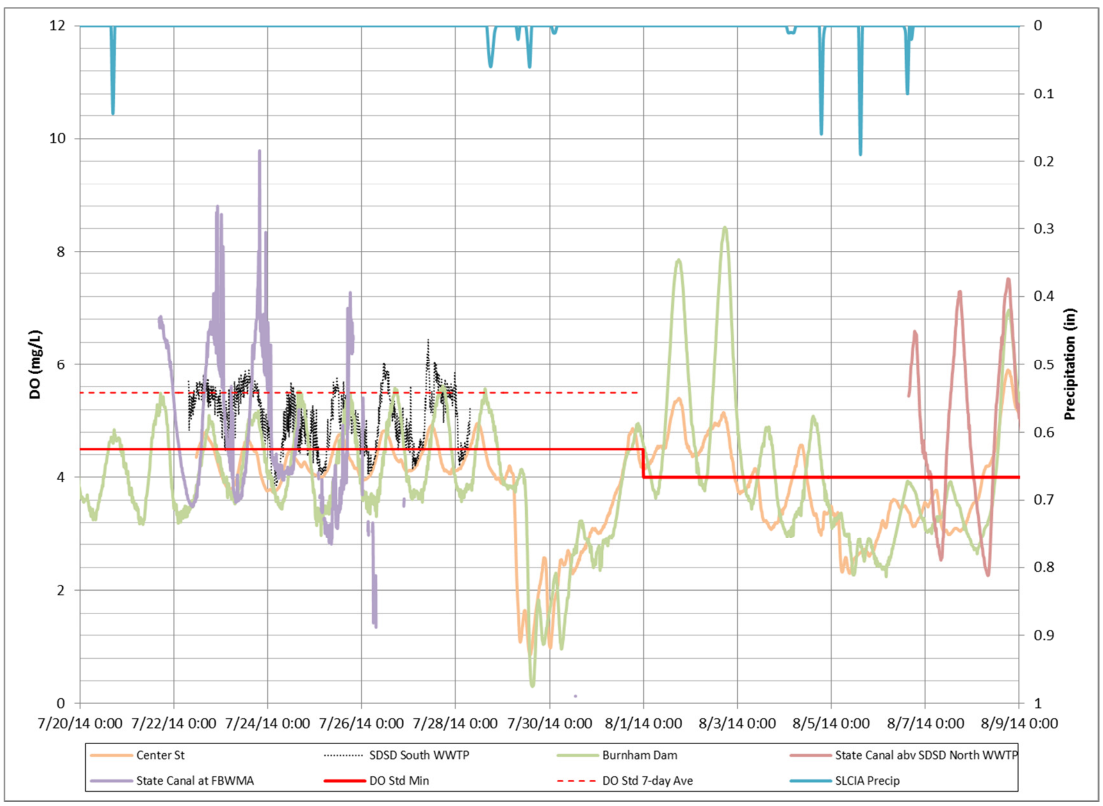


Figure 18: Continuous dissolved oxygen from Center Street (Cudahy Lane) to Farmington Bay WMA

### STREAM METABOLISM

A summary of the results utilizing the inverse model method for estimating stream metabolism is shown in Figure 19. The gross primary production (GPP) was lowest and ecosystem respiration (ER) was highest at the downstream sites in the lower Jordan River (Center Street and Burnham Dam). Interestingly, both GPP and ER were lower immediately downstream of Jordan Basin, South Valley and Central Valley WRFs as compared to the most immediate upstream sites, although there was a general upward trend in GPP and ER from 12600 South to 3300 South. Further investigation of this phenomenon on the Jordan River is warranted.

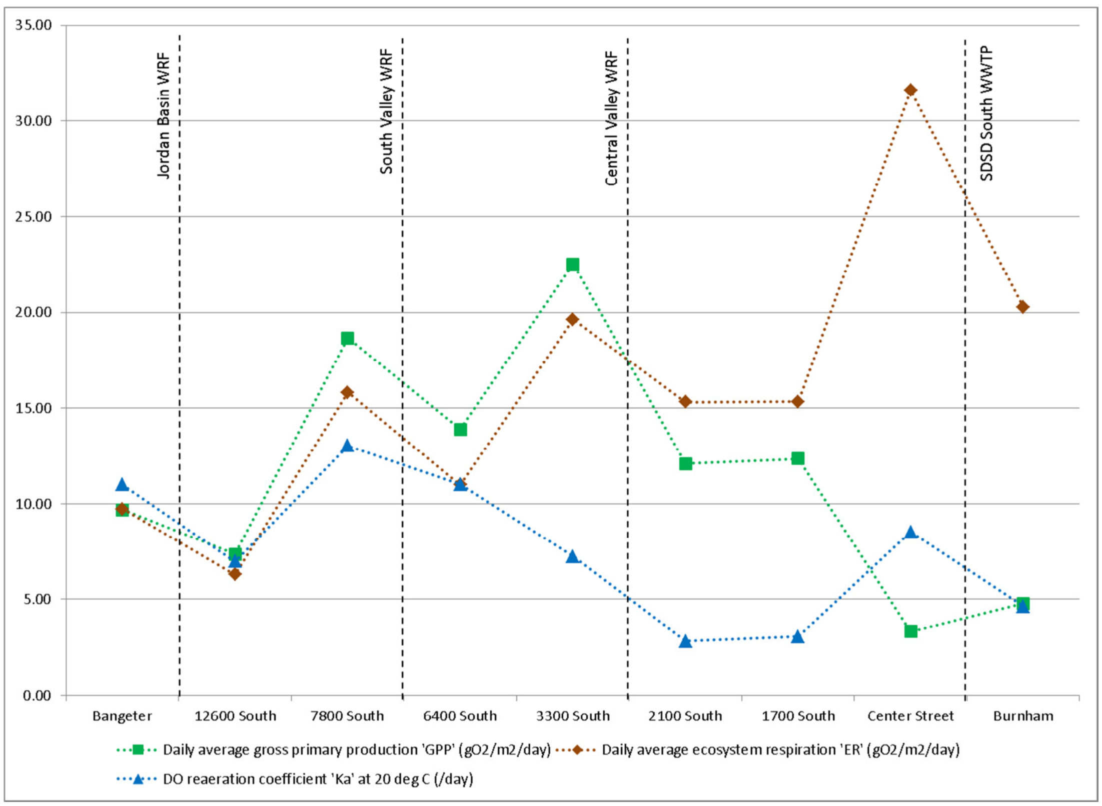


Figure 19: Stream metabolism during synoptic survey dry period

## METALS

Samples were analyzed for dissolved metals at selected sites, both during the dry weather and storm flows (Figures 20-28). Instream concentrations of aluminum, iron, mercury, and lead at several of the in-river sites was elevated during the storm flows. In-river concentrations of arsenic, copper, nickel, and zinc were similar during both dry and wet weather flows. Selenium concentrations were lower during the storm event. All samples were below the reporting limit for cadmium (1 µg/L) and silver (1 µg/L), and below or just above the reporting limit for chromium (1 µg/L). The in-river dissolved concentrations were significantly below water quality criteria, with the exception of iron and lead (Table 5).

Table 5: Dissolved metals criteria and maximum observed concentration (µg/L)

| Dissolved Metal | Dry Weather | | Wet Weather | |
|---|---|---|---|---|
| | Chronic Criteria (4-day Average) | Jordan River Maximum | Acute Criteria (1-hour Average) | Jordan River Maximum |
| Aluminum | 87 | 2.3 | 750 | 1.3 |
| Arsenic | 150 | 19.5 | 340 | 15.8 |
| Copper | 26.1 | 12.0 | 43.8 | 12.5 |
| Iron | N/A | | 1,000 | 1,380 |
| Lead | 9.5 | 13.2 | 245 | 17.6 |
| Mercury | 0.012 | <0.1 | 2.4 | 0.54 |
| Nickel | 150 | 4.7 | 1,351 | 3.7 |
| Selenium | 4.6 | 3.3 | 18.4 | 2.4 |
| Zinc | 341 | 93 | 339 | 55 |

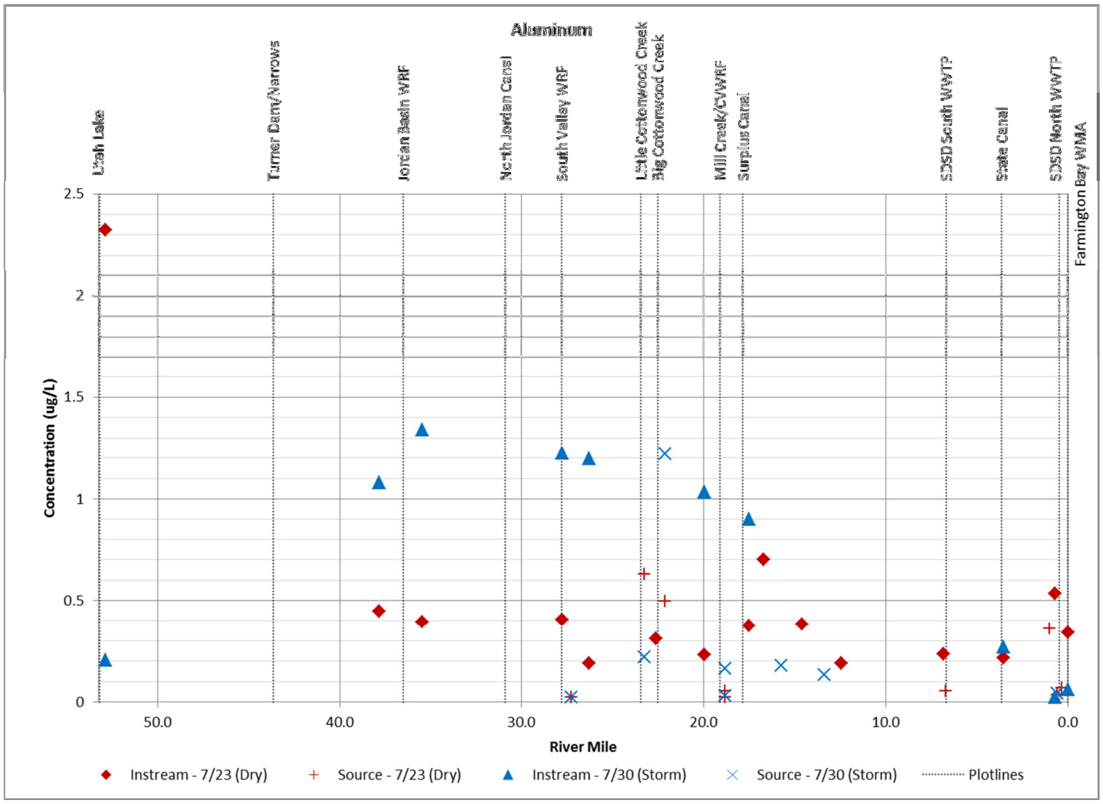


Figure 20: Dissolved aluminum concentration

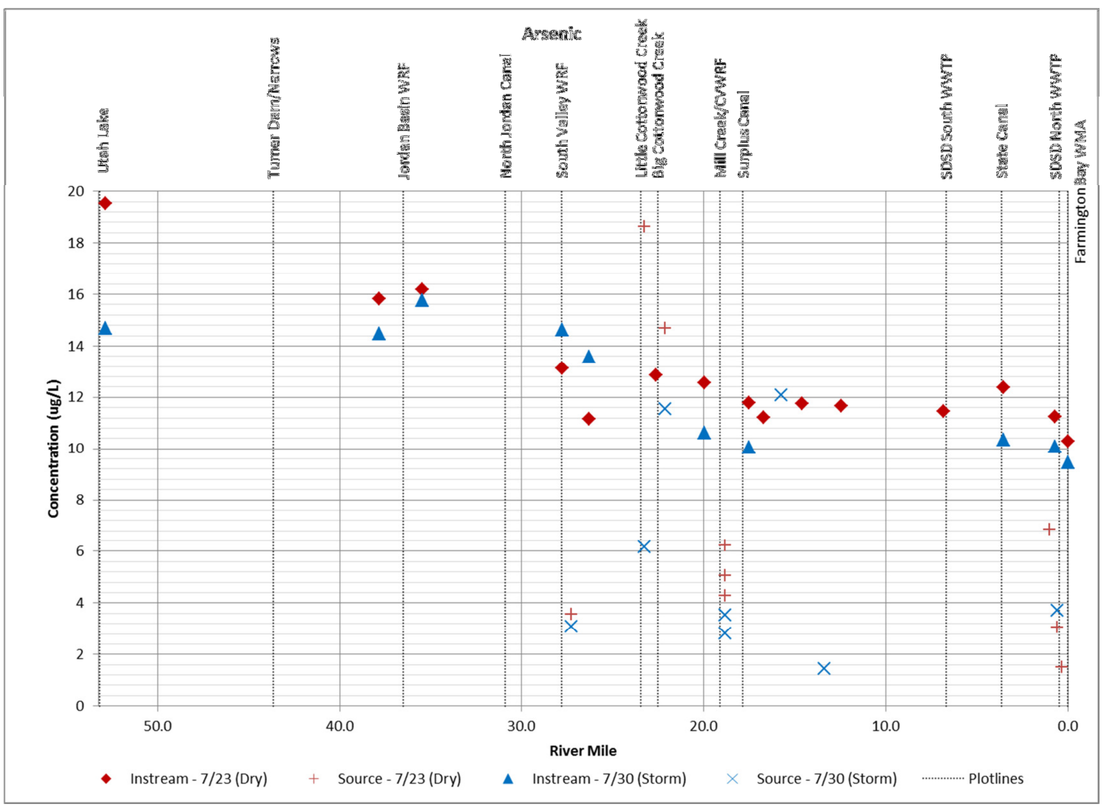


Figure 21: Dissolved arsenic concentration

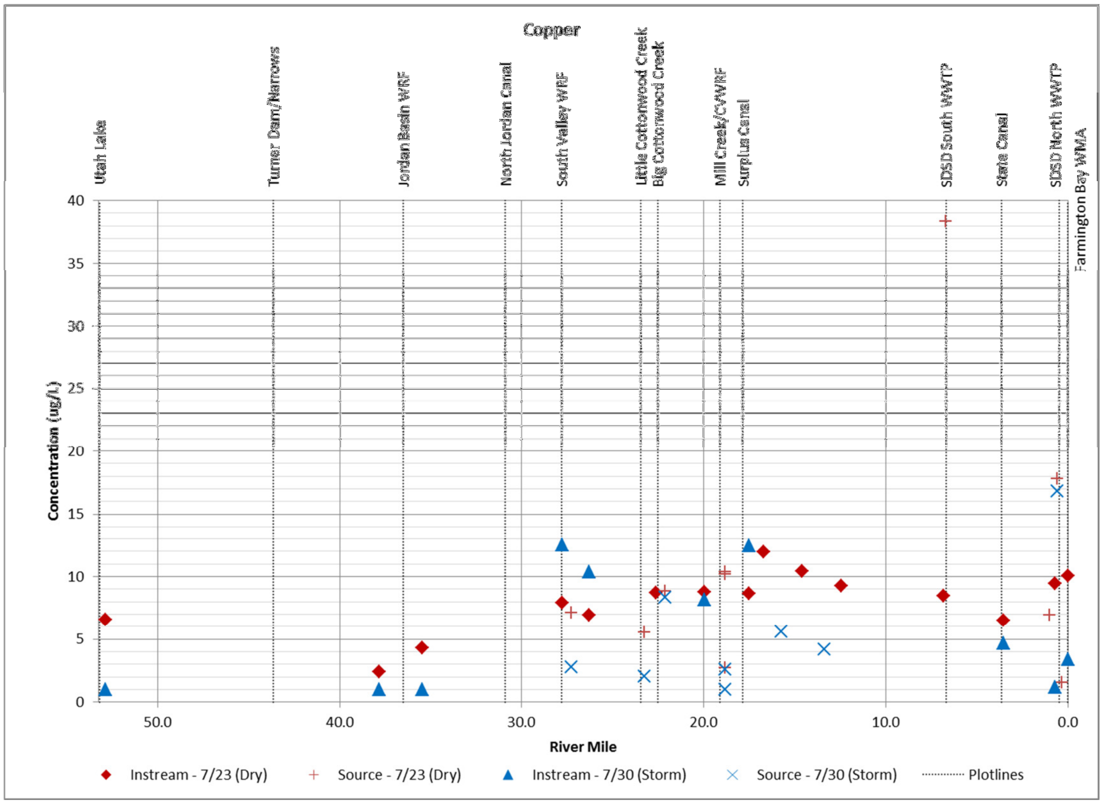


Figure 22: Dissolved copper concentration

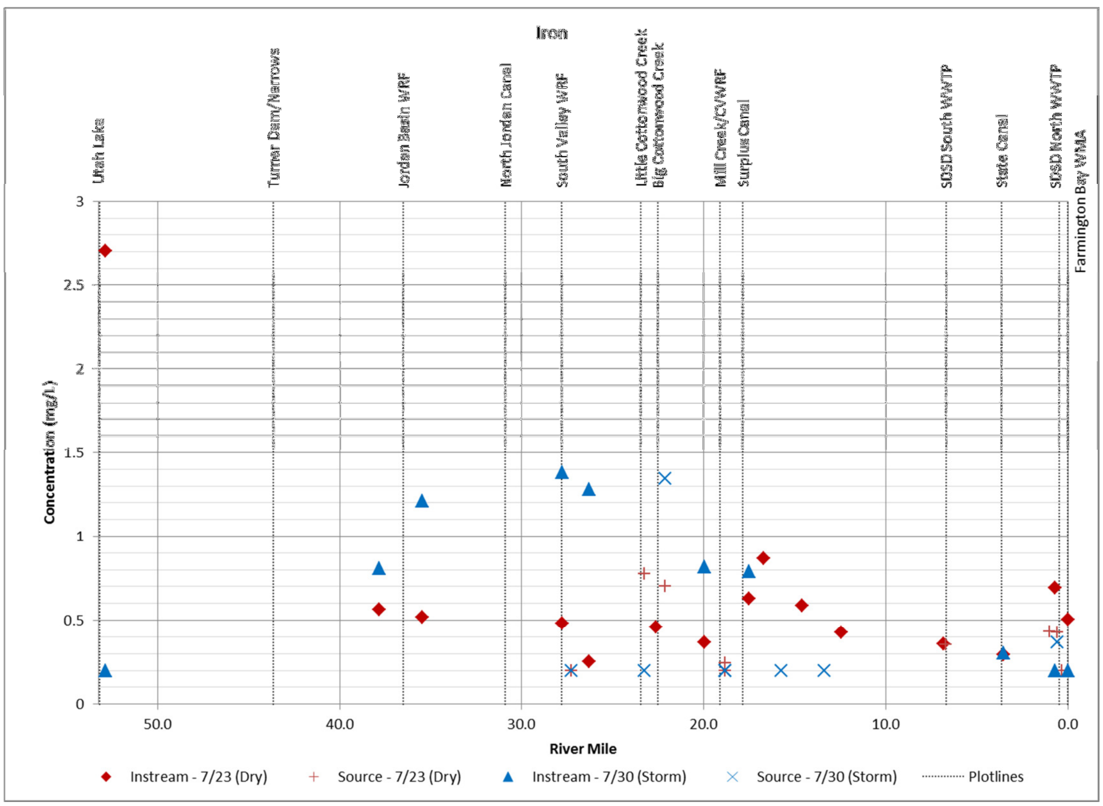


Figure 23: Dissolved iron concentration

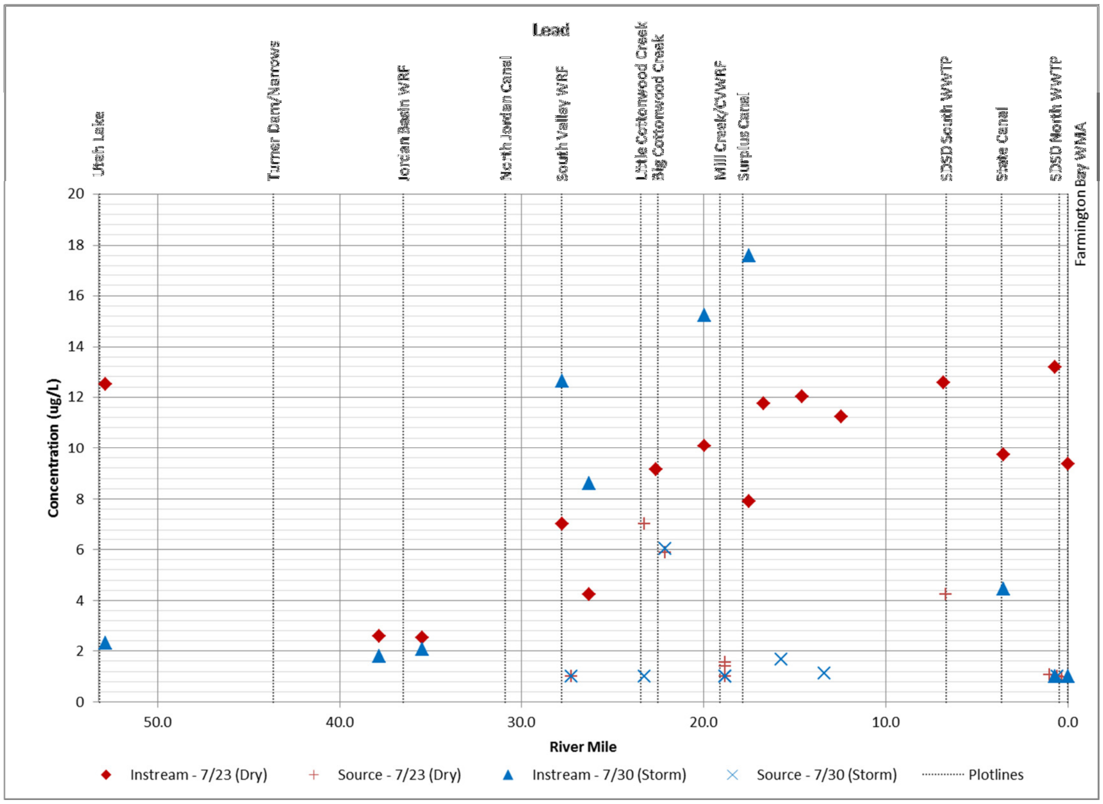


Figure 24: Dissolved lead concentration

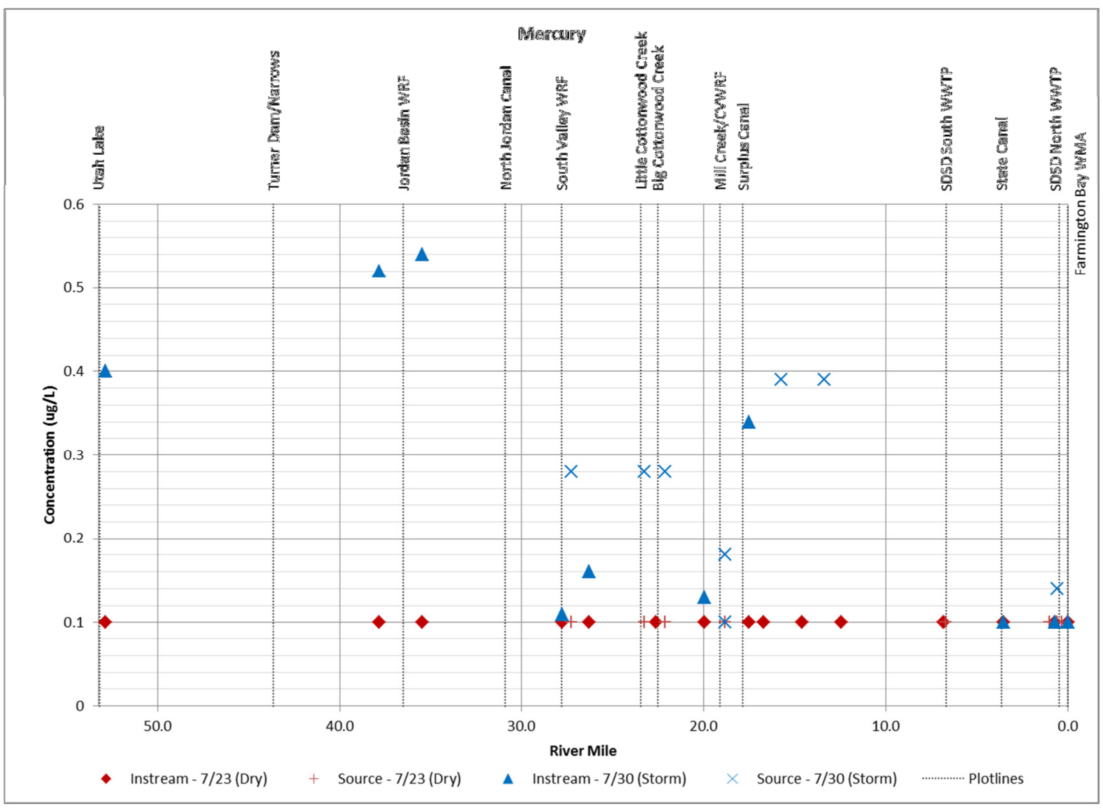


Figure 25: Dissolved mercury concentration

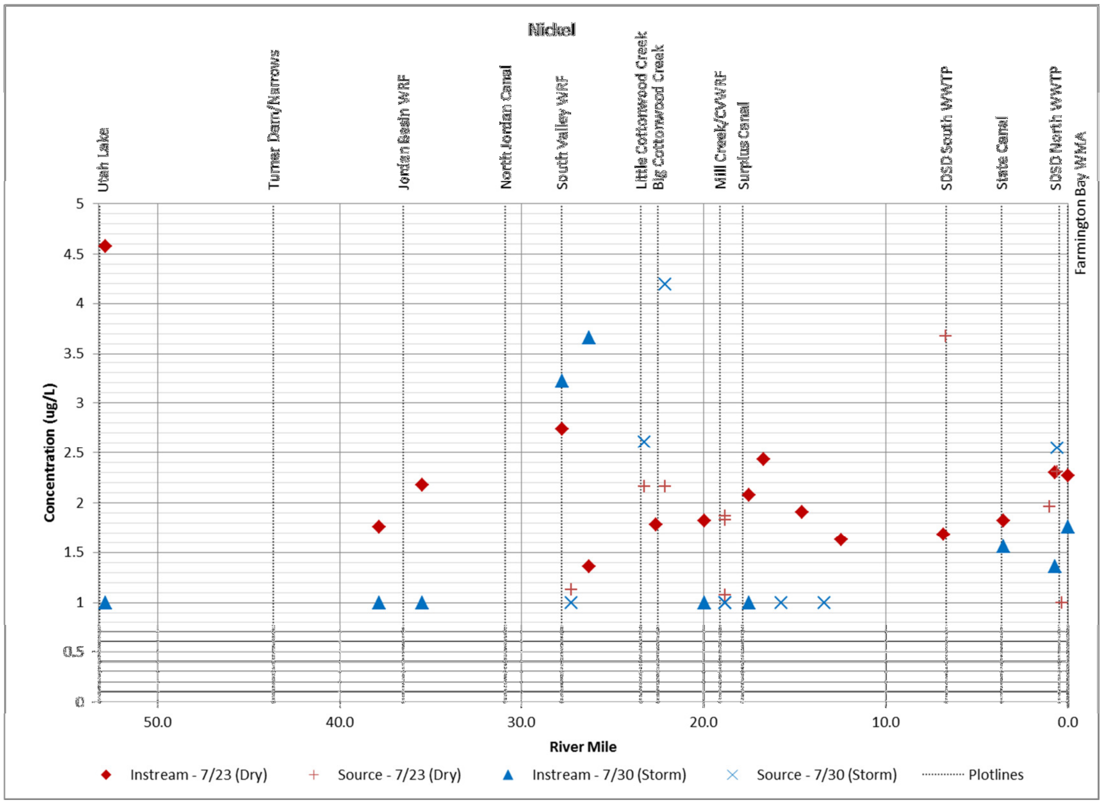


Figure 26: Dissolved nickel concentration

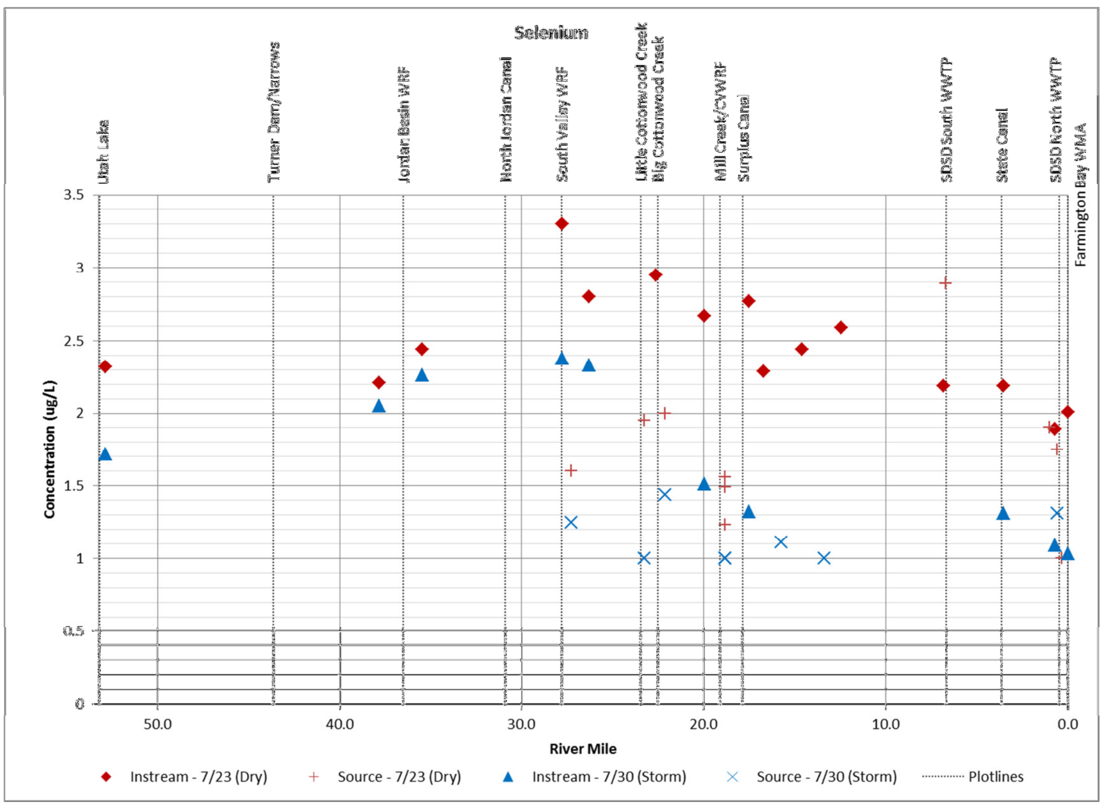


Figure 27: Dissolved selenium concentration

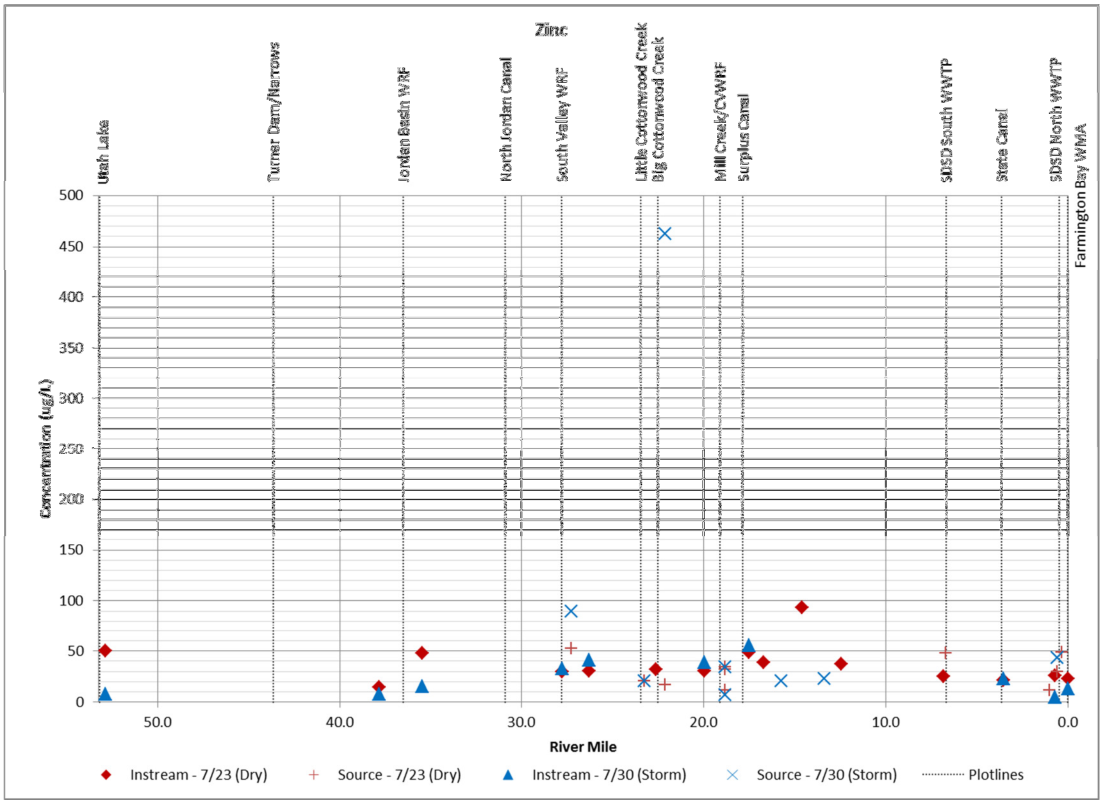

Figure 28: Dissolved zinc concentration

## Findings and Recommendations

Following are the key findings from the synoptic survey and model validation:

1. High levels of primary production, as evidenced by large diel DO ranges, were observed in the upper Jordan River between the Narrows and 3300 South. The level of productivity did not appear to be significantly impacted by the discharges from the water reclamation facilities (Jordan Basin, South Valley, and Central Valley).

2. Confirmation of a high assimilation rate of orthophosphate and nitrate downstream of South Valley WRF, which was also observed during previous synoptic surveys. The cause of this phenomenon warrants further investigation.

3. DO excursions below the minimum DO criteria in the lower Jordan River were observed both during dry periods, and during and immediately following storm events. The storm event on July 29-30 resulted in very low DO at Center Street and near anoxic conditions at Burnham Dam. Review of continuous DO data from the permanent sonde stations confirms that acute DO excursions occur as a result of storm events.

4. The model performance during validation was generally good for many constituents including specific conductivity, temperature, TSS, TN, TP; however, pH was generally over-predicted throughout the Jordan River, ammonia assimilation was over-predicted and DO diel range was under-predicted in the upper Jordan River, and DO was over-predicted in the lower Jordan River.

5. Dissolved metal concentrations were generally low in the Jordan River, with the exception of exceedances of water quality criteria observed for lead during dry weather and iron during wet weather.

Based on the findings of this study and other related studies, the following recommendations for modeling eutrophication in the Jordan River are made.

Although pH and ammonia assimilation were generally over-predicted in the model, these inaccuracies are offsetting with regard to compliance with ammonia criteria, as elevated pH results in lower ammonia criteria and higher assimilation results in lower ammonia concentrations. Therefore, the model represents the best available tool currently available and is considered suitable for application to the wasteload allocation for the Jordan River POTW permit renewals in 2015 and 2016.

Since the original selection of the QUAL2Kw model for the TMDL, it has been discovered that the DO excursions are linked to the build-up and decomposition of organic matter in the lower

Jordan River (Cirrus Ecological Consultants 2013). Due to the need to prescribe SOD from the deposition of organic matter outside of the steady-state model simulation period, the current QUAL2Kw model is not well-suited to linking sources of organic matter to low DO in the lower Jordan River, which will be required for the final TMDL. Also, since the selection of QUAL2Kw, the phenomenon of acute DO excursions during storm events has been observed, which is not possible to simulate utilizing a steady-state model. For these reasons, the current QUAL2Kw model should be transitioned to a dynamic modeling platform for future application to the wasteload allocation and TMDL.

The latest version of QUAL2Kw can simulate unsteady flows for up to one year of input data. However, there is evidence that the build-up and decomposition of organic matter in the Jordan River is a multiple year, perhaps even decadal, phenomenon. One model option that should be considered would be to transition the QUAL2Kw model into the EPA WASP model (Wool et al. 2005). The WASP model has many of the same parameters as QUAL2Kw but can be run for multiple years with continuous inputs. In addition, WASP allows the user to parameterize decomposition and nutrient transformation rates in the sediment, whereas sediment diagenesis in QUAL2Kw is “black box.” For tributary, point source, and non-point source inputs, the WASP model could be linked to the existing HSPF model of the Jordan River watershed within Salt Lake County, which simulates flow and water quality on an hourly time step between 1994 and 2006 (Stantec Consulting 2011).

Any new dynamic model would require some level of calibration, which should be conducted in consultation with the modeling workgroup associated with the TMDL, as was done for the original calibration (von Stackelberg and Neilson 2014).

Following are additional recommendations for improving the modeling of eutrophication in the Jordan River and State Canal for the purposes of the wasteload allocation and TMDL:

1. Revisit the calibration of selected parameters related to simulating benthic algae growth, as well as pH and ammonia decay and plant uptake, particularly in the upper Jordan River.

2. Evaluate potential enhancements to the model to improve simulation of sediment oxygen demand, including specification of decay rate parameters.

3. Improve understanding and simulation of scour of benthic algae from the upper Jordan River during storm events and at senescence, and subsequent deposition in the lower Jordan River.

4. Conduct another synoptic survey during the non-irrigation season, when the Jordan River is not influenced by releases from Utah Lake. The data set in part could be used to validate the model during the clear phase of the river.

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